Canyon Legacy

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GEOLOGY OF THE CANYONLANDS

Canyon Legacy

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Canyon Legacy was established in 1989 to publish articles on the history, prehistory and natural history of the Colorado Plateau in Southeastern Utah and the Four Corners region.

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WITHIN...

Anticlines, basins, cross-bedding, desert varnish, faults, fins, folds, grabens, joints, laccoliths, petrified dunes, potholes, salt valleys, slickrock, spires and uplifts: these terms -- and many more -- describe the surface features of Canyon Country. In few other places on this earth is geology more exposed to view.

Everything of magnificence within this section of the Colorado Plateau is a result of geologic forces at work, past and present. As the days warm, the rivers rise and blossoms begin to carpet the desert, explore with us the ***Geology of the Canyonlands.***

Photo by Jean Akens

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FRONT COVER: Photo by talented Moab writer/photographer/ mountain bike enthusiast Todd Campbell, whose contributions to the Canyon Legacy are much appreciated.

INTRODUCTION TO THE GEOLOGY OF THE COLORADO PLATEAU

by Michael J. Price

SUMMARY The Colorado Plateau is acclaimed for its vast abundance of geologic wealth. Prospectors have long explored for mineral and petroleum riches and have discovered uranium, vanadium, gold, silver, copper, potash, oil, natural gas, coal, and others. Now, a new and exciting geologic resource emerges on the Plateau: the study of geology for geology itself, for fun, enjoyment, and to obtain a better understanding of man's place on our planet. The area has captivated the interest of professional and academic geologists for years, but a new class of casual, recreational geologists is discovering the Colorado Plateau.

Southeast Utah is a prime area for recreation and tourism. Visitors notice the fascinating variety of colorful cliffs, canyons, arches, and spires that make up the unusual topography that has helped to draw them here. Many are now asking serious, probing questions about the origin of the unusual landforms and rock formations that they have come here to enjoy. Many excellent guidebooks acquaint the lay person with the geology of Southeastern Utah. They help make the complex geologic history of the Colorado Plateau less mysterious. This paper will further acquaint visitors with the fascinating and complex geologic history of our area.

THE PLATEAU Geologists consider the Colorado Plateau as a physiographic province, or subdivision, of the Western North American continental plate. As a physiographic province, the plateau exhibits characteristics found to be similar throughout its vast extent. The Basin and Range Province borders the Colorado Plateau on the west and southwest. The Sevier Orogenic belt, or Overthrust Belt, defines the western boundary. The Mogollon Rim and Datil Highland define the southern limit of the Plateau. The Rio Grande Rift borders the Plateau on the southeast side. The Rocky Mountains flank the Plateau on its east side and an extension of the Rockies, the Uncompahgre Uplift, penetrates deep into the Plateau from the east. The Wyoming Basin and the Uinta Uplift define northern limits of the Colorado Plateau.

Moderate to high average elevation characterizes the plateau's topography. At its lowest western point, where the Colorado River leaves the western Grand Canyon and enters Lake Mead, the elevation is 1000 feet. The summit of Mt. Peale, the highest peak in the La Sal Mountains (also Utah's second highest mountain range), is over 12,700 feet high. The average elevation of the Plateau is over 6000 feet. Up river from Moab, elevations rise from 4060 feet on the Colorado River at Professor Valley to 12,331 feet at the summit of Mt. Waas, the highest peak in the north La Sal group. This elevation change of over 8,270 feet occurs in less than 14 miles, with an average rise per mile of almost 600 feet. Extreme relief is very common.

Canyons are often several thousands of feet deep and sheer cliffs over 1000 feet high are not uncommon. Rivers, including the Colorado, Green, Dolores, Yampa, and Gunnison have cut deeply into the sedimentary blanket. Their canyons may expose rocks over 2 billion years old. Angular topography and dramatic erosional forms are the norm. High buttes, mesas, deep canyons, balanced rock pinnacles and, of course, graceful natural arches and bridges, are common.

Extensive layers of sedimentary rocks dominate the geology of the Plateau. Rock material eroded from earlier landscapes, to be transported by wind and water, then deposited in colorful layers across the entire area. Brilliant colors in the sediments come from minerals containing iron, manganese, copper, and other metals. The semi-arid climate provides excellent exposures of outcrop. Extensive areas of bare, unvegetated sandstone or "slickrock" occur in many parts of the Plateau. Recreational users have found that, in addition to providing outstanding scenery, slickrock can provide a challenging footing for jeep touring, mountain biking, and hiking.

Although Plateau geology is dominated by sedimentary rocks, some of its highest peaks are formed by very unusual igneous intrusions called laccoliths. The term laccolith comes from a Greek root meaning "cistern." Laccolithic intrusives represent large pools or blisters of molten rock, termed magma, that cooled slowly at fairly shallow depths. Large crystals formed in the igneous rocks, which were insulated by blankets of overlying sediments. (See Laccolithic Mountains, page 18, this issue.)

Prospectors have searched for and exploited the mineral resources of the Plateau since prehistoric time. The "Uranium Boom" (or "Booms") of the 1950s, 60s, and 70s have left their mark in many places. Early prospectors searched for high grade pitchblende deposits long before uranium was mined for use as a peacetime fuel. The ore was shipped to Europe and processed for the Radium and other radioactive elements that it contained. Vanadium often occurred with radium. It has been mined periodically since the early 1900s for use as a steel alloy. Copper occurs in selected parts of the Plateau, notably along faults that border collapsed salt anticlines. Copper and some silver have been mined infrequently from some of the higher grade deposits.

Placer gold has been found in old river gravel above the Colorado and Dolores Rivers. The discovery of gold in the La Sal Mountains in the late 1800s drew many prospectors into the area with hopes of "striking it rich." The gold ores soon played out but many of the miners decided to stay on in the rugged, untamed area.

Fossil fuels resources, including coal, oil, natural gas, tar sand, and oil shale have been developed in many areas of the Colorado Plateau. Recent discoveries have renewed interest in oil exploration in the Paradox Basin near Moab. Specialized horizontal drilling technologies are now being implemented to develop deep oil and gas reserves with minimal surface impact.

Potassium and sodium salts are now being mined in the Paradox Basin. Solution mining techniques dissolve soluble salts deep underground. Saturated brines flow into shallow surface ponds where they concentrate by evaporation during the warm summer months. Potash chloride (Potash) then travels to agricultural markets throughout the west. Sodium chloride salt, once an unmarketable by-product, now finds agricultural, water treatment, and de-icing use.

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GEOLOGIC TIME The concept of geologic time is difficult to perceive, even for professional geologists. The typical human life span of less than 100 years does not allow one to observe and to appreciate the true extent of geologic time. Most earth processes proceed at such a slow rate that it would require many lifetimes to investigate even the fastest of geologic phenomena.

Many analogies have illustrated the vastness of geologic time. A useful comparison is to relate blocks of geologic time to the viewing of a motion picture. Movie film often projects onto a screen sixteen frames per second. If each frame represents one thousand years of earth history, geologic time condenses into an epic motion picture. One second of the film's showing represents 16,000 years in the development of our earth. One minute displays the geologic processes of one million years. At this rate, all of the time that has passed since the birth of Christ would flash by in one eighth of a second! The time that has passed since the last Ice Age (about 18,000 years ago) would fly past in just over one second. When rewound from the present, it would take one hour and nine minutes to view history back to the end of the Age of Dinosaurs, approximately 66 million years ago. Complex animal life first appeared on the Earth at the beginning of Cambrian time, about 570 million years ago.

Our movie of the Earth's history would have to rewind continuously for 9 hours and 55 minutes to show all that has happened since the first trilobites crawled on the sea floor. If we were to rewind the film back to Day One, about 4.5 billion years ago, it would continue for 68 more hours to return to the time when our planet first cooled. The total playing time of the film would be approximately three days and six hours, not including trips to the rest rooms or for popcorn!

The following discussion presents a summary of the geologic history of the Colorado Plateau. In the essence of time, the story will begin at the start of the Cambrian Period, when complex life formed in the sea, 570 million years before present. Fast forward will allow us to jump past the first 3.93 billion years of the Earth's history and start with a point in time when things really started to happen in Southeast Utah. Remember though that even this condensed version of the history of the Colorado Plateau will still require nearly ten hours to view in its entirety. In fairness to the oldest rocks, Precambrian history is quickly summarized just before the show. Early history is much more important than one might think.

A SUMMARY OF THE GEOLOGIC HISTORY OF THE CANYONLANDS AREA, SOUTHEASTEN UTAH

INTRODUCTION A brief review of early geologic history is a necessary introduction to our movie history of the Colorado Plateau. The oldest rocks found on the surface of the earth date at approximately 3.8 billion years old. The oldest rocks found on the Plateau are around 2.4 billion years old. Geologists have named this early time in earth history the Precambrian Era. Geologic processes of erosion, metamorphism, or remelting since Precambrian time have changed many old rocks. creating "newer" rocks. Not too many old rocks are still around. The Law of Superposition requires that older rocks occur under younger layers; that is the case throughout our area. Precambrian rocks are present on the Colorado Plateau, but they lie under thousands of feet of younger sedimentary strata. Only the deepest

The Colorado Plateau is renowned for its very rugged topography. Sedimentary rocks dominate the landscape. Igneous laccoliths such as the Abajo Mountains (background) add to the geologic diversity. Photo by Todd Campbell.

canyons, such as Westwater, or the highest upwarps, as the Uncompahgre Uplift, will expose the oldest rocks. Precambrian rocks, buried deep under our feet, include metamorphic (changed) schists and gneiss. They lie under slightly younger sedimentary rocks - limestones, stream sediments, beach sands, and basalts.

Approximately 1.5 billion years ago, movement of continental plates squeezed the Colorado Plateau in a huge vise. Compression from the north and south caused deep cracks, or faults, to form in the old, brittle rocks. Two sets of faults developed. One trended in a southeast-northwest direction, the other in a southwest-northeast direction. these faulted blocks were covered with the many layers of softer sedimentary rocks that we see today. Compression from the north and south continued for millions of years. In the last 70 million years, compressional forces changed orientation, directed instead from east and west. The persistent squeezing of the Plateau and the periodic movement along basement faults would influence geologic processes on the Plateau from the late Precambrian to the present.

Enough of an introduction, our movie is ready to begin. Remember that this showing will require nearly ten hours. There will be intermissions, however, so it will be possible to sneak out for snacks.

Sedimentary rocks erode with differing form. The resistant Wingate Sandstone and Kayenta Formations form sheer cliffs above the softer slopes of the Chinle and Moenkopi formations. Photo by Todd Campbell.

IN THE BEGINNING

The opening scene of the motion picture shows the western edge of the Colorado Plateau, west of the Grand Canyon. The time is approximately 570 million years before the present, at the beginning of the Cambrian Period. A broad, shallow downwarp, or geosyncline, is beginning to form in shallow seas off our western coast. Global rise of sea level begins about 550 million years ago, twenty minutes into the film. The Cambrian Sea is beginning to advance, or transgress, in an easterly direction, depositing beach sands along its shoreline. As the sea advances, coarse sandstones drop in layers on the tilted and eroded Precambrian landscape. The contact between the "old" rocks and our new beach sandstone represents an angular unconformity. This particular relationship will be studied worldwide and named the "Great Unconformity."

CAMBRIAN TIME

About 35 minutes into the film, shoreline reaches the Canyonlands area. Coarse, quartz-rich beach sands of the Tintic Quartzite lie as a blanket thinning from west to east. As the sea continues its eastward advance, fine silt and clay settle in quiet waters just off shore. As waters over Moab continue to deepen, lime muds and dolomites begin to form. One hour has now passed and the shoreline has reached western Colorado. Abruptly, the Cambrian sea retreats back to the west, leaving limestones, silt, and mud exposed on an extensive tidal flat. These sediments are soon lithified, or turned to stone, forming the Lynch Dolomite. We are now at the end of Cambrian time, 505 million years before present. We have been sitting in our seats for just over one hour and we're getting restless. Fortunately, there is a break just ahead.

ORDOVICIAN AND SILURIAN EROSION; DEVONIAN DEPOSITION

At the end of Cambrian time, the entire region suddenly rises. Deposition ceases and erosion takes over. Erosion continues through the Ordovician, Silurian, and Devonian Periods, for about 125 million years in total. The landscape of the Canyonlands area erodes to a fairly smooth, level surface. Two hours and nine minutes of film drag by without anything being recorded in the rock record.

We are now in the middle of the Devonian Period, about 380 million years ago. The movie has been playing for three hours and seventeen minutes. Sea level is again rising and the sea advances towards the Canyonlands. This time there are no sandy beaches, instead lime-rich muds dominate the shoreline. Offshore to the west a few primitive organisms reside. They soon die, leaving sparse fossil records of their presence. Their fossil remains, trapped in limestone muds and sparse sand layers, will soon be lithified. They will become the Aneth Formation, the Elbert Limestone and the Ouray Limestone. This period of Devonian deposition lasts less than 15 million years, showing on the big screen for all of fifteen minutes. An erosion interval of approximately the same duration immediately follows.

MISSISSIPPIAN TIME

It is now the early Mississippian Period, 350 million years before present. Again, the sea advances from the west, extending across Colorado and north into Canada. By now, marine organisms have developed into sophisticated forms. Crinoids, a cousin to sea urchins and starfish, flourish on the floor of the shallow Mississippian sea. Brachiopods, early clam-like organisms, thrive in areas of slow sedimentation. The remains of these organisms are trapped in thick limestones of the Leadville Limestone. The Leadville Limestone in Canyonlands is 600 feet thick in the west and 100 feet in the east. Outcrops are unknown, it is described instead from the many test wells drilled to evaluate its host potential for oil and gas. The extensive Mississippian Leadville sea is fairly short lived, as were its predecessors. Sea water covers the region for only ten to twelve million years, retreating again to the west. Another period of no deposition follows, lasting until the beginning of the Pennsylvanian Period, 320 million years ago. In the time frame of our movie, four hours and twenty minutes will have elapsed, with five hours and forty minutes to go.

Interesting happenings are just around the corner, so maybe this will be a good time to grab a snack. Be sure and hurry. This period of late Mississippian erosion will be over in just twenty minutes.

PENNSYLVANIAN TIME

At the close of Mississippian time, weathered Leadville limestone erodes. It is now redeposited as the reddish brown, iron stained Molas Formation. Canyonlands is not exposed to a subaerial, oxidizing environment for long, however. The familiar old sea to the west is again advancing in our direction. Thin fossiliferous limestones of the Pinkerton Trail Formation form beds on the red Molas muds as the shoreline moves eastward.

As the sea advances from the west, another spectacular event is beginning just east of Canyon Country. Along old basement faults created by squeezing in the Precambrian vice, major vertical movement begins. Renewed north-south compression is causing at least one large northwest trending block located east of Gateway, Colorado to rise abruptly. The mountain building event, or orogeny, controls the geology of Canyonlands for many millions of years. The mountains that form will become known as the Uncompahgre Uplift, also referred to as the "Ancestral Rocky Mountains." Less dramatic vertical movements also occur along western basement faults. They will also influence depositional patterns. Huge amounts of sediment eroded from the Uncompahgre Uplift will be carried into the western sea. Local uplifts around the margin of the sea will control just where the sediments are finally deposited.

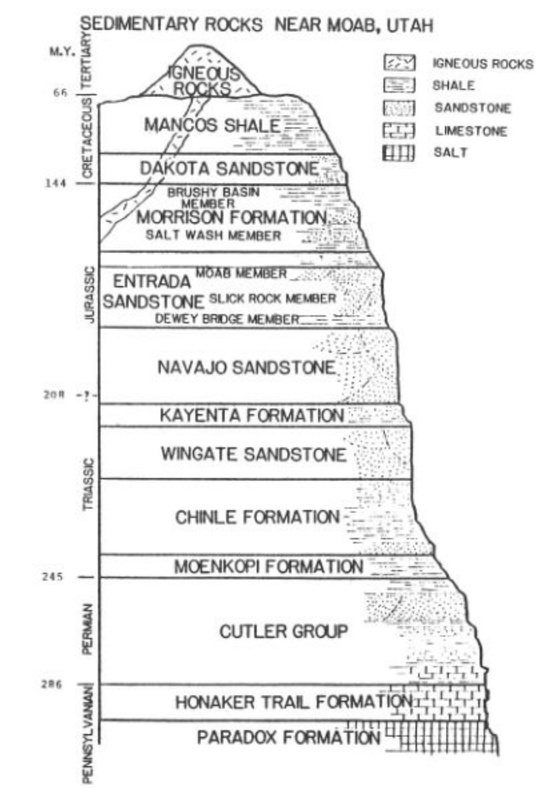
As the Uncompahgre Uplift rises to the east of Canyonlands, a deep trough forms just to the southwest of the mountains. Sediments eroded from mountainous regions fill the trough, causing it to sink even faster. Land derived sediments are trying to push the sea back home to the west. The sea, in turn, looks for areas of maximum subsidence and tries to hold its line. Two minor uplifts in the west, the Monument Upwarp and the Piute Platform, are trying to cut a portion of the sea off from open water to the west. All of the infighting, coupled with a warm, dry environment, causes the water in the enclosed sea to become progressively salty. This salty sea, filling the newly formed Paradox Basin, will deposit thousands of feet of layered salt. Salt will play a leading role in the geologic and erosional history of the Canyon Country.

