Hexagonal Fracture Patterns On Navajo Sandstone Crossbeds At Yellow Knolls, Washington County

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Utah Geosites
2019

Utah Geological Association Publication 48

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

Cover Image: *Southward-sloping crossbeds in the Navajo Sandstone at Yellow Knolls.*

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

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

Design and desktop publishing by Jenny Erickson, Graphic Designer, dutchiedesign.com, Salt Lake City, Utah.

Suggested citation for this geosite:

Loope, D.B., 2019, Hexagonal fracture patterns on Navajo Sandstone crossbeds at Yellow Knolls, Washington County, *in* Milligan, M., Biek, R.F., Inkenbrandt, P., and Nielsen, P., editors, Utah Geosites: Utah Geological Association Publication 48, 5 p., https://doi.org/10.31711/geosites.v1i1.62.

PRESIDENTS MESSAGE

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

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

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

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

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

Peter J. Nielsen
2019 UGA President

INTRODUCTION

At this geosite, the main features of interest—remarkably uniform and beautiful fracture patterns dominantly composed of linked hexagons (figures 1 and 2)—are present on outcrops of the Jurassic Navajo Sandstone. The Navajo was deposited by large, southward-migrating desert dunes about 200 million years ago, but the fractures that define the hexagons here are just a surficial veneer less than 20 inches (half a meter) deep. The fractures are a weathering phenomenon that developed under climate conditions similar to today's. Steep thermal gradients develop in the sandstone because it is exposed to solar radiation and changing air temperature. Polygonal fracturing is present in other Navajo exposures in southern Utah, but only in non-bedded (homogeneous) rock. The beautiful, bedding-parallel fracture pattern developed here is very rare; it developed because the bedding planes in the rock at Yellow Knolls are unusually wide-spaced.

Driving and Hiking

The Yellow Knolls Trail lies within the Red Cliffs Natural Reserve (http://www.redcliffsdesertreserve.com/yellow-knolls). There is a well-signed parking area along the unpaved portion of Cottonwood Springs Drive 5.5 miles (9 km) north of East Red Hills Parkway (figures 3 and 4) on the right side of the road. A good trail leads to an excellent outcrop (figure 1) about 1.2 miles (2 km) from the parking area.

GPS Locations: Parking area: N37°11'24", W113°34'42" (WGS84). Destination (figure 1): N37°12'15"; 113°34'23.6"

Figure 1. Domed hexagons developed parallel to bedding in the Navajo Sandstone at Yellow Knolls. Field of view is about eight feet (2.5 m) wide.

Figure 2. Southward-sloping crossbeds in the Navajo Sandstone at Yellow Knolls. The exposed surfaces of many different beds are covered with highly ordered, polygonal fracture patterns. Underlying, unexposed beds remain unfractured. N37°12'11.9", W113°34'18.4"

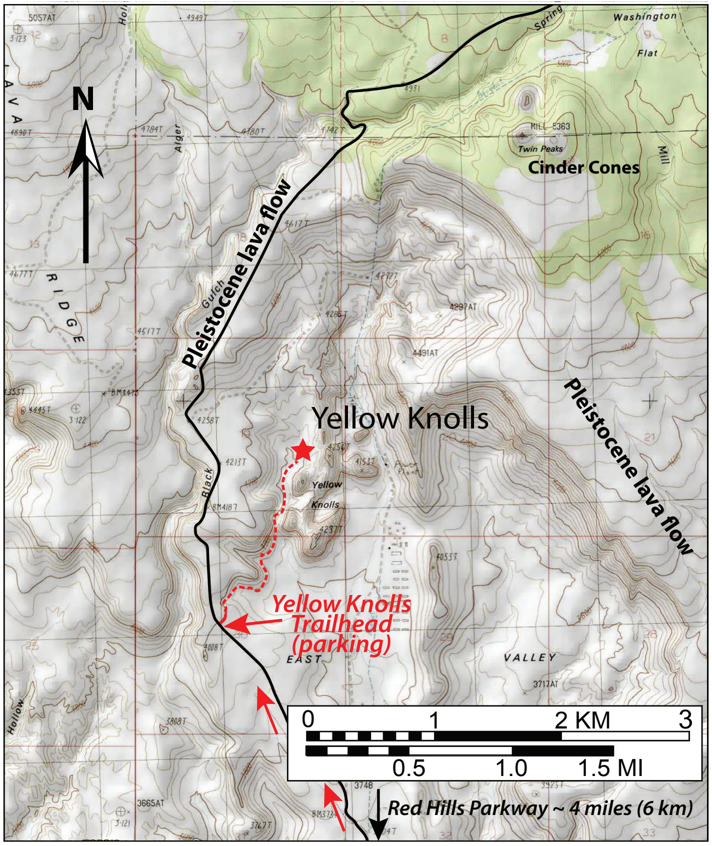

Figure 3. Topographic map of the Yellow Knolls vicinity showing the location of the trailhead and parking area. Red star shows location of photo in figure 1.

