# Dead Horse Point, Southeastern Utah

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Utah Geosites
2019

Utah Geological Association Publication 48

M. Milligan, R.F. Biek, P. Inkenbrandt, and P. Nielsen, editors

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***Cover Image:*** *Panorama to the east-northeast from Dead Horse Point.*

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*Utah Geosites* showcases some of Utah's spectacular geology, both little-known localities and sites seen by visitors to Utah's many national and state parks and monuments. The geosites reflect the interests of the many volunteers who wrote to share some of their favorite geologic sites. The list is eclectic and far from complete, and we hope that additional geosites will be added in the coming years. The Utah Geological Survey also maintains a list of geosites https://geology.utah.gov/apps/geosights/index.htm.

We thank the many authors for their geosite contributions, Utah Geological Association members who make annual UGA publications possible, and the American Association of Petroleum Geologists—Rocky Mountain Section Foundation for a generous grant for desktop publishing of these geosite papers.

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## Presidents Message

I have had the pleasure of working with many different geologists from all around the world. As I have traveled around Utah for work and pleasure, many times I have observed vehicles parked alongside the road with many people climbing around an outcrop or walking up a trail in a canyon. Whether these people are from Utah or from another state or country, they all are quick to mention to me how wonderful our geology is here in Utah.

Utah is at the junction of several different geological provinces. We have the Basin and Range to the west and the Central Utah Hingeline and Thrust Belt down the middle. The Uinta Mountains have outcrops of some of the oldest sedimentary rock in Utah. Utah also has its share of young cinder cones and basaltic lava flows, and ancient laccoliths, stratovolcanoes, and plutonic rocks. The general public comes to Utah to experience our wonderful scenic geology throughout our state and national parks. Driving between our national and state parks is a breathtaking experience.

The "Utah Geosites" has been a great undertaking by many people. I wanted to involve as many people as we could in preparing this guidebook. We have had great response from authors that visit or work here in the state. Several authors have more than one site that they consider unique and want to share with the rest of us. I wanted to make the guidebook usable by geologists wanting to see outcrops and to the informed general public. The articles are well written and the editorial work on this guidebook has been top quality.

I would like to personally thank Mark Milligan, Bob Biek, and Paul Inkenbrandt for their editorial work on this guidebook. This guidebook could not have happened without their support. I would like to thank Jenny Erickson for doing the great desktop publishing and the many authors and reviewers that helped prepare the articles. Your work has been outstanding and will certainly showcase the many great places and geology of Utah. Last, but not least, Thank you to the American Association of Petroleum Geologists, Rocky Mountain Section Foundation for their financial support for this publication.

Guidebook 48 will hopefully be a dynamic document with the potential to add additional "geosites" in the future. I hope more authors will volunteer articles on their favorite sites. I would like to fill the map with locations so that a person or family looking at the map or articles will see a great location to read about and visit. Enjoy Guidebook 48 and enjoy the geology of Utah.

Peter J. Nielsen
*2019 UGA President*

## INTRODUCTION

The Dead Horse Point geosite, within the state park by the same name, is located in the heart of the Canyonlands region of Utah between Canyonlands and Arches National Parks (figure 1). The views are spectacular, sublime, awe-inspiring, and majestic, and hard to surpass anywhere on the Colorado Plateau. The mood of the vistas changes by season and time of day. Here, one of nature's engineers, in this instance the Colorado River and its tributaries, has carved and exposed strata of Late Pennsylvanian (307 million years ago [Ma]) to Early Jurassic (200 Ma) age within just the past 5 million years (figures 2 and 3).

Dead Horse Point State Park is located in a geologic area known as the Paradox fold and fault belt in the northern part of the Paradox Basin, southeastern Utah and southwestern Colorado. The regional structural setting was created by the (1) movement of subsurface salt layers in the Paradox Formation (intermittently active from the Pennsylvanian to the present day), (2) Late Cretaceous-early Tertiary (about 70 to 30 Ma) Laramide orogeny (a regional mountain-building event), and (3) late Tertiary-Quaternary (23 Ma to the present) regional uplift. These structural events have locally folded and fractured the rock layers in a manner that favored the deposition or accumulation of economic natural resource deposits (oil and gas, uranium, and potash). The signs of human activity to extract these deposits are apparent as one approaches the park or looks from the canyon edge at Dead Horse Point.

The question is often asked "Why the name Dead Horse Point?" According to one legend, around the late 1800s, Dead Horse Point was used as a corral for wild horses roaming around the mesa that now includes an area called Big Flat to the north and the Island in the Sky District of Canyonlands National Park to the west. Cowboys rounded up these horses and herded them across the narrow neck of land that separates the mesa from the point (figure 2). The neck, which is only 90 feet (27 m) wide, was then fenced off with juniper branches and brush. This created a natural corral surrounded by precipitous cliffs which afforded no escape. Sadly, one time for some unknown reason, horses were carelessly left corralled on the waterless point where they died of thirst within view of the Colorado River, 2000 feet (600 m) below (Utah Division of State Parks, 2018).

Dead Horse Point is one of Utah's most visited scenic sites, and like Delicate Arch and the Green River Overlook (see these geosites elsewhere in this volume), the views are used on book covers, scenic calendars, and postcards. Along with the incredible layered rocks, prominent features viewed from Dead Horse Point include large up-ward folds called anticlines, mountains cored by volcanic remnants (laccoliths), immense solar evaporation ponds, and entrenched meanders of the Colorado River—all revealing a geologic story. No compilation of classic Utah geosites would be complete without Dead Horse Point.

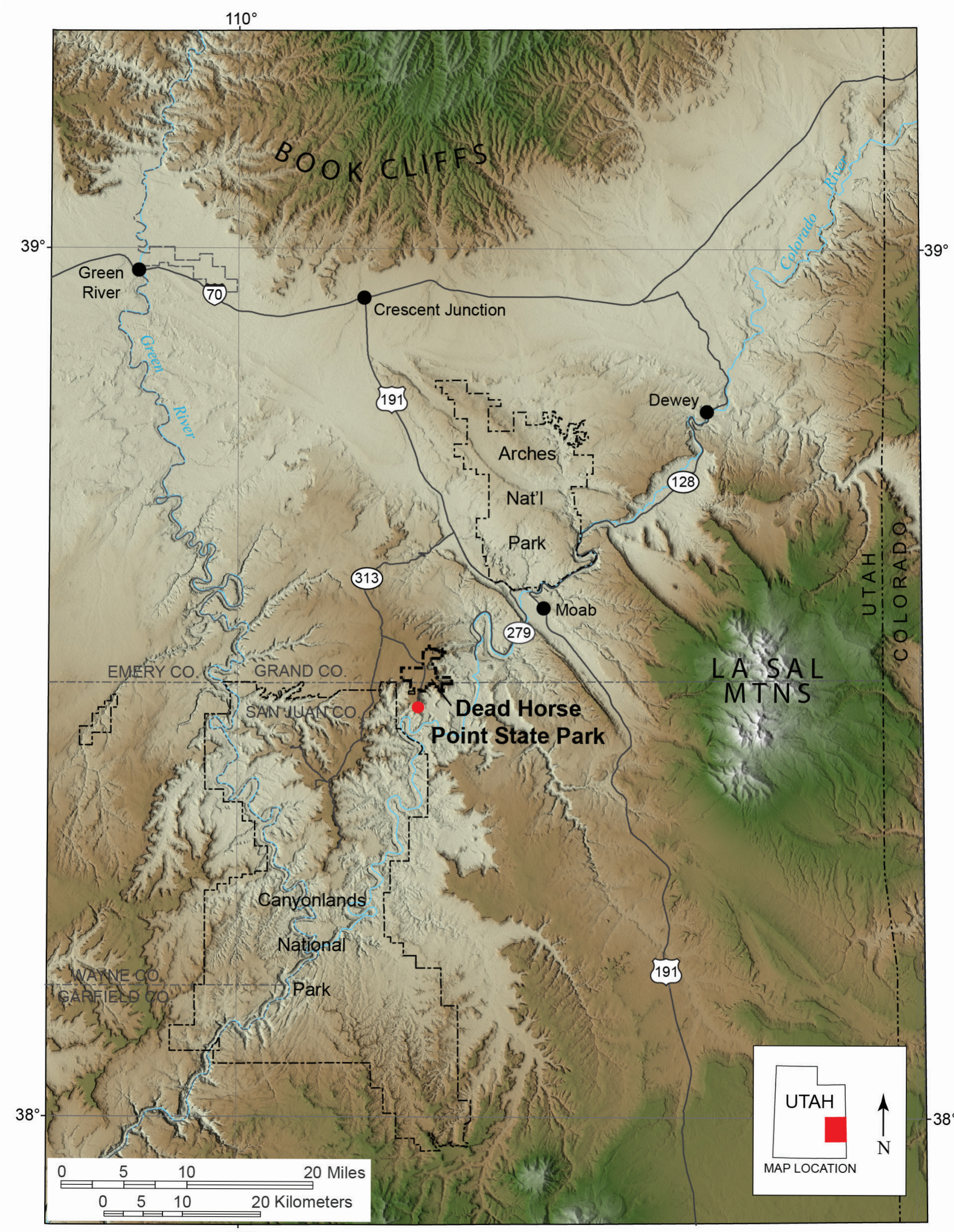


*Figure 1. Location map for the Dead Horse Point geosite (red dot), southeastern Utah, and surrounding parks, towns, and highways.*

