Geology of Utah's Parks and Monuments
2000 Utah Geological Association Publication 28
D.A. Sprinkel, T.C. Chidsey, Jr., and P.B. Anderson, editors

Depositional Environments and Paleotectonics of the Organ Rock Formation of the Permian Cutler Group, Southeastern Utah

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ABSTRACT

The Lower Permian Organ Rock Formation of the Cutler Group is exposed in outcrops across southeastern Utah from Monument Valley to Canyonlands National Park. The Organ Rock Formation conformably overlies the Cedar Mesa Sandstone of the Cutler Group throughout the region. The Organ Rock is overlain conformably to erosionally by the De Chelly Sandstone at Monument Valley and by the White Rim Sandstone at Canyonlands. Along the Monument upwarp the Organ Rock is truncated by an erosion surface that is overlain by the Triassic Moenkopi Formation. The Organ Rock Formation grades laterally to the east into undivided Cutler Formation and to the west into marine and eolian deposits of the Cedar Mesa and White Rim Sandstones.

In the vicinity of Monument Valley the Organ Rock consists primarily of pale-red, very fine grained sandstones, siltstones, and limestone-nodule conglomerates deposited in fluvial channels and on floodplains associated with north to northwest-flowing, meandering streams. Numerous rhizolith-bearing horizons indicate extended periods of soil development on the floodplains. Near the top of the unit, very-fine-grained sandstones and siltstones interpreted as loessites grade upward into eolian deposits of the overlying De Chelly Sandstone.

To the northeast, in exposures of the Organ Rock near Canyonlands National Park, eolian dune and sand-sheet deposits are interbedded with arkosic, medium-grained sandstone to conglomeratic fluvial channel deposits. The coarser grain size reflects the proximity of the Uncompahgre Highland source area. Paleocurrents in fluvial rocks in this area indicate west to northwest-directed flow.

West of the Colorado River, near the Maze Overlook in Canyonlands National Park, the Organ Rock interval consists almost exclusively of eolian dune and sand sheet deposits. The size and orientation of cross-strata suggest that the dunes were primarily transverse or barchanoid ridges that migrated toward what is presently the southeast. Several rhizolith-bearing paleosol horizons attest to extended periods of landscape stability in the dune field. The quantity and thickness of eolian deposits in the Organ Rock decrease southeastward toward the axis of the Monument upwarp.

Isopachs and depositional trends in the Organ Rock suggest that, during the Permian, the axis of the Monument upwarp trended northeast-southwest and was located to the west of its present position. Fluvial channels in the Organ Rock were diverted northwestward around the northern edge of the upwarp whereas eolian deposits onlapped the structure from the west. The entire Organ Rock interval was thinned across the axis of the Monument upwarp due in part to truncation by the Permian-Triassic unconformity.

INTRODUCTION

The Permian Organ Rock Formation forms some of the most spectacular scenery that the canyon country of southeastern Utah has to offer. It has a supporting role as the lower slope-forming unit in the mesas and spires of Monument Valley (figures 1 and 2) and forms monoliths of its own near Hite crossing at the northern end of Lake Powell and in the Land of Standing Rocks west of the Colorado River (figures 1 and 3). It is also part of the dramatic scenery near Natural Bridges National Monument and at Canyonlands National Park where its red color stands in stark contrast to the white sandstones that lie above and below (figures 1 and 4).

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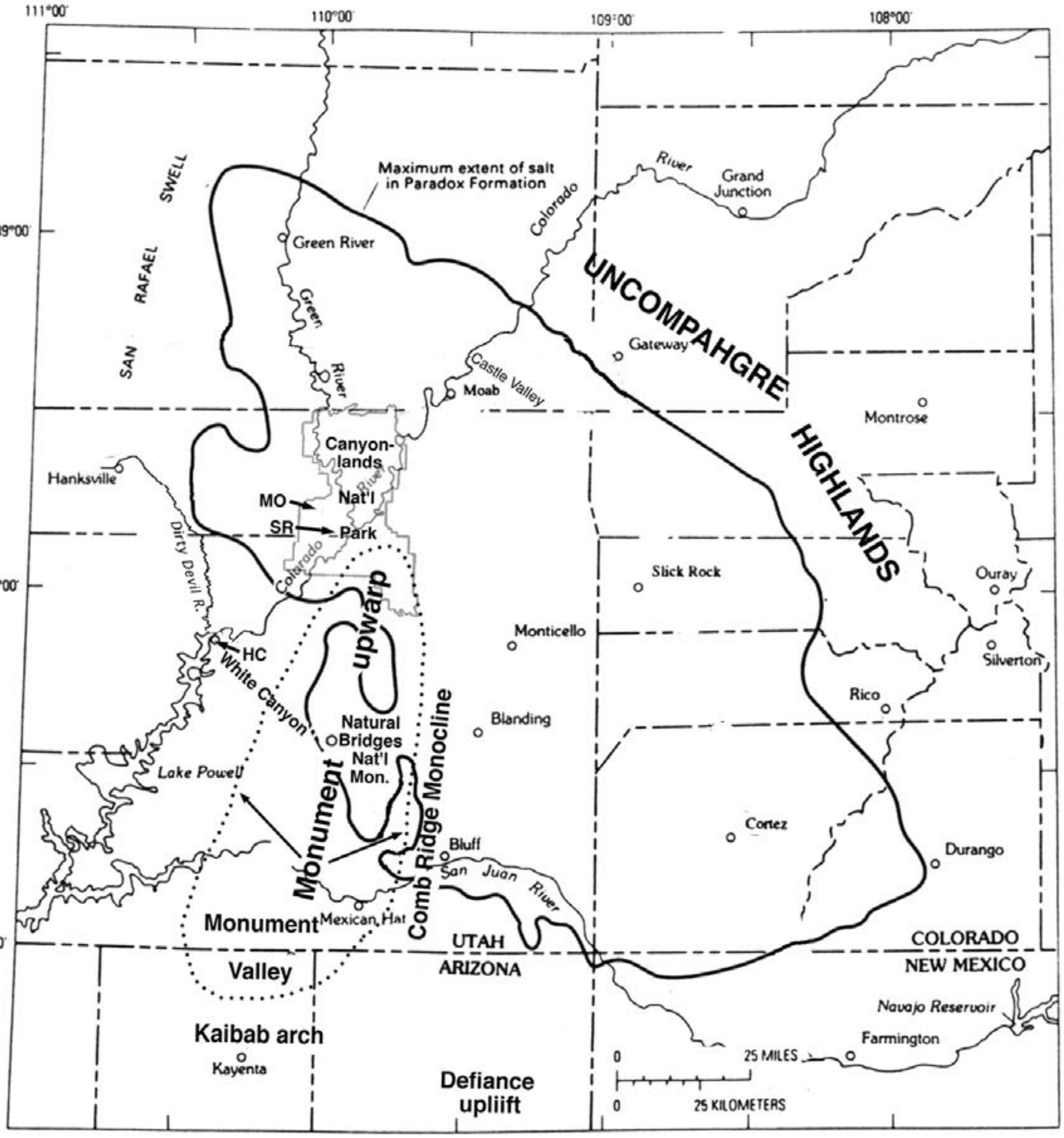

Figure 1. Map showing geographic features in southeastern Utah, southwestern Colorado, northeastern Arizona and northwestern New Mexico. Other locations mentioned in the text are: MO, Maze Overlook; SR, Land of Standing Rocks; HC, Hite Crossing. Outline of Paradox Basin corresponds to maximum extent of salt in the Pennsylvanian-age Paradox Formation.

Figure 2. The Mittens in Monument Valley along the Utah-Arizona border. Fluvial and flood plain deposits in the Organ Rock Formation (Po) form a slope beneath eolian strata of the De Chelly Sandstone (Pd).