GENERAL GEOLOGY

Two very different rock types are exposed along the trail leading away from the Yellow Knolls parking lot. First, the trail winds through a cluster of large black boulders. They are basalt—the boulders were eroded from broad, 1- to 2-million-year-old lava flows that spewed from a volcanic vent 2.9 miles (4.6 km) northwest and upslope from the trailhead (figure 4). The hot lava followed stream courses that had been cut into a Jurassic sandstone formation called the Navajo (the tan rock with lots of fractures and bedding planes). The geologic map (figure 4) shows that the sandstone forming Yellow Knolls is surrounded by basalt; the sandstone was buried by lava, and now lies in an erosional "window" that was cut by ephemeral streams in the last million years—these were likely the same streams that had cut the valley that the lava followed.

Because the Navajo Sandstone was deposited by migrating sand dunes, its sand layers were not laid down parallel to the floor of the Jurassic desert. Sand instead was deposited on the downwind slopes of the dunes, at an angle of about 30° (the angle of repose for dry sand). As the desert floor slowly subsided, the wind kept blowing southward, and the dunes piled up sloping layers as they climbed over one another, burying thick crossbeds. And, also importantly, rivers kept delivering more sand. Although most of the grains in the Navajo are abraded crystals of quartz, there are also some abraded zircon crystals. Because each zircon crystal contains uranium, these crystals can be precisely dated. Conclusions from this dating are: 1) as expected, the zircons are much older than the Jurassic dune fields, and are about one billion years old; 2) they came from granite and gneiss in the Appalachian mountain chain in what is now eastern United States; 3) they were delivered to the Navajo dune field by westward-flowing rivers (Dickinson and Gehrels, 2003).

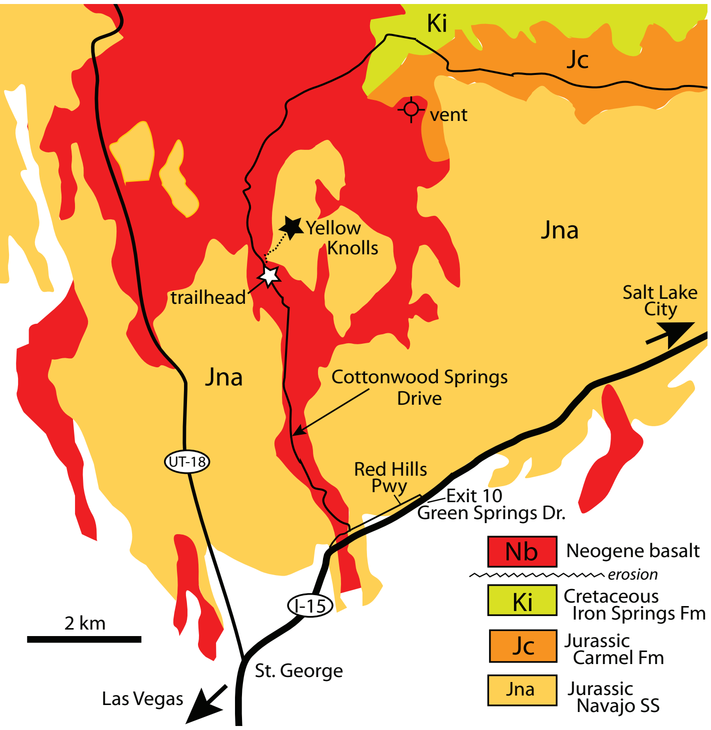

Figure 4. Simplified geologic map of Yellow Knolls site showing distribution of bedrock and access routes.

