The Jurassic Wanakah and Morrison Formations in the Telluride–Ouray–Western Black Canyon Area of Southwestern Colorado

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The Jurassic Wanakah and Morrison Formations in the Telluride–Ouray–Western Black Canyon Area of Southern Colorado

By ROBERT B. O'SULLIVAN

Revision of the Wanakah Formation and basal Morrison Formation in part of the Black Canyon of the Gunnison River

U.S. GEOLOGICAL SURVEY BULLETIN 1927

U.S. DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, JR., Secretary

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

UNITED STATES GOVERNMENT PRINTING OFFICE: 1992

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Federal Center
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Denver, CO 80225

Library of Congress Cataloging-in-Publication Data

O'Sullivan, Robert Brett, 1923–
The Jurassic Wanakah and Morrison Formations in the Telluride-Ouray-western Black Canyon area of southwestern Colorado / by Robert B. O'Sullivan.
p. cm. — (U.S. Geological Survey bulletin ; 1927)
Includes bibliographical references.
Supt. of Docs. no.: I 19.3:1927
1. Geology, Stratigraphy—Jurassic. 2. Geology—Colorado. 3. Wanakah Formation. 4. Morrison Formation. I. Title II. Series.
QE75.B9 no. 1927
[QE681]
557.3 s—dc20 91–14039
[551.7'66'09788] CIP

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The Jurassic Wanakah and Morrison Formations in the Telluride-Ouray-Western Black Canyon Area of Southwestern Colorado

By Robert B. O'Sullivan

Abstract

Rocks exposed in deep canyons along the San Miguel River in the Telluride area, along the Uncompahgre River in the Ouray area, and in the western part of the Black Canyon of the Gunnison River include the Middle Jurassic Entrada Sandstone and Wanakah Formation and the Upper Jurassic Morrison Formation. The Entrada Sandstone, 45–95 ft thick, and the Wanakah Formation, 45–125 ft thick, are present throughout the area. The Wanakah Formation consists, in ascending order, of the Pony Express Limestone Member and Bilk Creek Sandstone Member, named in the Telluride-Ouray area, and an upper red-bed sequence termed the beds at Sawpit. The Bilk Creek Sandstone Member and the beds at Sawpit are here correlated into western Black Canyon where they had not previously been described. The Tidwell Member, about 50–210 ft thick, a basal member of the Morrison Formation, is here recognized in the Ouray and western Black Canyon areas. Locally in western Black Canyon, an eolian sandstone 73 ft thick and 90 ft above the base of the Morrison Formation is termed the bed at Smith Fork; previously it was correlated with the Junction Creek Sandstone. Gypsum is found (1) at the top of the Pony Express Limestone Member near Ouray and in western Black Canyon, (2) in the beds at Sawpit in western Black Canyon, and (3) in the Tidwell Member in western Black Canyon. The gypsum in the Tidwell Member is similar to gypsum beds in the Tidwell of Utah and probably in basal beds of the Morrison in eastern Colorado. Previously, all gypsum-bearing beds were assigned to the Wanakah Formation. The Junction Creek Sandstone is now recognized along the Gunnison River, east of western Black Canyon, but its relationship to the Junction Creek of the Durango area is uncertain.

INTRODUCTION

Jurassic rocks discussed herein crop out along three deep canyons in southwestern Colorado. In the San Juan Mountains the strata are exposed in the Telluride and Ouray areas near the heads of the San Miguel and Uncompahgre Rivers, respectively, and north of Montrose the rocks are exposed in the western part of Black Canyon of the Gunnison River. Western Black Canyon, as used in this study, refers to the area along the Gunnison River from Chukar trail to Smith Fork (fig. 1). The rocks consist of the Middle Jurassic San Rafael Group and the overlying Upper Jurassic Morrison Formation. The San Rafael Group is underlain by the Upper Triassic Dolores Formation in the San Juan Mountains and by Precambrian rocks in western Black Canyon. Formations of Cretaceous or younger age overlie the Morrison Formation.

In the San Rafael Swell in Utah, about 160 mi west of Telluride, the San Rafael Group consists of five formations, in ascending order, Page Sandstone, Carmel Formation, Entrada Sandstone, and Curtis and Summerville Formations. In the study area along the San Miguel and Uncompahgre Rivers and in western Black Canyon, the San Rafael Group consists of Entrada Sandstone overlain by Wanakah Formation. Eastward from the San Rafael Swell, the Page Sandstone, Carmel Formation, and the lower part of the Entrada Sandstone lap out on to a west-sloping surface of erosion truncating the underlying rocks. The Wanakah Formation in the study area is equivalent to the upper part of the Entrada and lower part of the Curtis in the San Rafael Swell. In the study area, any equivalents of the upper part of the Curtis and the Summerville Formation (fig. 2) were removed before deposition of the Morrison Formation.

Several aspects of the Wanakah Formation and the basal part of the Morrison Formation are discussed herein. The Wanakah Formation and its subdivisions are correlated from the Wanakah mine area near Telluride and Ouray into western Black Canyon. As a consequence the Wanakah Formation in western Black Canyon is revised to agree with the formation in the Wanakah mine area. The relationship between the lower part of the Morrison Formation and the

Manuscript approved for publication March 15, 1991.

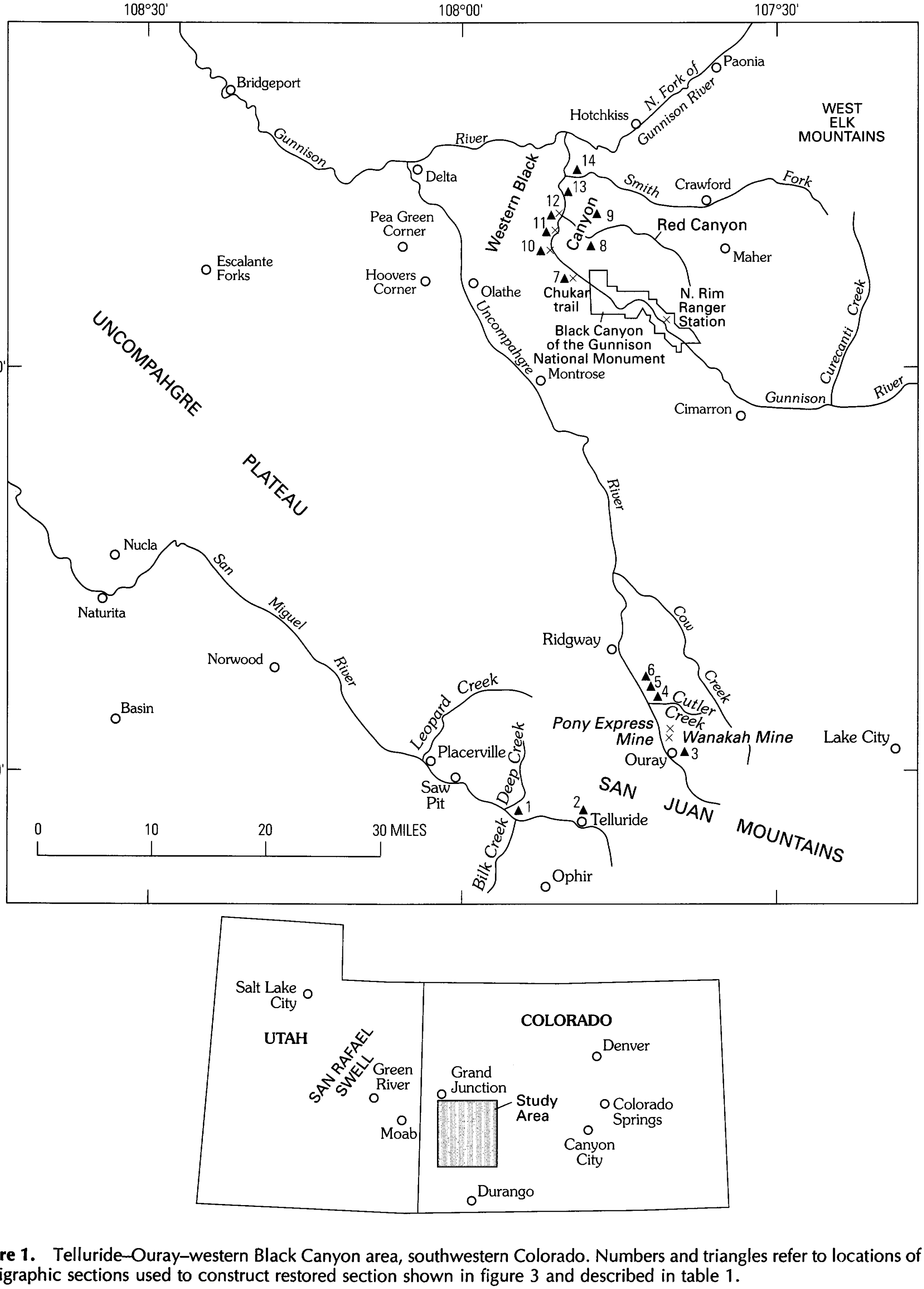


Figure 1. Telluride–Ouray–western Black Canyon area, southwestern Colorado. Numbers and triangles refer to locations of stratigraphic sections used to construct restored section shown in figure 3 and described in table 1.

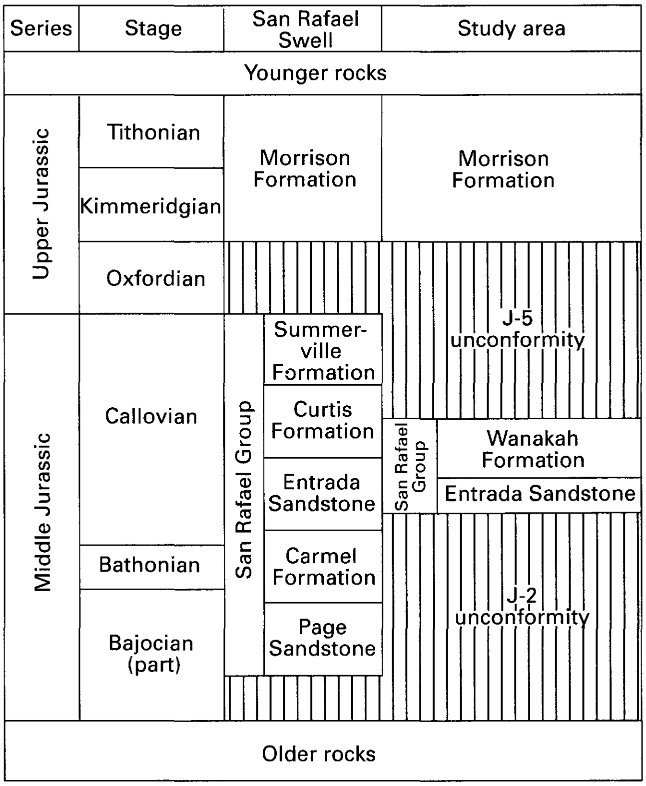


Figure 2. Some Jurassic nomenclature in the San Rafael Swell and study area. Fission-track dating (Kowallis and Heaton, 1987) indicates that upper part of the Morrison Formation may be of Cretaceous age.

Wanakah Formation is described as is the areal distribution of gypsum in the two formations. The stratigraphic nomenclature and previous correlations of Jurassic rocks in the study area are reviewed. Finally, a reference section is established in western Black Canyon for the Wanakah Formation and the lower part of the Morrison Formation.

Acknowledgment.—Thanks are due G.N. Pipiringos for sharing with me his extensive knowledge of Jurassic rocks in the Western Interior of the United States. His visits to western Colorado on several occasions materially aided my understanding of the stratigraphic relations described herein.

STRATIGRAPHY

Jurassic rocks described herein are exposed around Telluride and Ouray. At Ouray, Jurassic rocks dip north beneath Cretaceous rocks and reappear in western Black Canyon. A distance of about 35 mi separates exposures around Ouray from those in western Black Canyon. A restored section (fig. 3) shows the correlation of the Entrada Sandstone, Wanakah Formation, and lower part of the Morrison Formation through the study area. The restored section extends from Bilk Creek on the San Miguel River through Ouray northward to western Black Canyon and is based on detailed sections measured in the field. The section at Cutler Creek (sec. 4, fig. 3) was measured by Steele (1985), and the section at Cedar Hill 6 mi north of Ouray (sec. 5, fig. 3) was measured by Burbank (1930). The rest were measured by the writer. The locations of the measured sections and the thicknesses of individual units are shown on table 1. The correlation of Jurassic rocks is complicated somewhat by the distribution of gypsum at different stratigraphic levels. The correlation benefits from recognition of the subdivisions of the Wanakah Formation and of several stratigraphic marker beds in the Wanakah and Morrison Formations.

Two Jurassic unconformities in the Telluride–Ouray–western Black Canyon area are recognized throughout much of the Western Interior of the United Sates. These unconformities form the boundaries of the San Rafael Group and are termed J–2 at the base of the group and J–5 at the top. Other Jurassic unconformities, such as J–1, J–3, and J–4, are not present in the study area. The unconformities, their distribution, and their regional stratigraphic significance are discussed more completely in a report by Pipiringos and O'Sullivan (1978).

