DELINEATION OF GEOHERITAGE SITES IN UTAH

by

Jim Davis, Mackenzie Cope, and Mark Milligan

Suggested citation:

Davis, J., Cope, M., and Milligan, M., 2025, Delineation of geoheritage sites in Utah: Utah Geological Survey Data Series 3, 21 p., 1 appendix, https://doi.org/10.34191/DS-3.

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DATA SERIES 3
UTAH GEOLOGICAL SURVEY
UTAH DEPARTMENT OF NATURAL RESOURCES
2025

INTRODUCTION AND METHODS

This study compiled, identified, and assessed geoheritage locations within the State of Utah to create a ranked inventory of sites based on multiple criteria. This project was funded in part by USGS STATEMAP Grant # G23AC00466. Geoheritage sites are defined broadly as having "exceptional elements of geodiversity, namely minerals, fossils, rocks, landforms, and their landscapes, soils, and active geological and geomorphological processes" (Brilha, 2018). Many of these sites are not actively protected within a park or conservation area, making them a priority for both cataloging and digital preservation efforts (Burnham et al., 2022).

The inventory process started by defining geoheritage criteria based on recent descriptions of geoheritage (Carleton College, 2020). The first step was compiling sites from existing Utah Geological Survey (UGS) datasets that include *Survey Notes'* GeoSights (UGS, 2000–2025) and Rockhounder (which preceded GeoSights) articles (UGS, 1994–2000), *Visitor Information Guide to Fossils in Utah* (UGS, undated), and Utah Geological Association Geosites (Milligan et al., 2019) and Road Signs (Utah Geological Association, undated). In addition to compiling existing data, we also solicited UGS staff, as well external geoscientists, for potential geoheritage sites. To gather ideas from external geoscientists we crowd sourced potential sites with an exhibitor's table, poster, and fliers at the 2024 Geological Society of America Joint Cordilleran and Rocky Mountain Section Meeting held May 15–17, 2024, in Spokane, Washington. Our meeting provided background information and a QR code linked to a 5-minute survey that allowed attendees to recommend sites. Multiple people in the geologic community took the survey or contacted us to endorse sites. Finally, we published an article titled *Utah—The Geoheritage State* in *Survey Notes* (Milligan et al., 2025) that solicited geoheritage sites from the public. These combined efforts produced a total of 620 sites.

Based on the authors' knowledge of sites that meet the criteria of a geoheritage location, an additional 119 sites were added, bringing the total to 739 sites. These sites were then screened based on various criteria described below to create a condensed list of 129 sites. More than four-fifths of the sites from the initial 739 site list were removed because they did not meet certain criteria (or were low scoring in several categories of the ranking system), were duplicates, were on private property, or did not have detailed location information.

All potential sites in our dataset have attributes assigned in the following fields: Site ID, Name, Description, Lithology/Age, Notes, Scientific Value, Educational Value, Cultural Value, Economic Value, Aesthetic Value, Score, Threat Sensitivity, Social Significance, Proximity 20 Miles, Management Agency, Designation, County, State, Latitude, Longitude, Projection, and Coordinate System. For the value fields (scientific, educational, cultural, economic, aesthetic), each site was given a rank of 1 through 5. Each site was researched specifically for each of the five ranking categories and sites were ranked relative to all other sites for each criteria. Sites were also assigned a low, medium, or high rating for threat sensitivity (alteration or destruction potential), Social Significance, and proximity to other sites (Proximity 20 Miles field). All rankings were given by one person to maintain standardization. The database can be accessed at https://ugspub.nr.utah.gov/publications/data_series/ds-3/ds-3a.xlsx.

The UGS is not the only organization that has considered Utah sites worthy of geoheritage designation. The International Union of Geological Sciences extensive list of world geoheritage sites includes three in Utah: Great Salt Lake, the Henry Mountains, and The Carnegie Quarry Exhibit Hall, situated in Dinosaur National Monument. For more information on these sites visit https://iugs-geoheritage.org/. However, Utah does not contain any UNESCO Global Geoparks, which are sites and landscapes of international geological significance (UNESCO, 2025).

RANKING POTENTIAL GEOHERITAGE SITES

The following attributes were given a rank of 1 to 5, with 5 being the best: scientific significance, educational value, cultural importance, economics, and aesthetics.

Scientific Significance

Scientifically significant sites have current and potential for new discoveries. As such, these sites are difficult to score because the importance of sites may change with evolving scientific tools, technologies, and paradigms. Scientific significance may be considered the most important attribute, however, all attributes were scored without bias.

Bear Lake, Fish Lake, and Great Salt Lake scored high (5) in scientific value due in part to their old, deep, tectonically controlled sediment-filled basins that are natural archives of paleoenvironmental data such as precipitation and temperature.

Sites with continuous stratigraphic sections or sections spanning geologic age boundaries, such as the Newfoundland Mountains (Cambrian to Permian Periods, score of 5) and San Rafael Reef (Permian to Jurassic Periods, score of 4) also scored high, due to the opportunity for study of past environments and times of environmental transition. Similarly, sites with significant fossil assemblages scored high.

Geologically, biologically, and climatically isolated places, such as the Henry Mountains, Deep Creek Range, Newfoundland Mountains, Bear Lake, and Boulder Mountain scored high (all 5) because of their isolated populations and "island" biogeography that includes endemic species, founder effects, and species refugia.

Volcanic and plutonic areas, such as the Deep Creek Range (score of 5), La Sals (score of 4), Notch Peak intrusion (score of 4), and Henry Mountains (score of 5), had notable scores due to their value for studying Earth's internal processes, plate tectonics, paleomagnetism, and geochronology.

Educational Value

Educational value spotlights teaching and learning about the Earth. It is weighted for textbook examples of landforms that exemplify Earth's processes. Superlatives are valuable educational tools.

For example, the Goosenecks of the San Juan River (score of 5) is a superb occurrence of entrenched meanders, and the San Juan River Rincon (score of 5) is an excellent example of an abandoned perched meander. Salina Canyon (score of 4) is an easily discernable angular unconformity. Bells Canyon (score of 4) and Little Cottonwood Canyon (score of 5) are distinctive U-shaped alpine glacial valleys and contain easily visible active rock glaciers, erratics, and moraines that are clearly dissected by the Wasatch fault zone.

Consideration was also given to outdoor classrooms that are safe, accessible to all, and conveniently located near populated areas. A prime example is Salt Lake County's G.K. Gilbert Geologic View Park (score of 5), which has been used by educators from primary schools to universities for decades. The park is a stunning place for teaching about glaciation, Pleistocene-age Lake Bonneville, the Basin and Range and Rocky Mountain physiographic provinces, seismic hazards, mining, and more.

Natural hazard locations, such as landslides, prominent active fault scarps, and sinkholes scored well as they provide an opportunity to educate the public, regulatory agencies, and policymakers about geology that can have dire public safety consequences. For instance, the 1983 Thistle Landslide (score of 4) remains the most economically costly landslide in the nation, and is clearly visible and easily accessible.