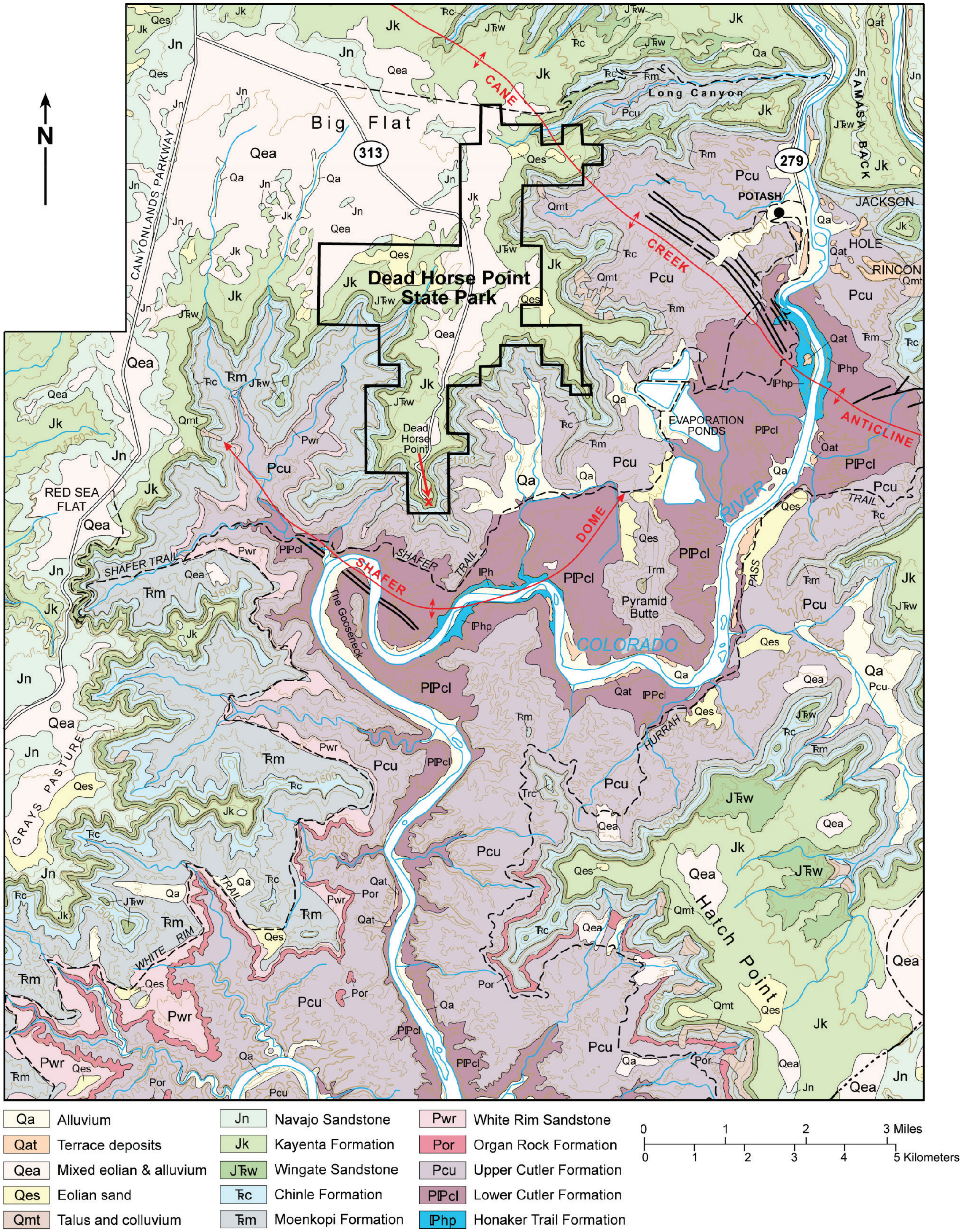


*Figure 2. Geologic map of the Dead Horse Point area, Grand and San Juan Counties, Utah. Modified from Hinrichs and others (1967), Huntoon and others (1982), and Doelling (2001).*

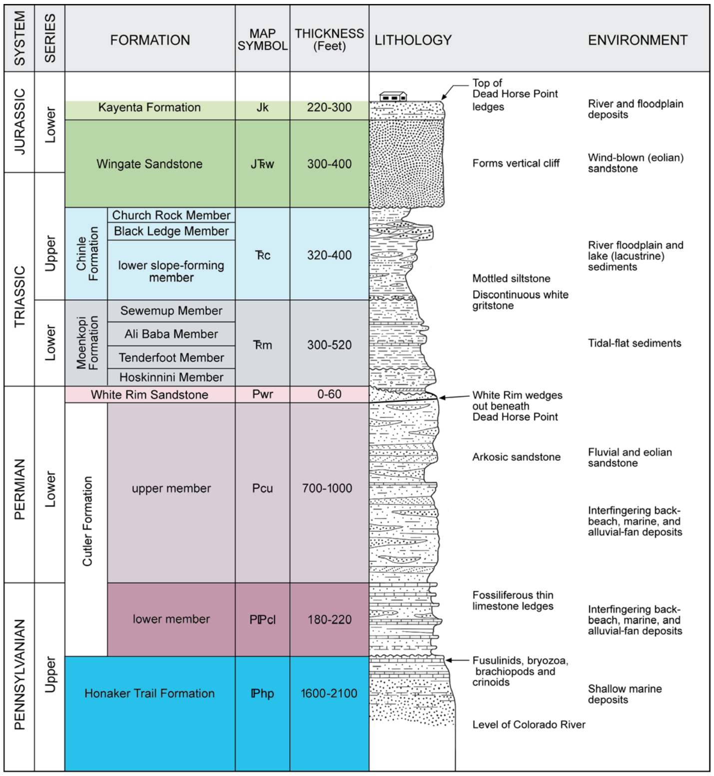


*Figure 3. Lithologic column showing formations and members exposed below Dead Horse Point, including environments of deposition, thickness, age, weathering habits, and lithology. After Doelling and others (2010).*

## HOW TO GET THERE

Dead Horse Point State Park is about 250 miles (400 km) or a little less than a 4-hour drive from Salt Lake City, Utah, via Interstate 15 (I-15), U.S. Highway 6, I-70, and U.S. Highway 191; 33 miles (53 km) or about 40 minutes if coming from the town of Moab, Utah. From Highway 191 turn west onto State Highway 313 and proceed 30 miles (48 km) to Dead Horse Point State Park (figure 1), bearing left at the junction with Grand View Point Road, passing through the entrance station (fee required) to the parking lot for the overlook (restroom facilities, camping, and picnic grounds are available). A short walk along a flat, paved sidewalk leads to the overlook, 38°28'10" N., 109°44'21" W., elevation 5967 feet (1819 m). A stone wall separates the view areas from dangerous sheer cliffs. The visitor should walk west to east (or east to west) to obtain various panoramic views of the Canyonlands area described in detail below.

## STRATIGRAPHY AND DEPOSITIONAL HISTORY

Consolidated sedimentary rocks seen in the vistas from Dead Horse Point include strata of Late Pennsylvanian to Early Jurassic age. These strata have a cumulative thickness of 2700 to 3600 feet (820–1100 m) depending on which direction one looks (Doelling and others, 2010) (figures 3 through 6). Data in this section is largely taken from Doelling and others (2010).

