The Navajo Sandstone Color Palette and Marvelous Marbles

by Marjorie A. Chan, William T. Parry, and Brenda Beitler

Utah's red rock and canyon country is famous for the vivid coloration of the landscape, but until recently many of the reasons behind the pattern of colors were a mystery. Our research focuses on the Jurassic-age (180 million years old) Navajo Sandstone that is well exposed across much of the Colorado Plateau. The Navajo Sandstone has prominent outcrops in National and State parks and nearby areas from Arches National Park near Moab, Utah, to Zion National Park near St. George, Utah. It comes in a variety of colors, from deep red through pink, yellow, to nearly pure white.

This is a story of iron and water mixing and reacting within the pore space inside solid rock, well beneath the Earth's surface long ago. Sedimentary rocks such as sandstones, are the most abundant sedimentary rocks on the Earth's surface. The sandstone layers as well as their internal fossils and structures tell about much of Earth's past history and geological processes. In certain layers, the sandstone's color is intimately tied to the presence of fantastic-shaped iron-rich concretions (cemented mineral masses often known as "moki marbles," spherules, or nodules); they are two parts of a system. The iron-rich concretions were not present in the sandstone when it accumulated. The concretions formed later. Sandstones in canyon country have a long history of formation of the sand grains as mountain roots are eroded, sand accumulation, sand burial, and moving groundwater. This long history spans from before the time of the dinosaurs, up to the present day where processes of weathering and erosion now expose the beautiful landscape. Even more remarkable, recent NASA pictures from Mars tell us similar processes created analogous concretions on the red planet Mars.

This story results from trying to read the rock layers, much like reading a story from the pages of a book. The Earth records the story in the layers of rocks. These can reveal the past for those with the curiosity to seek out the intricacies of the tale. We outline this fascinating short story in four chapters.

Figure 1. Colorful Jurassic Entrada Sandstone with a dark layer of "tar sand" with hydrocarbons that contribute the bleached selvages in the otherwise red sandstone. Hydrocarbons in this tar sand are one of the known reducing fluids that have permeated the sandstone pores and removed the hematite pigment. All photos courtesy of Brenda Beitler.

Chapter 1 - Original Orange Red Sandstone Color

When the Navajo Sandstone accumulated, Utah was not at its present latitude of 38°, but instead was located at about 20° north in the zone of the northeast trade winds. That is the approximate latitude of the tropical and subtropical deserts of North Africa and Saudi Arabia today. In a desert, the surface sands remain dry and are subject to wind transport. At the time of Navajo Sandstone accumulation, the earth was warmer than today, and the deserts may have been drier.

The vast ancient desert represented by the Navajo Sandstone was covered by sand dunes, much like the widespread Sahara Desert of Africa today. The loose quartz sand was blown into dunes by strong winds during the same geologic time interval that dinosaurs lived (the Mesozoic era). The Navajo desert covered much of Utah, and its related fingers reached into surrounding states such as Nevada, Arizona, New Mexico,

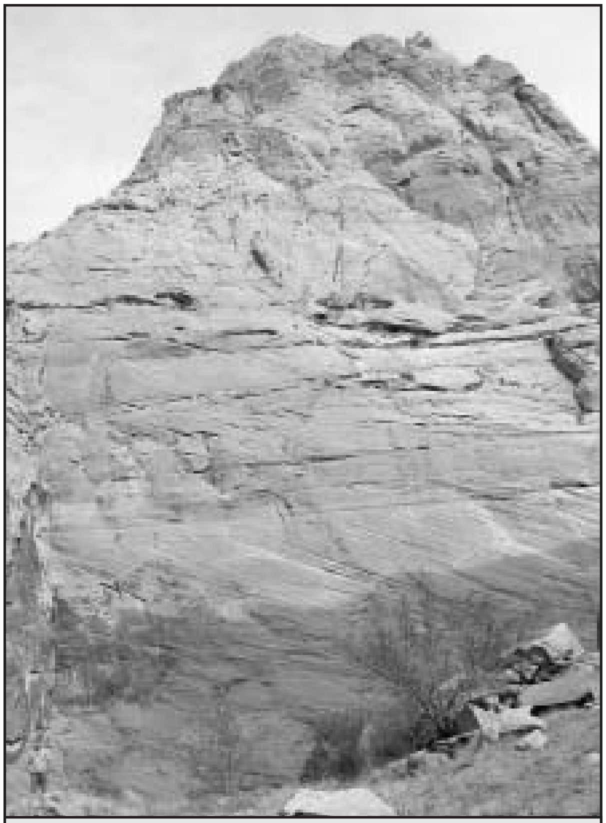

Figure 2. In some areas of southern Utah, the source of the bleaching is now gone, but huge expanses of Navajo Sandstone have had the color removed from fluids flushing through. The crosscutting relationship between primary bedding and the color transition from red to white reveals that the color change came much later than deposition of the sandstone.

