Revisions to Stratigraphic Nomenclature of Jurassic and Cretaceous Rocks of the Colorado Plateau

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Revisions to Stratigraphic Nomenclature of Jurassic and Cretaceous Rocks of the Colorado Plateau

Revisions in Nomenclature of the Middle Jurassic Wanakah Formation, Northwestern New Mexico and Northeastern Arizona

By STEVEN M. CONDON and A. CURTIS HUFFMAN, JR.

Stratigraphy and Nomenclature of Middle and Upper Jurassic Rocks, Western Colorado Plateau, Utah and Arizona

By FRED PETERSON

The Encinal Canyon Member, a New Member of the Upper Cretaceous Dakota Sandstone in the Southern and Eastern San Juan Basin, New Mexico

By WILLIAM M. AUBREY

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DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

UNITED STATES GOVERNMENT PRINTING OFFICE: 1988

For sale by the
Books and Open-File Reports Section
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Federal Center, Box 25425
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Library of Congress Cataloging-in-Publication Data

Revisions to stratigraphic nomenclature of Jurassic and Cretaceous rocks of the Colorado Plateau.
(U.S. Geological Survey bulletin ; 1633 A-C)
Includes bibliographies.
Supt. of Docs. no.: I 19.3:1633A-C
Contents: Revisions in nomenclature of the Middle Jurassic Wanakah Formation, northwestern New Mexico and northeastern Arizona / by Steven M. Condon and A. Curtis Huffman — Stratigraphy and nomenclature of Middle and Upper Jurassic rocks, western Colorado Plateau, Utah and Arizona / by Fred Peterson — The Encinal Canyon Member, a new member of the Upper Cretaceous Dakota Sandstone in the southern and eastern San Juan Basin, New Mexico / by William M. Aubrey.
1. Geology, Stratigraphic—Jurassic—Nomenclature. 2. Geology, Stratigraphic—Cretaceous—Nomenclature. 3. Geology, Stratigraphic—Nomenclature—Colorado Plateau. I. Condon, Steven M. II. Series.
QE75.B9 no. 1633 A-C 557.3 s 87-600053
[QE681] [551.7′66′014]

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Revisions in Nomenclature of the Middle Jurassic Wanakah Formation, Northwestern New Mexico and Northeastern Arizona

By STEVEN M. CONDON and A. CURTIS HUFFMAN, JR.

"Wanakah Formation" replaces
"Summerville Formation" in
New Mexico and Arizona

U.S. GEOLOGICAL SURVEY BULLETIN 1633–A

REVISIONS TO STRATIGRAPHIC NOMENCLATURE OF JURASSIC AND CRETACEOUS ROCKS OF THE COLORADO PLATEAU

CONTENTS

FIGURES

Revisions in Nomenclature of the Middle Jurassic Wanakah Formation, Northwestern New Mexico and Northeastern Arizona

By Steven M. Condon *and* A. Curtis Huffman, Jr.

Abstract

Use of the name Summerville Formation in northwestern New Mexico and northeastern Arizona is here discontinued, and this name is replaced by the name Wanakah Formation in that area. In New Mexico and Arizona the Wanakah consists of the basal Todilto Limestone Member and two new members, the Beclabito and Horse Mesa Members. The Wanakah overlies the Entrada Sandstone, underlies the Morrison Formation, and intertongues laterally with the Cow Springs Sandstone. On the basis of previously established stratigraphic relations, the Wanakah is considered to be Middle Jurassic in age.

INTRODUCTION

The Middle Jurassic Wanakah Formation of the San Rafael Group is here reinstated throughout northwestern New Mexico and northeastern Arizona and replaces the name Summerville Formation in those areas. This change in stratigraphic nomenclature is necessary because recent stratigraphic reports (O'Sullivan, 1980a, 1981; O'Sullivan and Pierce, 1983) have documented the reasons for limiting use of the name Summerville Formation to the San Rafael Swell–Monument upwarp area of Utah (fig. A1). These reports have applied the name Wanakah Formation to red beds in southeastern Utah and southwestern Colorado where the Summerville was previously recognized.

The Wanakah was named by Burbank in 1930 for exposures in the Wanakah mine, near Ouray, Colo., and was originally assigned as the basal member of the Morrison Formation (fig. A2). The Wanakah near Ouray included all strata between the Upper(?) Jurassic sandstone (now named the Entrada Sandstone) and the lower part of the sandstone member of the Morrison (now assigned to the Tidwell Member of the Morrison; Peterson, this volume) (Burbank, 1930, p. 172). Goldman and Spencer (1941) also considered the Wanakah to be a member of the Morrison; however, they restricted the name to sandy, red, argillaceous strata that are now called the upper or marl member of the Wanakah. They named an underlying red sandstone the Bilk Creek Sandstone Member of the Morrison, and assigned Burbank's "Pony Express beds" to the base of the Morrison as the Pony Express Limestone Member. Eckel (1949, p. 28) elevated the Wanakah to formation rank and extended the name to the La Plata Mountains area (fig. A1), where it consists of the Pony Express Limestone Member at the base, the Bilk Creek Sandstone Member, and the marl member. In this report, our use of the name Wanakah Formation in northwestern New Mexico and northeastern Arizona follows that of Baker and others (1947, p. 1668) and Imlay (1952, p. 960), who included the Todilto Limestone, an equivalent of the Pony Express, as the basal member of the Wanakah Formation (fig. A2).

In this report we are establishing a reference section for the Todilto Limestone Member and the Wanakah Formation, and a type section for the Beclabito (bek-'labitō) and Horse Mesa Members at Horse Mesa, Arizona and New Mexico, in sec. 17, T. 38 N., R. 31 E. (Gila/Salt River grid) and secs. 26 and 27, T. 29 N., R. 21 W. (New Mexico grid). At Horse Mesa the Wanakah consists of the Todilto Limestone Member at the base, the Beclabito Member, and the Horse Mesa Member. The Beclabito is named in this report for exposures at Beclabito dome, 7 mi (11 km) north-northeast of Horse Mesa. The name Horse Mesa Member is applied here to rocks between the Beclabito Member of the Wanakah and the Salt Wash Member of the Morrison Formation on Horse Mesa. A comparison of the nomenclature of this report with that used previously and in other areas is shown as figure A2. The measured section at Horse Mesa is shown as figure A7.

The Todilto Limestone, named by Gregory (1917) for exposures at Todilto Park, N. Mex. (fig. A1), is here

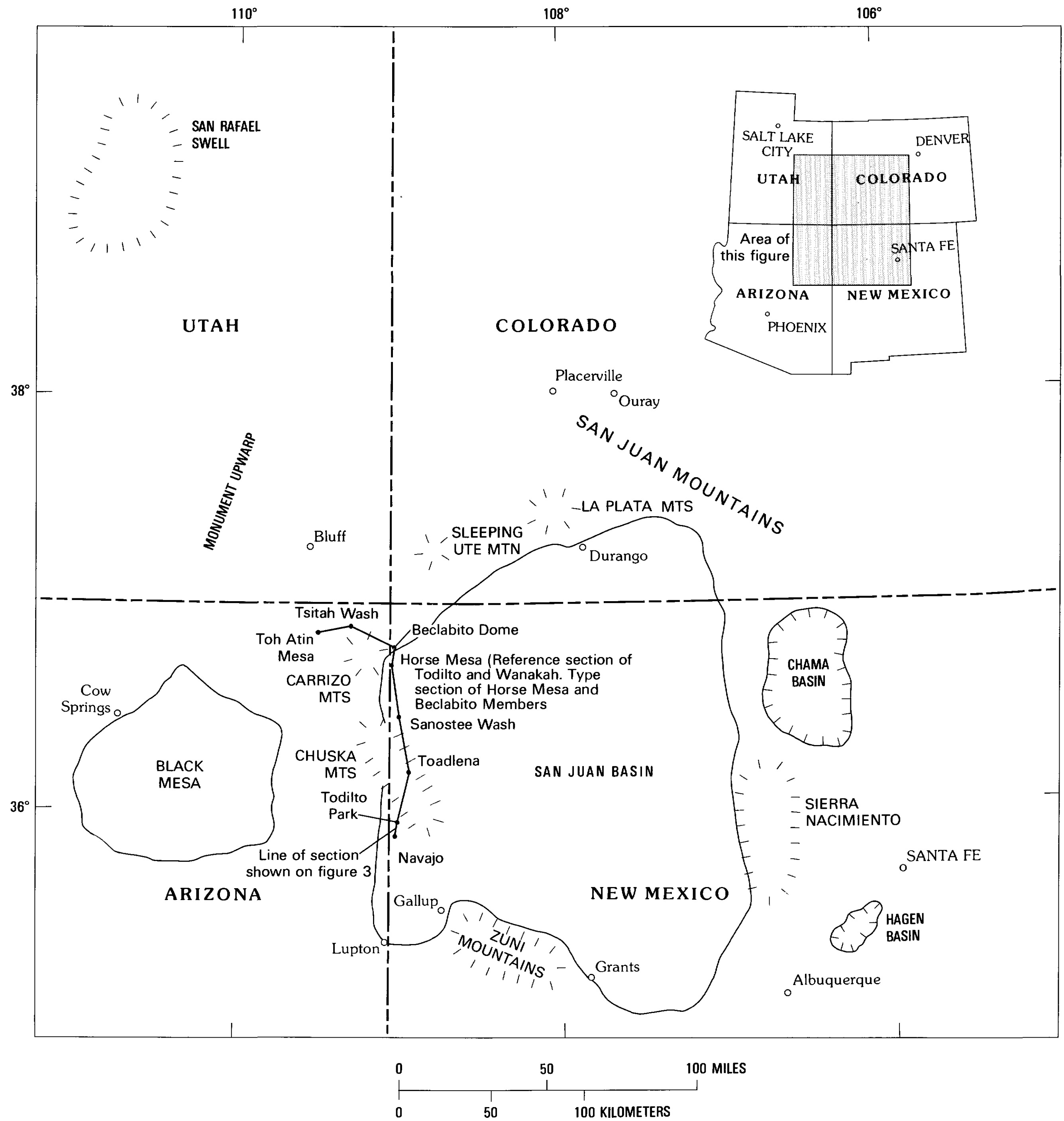


Figure A1. Location map of northwestern New Mexico, northeastern Arizona, and adjacent areas.

lowered in rank and made the basal member of the Wanakah Formation, because its equivalent in Colorado, the Pony Express Limestone, is the basal member of the Wanakah in that area (fig. A2). This reassignment makes the base of the Wanakah consistent from Colorado to Arizona and New Mexico. The name Beclabito Member is here introduced to describe the red beds previously named Summerville Formation in Arizona and New Mexico. Above these red beds the name Bluff Sandstone was applied incorrectly to both the Bluff Sandstone Member of the Morrison Formation and an underlying sandstone unit in the Carrizo Mountains area (Strobell, 1956); use of the name Bluff Sandstone in the Carrizo Mountains area is here restricted, and the lower sandstone unit or "A unit" of the Bluff is renamed the Horse Mesa Member of the Wanakah. The Horse Mesa is the

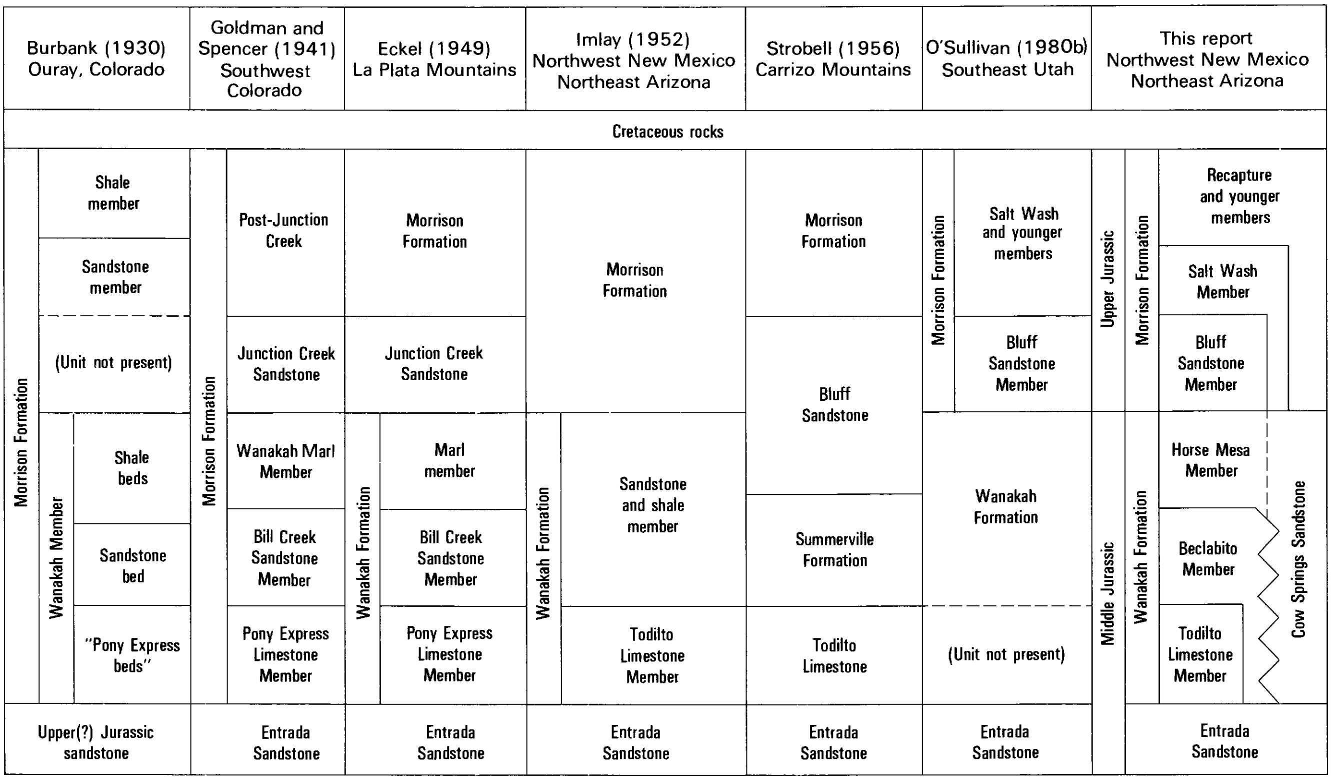


Figure A2. Nomenclature applied by various authors to Jurassic rocks in the Four Corners region. This report establishes new nomenclature for northeastern Arizona and northwestern New Mexico; the nomenclature of Eckel (1949) is still applied in southwestern Colorado, and that of O'Sullivan (1980b) is used in southeastern Utah.

uppermost member of the Wanakah in the Carrizo Mountains area.

Figure A3 is a cross section from Toh Atin Mesa in northeastern Arizona to Navajo in northwestern New Mexico that shows the thickness of the Wanakah in the area of this report. See Condon (1985a) for detailed lithologic descriptions of the stratigraphic sections used for the cross section. Figure A4 comprises photographs of most of the outcrops that are control points for the cross section. Also see Condon (1985b) for lithologic descriptions of the Wanakah Formation and adjacent units along the south side of the San Juan Basin.

STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS

The Todilto Limestone is the basal member of the Wanakah Formation in northeastern Arizona and northwestern New Mexico and is the same lithostratigraphic unit as the Pony Express Limestone Member of southwestern Colorado (Wright, 1959, p. 62). The nomenclature change from Todilto to Pony Express is placed arbitrarily at the New Mexico–Colorado State line. The Todilto Limestone Member consists of limestone, gypsum, anhydrite, and minor amounts of calcareous sandstone and siltstone (fig. A4*D*). The limestone forms a unit that ranges in thickness from 0 to 40 ft (12 m); it is light to dark gray, is laminated to structureless, and contains algal structures, ostracodes, and a few fish but is otherwise generally unfossiliferous. In part of the Todilto–Pony Express basin of deposition, the limestone is overlain by a white gypsum-anhydrite unit 0 to 125 ft (38 m) thick (fig. A5). This unit is predominantly gypsum at or near the surface and predominantly anhydrite in the subsurface; it includes bedded and nodular types of both minerals. Near the margins of the basin of deposition of the Todilto–Pony Express (fig. A5), the limestone grades laterally into calcareous sandstone and siltstone of the Beclabito Member or equivalents. Green and Jackson (1976) and Condon (1985b) report that granules and pebbles of chert occur at the stratigraphic position of the Todilto in the Gallup, N. Mex., area, where the limestone pinches out. The Todilto is recognized throughout most of the New Mexico part of the San Juan Basin, as well as in the Chama basin, the Hagan basin, and other areas of northwestern New Mexico (figs. A1, A5).

The Todilto has been interpreted alternatively as deposits of (1) a fresh to saline inland lake (Anderson and Kirkland, 1960; Tanner, 1965, 1970; Rawson, 1980) or (2) a restricted marine basin (Harshbarger and others, 1957; Ridgley and Goldhaber, 1983; Ridgley, 1984).

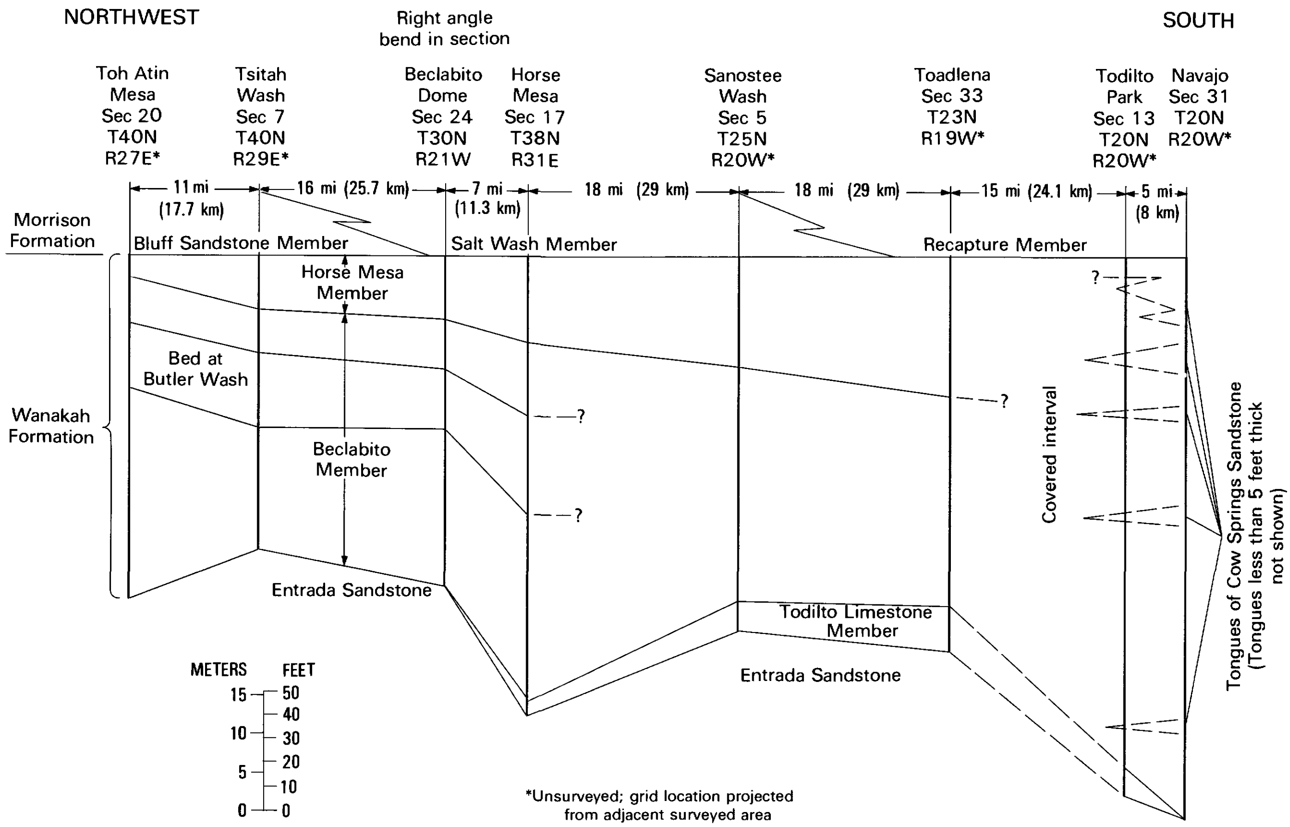


Figure A3. Cross section of the Wanakah Formation from Toh Atin Mesa, Ariz., to Navajo, N. Mex. See line of section on figure A1.

Five main reasons have been given for interpreting the Todilto as a continental deposit: (1) A nonmarine ostracode species has been found in the Todilto (Swain, 1946). (2) No fossils that are clearly marine have been found (Anderson and Kirkland, 1960, p. 45). (3) The Todilto doesn't interfinger with or extend into marine deposits (Tanner, 1970, p. 286). (4) The paleogeographic position of the Todilto basin of deposition has been interpreted by some to be an inland, shallow depression that was bordered by low hills on three sides and open to an alluvial plain on the east (Tanner, 1965, p. 568). (5) No dolomite is associated with gypsum in the Todilto (Rawson, 1980, p. 305).

Reasons given for interpreting the Todilto as a marine deposit are these: (1) Limestone is associated with gypsum in the member, and chloride salts are absent (Harshbarger and others, 1957, p. 46). (2) Whole-rock carbon, oxygen, and sulfur isotope studies point to a marine rather than a lacustrine origin for limestone of the Todilto (Ridgley and Goldhaber, 1983). (3) Other paleogeographical reconstructions indicate deposition in a craton-margin basin (Ridgley, 1984). (4) Recent re-evaluation of Jurassic fish from the Western Interior suggests that two fish taxa in the Todilto entered the Todilto basin from marine waters (Schaeffer and Patterson, 1984, p. 12).

The data presented are thus somewhat contradictory, and this issue remains unresolved. It seems to the present writers that the isotope studies of Ridgley and Goldhaber (1983) are perhaps the best quantitative data for supporting a marine origin over a lacustrine origin. Figure A6 is a general paleogeographical reconstruction of the Four Corners region in Todilto-early Beclabito-early Cow Springs time.

The Beclabito Member of the Wanakah (the Summerville Formation of previous reports) conformably overlies the Todilto and consists of 125–200 ft (38–61 m) of interbedded reddish-orange to reddish-brown, fine-grained, well-sorted sandstone, siltstone, sandy siltstone, and mudstone. Sedimentary structures consist of ripple cross-stratification, small-scale trough crossbeds, and wavy, subparallel, horizontal laminations. In most of the outcrops examined in Arizona and New Mexico, the Beclabito includes a thick-bedded to massive, dominantly structureless sandstone unit at its base, immediately overlying the Todilto Limestone Member. This sandstone, which is about 35 ft (10.6 m) thick at the type section (figs. A4*E*, A7), occupies the same stratigraphic position as the Bilk Creek Sandstone Member in Colorado, although exact equivalence of the units has not been established. The carnelian sandstone marker bed, which is at the top of the Bilk Creek Sandstone Member in many areas of southwestern Colorado, was not found in the Carrizo Mountains area. The Beclabito Member is recognized throughout northwestern New Mexico and northeastern Arizona where the Summerville Formation was previously recognized.

At the type section, 108 ft (33 m) of interbedded sandstone, siltstone, sandy siltstone, and mudstone overlie the basal sandstone of the Beclabito Member (fig. A7). Within this interval is the bed at Butler Wash (O'Sullivan, 1980b), which has been traced into northeastern Arizona and northwestern New Mexico from southeastern Utah but has not been identified in outcrops south of Horse Mesa (fig. A3). In many areas of southeastern Utah and northeastern Arizona, the part of the Wanakah below the bed at Butler Wash is greatly deformed (fig. A4*A*). In some localities, as at Tsitah Wash, Ariz. (fig. A4*B*), the entire Wanakah is contorted, but in other places there is little or no significant deformation of the formation (Beclabito Dome and Sanostee Wash, figs. A4*C* and A4*F*).

The Beclabito Member was deposited in environments marginal to the Todilto–Pony Express basin of deposition and is present in many areas of northwestern New Mexico, northeastern Arizona, southeastern Utah, and southwestern Colorado. It has been traced throughout the San Juan Basin in the subsurface (Summerville Formation of Lupe, 1983). The Beclabito intertongues with the Cow Springs Sandstone along outcrops south of Todilto Park (fig. A3) and in the subsurface west of Gallup, N. Mex. We stress that the contact between the Beclabito Member and the Cow Springs Sandstone is a broad zone of vertical and horizontal intertonguing (fig. A4*G*), and therefore the two units overlap somewhat. The unit that we are calling Cow Springs Sandstone in this report is the same as the Cow Springs Member of the Entrada Sandstone, as used by Peterson in the Black Mesa, Ariz., area. (See Peterson, this volume.)

The interpretation of the environment of deposition of the Beclabito depends in part on the interpretation of the underlying Todilto Limestone Member; that is, the Beclabito is either marginal lacustrine or marginal marine. In this case also, the rock unit has no truly diagnostic features—such as algal mats, desiccation features, or macrofossils—that allow for an unequivocal interpretation. Deposition at or near base level and periodic inundation by water are suggested by some features, such as the thin beds of limestone at the base of the member, the thin, intercalated mudstone and claystone beds within the generally silty or sandy sequence, the lateral continuity of beds, and the lack of lenticular, scour-based fluvial sandstone beds. The lateral north-to-south gradation of the Beclabito into the eolian Cow Springs Sandstone and its position above the marine(?) Todilto Limestone Member also indicate that the Beclabito has a coastal sabkha-marginal marine origin. Additionally, the Beclabito grades southward into coarse fluvial conglomerates in an area south and southeast of Grants, N. Mex. (figs. A1, A6). This area is shown on figure A6 as a positive area, although the extent and magnitude of this upland area is unclear.

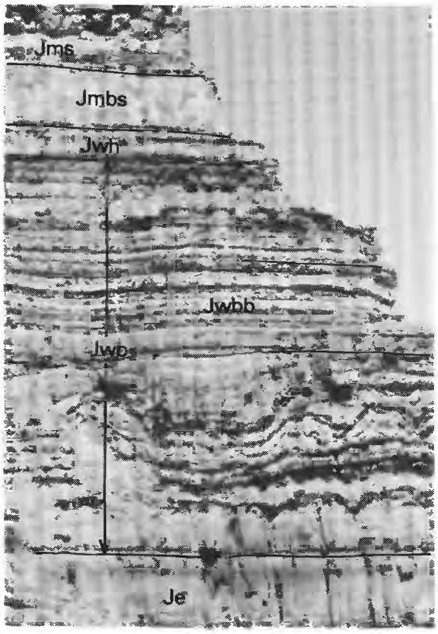
The Horse Mesa Member is the uppermost member of the Wanakah. At the type section the Horse Mesa consists of 36.5 ft (11.1 m) of red to orange, fine- to coarse-grained, crossbedded and flat-bedded sandstone. In some places its contact with the underlying Beclabito Member is sharp; in other places the contact is somewhat arbitrary and is placed at the top of the highest siltstone bed of the Beclabito Member. The Horse Mesa was deposited in eolian dune, interdune, and sabkha environments that prograded northward following the withdrawal of the body of water in which the Todilto-Pony Express was deposited.

The Horse Mesa was previously correlated with the Bluff Sandstone (Strobell, 1956; Huffman and Lupe, 1977), mainly on the basis of lithology and stratigraphic position. However, recent stratigraphic studies indicate that the Horse Mesa Member underlies the type Bluff Sandstone Member at Bluff, Utah, and is separated from it by an unconformity; hence the Bluff has now been reassigned as the basal member of the Morrison Formation (O'Sullivan, 1980b). A key outcrop on the west side of the Carrizo Mountains at Tsitah Wash, Ariz., clearly shows that the Horse Mesa Member was contorted along with the rest of the Wanakah prior to deposition of the overlying Bluff Sandstone Member (fig. A4*B*). We believe that the Bluff Sandstone Member is not present above the Horse Mesa Member in outcrops in northwestern New Mexico.

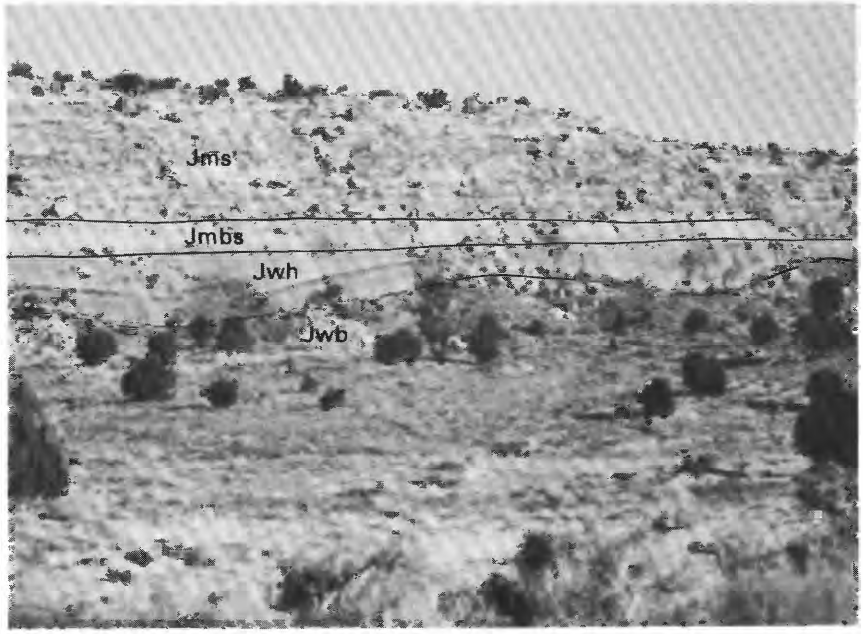
The Horse Mesa Member is recognized in northeastern Arizona and northwestern New Mexico. It thins northward from Arizona, and at Bluff, Utah, is a sandy unit at the top of the "middle member and younger parts of the Wanakah Formation" as used by O'Sullivan (1980b, sections 44, 46, 47, 50, and 52). Southward, the Horse Mesa Member grades laterally into the Cow Springs Sandstone. Westward, it has been removed by Cenozoic erosion, and eastward, in the subsurface, it grades into the Beclabito Member (Summerville Formation of Huffman and Lupe, 1977, p. 278). Outcrops in southwesternmost Colorado were not evaluated for the presence of the Horse Mesa Member in this study. However, the lower unit of the Junction Creek Sandstone (Ekren and Houser, 1965, p. 13) probably correlates with the Horse Mesa.

UPPER AND LOWER CONTACTS

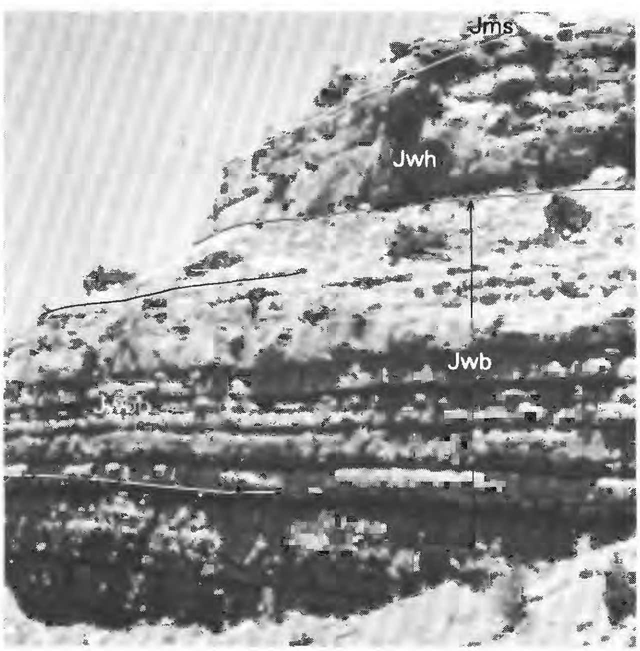
The Wanakah Formation conformably overlies the eolian Middle Jurassic Entrada Sandstone in northeastern Arizona and northwestern New Mexico. O'Sullivan



A, Toh Atin Mesa, Ariz. (sec. 28, T. 40 N., R. 27 E. (projected)).



