HYPOTHESIS: THE PINNACLES OF THE CHESLER PARK/ GRABEN REGION OF CANYONLANDS NATIONAL PARK RESULT FROM PALEOSTREAM INDURATION AND INVERTED TOPOGRAPHICAL RELIEF

by
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ABSTRACT

In the Needles District of Canyonlands National Park, Utah, a number of isolated Cedar Mesa Sandstone pinnacles meander across the western side of the Monument upwarp through the Chesler Park and graben regions. The pinnacles are not obviously linked to current stream erosion, and their existence has not been adequately explained. The hypothesis proposed herein is that the sinuous pattern of the pinnacles that borders the series of parks in this area (e.g., Chesler Park and Virginia Park), and that trends northwest across the grabens, is an example of inverted topographical relief. Cementation associated with early Permian rivers indurated the Cedar Mesa Sandstone when the overlying Organ Rock Formation was being deposited. Following the mass wasting that occurred upon the erosion of the Colorado Plateau and the flowage of the underlying Paradox salt into the Colorado River, the sinuous traces of the indurated Cedar Mesa Sandstone became exposed. This hypothesis is supported by several observations. The extant pattern of pinnacle orientation corresponds to the interpreted northwest trends of streambeds in the overlying Organ Rock Formation. The inferred seasonable, wet-dry semi-arid paleoclimate at the time of this proposed induration is known to induce calcrete formation of underlying sands in other units. The Organ Rock Formation streams are considered to be moderate-load rivers characteristic of streams that favor induration. The degree of sinuosity of the pinnacles, indicative of the meanderings of the overlying streams, predicts precipitation levels consistent with low storminess and a semi-arid climate. Importantly, the pinnacle origin appears to predate the formation and erosion of the Colorado Plateau. The northwest trend of these Canyonland pinnacles can be traced west across the modern Colorado River to the Dollhouse pinnacles in the Maze District. In several cases, where erosion has been especially severe, the meandering pinnacle pattern clearly crosses both the grabens and current streams, indicating prior existence of the pinnacles.

INTRODUCTION

The Needles District of Canyonlands National Park in southeastern Utah (figure 1) displays a number of interesting geological features. It is justly famous for the grabens that are situated in the western section of the Needles and that extend from the Colorado River to the Monument upwarp axis. Nearly parallel with the Monument upwarp axis are additional features from which the Needles District derives its name: a series of 100- to 170-meter high pinnacles (figure 2). These eponymous needles of the Needles District are formed from Cedar Mesa Sandstone. The pinnacles circumambulate around a series of parks and subsequently diverge in a meandering pattern west-northwestward across the grabens (figures 3 to 5). Whereas a number of studies have provided explanations and interpretations for most aspects of graben formation, there has been little geological investigation into the causes for the existence of the parks and their pinnacle boundaries.

Chesler Park, the premier hiking destination for the Needles District, is actually one of at least seven parks that describe a northwest trending arc near the crest of the Monument upwarp just south of the confluence of the Colorado and Green Rivers. These parks from north to south are Cyclone Park, Devils Parks North and South, Chesler Park, Virginia Park, Shisler Park, and Starvation Pocket (figure 3). There are also several mesas interspersed with the parks: Druid Arch Mesa, Molehill Mesa, and two unnamed mesas south of Starvation Pocket (not shown). Each of these parks is circumscribed by a row of pinnacles.

The pinnacles of the Needles District, consisting of Cedar Mesa Sandstone deposited during the Permian, are generally formed through fractures induced by underlying joints and subsequent processes of erosion (Baars, 2000).

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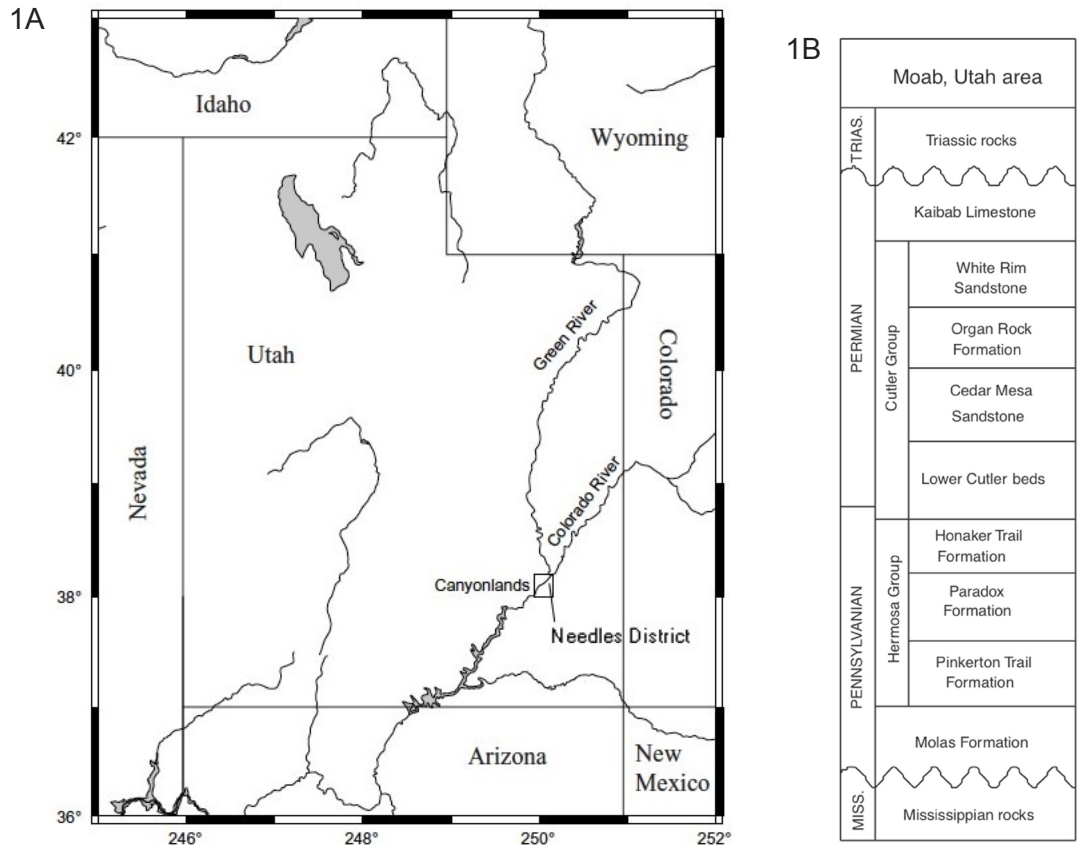

Figure 1. *A) Map of Utah showing the approximate location of the Needles District. B) Stratigraphic diagram showing late Paleozoic and Triassic units in the Canyonlands area. Drawing by Russell Dubiel.*

Figure 2. *Aerial view of Chesler Park and the Devils Pinnacles looking northeast.*

