United States
Department of the Interior
Bureau of Land Management

MINERAL POTENTIAL REPORT
for the
Lands now Excluded from Grand Staircase-Escalante National Monument

Garfield and Kane Counties, Utah

Prepared by:	Technical Approval:
[signature] (Signature)	[signature] (Signature)
Michael Vanden Berg (Print name)	LARRY GARAHANA (Print name)
Energy and Mineral Program Manager - Utah Geological Survey (Title)	GEOLOGIST, CME #147 (Title)
April 18, 2018 (Date)	APRIL 19, 2018 (Date)

LICENSED PROFESSIONAL GEOLOGIST No. 5553400 LARRY GARAHANA STATE OF UTAH

BUREAU OF LAND MANAGEMENT CERTIFIED Larry Garahana MINERAL EXAMINER 0147 U.S. DEPARTMENT OF THE INTERIOR

Management Acknowledgment:	Management Acknowledgment:
[signature] (Signature)	[signature] (Signature)
AHMED MOHSEN (Print name)	HARRY BAGGETT (Print name)
District Manager (Title)	MONUMENT MANAGER (Title)
4/20/2018 (Date)	4/20/18 (Date)

TABLE OF CONTENTS

FIGURES

TABLES

MAPS

MINERAL POTENTIAL REPORT
for the
Lands now Excluded from Grand Staircase-Escalante National Monument

SUMMARY AND CONCLUSIONS

Grand Staircase-Escalante National Monument (GSENM) in Kane and Garfield Counties, Utah, was declared in 1996 by President Bill Clinton; however, in late 2017, President Donald Trump rescinded parts of the monument. As a result of this change, the U.S. Bureau of Land Management (BLM) requested that the Utah Geological Survey (UGS) prepare a report that assesses the mineral potential of these newly excluded lands, which, for the purpose of this report, will be referred to as the Grand Staircase-Escalante excluded lands (GSEEL). This report assesses and documents the mineral resource occurrence potential within the GSEEL, as well as the development potential of oil, gas, coal bed methane, and coal.

Oil, Gas, and Coal Bed Methane

There are five oil and gas plays in the GSEEL: (1) Late Proterozoic/Cambrian (USGS-2403), (2) Paleozoic Devonian-Mississippian (UGS-2108), (3) Permo-Triassic Unconformity (USGS-2106), (4) Cretaceous Sandstone (UGS-2107), and (5) Coal Bed Methane (UGS-2100). Significant oil production from the Permian Kaibab Limestone and Triassic Moenkopi Formation occurs at Upper Valley field adjacent to the GSEEL. Therefore, the Permo-Triassic Unconformity Play has a high (H) rating for development potential for new oil discoveries whereas the other plays are rated low (L) to moderate (M), having no established production, most likely due to the lack of one or more basic criteria required for hydrocarbons to be present. Limited exploration and development for oil and gas has occurred within the GSEEL. A total of 26 well locations were drilled within the excluded lands between 1928 and 2017, all plugged and abandoned with no significant hydrocarbon shows. Given the extreme high exploration risk, remoteness of the region, lack of pipelines and infrastructure, depressed prices, and other factors, it is unlikely that much if any drilling activity will take place in the GSEEL. Most companies exploring in Utah will continue to focus their efforts in the Uinta and Paradox basins where there are high rates of drilling success, well-established infrastructure, and major exploitable oil and gas reserves.

Coal

Beds of coal thick enough to be mined commercially occur in the Cretaceous Dakota (more recently called the Naturita Formation) and Straight Cliffs Formations within the GSEEL of south-central Utah. The Dakota coals occur in the Alton coalfield, where only the far eastern side overlaps with the GSEEL, while the Straight Cliffs coals occur in the Kaiparowits Plateau coalfield, located in the north-central area and south-central area of the GSEEL. Substantial past coal exploration drilling in both the Alton and Kaiparowits Plateau coal fields has been sufficient to meet BLM requirements to delineate Known Recoverable Coal Resource Areas (KRCRA). The Alton coalfield within the GSEEL area contains coal beds that are greater than 4 feet thick and are under less than 3000 feet of cover, including a small area under less than 200 feet of cover potentially suitable for surface mining. However, despite the presence of several exploratory drill holes, no historic coal mining has occurred in the Alton coalfield within the GSEEL area. In addition, the area of the Alton coalfield in the GSEEL has been declared by the BLM as unsuitable for surface mining (and surface disturbance related to underground mining) due to its proximity to Bryce Canyon National Park. These declarations can change, but due to the mostly thinner nature of the coal beds, it is believed that development potential in this area is low. Up to 9 billion tons of potentially recoverable coal (not all in the GSEEL area), with beds thicker than 4 feet and under less than 3000 feet of cover, are in the Kaiparowits Plateau coalfield. Nearly 1000 exploratory holes have been drilled to define the resource. In addition, several small historic mines produced minor amounts of coal in the early 1900s, and a large underground mine (Smoky Hollow) was in the planning/permitting stages when the monument was declared. Therefore, the coal resources of the Kaiparowits Plateau within the GSEEL areas are rated high for development potential, except within Wilderness Study Areas, where the development potential is rated as low.

Tar Sands

Tar sand deposits occur in the Circle Cliffs area of the GSEEL. The occurrence potential for tar sand is rated as high (H) with a certainty of D at known prospects or occurrences. The rating is high (H) with a certainty of C where tar sands have been mapped at the surface, and a certainty of B is assigned to areas where tar sands are projected to be in the subsurface. Development of the tar sand deposits in the GSEEL is unlikely given minimal past development of Utah tar sands and lack of specific past interest in the Circle Cliffs deposit.

Uranium, Vanadium, Copper, and Minor Associated Metals

The occurrence potential for U, V, and Cu deposits in the GSEEL is rated as high (H) with a certainty of D at known sites of past U-V or Cu mines and prospects and moderate (M) with a certainty of B in the Shinarump Member of the Late Triassic Chinle Formation. The potential for the occurrence of U-V and Cu deposits is rated as low (L) with a certainty of A if the Chinle Formation is present without the Shinarump Member or if the Salt Wash Member of the Late Jurassic Morrison Formation is present.

Titanium and Zirconium

The occurrence potential for the Ti-Zr paleoplacer deposits in the GSEEL is rated as high (H) with a certainty of D at known prospects and low (L) with a certainty of A elsewhere in the John Henry Member of the Upper Cretaceous Straight Cliffs Formation in the Kaiparowits district.