Figure 3. Monoliths of the Organ Rock Formation rise above a light-colored bench of eolian Cedar Mesa Sandstone, Land of Standing Rocks in Canyonlands National Park (SR, figure 1). Elaterite Butte in the background consists of Mesozoic sedimentary rocks. View is to the northwest.

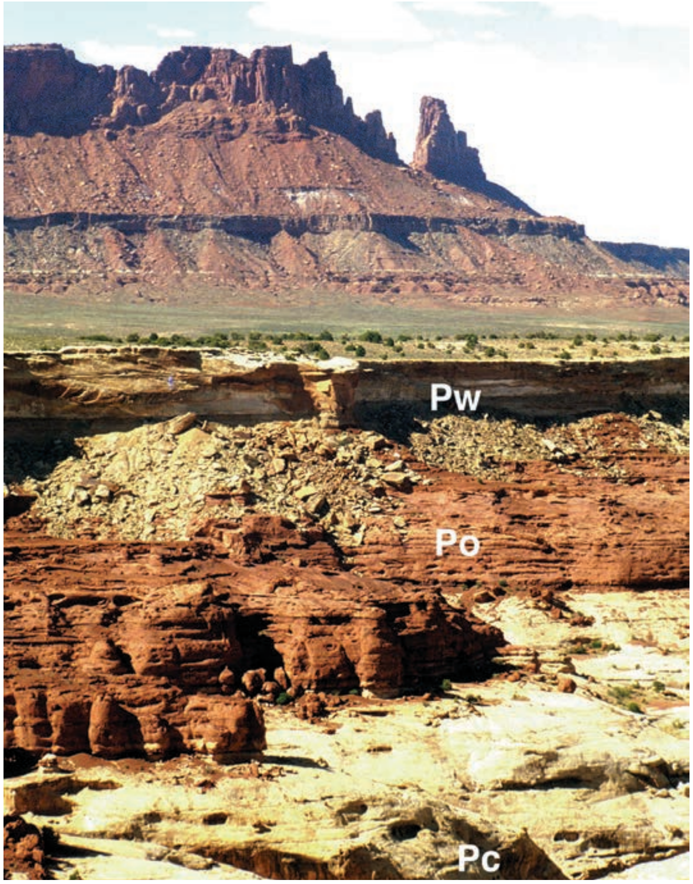

Figure 4. Red-colored strata of the Organ Rock Formation (Po) contrast with light-colored layers of the underlying Cedar Mesa Sandstone (Pc) and the overlying White Rim Sandstone (Pw) near the Maze Overlook (MO, figure 1) in Canyonlands National Park. The Organ Rock is of predominantly eolian origin at this location.

The Organ Rock Formation extends from Monument Valley near the Utah-Arizona border to the northern part of Canyonlands National Park in a broad band defined by Comb Ridge monocline on the east and the Dirty Devil River on the west (figures 1 and 5). The Organ Rock is recognized in the subsurface as far west as the San Rafael Swell in central Utah (Condon, 1997).

Despite its striking character and wide geographic extent, the Organ Rock Formation has received little scientific attention compared to other Permian strata in southeastern Utah. Baker and Reeside (1929) named the unit the Organ Rock Tongue and placed it within the Cutler Formation. The stratigraphy of the unit was discussed in descriptive reports by Gregory (1938), Sears (1956), Mullens (1960), Witkind and Thaden (1963), Lewis and Campbell (1965), and O'Sullivan (1965). Baars (1962) mapped the unit in the subsurface, and presented a summary of the Organ Rock's distribution and general depositional environments (Baars, 1975, 1985, 1987). Condon (1997), in a paper on the Pennsylvanian and Permian Cutler Group of the Paradox basin, constructed isopach maps and described the general geology of the Organ Rock, referencing preliminary studies by the authors of this report (Stanesco and Dubiel, 1992; Dubiel and others, 1996a). Mamay and Breed (1970) and Vaughn (1973) identified terrestrial plant

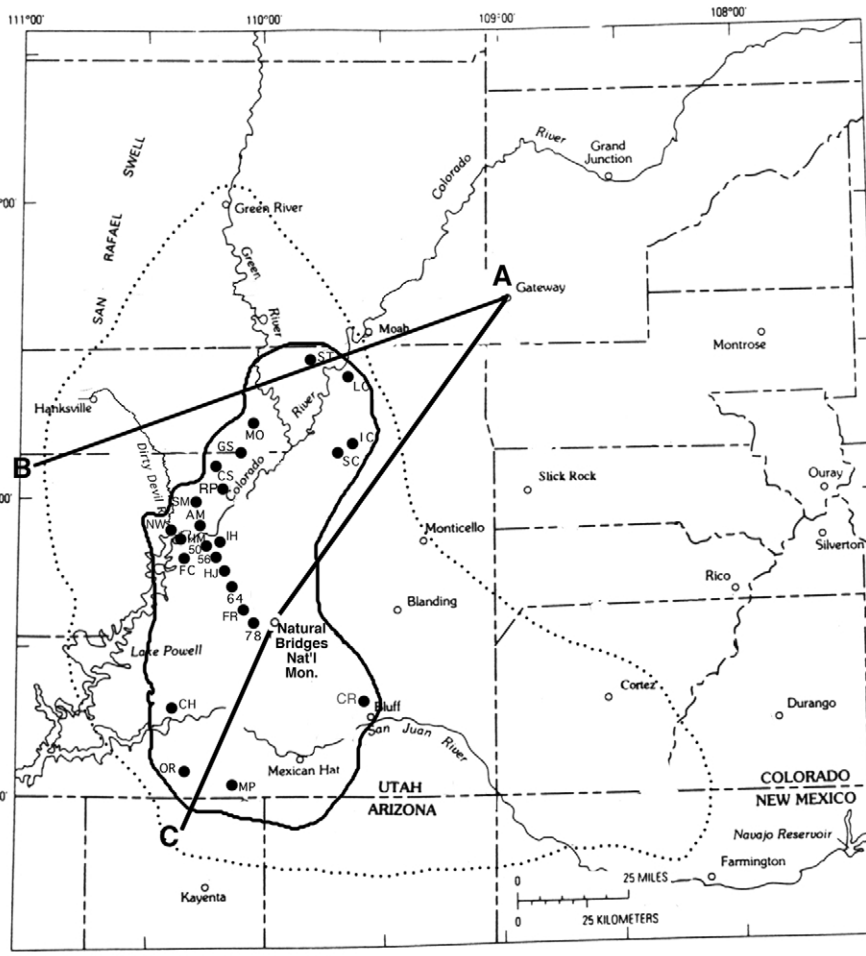

Figure 5. Map showing the location of stratigraphic sections in the Lower Permian Organ Rock Formation and equivalent strata that form the basis of this report. Lines A-B and A-C correspond to the cross sections of Permian strata shown in figures 6a and 6b. Stratigraphic sections are labeled as follows: MP, Monument Pass; OR, Organ Rock; CH, Clay Hills Crossing; CR, Comb Ridge; 78, Milepost 78 on U. S. Highway 95; FR, Fry Canyon; 64, Milepost 64; HJ, Happy Jack Mine; 56, Milepost 56; 50, Milepost 50; FC, Farley Canyon; IH, Indian Head Pass; HM, Hite Marina; NW, North Wash; AM, Andy Miller Flat; SM, Sewing Machine Butte; RP, Red Point; CS, Cove Spring; GS, Golden Stairs, MO Maze Overlook; SC Salt Creek, IC, Indian Creek; LC, Lockhart Canyon; ST, Shafer Trail. Solid dark line encloses the outcrop area of the Organ Rock Formation. Dotted line indicates the recognized extent of the Organ Rock Formation in the subsurface. Modified from Condon (1997).

and vertebrate fossils from the Organ Rock.

This paper describes the lithology, sedimentary structures, and inferred depositional environments of the Organ Rock Formation. It also discusses the influence of Permian tectonic features on the stratigraphy and deposition of the unit and on the development of regional unconformities. Twenty-four stratigraphic sections measured in the Organ Rock and equivalent strata form the basis for the interpretations presented in this paper (figure 5).