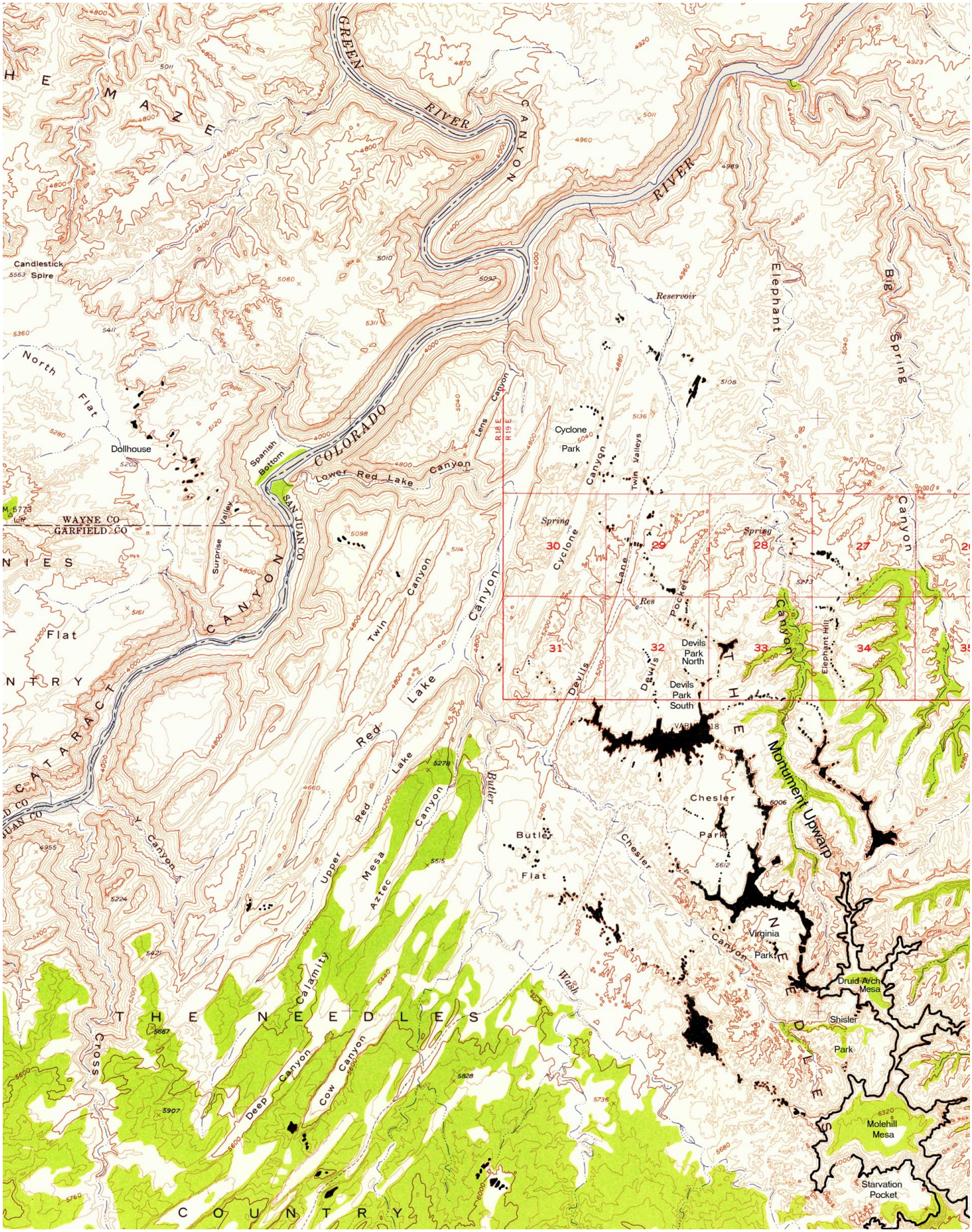

Figure 3. *Canyonlands. The pinnacles and erosionally resistant forms above the "mushroom" layer of the Cedar Mesa Sandstone are indicated in black. The pattern of the pinnacles was determined by numerous on-site visitations, from photographs of various regions, and from aerial photographs.*