Manganese

The occurrence potential for Mn deposits in the GSEEL is rated as high (H) with a certainty of D at the Manganese King mine and Van Hamet prospect.

Gypsum

Gypsum resources are present in multiple geologic units in the GSEEL and limited amounts have been produced. The occurrence potential of gypsum is rated as high (H) with a certainty of D at known mines and prospects. Occurrence potential of mapped exposures of gypsum-hosting members of the Carmel Formation are rated as high (H) with a certainty level of C. Occurrence potential for gypsum in the Shnabkaib Member of the Moenkopi Formation and Toroweap Formation is rated as moderate (M) with a certainty of C. Available information and past production suggests that the quality and quantity of gypsum in the Carmel Formation is likely superior to the Moenkopi and Toroweap Formations. Some development and production of gypsum is possible in the GSEEL in the future, but would likely be limited to extraction for sculpting alabaster as it has been in the past. Development of gypsum for more typical construction purposes is unlikely given the remoteness of the area and lack of infrastructure.

Silica and Industrial Sand

The potential for the occurrence of silica and industrial sand in the GSEEL is rated as high (H) with a certainty of C within the Navajo Sandstone and eolian dune and sand deposits. Any substantial development of silica resources in the GSEEL is unlikely given lack of past interest or development, remoteness of the area, and lack of infrastructure. In addition, the units with silica sand potential are abundant and widespread outside the GSEEL areas.

Sand and Gravel

Several unconsolidated, surficial geologic units in the GSEEL have sand and gravel resource potential. The occurrence potential of sand and gravel deposits in the GSEEL is rated as high (H) with a certainty level of D at known sites of past and present sand and gravel pits, quarries, and prospects. Elsewhere in the GSEEL, mapped stream alluvium, pediment deposits, terrace deposits, and alluvial gravel deposits are rated as high (H) with a certainty level of C based on past extraction and reported potential. Colluvial, eolian, and other unconsolidated deposits are rated as moderate (M) with a certainty of C. Future development will most likely occur at favorable locations within a short distance of major roads.

Crushed Stone and High-Calcium Limestone

Limestone-bearing geologic units in the GSEEL offer resource potential for both crushed stone and high-calcium limestone, but the occurrence potential for these commodities varies depending on geologic unit. Because the Kaibab and Toroweap Formations include massive beds of limestone, they are assigned a high (H) occurrence potential with a certainty of C for crushed stone. Although the Carmel and Moenkopi Formations possess some limestone, the varied lithologies found within the units, as implied by descriptions, do not suggest ideal conditions for uniform, high-quality, crushed stone deposits. These units area assigned a moderate (M) occurrence potential with a certainty of C for crushed stone. Available analytical data and geologic descriptions suggest moderate (M) occurrence potential with a certainty of C for all limestone-bearing units in regards to high-calcium limestone. Given lack of past production of either commodity, future development will probably be minimal.

Building Stone

Occurrence potential of building stone in the Moenkopi Formation is rated high (H) with a certainty of C, based on production of Moenkopi Formation elsewhere. Other host formations with building stone occurrence potential are rated as moderate (M) with a certainty of C. Although some future development of building stone in the GSEEL is possible, it will likely be limited given absence of past production.

Clay

Several geologic units in the GSEEL have clay resource potential and the area has seen some production. The potential for the occurrence of clay deposits is rated as high (H) with a certainty level of D at known sites of past clay mines and prospects. Elsewhere in the GSEEL, where clay-bearing host formations are present (includes the Chinle Formation, Morrison Formation, Dakota Formation, Tropic Shale, and Straight Cliffs Formation), the potential for occurrence is rated high (H) with a certainty level of C. The Carmel Formation is rated as moderate (M). Significant development of clay resources in the GSEEL is unlikely given the remoteness of the area and lack of infrastructure. Limited extraction could potentially occur for local purposes.

Humate

The potential for the occurrence of humate deposits is rated as high (H) with a certainty of C where the humate-bearing host formations of the Dakota and Straight Cliffs Formations are present within the GSEEL. Development of humate deposits is unlikely because better deposits with closer access to transport and market are available elsewhere in Utah. Thus, no exploration and development activities for humate are expected in the GSEEL.

1.0 INTRODUCTION

1.1 Purpose and Scope

Grand Staircase-Escalante National Monument (GSENM) in Kane and Garfield Counties, Utah, was declared in 1996 by President Bill Clinton; however, in late 2017, President Donald Trump rescinded parts of the monument (figure 1). As a result of this change, the U.S. Bureau of Land Management (BLM) requested that the Utah Geological Survey (UGS) prepare a report that assesses the mineral potential of these newly excluded lands, which, for the purposes of this report, will be referred to as the Grand Staircase-Escalante excluded lands (GSEEL). This report assesses and documents the mineral resource occurrence potential within the GSEEL, as well as the development potential of oil, gas, coal bed methane, and coal.