PALEOGEOGRAPHIC AND PALEOTECTONIC SETTING

Most outcrops of the Organ Rock Formation occur within the Paradox basin, an oval-shaped structural depression that formed during the Pennsylvanian Period and continued to be an active site of deposition during the Permian. The outline of the Paradox basin in figure 1 corresponds to the edge of salt deposits in the Pennsylvanian Paradox Formation (Condon, 1997). Throughout the late Paleozoic, the Paradox basin was bordered on its northeastern margin by the Uncompahgre Highlands (figure 1), the westernmost range of the Ancestral Rocky Mountains. Precambrian granites and metamorphic rocks were exposed in the core of the uplift.

In addition to the Uncompahgre Highlands, elevated areas were present to the south and west of the Paradox basin during the Permian (figure 1). The Defiance uplift and the Kaibab arch were less significant uplifts located to the south of the basin in northern Arizona and New Mexico (Blakey, 1996; Condon, 1997). The Monument upwarp was a broad, low-amplitude feature located near the southwestern edge of the basin (Blakey, 1980; Baars and Stevenson, 1981; Condon, 1997). The structure was active throughout much of the late Paleozoic and was reactivated during the Late Cretaceous Laramide orogeny. The Laramide-age Monument upwarp extends from Monument Valley to the confluence of the Green and Colorado Rivers in Canyonlands National Park (figure 1).

During the Early to Middle Pennsylvanian Period, cyclic deposits of marine shale and evaporites were concentrated in deeper parts of the Paradox basin, while carbonates interfingered in shallow water settings with clastic debris eroded from the Uncompahgre Highlands (Hite and Buckner, 1981). As the basin filled during the late Pennsylvanian, terrestrial fluvial and eolian strata interfingered with marine deposits. Mixed marine and terrestrial deposition continued into the Permian Period.

During the Permian, southeastern Utah and the Paradox basin were situated about 10-15º north of the paleoequator (Scotese and McKerrow, 1990). The Permian shoreline on the western edge of the continent trended approximately north-south across what is now central Utah (Stokes, 1988). Organ Rock strata were deposited on a seaward-sloping coastal plain between the ancestral Uncompahgre Highlands to the east and the marine shoreline to the west (Baars, 1962, 1975; Condon, 1997). However, it should be noted that during the Permian, the basin was rotated as much as 45º clockwise from its present orientation.

STRATIGRAPHY AND DEPOSITIONAL SETTING

The Organ Rock Formation is a member of the Cutler Group, a sequence of sedimentary rocks deposited in southwestern Colorado and southeastern Utah during the Early Permian. The stratigraphy and general thicknesses of units in the Cutler Group are shown in figures 6a and 6b. Along the eastern margin of the Paradox basin the Cutler consists almost exclusively of arkosic (feldspar-rich) conglomerates and sandstones that were shed westward from the ancestral Uncompahgre Highlands. These rocks are referred to as the Cutler Formation, undivided. Westward into the basin, the red arkosic rocks interfinger on a large scale with white quartzose sandstones and gray carbonates. Where the interbedding occurs, the Cutler is elevated to group status and is subdivided into six units. These six units are, in ascending order, the informal lower Cutler beds, the Halgaito Formation, the Cedar Mesa Sandstone, the Organ Rock Formation, the De Chelly Sandstone, and the White Rim Sandstone.

Lower Cutler Beds

The lower Cutler beds are the basal unit of the Permian Cutler Group (Loope and others, 1990; Condon, 1997) (figure 6a, b). The unit consists of interlayered red sandstones and mudstones and gray limestones that were deposited in both marine and terrestrial environments. These environments include shallow-marine shelves, coastal sand dunes, rivers, and fluvial floodplains (Baars, 1985, 1987; Campbell, 1980, 1987). South of Natural Bridges, the upper part of the lower Cutler beds grades into the thick-bedded red siltstones and very fine-grained sandstones of the Halgaito Formation (figure 6b). These rocks have been interpreted as loess deposits, that is, accumulations of wind-blown dust (Murphy, 1987). They may have formed as finer grained eolian deposits downwind of sand dunes preserved in the lower Cutler beds and Cedar Mesa Sandstone.

Cedar Mesa Sandstone

The Cedar Mesa Sandstone (figure 6a, b) is a dominantly white to yellow, cross-bedded quartz arenite that contains interbeds of red mudstone and discontinuous lenses of unfossiliferous gray limestone. Evaporites and algal-laminated limestones are locally present near Comb Ridge southeast of Natural Bridges National Monument (figure 1). Abundant sand-avalanche layers and inversely-graded wind-ripple laminae in the sandstone indicate a primarily eolian origin for the Cedar Mesa (Loope, 1984; Stanesco and Campbell, 1989). Along the eastern boundary of Canyonlands National Park, eolian beds in the Cedar Mesa interfinger with red mudstones, sandstones, and conglomerates that can be traced toward the Uncoma.

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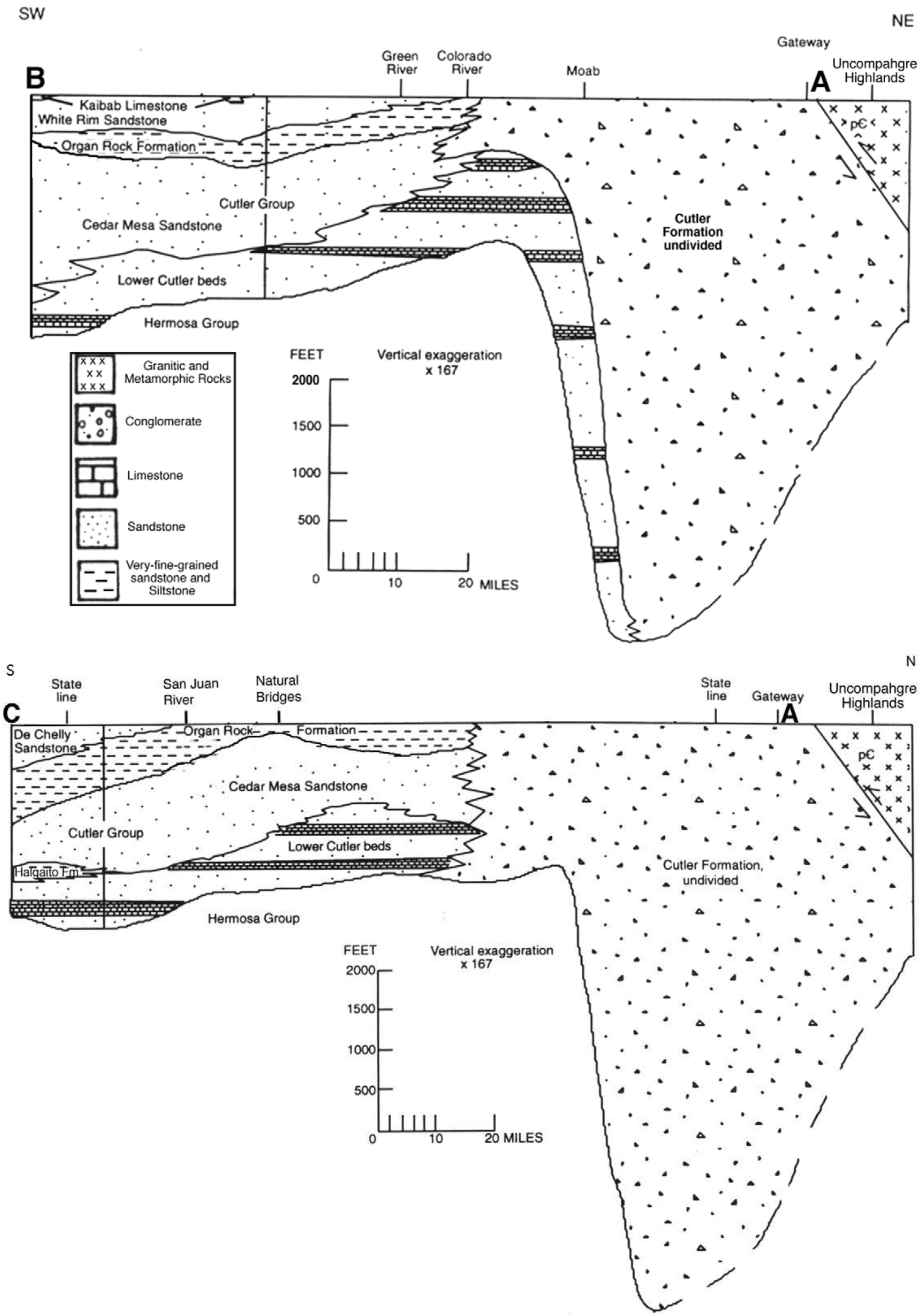