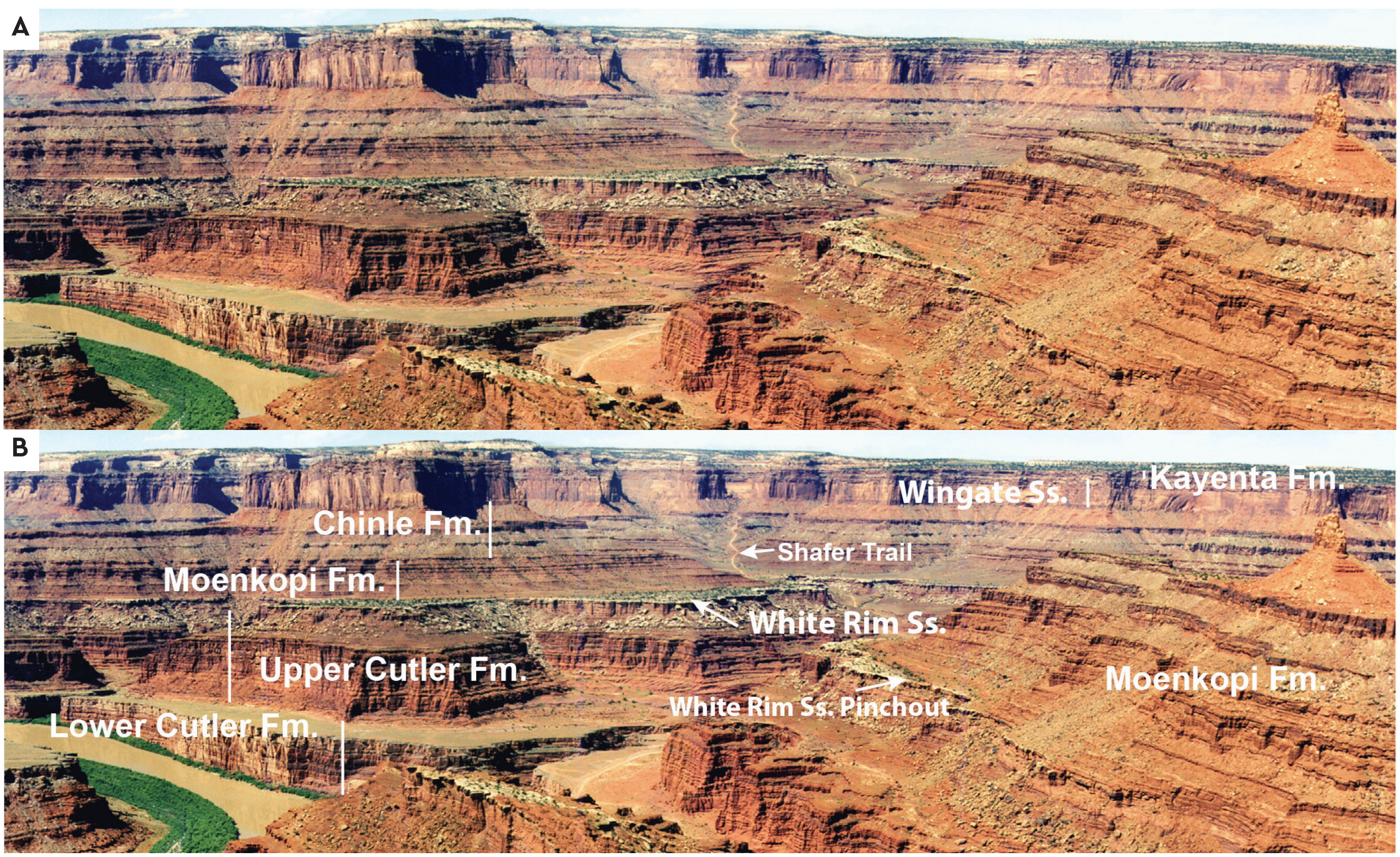


*Figure 4. Panorama to the southwest from Dead Horse Point; unannotated (A) and annotated (B). The Gooseneck of the Colorado River is on the left (south) and the Shafer Trail in the center; Permian Cutler Formation at river level to Jurassic Navajo Sandstone on the skyline in the distance in Canyonlands National Park (left of center). Dead Horse Point is in the transition area between the areas where Cutler facies change. Note that the White Rim Sandstone pinches out below Dead Horse Point (right of center). Modified from Doelling and others (2010).*

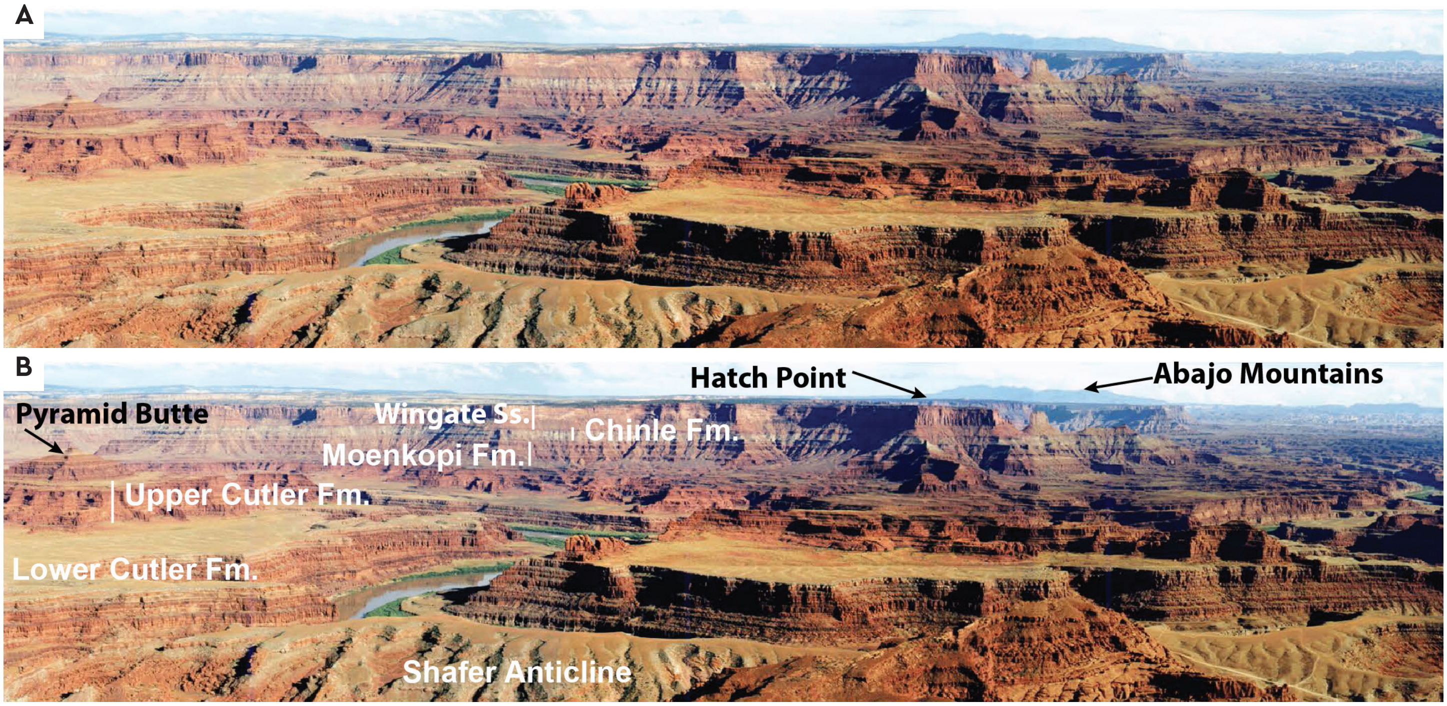


*Figure 5.* *Panorama to the southeast from Dead Horse Point; unannotated (A) and annotated (B). The view shows north-dipping Permian Cutler Formation of the Shafer anticline, Pyramid Butte, and the Colorado River; Abajo Mountains in the far distance. The Triassic through Lower Jurassic section is exposed in the distant cliffs and slopes below Hatch Point in distance (upper right). Modified from Doelling and others (2010).*