and Wyoming. Just as any desert sand soaks up water, the Navajo unit was porous like a sponge, and remained so even when the desert sand was buried and, over time, turned into hard sandstone (a process geologists refer to as lithification). Of the many sandstone units found on the Colorado Plateau, the Navajo Sandstone is one of the most porous, so fluids migrated through it in the past. Even today parts of the Navajo Sandstone are a reservoir for oil and gas, as well as an aquifer for water.

Most sedimentary rocks are derived from a ground-up granitic source rock so the minerals that make up the Navajo Sandstone include the minerals that formed in the original granite. These miner-als include quartz, feldspar, iron minerals and some minerals that occur in small amounts that have a special significance. The mineral zircon is one of the trace minerals. Zircon is zirconium silicate, but it contains traces of radioactive uranium. The uranium decays to lead at a known rate so that the age of zircon formation in the granite can be determined. The age of zircon in the Navajo Sandstone is 1.2 billion to 950 million years. Only one place in North America can supply zircons with these ages: the Appalachian Mountains of the eastern United States. Additional studies of the zircons indicate that the granite was exposed to weathering 250 to 500 million years ago. By 160 million years ago, the sand had been transported across the continent to accumulate in southern Utah.

Through weathering, the iron minerals break down releasing iron compounds that can be carried in water. When iron mixes with oxygen the resulting compound of iron-oxide is a strong pigment, and small amounts of the iron oxide minerals hematite (Fe_2O_3), named for blood, and goethite (FeOOH), named for the German poet, can color a large area of rock. From about 160 million years ago, most Navajo desert sand grains were coated with a microscopically thin film of hematite or goethite as the sand was exposed to air and water, or was buried early in its history and oxygenating waters carrying iron passed through and deposited the thin film. These small iron oxide films made the sandstone an “original” reddish orange color, even though the total amount of iron oxide may have been only about 1-3% of the total rock mass.

Chapter 2 -Bleached white sandstone color

Over millions of years, other sandstones and shales were piled on top of the Navajo Sandstone as the basin or collecting area continued to fill with sediments. Somewhere in its history from maybe 150 to 50 million years ago, other fluid types migrated through this porous rock when it was buried underground. Reducing waters (the opposite of oxygenating) have chemical properties that put iron into solution. Thus, reducing waters such as hydrocarbon fluids, sourced from other organic-rich rock units, moved through the Navajo Sandstone. However, the Navajo Sandstone contains little organic matter that could form liquid and gas hydrocarbon. The bleaching hydrocarbon must have come from other rock layers rich in organic material, and reached the Navajo Sandstone by percolating along faults. Because of the chemical reducing properties, these fluids could actually “clean,” dissolve, and remove the thin iron-oxide films previously deposited on the quartz grains, making the sandstone white. This concept is commonly referred to as sandstone “bleaching” because the chemical process leaves the sandstone white, even though this is not chemically the same reaction that occurs when we bleach our dirty laundry.

The color variation thus results from first "painting" a background color or red over the entire sandstone unit. Then, the painting color can be altered, by removing the red color so that the white color of the sand shows through. The "paint brush" removes, rather than adds, color. The water solutions that removed the color have traveled from deeper sediments rich in organic matter and petroleum. The solutions traveled from their source into the sandstone through faults. One example is the Moab Fault that bounds Moab valley on the west. There, plumes of bleaching extend from the Moab Fault westward through the Navajo Sandstone. Another example is the blind fault (fault that doesn't outcrop) that cores the Waterpocket fold at Capitol Reef. There plumes of bleaching are visible in the Navajo Sandstone and the underlying Wingate Sandstone.