Like all seas before it, the Paradox sea didn't stay around too long. An open marine environment returns to the region as the salty basin retreats to the northwest. Interbedded marine fossiliferous limestones, sandstones, and shales of the Honaker Trail Formation form above thick layers of Paradox salt, gypsum, and black shale. We are now at the close of the Pennsylvanian Period, 286 million years ago. Finally we are over half way through our movie. Just over five hours of the show have elapsed, slightly less than five hours are left to go.

PERMIAN PERIOD

The Permian Period is possibly the most impressive scene of our movie. Although it lasts only 41 million years (under 40 minutes of playing time), more things happened and more sediments formed in the Canyonlands than during any other time before. The Uncompahgre Uplift is turning out to be quite a mountain range. Huge quantities of arkosic (feldspar rich) sandstones erode from its granitic and metamorphic ridges. The coarse, poorly sorted sediments travel by streams westward toward the Permian sea. Coarser sediments remain behind in the east, not far from the range front. Finer sands, silts, and clays reach to the shore where they fall on the beach and in river deltas. These reddish brown land-derived sediments comprise the Cutler Group. The Cutler Group is many thousands of feet thick in the northeast, just off the flank of the Uncompahgre. It thins to less than two thousand feet in the west, where it interfingers with marine units.

Included within the Cutler Group are two impressive beach sandstones, the Cedar Mesa Sandstone and the White Rim Sandstone. Each unit may represent an eolian or wind blown environment at or near the Permian beach. High angle wind cross bedding is common in both units. Cross bedding suggests a prevailing wind direction from the northwest. Sands interfinger with marine units in the west and with fluvial units in the east. As both units are quite thick, there is some controversy regarding the source area for such a large amount of white, quartz beach sand.



Generalized stratigraphic section showing sedimentary rocks near Moab, Utah.

The end of the Permian Period brings a brief period of erosion, lasting less than ten million years. The Uncompahgre Uplift is highly eroded now. Only fine grained, highly oxidized sediments move west across Canyonlands. The Permian Period and the Paleozoic Era end rather quietly, about five hours and forty minutes into the movie.

TRIASSIC PERIOD

The Mesozoic Era begins on the Plateau just as quietly as the Paleozoic has ended. Iron rich silts and clays of the Moenkopi Formation lie on a broad tidal flat early in Triassic time. Mud cracks, raindrop imprints, ripple marks, occasional small dinosaur tracks, and a chocolate brown color, are all characteristic of the Moenkopi. The Moenkopi Formation is very important for a rather unusual reason. It is thin or absent in specific areas on the plateau, often near the famous salt anticlines of the Paradox Basin. The thin or missing Moenkopi is convincing evidence that the underlying salt is already starting to move in response to the weight of overlying Cutler sediments. Upward folds of sediments create local highlands above the mud flats. Interestingly, the higher ridges trend in a northwesterly direction, parallel to the old Precambrian basement faults.

After Moenkopi deposition, a period of middle Triassic erosion transpires. This event is short, lasting less than 15 million years, maybe 13 minutes of movie time. In upper Triassic time, the Uncompahgre highlands again rise and erosion increases. Fluvial sedimentation returns to the Canyonlands. Coarse fluvial streams of the Chinle Formation record a brief period of high energy runoff from two source areas, one in the east, another in the southwest. Thick layers of volcanic ash, carried by winds blowing from the south, cover the stream deposits. The fine ash will soon alter to clay minerals of many colors, forming the Painted Desert of northern Arizona and northern Utah. Stream systems dominate the area late in the history of Chinle deposition. Reddish brown sandstones, siltstones, and claystones comprise the upper Chinle slopes throughout Canyonlands. Maximum thickness of Chinle sediments in the area is 1200 feet. The average thickness is around 600 feet. Angular unconformities occur within the formation and there are local variations of thickness. These clues imply that underlying Paradox salt was actively moving during Chinle time.

Fluvial conditions soon give way to the first of several major desert events that will dominate the Colorado Plateau for millions of years to come. The Wingate Sandstone of late Triassic or early Jurassic age is a thick cliff forming unit on top of the Chinle redbeds. The Wingate cliff is one of the most distinct topographic features of the Canyonlands. The highly cross bedded unit varies in thickness from 250 to 400 feet, averaging around 300 feet. The Wingate cliff weathers to a dark reddish brown to black color, caused by iron and manganese staining, or desert varnish. Since it is so continuous and easily recognized, the Wingate Sandstone is an excellent unit to use to pinpoint one's position in the stratigraphic section. Cross bedding again records a prevailing northwesterly wind. The source of all the Wingate sand remains a mystery.

Mesas and buttes create an impressive skyline throughout the canyon country. Photo by Todd Campbell.

A brief period of increased moisture returns to the Colorado Plateau. Wingate sand dunes erode, carried by Kayenta stream systems. Ripple marks, raindrop imprints, and dinosaur tracks are common. The Kayenta sandstones create a hard, erosion-resistant cap above the Wingate cliff. Kayenta sandstones thicken in downfolded synclines. Paradox salt is continuing to move during the early Jurassic.

JURASSIC PERIOD

The end of Kayenta deposition marks the return of dry desert conditions to the Colorado Plateau and to much of the western North American continent. An extensive wind blown formation, the Navajo Sandstone creates dunes immediately above the Kayenta. The exact timing of the Navajo desert is uncertain, due to the lack of fossil material for dating. The Navajo desert dominates the landscape for twenty or twenty-five million years. It is one of the greatest deserts ever recorded in the geologic record. The Navajo Sandstone in Canyonlands is less than 600 feet thick. The massive sandstones thin very rapidly east of Moab. The same Navajo sands in Zion National Park, southwestern Utah, are nearly 2,500 feet thick! Thin fresh water limestones near the top of the Navajo Sandstone suggest that the harsh, dry climate moderates slightly near the end of Navajo time. A short period of erosion follows the end of the extensive Navajo desert. We are now in the middle of the Jurassic Period, almost 170 million years before present. The movie has been playing for exactly seven hours - only three more hours to go!

Soon after the demise of the Navajo desert, the sea tries to make one last advance from the west. The marine environments do not quite reach into Canyonlands. The bright reddish brown siltstones and claystones of the Dewey Bridge member of the Entrada Sandstone may represent marginal tidal flats east of the open sea. The Dewey Bridge Member is easily recognized by highly disturbed, or contorted, bedding. This feature probably formed by soft sediment deformation that occurred after overlying sands were deposited, before the soft muds lithified into stone. The Dewey Bridge Member is quite thin, often less than 50 feet thick. Like the Wingate Sandstone, the Dewey Bridge Member is easily recognized. It is a very useful stratigraphic marker, especially in and near Arches National Park.

After deposition of the Dewey Bridge Member, a dryer, more arid climate returns. The Slick Rock Member, best known for extensive development of natural arches in Arches Park, is a cliff forming dune deposit often over 250 feet thick. The Slick Rock member is a fine grained, thick bedded eolian sandstone. Stresses in the sandstone created by folding, due to salt movement, have created extensive sets of parallel stress relief cracks called joints. Preferential erosion along the softer joints creates fins - linear, parallel, free standing sandstone structures. Erosion at or near the base of a fin occasionally breaks through to form an arch. Arches commonly form in the lower Slick Rock Member, immediately above the Dewey Bridge Member.

For a very brief period at the end of Slick Rock deposition, the sea again pushes in from the west. Open water never reaches the eastern part of Canyonlands, but one last dune field develops just east of the beach. The Moab Tongue of the Entrada Sandstone represents this brief attempt to return to marine conditions.

We are now late in Jurassic time. The western sea retreats completely out of the area. The Uncompahgre Uplift erodes into obscurity. Major tectonic activity to the west is beginning to create a new highland area. The source area for sediments is now shifting from the east side of the Colorado Plateau to the west side. Streams are now flowing from the southwest. Vast areas once subject to continuous erosion are now sites for deposition. The Morrison Formation represents a complex sequence of fluvial cycles on the Colorado Plateau. In the Canyonlands area, streams carry sediment from the Mogollon highland, in the southwest, toward the northeast. The lower Tidwell Member includes siltstones, claystones, chert and gypsum. Tidwell sediments lie on top of the Moab Tongue. The Salt Wash Member records at least three major fluvial events transporting sediment from the Mogollon Highland east toward the central continent. The Brushy Basin Member consists primarily of claystones derived from altered volcanic ash. It also contains some coarse fluvial sandstones. Large dinosaurs thrive on the lush Morrison floodplains. Their remains bury rapidly under sediments carried by recurrent floods. The Morrison Formation becomes one of the greatest dinosaur graveyards of all time.

A short period of erosion appears to have transpired at the end of Morrison deposition. The exact timing of upper Morrison deposition is uncertain. Age dating of Brushy Basin clays suggest that the actual age of the Member may be lower Cretaceous rather than upper Jurassic. This change of timing may offset our movie clock slightly. We are now somewhere over seven hours, fifteen minutes into the show. There are at least two and one half hours (possibly plus a few minutes), to go.

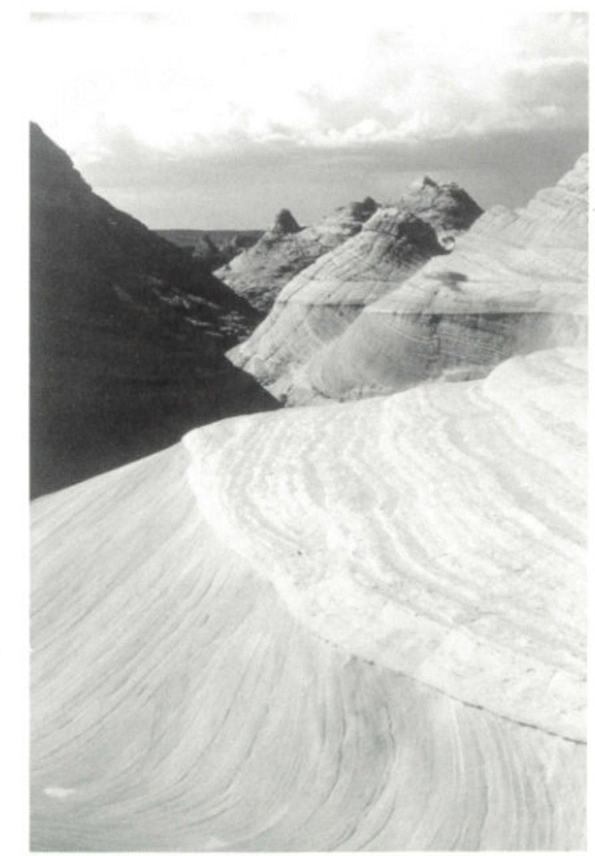
CRETACEOUS PERIOD

The major tectonic activity of the late Jurassic continues into the Cretaceous Period. It is now 144 million years before present. The Sevier Orogenic belt becomes the dominant tectonic force in western Utah. Compression from the west creates overlapping thrust faults west of the Plateau. Volcanic activity in the thrust areas adds to the mountain building process. The central part of the continent begins to subside and an extensive seaway is beginning to develop, extending from the Gulf of Mexico northward toward central Canada. Coarse fluvial sediments of the Burro Canyon and Cedar Mountain Formations cover the Canyonlands. Following is another short period of no significant deposition.

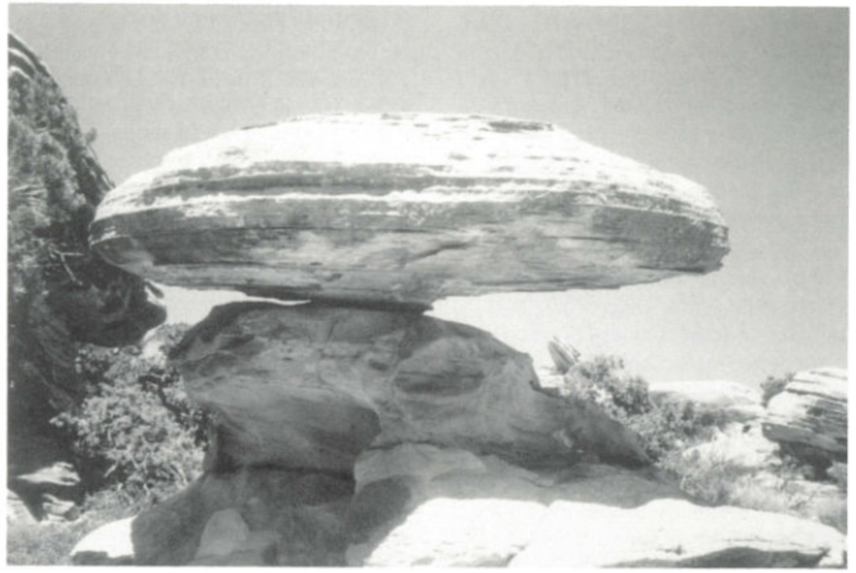
Finally, exactly eight hours into the show, 110 million years before present, cool sea breezes again blow across the Canyons. This time, however, they are coming from an easterly sea! The Dakota beach is finally at the Canyonland's eastern doorstep. As time continues, the Mancos sea advances across the area, eventually depositing it's Tununk Shale Member as far west as west central Utah. The sea is no match for intense mountain building in western Utah. By 95 million years before present, river deltas and coal swamps of the Mancos' Ferron Sandstone Member begin to push the sea back to the east.

Ferron deltas hold their own for about five million years (five minutes left in the movie) before a second major transgression, or sea advance, ensues. The Mancos Sea again moves into western Utah, depositing the Blue Gate Shale in its path. The total thickness of all Mancos Members eventually reaches 3500 feet.

At 85 million years before present, mountain building and erosion to the west again push the sea eastward. Thick offshore, deltaic, and fluvial sands of the Mesa Verde Group develop, followed by backwater shales and coal measures. Finally, about 80 million years before present, eight and one half hours into our epic drama, the sea leaves Canyonlands forever. From this



Cross-bedded dunes of the Jurassic Navajo Sandstone preserve ancient wind directions. These extensive sandstone knobs form Canyonlands' famous "slickrock." Photo by Todd Campbell.



Unusual balanced rock formations are common throughout the Canyons. Photo by Jean Akens.

time forward, land derived processes dominate Canyonlands geology.

From now to around 65 million years before present, sediment laden streams flow from the west. They continue to bury the old marine sediments in the debris of the rapidly eroding Sevier overthrust highland.

It is important to note that very little Mancos Shale and no Mesa Verde Group sediments now occur in Canyonlands proper. There is no mistake though that they were once deposited here, in thicknesses of thousands of feet. Extensive erosion has removed these soft, younger sediments from all but the lowest down-dropped fault blocks.

TERTIARY PERIOD So, here we are, at the beginning of the Tertiary Period. It is 66 million years before present and the film has been playing for over eight and three quarter hours. It's nice to know that only one hour and ten minutes of viewing remain. Ahead, though are some of the most interesting scenes yet!

The Laramide Orogeny is beginning. It is a great mountain building event, responsible for the creation of today's Rocky Mountains. Forces of compression, originating in the west, are again squeezing the Colorado Plateau. The Uncompahgre Uplift, Monument Upwarp, and San Rafael Swell all experience renewed uplift. Sediments still erode from the Sevier highland west of Canyonlands.

The Colorado Plateau tilts northward and streams are being redirected. Large freshwater lakes form in basins north of Canyonlands. Sediments over Canyonlands rapidly erode and travel far to the north. These silts, sands and shales soon become the Flagstaff, Wasatch, Green River and Uinta Formations.

Now, only thirty minutes away from our film's dramatic finish, the entire Plateau rises further. Streams reverse direction and head for the south. Large quantities of sediment are still being eroded. Sand, silt and clay travels toward the southwest, into what will become the Gulf of California.

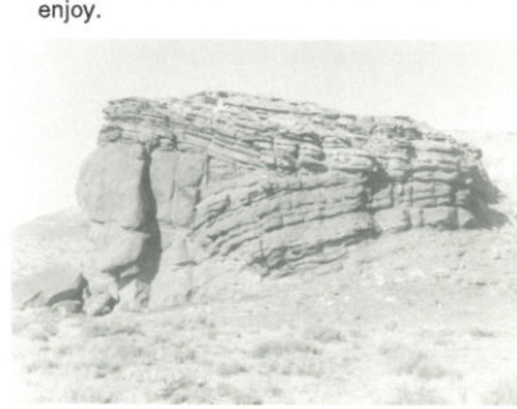
It's now about 30 million years before present. The forces of Laramide compression are relaxing. Canyonlands is being stretched just a bit. Basement faults are beginning to slip in response. Igneous magmas intrude along selected faults, creating the Plateau's famous laccoliths.

There are only a few minutes to go now! The Colorado and the Green Rivers are quickly downcutting into the uplifted strata. The rivers erode down into emerging structures, establishing courses that will not change for many years. Old meanders, reminders of a quieter time, cut into layered strata. Thick, hard limestones and sandstones erode into vertical cliffs hundreds of feet high. Softer siltstones and shales strip away to form slopes separating the massive cliffs.

Northwest trending anticlines, formed by migrating salt, continue to rise and collapse. Streams flow down the weakened centers of the structures. They develop into broad, parallel valleys, following faulted structures hidden far below the surface. Stress release fractures, called joints, develop in thick bedded sandstones on the flanks of salt anticlines. Continued erosion carves jointed sandstones into crowds of parallel fins. A few fins are eroded through near their base, forming the Canyonlands famous arches.