The J–5 unconformity is a widespread break that marks the top of the San Rafael Group and consequently the base of the Morrison Formation. At some places, particularly in the San Rafael Swell area of Utah, the J–5 surface is angular on underlying rocks. Generally beds above and below the unconformity are parallel or almost so, and the J–5 surface shows only very slight relief. Regionally, however, the unconformity bevels across progressively older rocks from the San Rafael Swell eastward into Colorado. From east-central Utah into the study area all of the Summerville Formation and the upper part of the Curtis Formation have been eroded from beneath the J–5 unconformity.

In the study area, the J–5 unconformity is the sharp contact between the Wanakah and Morrison Formations. The surface represents a hiatus that probably includes all of the Oxfordian and much of the upper Callovian (fig. 2). Beveling of individual beds was not noted, although the marked thinning of the upper part of the Wanakah Formation (fig. 3) from the Telluride-Ouray area to western Black Canyon is possibly due to truncation beneath the J–5 surface. About 20 mi east of Chukar trail the surface of unconformity bevels out all of the underlying San Rafael Group, and the Morrison Formation directly overlies Precambrian rocks.

Entrada Sandstone

In the study area the Entrada Sandstone is the basal formation of the San Rafael Group. The Entrada ranges in thickness from 45 ft at the Smith Fork measured section

Table 1. Number, name, and location of measured sections and thicknesses of the Entrada Sandstone and parts of the Wanakah Formation and Tidwell Member of the Morrison Formation

[Thickness in feet, totals rounded; N, not recognized; e, estimated. At section 4 thickness of Entrada Sandstone estimated by Steele (1985, p. 29); at section 5 thickness of Entrada and Tidwell Member of Morrison Formation estimated by the writer judged from thicknesses at adjacent sections]

		Wanakah Formation								Lower part of Morrison Formation			
				Bilk Creek Sandstone Member		Beds at Sawpit				Tidwell Member			
Number, name, and location	Entrada Sandstone	Total thickness	Pony Express Limestone Member	Total thickness	Carnelian sandstone marker bed	Total thickness	Lower marker bed	Bed at Chukar Trail	Upper beds	Total thickness	Bed A	Lower gypsiferous beds	Upper beds
1. Bilk Creek—Measured northeast from lat 37°57′05"N., long 107°55′28"W., to lat 37°57′08"N., long 107°55′24"W.	53	91	11	27	2	53	N	N	N	67	16	N	N
2. Telluride—Measured northwest from lat 37°56′22"N., long 107°48′03"W., to lat 37°56′30"N., long 107°48′14"W.	47	92	20	22	2	50	N	N	N	51	20	N	N
3. South Ouray—Measured north from lat 38°01′26"N., long 107°39′13"W., to lat 38°01′28"N., long 107°39′12"W.	49	84	21	21	1	42	N	N	N	56	27	N	N
4. Cutler Creek—Measured in SW¼SE¼ sec. 1, T. 44 N., R. 8 W., by Steele (1985)	80e	111	22	27	2	62	N	N	N	54	33	N	N
5. Cedar Hill—Measured 6 mi north of Ouray, approximately in NE¼SE¼ sec. 35, T. 45 N., R. 8 W., by Burbank (1930, p. 174)	77e	125	59	20	1	46	N	N	N	54e	27e	N	N
6. North Ouray—Measured in SW¼NE¼NW¼ sec. 35, T. 45 N., R. 8 W.	73	87	9	25	1	53	N	N	N	53	21	N	N
7. Chukar trail—Measured west from lat 38°36′40"N., long 107°50′33"W., to lat 38°36′42"N., long 107°50′39"W.	95	59	2	33	14	24	3	6	15	164	14	79	71
8. Pleasant Park—Measured northeast from lat 38°38′09"N., long 107°48′56"W., to lat 38°38′15"N., long 107°48′48"W.	64	56	2	31	9	23	2	7	14	209	15	82	112

Table 1. Number, name, and location of measured sections and thicknesses of the Entrada Sandstone and parts of the Wanakah Formation and Tidwell Member of the Morrison Formation—Continued

		Wanakah Formation								Lower part of Morrison Formation			
				Bilk Creek Sandstone Member		Beds at Sawpit				Tidwell Member			
Number, name, and location	Entrada Sandstone	Total thickness	Pony Express Limestone Member	Total thickness	Carnelian sandstone marker bed	Total thickness	Lower marker bed	Bed at Chukar Trail	Upper beds	Total thickness	Bed A	Lower gypsiferous beds	Upper beds
9. Red Canyon—Measured northeast from lat 38°40´08"N., long 107°48´29"W., to lat 38°40´14"N., long 107°48´21"W.	70	50	3	29	7	18	1	6	11	189	19	62	108
10. Bobcat trail—Measured northeast from lat 38°38´05"N., long 107°51´41"W., to lat 38°38´08"N., long 107°51´48"W.	78	52	*3	27	7	22	2	8	12	104	16	70	18
11. Duncan trail—Measured northwest from lat 38°39´40"N., long 107°51´47"W., to lat 38°39´44"N., long 107°51´52"W.	85	46	*2	29	8	15	1	6	8	163	14	57	92
12. Ute trail—Measured northwest from lat 38°41´14"N., long 107°51´04"W., to lat 38°41´18"N., long 107°51´09"W.	71	57	*2	32	11	23	2	8	13	193	18	64	111
13. South Smith Fork—Measured north from lat 38°42´53"N., long 107°50´18"W., to lat 38°43´09"N., long 107°50´17"W.	71	58	*1	33	11	24	2	9	13	195	16	105	74
14. Smith Fork—Measured north from lat 38°44´06"N., long 107°49´03"W., to lat 38°44´15"N., long 107°49´07"W.	45	57	*5	31	11	21	1	7	13	190	15	61	**114

*Thickness of Pony Express equivalent.

**Includes bed at Smith Fork 73 ft thick; the upper beds below and above the bed at Smith Fork are 15 and 26 ft thick, respectively.

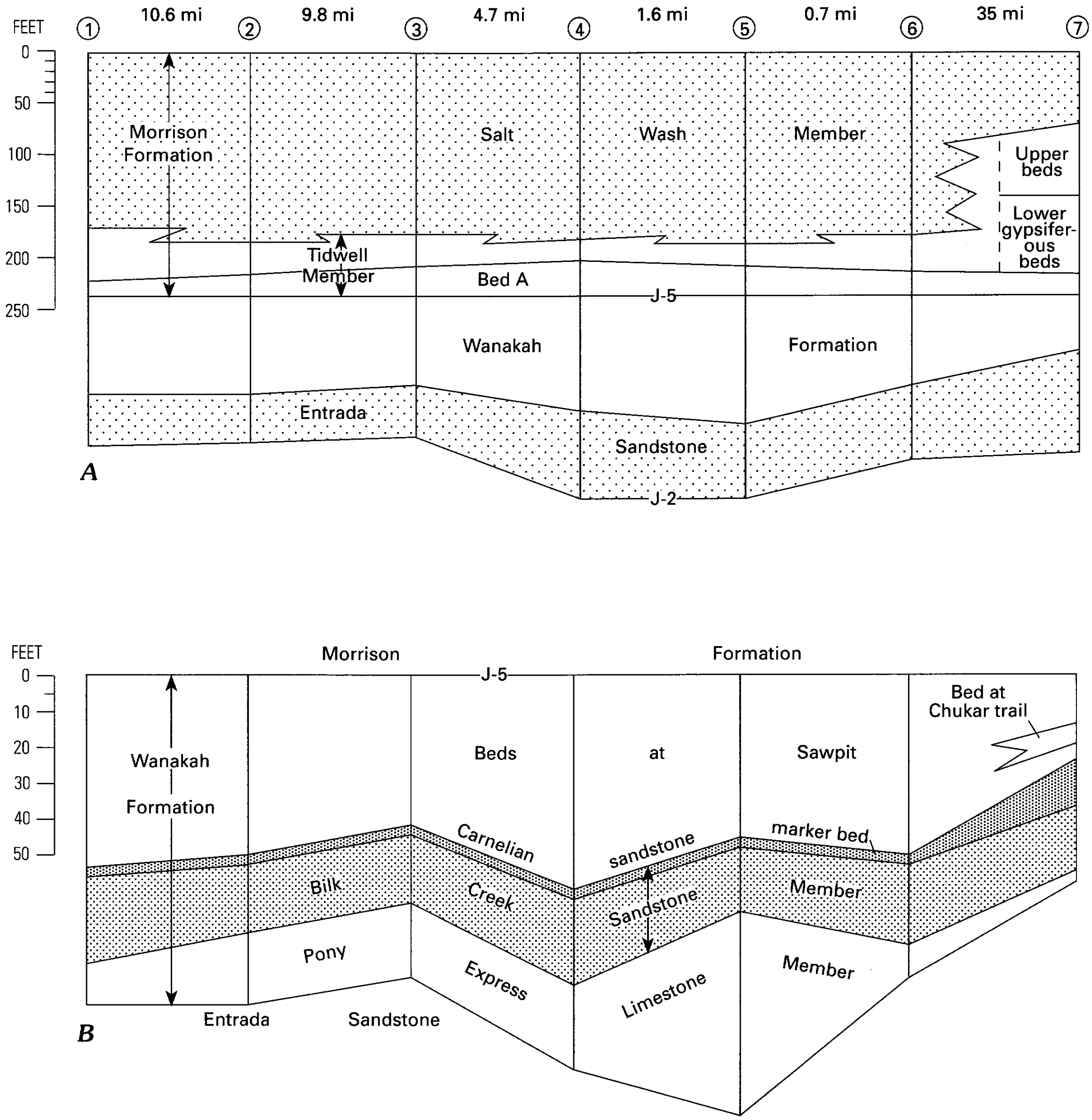
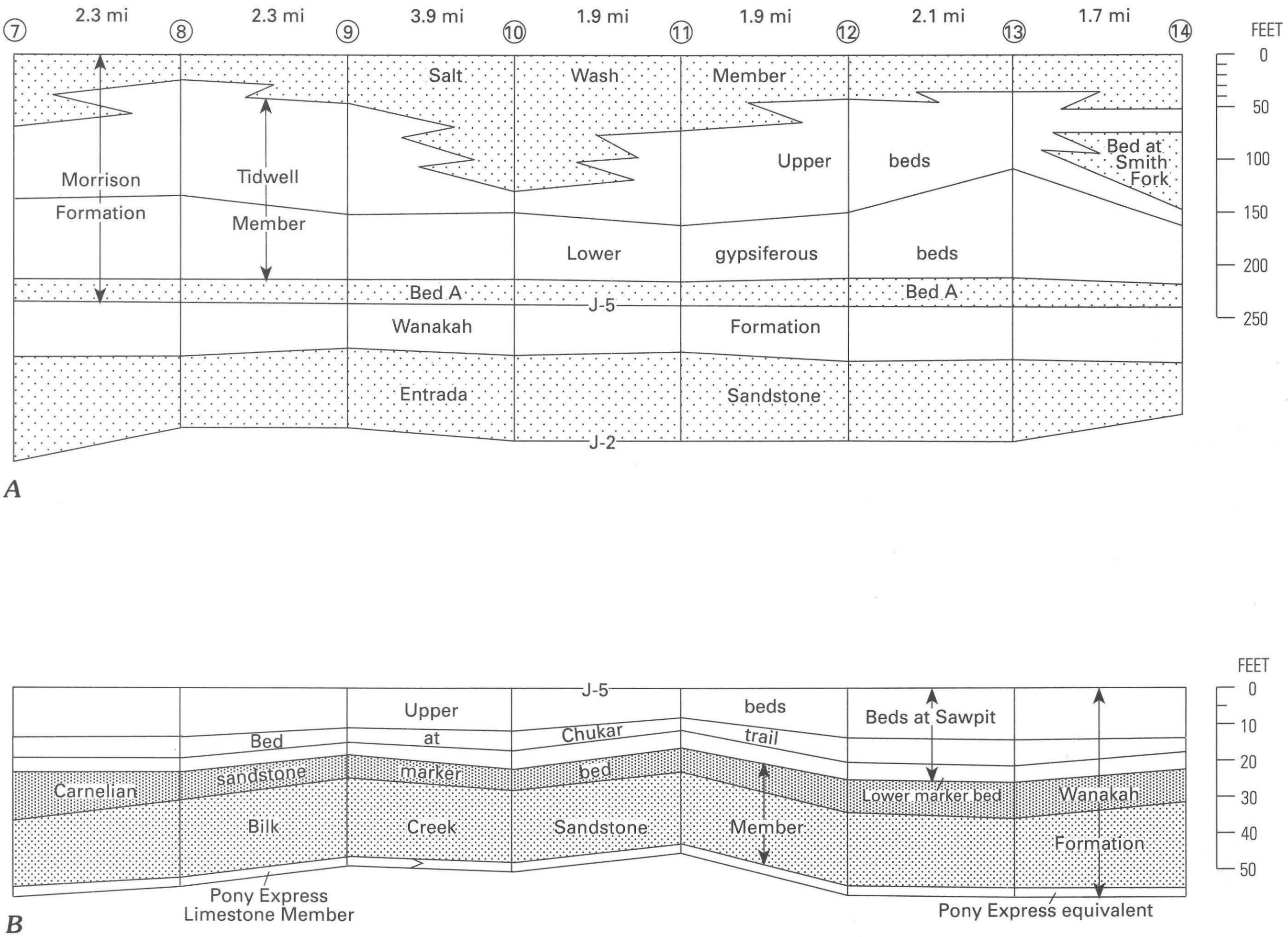


Figure 3 (above and facing page). Restored sections showing correlation of some Jurassic rocks. Line of section extends from Telluride-Ouray area to western Black Canyon and is shown on figure 1. Measured sections are described in table 1. *A*, Correlation of Entrada Sandstone, Wanakah Formation, and Morrison Formation. *B*, Correlation of Wanakah Formation and its subdivisions.

