the geology of goblin valley state park

by mark milligan

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Jayne Belnap, U.S. Geological Survey, Biological Resources Division, introduced me to the soils of the Colorado Plateau. Utah Geological Survey geologists Sandy Eldredge and Christine Wilkerson provided helpful reviews of the original draft of this paper.

While previous geologic work specific to the area of Goblin Valley State Park has been limited, numerous geologists have added to the understanding of this part of the Colorado Plateau. The listed references include only a few such contributors.

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The wonderfully grotesque stone sculptures that are Goblin Valley State Park's main attraction are the consequence of millions of years of geologic history. Within the park are rocks composed of sediments from ancient seas, shorelines, river channels, and playas. With the passage of time these layers of sand, silt, and clay became deeply buried and transformed to rock. Much later, large-scale tectonic forces uplifted the area and prompted erosion to begin to expose the deeply buried layers of rock. Once the rocks were back on the surface, fractures and variations in hardness within the rocks facilitated carving of the goblins by the erosional power of water, wind, and frost.

Looking east from the main parking area, the light-colored Curtis Formation caps the reddish-brown suite of rocks called the Entrada Sandstone. The Entrada Sandstone is the preeminent rock unit in the park. Goblins form exclusively within it, and the campground and parking area are also built on Entrada rocks and sediment.

Understanding the rocks and structures of Goblin Valley State Park requires not only an investigation of past and present events that have acted on a small scale within the park, but of past large-scale tectonic events and processes. This booklet is intended to further your understanding of the formation of the goblins, soils, and surrounding scenery or "how they came to be."

geologic setting

Goblin Valley State Park lies within the Colorado Plateau physiographic province, an area of the earth's crust that has experienced broad, regional uplift. The Colorado Plateau encompasses southeastern Utah and parts of Colorado, Arizona, and New Mexico, and reaches elevations of more than 10,000 feet (3,000 meters) above sea level. Buttes, mesas, and deep, narrow canyons expose layer upon layer of nearly undeformed, flat-lying beds of rock. These flat-lying rocks are generally sedimentary, meaning they are composed of weathered fragments of older rock that were transported, deposited in layers, and then consolidated into rock once again. The hows and whys of such a large area rising to such heights with so little deformation are still somewhat a mystery. In any case, uplift of the Colorado Plateau seems to have begun within the past 10 million years. With uplift, the erosive power of water took over to cut and sculpt the exquisite scenery of the plateau.

Within the Colorado Plateau exceptions can be found to this rule of nearly flat-lying "layer-cake" geology. Excellent examples of two different styles of deformed rocks can be seen from the park: the San Rafael Swell immediately to the northwest and the Henry Mountains to the south.

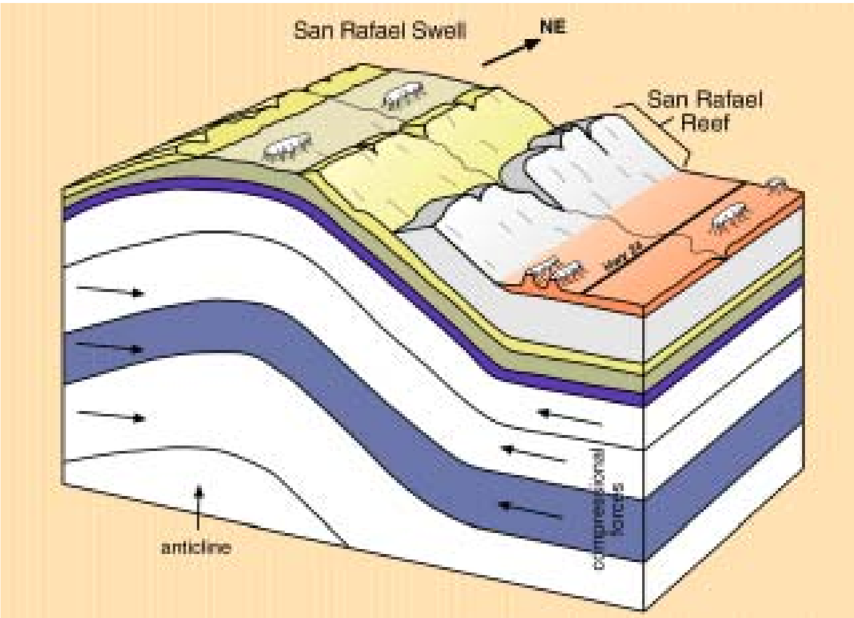
Goblin Valley State Park lies within the Colorado Plateau physiographic province (green outline), an area characterized by broad regional uplift of layer upon layer of nearly flat-lying sedimentary rock.

Wild Horse Butte near the park's entrance, viewed from the west. Typical of the Colorado Plateau, steep cliffs expose nearly flat-lying beds of sedimentary rock. Buttes like these are erosional islands of once-continuous horizontal rock layers.