Finally, just one second before the film runs out, the climate again cools. Alpine glaciers, steep rivers of ice, grow high in the La Sal Mountains. The climate continues to cool and they attempt to travel down high valleys. It's not cold enough this far south to keep the glaciers alive for long. The glaciers melt back quickly, leaving ridges of gravel high on the mountain to remind us of their efforts.

It's now been ten hours since we dimmed the lights and started rolling the film. We seem to reach the conclusion of our epic drama. Or have we? All across the Canyon Country, earth forming processes continue right before our eyes. Arches continue to develop, then erode. Rockfalls tumble down sheer cliffs during the spring thaw. Summer thunderstorms create flash floods that race down side canyons into lazy rivers. Winter snows accumulate high in the mountains, preparing for next spring's run-off. Yes, even the salt which has contributed so much to the creation of our landscape may not be finished. There is plenty of it still under foot, just waiting for the right conditions to again start it in motion. The show must go on -- and best of all, there is no admission to pay! Feel free to participate, to explore, to interpret and to enjoy.



UPHEAVAL DOME and ROBERTS RIFT

UPHEAVAL DOME Geologic mysteries abound in southeastern Utah's colorful and spectacular canyon country. Some of these strange phenomena are just little things that are fascinating and puzzling to regional visitors, but insignificant to professional geologists, who find them easier to ignore than resolve. Further, the serious study of some of these little mysteries would require geologists to venture into the fringes of other scientific disciplines, such as paleontology or paleoclimatology, so geologists settle for labeling the curious phenomena--like "concretions" or "bioturbation"--then consider the matter settled.

To amateur geologists and curious canyon country visitors, this labeling without explanation is not very satisfying. It leaves too many unsettled matters, too many unexplained geological curiosities, too many unanswered questions about things they see all around them as they explore canyon country, often far more thoroughly than the professionals do. Canyon country also has some major mysteries, such as the causes of great faults, uplifts and synclines. These generally receive more attention from professional geologists because they are too obvious to ignore. However, this attention does not, as one might suppose, automatically lead to quick and incontestable resolution of the mysteries.

One such long-standing canyon country geologic mystery that is still unresolved to everyone's satisfaction is Upheaval Dome, in the Island-in-the-Sky District of Canyonlands National Park. The first scientific description of Upheaval Dome was written in 1927 by geologist T.S. Harrison. In 1940, another geologist, E.T. McKnight, wrote a U.S. Geological Survey Bulletin concluding that the strange crater had been formed by erosion of a salt dome. Since then, studies of this immense crater in solid rock, with its sheer inner walls and concentric rings of ancient geologic strata, have produced a number of widely differing reports, and two sharply differing hypotheses as to its original cause, plus several less likely possibilities.

by F.A. Barnes

The salt dome idea--reflected in the crater's name, "Upheaval Dome"--seemed incontestable to geologists. In a region replete with dozens, even hundreds of massive salt anticlines and salt domes, it was natural, although unscientific, to conclude that Upheaval Dome was just another example of this kind of geologic phenomenon. Hence its name, with the clear implication that the crater was just a severely eroded salt dome.

When Canyonlands National Park was established in the mid-1960s, its early interpretive brochure noted the salt dome concept. Its brochure dated 1968 described and illustrated the deposition of the deep Paradox Basin salt beds, then went on to explain how later, when the salt was deeply buried under thick and heavy layers of rock:

> ...the salt flowed upward into the anticline. It pushed and caused more doming, deforming the layers above...turning them almost on edge.

In a stratigraphic cross-section of Upheaval Dome, this brochure showed the Paradox Formation immediately underlying the White Rim Sandstone, omitting several very thick formations in order to show the supposed doming of the Paradox salt beds. Perhaps significantly, it also showed anatomically incorrect "pterodactyls" soaring over ancient seas during the deposition of the Paradox salts, at least 150 million years before such creatures existed.

This description of Upheaval Dome remained the official Park Service interpretation for more than a decade. Then, in 1979, in response to criticism, the park naturalist wrote a letter to a well-known geologist asking for help in upgrading the Upheaval Dome brochure, noting that:

> ...the cross-section will have to be redrawn in order to differentiate strata and incorporate names...not in the old one. ...That degree of accuracy, of course, is neither needed nor of value to most recipients of the folder, but there is a small minority to which it is important.

Once more scientific accuracy was given low priority. The letter went on to state that the naturalist was:

> ...deleting the pterodactyls...the original artist apparently erred in his representation of the forelimbs, which may be why (they resembled) seagulls.

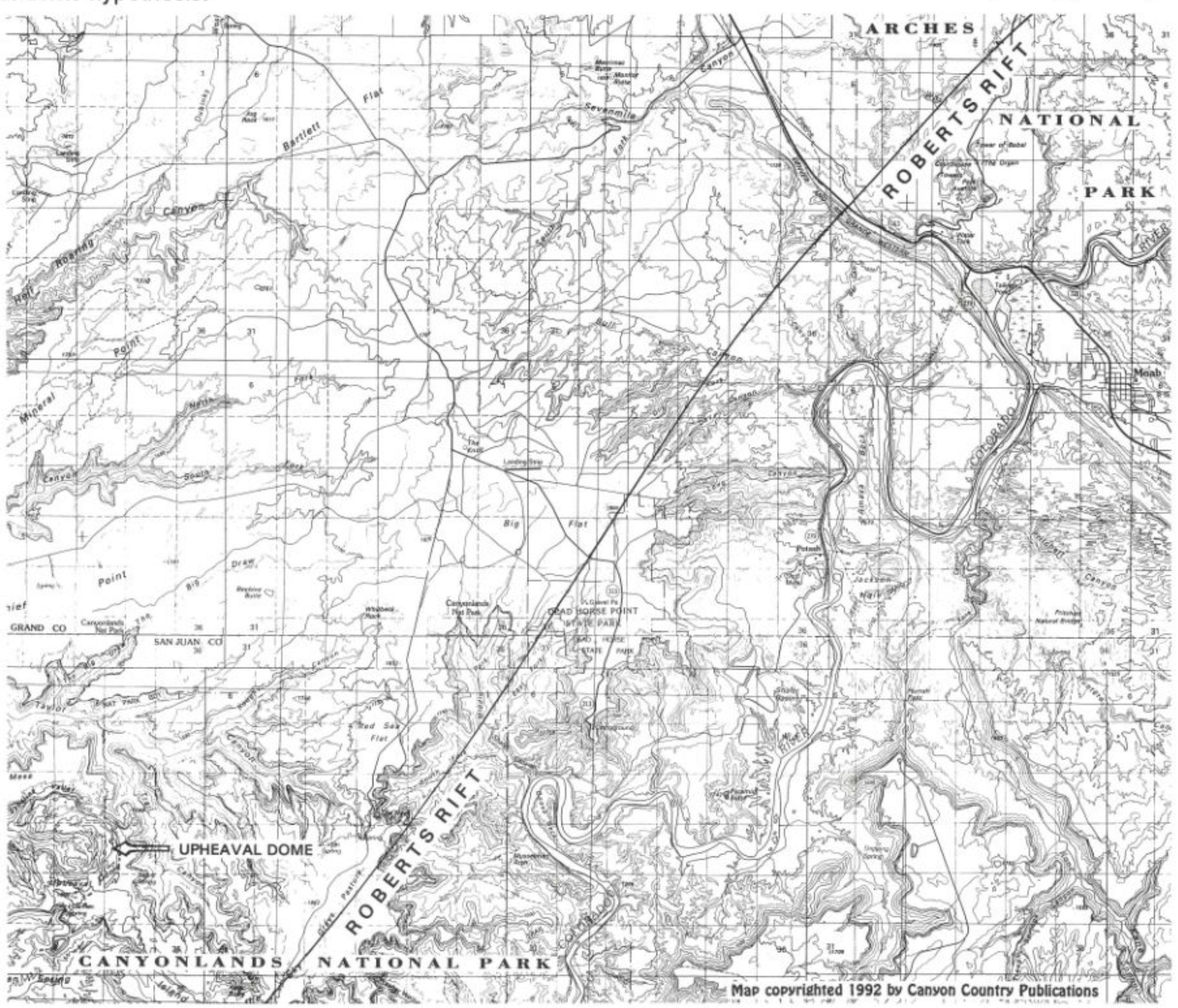
Neither seagulls nor pterodactyls were to exist yet for hundreds of millions of years. Apparently neither the park naturalist nor the geologist ever considered challenging the authenticity of the salt dome hypothesis.

Meantime, another well-known geologist, E.M. Shoemaker, who was with the U.S. Geological Survey at the time, was not so convinced. After performing extensive studies on known meteor impact craters, as well as Upheaval Dome, in March, 1984 he presented a paper titled "Upheaval Dome, Impact Structure" to the Fifteenth Lunar and Planetary Science Conference.

This scientific paper described in considerable detail several characteristics of Upheaval Dome that did not fit the salt dome hypothesis, but that did fit the idea of a meteorite impact crater. The report called attention to several similarities between Upheaval Dome and other impact craters that he and other geologists had studied, and concluded that the evidence pointed to an explosive meteorite impact about 65 million years ago, rather than to glacially-slow stratigraphic deformation caused by salt doming.

Shoemaker's report, prepared for presentation to a scientific group, was written in technical terms not within the vocabularies of most non-professionals, and is thus not very quotable in a non-technical article such as this, but a later abstract of his report was much more readable:

> Re-examination of Upheaval Dome in Canyonlands National Park, Utah, has shown that the structure of this remarkable feature conforms with that expected for a deeply eroded astrobleme. The structure is definitely not compatible with an origin due simply to plastic flowage of salt and other rocks in the underlying Paradox Formation, as suggested by McKnight.



This map shows the approximate known alignment of Roberts Rift, beginning in the Windows Section of Arches National Park and going underground in the Grays Pasture area of Island in the Sky. The rift is exposed and clearly visible in the canyon walls of Courthouse Wash, Little Canyon and the two main branches of the Bull Canyon system, but goes underground between these exposures. There is little doubt that the Upheaval Dome meteorite impact provided the immense energy needed to form Roberts Rift and fill it with material thrust upward from 2,500 feet below.

> The most strongly deformed rocks at Upheaval Dome are bounded by a series of circumferential listric faults. Beds of the Wingate Sandstone, Kayenta Formation, and Navajo Sandstone, are displaced toward the center of the dome. Near the center, these same beds have been deformed by convergent flow into tight to open folds that plunge away from the apex of the dome. Thinning of the Wingate Sandstone reported by McKnight is due entirely to faulting. At the center of the dome, beds of the Moenkopi Formation are duplicated by displacement along numerous small thrust faults. Sand from the underlying White Rim Sandstone Member of the Cutler formation has been mobilized and injected into the Moenkopi as large massive clastic dikes.
>
> The convergent displacement of the rocks at Upheaval Dome corresponds to the deformation that results from collapse of a transient cavity produced by high-speed impact. Beneath the listric faults, beds are deformed in a broad structural dimple that is bounded, at least on the north, by a partial circumferential anticline. This type of structure is produced by plastic flow of rocks at great depth beneath large impact craters. Asymmetry of the development of the deep anticline suggests that impact may have been from the south. Growth of a central dome probably was due partly to early convergent flow during opening of the initial cavity, as well as to late stage collapse. It is likely that the presence of plastic beds in the Paradox Formation at depth facilitated early growth of the dome.
>
> From considerations of the probable depth of exposure of the impact structure and upward extrapolation of the listric faults, the final collapsed crater is estimated to have been about 8 to 10 km in diameter; the impacting body probably was on the order of 0.5 km in diameter. As much as 2 km of beds appear to have been removed by erosion since the impact structure was formed. Restoration of this thickness of rocks suggest that the impact occurred in latest Cretaceous or Paleogene time.

Was this timing just coincidental, or could the Upheaval Dome meteorite have been related to the immense meteor impact that many scientists are now convinced triggered the extinction of dinosaurs and other life at the end of the Cretaceous? Was the Upheaval Dome meteorite another of a swarm of meteors that passed through our solar system during that period of time?

One might think that the Shoemaker studies and report would have settled the controversy over Upheaval Dome,

The circular nature of Upheaval Dome is clearly visible from the air. The crater has been revealed by erosion, with the erosion products carried into the nearby Green River through a canyon. Were it not for this fortuitous drainage, the crater might still be underground and invisible. Upheaval Dome registers on certain geological survey instruments as a circular magnetic anomaly. Another such circular anomaly exists in nearby Grays Pasture on Island-in-the-Sky.

This series of sketches by Moab artist Rick Showalter illustrates the dynamics and aftermath of a sizable meteorite impact. The first two sketches show the physical penetration and subsurface stress patterns developing within the first seconds of impact.

The third sketch shows the fully-developed shock pattern in the underground rock strata, and the scope of the enormous, shallow blast crater created by the stupendous kinetic energy of the impact. These illustrations show the actual geologic strata as they existed at the time of the Upheaval Dome meteorite impact.

Sketch four depicts the probable configuration of the crater after impact, the debris that partly filled the crater, and the subsurface faulting and stratigraphic deformation caused by the enormous force of the impact. Note that the highly compressed cone of rock directly beneath the impact that was momentarily heated to extreme, almost molten temperatures, has rebounded in the only direction available--upward--thus creating the subsurface configuration of rock strata to be revealed by erosion 16 million years later as Upheaval Dome.

Sketch five shows the present erosional surface of the Upheaval Dome meteorite impact crater, which was far below the surface at the time of impact. Yes, the plastic-like Paradox salts far below the impact did dome upward, but as a short-term reflexive response to the compression of the meteorite impact, not from the glacially-slow normal flow of a salt anticline. In one sense, Upheaval Dome is a "salt dome," but a meteorite impact caused that brief upsurge of ancient marine evaporites.

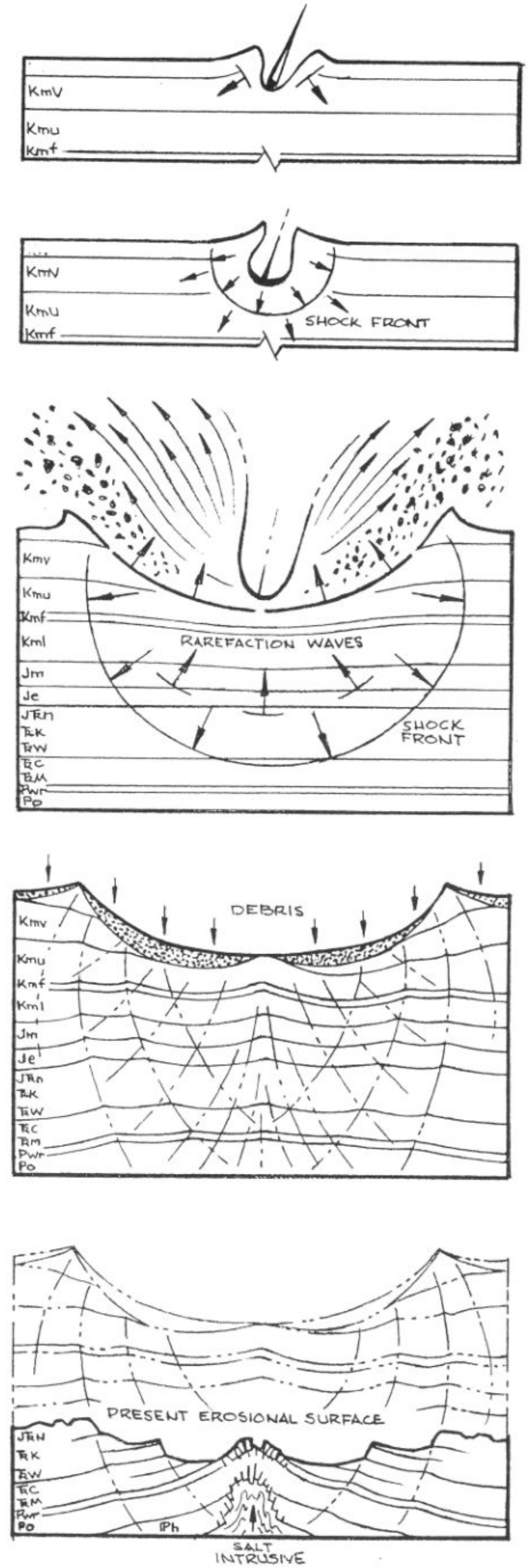
These illustrations were based upon scientific studies of continental meteorite impact craters by E.M. Shoemaker and other geologists who have specialized in this field of study.

perhaps leading to its being given a more appropriate name, but this was not to happen. As with so many other so-called "sciences," geology is sometimes more of an art than a pure science, in which strict rules of evidence apply.

Rather, the proponents of the salt dome hypothesis continued to cling to and rationalize their beliefs, and to discount the new evidence accumulated by Shoemaker and his associates, such as Professor Peter Huntoon, Department of Geology and Geophysics, at the University of Wyoming.