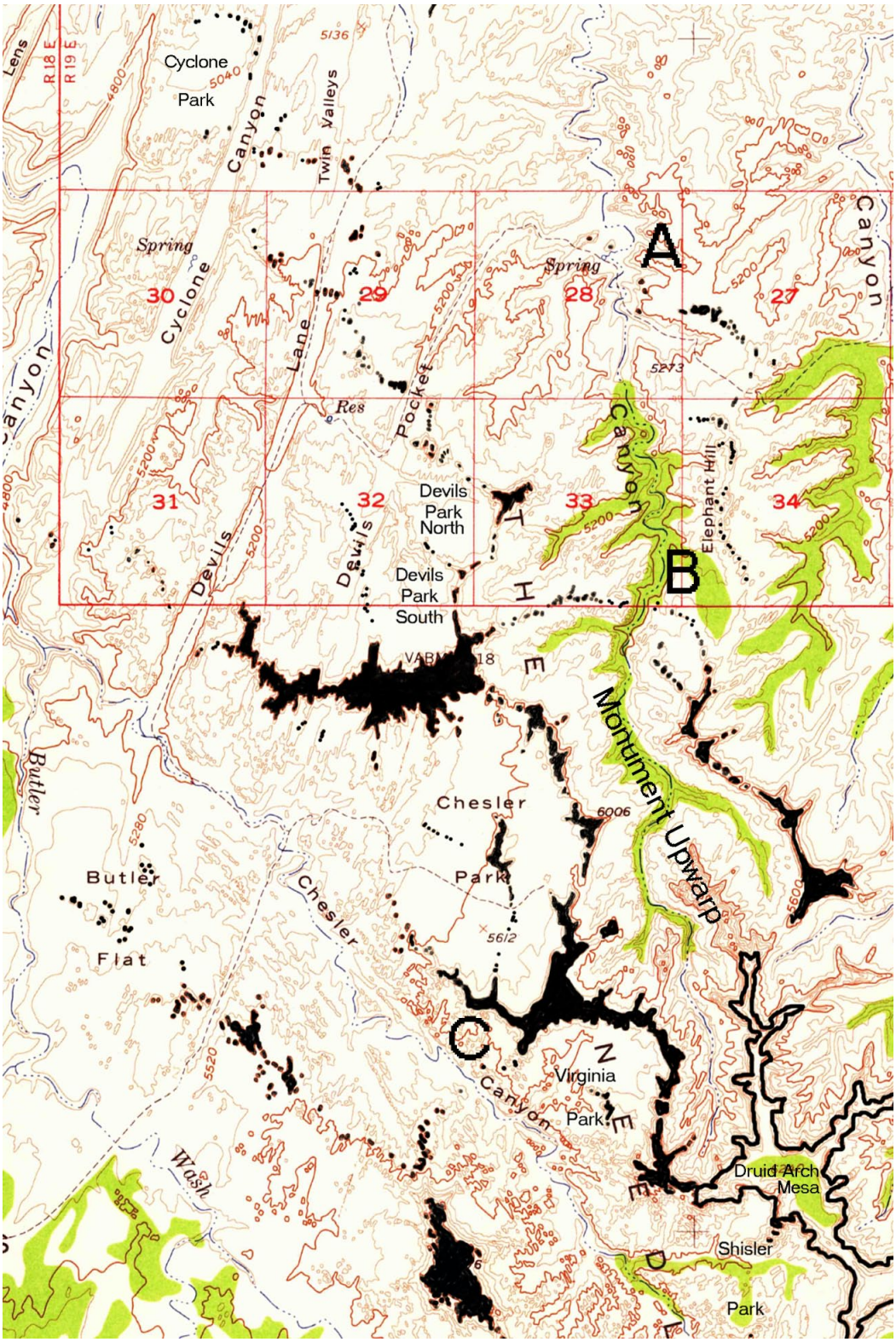

Figure 4. *Enlarged map of Chesler Park/graben area. The letters "A" and "B" mark the points where the pinnacles cross Elephant Canyon and "C" marks the crossing of Chesler Canyon.*

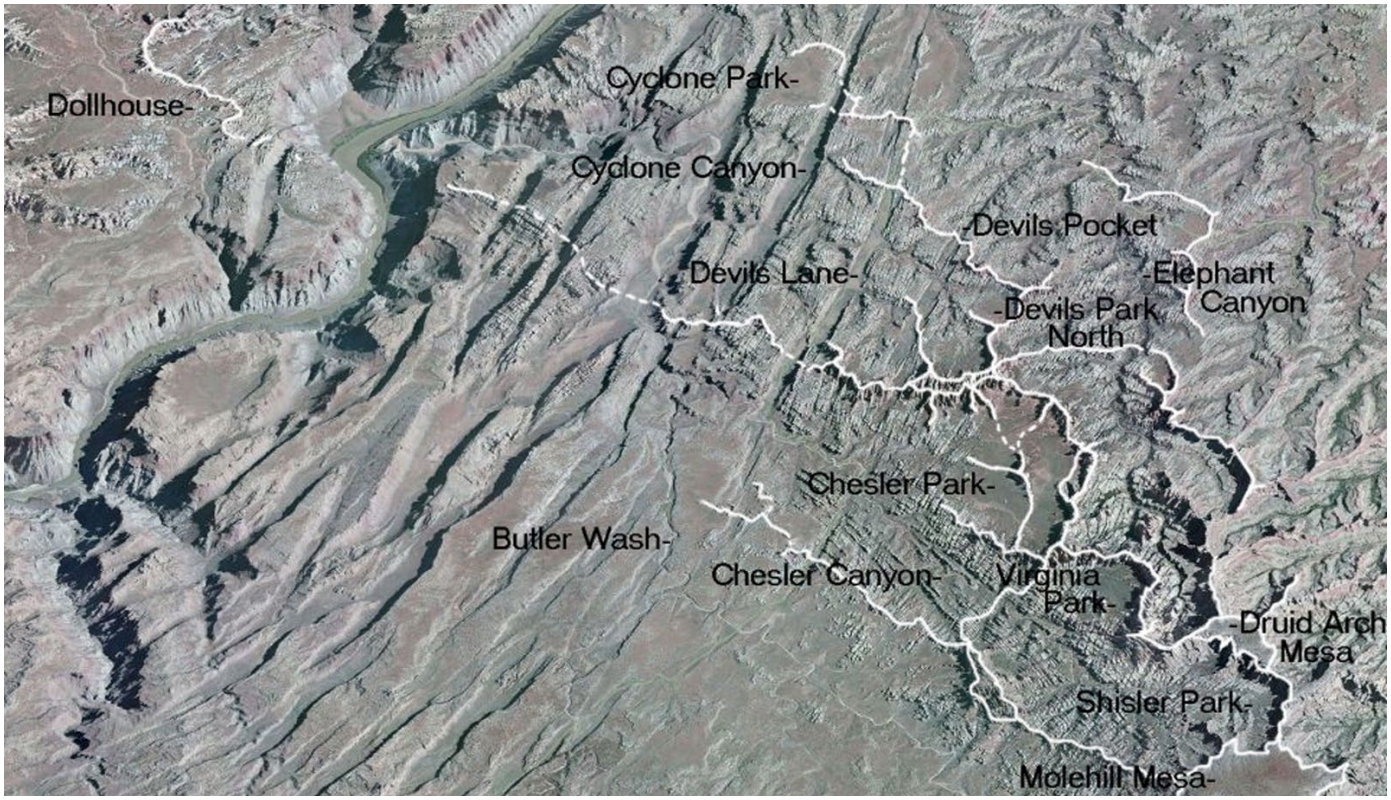

Figure 5. *Satellite map of Chesler Park/graben area with traces of pinnacles trends. Based on the location of the pinnacles marked on figure 3, the predicted traces of the pinnacle paths are marked in white. Dotted lines indicate where the pinnacle trends are uncertain.*

They exist throughout the Needles District and on both eastern and western sides of the Monument upwarp. Their height above the surrounding rocks (often up to at least 170 meters) and the fracturing gives them their particular "needle"-like appearance. The pattern of the pinnacles on the two sides of the Monument upwarp is different, however. On the eastern side erosional processes have been much less active, and the pinnacles are generally present throughout the area except where streams have evidently eroded the Cedar Mesa Sandstone. On the western side of the Monument upwarp, erosion has been much more severe, and fewer pinnacles remain. Recent data indicate that the region west of the Monument upwarp is subsiding by about 2-3 mm/yr compared with no change on the eastern side (Furuya and others, 2007). Distinctively, on the western side of the Monument upwarp the plan-view serpentine pattern formed by the pinnacles in and around the parks and across the grabens (e.g., Devils Pocket, Devils Lane, and Cyclone Canyon) is reminiscent of patterns formed by meandering streams (figures 3 to 5). This pattern suggests depositional processes operating during the Permian have influenced modern-day geomorphic relief. This study proposes induration of the Cedar Mesa Sandstone occurred during streambed deposition of the conformably overlying Organ Rock Formation during the Late Permian Period. These indurated sandstone streambed traces subsequently resisted, relative to adjacent rocks, both the erosion that followed the incision of the Colorado Plateau and the excessive erosion west of the Monument upwarp that occurred as the Paradox Basin salt underneath the Chesler Park/graben region flowed towards the Colorado River.