Figure 6 Cross sections showing stratigraphic relationships of Permian strata discussed in this report. Cross section (a) corresponds to line A-B in figure 5. Cross section (b) corresponds to line A-C. Modified from Condon (1997).

pahgre Highlands. These red beds are interpreted as the depositional product of floods that periodically inundated the dune field (Langford and Chan, 1988). The evaporites and algal limestones along Comb Ridge are interpreted to represent a coastal sabkha succession (Stanesco and Campbell, 1989; Lock and Pelfrey, 1997).

Although the contact between the Cedar Mesa Sandstone and the overlying Organ Rock Formation is locally sharp and erosional, the contact is considered to be conformable. On a regional scale the contact is marked by the interbedding of Cedar Mesa and Organ Rock strata, indicating a gradual and fluctuating change of environments from those characteristic of the Cedar Mesa to those of the Organ Rock.

Organ Rock Formation

The Organ Rock Formation (figure 6a, b) is exposed along the canyons of the Colorado, Green, and San Juan Rivers and their tributaries between Monument Valley and Canyonlands National Park (figure 1, figure 5). In the subsurface, the eastern edge of the Organ Rock trends southeastward from Green River, Utah into the San Juan Basin in New Mexico (Condon, 1997). To the east of this trend the Organ Rock merges with the Cutler Formation, undivided (figure 6a). The Organ Rock is also recognized in the subsurface to the northwest in the San Rafael Swell where it pinches out into the Cedar Mesa and White Rim Sandstones (Baars, 1979; Condon, 1997). It may correlate with the Hermit Shale in the Grand Canyon (Blakey, 1996).

The Organ Rock was originally named the Organ Rock tongue of the Cutler Formation (Baker and Reeside, 1929), but Wengerd and Matheny (1958) raised the Cutler to Group status, a terminology subsequently followed by Baars (1962) and many others. In those latter papers, the unit was referred to as the Organ Rock Shale; however it contains little if any shale, being composed primarily of very fine to fine grained sandstone and siltstone, with lesser amounts of mudstone, arkosic sandstone and conglomerate, and carbonate-pebble conglomerate. The unit was referred to as the Organ Rock Formation by Blakey (1980), a terminology also employed by Dubiel and others (1996a, 1996b). Detailed descriptions and interpretations of the Organ Rock Formation form the primary focus of this paper and will be discussed later.

The Organ Rock conformably overlies the Cedar Mesa Sandstone and locally interfingers with it on a regional scale (Condon, 1997). In the Monument Valley area, the Organ Rock appears to be similarly gradational with the overlying De Chelly Sandstone. To the north, near Canyonlands National Park, the Organ Rock Formation is overlain by the White Rim Sandstone. The contact between the two formations ranges from gradational to sharp. Wherever the Permian formations above the Organ Rock were removed by erosion during the Late Permian or Early Triassic, the Organ Rock is unconformably overlain by the Lower Triassic Moenkopi Formation.

De Chelly Sandstone

In the Monument Valley region, the Organ Rock Formation is overlain by the De Chelly Sandstone (figure 6b), a white to yellow quartz arenite of eolian origin (Baars, 1985, 1987, Stanesco, 1991a). The De Chelly is dominated by large-scale, high-angle cross-stratification that dips to the south. Sand-avalanche layers and inversely graded wind-ripple strata are common. The absence of interbedded fluvial or marginal marine strata within the De Chelly at Monument Valley suggests deposition near the center of an erg. The De Chelly dune field extended southward into New Mexico and Arizona where it prograded into sabkha facies of the Yeso and Schnebly Hill Formations respectively (Stanesco, 1991b; Blakey and others, 1988; Blakey, 1996). Blakey (1996) recognizes an unconformity between the Organ Rock Formation and the De Chelly Sandstone. In the Monument Valley region however, the vertical transition from the Organ Rock to the De Chelly is marked by interbedding of strata characteristic of the two formations. This suggests a conformable relationship between the Organ Rock and the De Chelly in southern Utah.

White Rim Sandstone

In the Canyonlands region, the Organ Rock Formation is overlain by the White Rim Sandstone (figure 6a). Like the De Chelly, the White Rim Sandstone contains stratification types and sedimentary structures indicative of wind deposition and is considered primarily eolian in origin (Huntoon and Chan, 1987). A thin marine veneer at the top of the formation contains wave ripples, small-scale, low-angle cross-beds, granule-size chert clasts, and megapolygons that resulted from displacive salt crystal growth during final deposition of the formation (Huntoon and Chan, 1987).

To the west of the confluence between the Green and Colorado Rivers, the contact between the Organ Rock and the White Rim appears to be sharp, and possibly erosional.

Permian-Triassic Unconformity

The upper portions of both the De Chelly Sandstone and the White Rim Sandstone are truncated by the Permian-Triassic unconformity. The De Chelly thins to the northwest of Monument Valley because of erosion along the unconformity and is completely absent in outcrops along the San Juan River (figure 6b). Similarly, erosion of the White Rim beneath the Permian-Triassic unconformity increases toward the southeast, so that the formation is generally absent south and east of the Colorado River. An isolated outcrop of the White Rim is present in Castle Valley, ten miles northeast of Moab, Utah (Condon, 1997) where it was likely preserved due to subsidence along a salt syncline below the level of erosion along the Permian-Triassic unconformity.

Despite their similar lithology, sedimentary structures, depositional environment, and stratigraphic position below the Permian-Triassic unconformity, the De Chelly and White Rim Sandstones are not correlative (Blakey, 1996). Physical correlation with other eolianites to the south in Arizona and New Mexico indicates that the De Chelly is part of an older erg system than the White Rim (Blakey, 1996).

Moenkopi Formation

Both the De Chelly Sandstone and the White Rim

Sandstone are unconformably overlain by the Lower Triassic Moenkopi Formation in eastern Utah. Where the De Chelly and White Rim Sandstones are completely removed beneath the Permian-Triassic unconformity, the Moenkopi directly overlies the Organ Rock Formation. The basal part of the Moenkopi Formation exhibits a pronounced facies change from west to east between Hite Crossing at Lake Powell and Natural Bridges National Monument (figure 1), (Huntoon and others, 1994). To the west, the Black Dragon Member of the Moenkopi is a fluvial chert-pebble conglomerate. This facies interfingers to the east with sabkha deposits of the Hoskinnini Member of the Moenkopi. (Huntoon and others, 1994; Dubiel and others, 1996a, 1996b).

SEDIMENTOLOGY OF THE ORGAN ROCK FORMATION

The Organ Rock Formation consists of reddish-brown to light-red sandstone, siltstone, carbonate-pebble conglomerate, and minor mudstone. Several distinct depositional facies associations can be recognized in the Organ Rock based on variations in grain size, bedding characteristics, and sedimentary structures.