Even though Huntoon wrote an article in the August, 1986 issue of *From The Canyons,* a publication of the Canyonlands Natural History Association, summarizing the controversy and firmly supporting the meteorite impact concept, the National Park Service decided to "sit on the fence," so to speak. Its 1990 brochure about Upheaval Dome asks:

> What caused this medley of rock to dome up in the first place? Geologists don't know for sure. As you look at the crater, it is easy to imagine that it might be the result of an ancient impact of a meteorite. Perhaps, as another popular theory states, it is the result of a more subtle process: a deep layer of salt squished up, bending and pushing the layers of rock above it.



The brochure fudged the matter of correct stratigraphic sequence by simply not showing the names of any strata below the White Rim Sandstone, including the Paradox salt beds. The present displays about Upheaval Dome in the Island-in-the-Sky visitor center explain and illustrate both ideas, but place more emphasis on the salt dome hypothesis.

ROBERTS RIFT

In a professional paper dated 1975, geologist Robert J. Hite described a strange rift--a special kind of fault--that is exposed in several canyons to the northwest of Moab, Utah. He dubbed this gigantic vertical crack in the area's geologic strata "Roberts Rift."

This miles-long rift is one of several northeast-southwest trending faults in the region, all of them above the ancient Paradox Basin, so was apparently related to the others in some general structural manner. Yet is was quite different in a very important way--the rift contained material, including large rocks and datable marine fossils, from the Honaker Trail Formation 2,500 feet below.

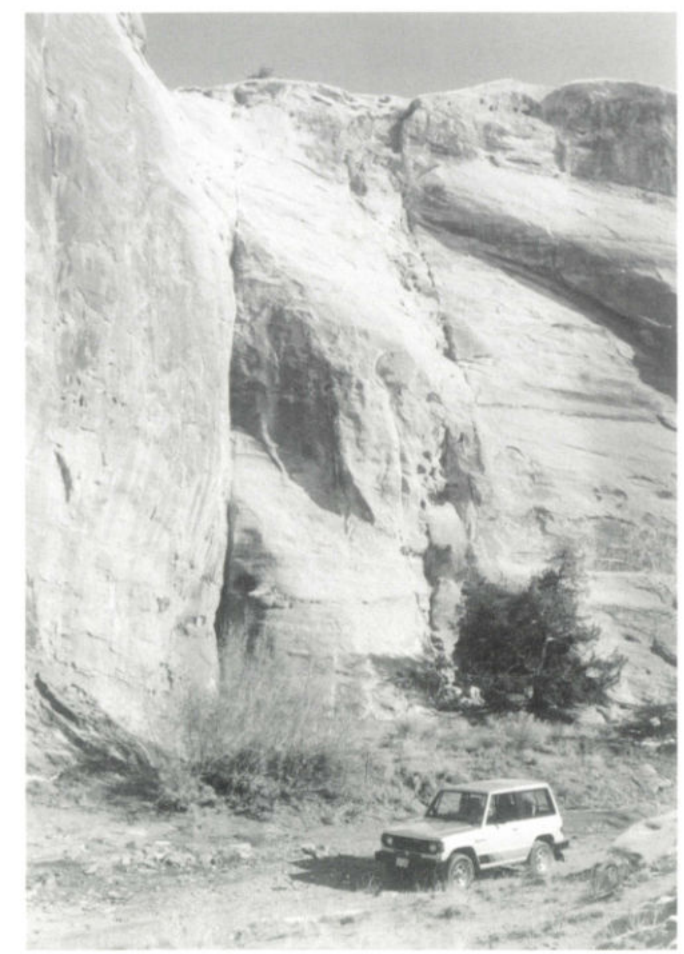
Further, some of the original material injected from below into the rift had been fluids containing minerals capable of chemically affecting the iron oxide within the younger strata in which the rifting occurred. These included strata presently known as the Chinle, Wingate, Kayenta, Navajo and Entrada. Where the rift is exposed in these iron-rich strata, the reddish color of the surrounding rock has been bleached to white or pale yellow.

Roberts Rift is visible in several canyon systems near Moab. As reported by Hite, it begins in Arches National Park as a series of "calcite veinlets" in the vicinity of The Windows, but is clearly visible within the park--if you know what to look for--only in parts of Courthouse Wash. In that area, to the east of U.S. Highway 191, the rift is exposed within the Slickrock Member of Entrada Sandstone. In one canyon wall, it is visible as a sloping crevice mostly covered with rubble, at the end of a short eastern spur canyon of Courthouse Wash. On the western side of the canyon, the rift has formed a much deeper side-canyon, with the near-vertical plane of the rift becoming one wall of the side-canyon.

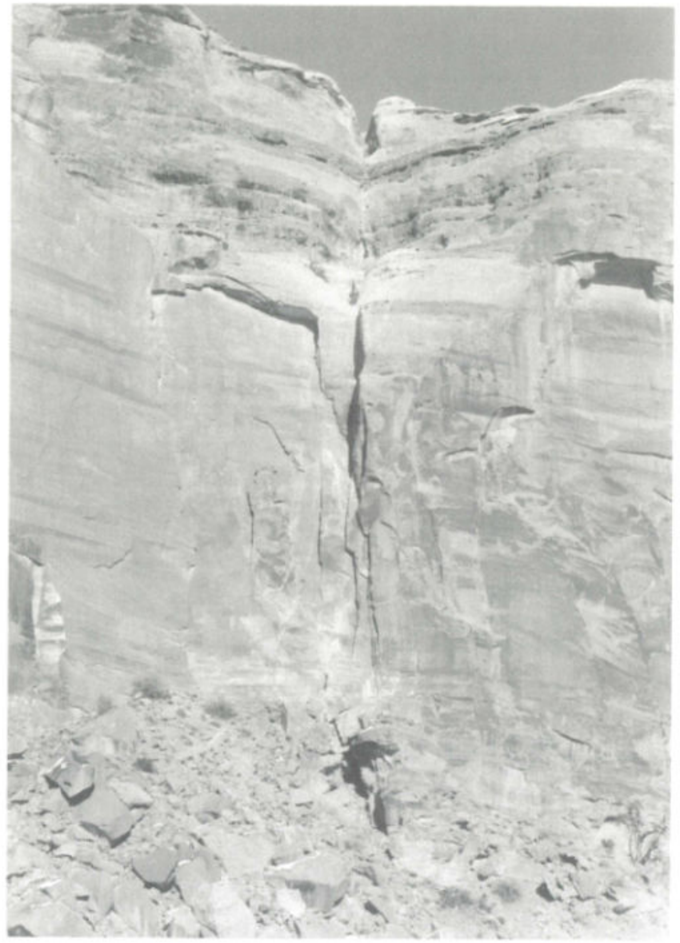
To the west of U.S. 191, Roberts Rift is clearly visible on both sides of Little Canyon. On the eastern side, very near the confluence of the two major upper tributaries of the canyon, it consists of a near-vertical crack in the Wingate Sandstone wall about one inch wide and filled with white mineral salts. On the opposite side, erosion and rock collapse caused by the rift has largely covered the actual crack in the vicinity of the off-road vehicle trail that ascends the dugway out of the canyon at the confluence. However, the rift is clearly visible to hikers as an arrow-straight, southwest-trending joint in the surface rock on the relatively level terrain above and beyond the canyon, until it eventually disappears beneath higher layers of the Kayenta Sandstone. The rift, together with erosional forces, has also contributed to the formation of the dogleg in the upper end of the Little Canyon tributary that contains the rock spire known as The Bride.

Roberts Rift also cuts across the two main tributaries of the Bull Canyon system farther southwest. There, it is again visible in two walls as near-vertical cracks filled with mineral salts and smaller rocks, with the surrounding native rock bleached of its natural reddish color. In the dry fork of Bull Canyon, the rift has contributed to the erosional formation of a large tributary canyon. At the end of this side canyon, the rift joint is prominent at the upper end of the drainage in the eroded Wingate Sandstone walls, even from a distance. Beyond this tributary of Bull Canyon the rift heads across Grays Pasture in the Island-in-the-Sky, in a direction generally tangent to the circular structure of Upheaval Dome.

The author of this article has walked out all surface exposures of Roberts Rift, and has noted that to the west of U.S. 191 the rift apparently did not progress



This exposure of Roberts Rift in the north wall of the main branch of Bull Canyon is about one mile upcanyon from its confluence with the Dry Fork of Bull Canyon. The rift is also clearly visible in the south wall, where it has promoted the formation of a short side canyon.



This exposure of Roberts Rift in the north wall of the Dry Fork of Bull Canyon is about two miles upcanyon from it confluence with the main canyon branch. In this fork's southern wall, the rift has formed a long sidecanyon, with the rift clearly visible in its upper end.

upward entirely through the Kayenta Sandstone strata when it first formed. The visible rift thus "goes underground" about midway in the Kayenta when it is being traced on the ground. The fact that the rift appears in the much younger Entrada Sandstone east of U.S. 191 and the Moab Fault is a good indication that the Moab Fault is older than Roberts Rift. The large vertical Moab Fault offset allowed Roberts Rift to cut into much younger strata east of the fault than west of it--at the same approximate level.

The map accompanying this article shows the approximate alignment of Roberts Rift as described by R.J. Hite, and in a subsequent professional paper authored by geologists Peter W. Huntoon and Eugene M. Shoemaker. That report proposed a possible cause for Roberts Rift. As the authors noted:

> We concur with (Hite's) conclusion that altering fluids circulating upward from deep sources tapped by the rift. (However) we respectfully differ with the genesis of the rift as proposed by Hite...

Huntoon and Shoemaker then proposed a cause for the rift that would fully explain the origin of the enormous amount of energy that would force up into it materials from 2,500 feet lower. Hite had indicated that the rift probably formed as a result of severe "wrench faulting," and hinted that Paradox salt flow had somehow thrust the older material upward into the resulting rift. He did not address the matter of the energy required for such a process, nor mention that no remnants of Paradox Basin evaporites had been found within the rift.

The Huntoon-Shoemaker report addressed these factors and concluded that the rifting, and the subsequent filling of the rift with older and much lower material, were directly related to the immense forces that formed Upheaval Dome. The report first analyzed the geologic setting at the time of the meteorite impact and rifting. It noted that:

> Deposition of the Mesa Verde Group was nearing completion... (and)...what is now the rim of Upheaval Dome was buried by almost a mile of younger sediments...

The report went on to say that the surface deposits in the region were either on a near-sea-level alluvial plain or in a shallow marine environment. It also pointed out that the much deeper Honaker Trail deposits were highly pressurized by still deeper Pennsylvanian organic deposits that were confined by the effective seals of higher and younger strata, thus producing conditions that could be triggered by some violent geologic event--such as a meteorite strike. As noted by the Huntoon-Shoemaker report:

> Linking the origin of the Roberts rift to the impact of the Upheaval Dome meteorite near the close of the Cretaceous time very conveniently accounts for the tremendous energy required to form the rift. What was needed was a sudden influx of energy. Such energy requirements implied an extraordinary event unlike any geologic process known to have occurred spatially near the rift. Extraordinary occurrences require extraordinary explanations. A meteorite impact satisfies both.

The report supported its conclusions with a stress analysis that showed a definite relationship between Roberts Rift and Upheaval Dome, and showed how the explosive impact of the meteorite could have provided the enormous energies required for the rift formation, and for the injection of solids and liquids into the momentarily-open rift from as much as 2,500 feet below.

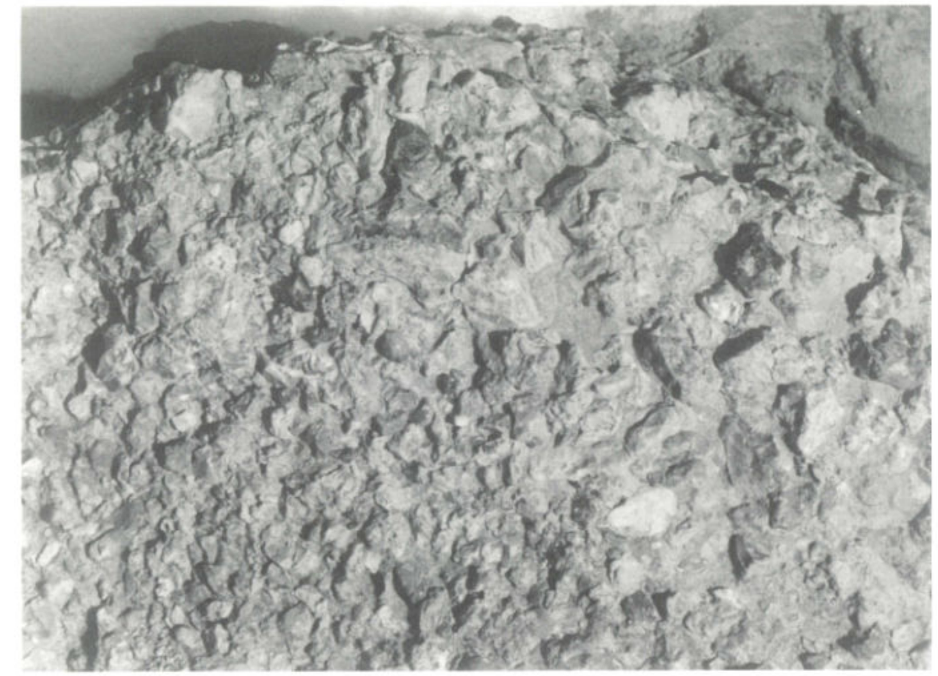
SUMMARY AND CONCLUSION

When all of the presently available evidence is considered, little doubt remains that Upheaval Dome and Roberts Rift were formed at the same time by the impact of a meteorite or cometary body about 1,600 feet in diameter and probably composed largely of ice, as many such astronomical objects are. The shape of the disturbed geologic strata in the vicinity of the crater matches that of other known impact craters, and the immense energy required for the formation of Roberts Rift could easily have been provided by such a violent impact.

Since the time of that impact, at about the close of the Cretaceous, the impact site rose from around sea level to its present elevation about 6,000 feet above sea level. Furthermore, more than a mile of rock has eroded from what was the sedimentary surface at the time of the impact. This erosion has left only remnants of the geologic strata deformed by the impact far below the lower tip of the original impact crater, and has exposed in some Moab-area canyons the upper zones of Roberts Rift.

Since the meteorite impact took place at about the same point in geologic time as the much larger one that brought on the Great Extinction of dinosaurs and other forms of life at that time, it is probable that both of these meteors were part of a general swarm of such space debris that our solar system has encountered periodically over an immense span of time. Each such encounter has produced mass extinctions of life on Planet Earth, and has left deep scars on its surface, some of them obvious--such as Upheaval Dome--and others obscured by this planet's seas. Only recently have scientists found, in the Gulf of Mexico, the remains of the crater of the immense meteor that is believed to have caused the Great Extinction at the end of the Cretaceous.

Thus, visitors to the Moab area have a chance to marvel at a rare phenomenon--visible remnants of one of the visitors from outer space that have so devastated this planet in the past.



Large boulders of this conglomerate-type "clastic" material have eroded from Roberts Rift and lie around in the drainages between the rift exposures in the Bull Canyon walls. Most of the material in this strange rock was thrust upward into the rift from as much as 2,500 feet below by the immense pressures of the Upheaval dome meteorite impact. These specimens, now at the same stratigraphic level as Wingate Sandstone, contain marine fossils and minerals from the Honaker Trail formation. No signs of Paradox Basin salts were found in Roberts Rift.

UPHEAVAL DOME AND ROBERTS RIFT

Perhaps someday, when the meteorite-impact origin of Upheaval Dome is no longer disputed, the Park Service will revise its brochure, interpretive displays and nomenclature to reflect the known facts. The name "Upheaval Dome" is appropriate for a salt dome, but not for a meteorite crater. Perhaps "Impact Crater?"