GEOLOGICAL SETTING

Canyonlands National Park resides in the Paradox Basin, an oval area in southeastern Utah and southwestern Colorado. For this study, the Paradox Basin is defined as the maximum extent of halite and potash salts in the Middle Pennsylvanian Paradox Formation (Condon, 1997). These ancestral salt and gypsum are as much as several hundred meters thick in the Canyonlands region. The Paradox Basin itself is a local area of reduced elevation that appears to have become greatly accentuated with the concomitant rise of the Uncompaghre uplift mountain range on its eastern side. The Uncompaghre mountains extended southeastward from east-central Utah through Gateway, Colorado, toward northern New Mexico (Baars, 2000). Forces that created the rise of the Uncompaghre correspondingly accentuated a deep hollow directly to its west, the Paradox Basin, which became progressively less deep to the southwest where the Needles District now lies. The basin ended just southwest of present day Canyonlands National Park, for there are no salts southwest of this point (Nuccio and Condon, 1996).

The strata above these Pennsylvanian rocks in Canyonlands make up the Permian Cutler Group (figure 1B). The Cutler Group comprises the lower Cutler beds, the Rico Formation of some reports and the Halgaito Forma-

tion, the Cedar Mesa Sandstone, the Organ Rock Formation, and the White Rim Sandstone (Condon, 1997). These formations consist of eolian and marine sands, shore and marine limestone, and fluvial strata derived in part from the Uncompaghre Highlands.

The Paradox Basin salt was overlain by clastic debris derived from the northeast due to the erosion of the Uncompaghre mountains from about 305 to 260 million years ago and from eolian sands derived from the west and north. Extensive seas periodically flooded the basin, resulting in limestone beds extending from the Halgaito Formation to the top of the Cedar Mesa Sandstone (Loope, 1983, 1985). The Needles District's extensive pinnacles, as seen today, consist of the Cedar Mesa Sandstone that represents mixing or layering of easily eroded red arkosic sand and pebbles from the ancestral Uncompaghre mountains and resistant white sands derived from the northwest. The extensive fluvial networks and corresponding flooding resulted in material that gives the distinctive salmon coloring seen in the Cedar Mesa Sandstone and the primarily red sandstones in the Organ Rock Formation (Stanesco and others, 2000). Below the Cedar Mesa interval, layers of eolian sandstones are interbedded with limestone (Loope, 1983). Within the Cedar Mesa, layers of eolian sand are separated by thin surfaces formed by stabilization of the dune sea or by fluvial floods into the dune sea (Langford and Chan, 1988; Mountney and Jagger, 2004; Driese and others, 2006). Lenses of shale and limestone within the dunes mark where ephemeral floods left clay pans or semi-permanent ponds deposited in thin limestone beds (Driese and others, 2006).

The pinnacles, therefore, are alternating red and white sandstone beds. During more arid periods, probably the result of glacial periods when sea levels were low, more sands were delivered to the area (Langford and Chan, 1989; Mountney, 2006). Non-glacial periods, with increased humidity, precipitation, and warmth, resulted in greater erosion of the Uncompaghre mountains and more fluvial systems. As the Colorado Plateau became elevated at least 5 million years ago, erosion began to remove vast areas of the Plateau. In the Needles District, particularly, overlying sandstones were worn away, including the layers immediately overlying the Cedar Mesa Sandstone. When the modern Colorado River cut its canyon into the underlying Pennsylvanian strata, the Paradox Formation salt began to flow into the Colorado River (Baars, 2000). Due to a slight downward slope (2° to 4°) of the region westward from the eastern side of Chesler Park to the Colorado River because of the Monument uplift, the salt flowed westward into the Colorado River (Baker, 1933; McGill and Stromquist, 1979; Ely, 1989). As the salt flowed westward, the overlying sandstone rocks acted like a large brittle sheet and began to move westward and fracture in the process (Schulz-Ela and Walsh, 2002; Walsh and Schulz-Ela, 2003). These fractures resulted in the grabens extending eastward from the river in an arc that initially starts at the north running mainly parallel to the Colorado River and westward of Chesler Park. The earliest age for graben formation has been constrained at 50,000 years ago (Biggar and Adams, 1987), but others have proposed a much earlier age (Moore and Schultz, 1999; Grosfils and others, 2003). Each graben consists of a down-faulted zone as much as one hundred meters wide creating the long canyon passageways. Rocks within the down faulted regions were covered with eolian deposited sands (up to 60-90 meters in Cyclone Canyon and Devils Lane) (Moore and Schultz, 1999; Grosfils and others, 2003). Graben formation hastened erosion throughout the region, especially in the graben canyons. Importantly, within the grabens little is seen of the original overlying rocks except in certain cases, as noted below, where pinnacles that were initially more resistant crossed the grabens.

Underlying all of these processes are two perpendicular ancestral stress fields (Baars and Stevenson,1981). The two joint systems are oriented northwest and northeast and are responsible for the extensive surface fracturing of the Cedar Mesa Sandstone into rhomboidal blocks (Baars, 2000). This is most obvious when visualizing the intermediate strata of Cedar Mesa eolian sandstone that have been eroded to form white rhomboidal "mushrooms" or "toadstools" across the landscape from Squaw Park near the Needles District Visitor Center to the Colorado River and beyond (figures 6 and 7). These same joint patterns are responsible for formation of the oval shape of the pinnacles.

A principal distinction of the Chesler Park/graben part of the Needles District is that the parks and the area to the west of the Monument upwarp generally slope downward toward the Colorado River while the region to the east of the parks is flat. The change in surface orientation exactly parallels a major row of pinnacles that borders the eastern edge of each of the parks. The erosional patterns are also distinct between the regions to the east and west of the Monument upwarp. To the east the streams that run north to the Colorado River have clearly cut through the Cedar Mesa Sandstone, forming distinct canyons. The pattern of the pinnacles appears to be distinctly related to the drainages of each canyon. In contrast, to the west of the Monument upwarp where the parks and grabens are located, the pinnacles meander across the area and are not directly linked to stream erosion.

HYPOTHESIS

It is proposed that the serpentine pattern of the pinnacles traversing the western side of the Monument upwarp describes the geomorphological foundation of the pinnacles and parks. These sinuous pinnacles are reminiscent of streams themselves. It is hypothesized that the pinnacles on the western side of the Monument upwarp are the less eroded remnants that were indurated by former streambeds.