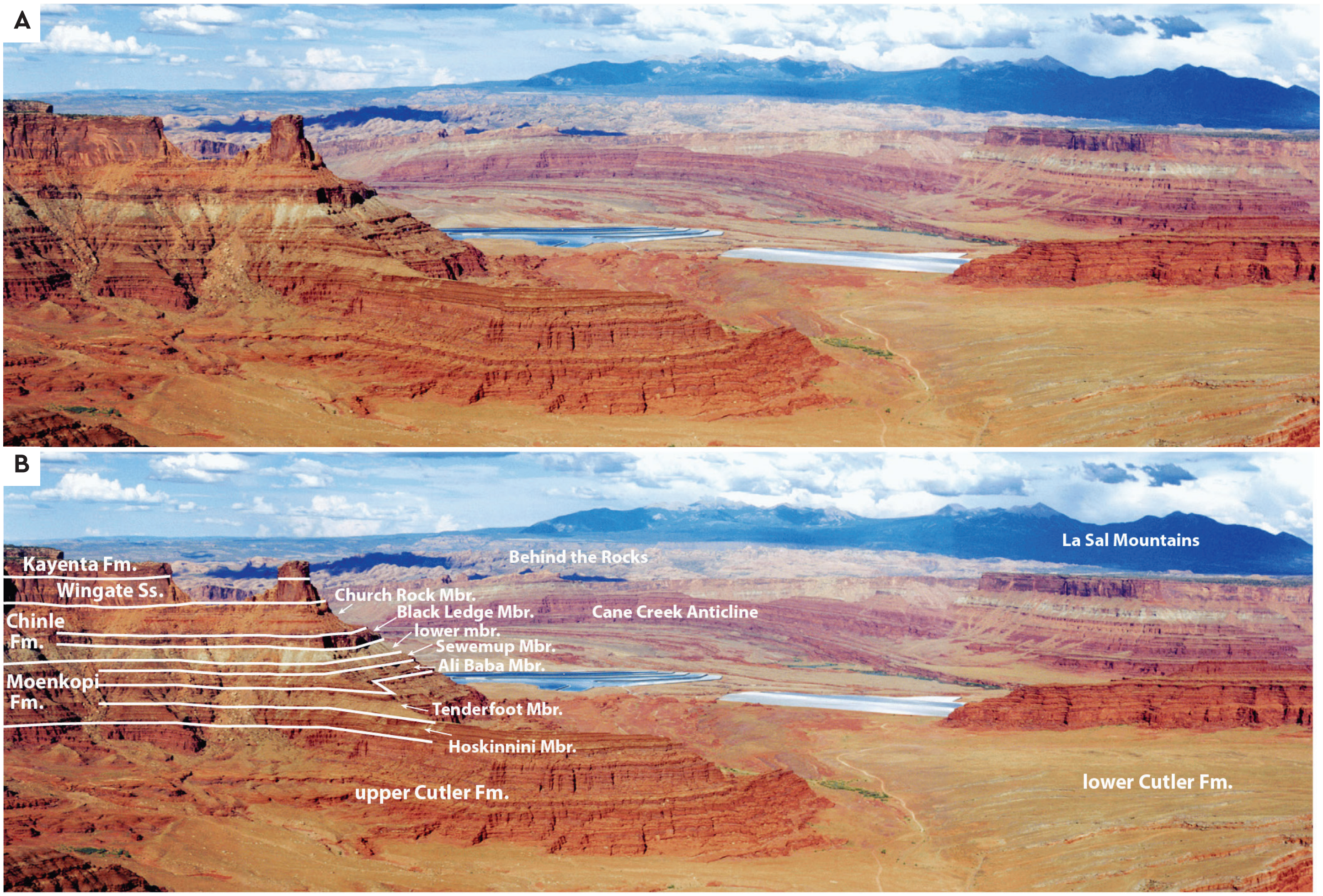


*Figure 6.* *Panorama to the east-northeast from Dead Horse Point; unannotated (A) and annotated (B). The view shows the Cane Creek anticline, solar evaporation ponds, and jointed Navajo Sandstone outcrops of the Behind the Rocks area in front of the La Sal Mountains in the distance. The Jurassic Kayenta Formation forms the rim of the overlook at the Point followed down section by Wingate, Chinle, Moenkopi, and Cutler Formations at the base. Modified from Doelling and others (2010).*

## Rocks of the Pennsylvanian Period

Pennsylvanian Period rocks were deposited in a subsiding Paradox Basin beneath a restricted sea or embayment of an ocean that extended to the west of the park. To the northeast of this embayment, a land mass, known as the Uncompahgre Highland, emerged and rose (figures 7A and 7B). The boundary between the embayment and mountainous uplift was a sharp northwest-trending fault that lay to the northeast of Dead Horse Point. Rivers and streams carried the erosional debris from the mountains to the embayment where it was deposited. The uplift did not occur at a uniform rate. When the mountains rose rapidly, erosional debris and sediment were dumped into the embayment. When the uplift slowed, marine precipitates, such as gypsum, limestone, and salt were deposited. In Middle Pennsylvanian time, when the Paradox Formation was laid down, the embayment was intermittently cut off from open-ocean circulation and thick layers of salt were deposited. In Late Pennsylvanian time, the Honaker Trail Formation was laid down (early to middle Virgilian), and ocean waters freely circulated into the subsiding embayment, which continued to receive the erosional debris shed from the Uncompahgre Highland.

### Paradox Formation

Although not exposed in the area observed from Dead Horse Point, the Paradox Formation played an important role in shaping the surrounding geology. It was deposited beginning about 308 Ma as a marine deposit consisting of layered salt, anhydrite, shale, siltstone, limestone, and dolomite. These rocks were laid down within the subsiding basin in cycles that alternated from restricted-marine conditions with limited communication to the ocean (figure 7A) to open-marine conditions where the connection with the ocean was unimpeded and water circulated freely into the embayment. More often than not, physical barriers were established that cut off circulation with the ocean. The area had a hot, dry climate with high rates of evaporation. As the water evaporated, the dissolved salt was precipitated in the bottom of the bay. Most of this salt is halite (NaCl) (common table salt). However, at times the magnesium and potassium content of the seawater increased and sylvite (KCl) and carnallite ($KClMgCl_2.6H_2O$) were deposited.

A typical Paradox cycle began when connection with the open ocean was hindered. Limestone and dark shale beds were first deposited; ensuing evaporation led to deposition of dolomite (primary), gypsum, and finally salt. Thereafter free circulation with the open ocean was re-established only to gradually be hindered again. As many as 35 such depositional cycles are recognized in the Paradox Formation (Rasmussen, 2010). These cycles have been correlated to glacio-eustatic sea-level fluctuations (Goldhammer and others, 1991).

The Paradox Formation is probably 3000 to 5500 feet (900–1700 m) thick beneath the area around Dead Horse Point. Of this amount, 75% consists of soluble salts. A single salt bed may be as much as 300 feet (90 m) thick.

### Honaker Trail Formation

Like the Paradox Formation, most of the Honaker Trail Formation is in the subsurface. However, the uppermost strata of the formation are exposed on the tops of the Cane Creek and Shafer anticlines (figures 2, 5, and 6). The outcrops consist of interbedded sandstone, limestone, and siltstone. The sandstone is very fine to fine grained, well to moderately sorted, micaceous, and calcareous; some beds are cross-bedded. Bedding is thick to massive. Limestone interbeds are gray to very light gray, variably argillaceous (clayey), and 1 to 10 feet (0.3–3 m) thick. Many limestone beds are fossiliferous, containing a marine fauna of crinoid debris, brachiopods, bryozoans, gastropods, foraminifera, and rare trilobites. The siltstone is micaceous, locally bioturbated, and cross-stratified.

The Honaker Trail Formation was deposited in the same embayment as the Paradox Formation (figure 7B). However, the circulation of seawater with the open ocean was no longer impeded. Deposition was in very shallow water and the deposits were laid down in shallow marine, beach, lagoonal, and deltaic depositional environments. Marine fusulinids indicate a latest Pennsylvanian age (Virgilian) for the Honaker Trail below Dead Horse Point (Doelling and others, 1994). The formation was deposited between 305 and 295 Ma.

From subsurface data we learn that the total Honaker Trail Formation is 1600 to 2100 feet (490–640 m) thick (figure 3). The contact between the Pennsylvanian Honaker Trail Formation and the overlying Pennsylvanian-Permian rocks of the Cutler Formation is a paraconformity—rocks above and below the contact show little or no erosional relief, with beds of both formations parallel to one another but separated by a 10-million-year time gap.

## Rocks of the Pennsylvanian-Permian Period

During latest Pennsylvanian (late Virgilian) time and throughout the Permian, the Uncompahgre Highland to the northeast continued to rise and erosion eventually exposed Proterozoic granitic and mafic rocks; radiometric ages of these rocks from near Grand Junction, Colorado, range between about 1740 to 1400 Ma (Scott and others, 2001). The clastic erosional debris shed to the southwest into the Dead Horse Point area was deposited as a series of alluvial fans at the foot of the highlands; the embayment was filled and the ocean shorelines retreated farther to the southwest (figure 7C). The iron content of the source rocks imparted a red coloration to the rocks deposited in this area. Granites, made up of quartz, feldspar, mica, and small percentages of dark iron-bearing

