A Breccia Pipe in the Deseret Limestone, South Flank of the Uinta Mountains, Northern Utah

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

Cover Image: *Large breccia pipe penetrating the Deseret Limestone—the unique feature that defines the geosite.*

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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

A breccia pipe is a cylindrical- or irregular-shaped mass of brecciated rock. A breccia consists of broken, angular fragments of rock cemented together by a fine-grained matrix. Hydrothermal breccia pipes form when hydrothermal solutions force their way towards the surface through zones of weakness or fracture zones and naturally break up the rocks in the process, i.e., hydrofracturing (figure 1); breccia pipes can also form by collapse. Hydrothermal breccia pipes can contain ore deposits and, as will be discussed later, are associated with some large oil and gas accumulations in southeastern Utah.

Figure 1. Large breccia pipe penetrating the Deseret Limestone—the unique feature that defines the geosite. Note pulverized nature of the material that comprises the pipe, the sharp contact with the country rock and parallel, calcite-filled vertical fractures.

Mississippian (359 to 318 million years ago [Ma]) rocks outcrop along the flanks of the east-west-trending Uinta Mountains in northern Utah (figure 2). Uplift of this range occurred during the Laramide orogeny, a regional mountain-building event, between the latest Cretaceous (Maastrichtian, about 70 Ma) and the Eocene (about 34 Ma). The Mississippian rock section along the south flank of the Uinta Mountains is over 1600 feet (490 m) thick (Sprinkel, 2018) (figures 2 and 3). Units include the Fitchville (Upper Devonian-Lower Mississippian [385–340 Ma]), Gardison, Deseret, Humbug, and Doughnut Formations (figure 3). These units collectively were mapped as the Madison Limestone by Bryant (1990). These formations generally have the same characteristics as the oil- and gas-productive Mississippian Leadville Limestone in fields of the Paradox fold and fault belt of the northern Paradox Basin (southeastern Utah and southwestern Colorado (figure 4).

The Deseret Limestone (Osagean [346 Ma] through middle Meramecian [334 Ma]) contains local zones of breccia due to either natural hydrofracturing or collapse. A hydrothermal breccia pipe in the Deseret is well-exposed on the western end of the south flank of the Uinta Mountains and is the main focus of this geosite (figures 2 and 5). Breccia associated with sediment-filled collapsed cavities is also present in nearby outcrops. Brecciation caused by explosive natural hydrofracturing, described below, created similar shattered-looking, pulverized rock in well cores from the Paradox Basin. The best examples are identified from Lisbon field (figure 4), the largest Leadville oil field in Utah (about 51.5 million barrels of oil produced through 2018 [Utah Division of Oil, Gas and Mining, 2019]). Breccia pipes and high-temperature dolomitization (the process by which the mineral dolomite is formed when magnesium ions replace calcium ions in the mineral calcite, $2CaCO_{3(calcite)} + Mg^{2+} \leftrightarrow CaMg(CO_3)_{2(dolomite)} + Ca^{2+}$) may be related to past hydrothermal activity (Eby and others, 2005).