Following the erosion of the Colorado Plateau, erosion of the softer shales of the Organ Rock Formation ex-

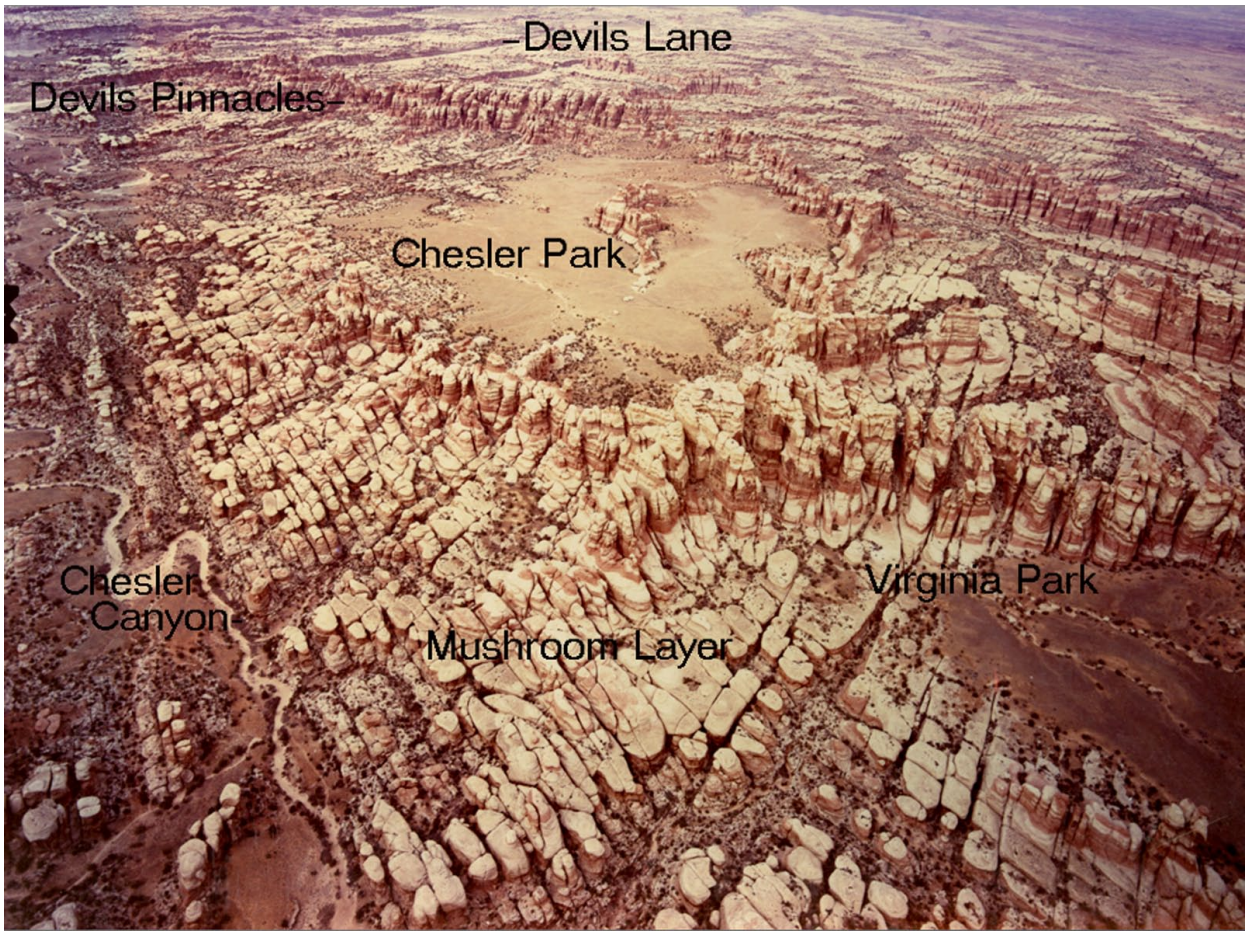

Figure 6. *Aerial photo of Chesler and Virginia Parks showing resistant "mushroom" layer of sandstone. Direction of view is north. Photo by Owen Severance.*

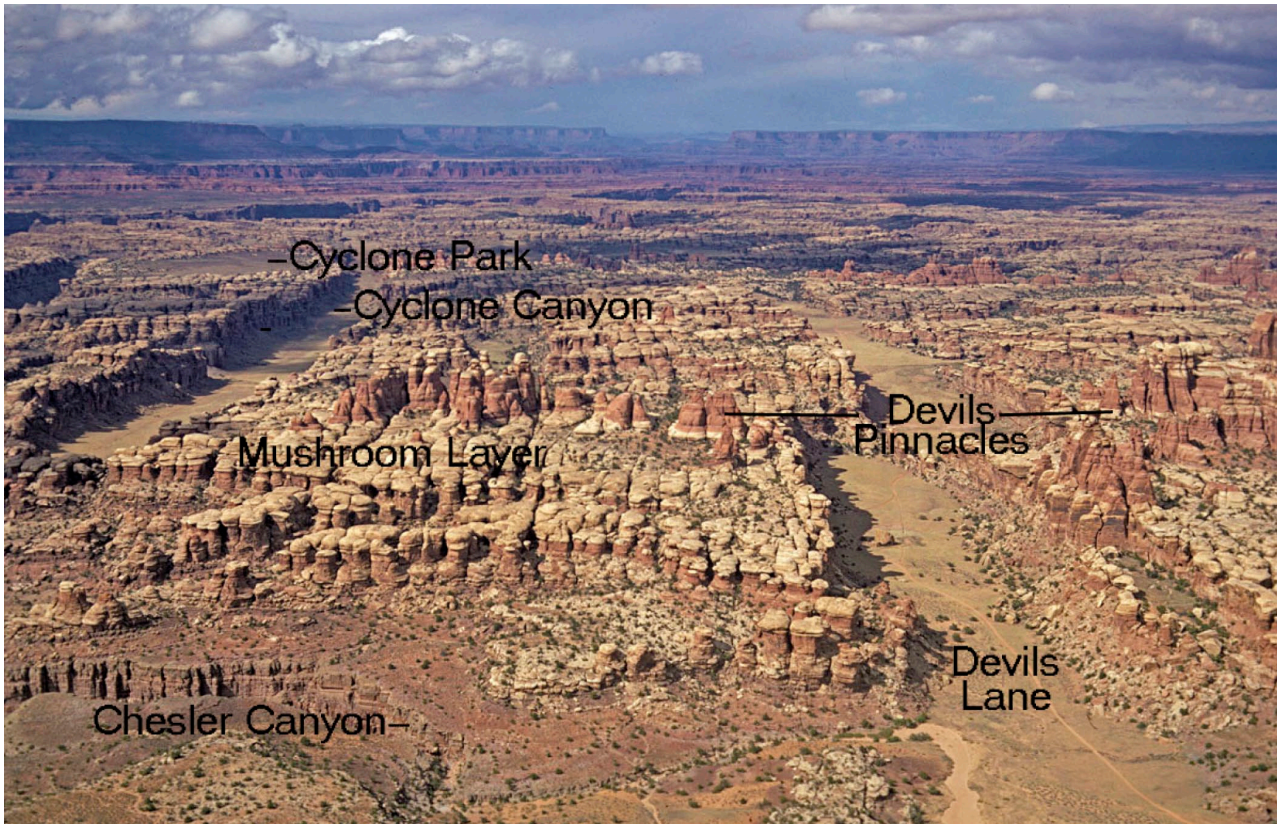

Figure 7. *Aerial photo of Devils Lane and resistant mushroom layer of sandstone. Direction of view is north/northeast. Photo by Owen Severance.*

posed the Cedar Mesa Sandstone. On the western side of the Monument upwarp in this region, the upper less indurated Cedar Mesa Sandstone became further eroded to a particularly hardened layer of sandstone (most often the top of the "mushroom" rocks that cross this section of the Needles District). The major stone elements left above this layer of mushrooms were sinuous patterns of pinnacles. The pinnacles represent, therefore, an instance of inverted topographical relief in which the water percolating down from ancient streambeds in the Organ Rock Formation carried minerals that selectively cemented the Cedar Mesa Sandstone.