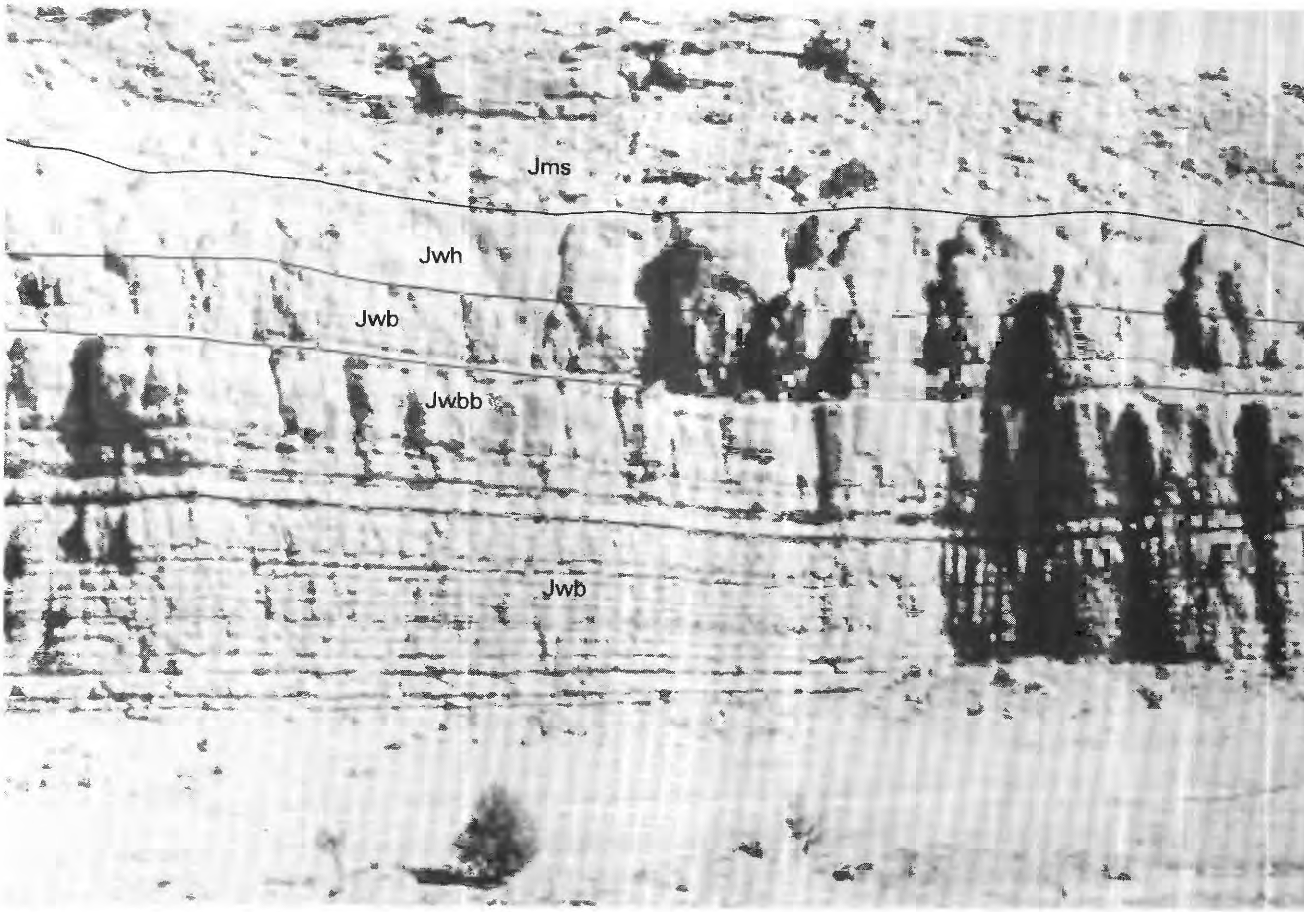
B, Tsitah Wash, Ariz. (sec. 7, T. 40 N., R. 29 E. (projected)). Note that Horse Mesa Member was folded and later truncated by the Bluff Sandstone Member.



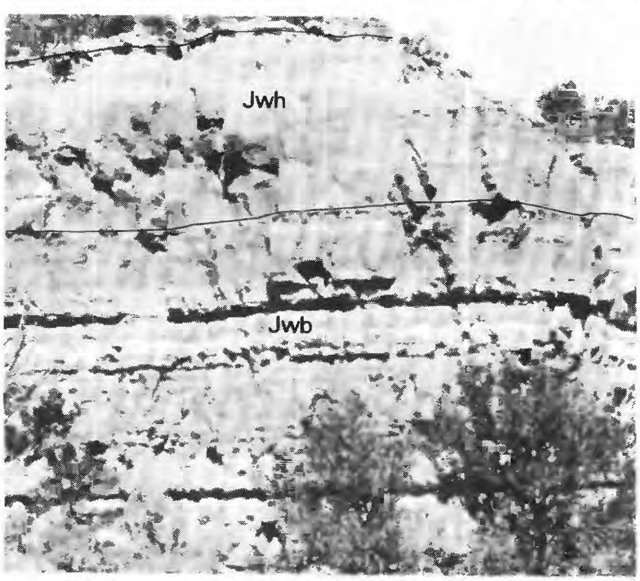
C, Beclabito Dome, N. Mex. (sec. 24, T. 30 N., R. 21 W.).

D, Reference section for Todilto Limestone Member of Wanakah Formation at Horse Mesa, Ariz. (sec. 17, T. 38 N., R. 31 E.). Photograph by J. L. Ridgley.

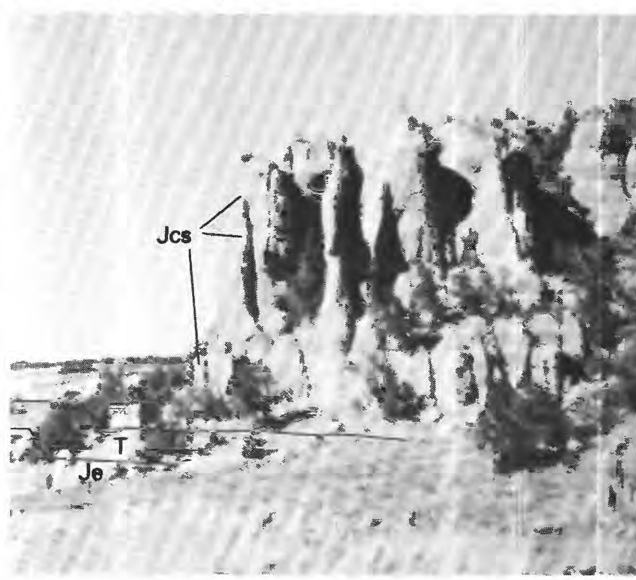
Figure A4 (above and facing page). Wanakah Formation and adjacent formations at measured section localities in northeastern Arizona and northwestern New Mexico. Je, Entrada Sandstone; Jwb, Beclabito Member of the Wanakah; Jwbb, bed at Butler Wash; Jwh, Horse Mesa Member of the Wanakah; Jmbs, Bluff Sandstone Member of the Morrison Formation; Jms, Salt Wash Member of the Morrison. Note that large-scale deformation features below the bed at Butler Wash are present at Toh Atin Mesa (*A*) but not at Horse Mesa (*E*). Also note that the percentage of sandstone in the Wanakah increases southward from *C* to *E* to *F*.



E, Type section for Beclabito and Horse Mesa Members of Wanakah Formation at Horse Mesa, Ariz. (sec. 17, T. 38 N., R. 31 E.). Massive, parallel-bedded sandstone behind tree is near the base of the Beclabito Member.



F, Sanostee Wash, N. Mex. (sec. 5, T. 25 N., R. 20 W. (projected)).



G, Near Navajo, N. Mex. (sec. 31, T. 20 N., R. 20 W. (projected)). Jcs, Cow Springs Sandstone; "T," calcareous zone that corresponds to the Todilto Limestone Member. The Todilto pinches out about 1.5 mi (2.5 km) east of this outcrop (R. E. Thaden, oral commun., 1984). The Cow Springs forms tongues of light-colored, crossbedded sandstone that thin northward into the Wanakah.

Figure A4. Continued.

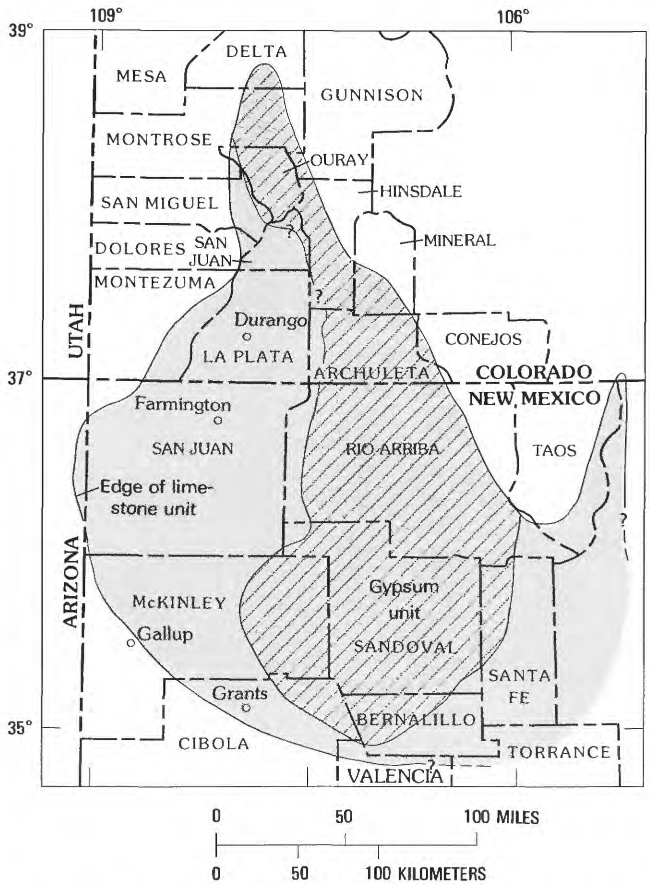


Figure A5. Outline of the Todilto–Pony Express basin of deposition and the approximate distribution of the gypsum-anhydrite unit. Modified from Wright (1959).

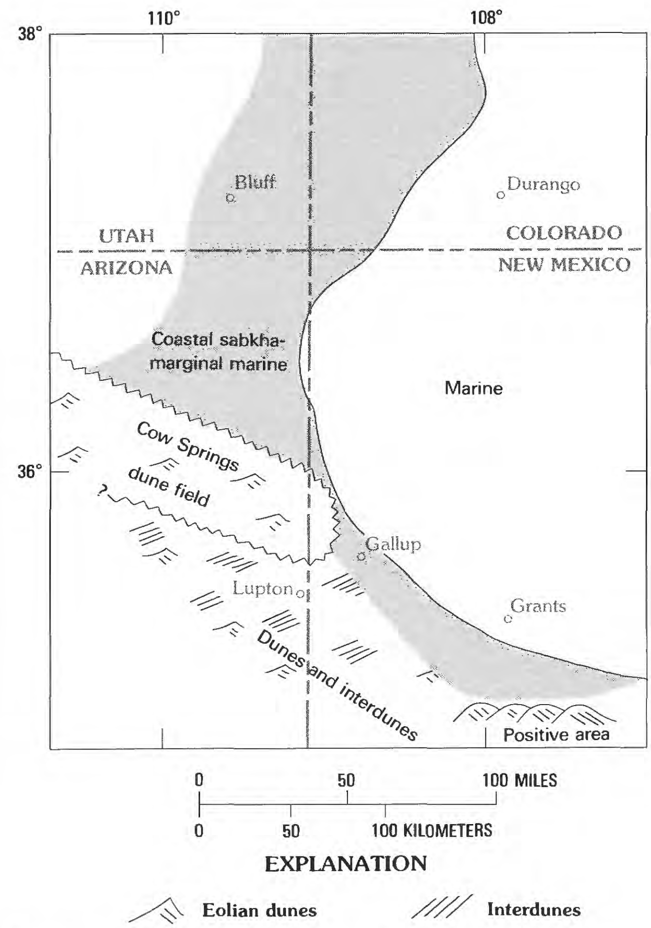


Figure A6. General paleogeography of the Four Corners region in Todilto–early Beclabito–early Cow Springs time.

(1980b) shows that the lower part of the Wanakah intertongues with and is replaced by the Entrada Sandstone in southeastern Utah.

In parts of southwestern Colorado, southeastern Utah, and northeastern Arizona the Wanakah is overlain by the B unit of the Bluff Sandstone Member of the Morrison Formation or the correlative B unit of the Junction Creek Sandstone (Craig and Cadigan, 1958, p. 182). The A units of the Bluff and the Junction Creek are now known to be pre-Morrison in age. As now used, the Junction Creek Sandstone is therefore of Middle and Late Jurassic age and is not considered part of the San Rafael Group in this report. In the northwestern part of the San Juan Basin either the Salt Wash Member or the Recapture Member of the Morrison Formation overlies the Wanakah at a sharp, erosional contact. Although O'Sullivan (1980b) recognizes an unconformity between the Morrison and the Wanakah in southeastern Utah, the presence of an unconformity at this position in Arizona and New Mexico has not been determined.

REFERENCE SECTION

The reference section for the Wanakah Formation in northeastern Arizona and northwestern New Mexico is at Horse Mesa (Horse Mesa 7.5-minute quadrangle), approximately 6 mi (9.6 km) north of the Red Rock Trading Post, Ariz. Figure A7 shows the lithology and thickness of the Wanakah at the reference section.

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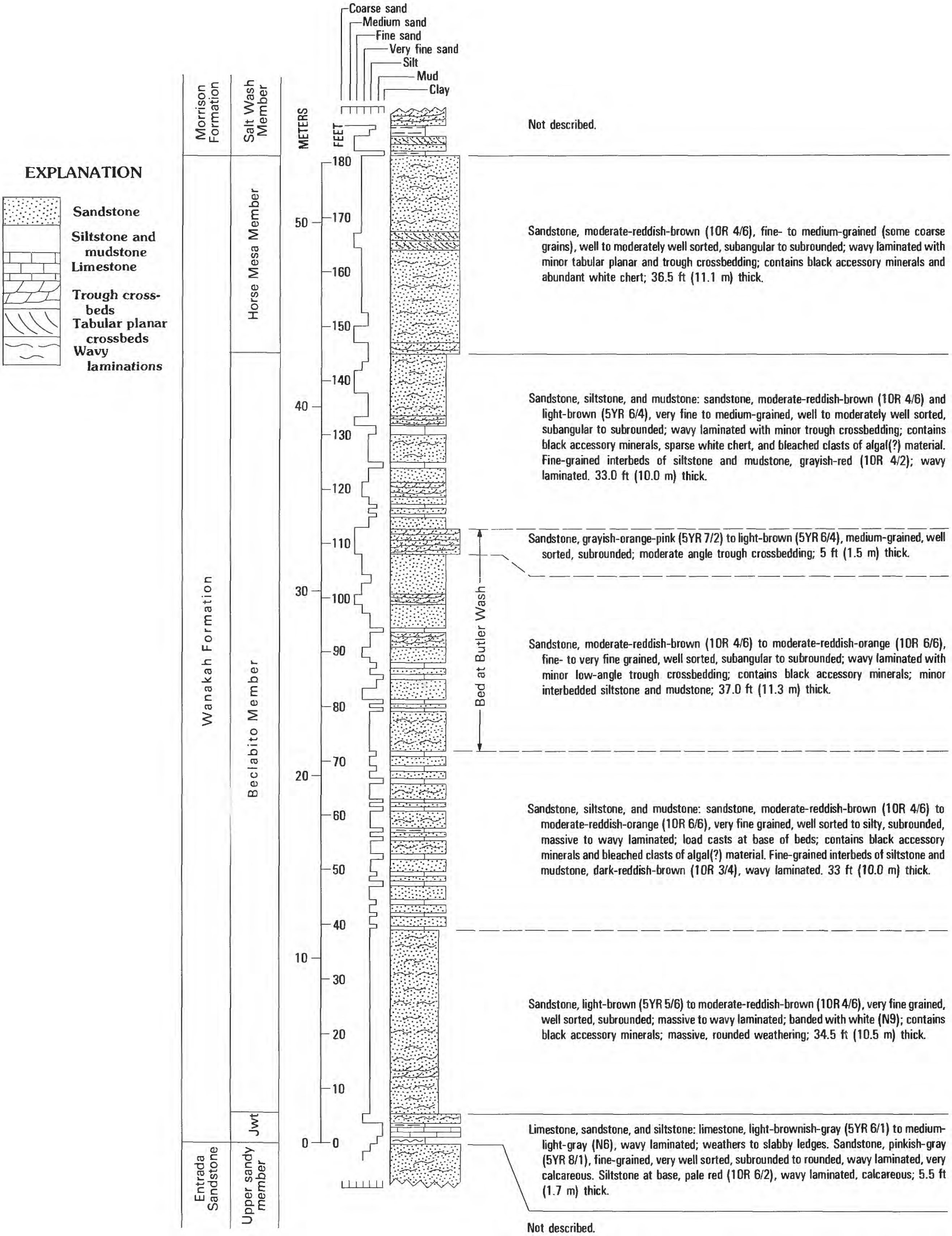

Figure A7. Reference section of the Wanakah Formation and its Todilto Limestone Member (Jwt), and type section of its Beclabito and Horse Mesa Members at Horse Mesa, Ariz. and N. Mex. Color terms are those of Goddard and others (1948).

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Chapter B

Stratigraphy and Nomenclature of Middle and Upper Jurassic Rocks, Western Colorado Plateau, Utah and Arizona

By FRED PETERSON

A revision of units in the
San Rafael Group and the
Morrison Formation

U.S. GEOLOGICAL SURVEY BULLETIN 1633-B

REVISIONS TO STRATIGRAPHIC NOMENCLATURE OF JURASSIC AND CRETACEOUS ROCKS
OF THE COLORADO PLATEAU

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REVISIONS TO STRATIGRAPHIC NOMENCLATURE OF JURASSIC AND CRETACEOUS ROCKS OF THE COLORADO PLATEAU

Stratigraphy and Nomenclature of Middle and Upper Jurassic Rocks, Western Colorado Plateau, Utah and Arizona

By Fred Peterson

Abstract

Recent studies on the west side of the Colorado Plateau revealed certain key problems in the existing stratigraphic concepts and terminology for the upper part of the San Rafael Group and the Morrison Formation:

1. An eolian sandstone unit at Black Mesa, Ariz., that was formerly known as the Cow Springs Sandstone does not interfinger with the Summerville and Morrison Formations, as had been supposed.
2. Marginal marine and eolian strata in the Kaiparowits basin, previously included in the Entrada Sandstone or the Morrison Formation, are separated from both of these formations by unconformities, are a sandstone facies of the Summerville Formation, and are sufficiently distinct to merit formation status.
3. A predominantly mudstone unit at the base of the Morrison, variously assigned to either the Salt Wash Member or the underlying Summerville Formation, is separated from the Summerville by an unconformity, interfingers with the Salt Wash, and is lithologically distinct from the Salt Wash.
4. A thick sequence of interbedded mudstone and sandstone in the Kaiparowits basin of southern Utah, included by some workers in the upper part of the Salt Wash Member, correlates largely with the Brushy Basin Member but is readily distinguished from both the Brushy Basin and the Salt Wash.

To rectify these problems, the following revisions in Jurassic stratigraphic nomenclature on the west side of the Colorado Plateau are here made:

1. The unit formerly known as the Cow Springs Sandstone is reduced in rank to the Cow Springs Member of the Entrada Sandstone of the San Rafael Group.
2. The southern facies of the Summerville Formation in the Kaiparowits basin is named the Romana Sandstone of the San Rafael Group.
3. The predominantly mudstone unit at the base of the Morrison Formation is named the Tidwell Member of the Morrison Formation.
4. The southern facies of the Brushy Basin Member in the southeastern Kaiparowits basin is named the Fiftymile Member of the Morrison Formation.

These revisions clarify stratigraphic relationships in the Jurassic System of the Colorado Plateau and facilitate regional sedimentologic and paleotectonic syntheses.

INTRODUCTION

Although considerable effort has been devoted to unraveling the stratigraphic and sedimentologic framework of Middle and Upper Jurassic strata on the Colorado Plateau, the rocks remain, as Oriel and Craig (1960, p. 43) pointed out more than 25 years ago, "the stormy center of prolonged geologic controversy." Many of the older problems concerning the stratigraphic relationships of these rocks have been studied and, to varying degrees, resolved, but a review of the accomplishments of the past 40 years shows that almost every resolution of a specific stratigraphic problem has led to another controversy.

This report revises the stratigraphic framework for these rocks based on an understanding of their relationships that has evolved during the course of field work during the past 20 years. The studies clearly demonstrate that the previous nomenclature is not only inadequate but confusing and, hence, the need for the revisions. This study chiefly considers two stratigraphic problems in the region: (1) the lateral relationships of the various lithologic units and (2) the nature of certain surfaces that are thought to be unconformities.

The stratigraphic nomenclature varies from region to region in the area of study on the west side of the Colorado Plateau (fig. B1). The new nomenclature and the approximate time-stratigraphic relationships of the various Middle and Upper Jurassic rocks are depicted schematically in figure B2.

The San Rafael Group is considered Middle Jurassic in age and the Morrison Formation is considered

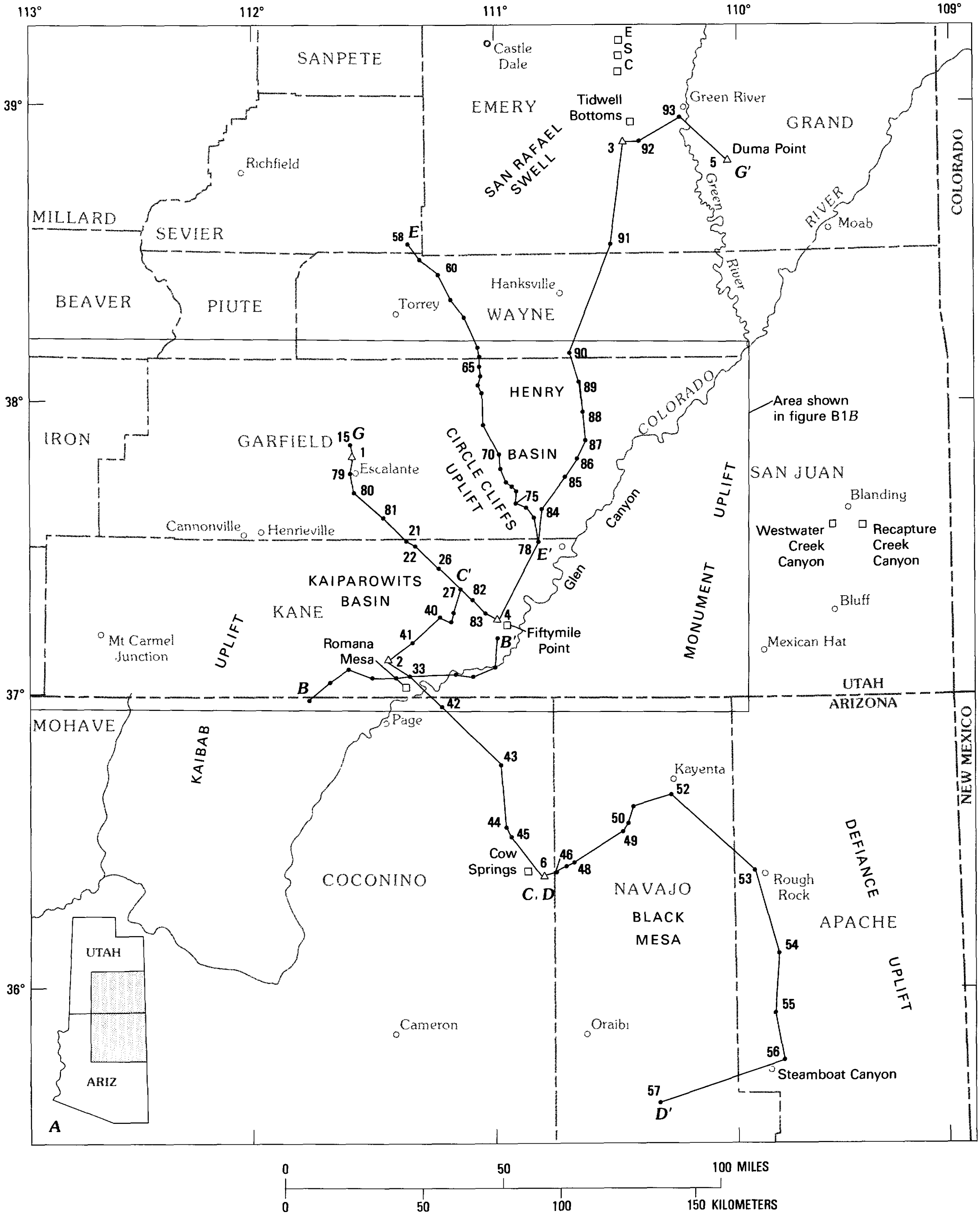


Figure B1 (above and facing page). Locations of measured sections, lines of stratigraphic sections, and other features mentioned in this report. Triangles indicate type or principal reference sections for units defined or revised herein. Names and locations of measured sections 1-93 are listed at end of text; stratigraphic sections *A–A'* through *F–F'* are presented in figures B5, B7, B8, B10, B11, B13, and B21. ***A*** (above), Regional map of southeastern Utah and northeastern Arizona. E, S, and C indicate Entrada, Summerville, and Curtis Points, respectively.

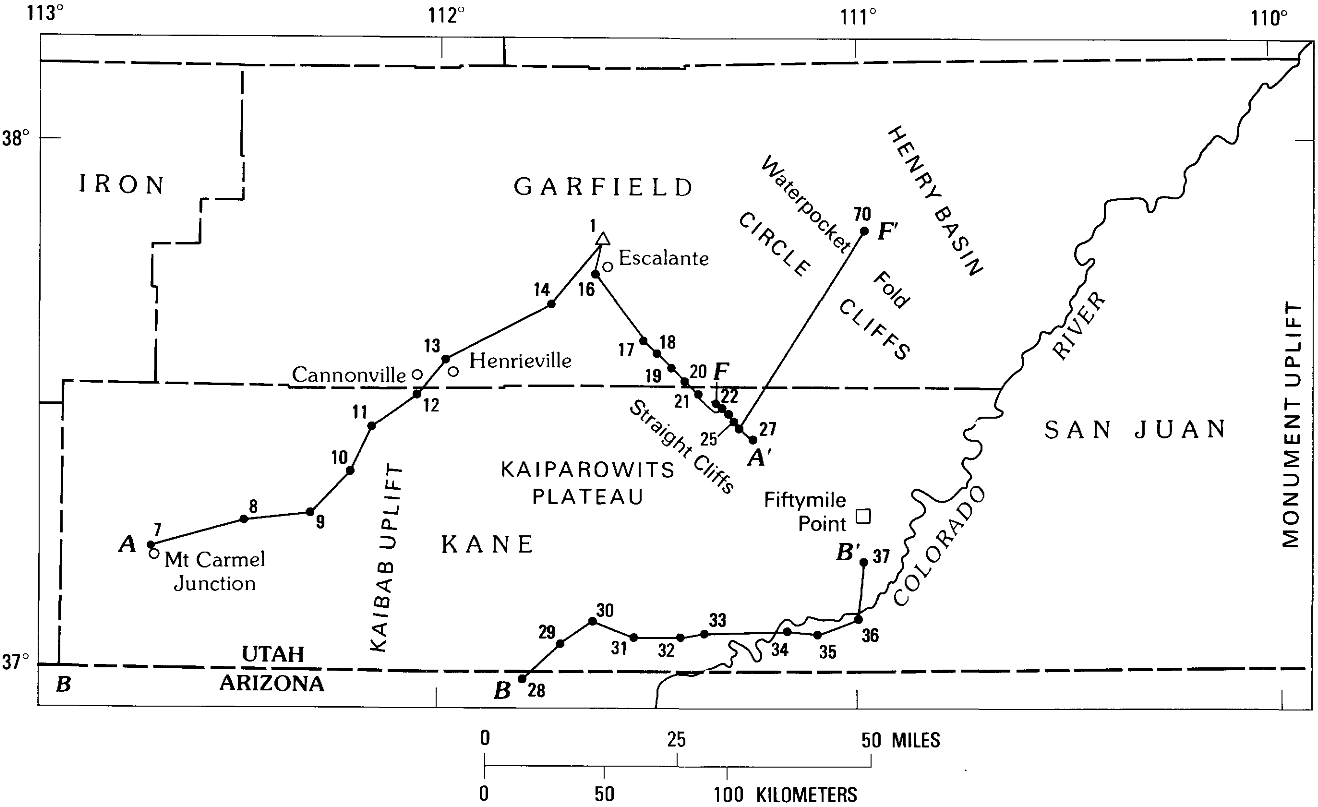


Figure B1—Continued. ***B***, Enlarged map of south-central Utah.

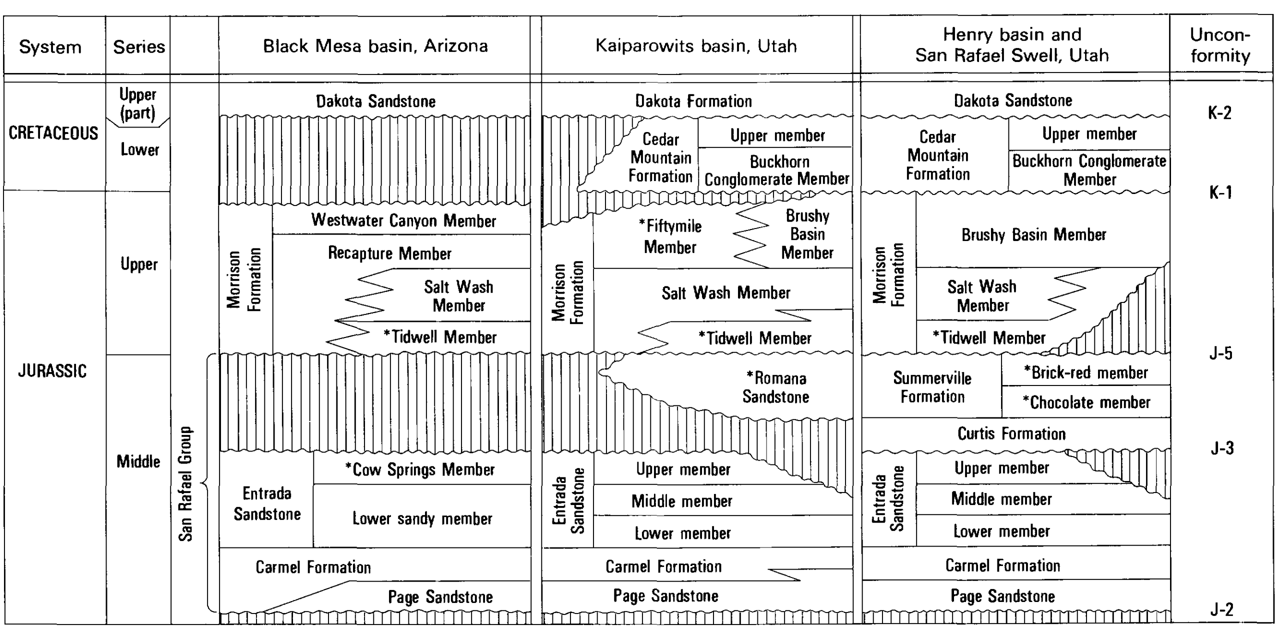


Figure B2. Stratigraphic nomenclature of Jurassic and Cretaceous rocks on the west side of the Colorado Plateau that are discussed in this report. Asterisks indicate new or reassigned units. Unconformity designations at right are those of Pipiringos and O'Sullivan (1978).

Late Jurassic in age, according to a fairly recent evaluation by Imlay (1980). Throughout the region of study, the San Rafael is underlain by the Glen Canyon Group of Late Triassic to Early Jurassic age. The Morrison is unconformably overlain by either the Lower Cretaceous Cedar Mountain Formation or, where the Cedar Mountain is missing, the lowermost Upper Cretaceous Dakota Sandstone or Formation (Peterson and Kirk, 1977). Prior to deposition of the Dakota, the southwestern part of the Colorado Plateau was elevated, allowing the Dakota to truncate progressively lower formations southwestward.

This report only discusses strata in the middle and upper parts of the San Rafael Group and the Morrison Formation in the western part of the Colorado Plateau (fig. B1). Stratigraphic relationships of older strata in the San Rafael Group, including the Temple Cap, Page, and Carmel Formations, were described in an earlier report (Peterson and Pipiringos, 1979).

Middle and Upper Jurassic strata on the Colorado Plateau contain several marker surfaces of broad regional extent that help to separate the sedimentary sequence into smaller subdivisions of related formations or members. Conflicting opinions concerning the conformable or unconformable nature of these surfaces may be the result of differences in the surfaces at different localities. Recent studies by Condon and Kirk (1983), Kirk and Condon (1986), Peterson (1980b, 1984, 1986), and Santos and Turner-Peterson (1986) indicate that many of the basins and uplifts on the Colorado Plateau were tectonically active during the Jurassic, allowing the possibility that more or less continuous deposition in the deeper parts of some of the basins may have coincided with nondeposition or even erosion on flanking uplifts. Consequently, a surface that is unconformable in one area may be conformable in another area. Furthermore, an unconformity may be planar and separate beds that are parallel to that surface (a paraconformity in the terminology of Dunbar and Rodgers, 1957), making it difficult to determine from physical relationships whether any particular surface is indeed an unconformity. Locally, angular relationships are so slight that the beds appear to be parallel and conformable; in many such cases, angular beveling is only apparent when the broad regional relationships are considered. The lack of age-diagnostic fossils and conflicting results from isotopic dating also preclude accurate dating of these rocks, which would aid immeasurably in identifying any given surface as an unconformity.

ACKNOWLEDGMENTS

Discussions with S. M. Condon, L. C. Craig, M. W. Green, M. E. MacLachlan, R. B. O'Sullivan, C. E. Turner-Peterson, and H. D. Zeller were very helpful in the evolution of my thoughts concerning the relationships of Middle and Upper Jurassic strata of the Colorado Plateau. Capable assistance during the course of field work was lent by Craig Buth, J. D. Craig, M. A. Cutler, Brad Esslinger, M. J. Larson, D. C. Logan, Paul Milde, R. A. Moore, M. C. Pope, and J. V. Roberts. The report was significantly improved by the helpful comments and thoughtful reviews of M. E. MacLachlan, P. L. Martin, and R. B. O'Sullivan.

METHODS

About 150 or more sections were measured during this investigation. Sections were measured with Brunton compass and tape or with a 5-foot Jacob's staff where the beds dip more than approximately 5 degrees. All of the stratigraphic units proposed in this report, whether formations or members, are considered mappable entities, and some have already been mapped as informal stratigraphic units in the southeastern Kaiparowits region (Peterson, 1975, 1980a).

Crossbedding was measured by the methods of Reiche (1938) and Curray (1956), and vector resultants and consistency factors (vector mean strength) were calculated using a small programmable pocket calculator with programs prepared by M. B. Sawyer (U.S. Bureau of Mines) or the author. Where possible, 25 or more measurements were made at each locality. However, in some places, lack of outcrops or difficult access made it impossible to obtain 25 measurements and a smaller number (not less than 15) had to suffice. The vector resultants obtained from these studies aid in distinguishing some of the crossbedded eolian sandstone units. The consistency factor (Reiche, 1938; multiplied by 100 to eliminate decimals and read as percent) is a measure of vector strength and aids in evaluating the amount of variation between the individual crossbedding measurements that make up the resultant. Consistency factors near 100 percent (the maximum) indicate a tendency toward unidirectional-dipping cross-strata; low values reflect a tendency for the individual measurements to dip in many directions. In most cases, consistency factors less than about 20 percent are considered random and therefore meaningless.