True to the regional pattern of flat-lying beds, goblins within the park are forming in continuous, horizontal sandstone beds interbedded with and underlain by horizontally layered siltstone and shale. Notice the goblins forming in this cliff face of such rock layers. The apparently isolated goblins in the foreground were once part of the same, once-continuous horizontal beds exposed in the cliff face.

san rafael swell

Lying about one mile (1.6 km) northwest of the park entrance is a large wrinkle in the earth's crust, known as the San Rafael Swell. Although originally horizontal, the rock layers that make up this structure have been compressed into a convex-upward fold, with the older rocks exposed in the center (see diagram). This fold is roughly 75 miles (120 km) long (extending northeast-southwest) and 30 miles (48 km) wide. Geologists label these types of structures anticlines. The limbs or sides of this anticline are not symmetric. As seen from Goblin Valley State Park, the eastern limb, called the San Rafael Reef, is steeply inclined to nearly vertical, in contrast with the more gently inclined western limb. Alternating hard and soft rock layers dissected at nearly right angles by washes account for some of the San Rafael Swell's spectacular scenery



Diagrammatic illustration of the structure of the San Rafael Swell. Because they have been partially removed by erosion, the uppermost rock layers are no longer continuous over the anticline.

The San Rafael Swell has a complex history. It was probably originally upwarped approximately 60 to 65 million years ago during the Laramide orogeny, a regional-scale mountain-building event that also formed Waterpocket Fold in Capitol Reef National Park to the southwest and the Uinta Mountains in northeastern Utah. Laramide mountain building presumably resulted from events that happened far to the west. The earth's outermost layer, or crust, is composed of individual plates that are in motion relative to one another. In the area that is now coastal California, two plates, the North American plate and the precur-

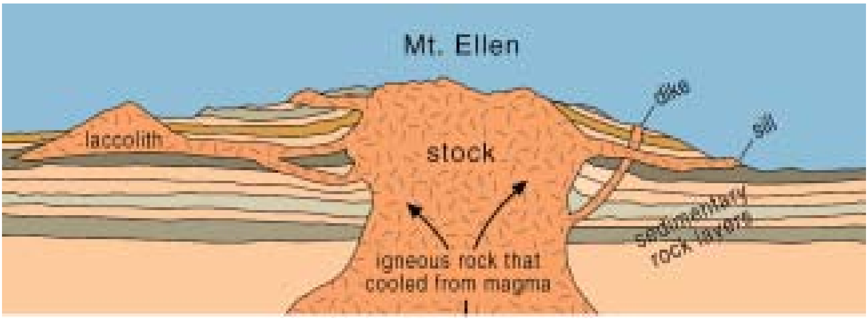
As seen from Goblin Valley State Park, the San Rafael Swell forms a ridge against the sky-line. An exception to the flat-lying rock layers or beds found across the Colorado Plateau, the slope seen from this view is due to the steep incline of the beds.

sor to the Pacific plate, collided. This head-on collision created compressional forces far inland causing the crust to buckle and create features like the San Rafael Swell.

Following Laramide uplift, the top of the original San Rafael anticline was removed by erosion and may have been partially buried. It wasn't until the entire Colorado Plateau was uplifted and the modern Colorado River drainage system developed, that erosion re-exhumed the preexisting structure of the San Rafael Swell.

henry mountains

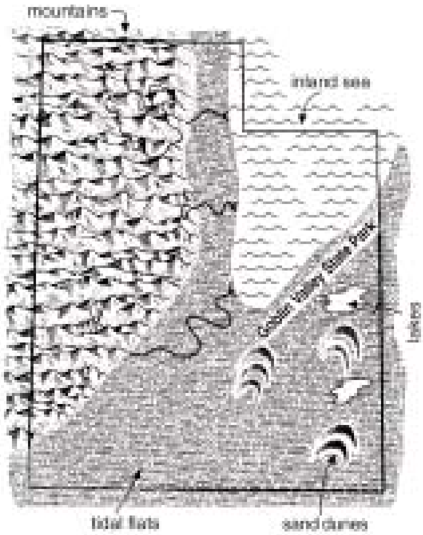
Another prominent skyline feature is the Henry Mountains, which lie to the south. In contrast to the layers of sedimentary rocks that compose most of the Colorado Plateau, igneous rocks that cooled from once-rising magma form the heart of the Henry Mountains. The Henry Mountains are similar to a volcano except that the rising magma cooled before it could reach the surface. The magma was injected through and between the sedimentary rock layers about 24 to 28 million years ago. Since the igneous rocks are more resistant to weathering than the surrounding sedimentary rocks, they stand out in relief as erosion lowers the surrounding landscape. On a clear day, two more igneous intrusions may be visible on the horizon, the La Sal Mountains to the east and Abajo Mountains to the southeast.