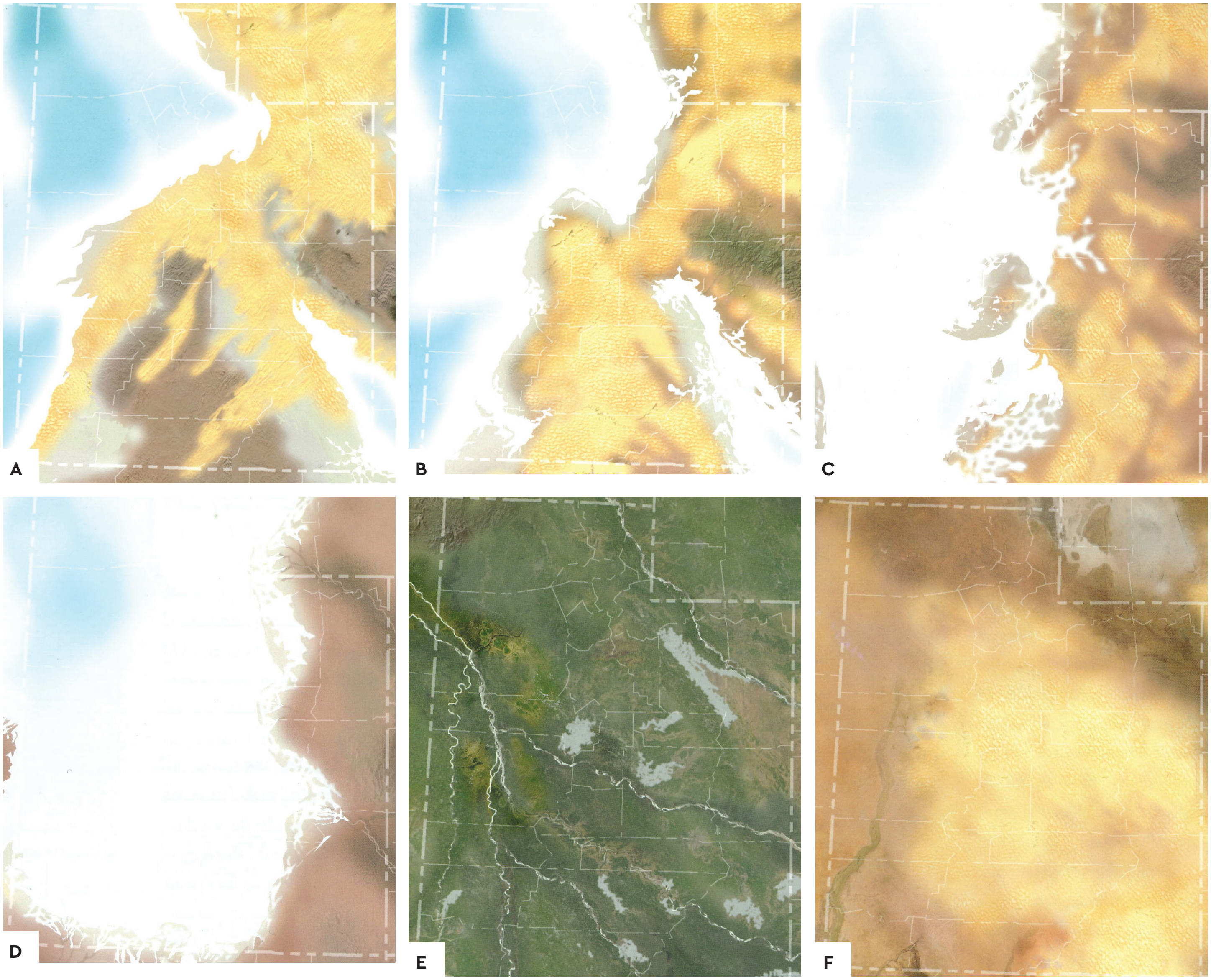



***Figure 7.*** *Paleogeographic maps of Utah during the: (A) Middle Pennsylvanian, Paradox Formation – 308 Ma; (B) Late Pennsylvanian, Honaker Trail Formation – 300 Ma; (C) late Early Permian, Cutler Formation – 272 Ma; (D) Early Triassic, Moenkopi Formation – 245 Ma; (E) Late Triassic, Chinle Formation – 215 Ma; (F) Late Triassic-Early Jurassic, Wingate Sandstone – 205 Ma; and (G) Early Jurassic, Kayenta Formation – 200 Ma. Modified from Blakey and Ranney (2008).*

minerals, were eroded and provided source material for sandstones rich in feldspar, or arkoses. The Permian rocks below Dead Horse Point were deposited between 285 and 270 Ma.

Pennsylvanian-Permian rocks in the Dead Horse Point area are part of the Cutler Formation/Group. Northeast of Dead Horse Point, these rocks are part of a thick sequence of conglomeratic, arkosic alluvial-fan sediments deposited in front of the Uncompahgre Highland and are given formation status (figure 3). These strata grade southwest into fluvial, coastal dune, and tidal flat deposits that are exposed in Canyonlands National Park southwest of Dead Horse Point, where they are divided into five units—the Pennsylvanian Halgaito and Elephant Canyon Formations, and the Permian Cedar Mesa Sandstone, Organ Rock Formation, and White Rim Sandstone (see Green River Overlook geosite, Island in the Sky District, Canyonlands National Park, this volume). In that area, the Cutler is elevated to group status and the five units are considered formations. Dead Horse Point is in the transition between these areas. The eolian White Rim Sandstone (the upper formation) is the only formation of the Cutler Group that extends as far as Dead Horse Point. The point where the White Rim pinches out is visible below Dead Horse Point (figure 4). In this area, beds below the White Rim are more like the northeast facies than the other four formations of the Cutler Group. Thus, these arkosic beds are still considered Cutler Formation, but are divided into informal upper and lower members (Condon, 1997). The lower member is Late Pennsylvanian (late Virgilian) to Early Permian (Wolfcampian) in age based on regional correlations and fusilinid zones (Sanderson and Verville, 1990; Condon, 1997).

The upper and lower members of the Cutler Formation near Dead Horse Point are alike and consist of interbedded arkosic sandstone, subarkosic sandstone, sandstone, conglomerate, micaceous siltstone, and limestone. Many of the arkosic and subarkosic sandstone beds display trough cross-bedding, and cut-and-fill structures indicating fluvial deposition. Conglomeratic lenses locally contain pieces of granite as much as 15 centimeters (6 in.) in diameter. Quartzose sandstones are mostly fine grained, well sorted, and micaceous. Many were deposited by the wind. The eolian rocks are mostly orange and red-orange, whereas the fluvially deposited arkoses, subarkoses, and conglomerates are dark red to purple. The gray limestones are marine deposits laid down during short intervals when the sea was able to push shorelines northeastward. These beds are more prevalent in the lower member of the Cutler Formation and form the basis for dividing the lower from the upper member (the popular Shafer Trail is located on this boundary below Dead Horse Point). The number of limestone beds decreases northeastward. These are locally fossiliferous, containing brachiopods, bryozoans, gastropods, crinoid debris, and rare cephalopods and trilobites.

The Lower Permian White Rim Sandstone is only present southwest of Dead Horse Point and forms a white rim around the Island in the Sky in Canyonlands National Park (figure 4). The White Rim is a fine- to medium-grained quartzose sandstone exhibiting both planar and cross-stratified beds. The White Rim formed as a near-shore, beach, and back-beach deposit. The White Rim Sandstone is 0 to 60 feet (0–18 m) thick.

The upper contact of the Permian strata with the overlying Triassic beds is sharp, marked by local scouring and channeling and is unconformable. In most cases the plane of unconformity appears flat. The unconformity is regional and indicates a period of non-deposition lasting at least 30 to 35 million years. The lower member of the Cutler Formation is 180 to 220 feet (55–67 m) and the upper member is 700 to 1000 feet (200–300 m) thick in the Dead Horse Point area (figure 3).

## Rocks of the Triassic Period

The Triassic Period in the Dead Horse Point area is represented by the Moenkopi and Chinle Formations and part of the Wingate Sandstone (figure 3). During deposition of the Moenkopi, the open sea or ocean retreated farther to the southwest and deposition was from sluggish streams migrating over broad tidal flats that were at or near sea level (figure 7D). The Uncompahgre Highlands to the northeast were now much lower and the sediments derived from them contain more mica. Fluvial environments dominated during deposition of the Chinle (figure 7E) and the influence of the sea was gone. Toward the end of Chinle deposition, the Uncompahgre Highlands were nearly leveled or reduced to very low relief near Dead Horse Point.

Moenkopi deposits were laid down approximately 244 Ma and again between 242 and 238 Ma and Chinle deposits were laid down from 220 to 215 Ma. Events occurring between deposition of the Moenkopi and Chinle Formations are not recorded by rocks in this area. Sediments may have been deposited, but were later eroded during those 18 million years. The top of the Triassic is within the Wingate Sandstone of the Glen Canyon Group.

### Moenkopi Formation

The Moenkopi Formation is divided into four members in the Dead Horse Point area (figures 3 and 6), which in ascending order are: Hoskinnini, Tenderfoot, Ali Baba, and Sewemup (Sew-em-up). All four members total about 300 to 520 feet (90–160 m) thick at Dead Horse Point. Thicknesses of the four members vary independently.

The Hoskinnini Member consists mostly of a chocolate-brown, fine-grained, poorly sorted, micaceous to sub-arkosic sandstone. It is poorly bedded and displays irregular to wavy laminae. Locally, it has a thin bed of gypsum near the base. It forms a steep slope in its lower part and a cliff in its upper part (figure 6). The Hoskinnini Member here is generally 60 to 110 feet (18–34 m) thick. Its upper contact with the Tenderfoot Member is mostly sharp, an unconformity leaving as much as 2 million years with no record.

The Tenderfoot Member forms a 100- to 160-foot-thick (30–49 m) slope of light chocolate-brown, thin-bedded siltstone with widely spaced, 1- to 3-foot-thick (0.3–1 m) sandstone ledges (figure 6). Ripple cross-stratification is particularly widespread.

The Ali Baba Member forms a 100- to 160-foot-thick (30–49 m) series of chocolate-brown ledges and slopes (figure 6). It consists of thin- to medium-bedded siltstone with numerous sandstone beds. The sandstone beds are 1 to 10 feet (0.3–3 m) thick and display low-angle cross-stratification. The Ali Baba Member locally contains a thin, yellow-gray limestone and calcareous siltstone at its base, which may correlate with the Sinbad Member of the Moenkopi Formation in the San Rafael Swell and Circle Cliffs areas of Utah.

The Sewemup Member is a 60- to 120-foot- (18–37-m) thick slope-forming unit consisting of homogeneous, gray-red to pale-red-brown siltstone, with widely spaced, thin (less than 3 feet [1 m] thick) sandstone ledges. The siltstone displays horizontal and ripple cross-lamination and is crisscrossed by thin gypsum veinlets. The contact with the overlying Chinle Formation is sharp and unconformable, but commonly poorly exposed. It is placed at the base of a distinctive white to mottled gritstone (figure 6), or between the gray-red or gray-green mudstone and siltstone of the lower part of the Chinle and the orange-red siltstones of the upper part of the Moenkopi.