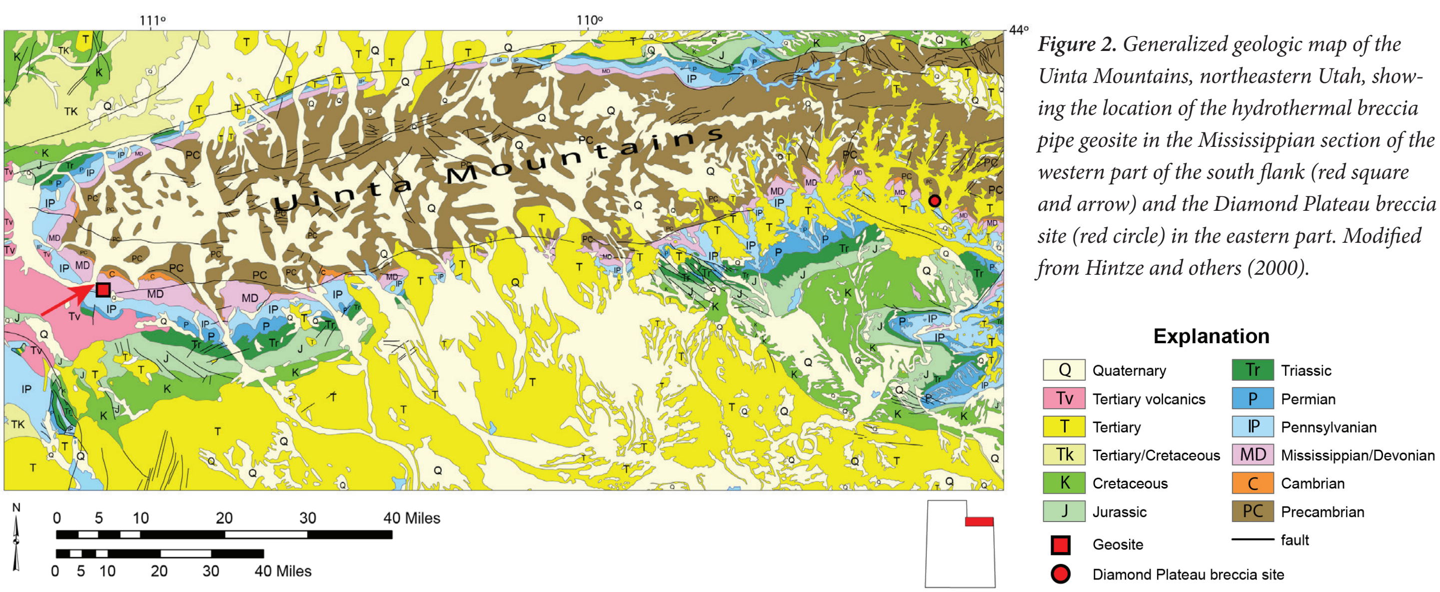

Figure 2. Generalized geologic map of the Uinta Mountains, northeastern Utah, showing the location of the hydrothermal breccia pipe geosite in the Mississippian section of the western part of the south flank (red square and arrow) and the Diamond Plateau breccia site (red circle) in the eastern part. Modified from Hintze and others (2000).

Thus, the hydrothermal breccia pipe and nearby features were selected as a geosite because they serve as a visible example of an oil and gas reservoir model for the Lisbon and other oil fields in the Paradox Basin (Eby and others, 2009). Combined with the details and characteristics of nearby outcrops, the breccia pipe can be used as a "template" for evaluating data from conventional oil well core, well logs (geophysical and petrophysical), and possibly subsurface imagery created with seismic surveys in the basin.

Age	Formation		Thickness (ft)	Lithology
Permian	Quirrh Group	Weber Sandstone	1700	
Pennsylvanian	Quirrh Group	Morgan Fm	200–325	
Pennsylvanian	Quirrh Group	Round Valley Ls	200–300	
Mississippian	Doughnut Fm		200–300	
Mississippian	Humbug Fm		360–410	
Mississippian	Deseret Limestone		590–650	Solution cavities with breccia
Mississippian	Gardison Limestone		250	Delle Phosphatic Member
Devonian	Fitchville Fm		150	
Cambrian	Tintic Quartzite		0-395	
Precambrian	Uinta Mountain Group (part)	Red Pine Shale	0–1800	

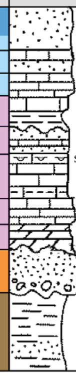

Figure 3. Lithologic column of a part of the Paleozoic section along the western end of the south flank of the Uinta Mountains. Modified from Hintze and Kowallis (2009), and Sprinkel (2018).