Mount Ellen, at the northern end of the Henry Mountains, is a prominent feature seen from Goblin Valley State Park. As shown in the illustration, Mount Ellen is composed of igneous rock bodies that include a stock (a cylindrical vertical intrusion) with branching offshoots called dikes (tabular intrusions injected across rock layers), sills (tabular intrusions injected parallel with rock layers), and laccoliths (dome-shaped sills).

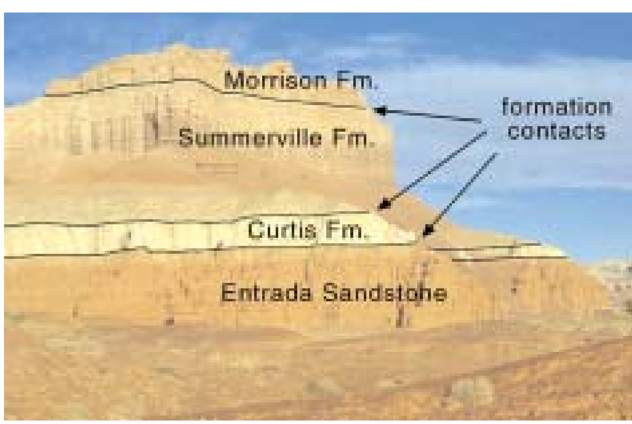
deposition of the park's rock layers

To look at the rock layers in the park is to glimpse forces of nature that occurred about 145 to 170 million years ago, during the middle to latter part of the Jurassic Period on a geologic calendar. A lot has changed in the past 170 million years; one alteration is the position of the earth's continents. During the Middle to Late Jurassic, North America and Eurasia were pulling apart from South America and Africa as part of the breakup of a supercontinent named Pangea. The area that we now call Utah was closer to the equator at this time. Much of eastern Utah was a dry Sahara-like desert, but shallow seas intermittently covered what is now the area of Goblin Valley State Park. Northwestern Utah consisted of granitic highlands. The silts, sands, and clays that comprise the rocks now exposed in Goblin Valley State Park were formed primarily from erosional debris shed from these highlands and redeposited in seas, on shorelines, in river channels, and on playas.



Utah as it may have looked approximately 170 million years ago (Middle Jurassic) during deposition of the goblin-forming Entrada Sandstone (from Stokes, 1986).

When attempting to unravel the mysteries locked in rocks, geologists find it useful to recognize and name units of rock based upon features that distinguish them from overlying, underlying, and adjacent rock units. These fundamental units are called formations. Four rock formations are exposed in Goblin Valley State Park. The lowest and oldest exposed formation, the one in which the goblins form, is the Entrada Sandstone. Above the Entrada lies the Curtis Formation, which is overlain by the Summerville and Morrison Formations, respectively. To be formally named, a formation must be large enough to be mappable. The four formations exposed in the park have been mapped across southeastern Utah and into surrounding areas on the Colorado Plateau. Formations can be combined into groups. The

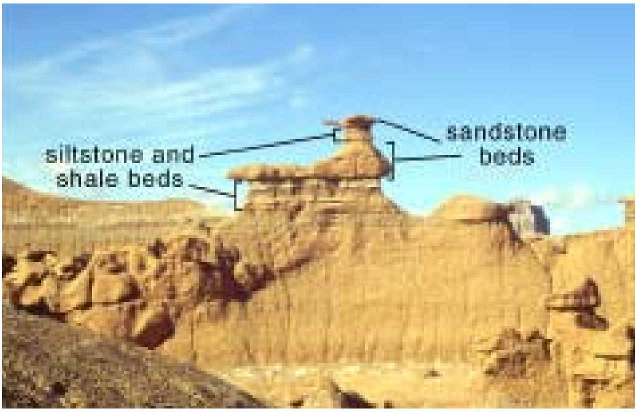


Wild Horse Butte exposes all four rock formations found within Goblin Valley State Park.

lower three formations, Entrada, Curtis, and Summerville, belong to the San Rafael Group. Two additional formations of the San Rafael Group are exposed elsewhere, but remain buried beneath the surface in the park. Below the San Rafael Group, a series of progressively older and deeper formations continues far beneath the surface.

goblin-forming entrada sandstone

While formally named the Entrada "Sandstone," shale, siltstone, and sandstone comprise this formation at Goblin Valley State Park. Named from Entrada Point in the northern part of the San Rafael Swell, it is the same formation that erodes to arches, fins, and spires in Arches National Park and hoodoos in Cathedral Valley of Capitol Reef National Park. The Entrada in Cathedral Valley is similar to that of Goblin Valley State Park, and consists of interbedded shale, siltstone, and sandstone deposited on tidal flats. In Arches, however, sandstone, originally deposited as sand dunes, dominates the Entrada. Hence this formation changes laterally, much the same way modern landscapes change as you drive across southern Utah.