MIDDLE PART OF THE SAN RAFAEL GROUP

The middle part of the San Rafael Group includes the Entrada Sandstone and correlative rocks formerly known as the Cow Springs and Henrieville Sandstones. Regional studies by Imlay (1980) indicate that the Entrada is Middle Jurassic (early to middle Callovian) in age.

Entrada Sandstone

The Entrade Sandstone was named by Gilluly and Reeside (1928) for strata at Entrada Point in the northeastern part of the San Rafael Swell (fig. B1). There, the formation consists largely of red, very fine- to fine-grained, flat-bedded silty sandstone and lesser quantities of interbedded red mudstone that tend to form slopes or a series of ledges and slopes. The term "earthy" facies has been applied to this sequence and similar rocks in and near the type section. South and east from Entrada Point, beds approximately correlative with the type Entrada grade into a cliff-forming red or white crossbedded sandstone unit referred to by some as the "slick rock" facies. Many authors consider the slick rock facies more representative of the formation as a whole than the earthy facies, not only because it is the dominant facies throughout much of the central and eastern parts of the Colorado Plateau, but also because it is present at many of the well-visited scenic and recreation areas in the region. West of the Monument upwarp the Entrada is separated from overlying beds in the San Rafael Group by the J–3 unconformity of Pipiringos and O'Sullivan (1978). O'Sullivan (1980b) showed that the J–3 unconformity fades out eastward along the crest of the Monument uplift and that the undivided Entrada east of the uplift is approximately equivalent to the Entrada and some of the younger beds of the San Rafael Group farther west.

Informal members

In most of the Colorado Plateau, the Entrada can be readily divided into several members based on contrasting lithologies. A representative section of the Entrada of the Colorado Plateau, consisting of three clearly defined members, is well exposed at Pine Creek, about 5 km north of Escalante, Utah, in the northern part of the Kaiparowits basin (fig. B1). Because this section is representative of the Entrada in much of the western Colorado Plateau, has frequently been cited (for example, Baker, Dane, and Reeside, 1936), and because it is readily accessible, the Pine Creek section is here proposed as the principal reference section for the Entrada Sandstone (figs. B3, B4; measured section 1 at end of report).

At Pine Creek, the three units of the Entrada are informally designated the lower, middle, and upper members. The lower member consists of a reddish-orange, flat-bedded, slope-forming silty sandstone of the earthy facies, similar to the sequence at the type section of the Entrada. (See map of nearby area by Zeller, 1973.) About 25 km southeast of Pine Creek, the lower member grades into a reddish-orange, largely crossbedded, cliff-forming slick rock facies that is present throughout the eastern and southern parts of the Kaiparowits basin. (See maps by Peterson, 1975, 1980a.) The lower member at Pine Creek apparently correlates with the entire section of the type Entrada in the northeastern part of the San Rafael Swell.

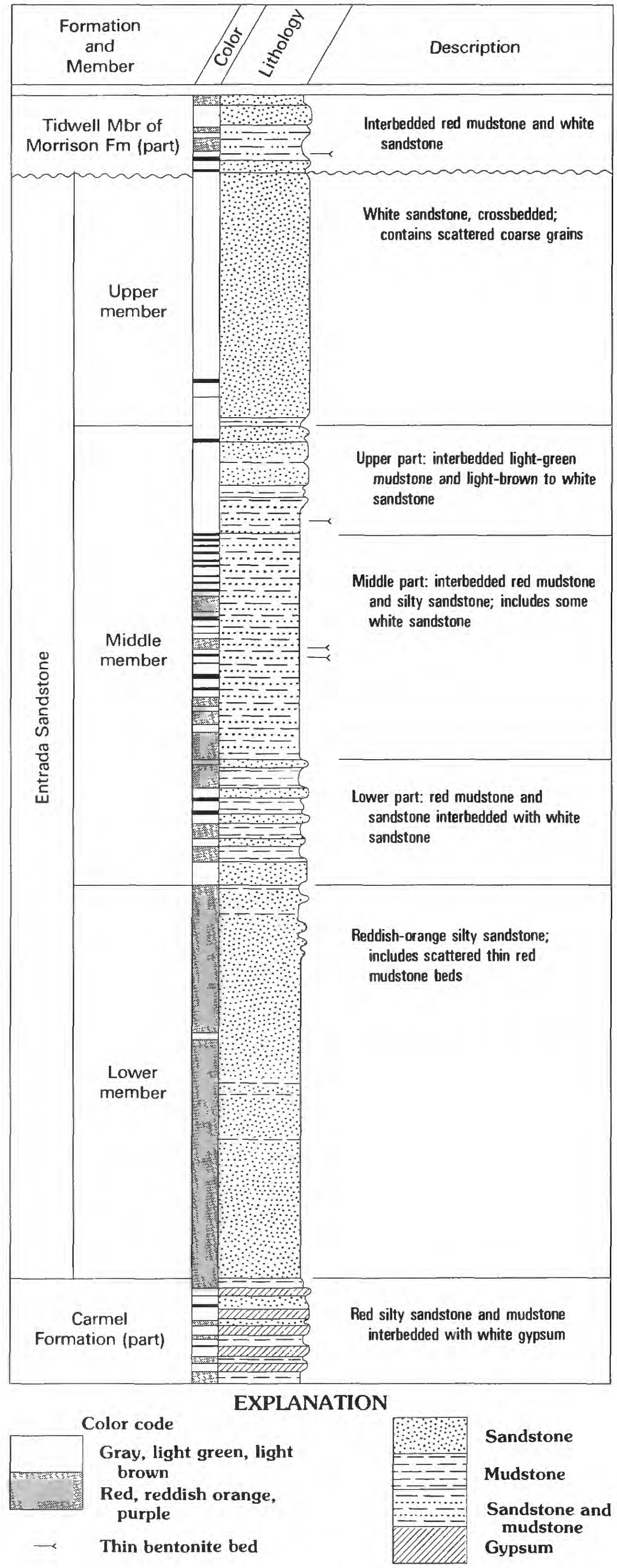


Figure B3. Columnar section for the principal reference section of the Entrada Sandstone at Pine Creek near Escalante, Utah. This is section 1 on figure B1.

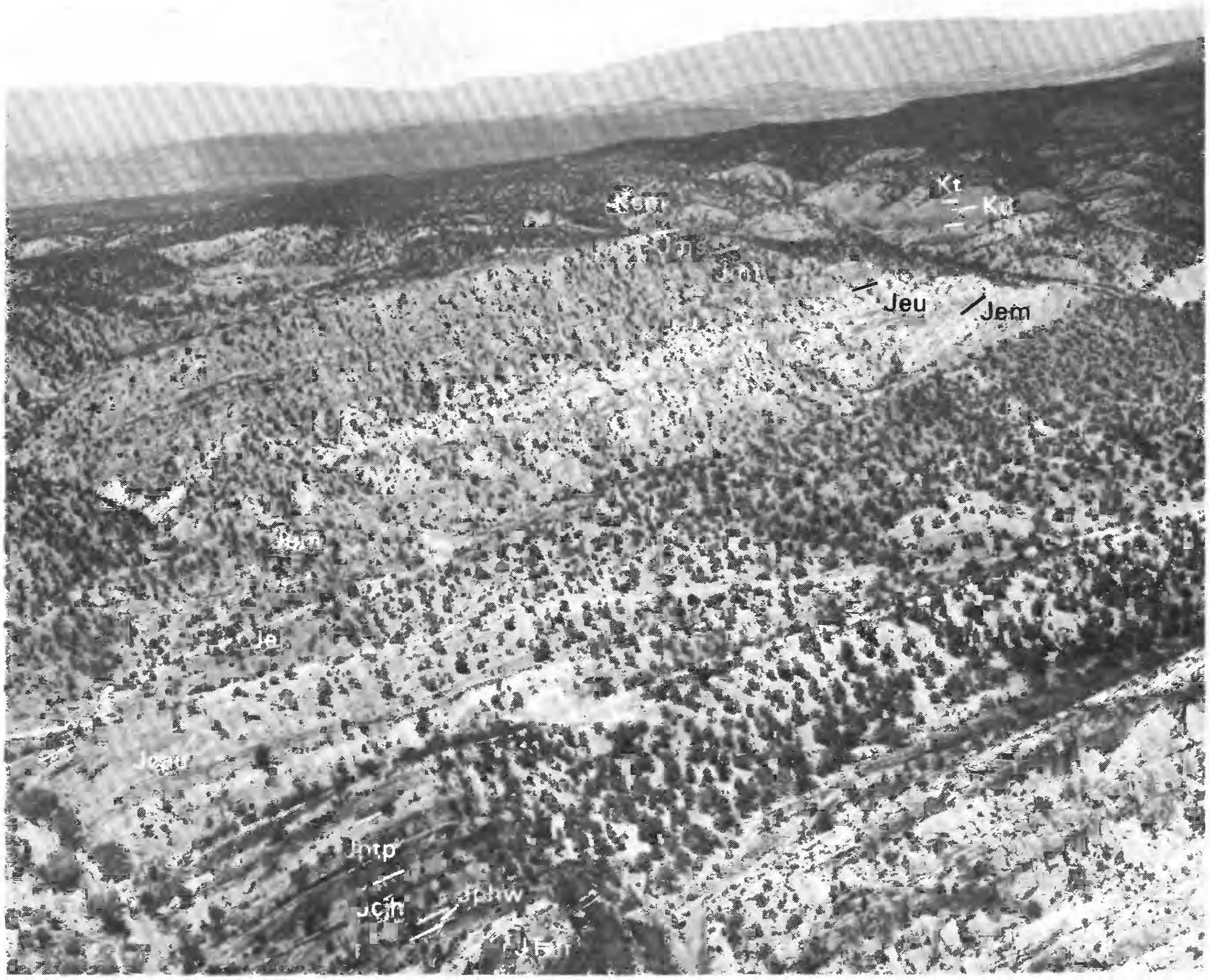


Figure B4. Photograph of the Pine Creek principal reference section for the Entrada Sandstone. The strata dip about 45 degrees to the upper left. For scale, the Entrada Sandstone is 314.1 m thick. The principal reference section at the end of the report was measured where the units are labeled. JTRn, Navajo Sandstone; Jphw, Harris Wash Tongue of Page Sandstone; Jcjh, Judd Hollow Tongue of Carmel Formation; Jptp, Thousand Pockets Tongue of Page Sandstone; Jcau, upper member of Carmel Formation; Entrada Sandstone: Jel, lower member, Jem, middle member, Jeu, upper member; Morrison Formation: Jmt, Tidwell Member, Jms, Salt Wash Member; Kcm, Cedar Mountain Formation; Kd, Dakota Formation; Kt, Tropic Shale.

The middle member at Pine Creek consists of red to light-gray or light-greenish-gray, generally flat-bedded sandstone and silty sandstone that tends to weather to slopes in the northern part of the Kaiparowits basin. To the southeast, the content of resistant crossbedded sandstone increases and the member weathers to steep slopes or cliffs, especially where protected by resistant overlying strata. The middle member is similar to the earthy facies of the lower member that is present in the northern and western parts of the Kaiparowits basin. The two members may be distinguished by the bedding, which tends to be thinner in the middle member (generally less than a meter thick) and thicker in the lower member (generally more than a meter thick). Also, the lower member is mostly reddish orange, whereas the middle member is reddish brown or reddish orange and contains several thin but conspicuous, very light-gray sandstone beds (fig. B3).

The upper member at the Pine Creek principal reference section consists of light-gray, largely crossbedded, cliff-forming sandstone. In a few localities, the upper member is reddish orange. Uppermost beds of the middle member at Pine Creek have been bleached to very light gray or light greenish gray (figs. B3, B4, B5) and therefore resemble the upper member in color. The light-colored parts of the two members are readily distinguished, however, by bedding differences: the middle member is predominantly flat-bedded and the upper

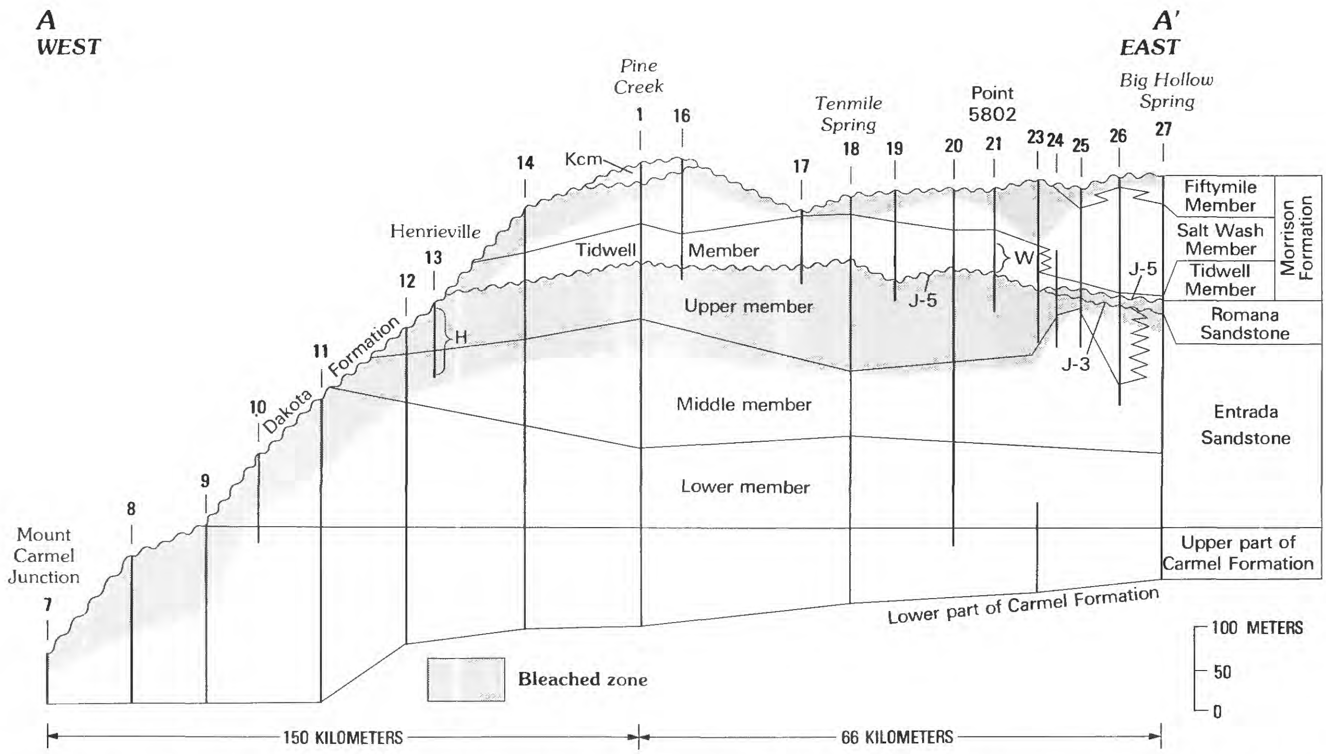


Figure B5. Stratigraphic section *A–A'* from Mount Carmel Junction, Utah, to the northeast side of the Kaiparowits basin showing bleached zones beneath unconformities. Section 13 at Henrieville is the type section of the Henrieville Sandstone (H) of Thompson and Stokes (1970); section 21 at Point 5802 is at or near the type section of the White Point Member (W) of the Summerville Formation of Thompson and Stokes (1970). Neither name is retained in this report. Kcm, Cedar Mountain Formation; J-3, J-5, unconformities of Pipiringos and O'Sullivan (1978). For location see figure B1.

member is predominantly crossbedded. The upper member is truncated by the J-3 unconformity in several places (figs. B6, B12). Locally along the Straight Cliffs (fig. B1), in an area of poor exposures, the lowermost beds of the upper member appear to grade southeastward into the uppermost part of the middle member (fig. B5).

The three members are also readily identified in the the Henry basin, where their lithologies are essentially the same as in the Kaiparowits basin. The lower member consists of flat-bedded silty sandstone of the earthy facies in the northern part of the Henry basin, and crossbedded sandstone of the slick rock facies in the central and southern parts of the basin. Along the Waterpocket Fold on the west side of the Henry basin, the middle member contains a cliff-forming crossbedded sandstone unit about 20 m thick that is lithologically similar to the slick rock facies of the lower member. Although the middle member is largely concealed by colluvium along the Waterpocket Fold, studies there suggest that crossbedded sandstone becomes progressively more dominant in the member toward the southern end of the fold. The upper member apparently is cut out in the northwestern half of the Henry basin by the J-3 unconformity. Part of the upper member is present in the southeastern half of the basin, but its relationships are not clear owing to poor access, the lack of stratigraphic marker beds or surfaces, and a southeastward change of its color to moderate reddish orange, similar to the colors in underlying members. Observations from a light plane suggest that the upper part of the upper member is cut out there but that the lower part may be present. Thus, the lower and middle members and part of the upper member appear to grade southeastward into moderately reddish-orange, cliff-forming crossbedded sandstone of the undivided Entrada in the southeastern Henry basin.

The lower contact of the Entrada is a surface generally marking a sharp vertical change in lithologies, but it is not an unconformity. Detailed work in the southeastern Kaiparowits basin along the Colorado River (now inundated by Lake Powell) showed some interfingering involving about 2 m of beds in the Entrada and Carmel Formations. The presence of large, highly irregular, slumped masses of Entrada that moved downward into the upper part of the Carmel in the Kaiparowits and Henry basins (Peterson, 1975, 1980a) supports the contention that no significant period of erosion, nondeposition, or compaction separates the Carmel and the Entrada.

Some of the colors in the Entrada and in other Jurassic formations were caused by bleaching, which has

Figure B6. Bleaching at the top of the middle member of the Entrada Sandstone (Jem) beneath the J–3 unconformity. Southwestern Kaiparowits basin at the type section of the Romana Sandstone (Jr) (fig. B1, section 2). The red band marker bed is the dark zone at the base of the Romana and is about 2.6 m thick.

caused considerable confusion in deciphering the stratigraphic relationships within the Entrada and between the Entrada and other formations. When viewed from a distance of half a kilometer or more, a color boundary between bleached and unbleached rocks appears as a planar surface that might easily be mistaken for a contact between stratigraphic units because it is so obvious. However, from a distance of several meters or tens of meters, the color boundary can be seen to cut across the bedding; it clearly is the result of postdepositional alteration processes (fig. B6). Regional stratigraphic studies also confirm this (figs. B5, B7, B8).

Bleached sandstone beds generally are white, very light gray, very light yellowish gray, very light greenish gray, or light grayish brown, and contrast markedly with the reddish-brown to reddish-orange unbleached sandstone beds. Bleached mudstone beds tend to be medium to light greenish gray, which also contrasts with unbleached dark-reddish-brown mudstones, but some unbleached mudstone beds deposited in marine and lacustrine waters are also medium to light greenish gray and therefore are not readily distinguished from bleached mudstones. For the most part, the thickness of rock affected by bleaching is considerably greater for porous, permeable sandstone strata than for less permeable mudstone strata. In the southwestern part of the Kaiparowits basin just northwest of Page, Ariz., the entire 200-m thickness of the Entrada, consisting largely of porous and permeable eolian sandstone, was bleached to white or very light gray (fig. B7). In this same area the bleaching fluids altered only the uppermost 3 m of mudstone in the underlying Carmel Formation.

Bleaching is common throughout the region beneath the J–3 unconformity (underlying the Curtis, Summerville, or Romana Formations) and the J–5 unconformity (base of the Morrison Formation), and it is especially extensive beneath the unconformity at the base of the Upper Cretaceous Dakota Formation. The bleaching is particularly evident where the Dakota contains coaly and carbonaceous mudstone beds and where underlying rocks consist of porous, permeable sandstone. This relationship strongly suggests that the bleaching was

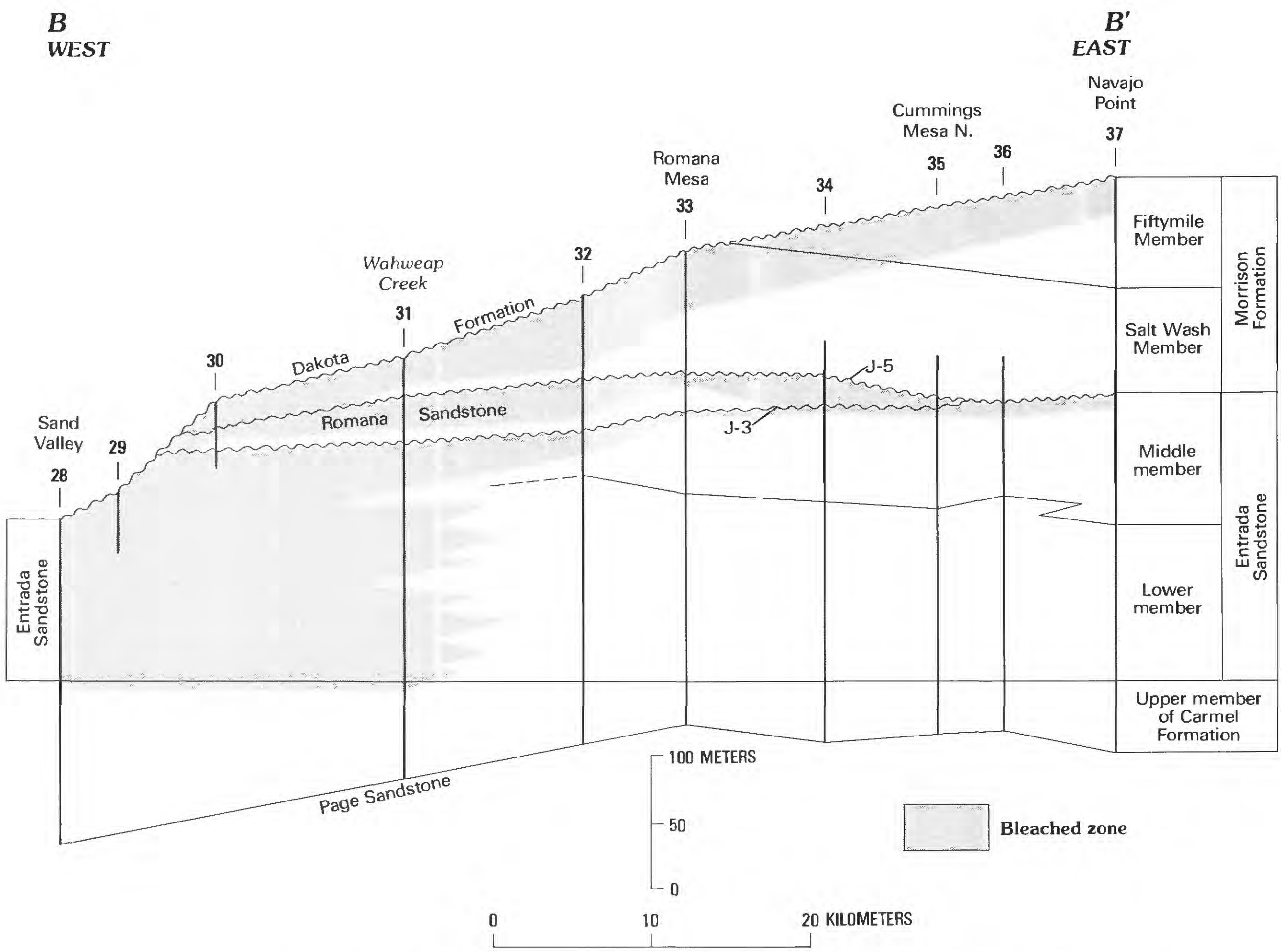


Figure B7. Stratigraphic section *B–B′* along the south side of the Kaiparowits basin showing bleached zones beneath unconformities. For location see figure B1.

caused by organic-rich fluids that seeped into underlying strata and altered some of the minerals, especially feldspars and the more readily destroyed iron-bearing minerals. Mackin and Schmidt (1956) and Lynd (1960) showed that organic-rich fluids can easily destroy iron-titanium oxide minerals. Organic matter is not abundant in the Curtis, Summerville, Romana, and Morrison Formations, but the Romana and Morrison do contain petrified logs, and the Morrison also contains carbonized plant material, which is locally abundant in lacustrine mudstone and some fluvial sandstone beds (Peterson, 1980b). Thus, it appears likely that bleached zones beneath unconformities are the product of alteration by organic-rich fluids that seeped into underlying rocks while the overlying formation was being deposited. Alternatively, organic-rich fluids produced by soil-forming processes might have seeped into underlying rocks during an erosion interval and caused the bleaching.

Westward from the Kaiparowits basin to Mount Carmel Junction (fig. B5), a bleached zone is at the top of Jurassic rocks just below the Dakota Formation. The bleached zone cuts across the various formation and member boundaries and clearly bears no relationship to the stratigraphy. Elsewhere in the study area, bleached rocks are present beneath the J-3 and J-5 unconformities, indicating that the bleaching is not a phenomenon restricted solely to strata underlying the Dakota.

The Henrieville Sandstone of Thompson and Stokes (1970) was named for light-gray sandstone and mudstone strata that lie beneath the Dakota Formation near Henrieville in the western part of the Kaiparowits basin (fig. B9). Regional relationships show that these rocks are within the bleached zone beneath the Dakota Formation (fig. B5) and actually comprise the upper part of the middle member and all of the upper member of the Entrada of this report. Because the bleached zone has no significance as far as stratigraphic relationships are concerned, and because the Henrieville includes part or all of two stratigraphic units that do have stratigraphic importance and are recognized elsewhere in the Kaiparowits basin, the Henrieville Sandstone is not recognized here as a valid formation.

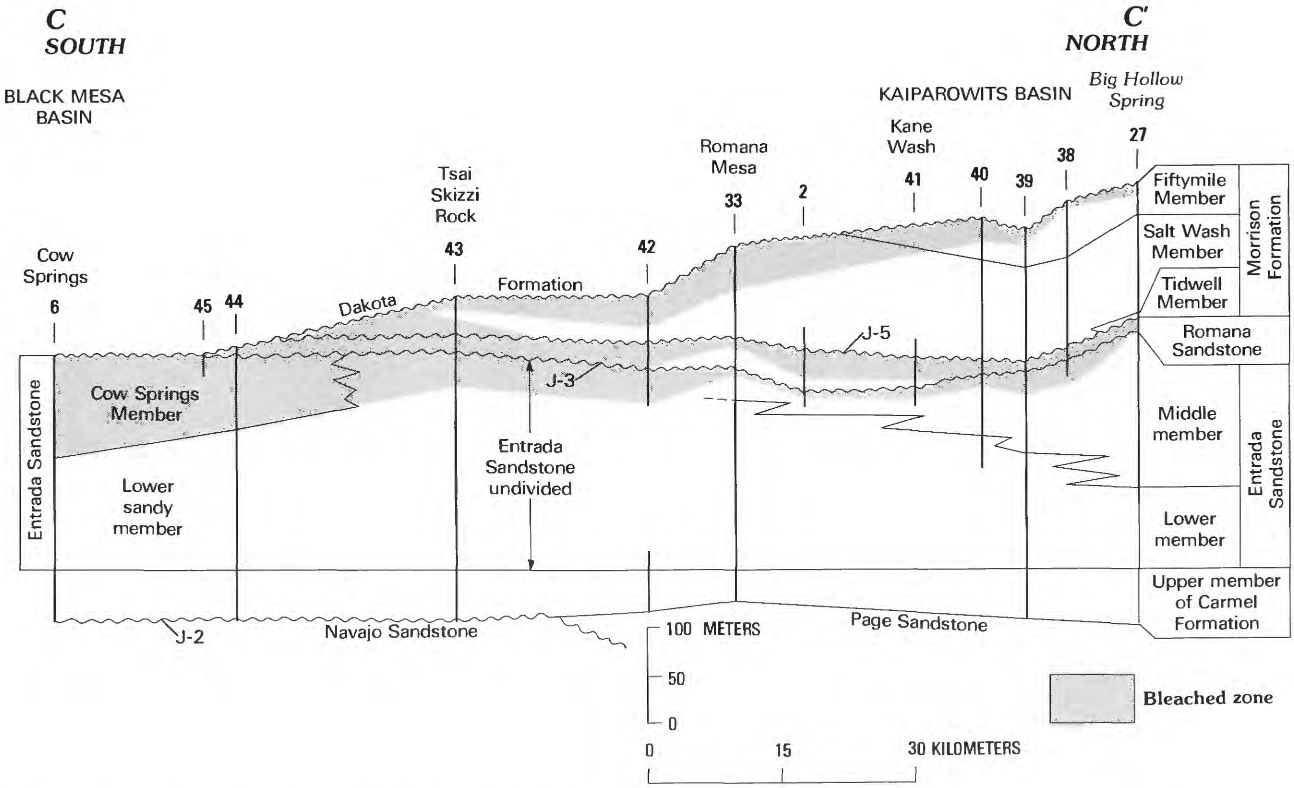


Figure B8. Stratigraphic section C–C′ from Cow Springs, Ariz., to the Straight Cliffs escarpment on the northeast side of the Kaiparowits basin. Section 6 at Cow Springs is the type section of the Cow Springs Member of the Entrada Sandstone; section 2 near Romana Mesa is the type section of the Romana Sandstone. For location see figure B1.

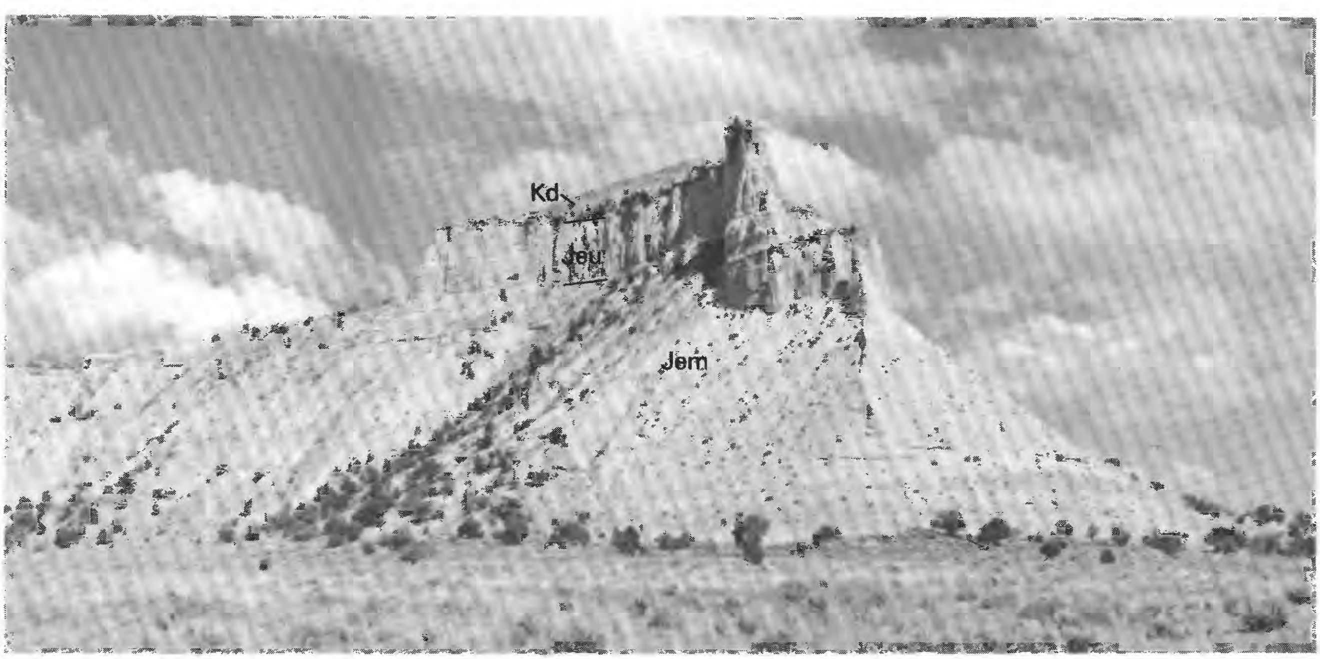


Figure B9. Middle (Jem) and upper (Jeu) members of the Entrada Sandstone exposed on an unnamed butte about 3 km west of Henrieville in the western Kaiparowits basin, NW¼ sec. 28, T. 37 S., R. 2 W., Garfield County, Utah. The Henrieville Sandstone of Thompson and Stokes (1970) is the bleached zone beneath the Dakota Formation (Kd) that extends down to red beds (dark gray in the photo) near the base of the slope. The upper member of the Entrada is about 25 m thick.

Cow Springs Member

Bleaching beneath unconformities is also present in the region south and southeast of the Kaiparowits basin (figs. B7, B8). Southeastward from the Kaiparowits region the Dakota truncates successively older strata, and at Cow Springs, Ariz., it lies on strata here considered to be part of the Entrada Sandstone.

The Entrada consists of two stratigraphic units at Cow Springs. A lower unit contains mostly reddish-orange crossbedded to flat-bedded sandstone that was called the lower sandy member of the Entrada by Harshbarger and others (1957). An overlying unit consisting largely of light-colored crossbedded sandstone was originally named the Cow Springs Sandstone by Harshbarger and others (1951). Like similar strata farther north, in southern Utah, the porous and permeable, crossbedded sandstone beds of the Cow Springs have been bleached to very light gray, very light greenish gray, or light grayish brown.

Exposures of the basal contact of the Cow Springs are poor at the type locality. A color boundary that cuts across bedding is identifiable in some of the small nearby canyons but is clearly a postdepositional phenomenon. To the east, at exposures just southwest of Kayenta, Ariz., and in the eastern and southeastern parts of Black Mesa, the large-scale crossbedded, cliff-forming sandstone of the Cow Springs can be distinguished reasonably well from the underlying Entrada strata, which consist of flat-bedded silty sandstone in that area. However, northwest of Cow Springs, around Square Butte and White Mesa (sections 44 and 45 on fig. B1), the contact between the Cow Springs and underlying beds of the Entrada is within predominately crossbedded sandstone strata and is difficult to define, even though the exposures are good. In this area, as at the type locality, the color boundary cuts across the bedding and is therefore clearly postdepositional.