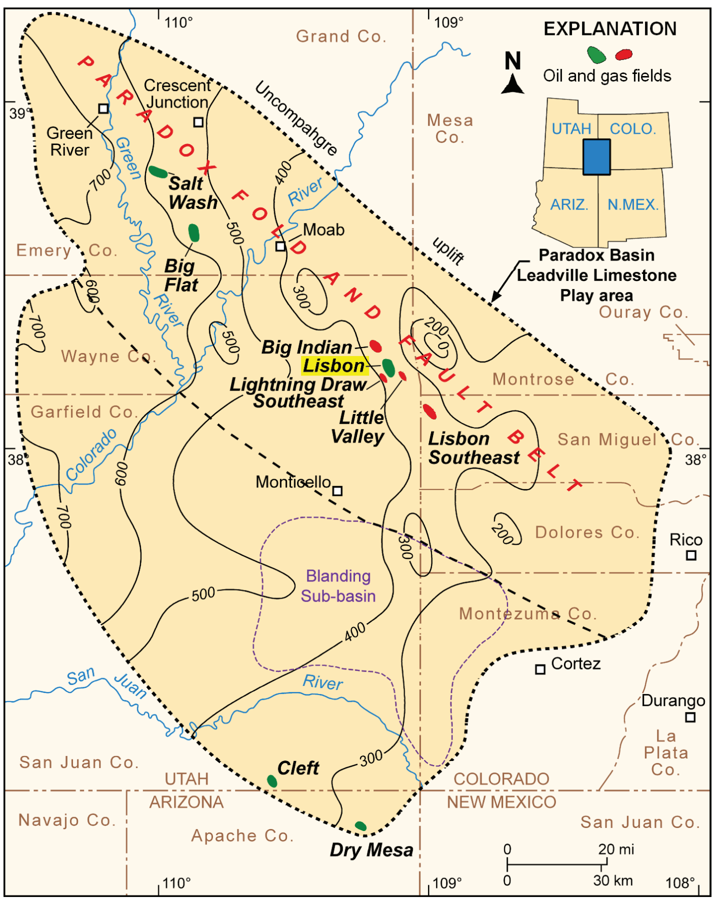

Figure 4. Location of fields (Lisbon highlighted) that produce from the Mississippian Leadville Limestone, Arizona, Utah, and Colorado. Thickness of the Leadville is shown; contour interval is 100 feet (30.3 m) (modified from Parker and Roberts, 1963). The Leadville Limestone Paradox Basin play area is colored dark tan. Modified from Morgan (1993).

HOW TO GET THERE

The Deseret Limestone hydrothermal breccia pipe geosite is located along the South Fork Provo River on the western end of the south flank of the Uinta Mountains, Wasatch County (figures 2 and 5). The breccia pipe geosite is about 50 miles (83 km) or a little less than an hour drive from Salt Lake City, Utah, via Interstate 80 and U.S. Highway 40 to State Highway 32. Proceed eastbound on State Highway 35 past the town of Francis for 11 miles (18.4 km) to the a large roadcut on the east side which exposes the breccia pipe (40°33'03" N., 111°06'11" W., elevation 7400 feet; 2242 m) (figures 1 and 5); the geosite is about 25 miles (41.8 km) northwest of the town of Hanna, Utah, to the south on State Highway 35.

Upon approaching the breccia pipe geosite, carefully slow down with flashers on and cross the westbound lane to park on the east side just below the roadcut, thus avoiding having to walk across the highway. To examine the outcrops up close requires scaling a fairly steep slope with loose rocks; caution is urged (figure 1)!

GENERAL GEOLOGIC CHARACTERISTICS OF THE MISSISSIPPIAN SECTION, UINTA MOUNTAINS

The Deseret Limestone and other carbonate formations in the Mississippian section around the Uinta Mountains were deposited in a shallow, warm-water, variable energy, epicontinental sea that extensively covered a large part of the craton (figure 6). The Deseret is mostly light- to dark-gray, fine- to coarse-crystalline, cherty limestone (figure 7). Dolomitic units are gray to tan, sucrosic to crystalline, and medium bedded with occasional silty partings; both limestone and dolomite would be prime reservoir lithologies as found in the Leadville Limestone. Chert is typically light gray, forming lenses and nodules. The most common carbonate fabrics of the Mississippian rocks in northeastern Utah include peloidal, skeletal, and oolitic grainstones, packstones, and wackestones; skeletal and intraclast rudstones and floatstones are also present. Cross-bedded grainstones of crinoid debris are referred to as encrinites. Mudstone appears as microcrystalline and cryptocrystalline limestone and dolomite. The Mississippian section is generally thick to massive and unevenly bedded, forming vertical cliffs and dip slopes.

Marine fauna in the Mississippian section are represented by corals, brachiopods, pelecypods, bryozoans, and crinoids; however, fossils are relatively rare in some areas. Other common biota include ostracods, benthic forams, and gastropods. Microbial-dominated rocks are present but uncommon. Depositional environments include muddy tidal flats; burrowed peloidal muds in subtidal settings; high-energy oolitic shoals; storm-dominated, outer shelf open-marine, crinoid shoals with muddy intershoals; and offshore low-energy, open-marine settings below wave base.