Cultural Importance

Culture importance–human stories can be modern, historical, and prehistoric. Lake Powell (Glen Canyon National Recreation Area [GCNRA]), which includes multiple sites, exemplifies all three aspects. Padre Bay in GCNRA (score of 4) is a modern Utah cultural phenomenon because generations of Utahns have vacationed here and exhibited emotional and cognitive connection to this place. In 2023 Lake Powell was the most visited attraction in Utah, with 5.2 million visitors (U.S. National Park Service, 2024). The reservoir itself is historical, dating from the late 1960s and is the last American dam of the Big Dam Era. Adding to the historical cultural importance, more than 40 movies and many television episodes have been filmed here. Glen Canyon, which Lake Powell has buried in mud, is filled with prehistoric archeological sites from the Basketmaker and Pueblo eras that included artifacts, granaries, petroglyphs, and pictographs.

Frisco (score of 5) is a prominent example of a historical cultural resource. The ghost town, formerly known as the wildest town in the Great Basin with 6000 inhabitants and 23 saloons, provides a snapshot of western history from the late 19th and early 20th century (Carr, 1987). Among the remains of Frisco are beehive charcoal kilns, dilapidated buildings, and a cemetery. The associated San Francisco mining district produced an estimated $907 million in metals, at modern prices (Krahulec, 2018).

An example of prehistoric cultural importance includes Danger and Jukebox Caves (score of 5) in the Silver Islands Mountains. As soon as Pleistocene-age Lake Bonneville retreated to an elevation allowing cave access, they became a succession of continuous human occupation for 9,000 years.

Economics

Mines and geotourism sites scored high in the economic value category. By far, the Bingham Mine (score of 5) had the single biggest economic impact of any mine-related site. Since its beginning in 1906, the mine has extracted around $200 billion in minerals and other commodities, producing more copper than any mine in history (Krahulec, 2018; Rupke et al., 2024).

Known geothermal resources and areas with geothermal energy production, such as Roosevelt Hot Springs (score of 5), or those with future potential like Black Rock Desert (score of 4) also weighed more economically. Volcanic areas such as Spor Mountain (score of 5), which contains a notable number of rare earth elements and other strategic metals (Krahulec, 2018), were also given a high economic value rank.

Tourism is a significant industry in Utah, contributing $12 billion in visitor spending in 2022, over $23 billion in economic output, and providing more than 150,000 jobs (Leaver, 2024). A sizable portion of these tourists come to see the natural features of the state, and sites with tremendous visitation rates score high. A case in point, Zion National Park had 4.9 million visitors in 2024, and therefore this site scored a 5.

Aesthetic

Many locations in the Utah geoheritage database scored high for aesthetics: over 40% of ranked geoheritage sites were designated a maximum score because of their splendor, as were all the following examples.

Aesthetic sites can be both well trodden or unrecognized. Window Blind, Bottleneck, and Assembly Hall peaks—strictly all buttes—are relatively unknown even to Utahns. These buttes are quintessential American Southwest landforms that can be viewed together or from above at another geoheritage site on the list, the Wedge Overlook in the San Rafael Swell. On the other end of the notoriety spectrum are Raplee Ridge, Reflection Canyon, Bryce Canyon, Zion, Coyote Gulch, Mesa Arch, and Delicate Arch. These sites are among the most photographed natural landscapes in the country, the latter occasionally ranking in the top ten of most photographed natural places in America.

Highly aesthetic Geoheritage sites can also be enhanced by humans. Fremont Indian State Park displays a corridor of pictographs and petroglyphs with a patina on tuff of the Miocene-age Mount Belknap volcanics. Robert Smithson's 1970 land art piece–Spiral Jetty is constructed of black boulders that contrast with the North Arm of Great Salt Lake's white salt crystals and red water that is tinted by halophilic bacteria and algae. In 2017 the Utah legislature formally recognized the Spiral Jetty as "the state work of land art," the only state to have an official work of land art.

DATABASE SUMMARY

The database contains the final selection of potential geoheritage sites from the existing UGS databases of geologic locations and other known geologically important sites in Utah. The database largely follows the format of the U.S. Geological Survey (USGS) national geoheritage database. In addition to numerical rankings, non-numerical rankings were added for additional context to assist in assigning scores to the numerical fields. The database includes the following fields:

SITE_ID: Unique identifier for each site. "G-" sites are from GeoSights (UGS, 2000–2025); "M-," "R-," and "F-" are from Utah Rockhounder (UGS, 1994–2000); "FG-" is from *Visitor Information Guide to Fossils in Utah* (UGS, undated); "UGAS-" is from Utah Geological Association geologic road signs (Utah Geological Association, undated); and "A-" sites are new for this dataset.

NAME: The official or widely-recognized name of the site.

DESCRIPTION: A general characterization of the geological feature type.

LITHOLOGY_AGE: Formations, ages, and other basic geologic information.

NOTES: Additional notes describing the formations, special features present, and other details.

SCIENTIFIC_VALUE: Numerical field ranking a site's scientific value from 0 to 5.

EDUCATIONAL_VALUE: Numerical field ranking a site's educational value from 0 to 5.

CULTURAL_VALUE: Numerical field ranking a site's cultural value from 0 to 5.

ECONOMIC_VALUE: Numerical field ranking a site's economic value from 0 to 5.

AESTHETIC_VALUE: Numerical field ranking a site's aesthetic value from 0 to 5.

SCORE: The sum of all ranking category scores: Scientific Value, Educational Value, Cultural Value, Economic Value, and Aesthetic Value.

THREAT_SENSITIVITY: Non-numerical rating using a "low" to "high" scale for threat sensitivity. Threat sensitivity was determined based on previous/future development or vandalism history at the site or in nearby areas.

SOCIAL_SIGNIFICANCE: Non-numerical rating using a "low" to "high" scale for social significance. Social significance was established based on the popularity of the site to visitors, public inquiries about the site, and any past/current events or news about the location.

PROXIMITY_20MI: A 20-mile radius around each site was used in a GIS analysis to determine the presence of site concentration patterns. This field reflects the number of total sites within each site's radius. A "1" indicates the site is isolated with no other sites within the radius, "2" means one other site is nearby, and so forth.

PROXIMITY_RATING: Non-numerical rating using the value in PROXIMITY_20MI to assign a score. 1 = "Isolated," 2 = "Low," 3 = "Medium," 4 and higher = "High."

MANAGED_BY: The land management agency encompassing the site.

DESIGNATION: The official designation of the site or general area, as applicable.

COUNTY, STATE: The county and state where the site is located.

LATITUDE, LONGITUDE, PROJECTION, COORDINATE_SYSTEM: Each site contains latitude and longitude coordinates with the projection and coordinate system used to map them for GIS analyses. Some coordinates were estimated because the location was a larger area instead of a single point.