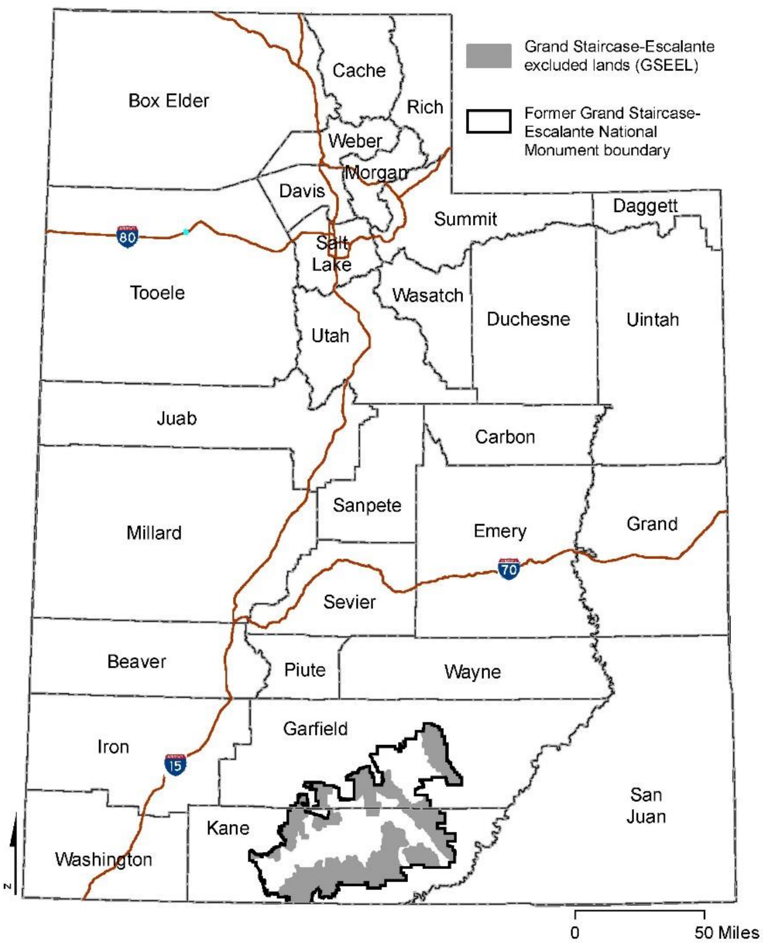


Figure 1. *Grand Staircase-Escalante excluded lands location map.*

This report provides an intermediate level of detail for mineral assessment as prescribed in BLM Manual 3031 for planning documents. BLM minerals management policy falls into the categories of leasable, locatable, or salable, and the occurrence potential for each of these types of resources in the GSEEL has been determined. Leasable resources evaluated in this report include oil, gas, coal bed methane, coal, and tar sands. Locatable resources evaluated include uranium, vanadium, copper (and minor associated metals), titanium, zirconium, manganese, gypsum, high-calcium limestone (included in crushed stone section), and silica/industrial sand. Salable resources evaluated include sand and gravel, crushed stone, building stone, clay, and humate. Given the lack of resource potential in the GSEEL areas, geothermal, helium, and lithium are not evaluated in this report. This report is not a decision document and does not present recommendations on the management of mineral resources.

Leasable minerals are subject to disposal under the authority of the Mineral Leasing Act of 1920, as amended by lease or exploration license/permit. A classification for leasable minerals, such as a Known Recoverable Coal Resource Area (KRCRA), defines an area where a potentially valuable deposit has been identified and where competitive leasing is required. Locatable minerals are subject to mining claim location under the amended authority of the Mining Law of 1872. Salable minerals are subject to disposal under the authority of the Materials Act of 1947, as amended, by contract sale or free use permit. There can be controversy over whether a commodity is common, and therefore disposed of as salable, or whether the material is uncommon, and therefore disposed of by location. So some commodities or resources can overlap in those categories. Historic oil/gas and coal leases within the GSEEL are shown on map 1.

1.2 Lands Involved

The GSEEL and former GSENM are located in south central Utah and cover parts of Kane and Garfield Counties (figure 1 and 2). The former GSENM covered an area of nearly 1.9 million acres but has been reduced to slightly over 1 million acres and separated into three separate monuments. The area of the GSEEL is approximately 870,000 acres. Overlapping the GSEEL are approximately 220,000 acres of the Blues, Burning Hills, Carcass Canyon, Cockscomb, Death Ridge, Escalante Canyons Tract, Fiftymile Mountain, Paria-Hackberry, Scorpion, and Wahweap Wilderness Study Areas (WSA). Most of the GSEEL fall under BLM ownership (about 860,000 acres), but a little over 10,000 acres within the GSEEL are private (map 2).

1.3 Acknowledgments

This report was prepared by the Utah Geological Survey at the request of the BLM Utah State office. The report was prepared under the direction of Michael Vanden Berg, Energy and Mineral Program Manager for UGS. The oil and gas sections were written by Tom Chidsey; the coal sections were written by Michael Vanden Berg; the uranium and metals sections were written by Ken Krahulec; and the industrial minerals sections were written by Andrew Rupke. Larry Garahana, Stan Perks, and Jeff McKenzie, all with the Utah BLM office, provided helpful guidance for the report. Martha Jensen of the UGS prepared several of the figures and maps and Michael Hylland, UGS Deputy Director, provided a useful review.

