Sedimentology and revised nomenclature for the upper part of the Upper Triassic Chinle Formation and the lower Jurassic Wingate Sandstone, northwestern New Mexico and northeastern Arizona

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SEDIMENTOLOGY AND REVISED NOMENCLATURE FOR THE UPPER PART OF THE UPPER TRIASSIC CHINLE FORMATION AND THE LOWER JURASSIC WINGATE SANDSTONE, NORTHWESTERN NEW MEXICO AND NORTHEASTERN ARIZONA

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Abstract—Sedimentologic and stratigraphic study of the Upper Triassic Chinle Formation in the area around the Defiance uplift in northwestern New Mexico and northeastern Arizona indicates that the uppermost Petrified Forest, Owl Rock and Rock Point members were deposited in fluvial, lacustrine and eolian environments. A Late Triassic age for Owl Rock and Rock Point fossils compared to an Early Jurassic age for palynomorphs from rocks equivalent to the overlying Wingate Sandstone, and lithologies of the Owl Rock and Rock Point members related to depositional environments, indicate a closer affinity of the Rock Point to the Chinle Formation than to the overlying Wingate Sandstone. The Rock Point Member contains mudflat, eolian sand-sheet and eolian dune deposits, and represents a transition from underlying Owl Rock fluvial and lacustrine systems to overlying eolian erg deposits of the Wingate Sandstone. The Rock Point is here recognized as a member of the Chinle Formation, and the name of the overlying Lukachukai Member is here abandoned in favor of the name Wingate Sandstone. Recurrent stratigraphic problems underscore the need for continued research on depositional environments, the designation of a type section for the Wingate Sandstone and recognition of the stratigraphic position of the Triassic-Jurassic boundary and regional unconformities.

INTRODUCTION

Considerable effort has been expended regarding the stratigraphy of the Triassic Chinle Formation and the overlying Jurassic Wingate Sandstone on the Colorado Plateau. A summary of that work is presented by Stewart et al. (1972a). Despite those efforts, persistent stratigraphic problems are related to the lack of type sections of key units and assignment of ages to units that contain sparse paleontologic remains. In fact, paleontologists continue to debate both the definition and placement of the Triassic-Jurassic boundary on the Colorado Plateau (Padian, 1986). This paper discusses the history of nomenclature and stratigraphy of the upper part of the Chinle Formation and the overlying Wingate Sandstone, sedimentologic interpretations of depositional environments of those units and persistent problems in Late Triassic and Early Jurassic stratigraphy in northwestern New Mexico and northeastern Arizona.

Stratigraphic subdivisions recognized by Gregory (1917, p. 37–50) in northeastern Arizona and adjacent areas include the Shinarump Conglomerate, the Chinle Formation and the Wingate Sandstone, in ascending order. Gregory (1917, p. 42–43) distinguished four units in the Chinle Formation, which he designated in ascending order as Divisions D, C, B and A. These divisions of the Chinle Formation have subsequently been renamed. Gregory (1950, p. 67) used the name Petrified Forest Member in the Zion Park region of southwestern Utah for rocks of his Division C. Formal member names were assigned to the other lettered subdivisions of the Chinle based on studies in southeastern Utah and the Monument Valley area of Arizona (Stewart, 1957; Stewart et al., 1959; Witkind and Thaden, 1963). The name Owl Rock was applied to Gregory's Division B, and Monitor Butte was applied to his Division D. The Shinarump Conglomerate was reduced to member status and assigned to the Chinle Formation.

Division A was defined by Gregory (1917, p. 42) as the highest strata of the Chinle. Gregory's Division A subsequently has been given two different names and assigned to two formations. Harshbarger et al. (1957) removed Division A from the Chinle Formation and assigned it as the Rock Point Member of the Wingate Sandstone; the remaining upper part of the Wingate was named the Lukachukai Member. Witkind and Thaden (1963, p. 22) named Division A the Church Rock Member in Monument Valley and left it in the Chinle. An arbitrary decision was made, and north of Laguna Creek (Fig. 1) Division A was known as the Church Rock Member of the Chinle Formation, and south of Laguna Creek Division A was known as the Rock Point Member of the Wingate Sandstone (Witkind and Thaden, 1963, p. 34).

Sedimentologic and stratigraphic study of the Petrified Member, Owl Rock and Church Rock members of the Chinle Formation and the Rock Point Member of the Wingate Sandstone in the area around the Defiance

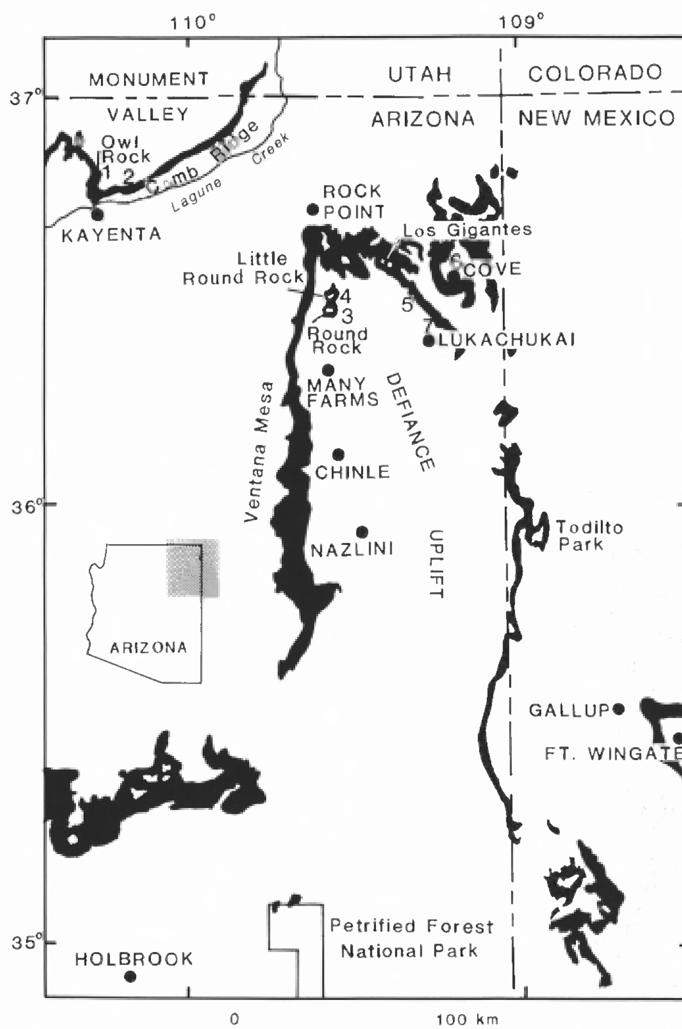

FIGURE 1. Map of northeastern Arizona and adjacent areas. Black pattern is approximate outcrop distribution of upper part of the Chinle Formation. Numbers refer to measured sections: 1–Owl Rock, 2–Comb Ridge, 3–Round Rock, 4–Little Round Rock, 5–Lukachukai North, 6–Cove, 7–Lukachukai. (Derived in part from O'Sullivan, 1970).

uplift in northwestern New Mexico and northeastern Arizona (Fig. 1) indicates the units represent lacustrine, eolian and minor fluvial deposition in a subsiding continental basin centered near the Four Corners region of Arizona, New Mexico, Colorado and Utah. The uppermost part of the Petrified Forest Member was deposited in small fluvial channels and on marginal-lacustrine mudflats. The strata reflect the change from dominantly fluvial and floodplain deposition in the Petrified Forest Member to primarily lacustrine sedimentation in the overlying Owl Rock Member. The Owl Rock Member was deposited in a large lacustrine system centered near the Four Corners region that underwent cyclic and periodic expansions and contractions in size. The marked fluctuations in lake area resulted in complexly interfingered lithofacies. Red beds above the Owl Rock Member were deposited in depositional environments ranging from lacustrine mudflats to eolian sand sheets and small eolian dunes. The locus of deposition of these red beds was within the same subsiding continental basin centered near the Four Corners region.