Thus, the Cow Springs is closely related to underlying strata of the Entrada Sandstone but is also distinct from these underlying beds in much of its range. The Cow Springs serves as a stratigraphic marker that is useful in evaluating sedimentologic and paleotectonic conditions at the close of deposition of the Entrada Sandstone. For these reasons, the crossbedded, cliff-forming sandstone unit at the top of the Entrada at Black Mesa is here reduced in rank to the Cow Springs Member of the Entrada Sandstone. The Cow Springs was not included in the San Rafael Group by the original workers (Harshbarger and others, 1951, 1957), but its reassignment here to the Entrada places it within the San Rafael Group.

The Cow Springs Member may be roughly equivalent in age to the upper member of the Entrada in southern Utah or, as the correlations in figure B8 suggest, the Cow Springs may be slightly older than the upper member. Correlations along this line of section indicate that both members lie beneath the J-3 unconformity. Because the upper member is at the top of the Entrada but beneath the J-3 unconformity, and because it is similar lithologically to the Cow Springs, the two members once may have been deposited as a single large sandstone body. If so, the sandstone body was later divided into two parts by upwarping and erosion, during the J-3 erosion interval, in the area between Black Mesa and the Kaiparowits basin. The name Cow Springs is not applied to similar strata of the upper member of the Entrada in the Kaiparowits and Henry basins because the regional relationships of the two members are not yet clear. The Cow Springs could not be distinguished from underlying beds of the Entrada in the area north and northwest of White Mesa and Square Butte (sections 44 and 45, fig. B8).

The Cow Springs, as here defined, is recognized on the northwest side, part of the east side, and the southeast side of Black Mesa basin (fig. B10), where it contrasts markedly with underlying red sandstone and silty sandstone beds in the Entrada Sandstone. It is not present on the southwest side of the basin owing to southwestward regional truncation beneath the Dakota Sandstone, and it is difficult to distinguish from crossbedded sandstones of the Entrada on the west side of the basin. Farther east, in northwestern New Mexico, the Cow Springs is recognized on the southwest side of the San Juan Basin, and formation status (within the San Rafael Group) is retained there pending further studies (Condon and Peterson, 1986).

The relationships of the lower sandy, medial silty, and upper sandy members of the Entrada (Harshbarger and others, 1957) in Black Mesa basin to the members of the Entrada recognized farther northwest, in the Kaiparowits basin, are not clear. Tentative correlations suggest that the three informal members in the Black Mesa region may correlate with the lower member and possibly the middle member of the Entrada in the Kaiparowits basin.

Assignment of the Cow Springs Member to the Entrada means that its relationship to other Middle and Upper Jurassic rocks on the Colorado Plateau must be reconsidered. The Cow Springs was originally thought to be a southern eolian sandstone facies of parts of the Summerville and Morrison Formations (Harshbarger and others, 1957, p. 48). As shown in figure B8, however, the type Cow Springs is entirely older than the Morrison Formation and the Romana Sandstone, which is a correlative of the Summerville in the Kaiparowits basin discussed later in this report. Thus, the Cow Springs, at least as represented by strata at the type locality, cannot be considered equivalent in age to, and a facies of, the Summerville and Morrison Formations.

Large-scale crossbedded eolian sandstone, which typifies the Cow Springs, also is present in some beds of

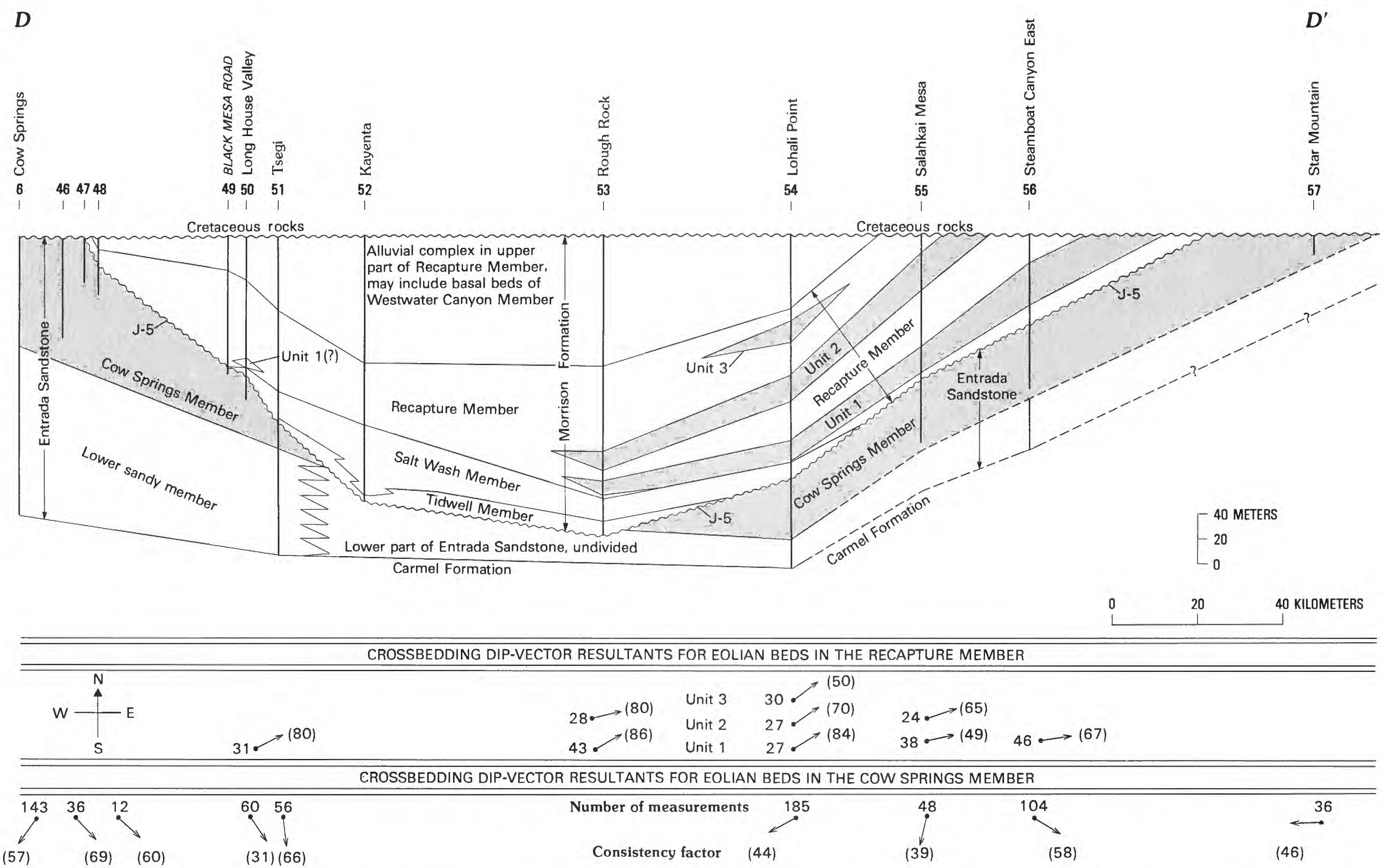


Figure B10. Stratigraphic section *D–D'* along the north, east, and south sides of Black Mesa, Ariz., showing stratigraphic relationships in the Morrison Formation and Entrada Sandstone and crossbedding dip-vector resultants for eolian strata in both formations. Units 1, 2, and 3 are eolian sandstone units in the Recapture Member of the Morrison Formation (locally these may include some fluvial strata). J–5, unconformity of Pipiringos and O'Sullivan (1978). The lower part of the Entrada includes the lower sandy and medial silty members and the beds at Baby Rocks (O'Sullivan (1978). Numbers by dip-vector resultants show number of measurements and consistency factor (in parentheses). For location see figure B1.

the Romana Sandstone and the Morrison Formation, and therefore the name Cow Springs has been applied to some of these eolian beds by previous workers. Studies of crossbedding dip vectors suggest one method of distinguishing eolian beds of the Cow Springs from those of the Romana and Morrison Formations. Crossbedding in the Cow Springs at Black Mesa tends to dip toward the southeast, south, southwest, and west (fig. B10). Some thin units within the Cow Springs have crossbedding that dips to the northeast but these anomalous dips are insignificant in dip-vector studies of an appreciable thickness of strata or of the entire member. Crossbedding in eolian strata of the Recapture Member of the Morrison Formation at Black Mesa dips consistently toward the northeast or east-northeast (fig. B10), about 70 degrees or more away from crossbedding dip vectors in the Cow Springs Member. A thick, largely crossbedded, predominantly eolian sandstone unit near the town of Bluff, Utah (fig. B1), is recognized as the Bluff Sandstone Member of the Morrison Formation (O'Sullivan, 1980a). Crossbedding dip vectors in the Bluff measured about 5 km north of Bluff, Utah, dip north 81 degrees east with a consistency factor of 70 percent, based on 40 measurements. These data suggest that the direction of crossbedding dip in eolian strata is a helpful method of distinguishing the Cow Springs from eolian beds in the Morrison Formation. Furthermore, eolian crossbedding in the Romana Sandstone of the southwestern Kaiparowits basin dips north 87 degrees east with a consistency factor of 81 percent, based on 55 measurements. Hence, the same method can be used to distinguish the Romana from the Cow Springs.

Studies northeast of Black Mesa suggest that the Cow Springs of the Black Mesa region grades into some of the flat-bedded silty sandstone beds of the Wanakah Formation in northeasternmost Arizona, southeastern Utah, and along the west side of the San Juan Basin in northwestern New Mexico, (O'Sullivan, 1978; Condon and Peterson, 1986). The unit called the Cow Springs Sandstone on the southwest side of the San Juan Basin (as restricted by Condon and Peterson, 1986) appears to correlate with the Cow Springs Member of Black Mesa.

In the south-central part of the San Juan Basin, eolian strata in the Recapture Member of the Morrison Formation can be distinguished from eolian strata in the Cow Springs by differences in lithologies (Peterson and Condon, 1984). Recent observations show that some of the eolian crossbedding in the Recapture Member dips southeast or east-southeast in the southern San Juan Basin, suggesting that crossbedding dip vector differences may not be as helpful in distinguishing Recapture and Cow Springs eolian strata in the San Juan Basin as they are farther west in Black Mesa basin.

The Entrada is interpreted as largely eolian and sabkha in origin (Kocurek and Dott, 1983). For the Entrada in general, eolian strata dominate over sabkha strata throughout most of the Colorado Plateau. Sabkha and possibly tidal-flat or shallow-water hypersaline marine deposits dominate in the westernmost part of the plateau and farther west in the easternmost part of the Basin and Range province of west-central Utah.

UPPER PART OF THE SAN RAFAEL GROUP

The upper part of the San Rafael Group includes the Curtis and Summerville Formations and the Romana Sandstone. The Romana is newly named in this report for uppermost San Rafael Group strata in the Kaiparowits basin that correlate with the Summerville Formation and possibly the Curtis Formation farther north. Regional studies by Imlay (1980) and Pipiringos and Imlay (1979) indicate that these beds are late Middle Jurassic (middle and late Callovian) in age.

Curtis Formation

The Curtis Formation was named by Gilluly and Reeside (1928) for sandstone strata lying above the Entrada Sandstone at Curtis Point in the northeastern part of the San Rafael Swell (fig. B1). The formation generally forms greenish-gray cliffs or ledges, which contrast markedly with red beds in underlying and overlying formations.

The Curtis is mainly composed of grayish-green, glauconitic, flat-bedded and crossbedded sandstone. Thin beds of grayish-green mudstone also are present, thin beds of dense gray limestone have been found near the depositional edge of the formation in the Henry basin, and a thin bed of gypsum was found at the top of the formation at Penitentiary Point about 10 km south of Hanksville, Utah. Stratigraphic relationships of the Curtis to other rocks in part of the region are shown in figure B11.

On the west side of the Colorado Plateau, the basal surface of the Curtis, or of the Summerville where the Curtis is missing, is the J-3 unconformity (Pipiringos and O'Sullivan, 1978). Intraformational folds or primary inclined bedding within the Entrada are truncated by this surface in several places in the Henry basin and the San Rafael Swell (fig. B12; Gilluly and Reeside, 1928; Hunt and others, 1953). Farther south, in the Kaiparowits basin, the Romana Sandstone, a southern facies of the Summerville, also truncates intraformational folds in the middle and upper members of the Entrada (figs. B5, B13). The time represented by the erosion surface probably was brief (Imlay, 1980, p. 77); the unconformity appears to die out eastward and is not recognized east of the Monument uplift on the east side of the Colorado Plateau (O'Sullivan, 1980b).

The Curtis is mostly a marine formation, as indicated by marine fossils found in the formation in the San Rafael Swell (Gilluly and Reeside, 1928). The

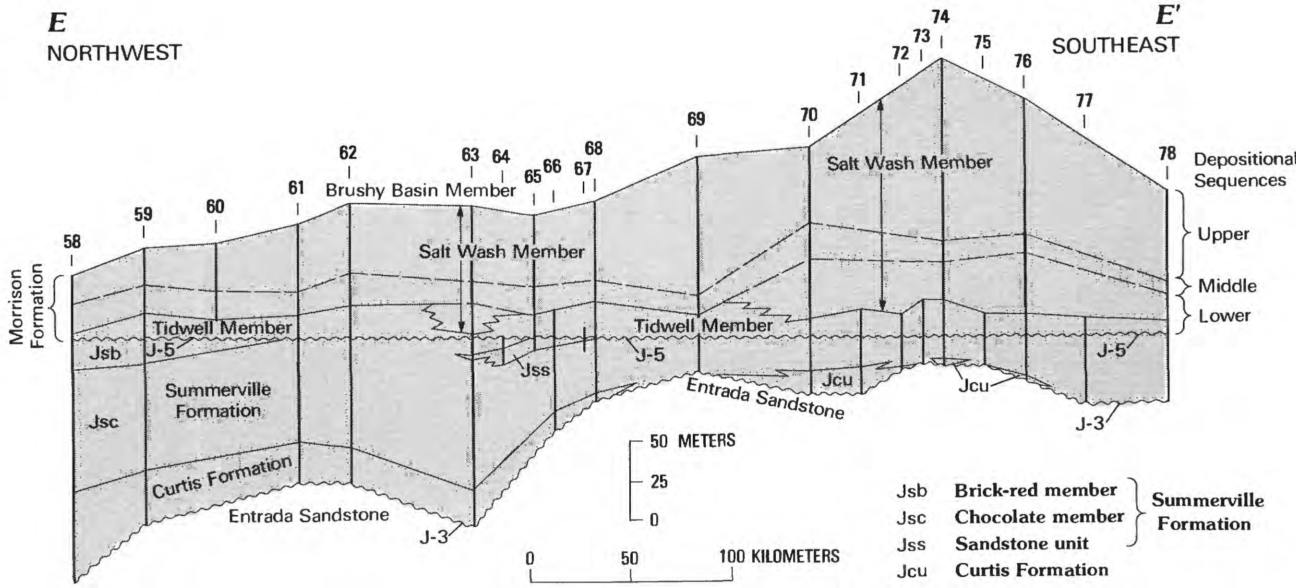


Figure B11. Stratigraphic section *E–E'* along the Waterpocket Fold showing stratal relationships in the upper part of the San Rafael Group and the Morrison Formation. J-3, J-5, unconformities of Pipiringos and O'Sullivan (1978). For location see figure B1.

presence of fairly abundant glauconite also suggests a marine origin. Thin lenses of gypsum indicate local evaporative conditions, probably during brief periods of shallowing of the Curtis sea, or perhaps in small and isolated embayments.

Summerville Formation

The Summerville Formation was named by Gilluly and Reeside (1928) for strata at Summerville Point in the northeastern part of the San Rafael Swell (fig. B1), where it consists largely of slope-forming reddish-brown mudstone. The formation is here divided into two members informally named the chocolate member and the brick-red member (fig. B11) based on slight differences in the color of the mudstones and differences in some of the lithologies.

Chocolate member

The chocolate member of the Summerville is as much as 96 m thick and is the part of the Summerville that is present at the type locality. The member consists largely of laminated to ripple cross-laminated, reddish-brown mudstone and siltstone, although it also contains minor thin beds of light-greenish-gray mudstone. The member tends to weather to fairly steep slopes or, where capped by a resistant sandstone bed near the base of the Morrison Formation, it may form steep slopes or cliffs (fig. B12). The chocolate member contains scattered thin beds of very fine-grained, laminated, reddish-brown sandstone. In the northern part of the Henry basin and in much of the San Rafael Swell, the member contains scattered thin beds as much as 3 m thick of white or very light-red gypsum. In some places, several sandstone beds are present in a poorly defined zone in the middle of the member, and these are helpful for determining stratigraphic relationships to the overlying Morrison Formation (fig. B11).

Brick-red member

The brick-red member, at the top of the Summerville, is only present in the western part of the San Rafael Swell, where it ranges in thickness from 0 to 21 m. These beds were recognized as slightly different from typical Summerville strata by Smith and others (1963, p. 30), but thus far they have received little study. The member consists largely of laminated to ripple cross-laminated, bright red mudstone. It also includes thin beds of very fine- to fine-grained, laminated, red or white sandstone and scarce but conspicuous cliff-forming beds (3–6 m thick) of pebbly, crossbedded, light-brown sandstone. Thin white gypsum beds, generally less than 0.3 m thick, are scarce but locally present. Thus far, no fossils have been found in, or reported from, the member.

The brick-red member ultimately may prove to be more significant than is now apparent. It is the youngest unit in the San Rafael Group and could be earliest Late Jurassic (early to middle Oxfordian) in age if it proves to correlate with the Redwater Shale Member of the Sundance Formation. The Redwater is found in much of Wyoming and extends southward into northeastern Utah

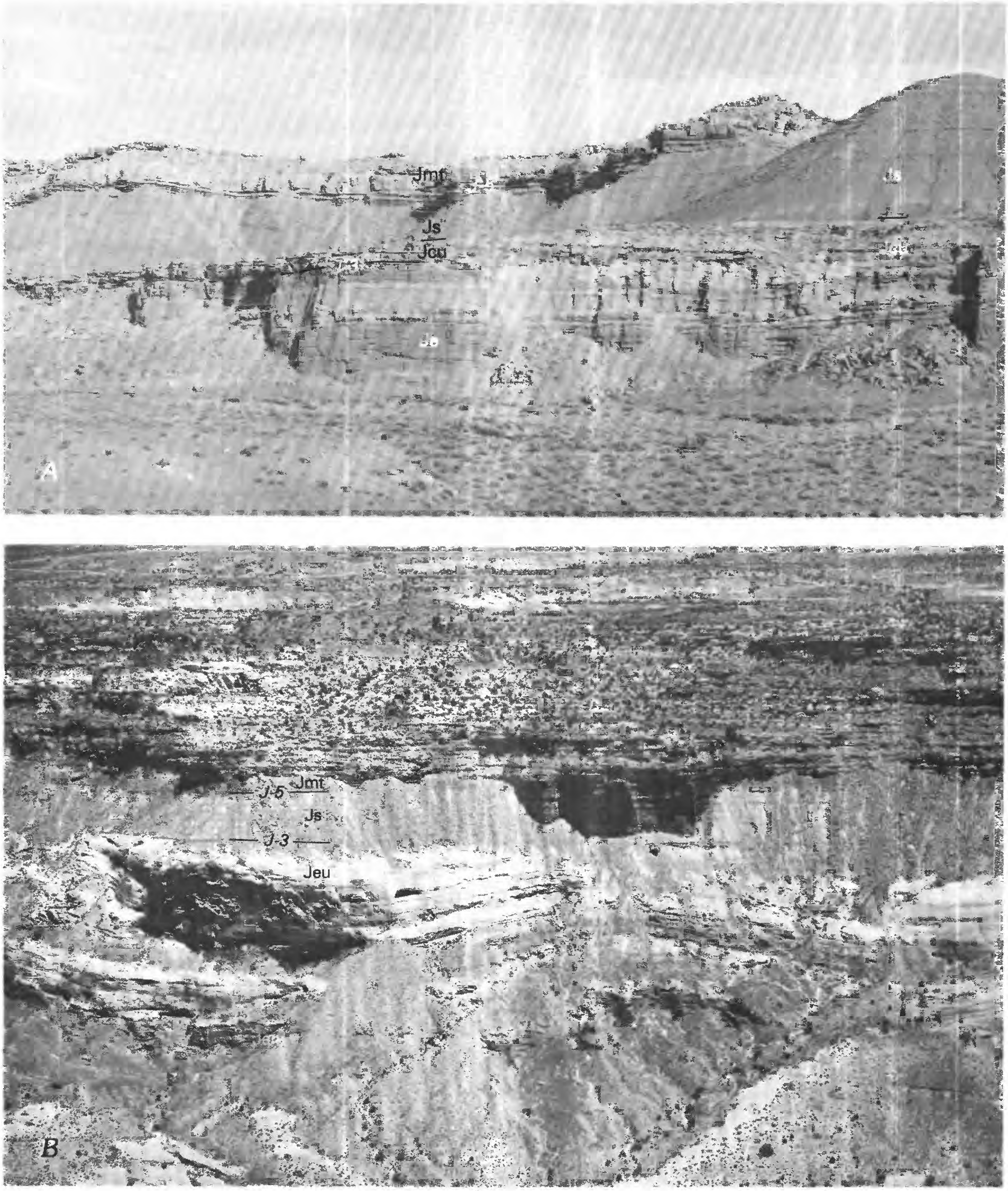


Figure B12. Truncation of beds beneath the J-3 and J-5 unconformities in southeastern Utah. ***A***, East side of San Rafael Swell, several hundred meters south of Interstate Highway 70 in the SE¼ sec. 7, T. 22 S., R. 14 E. ***B***, Folds in the Entrada Sandstone truncated beneath the J-3 unconformity along the Waterpocket Fold. Je, Entrada Sandstone: Jem, middle member, Jeu, upper member; Jcu, Curtis Formation; Js, Summerville Formation; Morrison Formation: Jmt, Tidwell Member, Jms, Salt Wash Member. For scale, in ***A***, the cliff-forming gypsum bed at the base of the Tidwell is about 6 m thick, and, in ***B***, the entire Tidwell Member is about 20 m thick.

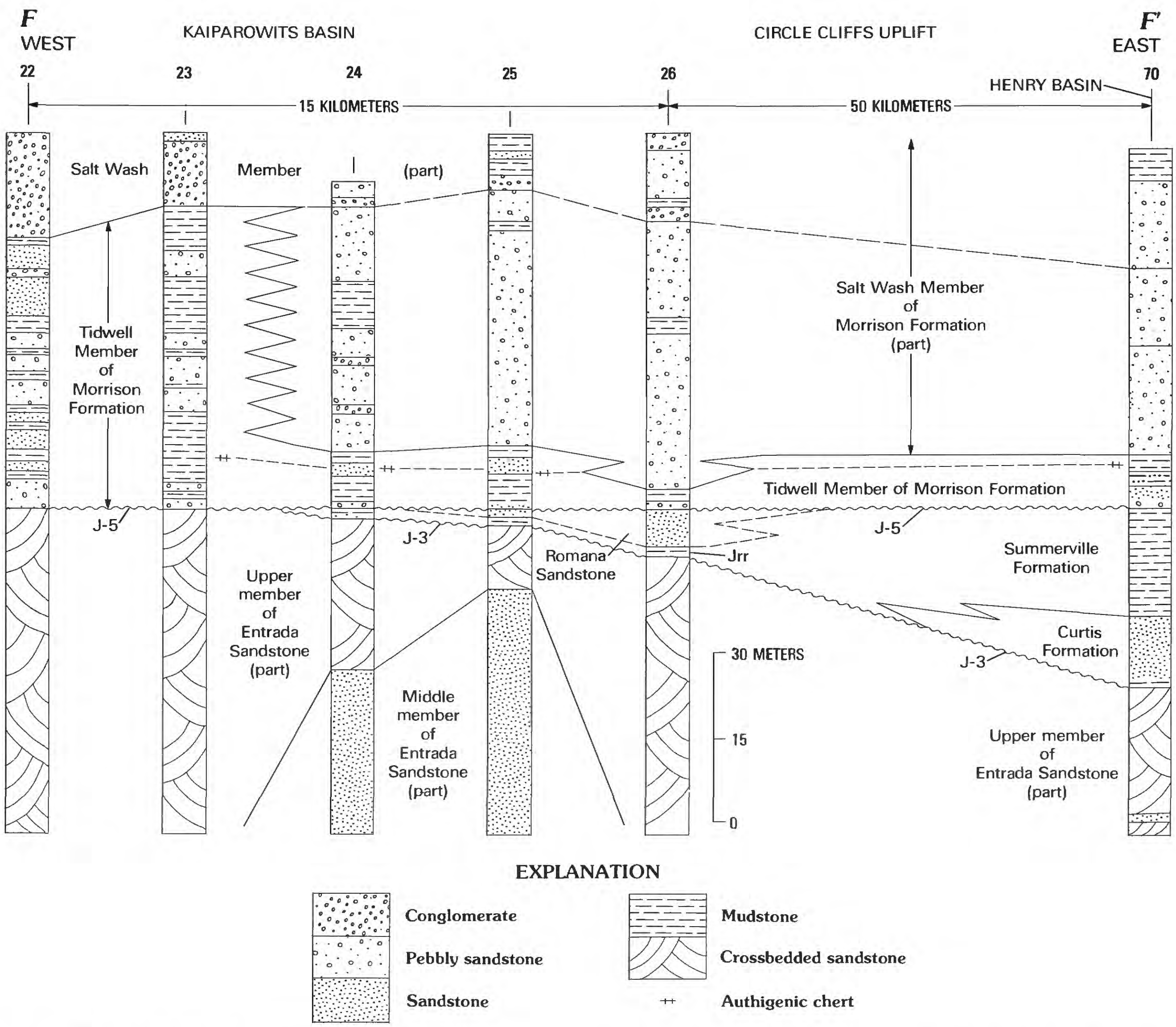


Figure B13. Stratigraphic section *F–F′* from the Henry basin to the Kaiparowits basin showing correlation of stratigraphic units and truncation of beds beneath the J–3 and J–5 unconformities. Jrr, red band marker bed at the base of the Romana Sandstone. For location see figure B1.

and northwestern Colorado, where it is truncated by the J–5 unconformity at the base the Morrison Formation (Pipiringos and O'Sullivan, 1978). The J–4 unconformity is at the base of the Redwater, but thus far an unconformity has not been identified at the base of the brick-red member. For this reason the brick-red member is here considered a part of the Summerville and of late Middle Jurassic age.

Romana Sandstone

Regional correlations indicate that rocks in the Kaiparowits basin, here named the Romana Sandstone, most likely correlate with the Summerville Formation (fig. B13), although correlation with the uppermost part of the Curtis cannot be ruled out. Correlations into the Kaiparowits region are based on the stratigraphic position of the Romana between the J–3 and J–5 unconformities at the top of the Entrada Sandstone and the base of the Morrison Formation, respectively (fig. B13). The Romana was previously referred to informally as a gray sandstone unit (Peterson, 1974) and as the sandstone at Romana Mesa (Peterson, 1975, 1980a).

The Romana Sandstone is here named for a sandstone unit in the Kaiparowits region as much as 46 m thick that tends to form a sheer cliff between the Entrada Sandstone and the Morrison Formation (fig. B14). The

Romana takes its name from Romana Mesa, an imposing promontory on the north side of Lake Powell about 12 km southeast of the type section (fig. B1, locality 2). The type section (fig. B14) is in Crosby Canyon, a small and easily accessible tributary canyon to Warm Creek canyon in southernmost Utah about 18 km north of Page, Ariz. Romana Mesa received its name from a nearby campsite (Camp Santa Francisca Romana) that was used by members of the Dominguez-Escalante expedition on November 5, 1776 (Bolton, 1950).

The formation is 44.2 m thick at the type section, where it consists largely of very fine- to fine-grained, moderately sorted to well-sorted, flat-bedded and crossbedded gray sandstone (fig. B15; measured section 2 at the end of this report). It contains scattered coarse and very coarse grains at or near the base in many places (fig. B16), especially where a basal red marker bed is absent. The coarse and very coarse grains are of great value in distinguishing the Romana from underlying sandstone beds of the Entrada Sandstone, which generally lack such coarse constituents. In the southwestern part of the Kaiparowits basin, the Romana locally contains scarce small pebbles of chert concentrated along some of the bedding planes.

In much of the structurally deeper part of the Kaiparowits basin, the basal part of the Romana contains a thin unit of flat-bedded red mudstone or silty sandstone, informally named the red band, which makes a convenient marker bed (fig. B15). The red band pinches out southeastward by lateral gradation into the gray sandstone that is typical of the rest of the formation. At localities where the red band is missing, the scattered coarse and very coarse grains are especially helpful in identifying the basal contact (fig. B16).

The Romana has a limited distribution; it has been mapped in the Kaiparowits basin in Kane County, Utah, and it extends southward into northernmost Coconino County, Ariz. Correlations in the southern part of the Kaiparowits basin (fig. B7) and south from there toward Black Mesa (fig. B8) indicate that the Romana is beveled to some degree by the unconformity at the base of the Morrison Formation and, farther south, it is cut out by the unconformity at the base of the Dakota Formation. The Romana Sandstone is not present at Cow Springs, Ariz., and neither it nor correlatives of the Summerville and Curtis Formations appear to be present anywhere else in the Black Mesa area.

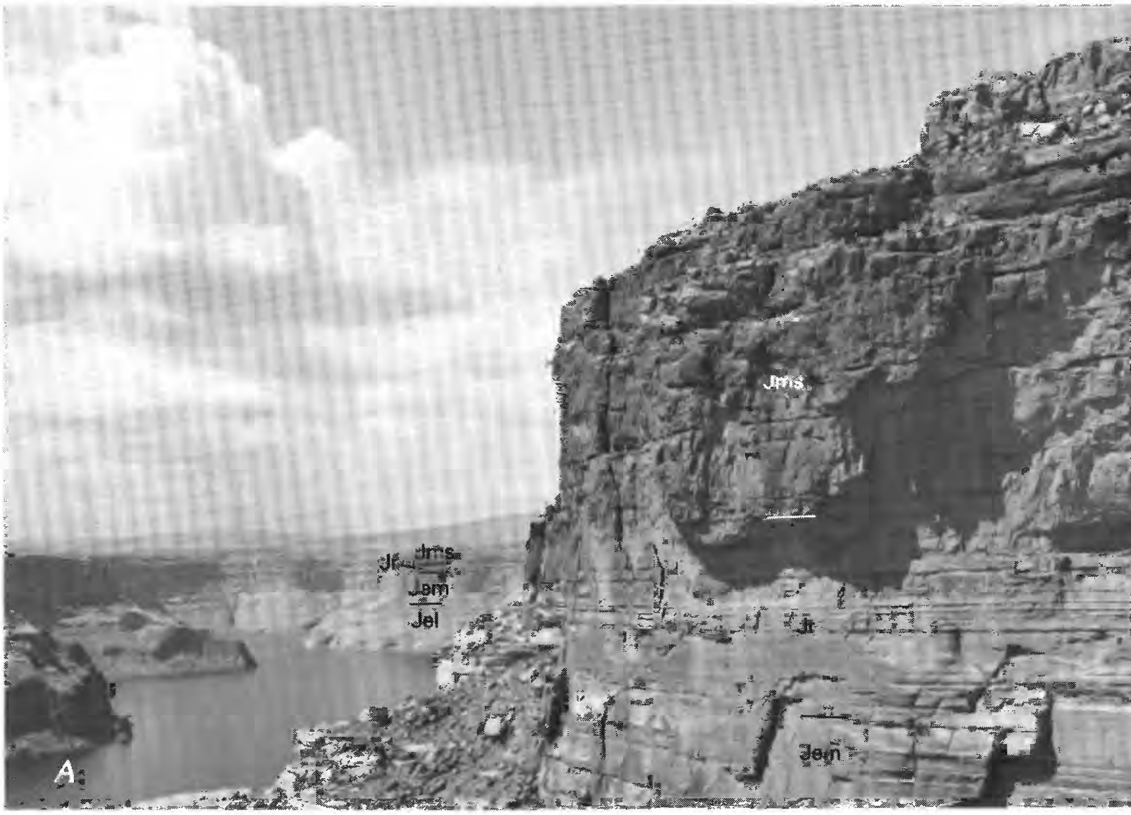
The Summerville, Curtis, and Romana are interpreted as having been deposited in or along the margin of a narrow seaway that extended as far south as the Kaiparowits basin. Paleontologic evidence indicates that the Curtis was largely deposited in normal marine waters (Gilluly and Reeside, 1928; Imlay, 1980) during the initial stages of advance of the seaway into south-central Utah. The chocolate member of the Summerville probably is a shallow-water hypersaline marine unit deposited mostly during a regressive phase when the seaway became restricted farther north, permitting gypsum to precipitate locally and intermittently. The brick-red member was deposited largely in overbank floodplain and mudflat environments and locally in hypersaline environments; most of the crossbedded pebbly sandstone beds were deposited by streams that flowed eastward or northeastward from a highland source area farther west.

The lower part of the Curtis thins by onlap onto the J–3 unconformity, but some of the upper beds of the Curtis grade southward and southeastward into basal Summerville red mudstone strata (fig. B11), as Hunt and others (1953, p. 69) showed in the Henry basin and McKnight (1940, p. 90) and O'Sullivan (1980) showed farther north, suggesting that hypersaline conditions may have existed in the shallow waters near the edge of the Curtis sea. The Romana Sandstone is interpreted as a southern facies of the Summerville Formation (fig. B17) and quite likely of the chocolate member of the Summerville. Crossbedding in eolian strata of the Romana dips mostly due east, suggesting that the shallow Summerville seaway in the Kaiparowits region was gradually filled in by windblown sand that prograded eastward across the southwestern margin of the seaway. Eolian sandstone beds are lacking in the Summerville of the San Rafael Swell, indicating that the dune field did not extend much farther north than the Kaiparowits region.

