Crystal Geyser: An Unusual Cold Spring System, Grand County

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Cover Image: *Crystal Geyser terraces of calcium carbonate and iron oxide and iron oxyhydroxide minerals.*

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

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

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PRESIDENTS MESSAGE

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

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

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

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

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

Peter J. Nielsen
2019 UGA President

INTRODUCTION

Crystal Geyser is a cold carbon dioxide (CO_2) geyser, part of a natural spring system along the Little Grand Wash fault south of Green River, Utah (figure 1). The spring system hosts a series of CO_2-driven geysers and springs with active and fossil microbial mats and tufa deposits composed of carbonate and iron oxide and iron oxyhydroxide minerals (Potter-McIntyre and others, 2017; Knuth and Potter-McIntyre, 2018) (figure 2). Additionally, progressively older carbonate spring deposits crop out on some of the topographic highs in the area because these relatively erosion-resistant deposits armor the paleo-land surface and slow down erosion (Shipton and others, 2004; Burnside, 2010) (figures 1 and 2). Recent radiometric U-Th dating of carbonate terraces and embedded veins reveal that CO_2-charged fluid has constantly leaked to the surface for over 400 thousand years during the Pleistocene (Burnside, 2010). Crystal Geyser is a popular place for tourists, and it is not uncommon to see children playing in the spring.

The Crystal Geyser conduit is actually an abandoned petroleum exploration well through which water emanates. Surrounding the pipe are terraces of primarily carbonate mineral deposits (Shipton and others, 2004; Potter-McIntyre and others, 2017; figure 2), dull to brilliant orange in color owing to minor iron precipitated from the spring water (figure 2). These terraces cascade down to the river, and include orange and green pools depending on the microbes within them—the green color indicates photosynthesizing microbes. Larger terraces are composed of multiple small terracettes that are thought to be microbially-induced structures (Fouke and others, 2000). Also present around the drill pipe are collections of spheroidal mineral masses called pisoids. These are formed from agitation of minerals when the geyser erupts, causing spheres of precipitate to roll around and accrete new layers of carbonate minerals.

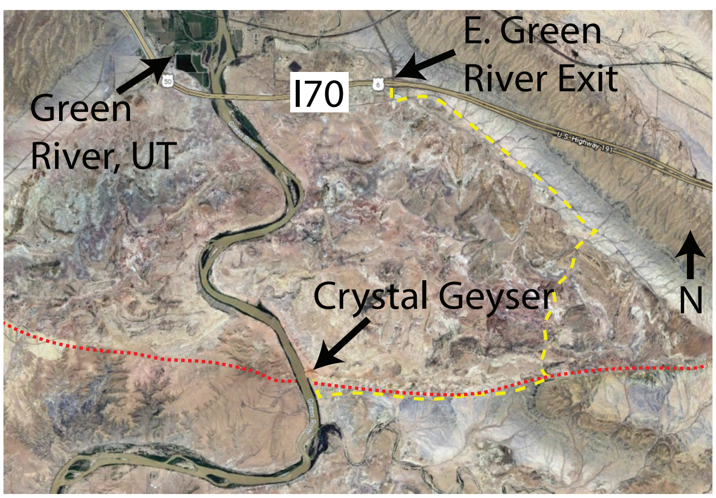

Figure 1. Location map for Crystal Geyser. The yellow dotted line is the road. The dotted red line is the Little Grand Wash fault. Note that the rocks are tan and purple on the north side of the fault (the Jurassic rocks) and dark grey on the south side (the Cretaceous Mancos Shale). See figure 3 for stratigraphy.