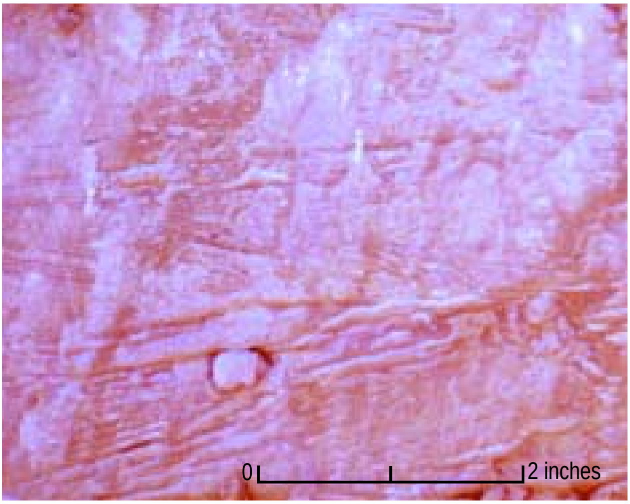
Found only within the reddish-brown Entrada Sandstone, goblins are composed of sandstone interbedded with and underlain by shale and siltstone. Though now an erosional island, the beds that form this goblin were once laterally continuous. Below the goblin, bedding is masked by a veneer of soil, called colluvium.

Turn back the clock about 170 million years and the area that is now Goblin Valley State Park is a wide tidal flat between the sea to the north and continental mountains and hills to the west. Oscillatory motions of tides were a dominant force in the deposition of the

This tidal channel in the Entrada Sandstone was produced when water flowing toward the open sea cut a channel that later filled with mud and silt. In this picture water would have been flowing either towards or away from the camera.

interbedded sandstone, siltstone, and shale that now compose the goblins. Tidal channels migrated across the tidal flats, routing flowing water to the open sea. Coastal sand dunes also covered parts of the tidal flats, an example of which is exposed in the rock along the road, just north of the park's main parking area.

Careful observation of some of the Entrada's sandstone beds reveals a structure called herringbone cross-bedding. Notice how the thin banding slants in opposite directions, left near the bottom, then right, then left. This is caused by the alternating direction of the incoming flood tide and outgoing ebb tide.



Similar to many rocks across the Colorado Plateau, the Entrada's reddish hue comes mainly from hematite staining. The mineral hematite is an iron oxide and the principal ore of iron. A nickel's worth of iron will color a mountain red; in other words, it doesn't take much iron to make a rock red. These rocks do not contain enough iron to be mined for iron ore.

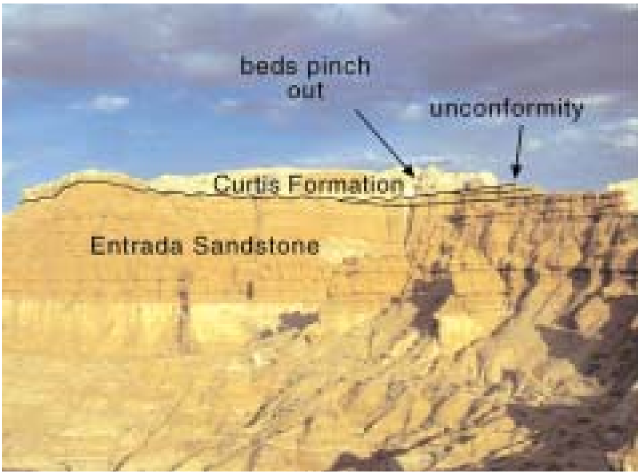
Found along the road, just north of the park's main parking area, this outcrop displays an interesting layer within the Entrada Sandstone. Lines formed by slight variations in grain size define individual beds of sand. These beds slope downward to the right. The single direction and relatively large scale of this cross-bedding (vs. the cross-bedding in previous figure) suggests that this rock layer may have once been a shifting sand dune The daypack is for scale.

curtis formation

The Curtis Formation overlies the Entrada, forming the greenish-gray caprock on the buttes east of the parking area. This formation takes its name from Curtis Point in the northern part of the San Rafael Swell. Fossils in locations outside the park show that the sandstone and siltstone comprising the Curtis was deposited in an ancient (Late Jurassic) sea. The greenish color comes from minor amounts of glauconite, a mineral that contains iron and forms in modern ocean sediments. The presence of glauconite in the Curtis Formation is significant because it further supports the idea that this rock unit was originally deposited in an ocean or sea. Another prominent feature of the Curtis Formation rock layers is the undulatory surfaces of small parallel ridges and hollows, called ripple marks. The type of ripple marks (see figure) displayed in the Curtis suggests that at least parts of this area were once a beach of this ancient sea.