MORRISON FORMATION

The Morrison Formation was named by Eldridge (1896) for rocks exposed near the town of Morrison, in east-central Colorado. At the type locality, the formation largely consists of greenish-gray mudstone interbedded with thin beds of gray limestone and light-brown sandstone (Waldschmidt and LeRoy, 1944). Lithologically, the type Morrison is not typical of most of the formation on the Colorado Plateau, although it most closely resembles the Tidwell Member of this report. The Morrison is divided into eight members on the Colorado Plateau, including the two new members proposed in this report (fig. B18).

The Morrison can be divided into two large parts, each of which contains several members. The lower part includes the Salt Wash (Lupton, 1914), Bluff Sandstone (Gregory, 1938), and Tidwell (of this report) Members; the upper part includes the Westwater Canyon (Gregory, 1938), Fiftymile (of this report), Brushy Basin (Gregory, 1938), and Jackpile Sandstone (Owen and others, 1984) Members. Additionally, beds of the Recapture Member (Gregory, 1938) occur in both the lower and upper parts of the formation (fig. B18). Although there is some interfingering between strata in the two parts of the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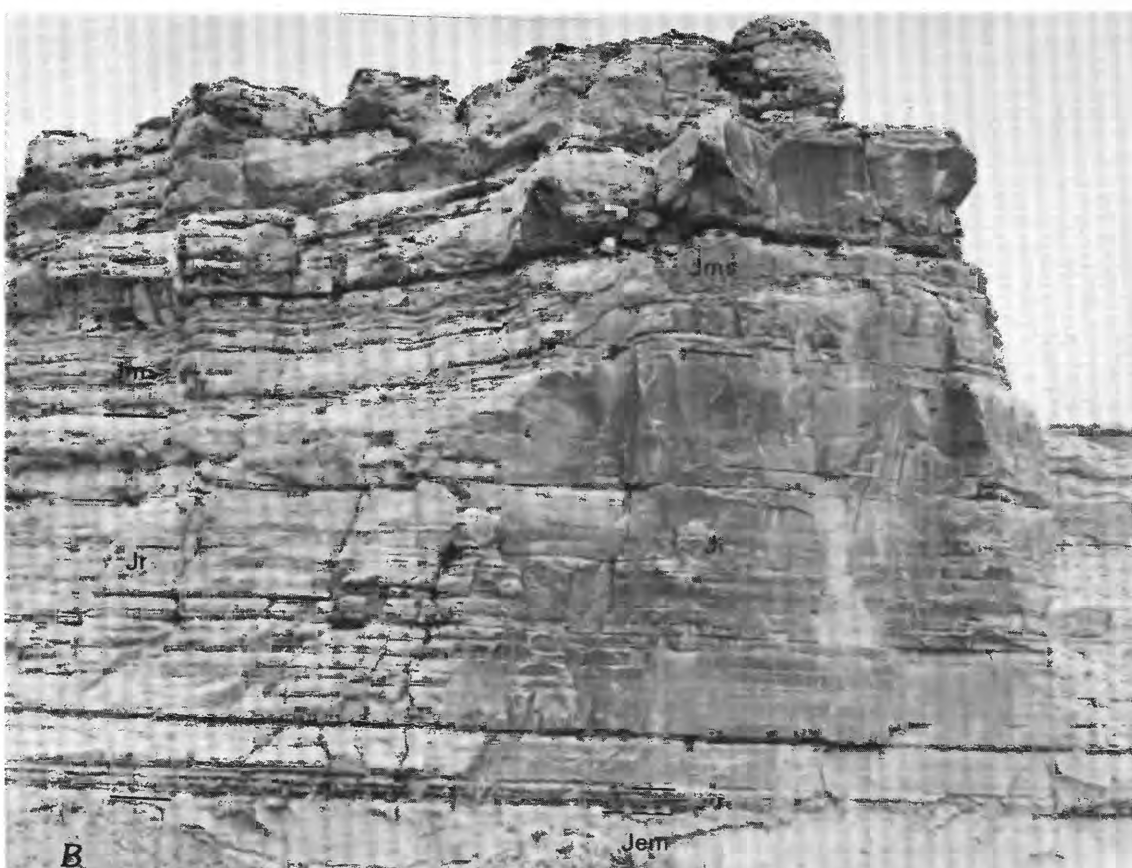
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formation on the west side of the Colorado Plateau, the interfingering generally does not involve as great a thickness of beds as the interfingering that exists between the various members within each of the parts.

The surface at the base of the Morrison Formation is considered an unconformity because it truncates underlying strata of the San Rafael Group (figs. B5, B7, B8, B10, B11, B12, B13). Slightly angular relationships can be seen locally as well as regionally along this unconformity (figs. B11, B12, B13; Gilluly and Reeside, 1928; Hunt and others, 1953). A stratigraphic section on the west side of the Henry basin (fig. B11) shows truncation of the brick-red member of the Summerville Formation in the northwestern part of the Waterpocket Fold. Farther southeast, the unconformity bevels out strata from the top of the chocolate member of the Summerville down through a sandstone unit in the middle of that member. Similarly, the unconformity bevels out the Romana Sandstone in the Kaiparowits basin (figs. B5, B13). Thinning of the Romana is not due entirely to depositional onlap, for a stratigraphic section on the northeast side of the Kaiparowits basin (fig. B15) shows that the red band at the base of the Romana does not thin toward the wedge edge of the formation but, instead, is truncated by the J–5 unconformity.

Tidwell Member

The Tidwell Member is here named for grayish-green mudstone strata at the base of the Morrison Formation exposed about 26 km southwest of the town of Green River, Utah (fig. B1, locality 3). The member takes its name from Tidwell Bottoms, a marshy area along the San Rafael River about 5–10 km north of the type section. The type section is shown in figures B19 and B20, and the measured type section is described at the end of the report. The name Tidwell was first applied to these beds in unpublished maps in the files of the U.S. Department of Energy (formerly the U.S. Atomic Energy Commission), which were made by R. G. Young in the 1950's (R. G. Young, oral communication, 1986), though no authorship was credited. I have decided to resurrect this name and formally apply it to these beds.

Figure B14 (on facing page). Outcrops of the Romana Sandstone (Jr) in south-central Utah. ***A***, Northwest side of Cummings Mesa, above Lake Powell in Glen Canyon. ***B***, Type section in Crosby Canyon, southwest side of the Kaiparowits basin in SE¼ sec. 8, T. 43 S., R. 4 E., Kane County, Utah. The type section was measured along the left side of the photographed area. The red band marker bed (Jrr) shown at the base in ***B***, is not present at the outcrop in ***A***; there, the basal contact of the Romana was identified by differences in grain size. (See fig. B16.) Entrada Sandstone: Jel, lower member; Jem, middle member. Jms, Salt Wash Member of the Morrison Formation. The Romana is 25.6 m thick in ***A*** and 44.2 m thick in ***B***.

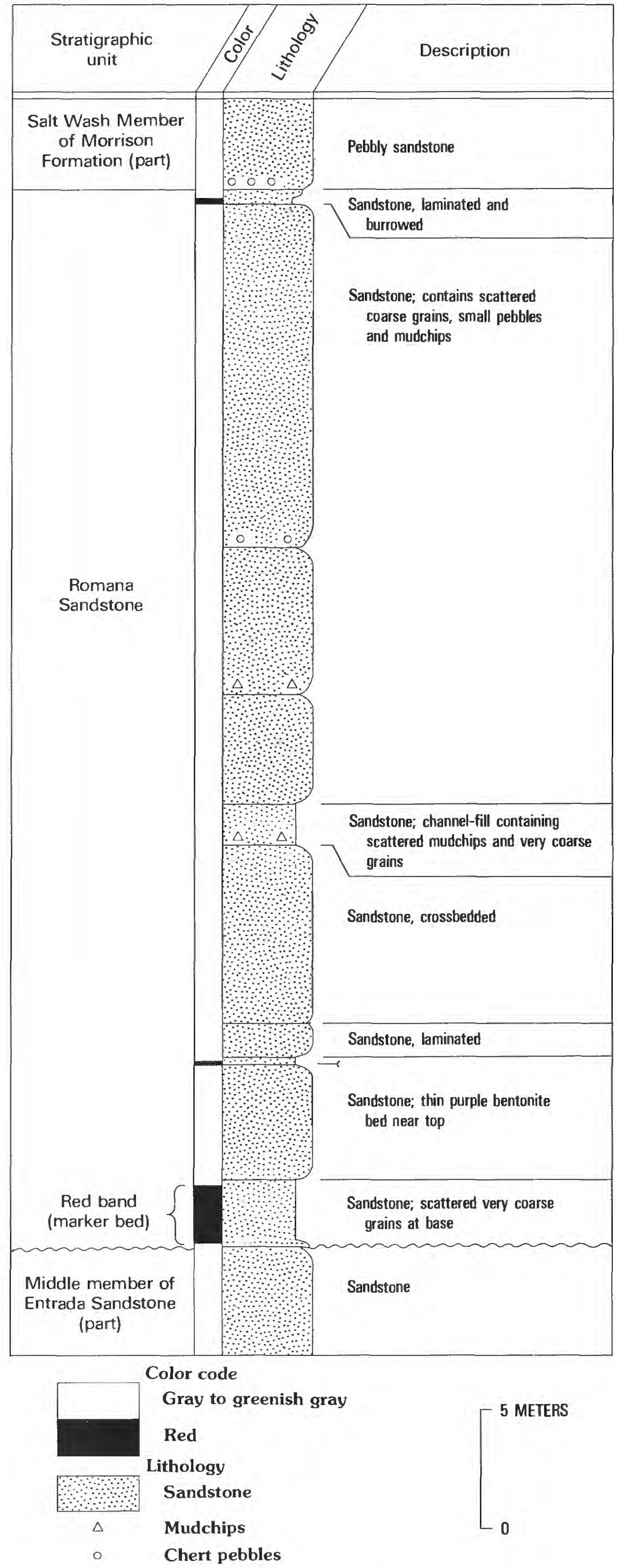

Figure B15. Columnar section of the type section of the Romana Sandstone in Crosby Canyon, southwestern Kaiparowits basin. For location, this is section 2 on figure B1.

Recognition of the Tidwell as a separate member of the Morrison helps resolve longstanding problems concerning the nature of the basal contact of the formation and the relationships of the Summerville Formation to the Morrison. Strata here assigned to the Tidwell apparently were not included in the original definition of the Salt Wash Member by Lupton (1914). (At the time of Lupton's study, strata from the base of the Entrada Sandstone up through the Lower Cretaceous Cedar Mountain Formation, including the Salt Wash Member, were considered part of the "McElmo Formation," which has since been abandoned as a formation name.) Lupton (1914) originally named the Salt Wash for exposures near Duma Point, about 34 km east of the type section of the Tidwell (fig. B21), although he did not recognize an unconformity at or near the base of the Salt Wash. Gilluly and Reeside (1928) and Gilluly (1929), in their study of the San Rafael Swell, recognized the unconformity at the base of strata here included in the Tidwell Member but they included these beds in the Salt Wash Member of the Morrison Formation. Hunt and others (1953) placed gray mudstone strata (Tidwell of this report) on the east side of the Henry basin in the Salt Wash and recognized an unconformity at the base of that member. However, on the west side of the basin the Tidwell Member is red (fig. B22), and they apparently included it with other red beds in the Summerville Formation. Later, but also along the west side of the Henry basin, Davidson (1967) placed the base of the Salt Wash at about the middle of the Tidwell at the base of the lowest limestone bed present. Near Green River, Utah, Trimble and Doelling (1978) placed the lower contact of the Salt Wash at the top of the thick gypsum bed that is here included in the lower part of the Tidwell. They considered the irregular surface at the top of this gypsum bed to mark an unconformity, but this surface is here interpreted to be a result of local dissolution of the gypsum rather than an erosion surface.

Figure B16. Scattered coarse and very coarse grains at the base of the Romana Sandstone (Jr) marking the contact with the middle member of the Entrada Sandstone (Jem). The middle member is very fine to fine grained and lacks the large grains found in the Romana. Dangling Rope Canyon on the southeast side of the Kaiparowits basin, sec. 17, T. 42 S., R. 8 E., Kane County, Utah. The pick head is scaled in inches.

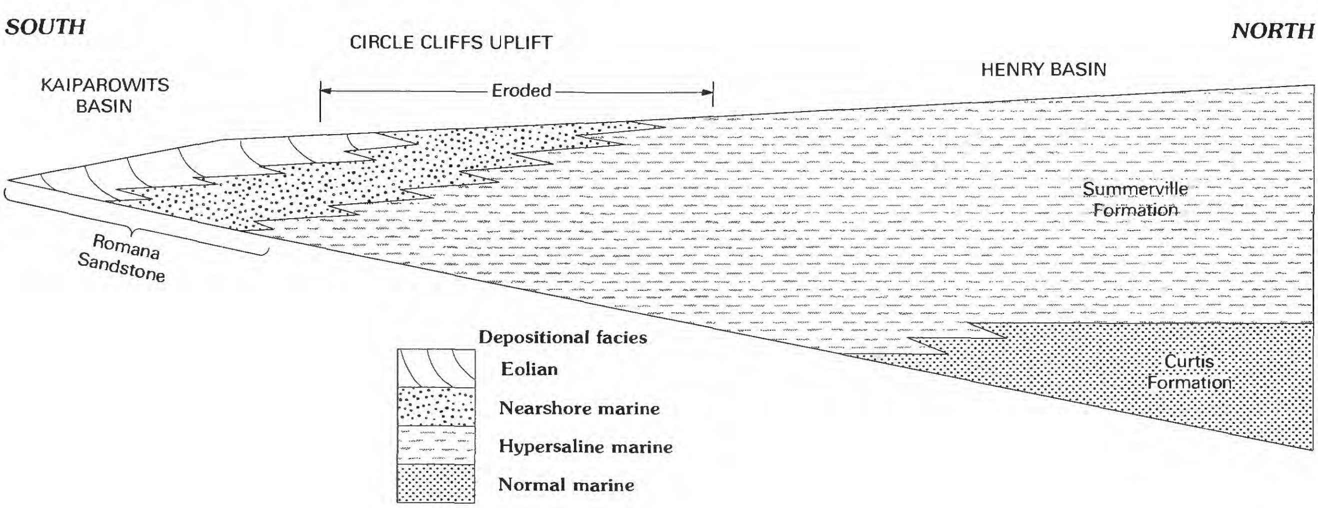

Figure B17. Schematic north-south section showing interpreted facies relationships among formations in the upper part of the San Rafael Group. (Not to scale.)

The Tidwell is at the base of the Morrison throughout most of the western part of the Colorado Plateau, with three known exceptions: (1) In much of the southeastern part of the Kaiparowits basin the Salt Wash lies directly on the J-5 unconformity (figs. B7, B8, B14, B21). (2) On the southwest side of the San Rafael Swell in the outcrop belt between the NE¼ sec. 28, T. 25 S., R. 5 E. and the NE¼ sec. 13, T. 24 S., R. 6 E., Sevier and

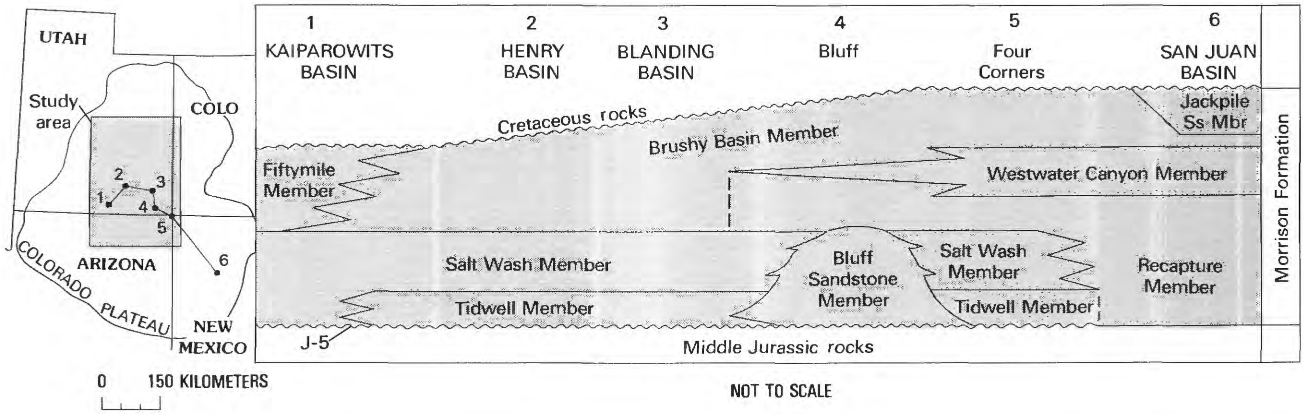

Figure B18. Relationships of members in the Morrison Formation on the Colorado Plateau. J-5, unconformity of Pipiringos and O'Sullivan (1978); this unconformity has not been clearly identified in the San Juan Basin.

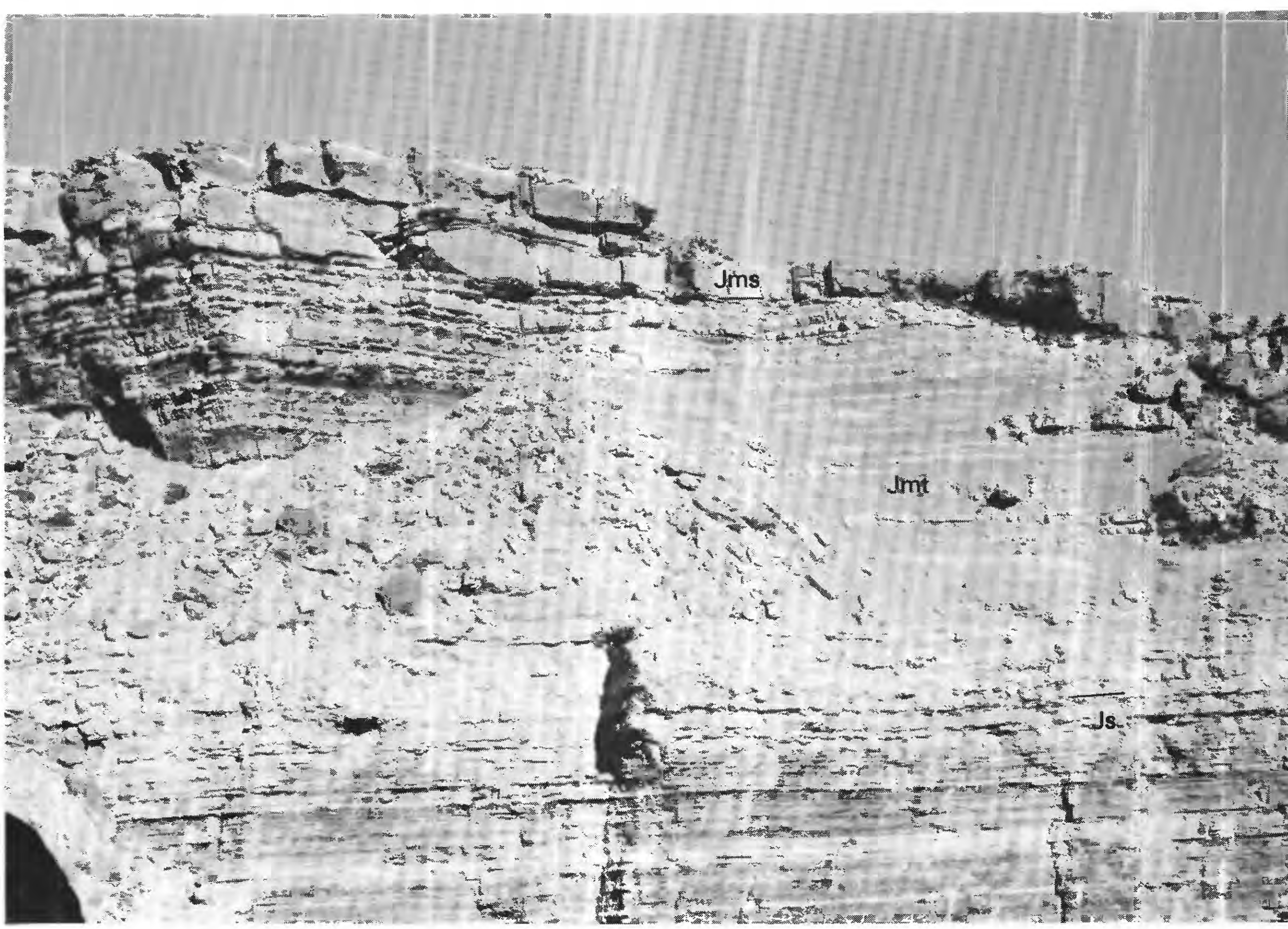

Figure B19. Type section of the Tidwell Member of the Morrison Formation (Jmt) about 26 km southwest of Green River, Utah. Js, Summerville Formation; Jms, Salt Wash Member of the Morrison Formation. The Tidwell Member is 29.3 m thick here. This is section 3 on figure B1.

Emery Counties, Utah, the entire lower part of the Morrison is locally missing and the Brushy Basin Member rests directly on the brick-red member of the Summerville Formation. In this area the Tidwell and Salt Wash thin and pinch out by onlap onto a paleotopographic high that is attributed to growth on the Emery uplift just before or during deposition of these members (Peterson, 1986). (3) At Black Mesa the Tidwell pinches out by onlap onto another paleotopographic and paleostructural high (fig. B10; Peterson, 1986).

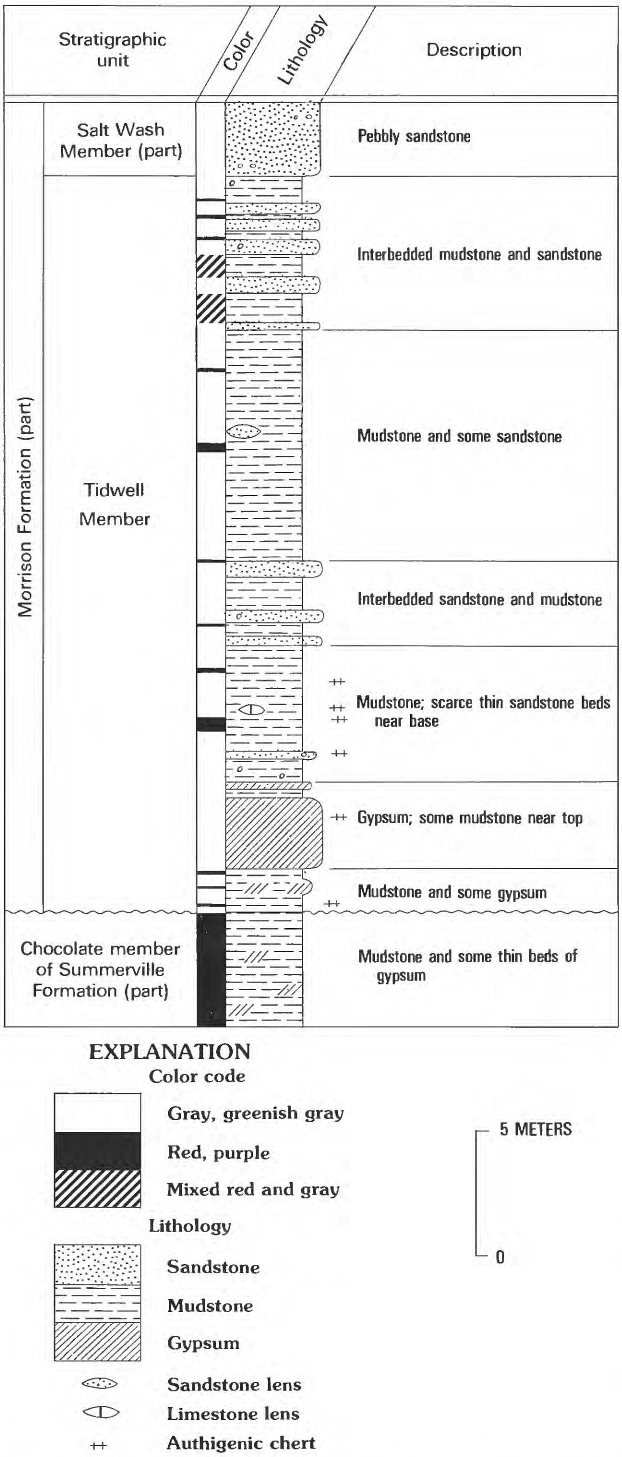

Figure B20. Columnar section of the type section of the Tidwell Member of the Morrison Formation, 26 km southwest of Green River, Utah. This is section 3 on figure B1.

Recognition of the Tidwell helps resolve some of the differences of opinion concerning the nature of the basal contact of the Morrison. The contact of the Morrison with the Summerville was thought to be conformable and interfingering by some workers and an unconformity by others. Either interpretation may seem justified, depending on where the contact is placed. If the lower contact of the Morrison is placed at the base of strata here included in the Tidwell Member, then an unconformity is apparent (for example, fig. B11). Some geologists considered erosional irregularities at the base of the lowest fluvial sandstone bed in the Salt Wash to represent the basal unconformity of the formation. However, this interpretation does not seem entirely consistent because erosional irregularities are present at the base of most fluvial sandstone beds.

On the other hand, interfingering between the Morrison and the Summerville can easily be interpreted if the contact is placed somewhere within beds here assigned to the Tidwell. The lowest limestone bed, selected by several geologists as the base of the Morrison, lies above the J-5 unconformity. Furthermore, limestone beds in the Tidwell are highly lenticular, and a contact based on this criterion would be placed at different stratigraphic positions in different areas. This variability would suggest that the boundary between the Morrison and Summerville is interfingering. Most if not all of these problems dealing with interfingering can be resolved by recognizing that the Tidwell Member interfingers with lowermost Salt Wash strata and that the proper base of the formation is the base of Tidwell strata.

The Tidwell ranges in thickness from 0 to 89 m, though it is generally about 8–21 m thick in the Henry basin and 0–30 m thick in the San Rafael Swell. The member consists largely of grayish-green calcareous mudstone at the type section (figs. B19, B20; section 3 at the end of this report), around the San Rafael Swell, and along the east side of the Henry basin. In contrast, red mudstone is the dominant lithology along the west side of the Henry basin (fig. B22) and in the Kaiparowits basin. Beds of white gypsum as much as 14 m thick are at the base of the member in the northern part of the Henry basin, around most of the San Rafael Swell, and at the type section (fig. B19). Thin beds of gray, dense limestone, some of which have a fetid odor, are present at most localities where grayish-green mudstone is the principal rock type. Dark-gray to dark-greenish-gray mudstone containing minute flecks of carbonized plant

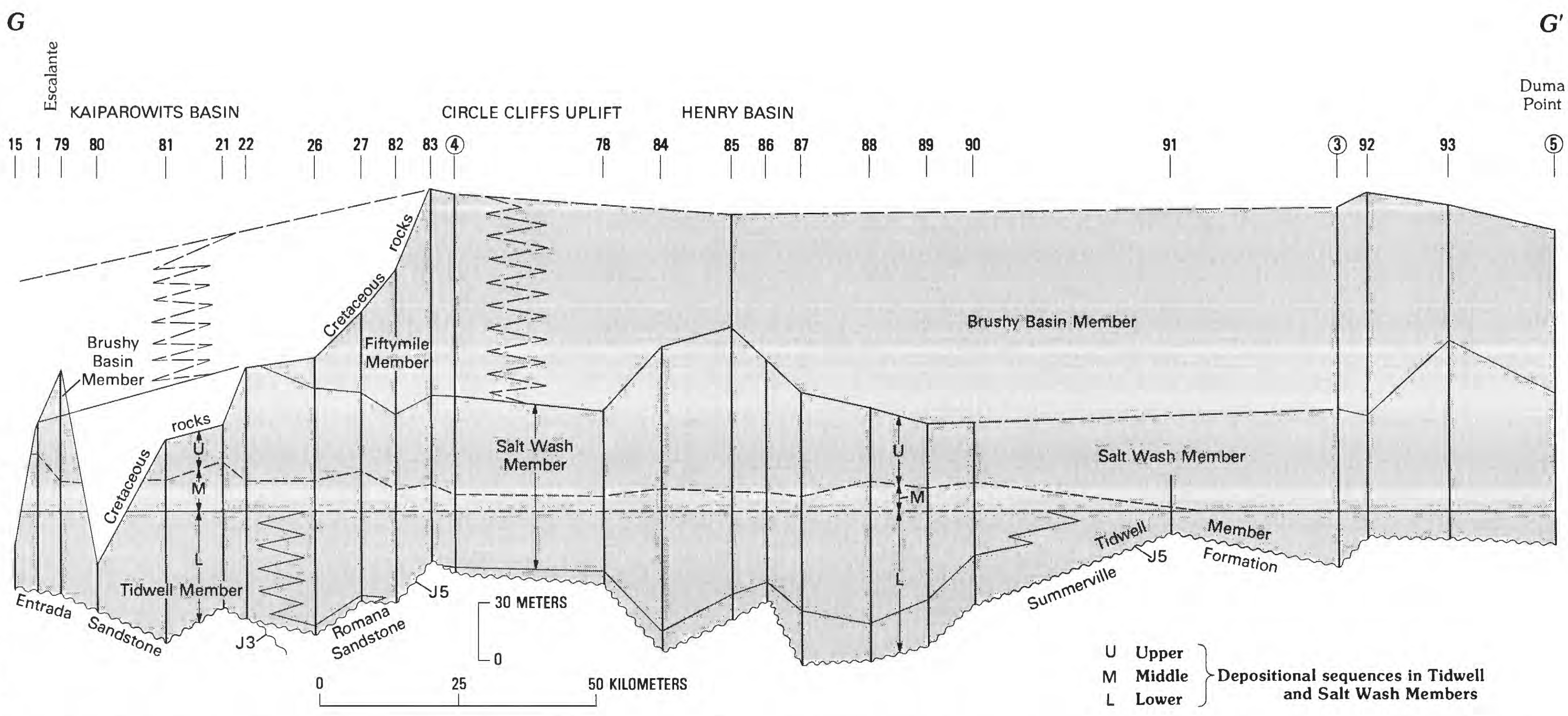

Figure B21. Stratigraphic section *G–G'* from Escalante to Duma Point, Utah, showing relationships of members and sequences in the Morrison Formation on the west side of the Colorado Plateau. Circled section numbers are type localities of the Fiftymile (4), Salt Wash (5), and Tidwell (3) Members. For location see figure B1.

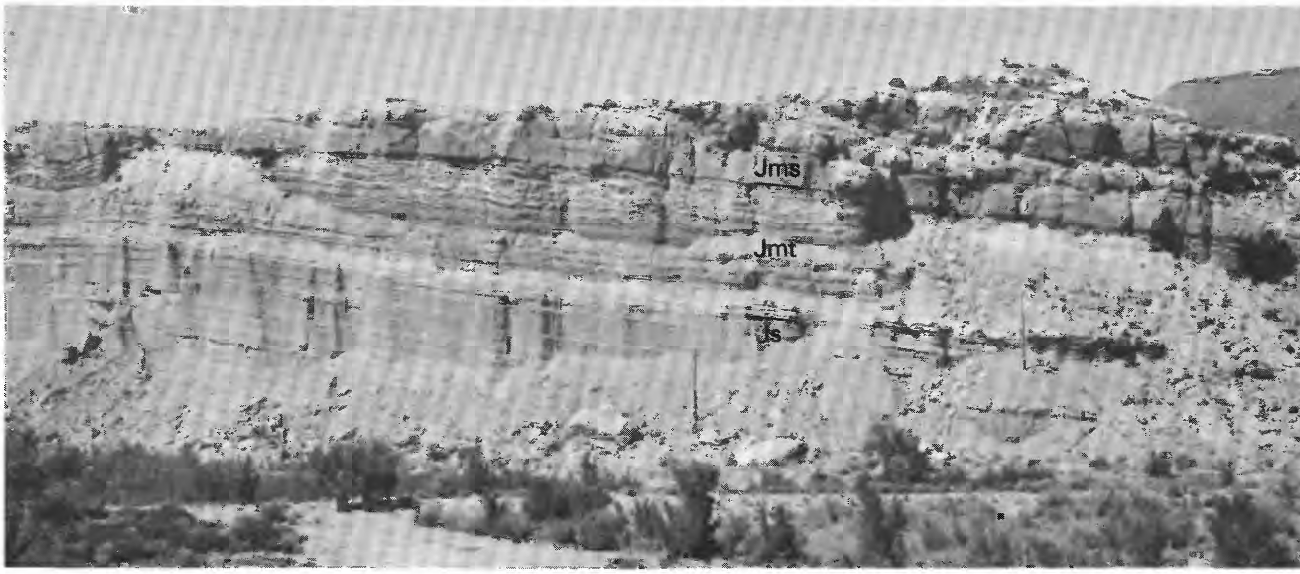

Figure B22. Tidwell Member of the Morrison Formation (Jmt), about 15 m thick, well exposed in South Desert near the confluence of Deep Creek with the Fremont River, western Henry basin, sec. 24, T. 29 S., R. 7 E., Wayne County, Utah. Beds in the Tidwell are irregular and slightly contorted, whereas Summerville beds (Js) tend to be planar. A thin conglomerate bed about 15 cm thick is locally present at the base of the Tidwell. Jms, Salt Wash Member of the Morrison Formation.

fragments is a relatively rare lithology found at the type section and several other places. Some of these beds in the eastern part of the Henry basin yielded an excellent suite of palynomorphs, including the lacustrine alga *Botryococcus* sp. identified by R. H. Tschudy (written commun., 1978–80).

A stratigraphic marker in the Tidwell that is useful in some places consists of authigenic red and (or) yellow chert in small blebs 1–2 mm in diameter or in nodules or concretions as much as a meter long. The chert replaces limestone, gypsum, mudstone, and flat-bedded sandstone, but it has only rarely been found in any of the scarce crossbedded fluvial sandstone beds in the member. In most places the chert is about 7–11 m above the base of the member, although locally it is as much as 38 m above the base in the area about 8–30 km southeast of Escalante, Utah. The greater thickness of Tidwell beneath the chert zone in this area probably reflects deposition in ancient valleys that did not exist elsewhere in the region. Because the chert is found at several stratigraphic levels at the type section (fig. B20) and several other localities, it is not an ideal stratigraphic marker. However, the chert does seem to be useful where it is present only at one stratigraphic horizon, as is the case in most of the Henry and Kaiparowits basins. Where several zones are present, the most persistent zone of this chert generally is the most useful for correlation purposes. The red and yellow chert has been named Sunset Agate by rock collectors, who use it for making polished rock pendants, belt buckles, and bolo ties.