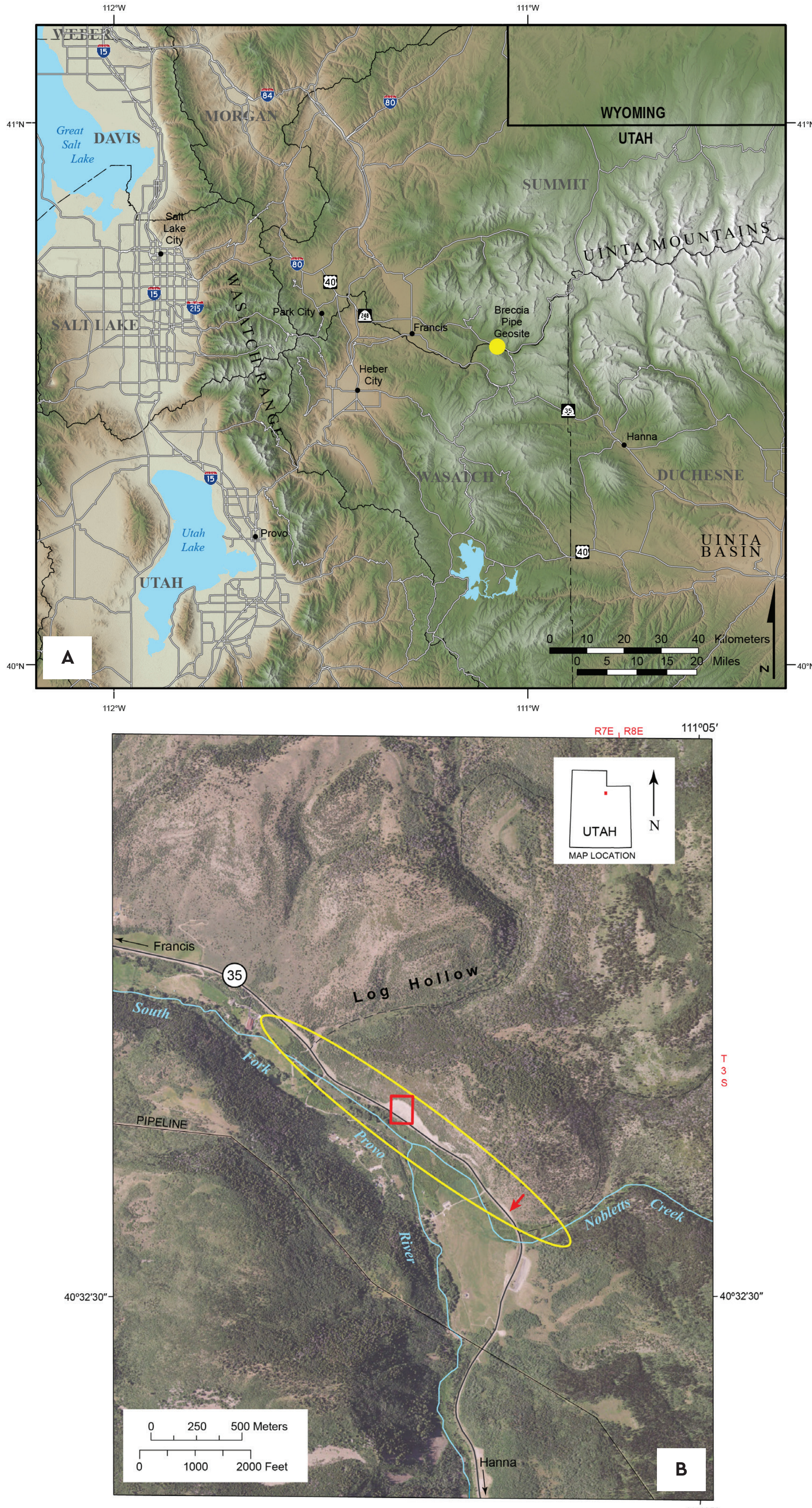

Figure 5. A – Location map for the breccia pipe geosite (yellow dot), northern Utah, and major highways, cities, and towns. B – Google Earth image (© 2018 Google) showing the location of the hydrothermal breccia pipe geosite along the western end of the south flank of the Uinta Mountains in Wasatch County, Utah. The Mississippian Deseret Limestone outcrops are best exposed in roadcuts within the elongated yellow oval; the red square is the location of the breccia pipe and red arrow is the location of possible paleokarst features.