The Rock Point Member is stratigraphically equivalent to both the Church Rock Member of the Chinle Formation and to part of the Upper Triassic Dolores Formation in southwestern Colorado (Stewart et al., 1972a; Blodgett, 1984). Meager fossil remains from the Rock Point Member indicate a Late Triassic age (Harshbarger et al., 1957, p. 10). Pipiringos and O'Sullivan (1979) recognized several regional unconformities within Triassic and Jurassic rocks of the Colorado Plateau. The placement of the J-O unconformity at the base of the Lukachukai Member of the Wingate Sandstone (Pipiringos and O'Sullivan, 1978; Peterson and Pipiringos, 1979) and palynological evidence from rocks that interfinger with the Wingate suggest an Early Jurassic age for the Lukachukai Member (Peterson and Pipiringos, 1979, p. 33–34; Edwards, 1985). This paleontologic evidence and the fact that Gregory (1917) originally defined Division A as part of the Chinle indicate that the Rock Point Member has a closer affinity to the Chinle than to the Wingate. The Rock Point is here recognized as a member of the Upper Triassic Chinle Formation. The name Lukachukai Member is superfluous as the sole member of the Wingate Sandstone and is here abandoned. Though the name Lukachukai was applied to the upper sandstone of the Wingate, Lukachukai has been used only locally in the Four Corners area, whereas the name Wingate has been applied regionally to the eolian sandstone beyond the limits of the Rock Point Member. The assignment of the Rock Point Member to the Chinle parallels Gregory's (1917, p. 42–43) original assignment of Division A, which includes the Rock Point and Church Rock members, to the Chinle Formation. Several recurrent problems are the focus of continuing research, including the designation of a type section for the Wingate Sandstone, definitive age assignments of several units, and the stratigraphic placement of the Triassic-Jurassic boundary and the J-O unconformity in the area of the Defiance uplift.

STRATIGRAPHY AND HISTORY OF NOMENCLATURE

The complexly interfingered continental lithofacies in the Chinle Formation are paralleled by the abundance of names assigned to Chinle stratigraphic units throughout the Colorado Plateau (Stewart et al., 1972a, b). This report considers mainly the upper part of the Chinle in the vicinity of the Defiance uplift (Fig. 1). Brief mention will be made of the lower part of the Chinle for completeness. This report discusses only the nomenclature of the upper, or red-bed, part of the Chinle, defined by Stewart (1959) and Stewart et al. (1972a) to include the Owl Rock and Church Rock members of the Chinle and the related Rock Point Member. For a discussion of nomenclature of older Chinle units, the reader is referred to Stewart et al. (1972a, b).

Around the Defiance uplift (Fig. 1), the Chinle Formation consists of several members and unconformably overlies the Permian De Chelly Sandstone or locally the De Chelly Sandstone member of the Cutler Formation. The Shinarump Member fills large valleys and smaller scours eroded into the underlying De Chelly Sandstone. The Shinarump is overlain and in places grades laterally into the Monitor Butte Member or the stratigraphically equivalent lower red member. These units are overlain by the Petrified Forest Member.

The Petrified Forest Member was named by Gregory (1950, p. 67) after Petrified Forest National Park in eastern Arizona, but he regarded the unit as being most typically exposed in Zion National Park in southwestern Utah. The Petrified Forest Member consists of complexly interfingered sandstones, siltstones and mudstones characterized by bright, variegated colors. The Petrified Forest Member is conformably overlain by and interfingers laterally on a regional scale with the Owl Rock Member.

The term Owl Rock Member was used by Kiersch (1956, p. 4), Witkind (1956, pl. 6) and Stewart (1957). The type locality was defined and described by Witkind and Thaden (1963, p. 30–32) as outcrops below Owl Rock, northeast of Kayenta. The distinctive pastel siltstone slopes and gray limestone ledges facilitiate recognition of the Owl Rock over much of the Colorado Plateau. The Owl Rock interfingers with the overlying orange siltstone member, Rock Point Member and Church Rock Member and the underlying Petrified Forest Member. On a regional scale, the Owl Rock changes facies into other stratigraphic units. O'Sullivan (1970) described a gradation of the Owl Rock into red siltstone of what has been termed Church Rock Member in other parts of southeastern Utah, and that interpretation has been supported by recent sedimentology studies (Dubiel, 1987a). In addition, the upper red-bed part of the Chinle near Ghost Ranch in the eastern San Juan Basin has been interpreted as a marginal lacustrine facies of the Owl Rock (Dubiel, in press). Work in progress suggests that the upper part of the Chinle southwest of Albuquerque, New Mexico, which has been mapped as Rock Point Member (Maxwell, 1979, 1982, 1988a, b), is also a marginal lacustrine facies of the Owl Rock lacustrine system (Dubiel, unpublished data 1988). The recognition of these regional lateral facies changes is critical in defining the geographic extent of Owl Rock depositional systems.

The name Church Rock Member was first used by Stewart (1957, p. 459) in referring to a report in preparation by Witkind and Thaden. Subsequently, Witkind and Thaden (1963, p. 33) published a measured section of the Church Rock Member along Comb Ridge and just north of Kayenta, but despite stating that the section was typical, they did not designate it as the type section. Stewart et al. (1972a, p. 41) later declared Witkind and Thaden's (1963) section to be the type. Harshbarger et al. (1957) named the Rock Point Member, and neither the Rock Point nor the Church Rock has precedence because of the dates of the published reports. Arbitrarily, the Church Rock Member of the Chinle Formation is recognized north of Laguna Creek. South of Laguna Creek, the same stratigraphic sequence is referred to as the Rock Point Member of the Wingate Sandstone (Witkind and Thaden, 1963, p. 34). As pointed out by O'Sullivan (1970, p. 3), there apparently is no dispute about the correlation of the Church Rock and Rock Point across Laguna Creek.

The Hite Bed is a fluvial unit at the top of the Church Rock Member of the Chinle and below the Wingate Sandstone, over much of southeastern Utah and into northeastern Arizona (Stewart et al., 1959). The relationships between the Hite Bed and the type Church Rock Member of Monument Valley are discussed in detail by O'Sullivan (1970). Recent interpretations of the Chinle Formation in the White Canyon area of southeastern Utah (Dubiel, 1987a, b, c) support O'Sullivan's (1970) contentions that: (1) rocks assigned to the Church Rock Member of some parts of southeastern Utah are older than the type Church Rock near Kayenta, Arizona; (2) the Church Rock in southeastern Utah is equivalent to the unnamed reddish-orange siltstone member along Comb Ridge; and (3) the units older than type Church Rock can be considered a lateral facies of the Owl Rock Member or should be renamed.

To quote Stewart et al. (1972a, p. 43), "Considerable disagreement has arisen about the stratigraphic assignment of the strata here described." Gregory (1917, p. 42) recognized and defined a sequence of red beds as Division A at the top of the Chinle Formation. The type locality was at Mesa Ventana (now Ventana Mesa) on the west side of the Defiance uplift and Todilto Park on the east side. Division A later was removed from the Chinle, assigned to the basal part of the Wingate Sandstone, and named the Rock Point Member for ". . . the lower slope-forming unit exposed in Little Round Rock, a prominent butte . . . south of Rock Point School . . ." (Harshbarger et al., 1957, p. 59).

Harshbarger et al. (1957, p. 59–60) published a measured stratigraphic section that included the type locality of the Rock Point on the slope at Little Round Rock, but they did not describe the contact between the Lukachukai and Rock Point members that occurs at an offset in their section between the two members. Harshbarger et al. (1957, p. 7–8, figs. 4, 6) also did not designate the contact between the units on photographs of the Rock Point and the Lukachukai members. Apparent intertonguing between the Rock Point and the Lukachukai was cited as a major criterion, along with similarities in grain size and composition, areal distribution and physical relationships, for the assignment of the Rock Point to the Wingate Sandstone (Harshbarger et al., 1957, p. 5–8). However, Stewart et al. (1972a, p. 43–44) suggested that ". . . only a few of the so-called tongues actually merge with the overlying part of the Wingate, and that many may be isolated lenses in the Rock Point Member . . ." and that ". . . the main lithologic type of the Rock Point Member, horizontally stratified red siltstone, is more characteristic of the Chinle Formation . . ." and is ". . . included with the Chinle Formation on the isopach and lithofacies maps." Clearly, there was disagreement over the stratigraphic assignment of the unit that is reflected by the assignment of the same stratigraphic unit near Kayenta to the Church Rock Member of the Chinle Formation.

The Wingate Sandstone was first described by Dutton (1885, p. 136–137) for exposures of a cliff-forming sandstone north of Ft. Wingate, New Mexico. These outcrops were designated as the type locality of the Wingate Sandstone by Baker et al. (1936), even though they were recognized to include only part of Dutton's Wingate. Subsequent stratigraphic studies (Baker et al., 1947) recognized that the upper part of Dutton's type Wingate was equivalent to the Entrada Sandstone elsewhere on the Colorado Plateau. Despite the fact that Dutton's (1885) Wingate Sandstone had historical, and thus stratigraphic, precedence, the name Entrada Sandstone (Gilluly and Reeside, 1928; Gilluly, 1929) was retained because it was firmly established in the literature. The name Entrada Sandstone should have been abandoned, and the name Wingate Sandstone should have been extended northward and into the San Rafael Swell. Alternatively, the Entrada and Wingate could have been considered stratigraphic equivalents in the same sense that the upper part of the Chinle and the Dolores formations today are considered to be equivalent. However, Wingate was retained for the lower part of the exposures north of Ft. Wingate, and Harshbarger et al. (1957) restricted the Wingate Sandstone to the lower part of Dutton's (1885) section.