Fracture Patterns On The Navajo Sandstone

The patterns contain polygons with four, five, six, seven, eight, or more sides, but they are dominated by hexagons (figure 5). The patterns are developed on many of the southward sloping crossbeds of the formation, and the fractures that define most of the polygons are only about 6-10 inches (15-25 cm) deep. Chan and others (2008) described polygonal fractures of similar length and depth that are largely confined to outcrops of massive (unbedded) Navajo Sandstone. When the cracks formed, the rock surface must have been flat. Through time, weathering along the cracks has given each polygon a convex, dome-like upper surface (Chan and others, 2008). There are virtually no extensive flat (unfractured) surfaces visible at Yellow Knolls—all the broad surfaces that could crack, did crack long ago, and all polygons are now domed. Because new, unfractured bedding surfaces are hard to find, it is difficult to tell if (or how often) new fractures form in the present climate, but because the fracture patterns follow many of the small-scale erosional features here, some of them must be quite young (no more than a few hundred years).

Highly ordered patterns—like those displayed by daisies and leopards—are common in nature, and humans (even geologists) find them aesthetically pleasing. Highly ordered fracture patterns develop only in homogeneous material (materials without preferred lines of weakness) like mud, lava, granite, and some sandstone. For example, as lava flows solidify and then continue to cool, they commonly break into uniform, 5-, 6-, and 7-sided columns. Vast areas in the Arctic, where the average air temperature is below the freezing point of water, are underlain by permafrost (frozen

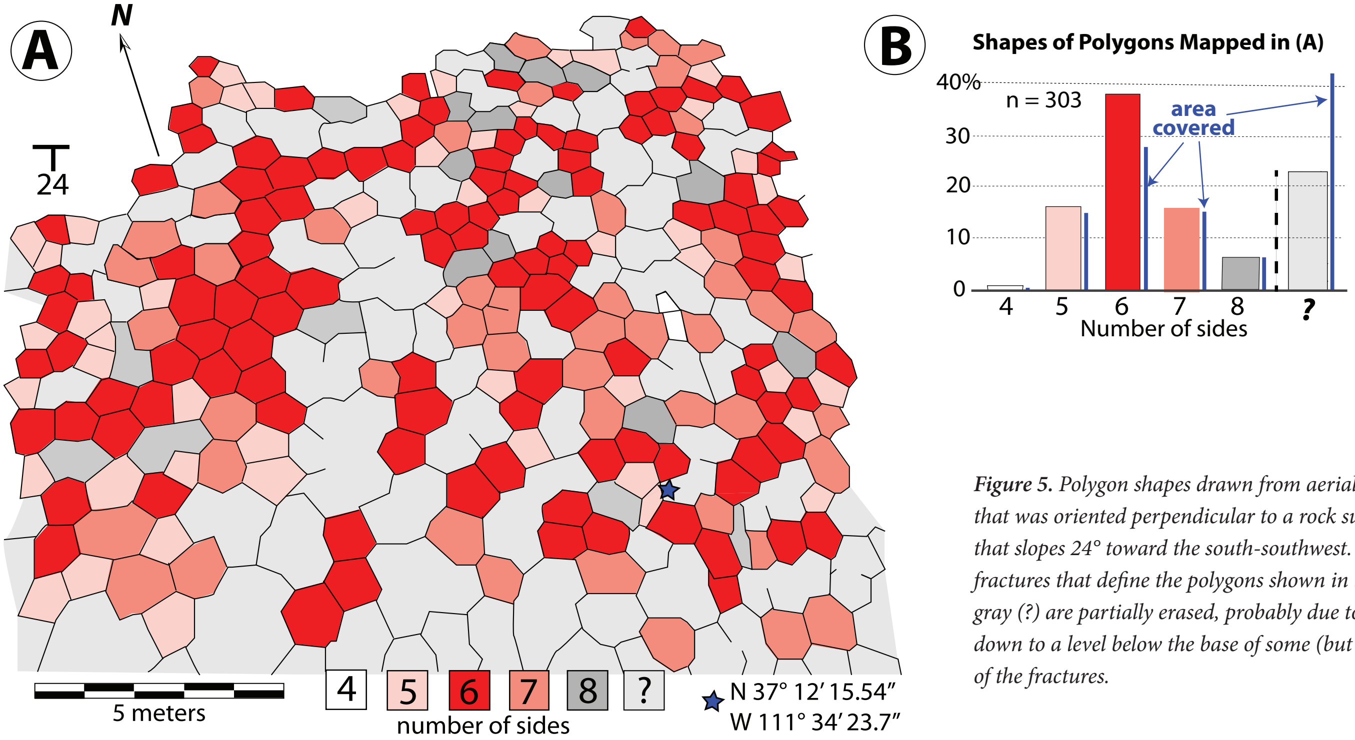

Figure 5. Polygon shapes drawn from aerial photo that was oriented perpendicular to a rock surface that slopes 24° toward the south-southwest. The fractures that define the polygons shown in light gray (?) are partially erased, probably due to erosion down to a level below the base of some (but not all) of the fractures.