### Chinle Formation

The Chinle Formation is divided into three members in the cliffs below Dead Horse Point: an unnamed lower slope-forming member, the Black Ledge Member, and the upper Church Rock Member (figures 3 and 6). The formation consists of complex interbedding and lensing arrangements of sandstone, pebble conglomerate, siltstone, mudstone, and rare limestone. The red-brown, tan, and gray-red sandstones are very fine to coarse grained, moderately to well sorted, quartzose, and slightly micaceous. Primary sedimentary structures include low-angle cross-stratification, horizontal stratification, asymmetric ripples, and channeling, all of which point to deposition in a floodplain with northwest-flowing river channels, adjacent oxbow lakes, ponds, and swamps (figure 7E) (Blakey and Ranney, 2008). Soft-sediment deformation, including disharmonic folds and low-angle detachments, is common, especially below thick sandstone ledges. Pebble and intraformational conglomerates occur as lenses and in scour channels concentrated in the lower parts of sandstone beds. Quartzose and micaceous siltstone is interbedded with the sandstones and conglomerates and displays low-angle cross-stratification and ripple lamination. Mudstone is gray red to gray green, bentonitic, and poorly exposed. A few gray red nodular limestone beds are locally present. White to variegated gritstone locally marks the base of the Chinle Formation. The grit is poorly sorted and contains rounded to angular, coarse to pebble-size grains of quartz. Where variegated, the gritstone may have existed as a paleosol. Mudstone and siltstone dominate in the lower slope-forming member. Sandstone and conglomerate channels, when found in the lower slope-forming member, are locally mineralized with uranium, vanadium, and copper minerals. Fine carbonaceous plant debris is abundant in these channels. The lighter overall color of this lower member is caused by reduced iron in this part of the formation. This reduction of iron commonly extends as much as 3 feet (1 m) into the underlying Moenkopi Formation. The lower slope-forming member is 70 to 90 feet (20–30 m) thick, and the upper contact is abrupt.

The Black Ledge is dominated by red-brown sandstone and black, desert varnish-stained conglomerate. The sandstones commonly contain scattered logs and branches of petrified wood. Lowermost lenses of sandstone are locally mineralized with uranium and copper minerals. The Black Ledge is about 90 to 110 feet (30–34 m) thick. The upper contact is gradational into the Church Rock Member.

The Church Rock Member is mostly a red-brown sandstone and siltstone, but sandstone ledges are more common in the lower part. Some beds include distinctive ripple-laminated sandstone, but the bedding in much of this unit is indistinct, and the rock breaks into equidimensional fragments. Blocky, red-brown, fine-grained, well-sorted, thick-bedded sandstone, that mimics the overlying Wingate Sandstone, is common in the upper 10 to 30 feet (30–49 m) of the member. These upper sandstones have informally been referred to as the Hite beds. The Church Rock Member is 160 to 200 feet (49–60 m) thick.

The contact of the Church Rock Member with the overlying Wingate Sandstone is sharp but conformable, commonly being placed below the massive cliff of well-sorted sandstone typical of the Wingate. No regional channeling or angular unconformity is apparent, and the lowermost part of the Wingate does include thin, bedding-parallel sandstone and siltstone beds that suggest continuous deposition across the Chinle and Wingate contact. The Chinle and Wingate contact was once thought to represent an unconformity, named the J-0 unconformity, at the Triassic-Jurassic boundary (Pipiringos and O'Sullivan, 1978). However, the Wingate contains beds of both Triassic and Jurassic age (Molina-Garza and others, 2003; Lockley and others, 2004; Lucas and others, 2005). The J-0 unconformity, if it exists here, is within the Triassic and likely represents a short period of time.

## Rocks of the Triassic-Jurassic Period

The Wingate Sandstone is a prominent cliff former below the promenade at Dead Horse Point and below the Island in the Sky bench to the southwest (figures 4 through 6). The Wingate forms red-brown, nearly vertical cliffs streaked and stained with "desert varnish." The Chinle and Moenkopi slopes below the cliff are commonly littered with large blocks of the Wingate. The Wingate Sandstone is ordinarily described as one massive unit because partings or bedding planes are rare except near the base of the formation. The Wingate consists mostly of light-orange-brown, moderate-orange-pink, or pale-red-brown, fine-grained, well-sorted, cross-bedded sandstone. The rock is usually well cemented and well indurated; weathered exposures are nearly smooth. The eolian Wingate was deposited in a great erg that extended from the Four Corners area to north-central Utah (figure 7F) (Blakey and Ranney, 2008), as indicated by the high-angle cross-bedded sandstone. However, the bedding-parallel sandstone beds near the base of the formation suggest that fluvial processes were still a large part of its early depositional history.

The formation is 300 to 400 feet (90–120 m) thick in the Dead Horse Point area. The contact of the Wingate with the overlying Kayenta Formation is generally sharp and conformable as seen from a distance, but difficult to place close-up (figures 4 through 6). Generally, the line is placed at the horizon where the smooth cliff is replaced by thick cliffy ledges.

## Rocks of the Lower Jurassic Period

With the exception of the Quaternary unconsolidated sediments, Lower Jurassic strata form the top of the geologic column at Dead Horse Point (figure 3). These strata include the upper part of the Wingate Sandstone, Kayenta Formation, and Navajo Sandstone, and were deposited between 205 and 187 Ma. The Kayenta was deposited in a fluvial environment (figure 7G), whereas the Navajo formed in a sand-dune desert. A few sandstone beds in the upper Kayenta were also deposited by the wind.

### Kayenta Formation

The Kayenta Formation caps most of the upper benches at Dead Horse Point; the view points are located on this unit (figures 3 through 6). The Kayenta consists mostly of stream-deposited sandstone lenses, with lesser amounts of eolian sandstone, intraformational conglomerate, siltstone, and shale. The unit is primarily red brown, but individual lenses and beds vary considerably in color; some are purple, lavender, tan, orange, or white. In outcrop, the Kayenta is ledgy and step-like. Sandstone in the Kayenta exhibits both high-angle and low-angle cross-bedding. Some lenses display channeling, current ripple marks, and rare slump features. The grain size is more variable than in the Wingate and Navajo, ranging mostly from fine to medium. Siltstone, shale, and intraformational conglomerate appear as partings or are interlayered with the sandstone. These softer constituents are rare in the lower half of the formation and become common in the upper part.
The Kayenta Formation was deposited in a sandy braided river system although the environment was arid (figure 7G). Perennial streams flowed west from the remaining Ancestral Rockies and the Appalachians far to the east (Lynds and Hajek, 2006; Blakey and Ranney, 2008). Floodplains (overbank deposits) formed adjacent to active channel belts where the channel threads were only about 3 feet (1 m) deep. Tracks of dinosaurs, including Eubrontes, a tridactyl (three-toed) theropod (bipedal) dinosaur, are commonly found in the Kayenta in Dead Horse Point State Park and elsewhere in southern Utah.

The Kayenta Formation is 220 to 300 feet (67–90 m) thick in the Dead Horse Point area. It forms the bench tops and is rarely completely exposed. The upper contact is mostly sharp, but intertonguing between the Kayenta and the overlying Navajo Sandstone is common. Remnants of the Navajo Sandstone rest on the benches, and at least at Dead Horse Point, are far from the cliff edge.

### Navajo Sandstone

The Navajo Sandstone is not exposed at Dead Horse Point but can be viewed to the east in an area known as Behind the Rocks (figure 6). The Navajo is mostly exposed as cliffy to rounded bare sandstone. The formation is an orange to light-gray, massive cross-bedded sandstone. The eolian Navajo is a classic example of a major Sahara-like erg (dune) environment.

# STRUCTURAL AND GEOLOGIC HISTORY

## Regional Setting

The fold and fault belt of the Paradox Basin, where Dead Horse Point is located, extends southeast from here into Colorado. This structural belt is characterized by a series of northwest-trending anticlines and faults that developed in response to movement caused by crustal forces or by shallow deposits of Pennsylvanian salt. The most obvious structural feature observed from Dead Horse Point is the spectacular Cane Creek anticline that fills the panoramic view to the east (figure 6). The events that caused this and other structural features to form in the region began over a billion years ago during the Precambrian (Proterozoic) when movement began on high-angle basement faults and fractures 1700 to 1600 Ma (Stevenson and Baars, 1987).

The Paradox Basin of southeastern Utah and southwestern Colorado, like the fold and fault belt within it, is an elongate, northwest-southeast-trending evaporitic basin. The Paradox Basin predominantly developed during Pennsylvanian time about 318 to 300 Ma as part of a pattern of basins and fault-bounded uplifts from what is now Utah to Oklahoma. One result of this tectonic event was the uplift of the Ancestral Rockies in the western United States. The Uncompahgre Highland (uplift) of eastern Utah and western Colorado formed the westernmost range of the Ancestral Rockies during this ancient mountain-building period. The Uncompahgre Highland is bounded along its southwestern flank by a large basement-involved, high-angle reverse fault (Frahme and Vaughn, 1983; Kluth and DuChene, 2009). This fault has been identified from geophysical seismic surveys and exploration drilling. As the mountains rose, movement along this fault caused an accompanying depression, a foreland basin, to form to the southwest—the Paradox Basin. Rapid basin subsidence, particularly during the Pennsylvanian and into the Permian, accommodated deposition of large volumes of deeper basin evaporitic and marine sediments which intertongued with basin-margin non-marine arkosic material shed from the mountain area to the northeast (Hintze and Kowallis, 2009).