Harshbarger et al. (1957) recognized two mappable units in the Wingate, the lower unit described as the Rock Point Member for exposures south of Rock Point School, Arizona, and the upper unit referred to as the Lukachukai Member for typical exposures north of Lukachukai, Arizona. Harshbarger et al. (1957) further stated that the Lukachukai is the only member of the Wingate Sandstone present at the type locality near Ft. Wingate, constituting the lower part of the original Wingate Sandstone defined by Dutton (1885). Later, Green (1974) defined and named the lower part of the sandstone exposures north of Ft. Wingate as the Iyanbito Member of the Entrada Sandstone. The Lukachukai Member of the Wingate Sandstone was no longer recognized at the Wingate cliffs near Gallup, and the Wingate Sandstone is left without a designated type section. The exposures north of Lukachukai were chosen as the type locality of the Lukachukai Member because the lithology is typical of the Wingate Sandstone throughout the Colorado Plateau (Harshbarger et al., 1957, p. 10). A type section was not described, and on two outcrop photographs (Harshbarger et al., 1957, figs. 4, 6) they did not show a contact line to distinguish the base of the Lukachukai Member. These omissions are germane to the subsequent discussion on placement of the Chinle-Wingate contact.

SEDIMENTOLOGY

Sedimentologic study of the Chinle Formation around the Defiance uplift and the southern part of Monument Valley (Fig. 1) provides the basis for the interpretation of depositional environments and stratigraphic assignments of the upper part of the Chinle Formation. Measured stratigraphic sections (Figs. 1, 2) and facies analysis provide the basis for stratigraphic and sedimentologic interpretations presented in this report. The section at Owl Rock (Fig. 2, sec. 1), measured at the type section of the Owl Rock Member directly below Owl Rock, comprises the uppermost part of the Petrified Forest Member, the type section of the Owl Rock Member (Witkind and Thaden, 1963, p. 31) and the Church Rock Member, including the Hite Bed, of the Chinle Formation. The section at Comb Ridge (Fig. 2, sec. 2), about 10 km north of Kayenta, encompasses the type section of the Church Rock Member (Witkind and Thaden, 1963, p. 33) and includes the Hite Bed. The section at Round Rock (Fig. 2, sec. 3) begins along State Highway 63 between Chinle Wash and the town of Round Rock in the uppermost part of the Petrified Forest Member, and extends north through the Owl Rock and Rock Point members on the south-facing slopes of Round Rock. This section provides a good control for comparison to the type locality of the Rock Point Member at Little Round Rock. The section at Little Round Rock (Fig. 2, sec. 4), measured on the southeast ridge of Little Round Rock, is the type locality of the Rock Point Member as defined by Harshbarger et al. (1957). The section at Lukachukai North (Fig. 2, sec. 5) begins about eight km north of Lukachukai in the uppermost part of the Petrified Forest Member and extends through the Owl Rock and Rock Point Member. The section at Cove (Fig. 2, sec. 6) extends from the Petrified Forest Member through the Owl Rock Member into the Rock Point Member. The section at Lukachukai (Fig. 2, sec. 7) begins north of the road from Lukachukai to Shiprock in the Owl Rock and includes the Rock Point Member.

Petrified Forest Member

The uppermost part of the Petrified Forest Member at Owl Rock, Cove and Round Rock comprises conglomerate, very fine sandstone, siltstone and mudstone. The medium-gray (rock-color-chart terms are those of Goddard et al., 1979) conglomerate is composed of rounded limestone nodules and siltstone or mudstone pellets as much as 1.5 cm in diameter. The conglomerate fills large, convex-downward and lenticular scours eroded into the underlying mudstones and exhibits large-scale trough crossbeds (Fig. 3). Locally, the conglomerate contains disarticulated fossil vertebrate bones of a small metoposaur, aetosaurs, phytosaurs and lungfish teeth (J. M. Parrish, written commun., 1989) and unionid bivalves (S. C. Good, written commun., 1988). The conglomerate grades upward into moderate-reddish-brown, silty to muddy sandstone and mudstone characterized by large-scale, low-angle trough crossbeds. The mudstone locally contains abundant freshwater gastropods.

In general, the Petrified Forest Member fines upward, and the uppermost part is composed dominantly of moderate-reddish-brown to pale-reddish-brown, bentonitic, muddy siltstone and mudstone (Fig. 4). Siltstones are thin to medium bedded, and exhibit very thin horizontal laminations and vertical and horizontal trace fossils that are as much as 0.5 cm in diameter. Locally, limestone nodules 1–2 cm in diameter are present in the mudstones, and, in places, the nodules coalesce into larger masses. From a distance, the mudstone appears to be horizontally bedded, and individual thin- to medium-bedded units can be traced laterally, but on closer inspection it is difficult or impossible to discern individual beds.

The fine-grained upper part of the Petrified Forest Member contrasts with the lower and middle part of the Petrified Forest Member, which contains abundant siliciclastic conglomerate, coarse-grained, quartz-rich sandstones and variegated mudstones. The lower and middle parts of the Petrified Forest are particularly well exposed in Petrified Forest National Park and are believed to represent braided and meandering stream deposits (Darr, 1985; Espegren, 1985) and fluvial point bar deposits with associated floodplain paleosols (Bown et al., 1983; Middleton et al., 1984; Kraus et al., 1984). Kraus and Middleton (1987) also recognized paleogullies eroded into fluvial and floodplain strata that were subsequently filled with other Chinle fluvial and paleosol deposits. The lower and middle parts of the Petrified Forest Member observed near Lukachukai, Nazlini, Chinle and Many Farms, Arizona appear to be similar to equivalent strata in the Petrified Forest National Park and represent similar fluvial and floodplain environments. However, the lower and middle parts of the Petrified Forest Member contrast markedly in lithology and sedimentary structures with the upper part

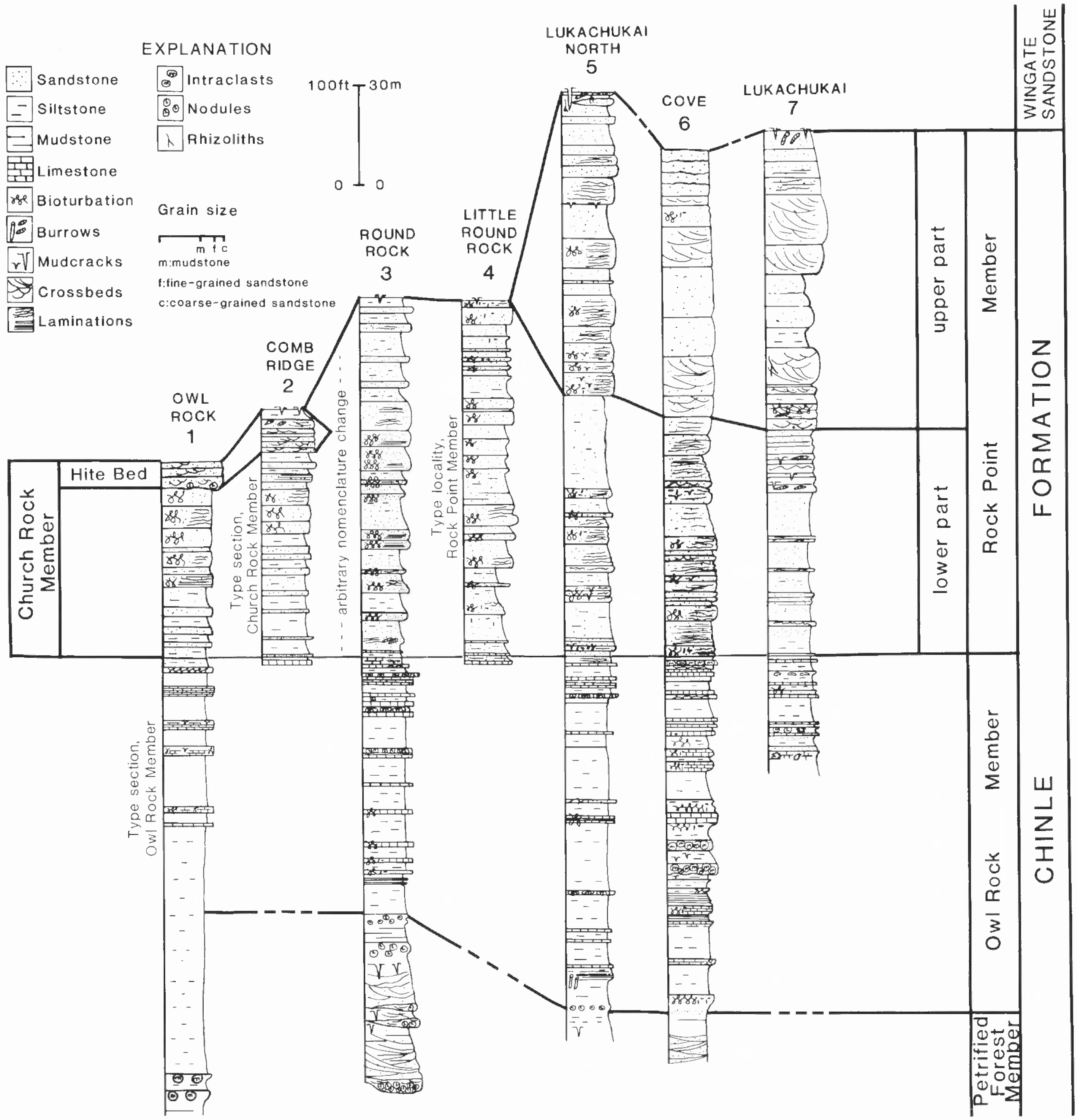

FIGURE 2. Measured sections of upper part of the Chinle Formation.