A block of the Curtis Formation displays a surface of ripple marks frozen in time. Note how some ripple crests fork. The oscillating action of waves created these bifurcating or branching ripple marks on the beach of the ancient Curtis Sea. The block is approximately 3 feet (1 meter) long.

As seen in this cliff face at the eastern edge of the park, the Entrada Sandstone layers are not perfectly parallel with the overlying Curtis Formation. Some of the Entrada beds pinch out (disappear) against the bottom of the Curtis. This reveals that the originally horizontal beds of Entrada were slightly uplifted, tilted, and planed off by erosion before the Curtis Sea encroached upon the area. Called an unconformity, this erosional surface marks a gap in the geologic record.



summerville formation

In Late Jurassic time the deeper waters of the Curtis Sea retreated northward, and again the area took on the attributes of a seaside tidal flat. The sediments preserved in these tidal flats are called the Summerville Formation. This formation gets its name from Summerville Point in the northern part of the San Rafael Swell. Locally, the Summerville can be seen overlying the Curtis Formation on the highest buttes at the north end of the park. It consists of distinctive, thin beds of chocolate- to bone-colored shale, siltstone, and sandstone. Thin beds and veinlets of gypsum found within the shale suggest a dry climate where ponded tidal water readily evaporated.

Surrounding Wild Horse Butte near the park entrance, cliffs of the Summerville Formation expose chocolate- to bone-colored shale beds interlayered with thin, whitish gypsum beds.

Veinlets of gypsum form a lace-like pattern in cliffs of the Summerville Formation around Wild Horse Butte. Beds of gypsum are also found elsewhere in the Summerville.

morrison formation

Following deposition of the Summerville, this area experienced slight uplift and erosion. When deposition resumed, the seas had not returned and exclusively continental conditions existed across the Colorado Plateau. Floodplains or playas left behind varicolored mudstones, and streams crossed the area depositing sandstones and conglomerates in their channels. These deposits are called the Morrison Formation, which takes its name from exposures near the town of Morrison in Jefferson County, Colorado. Within the park it is only found on the top of Wild Horse Butte. The Morrison Formation is famous for the dinosaur bones found within it. No dinosaur bone discoveries have been reported on Wild Horse Butte, but they have been found just west of the park in this formation.

Just because the Morrison is the uppermost formation in the park does not mean deposition stopped after it was laid down. In fact, layer upon layer of additional sediments deeply buried the four formations in the park. These overlying formations have long since been removed by erosion in the park. However, some of these formations still exist outside the park and as many as eleven formations totaling thousands of feet overlie the Morrison elsewhere.

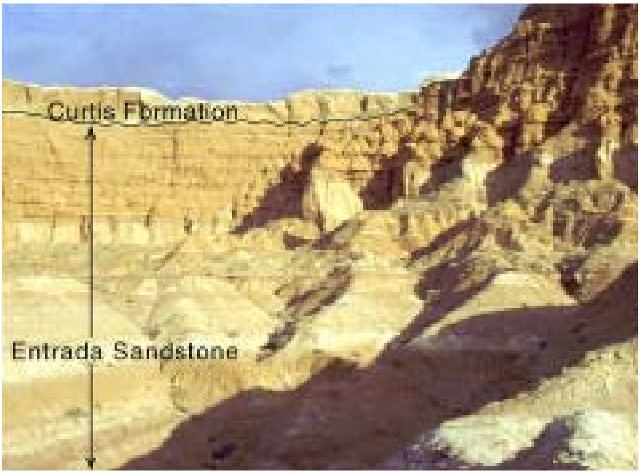
Soon after deposition, the loose, uncemented sediments of the Morrison and other formations found in the park began to change. Compaction due to burial by the overlying layers, cementation by the growth of new minerals precipitated from circulating ground water, and a host of other physical and chemical processes converted the loose sediments into the sedimentary rocks found in the park today - a process called lithification.

weathering & erosion - sculptors of the goblins

After setting the geologic stage with deposition, burial, and lithification, what is left in the evolution of the Colorado Plateau and Goblin Valley State Park? Weathering and erosion.

Erosion by definition includes both the decay and subsequent transport of rock and rock fragments. Weathering involves only the decay, not the transport. Two types of processes act as the agents of weathering: chemical and physical. Chemical weathering attacks and decomposes

An area of goblins near the park's southern boundary (view to the north). Notice the roughly north-south-trending set of vertical joints in the goblin-forming sandstone beds of the Entrada. Such fractures form planes of weakness. Intersecting fracture planes initially form sharp edges and corners that are more susceptible to attack by weathering. Called spheroidal weathering, this preferential breakdown of edges and corners imparts a spherical shape to the goblins.