Later, the Uncompahgre Highland was eroded down during the Triassic and Jurassic. The area was uplifted again during the Late Cretaceous and early Tertiary Laramide orogeny to form the Uncompahgre uplift observed today (Hintze and Kowallis, 2009).

### Salt Movement

Salt, which was deposited as part of the Paradox Formation, has a low specific gravity, is ductile and less dense than the surrounding rocks, and behaves plastically. The salt moves due to high confining pressure from the weight of the overlying column of rocks or sediments. Salt movement can push up and raise overlying strata in some places, while the salt is squeezed and thinned in others. This movement (often piercing the strata above [diapiric movement]) progresses along zones of weakness or areas of low confining pressure, forming large folds such as the Cane Creek and Shafer anticlines (figures 2, 5, and 6). The weak zones likely developed above and along the northwest-trending basement faults in the region which experienced continued movement (Shoemaker and others, 1958). Salt-cored anticline development has been intermittently active from the Pennsylvanian to the present day (Shoemaker and others, 1958; Cater, 1970; Case and Joesting, 1973; Baars and Doelling, 1987; Doelling, 1988; Oviatt, 1988).

### Jurassic and Cretaceous Sedimentation

The region continued to lie near sea level, but received continental deposition through Early Jurassic time. Because no bedrock units younger than the Early Jurassic Navajo Sandstone are present near the park, no record exists here of the geologic events that happened in the interval from 187 to 1.5 Ma. The area likely received continental deposition during the remainder of the Jurassic and the Early Cretaceous and shallow-marine deposition during the Late Cretaceous, as attested in surrounding areas.

### Late Cretaceous–Early Tertiary Folding, Faulting, and Intrusions

Large uplifts and basins developed in the Colorado Plateau during the Laramide orogeny between the latest Cretaceous (Maastrichtian, about 70 Ma) and the Eocene (about 38 Ma). The northern end of the Laramide Monument upwarp can be viewed to the south from Dead Horse Point where Permian-age rocks are extensively exposed (figures 2, 4, and 5). Other nearby Laramide features include the San Rafael Swell to the west, the Circle Cliffs uplift and Henry Mountains Basin to the southwest, the Uinta Basin to the north, and a rejuvenated Uncompahgre uplift to the northeast.

The regional dip of strata in the area is 2 to 4 degrees northward. The gentle northwest-trending anticlinal and synclinal folds in the Dead Horse Point area disrupt this regional slope. The axes of the Cane Creek and Shafer anticlines (figures 5 and 6) are aligned directly over local bulges of Paradox salt. The overlying rocks were fractured and locally extended by minor faults just off the crest of the anticlines (Morgan and others, 1991). Other anticlines in the Paradox fold and fault belt that are aligned with salt walls have major normal faults such as the Moab fault to the northeast. Total displacement across the Moab fault is estimated at 1500 to 2400 feet (460–730 m) of displacement (Doelling and others, 1994; Mauch and Pederson, in press). The timing of these events is unclear, except that they occurred between 80 and 15 Ma.

The La Sal Mountains (figure 6), on the horizon to the east above the Cane Creek anticline, are a classic example of a laccolithic intrusion. The La Sal Mountains are a complex of granitic (diorite porphyry) rocks intruded into a salt wall about 27.9 to 25.1 Ma during the Oligocene (Nelson, 1998). These peaks are more than 12,000 feet (3600 m) above sea level and were glaciated during the Pleistocene ice ages (Hintze and Kowallis, 2009). In the distance to the southeast, another laccolithic intrusion, the Abajo Mountains, can be seen. This intrusion is dated between 28 and 25 Ma (Nelson, 1998).

### Jointing and Fractures

The sandstones in and around Dead Horse Point are brittle and when folded or bent produce joints and fractures. Fracture patterns and joint sets are related to regional tectonics and salt movement. Large-scale, northeast-trending fractures are found along the Cane Creek anticline (Morgan, 1992). Jointing is prevalent in the Cutler, Wingate, and Kayenta Formations. A dominant set of joints strikes northwest to north-northwest (Doelling and others, 1994). Joints are closely spaced in many areas, but vary with lithology and bed thickness.

### Late Tertiary–Quaternary Regional Uplift and Erosion

The Colorado Plateau began rising in late Cenozoic time during the Miocene (23 Ma) (Hunt, 1956; Lucchitta, 1979; Hintze and Kowallis, 2009). This regional uplift changed the landscape from one of deposition to one of massive erosion. Several thousand feet of sedimentary rocks have been removed by the erosive processes of mass wasting, wind, and running water. Most of this material has been carried to the sea by the Colorado River system.

As the Colorado Plateau rose, the Colorado River and its tributaries rapidly cut into the strata. The incision rate near the center of the Colorado Plateau (Lee's Ferry, Arizona) is calculated at about 35 centimeters per thousand years (14 in./k.y.) (Pederson and others, 2013). The results of this action are the countless canyons and entrenched meanders visible from Dead Horse Point. Most of the eroded material from the Colorado Plateau has been carried to the sea by the Colorado River system.

## ECONOMIC GEOLOGY

Dead Horse Point is surrounded by activity associated with the extraction of three principal minerals—potash, petroleum, and uranium. All three saw periods of "boom and bust" during the 20th century. They have been, and remain, an important part of the local economy, as well as the subject of debate in how the lands around the Dead Horse Point State Park should be managed. Only the activities of potash production and targets for oil drilling can be seen from Dead Horse Point.

### Potash

This region of the Paradox Basin is underlain by the salt-bearing Paradox Formation. Seventeen of the depositional cycles in the Paradox Formation contain halite (common table salt [NaCl]) and potash salts which are mined near Dead Horse Point (Doelling and others, 1994). The most common question asked at Dead Horse Point State Park is "what are those big blue ponds off to the east?" The "big blue ponds" are solar evaporation ponds (figure 6) designed to extract potash from brines pumped from wells penetrating the salts of the Paradox Formation. Potash is an important economic resource used to manufacture a variety of products including fertilizer (93%), chemicals, pharmaceuticals, soap, glass, synthetic rubber, and explosives (Tripp, 2010; Carney, 2019). The potash minerals are carnallite and sylvite (Ritzma, 1969). Sylvite is less abundant but is the primary commercial mineral. Chemically, it is composed of 52.4% potassium and 47.6% chlorine.

In 1964, Texas Gulf Sulfur Inc. (now Intrepid Potash, Inc.) began underground room-and-pillar mining of potash from the Paradox Formation cycle number 5 along the Cane Creek anticline at depths from 2500 to 3000 feet (760–900 m). Underground mining operations were difficult due to intensely folded and faulted salt beds, salt movement, pockets of natural gas, high temperatures, and mine-roof maintenance problems that made it uneconomic to mine underground (Phillips, 1975). Before mine operations began, 18 miners were killed in a gas explosion while constructing lateral shafts (Huntoon, 1986). In 1970, the operations were converted to solution mining. Colorado River water is now pumped into the old mine workings to dissolve the potash and salt (figure 8). The resulting brine is pumped out and piped to the solar evaporation ponds where the minerals are eventually harvested.

Potash production is roughly 100,000 tons annually (Andrew Rupke, Utah Geological Survey, verbal communication, 2019). Halite is a by-product and 40,000 to 60,000 tons are produced annually.

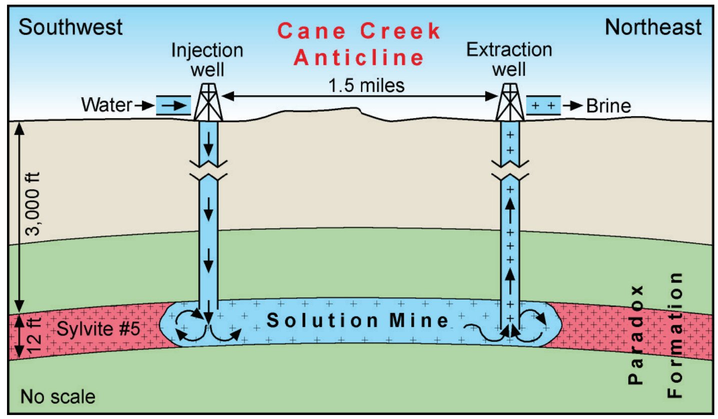


*Figure 8. Schematic cross section showing the solution-mining process on the Cane Creek anticline where salt and potash in the sylvite number 5 depositional cycle of the Pennsylvanian Paradox Formation are dissolved by injecting river water. The resulting brine is withdrawn by an extraction well and pumped to the solar evaporation ponds where the minerals are eventually harvested. From Doelling and others (2010).*

The halite is used in water softeners, animal feed, for road salt, and oil field drilling fluids. Between 1994 and 2003, potash prices remained stable ranging from $150 to $200 per ton. Potash prices started rising in 2005 and peaked during 2009 at nearly $800 per ton, but by 2019 had declined to over $250 per ton (Andrew Rupke, Utah Geological Survey, verbal communication, 2019).