EVIDENCE FOR THE PINNACLES AS INVERTED TOPOGRAPHICAL RELIEF

Park Formation

The key feature of Chesler Park is that it is similar to an eroded plain surrounded by the Cedar Mesa Sandstone pinnacles. These pinnacles rise approximately 200 meters above the plain. The other parks are similar except that the park-like areas consist of less grassland area. For example, beneath the tall pinnacles at Devils Park North and South there are small grasslands, but the bulk of the area is the top of the sandstone that makes up the resistant "mushroom" rocks described above. Each of the park grasslands has resulted from substantial accumulations of modern sands transported from the west and deposited at the eastern border of pinnacles, most noticeable in Chesler, Virginia, and in Devils Parks. Of the parks mentioned, only Cyclone Park today lacks a distinct row of pinnacles bordering its north, east, and south sides due to the extensive erosion that has occurred in the graben area west of Devils Lane. As marked in figure 8, however, salmon colored rocks, the remnants of pinnacles above the "mushroom" layer of hardened sandstone, surround Cyclone Park. In contrast, other areas just west, north, and south of the perimeter of Cyclone Park lack these distinct salmon colored rocks.

Day (2004) suggested that the parks are similar to the grabens, representing sunken basins modeled on the graben down faulting or the result of collapse structures. Collapse structures do occur sporadically in and around Canyonlands National Park (Sugiura and Kitcho, 1981) and are generated by dissolution of salts in the Paradox Basin salt layer. The parks are not formed by collapse of the overlain rocks, as sandstone remnants within the interior of all of the parks are on the same horizontal level as the coeval sandstone layers in the surrounding pinnacles. In the case of collapse structures or graben downfaulting, this is not the case, as the remnants lie locally at least 20 to 30 meters below the corresponding layer in the surrounding rocks.

Another possible cause of the parks would be increased fracturing of rocks leading to erosion of the park areas. There is no evidence, however, for increased fracturing. For example, stream down-cutting does not take place extensively on the western side of the Monument upwarp. There are no streams or rivers emanating from any of the tops of the pinnacle regions for any of the parks that could have caused the parks to form their large circular enclosures. Moreover, stream erosion would have created talon-shaped erosional patterns (Howard and Selby, 2009), and the parks are definitely oval in shape.

If the parks are not excessively eroded regions, then a possible explanation for their existence must derive from the second element, the pinnacles. The question becomes, then, why are the pinnacles more resistant, and why have they not eroded to the same level as the parks?

Induration of Sandstone and Calcrete Formation

The varied features apparent in desert geomorphology depend critically on the resistance of different strata to erosion. Where features exist, the caprock contains stone that is more resistant than nearby materials. This resistance derives from increased cementation of the sandstones. One such process is due to diagenetic calcrete (predominantly carbonate cementation of sandstones) formation. The entry of carbonate and other minerals into sandstones and the cause for this hardening derives generally from either upwelling of groundwater or from downflowing of overlying water, such as streams, ponds, or rivers. Lattman (1983) proposed downflowing of overlying water as the major cause, and Dixon and McLaren (2009) proposed the majority of the induration observed in the Cedar Mesa Sandstone resulted from this downward percolation. As an example of this behavior, Ollier and Sheth (2008) described ancient riverbeds in India as creating meandering mesas of inverted topographical relief. In that case, however, the hardening chemicals were iron carbonates resulting in ferricrusts rather than the calcretes (calcium carbonates).

Lattman (1983) showed induration to be a relatively rapid process, occurring within six months of calcrete cementation. Because the rate of hardening depends on climate, topography, the availability of calcium carbonate, and the type of cemented material, it is difficult to relate degree of hardness to a particular time period. An annual precipitation of 100 mm to 500 mm (considered semi-arid) is known to be especially conducive to the calcrete formation that is occurring in many locations today (Lattman, 1983; Goudie, 1985). Recently, the middle reaches of the Gilbert River in Australia have been hardened within 4,000 to 15,000 years (Nanson and others, 2005). This occurred in a semi-arid region that was subject to seasonal spells of dryness alternating with wet seasons, similar to the predicted climate present when the Organ Rock Formation was laid down (Huntoon and others, 2002). This intermittent wet/dry cycle is especially conducive to forming calcretes (Lattman, 1983). In addition, the induration of the Gilbert River channels resulted in preservation of the channel and