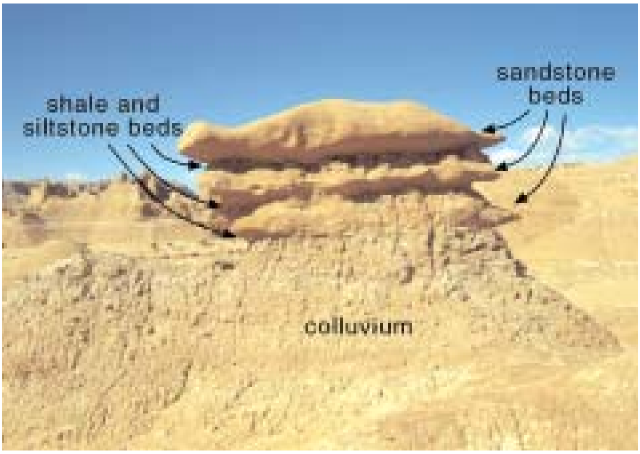
This cliff face shows progressive goblin development within the Entrada Sandstone. In the cliff face in the left half of the photo, continuous sandstone beds display fresh, unweathered vertical fracture or joint patterns. These vertical joints form zones of weakness that are more susceptible to attack by weathering. In the right half of the photo, cliff retreat and erosion along the joints leave rounded goblins standing out in relief.

rock through chemical reactions. Physical weathering disintegrates rock through mechanical processes such as abrasion by wind and water-borne sand and silt particles, and the expansions and contractions associated with temperature fluctuations and freeze-thaw cycles.

The various processes of weathering can go a long way in transforming solid rock, but transport of the broken-down fragments is needed to expose fresh rock and continue the process. Wind plays an important role in the removal process, but water is the workhorse of erosion. Water, however, needs the power of gravity to transport material. Therefore, topographic relief created by uplift of the affected rocks must precede erosion. In other words, water needs to flow downhill. As discussed in the Geologic Setting section, the most recent uplift of the Colorado Plateau began within the past 10 million years. With uplift, water began to peel off layer after layer of overlying sediments and rocks until the Morrison, Summerville, Curtis, and Entrada Formations were eventually exposed in Goblin Valley State Park.

In addition to exposing the Entrada Sandstone, weathering and erosion also carve the individual goblins from this formation. Joint or fracture patterns within the Entrada's sandstone beds play an important role in goblin development by creating initial zones of weakness. Unweathered joints intersect to form sharp edges and corners. These edges and corners are more susceptible to weathering because they have a greater surface-area-to-volume ratio than the faces. As a result, they weather more quickly, producing spherical-shaped goblins through a process called spheroidal weathering. Spheroidal weathering helps shape the goblins, but it is only part of the larger erosion process that forms and exhumes the goblins.

The interbedded and underlying shale and siltstone beds are less resistant to weathering and erosion than the sandstone beds that form the goblin bodies. Combined with spheroidal weathering of the sandstone beds, these softer shale and siltstone beds give the goblins their often elongated shapes, flat bottoms, stacked appearance, and the pedestals upon which they are displayed.



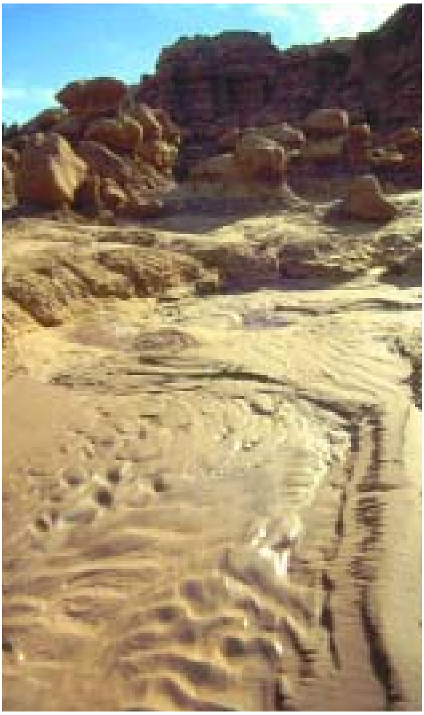
Softer shale and siltstone beds weather more readily than the harder sandstone beds. Alternating sandstone, shale, and siltstone beds cause this goblin to have a flattened and elongated shape, and a stacked appearance. A thin veneer of soil (colluvium) covers the base of the goblin.

Minerals precipitated in the tiny spaces between individual sand grains provide a degree of hardness to the sandstone beds. Variations in the amount and/or type of cement may also contribute to the unusual shapes of specific goblins, although a detailed study of the cementation has yet to be undertaken. Perhaps the neck on this “turtle” can be attributed to varying degrees or types of cementation?

the dirt on top - quaternary deposits

A by-product of weathering is the production of new sediment and soil that are redistributed and redeposited. Such geologically young material was and continues to be deposited during the Quaternary Period of geologic history. The Quaternary Period only includes the past 1.6 million years, a mere flash in geologic time. In Goblin Valley State Park, these young sediments, which partially cover the older bedrock formations, include: (1) talus consisting of blocks, boulders, and smaller angular rock fragments at the bases of cliffs and steep slopes, deposited by gravity, (2) colluvium consisting of loose masses of soil material on gentle slopes, deposited by unconfined surface water runoff, (3) alluvium consisting of sediments deposited by intermittent streams, and (4) eolian deposits consisting of wind-blown sediments such as active and inactive (stabilized by vegetation) sand dunes.