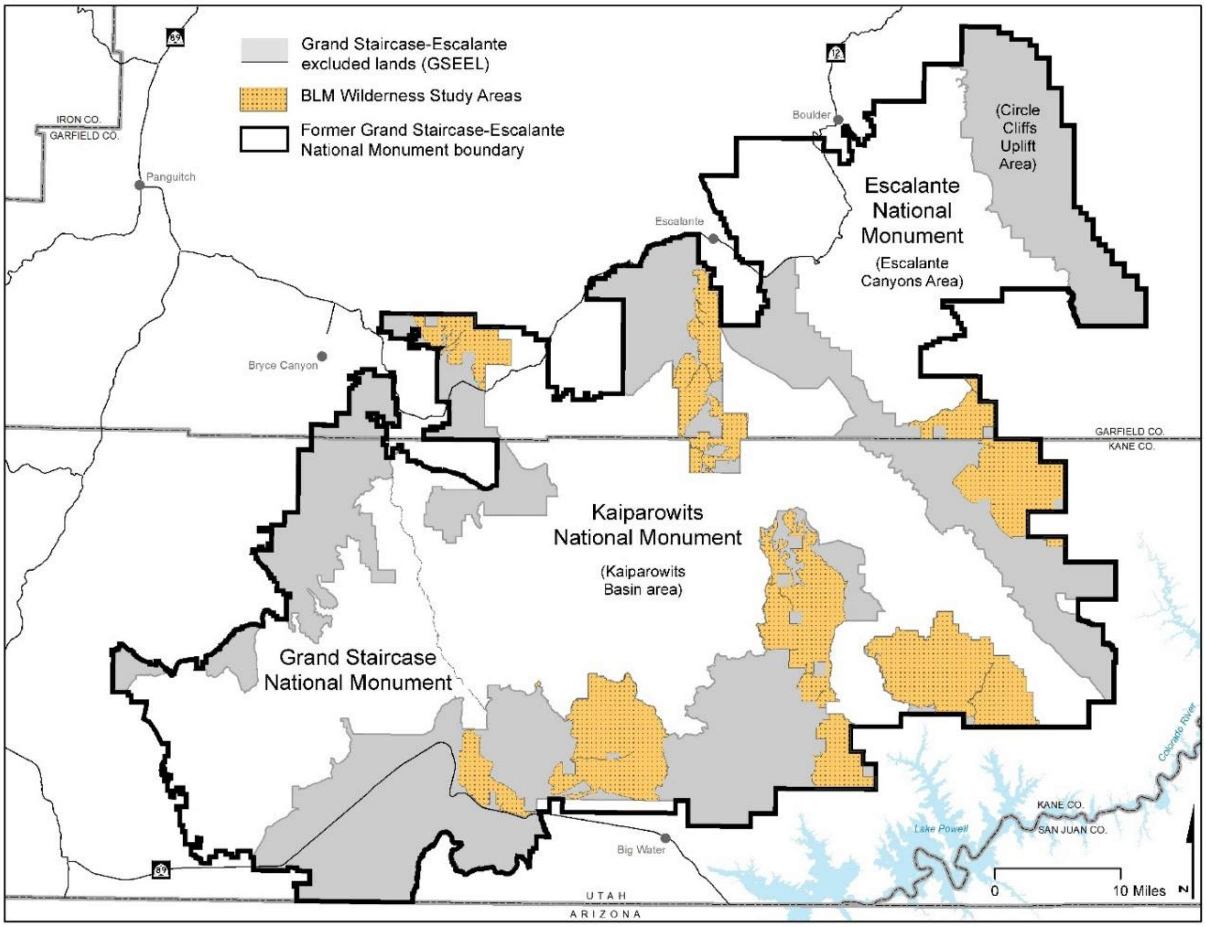


Figure 2. *Grand-Staircase Escalante excluded lands, Wilderness Study Areas, new monument areas, and physiographic area locations. Physiographic areas are somewhat coincident with new monument names.*

2.0 DESCRIPTION OF GEOLOGY

2.1 Physiographic Setting

The GSEEL cover parts of Garfield and Kane Counties within the Colorado Plateau near its western border in south-central Utah (figure 1). Annual precipitation in the region varies from about 6 inches at the lowest altitudes near Lake Powell (4000 feet), to about 25 inches at the highest altitudes near Canaan Peak (9280 feet). The variations in altitude and precipitation produce three climatic zones: upland, semi-desert, and desert. At the highest altitudes, precipitation falls primarily during the winter. The majority of precipitation in the semi-desert and desert areas occurs during the summer months (Doelling and others, 2010).

The GSEEL, as well as the GSENM, can be divided into four areas: from west to east these are the Grand Staircase, Kaiparowits Basin, Escalante Canyons, and Circle Cliffs uplift (figure 2). The Grand Staircase is a broad feature that encompasses the western third of the region and consists of a series of topographic benches and cliffs that, as its name implies, step progressively up in elevation from south to north. The risers correspond to cliffs and the steps correspond to the benches, terraces, or plateaus in the staircase (figure 3). The bottom of the staircase commences at the top of the Kaibab uplift, which correlates with and is in the same stratigraphic position as the highest bench of the Grand Canyon in Arizona. The first riser above this bench is the Chocolate Cliffs and consists of the Triassic Moenkopi Formation capped by the Upper Triassic Shinarump Member of the Chinle Formation. The Vermilion Cliffs form the next riser, which is well developed in the region. The cliffs are made up of the resistant red sandstone beds of the Triassic-Jurassic Moenave and Lower Jurassic Kayenta Formations. The Wygaret Terrace forms the next step and includes the soft upper part of the Kayenta and the lower parts of the Lower Jurassic Navajo Sandstone. The imposing White Cliffs form the next riser and consist of the upper part of the Navajo Sandstone and the lower part of the Middle Jurassic Carmel Formation. The bench on this riser is the Skutumpah Terrace built on the remaining soft parts of the Carmel Formation and the overlying Entrada Sandstone. The Gray Cliffs are a series of low cliffs formed by hard Cretaceous sandstone beds. Several benches have formed between these cliffs in the softer shales and sandstones of the Tropic, Straight Cliffs, Wahweap, and Kaiparowits Formations (Doelling and others, 2010). Descriptions of these formations are given in the stratigraphy section of this report.

The boundary between the Grand Staircase and Kaiparowits Basin of the excluded lands and the GSENM is The Cockscomb, a series of hogbacks along the East Kaibab monocline, where strata are folded sharply downward to the east. The Cockscomb trends approximately N. 20° E. from the Arizona border to about 12 miles east-southeast of the town of Henrieville (Doelling and others, 2010).

The Kaiparowits Basin is centrally situated in between the Grand Staircase and Escalante Canyons areas and consist of the majority of the GSEEL. It is physically exposed as the Kaiparowits Plateau. Doelling and Davis (1989) described this area as “a series of plateaus, buttes, and mesas carved in Cretaceous rocks that reflect the structures of the underlying geologic strata.” The Kaiparowits Basin covers about 1650 square miles (figure 4). The feature is a broad structural basin; however, the topographic expression is that of a northward-tilted, highly dissected plateau that has been modified by generally north-south-trending folds. The Kaiparowits Plateau is bounded by the base of the Cretaceous strata (Hettinger and others, 1996) or the base of the Dakota Formation. The Straight Cliffs form a prominent escarpment that rises 1100 feet or more and extends for more than 50 miles northwest to southeast above the Dakota and Tropic Formations. The cliffs roughly mark the plateau’s east boundary with the Escalante Canyons area. Some Jurassic strata are exposed in the Kaiparowits Basin, along its southern boundary, below the Cretaceous cliffs. These Jurassic rocks have a “Canyonlands” character (Doelling and others, 2010).