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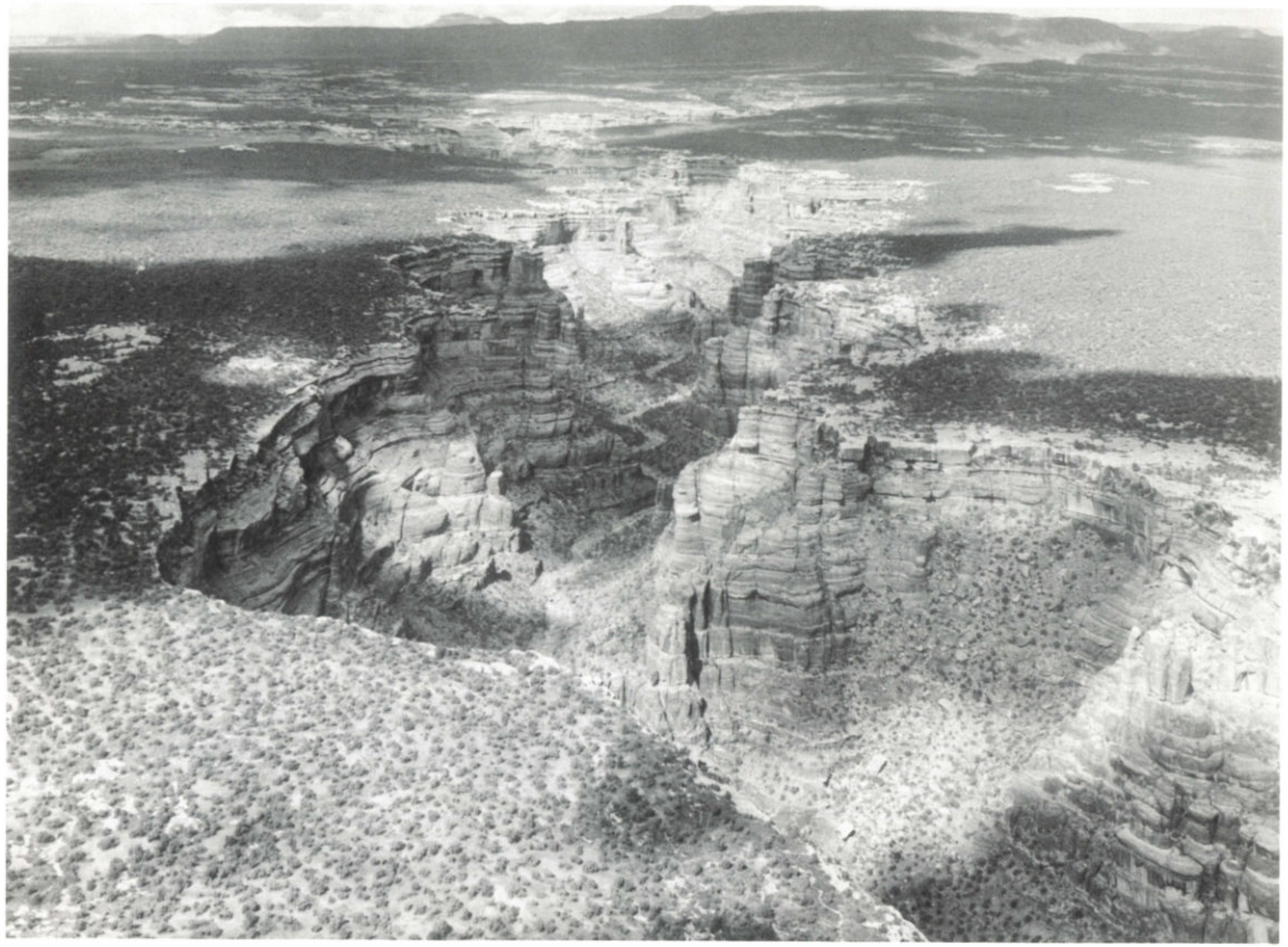
NOTE: This illustrated article, in somewhat different form, will appear in a Canyon Country Publications book presently being researched and written by F.A. Barnes. The book is scheduled for release in early 1993.



South of the Bears Ears near the Abajo Mountains, massive erosion into the rock strata elevated by the Monument Uplift has formed spectacular canyons such as Grand Gulch, Slickhorn Canyon, Arch Canyon and many others. Note the Bears Ears on the distant horizon. Aerial photo by F.A. Barnes.

The center of Monument Uplift lies in Monument Valley, where the jointing caused by the uplift in the massive Canyon de Chelly Sandstone there contributed to the formation of the complex valley's numerous spires. The uplift continues on south into Arizona, in a roughly north-south alignment. Photo by F.A. Barnes.

MONUMENT UPLIFT

Some geologists call this immense geologic deformation an "upwarp," rather than "uplift," but the meaning is the same. In the distant geologic past, stupendous natural forces caused the crust of the Earth to bulge upward in an immense, elongated blister. The remnants of this physical deformation of the region's sedimentary strata are still highly visible today, as major landforms within the general Four Corners region, some of them within Utah's Canyon Country.

Monument Uplift is about 100 miles long, on the surface, but, as with most such anticlines, it is probably even longer if the distorted strata still deeply underground are considered. The uplift formed during a long period of severe geologic activity called the Laramide Orogeny, which took place during the late Cretaceous and early Tertiary, about 50 to 80 million years ago, although geologists differ about the time period.

This long period of crustal deformation was caused by continental drift activity. It produced the present Rocky Mountains, the Kaibab Uplift in the Grand Canyon vicinity, the Defiance Uplift in Arizona, the Zuni Uplift in New Mexico, and the San Rafael Swell and Circle Cliffs uplifts in central Utah, as well as other major tectonic features such as subsiding basins.

Some geologists think that during this period of severe tectonic activity the Colorado Plateau, the immense oval of continental crust that is the heartland of the Four Corners States, was rotating somewhat in relation to the surrounding North American continental plate, and that this contributed to the deformation processes. Although this concept has yet to be widely accepted, it is entirely possible because during that period of time the continental plate changed its direction and rate of travel at least three times. These directional changes may also have triggered the Laramide Orogeny and provided the stupendous amounts of energy involved in the resulting tectonic activity.

Regardless of the causes of its formation, and despite millions of years of subsequent erosion, there are still many prominent remains of the Monument Uplift. During its erosional phase, which is still going on, the more fractured rock in the arching dome of the uplift eroded away more easily, although parts of it still remain, as highlands or cliffs and spires.

The northern nose of the uplift, or immense anticline, dives downward in the Needles District of Canyonlands National Park and adjacent areas of the Beef Basin District of Canyon Rims Recreation Area. The spectacular sandstone spires and fins of The Needles were formed by the erosion of sandstone strata cracked in an intricate checkerboard pattern by the upward bulging of the uplift. The numerous grabens there and in the adjacent Beef Basin District are also a part of that faulting and jointing.

The Colorado River formed Cataract Canyon along the northwestern flank of the uplift. The Elk Ridge highlands and on south are part of the uplift's remaining spine. In this vicinity, ancient geologic strata have been raised more than 4,000 feet by the uplift. The region's deepest gorge, Dark Canyon, formed in the uplifted strata.

Farther south, Comb Ridge, Lime Ridge and Raplee Anticline are part of the eastern flank of the Monument Uplift, and the spectacular spires and cliffs of Monument Valley are part of its central heartland.

South of the Abajo Mountains, the San Juan River cuts through the uplift, just as the Colorado River once cut through the Uncompahgre Uplift and still goes through the Kaibab Uplift in the Grand Canyon and the Moab Valley salt anticline. Similarly, the Green River slices through the Uinta Mountains and the Dolores River cuts through the Gypsum and Paradox salt anticlines. How these rivers were able to cut through these huge ranges and anticlines is fascinating, but too complex for discussion here.

The Abajo Mountains thrust upward through the Monument Uplift millions of years later, adding to the deformation of the rock strata in that vicinity. See the article titled "Laccolithic Mountains" for more details about the several island mountain ranges in the general Four Corners region.

LACCOLITHIC MOUNTAINS

According to one dictionary of geologic terms, a volcano is "a mountain which has been built up by the materials ejected from the interior of the earth through a vent."

But what if such molten rock rising through a weakness in the earth's crust were to meet so much resistance from massively thick layers of stratified rock that it could not break through the surface, yet still had pressure from below to relieve?

In that case, the molten rock would flow laterally between the rock strata, forming broad fans, or sills, somewhat like great spatulate leaves growing horizontally from a gigantic central stalk. A "sill" is defined as "an intrusive body of igneous rock of approximately uniform thickness and relatively thin compared with its lateral extent, which has been emplaced parallel to the bedding of the intruded rock."

Then, if the subterranean pressure was still not relieved, these sills of molten rock would fatten, bulging upward, forming what geologists call "laccoliths," or "stone cisterns." Without this final upward bulging of their sills, such mountains would be called "intrusive igneous," but not "laccolithic."

Once a balance was reached between the pressures far below and those in the vent's central stock and branching laccoliths, the molten rock would slowly cool under this pressure, allowing the minerals in it to form crystalline structures not unlike those in granites, but not truly granite. Granite forms deep within the earth when sedimentary rock is subjected to heat and pressure over a long period of time.

Thus, in non-technical terms, laccolithic mountains are volcanoes that "died a-borning," they are mountains built by volcanic forces that were not great enough to break through the earth's surface, but that still raised great mountains of sedimentary strata above their central stocks and lateral intrusions, and then fattened those intrusions. They are mountains built by "intrusive" molten rock, rather than "extrusive" flows of lava.

As time passes after the formation of such mountains, erosion wears away the fractured rock on their tops and sides, gradually exposing the tops of their central stocks and even a few lateral structures. The igneous rock thus exposed has the appearance of gray rubble, which often forms great barren slopes so steep that trees and shrubs have trouble taking root on them, slopes where landslides can be, and have been, triggered even by the weight of a hiker.

Within the general Four Corners region there are seven, possibly eight, laccolithic mountain ranges. These are the Abajos, the La Sals and the Henrys, which are in southeastern Utah's Canyon Country, the Ricos, the Utes, the La Platas and the Carrizos. The laccolithic nature of Navajo Mountain is not certain. It may simply be intrusive, without the bulging sills that define it as laccolithic.

The three laccolithic mountain ranges within southeastern Utah formed at different times. According to the potassium-argon dating method sometimes used to determine the age of ancient rock, the Henry Mountains formed about 48 millions years ago (MYA), the Abajos about 28 MYA and the La Sals about 24 MYA.

The erosional cycle that emphasized these laccolithic mountain ranges and exposed their intrusive components began about 10 million years ago, with most of this erosion occurring within the last 5 million years. During this period, almost 5,000 feet of the region's rock was removed, leaving the harder, more erosion-resistant mountains looming high above the surrounding terrain.

Rain and snowmelt runoff from the La Sal and Abajo mountains, as well as from the slanting rock strata on the northern nose of the Monument Uplift, has played a major part in the formation of the magnificent canyons, basins, plateaus and lowlands that are characteristic of Canyon Country.

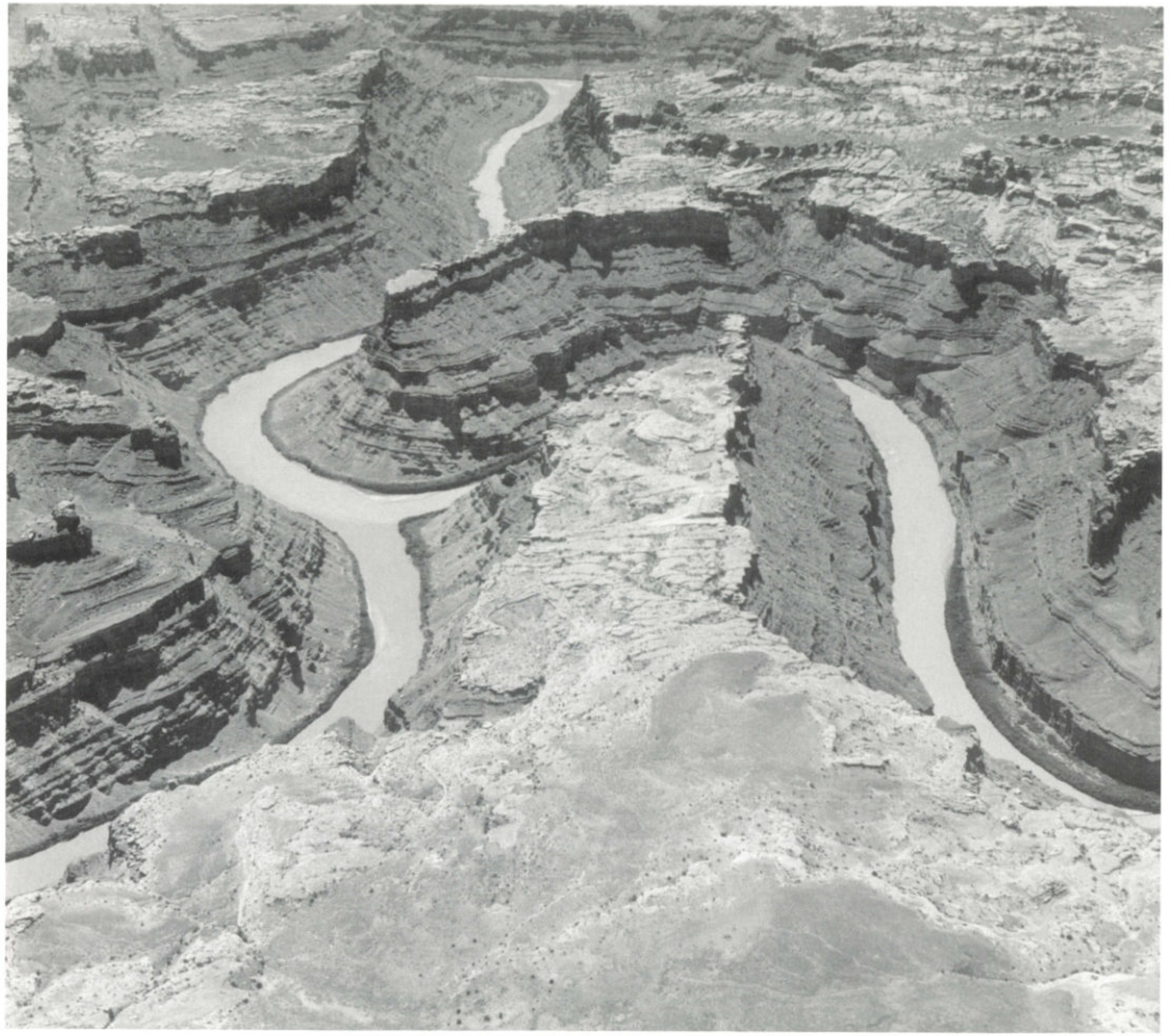
In the Abajo Mountains, the laccolithic range that has contributed most to the shaping of the southern districts of Canyonlands National Park and Canyon Rims Recreation Area, there are four central igneous stocks, or columns through which molten rock rose from beneath the continental crust. The three most prominent are Shay Mountain, East Mountain (Abajo Peak) and West Mountain. Inconspicuous Johnson Creek Dome is the fourth, lying between the other three.

The parent stocks of East and West mountains have been exposed by erosion, but only the roofs and laccoliths of the other two stocks are presently exposed. Geologists have estimated the total volume of the igneous rock intruded to form the Abajo Mountains to be 5.2 cubic miles.

The laccolithic mountains of the Four Corners region are unique within the United States. They have played, and are continuing to play, a vital part in shaping the magnificent topography of Canyonlands National Park, Canyon Rims Recreation Area and adjacent canyon country.

The LaSal Mountains are one of the three ranges of laccolithic mountains in canyon country. The intrusive igneous cores of these mountains have been exposed by millions of years of erosion, then decomposed into the gray-colored rubble that dominates the mountain slopes and peaks. Photo by F.A. Barnes.

Aerial photograph of the Henry Mountains, one of several laccolithic ranges in the general Four Corners region and one of the three within southeastern Utah's canyon country. Photo by F.A. Barnes.



This aerial view of the Green-Colorado river confluence shows the inner walls of the Colorado River gorge. The studies that first established the "Elephant Canyon Formation" were made in this vicinity, as were those that refuted the findings of that effort. Much of the "evidence" for the creation of the Elephant Canyon Formation turned out to be an optical illusion perceptible only from the river level. Photo by F.A. Barnes.

YES -- GEOLOGISTS ARE HUMAN

Between 1933 and 1946, long before the establishment of Canyonlands National Park and Canyon Rims Recreation Area, geologists A. A. Baker and E. T. McKnight made detailed studies of the Colorado and Green river gorges in that vicinity, and established the identities of the rock strata there.

In 1962, geologist D. L. Baars asserted that the earlier geologic studies of that area were incomplete and in error. He claimed that much of the rock in the area was a previously undescribed formation he named "Elephant Canyon Formation," and that this was underlain by strata of the Honaker Trail Formation that was first identified in the San Juan River gorge farther south.

When geologist D. B. Loope and others expressed serious doubts about the existence of the "Elephant Canyon Formation," Baars defended his position in professional papers published in 1971 and 1987. Significantly, the U. S. Geological Survey did not accept the "Elephant Canyon Formation" as a valid designation, although some geologists did to the extent that the name appeared in their published books, maps and papers about Utah geology.

In a professional paper by D. B. Loope, G. A. Sanderson and G. J. Verville titled **"The Abandonment of the Name 'Elephant Canyon Formation' in Southeastern Utah: Physical and Temporal Implications,"** published October, 1990 in **The Mountain Geologist,** the journal of the Rocky Mountain Association of Geologists, this controversial matter was finally settled, once and for all --

> " -- *the Elephant Canyon Formation is not a valid lithostratigraphic unit. We advocate a return to pre-1962 nomenclature -- we suggest use of a temporary formal term 'lower Cutler beds' --* "

The report also confirmed earlier studies that questioned the establishment of the "Honaker Trail Formation," stating that --

> "-- *'upper member of the Hermosa Formation' is a more appropriate name than 'Honaker Trail Formation' --* "

While the suggested substitution of the term "lower Cutler beds" had not yet been formally accepted when this book was written, it was nonetheless descriptive and hence used throughout this book pending official designation. The original term "Hermosa Formation" was used for the same reason.

This summary is presented here for readers who are curious about the fascinating geology of Canyon Rims Recreation Area and adjacent Canyonlands National Park, and who may wonder about the discrepancies between this book and others that describe this region's geology in the Colorado River gorge. While the erroneous terms "Elephant Canyon Formation" and "Honaker Trail Formation" appear in a number of scientific papers, such papers are not in widespread distribution, nor were they written for the general public.

The following publications, however, were intended for general readership and are therefore for sale and accessible in some libraries. *They are in error to the extent that they apply the terms* "Elephant Canyon Formation" *and* "Honaker Trail Formation" *to the geology of Canyonlands National Park, Canyon Rims Recreation Area and the southeastern Utah region.*

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Yes -- geologists are human and, like other humans, they make errors, sometimes big ones!