Floodplain and Channel Facies

In most of the sections measured for this study, the lower half of the Organ Rock Formation is a reddish-brown, generally slope-forming unit composed of two texturally distinct lithofacies (figure 7): a fine-grained facies and a coarse-grained to conglomeratic facies.

The dominant lithologies in the fine-grained facies are silty sandstone, sandy siltstone, and minor mudstone. All exist as thin to thick beds that extend laterally for several hundred yards to over a mile. Many of these beds either change facies into or interfinger with the coarse-grained to conglomeratic facies. Internally the fine-grained beds contain lavender alteration haloes which are tubular, vertically elongated areas of altered iron oxides that branch and bifurcate downward. The haloes are roughly circular in cross section, and are about 1 to 1 1/2 inches in maximum diameter. The beds also locally contain carbonate nodules that range in size from 1/16 of an inch to as much as 1 inch in diameter. The nodules occur as isolated knobs randomly distributed within the beds, as accumulations of coalesced nodules, and as vertically stacked nodules adjacent to the lavender alteration haloes. Fine-grained beds locally contain small horizontal and vertical burrows. Many of the fine-grained beds appear structureless and lack obvious physical sedimentary structures.

The coarse-grained to conglomeratic facies is composed of fine to coarse, subrounded to well-rounded siliciclastic and carbonate sand and carbonate nodules that range in size from 1/8 inch to 1 1/2 inches. Beds within this facies overlie and fill scour surfaces and are broadly lenticular. The beds interfinger laterally with the fine-grained facies described above. Beds range from one foot to as much as 20 feet in thickness and are as much as several hundred yards wide. Internally they are characterized by lateral accretion stratification. Small- to medium-scale cross-bedding within the lateral accretion strata is oriented perpendicular to the lateral accretion bedding.

These associated fine-grained and coarse-grained to conglomeratic lithofacies are interpreted to represent associated floodplain and fluvial-channel deposits, respectively (figure 8). The fine-grained sediment was deposited on the floodplains during flood events in the adjacent fluvial

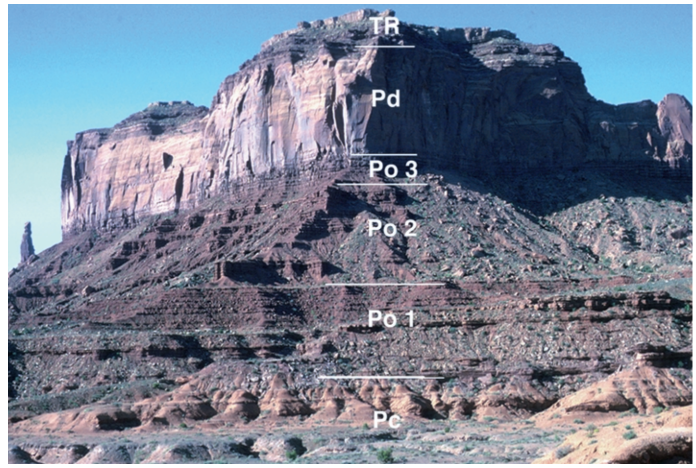

Figure 7. Permian and Triassic strata at Monument Pass section (MP, figure 5). The foreground consists of the Permian Cedar Mesa Sandstone (Pc). Prominent ledges composed of the fluvial channel and floodplain facies of the Organ Rock Formation (Po 1) are overlain by slope-forming channel, floodplain and rare loessite deposits (Po 2). Paleosols are common throughout Po 2. Ledges that underlie the massive cliff consist of floodplain, loessite and sand sheet deposits. They mark the gradational transition (Po 3) between the Organ Rock Formation and the overlying De Chelly Sandstone (Pd). The contact between the De Chelly and the overlying Moenkopi Formation (TR) is the Permian-Triassic unconformity. View is to the south.

Figure 8. Massive, conglomeratic fluvial channel in the Organ Rock thins to the left into levee and floodplain sediments. The De Chelly Sandstone, the light-colored unit in the middle of the cliff in the background, is thinned by erosion along the Permian-Triassic unconformity. Organ Rock section (OR, figure 5). View is to the west.

Figure 9. A rhizolith, or root trace fossil, extends down into a bed of sediments deposited in a flood plain environment at Monument Pass (MP, figure 5). Scale is 10 cm (4 in) long.

Figure 10. Floodplain facies at Clay Hills Crossing (CH, figure 5). Color alterations and nodular textures are due to paleosol development on the floodplain strata. Calcareous nodules eroded from paleosols are found as clasts in Organ Rock fluvial channels.

channels. The fluvial channels are interpreted to represent deposition in meandering streams based on the lateral accretion stratification and fine grain size of the adjacent floodplain deposits. Tracing of channel orientations on successive mesas throughout the Monument Valley area indicates a north to northwest paleoflow direction for these streams. The carbonate nodules found along the thalweg of the fluvial channels were sourced from the adjacent floodplain deposits when meandering streams cut their banks into adjacent units. The floodplain deposits are locally structureless due to bioturbation by both plant roots and invertebrate organisms. The lavendar alteration haloes are interpreted as rhizoliths (plant root trace fossils) (figure 9) based on their downward bifurcating morphology and their similarity to rhizoliths in other red-bed units on the Colorado Plateau and elsewhere (Dubiel and others, 1991; Dubiel and Smoot, 1994). The carbonate nodules in the floodplain deposits formed as a result of pedogenic processes in paleosols that developed during episodes of exposure (figure 10). Their penecontemporaneous formation within paleosols is evidenced by the occurrence of reworked nodules as clasts in the adjacent channel deposits, indicating that they were already formed when the fluvial systems scoured into the floodplains. The distribution in fine-grained floodplain strata of pedogenic carbonate nodules ranging from isolated to coalesced nodules is typical of tropical paleosols that developed under an arid climate (Dubiel and Smoot, 1994). However, the presence of abundant rhizoliths, the fine-grained floodplain deposits, and the meandering stream channels suggests that at least periodically there was abundant water in the depositional system. Although the channel and floodplain facies are most common at or near the base of the Organ Rock, particularly where the formation is thickest between Monument Pass (MP, figure 5) and the San Juan River, they are also present at stratigraphically higher levels throughout the study area.

In the western part of White Canyon (figure 1), there are several exposures near the base of the Organ Rock composed of broadly lenticular beds overlying scour surfaces. The beds are composed of thin to very thin layers of dark-red sandstone and reddish-brown mudstone. The layers exhibit numerous mud drapes, sand-filled desiccation cracks and abundant small-diameter horizontal and vertical burrows, but there are no occurrences of rhizoliths or other pedogenic features within these strata. These beds possibly formed in low-energy channels on the distal coastal plain, as evidenced from their sedimentary structures and their palegeographic position. Katpah (1995) suggested that these fluvial channels were tidally influenced. A similar interpretation was made by Baars (1962, 1975,1979).

In the northeast part of the study area, near the eastern boundary of Canyonlands National Park (figure 1), floodplain and fluvial channel deposits differ from those described above. Floodplain deposits occur as thick, tabular beds consisting of fine- to medium-grained sandstone and micaceous mudstone. They commonly contain very thin layers of medium- to coarse-grained sand that we interpret as lag deposits caused by eolian reworking of the sediment. The floodplain deposits are a less-significant component of the stratigraphic sections in this region than they are in sections farther to the south, and they are interbedded with eolian sand sheet and dune deposits (described below).

Fluvial channel deposits in the northeast part of the study area are reddish-brown to purple arkosic sandstones and conglomerates. They contain numerous pebble- to cobble-size granitic and metamorphic clasts and occur in stacked channels with few intervening fine-grained floodplain deposits. Mudstone and sandstone rip-up clasts are common, but carbonate clasts are rare. Fluvial channels scour into underlying floodplain, sand sheet, and channel deposits to depths of up to 7 feet. The channels lack the lateral accretion stratification that characterizes the channels in the Monument Valley region. The coarse grain size, as well as the paucity of lateral accretion stratification and associated floodplain deposits, indicates that the fluvial systems in the northeast part of the study area were bedload dominant and probably braided streams. Paleocurrent indicators suggest that the streams in the northeast part of the study area flowed to the west-northwest.