of the Petrified Forest Member around the Defiance uplift.

The laterally extensive, thin- to medium-bedded siltstones and mudstones of the uppermost Petrified Forest Member appear to be transitional between the dominantly fluvial and floodplain setting of the underlying parts of the Petrified Forest Member and the dominantly lacustrine environments of the overlying Owl Rock Member. The lenticular limestone-nodule conglomerates decrease in both size and number upward in the section, and are replaced by abundant beds of siltstone and mudstone. The fine-grained strata are light to medium brown in contrast to the stark, variegated hues of the underlying parts of the Petrified Forest and the pastels of the overlying Owl Rock strata. The lower and middle parts of the Petrified Forest contain isolated carbonate nodules generally ascribed to pedogenic carbonate accumulation in floodplain deposits (Dubiel, 1987a, in press), whereas the upper part of the Petrified Forest contains coalesced nodules and irregular masses of carbonate in mudstone. The irregular and coalesced carbonate masses appear to be transitional from isolated nodules in the Petrified Forest to laterally extensive carbonate beds in the Owl Rock Member.

The nodular and coalesced carbonates exhibit features inherent in both calcrete–soil horizons (Gile et al., 1966) and ground-water carbonates (Carlisle, 1978; Mann and Horowitz, 1979; Goudie, 1983). The upper part of the Petrified Forest Member lies between fluvial and

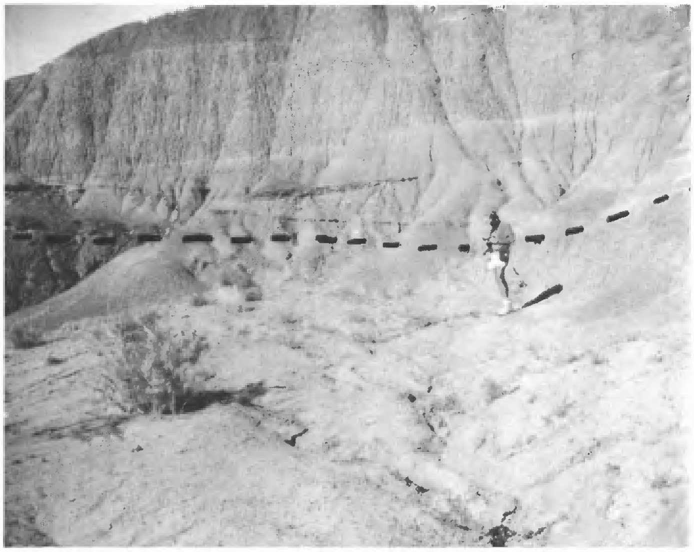

FIGURE 3. Upper part of the Petrified Forest Member on the south side of Round Rock. Fluvial limestone-nodule conglomerate shows large-scale crossbeds and fills a lenticular scour in mudstone of the upper part of the Petrified Forest Member at Round Rock.

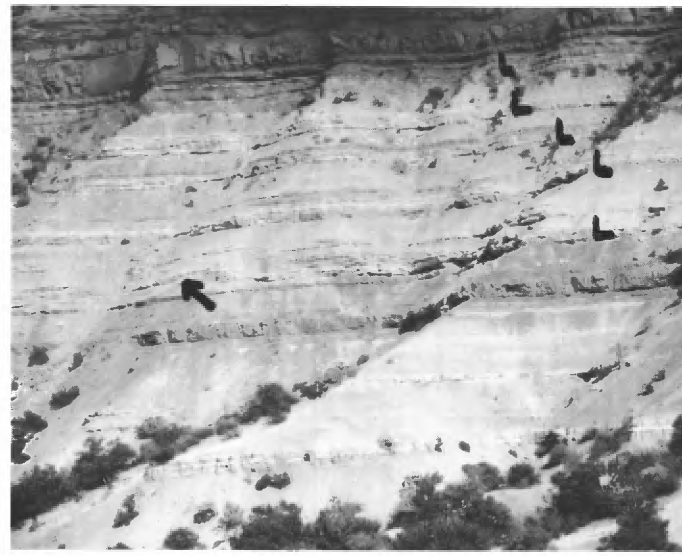

FIGURE 5. Owl Rock Member at Cove. Lacustrine-basin limestone ledges and lacustrine-margin siltstone and mudstone slopes. Note the cyclic alternating lacustrine limestones (L) and fine-grained clastics reflecting climatic cycles, and the large-scale crossbedding in the lowest limestone ledge (arrow).

FIGURE 4. The upper part of the Chinle Formation on the south side of Round Rock. Horizontally bedded lacustrine siltstone and mudstone in the upper part of the Petrified Forest Member (PF) grades upward into limestone ledges and siltstone slopes of the Owl Rock Member (OR).

floodplain rocks and overlying lacustrine strata. This suggests that the upper part was deposited in a marginal lacustrine setting on fine-grained clastic mudflats in which ground-water and pedogenic carbonate precipitated during periods of lake regression. The limestone-nodule conglomerates were deposited in paleogullies and small channels that supplied intraclasts and fine-grained clastics to the adjacent lacustrine system. The channels represent fluvial, crevasse splay or low-gradient lacustrine delta deposits. The decreasing size and abundance of these channel deposits upward in the section indicates a subsequent expansion and transgression of the Owl Rock lacustrine system.

Owl Rock Member

The Owl Rock Member comprises pale-red to light-greenish-gray carbonate ledges interbedded with pale-brown to light-brown and pale-red mudstone, siltstone, and very fine-grained sandstone slopes (Fig. 5). Individual strata are thin- to very thick-bedded and are laterally persistent for several km on the outcrop. There is a gradational and locally interfingered contact with the underlying Petrified Forest Member and generally a sharp contact with the overlying Rock Point Member. The lower contact of the Owl Rock Member is commonly chosen at the first limestone ledge (Witkind and Thaden, 1963, p. 30–31), but is more accurately defined at the change from moderate-reddish-brown and grayish-red bentonitic mudstones and siltstones below to more pastel pale-red and moderate-reddish-orange, nonbentonitic mudstones and siltstones above (Stewart et al., 1972a, p. 39–40; Dubiel, 1987a). The upper contact is often chosen at the top of the uppermost limestone ledge (Witkind and Thaden, 1963, p. 31–32). However, the close of Owl Rock deposition is more precisely defined at the change from pastel-colored limestone, siltstone or mudstone below to moderate-reddish-brown siltstone and sandstone above (Stewart et al., 1972a, p. 40; Dubiel, 1987a).

Carbonate beds of the Owl Rock are composed of micritic limestone, dolomitic limestone and calcite-cemented limestone-, mudstone- and siltstone-pellet conglomerate. Limestones and dolomitic limestones are thin- to thick-bedded, are very extensive laterally, and can be traced for several km along the outcrop. They exhibit a range in texture from very thinly laminated to, in part, bioturbated, nodular, or irregular coalesced carbonate masses. Siltstones, mudstones and very fine-grained sandstones also are very laterally extensive. Contacts between units are generally gradational, and, in part, the partially obscured contact reflects the activity of bioturbating organisms. Small-diameter, vertical and horizontal trace fossils are common in all the carbonate and fine-grained clastic units. Symmetrical, oscillation ripple marks locally are found on the upper surfaces of limestones. The conglomerates are composed of well-rounded, grain-supported clasts derived from older Owl Rock, and possibly Petrified Forest, limestones, siltstones and mudstones. In general, the conglomerates occur as laterally extensive, thin to medium beds that have gradational lower contacts with underlying siltstones and mudstones. Locally, however, the conglomerate beds exhibit a sharp, scoured, convex-downward base and large-scale, epsilon crossbedding (Fig. 5).