F. A. Barnes

THE PARADOX OF THE PARADOX BASIN

By A. Lynn Jackson

Canyon Country is located in the heart of the physiographic province known as the Colorado Plateau. Within this province geologists have further sub-divided various areas--as geologists are prone to do--based on geologic features. One of the more important of these sub-divisions is the Paradox Basin. In addition to some of the unique geologic features of this basin, which have fascinated and perplexed geologists for years, it would be safe to say that the beauty of the present day Canyon Country is due in no small measure to the basin's existence and its inherent geologic characteristics.

The name "Paradox" is applied to several geologic and physiographic characteristics found in the region. The origin of the term seems to have stemmed from early day settlers in the region, who were used to seeing rivers run "down" valleys--which seemed perfectly logical for any self-respecting river to do. However, when the settlers arrived at a valley on the Utah-Colorado stateline east of the LaSal Mountains, they found the Dolores River "crossed" the valley at right angles. It came abruptly into the valley from the south side, ran straight across, and just as abruptly exited the north side! This seemed to them to be somewhat of a "paradox," and the valley was subsequently named Paradox Valley.

Location Okay, so what is the Paradox Basin, you ask? In its simplest terms, the Paradox Basin was an ancient gulf, formed approximately 280 to 300 million years ago in a geologic era known as the Pennsylvanian Period. (Figure No. 1 shows the present day boundaries.) The basin formed an elongate north-westerly trending seaway roughly 200 miles long and 80 miles wide, that extended from present day Green River, Utah to Shiprock, New Mexico.

The basin was asymmetrical, meaning it was deeper on the northeastern margin than the southwestern margin. In the northeastern portion of the basin, thousands of feet of salt accumulated in a deep structurally-subsiding trough. In contrast, the northwestern portion was a relatively shallow shelf, subject to normal marine deposition of carbonates.

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Formation of the Paradox Basin The birth of the Paradox Basin was preceded--and set up--by the formation of what are referred to as the Ancestral Rocky Mountains. The Ancestral Rockies formed 320 million years ago during a mountain building episode called an "orogenic" event. this orogency resulted in the formation of several mountain ranges running northward through New Mexico, Colorado and Wyoming, with one branch curving westward into Utah. The westward component has been named the Uncompahgre Uplift. No one is quite certain what caused this relatively abrupt period of mountain building, but it more than likely was related to plate tectonics and rifting (Hintze, 1988), when the North American continent was still connected to the supercontinent called Pangea.

The appearance of the Uncompahgre Uplift and the Ancestral Rockies was geologically abrupt. In just a few million years, at the beginning of the Pennsylvanian Period, the range appeared and grew to an estimated elevation of 12,000 to 15,000 feet (Stokes, 1987). Such uplifts are characteristically associated with an adjacent area of corresponding down-faulting and the subsequent formation of a structural depression or trough. In the case at hand, this structural depression became the Paradox Basin. This trough, or basin, formed immediately adjacent to the Uncompahgre on its southwestern flank and may have subsided as much as 20,000 feet in its deepest section.

As the basin subsided it allowed the entry of the ocean from the northwest and southwest, which had been minding its own business to the west of the continental margin in an area of present day western Utah and Nevada. This new seaway was bounded on the north, northeast, and east by the Uncompahgre Uplift. On the west and southwest the boundaries were formed by smaller uplifts on the Piute Platform. Evidence indicates these smaller uplifts may have been ancient predecessors of the present day San Rafael Swell, Circle Cliff Uplift and Monument Upwarp. The southern boundary was formed by the Four Corners Platform consisting of the ancestral counterparts of the Zuni and Defiance uplifts.

The effect of these boundaries was to provide an isolated and restricted basin somewhat similar to the present day Persian Gulf. The main access to the ocean appears to have been on the northwest end, in a broad, shallow sag between the ancient San Rafael Swell and the Uncompahgre Uplift. However, the uplifts on the southern boundary were apparently low enough that any slight rise in sea level resulted in the flooding of the basin from that region, and any lowering of sea level cut off the supply of sea water.

Figure No. 2 is a cross-section through the Paradox Basin at the time of its deposition. The cross-section would be typical of a line drawn roughly from Mexican Hat, Utah (on the right side of the diagram) to Gateway, Colorado (on the left side). It can be seen that the southwestern margin of the Paradox Basin consisted of relatively shallow marine environments teeming with life, while along the northeastern margin was a deep salty lifeless trench, rapidly subsiding along deep faults.

If we were to go back in time approximately 300 million years and take a walk along this line we would have a better idea of what the area looked like during the deposition of the Paradox Basin. We would start at Mexican Hat on a low coastal plain. As we look out to the northeast we see a vast watery gulf with a range of mountains on the distant horizon. Entering the sea, we notice how shallow and warm it is, with soft limy muds squeezing between our toes. There would be huge mats of algae all around us, building up into mounds with abundant sea-life living around them, much like present day coral reefs. We would also see meadows of crinoid plants, mollusks, brachiopods, corals, and bryzoans.

As we continue to the northeast, the sea would gradually deepen until just after passing Monticello. Suddenly, the sea floor would drop noticeably as the calm sunlit marine shelf gave way to a deep dark abyss. As we drop down into this abyss there would be no more signs of life, the water would become extremely salty and the light would begin to fade. We would drop off cliff after cliff, the remains of fault scarps in older Mississippian age rocks, eventually reaching the bottom of a vast, lifeless and featureless plain composed of crystallized salts and black, decaying muds. We would continue on past the Moab area, and as we approached Gateway we would begin a steep climb up slopes composed of large broken boulders, rocks and sub-sea alluvial fans in muddy turbid waters. After a short steep climb we would finally re-emerge at the foot of a large mountain, the Uncompahgre. What had started as a stroll through a warm shallow sea ended up with a walk through a lifeless, salty quagmire. It will be good to get back home, Toto.

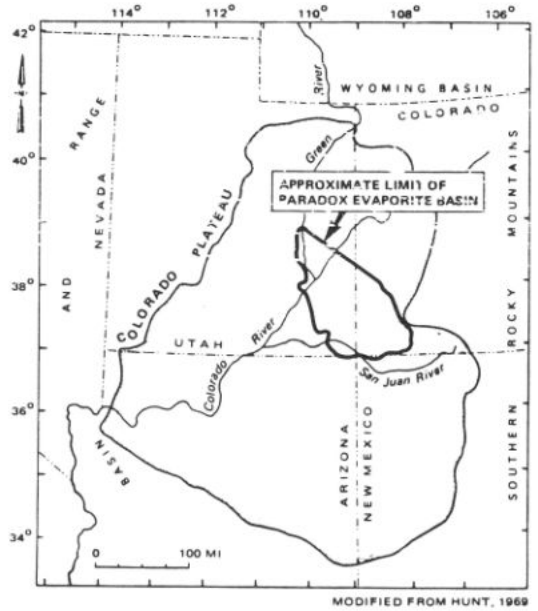

Figure 1
Paradox Basin Location Map. From Hunt, 1969.

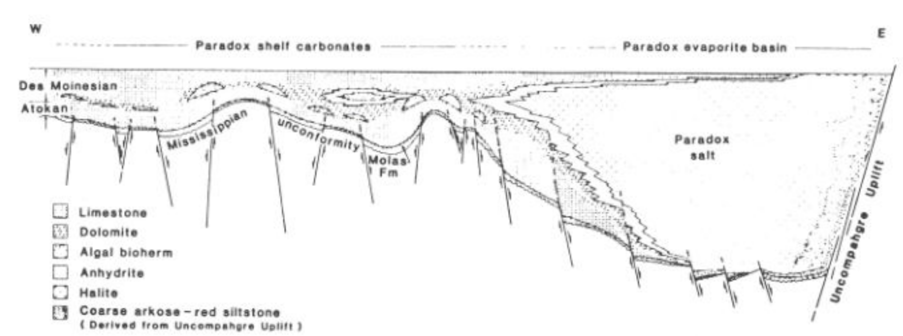

Figure 2
Cross-section through the Paradox Basin. From Baars and Stevenson, 1981.

Invasion of the Salt During the formation of the Paradox Basin there is evidence of dramatic and cyclic fluctuations in sea level on a worldwide scale. Many experts attribute this phenomena to periods of cyclic glaciation (Hite and Buckner, 1981). When polar ice caps melt, sea levels consequently rise. No one has yet conclusively demonstrated what caused the cyclicity of this worldwide glaciation, but it produced profound effects in the sedimentation of the Paradox Basin.

Whenever sea levels rose, the Paradox Basin flooded with seawater. When sea levels fell the basin was left without a continuous supply of fresh seawater and would stagnate. As a result of these fluctuations, whenever the sea retreated the water began to evaporate and the deeper sections of the basin got saltier and saltier. This resulted in the precipitation of the salts on the basin floor. When the sea level again rose it would bring in a fresh supply of seawater and the process would begin again.

Over millions of years, with sea levels continuously raising and falling, the salts accumulated to a thickness of thousands of feet on the basin floor. Some estimates put the total accumulation of salts at 5,000 to 6,000 feet in the deeper portions of the basin (Baars, 1972). The degree of evaporation was greatly enhanced as a

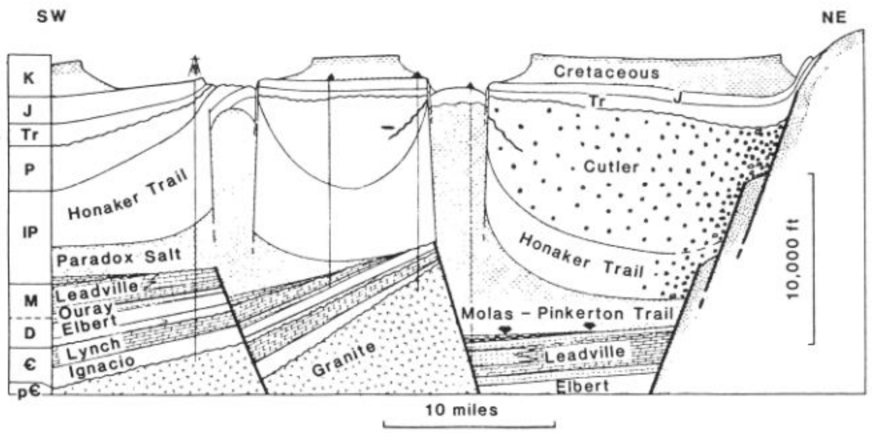

Figure 3
Cross-section through the Paradox Basin demonstrating salt flowage. From Baars and Stevenson, 1981.

result of Utah's position along the equator at this time (Hintze, 1988), which added to the aridity of the region due to the hotter temperatures. Plate-tectonic movements have of course moved Utah significantly further north of the equator since Pennsylvanian time.

Also interlayered with the salts were sediments consisting of black organic-rich shales and carbonates, brought into the basin and formed when the sea levels rose. Collectively, these sediments shape what is called--surprise--the Paradox Formation. It has been estimated that up to 29 cycles of such deposition occurred within the basin during this time (Hite and Buckner, 1981). Studies have indicated that these cycles lasted on the order of 100,000 years each (Hite and Buckner, 1981).

At some point towards the end of this cyclic salt deposition, uplift on the Uncompahgre seemed to have been rejuvenated. If there is anything the forces of erosion dislike, its an uppity mountain range. The higher a mountain rises, the more ferociously erosion attacks it, trying to bring it down. Such a battle brought about the end of deposition in the Paradox Basin, which became another in a long line of innocent bystanders in such wars.

The Uncompahgre's rejuvenated uplift was rapid enough and the erosive counterattack so swift, that thousands of feet of sediments from the Uncompahgre were literally dumped into the adjacent Paradox Basin, and on top of the just-deposited salts. These clastic sediments (the material eroded from the previously formed rocks in the Uncompahgre mountain range) today form the Cutler Formation of Permian age.

The larger-grained and heavier sediments deposited closest to the mountain range formed the undifferentiated Cutler Formation, which is seen as a purplish colored sandstone as one travels up Moab Canyon. As the gradient and subsequent energy of the erosive streams decreased away from the mountains, they were only able to carry the finer-grained and lighter sediments out into the basin. The Cutler in these areas subsequently differentiated (separated) into the White Rim Sandstone, Organ Rock and the Cedar Mesa Formations which form the rocks in the heart of Canyonlands National Park. But back to the story of the squeeze play...

The previously deposited salts did not appreciate the enormous weights placed on their shoulders by the thousands of feet of overlying Cutler sediments. Since salt has the peculiar nature of being able to flow in a sort of plastic state when subjected to high pressures, it decided to "leave."

Since the greatest pressure was being exerted by the thousands of feet of clastics next to the Uncompahgre, the salt decided to head the other way, to the southwest. As it migrated laterally beneath the Cutler sediments, it encountered the remains of old fault scarps in Mississippian age rocks which it had previously buried (See Figure No. 3). As it hit these fault scarps it turned and flowed upward, arching the overlying sediments, and forming the linear salt valley anticlines we see at the surface today, such as in Spanish Valley where Moab is located and in Salt Valley in Arches National Park. Fifteen of these salt anticlines formed in the northeastern portion of the basin and this area is today referred to as the Paradox Fold and Fault Belt (see Figure No. 4). The salt flowed until it was essentially all squeezed into these salt valley anticlines.

With the erosive stripping of the Uncompahgre and subsequent dumping of the sediments into the basin, the Paradox was stuffed full. The vast quantity of sediments unloaded into the basin essentially forced the sea out and brought about an end of deposition in the Paradox Basin proper. It would be another 140 million years before this area would see the return of such a vast seaway, during the Cretaceous period--but that's another story.

This is a very brief and simplified version of complex geology. For example, the salt flowage occurred over a period of 150 million years and the upward arching of the overlying sediments affected more than just the Cutler Formation. The flowage also influenced later deposition on top of the Cutler Formation, and filled in the valleys created around the salt structures. Additionally, these salt anticlines were later buried by thousands of feet of Jurassic and Cretaceous sediments.

The salt anticlines are visible today because of the erosive processes that attacked the entire Colorado Plateau approximately 35 million years ago when it was lifted and tilted as a region thousands of feet above sea-level. Present day river systems appear to have been in place 10 million years ago and have since removed the overlying sediments and have cut approximately 5,000 feet into the underlying strata (Hunt, 1969). This uplift and erosion resulted in the removal of these younger sediments and exposed the old salt anticlines in all their glory. It also carved the spectacular scenic formations and canyons seen at the surface today.

Arches National Park sits directly on top of one of the salt anticlines, referred to as the Salt Valley anticline. The folding and faulting of the rocks on the margins of the anticline created zones of weakness which paralleled the salt anticline. Erosion then worked along these zones of weakness creating the

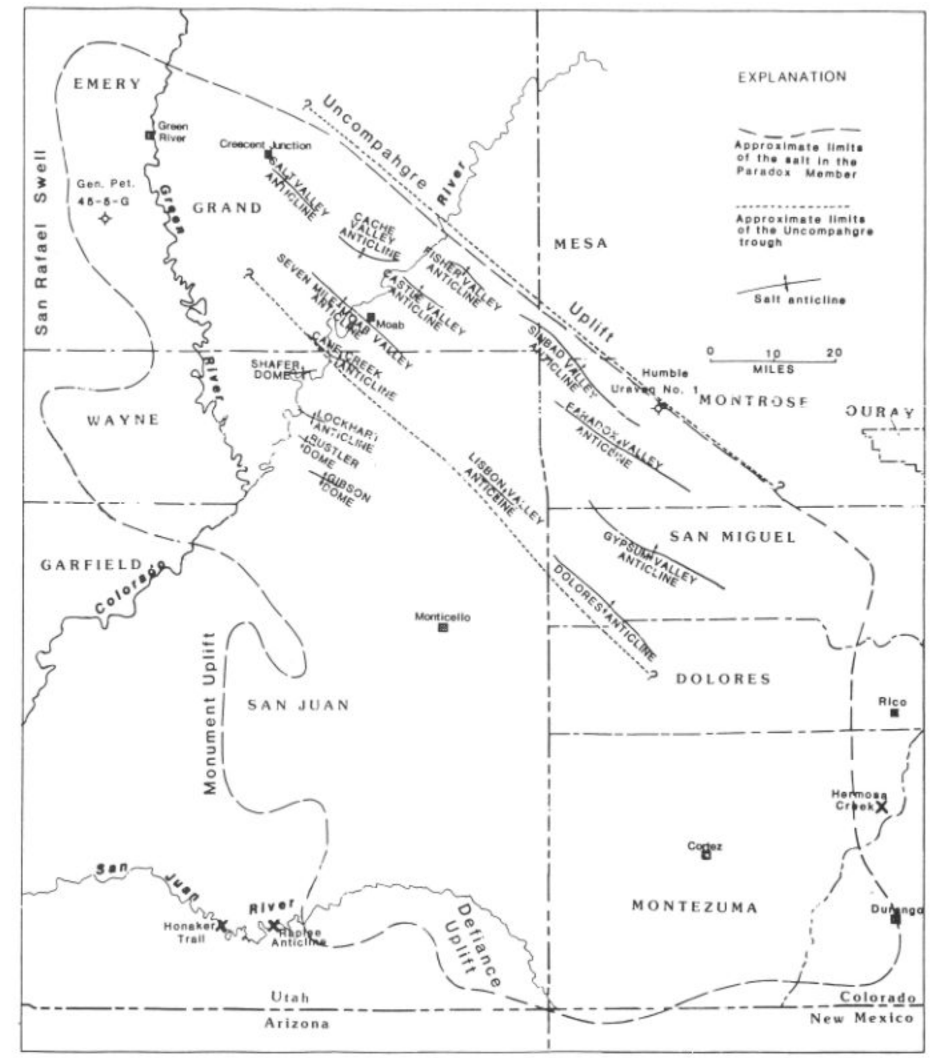

Figure 4
Location of Salt anticlines in Paradox Basin. From Hite and Buckner, 1981.

thin fins and forming the arches in the park.