Thin beds of very fine- to fine-grained, laminated to massive, light-brown sandstone are fairly common, although not dominant, in the member, and beds of fine-grained, crossbedded, light-brown pebbly sandstone are scarce. In much of the central and eastern parts of the Colorado Plateau, the base of the member is marked by a flat-bedded, fine-grained, light-brown sandstone bed containing scattered coarse and very coarse grains or small pebbles, often of colorful varieties of chert (fig. B23). This bed is especially helpful in identifying the basal contact where it separates overlying red mudstone of the Tidwell from red beds of the Summerville Formation. The basal bed is informally called bed A by O'Sullivan (1980b, 1984) and is thought to correlate with the Windy Hill Member of the Sundance Formation of Wyoming, northern Colorado, and northeastern Utah (Pipiringos, 1968, Pipiringos and O'Sullivan, 1976, 1978).

Locally, the Tidwell Member contains very fine- to fine-grained, very light-brown sandstone beds or lenses several meters thick that are laminated, crossbedded, or massive. Where these beds are at the base of the Tidwell their lower surfaces are flat, but the basal surfaces of similar beds farther up in the Tidwell tend to be concave upward. These beds and lenses are interpreted as lacustrine bars, and the configuration of their lower surface apparently was determined by the degree of lithification of the underlying strata. Where the lacustrine bars were deposited directly on the Summerville Formation, the basal surface is flat because the Summerville was at least partly lithified prior to deposition of the Tidwell and

Figure B23. Basal pebbly sandstone bed of the Tidwell Member of the Morrison Formation (Jmt) along Waterpocket Fold in the western Henry basin. The bed contains scattered colorful chert pebbles and contrasts markedly in texture and color with underlying mudstone beds of the Summerville Formation (Js). Near section 70 (figs. B1, B11), sec. 7, T. 32 S., R. 8 E., Garfield County, Utah.

therefore resisted deformation due to loading. Where the lacustrine bars occur higher in the member and are enclosed entirely within Tidwell mudstone, the basal surface is concave upward because the enclosing mudstone beds were not lithified during deposition of the bars, allowing them to slump downward into the relatively soft, unconsolidated muds.

Channelized fluvial beds composed of fine-grained, crossbedded, light-brown, pebbly sandstone are scarce in the Tidwell but have been found in several areas. One of these beds was found at the base of the Tidwell in the Kaiparowits basin about 38.6 km southeast of Escalante, Utah.

The Tidwell also contains rare beds of fine-grained, well-sorted, light-gray to white sandstone that contains thick sets of trough and tabular crossbedding. These are interpreted as eolian strata deposited in small dune fields. Only two of these beds have been found in the region; one is in the Kaiparowits basin 8 to 24 km southeast of Escalante, Utah, and the other is in the Henry basin, extending about 2 km along the outcrop near Trachyte Ranch (section 87, figs. B1, B21). Crossbedding dip vector resultants obtained from the eolian sandstone beds are oriented due east to northeast, essentially the same as resultants obtained from eolian strata in the Recapture Member of the Morrison at Black Mesa, Ariz. (fig. B10).

The part of the Morrison Formation that includes the Tidwell and Salt Wash Members has been divided into three sequences that are useful in describing and understanding the sedimentology of these rocks in south-central Utah and north-central Arizona (Peterson, 1980b). The distinction between the sequences is based on differences in bedding ratios and crossbedding dip vector resultants (Peterson, 1980b) and not on obvious lithologic differences. For this reason, the three sequences do not constitute members. Nevertheless, recognition of the three sequences is helpful in understanding the stratigraphic relationships of the Salt Wash and Tidwell Members (fig. B21) and for reconstructing the sedimentologic and paleotectonic evolution of the region during Late Jurassic time (Peterson, 1984; 1986).

The Tidwell interfingers with the Salt Wash Member in many places in the study area (figs. B10, B11, B13, B21). Not only does the Tidwell replace lower-sequence fluvial sandstone beds that are included in the Salt Wash, but it replaces the entire Salt Wash at a few localities along the west side of the San Rafael Swell. In that area, the Tidwell can be distinguished readily from the overlying Brushy Basin Member where the Salt Wash is missing; the Tidwell contains thick gypsum beds (generally 3–20 m thick) and mudstone composed largely of nonswelling clays whereas the Brushy Basin lacks these lithologies and consists largely of mudstone rich in swelling clays. Thompson and Stokes (1970) considered part of the Tidwell Member a southern extension of the Summerville Formation and called these beds the White Point Member of the Summerville Formation in the southeastern part of the Kaiparowits basin. However, regional stratigraphic relationships indicate that these beds are part of the Morrison Formation (fig. B5), and therefore the White Point Member of the Summerville Formation of Thompson and Stokes (1970) is not recognized in this report.

The Tidwell Member was deposited in a variety of environments, including lacustrine, evaporative, mudflat, and minor eolian and fluvial environments. These beds were distal or lateral equivalents of Salt Wash alluvial complexes deposited by streams that flowed northeastward to southeastward across much of the Colorado Plateau from highland source regions in southeastern Nevada and southwestern Utah (Peterson, 1984).

Salt Wash Member

The Salt Wash Member of the Morrison Formation was named by Lupton (1914) for exposures of cliff-forming sandstone beds interbedded with minor quantities of red or grayish-green mudstone near Duma Point, Utah (fig. B21; O'Sullivan, 1984, fig. 4). The sandstone beds are resistant to erosion and, in the southeastern Kaiparowits basin, the member tends to form steep dark-brown cliffs (figs. B14, B24), which add much to the scenic beauty of Glen Canyon and Lake Powell. Sandstone beds in the Salt Wash are generally light grayish brown to light gray in fresh exposures, fine to medium grained, and highly crossbedded. Although beds composed solely of flat-laminated sandstone are found in the member, they are not nearly as common as in the overlying Fiftymile Member. Mudstone beds in the Salt Wash are reddish brown to light grayish green and laminated to very thin bedded. Thin beds of gray to grayish-green, laminated to very thin-bedded, carbon-bearing mudstone containing comminuted and carbonized plant fragments are scarce but have been found in the member on the east side of the Henry basin, where they are associated with tabular sandstone-type uranium-vanadium deposits (Peterson, 1980b). Mudstone strata in the Salt Wash tend to be thin and inconspicuous, forming narrow benches, short steep slopes, or thin notches between the thick sandstone beds.

Fiftymile Member

A series of interbedded sandstone and mudstone beds as much as 107 m thick lies above the Salt Wash Member and below the Dakota Formation in the southeastern part of the Kaiparowits basin. Previously, these beds were included in the Salt Wash because they contain a significant amount of sandstone. However, regional relationships indicate that these beds are a facies of the Brushy Basin Member and therefore should be assigned to the upper part of the Morrison. Moreover, important lithologic differences distinguish these beds from the Salt Wash. For these reasons, this thick sandstone-mudstone sequence is here named the Fiftymile Member of the Morrison Formation. The type section is about 2 km northwest of Fiftymile Point, a bold promontory at the foot of the Straight Cliffs on the northeastern side of the Kaiparowits basin approximately 80 km southeast of Escalante, Utah (figs B25, B26).

The Fiftymile Member tends to form a series of ledges and slopes above the steeper cliffs of the Salt Wash Member (figs. B24, B26). Sandstone beds in the Fiftymile are light brown to light gray, are fine grained, contain pebbles, and are crossbedded, flat-laminated, or massive. Sandstone beds in the lower part of the member tend to be laminated to very thin bedded, as contrasted with highly crossbedded sandstone beds in the underlying Salt Wash Member. In addition, conglomerate beds are scarce but, where present, as at the type section (fig. B25; section 4 at the end of this report), they contain pebbles of red, orange, tan, green, black, gray, white, brown, and banded light- and dark-gray chert.

The suite of brightly colored pebbles has been known by field workers as the "Christmas tree" conglomerate or pebble suite, in allusion to the colorful ornaments on a Christmas tree. The "Christmas tree" suite of pebbles is especially common in the Brushy Basin Member, and Craig and others (1955) used this suite of pebbles to distinguish the Salt Wash and Brushy Basin Members. Similar colorful chert pebbles have been found in the Salt Wash and Tidwell Members, in the Romana Sandstone, and in westernmost exposures of the Entrada Sandstone, but in general they are not nearly as common in those units as they are in the Brushy Basin and Fiftymile Members. Exceptions are the uppermost bed of the

Figure B24. Morrison Formation, about 158.3 m thick, in the southeastern Kaiparowits basin on the east side of Rock Creek canyon, sec. 18, T. 43 S., R. 7 E., Kane County, Utah. The Fiftymile Member of the Morrison Formation (Jmf) contains more mudstone and less sandstone than the underlying Salt Wash Member (Jms); it tends to form ledges and slopes whereas the Salt Wash tends to form irregular cliffs and thin slopes. The uppermost sandstone beds in the Fiftymile are nearly white from alteration by fluids that seeped down from the Dakota Formation (Kd). Jem, middle member of the Entrada Sandstone; Jr, Romana Sandstone.

Salt Wash Member, which contains this colorful suite of pebbles at many localities in the Henry basin and the San Rafael Swell, and most Salt Wash sandstone beds in the southwestern Kaiparowits region. Mudstone strata in the Fiftymile are reddish brown to light grayish green, are laminated to very thin bedded, and weather to form slopes that are covered or partly covered with rubble from overlying sandstone beds. Commonly, the uppermost beds of the Fiftymile have been bleached from fluids that seeped into the member from the overlying Dakota Formation. The uppermost sandstone bed of the Fiftymile generally is white (figs. B5, B7, B8, B24), and the intense alteration has obliterated all traces of bedding in many places. For the most part, mudstone beds at or near the top of the Fiftymile have been altered to grayish green.

The lower contact is placed where the lowest thick mudstone unit in the Fiftymile lies on the uppermost thick sandstone bed of the Salt Wash. Some interfingering involving about 5–10 m of beds has been observed in mapping this contact, but, in most localities, it is a fairly planar surface; replacement of appreciable thicknesses of one member by the other has not been observed.

The upper contact of the Fiftymile Member is the regional unconformity at the base of the Dakota Formation, which cuts out the entire Morrison Formation, as well as the Romana and Entrada Sandstones, in southwestern Utah (figs. B5, B7, B8, B10, B21). The basal stratum of the Dakota generally is a thin, light-gray sandstone bed that may be difficult to distinguish from sandstone beds in the Fiftymile. The basal sandstone bed of the Dakota generally contains minute carbonaceous plant fragments, which are lacking in the Fiftymile. Locally, the basal stratum of the Dakota is a conglomerate bed that is easily recognized by the lack of the colorful red, orange, or green chert pebbles that are characteristic of conglomerates in the Fiftymile. Basal Dakota beds,

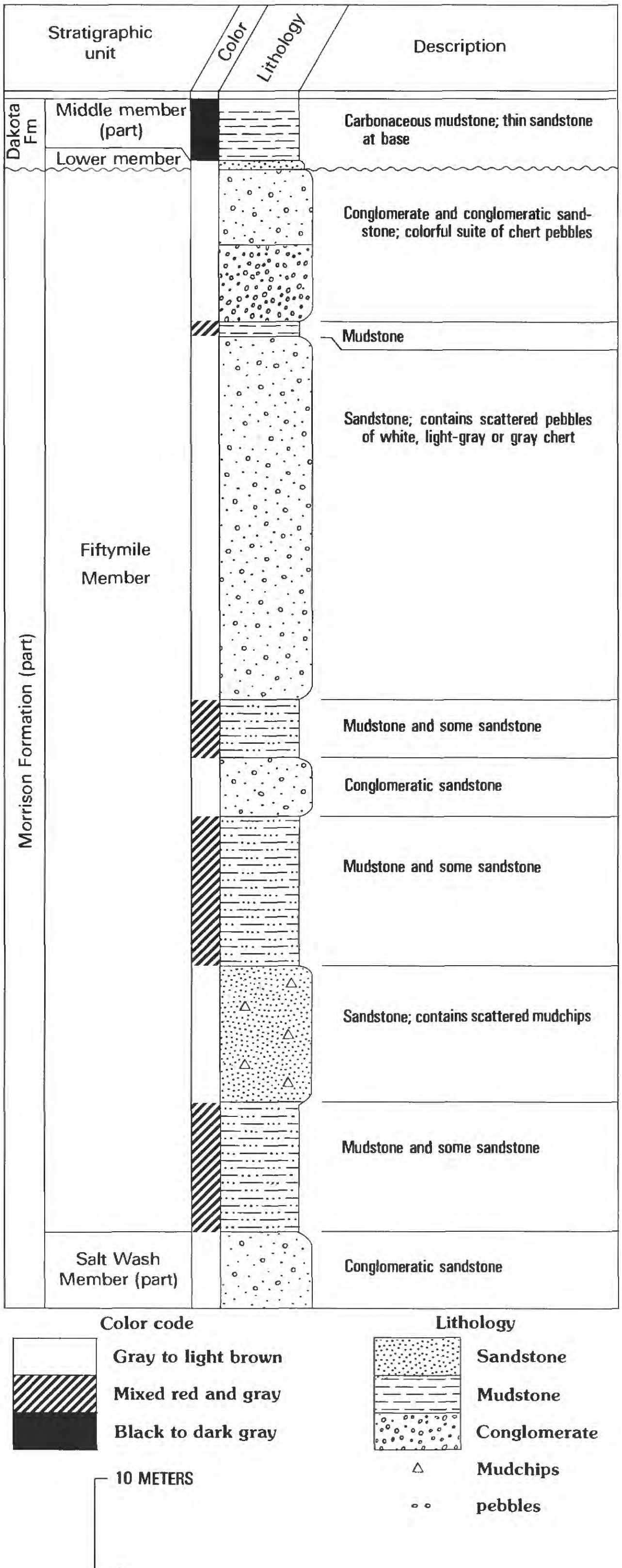

Figure B25. Columnar section of the type section of the Fiftymile Member of the Morrison Formation in the southeastern Kaiparowits basin near Fiftymile Point. This is section 4 on figures B1 and B21.

whether sandstone or conglomerate, may contain or interfinger with carbonaceous mudstone beds that are also diagnostic of the Dakota.

It is not possible to physically trace the Fiftymile Member into the Brushy Basin Member on the outcrop; therefore, the stratal relationships between these two members were determined from regional relationships. About 10–50 km southeast of Escalante, Utah, the unconformity at the base of the Dakota truncates the Fiftymile and Salt Wash Members, allowing the Dakota to locally rest on uppermost beds of the Tidwell (fig. B21). The Fiftymile Member cannot be traced northward across the Circle Cliffs uplift into Brushy Basin strata of the Henry basin because Tertiary erosion has removed these rocks from the uplift.

Correlation of the Fiftymile with the Brushy Basin is based on its stratigraphic position between the Salt Wash and Cretaceous strata and on lithologic and sedimentologic differences, previously discussed, between the Fiftymile and the Salt Wash. Thus, the regional stratigraphic framework indicates that the Fiftymile Member is a southern facies of the lower part of the Brushy Basin. (As shown in figure B18, the uppermost beds of the Brushy Basin may be younger than the Fiftymile.) This interpretation considerably revises earlier thoughts about the Salt Wash Member. Heretofore, the Salt Wash was considered to be a large alluvial fan deposit whose apex was in the southern Kaiparowits region, because the greatest thickness of Salt Wash was thought to be there and because pebbly sandstones of the Salt Wash in that region were thought to represent the most proximal facies of the member. However, the revised correlations show the greatest thickness of the Salt Wash is in the southern part of the Henry basin, where it is related more to subsidence of that basin during deposition than proximity to the source region (Peterson, 1980b). In addition, a more proximal facies of the Salt Wash is present in the northwestern part of the Henry basin and southwestern San Rafael Swell, where thick conglomerate beds contain chert and quartzite pebbles, cobbles, and rare boulders as much as a meter long.

Correlations in north-central Arizona suggest that the lower part of the Fiftymile Member correlates with the upper part of the Recapture Member of the Morrison Formation in the Black Mesa, Ariz., area (figs. B10, B18). It also seems likely that some of the upper beds of the Fiftymile correlate with strata currently known as the Westwater Canyon Member of the Morrison at Black Mesa. Reconnaissance studies between Black Mesa and the San Juan Basin of northwestern New Mexico by C. E. Turner-Peterson (oral commun., 1985) suggest that some of the unit formerly called the Westwater Canyon Member of the Morrison at Black Mesa could constitute an alluvial complex within the Recapture Member. However, further work is needed to adequately test this hypothesis.

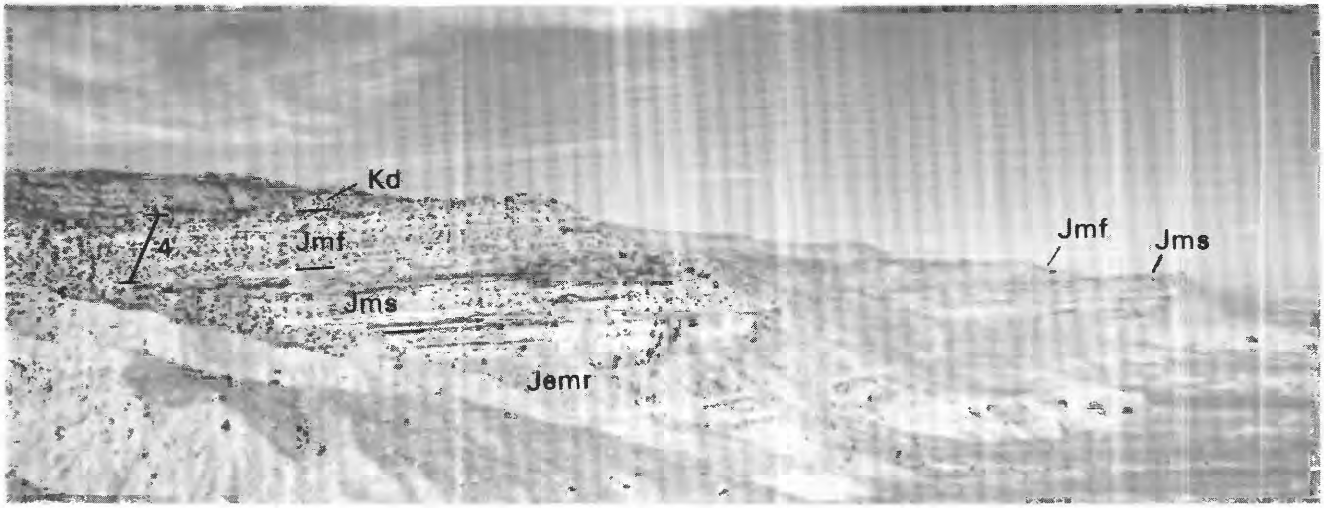

Figure B26. View northwest from Fiftymile Point, southeastern Kaiparowits Plateau, toward the type section (4) of the Fiftymile Member of the Morrison Formation (Jmf). The Fiftymile is 107.1 m thick and tends to form a series of slopes and ledges above irregular cliffs of the Salt Wash Member (Jms). Jemr, middle member of Entrada Sandstone and Romana Sandstone, undivided; the Romana is only about 5.1 m thick here. Kd, Dakota Formation.

Brushy Basin Member

The Brushy Basin Member (Gregory, 1938) is at the top of the Morrison Formation in most of the Colorado Plateau. However, the Fiftymile Member replaces the Brushy Basin in the southeastern part of the Kaiparowits basin, and neither of these members is present in southwestern Utah, owing to pre-Dakota erosion. A reported occurrence of the Brushy Basin on the east side of Black Mesa (Harshbarger and others, 1957, pl. 3) is provisionally interpreted as a mudstone bed that was originally deposited within the alluvial complex that includes the Recapture Member and possibly part of the Westwater Canyon Member of the Morrison. By this interpretation, sandstone beds of the Westwater Canyon that normally overlie this mudstone bed were removed by pre-Dakota erosion at Black Mesa. Generally, the Brushy Basin forms a red and light-gray slope at lower elevations where there is little vegetation cover. At higher elevations with greater precipitation, the Brushy Basin forms a tree-covered, hummocky slope affected by many landslides.

The Brushy Basin is composed predominantly of reddish-brown and light-greenish-gray, laminated to thin-bedded mudstone. The mudstone contains appreciable quantities of swelling clays in many areas and weathers to produce a frothy surface resembling red or gray popcorn. Light-brown ledges composed of fine-grained, laminated to very thin-bedded or crossbedded pebbly sandstone and dark-brown crossbedded conglomerate also form a small but conspicuous part of the member. Other minor lithologies are thin beds of red or very light brown bentonite, thin beds or lenses of dense gray limestone, and thin zeolite beds (J. E. Johnson, University of California at Berkeley, written commun., 1980).

The lower contact of the Brushy Basin Member is placed at various stratigraphic levels by different geologists. Opinions differ mainly over the stratigraphic placement of a pebbly sandstone or conglomerate marker bed at the boundary. This marker bed contains the "Christmas tree" suite of colorful chert pebbles found throughout a large part of southeastern Utah and western Colorado. Craig and others (1955, p. 156) put the contact at the base of this bed and included the marker bed in the Brushy Basin Member. In so doing, they place a mudstone bed at the top of the Salt Wash Member, which differs from Lupton's (1914) original definition of the Salt Wash and also differs from the generally held concept that the Salt Wash is the cliff-forming, predominantly sandstone unit beneath the slope-forming, predominantly mudstone unit of the Brushy Basin (Gregory, 1938). Where the colorful chert pebbles are absent, Craig and others (1955) placed the contact at the top of the highest sandstone bed in the Salt Wash. It is noteworthy that some of the coauthors of the Craig and others (1955) study placed the contact at the top of the bed containing the colorful chert pebble suite. (Compare various sections in Craig and others, 1959.)

In southeastern Utah and adjacent parts of Arizona, New Mexico, and Colorado, the Recapture Member lies above the Salt Wash. The contact in these areas is placed at the top of the highest sandstone bed in the Salt Wash Member and at the base of a relatively thick series of slope-forming mudstone and sandstone beds typically included in the Recapture (Craig and others, 1955). In a somewhat similar manner in this report, the contact of the Salt Wash with the Fiftymile Member is placed at the top of the highest typical sandstone bed in the Salt Wash and at the base of the lowest thick mudstone unit in the Fiftymile. Likewise in this report, the contact between the Salt Wash and Brushy Basin Members is placed at the top of the thick series of sandstone beds, or conglomerate if present, of the Salt Wash. This closely follows the original and most commonly held definition of the Salt Wash as a predominately cliff-forming sandstone member (Lupton, 1914), whereas the Brushy Basin is a predominately slope-forming mudstone member (Gregory, 1938).

In some areas on the west side of the Colorado Plateau, the Brushy Basin Member is overlain by the Lower Cretaceous Cedar Mountain Formation. The Cedar Mountain is difficult to distinguish from the Brushy Basin where basal conglomerate or sandstone units of the Cedar Mountain are absent. The Cedar Mountain above the basal coarse clastics consists of light-greenish-gray bentonitic mudstone that is, for all intents and purposes, identical to the mudstone at the top of the Brushy Basin. Because of the similarity of these lithologies, the light-greenish-gray mudstones are variously assigned either to the top of the Brushy Basin or to the base of the Cedar Mountain Formation where the basal coarse clastics of the Cedar Mountain are absent—an inconsistent and unsatisfactory stratigraphic arrangement.

Craig (1981, p. 195) reports that Cedar Mountain mudstones can be distinguished from Brushy Basin mudstones by the lack of brilliant colors and color banding and by the presence of abundant limestone nodules in the Cedar Mountain. However, mudstone beds at the top of the Brushy Basin also tend to lack brilliant colors or color banding, and limestone nodules are locally common in undoubted Brushy Basin mudstones but are absent from the Cedar Mountain at many localities. Thus, no satisfactory sedimentologic method is currently known that will help in distinguishing Cedar Mountain and Brushy Basin mudstone beds where the basal coarse clastic beds of the Cedar Mountain are missing. Isotopic dating of minerals in altered ash beds of the Brushy Basin and Cedar Mountain (for example, see Kowallis and Heaton, 1984) might help, but this requires considerable laboratory work and is not a satisfactory solution to what is basically a field problem. The problem obviously is in need of further study.

Dark-gray carbonaceous mudstone beds or sandstone and conglomerate beds that contain or interfinger with carbonaceous mudstone within the Dakota Formation readily distinguish it from the Brushy Basin Member of the Morrison.

The Brushy Basin is poorly understood because few detailed studies have been done on it. The member apparently was deposited in mudflat and lacustrine environments, but a small part was also deposited in fluvial and overbank floodplain environments. Strata containing authigenic zeolites, analcime, and feldspars, indicating deposition in saline-alkaline lakes, have been identified in the Brushy Basin in northwestern New Mexico (Turner-Peterson, 1985; Bell, 1986), and the same authigenic minerals have also been found in southeastern Utah and southwestern Colorado (Keller, 1962; J. E. Johnson, University of California at Berkeley, written commun., 1980; C. E. Turner-Peterson, oral communication, 1985; F. Peterson, unpublished data). The Fiftymile Member is interpreted as a proximal facies of the Brushy Basin and probably was deposited in mudflat, nearshore lacustrine, and fluvial environments. Bentonite beds in the Brushy Basin represent alteration products of volcanic ash that may have been reworked slightly by fluvial and lacustrine processes. The ash probably was blown into the region from volcanic areas far to the west. One of the geologic enigmas on the Colorado Plateau is the nature of conditions that allowed deposition of a few high-energy fluvial conglomerate beds within the abundant low-energy mudstone deposits that compose the bulk of the Brushy Basin Member. The Brushy Basin generally is considered Late Jurassic in age, but a recent discovery of Early Cretaceous zircons in ash beds of the member (Kowallis and Heaton, 1984; Kowallis and others, 1986) suggests that this interpretation may be in error and that further study is needed.

NAME AND LOCATION OF MEASURED SECTIONS

[Quotation marks denote local names not shown on U.S. Geological Survey maps]

Section No.	Name	Location
1.	Pine Creek	SW¼ sec. 29, SE¼ sec. 30, T. 34 S., R. 3 E., Garfield County, Utah
2.	Crosby Canyon	SE¼ sec. 8, SW¼ sec. 9, T. 43 S., R. 4 E., Kane County, Utah
3.	Moonshine Tanks	SE¼ SE¼ sec. 24, T. 22 S., R. 13 E., Emery County, Utah
4.	Fiftymile Point	C-S½ sec. 14, T. 41 S., R. 8 E., Kane County, Utah
5.	Duma Point	NE¼ sec. 24, T. 23 S., R. 17 E.; NW sec. 19, T. 23 S., R. 18 E., Grand County, Utah
6.	Cow Springs	36°24′15″ N., 110°47′45″ W., Coconino County, Ariz.
7.	Mount Carmel Junction	Sec. 12, 25, NE¼ sec. 36, T. 41 S., R. 8 W., Kane County, Utah
8.	Brown Canyon	SE¼ sec. 7, NE¼ sec. 19, T. 41 S., R. 5 W.; NW¼ sec. 32, T. 40 S., R. 5 W., Kane County, Utah

Section No.	Name	Location
9.	Carly Knoll	W½ sec. 30, SW¼ sec 31, T. 40 S., R. 4 W.; SE¼ sec 21, T. 40 S., R. 4½ W., Kane County, Utah
10.	Lick Wash	SE¼ sec. 36, T. 39 S., R. 4 W., Kane County, Utah
11.	Little Bull Valley	Sec. 19, T. 38 S., R. 3 W., Kane County, Utah
12.	Kodachrome Flat	E½ sec. 3, T. 38 S., R. 2 W., Kane County, Utah
13.	Henrieville	NW¼ sec. 23, T. 37 S., R. 2 W., Garfield County, Utah
14.	"Upper Valley #1 unit"	NW¼ sec. 12, T. 36 S., R. 1 E., Garfield County, Utah
15.	Black Hills	SE¼ sec. 13, T. 34 S., R. 2 E., Garfield County, Utah
16.	Point 7037	SE¼ sec. 19, T. 35 S., R. 3 E., Garfield County, Utah
17.	Point 6077	NW¼ sec. 27, T. 36 S., R. 3 E., Garfield, County, Utah
18.	Tenmile Spring	SE¼ sec. 17, W½ sec. 20, T. 36 S., R. 4 E., Garfield County, Utah
19.	Slickrock Water	SW¼ sec. 14, T. 37 S., R. 4 E., Garfield County, Utah
20.	Collet Canyon	E½ sec. 35, T. 37 S., R. 4 E., Garfield County, Utah
21.	Point 5802	W½ sec. 5, SE¼ sec. 6, T. 38 S., R. 5 E., Kane County, Utah
22.	Point 5740	SW¼ sec. 10, T. 38 S., R. 5 E., Kane County, Utah
23.	Point 5549	SE¼ sec. 23, SW¼ sec. 24, T. 38 S., R. 5 E., Kane County, Utah
24.	Point 5603	SE¼ sec. 24, T. 38 S., R. 5 E., Kane County, Utah
25.	Point 5523	NW¼ sec. 30, T. 38 S., R. 6 E., Kane County, Utah
26.	Point 5437	SW¼ sec. 29, T. 38 S., R. 6 E., Kane County, Utah
27.	Big Hollow Spring	SE¼ sec. 11, sec. 12, T. 39 S., R. 6 E., Kane County, Utah
28.	"Sand Valley"	SE¼ sec. 33, S½ sec. 34, T. 42 N., R. 7 E., Coconino County, Ariz.
29.	Blue Pool Wash	C–S½ sec. 30, T. 43 S., R. 3 E., Kane County, Utah
30.	"Twin Red Buttes"	NE¼ sec. 22, T. 43 S., R. 3 E., Kane County, Utah
31.	Wahweap Creek	W½ sec. 29, E½ sec. 32, T. 43 S., R. 4 E.; E½ sec. 5, T. 44 S., R. 4 E., Kane County, Utah
32.	Castle Rock	NE¼ sec. 3, T. 44 S., R. 4 E., Kane County, Utah
33.	Romana Mesa	NE¼ sec. 21, T. 43 S., R. 5 E., Kane County, Utah
34.	Cummings Mesa W	SW¼ sec. 8, T. 43 S., R. 7 E., San Juan County, Utah
35.	Cummings Mesa N	37°03′30″N., 111°07′00″W., San Juan County, Utah
36.	Cummings Mesa E	37°05′30″N., 111°01′30″W., San Juan County, Utah
37.	Navajo Point	Secs. 24, 25, T. 42 S., R. 8½ E., Kane County, Utah
38.	Rock Creek N	SW¼ sec. 5, T. 41 S., R. 7 E., Kane County, Utah
39.	Rock Creek E	37°13′30″N., 111°09′00″W., Kane County, Utah
40.	Little Valley Canyon	37°14′00″N., 111°16′30″W., Kane County, Utah
41.	Kane Wash	SE¼ sec. 1, T. 43 S., R. 5 E.; NW¼ sec. 7, T. 43 S., R. 6 E., Kane County, Utah
42.	Cummings Mesa SW	36°59′30″N., 111°05′30″W., Coconino County, Ariz.
43.	Tsai Skizzie Rock	36°48′30″N., 111°06′10″W., Coconino County, Ariz.
44.	White Mesa NE	36°35′00″N., 110°56′00″W., Coconino County, Ariz.
45.	White Mesa E	36°33′00″N., 110°56′30″W., Coconino County, Ariz.
46.	Klethla Valley 361	36°26′40″N., 110°40′40″W., Navajo County, Ariz.
47.	Klethla Valley 362	36°27′22″N., 110°40′10″W., Navajo County, Ariz.
48.	Klethla Valley 364	36°27′50″N., 110°39′15″W., Navajo County, Ariz.
49.	Black Mesa Road	36°33′20″N., 110°30′00″W., Navajo County, Ariz.
50.	Long House Valley	36°34′40″N., 110°28′17″W., Navajo County, Ariz.
51.	Tsegi	36°37′30″N., 110°27′07″W., Navajo County, Ariz.
52.	Kayenta	36°39′37″N., 110°14′45″W., Navajo County, Ariz.
53.	Rough Rock	36°26′45″N., 109°52′05″W., Apache County, Ariz.
54.	Lohali Point	36°08′40″N., 109°48′35″W., Apache County, Ariz.
55.	Balakai (Salahkai) Mesa	36°56′10″N., 109°51′15″W., Navajo County, Ariz.
56.	Steamboat East	35°46′05″N., 109°46′20″W., Navajo County, Ariz.
57.	Star Mountain	SW¼ sec. 27, T. 26 N., R. 19 E., Navajo County, Ariz.
58.	Jones Bench	NW¼ sec. 21, T. 26 S., R. 5 E., Sevier County, Utah
59.	Hartnet Draw NW	NE¼ sec 14, T. 27 S., R. 5 E., Wayne County, Utah
60.	Hartnet Draw	C–E½ sec. 26, T. 27 S., R. 6 E., Wayne County, Utah
61.	The Notch	C–W½ sec 28, T. 28 S., R. 7 E., Wayne County, Utah