(sec. 14, fig. 3) to 95 ft at the Chukar trail measured section (sec. 7, fig. 3). At the type locality at Entrada Point in the San Rafael Swell, the Entrada is 312 ft thick (Gilluly, 1929, p. 104–105). The Entrada is thinner in the study area partly because of internal thinning, partly because of lateral gradation into the Wanakah Formation, and partly because basal parts of the Entrada lap on to the J–2 surface of unconformity. The Entrada wedges out completely along the north rim of the Black Canyon about 11.5 mi southeast of Chukar trail (Hansen, 1971).

The Entrada Sandstone generally forms a bold cliff throughout the area. In the Telluride-Ouray area the Entrada is light gray, in contrast to the underlying red Triassic and Permian rocks. In western Black Canyon the Entrada is gray in most places, but varied amounts are red or banded red and gray. At the Pleasant Park section (sec. 8, fig. 3) only the basal 3 ft is red, the rest is gray. At Bobcat trail most of the Entrada (68 of 78 ft) is banded red and gray. The red and gray of the Entrada stand out from the underlying dark Precambrian rocks. The Entrada is mainly a fine to very fine grained sandstone, but it contains disseminated, sparse, well-rounded, medium grains of clear quartz. The coarser grains of the Entrada, which are informally termed "Entrada berries," contrast markedly with the finer grained matrix.



The Entrada was deposited in a sequence of alternating crossbedded and flatbedded units. The crossbedded units are eolian deposits; the flatbedded units are interpreted as interdune deposits.

Wanakah Formation

The Wanakah Formation conformably overlies the Entrada Sandstone in the study area and tends to form a rough slope (fig. 4) beneath the Morrison Formation. The Wanakah was named by Burbank (1930, p. 172) for exposures at the Wanakah mine about a mile north of Ouray. The name Pony Express, derived from the Pony Express mine 4 mi north of Ouray, was introduced for basal beds of the Wanakah.

The following section, measured by Burbank (1930, p. 174), shows the thickness and arrangement of the Wanakah at Cedar Hill 6 mi north of Ouray. The Wanakah was assigned as a member of the Morrison Formation but has since been raised to formational status. The "Pony Express beds" are now the Pony Express Limestone Member of the Wanakah Formation. The "sandstone bed" or unit 5 and unit 6 now constitutes the Bilk Creek Sandstone Member. The "upper shale beds" less unit 6 are now recognized as the beds at Sawpit. The entire section is quoted directly from Burbank (1930, p. 174).

Section of the Wanakah member on the east side of the Uncompahgre Valley 6 miles north of Ouray.

Wanakah member of the Morrison formation:

	Thickness (feet)
UPPER SHALE BEDS:	
19. Shale or mudstone; weathers to small angular fragments; color brown; weathered surface yellowish	1.5
18. Limestone, crystalline; contains a few shale pellets; color brownish; weathers rusty brown..	0.5
17. Shale or mudstone; breaks into angular fragments; color brown	1.3

Figure 4. Wanakah Formation near Bilk Creek. View looking northeast ½ mi east of Deep Creek and north of junction of Bilk Creek with San Miguel River. Dolores Formation (D); Entrada Sandstone (E); Wanakah Formation consists of Pony Express Limestone Member (PX), Bilk Creek Sandstone Member (BC), and beds at Sawpit (SP); Morrison Formation consists of Tidwell Member (TM) with bed A (A) at base, Salt Wash Member (SW), and Brushy Basin Member (BB). Cretaceous sandstones of Burro Canyon Formation overlie Morrison Formation. Entrada Sandstone is about 50 ft thick. Photograph by A.L. Bush.

UPPER SHALE BEDS:—Continued	Thickness (feet)
16. Limestone; lenticular bed; white and crystalline, weathering brown	0.3
15. Shale; like 17 above	0.7
14. Limestone; nodular and crystalline; color brown	0.3
13. Shale; limy and sandy layers; breaks to angular fragments; color brown, somewhat reddish or yellowish; it contains brown and gray crystalline lime nodules and lenses and a few limy layers are persistent enough to form thin limestone beds; near the top some of the calcareous nodules are partly altered to red chert and quartz	26.0
12. Limestone; gray; dense	0.6
11. Clay shale; greenish gray	1.8
10. Shale; sandy and brown at top grading down into fine blocky shale of greenish color at base	6.5
9. Shale, brown	0.5
8. Shale, sandy, olive gray; impregnated with gypsum in cracks	2.4
7. Sandstones and sandy shales, greenish and brownish colors, partly slumped	4.0
6. Sandstone; hard; greenish gray; consists of clean quartz grains and grains of bright red chert; appears glauconite	1.0
Total thickness shale beds	47.4

	Thickness (feet)
SANDSTONE BED:	
5. Sandstone; soft and friable; clayey layers near top; color somewhat olive gray near top; near base color gray weathering buff	19.0
"PONY EXPRESS BEDS":	
4. Gypsum; banded; white with black shaly layers	1.7
3. Gypsum; nodular; roughly bedded; with subordinate black interstitial shale and irregular shale partings	50.0
2. Shale and limestone breccia; small angular fragments of limestone and shale partly cemented with calcite; porous	1.8
1. Shale and limestone; thin alternations of black shale and dark limestone; some beds have a bituminous odor when struck........................	5.0
Thickness "Pony Express beds"	58.5
Total thickness of Wanakah member	124.9

Gray cross-bedded sandstone of Jurassic age, upon which the Wanakah shale rests conformably.

Pony Express Limestone Member

The Pony Express Limestone Member forms a distinctive lithologic unit within the San Rafael Group. The member is at the base of the Wanakah Formation between the Bilk Creek (fig. 3, sec. 1) and Red Canyon (fig. 3, sec. 9) measured sections. The Pony Express is 2–3 ft thick in western Black Canyon, 11–20 ft thick near Telluride, and as thick as 59 ft near Ouray.

The Pony Express Limestone Member throughout its extent from Bilk Creek to western Black Canyon is dominantly limestone; near Ouray it also includes other rock types. The limestone is dark gray, and fresh surfaces have a petroliferous odor. The member is characterized by wavy bedding of low amplitude in beds as thick as half a foot. Near Ouray, thin beds of dark-gray shale and sandstone are interbedded with the limestone.

Also near Ouray the limestone just described is overlain by a sedimentary breccia, which in turn is overlain locally by a thick lens of gypsum. The breccia consists of small bits of limestone, shale, and siltstone generally set in a dense limestone matrix. The breccia is present at the South Ouray, Cutler Creek, Cedar Hill, and North Ouray measured sections (secs., 3, 4, 5, and 6, respectively, fig. 3). The gypsum, about 50 ft thick, is present above the breccia only at the Cedar Hill section 6 mi north of Ouray (sec. 5, fig. 3).

The limestone breccia and the thick gypsum bed are related. According to Burbank (1930, p. 173), the "breccia is from a few feet to 20 feet in thickness, shows an indistinct stratification at places, and commonly has been cemented by calcareous material. The limestone and shale fragments composing the breccia are small, rarely exceeding 2 inches in diameter and usually much smaller, and are sharply angular. At some places particularly where the formation [Pony Express] is unaltered a minimum of cementing matter is present and the breccia is consequently extremely porous." Northward from the Cedar Hill section, where gypsum is present, Burbank (1930, p. 175) found "that the gypsum beds rapidly wedge out and entirely disappear within a few hundred feet, while the breccia within the same range increases in thickness from less than 2 feet to about 8 feet. It is apparent from the local relations that the breccia has been formed by the dissolving of the gypsum and the gradual accumulation in place of the interstitial fragments and layers of less soluble limy shale. The shape and nature of the interstitial shale masses in the gypsum beds are identical with the fragments composing the breccia."

The limestone breccia indicates that gypsum was once more widespread around Ouray than is indicated by the single occurrence of gypsum at the Cedar Hill location. Neither gypsum nor limestone breccia is at the top of the Pony Express Limestone Member in the Bilk Creek–Telluride area or in western Black Canyon. Along Cow Creek (location A, fig. 5), 6 mi northeast of Ouray, the Pony Express Limestone Member is 1.2 ft thick, and gypsum and limestone breccia are absent. Gypsum is at least locally present near the rim of the Black Canyon east of the area studied. J.L. Ridgley (U.S. Geological Survey, oral commun., 1989) reported that a bed of gypsum 5–8 ft thick directly overlies the Pony Express Limestone Member 8.7 mi southeast of the Chukar trail section (fig. 3) and 1 mi northwest of the North Rim Ranger Station of the Black Canyon of the Gunnison National Monument (location B, fig. 5).

Gypsum associated with the basal limestone member of the Wanakah Formation is much more widespread south of the study area. In New Mexico gypsum is widespread at the top of the Todilto Limestone Member of the Wanakah, an equivalent of the Pony Express (fig. 5), and is present as far north as the Piedra area in southern Colorado, south of the San Juan Mountains. Tertiary volcanic rocks and post-Jurassic erosion in the San Juan Mountains obscure the extent of the gypsum in the area between Piedra and Ouray. However, the limestone breccia and isolated lenses of gypsum indicate that calcium-sulfate–laden waters extended from New Mexico into the study area near the end of Pony Express deposition.

The environment of deposition of the Pony Express–Todilto Limestone is uncertain; both unusual marine and unusual lacustrine origins have been proposed. Sulfur-isotope (Adler, 1974, p. 630) and whole-rock carbon, oxygen, and sulfur isotope studies (Ridgley and Goldhaber, 1983, p. 414) suggest a marine rather than a lacustrine origin.

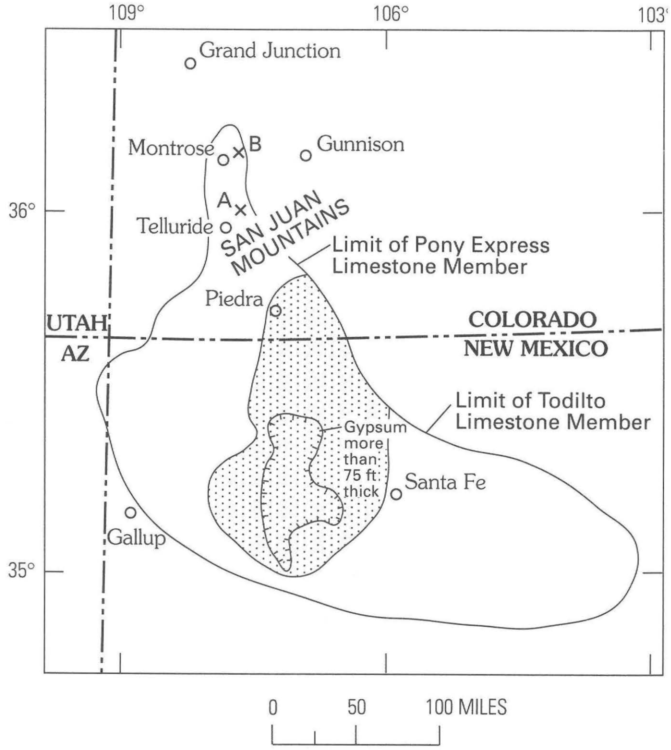


Figure 5. Areal extent of basal limestone of Wanakah Formation showing distribution of Pony Express Limestone Member in Colorado and equivalent Todilto Limestone Member in New Mexico. Stippled area indicates distribution of gypsum. A and B are locations discussed in text. Modified from Wright (1959); eastern limits of Todilto Limestone Member in New Mexico from J.L. Ridgley (written commun., 1989).

Pony Express Equivalent

The Pony Express equivalent is recognized beyond the limits of the Pony Express Limestone Member. The Pony Express wedges out between the Red Canyon (sec. 9, fig. 3) and Bobcat trail (sec. 10) measured sections. From Bobcat trail north to Smith Fork (sec. 14), the Entrada Sandstone is overlain by a sandstone termed, for convenience, the "Pony Express equivalent." The Pony Express equivalent is 1.4–4.5 ft thick and yellowish gray or light brown except at Bobcat trail where it is reddish tan. It is fine grained and flatbedded and overhangs the underlying Entrada Sandstone. Sparse, rounded, medium grains are present at the Duncan trail (sec. 11) and Ute trail (sec. 12) measured sections. The Pony Express equivalent is a water-laid sandstone deposited at the periphery of the Pony Express Limestone Member.

