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to arrive at a satisfactory correlation of the Jurassic rocks of the Navajo country and a satisfactory interpretation of their environmental history.

PROBLEMS OF JURASSIC STRATIGRAPHY OF THE COLORADO PLATEAU AND ADJOINING REGIONS.

Clay T. Smith *

Stratigraphic problems in the Jurassic section of the Colorado Plateau and surrounding regions can be grouped into three closely related categories: the first type of problems are those which are concerned with the areal distribution of the various rock units and their correlations. A second type of problem is paleogeographic in nature: the delineation of source areas for the complex sedimentary series which have already been defined and whose distribution is at least partly known. A third type of problem is more detailed; it involves the recognition of facies changes within the units and interpretation of sedimentary environments. Solutions for all these problems have become critical because of the extensive distribution of uranium ore in the Jurassic system. Extensive and continuing revision of correlations and nomenclature has often contributed to confusion and misunderstanding, even among those who are most familiar with the area.

Several facts regarding this rock sequence bear repeating: The section is composed almost entirely of clastic sediments with considerably more than half the accumulation being silt or coarser sized. Cross bedding of all types is the general rule and evenly or parallel bedded sediments comprise a subordinate part of the assemblage. Fossils are so rare as to be essentially non-existent and age assignments are based upon either over-extended lithologic correlations or upon broader relationships with overlying and underlying sediments. Volcanic rocks or intrusive igneous masses which characterize the Jurassic rocks farther west are absent; a considerable proportion of some of the claystone sequences contain ash beds. Mineralogically the sediments are monotonous, and heavy minerals which might be of considerable assistance in correlation are sparse.

The classic three-fold division of the Jurassic rock units on the Colorado Plateau is utilized to illustrate the broad features of the distribution patterns of these rocks. The isopach and facies maps (See Figures 1-4) which are used include little data other than surface sections because of the great difficulty in separating many of the group sequences in well logs. In southwestern Colorado and adjacent parts of Utah, the Dolores formation contains equivalents of both the Chinle formation and the Glen Canyon Group throughout much of its extent. Other units which have variously been included with both the Morrison formation or with parts of the San Rafael Group have been placed where most of the present day workers in the area believe they belong.

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McKee (1951, p. 488) has suggested that during Paleozoic time there were two consistently postive areas in Arizona; one occupying roughly the position of the Defiance uplift in northeastern Arizona and the other in southwestern Arizona. The Uncompahgre and Front Range positive elements and the Sierra Grande Arch were also well-defined structural highs in Colorado and New Mexico. By upper Triassic time these positive elements were greatly reduced, particularly the Defiance uplift. The Chinle formation was a very widespread formation accumulating material from multiple sources (See figure 1).

A marked change from earlier time in the distribution of positive areas accompanied the transition to Glen Canyon time; these changes exerted continuing controls over all of Jurassic sedimentation. The Defiance positive element was reduced to the extent that it was no longer effective in controlling sedimentation in the Four Corners area. A new positive element trending slightly north of west began to rise in central Arizona and New Mexico; it apparently restricted Chinle deposition from extending southward. This positive element might be termed the "Navajo Highland" because of its marked and continuing effects on the rocks exposed on the Navajo Reservation. Two things are noteworthy about the Navajo Highland; first, it did not contribute materially to the accumulations of Glen Canyon time, except perhaps to the fluviatile facies of the Wingate formation described by Harshbarger which may have derived some of its material from this area; second, the gradual rise of the Navajo element caused a general westward tilting of the Glen Canyon depositional basin so that its Kayenta and Navajo formations extend only a short distance eastward into New Mexico and the deepest parts of the depositional basin lie several hundred miles to the west of the New Mexico-Arizona state line.