Section No.	Name	Location
62.	Fremont River	SE¼ sec. 14, T. 29 S., R. 7 E., Wayne County, Utah
63.	Tergeson Flats	SE¼ sec. 27, T. 30 S., R. 8 E., Wayne County, Utah
64.	Sandy Creek 1	NW¼ sec. 5, T. 31 S., R. 8 E., Garfield County, Utah
65.	Sandy Creek 2	NE¼ sec. 17, T. 31 S., R. 8 E., Garfield County, Utah
66.	Dogwater Creek	NE¼ sec. 29, T. 31 S., R. 8 E., Garfield County, Utah
67.	Sandy Creek Benches	NW¼ sec. 4, T. 32 S., R. 8 E., Garfield County, Utah
68.	Spring Canyon	NE¼ sec. 8, T. 32 S., R. 8 E., Garfield County, Utah
69.	Bitter Creek Divide	SW¼ sec. 17, T. 33 S., R. 8 E., Garfield County, Utah
70.	The Post	NE¼ sec. 25, T. 34 S., R. 8 E., Garfield County, Utah
71.	Muley Twist	NW¼ sec. 18, T. 35 S., R. 9 E., Garfield County, Utah
72.	Deer Point	NW¼ sec. 29, T. 35 S., R. 9 E., Garfield County, Utah
73.	"Red Slide"	C-W½ sec. 33, T. 35 S., R. 9 E., Garfield County, Utah
74.	"Wingate Bridge"	NW¼ sec. 4, T. 36 S., R. 9 E., Garfield County, Utah
75.	Hall Divide	C-sec. 27, T. 36 S., R. 9 E., Garfield County, Utah
76.	Long Canyon	NW¼ sec. 30, T. 36 S., R. 10 E., Garfield County, Utah
77.	"Pine"	NE¼ sec. 3, T. 37 S., R. 10 E., Garfield County, Utah
78.	Baker Ranch	SE¼ sec. 5, T. 38 S., R. 10 E., Kane County, Utah
79.	Escalante	SW¼ sec. 7, T. 35 S., R. 3 E., Garfield County, Utah
80.	Escalante Rim	SW¼ sec. 4, T. 36 S., R. 3 E., Garfield County, Utah
81.	Point 5948	NE¼ sec. 9, T. 37 S., R. 4 E., Garfield County, Utah
82.	Point 6069	SW¼ sec. 24, T. 40 S., R. 7 E., Kane County, Utah
83.	Sooner Slide	Sec. 32, T. 40 S., R. 8 E., Kane County, Utah
84.	Bullfrog Creek	SE¼ sec. 34, T. 36 S., R. 10 E., Garfield County, Utah
85.	"Shootaring Canyon"	SE¼ sec. 16, T. 35 S., R. 11 E., Garfield County, Utah
86.	Star Spring Road	NW¼ sec. 31, T. 34 S., R. 12 E., Garfield County, Utah
87.	Woodruff Hole	NE¼ sec. 8, T. 34 S., R. 12 E., Garfield County, Utah
88.	Trachyte Ranch	NE¼ sec. 6, T. 33 S., R. 12 E., Garfield County, Utah
89.	Little Egypt	NW¼ sec. 30, T. 31 S., R. 12 E., Garfield County, Utah
90.	Goatwater Spring	SW¼ sec. 36, T. 30 S., R. 11 E., Wayne County, Utah
91.	Little Flat Top	SW¼ sec. 15, T. 26 S., R. 13 E., Emery County, Utah
92.	Hatt Ranch	NW¼ sec. 26, SE¼ sec. 27, T. 22 S., R. 14 E., Emery County, Utah
93.	Little Grand fault	C-sec. 29, T. 21 S., R. 16 E., Emery County, Utah

MEASURED SECTIONS

[The locations of the measured sections are shown on figure B1]

Section 1.—Principal reference section of the Entrada Sandstone

[Measured about 5 km north of Escalante, Utah, just west of Pine Creek, in the SW¼ SW¼ sec. 29, SE¼ sec. 30, T. 34 S., R. 3 E., Garfield County, Utah. Shown as section 1 on figs. B1 and B5]

	Thickness (meters)
Morrison Formation (part):	
Tidwell Member (part):	
75. Sandstone, dark-reddish-brown, very fine-grained; bedding indistinct; forms slope .	0.3
74. Sandstone, yellow to light gray, fine-grained, bedding indistinct but appears to be very thin-bedded to low-angle crossbedded; slight ledge	0.9
Total measured Tidwell Member of Morrison	1.2
J-5 unconformity.	
Entrada Sandstone:	
Upper member:	
73. Sandstone, light-gray, light-reddish-brown-weathering, very fine- to fine-grained; basal 2.1 m is irregularly very thin bedded, remainder is crossbedded with some sets as much as 6.1 m thick; medium and coarse grains locally concentrated along some of the bedding planes; about 8.2 m above base is 0.3-m-thick reddish-brown band, and about 12.2 m above base is another reddish-brown band about 1.5 m thick; forms cliffs and ledges	69.5
Total upper member	69.5

Entrada Sandstone—Continued

Middle member:

Unit	Description	Thickness (meters)
72.	Sandstone, light-reddish-brown to pinkish-brown, fine- to medium-grained, irregularly very thin-bedded; forms slight ledge ..	2.4
71.	Sandstone, light-grayish-green, very fine- to fine-grained, very thin- to thin-bedded; alternates with light-green, laminated to very thin-bedded mudstone; top 2.5 cm is pinkish-brown sandstone; forms notch	0.6
70.	Sandstone, light-gray, very fine- to fine-grained; some low-angle crossbedding apparent; forms slight ledge	0.9
69.	Sandstone, light-gray to light-grayish-green, very fine- to fine-grained, very thin- to thin-bedded; basal 0.2 m is sandstone alternating with light-green mudstone; forms notch .	1.8
68.	Sandstone, pink, light-grayish-green-weathering, very fine- to fine-grained, laminated; forms slight ridge	0.6
67.	Sandstone, light-grayish-green, very fine- to fine-grained, very thin- to thin-bedded; alternates with light-green, laminated to very thin-bedded mudstone; forms notch	0.3
66.	Sandstone, yellowish-brown, very fine- to fine-grained, laminated; 0.9 m above base is 2.5 cm of light-green mudstone; 3.0 m above base is 2.5 cm of light-green mudstone; forms slight ridge	5.5
65.	Sandstone, light grayish-green, very fine- to fine-grained, very thin- to thin-bedded; includes some light-green mudstone; forms slope	0.5
64.	Sandstone, yellowish-brown, very fine- to fine-grained, laminated; forms slight ridge	6.9
63.	Sandstone, light-grayish-green, very fine- to fine-grained, very thin- to thin-bedded; in thin beds alternates with light-green, laminated to very thin-bedded mudstone; forms notch	1.5
62.	Sandstone, light-grayish-green, very fine- to fine-grained, laminated to very low-angle crossbedded; forms slight ridge	0.6
61.	Sandstone, light-grayish-green, very fine- to fine-grained, very thin- to thin-bedded; alternates with light-green, laminated to very thin-bedded mudstone; forms slight notch	0.9
60.	Sandstone, light-grayish-green, very fine- to fine-grained; some low-angle crossbedding apparent; 0.3 m above base is 5-cm zone of light-green mudstone; contains yellowish-orange-brown nodules of pyrite(?) surrounded by limonitic material in a zone about 0.6–0.9 m above base of unit; 3.4 m above base is 5-cm-thick light-green bentonitic mudstone bed; 6.1 m above base is 1.0-m-thick yellowish-brown zone; 7.0 m above base is zone 0.3 m thick of light-green mudstone alternating with light-grayish-green sandstone; top of unit holds up slight ridge	10.1
59.	Sandstone, silty, reddish-brown (mottled very light gray), very fine- to fine-grained, irregularly very thin-bedded; includes some low-angle crossbedding; contains about 20–40 percent dark reddish-brown, laminated mudstone; forms slope	0.2
58.	Sandstone, light-gray, very fine- to fine-grained; indistinct bedding; 2.1 m above base a reddish-brown sandstone bed makes a 0.5-m ledge; forms slope	3.7
57.	Sandstone, silty; same as unit 59	0.3
56.	Sandstone; same as unit 58	0.3
55.	Sandstone, silty; same as unit 59	0.6
54.	Sandstone, light-gray (mottled with some reddish brown), very fine- to fine-grained, irregularly laminated to very thin-bedded; 1.5 m above base is 1.5-m-thick zone that is light reddish pink to reddish brown at the top; 4.9 m above base is 0.3 m of light-green mudstone, overlain by 0.5 m of dark-reddish-brown mudstone, 0.6 m of pink sandstone, and 1.2 m of light-gray sandstone; forms ridge	7.5
53.	Sandstone, silty; same as unit 59	0.5
52.	Sandstone; same as unit 58	0.6
51.	Sandstone, silty; same as unit 59	0.5
50.	Sandstone; same as unit 58	1.8
49.	Sandstone, silty; same as unit 59	1.2
48.	Sandstone; same as unit 58	1.2
47.	Sandstone, silty; bedding indistinct; 1.5 m above base is 0.6 m of white sandstone; otherwise same as unit 59	6.1

	Thickness (meters)
Entrada Sandstone—Continued	
Middle member—Continued	
46. Sandstone; same as unit 58	1.8
45. Sandstone, silty; same as unit 59	2.7
44. Sandstone; same as unit 58	1.5
43. Sandstone, silty, reddish-brown and some light-gray, very fine- to fine-grained, irregularly very thin-bedded and some low-angle crossbedded; contains some dark-reddish-brown mudstone; 7.5 cm of dark-reddish-brown and light-green mudstone at the base; forms slope	3.0
42. Sandstone; same as unit 58; 1.2 m above base is 0.3 m of reddish-brown sandstone and dark-reddish-brown to light-green mudstone; forms ridge	3.4
41. Sandstone, silty; same as unit 59	0.9
40. Sandstone; same as unit 58	1.8
39. Sandstone, silty; bedding indistinct; otherwise same as unit 59	2.1
38. Sandstone; same as unit 58	1.5
37. Sandstone, silty; same as unit 59	1.5
36. Sandstone; bedding indistinct; otherwise same as unit 59	1.5
35. Sandstone, silty; 0.6 m above base is 7.5-cm-thick bed of dark-reddish-brown mudstone; 1.2 m above base is 0.3-m-thick bed of dark-reddish-brown to purple mudstone; otherwise same as unit 59	4.3
34. Sandstone; same as basal part of unit 58	0.6
33. Sandstone, silty; 4.6 m above base is 0.3 m of dark-reddish-brown mudstone; 8.5 m above base is 0.6 m of white, irregularly thin-bedded sandstone; top 0.6 m is interbedded grayish-green mudstone and sandstone; otherwise same as unit 59	13.7
32. Sandstone; same as unit 58 but tends to form ledge; unit is highest of the ledge-forming light-gray sandstone beds in the middle member	1.2
31. Sandstone, silty; basal 0.9 m is a partly covered slope; same as unit 59	5.8
30. Sandstone, light-gray; top 1.2 m is partly covered slope; forms ridge	3.4
29. Sandstone, silty; top 0.4 m consists of 0.2 m of light-gray sandstone overlain by 0.2 m of grayish-green mudstone; otherwise same as unit 59	1.1
28. Covered slope; probably same as unit 59	1.1
27. Sandstone; same as unit 58 but forms ridge	1.4
26. Sandstone, silty; same as unit 59	1.4
25. Sandstone; top 0.6 m contains low-angle crossbedding; otherwise same as unit 58; forms ridge	2.1
24. Sandstone, silty, reddish-brown, very fine- to fine-grained, very thin- to thin-bedded; basal meter includes three beds of white sandstone each 0.2 m thick; forms slope	4.7
23. Sandstone; 0.3 m below top is a 0.2-m-thick dark-reddish-brown mudstone bed; otherwise same as unit 58	1.5
22. Sandstone, silty, reddish-brown (with minor white mottles), very fine- to fine-grained, irregularly very thin bedded; some low-angle crossbedding; contains about 20–40 percent dark-reddish-brown mudstone; forms slope	5.2
21. Sandstone, light gray (mottled with some reddish-brown), very fine- to fine-grained, irregularly laminated to very thin-bedded; some low-angle crossbedding; top has closely spaced ripples with crests about 2 cm apart; forms ridge	5.8
Total middle member	132.1
Lower member:	
20. Sandstone, orange-brown, very fine- to fine-grained, laminated to very low-angle crossbedded; 1.2 m above base are ripple cross-laminae; 10.7 m above base is 1-cm-thick dark-reddish-brown mudstone bed; 15.5 m above base is some dark-reddish-brown mudstone interbedded with approximately equal proportions of reddish-brown sandstone; forms ridges and swales	23.8

Entrada Sandstone—Continued

Lower member—Continued

	Thickness (meters)
19. Sandstone, reddish-brown to orange-brown, very fine-grained, includes several dark-reddish-brown sandstone beds about 0.3 m thick; bedding obscure; forms slope	2.3
18. Sandstone, reddish-brown, very fine-grained, and dark reddish-brown mudstone; both very thin-bedded; 2.5-cm-thick pink limey siltstone or silty limestone in middle; forms slope	0.6
17. Sandstone, orange-brown; same as unit 19; 0.6 m above base is 0.3-m-thick bed of dark-reddish-brown, very fine-grained sandstone; contains some thin sets of crossbeds; forms slope	7.8
16. Sandstone, dark-reddish-brown, very fine-grained, and mudstone, dark-reddish-brown; very thin-bedded; includes about 5 percent white sandstone; forms slope	1.5
15. Sandstone, reddish-brown to orange-brown, very fine-grained; locally altered to very light gray; 1.5 m above base is 0.2 m of very fine-grained sandstone; forms slope	9.8
14. Sandstone, dark-reddish-brown, very fine-grained, and dark-reddish-brown mudstone; both very thin-bedded; top has 0.3-m-thick interval that is largely pink platey limestone or possibly highly calcareous siltstone; forms slope	1.1
13. Sandstone; same as unit 19 but laminated to very thin bedded in part; forms slope ...	6.1
12. Sandstone, dark-reddish-brown, very fine-grained, and dark-reddish-brown mudstone; both very thin-bedded; about 5 percent is mottled white; forms slope	0.6
11. Sandstone; 2.7 m above base is 7.5-cm-thick bed of dark-reddish-brown mudstone; otherwise same as unit 19; forms slope	6.4
10. Sandstone, dark-reddish-brown, very fine-grained; interbedded with about 20 percent dark-reddish-brown mudstone; very thin bedded; appears as a conspicuous dark band; forms slope	0.5
9. Sandstone, reddish-brown to orange-brown, very fine-grained; bedding difficult to identify but appears very thin to thin and includes some thin sets of crossbeds; forms slope	12.8
8. Mudstone, dark-reddish-brown to purple, very thin-bedded; grades upward into silty sandstone containing biotite grains, sandstone locally altered to very light gray; forms slope	0.3
7. Sandstone, reddish-brown to orange-brown, very fine-grained; contains several dark-reddish-brown sandstone beds about 0.3 m thick; largely covered with red soil; 3.4 m below top is 5.0-cm-thick bed of dark-reddish-brown, silty mudstone overlain by about 25-cm-thick dark-reddish-brown sandstone bed; basal contact essentially a planar surface; best exposed in stream cuts of Pine Creek; forms slope	39.0
Total lower member	112.6
Total Entrada Sandstone	314.2

Carmel Formation (part):

Upper member (part):

	Thickness (meters)
6. Mudstone, reddish-brown, purple weathering, laminated to very thin-bedded; forms slope. Used as the contact marker bed in the vicinity of Escalante, Utah, where the lower member of the Entrada is reddish-brown silty sandstone similar to that in the underlying upper part of the Carmel	0.3
5. Sandstone, reddish-brown, very fine-grained; bedding indistinct; forms slight ledge	1.8
4. Mudstone, reddish-brown; forms notch .	0.5
3. Sandstone, reddish-brown, very fine-grained, irregularly very thin-bedded and ripple cross-laminated; forms slight ledge ..	0.3
2. Sandstone, silty, reddish-brown, very fine-grained; bedding indistinct; forms notch	0.6
1. Gypsum, gray, wavy-bedded; stratigraphically highest gypsum bed in the Carmel; forms ledge	0.3
Total measured upper member of Carmel Formation	3.8

Section 2.—Type section of the Romana Sandstone

[Measured on northeast side of Crosby Canyon, a side canyon to Warm Creek canyon. Section measured in the SE¼ NE¼ SE¼ sec. 8., T. 43, S., R. 4 E., Kane County, Utah. Shown as section 2 on figs. B1 and B8.]

	Thickness (meters)
Morrison Formation (part):	
Salt Wash Member (part):	
14. Sandstone, grayish-brown; weathers dark-yellowish-brown; fine grained but contains scattered conglomerate lenses and stringers; contact locally has about 0.3–0.6 m of relief. Thickness estimated	4.6
Total measured Salt Wash Member (incomplete)	4.6
J–5 unconformity.	
Romana Sandstone:	
13. Sandstone, light-greenish-gray, fine-grained, moderately sorted, crossbedded; contains scattered coarse to very coarse grains; forms cliff	0.6
12. Mudstone, dark-reddish-brown and minor grayish-yellow-green; sandstone-filled desiccation cracks near top; forms notch	0.3
11. Sandstone, light-greenish-gray, fine-grained, moderately sorted, crossbedded; contains scattered coarse and very coarse grains; forms cliff	15.2
10. Sandstone, light-greenish-gray, fine-grained, moderately sorted to well-sorted, crossbedded; includes scattered mud chips near base; forms cliff	4.9
9. Sandstone, light-greenish-gray, fine-grained, moderately sorted, crossbedded to very thin-bedded; scattered coarse and very coarse grains in middle; top includes 2.5-cm-thick grayish-green mudstone bed containing sandstone-filled desiccation cracks; forms cliff	4.6
8. Sandstone, light-grayish-green, fine-grained, moderately sorted; scattered coarse to very coarse grains; some crossbeds; contains scattered mud chips; unit fills a channel, thickness measured in deepest part of channel; forms notch	1.8
7. Sandstone, light-grayish-green, fine-grained, well-sorted, crossbedded; scattered coarse grains; forms cliff	7.3
6. Sandstone, light-grayish-green to light-olive-green, very fine-grained, moderately sorted, very thin-bedded; forms cliff	1.5
5. Sandstone, silty, reddish-brown to light-grayish-green, very fine-grained, moderately sorted, very thin-bedded; basal 2.5 cm is a purple bentonite bed; forms ledge	0.3
4. Sandstone, very light-gray, very fine-grained, moderately sorted, very thin- to thin-bedded; forms cliff	4.9
3. Sandstone, reddish-brown (locally mottled to light-greenish-gray), very fine-grained, moderately to poorly sorted, very thin- to thin-bedded; includes some dark-reddish-brown silty mudstone; forms notch. Unit is the red band or marker bed that is lithologically related to the Summerville Formation	2.6
2. Sandstone, light-greenish-gray, white, and light-yellowish-green (locally mottled to reddish brown near top), fine-grained, moderately-sorted, very thin-bedded; scattered very coarse grains; lower part forms slightly overhanging ledge; basal contact is a planar surface	0.2
Total thickness Romana Sandstone	44.2
J–3 unconformity.	
Entrada Sandstone (part):	
Middle member (part):	
1. Sandstone, white to very light-gray, very fine-grained, crossbedded; forms cliff. Thickness incomplete	3.0
Total measured Entrada Sandstone	3.0

Section 3.—Type section of the Tidwell Member of Morrison Formation

[Measured on the east side of a small southward-draining canyon in the NE¼ SE¼ SE¼ sec. 24, T. 22 S., R. 13 E., Emery County, Utah. Shown as section 3 on figs. B1 and B21.]

	Thickness (meters)
Morrison Formation (part):	
Salt Wash Member (part):	
8. Sandstone, light-gray, grayish-brown-weathering, fine-grained, moderately sorted, crossbedded; forms cliff	2.4

Thickness (meters)

Morrison Formation (part)—Continued

Salt Wash Member (part)—Continued

Total measured Salt Wash Member (incomplete) ... 2.4

Tidwell Member:

7. Mudstone, grayish-green and dark-reddish-brown, laminated to very thin-bedded; contains several thin beds of light-gray, very fine- to fine-grained, moderately sorted, locally burrowed sandstone; scattered small chert pebbles in a bed in middle of unit; forms slope ... 6.4

6. Mudstone, grayish-green to grayish-yellow-green (with a few thin grayish-purple to dark-reddish-brown beds), laminated to very thin-bedded; 4.9 m above base is a 1-m-thick lens of sandstone that is very fine grained and ripple cross-laminated; 7.3 m above base is 0.3-m-thick bed of gray mudstone containing black carbonaceous blebs; forms slope 9.0

5. Mudstone, grayish-green (with a few grayish-purple beds), laminated to very thin-bedded; contains several thin sandstone beds that are light gray, very fine to fine grained, and laminated to very thin bedded or small-scale crossbedded; one sandstone bed 1.4 m above the base contains scattered small chert pebbles; forms slope ... 3.4

4. Mudstone, grayish-green, grayish-yellow-green, and light-grayish-green; a few beds are dark reddish brown; small blebs of red authigenic chert at several horizons; thin bed of gray, dense limestone found 2.7 m above base; scarce scattered small chert pebbles in some beds; forms slope ... 5.3

3. Gypsum, white and minor very light-grayish-green and light-grayish-pink, nodular; locally contains small blebs and nodules of red or yellow authigenic chert; includes about 20 percent grayish-green mudstone; one bed of light-grayish-green mudstone 0.3 m thick and 0.3 m below top forms a notch; otherwise the unit tends to form a cliff ... 3.5

2. Mudstone, light-grayish-green and minor dark-reddish-brown, laminated to very thin-bedded; contains gypsum as veins, nodules, and thin beds; thin lenses of gray, dense limestone about 0.6 m above base; forms slight ledge ... 1.7

Total thickness Tidwell Member ... 29.3

Thickness (meters)

J-5 unconformity.

Summerville Formation (part):

Chocolate member (part):

1. Mudstone, dark-reddish-brown, very thin- to thin-bedded; contains several thin beds 0–15 cm thick of white gypsum; also includes many thin gypsum veins; upper 0–15 cm bleached to light grayish green; forms cliff; thickness incomplete ... 4.6

Total measured Summerville Formation .. 4.6

Section 4.—Type section of the Fiftymile Member of the Morrison Formation

[Measured on the southeast side of a northeast-trending ridge in the SW¼ SE¼ sec. 11, NW¼ NE¼ sec. 14, T. 41 S., R. 8 E., Kane County, Utah. Shown as section 4 on figs. B1 and B21.]

Thickness (meters)

Dakota Formation (part):

11. Mudstone, black to dark-gray, carbonaceous, laminated to very thin-bedded; includes some light-gray sandstone; forms slope. Basal contact is planar; regional relationships indicate it is an unconformity. Thickness incomplete ... 3.0

Total measured Dakota Formation ... 3.0

Morrison Formation (part):

Fiftymile Member:

10. Sandstone, light-gray, medium-grained, moderately to poorly sorted, thin-bedded to crossbedded, conglomeratic; forms cliff . 7.6

9. Conglomerate, grayish-brown, very thin- to thin-bedded and crossbedded; pebbles include white, very light-gray, gray, black, light-brown, orange, light-green, and dark-red chert and some dark-red quartzite; average pebble size about 4 mm; contains scattered cobbles and small blocks of sandstone as much as 20 cm long; also contains several thin sandstone beds; forms cliff ... 7.8

8. Mudstone, dark-purple and light-green, laminated to very thin bedded, and some red siltstone; forms slope ... 1.2

Morrison Formation (part)—Continued	Thickness (meters)
Fiftymile Member—Continued	
7. Sandstone, light-gray, fine-grained, moderately sorted, laminated and crossbedded; contains scattered pebbles of white, light-gray, light-brown, and gray chert; forms cliff	36.9
6. Mudstone, dark-reddish-brown, and several thin beds of light-gray sandstone; partly covered; forms slope	5.6
5. Sandstone, light-gray, fine-grained, moderately sorted, crossbedded, conglomeratic; forms cliff	5.8
4. Mudstone, dark-reddish-brown; includes several thin beds of light-gray sandstone; partly covered slope	15.4
3. Sandstone, light-gray, fine-grained, moderately sorted, laminated; contains some crossbeds; forms cliff	13.4
2. Mudstone, dark-reddish-brown; includes several thin beds of light-gray sandstone; partly covered slope	13.4
Total thickness of Fiftymile Member	107.1
Salt Wash Member (part):	
1. Sandstone, light-gray, fine-grained, moderately to poorly sorted, crossbedded; contains scattered pebbles and conglomerate lenses; basal 4.6 m includes several thin dark-reddish-brown mudstone lenses to the north of the line of section; about 15.2 m above base is a 1-m-thick lens of dark-reddish-brown mudstone; 17.7 m above base is another dark-reddish-brown mudstone bed that wedges out to the north; about 24.4 m above base is a 2- to 3-m-thick conglomerate lens; forms large cliff	40.5
Total measured Salt Wash Member (incomplete)	40.5

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Chapter C

The Encinal Canyon Member, a New Member of the Upper Cretaceous Dakota Sandstone in the Southern and Eastern San Juan Basin, New Mexico

By WILLIAM M. AUBREY

Studies of a newly recognized fluvial sandstone unit clarify the nature of a major regional unconformity

U.S. GEOLOGICAL SURVEY BULLETIN 1633-C

REVISIONS TO STRATIGRAPHIC NOMENCLATURE OF JURASSIC AND CRETACEOUS ROCKS OF THE COLORADO PLATEAU

CONTENTS

FIGURES

The Encinal Canyon Member, a New Member of the Upper Cretaceous Dakota Sandstone in the Southern and Eastern San Juan Basin, New Mexico

By William M. Aubrey

Abstract

A thin, discontinuous, fluvial conglomeratic sandstone unit that occurs at the base of the Upper Cretaceous Dakota Sandstone throughout most of the southern and eastern San Juan Basin and contiguous areas in north-central New Mexico is herein named the Encinal Canyon Member of the Dakota Sandstone. The unit is characterized by conglomeratic beds that contain abundant white, angular, chalky chert clasts, by dark-gray shale and mudstone beds, and by locally abundant carbonaceous debris. In the past, part or all of the sandstone beds that are placed here in the Encinal Canyon have been included in the Jackpile Sandstone Member of the Morrison Formation, in the Lower Cretaceous Burro Canyon Formation, or in the Upper Cretaceous Dakota Sandstone.

Recognition of the Encinal Canyon Member helps clarify the nature of the sub-Dakota unconformity throughout the region. In the past, this erosion surface was thought by many workers to be at the base of the marine and paralic sedimentary rocks of the Oak Canyon Member of the Dakota Sandstone, which overlies the Encinal Canyon Member. The unconformity is shown here to be at the base of the fluvial rocks of the Encinal Canyon Member.

Local relief of as much as 100 feet (30 m) at the base of the Encinal Canyon indicates that the sub-Dakota erosion surface formed during a time of regional degradation. Easterly flowing streams carved this paleo-land surface, eroding the underlying units and locally cutting completely through the Burro Canyon Formation and the Jackpile Sandstone Member. The Encinal Canyon was deposited in valleys as the base-level rose, in response to the initial transgression of the Dakota sea. As the sea inundated the area, waves and currents reworked some of the Encinal Canyon and truncated the tops of high areas of Lower Cretaceous or older bedrock intervening between the valleys. As the transgression continued paralic and marine sediments of the overlying Oak Canyon Member were deposited.

INTRODUCTION

Most previous workers have recognized fluvial rocks at the base of the Dakota Sandstone in the northern and western parts of the San Juan Basin, but not in the southeastern part of the basin (fig. C1). In this area, it was believed that basal Dakota strata consisted almost entirely of marginal marine or marine rocks of the Oak Canyon Member (Landis and others, 1973; Molenaar, 1977; Owen, 1973) and that the sub-Dakota regional unconformity lay at the base of these rocks. Studies now show, however, that fluvial strata genetically and temporally related to the Dakota Sandstone underlie the Oak Canyon Member and that the regional unconformity is at the base of these fluvial rocks. A newly recognized unit consisting of these thin, discontinuous, locally conglomeratic fluvial sandstone strata is here named the Encinal Canyon Member of the Dakota Sandstone. Recognition of the Encinal Canyon Member is important because it marks the correct stratigraphic position of the sub-Dakota regional unconformity and because it changes concepts concerning sedimentologic processes during the early stages of the deposition of the Dakota.

PRE-DAKOTA ROCKS

The Dakota Sandstone truncates successively older stratigraphic units from northeast to southwest along the southeastern side of the San Juan Basin (fig. C2). In ascending order, the units that lie directly beneath the Dakota in one place or another in the study area are the Zuni Sandstone, the Brushy Basin and Jackpile Sandstone Members of the Morrison Formation, and the Burro Canyon Formation. These units are briefly described below.

The Zuni Sandstone consists largely of fine- to medium-grained, generally yellowish-gray or grayish-yellow-green eolian sandstone (Maxwell, 1976). It is Jurassic (probably Middle Jurassic) in age and lies below the Encinal Canyon at El Morro National Monument and in the Acoma area. The Zuni lies below the Morrison Formation on the east side of the basin.

The Brushy Basin Member of the Morrison Formation consists of thick montmorillonitic beds of

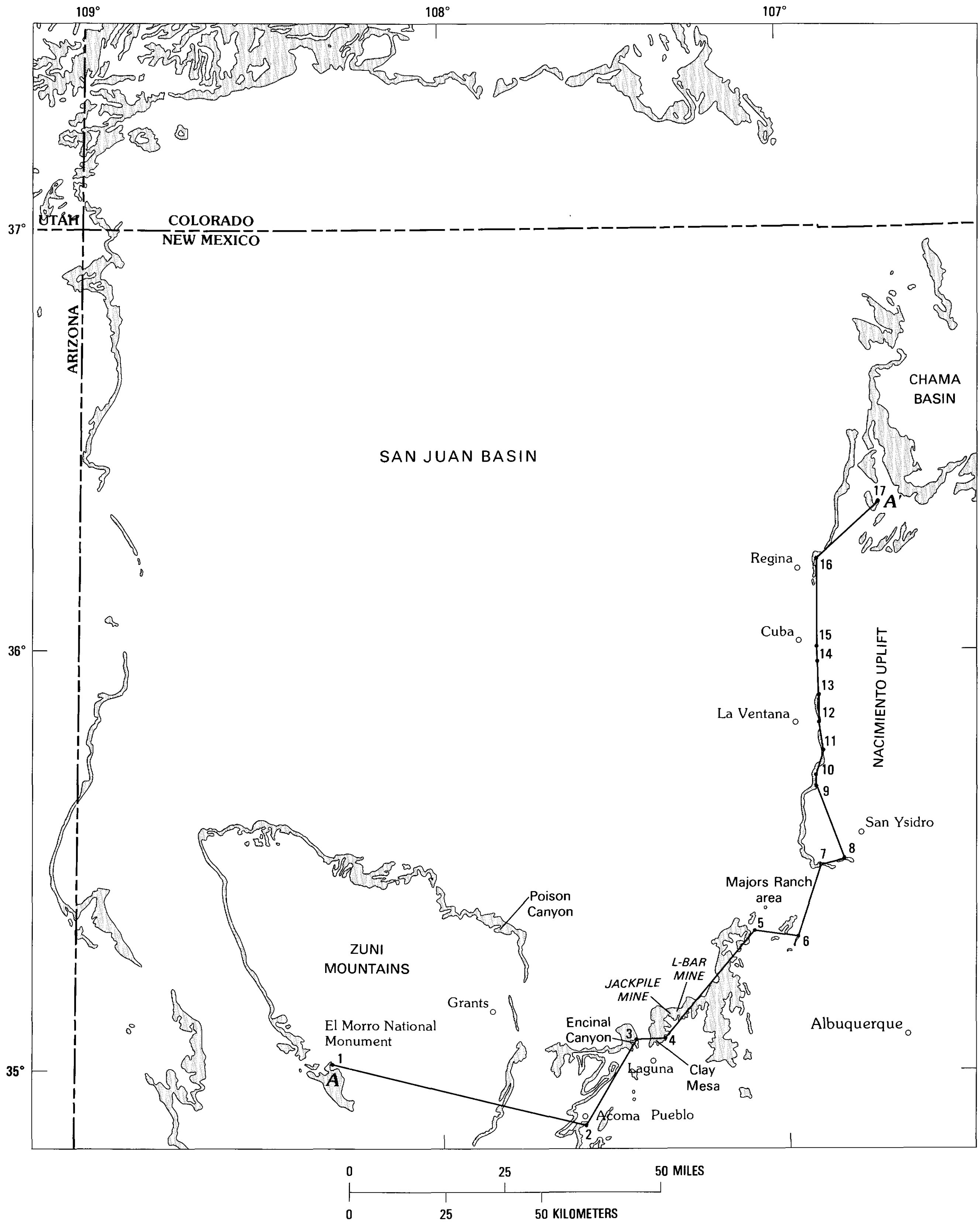

Figure C1. Locations of stratigraphic cross section *A–A'*, measured sections 1–17 (both shown in fig. C2), and other features of interest in and near the San Juan Basin, New Mexico. Patterned areas are outcrops of Dakota Sandstone.