SUMMARY OF HIGH RANKING GEOHERITAGE SITES

Based on the ranking process described above, Utah has a range of geoheritage site quality. We present and discuss 16 sites below that represent the highest ranked sites in Utah. These sites represent the sites of greatest importance for inclusion in any national dataset of geoheritage sites. Of the 129 total sites compiled, 94 sites scored 16 points or higher, 73 sites scored 17 or higher, 56 sites scored 18 or higher, 46 scored 19 or higher, 33 scored 20 or higher, and 16 sites scored higher than 20 points. The top scoring potential geoheritage sites are Great Salt Lake (25 points) and Bear Lake (23). Seven sites scored 22 points, including; Upheaval Dome, Fremont Indian State Park, Deep Creek Range, Arches National Park, Zion National Park, Dinosaur

National Monument, and the San Rafael Reef. The next seven sites scored 21 points and include: Henry Mountains, Antelope Island, La Sal Mountains, Jurassic National Monument, Black Rock Desert, Bryce Canyon National Park, and Split Mountain.

1. Great Salt Lake had the maximum possible point total, scoring 5 points for each category. It was considered as one entity although its area is 1600 square miles at historical average lake levels. The lake has 17 or 18 named islands including Stansbury at more than 22,000 acres and Antelope Island at more than 28,000 acres. Multiple large sections of the lake are dissected by causeways and dikes that create distinctive water colors, aquatic chemistry, and ecology. Several lake-adjacent sites including Fremont Island, Antelope Island, and The Fingerpoint were listed as potential geoheritage sites in this report.

Biologically the lake has great productivity. Two aquatic animals, brine shrimp and brine flies, number in the trillions and billions, respectively. Microbialites or algal bioherms, which at one time dominated the biota of early Earth, occupy a sizable part of the lakebed, around 20%, and are the largest areal extent of modern bioherms on the planet. This elevated level of productivity makes the largest saline lake in the Western Hemisphere a global hotspot for bird migration and reproduction. The lake is essential for species of birds. It is one of the world's largest staging or breeding areas for the Eared Grebe, Wilson's Phalarope, American Avocet, Black-necked Stilt, Long-billed Dowitcher, California Gull, American White Pelican, White-faced Ibis, and Tundra Swan. More than 330 bird species have been recorded here, some number in the tens to hundreds of thousands, and annual counts of individual species can range from 10 to 12 million.

Figure 1. *Great Salt Lake achieved the top score of all potential Geoheritage sites in this report. Image of mirabilite spring mounds on the south shore of Great Salt Lake.*

The lake's history is deeply entwined with the history of the state and gives a sense of identity to Utahns. The lake's prehistory is marked by numerous shoreline caves with long-running human occupations that provide valuable data on desert culture and adaptation to environmental change. The lake's name is the same as Utah's capital city, and it is the home of the state bird and state crustacean. Massive construction projects throughout the nation's 20th century history (e.g., the 1904 Lucin Cutoff trestle and 1959 causeway, the 1983 boxcar seawall and 1984 breach, and the 1987 West Desert Pumping Project) have been completed over or around the lake. The lake generates nearly $2 billion annually to the state's economy through mineral extraction, brine shrimp harvest, hunting, and tourism. Additionally, lake-effect snow, up to 10% of the wintertime total in the Wasatch Range, provides water storage for the dry season and enhances and prolongs the bustling ski industry (a $2 billion a year industry in the state). Mining of the lake has included halite, potassium sulfate (only domestic producer), lithium, and magnesium (Rupke et al., 2022).

Scientifically, the lake provides a long-term archive of environmental conditions in the Great Basin. Cores in lake sediments span 780,000 years and provide a record of four pluvial lakes that have existed through that time (Eardley et al., 1973; Kowalewska and Cohen, 1998; Oviatt et al., 1999). The lake hosts extreme organisms such as halophiles in the salt-saturated North Arm that can provide analogs to life on other planets (Davis et al., 2022). The continuously changing volume of the lake and its chemistry provide a laboratory in which to study ecosystem change. In the late 19th century G.K. Gilbert developed the concept of isostacy for the first time using shoreline elevation points from Great Salt Lake's predecessor, Lake Bonneville. In the past few decades, the lake has been a valuable source of data on Pleistocene climatic change, life in extreme environments, and the oolitic sands and microbialites give a modern example of carbonate sedimentation.

In the last few decades, the future of the lake has become uncertain. In 2022, and again in 2023, an all-time low lake level was documented after more than 170 years of records. Agricultural diversions, municipal use, and a long-term drought have threatened to immensely shrink the lake and saturate its waters with salt, altering the ecosystems on which wildlife, industry, and tourism depend (Abbott et al., 2023). Furthermore, toxic dust from the exposed lakebed could threaten the health of millions of people living downwind of the lake.

2. Bear Lake occupies a normal fault-controlled half graben. Bear Lake is the deepest lake in the state (94 feet average, 208 feet maximum) and freshwater. The counterpart to Lake Tahoe at the eastern edge of the Great Basin, Bear Lake is among the oldest lakes in North America. A core extracted from the lakebottom yielded ages up to 250,000 years, but the lake could be several million years in age (Reheis et al., 2009). The lake contains four species of endemic fish: the Bonneville Whitefish, Bear Lake Whitefish, Bonneville Cisco, and Bear Lake Sculpin (Davis and Milligan, 2011). Bear Lake is a recreational destination either for summer water sports or winter ice fishing and generates more than 48 million dollars in recreation and tourism annually (Hjepe et al., 2022). Its calcium carbonate-rich turquoise waters are set among the Bear River Plateau and Bear River Range. The lake is surrounded by Paleozoic, Mesozoic, and Tertiary volcanic rock.

Figure 2. *Bear Lake scored second. View to the east, where the eastern Bear Lake fault creates a steep linear transition to the Bear Lake Plateau.*

3. Upheaval Dome is currently regarded in the scientific community as an eroded meteorite impact. For most of the 20th century it was thought to be a salt dome of the Paradox Basin (Case, 2009). It is thought to be younger than 170 million years old and is composed of the characteristic Permian, Triassic, and Jurassic rock formations of the Colorado Plateau (Doelling, 2004; Case, 2009). The central uplift of the dome is the Permian Organ Rock Shale, and the rim of the crater is the Jurassic Navajo Sandstone. These rocks are intensely faulted and folded. Clastic dikes are common to the area and impactites are found in some drainages (Kriens et al., 1997). The anticline of Upheaval Dome is over 6 miles across, and the steeply dipping rock stands in contrast to the horizontal rock across the plateau.