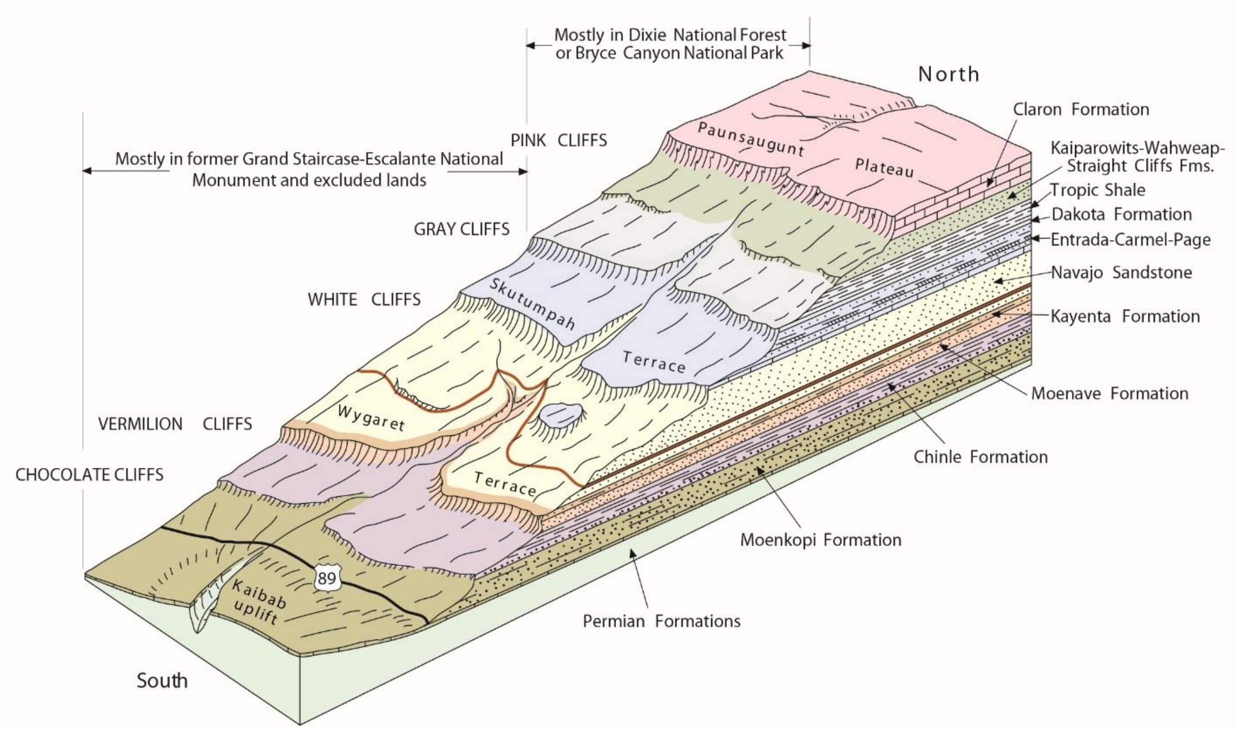


Figure 3. *Diagrammatic block diagram of the Grand Staircase area of the GSENM region. Strata dip generally northward. See text for descriptions of map units. After Doelling and others, 2010.*

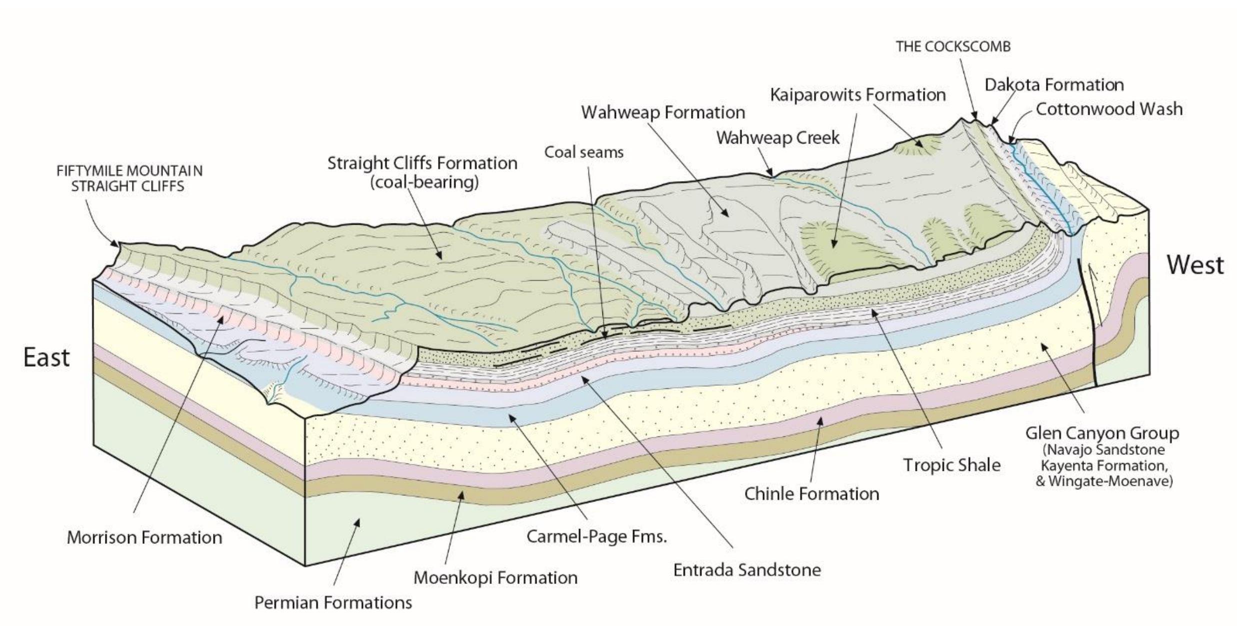


Figure 4. *Diagrammatic block diagram and east-west cross section across the Kaiparowits Basin area of the GSENM region. View is from the north looking south. The deepest part of the basin is aligned north-south along Wahweap Creek. The strata dip generally northward, but north-south-trending anticlines and synclines warp the block. The Straight Cliffs mark the east boundary and the Cockscomb marks the west boundary of the area. From Doelling and others, 2010.*

The Escalante Canyons area provides a web of multihued, steep, narrow canyons and “slickrock,” sculpted in the drainage basin of the Escalante River (figure 5). The area is bounded on the southwest by the Straight Cliffs, on the north by the Aquarius Plateau and Boulder Mountain, on the east by the Circle Cliffs uplift, and on the south by Glen Canyon of the Colorado River. The Circle Cliffs uplift area is a large doubly plunging anticline (figure 5), the core of which is eroded into a large kidney-shaped physiographic basin surrounded by the imposing vertical cliffs of the Wingate Sandstone and bounded on the east by the Waterpocket fold (Doelling and others, 2010). Essentially all lands in the Circle Cliffs area are now excluded from the GSENM.