The Paradox of the Paradox Basin

So what is the paradox of the Paradox Basin? You have read all the way through this article trying to get the answer. Quite simply, Mother Nature has given the Basin a paradox of resources. The country found within the Paradox Basin is perhaps the most beautiful in the world. The multi-colored rocks, the narrow deeply incised canyons, the awe inspiring buttes, pinnacles and arches, the majestic alpine mountain ranges of the Henrys, La Sals and Blues, the mighty rivers of the Colorado and the Green, and the remoteness, desolation and wilderness, all add to this beauty.

But within this landscape Mother Nature bestowed a vast amount of mineral wealth in the form of oil, natural gas, and potash. Millions and millions of barrels of oil and associated natural gas are found within the Paradox Formation in the organic rich black shales interlayered in the thousands of feet of salts deposited in the ancient basin, and within the large algal mounds found on the shallow southwestern shelf of the basin. In addition, millions of tons of potassium and sodium salts are found within the salt layers themselves. Recent exploration has also indicated there may be millions of tons of other valuable minerals in the salt brines deep underground, minerals such as boron, lithium, magnesium, strontium and bromine.

These resources--the unparalleled scenic beauty and the vast treasure house of minerals--have coexisted for millennia, therefore the paradox may only be for mankind. Will we make wise use of these magnificent resources that were given us some 300 million years ago within the empty and desolate confines of an ancient salt-laden seaway? Time will tell.

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GEOLOGY AT A SNAIL'S PACE

by Saxon Sharpe

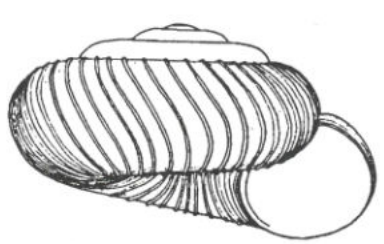
Geology. The word may bring to mind the massive laccolithic La Sal Mountains, the red-orange sandstone fins of Arches National Park, or the deeply incised Grand Canyon. But geology also includes evidence of the Earth's history preserved on a much smaller scale.

Records of past local environments can often be found in the alluvial banks of sandy washes in canyon country if you stop to examine the sediment. Look closely for the remains of mollusks. These snails, mollusks contained in dry sediments, are usually assemblages from a different, older time period. Paleoecologists refer to them as "fossils" although the shells are still composed of calcium. In this sense, "fossil" simply means old. To interpret this past geologic record it is important to understand the lives of present-day snails.

There are many different species of land snail. They are found all over the world ranging in size from African snails bigger than your fist to shells smaller than the period at the end of this sentence. These tiny snails are called the Dot Snails, of the genus *Punctum*, and they are Utah's smallest snail. Shells can be circular and flat like coins, dome-shaped like the Utah State beehive, and swirled-elongate like dairy-queen ice cream cones. Shells can spiral to the left or right, and have different bands of color. Each species fills different ecological niches, lives in completely different environments, and eats different meals. They all need shelter, moisture, and a specific temperature range to survive. They eat live or decaying plants, decaying animals, lichens, fungi, and/or minerals. There are almost as many variations of Colorado Plateau land snails as variations in the landscape of the Plateau itself.

Most of the canyon country mollusks are quite a bit smaller than the typical "escargot-type" shell. The biggest and most common Utah snail, *Oreohelix strigosa* (oreo, of mountains + snail), is about the diameter of a penny. Living *Oreohelix* were collected by malacologists in the La Sal Mountains on Mt. Tukuhnikivatz (1927) and on Geyser Pass (1934). These early collecting expeditions found *Oreohelix* inhabiting rocky talus slopes as high as 10,000 feet and feeding on both live and decayed vegetation.

Vitrina pallucida.
Width = 3/16"



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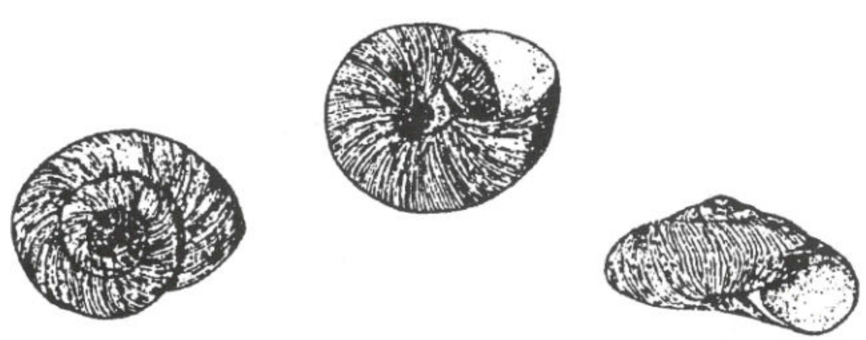
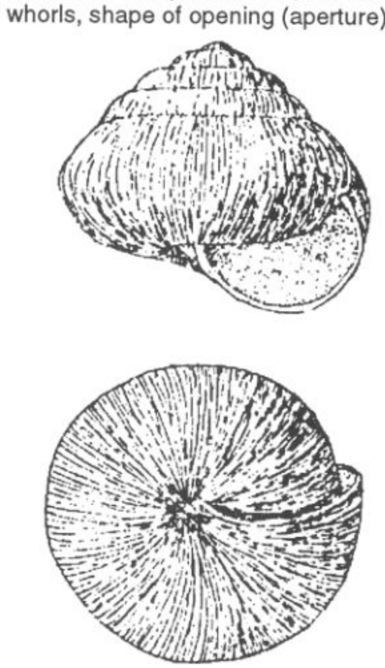


Oreohelix strigosa. Width = 3/4"

Another widely distributed Utah mollusk first collected in the 1920s and 30s near Monticello and on Geyser Pass is *Vitrina pallucida. Vitrina* comes from the latin word *vitrum*, or glass. And glass snails they are; their shells are completely transparent! These snails live under moss near spring seeps at high altitudes although they are also common in favorable conditions at lower elevations.

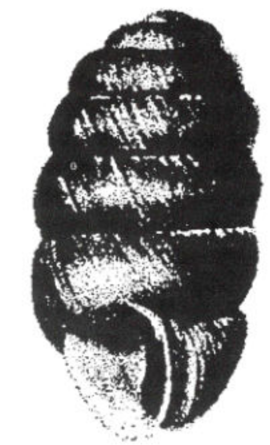
Early collecting expeditions gathered and described other mollusks as well. Snails are identified to the species level using their soft anatomy. Physical characteristics of the body and shell, the snail's location, and its habitat are also carefully recorded.

Fortunately for paleoecologists, shells are noted in detail when a species is described, for shells are all that remain in the geologic record once a snail dies. Shape and size, number of whorls, shape of opening (aperture), and texture of the shell all help to determine the genus, and sometimes species, of fossil snail. Quaternary scientists use original descriptions, such as those from the 1927 and 1934 expeditions to the La Sal Mountains, to identify snails from past environments.



Euconulus fulvus. Width = 3/16"

Since each snail has specific ecological tolerances its past local habitat can often be ascertained. Different habitats include grassland, leaf litter in deciduous woodland, pond edges, under water, shade, and rotting logs to name a few. Two tree-loving snails, *Euconulus fulvus* (a real little cone) and *Zonitoides arboreus* (the Tree Snail), are presently found under leaves at the base of trees. Found under stones in spring seeps is *Pupilla hebes*, the plain columnar snail, shaped like the pupa of an insect.

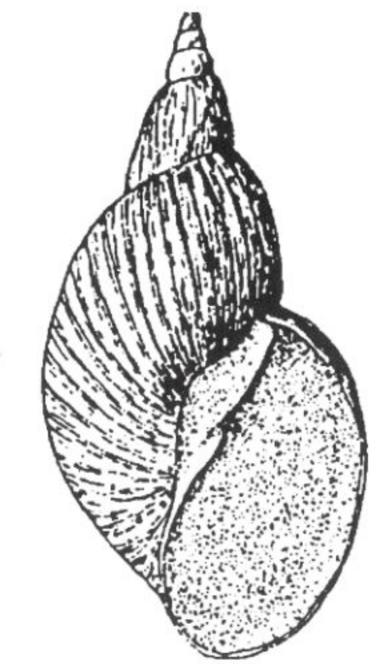


Pupilla hebes.
Width = 1/16"

The remains of most snails can tell us something of past environments. Today *Oreohelix* lives on dry warm slopes; if unbroken shells (indicating an in situ colony assemblage) are embedded in sediments, the slope was probably dry and warm when this snail colony was alive. *Vitrina* inhabits a completely different environment. It must have a wet, moist location to survive. If found in a dry location today we could infer that this area was once wet and cool. Discovering a fragile shell of *Succinea*, (the Swamp Snail), means the area was once moist ground--either a flood plain or marsh environment--because this invertebrate lives on reeds and floating material. *Pseudosuccinea columella*, (the Large Stagnant Pond Snail), must have freshwater ponds or streams to survive for it lives under water and feeds upon aquatic plants. It often surfaces to take in air and glide on the pond backstroke style with its shell pointing downward.

Mollusks can be excellent indicators of past environments. First, the ecological tolerances of individual species are small so specific local habitats can be determined. Secondly, snail shells preserve fairly well and there are many individuals so the chances are good that assemblages will survive to become part of the geologic record. Finally, snails can provide accurate radiocarbon dates so spatial shifts in their geographic ranges can be determined over time.

On your next outing, spend some time looking for fossil or live snails. The search for mollusks can be rewarding. Their shells are intricately beautiful plus they're easy to catch! If asked why you are staring intently at sediments in a wash, just say you're hunting paleo-escargot.



Pseudosuccinea columella.
Width = 1/2"

Drawings:

"The Mollusca of Utah," Ralph V. Chamberlain and David T. Jones, Bulletin of the University of Utah, Vol. 19(4), Salt Lake City, 1929.

Land Mollusca of North America, Henry A. Pilsbry, The Academy of Natural Sciences of Philadelphia Monographs #3, Volumes 1-4, Philadelphia, 1939.

After completing graduate work in Quaternary Studies at Northern Arizona University, Saxon Sharpe has returned to Moab and the Quaternary Corner column.

Permian Geology in the Canyonlands Province

By John Weisheit

While employed as a river guide on the Colorado Plateau, the author became fascinated with geology of the Permian Period. In the Grand Canyon's 277 river miles, Permian strata exhibit uniform layers (except for a gradual thinning toward the western region). In contrast, in the 94 miles from Potash, south of Moab, to Hite marina on Lake Powell, dramatic changes in the thickness of Permian rock occur, along with complex depositional interfingering.

History of the Permian Period The Permian period, named in reference to a region of Eurasia called Perm, is a classification of geologic time that was established in the 19th century. It is the last period of the Paleozoic era, which literally means "ancient life," as depicted by its fossil record. In classical interpretation, the Permian period constitutes an interval of geologic time from about 280 to 225 million years ago. This period is marked by extensive glaciation, the decline of amphibians, and the increase of primitive reptiles.

The members of the Permian period in the Canyonlands Province were first designated into a formation, specifically called the Cutler Formation. (Units of geology are usually named after the place in which they were first extensively studied, in this case at Cutler Creek near Ouray, Colorado, by geologists C.W. Cross and E. Howe in 1905.) The Cutler Formation was raised to Group status in 1958 by geologists S.A. Wengerd and M.L. Matheny.

The members of the Cutler Group in the Permian strata of Canyonlands are: Lower Cutler Beds, Cedar Mesa Sandstone, Undivided Cutler-Cedar Mesa Sandstone, Organ Rock Shale, Undivided Cutler-Organ Rock Shale, White Rim Sandstone, and Undivided Cutler (refer to stratigraphic chart).

NOTE: The age of Permian rock in Canyonlands can be relative. For example, since Undivided Cutler is represented throughout the Permian time, it could be interpreted as the oldest as well as the youngest unit. Also, interfingering (transitional) deposits, such as the Undivided Cutler-Cedar Mesa Sandstone, will share the same age as the Cedar Mesa Sandstone. In other words, Permian stratigraphy in C.N.P. should be termed horizontally, as well as vertically.

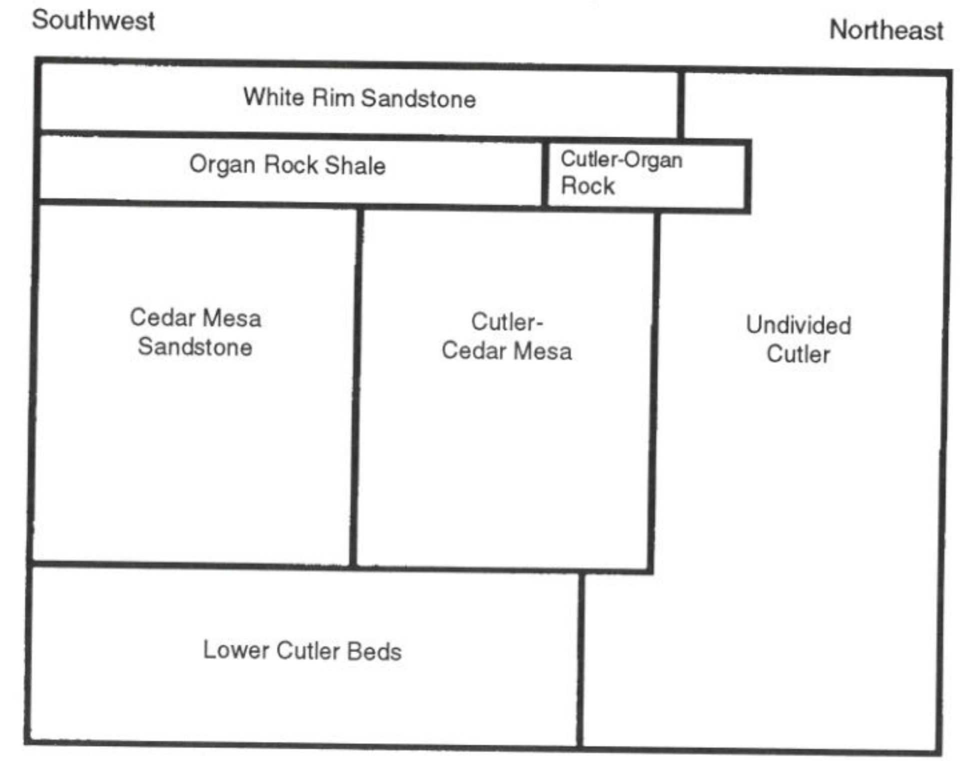
John Weisheit is a commercial river guide in Utah and Arizona, currently guiding for Navtec Expeditions, based in Moab. John is working with a publisher to produce a river guide through Canyonlands National Park and volunteers time organizing the photoarchives at the Dan O'Laurie Museum.

Canyonlands Permian Strata Permian strata in C.N.P. have three sources of deposition: (1) Reddish sediments from a highland area; (2) Limestones on a sea floor; (3) white sand as drift from a continental source. These three occasionally interfinger due to fluctuating ocean levels that resulted from continental glaciation and tectonic plate activity.

If we were to go back into Permian times to the vicinity of what is now C.N.P., we would need a boat from time-to time. Occasionally our ocean would be deep, sometimes shallow, and other times it would completely withdraw to the west, leaving our boat grounded. Off on the eastern horizon--near the present Utah/Colorado border--there would be towering mountains, called the Ancestral Rocky Mountains, which were formed some 315 million years ago in the Pennsylvanian Period.

These mountains consisted mostly of a metamorphic gneiss. The eroded materials were high in feldspar and reddish in color. Flowing from these mountains were streams that carried materials that they deposited onto the foothills or into the ocean. These sediments, called arkose, form the strata that make the red beds of the Cutler Group.

Permian Strata of Canyonlands



Offshore and in the ocean, limestones were forming over time. Marine organisms lived and died, their bodies settling on the ocean floor and accumulating into thick limy mud. This limestone and arkose deposition form the first member of the Cutler Group. Since deposition was cyclic from rising and falling seas, the beds are interfingered with limestone, dolomite (magnesium bearing limestone), shale, siltstone, or sandstone. At present, the only place the lower Cutler beds can be seen are along the Colorado and Green Rivers, with prime examples above the Confluence of the two rivers. On the Colorado, it is exposed first near the salt mining operations at Potash. (Keep in mind that the Permian/Pennsylvanian boundary and thicknesses of the lower Cutler beds are yet to be determined.)