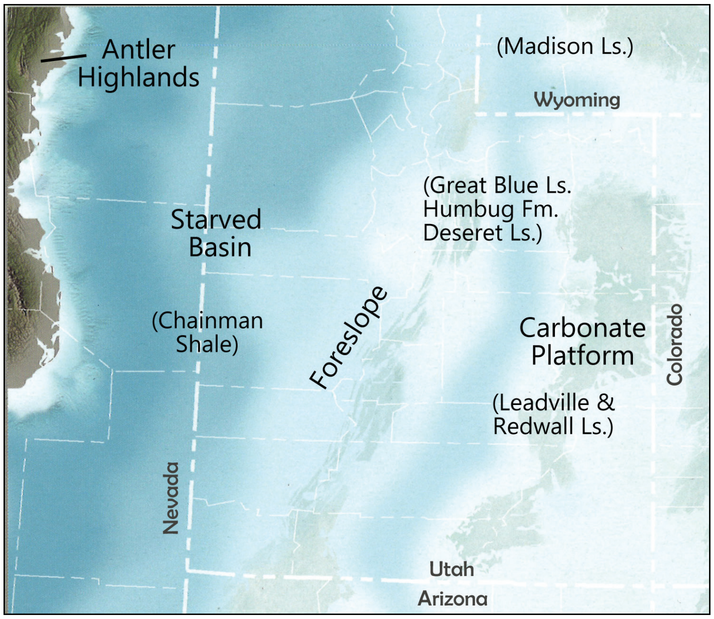

Figure 6. *Paleogeography of Utah and eastern Nevada during Mississippian time. A warm shallow sea covered much of Utah during the early Meramecian (340 million years ago). Western Utah was the site of a deep starved basin. Modified from Blakey and Ranney (2008).*

The contacts between the Fitchville, Gardison, Deseret, Humbug, and Doughnut Formations are mostly conformable (Sadlick, 1955, 1957; Carey, 1973; Hintze and Kowallis, 2009), whereas the Mississippian Leadville Limestone and overlying Pennsylvanian Molas Formation are separated by a major unconformity in southeastern Utah. This same unconformity is found at the top of the stratigraphically equivalent Mississippian Redwall Limestone in the Grand Canyon (McKee, 1969), where subaerial exposure resulted in development of karst topography with carbonate breccia-filled collapse features (paleo-sinkholes) and terra rosa (cave fills) near the top of the formation.

Fractures are common in the Mississippian section. They are best expressed as closely spaced, vertical fractures throughout thin- to medium-thick beds or as swarms associated with large and small faults and collapse features. Stylolites and jointing are also present.

GEOLOGY OF THE HYDROTHERMAL BRECCIA PIPE

Description

The region that includes the Deseret Limestone hydrothermal breccia pipe geosite was mapped by Eskelsen (1953), McDougald (1953), and Bryant (1990). Sprinkel (2018) mapped the adjacent region along the south flank of the Uinta Mountains and western Uinta Basin. Dockal (1980) published ten nearly complete measured sections of the Mississippian units from the canyons around the core of the Uinta Mountains and they serve as an excellent reference set for further comparison.

The Deseret Limestone at the geosite is typically dark- to light-gray limestone consisting of skeletal grainstone to packstone (figure 7A). Skeletal grains are composed of disarticulated crinoids and rugose coral fragments representing a high-energy, open-marine environment. Some units contain in-place *Syringopora* corals and common burrows (figure 7B), indicating a low-energy environment. Other units are dolomitized and include chert nodules (figure 7C). Vertical fractures are also common (figure 7D). The contact with the overlying Humbug Formation is difficult to recognize due to the poor nature of the outcrops and extensive slope cover. Eskelsen (1953), McDougald (1953), and Bryant (1990) mapped them together in the area as Deseret-Humbug undifferentiated.

The large breccia pipe is the most striking feature at the geosite (figure 1). The subvertical pipe is about 17 feet (~5 m) wide at the base of the outcrop and cuts vertically through about 30 feet (9 m) of Deseret Limestone. The interior of the pipe contains a poorly sorted breccia with small to large clasts surrounded by pulverized rock (figure 8A). Calcite veins, dolomitized zones, and vugs are widespread (figure 8B). The contacts of the pipe with the unaltered limestone country rock are sharp. Vertical, commonly calcite-filled fractures are prevalent on both sides of the breccia pipe. Thin sections reveal the presence of mini-Herkimer (i.e., doubly terminated) quartz crystals (figure 8C), which were also found in Leadville cores from Lisbon field. There, the mini-Herkimer crystals had high-temperature fluid inclusions (Joseph N. Moore, Energy & Geoscience Institute, written communication, 2009). The presence of mini-Herkimer crystals suggests that a high-temperature event occurred at the geosite, presumably emplacing the breccia pipe.