Figure 3. *Upheaval Dome, in Canyonlands National Park, scored third. Currently thought to be an eroded meteorite impact, it has also been interpreted as a salt dome. Image from Google Earth, ©2025 Maxar Technologies.*

4. Fremont Indian State Park has the remains of one of the largest and most complex Fremont Indian (300–1300 AD) communities discovered, a culture that occupied nearly all of Utah. This area has yielded thousands of artifacts in addition to hundreds of petroglyphs and pictographs found on the cliffs and alcoves of Clear Creek Canyon. The villages here practiced early dryland farming from around 900 to 1170 AD on alluvial fans entering the canyon. The canyon is eroded in tuffs expelled during volcanism associated with the Marysvale Volcanic Field (Rowley et al., 2002; Hintze et al., 2003).

5. The Deep Creek Range and Gold Hill is an isolated range in far western Utah at the edge of the Great Salt Lake Desert and the ancestral homeland of the Goshute, Paiute, and Shoshone peoples. The imposing range rises 7800 feet above the basin floor and has two peaks over 12,000 feet. The highest is Ibapah Peak, one of 356 ultra prominent peaks in the nation with a prominence of 5252 feet, the third highest prominence in Utah. Four mining districts are found in the Deep Creeks: Gold Hill, Willow Springs, Spring Creek and Trout Creek that extracted a combined $133 million (2017 value) in gold, arsenic, silver, lead, zinc and tungsten (Krahulec, 2018). The Gold Hill district is the most significant in the range and is structurally complex, hosting mineralization in volcanics from the Jurassic Period and Eocene and Miocene Epochs. The geology of the range is diverse, having Proterozoic metamorphic rocks, Paleozoic carbonates and shale, and Jurassic and Eocene igneous intrusions.

The Deep Creeks contain eight perennial streams, two of which host the Utah State Fish (the Bonneville cutthroat trout), 12 endemic plants including wildflowers and cactus, sixty families of plants, Great Basin bristlecone pines, and the Giant Stonefly that is ordinarily only found within the Pacific drainage basin. The range is zoned into desert, xeric, mesic, and alpine ecosystems.

Figure 4. *Fremont Indian State Park ranked fourth. Image shows eroded tufts of the Marysvale Volcanic Field.*

Figure 5. *The Deep Creek Range and Gold Hill ranked fifth. Image of Indian Canyon in the Deep Creek Range.*

6. Arches National Park has the highest concentration of stone arches in the world. The park has more than 2000 documented arches, which is 12% of Earth's arches in just 119 square miles. It hosts Landscape Arch, the world's fifth largest arch. The park lies in the Paradox Basin, named after streams striking perpendicular to valleys due to rising salt diapirs causing collapsed anticlines. Jointing in the Entrada Sandstone creates sandstone fins that often weather further to form arches. In 1929, Arches became a national monument and a national park in 1972. American author Edward Abbey, pioneer of environmental activism and wilderness preservation, worked here as a park ranger in the mid-1950s, and penned *Desert Solitaire* recounting his experiences in Arches.

Figure 6. *Arches National Park ranked sixth. Image of Turret Arch viewed through North Window arch in Arches National Park. Photo by Gregg Beukelman, © 2014.*

7. Zion National Park became a national monument in 1909 and a national park in 1919. In recent years it is the third most visited national park in the U.S. Its centerpiece is the canyon of the Virgin River that has cut through more than 2000 feet of Navajo Sandstone. This area is the thickest part of the Jurassic North American Erg. The geology of Zion includes nine Mesozoic-age Formations as well as Quaternary-age basalt flows. Zion is on the western edge of the Colorado Plateau and largely owes its cliffs exposure to uplift across the Hurricane fault zone. The park holds slot canyons, waterfalls, the world's sixth-largest arch (Kolob Arch at 288 feet), and hanging gardens of alcoves and cliff walls that emerge at geologic contacts and are hotspots for biodiversity and endemism in the Colorado Plateau.

Figure 7. *Zion National Park ranked seventh. Image of Angles Landing in Zion National Park. Photo by Adam Mckean, © 2015.*

8. Dinosaur National Monument was created in 1915 and contains one of the world's most famous dinosaur quarries. It is highly popular with the public and the scientific community. It has more than 800 paleontological sites with rich fossil assemblages found in the Jurassic Morrison Formation. Today more than 1500 bones can be seen on the "wall of bones" inside the Quarry Exhibit Hall. The park also contains paleontological resources that include fossil pollen, mammals, amphibians, reptiles, and exceptionally well-preserved fossil frogs and salamanders. There are 23 rock formations in Dinosaur representing desert, floodplain, and ocean environments.

The park encompasses the confluence of the Green and Yampa Rivers in Colorado, the latter of which is one of the few remaining largely free-flowing rivers in the Western U.S. and contains two species of fish that are endangered and critically imperiled due to river engineering. Split Mountain, where the Green River cuts through an anticline, intrigued John Wesley Powell and he suspected antecedence of its origins, though now it is suspected to be superimposed. The park has an estimated 25,000 petroglyphs and pictographs made by Fremont Indians. The Green River is also a haven for river runners. The park's varied landscape is home to some 400 species of animals and 650 vascular plants, including the endemic dinosaur milkvetch, found only in the park.

Figure 8. *Dinosaur National Monument ranked eighth. Image of Green River and Split Mountain. View to the south. Photo by Jen Miller, © 2019.*

9. The San Rafael Reef is a spectacular ~75-mile-long hogback with flat irons and steeply eastward-dipping strata. The reef is the eastern and southern edge of the San Rafael Swell, a large doubly plunging anticline formed during the Laramide orogeny.The reef is dissected by dozens of slot canyons (Utah is thought to have the highest concentration of slot canyons on Earth, [Duncan, 2025]). The reef contains four mining districts that produce uranium and vanadium ore. Interestingly, the Temple Mountain mining district deposits are associated with sedimentary collapse breccia pipes that range from 100 to 2500 feet across and have as much as 400 feet of vertical down-drop from their original stratigraphic position. Designation of the San Rafael Swell as a National Monument was proposed by Utah's governor in 2002.

***Figure 9**. The San Rafael Reef ranked ninth. Aerial view looking west across south end of San Rafael Swell. Photo by Grant Willis,© 2015.*

10. The Black Rock Desert includes a Late Pleistocene to Early Holocene volcanic field. The Black Rock Desert is west of the Pahvant Range and includes landmarks such as White Mountain, the youngest rhyolitic dome in the state at 430,000 years old (Lipman et al., 1978); the Ice Springs Flow that has cinder cones and the state's youngest lava flow at 9800 to 11,100 years old (Judge et al., 2019); Tabernacle Hill with a lava lake, pressure ridges and lava caves; and Pahvant Butte that erupted above pluvial Lake Bonneville 16,000 to 18,000 years ago (Best et al., 1980). These locations are all proximal and can be seen from a single viewpoint. The volcanic field has been active for more than 6 million years, though most of the volcanic features are less than 3 million years old. The Black Rock Desert has basalt, andesite, dacite, and rhyolite.