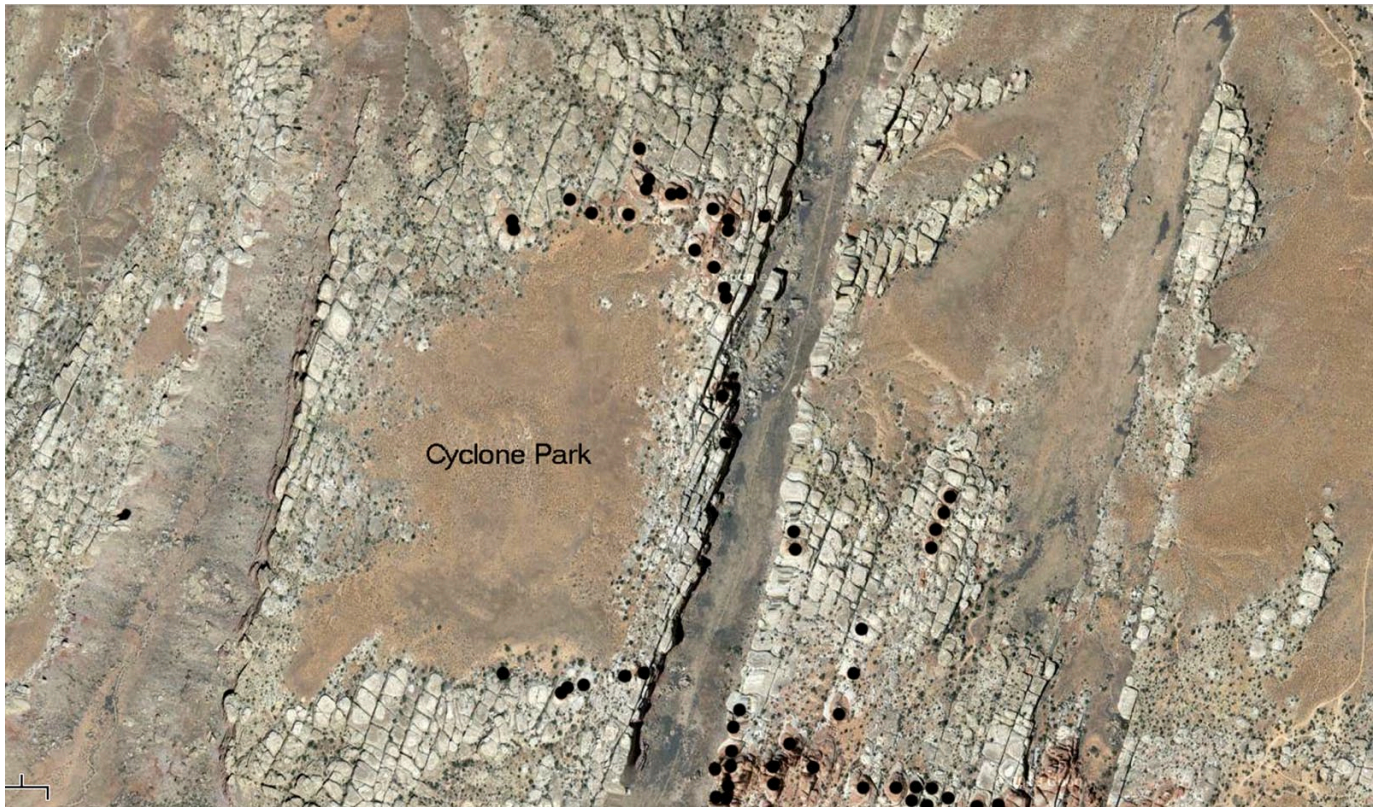

Figure 8. *Satellite map of Cyclone Park with pinnacle remnants. The dots indicate where salmon-colored sandstone exists above the layer of rhomboidal "mushroom rocks."*

precluded extensive changes in channel placement. Once induration begins to take place, therefore, it results in channel entrenchment. More distal reaches of the river, closer to the sea and lacking sufficient slope, do not display induration and instead form meandering riverbeds without entrenchment. In contrast, upstream reaches of the river with more rapid movement of water do not result in the periodic drying/wetting cycle that seems critical for calcrete formation.

Evidence of Pinnacles Resulting from Organ Rock Formation Stream Beds

The strata directly overlying the Cedar Mesa Sandstone at the top of the present day pinnacles are Organ Rock Formation shales and sandstones deposited in fluvial systems deriving from the Uncompaghre uplift in western Colorado (Cain and Mountney, 2009). These fluvial systems had moderate inclines on a coastal plain of low-relief and were not subject to extensive flooding characteristic of meandering streams (as observed further distal and south of the Uncompaghre mountains in White Canyon) (Stanesco and others, 2000; Huntoon and others, 2002; Cain and Mountney, 2009). Especially in the Needles area, the streams of medium bed-load appear braided, which is very similar to the braided pattern of pinnacles seen throughout the Chesler Park/graben area (figure 5) (Stanesco and others, 2000).

Moreover, the predicted climate at the time of Organ Rock Formation deposition was that of alternating dry/wet seasons in a semi-arid climate (Huntoon and others, 2002). The location of the present Colorado Plateau region at that time was on the western edge of Pangea at about 10° north of the equator. A change to a monsoonal weather pattern during the Late Pennsylvanian Period would have ensured that continental moisture-bearing winds bypass the Colorado Plateau region, creating a climate of increased aridity and seasonal precipitation for the region (Dubiel and others, 1996; Huntoon and others, 2002). The extensive eolian dune fields of Cedar Mesa and White Rim Sandstones support these observations. During the Organ Rock deposition, however, the presence of both paleosols and rhizoliths suggests an alternating wet/dry climate. These characteristics of semi-aridity, alternating wet and dry seasons, and medium bed-loaded rivers are conducive to calcrete formation and fit a similar model as proposed for the Gilbert River induration that has taken place in the last 15,000 years (Nanson and others, 2005).

Evidence in support of low levels of seasonal precipitation at the time these rivers were extant derives also from the measurements of the sinuosity of the present day pinnacles. River sinuosity has been directly correlated with increasing storminess of the climate, irrespective of the underlying rocks through which the rivers run (Stark and others, 2010). The calculated sinuosity (curvature divided by linear distance covered) for the pinnacles is 1.1 (stand-

ard error of 0.015 for sixteen segments). This low value of sinuosity suggests that the likelihood of stormy weather events and of precipitation greater than 50 mm at a time was near zero for these sandstone-embedded rivers.

Importantly, based on the deposition from these rivers at the time of the Organ Rock Formation, they trended west and northwest in the vicinity of the Needles District (Stanesco and others, 2000). Since they were emanating from the Uncompaghre uplift, they should have been directed southwest unless something interfered with their path. Studies have shown that the ancestral Monument uplift was a slightly positive feature at the time of the Organ Rock Formation (Dubiel and others, 1996; Stanesco and others, 2000). Whereas its exact location and elevation are not known, it appears to have run in a slightly northeast direction parallel to and perhaps overlapping the location of the present day Colorado River. As early as 300 million years ago during the deposition of the lower Cutler beds beneath the Cedar Mesa Sandstone, it was apparent that a locally positive topographical formation was present in this region that ran nearly to the confluence of the present day Green and Colorado Rivers: deposition of the lower Cutler beds is particularly sparse in this region, suggesting that the Monument upwarp was active and present at that time (Condon, 1997). The slight positive elevation of this ancestral Monument upwarp continued through the deposition of the Cedar Mesa Sandstone in what should still be considered a relatively low topographical area throughout the Four Corners region (Condon, 1997), as evidenced by the many layers of limestones deposited between sandstone levels throughout the Cedar Mesa (Loope, 1985). Similarly, during Organ Rock Formation deposition, thinning of this material in areas of the Needles suggests the presence of an ancestral Monument upwarp (Condon, 1997; Stanesco and others, 2000). Furthermore, the White Rim Sandstone, which overlies the Organ Rock Formation, is noticeably thinned as it approaches the Colorado River from the west. In fact, it becomes absent in the present day Needles District, again supporting a low relief structure parallel to the Colorado River and ending just south of the present day confluence with the Green River (Condon, 1997). That the structure of the paleo-Monument upwarp during any of these times was low relief is evidenced by the lack of any particular erosional material deriving from the structure at subsequent times. The presence of the Monument upwarp at the time the rivers flowed over the Cedar Mesa Sandstone within the Organ Rock Formation would have forced the streams to the west and northwest. These are the same directional trends that the pinnacles take across the graben area.