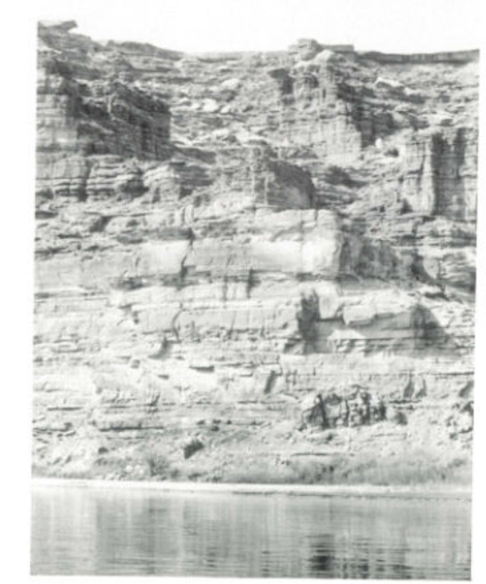
The second Cutler member is a massive, white-to-tan, crossbedded sandstone called the Cedar Mesa Sandstone, first discussed by geologists A.A. Baker and J.B. Reeside in 1929, at Cedar Mesa, northwest of Mexican Hat, Utah. The substance forming the Cedar Mesa Sandstone came from a continent lying to the northwest, that had the appearance of today's Sahara Desert, with classic dunes of sand. Wind currents transported sand grains as drift, and formed what geologists call an eolian deposit. Since the Permian ocean was fluctuating, it is possible that these sand grains were also deposited by ocean currents. Near Mille Crag Bend on Lake Powell, the Cedar Mesa Sandstone is 1000 feet thick; yet, 25 miles to the north it thins and disappears above the Confluence near the Colorado River meander called the Loop.

Undivided Cutler-Cedar Mesa Sandstone is the third Cutler member. It is a localized interfingering unit of the white Cedar Mesa Sandstone that shared a simultaneous deposition with the red Undivided Cutler. This zone of interfingering is called a facies change. Exposures of the Undivided Cutler-Cedar Mesa Sandstone are found in the cliffs above the Colorado River in the area of the Indian Creek drainage.

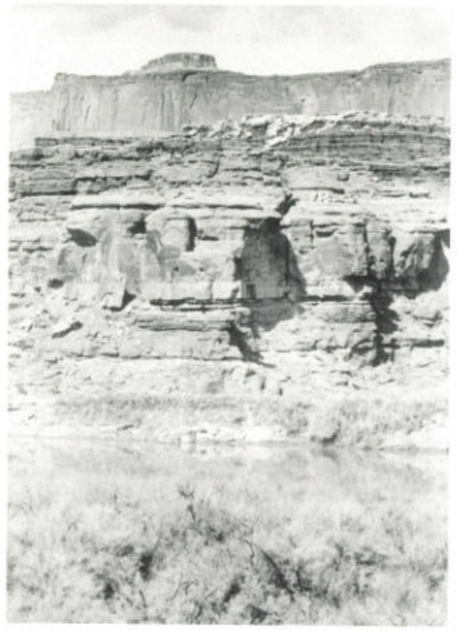
The fourth Cutler member is the Organ Rock Shale; it was first described by geologists A.A. Baker and J.B. Reeside in 1929, at Organ Rock in Monument Valley on the Navajo Reservation. Organ Rock Shale is an easily identified unit of red shale that spreads southerly from C.N.P., attaining 900 feet in thickness in places. (This unit is called Hermit Shale in Grand Canyon National Park.) Like Undivided Cutler-Cedar Mesa Sandstone, Organ Rock Shale in C.N.P. is first exposed in the cliffs above the Colorado River, in the vicinity of the Indian Creek drainage.

Undivided Cutler-Organ Rock Shale is the fifth Cutler member. It is another localized interfingering deposit. Here the interfingering is with the Undivided Cutler and the Organ Rock Shale. This unit has only been found with the previous two, in the cliffs above the Colorado River in the vicinity of the Indian Creek drainage of C.N.P. It is not exposed on the Green River side of the park.

The sixth Cutler member is a white sand deposit of continental drift, and is called the White Rim Sandstone. It was first described by geologists A.A. Baker and J.B. Reeside in 1944. Although it is 250 feet thick in places on the Colorado River, it pinches out completely on the Green, near Potato Bottom. It clearly overlies the Organ Rock Shale to the south, especially in the sheer cliff faces near Hite Marina on Lake Powell. Towards the west, however, the Organ Rock pinches out and the White Rim Sandstone overlies the Cedar Mesa Sandstone. In the San Rafael Swell, the Cedar Mesa and White Rim Sandstone associates with the Coconino



One-half mile above the mouth of Indian Creek. Top layer is White Rim sandstone. Directly underneath is the Organ Rock shale. Undivided Cutler-Cedar Mesa sandstone are in the middle ledges and lower Cutler beds are river level. Photo by Susette DeCoster.



Just upstream from Lathrop Canyon. The White Rim sandstone form talus boulders on the Undivided Cutler-Organ Rock Shale. Undivided Cutler forms the ledges near the river. River sediments, talus and vegetation cover the top-most section of the lower Cutler beds at water level. The slopes and cliffs in the background are of the Triassic and Jurassic Periods. Photo by Susette DeCoster.

Sandstone, a Grand Canyon Permian member. Interestingly, no deposition of White Rim Sandstone occurs east of the Colorado River in the Needles District of C.N.P., although there is a White Rim Sandstone deposit to the north in Castle Valley, which is on the east side of the river. In the Island-in-the-Sky District of C.N.P. a bench of White Rim Sandstone hosts the White Rim Trail and is the easiest Permian member to identify.

As the Permian period was ending, the Ancestral Rockies were nearly eroded away and still depositing the reddish Undivided Cutler, which is exposed along the Colorado River from Potash to a few miles north of Indian Creek. In proper order the Undivided Cutler underlies the White Rim Sandstone near Dead Horse Point and is the older of the two members. However, since there is no northern deposition of White Rim Sandstone between Dead Horse Point and Castle Valley, the Undivided Cutler underlies rocks of the younger Triassic period. Considering that this position is normally held by the White Rim Sandstone, we can further illustrate Permian complexities. An excellent exposure of Undivided Cutler, as an all-encompassing Permian red bed, can best be observed along Highway 191 near Arches National Park. Although it is not exposed on the Green River side of C.N.P., it is seen along the Colorado River in the cliffs from Potash to Indian Creek.

Conclusion Perhaps you too appreciate the complexities of Permian strata in Canyonlands and with me will express empathy toward the geologists who have the difficult task of defining them. In following this narrative you will notice that most of the interfingering is located above the Confluence of the Colorado and Green rivers, particularly in the vicinity of the Indian Creek drainage. This area obviously acted as a fulcrum for the pivotal Permian Ocean. It is also interesting how such a small area, when compared to the Colorado Plateau as a whole, has such a vast diversity of Permian strata. I encourage you to share in a Colorado River trip through C.N.P. It is a journey through a Permian wonderland.

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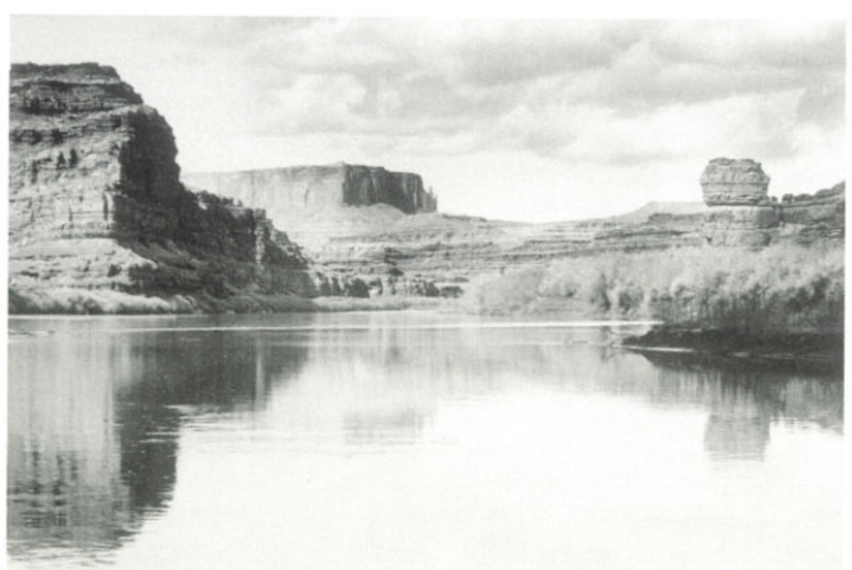
Loope, David B., George A. Sanderson, George J. Verville, 1990, "Abandonment of the name 'Elephant Canyon formation' in Southeastern Utah: Physical and Temporal Implications," *The Mountain Geologist*, Vol. 27, No. 4, The Rocky Mountain Association of Geologists.



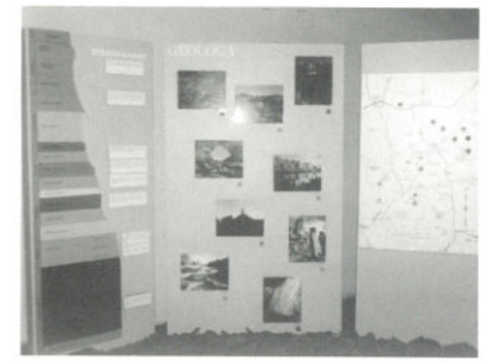
Looking upstream between Indian Creek and Lathrop Canyon. Bottom to top: lower Cutler beds, Undivided Cutler, Undivided Cutler-Organ Rock Shale, and White Rim Sandstone. the slopes and cliffs in the background are of the Triassic and Jurassic Periods. Photo by Susette DeCoster.

Special thanks to David May, Susette DeCoster and Julie Gillum for their assistance in preparing this article.

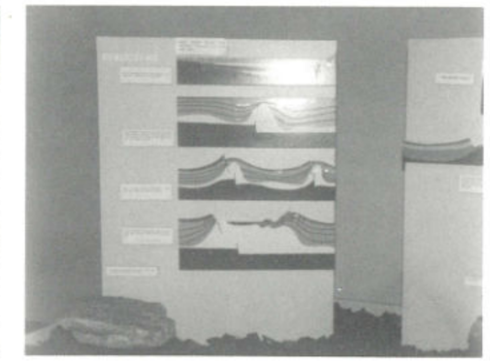
ON DISPLAY

Geology Exhibit

by Jean McDowell, Curator



Stratigraphy
A multicolored stratigraphic column is accompanied by colored photographs showing typical outcroppings of the formations. Next to the photographic panel is a map of the nearby area. Both the photos and the map have color-coded discs that relate to the column.



Structure
A series of colored panels illustrate the formation of Moab Valley, which is a typical salt valley. There is a specimen of the salt in front. Another panel illustrates the Moab Fault and the relationship of strata on either side of it.

Mineralogy
Locally found minerals are displayed. They include the copper minerals, azurite and malachite, and crystals of quartz, calcite and selenite. A panel illustrated the deposition of uranium ores.

Paleontology
A slab of Kayenta Formation contains several tracks of an Allosaurs-type dinosaur. A large Anatosaurus track found in a coal mine is displayed. Fossils include a cycad, a petrified fern trunk, and shell fish from different geologic periods. A separate display shows wood from a petrified mini forest in the Navajo Sandstone.

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Canyon Legacy would like to thank Bob Norman and Buttes Resources for the contribution to this issue.

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BOOKS OF INTEREST

by Jacki Montgomery

ROADSIDE GEOLOGY OF UTAH
by Halka Chronic
Mountain Press Publishing Company
Missoula, 1990
326 pages, Illus.
$12.95

This guidebook is an ideal traveling companion for those interested in the geologic history and scenery of Utah. Well organized and profusely illustrated, this publication describes the intriguing and diverse geologic landscape of the plateau, basin, high country and Wasatch Front. Primarily the main highway routes are followed, with selected loops covering a few less-frequented but geologically interesting byways. The last chapter gives an introduction to the geology of the national parks and monuments across Utah.

A geologic map is provided for each roadlog section, identifying the age of rocks visible on the surface; geologic terms are defined in a glossary at the end of the book.

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GEOLOGY OF UTAH
by William Lee Stocks
Utah Museum of Natural History and Utah Geological and Mineral survey
Salt Lake City, 1986
280 pages, Illus.
$12.00

For over twenty years, Dr. W.L Stokes taught an extraordinarily popular course, Geology and Scenery of Utah, at the University of Utah. This book is an important by-product of his teachings, directed to the intelligent and curious reader, professional as well as novice. This book is mainly about understanding and appreciating Utah's geology, and details the geomorphology, fossils, paleogeography, scenery and economics of the various geologic time periods. The landscape of the Colorado Plateau is described throughout the text, especially in the Jurassic Period section. The closing chapter "Face of the Land" describes the physiographic provinces of the state accompanied by individual maps. The profuse illustrations and photographs are as important as the text in clarifying the simple-to-complex geologic history of Utah.

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CANYON COUNTRY ARCHES AND BRIDGES
by F.A. Barnes
Canyon Country Publications
Moab, 1987
415 pages, Illus.
$9.95

The towering sandstone arches and bridges of southeastern Utah are among the natural wonders of the country. Fifteenth in a series of outstanding guides to Canyon Country geology, prehistory and travel, this is an interesting and scholarly work about these natural stone openings. The discovery and early history of the most famous arches and bridges is covered, as well as the geologic history. Chapters also describe the physical aspects of numerous arches and bridges, accompanied by many black-and-white photographs taken by the author. Of special interest to visitors is the chapter on the natural spans in accessible areas within the national parks and scenic areas of Utah. ARCHES AND BRIDGES is a fascinating and definitive contribution to the geology of the Colorado Plateau.

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CANYON COUNTRY GEOLOGY
by F.A. Barnes
Wasatch Publishers, Inc.
Salt Lake City, 1978
160 pages, Illus.
$5.00

In its sixth printing, this popular guide presents the spectacular and unique geological history of Canyon Country, an area that is attracting more visitors each year. This is an essential guide for the laymen, describing the geologic time periods and stratigraphy of southeastern Utah. Introductory chapters outline the usually complex geology of the plateaus and major events which shaped the area. Included are descriptions of geologic features such as arches, bridges, fins, petrified dunes, spires and balanced rocks. Visual aids compliment the text, including charts, diagrams, and original black-and-white photographs.

****

Also:
FAMILIAR ROCKS AND MINERALS: The Audubon Society Pocket Guide
by Charles W. Chesterman

And for children:
EYEWITNESS BOOKS: ROCKS AND MINERALS
by R.F. Symes

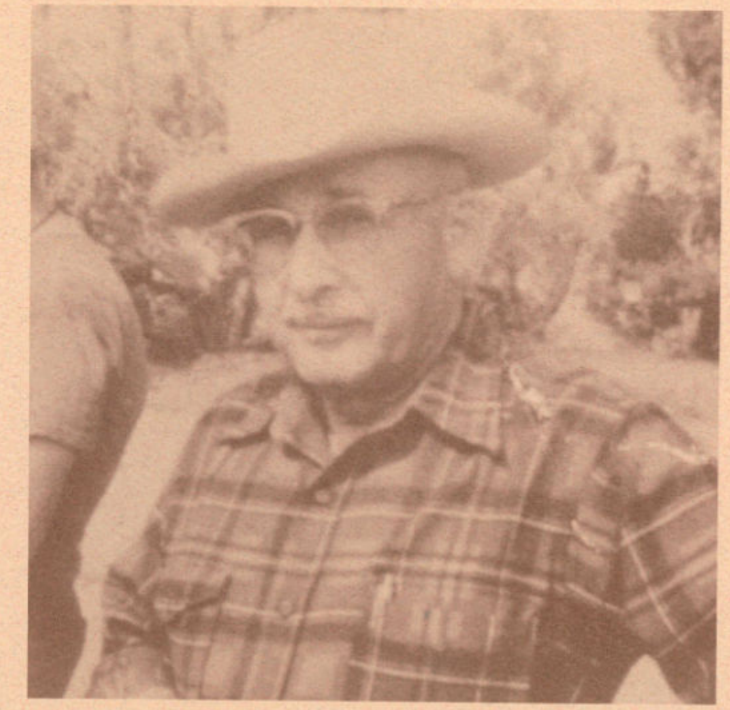
(See bibliographies at end of each article for further suggested reading.)

In the next issue of Canyon Legacy.....

On a hot early summer's day in 1952 a discovery was made that was to change the course of history for a small, remote town in the midst of the scenic red rock desert of southeastern Utah.

"Moab erupted from a sleepy Mormon cowtown into an enormously busy and surprisingly cosmopolitan little city. Events arising directly from Steen's discovery of [a] massive uranium deposit not only changed the community at that time, but initiated further changes which affect all of us today." (Dave May, *Times-Independent*, Jan. 1992.)

The Summer issue of Canyon Legacy will focus on the 40th anniversary of Charlie Steen's discovery of the richest body of uranium ore known. Join us for the celebration.



Philanthropist Dan O'Laurie was one of the individuals who came to Moab following the discovery of uranium. He played a major role in changing the look of the community by donating the money for construction of the museum that bears his name.

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Dan O'Laurie Museum
118 East Center Street
Moab UT 84532

North of the Abajo Mountains and Elk Ridge, which is the spine of Monument Uplift to the west of the Abajos, the northern nose of the uplift tilted and severely fractured the rock strata there, creating massive cross-jointing. As this jointing has been exposed by megayears of erosion, the rock has formed the countless fins, domes and spires of Cedar Mesa Sandstone that dominate the Needles District of Canyonlands National park. This aerial view shows some of the "needles" and checkerboard jointing. Photo by F.A. Barnes.