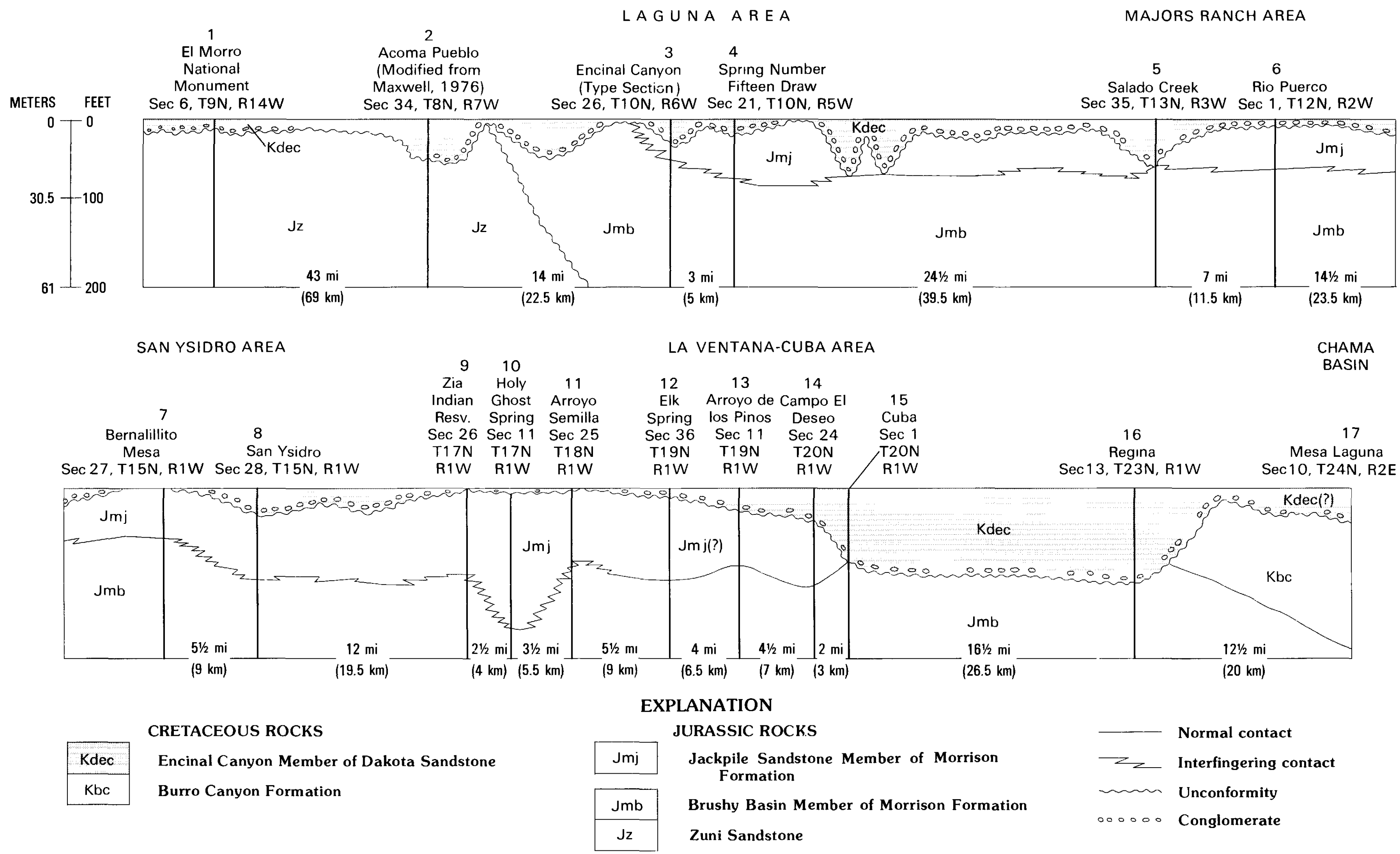

Figure C2. Schematic cross section *A–A′* showing uppermost Jurassic and lowest Cretaceous rocks in southeastern part of San Juan Basin. Relations are queried where uncertain. Datum is the base of the Oak Canyon Member of the Dakota Sandstone. See figure C1 for location.

light-grayish-green mudstone, claystone, and siltstone which alternate with thinner lenses of sandstone, conglomeratic sandstone or conglomerate. The mudstone unit also contains scattered thin limestone beds and thin, well-indurated, orange and grayish-green zeolitic beds. This unit is considered to be Late Jurassic in age in the southeastern San Juan Basin (Santos, 1970).

The Jackpile Sandstone Member of the Morrison Formation locally overlies the Brushy Basin Member in the southeastern part of the basin. The Jackpile is a white, kaolinitic, fine- to medium-grained, crossbedded fluvial sandstone with thin interbeds of pale-green mudstone and siltstone. It interfingers with the underlying Brushy Basin mudstones in the Laguna area and is generally thought to be of Late Jurassic age, although no age-diagnostic fossils have been found in the unit.

Sandstone similar to the Jackpile rests on Brushy Basin mudstones in the northern part of the region in the Chama basin. This sandstone is considered probable Burro Canyon Formation by most recent authors (McPeek, 1965; Saucier, 1974; Ridgley, 1977, 1979). The Burro Canyon Formation in the Chama basin is a tan, kaolinitic, fine- to medium-grained, fluvial, crossbedded, locally conglomeratic sandstone with interbeds of green and red claystone and siltstone. It generally has a sharp basal contact and may be disconformable with the underlying Brushy Basin (Ridgley, 1979). No age-diagnostic fossils have been found in the unit in the Chama basin. However, it may be Early Cretaceous in age if it correlates with the Burro Canyon Formation at its type locality in southwestern Colorado (Stokes, 1952; Craig, 1981), about 150 miles (240 km) to the northwest.

The Jackpile and the Burro Canyon are lithologically similar fluvial sandstone units that occupy the same stratigraphic position between the Brushy Basin mudstone unit and the Dakota Sandstone; the relationship between these two units is uncertain (Owen and Siemers, 1977). Probably the most obvious difference between the Burro Canyon in the Chama basin and the Jackpile Sandstone Member in the Laguna area is that the Burro Canyon is conglomeratic. Conglomeratic beds occur in the Jackpile–Burro Canyon interval as far south as the La Ventana area (Saucier, 1974) and consist of varicolored chert and quartzite and abundant tan chert pebbles. The tan chert is generally nonporous and has a somewhat earthy appearance. It is commonly rounded; however, it may be fragmented. Broken surfaces are generally even or have conchoidal fractures.

DAKOTA SANDSTONE

Encinal Canyon Member

The Encinal Canyon Member tends to form light-gray or light-brown cliffs beneath ledge-forming sandstone or slope-forming shale units in the overlying parts of the Dakota. It is generally well exposed throughout most of the study area. However, because of faulting, exposures are scattered and scarce north of Cuba, N. Mex., along the western flank of the Nacimiento uplift. The type section is in Encinal Canyon, approximately 4 miles northwest of Laguna, N. Mex. (fig. C1), and is shown in figure C3. The type section is illustrated in figure C4 and the measured section is given at the end of the report.

The Encinal Canyon Member is a very light-gray or light-brown, quartzose, fine- to medium-grained, cross-stratified sandstone unit that is commonly conglomeratic, especially at its base. Typically it has a clay-rich or calcareous cement or matrix but locally it is cemented with silica, especially near its top. The Encinal Canyon commonly contains black disseminated carbonaceous debris and thin, discontinuous lenses of gray mudstone. Thin beds of coal are also locally present. Typically the Encinal Canyon is trough crossbedded but it also has tabular planar crossbeds and, more rarely, horizontal or nearly horizontal laminations at some localities. Massive and horizontally stratified conglomeratic beds are interbedded with poorly defined crossbedded sandstone beds locally on the eastern side of the basin north of Cuba along the Nacimiento uplift.

Clasts in the conglomeratic beds of the Encinal Canyon consist of varicolored chert and quartzite and abundant and distinctive white chalky chert. This chalky chert is generally finely porous and pulverulent in appearance. Although the white chalky chert pebbles may be rounded, they are more commonly fragmented and have highly irregular shapes because of uneven, rough fracture surfaces. Their brilliant white color and angular shapes give the chalky chert pebbles a distinctive appearance, especially on a broken surface. The chert clasts generally range in size from very coarse sand to large pebbles, but rare chert boulders as large as 1.5 feet (0.5 m) are seen locally. The chalky chert is one of the most distinctive characteristics of the Encinal Canyon Member, and its recognition aids in the correlation of this important unit throughout the region.

The Encinal Canyon Member ranges from 0 to 75 feet (23 m) in thickness in most of the region. However, it may be as thick as 100 ft (30 m) along the Nacimiento uplift north of Cuba on the eastern flank of the San Juan Basin (fig. C2). The Encinal Canyon Member occurs at least as far south and west as El Morro National Monument, and it extends at least as far northeast as Mesa Laguna in the Chama basin (fig. C2). In Poison Canyon, north of Grants, N. Mex., a thin, lithologically similar sandstone unit containing thin coaly interbeds may be equivalent to the the Encinal Canyon Member. West and northwest of Grants the Encinal Canyon—along with the Oak Canyon and other members that make up the lower part of the Dakota Sandstone in the southeastern San Juan Basin—is undifferentiated and is included in the main body of the Dakota Sandstone (Landis and others,

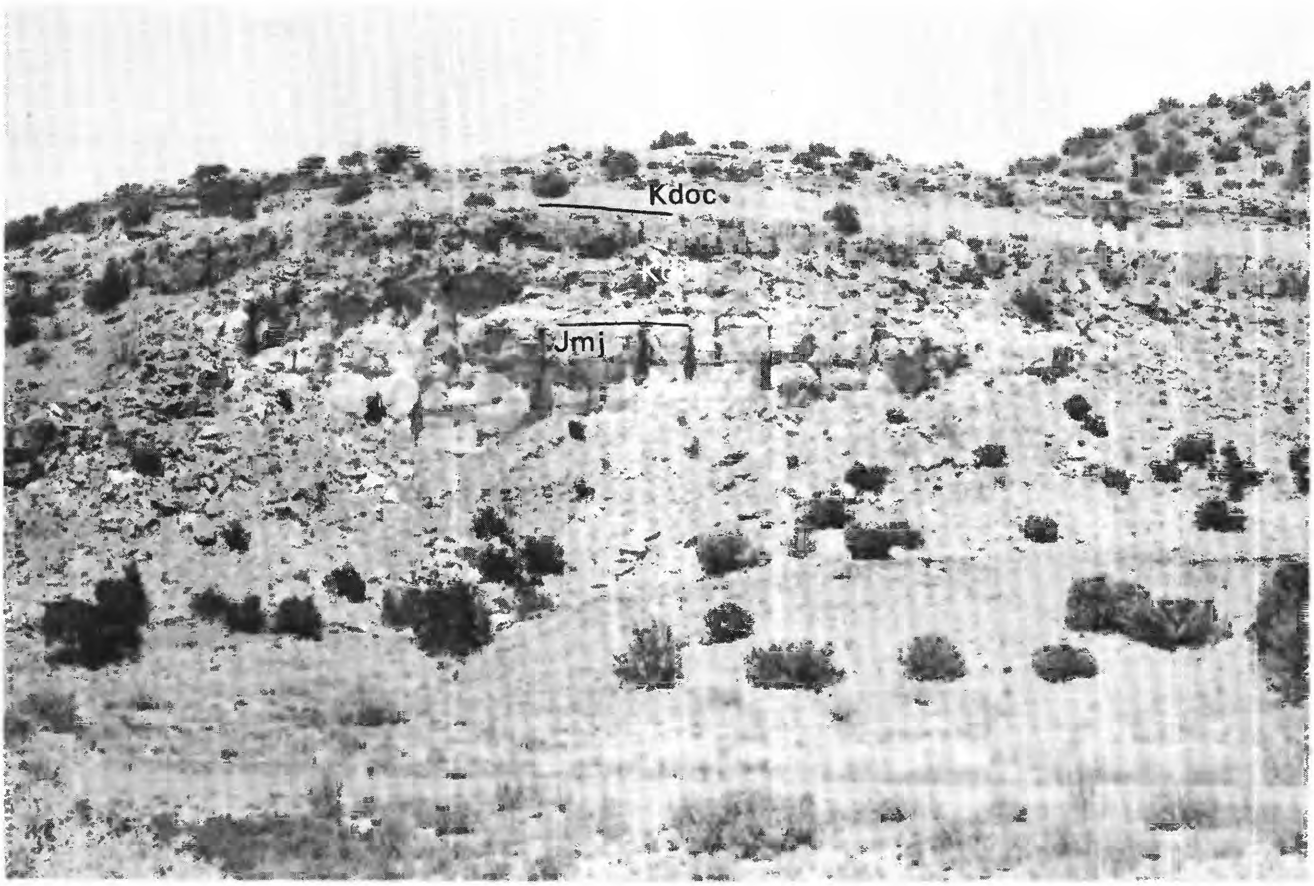

Figure C3. Type section of the Encinal Canyon Member of the Dakota Sandstone (sec. 26, T. 10 N., R. 6 W.) on the east side of the road in Encinal Canyon northwest of Laguna, N. Mex. Jmj, Jackpile Sandstone Member of the Morrison Formation; Kdec, Encinal Canyon Member of the Dakota Sandstone; Kdoc, Oak Canyon Member of the Dakota Sandstone.

1973). Encinal Canyon equivalents probably occur at the base of the main body of the Dakota in the western and northern San Juan Basin.

The base of the Encinal Canyon is a scour surface with tens of feet of local relief, and its lowest beds locally contain rip-up clasts of sandstone or mudstone derived from the underlying units. Locally this surface cuts completely through underlying units; for example, it cuts through the Jackpile Sandstone Member in the subsurface in the L-Bar mine area northeast of Laguna (H. F. Bartlett, Sohio Petroleum Co., oral commun., 1983) and has probably scoured through the Jackpile and the Burro Canyon Formation in outcrops along the Nacimiento uplift north of Cuba (fig. C2). The scour surface at the base of the Encinal Canyon truncates progressively older units from north to south (fig. C2) and is considered to be a regional unconformity. In the southern part of the area the unconformity is slightly angular but has less than 1 degree of angular discordance.

The Jackpile Sandstone Member and the Burro Canyon Formation, which underlie the Dakota in most of the study area, are both fluvial sandstone units similar to the Encinal Canyon Member. They differ from the Encinal Canyon, however, in that they are devoid of black carbonaceous debris and they contain green, greenish-gray, or red mudstone rather than gray mudstone or shale interbeds. Conglomeratic beds in the Jackpile-Burro Canyon interval in the northern part of the region are also different from those found in the Encinal Canyon. Conglomerate in this interval is characterized by abundant earthy chert clasts, whereas conglomerate in the Encinal Canyon is characterized by abundant chalky chert clasts. Jackpile-Burro Canyon clasts are generally tan and well rounded, and they tend to break with conchoidal fracture surfaces. Encinal Canyon clasts, however, are commonly white, are highly irregular in shape, and break with rough and uneven fracture surfaces. Chert clasts larger than 2 inches (5 cm) appear to be restricted to the Encinal Canyon Member.

Oak Canyon Member

At its type section in the Laguna area, the Oak Canyon is divided into two parts, a lower part consisting

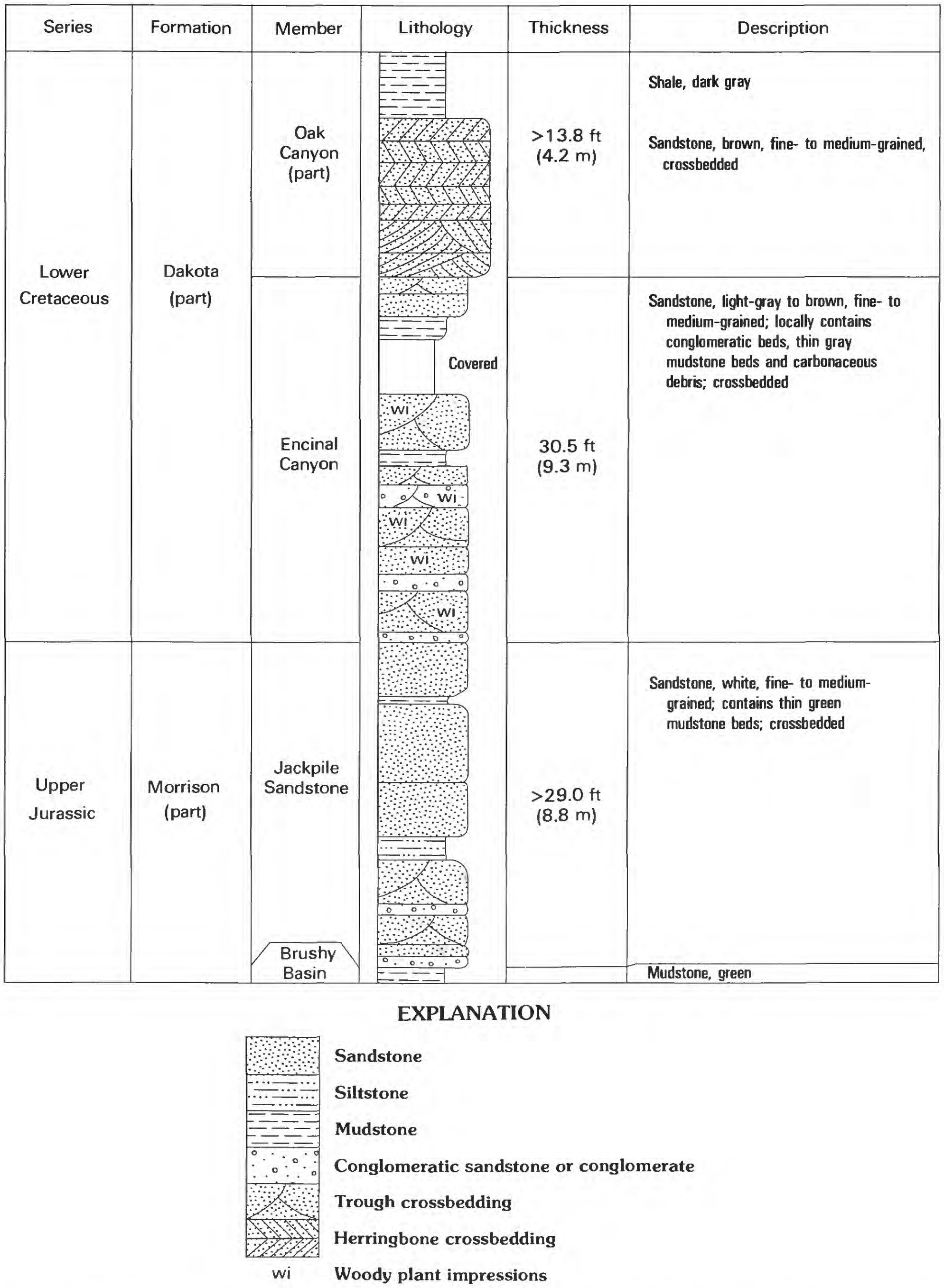

Figure C4. Columnar section of the Encinal Canyon Member of the Dakota Sandstone at the type section in Encinal Canyon, southeastern San Juan Basin, New Mexico.

largely of paralic and marginal marine sandstone and shale with some possible fluvial sandstone beds, and an upper part consisting of beds of marine shale (Landis and others, 1973). Sandstone is only locally present at the base of the Oak Canyon. Northeast of Laguna, in the San Ysidro and Holy Ghost Spring areas, the paralic sandstone and shale appear to be absent, and marine shales lie directly on the pre-Dakota rocks.

The contact between the Oak Canyon Member and the underlying fluvial sandstone of the Encinal Canyon Member of the Dakota Sandstone is a sharp, planar surface. It is placed where the light-gray to light-brown, mostly clay-rich or calcite-cemented, cliff-forming sandstone units of the Encinal Canyon Member are in contact with the overlying, generally grayish-orange, silica-cemented sandstone and black shale of the Oak

Canyon Member. Where present, sandstone beds at the base of the Oak Canyon form a resistant, slightly overhanging ledge above the Encinal Canyon. In the past the Oak Canyon was thought to be the basal unit of the Dakota. Recognition of Encinal Canyon has resulted in a redefinition of the Dakota contact in the southeastern San Juan Basin. The base of the Encinal Canyon is a regional unconformity, and the base of the Oak Canyon, previously thought to be a major unconformity, is now considered to be only a discontinuity resulting from minor reworking of previously deposited Dakota strata as the sea transgressed across the area.

PREVIOUS CORRELATIONS

In the past, the sandstone beds that compose the Encinal Canyon were included in the Dakota Sandstone, in the Jackpile Sandstone and Brushy Basin Members, and in the Burro Canyon Formation. The probable reason for miscorrelation of Encinal Canyon beds with the Jackpile and the Burro Canyon is that all of these fluvial units closely resemble one another physically and lithologically. In addition, the irregular surface at the base of the Encinal Canyon was probably misidentified as a local scour surface. Irregular scour surfaces of this type are fairly common in the Jackpile and the Burro Canyon. Some workers have recognized local but discrete fluvial sandstone units at the base of the Dakota Sandstone at various places throughout the study area, and these are included in the Encinal Canyon. Maxwell (1976) mapped a discontinuous "lower fluviatile conglomerate and sandstone" unit at the base of the Dakota in the Acoma area. Nash and Kerr (1966) reported a thin unit of "reworked" Jackpile that truncates sandstone-hosted uranium ore in the Jackpile at the Jackpile mine near Laguna. This unit probably is part of the Encinal Canyon Member. Reutschilling (1973, p. 46) informally called Encinal Canyon equivalents the "unnamed basal sandstone" in the San Ysidro area. Owen and Siemers (1977) recognized fluvial sandstone units at the base of the Dakota on the east side of the basin in the San Ysidro (Ojito Springs) area, but they included these units in the Oak Canyon Member of the Dakota Sandstone. The lowest unit of the Dakota Sandstone in the Chama basin is a conglomeratic fluvial sandstone 30 to 60 ft (9 to 18 m) thick (Grant and Owen, 1974; Ridgley, 1977, 1979). Based on stratigraphic position and similarity of lithology, particularly the presence of white chalky chert clasts, the Encinal Canyon and lower fluvial unit of the Dakota Sandstone in the Chama basin probably are correlative. Correlation of units between the Chama basin and the region farther south along the eastern flank of the San Juan Basin is difficult because of faulting and scarcity of outcrops along the west side of the Nacimiento uplift north of Cuba.

AGE

Palynomorphs from the Encinal Canyon Member collected by R. H. Tschudy (U.S. Geological Survey, oral commun., 1983) in the Jackpile mine near Laguna indicate that it is earliest Late Cretaceous (early Cenomanian) in age. A very similar age (Cenomanian) has been assigned to the overlying Oak Canyon Member of the Dakota Sandstone based on fossil mollusks (Cobban, 1977) and palynomorphs (R. H. Tschudy cited in Cobban, 1977). The presence of carbonaceous material in the Encinal Canyon also suggests its age is close to that of overlying Dakota strata. Carbonaceous debris is common in the Dakota Sandstone, whereas it is rare or absent from Lower Cretaceous and Upper Jurassic rocks in the region. Moreover, regional stratigraphic relationships indicate that the Encinal Canyon is part of the Dakota. Its basal contact is an unconformity that truncates Middle and Upper Jurassic and Lower Cretaceous rock units, whereas its upper contact, which separates it from the overlying Oak Canyon Member, is only a discontinuity that formed as the sea transgressed across the region.

DEPOSITIONAL HISTORY

The large amount of relief (several tens of feet) on the base of the Encinal Canyon indicates that the sub-Dakota erosion surface in the southeastern San Juan Basin formed as a surface of degradation. This surface probably was the result of a lowering of base level that postdated deposition of the Burro Canyon Formation. Easterly flowing streams, which carved the paleo-land surface preserved at the unconformity, scoured all the underlying units and in some places cut completely through the Jackpile Sandstone Member or the Burro Canyon Formation. A main trunk of this stream system probably passed through the area north of Cuba on the east flank of the San Juan Basin, where the Encinal Canyon Member is thickest (fig. C2). Encinal Canyon streams began to aggrade and the member was deposited as backfill, first in the lower part of the river valleys and later in topographically higher areas, in response to a rise in base level that was probably associated with the encroachment of the Dakota sea into the region. Most of the Encinal Canyon is interpreted to be fluvial in origin. However, locally, near its top, the Encinal Canyon may include some paralic beds deposited during minor stillstands as the sea intermittently transgressed across the area. The top of the Encinal Canyon is placed just below the flat surface that formed as the Late Cretaceous sea advanced over the area. During this marine transgression waves and currents reworked some of the previously deposited Encinal Canyon Member and truncated the tops of high areas of bedrock intervening between the valleys (composed of Lower Cretaceous or older rocks). After the shoreline advanced across the region, the Oak Canyon was deposited in paralic, marginal marine, and offshore marine environments.

CONCLUSIONS

The Dakota Sandstone, in the southeastern San Juan Basin, was thought to consist of marginal marine and marine sedimentary facies, and its base was thought to be an erosional surface formed during a marine transgression. The newly recognized Encinal Canyon Member is important because it changes our understanding of the stratigraphy of this interval and, consequently, of the depositional history in the region during earliest Late Cretaceous time. The member is a mappable fluvial unit lying beneath strata previously thought to be at the base of the Dakota. Significant relief on the base of the Encinal Canyon indicates that the sub-Dakota erosion surface is a result of regional degradation by streams flowing over the area. This surface is a major unconformity that truncates Lower Cretaceous and Upper Jurassic formations. However, the contact between the Encinal Canyon and the overlying Oak Canyon is only a discontinuity formed as the sea transgressed across the region.

MEASURED SECTION

Type section of the Encinal Canyon Member of the Dakota Sandstone

[Measured on east side of road in Encinal Canyon approximately 4 miles (6.4 km) northwest of Laguna, N. Mex. (fig. C1), in the W½ NE¼ sec. 26, T. 10 N., R. 6 W., Laguna 7½-minute quadrangle, Valencia County, N. Mex.]

	Thickness Feet	Thickness Meters
Top of measured section.		
Dakota Sandstone (part):		
Oak Canyon Member (part):		
28. Sandstone, light-brown (5YR5/6) to dusky-brown (5YR2/2), fine- to coarse-grained, moderately well sorted, subrounded; has silica cement (quartz overgrowths); quartzose with less than 1 percent red accessory grains; tabular herringbone crossbeds in sets 1–2 ft (0.3–0.6 m) thick contain graded foresets ½ to 1 in. (1.3 to 2.5 cm) thick that exhibit opposing dip directions	9.0	2.7
27. Sandstone, light-brown (5YR5/6) to dusky-brown (5YR2/2), fine- to medium-grained, moderately well sorted, subrounded; has silica cement (quartz overgrowths); quartzose with less than 1 percent black accessory grains; wedge-shaped crossbeds in sets 6–10 in. (15.2–25.4 cm) thick	2.8	0.9
26. Sandstone, light-brown (5YR5/6) to dusky-brown (5YR2/2), fine- to medium-grained, moderately well sorted, subrounded; has silica cement (quartz overgrowths); quartzose with less than 1 percent pink and black accessory grains; wedge-shaped crossbed sets approximately 2 ft (0.6 m) thick contain graded foresets 1–3 in. (2.5–7.6 cm) thick; forms an overhanging resistant ledge above the Encinal Canyon	2.0	0.6
Total thickness of the Oak Canyon Member (part)	13.8	4.2
Encinal Canyon Member:		
25. Sandstone, very light gray (N8) and moderate-reddish-orange (10R6/6) to moderate-reddish-brown (10R4/6), fine- to medium-grained, moderately well sorted, subrounded; has silica (quartz overgrowths), calcite (minor), and clay (minor) cement; quartzose with less than 1 percent black accessory grains; trough crossbeds in sets as thick as 8 in. (20.3 cm) contain graded foresets 1–2 in. (2.5–5.1 cm) thick	1.5	0.5
24. Sandstone, moderate-reddish-orange (10R6/6) to moderate-reddish-brown (10R4/6), fine-grained, well sorted, subrounded; has silica (quartz overgrowths), calcite (minor), and clay (minor) cement; quartzose with less than 1 percent black accessory grains; massive	2.0	0.6
23. Shale, light-brownish-gray (5YR6/7) and grayish-black (N2)	2.0	0.6
22. Covered interval	5.0	1.5
21. Sandstone, very light gray (N8) to light-gray (N7) and moderate-yellowish-brown (10YR5/4), very fine- to medium-grained, moderately well sorted, subangular; has silica (quartz overgrowths) and calcite (minor) cement;		

	Thickness Feet	Thickness Meters
Dakota Sandstone (part)—Continued		
Encinal Canyon Member—Continued		
quartzose; woody plant fragment impressions along the basal surfaces of some troughs; broad trough crossbeds in sets approximately 1 ft (0.3 m) thick	5.0	1.5
20. Shale, medium-gray (N5) to medium-dark-gray (N4)	0.5	0.2
19. Sandstone, light-gray (N7), dark-yellowish-brown (10YR4/2), and dusky-yellowish-brown (10YR2/2), fine- to medium-grained, well-sorted, subrounded; has silica (quartz overgrowths) and calcite (minor) cement; quartzose with less than 1 percent black accessory grains; limonite and hematite staining and woody plant fragment impressions concentrated along basal surface; faintly crossbedded	1.5	0.5
18. Sandstone, pebbly, very light gray (N8), dark-yellowish-orange (10YR6/6), and dark-reddish-brown (10R3/4), medium- to coarse-grained (with some pebbles as long as ¼ in.; 0.6 cm), poorly sorted, subangular, clay-cemented, quartzose; pebbles include white angular chalky chert; locally contains woody plant fragment impressions; trough crossbeds approximately 1 ft (0.3 m) thick contain graded foresets 4–6 in. (10.2–15.2 cm) thick	2.0	0.6
17. Sandstone, very light gray (N8), dark-yellowish-orange (10YR6/6), and moderate-reddish-brown (10R4/6), fine- to medium-grained, moderately to moderately well sorted, subrounded, clay- and calcite- (minor) cemented, quartzose; trough crossbeds in sets 1–2 ft (0.3–0.6 m) thick contain graded foresets as thick as ½ in. (1.3 cm); limonite stain and woody plant fragment impressions concentrated along basal scour surfaces of trough cross sets ..	3.5	1.1
16. Sandstone, very light gray (N8), dark-yellowish-orange (10YR6/6), and moderate-reddish-brown (10R4/6), fine- to coarse-grained, moderately sorted, subrounded, calcite- and clay-cemented; quartzose with less than 1 percent green and black accessory grains; also contains thin carbonaceous laminations and abundant disseminated carbonaceous plant debris; poorly defined trough crossbeds(?) in sets approximately 1 ft (0.3 m) thick contain graded foresets ½–1 in. (1.3–2.5 cm) thick	2.5	0.8
15. Sandstone, pebbly, dark-yellowish-orange (10YR6/6), and very light gray (N8), fine- to coarse-grained (with pebbles as long as ½ in.; 1.3 cm), poorly sorted, subangular, clay-cemented; pebbles include clasts of white, angular to subangular, chalky chert and subrounded black and gray smooth chert as long as ¼ in. (0.6 cm), and very light gray siltstone clasts as long as ½ in. (1.3 cm); contains thin carbonaceous laminations; massive	0.5	0.2
14. Sandstone, very light gray (N8), dark-yellowish-orange (10YR6/6), and grayish-orange-pink (5YR7/2), fine- to coarse-grained, moderately well sorted, subrounded, clay- and silica- (minor) cemented, quartzose; contains occasional thin laminations of carbonaceous material; faint trough crossbeds in sets as thick as 8 in. (20.3 cm) contain graded foresets 1–4 in. (2.5–10.2 cm) thick; scoured basal surface	3.5	1.1
13. Pebble conglomerate, sandy, dark-yellowish-orange (10YR6/6) and very light gray (N8), poorly sorted, subangular, matrix-supported, clay-cemented, quartzose; matrix is fine to coarse grained; pebbles are as long as ¾ in. (1.9 cm) and include abundant white, angular chalky chert clasts and black, gray, and white subrounded smooth chert clasts; locally contains woody plant fragment impressions and limonite staining near or along the basal scour surface; poorly defined crossbedding	1.0	0.3
Total thickness of the Encinal Canyon Member	30.5	9.3
Morrison Formation (part):		
Jackpile Sandstone Member:		
12. Sandstone, white (N9; locally stained dark yellowish orange, 10YR6/6), fine-grained, moderately well sorted to well sorted, subrounded, clay-cemented, quartzose, massive	5.0	1.5

	Thickness Feet	Meters
Morrison Formation (part)—Continued		
Jackpile Sandstone Member—Continued		
11. Silty mudstone, light-brownish-gray (5YR6/1) and grayish-yellow-green (5GY7/2); locally fissile	0.5	0.2
10. Sandstone, white (N9; locally stained dark yellowish orange, 10YR6/6), fine-grained, moderately well sorted to well sorted, subrounded, clay-cemented, massive	7.0	2.1
9. Sandstone, grayish-orange (10YR7/4) and very pale orange (10YR8/2), fine- to medium-grained, moderately well sorted, subrounded, clay-cemented; quartzose with less than 1 percent black accessory grains; massive	5.0	1.5
8. Sandstone, silty, white (N9) and moderate-reddish-orange (10R6/6); silt to medium-grained sand; poorly sorted to moderately sorted; trace of calcite cement; contains sandy siltstone rip-up clasts as long as ½ in. (1.3 cm)	0.5	0.2
7. Siltstone, sandy, light-brownish-gray (5YR6/1) and light-greenish-gray (5G8/1); silt to very fine grained sand; moderately well sorted; trace of calcite cement; quartzose	1.5	0.5
6. Sandstone, moderate-orange-pink (5YR8/4), medium- to coarse-grained (with a few scattered pebbles as long as ¼ in.; 0.6 cm), poorly to moderately sorted, subrounded, clay-cemented; quartzose with less than 1 percent black accessory grains; granules and pebbles include quartz clasts and gray chert clasts; faint trough crossbeds contain graded foresets 2-3 in. (5.1-7.6 cm) thick	4.0	1.2
5. Sandstone, pebbly, moderate-orange-pink (5YR8/4), medium- to coarse-grained (with some pebbles as long as ½ in.; 1.3 cm), poorly sorted, clay-cemented, quartzose; granules and pebbles include clasts of quartz, gray chert, and white rhyolite; trough cross-bedded; scoured basal surface	1.0	0.3
4. Sandstone, moderate-orange-pink (5YR8/4), medium- to coarse-grained, moderately well sorted, subrounded, clay-cemented, quartzose; faint crossbeds contain graded foresets 1-2 in. (2.5-5.1 cm) thick	2.5	0.8
3. Sandstone, very pale orange (10YR8/2), medium-grained, moderately well sorted, subrounded, clay-cemented, quartzose, massive	1.0	0.3
2. Sandstone, pebbly, very pale orange (10YR8/2), medium- to coarse-grained (with some pebbles as long as ¾ in.; 1.9 cm), poorly sorted, subrounded, calcite- and clay- (minor) cemented; quartzose with less than 1 percent pink and black accessory grains; pebbles include clasts of tan, light-gray, and black chert, white rhyolite, and green mudstone; massive	1.0	0.3
Total thickness of the Jackpile Sandstone Member	29.0	8.9
Brushy Basin Member (part):		
1. Mudstone, grayish-yellow-green (5GY7/2); forms slope	Not measured.	

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