### Petroleum

Since the early 1920s, the immediate area around Dead Horse Point has been the site of oil and gas exploration drilling (Chidsey and others, 2016; Chidsey and Eby, 2017). Oil and gas is produced from the Cane Creek shale zone of the Paradox Formation. The Cane Creek shale zone consists of thinly interbedded, black, organic-rich marine shale, dolomitic siltstone, dolomite, and anhydrite (Morgan, 1992; Grove and others, 1993; Chidsey and others, 2016). Petroleum is trapped in fractured reservoirs usually on the crest of anticlinal closures.

The Cane Creek anticline (figure 6) was the most obvious structural drilling target and was tested sporadically in the Cane Creek oil field near the Colorado River eight times since 1924. However, only 1887 barrels of oil and 25 million cubic feet of gas were produced from the structure (Stowe, 1972). In 1960, lands on the crest of the Cane Creek anticline were withdrawn from oil and gas leasing to prevent interference with potash mining (Smith, 1978).

The oil field area has since been abandoned as a target for oil. Horizontal drilling was never used at the Cane Creek anticline.

The 1990s saw dramatic improvements in the ability to successfully complete wells in fractured reservoirs using horizontal drilling technology and the Cane Creek shale zone again became an important target. Several new fields were discovered in the area near Dead Horse Point as seen on the drive to the park (Morgan, 1992; Grove and others, 1993; Chidsey and others, 2016) and exploration is ongoing; however, none of these fields can be seen from Dead Horse Point.

## PANORAMIC VIEWPOINTS

Dead Horse Point is well known for its remarkable panoramic views (figures 4 through 6). Although there are some features of interest on Dead Horse Point itself, most of the incredible sites associated with the park are not within its boundaries—the exciting panoramic views looking over the Canyonlands area of Utah. Changes in the strata's color, rock types, thickness, composition, weathering, and erosion enhance the interest of these magnificent sights.

If at all possible, the visitor should take advantage of road logs found in Doelling and Chidsey (2012). Dead Horse Point should be visited before and after enjoying the sites along these roads.

### Panoramic View #1 (figures 4 and 9)

The Colorado River meandering around The Gooseneck is a favorite view (figure 4); note the Shafer Trail. During the Laramide orogeny (latest Cretaceous through Eocene time [about 70 to 30 Ma]), the Colorado Plateau region developed basins and uplifts. These basins and uplifts were all elevated during the general uplift of the Colorado Plateau beginning during the Miocene Epoch (23 Ma). Rocks in the area of Dead Horse Point dip gently northward from the Monument uplift. The axis of the Monument uplift is north-south. The view from Dead Horse Point is generally along the axis, which plunges northward. Strata dip gently eastward and westward on each side of the axis. The Colorado River has therefore eroded deeper into the Earth's crust as it crossed the uplift axis, revealing the oldest formations exposed in this part of the Colorado Plateau region and creating the Canyonlands country. Dead Horse Point owes its beautiful panoramic vista to the fact that the river has cut into these older spectacularly colored rock formations.

The stratigraphic section begins with the Permian Cutler Formation at river level to Jurassic Navajo Sandstone on the skyline in the distance in Canyonlands National Park (figures 2 and 4). Dead Horse Point is in the transition area where Cutler facies change. The Permian White Rim Sandstone that was so well-displayed to the southwest pinches out just below Dead Horse Point (figure 4). Without the White Rim, the Cutler Formation is subdivided into informal upper and lower members. The upper member is dominated by fluvial and eolian arkosic sandstone, representing material shed from the Uncompahgre Highlands of the Ancestral Rockies to the northeast. The lower member forms a prominent bench (see Shafer Trail below) and is characterized by numerous, distinct, thin limestone ledges containing marine fossils.

### Panoramic View #2 (figures 5 and 9)

From panoramic view #2 we see Pyramid Butte, the Colorado River, and the north-dipping Cutler Formation on the flank of the Shafer anticline; the Needles District of Canyonlands National Park and Abajo Mountains are in the distance to the south (figure 5). The Abajos are another laccolithic intrusion, dated between 25 and 28 Ma (Nelson, 1998). The light band in the distant cliffs is in the lower part of the Chinle Formation with the vertical cliffs of the Wingate Sandstone above.

During the middle to late Cenozoic, the ancestral Colorado River and its tributaries flowed through meandering channels in wide valleys on easily eroded rocks such as the now-removed Cretaceous Mancos Shale. Once these river channels were established, they later became superimposed and entrenched into buried structures, such as the Shafer and Cane Creek anticlines, and into resistant rocks such as the Wingate and Navajo Sandstones. The deeply entrenched Gooseneck of the Colorado is a classic example of this geomorphologic process (figure 2). This magnificent entrenched meander of the Colorado River is easily seen just below Dead Horse Point to the southwest. At the narrowest neck of the peninsula, the distance across bedrock between the river channel on either side of the peninsula is less than a quarter mile (0.4 km). Here, it is entrenched into about 400 feet (120 m) of the lower Cutler Formation. The river level is about 2000 feet (600 m) below the elevation of the pavilion at the Dead Horse Point overlook. For a distance of about 4 river miles (6 km) along the Gooseneck, the river proceeds less than 0.3 land miles (0.5 km)! The river is capable of cutting through the 400-foot (120-m) wall of lower Cutler rocks and has cut through similar "necks" in other areas, but it will probably take thousands of years to do so.

The Shafer anticline (sometimes referred to as Shafer dome) can be seen just south of Dead Horse Point (figure 5). The axis curves essentially around The Point, trending northwest on the west, east-west to the south, and northeast to the east (figure 2). Although less obvious than the Cane Creek anticline to the east, the Shafer anticline is a major structural feature. Beds dip 5 to 10 degrees from the crest, where rocks as old as the Pennsylvanian Honaker Trail Formation are exposed along the Colorado River on the eastern axis of the structure. A series of minor, high-angle extension faults generally parallels the northwest-trending axis along the southwest limb (figure 2). The Shafer anticline most likely developed from salt bulging in the Paradox Formation, and movement on deep, older faults. The structure was drilled in a few localities, but no petroleum was found.


*Figure 9. Google Earth image (© 2018 Google) of Dead Horse Point (red dot) and surrounding area showing the direction (red arrows) of the views shown on figures 4 through 6.*

### Panoramic View #3 (figures 6 and 9)

Looking east we see an incredible view of the Cane Creek anticline (middle ground), solar evaporation ponds, and jointed Navajo outcrops of the Behind the Rocks area in front of the La Sal Mountains in the distance (figure 6). The northwest-trending Cane Creek anticline is the largest structural feature in the area (figure 2). Beds dip gently, 5 to 8 degrees in both directions away from the crest. A series of minor, high-angle extension faults parallel the axis of the anticline along the northeast limb (figure 2). The Cane Creek anticline likely developed from a combination of salt bulging and renewed movement on deep, older structures.

The Kayenta Formation forms the rim of the overlook followed down section by Wingate, Chinle, Moenkopi, and upper Cutler at the base. The various members of the Chinle and Moenkopi are well displayed (figure 6). The orange-red upper member of the Cutler Formation is very arkosic and forms steep, ledgy slopes, whereas the lower member of the Cutler capped by thin limestone overlying arkosic clastic rocks forms the relatively flat and extensive terrain observed. The Pennsylvanian Honaker Trail Formation is exposed in the core of the Cane Creek anticline where the Colorado River cuts across the axis of the structure. The upper 240 feet (73 m) of the Honaker Trail crops out here as yellow-gray to gray ledgy cliffs. It consists of interbedded sandstone, limestone, and siltstone. Some of the limestone beds are fossiliferous containing crinoid debris, brachiopods, bryozoa, corals, gastropods, and rare trilobites. These rocks are the oldest exposed in the area.

The brine from the solution mine (described earlier, figure 8) is pumped to the large solar evaporation ponds observed from Dead Horse Point (figure 6); it is saturated with respect to salt and close to saturation with respect to sylvite. Halite is a contaminant and is partially removed in a carefully controlled evaporative process. Brine, upon evaporating to a suitable concentration, is drained into a new pond, each time leaving some of the halite behind. The process is repeated several times before the final liquid becomes suitably concentrated in potassium salts. The slurry is then pumped to a processing facility where the potash is separated from the remaining salt by flotation (Bryce Tripp, Utah Geological Survey, verbal communication, 2009). The potash is then bagged and sold. The potash solar evaporation ponds so prominently displayed east of Dead Horse Point actually consist of 23 ponds in four areas. The ponds cover a total of 400 acres (160 ha) and are 2 to 3 feet (0.6–0.9 m) deep. The solar ponds are lined with heavy vinyl to prevent leakage of the brine into the groundwater aquifers and Colorado River. The beautiful blue color of the water is the result of a dye (similar to food coloring) which is introduced to enhance evaporation. After evaporation, the potash and salt crystals are harvested by 25-ton scraper-loaders that can also be seen from Dead Horse Point. If the product cannot be harvested within two years the operation becomes uneconomical. The operators do not like wet years and cloudy skies.

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