Figure 10. *Black Rock Desert ranked tenth. In this image, field trip participants explore a partially collapsed lava tube.*

11. The Henry Mountains are located in south central Utah on the Colorado Plateau. Their southernmost point is a National Natural Landmark (1975) called the Little Rockies. G.K. Gilbert pioneered the concept of "laccoliths" (which he originally called "laccolites") in the Henry Mountains. The mountains are cored by Oligocene-age igneous intrusive rocks that warped and folded the Permian to Cretaceous horizontal strata of the Colorado Plateau. The Henry Mountains were the last-named mountains (1872) in the conterminous United States, referred to as "Unknown Mountains" before this in English and in the Navajo language (Diné) "Mountain Whose Name is Missing" (Dził Bizhi' Ádiní). Three mining districts, one with minor historical gold production and two uranium and vanadium districts, are hosted in the mountains. The highest peak is Mt. Ellen at 11,527 feet. The mountains hold a variety of endemic plants, including some restricted to a single talus field, and are home to one of three herds of free ranging, genetically purebred American bison.

Figure 11. *The Henry Mountains ranked eleventh. View to the west with Mt. Ellen as the prominent peak. Photo by Ken Krahulec,© 2019.*

12. Antelope Island is the largest of the eight major islands in Great Salt Lake. Connected to the mainland by a seven-mile-long causeway, the island is the easiest way for visitors to experience the lake and its geology and wildlife. It is the third-most visited state park with more than one million visitors a year. Dozens of springs supply the desert island with a perennial water source and the island has one of the largest bison herds in America.

Notable bedrock of the island includes Precambrian (up to 2.7 billion years ago) metamorphic rock of the Paleoproterozoic Farmington Canyon Complex and Neoproterozoic Mineral Fork diamictite (deposited during Snowball Earth). The Kelley Canyon Formation, a dolomite cap carbonate above the Mineral Fork, was formed during the recession of continental glaciers during the super-greenhouse climatic event.

Prominent Bonneville shorelines adorn the hillsides; the island was an archipelago at the maximum highstand of the lake. Bridger Bay at the northwest of the island has an extensive field of bioherm microbialites that can be viewed at low lake levels. Offshore of the western side of the island are relict desiccation cracks, 50 to 330 feet across, that are from the Holocene Climatic Optimum around 5000 to 8000 years ago.

Figure 12. *Antelope Island ranked twelfth. View to the north on September 30, 1988, when Great Salt Lake was at approximately 4209 feet elevation.*

13. The La Sal Mountains, like the Henry Mountains, are an isolated complex of laccoliths from the Oligocene Epoch. The mountains were glaciated during the Last Glacial Maximum (about 32,000 to 14,000 years ago) and have extensive rock glaciers in the talus slopes of trachyte and rhyolite. A dozen peaks in the La Sals are above 12,000 feet. Mt. Peale (12,727 feet) has the second highest prominence in the state with a total prominence of 6181 feet above the Moab Valley (Peakbagger.com, undated). The La Sals are situated in the central Paradox basin and Jurassic and Cretaceous sedimentary rocks surround the igneous intrusive rocks of the La Sal Mountains.

Figure 13. *The La Sal Mountains ranked thirteenth. View to the east. Photo by Jay Hill, © 2011.*

14. Bryce Canyon is a national park at the edge of the Paunsaugunt Plateau that holds the world's largest assemblage of hoodoos, as well as many arches and windows. Headward erosion at the plateau has sculpted tens of thousands of rock spires, up to 150 feet in height, which are colorfully banded by the Pink and White members of the Paleocene and Eocene Claron Formation. In the 1870s geologist Clarence Dutton first abstracted Bryce Canyon as the top of the "Grand Staircase," an immense sequence of sedimentary rock that preserves Earth's longest exposed succession of geologic time, around 275 million years.

Figure 14. *Bryce Canyon ranked fourteenth. Image of Thor's Hammer, Bryce Canyon National Park. Photo by Grant Willis.*

15. Jurassic National Monument is located on the northeastern part of the Colorado Plateau in the northern San Rafael Swell. The quarry here is in the extensive and famous dinosaur-bearing Morrison Formation (~150 million years in age). The area began as the Cleveland-Lloyd Quarry, then became a national natural landmark in 1965 and a national monument in 2019. The first Bureau of Land Management visitor center was set up here in 1968. The quarry holds the largest concentration of Jurassic dinosaur bones in the world, including an unusual number of Utah's state fossil, the carnivorous *Allosaurus fragilis*, of which 47 individuals have been unearthed (75% of the quarry's collection) in various states of growth. More than 15,000 bones have been excavated. In 1987 the oldest dinosaur egg was found here. Over 65 museums from around the world contain Cleveland-Lloyd skeletal reproductions. Other dinosaur bones come from *Camptosaurus*, *Stegosaurus*, *Camarasaurus* and at least eight other dinosaur species.

Figure 15. *Jurassic National Monument ranked fifteenth. Image shows Allosaurus fragilis, Utah's state fossil. Photo courtesy of the U.S. Bureau of Land Management.*

16. Split Mountain is within Dinosaur National Monument (Utah-Colorado), and was named by John Wesley Powell in 1869. Split Mountain is a nearly symmetrical anticline that is beautifully exposed by the desert climate and the incising Green River that travels through the central part of the anticline over a course of 8 miles, cutting into the Permian and Pennsylvanian-age rock. The southern perimeter of Split Mountain has variegated flat irons from the Permian Weber Sandstone, Park City and Phosphoria Formations, and the Triassic Moenkopi and Dinwoody Formations. The mountain itself rises to 7700, about 2700 feet above the Green River.