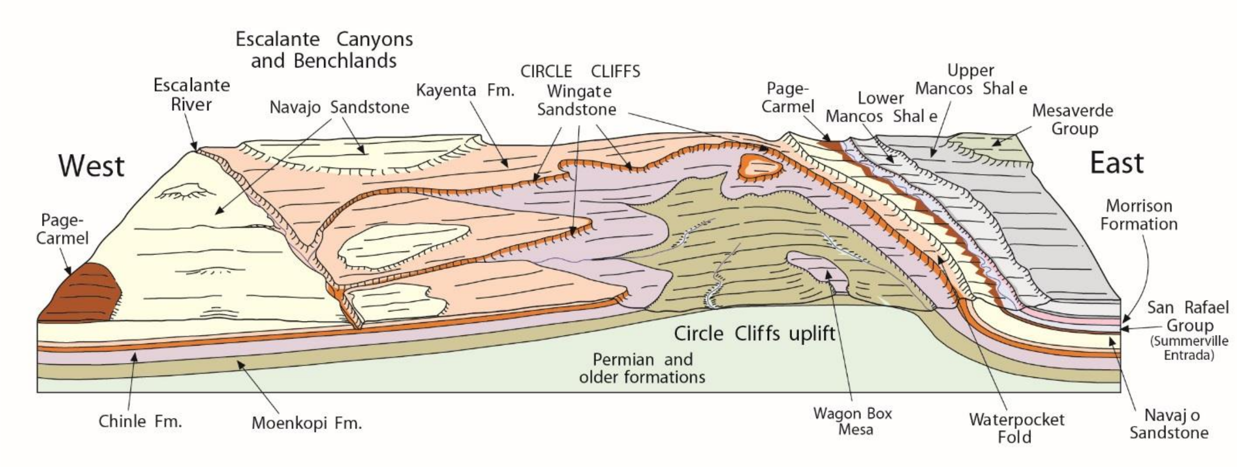


Figure 5. *Diagrammatic block diagram across the Escalante Canyons and Circle Cliffs uplift areas of the GSENM region. To the west are Glen Canyon Group bench and canyonlands incised by the Escalante River and its tributaries. To the east is the Circle Cliffs uplift, a large doubly plunging, north-south-trending anticline that exposes a fossil oil field in its core. The steeply dipping Waterpocket Fold makes up the east boundary of the uplift and is in Capitol Reef National Park. From Doelling and others, 2010.*

2.2 Stratigraphy

2.2.1 Introduction

This section presents a description of the lithology, depositional setting, and stratigraphic relations of the rock units present in the GSEEL. The units are described from oldest to youngest in age. Only Permian-aged and younger rocks are exposed at the surface under the excluded lands (map 3, figure 6); older units are known from the subsurface in the region (figure 7).

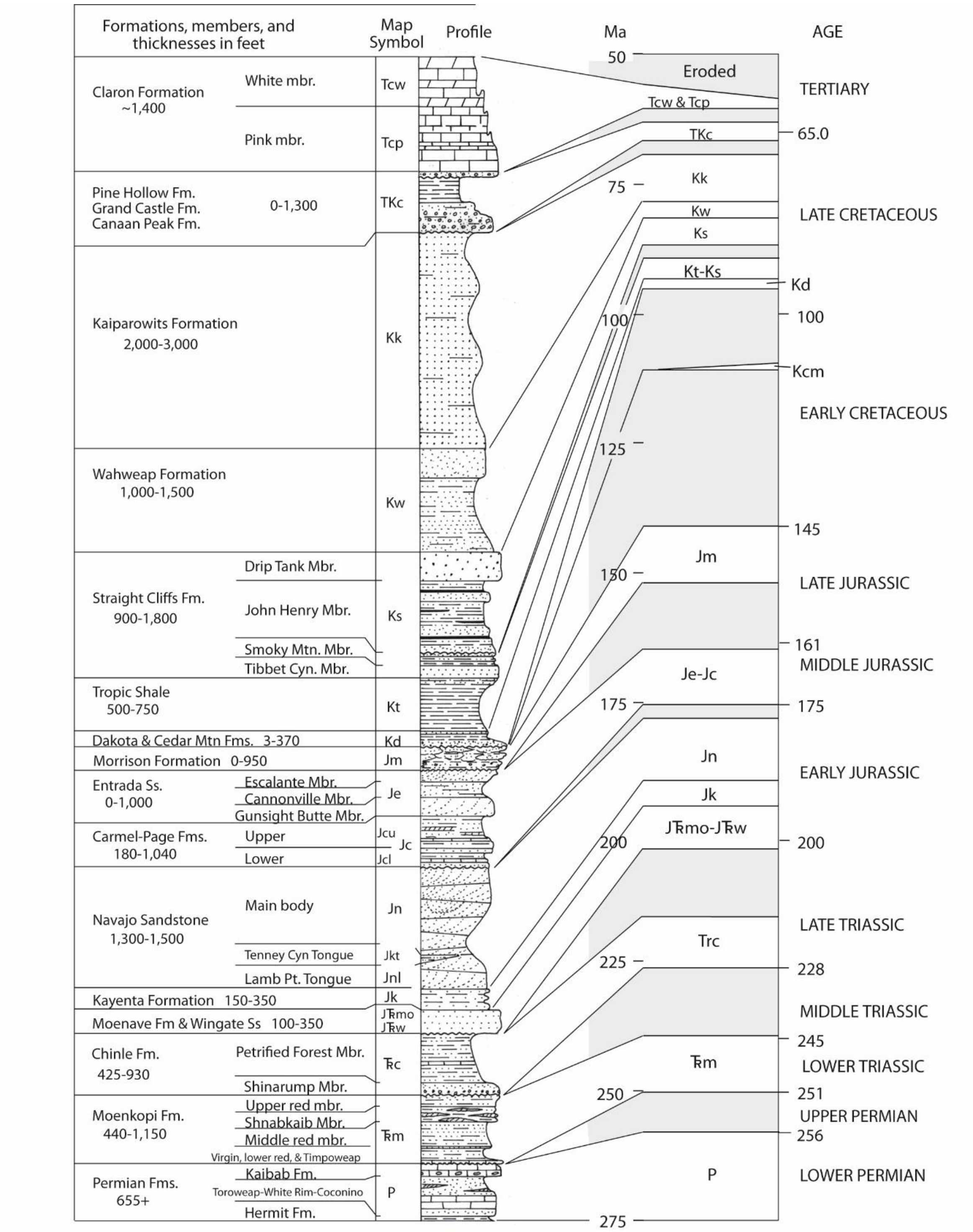


Figure 6. *Age, thickness, and names of formations and members of geologic units exposed in the Grand Staircase–Escalante National Monument region. Profile-lithology plot shows true relative thickness (averages) as compared with geologic time. Gray areas denote time with missing rock records. Je includes Romana Mesa Sandstone and Henrieville Formation. Ma stands for millions of years ago. Numbers between period designations indicate age of time boundary. From Doelling and others, 2010.*