Bilk Creek Sandstone Member

The Bilk Creek Sandstone Member overlies either the Pony Express Limestone Member or the Pony Express equivalent. It was named by Goldman and Spencer (1941, p. 1750) for Bilk Creek, which drains into the San Miguel River near section 1 (fig. 3). The Bilk Creek extends beyond the limits of the Pony Express Limestone Member along the Gunnison River (fig. 3) and along the San Miguel River (O'Sullivan, 1986). The Bilk Creek is light gray, greenish gray, and yellowish gray; the upper part of the member locally shows reddish-brown streaks or bands. The member is 20–33 ft thick and is mostly fine grained, although sparse medium grains were noted at Pleasant Park (sec. 8). Near Sawpit on the San Miguel River, Steele (1985, p. 9) found ostracodes and ooliths in the Bilk Creek. Bedding, wherever observed by the writer or by Steele (1985), is flat or not apparent; however, in the Placerville area on the San Miguel River, Bush and others (1959, p. 326) described some faint, small-scale, low-angle crossbedding. In general, the Bilk Creek Member is set back on underlying rocks and is poorly exposed, although it locally forms a small cliff (fig. 6).

The Bilk Creek Sandstone Member is capped by a very distinctive unit termed the "carnelian sandstone marker bed." The name is derived from the presence at many places of "autochthonous red chert, scattered through it to some extent but more characteristically on its upper surface" (Goldman and Spencer, 1941, p. 1749). The carnelian sandstone is poorly sorted and fine grained. It contains sparse to abundant, rounded coarse quartz grains as much as about 1 mm across. Its bedding is flat or not apparent. In southwestern Colorado, Bush and others (1960, p. 441) noted that the carnelian marker bed "is remarkably persistent over an area covering perhaps several thousand square miles."

The carnelian sandstone marker bed is thickest in western Black Canyon and pinches out westward near Norwood. In the Telluride-Ouray area the marker bed is only 1–2 ft thick; in western Black Canyon it is 7–14 ft thick. Both the thicker carnelian sandstone in western Black Canyon and the well-rounded grains disseminated throughout the sandstone suggest a nearby source. The coarse, well-rounded Entrada berries, a nearby potential source, could not have been the source because at the pinchout east of Chukar trail the Entrada Sandstone is directly and conformably overlain by the Pony Express Limestone Member (W.R. Hansen, U.S. Geological Survey, written commun., 1990). Perhaps the quartz-rich Precambrian metamorphic rocks were the source of the coarse grains during deposition of the carnelian sandstone.

The carnelian sandstone marker bed is undoubtedly a reworked zone closely related to overlying strata. As a reworked zone it should be assigned as the basal part of the overlying beds at Sawpit of the Wanakah Formation. The base of the ledge-forming carnelian sandstone is sharp, possibly a scour surface (Steele, 1985, p. 31, 52), and the bed commonly overhangs (fig. 6) the underlying lower parts of the Bilk Creek Member. In addition, coarse-grained sandstone beds similar to the carnelian marker locally present in equivalents of the beds at Sawpit indicate a continuation of carnelian depositional conditions. The

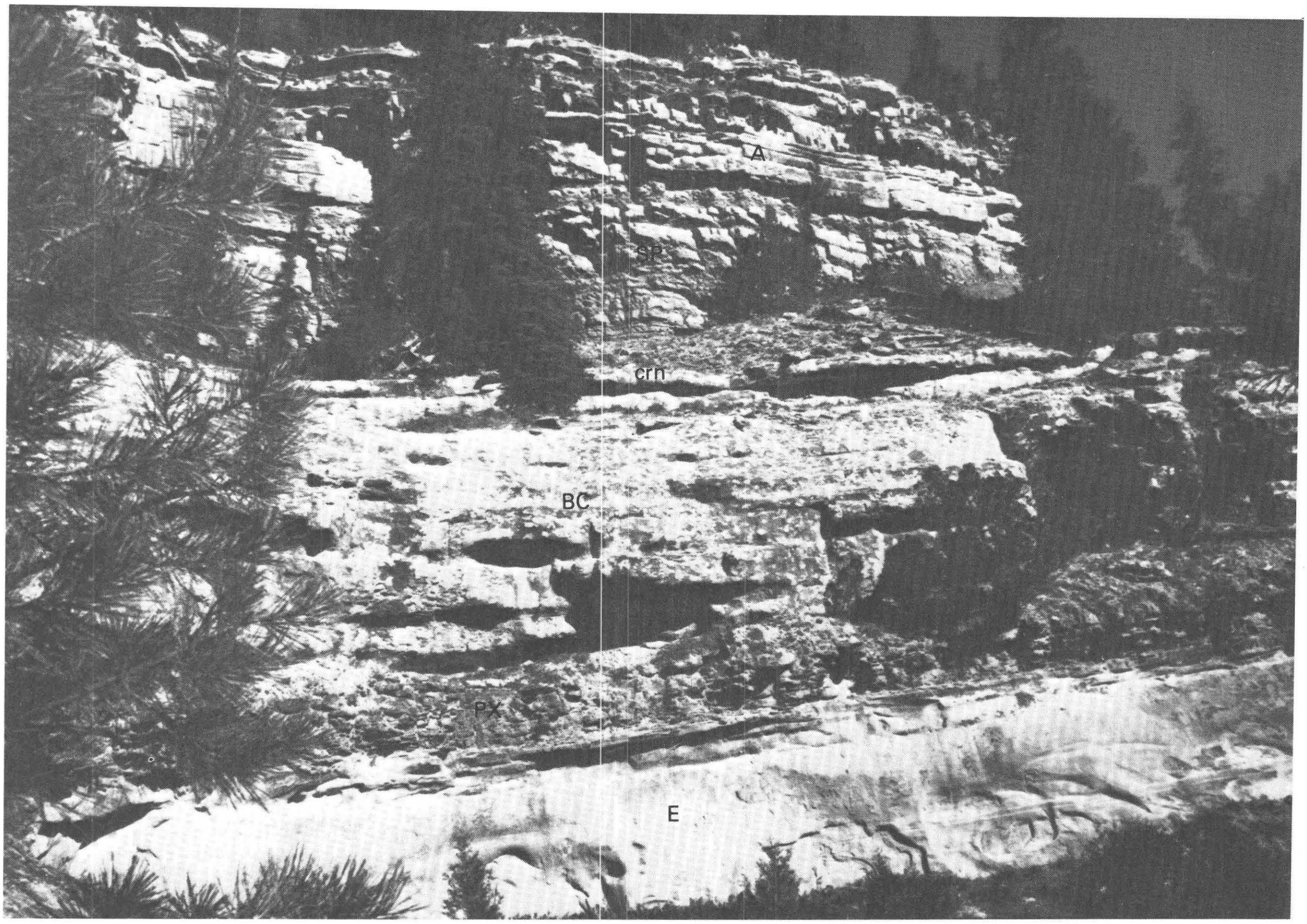


Figure 6. Bilk Creek Sandstone Member on west side of Leopard Creek, about 3 mi north of confluence of Leopard Creek and San Miguel River. Only top of Entrada Sandstone (E) exposed. Wanakah Formation consists of Pony Express Limestone Member (PX), Bilk Creek Sandstone Member (BC) with carnelian sandstone marker bed (crn) at top, and slope-forming beds at Sawpit (SP); bed A (A) at base of Tidwell Member of Morrison Formation overlies Wanakah Formation. Bilk Creek Member is about 25 ft thick.

coarse, rounded quartz grains in the marker bed are probably a lag accumulation resulting from the winnowing action of currents. As interpreted by Bush and others (1959, p. 327), the "extremely persistent carnelian sandstone***probably was deposited entirely in a seaway, within reach of wave base, and its sediments were constantly reworked and spread over the sea floor as an even uniform blanket."

Beds at Sawpit

The beds at Sawpit overlie the Bilk Creek Sandstone Member and are mostly a red sequence of sandstone and siltstone in strata that are generally less than 3 ft thick. The strata are mostly reddish brown to pale red and locally mottled or banded gray and commonly form a slope, parts of which cover the underlying bedrock. Gray and red ledge-forming sandstone beds, commonly less than 1 ft thick, and thin red clay beds are present at most locations.

The beds at Sawpit differ somewhat from the Telluride-Ouray area to western Black Canyon. From the Telluride-Ouray area to western Black Canyon, they diminish about one-half in thickness, owing possibly to truncation beneath the J–5 unconformity. East of Chukar trail, possibly 10–15 mi, the beds at Sawpit lap out, and younger strata rest on Precambrian rocks. Additionally, in western Black Canyon the beds at Sawpit are characterized by beds, seams, and nodules of gypsum.

The beds at Sawpit in western Black Canyon consist of three units, in ascending stratigraphic order, the lower marker bed, the bed at Chukar trail, and the upper beds. The lower marker bed is 1–3 ft thick and forms a conspicuous re-entrant under the bed at Chukar trail. The lower marker is made up of greenish-gray, locally gypsiferous siltstone and shale. The upper beds, 8–15 ft thick, are mostly reddish-brown siltstone and minor gray and greenish-gray bands and mottles. Locally, the upper beds contain nodules and thin seams of gypsum.

Table 2. Analytical data for gypsum samples from the bed at Chukar trail

[Sample localities described in text by sample number. All results in percent. Leaders (--) indicate below detection limit. All samples are grab samples from gypsum outcrops. Gypsum content and purity determined according to American Society for Testing and Materials standards; data from Brown (1988, p. 20)]

Sample no.	CaO	SO_3	Free H_2O	H_2O*	$CaSO_4$+ H_2O*	SiO_2	SiO_2+ insoluble	CO_2	Fe_2O_3	MgO	Al_2O_3	K_2O	Na_2O	NaCl	MnO	TiO_2
1	28.4	39.4	0.30	17.4	85.5	10.0	11.4	0.73	0.19	0.13	1.80	0.38	0.06	--	--	0.03
2	31.0	43.7	.40	18.9	93.6	3.1	4.6	.29	.13	.11	.49	.13	.08	--	.003	.13
3a	30.5	42.7	.40	18.1	91.3	5.2	6.7	.15	.14	.29	1.00	.18	.06	--	--	.03
3b	33.0	46.2	.50	19.8	99.0	.4	1.0	.22	.02	.01	.05	.04	.02	--	--	--

*Combined.

The bed at Chukar trail consists of gypsum, 6–9 ft thick, that forms a prominent ledge (see fig. 10) throughout western Black Canyon. Prospect pits in the bed at Chukar trail near Duncan trail and near Smith Fork indicate that attempts were made to evaluate or mine the gypsum. Grab samples (table 2) of the bed at Chukar trail from four localities contain 85–99 percent calcium sulfate (hydrated). Sample 1 is from an area of many prospects pits and trenches 1 mi south of the junction of Smith Fork with the Gunnison River and 0.5 mi north of the South Smith Fork measured section (sec. 13, fig. 3). Sample 2 was collected 500 ft south of the Ute trail measured section (sec. 12, fig. 3). Samples 3a and 3b are from Duncan trail: 3b is from a prospect pit at the end of the access road to Duncan trail, 3a was collected 300 ft to the north.

Morrison Formation

The Morrison Formation overlies the Wanakah Formation. Throughout the area it is made up of three parts: (1) the Tidwell Member at the base, (2) the Salt Wash Member, and (3) the Brushy Basin Member. The Tidwell Member rests on the J–5 unconformity and is discussed below. In the study area the Salt Wash Member is 300–400 ft thick and the Brushy Basin Member is 275–350 ft thick (Craig and others, 1955, figs. 21, 29). East of Chukar trail the Salt Wash Member thins to 250 ft (Hansen, 1965, p. 51, written commun., 1990). The Salt Wash is a sequence of light-colored, thick sandstone ledges interbedded with red and gray siltstone and shale. The overlying slope-forming Brushy Basin Member is mostly gray, green, and red siltstone containing minor amounts of limestone and conglomeratic sandstone. Only the lower part of the Morrison Formation is plotted on the restored section (fig. 3) and described in the text.

Tidwell Member

The Tidwell Member mostly forms an unbroken slope between the overlying thick sandstone ledges of the Salt Wash and the underlying Wanakah Formation. In the Telluride-Ouray area the Tidwell is 50–70 ft thick, whereas in western Black Canyon the member is much thicker, 105–210 ft thick. Several subdivisions are recognized. Bed A is present at the base of the member throughout the area, although the sloping sequence above bed A is unnamed in the Telluride-Ouray area. In western Black Canyon, where the Tidwell is thicker, the interval above bed A is divided into the lower gypsiferous beds and the upper beds. Along parts of Smith Fork, the upper beds contain a thick, crossbedded eolian sandstone that is informally named the bed at Smith Fork.