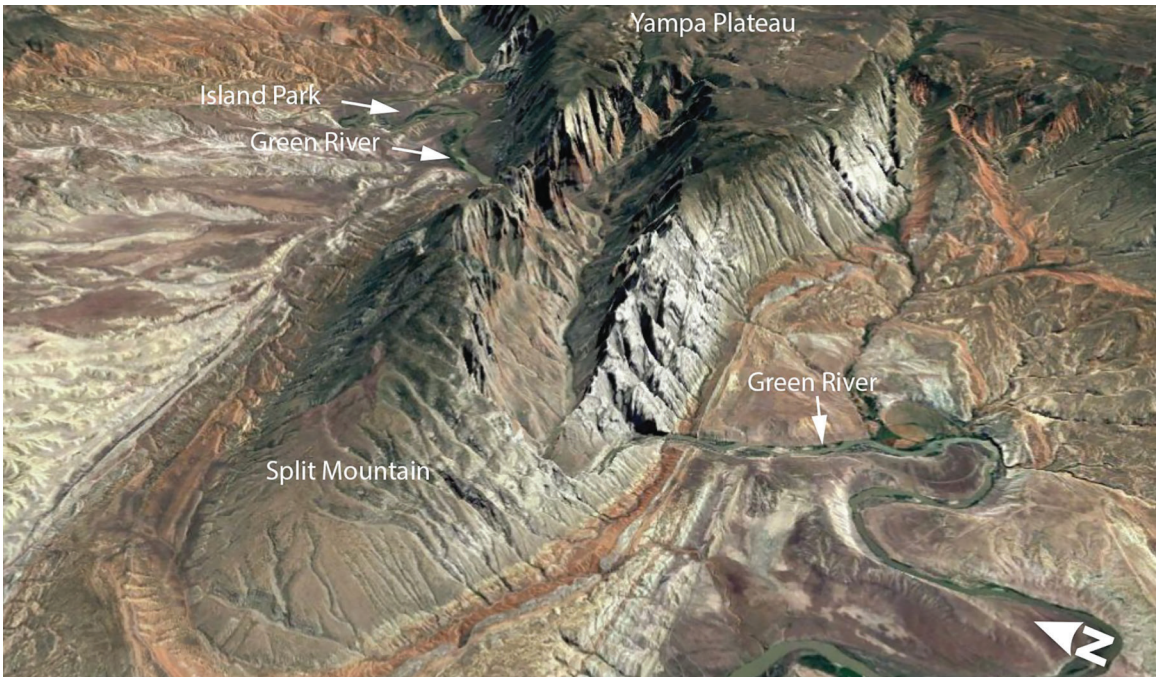

Figure 16. *Oblique view of Split Mountain, which ranked sixteenth. Image from Google Earth, ©2019 Google Earth.*

GEOGRAPHY OF UTAH'S POTENTIAL GEOHERITAGE SITES

Geoheritage sites are located across Utah (Figure 17). Twenty-eight of Utah's 29 counties have at least one site. The southernmost three counties, Washington, Kane, and San Juan,have high numbers of sites as do Grand, Garfield, Emery, Salt Lake, Tooele, Juab, and Millard Counties. High-scoring sites span across the state from border to border as do the lower scoring sites.

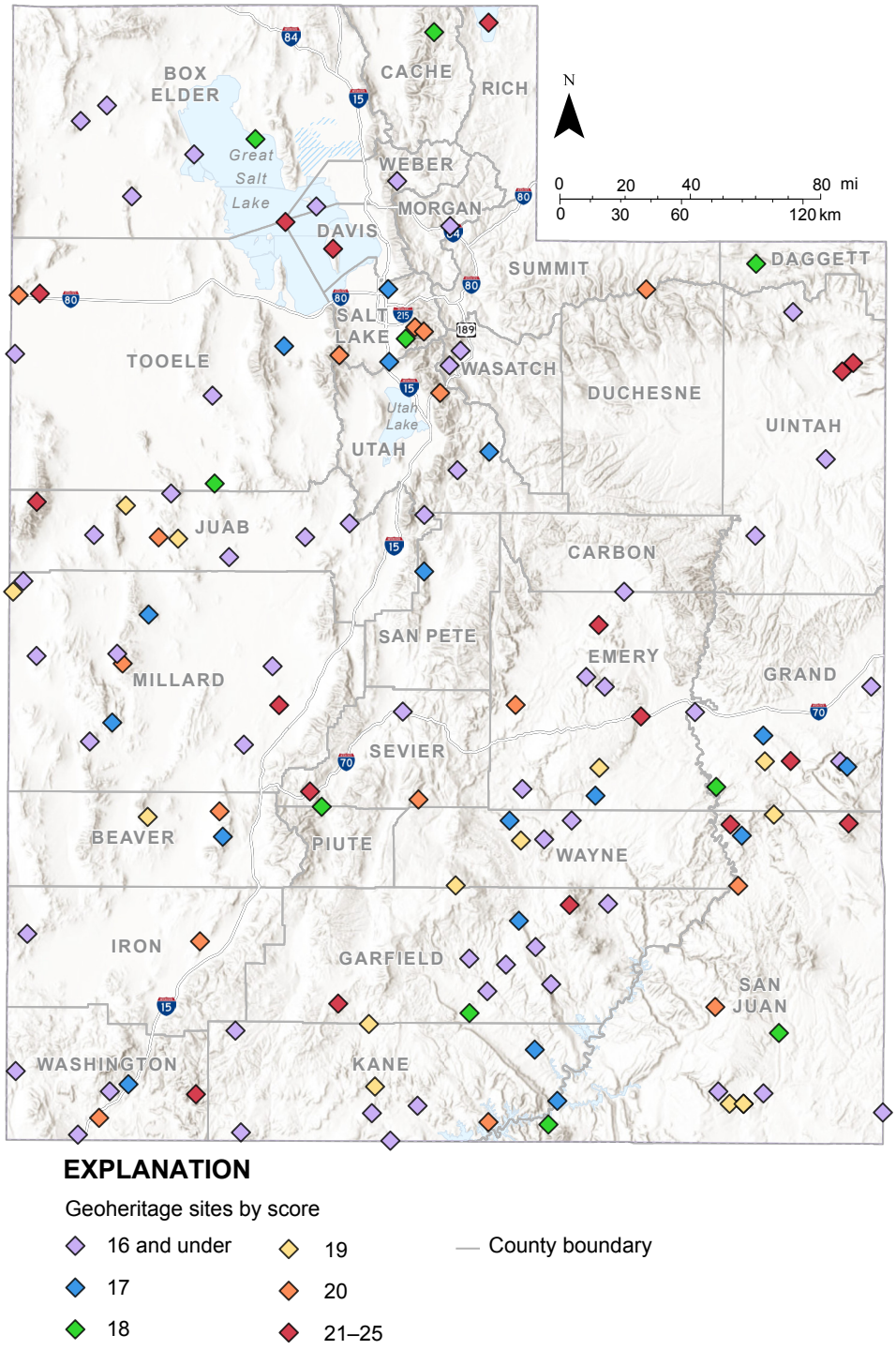

Figure 17. *Shaded relief map of 129 potential geoheritage sites by score value.*

The database includes potential geoheritage sites that are located dominantly on public lands with a smaller component on private land. Sixty-two of the 129 sites are on Bureau of Land Management land (Figure 18). The two next largest pie wedges are nearly equally split between National Parks, National Monuments, and recreation sites (18) and cities, counties, non-profits, and others (15). National Forest lands (16) and Utah State Park, Utah Trust, and Sovereign lands (14) follow. A few sites fall in National Wilderness Areas and Wildlife Reserves (3) and on Tribal lands (1). These sites will therefore be broadly accessible to various members of the public.