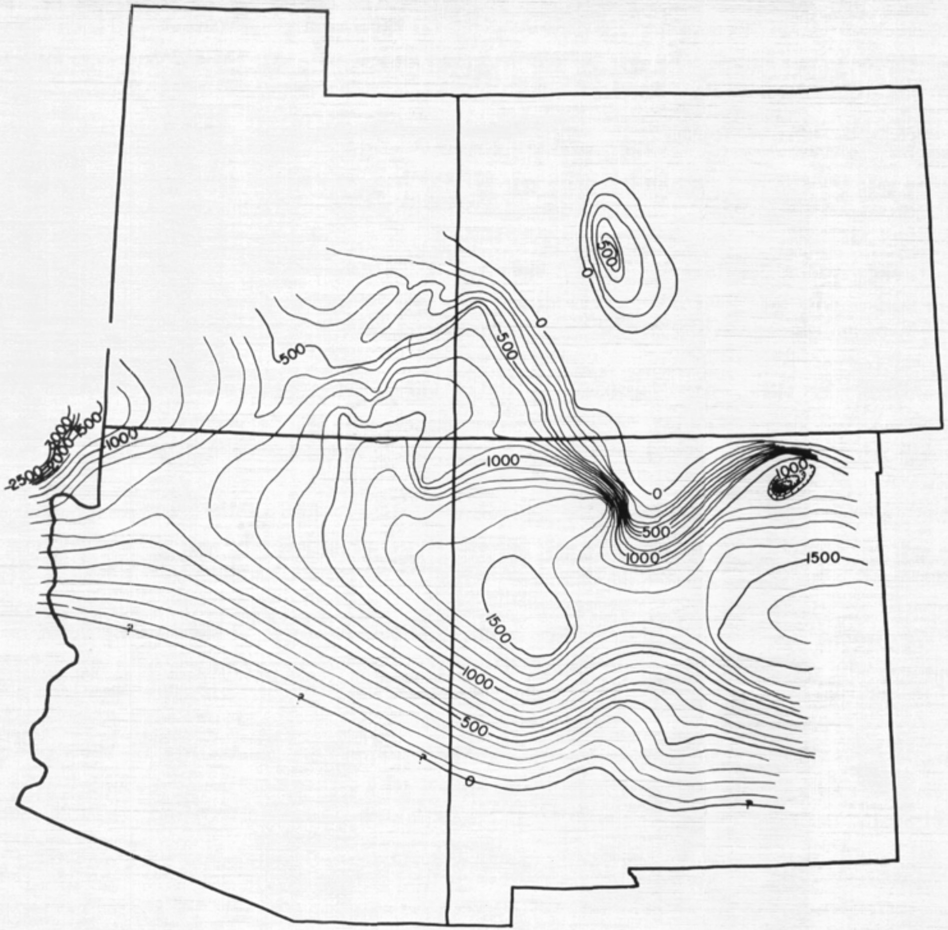

FIG. I – ISOPACH MAP OF THE CHINLE FORMATION

Contour Interval = 100 Feet

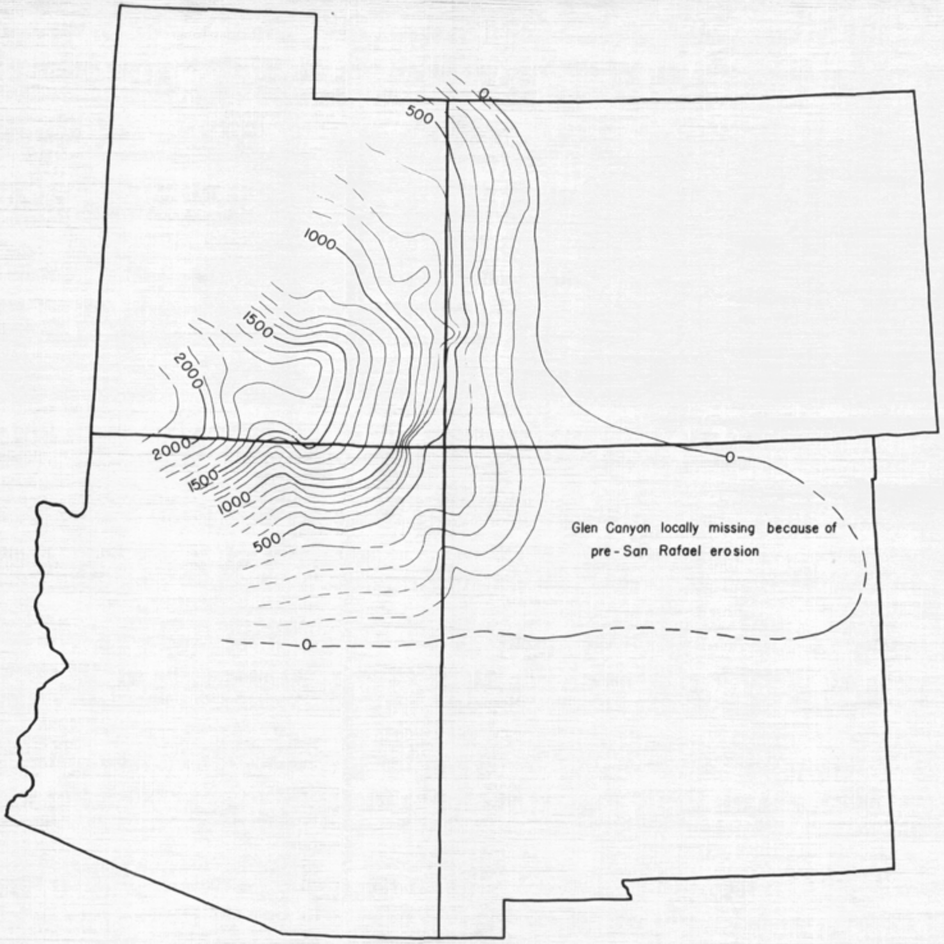

FIG. 2 - ISOPACH MAP OF GLEN CANYON GROUP

Contour Interval = 100 Feet

Figure 2 illustrates the distribution of the Glen Canyon Group of sediments in terms of the combined thicknesses of all units. The Wingate sandstone and its equivalents are the only representatives of the group in most of New Mexico. The Navajo sandstone is the only representative in far western Arizona and farther west. The depositional basin of Glen Canyon time seems, in many ways, a continuation of the upper Triassic depositional area although more or less continuously restricted toward the end of Glen Canyon time. Some authorities have argued that this coincidence of distribution pattern and the lack of a well-defined hiatus at the top of the Chinle formation in some areas is strong evidence for including all of the Glen Canyon group in the Triassic period.

The problems posed by the Glen Canyon group are summarized as follows:

1. Is the commonly accepted Jurassic (?) age of the group correct?
2. What were the source areas for these rocks? The Uncompahgre and Front Range highlands were too worn down to furnish much detritus, although they served as effective blocks to deposition.
3. What sedimentary environment results in the thick accumulation of cross-bedded sandstone such as the Navajo sandstone in Zion Canyon and to the west?
4. Why does the Navajo sandstone show little facies change over large areas in a region where changes are abundant and abrupt in super and subjacent strata?
5. Does the development and growth of the Navajo highland furnish an adequate explanation for the westward shift in deposition during Glen Canyon time?

The San Rafael group was originally defined from exposures in the San Rafael Swell of south-central Utah. By accretion and piracy from adjacent formations, the group has grown from the original four members to over a dozen correlated or related members. A good many of the correlations are reliable, particularly those with the Sundance sequence to the north; the San Rafael group contains the only marine faunas of any consequence in the entire Jurassic section on the Colorado Plateau. Other correlations have varying degrees of certainty, generally varying inversely as their distance from the type locality. The isopach map (see figure 3) combines most of the correlations and equivalents suggested in the previous papers.