In contrast to the west-northwesterly paleoflow directions of the Organ Rock streams in the northeast part of the study area, streams near Monument Valley flowed more toward the north. This suggests that there were two regional fluvial systems that may have drained distinct source areas during deposition of the Organ Rock Formation.

The fluvial channel facies is most common in the eastern-most sections of the study area. At Salt Creek (SC, figure 5) near Canyonlands National Park, fluvial channel strata comprise 56 percent of the section. At Monument Pass (MP, figure 5) fluvial channel strata comprise 15 percent of a section that is 700 feet thick. Fluvial channel strata become less abundant toward the west. They comprise only 2 percent of a thin section at milepost 64 (64, figure 5) and are absent from the Organ Rock section at Maze Overlook (MO, figure 5).

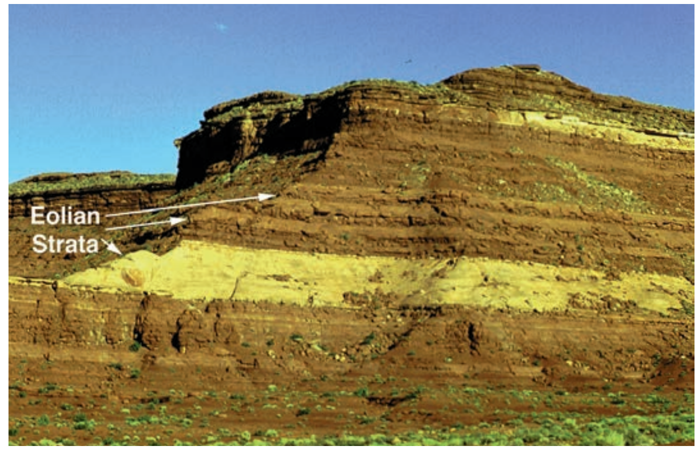

Figure 11. Light–colored eolian strata within floodplain facies in the Organ Rock Formation near Farley Canyon (FC, figure 5).

Fluvial flood plain beds comprise 75 percent of the section at Monument Pass but only 20 percent of the section at Salt Creek. They comprise 62 percent of the section at milepost 64 in White Canyon (figure 1) but only 20 percent of the section to the northwest at Maze Overlook.

Eolian Dune and Sand Sheet Facies

The second distinct lithofacies in the Organ Rock is characterized by its light- to pale-red and orange coloration that contrasts with the reddish-brown fluvial and floodplain deposits (figure 11). This facies is most common in the westernmost exposures of the Organ Rock and consists of very fine to medium-grained, cross-bedded to horizontally stratified, thin- to thick-bedded sandstone. Both the cross-bedded and horizontally stratified sandstone beds typically consist of repetitive, very-thin, evenly spaced laminations, both horizontal and sloping, that commonly exhibit inverse grading. Cross-bedded units in this lithofacies also contain internally massive laminations 0.25 to 2 inches thick that thin and taper out near the base of the cross-beds.

Both of these small-scale types of stratification are common in eolian dunes. The inversely graded layers are wind-ripple laminae, (figure 12), formed by the migration of wind-generated ripples (Hunter, 1977). They occur most commonly along the crests of eolian dunes and along the gently sloping aprons in front of dune slip faces. The tapered layers within the cross-beds are interpreted to be sand avalanche layers deposited on the slip faces of dunes (figure 13). Sand avalanches are caused by the flow of sand down the over-steepened slip face of the dune. In cross-sectional view, the avalanches commonly pinch out where the slope of the slip face decreases near the base of the dune. Thus, the avalanche deposits are commonly interlayered with the wind-ripple laminations on the dune apron.

Cross-beds in the dune facies range in thickness from 1 to 15 feet. Dune foresets dip uniformly toward the present-day southeast, indicating dune movement driven by

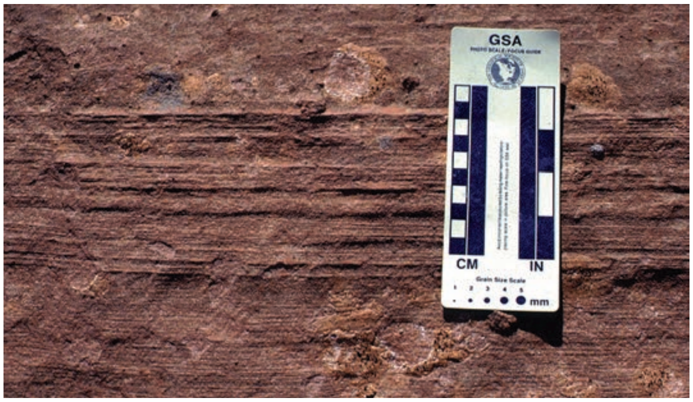

Figure 12. Wind-ripple laminae in eolian strata of the Organ Rock at Farley Canyon (FC, figure 5). Each pinstripe lamination forms by the migration of a wind-generated ripple.

Figure 13. Cross-bedded eolian dune deposit overlies red-colored fluvial floodplain facies at Farley Canyon (FC, figure 5). Sloping sand avalanche layers taper out near the base of the dune. Note sand-filled mud cracks extending downward from the dune into the fluvial deposits.

winds blowing from the northwest. The uniform direction of cross-bed dips suggests that the dunes were transverse or barchanoid in shape.

Orange, thin- to medium-bedded strata dominated by horizontally stratified, coarsening-upward wind-ripple laminae that lack sand avalanche layers and cross-beds are associated with the dune deposits. These strata are interpreted as sand sheet deposits that formed on sandy plains lying within and adjacent to the dune fields.

The lower contacts of the eolian dune and sand sheet layers are sharp and commonly marked by sand-filled desiccation cracks that extend down into underlying fluvial and floodplain strata (figure 13). Mud chips, presumably derived from the upturned edges of mudcracks in the underlying units, also occur along these contacts. Stratification near the tops of the beds in the eolian facies commonly becomes indistinct. The uppermost surfaces of these beds often contain rhizolith alteration haloes and root casts (figure 14) consisting of calcite and limonite. These plant trace fossils indicate episodes of stabilization

Figure 14. Root casts at the top of the conspicuous eolian bed (figure 11) near Farley Canyon (FC, figure 5).

Figure 15. Adhesion ripples in inferred loessites near the top of the Organ Rock at Monument Valley. Adhesion structures form when wind-blown silt or sand sticks to wet sediment. Pen is 5 1/2 inches long.

in the dune field during which dunes ceased migrating and incipient paleosols developed (Loope, 1985). The abundance of root traces replaced by calcite- and limonite within the eolian beds, in contrast to lavender alteration root haloes in the floodplain deposits, may be the result of higher porosity and groundwater flow rates in the eolian strata.

Eolian dune and sand sheet deposits comprise 80 percent of the section at Maze Overlook (MO, figure 5). They thin eastward, comprising only 8 percent of the section at Monument Pass (MP, figure 5).

Loessite Facies

Light-orange to pinkish-red, very fine-grained sandstone to siltstone beds that appear structureless and that exhibit a conchoidal fracture are common in the southernmost sections of the Organ Rock Formation. Locally the beds contain faint horizontal to wavy laminations characterized by very thin mud-laminae partings. On fortuitous exposures, many of the mud laminations exhibit a dimpled texture interpreted here to be adhesion ripples (figure 15). These structures are formed when wind-blown fine-grained sand or silt adheres to wet sediment. The adhesion ripples occur in beds immediately above and below eolian dune and sand sheet deposits within the Organ Rock and are particularly abundant in the beds at the top of the Organ Rock that appear to be transitional with the overlying eolian dune deposits of the De Chelly Sandstone (figure 7). Because the beds lack any other stratification and are uniformly composed of very fine-grained sandstone to siltstone, they are interpreted as loessites (see Murphy, 1987). The loessites within the Organ Rock locally exhibit lavender alteration haloes and dispersed carbonate-nodules similar to those described for the floodplain facies that are also interpreted to be rhizoliths and paleosol carbonate deposits, respectively.