Figure 6. *Checkerboard pattern composed of bedding planes and surface fractures. The sloping rock surface under the man’s feet is covered with hexagons (that sloping rock surface is among the ones shown in figure 2, but the camera is here facing in the near-opposite direction). The middle 60% of this photo shows a steep, north-facing slope, and the crossbeds are sloping away from the viewer. Note that in this view, bedding planes are represented by nearly horizontal, widely spaced lines, and because they are unexposed, they bear no fractures. The checkerboard pattern develops where there is a big difference between the orientations of bedding and the exposed rock surface. The fractures on this north-facing slope also demonstrate that maximal insolation is not required for thermal fracturing. N37°12’15”; W113°34’24”*

ground) up to hundreds of feet thick. The key thing to getting fractures is to develop a strong temperature gradient within solid, brittle material. On winter nights in the Arctic, when the air temperature drops far below the average air temperature, the frozen land surface gets much colder than the frozen material at depth. Because the surface material is solidly connected to the deeper material, when the surface contracts “something has to give”, and the land surface ruptures, forming polygons.

Thermal Fracturing In Southern Utah

Land surfaces underlain by homogeneous, brittle rock can also break into polygons when they are subjected to cooling. The average temperature of rocks, soil, and groundwater within a few meters of land surfaces is close to the average temperature of the air above them, but the temperature of rock cannot change as rapidly as the temperature of air can change. This means the temperature of rocks at the land surface will be out of phase with the temperature of deeper rock, generating a thermal gradient. Arctic-like, sub-zero temperatures are probably not responsible for Utah’s cracked rocks; here, the steepest temperature gradients in the sandstone likely develop during summer nights. After a long, sunny June or July day, the surface temperature of the Navajo Sandstone (a brittle material) gets very hot, and much of that heat flows into the rock. Before dawn the next day, much of that heat has flowed back out of the shallowest part of the rock, but the rock at depth is still hot. Like most rocks, sandstone is strong under compression, but weak under tension (stretching; Lachenbruch, 1962). This quick change of air temperature generates enough contractile (tensional) stress in the exposed rock to fracture it. Fracture patterns caused by this process are widespread on sandstone in southern Utah (Chan and others, 2008), but they are especially well exposed, very uniform, and quite beautiful at this site.

But is the Navajo Sandstone at this site really homogeneous? The fact that it is bedded means it cannot be completely homogeneous—instead, the rocks here are repeatedly homogeneous. Bedding is caused by abrupt variations in the size of sediment grains. In this case, the sand grains avalanching down the dune slopes were coarser than those falling onto the dune slope. The hexagonal fracturing here is possible because the bedding at Yellow Knolls is thicker and not as distinct as at other Navajo outcrops (Loope and others, 2019). The greater thickness allows polygonal fracturing because bedding surfaces (planes of weakness) are few and far between. When beds are thin, tensile stresses due to a thermal gradient cannot built up because sliding parallel to the stress occurs along the shallowest bedding plane and prevents rupture—in this case, “nothing has to give”. At Yellow Knolls, stacks of hundreds of (sufficiently) thick beds (figures 2 and 6) allowed tensile stresses to build to the point of rupture, producing linked hexagons in each one.

Not all of the thermally induced fractures here are polygonal. The fractured surfaces that are not aligned with bedding commonly produce a checkerboard pattern (figure 6; Chan and others, 2008). In this situation, the bedding planes act as slippage surfaces that prevent fracturing; only fractures oriented perpendicular to the bedding planes can open—that’s what makes the checkerboard pattern. The beautiful hexagonal patterns developed on south-facing slopes that, like solar panels, gather optimum radiant energy. Those slopes might seem the best place for thermal fractures to develop. A checkerboard pattern of similar scale, however, develops even on north-facing slopes at Yellow Knolls (figure 6), and those at Checkerboard Mesa in Zion National Park (Biek and others, 2010; Chan and others, 2008). This raises the question: with all the available solar energy and the resulting steep temperature gradients, why would any broad Navajo Sandstone exposure in southern Utah remain unfractured? It is likely that some Navajo outcrops are not strong enough to sustain large-scale fracture because tensional stress is relieved by failure at a much smaller (grain-to-grain) scale.

ACKNOWLEDGMENTS

Clint Rowe and Jon Mason provided helpful reviews, and Gerald Bryant assisted with field work and provided the photograph leading to figure 5.

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