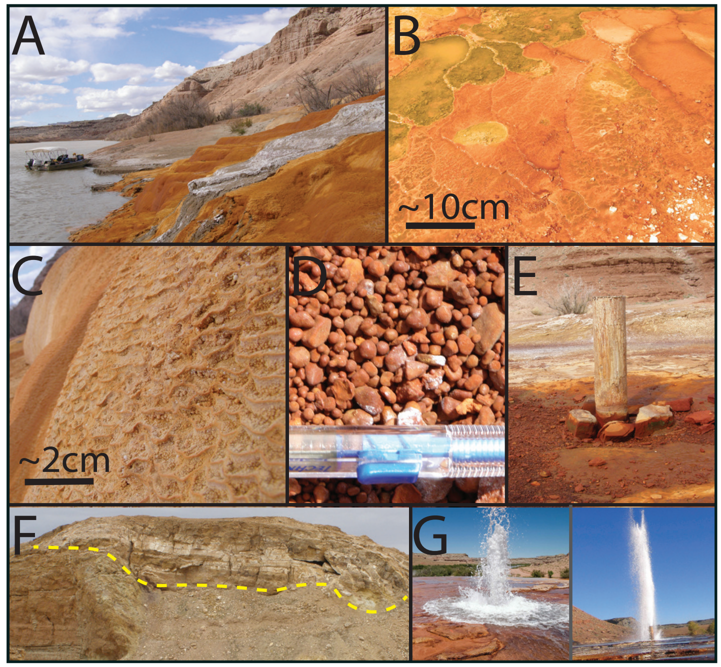

Figure 2. Crystal Geyser features. A. Terraces of calcium carbonate and iron oxide and iron oxyhydroxide minerals. B. Close up of pools of water at top of tufa terrace. Green pools contain photosynthetic organisms. C. Close up of terrace showing that the terraces are composed of small terracettes thought to be formed via the interaction of microbes during mineral precipitation. D. Spheroidal calcium carbonate mineral masses called pisoids. Photo is about 1 inch (2 cm) across. E. Drill pipe at Crystal Geyser is about 2 feet (1.5 m) high. F. 100,000-year-old tufa terrace atop paleo-land surface (yellow dotted line) just northeast of Crystal Geyser. Deposit is about 10 feet (3 m) thick. G. Two photos of Crystal Geyser erupting; left photo reproduced from https://fotospot.com/attractions/utah/crystal-geyser; photo on the right from https://commons.wikimedia.org/w/index.php?curid=4624320.

DIRECTIONS

From I-70 head south off the east Green River exit 164 and then turn east. Take a right at the sign for Crystal Geyser and follow the road. The road is a graded dirt road that is generally in good condition. If it has been raining a lot, the road may be more difficult to navigate. About halfway between the hairpin turn and Crystal Geyser, an oil seep is just off the north side of the road.

GPS Location: N38.94 W110.14

Where Does the Water Come From?

The artesian spring water emanates from deep subsurface reservoirs along geologic faults that bound Salt Wash and Ten Mile graben (Jung and others, 2014; figure 3). The source reservoirs are Jurassic and Permian units that recharge at the San Rafael Swell to the west (Baer and Rigby, 1978; McPherson and Heath, 2009; Dubacq and others, 2011; Kampman and others, 2014). The spring water is CO_2- and methane-charged, saline, and of neutral pH (6.2-7; Shipton and others, 2004; Potter-McIntyre and others, 2017). The source of CO_2 is likely from decarbonation of Paleozoic carbonate rocks (Leadville Limestone) deep below the reservoir