The conspicuous basal marker bed, bed A, is a yellowish-gray to white, fine-grained sandstone that is mostly coarse to very coarse grained. Bed A is 14–33 ft thick. Bedding is flat and commonly has well-formed current ripple marks. Some minor low-angle crossbeds were observed at the Bobcat trail, Duncan trail, and South Smith Fork measured sections (secs. 10, 11, 13, respectively, fig. 3). In the Telluride-Ouray area bed A contains many thin gray shale beds, whereas in western Black Canyon bed A contains gypsum in thin seams parallel with bedding or in coatings on the faces of joints. In the Telluride-Ouray area bed A forms a prominent and persistent ledge; its base is sharp, and the bed generally overhangs the underlying Wanakah Formation. In western Black Canyon bed A tends to form a slope covered with colluvium and cemented with gypsum.

In the Telluride-Ouray area the Tidwell Member above bed A has varied aspects of color, lithology, and thickness. The slope-forming sequence between bed A and the Salt Wash Member is about 20–50 ft thick and consists primarily of red or gray siltstone. Thin, dense, gray limestone beds and gray, ledge-forming sandstones in which bedding is flat or not apparent crop out at many locations. Thin beds of red claystone and sandstone are distributed throughout the sequence above bed A.

In western Black Canyon the lower gypsiferous beds overlie bed A and are about 55–105 ft thick. They form a gray slope except for the basal 12–20 ft, which is red. The lower beds are thinly bedded siltstone and minor sandstone and shale, mostly in beds less than 1 ft thick. Some sandstone beds, however, are as thick as 12 ft. Gypsum throughout the unit forms beds, very thin crosscutting seams, nodules, and disseminations. Locally, the lower gypsiferous beds contain as many as 22 distinct beds of gypsum, mostly less than 1 ft thick, but some as thick as 7 ft.

The upper beds at the top of the Tidwell Member form a gray slope interrupted by several ledge-forming beds of sandstone and limestone. Because the top of the upper beds is at the base of the lowest thick channel sandstone of the Salt Wash Member, the upper beds are from about 115 ft thick at Smith Fork (sec. 14) to as little as 18 ft at Bobcat trail (sec. 10, fig. 3). The upper beds lack gypsum; they consist mostly of siltstone, limestone, and minor sandstone. Sandstone beds are gray to yellowish gray, flatbedded, locally crossbedded at low angles, and mostly less than 3 ft thick. Limestone beds are gray and form ledges 1–3 ft high. Some sections contain as many as 13 limestone beds. Several limestone beds at the Duncan trail section (sec. 11, fig. 3) and elsewhere contain numerous charophytes on bedding planes. A limestone bed near the top of the upper beds contains *Echinochara spinosa*, indicating a Kimmeridgian age (R.M. Forester, U.S. Geological Survey, oral commun., 1986).

The bed at Smith Fork is in the upper beds of the Tidwell Member in the Smith Fork area (sec. 14, fig. 3), 90 ft above the J–5 unconformity. It is 73 ft thick, light gray to white, fine grained, and highly crossbedded. The upper 10 ft, however, is yellowish gray, and its bedding is flat or not apparent. The bed at Smith Fork is considered to be of eolian origin. It pinches out southward and is not present at the South Smith Fork measured section (sec. 13, fig. 3), less than 2 mi to the south. Less than 1 mi east of the Smith Fork measured section, the bed at Smith Fork dips beneath younger rocks.

The bed at Smith Fork is similar to other eolian sandstones in the Morrison Formation in nearby areas. At Bridgeport, about 30 mi northwest of Smith Fork, a cross-bedded sandstone near the middle of the Tidwell Member is interpreted as an eolian lens because of bedding and weathering characteristics. The bed at Bridgeport is as thick as 45 ft thick and lies 70 ft above the base of the Morrison Formation, but it is present only locally. A similar cross-bedded eolian sandstone is locally present along Escalante Creek about 25 mi west of Smith Fork; it is 65 ft thick and lies about 35 ft above the J–5 unconformity at the base of the Morrison Formation. Near Placerville on the San Miguel River a sandstone 47 ft thick lies 79 ft above the J–5 unconformity. It is described as "abundantly crossbedded on large scale. Forms smooth rounded cliff like those in Entrada sandstone; not characteristic of Salt Wash" (Bush and others, 1959, p. 335). The sandstone at Smith Fork, the sandstone at Bridgeport, the sandstone at Escalante Creek, and the sandstone at Placerville all are eolian and of limited extent (see fig. 9). They are similar to other eolian sandstone beds in the lower part of the Morrison Formation at scattered locations in western Colorado.

Gypsum in Morrison Formation

The flora and fauna of the Morrison, together with a multitude of bedding features, support a terrestrial origin for most of the Morrison. Locally, however, some of the basal part of the Morrison may be marine or quasi-marine. Imlay (1980, p. 95), for instance, stated that "the presence of massive gypsum at the base of the Morrison Formation in the San Rafael Swell***suggests deposition in lagoons at the margin of a shallow sea***." Similarly Holt (1940) noted that near Grand Junction "basal beds of the Morrison formation***were deposited in lagoons in the borders of the Upper Jurassic***sea." These marine or marginal-marine beds in the basal part of the Morrison correlate with the quasi-marine Windy Hill Sandstone Member of the Sundance Formation overlying the J–5 unconformity in north-central Colorado and adjacent parts of Wyoming.

The Windy Hill Sandstone Member is assigned to the Sundance Formation partly because it is too thin to map separately and partly because its marine or brackish-water fauna is thought to be more closely related to fauna of underlying parts of the Sundance than to the terrestrial fauna of the Morrison Formation (Pipiringos and O'Sullivan, 1976). The Windy Hill interfingers with and grades upward into the Morrison Formation, however, and is therefore closely related to the Morrison. Furthermore, the Windy Hill is everywhere separated from the middle and lower parts of the Sundance by the widespread regional J–5 unconformity.

The gypsum in the Morrison Formation is undoubtedly a product of deposition within the Windy Hill sea, which covered parts of northern Colorado and much of Wyoming and adjacent areas. The gypsum was deposited in narrow embayments that extended southward from the Windy Hill sea. One such embayment in Utah is termed the "San Rafael embayment" (fig. 7). In Colorado there are two similar features: the Black Canyon embayment in the study area and the Front Range embayment in eastern Colorado. The gypsum in the San Rafael and Black Canyon embayments is in the Tidwell Member of the Morrison, which lies beneath the Salt Wash Member. The gypsum in the Front Range embayment is probably in the basal part of the Morrison Formation in an area where the Salt Wash is not recognized; however, the gypsum and associated strata in the lower part of the Morrison Formation in the Front Range embayment probably correlate with the Tidwell Member in western Colorado.

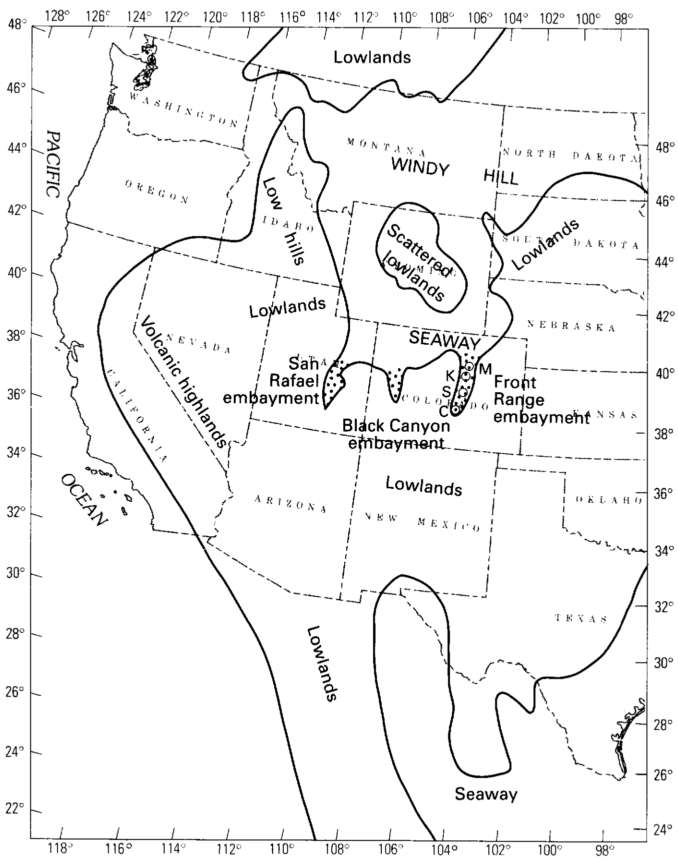


Figure 7. Paleogeography of western United States in Kimmeridgian time showing distribution of features associated with deposition of lower part of the Morrison Formation or equivalents during early Kimmeridgian. Heavy stipple indicates three gypsum-bearing embayments in Utah and Colorado. C, Canon City; K, Kassler; S, Colorado Springs; M, Morrison. Modified from Peterson (1988a, fig. 17) and Imlay (1980, fig. 10).

The San Rafael embayment in Utah lies east and south of the San Rafael Swell but also covers parts of it. The gypsum beds in the Tidwell Member were deposited in an evaporite basin, as described by Peterson and Turner-Peterson (1987, p. 6).

> Gypsum in units as much as 60 ft (18 m) thick, occurs at the base of the Tidwell throughout much of the San Rafael Swell and northern Henry basin. The gypsum is noteworthy because it has carbon isotope values that suggest a marine origin (Northrop, 1982). [Actually, the carbon is from limestone beds associated with the gypsum (F. Peterson, U.S. Geological Survey, oral commun., 1990).] The isotopic signature plus tentative correlation of lowermost Tidwell beds with the shallow marine Windy Hill Member of the Sundance Formation of Wyoming and nearby areas suggests that the gypsum was derived from evaporation of marine waters in the Windy Hill seaway. Correlation of basal Tidwell and Windy Hill is based on stratigraphic position of both members just above the J–5 unconformity and interfingering of both units with other beds in the Morrison Formation (Pipiringos, 1968, fig. 3). An alternative interpretation of the gypsum beds, here considered less likely, is that they were deposited in saline lakes under highly evaporative conditions. By this interpretation, the marine isotopes would have been inherited from eroded older marine evaporite deposits such as those in the underlying Summerville Formation.

The Black Canyon embayment in western Colorado is narrow and restricted and is defined by gypsum beds in the lower part of the Tidwell Member of the Morrison Formation. These beds extend from western Black Canyon into the Ridgway area. In western Black Canyon gypsum or gypsiferous beds were deposited throughout a stratigraphic interval as thick as 120 ft, and individual beds of gypsum are as thick as 7 ft. Gypsum, however, is absent from the Tidwell Member in outcrops along the northeastern margin of the Uncompahgre Plateau to the west of the study area and in the Black Canyon of the Gunnison National Monument to the east.

On the north side of Dallas Creek, about 2 mi north of Ridgway and about 30 mi south of Chukar trail, the upper 70 ft of the Tidwell Member crops out in cliffs. At a measured section in the NW¼SE¼SE¼, sec. 5, T. 45 N., R. 8 W., the upper 45 ft of the lower gypsiferous beds includes four thin gypsum beds and a gypsum pod about 25 ft thick. The gypsum beds are absent about 350 ft to the west. The Tidwell Member reappears at the surface along the Uncompahgre River about 5 mi south of the location just described and again lacks gypsum.

The Front Range embayment of the Windy Hill seaway is also probably narrow and restricted, although its limits are incompletely known. Thick beds of Jurassic gypsum that define the embayment crop out at several locations along the Front Range. Near Colorado Springs a gypsum unit as thick as 100 ft is placed at the base of the Morrison Formation (Noblett and others, 1987, p. 336). In the Canon City area gypsum as thick as 36 ft (Frederickson and others, 1956, p. 2144) is assigned to the Ralston Creek Formation (formerly the Ralston Formation). Gypsum beds to the north and south of the Kassler area are assigned to the Ralston Creek Formation (Scott, 1963, p. 91–92). A bed of gypsum 50 ft thick (LeRoy, 1946, p. 53) is at the base of the Ralston Creek Formation 2.5 mi south of Morrison .

The Ralston Creek Formation is closely related to the Morrison Formation. In discussing the Ralston Creek Formation, Scott (1963, p. 91) noted its "lithologic similarity to parts of the Morrison Formation." LeRoy (1946, p. 55), in describing the Ralston Creek Formation of Jurassic age and underlying Lykins Formation of Triassic and Permian age, stated that "Lithologically the sediments are more closely related to the overlying basal Morrison strata than to the underlying Lykins. At Ralston Creek, *Aclistochara* was noted in the uppermost part of the formation. This algal form is identical to that persistently present in the lower 40 or 50 feet of the Morrison."

Furthermore, fossils indicate that the Ralston Creek Formation is Kimmeridgian in age (Scott, 1963, p. 92), the same age as the Morrison Formation.

The gypsum-bearing beds in the Front Range embayment probably should be assigned to the Morrison Formation as a lower member. The term "Ralston Creek Formation" seems inappropriate and unnecessary because it is treated in different ways. At the type section a sandstone bed 17 ft thick at the base of the Ralston Creek Formation is equivalent to the Canyon Springs Sandstone Member of the Jurassic Sundance Formation, which is an equivalent of the Entrada Sandstone. The beds above the Canyon Springs, at the type section, are equivalent only to the Morrison Formation (see Pipiringos and O'Sullivan, 1976). Scott (1963, p. 91), however, excluded a possible Entrada Sandstone (or Canyon Springs equivalent) from the strata he assigned to the Ralston Creek Formation. The gypsum beds, whether assigned to the Ralston Creek or Morrison, probably are the same age as gypsum beds in the Black Canyon and San Rafael embayments. They represent an episode of evaporation in restricted embayments at the beginning of Morrison time—the final Jurassic marine invasion—an event related to the Windy Hill sea.