The Owl Rock Member was deposited in a variety of lacustrine and marginal lacustrine environments. Laminated limestones are interpreted to represent alternating carbonate precipitation and fine-grained clastic deposition within a lacustrine basin during an expanded or transgressive lacustrine phase as a result of seasonal, tropical monsoonal precipitation (Dubiel, 1987a, b; Parrish et al., in press). Mudstones and siltstones were deposited in marginal lacustrine settings on exposed and subaqueous mudflats during regressive phases while the lake was smaller and contracted. Pellet conglomerates indicate periods of lacustrine contraction, in which lacustrine margin mudflats were subaerially exposed and desiccated to form siltstone and mudstone clasts. This was followed by episodes of lacustrine expansion, in which transgression of lake waters ripped up, transported and redeposited the mudflat intraclasts as laterally extensive beds. The pellet conglomerates with scoured lower contacts indicate channelized transport of the clasts, and probably represent reworking by fluvial systems entering the lake. Alternating cycles of siltstone, mudstone and limestone in the Owl Rock Member reflect alternating episodes of lacustrine expansion and contraction due to longer-term climatic variations rather than the seasonal tropical monsoonal climate.

The Owl Rock Member was deposited in a large, subsiding lacustrine basin that was centered near the Four Corners area (Dubiel, 1987a). Cross sections and isopach maps of the Owl Rock Member (Stewart et al., 1972a), as well as isopach maps of the total limestone within the Owl Rock (Dubiel, 1987a), together with regional facies changes indicate that the major locus of sedimentation and subsidence was in northeastern Arizona. Carbonate-clay laminations in Owl Rock limestones probably reflect variations in the seasonal precipitation related to the Late Triassic tropical monsoonal climate (Dubiel, 1987a; Parrish et al., in press). Cyclic variations in the lithology of Owl Rock units reflect periodic expansions and contractions of the lacustrine system in response to longer-term climatic variations. Finally, the change from Owl Rock limestone, siltstone and mudstone lacustrine deposition to strata of the overlying Church Rock and Rock Point members indicates a significant drying of the climate in the latest Late Triassic (Dubiel, 1987a) and reflects the continued northward movement of Pangaea out of tropical latitudes dominated by monsoonal precipitation (Parrish et al., in press).

Church Rock Member

Despite their stratigraphic equivalence, the Church Rock and Rock Point members will be discussed separately to emphasize both similarities and differences in their depositional settings. The Church Rock Member lies between the Owl Rock Member and the Wingate Sandstone (Figs. 2, 6). A sharp contact separates the Church Rock Member from the underlying Owl Rock Member. The Church Rock consists of moderate-reddish-brown to moderate-reddish-orange siltstone to very fine-grained sandstone with a gradational transition upward to predominantly very thick-bedded, very fine-grained sandstone at the top of the section (Fig. 6). Where the thin- to thick-bedded units are considerably weathered, they exhibit thin horizontal laminations marked by very thin mud drapes. In places, the mud drapes display adhesion ripples and very small desiccation cracks. On fresh exposures, they are massive and display no physical sedimentary structures, but rather a homogenized, bioturbated texture. The bioturbated strata contain vertical and horizontal meniscate back-filled burrows as much as 0.5 cm in diameter.

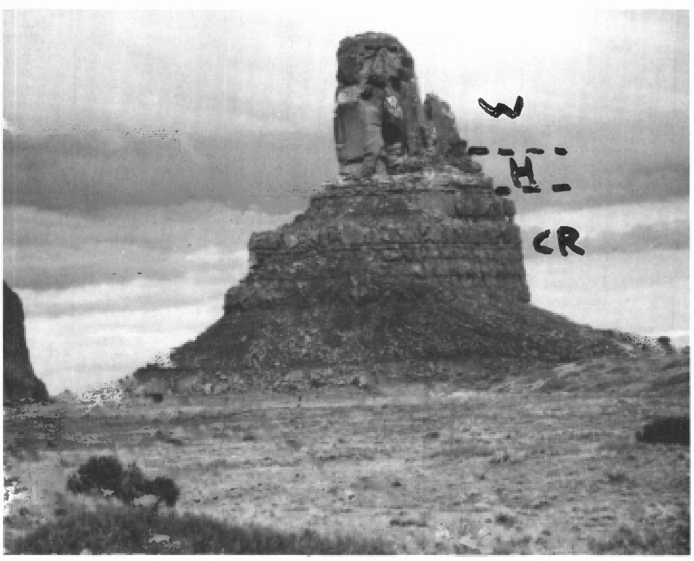

FIGURE 6. Church Rock Member at Owl Rock. Note horizontally bedded lacustrine mudflat and eolian sand-sheet siltstones and sandstones of the Church Rock Member (CR); Hite Bed (H); Wingate Sandstone (W).

The thinly laminated and bioturbated strata of the Church Rock Member resemble marginal lacustrine mudflats (e.g., Fouch and Dean, 1982) and eolian sand-sheets described from modern settings (Fryberger et al., 1979; Kocurek, 1986; Kocurek and Nielson, 1986) and from the coeval Upper Triassic Dolores Formation in southwestern Colorado (Blodgett, 1984; Kocurek and Nielson, 1986). The occurrence of very laterally extensive, thin-bedded sandstones and siltstones containing fine laminations, very thin mud drapes and small desiccation cracks indicates an environment of deposition with low relief, periodic sedimentation and episodic subaqueous and subaerial conditions. The preservation of abundant, small trace fossils that were probably produced by sediment ingesting nonmarine arthropods also indicates periodic damp to subaqueous conditions. Moreover, the Church Rock's stratigraphic occurrence above lacustrine strata of the Owl Rock indicates deposition was on a relatively flat subaqueous depositional surface that experienced episodic subaerial exposure and desiccation. This setting is interpreted as lacustrine margin mudflats that experienced episodic to periodic subaerial exposure, desiccation and deposition from eolian sand-sheet environments. It should be emphasized that the strata are not interpreted as playa-lake beds because there have been no reports from the Church Rock of large-scale desiccation features, nor of casts of evaporite minerals, nor of mineral pseudomorphs after saline or evaporative minerals as would be expected in playa-lakes that experienced prolonged subaerial conditions (Neal, 1975).

A coarse-grained and conglomeratic sandstone, the Hite Bed, is found at the top of the Church Rock Member and directly below the Wingate Sandstone (Fig. 6). The Hite Bed consists of grayish-red to dusky red, fine- to coarse-grained, medium- to thick-bedded arkosic sandstone and minor mudstone. The base of the Hite Bed is a sharp, scoured contact that has as much as 0.5 m of relief. Individual beds contain abundant small- to medium-scale trough and planar-tabular crossbeds. The contact with the Wingate Sandstone is marked by sand-filled desiccation cracks that extend down about 10 cm into the Hite Bed mudstones.

The coarse-grained texture, scoured and lenticular lower contact and abundance of trough and planar-tabular crossbeds of the Hite Bed indicate deposition by channelized flow of primarily bedload deposition on in-channel bars (Miall, 1978; Rust, 1978). The streams were probably braided fluvial systems. These fluvial systems traversed the lacustrine mudflats during regressive phases of the Owl Rock lacustrine system that reflect longer-term, drier climatic intervals.

Rock Point Member

The Rock Point Member is present in the Defiance uplift area south of Laguna Creek. A sharp contrast in lithology and texture distinguishes the Rock Point Member from the underlying Owl Rock Member (Fig. 7). The lower part of the Rock Point consists dominantly of moderate-reddish-brown, very fine-grained sandstone and minor siltstone and silty sandstone virtually identical to the Church Rock Member north of Laguna Creek. The lower part of the Rock Point Member weathers to thin- to thick-bedded, fine-grained sandstone ledges interbedded with siltstone and very fine-grained sandstone slopes. Thin horizontal laminations, 0.5-cm-diameter trace fossils, and a bioturbated texture are characteristic of the entire lower part. At Round Rock and at the type locality of the Rock Point Member at Little Round Rock, the contact with the overlying Wingate Sandstone is sharp. The Wingate is composed of moderate-reddish-brown to moderate-reddish-orange, fine-grained sandstone with large-scale, low-angle trough crossbeds composed of upward-coarsening laminae. Sandstone of the Wingate fills desiccation cracks that extend down as much as 15 cm into the top of the Rock Point (Fig. 8). No similar, large-scale sand-filled mudcracks have been observed in the underlying Church Rock or Rock Point strata. The mudcrack fills may be characteristic of the contact between the