The extreme facies changes in the San Rafael group and a lack of consistently recognizable formational breaks suggest that the group should be reduced to formational status or at least should comprise a two-fold division rather than the present four-fold sequence; furthermore, some of the facies changes are so well-marked that new formational names are justified.

The facies changes in the Carmel formation described in the previous papers probably reflect the uplift and westward tilting of the Navajo highland in late Glen Canyon time. During Entrada time some rejuvenation of the earlier positive masses must have taken place to result in the thinning of Entrada sandstone across the Sierra Grande arch in northeastern New Mexico and distortion of its isopachs around the Four Corners area above the old Defiance highland. The Uncompahgre highland may have had local rejuvenation but deposition was not completely blocked across it as had been the case earlier in Mesozoic time. The extreme easterly extent of the massive sandstone facies of the Entrada formation ("Slick Rim" of some authors) suggests that the effects of the westward tilting brought about by the rise of the Navajo highland were relatively nullified by erosion during Carmel time.

During Entrada time additional uplift took place on the Navajo highland; the maximum elevations on this renewal of activity were probably somewhat farther west than those which caused the tilting in late Glen Canyon time. For the first time since the development of the Navajo highland detritus was contributed to the Jurassic basin. Nearly all the material was derived from the erosion of sedimentary rocks; large amounts of sand were contributed to the southern part of the depositional basin almost continuously to the end of Morrison time.

The Curtis formation marks a second marine invasion from the north in Utah and Colorado; the Todilto formation of New Mexico may be a correlative of the Curtis and it indicates perhaps marine or lacustrine conditions encroaching from the east. Slight renewal of uplift on the old Defiance highland prevented the Curtis and Todilto seaways from joining and direct tracing of the equivalence of these two formations is, hence, not possible. The Todilto limestone and associated gypsum beds intertongue with the upper part of the rocks correlated with the Entrada sandstone. The unconformable relationships reported by Gilluly (1929) at the top of the Entrada sandstone in the type locality are not found. The Entrada sandstone may represent combined transgressive and regressive units which are not now differentiable. Similar relationships may be present in the Moab Tongue-Summerville sequence described by Craig and Holmes (1951).

The marine deposits of the Curtis and Todilto formations grade upward into siltstones and sandstones assigned to the Summerville formation. In the upper part of the Summerville there are several units whose stratigraphic positions have been in considerable doubt. Various authors have placed them as low as the Navajo or Entrada formations while others have considered them Morrison equivalents; a third alternative has been to give such beds formational rank. Some of these units, such as the Junction Creek sandstone or the Cow Springs sandstone, contain undifferentiated beds which are equivalent to both the San Rafael group and the Morrison formation.

The most significant feature of sedimentation in the San Rafael Group is the introduction of small local source areas giving rise to such units as the Junction Creek sandstone, the Bluff sandstone, the Wanakah formation and the like; where these units thin and die out they may show tongues or affinities to both San Rafael and Morrison sedimentation and thus their position is in considerable doubt. Another significant feature of San Rafael sedimentation is the continued contribution of sand from the Navajo highland which resulted in the marked facies changes of all the San Rafael beds to the south and southwest.

Questions raised by the relations in the San Rafael group are summarized as follows:

1. Is a four-fold formational division of the group warranted by the present information, or would understanding of these rocks be facilitated by reduction to formational and member rank?
2. How can the facies changes introduced by local source areas be reconciled with and integrated into the broader facies changes resulting from marine and non-marine environments of deposition and the introduction of the Navajo highland as a new regional source area?
3. What conditions of accumulation and sedimentation can give rise to such extensive distribution of cross-bedded sandstone as is illustrated by the development of the "Slick Rim" facies of the Entrada sandstone.