GEOGRAPHIC DISTRIBUTION OF FACIES IN THE ORGAN ROCK FORMATION

Facies in the Organ Rock Formation are not uniformly distributed throughout the study area (figure 16). Floodplain and fluvial channel deposits are more common in the eastern measured sections (figure 5), whereas eolian dune and sand sheet strata dominate the northwest sections. There is also geographic variability within the floodplain and fluvial channel facies itself. Fluvial deposits in the northeast part of the study area are composed of arkosic sandstones and conglomerates. They contain numerous granitic and metamorphic clasts and occur in stacked channels with few intervening fine-grained floodplain deposits. They probably formed in bed-load dominant braided channels that were proximal to the Uncompahgre Highlands source area and that flowed west to northwest away from the mountain front.

Farther south, near Monument Valley, the fluvial channels contain abundant limestone pebbles derived from reworked paleosol carbonates and calcareous rhizoliths within Organ Rock floodplain deposits. Granitic and metamorphic clasts are absent. The composition of the fluvial deposits in Monument Valley suggests a local, intrabasinal source area for the clasts rather than the granite and metamorphic rock-cored Uncompahgre Highland. Thick floodplain deposits as well as abundant lateral accretion deposits interpreted to represent point bars indicate that Organ Rock streams in the Monument Valley area were meandering streams. Paleocurrent indicators suggest north to northwest stream flow. The carbonate-nodule intrabasinal clasts indicate that these streams transported and reworked sediment derived in part from preexisting beds in the Organ Rock itself.

In the western part of the study area along White Canyon (figure 1), fluvial conglomerates are rare. Channel deposits occur as broad, shallow, mud-filled scours that

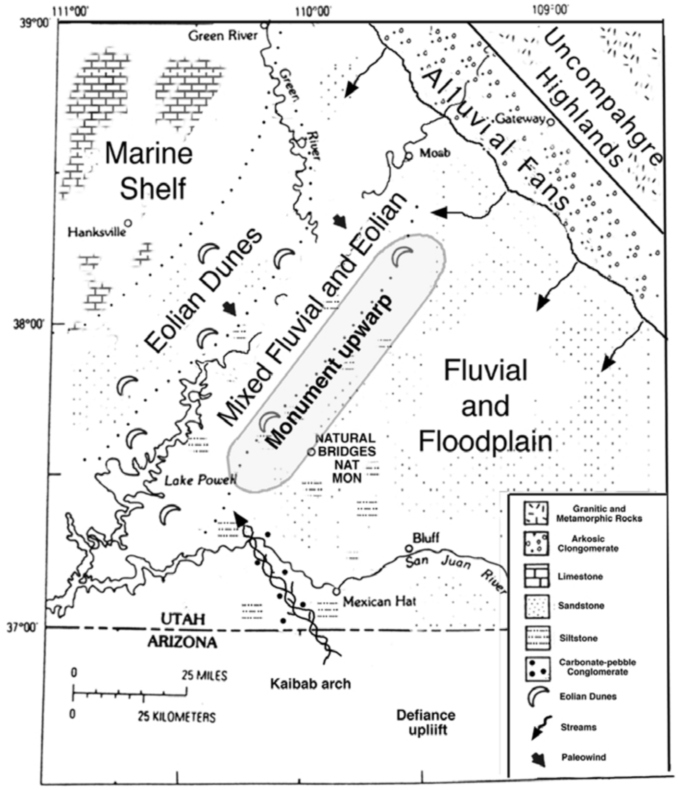

Figure 16. Lower Permian paleogeography of southeastern Utah during deposition of the Organ Rock Formation. Fluvial and floodplain sediments derived from the Uncompahgre Highlands and from areas to the south of the Paradox Basin dominate the eastern part of the study area. Eolian dunes prograde southeastward from a dunefield located to the northwest of the study area and pinch-out on the western flank of the Permian-age Monument upwarp.

exhibit numerous mud drapes, mud cracks, and small trace fossils. These fine-grained, low-energy deposits are interpreted as fluvial channels that flowed westward across a low-relief coastal plain toward a north-south trending marine shoreline.

There is also variation in the geographic distribution of eolian facies in the Organ Rock. Dune and sand sheet deposits comprise 80 percent of the section at the Maze Overlook (MO, figure 5) in the northwestern part of the study area. The dominance of eolian strata in this area probably indicates a continuation of erg deposition from the underlying Cedar Mesa Sandstone. The percentage of eolianites in the Organ Rock decreases southeastward from the area of the Maze Overlook toward White Canyon. A prominent eolian bed, and other minor eolian beds, (figure 11) thin and pinch out in the vicinity of the Happy Jack Mine (HJ, figure 5). In contrast, dune and sand-sheet deposits farther to the southeast near Monument Pass (MP, figure 5) are confined to the top of the Organ Rock where it grades into the overlying De Chelly Sandstone. In the northeast part of the study area, discontinuous eolian strata interfinger with braided stream deposits sourced from the Uncompahgre Highland.