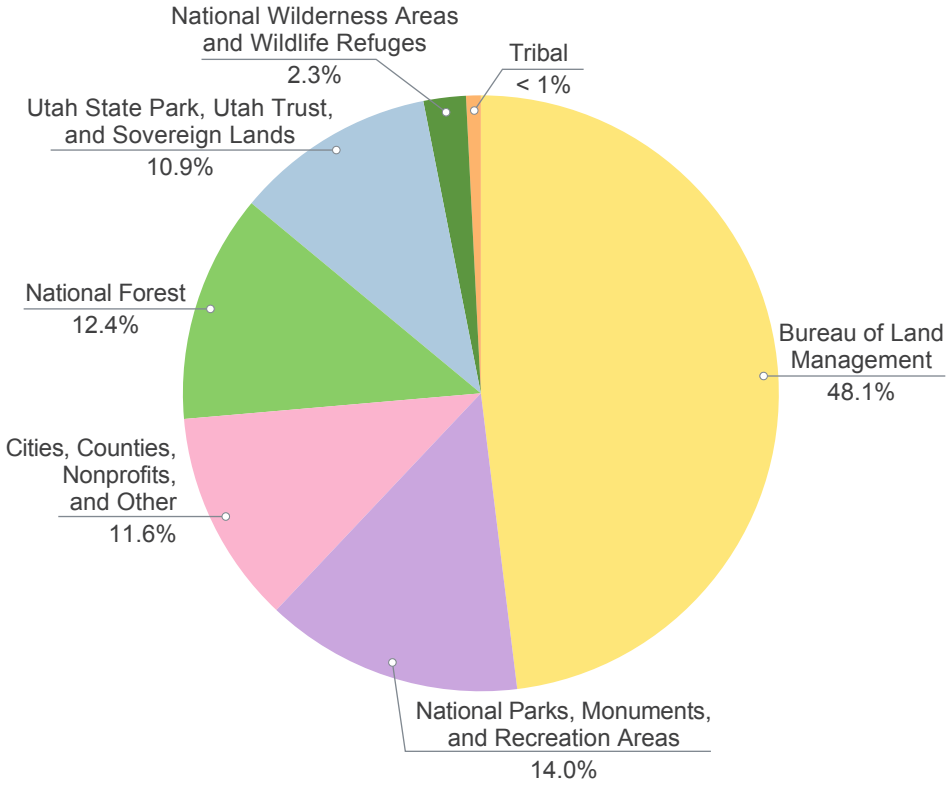

Figure 18. *Pie graph of potential geoheritage sites by land ownership.*

Although the identified sites are distributed widely across Utah, there are notable clusters of sites within 20 miles of other sites (Figure 19). The densest areas or hotspots are in San Juan and Salt Lake Counties. Other significant concentrated areas are scattered across the Colorado Plateau physiographic province. The Colorado Plateau and Basin and Range transition zone has one dense area in Washington County; and Juab County in the Basin and Range Province also has a cluster of sites.

The south-central San Juan County hotspot stems from the Goosenecks of the San Juan, Raplee Ridge, Rincon of the San Juan, Mexican Hat, and the Muley Point Overlook. Salt Lake County's cluster is due to the proximity of Bingham Mine, three locations in the Cottonwood Canyons, Point of the Mountain, and Wasatch Warm Springs.

Geoheritage sites in Utah occur across a range of landforms. The summary that follows depicts the relative importance of a given landform with respect to the delineated geoheritage sites. The 129 ranked potential geoheritage sites were divided into eight landform categories (Figure 20). The largest share, at 37%, is erosional and depositional landforms. These include all the National Parks in the dataset, which are all located on the Colorado Plateau. This category includes canyons, slot canyons, arches, buttes, caves, mesas, badlands, salt flats, sand dunes, sinkholes, landslides, concretions, hoodoos, and pinnacles. Volcanism, including intrusive and extrusive forms, was the second most common at 17%. Laccoliths, basalt and rhyolite flows, cinder cones, lava tubes, volcanoes, dikes, ash flow tuffs, and plutons define this category.

Structural and water came in a close third and fourth, at 13% and 12%, respectively. The structural category includes salt tectonics, anticlines, monoclines, meteorite impact, fault-facilitated cliffs and fault-bounded mountains, and folded and tilted strata. Water encompasses lakes, streams, islands and paleoshorelines, waterfalls, river bends, and rincons. The remaining near 25% of geoheritage sites includes four type categories: geothermal and cold springs (8%), paleontological (6%), mining and human landforms (5%), and glacial (5%). The paleontological category includes dinosaur quarries, trackways, fossil sites, and a petrified forest. Mining and human landforms encompass mines and mining districts, land art, and archeological caves. The glacial category includes all erosional alpine glaciers in origin and as well as cirques and tarn lakes, U-shaped valleys, biscuit board topography, and relict glacial surfaces.