The Morrison formation too has aroused contention among stratigraphers. Parts of many of the units described in this and the previous papers have at various times been included in it as well as units in sequences referred to the lower Cretaceous. The Morrison formation can be divided into two major facies; a lower sandstone (principally fluviatile), and an upper claystone (principally quiet water deposition) with minor sandstone and limestone. The claystone has much the greater extent of the two whereas the distribution of the sandstone was controlled at least slightly, by the western part of the Navajo positive area. Over most of the Colorado Plateau the facies are co-extensive and the formation averages from 800 to 1000 feet thick. Toward the southwestern margin of deposition the sand unit thickens and occupies all of the interval assigned to the Morrison formation. Along the southwestern margin of outcrop the formation thickness, measurements are of doubtful accuracy because separation of Morrison sand facies (Cow Springs sandstone) from similar sand facies in the San Rafael group (Cow Springs sandstone) is difficult. In northwestern Colorado and in the Dinosaur National Monument of Utah, the sandstone disappears and claystone represents Morrison time. The claystone thickens considerably to the west from this area and is somewhat thicker to the north. Eastward the claystone thins across the old Uncompahgre highland and then thickens again along the eastern slope of the Front Range highland. Figure 4 illustrates the general relations of the different facies as well as some of the more restricted members of the Morrison formation.

The claystone of the Morrison formation is the first unit in the Jurassic sequence to blanket all the old positive areas. Morrison conditions thus set the stage for the great Cretaceous inundations which were to follow.

In northern Utah and northeastern New Mexico alternating sandstone and shale beds referred to lower Cretaceous on the basis of marine faunas conformably overlie the Morrison formation. As these units are traced toward the Colorado Plateau region their identity becomes more or less inextricably merged with the uppermost units of the claystone facies of the Morrison formation. Such gradations serve to cast doubt upon the upper contacts drawn in some parts of the Colorado Plateau region.

The problems related to the Morrison formation are summarized as follows:

1. Many members described within the Morrison formation have distributions which overlap areas of major facies change. How should the resulting variations be interpreted and evaluated?
2. What are the source areas for most of the claystone facies and some parts of the sandstone facies?
3. What marks the upper contact of the Morrison formation and should the formation be assigned to parts of both Jurassic and Cretaceous periods? The tendency in recent years has been to remove beds formerly assigned to the formation.

Much of the confusion concerning the Jurassic stratigraphy of the south and west sides of the San Juan Basin in particular, and the Colorado Plateau in general, will be resolved when we have solved some basic geologic problems. For example: what sedimentary environments result in the distribution of coarse clastic deposits over large areas? What is the effect of local facies changes as a result of local uplift when these are superimposed upon broader regional facies changes? How can marine facies be separated from non-marine facies in areas where there is little lithologic change and fossil evidence is limited?