Chapter 3 - A real mixup- new concentrated red-gray and red-brown

Sometime within the last 100 million years or less, strong Earth forces related to plate tectonics lifted up the rock units in several major regions promoting more fluid movements and interactions. The iron that was removed from the surface of the quartz grains, that same small percentage of iron, was carried in solution (dissolved) by the reducing fluids until it met up and mixed with oxygenated groundwater. Then at the chemical mixing boundary of these two fluids, the oxygenated water caused the bleaching fluids to deposit the iron that it had been carrying. The end result was a deposit of very localized and concentrated iron, cementing and filling in the pore spaces between sand grains, making hard, resistant concretionary masses (iron-oxide cemented sandstone). The nature of flow of the two dissimilar waters, coupled with the chemical reactions that precipitated the iron led to a form of self-organization where the precipitates form regularly spaced concretions. Spherical marble forms are very common shapes of the concretions. In other locations, the iron precipitates in fractures that were pathways for solution movement. In fact, the form of the precipitated iron bodies offers clues to the movement of the solutions from which they precipitated. From 5-35% of the total rock is iron-oxide (hematite or goethite) in these concretions. The variation in sandstone coloration came from chemically different types of waters removing iron, and the cemented concretions are the concentrated masses of redistributed iron.

In the last 10 million years, the Colorado Plateau has tilted to the northeast, and the Colorado River and its tributaries cut down through the rock units to expose the sedimentary layers. Erosion and weathering removed a great deal of sandstone, leaving behind the resistant concretions that had previously been encased inside sandstone. In some places large quantities of concretions litter the flat eroded surfaces, telling a story of sandstones removed over time.

This seems like a simple story, but in reality, nature is more complicated and there are many variant expressions of this concept, as well as many episodes where these bleaching and transporting processes may have occurred repeatedly over time. The picture rock sandstones like the Kanab Wonderstone (from the Kanab, Utah area) are related types of coloration and banding that is caused by fluids moving and redistributing iron. Probably every combination of possibilities of fluid interaction and products are out there somewhere!

Different sandstone colors are due to different amounts of iron; the reason behind the amounts of iron has to do with the movement of chemically different types of waters that do the real work of removing and carrying the iron, as well as leaving behind tell-tale marbles.

Figure 3. Iron-oxide concretions take on many forms within the Navajo Sandstone. The iron-oxide cement makes the sandstone much more resistant to erosion than the surrounding rock, creating weathered-out pipes and spheres that accumulate on the sandstone surface.

Chapter 4 - To infinity and beyond?

Concretions come in all kinds of shapes and sizes, and can form from different minerals, not just iron. However, the sandstone color and abundance of iron-oxide concretions in the Navajo sandstone are clearly linked. Spherical shapes are some of the most common forms that occur along chemical reaction fronts because spheres are an easy shape to form in nature where there are no other barriers constraining fluid movement, or preferred pathways such as cracks in the rock for fluids to move along.

Through an amazing blend of planetary science and technology, hematite concretions have been recognized on Mars in remote images taken by NASA mechanical rovers. Some of the images with accumulations of spherical concretions are incredibly striking and eerie in their similarities to Utah landscapes in regions of Grand Staircase-Escalante National Monument and other areas. The mere presence of iron-rich concretions on Mars suggests that there has indeed been groundwater flow through sediments on the red planet. Water is the element most eagerly looked for in the quest for life. The red of the planet is from the mineral hematite, and there is still much yet to be analyzed and discovered through the analyses of the images, and data collection of the rovers.

It is a mind-boggling thought that the rocks that make up the landscapes of our parched redrock country have at times been flushed with different waters. This is nature's color palette of iron, leaving haunting images that hint to more canvases on Mars.

Figure 4. Spheres are one of the most common shapes of concretions within the Navajo Sandstone. They tend to form in areas where other fluid flow pathways are lacking, and the sandstone is very homogeneous.

Afterword

This article is dedicated to Fran Barnes who first got M. Chan started on this research by taking her to some concretion sites during a sabbatical. He generously shared his knowledge of localities that enabled us to piece together the geologic story. Drs. John Bowman and Erich Petersen helped perform analyses, and Drs. Jens Ormo and Goro Komatsu first brought the possible Mars connection to our attention. We are indebted to all who have supplied pieces to this story and who added to the enjoyment of this geologic endeavor.

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Other technical articles are published in professional journals, but related general material is available at: geology.utah.gov/online/pdf/pi-77.pdf.

Dr. Marjorie A. Chan is Professor and Department Chair in Geology & Geophysics at the University of Utah, where she has been on the faculty for 22 years. A number of professional journal articles on this topic of the sandstone color and iron-oxide concretions have been published, and a list is available from the author upon request.

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Brenda Beitler is a doctoral student in geology at the University of Utah who has been working with Drs. Chan and Parry for the last 4 years on understanding the complex variation in the sandstone color and alteration history. Part of her work involves using satellites and airborne spectral images to map out changes in the sandstone, allowing for an altogether different perspective on patterns in mineralogy and fluid flow pathways.