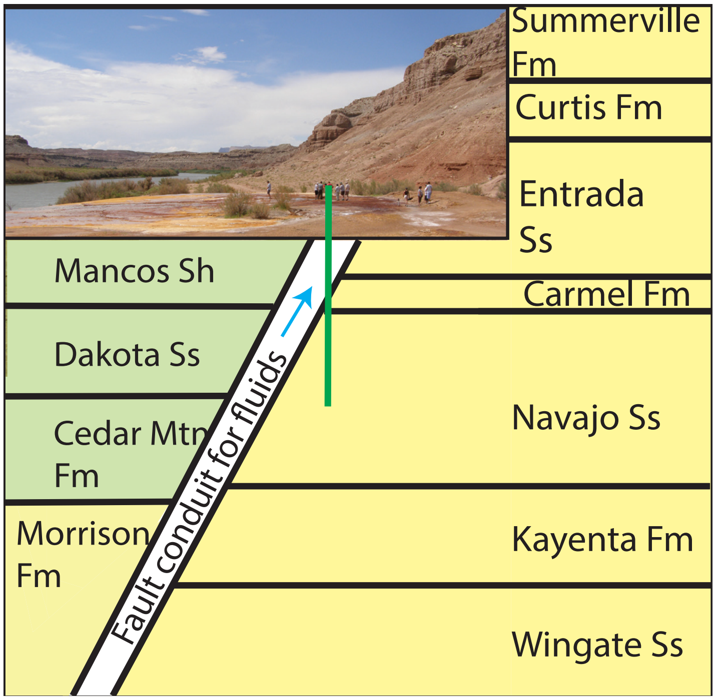

Figure 3. Stratigraphy at Crystal Geyser. The photo is looking north-northwest (upriver). To the right, the exposed rocks are the middle Jurassic section. As one drives along the Little Grand Wash Fault (see figure 1), the grey rocks to the south of the road are the Cretaceous Mancos Shale. These rocks are younger than the exposed rocks to the north of the fault and were downthrown relative to the Jurassic rocks. The well is in green and it extends 2627 feet below the surface. It is not cased, so the CO_2-charged water flows into the pipe in both the Entrada Sandstone and the Navajo Sandstone reservoirs (Watson and others, 2014). However, this fault serves as a conduit for fluid to flow upward to the surface and come out at Crystal Geyser, and for the oil seep you passed on the way in. Jurassic rocks are in yellow and the Cretaceous rocks in green.

(Shipton and others, 2004; Heath and others, 2009; Kampman and others, 2009; Probst and others, 2017). The tufa deposits are spatially dispersed and of variable volumes, suggesting that the location of CO_2 leakage has varied over geologic time depending on the ability of the faults to transmit fluid (permeabilty). The subsurface strata and faults exhibit strongly heterogeneous permeability owing to seismic activity, regional erosion, both mineral dissolution and precipitation, and changing fluid flow volumes owing to variability in climate over time (Burnside, 2010; Burnside and others, 2013; Kampman and others, 2014).

How Does Crystal Geyser Work?

As mentioned in the introduction, Crystal Geyser formed via a human-drilled wellbore. An oil seep along the Little Grand Wash fault motivated drilling of the oil exploration well in 1935 (Baer and Rigby, 1978). The well never produced oil; however, CO_2 dissolved and pressurized in the artesian aquifer at depth now discharges through the wellbore. This open conduit allows rapid depressurization and discharge as episodic geyser eruptions. Following each eruption, the wellbore again fills with water from the bottom up, with pressure building up during filling. The artesian pressure ultimately exceeds the rate of refill and causes another eruption (Watson and others, 2014). The cycle repeats, sometimes after a few hours and sometimes as long as a day or more between eruptions. Crystal Geyser's eruption intervals, durations, and intensities were at one time regular and consistent, but timing now is quite erratic, possibly related to vandalism. Tourists have dropped rocks and even reportedly dynamite into the geyser (Shipton and others, 2004). Other possible factors for variable eruption rates include seismic activity (Han and others, 2013) and/or interactions between recharge rates and CO_2 migration rates within the artesian aquifers (Kampman and others, 2014).

SITE OF ACTIVE SCIENTIFIC RESEARCH

Crystal Geyser and its related spring system are subjects of active scientific research on topics ranging from global warming to the search for extraterrestrial life. This section discusses topics of recent research, including analysis of the geyser's source aquifer as an analog to engineered carbon capture and sequestration, followed by analysis of microbial life, interactions between microbes and mineral precipitation and how these processes offer insight regarding the search for life on Mars and beyond.

CO_2 Sequestration

Global warming of our planet is attributable to the greenhouse effect, specifically increasing concentration of anthropogenic CO_2 in the atmosphere that traps heat from solar radiation after it is reflected from the earth's surface (e.g., Scheffer and others, 2006; Eby and others, 2009; Notz and Stroeve, 2016; Specht and others, 2016). Many ideas have been proposed to reduce CO_2 emissions and the greenhouse effect, one of which is carbon capture and sequestration (e.g., Yang and others, 2008; Dai and others, 2013; Rahman and others, 2017; Rackley, 2017). Carbon capture and sequestration (CCS) includes capture of CO_2 at point sources such as cement plants and power plants, pressurizing and condensing it to a fluid and then injecting that fluid into subsurface reservoirs. The fluid that emanates at Crystal Geyser comes from a natural subsurface CO_2 reservoir, but it leaks via migration upward along faults. The spring water degasses its CO_2 at the springs and geysers and effectively emits CO_2 into the atmosphere, similar to industrial sources (but much smaller in volume). Understanding how this gas moves upward, how the emissions vary from site to site along faults, and what impedes or promotes flow are all very important parameters to know before CCS becomes a viable mitigation strategy for anthropogenic CO_2 emissions (e.g., Shipton and others, 2005; Gouveia and Friedmann, 2006; Burnside and others, 2013; Watson and others, 2014).