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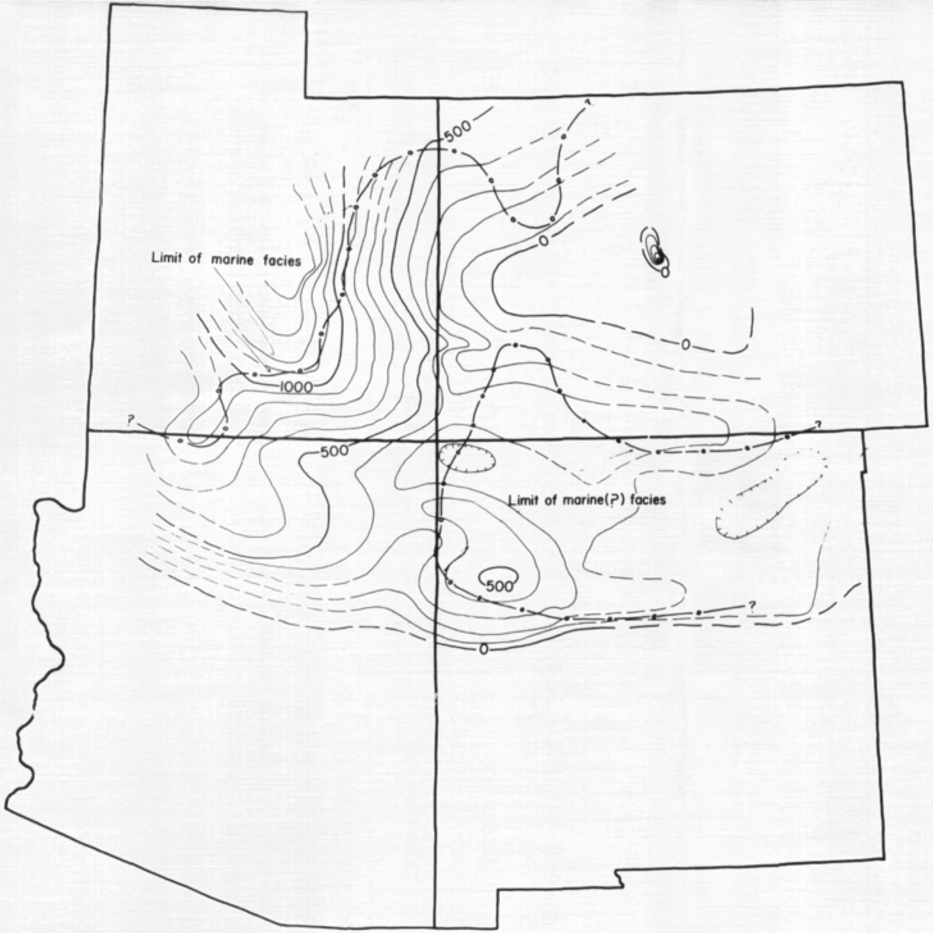