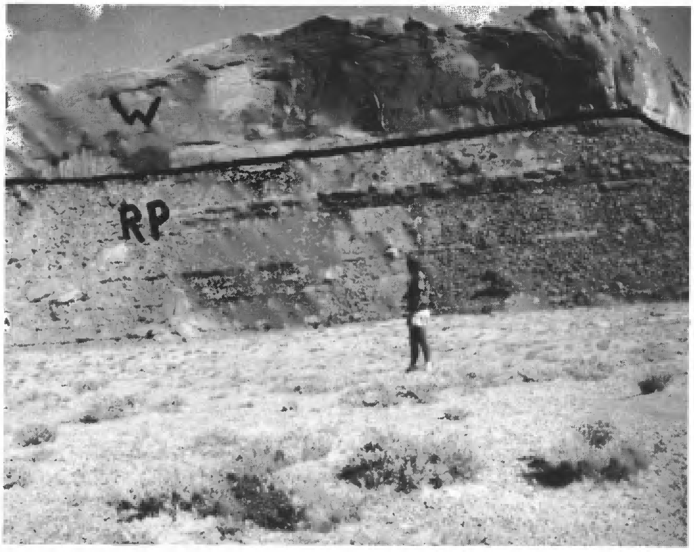

FIGURE 7. Rock Point Member at Round Rock. Note horizontally bedded lacustrine mudflat and eolian sand-sheet strata of the Rock Point Member (RP); Wingate Sandstone (W).

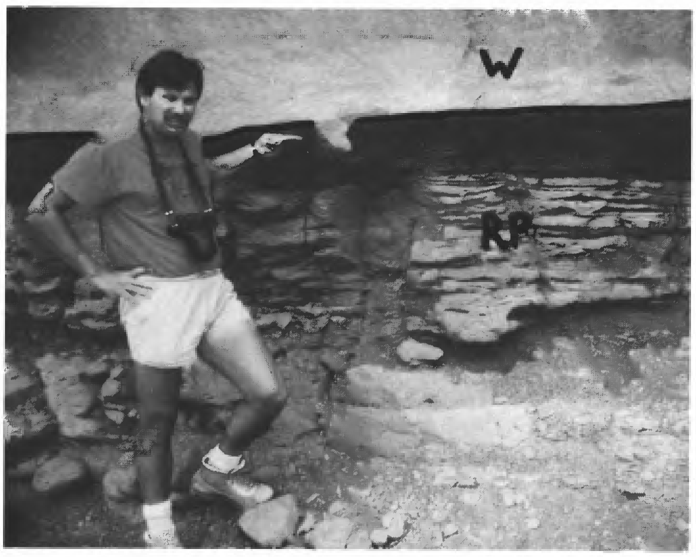

FIGURE 8. Base of the Wingate Sandstone at Little Round Rock. Site is at the type locality of the Rock Point Member on the southeast ridge of Little Round Rock. Geologist is pointing to the contact of the Wingate Sandstone (W) and the Rock Point Member (RP) marked by sand-filled desiccation cracks.

Chinle and the Wingate. Mudcracks at the top of the Chinle that are filled with sand of the overlying Wingate are found at numerous outcrops in southeastern Utah (Gilluly and Reeside, 1928, p. 68; Pipiringos and O'Sullivan, 1978, p. 19; Dubiel, 1987a).

At Round Rock and at the type locality at Little Round Rock, the Rock Point Member is considerably thicker than the Church Rock Member at its type section (Fig. 2). Lithologies are similar, except that the Rock Point Member contains no Hite Bed equivalent. The westward thinning of the strata, which are stratigraphic equivalents, reflects a regional westward beveling of successively older Chinle strata by an unconformity below the Wingate Sandstone. This unconformity has been recognized over a large part of the Colorado Plateau and has been termed the J-O unconformity (Pipiringos and O'Sullivan, 1978). The J-O unconformity rests on successively older Chinle strata to the west (Pipiringos and O'Sullivan, 1978; Dubiel, 1987a).

Despite the thicker section at Round Rock and Little Round Rock, similarities in lithology, bedding and sedimentary structures in the Rock Point Member represent depositional environments also present in the Church Rock Member north of Laguna Creek. In the Rock Point Member, thin to thick beds of siltstone and sandstone with abundant horizontal laminations, bioturbation and small diameter trace fossils represent lacustrine mudflat and eolian sand-sheet deposition. The alternating sandstone and siltstone, and the development of thin laminations and very small mudcracks, probably reflect fluctuating ground-water tables in the subsiding basin of deposition. Ground-water table was periodically high enough to pond water at the surface and support an infaunal invertebrate assemblage, and at times was low enough to produce subaerial exposure and eolian sand-sheet deposition. Fluctuating water tables are favorable for the formation of eolian sand sheets (Kocurek and Nielson, 1986). At Cove, Lukachukai North and Lukachukai, the lower part of the Rock Point Member consists of a lithofacies typical of the Rock Point at the type locality and of the Church Rock Member (Fig. 2). The environment of deposition of these strata is considered to be a lateral extension of the same lacustrine mudflat and sand-sheet setting present at the other localities.

However, at Cove, Lukachukai North and Lukachukai, the Rock Point is considerably thicker than at the type locality at Little Round Rock and contains a lithofacies not present at the type locality. At these three localities and in outcrops nearby to the south, the upper part of the Rock Point Member contains a lithofacies that appears to be transitional between the ledge-forming, lower part of the Rock Point and the cliff-forming part of the overlying Wingate Sandstone.

The upper part of the Rock Point Member consists of interbedded siltstones, sandy siltstones and very fine-grained sandstones. The siltstones and silty sandstones are massive or are horizontally laminated and exhibit a bioturbated texture and small-diameter trace fossils. The sandstones are moderate reddish orange, thin- to thick-bedded and very fine- to fine-grained. The sandstones are characterized by small- to medium-scale trough crossbeds and large-scale, low-angle trough crossbeds with upward-coarsening laminae (Fig. 9). The finer-grained, bioturbated units are distinguished on the outcrop by a slightly deeper red than the yellow-orange of the crossbedded strata. The crossbedded strata become thicker and more abundant upward in the section (Fig. 10) and to the south toward Lukachukai. North of Lukachukai toward Los Gigantes buttes, where the thick sandstones and interbedded siltstones weather as a cliff, it is difficult to distinguish the contact with the overlying, cliff-forming Wingate Sandstone. South toward Lukachukai, the crossbedded sandstones become thicker and more abundant in the section and weather as massive, rounded ledges easily distinguished

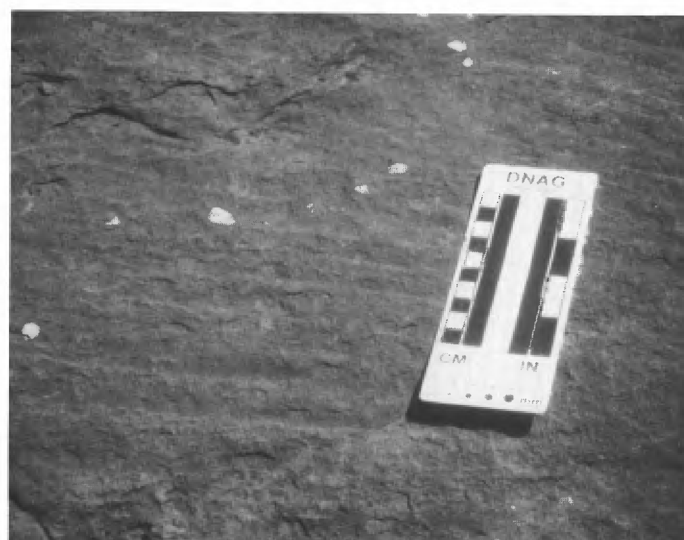

FIGURE 9. Rock Point Member at Lukachukai. Note the coarsening-upward laminae characteristic of eolian deposition in trough-crossbedded sandstone of the upper part of the Rock Point Member.