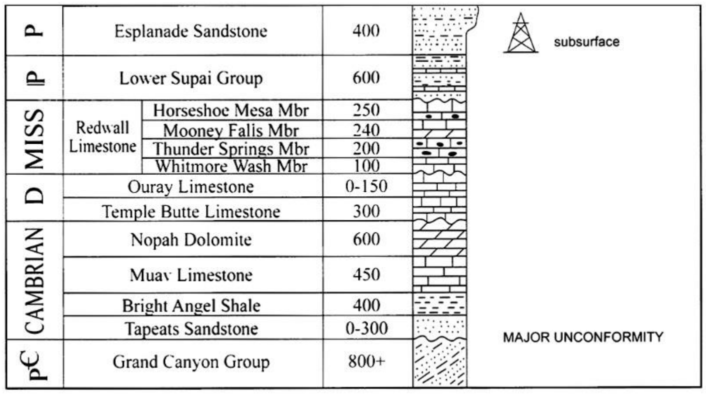


Figure 7. *Age, thickness and names of formations and members of geologic units in the subsurface in the Grand Staircase–Escalante National Monument region. Modified from Hintze and Kowallis, 2009.*

2.2.2 Precambrian Rocks

The exact distribution and nature of Precambrian rocks that underlie the GSEEL are not well known since their existence is only recognized from a few scattered drill holes (map 4). Most of the Precambrian rocks that underlie southwestern Utah are believed to be Early Proterozoic (1.8 to 1.1 billion years old) metamorphic rocks (Hintze and Kowallis, 2009). Younger Proterozoic (1.1 to 0.8 billion years old) sedimentary strata are reported to underlie the Kaiparowits basin, which is bounded on the west by the Kaibab uplift and on the east by the Circle Cliffs uplift (Uphoff, 1997). These strata are named the Grand Canyon Supergroup for exposures in the Grand Canyon of Arizona, where they consist of older redbed sandstones of the Nankoweep Formation and younger fine-grained sandstones, algal and stromatolitic limestones, and gray to black, organic-rich mudstones and siltstones of the Chuar Group. The extent of these younger Precambrian sedimentary strata in Utah is poorly defined since they are only exposed in the Grand Canyon, and only a small number of deep drill holes have penetrated the Chuar in southern Utah. The Nankoweep Formation appears to be a more blanket-type sandstone, while the Chuar is inferred to be a rift-filling sequence (Uphoff, 1997). The organic-rich mudstones and siltstones that make up about half of the Chuar Group have been identified as potential petroleum source rocks with total organic carbon contents up to 9% (Cook, 1991). Cook (1991) described the Chuar Group as two formations with a combined thickness of up to 6452 feet. Seeley and Keller (2003) have used geophysical techniques to identify two major Proterozoic extensional episodes that appear to control the probable subsurface occurrences of the Chuar Group. The Chuar and its potential source rocks are likely only preserved in undetermined northeast-tilted blocks along north-south-trending rift or normal faults as observed in the eastern Grand Canyon (Chidsey, 1997).

2.2.3 Cambrian Rocks

Although not exposed at the surface, Cambrian sedimentary strata are believed to unconformably overlie the Precambrian rocks in southern Utah (Hintze and Kowallis, 2009). These strata were deposited on a shallow shelf as a marine basin developed in western Utah. The Cambrian sea began slowly transgressing across southern Utah from west to east about 570 million years ago (Ma) and the shoreline nearly reached the Utah-Colorado border by the end of Middle Cambrian time about 525 Ma (Stokes, 1987). The total package of Cambrian strata remains fairly constant in thickness across the GSENM region at about 1950 feet. This package thins from north to south from 2500 feet thick near the northern border to 1820 feet at the southern border (Hintze, 1988).

The basal Cambrian unit is the Tapeats Sandstone (figure 7), which consists of medium- to coarse-grained, feldspathic sandstone that commonly has a small pebble conglomerate near the base (Uphoff, 1997). Cuttings from Tapeats in the Tidewater No. 1 Kaibab Gulch well (section 34, T. 42 S., R. 2 W., Salt Lake Base Line & Meridian [SLBL&M], Kane County, map 4), drilled in 1956 and now within excluded lands, contain white, fine-grained, well-sorted quartzarenites (Chidsey, 1997). Framework grains consist predominantly of well-rounded, monocrystalline quartz cemented by abundant silica overgrowths and minor amounts of dolomite, pyrite, calcite, and clay. Other Tapeats zones consist of pink, dolomitic and green- gray, glauconitic sandstones. The pink, dolomitic sandstones are medium- to coarse-grained. Framework grains are well-rounded, dominantly monocrystalline quartz, cemented by silica overgrowths and pore-filling dolomite. Green-gray, glauconitic sandstones consist of moderately sorted, laminated, very-fine- to fine-grained, micaceous sandstone alternating with laminae of siltstone (Chidsey, 1997). The quartzarenites are characterized by relatively well-developed primary intergranular porosity, some of which is solution enhanced. Bitumen partially fills intergranular pore space and is associated with pore-lining clay. The Tapeats was deposited in braided-stream to shallow-marine environments. Uphoff (1997) reported the porosity of the Tapeats ranges from less than 6% to over 13% with the best porosity in the coarser, lower portion of the unit, which was deposited in a braided-stream environment. Porosity values also tend to be higher in the less deeply buried, southern portion of the Cambrian basin. However, the pink, dolomitic and green-gray, glauconitic sandstones have low effective porosity and permeability in the cuttings evaluated (Chidsey, 1997). This unit ranges from 300 to 500 feet thick across the region and thins slightly to the northeast (Hintze and Kowallis, 2009).

The Bright Angel Shale (figure 7) has a gradational and conformable contact with the underlying Tapeats Sandstone. The majority of the Bright Angel consists of lenticular beds of very fine grained sandstone interbedded with micaceous shale (Uphoff, 1997). The thickness of the Bright Angel ranges from 250 to 600 feet under the GSENM and the excluded lands, and some of this variation is due to an intertonguing relationship with the overlying Muav Limestone or undifferentiated Cambrian carbonates (Hintze and Kowallis, 2009).