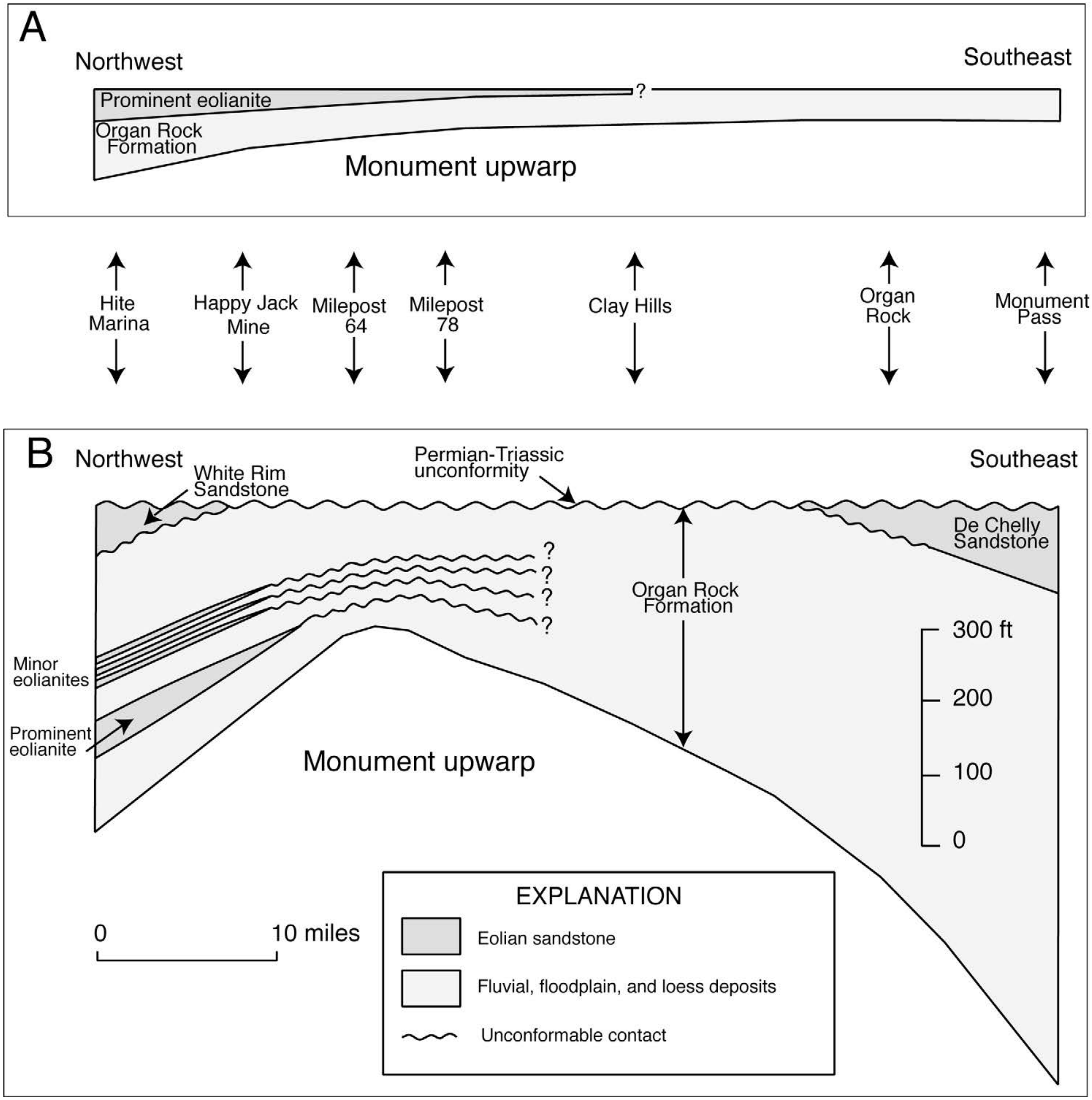

Figure 17. Diagrammatic representation of the Monument upwarp's influence on deposition of the Organ Rock Formation. Measured sections were projected to a line drawn between Hite Marina and Monument Pass (figure 5).

(a) During deposition of the lower part of the Organ Rock (beneath the prominent eolianite shown in figure 11) the Monument upwarp existed as a slightly positive feature. The prominent eolianite pinches out on the northwest side of the Permian-age Monument upwarp, indicating that the upwarp was elevated relative to the surrounding area.

(b) During deposition of the upper part of the Organ Rock Formation the Monument upwarp continued to be a positive feature. During generation of the Permian-Triassic unconformity, the White Rim and De Chelly Sandstones were removed from the central part of the upwarp. Vertical exaggeration in the diagram causes surfaces to tilt more steeply than the 2 to 3° dip measured in the field.

PALEOTECTONIC INFLUENCE ON DEPOSITION OF THE ORGAN ROCK FORMATION

The Uncompahgre Highlands were the primary source of Organ Rock Formation sediment in the northeast part of the study area (Baars, 1962; Rascoe and Baars, 1972; Langford and Chan, 1988). The textural and mineralogic composition of the formation, along with its overall coarsening toward the Uncompahgre Highlands, support this interpretation. There was, however, an additional contribution of clastic sediment from the southeast through the area near Monument Valley (figure 16). These streams may have been sourced in the Kaibab arch or Defiance uplift to the south of the Paradox basin (figure 1) or they may reflect a northward bend in a fluvial system draining the southern end of the Uncompahgre Highlands. These streams reworked pre-existing Organ Rock deposits as evidenced by the abundance of intraformational carbonate nodules in the fluvial channels.

The Monument upwarp also exerted influence on depositional facies distribution within the Organ Rock, and on the development of the unconformity at the top of the Permian system (figure 17). Eolian units within the Organ Rock thin from northwest to southeast along the western side of the Monument upwarp. This thinning is interpreted to indicate that the Monument upwarp was a positive feature at the time of deposition of the eolian rocks. This does not necessarily mean that the upwarp was an area of topographically high relief. At times it merely may have been subsiding at a slower rate than the surrounding basin.

Further evidence that the Monument upwarp was positive during the deposition of the Organ Rock is present within the floodplain and fluvial channel facies. The relatively coarse-grained, arkosic stream deposits on the east side of Canyonlands National Park were deposited by streams flowing west-northwest (figure 16). These streams would be expected to have flowed to the southwest (directly away from the Uncompahgre Highlands) if the Monument upwarp had not influenced their orientation.

Correlated measured sections indicate that the entire Organ Rock Formation thins across an area located northwest of the axis of the present (Laramide) Monument upwarp. Isopach maps based on subsurface data show a similar decrease in thickness of the Organ Rock in this area (Condon, 1997). These two lines of evidence indicate that the structure was oriented more to the northeast-southwest during the Permian as compared to its present north-south orientation. (figure 1, figure 16). In this study we assume that the basal contact of a prominent and extensive eolian unit (figure 11) within the Organ Rock Formation on the west side of the Monument upwarp represented an approximately horizontal surface at the time of deposition. Wherever possible, measured sections were hung on the base of that eolian layer for correlation purposes. Sections correlated in this way clearly demonstrate that the lower portion of the Organ Rock (below the eolian layer) thinned across the Permian-age Monument upwarp (figure 17). The eolian layer onlaps and/or pinches out onto the west side of the Monument upwarp, further supporting the interpretation that the upwarp was a positive feature relative to adjacent areas at the time of deposition of the Organ Rock Formation. Other less laterally extensive eolian units within the Organ Rock on the west side of the uplift also thin and pinch out across the stucture's axis. These layers can be traced laterally into internal diastems or unconformities within the Organ Rock Formation.

Based on the same correlated sections, it is also clear that the upper portion of the Organ Rock, above the distinct eolian layer, thins over the Monument upwarp. The thinning in the upper part of the Organ Rock is interpreted here as evidence that the upwarp continued to be a positive feature and that truncation occurred along the surface now identified as the Permian-Triassic unconformity. Erosion was more intense across the Monument upwarp during generation of the unconformity because the upwarp was elevated relative to the surrounding area.

Following deposition of the Organ Rock, differential erosion at the Permian-Triassic Systems boundary along the crest of the Monument upwarp produced an obvious unconformity, juxtaposing the Organ Rock and overlying Triassic rocks (Huntoon and others, 1994) where the White Rim and De Chelly Sandstones are no longer present.

CONCLUSIONS

Data presented in this paper indicate that the Organ Rock Formation was deposited in a mixed fluvial and eolian system (figure 16). In the southeast part of the study area, meandering streams sourced to the south of the Paradox basin eroded penecontemporaneous floodplain deposits, incorporating pedogenic carbonate nodules into their channels. The floodplains were laterally extensive and characterized by arid climate paleosols. Along the northeast part of the study area, the Organ Rock streams flowed west and northwest from the nearby Uncompahgre Highlands. This part of the fluvial system was dominated by coarse-grained braided streams with fewer floodplain deposits compared to the streams in the Monument Valley area. Winds reworked the floodplain sediments. Near the area of Lake Powell, the Organ Rock streams flowed in broad, shallow, mud-filled channels on a distal, low-relief coastal plain adjacent to marine environments that lay farther west.

Eolian dune and sand sheet deposits dominate the northwestern sections in the Organ Rock outcrop belt. The dunes were transverse or barchanoid ridges that migrated to the southeast. Eolian strata in this area interfinger with fluvial and floodplain deposits in the northeast sections but are rare southeast of the Monument upwarp, except near the contact between the Organ Rock and the overlying De Chelly Sandstone. Rooted horizons and incipient paleosols at the top of some eolian beds indicate periods of stability within the dune field. Loess deposits containing adhesion ripples mark the stratigraphic transitions between many fluvial and eolian dune strata in the Organ Rock.

The Monument upwarp influenced deposition of the Organ Rock Formation. The Permian-age Monument upwarp was located farther to the northwest and elongated more to the northeast than the Laramide-age structure that is prominent today. Eolian strata thin toward and pinch out on the northwestern side of the Monument upwarp, and the course of streams along its northeastern flank was influenced by its position and orientation. The Monument upwarp remained a positive area throughout the Permian, and Permian strata were deeply incised during the development of the Permian/Triassic unconformity.

ACKNOWLEDGEMENTS

The authors thank Debra Mickelson for her able assistance in the field and Steven Condon and Gerilyn Soreghan for their helpful reviews of the manuscript.

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