Previous Correlations

The stratigraphic arrangement of Jurassic rocks in southwestern Colorado was set forth by Burbank (1930). The formation at the base of the Jurassic is the Entrada Sandstone (fig. 8). Although Burbank (1930, p. 171) acknowledged the correlation of the sandstone at the base of the Jurassic with the Entrada because of a personal communication from J.B. Reeside, Jr., he did not use the name because the correlation was then unpublished. The distinctive Pony Express Limestone Member of the Wanakah above the Entrada forms an easily recognized marker wherever it is present. The Brushy Basin Member of the Morrison Formation at the top of Jurassic rocks also forms a distinctive stratigraphic unit.

The strata between the Pony Express Limestone and the Brushy Basin Members have been referred to in various ways. The Wanakah was originally defined as a member of the Morrison Formation. Later, the Wanakah was raised to formational rank and removed from the Morrison Formation (Eckel, 1949, p. 27–28). The Wanakah is commonly applied to the strata that Burbank selected for the unit (fig. 8). Near Bilk Creek, however, the term was restricted (Goldman and Spencer, 1941, p. 1753) to a part of the Wanakah as defined by Burbank; in the Black Canyon of the Gunnison the Wanakah as used by Hansen (1971) includes more than Burbank assigned to it, chiefly because beds now assigned to the Tidwell have a lithologic character more like the Wanakah than the overlying Salt Wash and because the Tidwell–Salt Wash contact is an easily mapped horizon.

The Bilk Creek Sandstone Member with the carnelian sandstone marker bed at its top overlies the Pony Express Limestone Member. At the Cedar Hill section of the Wanakah, measured 6 mi north of Ouray, a bed described as a hard, greenish-gray sandstone 1 ft thick and containing grains of bright-red chert (Burbank, 1930, p. 174, unit number 6) is the carnelian sandstone. The carnelian sandstone was assigned as the basal unit of the upper shale beds, which are equivalent mainly to the beds at Sawpit as used herein. Later the carnelian sandstone was included with the Bilk Creek Sandstone Member by Goldman and Spencer (1941, p. 1750, 1752) at their measured type section opposite the mouth of Bilk Creek.

The beds at Sawpit have previously been designated the marl member or upper unit. Near Ouray, equivalent beds were first termed the upper shale beds of the Wanakah Member of the Morrison Formation (Burbank, 1930, p. 176–177). Later Goldman and Spencer (1941, p. 1750) noted that because of "the high carbonate content of the argillaceous beds of this member, marl seems the appropriate term to apply to them." Bush and others (1959, p. 328) believed that the term marl was somewhat misleading and that "limy siltstone appears to be a far more accurate descriptive term." Marl, for instance, has been defined by Crandell (1958, p. 8) as "a partly consolidated sedimentary rock consisting of calcium carbonate and clay. If the material is more than 75 percent calcium carbonate, the rock is an argillaceous variety of limestone; if it is more than 75 percent clay, the rock is calcareous claystone or shale." Inasmuch as the descriptive term marl seems inappropriate, the unit is now referred to as the beds at Sawpit.

The Morrison Formation has been interpreted in different ways in the study area. It has included all strata between the Entrada and Cretaceous rocks (fig. 8) or all the strata or a part of the strata between the Wanakah, as defined by Burbank, and Cretaceous rocks. As used in this study the base of the Morrison is at the J–5 unconformity, a useful, convenient, and widespread break in Jurassic rocks (see O'Sullivan, 1984.) Gilluly (1929, p. 111) placed the base of the Morrison in the San Rafael Swell at an unconformity that is "both angular and erosional" when he extended the formation into Utah. Moreover, the unconformity recognized by Gilluly (1929, p. 110) is the J–5 surface at the upper boundary of the San Rafael Group. In the Telluride-Ouray area the J–5 unconformity coincides with the base of the Morrison as used near Placerville by Bush and others (1959) and Steele (1985). The J–5 surface also is the same as the basal Morrison contact mapped by Burbank and Luedke (1966) in the Telluride area. Near Ouray the base of the Morrison as mapped by Luedke and Burbank (1962) and the top of the Wanakah as defined by Burbank (1930, p. 172–179) coincide with the J–5 unconformity.

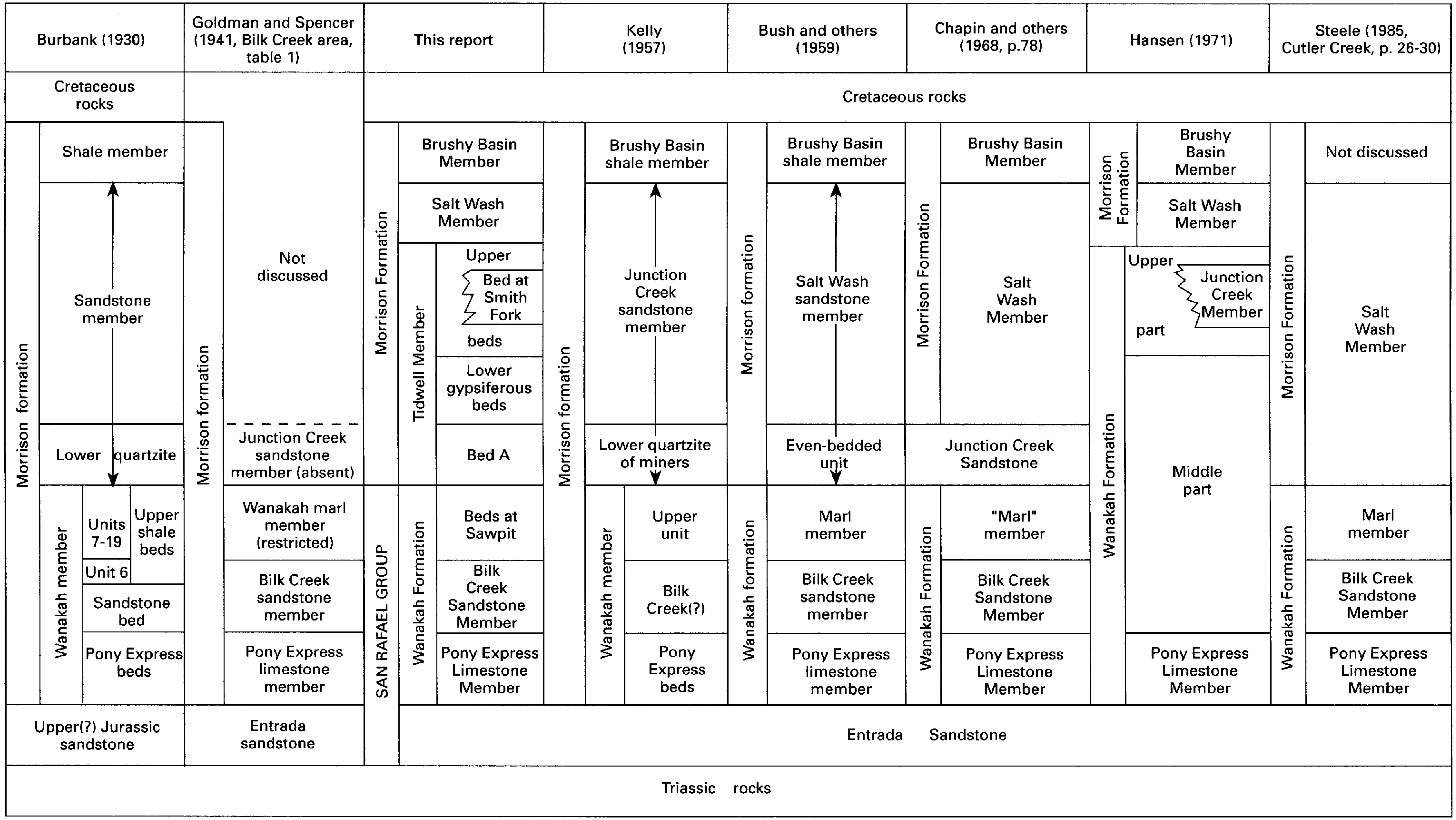


Figure 8. Nomenclature of Jurassic rocks in southwestern Colorado.

Different terms have been applied to the basal sandstone, where recognized, of the Morrison Formation. The "lower quartzite" (Burbank, 1930, p. 177) overlying the Wanakah Formation near Ouray, the "even-bedded unit" (Bush and others, 1959, plate 6) near Placerville, and bed A of this study are the same. Bed A is also the same as the "lower quartzite of miners" of the "Junction Creek sandstone member of Morrison formation" near Ouray (Kelly, 1957, p. 203). Bed A was not separately recognized in the Black Canyon of the Gunnison by Hansen (1971) or in the Placerville area by Steele (1985). Near Bilk Creek the Junction Creek Sandstone, as used by Chapin and others (1968, p. 78), is described as an "even-bedded sandstone forming [a] smooth vertical cliff" that is 26 ft high, and it is the same as bed A as used herein.

The Tidwell Member has not heretofore been identified in the area, mostly because the Tidwell was only recently named and described (Peterson, 1988b, p. 35–42). Instead, the slope-forming Tidwell has generally been incorporated in the Salt Wash Member, despite its distinctly different lithology. On the Uncompahgre Plateau near Grand Junction the Tidwell was formerly correlated erroneously with the Summerville Formation (Holt, 1940); however, the Tidwell has been included within the Junction Creek Sandstone Member near Ouray (Kelly, 1957, p. 203) and within the Wanakah Formation in the Black Canyon of the Gunnison (Hansen, 1971), although W.R. Hansen (written commun., 1990) recognized its temporal equivalence with the lower part of the Morrison. The Salt Wash was originally named by Lupton (1914, p. 127) for a series of ledgy sandstones that form high cliffs near Green River, Utah. The Salt Wash as used by Lupton (1914) near Green River, by Hansen (1965, 1968, 1971) in the Black Canyon, and in this study is the same.

The name Junction Creek Sandstone has been applied to different stratigraphic intervals in the study area. Chapin and others (1968, p. 78) used the name for a sandstone, 26 ft thick, overlying the Wanakah Formation and below their Morrison Formation. Kelley (1957, p. 203) applied the name Junction Creek Sandstone Member of the Morrison to 250–300 ft of beds between the Wanakah Formation and the Brushy Basin Member of the Morrison. In western Black Canyon, a thick eolian sandstone along Smith Fork and farther east on the north rim of the Black Canyon was termed the Junction Creek Sandstone Member of the Wanakah Formation (Hansen, 1968, 1971).

The name Junction Creek, derived from a creek near Durango, was applied to a thick, crossbedded sandstone in the Durango–La Plata Mountains area. As described by Goldman and Spencer (1941, p. 1749–1750), the Junction Creek Sandstone "is divided conspicuously into two parts, a lower more horizontally banded part with diagonal bedding within the horizontal layers, and an upper part with diagonal bedding on a large scale, that is, a single direction of diagonal bedding extending across a horizontal layer as much as 60 feet thick and continuing parallel with itself over long stretches, suggesting big decapitated dunes. This sandstone attains thicknesses as great as 500 feet." Goldman and Spencer (1941, p. 1750–1751) treated the sandstone as the Junction Creek Sandstone Member of the Morrison Formation. Near Durango the Junction Creek Sandstone is mainly of early Morrison age, although its base may be older.

The Junction Creek Sandstone is distributed over a part of southwestern Colorado (fig. 9). It forms a very thick and extensive curved lens in the La Plata Mountains–Dolores area, where it is 300–500 ft thick (Goldman and Spencer, 1941, fig. 1). From the thick lens the Junction Creek thins to the north and south. Along the Dolores River, about 20 mi southeast of Dove Creek, the sandstone was mapped to a northward pinchout by Haynes and others (1972). The Junction Creek was not recognized at Dunton (Goldman and Spencer, 1941, fig. 1). Along the Piedra River, east of Durango, the Junction Creek thins northward (Bush and others, 1983) from 120 to 25 ft, 4 mi and 15 mi, respectively, north of the settlement of Piedra (fig. 9, locations A and B). The rate of thinning along the Piedra River suggests, but does not prove, that the Junction Creek may pinch out not very far north of location B. A line connecting the pinchout along the Dolores River with a point south of Dunton (shown by an X in fig. 9) and a point near location B on the Piedra River forms a convenient, although partly arbitrary, northern limit of Junction Creek Sandstone. Extension of the name Junction Creek north of this line is unnecessary and misleading.