Astrobiology

Biosignatures are preserved fingerprints of past microbial life, which is the type of life scientists are searching for on Mars and icy moons within our solar system. Three types of biosignatures

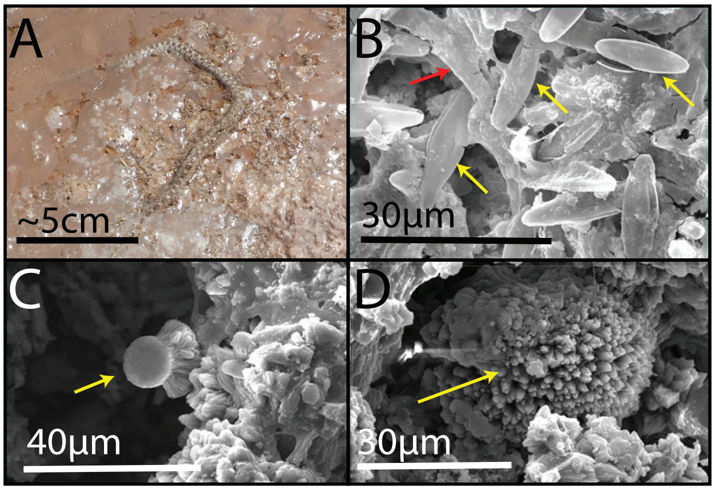

Figure 4. Life in Crystal Geyser. A. A snake did not fare well wandering into the water that is too salty for most organisms. B. Some organisms, called halophiles, love salty water. Yellow arrows point to diatoms from a microbial mat at one of the springs near Crystal Geyser. Red arrow points to exopolymeric substance that is produced by microbial life and provides a substrate onto which calcium carbonate minerals can easily precipitate. C and D. Yellow arrows point to unusual mineral forms likely produced by the interaction with microbes. Images B, C, and D scales are in microns (µm). A human hair is approximately 75 µm. (Images B, C, and D are after Knuth and Potter-McIntyre, 2019).

are described as follows: (1) carbonaceous body fossils of microbes, (2) microbially influenced sedimentary structures such as microbialites (laminated mineral deposits formed via microbial mats), and chemical fossils (such as organic molecules or minerals directly precipitated via the metabolisms of organisms like shells), and (3) isotopic signatures or concentrations of trace elements specific to sequestration by microbes (Cady and others, 2003; Westall, 2008; Potter-McIntyre and others, 2014). Crystal Geyser and nearby springs all host microbial life; the water is too salty for anything else to grow in it (figure 4). This section examines some ongoing research using Crystal Geyser as an analog to Mars and then to icy moons, such as Enceladus and Europa.

Mars

On Earth, microorganisms commonly enhance mineral precipitation and mediate mineralogical and chemical compositions of resulting deposits (e.g., Reid and others, 2000; Dupraz and others, 2009; Petryshyn and others, 2012; Corkeron and others, 2012). Many of the features at Crystal Geyser are thought to be created by microbes, such as the terracettes and the green color of some of the pools and even the orange color (Emerson and others, 2016; Potter-McIntyre and others, 2017; figure 2). Even though some research seems to suggest abiotic precipitation plays a large part in carbonate formation at springs due to degassing of CO_2 (e.g., Fouke and others, 2000; Takashima and others, 2011; Knuth and Potter-McIntyre, 2019), those studies acknowledge that microbial metabolisms do affect precipitation, particularly in minerals forming away from the vents (Fouke and others, 2000; Takashima, 2011). A host of micro-organisms and mineral habits that are likely microbially induced are present in the tufa deposits (Knuth and Potter-McIntyre, 2019; figure 4).

Icy Moons

Enceladus and Europa are high priority targets for future exploration because of their subsurface oceans, which make them potentially habitable environments (Hendrix and others, 2019). These moons exhibit plumes (geysers) of subsurface water that erupts to the surface. These plumes would make excellent targets for understanding the habitability of Enceladus and Europa because of their relative ease of accessibility. Studies of the microbial life deep within the Crystal Geyser waters have found a diverse population with adaptations to reside in CO_2-rich, saline environments (Santillan and others, 2015; Emerson and others, 2016; Probst and others, 2017; Knuth and Potter-McIntyre, 2019; figure 4). Ongoing studies seek to find ways to determine habitability from the geyser plumes to help design future missions.

SUMMARY

Crystal Geyser is a fascinating example of a rare cold spring and geyser system. It is a treasure trove of scientific information, as well as just a fun and scenic place to visit. Spend some time hiking around and looking at the fault and the older tufa deposits, and think about how these formed throughout the millennia—and think about similar features on Mars and other celestial bodies in our solar system!

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