In Deseret outcrops immediately southeast of the breccia pipe geosite, we recognized some of the same characteristics found in Leadville cores and the Redwall Limestone outcrops in the Grand Canyon. Stratiform brecciation (collapse) is extensive (figures 9A and 9B) but without the calcite veins, dolomitization, and explosive characteristic of a breccia pipe. Red staining at the top of the Deseret Limestone, mapped as the Madison Limestone by Bryant (1990), looks like possible terra rosa weathering (i.e., a reddish-colored clayey layer containing hematite that ranges in thickness from a few inches to several feet and can be found coating limestone in ancient and modern karst areas) but could be coming from the overlying Humbug Formation (figure 9C). Early karsting and formation of collapse breccias may have begun shortly after deposition of the Deseret, which would argue for an unconformity between the Deseret and Humbug; however, this has not been identified elsewhere in the region. Several sinkholes are mapped in undivided Deseret and Humbug outcrops, as well as the Gardison Limestone and Weber Sandstone (Pennsylvanian-Permian), in the area by Eskelsen (1953). These karst-related features likely postdate the Mississippian beginning as early as late Eocene to Oligocene (Godfrey, 1985; Spangler, 2005). Mayo and others (2010) also suggested the cave system formed relatively recently (Pleistocene).

Figure 7. *Typical characteristics of the Deseret Limestone just northwest of the breccia pipe (within the yellow oval on figure 5B).* ***A*** *– Skeletal (crinoid and rugose coral) grainstone and packstone.* ***B*** *– In-place* Syringopora *coral.* ***C*** *– Chert nodules in dolomitized packstone.* ***D*** *– Vertical fractures.*