The name Junction Creek has been used, however, north of the line just described. At Bilk Creek, Junction Creek Sandstone was applied (Chapin and others, 1968) to bed A of the Tidwell Member as used in this study. In the Placerville area, Bush and others (1959) used "even-bedded unit" for bed A. In discussing the unit, Bush and others (1959, p. 331–332) stated that "The relationship of the unit to the Junction Creek sandstone of Goldman and Spencer (1941) has not been determined, but the unit appears to be absent where typical Junction Creek is present. The unit may be a facies of the Junction Creek, with the sediments deposited in, and reworked by, the waters of a waning Late Jurassic seaway." Bed A most likely correlates with the lowermost part of the Junction Creek Sandstone; however, the even-bedded sandstone of bed A is best assigned to the Tidwell Member and can easily be separated from the thick, crossbedded, eolian Junction Creek Sandstone.

The name Junction Creek has been used at Ouray and in western Black Canyon. At Ouray the Junction Creek Sandstone used by Kelley (1957) as a member of the Morrison Formation is clearly equivalent to the Tidwell and Salt Wash Members and is unlike typical Junction Creek south of Dunton. In western Black Canyon a thick eolian sandstone in Smith Fork has been called Junction Creek Member of the Wanakah Formation (Hansen, 1968). In this

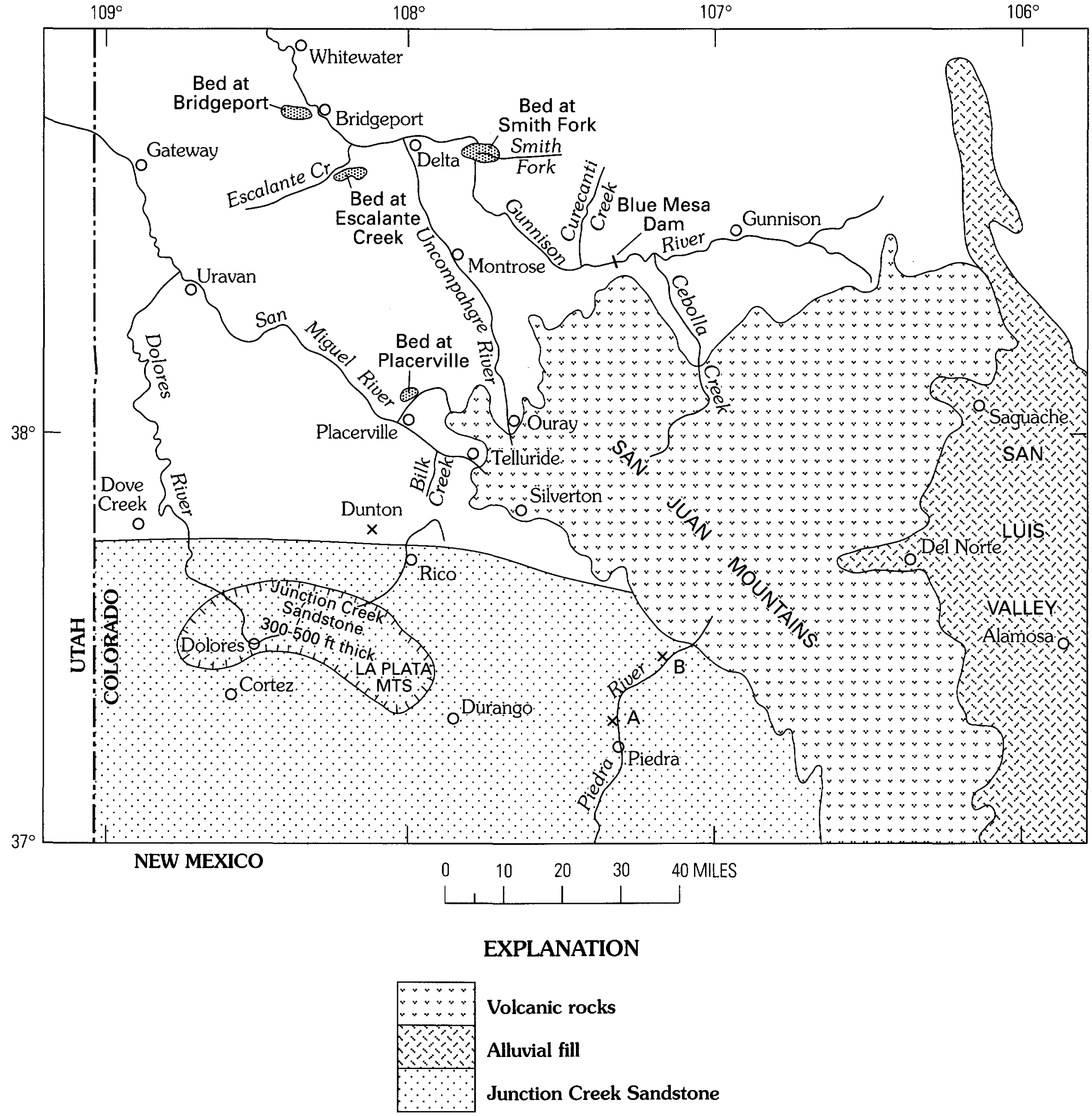


Figure 9. Distribution of Junction Creek Sandstone in southwestern Colorado. A and B along Piedra River are locations discussed in text. Modified partly from L.C. Craig (U.S. Geological Survey, written commun., 1973). Distribution of volcanic rocks and alluvial fill from King and Beikman (1974).

study the sandstone is termed "bed at Smith Fork" and is considered an isolated eolian sandstone of limited extent (fig. 9) positioned about 90 ft above the base of the Tidwell Member of the Morrison Formation. The bed at Smith Fork passes below drainage eastward along Smith Fork, so its true extent is unknown; however, it is probably a restricted local body of eolian sandstone because similar lenses of eolian sandstone—the bed at Bridgeport, the bed at Escalante Creek, and the bed at Placerville—are of limited extent (fig. 9).

The Junction Creek has also been recognized along other parts of the Gunnison River. From near Curecanti Creek (fig. 9) eastward to Gunnison a sandstone generally overlying Precambrian rocks has been termed Junction Creek Sandstone. Along Curecanti Creek the sandstone is 6–10 ft thick and is flatbedded, but a thicker eolian sandstone at about the same stratigraphic level crops out near Blue Mesa Dam and at many places upstream from the dam. The relationship between the sandstone along Curecanti Creek and the bed at Smith Fork is uncertain, but the physical appearance is similar. The bed does not crop out anywhere along the Gunnison River from a point about 3 mi west of Curecanti Creek (where the bed is in a faulted window between Tertiary volcanic rocks and Precambrian gneiss) to Smith Fork (Hansen, 1971). West of Curecanti Creek, however, the entire Jurassic section has been stripped off for several miles by early Tertiary, pre-volcanic truncation. Near Cebolla Creek, the bed mapped as Junction Creek Sandstone is 50–100 ft thick, generally has large-scale crossbedding, and probably is of eolian origin (Hedlund and Olson, 1973). Near Almont, north of Gunnison, the eolian crossbedded sandstone is 120 ft thick (Craig and others, 1959, measured section 2) and is referred to as Junction Creek Sandstone (Tweto, 1983). The sandstone along the Gunnison River east of Curecanti Creek is far to the north of the known distribution (fig. 9) of typical Junction Creek Sandstone in southwesternmost Colorado. The geologic record between the two areas is either obscured by Cenozoic volcanic rocks of the San Juan Mountains or has been removed by post-Jurassic erosion. A sandstone has been identified as Junction Creek (Gries, 1989, p. 72) in a drill hole through the volcanic cover in the eastern San Juan Mountains near Del Norte; thus, the total extent of the Junction Creek must be very broad. The extension of the name Junction Creek Sandstone into the Gunnison area seems tenuous. The sandstone might better be recognized as an extensive lentil of Morrison age of, as yet, uncertain correlation.

Reference Section

A reference section for the Wanakah Formation and the Tidwell Member of Morrison Formation in western Black Canyon is described below to show the thickness and arrangement of the various parts of the San Rafael Group and the lower part of the Morrison Formation. The section is well exposed (fig. 10) along the east-facing cliffs bordering the Gunnison River. The section is the nearest exposure of the Wanakah and related rocks to the north of the Wanakah mine near Ouray. The section (fig. 11) is accessible along a dirt road that ends in a parking area at the head of the Chukar trail, which leads down to the Gunnison River. The dirt road, impassable in wet weather, connects with paved Falcon Road, which in turn connects, about 10 mi north of Montrose, with U.S. Highway 50.

Black Canyon reference section for the Wanakah Formation and its Pony Express Limestone and Bilk Creek Members and the Tidwell Member of Morrison Formation

[Measured about ½ mi west of Chukar trail]

	Thickness (feet)
Morrison Formation (part):	
Salt Wash Member (part):	
82. Sandstone, gray, stained red by wash from above; fine grained, faintly crossbedded; contains flattened greenish-gray clay galls as much as 2 in. across; base is a scour surface; forms cliff..	15.0+
Total thickness measured Salt Wash Member	15.0+
Tidwell Member:	
Upper beds:	
81. Siltstone, greenish-gray; forms re-entrant	1.3
80. Limestone, medium-gray; dense; forms ledge	3.1
79. Siltstone, greenish-gray; forms re-entrant	0.9
78. Limestone, medium-gray; dense; forms ledge	1.7
77. Siltstone, greenish-gray; weathers nodular in vertical cliff; two thin sandstones in upper part.	4.4
76. Sandstone, gray; fine grained; flatbedded; forms ledge	0.6
75. Siltstone, greenish-gray; weathers nodular in a vertical cliff	2.9
74. Sandstone, yellowish-gray, weathers brown; very fine grained; flatbedded; forms hard ledge	1.3
73. Siltstone, banded reddish-brown and medium-gray; forms a well-exposed slope	11.7
72. Sandstone, yellowish-gray; very fine grained; flat-bedded; forms a ledge	0.4
71. Siltstone, medium-gray; forms a well-exposed slope	5.5
70. Limestone, light-gray; forms a ledge	0.7
69. Siltstone, medium-gray; forms well-exposed slope.	6.0
68. Sandstone, medium-gray; very fine grained; flat-bedded; forms a hard ledge	0.6
67. Siltstone, medium-gray; forms poorly exposed slope	2.4
66. Limestone, medium-gray; dense; forms ledge	1.2
65. Siltstone, medium-gray and reddish-brown; forms a poorly exposed slope	14.0
64. Sandstone, yellowish-gray; very fine grained; flat-bedded; forms hard ledge	0.5
63. Siltstone, medium-gray, forms poorly exposed slope	4.0
62. Sandstone, yellowish-gray; flatbedded; forms a ledge	0.4
61. Siltstone, medium-gray, and sandstone, yellowish-gray; interbedded in a poorly exposed slope	5.0
60. Sandstone, yellowish-gray; irregularly bedded, some poorly defined, very low angle crossbeds; forms a ledge	2.0
Thickness of upper beds	70.6
Lower gypsiferous beds:	
59. Siltstone, mostly medium-gray and minor reddish-brown; clayey; gypsum nodules 3–4 in. across in lower half; poorly exposed in a slope	15.1
58. Interbedded greenish-gray and medium-gray silt-stone, white sandstone, and gypsum in thin beds 0.1–0.4 ft thick; forms conspicuous ledge	17.8
57. Sandstone, white; poorly defined, very low angle crossbeds; interstitial gypsum; forms hard ledge	4.1
56. Siltstone, medium-gray; contains gypsum nodules .	0.5
55. Sandstone, white; very fine grained; forms slight ledge	1.1
54. Clay, medium-gray; fissile; contains nodules of gypsum as much as 2 in. across	2.3
53. Sandstone, white; very fine grained; forms slight ledge	0.6
52. Siltstone, medium-gray; contains seams and thin beds of gypsum	2.5
51. Gypsum, white; contains some interstitial gray siltstone	0.5