Sediments deposited in these various environments may either erode and be further redistributed, or be buried by continued deposition. With burial, modern sediments and soils may eventually harden into sedimentary rocks for study and exploration millions of years in the future. It is this cyclical nature that allows geologists to use modern sediments and depositional environments as keys to ancient deposits and environments. For example, modern tidal flats exhibit many of the features, such as tidal channels, found in the park's Entrada Sandstone.



Erosion actively disassembles goblins and redeposits their sediments in modern intermittent stream channels. Such modern environments are important analogs for deciphering the conditions under which ancient formations were deposited.

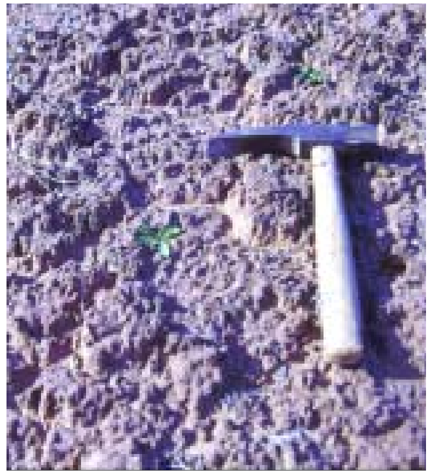
Soil covering this slope is self-derived from the Entrada Sandstone. The popcorn-like texture indicates expansive soil that shrinks and expands with drying and wetting cycles. Without proper building techniques, these unstable soils can heave and crack foundations, roads, and sidewalks. Mechanical and microbiotic crusts (discussed next) form a thin but hard veneer on the top of this expansive soil. The darker areas on the left are due to the presence of microbiotic crusts.

In addition to being keys to the past, Quaternary deposits are fundamental in identifying areas containing geologic hazards. Large talus blocks at the foot of a cliff are a reminder of the danger of rock falls. Many of the Entrada slopes are covered with a self-derived colluvium that exhibits a "popcorn" texture indicative of unstable, expansive soils. (Expansive soils expand when wet and shrink while drying. Without proper building techniques, this instability can heave and crack foundations, road surfaces, sidewalks, and buried utilities and cause failure of wastewater disposal systems.) Alluvium in normally dry stream channels may serve as a warning of the potential for flooding. Sand dunes and other wind-blown deposits can be unstable. Even dunes stabilized by vegetation can be disturbed and reactivated, leading to migration over roads and other structures.

microbiotic & mechanical crusts

In many places, Quaternary deposits overlie bedrock formations. In turn, microbiotic and mechanical crusts often cap Quaternary soils. These crusts stabilize soil and affect infiltration of rainwater, seed germination, and plant growth.

Mechanical crusts develop on the clay-rich soils derived from the Entrada Sandstone. These crusts are formed by a thin upper coating of clay particles oriented parallel to the surface.



A web of filaments secreted by microscopic cyanobacteria and green algae create this microbiotic crust. Such crusts are found throughout the park.

In contrast, microbiotic crusts are produced by living organisms and their by-products that bind together soil particles at or very near the surface. Many names (cryptogamic, cryptobiotic, microphytic, biological) have been applied to a variety of these organic crusts that are found throughout the world's deserts and semiarid grasslands, shrublands, and woodlands. The existence and type of microbiotic crust depends upon variables such as soil texture, conductivity, pH, and moisture. The general appearance of microbiotic crust varies widely, depending upon the relative abundance of different crust-forming organisms. Across the Colorado Plateau, cyanobacteria are the most abundant crust-forming organisms.

In a microbiotic crust, a web of organic filaments binds soil particles together, forming an interlocking network of grains. The filaments are composed of sticky sheath material secreted around the cells of cyanobacteria and green algae. Magnification nearly 90x. Photo courtesy Jayne Belnap, U. S. Geological Survey, Biological Resources Division.

Cyanobacteria are a group of microscopic organisms that harvest the sun's energy through photosynthesis. The cyanobacteria are not alone, as they are commonly found with green algae (another group of photosynthetic organisms). Mosses and lichen can also grow on crusts already stabilized by cyanobacteria and green algae. In Goblin Valley State Park, these well-developed crusts with abundant mosses and lichen can be found. However, cyanobacteria-dominated crusts (without mosses and lichen) are most common in the park.