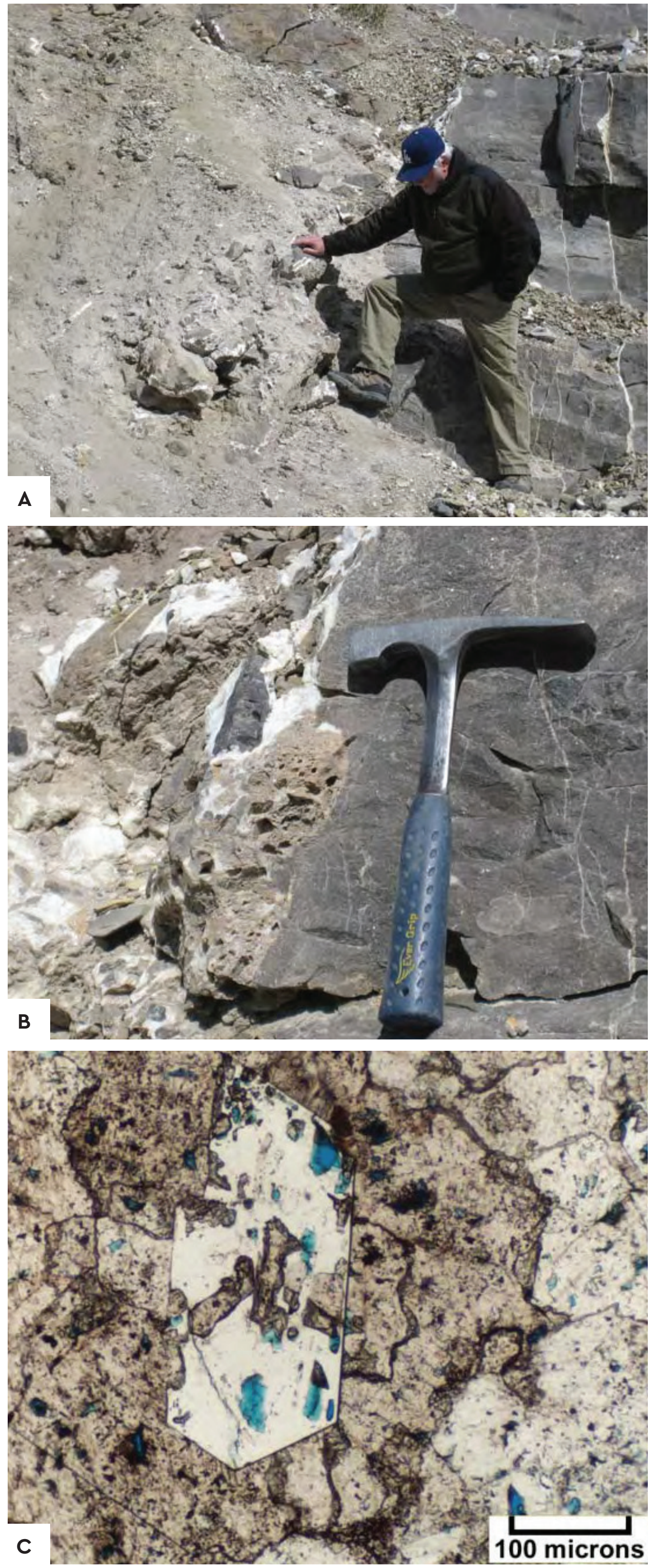

Figure 8. *Characteristics of the explosive nature of the hydrothermal breccia pipe.* ***A*** *– Brecciated rock in shattered-looking, pulverized groundmass.* ***B*** *– Close-up of sharp contact with unaltered limestone country rock. Note vuggy dolomite and white calcite veins.* ***C*** *– Photomicrograph (plane light) of dolomite containing a mini-Herkimer quartz crystal (center) suggesting a high-temperature event.*