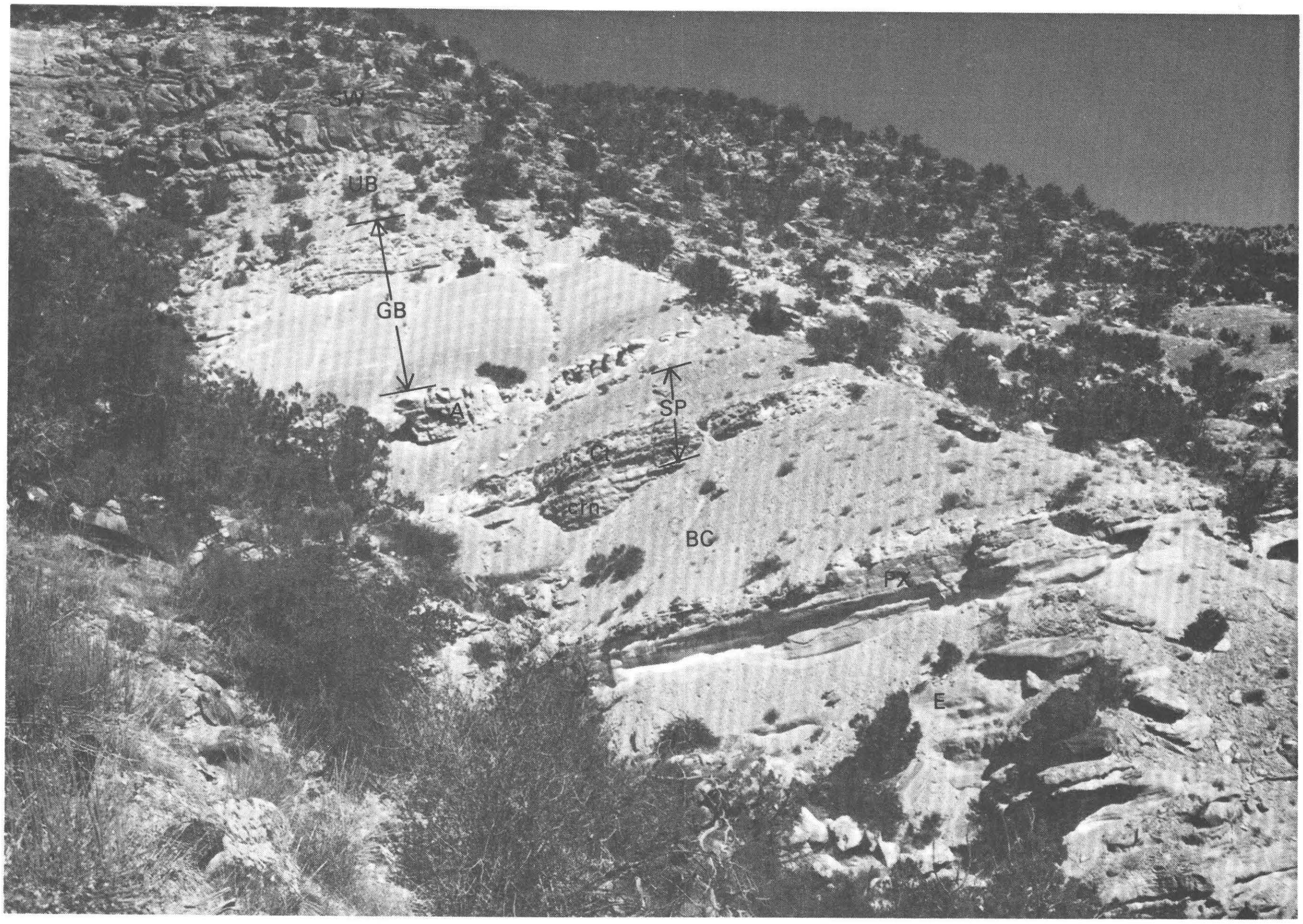


Figure 10 (above and facing page). Wanakah Formation and related rocks at Chukar trail. View looking north. Entrada Sandstone (E). Wanakah Formation comprises Pony Express Limestone Member (PX), Bilk Creek Sandstone Member (BC) with carnelian sandstone marker bed (crn) at top, and beds at Sawpit (SP) including gypsum layer termed bed at Chukar trail (Ct). Morrison Formation in view consists of Tidwell Member with bed A (A), lower gypsiferous beds (GB), and upper beds (UB) and Salt Wash Member (SW).

Lower gypsiferous beds—Continued	Thickness (feet)
50. Siltstone, medium-gray and streaks of dark yellow gray; contains vertical seams of gypsum	0.9
49. Gypsum, white	0.5
48. Siltstone, medium-gray; contains seams and thin beds of gypsum; forms slope	3.8
47. Gypsum, white; contains thin seams of gray siltstone	2.3
46. Siltstone, medium-gray, stained and streaked yellowish-gray; contains gypsum seams; forms slope	0.8
45. Gypsum, white	0.4
44. Siltstone, medium-gray, streaked yellowish-gray; forms slope	0.8
43. Gypsum, white	0.2
42. Siltstone, medium-gray, spotted, dark-yellowish-gray; contains gypsum seams; forms slope	1.1
41. Gypsum, white; forms a slight ledge	0.6
40. Siltstone, medium-gray; clayey; contains gypsum nodules and seams; forms a slope	1.2
39. Gypsum, white; contains a thin gray clay seam near the middle; forms a slight ledge	0.9
38. Shale, gray, fissile; minor thin reddish-brown and yellowish-gray siltstone; contains some thin gypsum seams and nodules; near middle is highest continuous red-bed in lower part of Tidwell Member; forms slope	2.6
37. Gypsum, white; minor interbedded gray siltstone forms slight ledge	0.5
36. Siltstone, banded reddish-brown, medium-gray, and yellowish-gray; shaley; forms slope	0.7
35. Gypsum, white; forms slight ledge	0.8
34. Siltstone, banded reddish-brown, medium-gray, and dark-yellowish-gray; forms slope	1.0
33. Sandstone, white; very fine grained; very hard; although hard forms a slope	0.9
32. Siltstone, streaked medium-gray and reddish-brown; thin white gypsum seam near middle	0.6
31. Gypsum, white; forms slope	0.3
30. Siltstone, medium-gray; forms slope	1.0
29. Siltstone, reddish-brown; forms slope	0.4
28. Siltstone, reddish-brown; contains nodules of gypsum and a thin bed of gypsum in upper 0.3 ft	1.1

Lower gypsiferous beds—Continued	Thickness (feet)
27. Siltstone, reddish-brown; forms slope	1.3
26. Sandstone, reddish-brown; some interstitial gypsum and some gypsum in thin seams; forms slight ledge	0.4
25. Siltstone, reddish-brown; forms slope	1.4
24. Gypsum, white; forms soft slope	1.0
23. Siltstone, reddish-brown; forms slope	0.9
22. Gypsum, white; nodular; contains some brown siltstone	0.4
21. Siltstone, medium-gray, greenish-gray, and yellowish-gray; very fine grained sandy; forms slope	1.8
20. Siltstone, reddish-brown; contains gypsum in thin seams and as nodules as much as 2 in. across; forms slope	1.8
19. Sandstone, yellowish-gray, weathers reddish-orange; very fine grained; forms hard ledge	0.3
18. Siltstone, reddish-brown; forms slope	1.6
Thickness of lower gypsiferous beds	78.8
Bed A	
17. Sandstone, white; fine grained; abundant very coarse grains both scattered and clustered in thin stringers; base is rippled marked; two thin seams of gypsum less than 1 in. thick in lower 5 ft; forms ledge	14.4
Thickness of bed A	14.4
Total thickness of Tidwell Member	163.8

	Thickness (feet)
Wanakah Formation:	
Beds at Sawpit:	
Upper beds:	
16. Siltstone, reddish-brown; small gypsum nodules scattered in lower 7.5 ft; a red, very fine grained sandstone 0.4 ft thick makes slight ledge 2.5 ft above base; a gray clay 1 in. thick 5.0 ft above base; a gray clay 0.3 ft thick 6.0 ft above base; forms slope	14.5
Bed at Chukar trail:	
15. Gypsum, white; forms conspicuous ledge	6.4
Lower marker bed:	
14. Siltstone, greenish-gray; contains flattened gypsum nodules parallel with bedding and several feet long; makes re-entrant	3.0
Total thickness of beds at Sawpit	23.9

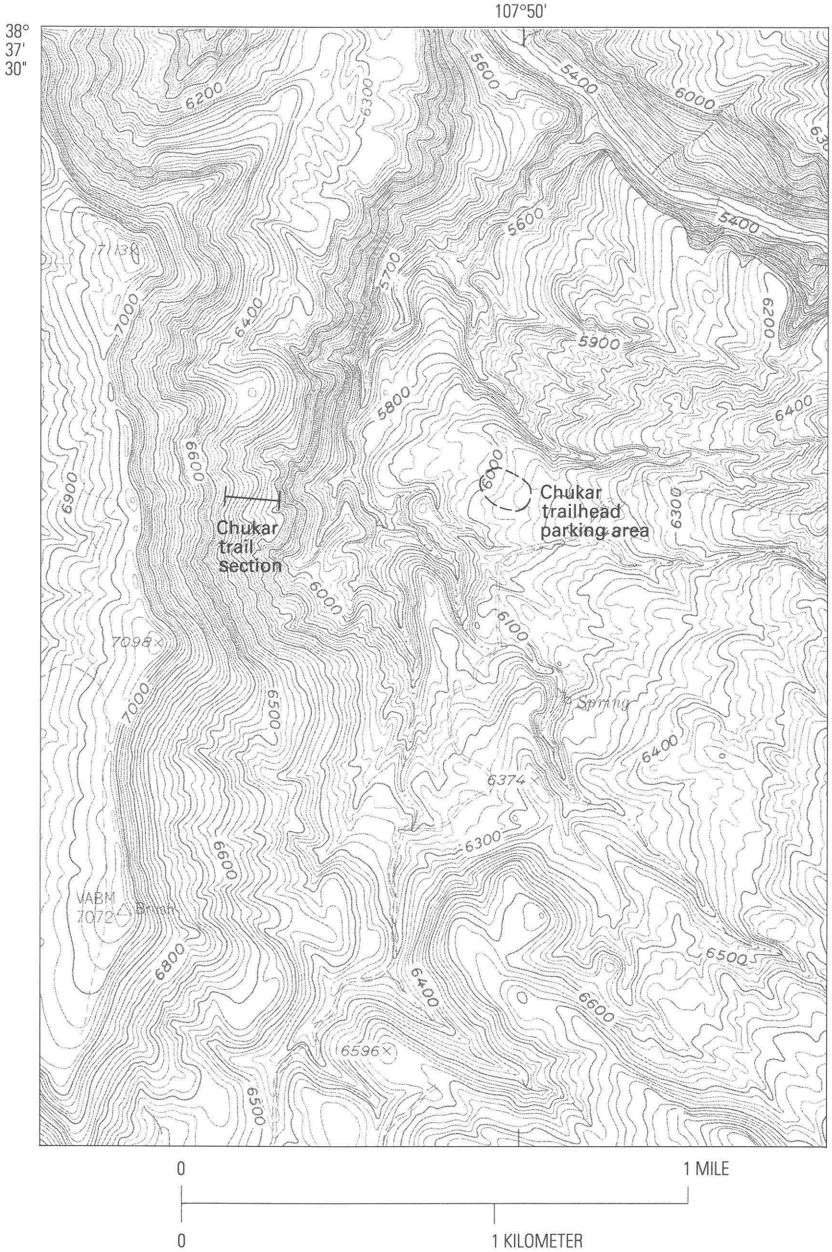


Figure 11. Location of Chukar trail reference section. Base is from Red Rock Canyon 7½-minute topographic quadrangle (1955); contour interval 20 ft.

	Thickness (feet)
Bilk Creek Sandstone Member:	
Carnelian sandstone marker bed:	
13. Sandstone, gray; fine grained with abundant medium rounded grains; sandstone in beds at base, middle, and top separated by reddish-brown siltstone about 0.5 ft thick; siltstone contains nodules and seams of gypsum; sandstone forms ledges, siltstone forms re-entrant	4.7
12. Sandstone, greenish-gray with minor reddish-brown bands near middle; fine grained; sparse rounded medium grains; sparse pink limestone nodules as much as ½ in. across; silty and shaley	8.6
11. Sandstone, gray to brownish-gray; abundant rounded medium grains; forms slope	1.1
Thickness of carnelian sandstone marker bed	14.4

Bilk Creek Sandstone Member—Continued	Thickness (feet)
10. Sandstone, yellowish-gray to greenish-gray; fine grained; flatbedded; a 0.3-ft-thick reddish-brown to brown shaley, silty, sandstone bed 18.9 ft above base; gypsum nodules ¼–½ in. across in lower 10 ft; forms slope	19.4
Total thickness of Bilk Creek Sandstone Member	33.8
Pony Express Limestone Member:	
9. Limestone, black; petroliferous; thinly laminated and in beds as thick as 4 in.	1.9
Total thickness of Pony Express Limestone Member	1.9
Total thickness of Wanakah Formation	59.6
Entrada Sandstone:	
8. Sandstone, yellowish-gray; fine grained; abundant rounded medium grains in upper part; lower 0.5 ft contains flattened limestone nodules as much as 1.25 in. across; flatbedded	1.5
7. Sandstone, yellowish-gray, banded reddish-brown; upper part finely cross laminated	3.4
6. Sandstone, yellowish-gray; flatbedded; base is a nick	12.4
5. Sandstone, yellowish-gray; flatbedded; base is a nick	4.5
4. Sandstone, yellowish-gray; flatbedded	6.0
3. Sandstone, very light gray; crossbedded	1.5
2. Sandstone, yellowish-gray with minor light-gray bands; flatbedded; unit in sharp color break with underlying sandstone	20.0
1. Sandstone, reddish-tan; a 0.7-ft-thick gray band 31.6 ft above base; flatbedded; lower 7 ft contains black mica schist pebbles as much as 10 in. across and pebbles of quartz as much as 2½ in. across	45.9
Total thickness of Entrada Sandstone	95.2

Precambrian: Dark-gray quartzitic gneiss.

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Geologic Quadrangle Maps are multicolor geologic maps on topographic bases in 7 1/2- or 15-minute quadrangle formats (scales mainly 1:24,000 or 1:62,500) showing bedrock, surficial, or engineering geology. Maps generally include brief texts; some maps include structure and columnar sections only.

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