Both microbiotic and mechanical crusts help stabilize soil. By stabilizing soil, they may also help stabilize the goblins. With microbiotic crust, filamentous sheaths hold soil particles in place and directly improve resistance to wind and water erosion. Microbiotic crust may also increase infiltration of rainwater, help retain soil moisture, and encourage seed germination and growth of native plants. Similar to microbiotic crust, mechanical crust greatly enhances resistance to wind erosion. However, mechanical crust is not nearly as resistant to erosion by water. Mechanical crust may also form an impermeable layer that decreases rainwater infiltration, further increasing runoff and downstream erosion.

Foot traffic damages both microbiotic and mechanical crusts. A single footprint will break mechanical crust and the filaments that create microbiotic crusts. Repeated foot traffic can completely remove this protective layer. Once damaged, the erosive powers of wind are unleashed and soil particles easily blow away. The loss of microbiotic crusts increases the erosive power of water as well. Fortunately, damage done to crusts is reversible, though it can take a long time.

Old goblins eventually topple and weather to oblivion as erosion unearths new goblins. Thus, on a geologic time scale, the park is being renewed and regenerated. However, the excavation process creating new goblins may not keep pace with goblin destruction if it is accelerated by visitor impact.

The recovery time for mechanical versus microbiotic crust varies greatly. Mechanical crusts begin substantial recovery with the first intense rainstorm. Microbiotic crusts take much longer to recover. Cyanobacteria and green algae secrete soil-binding sheaths only when wet, and therefore need repeated wet periods to construct their crust-forming network of filaments. Microbiotic crusts can begin to substantially recover in as little as one to five years, or may take more than 50 years, dependant upon crust type, soil type, climate, and extent of initial disturbance. These estimates are generalizations taken from other areas of the Colorado Plateau; no detailed studies have yet been completed in Goblin Valley State Park. The true extent of visitor impacts on soil stability, goblin formation, and the park's ecosystems are subjects in need of further study.

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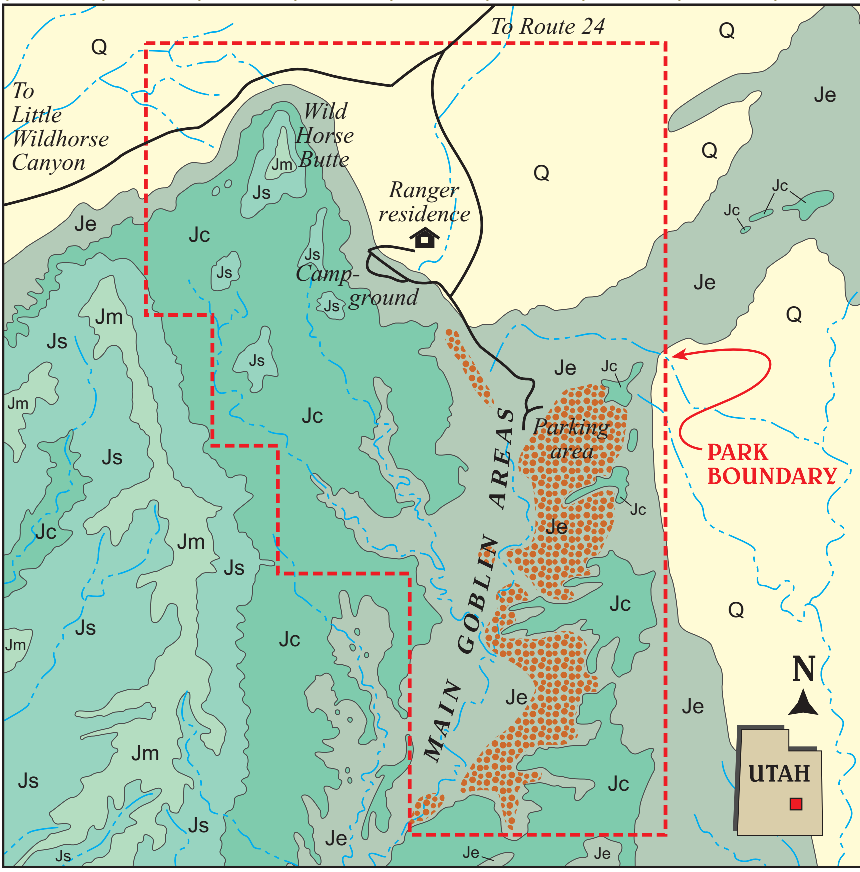

Q Quaternary deposits: wind-blown, stream-channel, and slope-wash sediments

Jm Jurassic Morrison Formation

Js Jurassic Somerville Formation

Jc Jurassic Curtis Formation

Je Jurassic Entrada Sandstone: goblins found exclusively within this formation

Intermittent stream

Road

goblin valley state park

Emery County, Utah

Geology modified from Orkid, 1953

0 0.5 1 mi

0 0.5 1 km