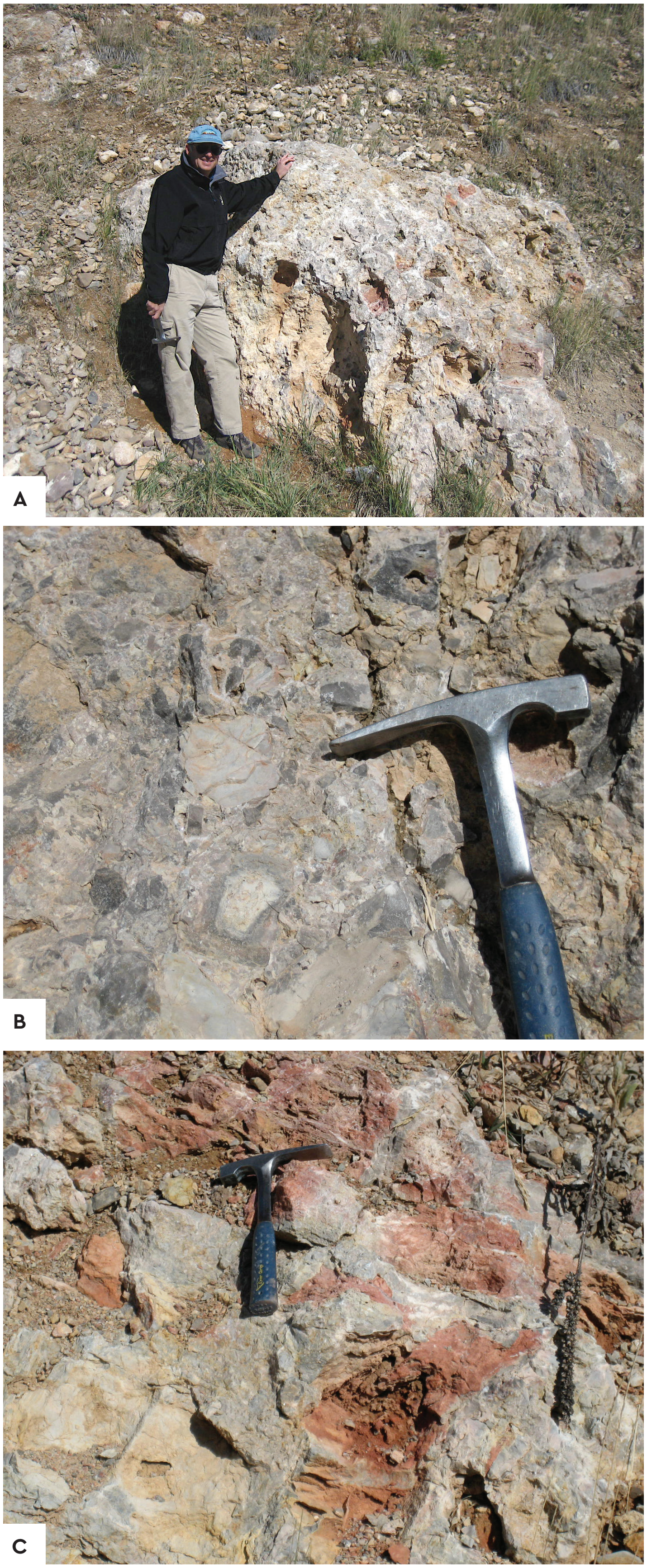

Figure 9. Possible paleokarst features just southeast of the breccia pipe (see red arrow within the yellow oval on figure 5B). A – Extensive collapse polymictic breccia. B – Close-up of limestone and chert breccia clasts. Note the lack of calcite veins and dolomite. C – Red staining, possibly terra rosa weathering, at the top of the Deseret Limestone near the contact with the overlying Humbug Formation(?).

DISCUSSION

All Deseret Limestone depositional environments described from outcrops above are also observed in Leadville cores from Lisbon field (figure 3) (Chidsey, 2004; Chidsey and others, 2004). Carbonate buildups having good porosity/permeability represent the best reservoir analog units, whereas low-porosity/permeability, open-marine packstones and wackestones represent less attractive reservoir analog units, unless they have experienced dolomitization in the subsurface that results in increased reservoir quality. Breccia pipes, paleokarst features, and fractures can also enhance reservoir quality. The post-burial breccias associated with hydrothermal events, fracturing, and dissolution in the Leadville Limestone yield the best reservoirs at Lisbon field (Eby and others, 2009).

The breccia pipe geosite and extensive breccia zones discovered on the Diamond Plateau northeast of Vernal, Utah (figure 1) (Eby and others, 2009) are likely the result of hydrothermal activity in the geologic past. The presence of the basal Cambrian Tintic Quartzite in the southern flank of the western Uinta Mountains (figure 2) and the stratigraphically equivalent Lodore Formation in the eastern part of the range, may serve as hydrothermal recharge aquifers and thus are important contributors to the hydrothermal story. The Tintic is a very coarse to granular, or pebble, sandstone with moderately sorted, subrounded to spherical, monocrystalline and polycrystalline quartz grains. It has thin to thick cross-bedding, is moderately indurated, and contains a few shaley partings, which have small amounts of mica and some biogenic feeding trails (Dockal, 1980). The Tintic's contact with overlying Mississippian strata is fairly sharp. The Lodore is a very fine to medium-grained, well-sorted, very thinly bedded to cross-bedded (with somewhat undulatory surfaces) sandstone marked by argillaceous partings. Quartz grains are subrounded to spherical. The Lodore can be calcareous and slightly ferruginous. The top appears to be eroded (Dockal, 1980). Both the Lodore and Tintic can have porous and permeable units. As aquifers, they likely supplied hot water to the former hydrothermal system.

Three-dimensional numerical models of seafloor hydrothermal convection by Coumou and others (2008) demonstrated that convection cells organize themselves into pipe-like upflow zones surrounded by narrow zones of warm downflow. Recharge can occur over an extensive area or along faults as water migration pathways. The Tintic Quartzite is mapped on the western end of the Uinta Mountains whereas the Lodore Formation is present on the eastern end. Through the central part of the south flank of the Uinta Mountains, porous Cambrian sandstone is absent and the Mississippian lies unconformably on Precambrian (middle Neoproterozoic) Red Pine Shale and older formations of the Uinta Mountain Group (figure 3). No hydrothermal breccia zones or pipes are found in the central part of the south flank, lending credence to the concept that aquifers in the Tintic and Lodore were a required condition for past hydrothermal activity to have occurred. After pressure builds up to a certain point, the hydrothermal fluids within the aquifer can very rapidly and explosively break through zones of weakness at the intersections of fractures or along faults; this can occur as a single event or over several stages. Thus, when targeting the Leadville Limestone in the Paradox Basin for potential hydrothermal dolomite and enhanced reservoir quality due to natural hydrofracturing, the presence of an underlying aquifer, and fracture zones or faults may be necessary ingredients, supported in part from what can be observed at the breccia pipe geosite.

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