FIG. 3 - ISOPACH MAP OF SAN RAFAEL GROUP
Contour Interval - 100 Feet

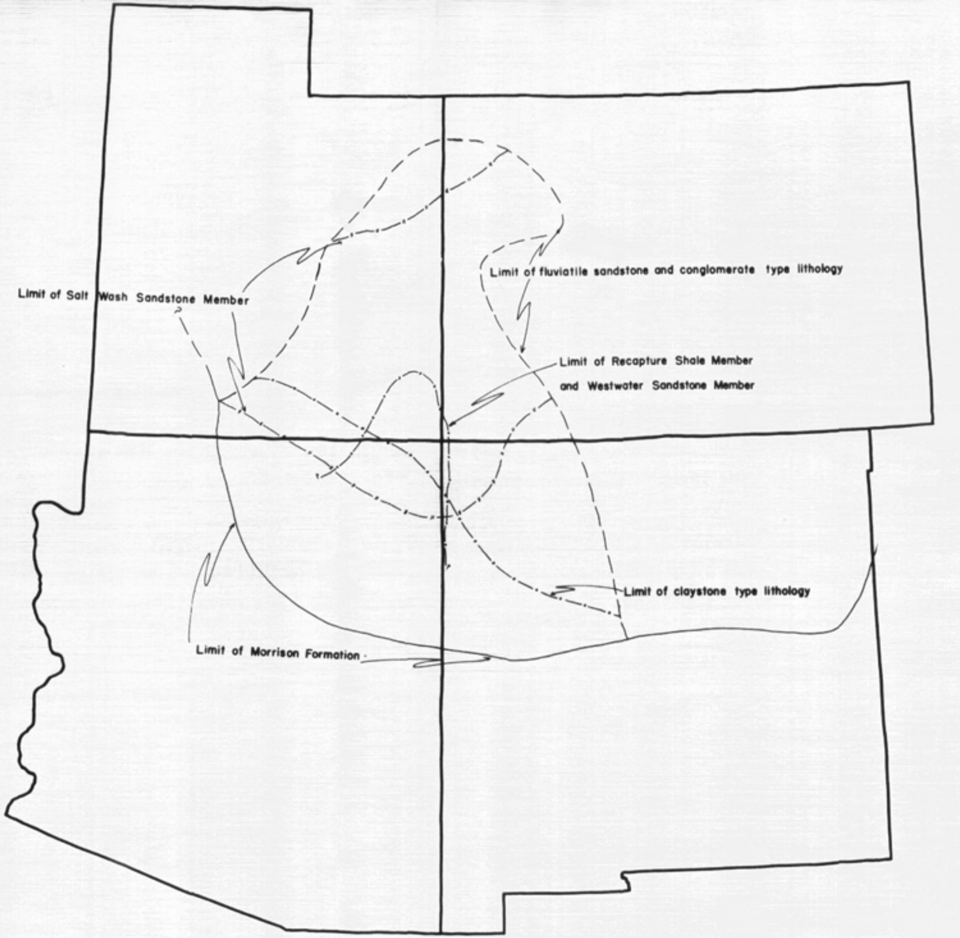

FIG. 4
GENERALIZED DISTRIBUTION MAP OF PART OF THE MORRISON FORMATION

APPENDIX

MEASURED STRATIGRAPHIC SECTION FOUR MILES EAST OF COW SPRINGS, ARIZONA

Measured by J. W. Harshbarger, 1947.

	FEET
CRETACEOUS:	
DAKOTA SANDSTONE:	
10 Sandstone: yellowish orange, fine-grained, thin-bedded (½ to 5 inches), cross-laminated; calcareous-ferruginous cement; abundant limonite streaks; forms rough cliff	15.0
UNCONFORMITY:	
Erosional relief, 4 inches to 1.5 feet; marked by coarse-grained sandstone and granule conglomerate; sharp contact due to color change.	
JURASSIC:	
COW SPRINGS SANDSTONE:	
9 Sandstone: light gray, fine-grained, thin-bedded (1 to 4 inches), partially flat-bedded and partially cross-bedded; firm calcareous-ferruginous cement; contains lenticular manganese beds (2 to 12 inches, 50 to 100 feet long) near base; iron-manganese concretions (6 inches to 3 feet common); forms rough pitted, rounded cliff	104.0
8 Sandstone: dusky-yellow, fine-grained, massive, flat-bedded, weak cement; contains manganese stringer near top; abundant black iron specks; forms smooth rounded cliff	28.0
7 Sandstone: like No. 4; contains abundant limonite nodules (½ to 3/4 inch)	51.0
6 Siltstone: greenish-gray, silty, thin-bedded (1/8 to 1/2 inch), flat-bedded; weak calcareous cement; forms recess in main rounded cliff	2.0
5 Sandstone: greenish-gray, very fine-grained, thin-bedded (1/16 to 4 inches) cross-bedded on large scale; firm calcareous cement; contains green, hard calcareous pods (1 x 6 inches); forms smooth, round, slick cliff	94.0
4 Sandstone: pinkish gray, very fine-grained, thick-bedded (6 to 14 inches); cross-bedded on large scale; firm cement; contains several green, weakly cemented, silty stringers (1 to 2 inches); forms smooth, round, slick cliff	40.0
3 Sandstone and siltstone: reddish-gray, very fine-grained, flat and cross-bedded, very weak cement; gradational unit between Entrada sandstone and Cow Springs sandstone; forms poorly exposed slope	23.0
	342.0
ENTRADA SANDSTONE:	
2 Sandstone: light brown, fine-grained, thin-bedded (1/8 to 3/4 inch) cross-laminated; very weak calcareous cement; alternates with light gray sandstone beds; contains several reddish brown shale partings (1/4 to 1 inch); forms poorly exposed, color-banded smooth slope	67.0
1 Sandstone: light-brown, very fine-grained, thin-bedded, cross-bedded on large scale; firm calcareous cement; contains numerous criss-cross light-gray streaks or bands; forms smooth, round, slick, steep slope	134.0
Total Entrada sandstone (incomplete)	201.0

Valley: covered by alluvium and vegetation.