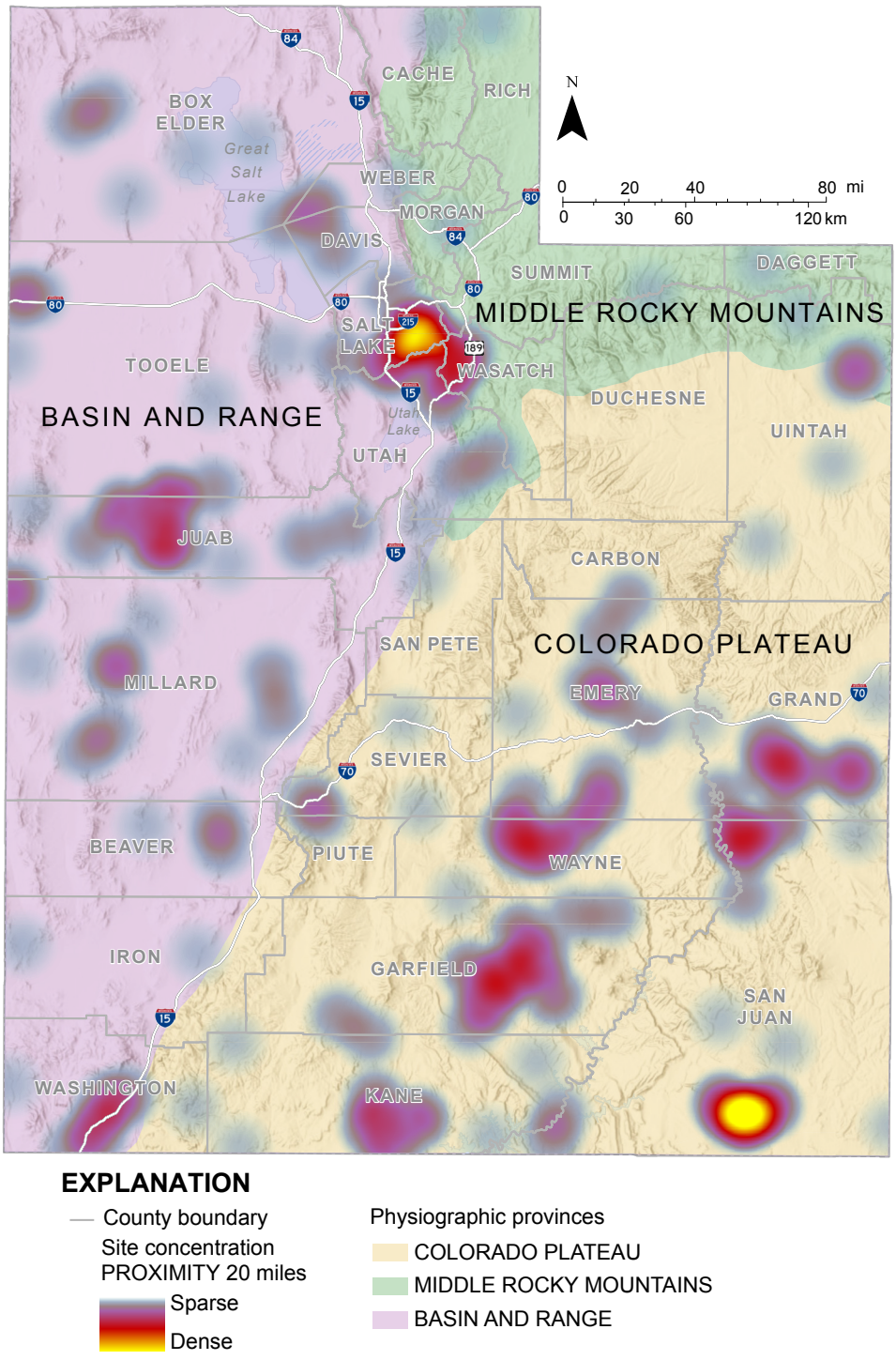

Figure 19. *Proximity analysis of 129 potential geoheritage sites across Utah.*

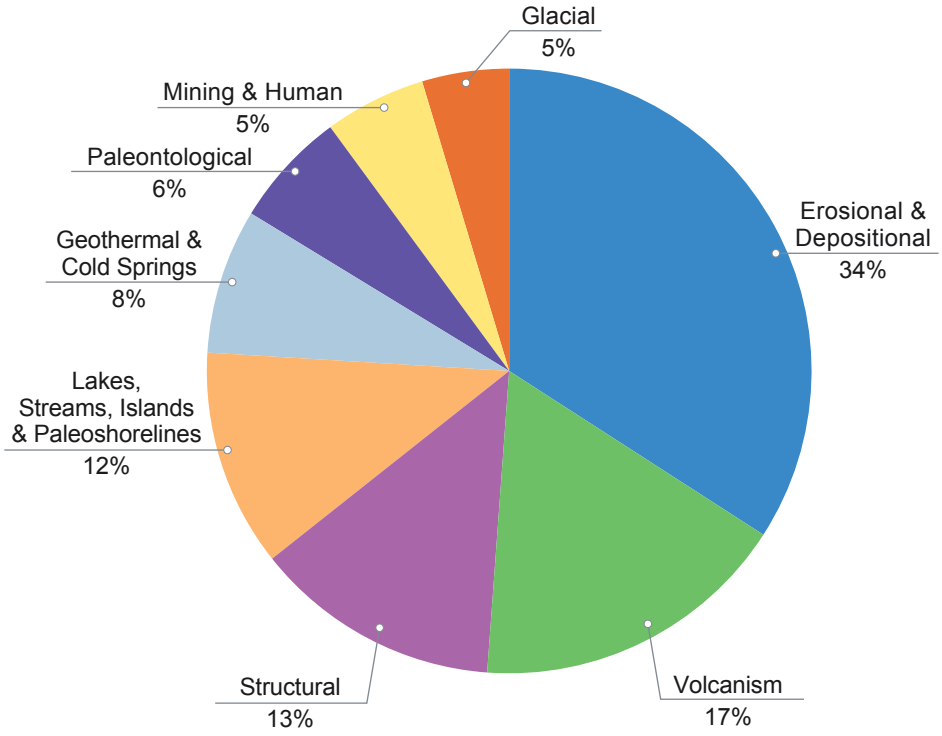

Figure 20. *Landform type categories of the 129 geoheritage sites.*

KEY TAKEAWAYS AND THE FUTURE OF THE UTAH GEOHERITAGE DATABASE

Delineation of geoheritage sites is an ongoing exercise and several recent sites have been identified since the database creation and ranking process was completed. As such, the database will continue to grow through site additions.

Scoring of geoheritage sites is necessarily qualitative. It was often challenging to objectively rank sites that have very different characteristics. Often when investigating a site, information became known that led to a higher or lower score. It also became clear that these scores could change with time. Both scientific and economic site rankings can change over time, such as from emerging technologies and changing prices on metals and industrial minerals. Whereas science importance can change as various geologic disciplines yield new information that could make a given site more or less scientifically important. Science can change the importance of sites based on things such as dating techniques or new hypotheses where certain sites might provide windows of evidence and therefore acquire increased importance.

An unforeseen complication in choosing sites was the problem of scale. For example, Great Salt Lake, which covers on average 1600 square miles and up to 2300 square miles at historically high levels, appeared too large and nebulous to meet the criteria for a geoheritage site. Moreover, the lake has distinct sections and divisions, such as the highly saline North Arm and the brackish South Arm, separated by a mostly impermeable stone causeway. Several elements of the lake were included in the database such as Fremont Island, Antelope Island, Rozel Point, and the Spiral Jetty. However, the recent confirmation of the International Union of Geological Sciences of world geoheritage sites of the extensive Great Salt Lake and Henry Mountains (IUGS, 2024) solidified our choice of their inclusion. Another example is the Old River Bed, which has historical, hydrological, pluvial, and anthropogenic importance, also rated higher than potential geoheritage sites such as Table Mountain, The Snowplow, and Cup Butte, which all exhibit excellent paleoshoreline landforms and processes. Counting all of them would require an area with a 20-mile-long axis that would be several miles wide. A similar problem of scale occurs with the Bentonite Hills, Blue Flats, Red Desert, North and South Caineville Mesas, and Factory Butte, and the nearby the Burpee Dinosaur Quarry, the Moon Overlook, and the North Caineville Reef as well as the Waterpocket Fold and many other smaller scale sites close by in Capitol Reef National Park. When sites cover large areas or consist of multiple possible sites we have chosen to list these as single sites.

Utah's rich geological history and diverse landscapes offer an exceptional array of geoheritage sites. From the vast Great Salt Lake to dramatic formations on the Colorado Plateau, these sites hold immense scientific, educational, cultural, economic, and aesthetic value. This dataset is the first systematic inventory and ranking of geoheritage sites in Utah. The dynamic nature of geological understanding and societal appreciation suggests that this database will continue to evolve. Future additions, refinements in scoring, and considerations of scale will further enhance our understanding and possible recognition or preservation efforts of Utah's outstanding geoheritage, ensuring these natural treasures can be appreciated and utilized for generations to come.

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APPENDIX A

Link to supplemental database:

https://ugspub.nr.utah.gov/publications/data_series/ds-3/ds-3a.xlsx