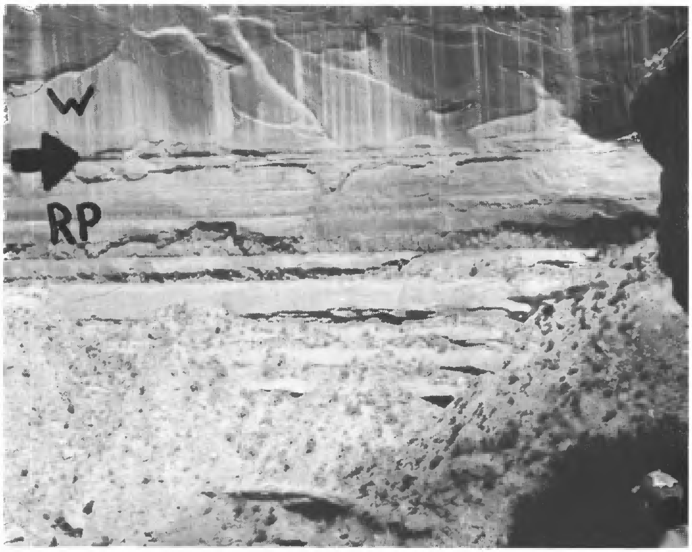

FIGURE 10. Upper part of the Rock Point Member at Lukachukai North. Note the contact (arrow) between the Rock Point (RP) and the Wingate Sandstone (W). Eolian dune deposits of the Rock Point Member weather to rounded ledges. Geologist in lower right corner.

from the intervening siltstones and silty sandstones (Fig. 10). Locally, and especially at the exposures at Lukachukai North, individual sandstone beds can be observed to pinch out northward along the outcrop and to the east in large reentrants.

Beds at the top of the Rock Point Member are characterized by abundant desiccation cracks and bioturbation. Sandstone- and siltstone-filled desiccation cracks that range from half a meter deep in polygons about a meter across to spectacular 3-m-deep desiccation cracks forming polygons estimated to be about 10–15 m across (Fig. 11). In places, the mudcracks extend down from a sandstone bed that contains reworked siltstone and mudstone clasts. The bed displays a dark-red color alteration. Locally, the mudcracked zone contains three distinct types of trace fossils. Meniscate, back-filled trace fossils as much as 3 cm in diameter (Fig. 12) are abundant and locally follow the fine-grained mudcrack fill. The meniscate traces also occur in the overlying Wingate Sandstone. Smaller meniscate traces about 0.5 cm in diameter are abundant in the mudcracked interval. The third type of trace forms vertical tubes about 0.5 cm in diameter that branch and taper downward over 0.5 m. A light lavender alteration halo surrounds the trace.

The upper part of the Rock Point Member is interpreted as interbedded lacustrine mudflat, eolian sand-sheet and eolian dune deposits. Criteria for the lacustrine mudflat and eolian sand-sheet deposits have been described above. The interpretation of small to large eolian dune deposits is based on the occurrence of trough crossbeds with upward-coarsening laminae, one of the few criteria considered distinctive of eolian depositional environments (e.g., Fryberger and Schenk, 1981). The large and small meniscate ichnofossils are considered to be fodinichnia (feeding traces) of sediment-ingesting arthropods based on their size and internal morphology (e.g., Basan, 1978). The downward branching traces are rhizoliths (plant–root trace fossils) similar to those reported from the Dolores Formation in southwestern Colorado (Blodgett, 1984) and from the Chinle Formation in western Colorado (Dubiel, 1988; Dubiel and Skipp, 1989). Continued subsidence during sedimentation resulted in the preservation of the upper part of the Rock Point Member in the area around Lukachukai and Cove. Equivalent units were eroded or never deposited away from the Lukachukai-Cove area where the Wingate overlies older Chinle units. The presence of large desiccation cracks indicates that the strata were saturated before they dried out, and indicates high water tables persisted in the upper part of the Chinle. In addition, the transition of Rock Point environments upward into eolian erg deposits of the Wingate reflects a large-scale change in climate from drier conditions that were periodically wet to dominantly dry conditions. The climatic change was in response to the continued northward movement of Pangaea from the Triassic to the Jurassic (Parrish et al., in press). This migration moved the Colorado Plateau north out of latitudes dominated by tropical monsoonal precipitation and resulted in predominantly drier conditions in the Jurassic.

Upper contact of the Chinle Formation

The upper contact of the Rock Point Member at Lukachukai, Lukachukai North and Cove was chosen at a surface that exhibits abundant sandstone- and siltstone-filled desiccation cracks that range from half

FIGURE 11. Sand-filled desiccation cracks at Lukachukai North. Desiccation cracks extend from the Wingate (W) 3 m down into the Rock Point (RP). These features indicate high water tables in strata that subsequently underwent desiccation.

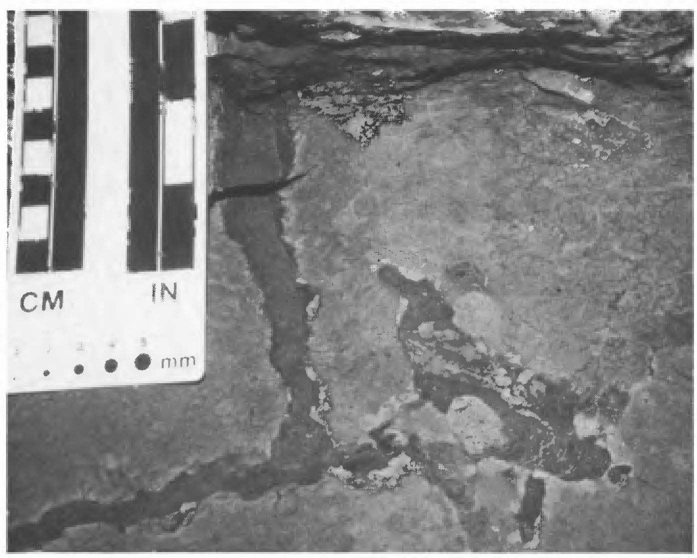

FIGURE 12. Large, cylindrical, meniscate backfilled burrows. Burrows are of probable arthropod origin within the mudcracked interval marking the top of the Rock Point Member at Lukachukai.

a meter deep in polygons about a meter across to spectacular 3-m-deep desiccation cracks forming polygons estimated to be 10–15 m across (Fig. 11). The surface here described was chosen as the upper contact of the Rock Point because it appears to represent the most pronounced break in deposition in what apparently is an essentially continuous depositional sequence from Chinle lacustrine, eolian sand-sheet and minor eolian dune strata to Wingate erg deposits. In addition, the surface is marked by extensive, large-scale mudcracks similar to those observed at the J-O unconformity separating the Chinle and the Wingate at other sections around the Defiance uplift (Fig. 2) and at sections in southeastern Utah and northern Arizona (Gilluly and Reeside, 1928, pl. 17A; Pipiringos and O'Sullivan, 1978, p. 19; Dubiel, 1987a).

It should be pointed out that the upper contact of the Rock Point Member has been placed in the past (Stewart et al., 1972a) and in concurrent studies (M. J. Nation and R. C. Blakey, oral commun., 1988) at a stratigraphic level different than that described above. The lithofacies here described at the top of the Rock Point Member has been the focus of considerable discussion in the past. Harshbarger et al. (1957) describe the top of the Rock Point as intertonguing with the overlying Wingate Sandstone and cite this as one line of evidence for their assignment of the Rock Point to the Wingate Sandstone. Stewart et al. (1972a, p. 3) suggest that intertonguing with the Wingate Sandstone is minor, and that many of the sandstone beds represent isolated lenses in the Rock Point Member. Stewart et al. (1972a) place the basal contact of the Wingate below that used in the present study (Fig. 13). Nation and Blakey (1988) used regional erosion surfaces within the Wingate to follow sedimentation units south from the area of Moab, Utah and chose the basal contact of the Wingate at a lower stratigraphic level than that recognized in this study (M. J. Nation and R. C. Blakey, oral commun., 1988). They considered at least the uppermost sandstone and siltstone units of the Rock Point Member of this report as eolian deposits related to the Wingate erg.

This study does not recognize intertonguing between the Rock Point Member and the Wingate Sandstone, a conclusion also suggested by Pipiringos and O'Sullivan (1978, p. 19). This study interprets the thick sand bodies within the upper part of the Rock Point Member as incipient eolian dune development reflecting the onset of drier climatic conditions at the close of the Triassic, alternating with eolian sand-sheet and lacustrine mudflat deposition during periodically wetter climatic conditions. High ground-water tables concomitant with subsidence active during the wetter climatic intervals controlled eolian sand-sheet and lacustrine mudflat preservation, resulted in laterally extensive beds and regionally traceable bedding planes and provided a moist substrate

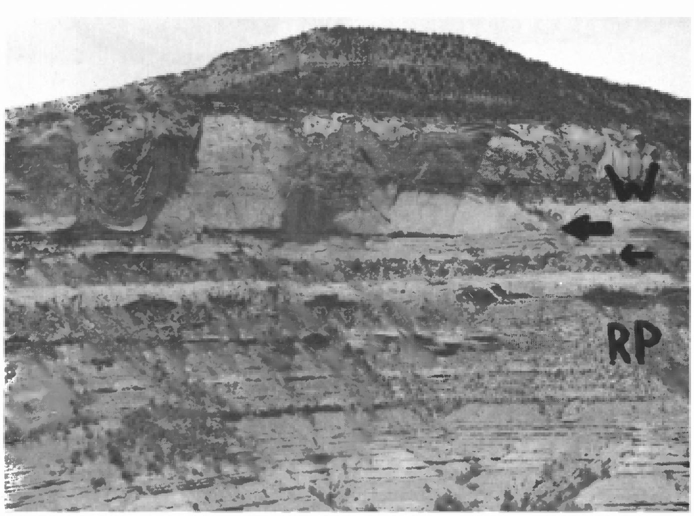

FIGURE 13. Chinle Formation north of Cove. The contact between the Rock Point (RP) and the Wingate (W) used by Stewart et al. (1972a) (small arrow) and the present interpretation of the contact (large arrow). Note the similarity of sandstones directly below the contact of this report to those lower in the Rock Point (Photo by J. H. Stewart).

inhabited by invertebrates. Persistent tectonic subsidence in the area localized around Lukachukai, Cove and to the south resulted in the selective preservation of the small dune deposits. In other areas, the upper part of the Rock Point was eroded or was never deposited.