Because the sea to which these Organ Rock Formation paleorivers would have flowed was present in the western reaches of the present day Maze District (Condon, 1997), one might expect to observe pinnacle remnants (that is, the results of inverted topographical relief) of these streams in the eastern zone of the Maze District. The comparable Dollhouse pinnacles just west of the Colorado River follow the same northwest trend as do the Devils Pinnacles (figure 3). In fact, the Devils Pinnacles (present just north of Chesler Park) appear to continue northwestward to the Dollhouse pinnacles, suggesting that they were part of the same paleostream induration. Except for the vast erosional surface created during the formation of the grabens, pinnacles would probably have readily been connected on both sides of the Colorado River.

Timing of Pinnacle Formation

The erosion that helped create the pinnacle relief seen today was exceedingly accelerated within the last 500,000 years as the graben rifts developed and spread eastward from the Colorado River (Walsh and Schulz-Ela, 2003; Furaya and others, 2007). It is likely that the pinnacles were already visible and obvious compared to the adjacent and less-eroded areas prior to the time when the Colorado River first cut into the Paradox salt. The pinnacles appear to predate graben formation in that the pinnacles cross the grabens at a number of locations. They cross Devils Pocket thrice (figure 9, points A to C), Devils Lane at least twice (points D and E), and Cyclone Canyon twice (points F and G). In several of the above cases the pinnacles are still extant in the graben (see north Devils Lane, figure 10, and all three cases for Devils Pocket, figure 9). Thus, these pinnacles were already present when graben formation occurred. Analysis of the stratification of the successive layers of Cedar Mesa Sandstone verify that the pinnacles in each of these grabens were once contiguous with the pinnacles on the adjoining horst sections, albeit now dozens of meters lower.

The sinuous pattern of the pinnacles also appears to predate the course of the present day streambeds in this area. Pinnacle rows cross Elephant Canyon twice (marked ‘A’ and ‘B’ in figure 4) and Chesler Canyon once (marked ‘C’). These observations suggest the process that formed the pinnacles took place long before the current drainages in the Chesler Park/graben area. The current drainages would have formed during the incision of the Colorado River, probably commencing 5 to 50 million years ago.

CONCLUSIONS

The sinuous pattern of pinnacles in the Chesler Park/graben area is interpreted to be the result of streambeds in the conformably overlying Organ Rock Formation that indurated the underlying Cedar Mesa Sandstone. The erosion of the Colorado Plateau and the subsequent erosion caused by the Colorado River cutting into the Paradox Formation underlying the Cedar Mesa Sandstone of this region resulted in significant mass erosion of the Chesler Park/graben region. The indurated Cedar Mesa Sandstone resisted this erosion, resulting in the sinuous pattern of pinnacles that

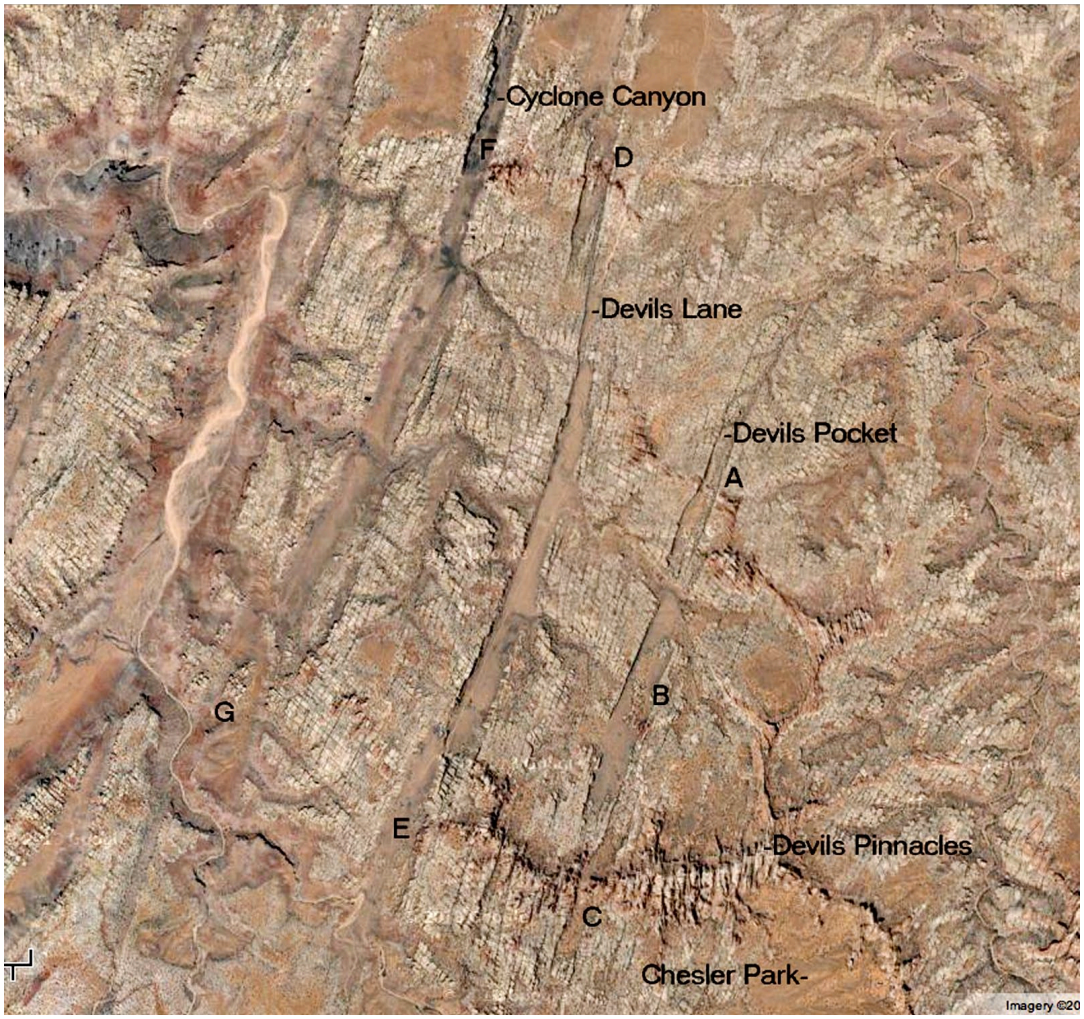

Figure 9. *Satellite map of grabens with pinnacle crossings. Letters "A" to "G" indicate locations where the pinnacles clearly cross the grabens. Down fallen pinnacles are most obvious at points "A" to "D."*

Figure 10. *Aerial view of northern Devils Lane looking southwest. The rhomboidal sandstone blocks in the forefront and upper right are the mushroom sandstone level described in the manuscript. The sinuous pinnacles marked "A" crossing the grabens are located at the north end of Devils Lane (marked "D" in figure 9). Cyclone Canyon is seen in the upper right part of the picture. Photo by Matt Sobey.*

form circular-like enclosures of the several parks in this area. This type of induration may also be responsible for other features of this region. The formation of the mesas, such as Molehill Mesa, that are interspersed with the parks could be the result of induration of the underlying Cedar Mesa Sandstone by small lakes present at the time of the deposition of the Organ Rock Formation.

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