Resolution of the placement of the Rock Point-Wingate contact in part depends on a designated type section of the Wingate Sandstone. A type section is needed to define and compare with the type locality and type section of the Rock Point Member and Church Rock Member, respectively, that lack eolian dune strata and to compare with sections that contain eolian dune strata.

REVISED NOMENCLATURE

The Rock Point Member has a lithology and age that indicate sedimentation was localized by the subsiding Chinle depositional basin centered in the Four Corners region. The Rock Point does not have a geographic distribution similar to the Wingate Sandstone as stated by Harshbarger et al. (1957, p. 7). The Wingate extends over a much larger area of the Colorado Plateau than does the Rock Point Member. The lithology, age and depositional environments of the Rock Point Member indicate that the strata are more closely related to the Chinle depositional system than to the Wingate depositional system. It is also apparent that the inception of eolian dune deposition in the upper part of the Rock Point reflects a transition to the eolian erg deposition of the Wingate Sandstone. The inception of eolian deposition is related to the northward migration of Pangaea and a change to drier Jurassic climates not dominated by monsoonal circulation.

Age assignment of the Rock Point Member to the Late Triassic is based on meager fossil evidence (Witkind and Thaden, 1963, p. 34). The placement of the J-O unconformity at the base of the Wingate Sandstone (Pipirigos and O'Sullivan, 1978; Peterson and Pipiringos, 1979), and a suggested Early Jurassic age for the Wingate Sandstone (Peterson and Pipiringos, 1979, p. 33–34) are supported by the recognition of interfingering between the Wingate Sandstone and Moenave Formation (Edwards, 1985) and the identification of Jurassic palynomorphs from the Dinosaur Canyon Member of the Moenave Formation (Litwin, 1986a, b). However, stratigraphic placement of the Triassic-Jurassic boundary based on paleontological criteria continues to be uncertain (Colbert, 1986). The stratigraphic placement of the Triassic-Jurassic boundary cannot be determined without detailed biostratigraphic data. This uncertainty relates to placement of the J-O unconformity in the area around the Defiance uplift. The J-O unconformity may represent the base of the Jurassic over much of the Colorado Plateau (Pipiringos and O'Sullivan, 1978) where it coincides with an obvious depositional break in the stratigraphic section. The base of the Wingate Sandstone represents the J-O unconformity where the Wingate overlies the lower part of the Rock Point or older Chinle strata (Fig. 2). However, around the Defiance uplift, the stratigraphic break in sedimentation is not so clear where the Wingate overlies the upper part of the Rock Point. In a section characterized by virtually continuous continental sedimentation, it is difficult to choose a surface that represents a systemic boundary ill-defined by paleontology.

Based on lithologic, stratigraphic, sedimentologic and paleontological evidence, the Rock Point Member is here recognized as a member of the Upper Triassic Chinle Formation. Moreover, the name Lukachukai Member of the Wingate Sandstone is here abandoned, and the Wingate Sandstone, which contains only one member, refers to the sandstone stratigraphically overlying the Chinle around the Defiance uplift and over much of the Colorado Plateau.

Despite the evidence for placing the Rock Point within the Chinle, the evidence is not so clear for designating the upper contact of the Rock Point with the overlying Wingate. The lack of properly defined and described type sections complicates placement of the J-O unconformity and recognition of the Triassic-Jurassic boundary. To further complicate matters, the Chinle-Wingate contact in the Defiance uplift may not coincide with the Triassic-Jurassic boundary, and the J-O unconformity may not be present in the area. Additional sedimentologic and stratigraphic studies are required to try and resolve these remaining problems.

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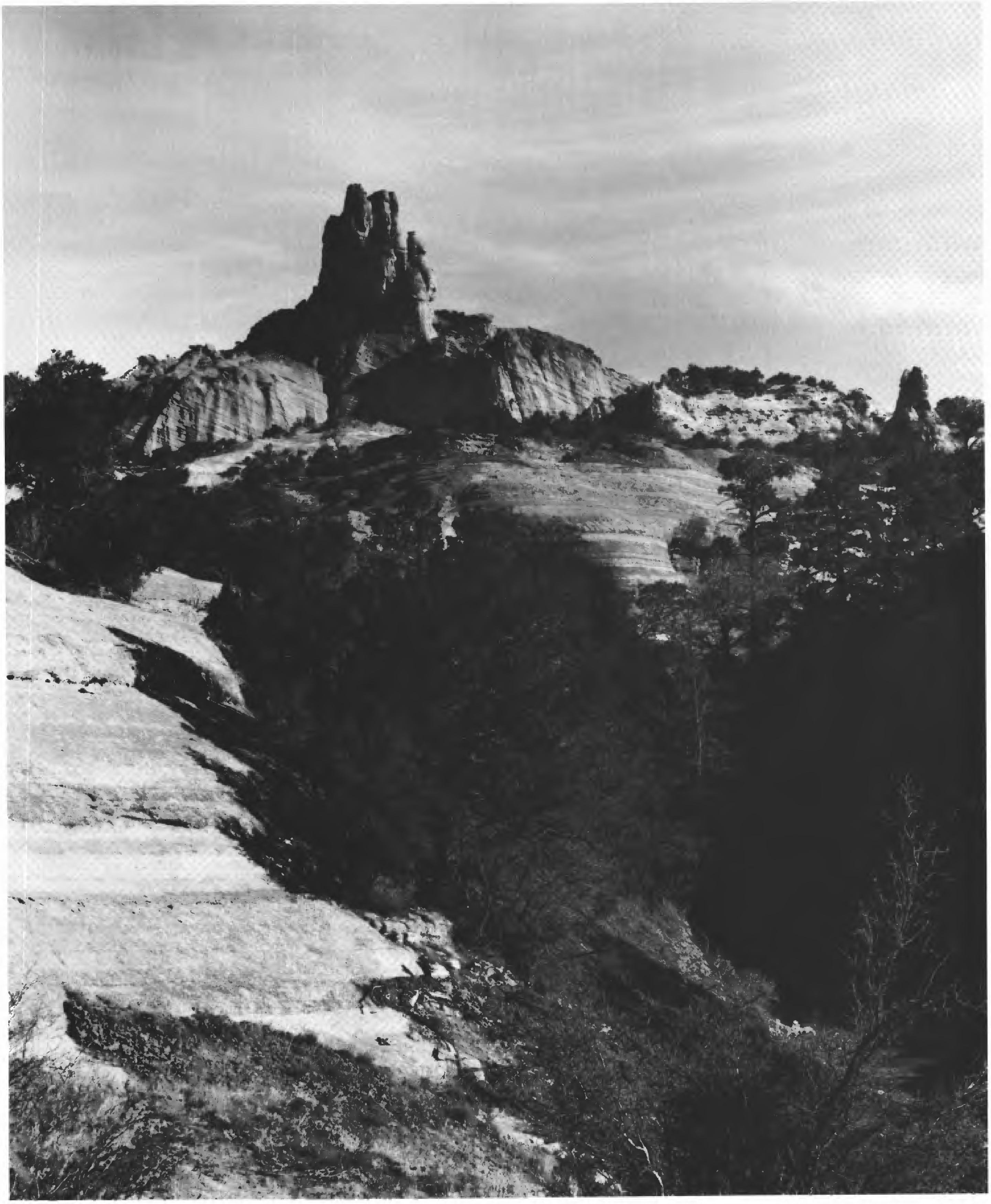

Navajo Church, looking N. Jurassic strata exposed here are Cow Springs Member of Entrada Sandstone (parallel-bedded sandstones in foreground) overlain by eolian facies of Recapture Member of Morrison Formation (crossbedded sandstone below pinnacle) capped by Westwater Canyon Member of Morrison Formation (pinnacle). Photograph taken 25 February 1989 by Paul L. Sealey.