The Muav Limestone (figure 7) ranges from 300 to 900 feet thick and consists of oolitic to dolomitic limestone and interbeds of micaceous shale, silty limestone, and glauconitic sandstone. A 0- to 400-foot thick Upper Cambrian unit that has been referred to as the Nopah Dolomite, or "Supra-Muav" by some, is found above the Muav in the western, deeper part of the Cambrian basin (Hintze and Kowallis, 2009). On the eastern side of the GSENM, the 0- to 630-foot thick Lynch Dolomite overlies the Muav Limestone.

2.2.4 Ordovician and Silurian Rocks

Ordovician and Silurian rocks are not present under the GSENM region (figure 7). The absence of these rocks represents a 100-million-year period of nondeposition or deposition and later removal by erosion, a significant unconformity (Stokes, 1987).

2.2.5 Devonian Rocks

The depositional hiatus of the Ordovician-Silurian continued into the Early Devonian for the area covered by the GSENM and the GSEEL. Devonian strata are not exposed at the surface in the region, so descriptive information about these rocks comes from exposures nearby or from limited drill-hole data. Only Middle to Upper Devonian strata of the Temple Butte in the western area (exposed in the Grand Canyon) and Elbert in the eastern area, and overlying Ouray Formations are found in the subsurface in south-central Utah (figure 7). These strata were deposited in shallow-marine conditions near a fluctuating shoreline when the Late Devonian sea transgressed across the area from west to east (Doelling and others, 1989).

The Temple Butte and Elbert Formations consist of 200 to 300 feet of thin-bedded limestone and dolomite interbedded with gray-green shale and glauconitic sandstone. Discontinuous sandstones of marine origin are present locally near the base of this formation (Doelling, 1975; Doelling and others, 2010).

The Ouray Formation thins to the southwest across the region. The Ouray ranges in thickness from 0 to 160 feet and consists of tan to light-gray limestone or dolomite with minor green shale partings. The upper part of the Ouray is similar in appearance to the overlying Mississippian rocks, making the unconformity between them difficult to recognize (Doelling and others, 1989).

2.2.6 Mississippian Rocks

The Lower Mississippian strata in the region are limited to one formation, the Redwall Limestone (figure 7) (Doelling, 1975; Doelling and others, 1989). These strata were deposited along a shallow cratonic shelf that existed at least 350 Ma. The Lower Mississippian carbonate rocks unconformably overlie Devonian strata. They thicken to the northwest in a basinward direction to the shelf margin that existed near the Utah-Nevada border. Only to the west of the GSENM do deep-basin Mississippian facies exist. These organic-rich, deep-basin facies, particularly the Delle Phosphatic Member of the Chainman Shale in western Utah and eastern Nevada, have been identified as good source rocks for generation of petroleum (Sandberg and Gutschick, 1984; Bereskin and others, 2015). The Thunder Springs Member of the Redwall Limestone (figure 7) provides a possible local hydrocarbon source. In 1990, Beard Oil Company drilled the Tanner 1-27 well (section 27, T. 28 S., R. 3 E., SBL&M, Wayne County) near the town of Loa in Wayne County. Well cuttings indicated characteristics of source rocks in the Thunder Springs Member (Martin Pruatt, Beard Oil Company, verbal communication, 1990). A drill-stem test of the Redwall in this well, however, recovered only muddy and gassy water.

The Redwall Limestone consists of limestone and dolomite; it is commonly cherty. The Redwall is often porous and could make a good petroleum reservoir rock. In fact, minor amounts of oil have been produced from the Redwall at the Upper Valley field about 10 miles southwest of Escalante (map 5). Where it is dolomitized, the Redwall usually has vuggy to cavernous porosity and may be extensively fractured; where it is unaltered, it commonly is composed of oolites and crinoid fragments that also create good porosity (Lessentine, 1965). Lessentine (1965) showed the Redwall strata thicken rather uniformly from about 700 feet under the southeastern part of the GSENM and the excluded lands, to about 1200 feet thick under the northwestern part of the region.

2.2.7 Pennsylvanian Rocks

As determined from subsurface data, an unconformity separates the Mississippian and Pennsylvanian strata that underlie the GSENM region, and represents the depositional hiatus caused by the withdrawal of the Mississippian sea. While the sea was absent from southern Utah during earliest Pennsylvanian time (about 320 Ma), an erosional regolith of reddish soils developed over the undulating Mississippian surface (Lessentine, 1965). Transgression of the Pennsylvanian sea occurred from both the east and west in the GSENM region, as the Paradox Basin formed to the east, and a shallow shelf developed farther to the west. On the eastern side of the GSENM region, the thicker regolith is mapped as the Molas Formation. On the western half, the Pennsylvanian is represented by fluvial sand and silt deposits of the lower Supai Group on the Piute Platform (Hintze and Kowallis, 2009). Where mapped, the Molas Formation ranges from 50 to 300 feet thick whereas the Supai is up to 600 feet thick (figure 7). Some of the thicker, shaly portions of the Molas and Supai, can act as a seal for petroleum in the Mississippian.

Through the Middle Pennsylvanian, a seaway covered south-central Utah; the western part of the GSENM region saw continued continental as well as eolian sand deposition of the Supai Group (figure 7), while the easternmost part of the region was on the western margin of the Paradox Basin and received interbedded carbonate and sand deposition to form the Hermosa Formation (Doelling, 1975; Doelling and others, 1989). During Late Pennsylvanian time, the sea retreated to the Paradox Basin in southeastern Utah, and south-central Utah was subject again to erosion (Welsh and Bissell, 1979; Blakey and Ranney, 2008). Subsequent erosion has left the total thickness of Pennsylvanian rocks across south-central Utah quite variable, ranging from 130 to 1050 feet (Lessentine, 1965; Hintze and Kowallis, 2009).

2.2.8 Permian Rocks

The Permian period, which began about 290 Ma, started with a time of erosion or a depositional hiatus that created an unconformity with the underlying Pennsylvanian strata. During the Early Permian, a basin in western Utah underwent episodes of subsidence that caused a series of marine incursions from the west. Because of lateral facies changes and limited exposures, some of the Permian strata are hard to correlate and confusion in nomenclature exists (Doelling, 1975). The earliest Permian units under the GSENM region are the Esplanade Sandstone of the upper part of the Supai Group in the west (figure 7) and the Elephant Canyon Formation of the Cutler Group in the east (known only from the subsurface), which are lateral equivalents and similar in age. The Esplanade consists of fine-grained sandstone and siltstone representing beach and dune deposition (Blakey and Ranney, 2008; Hintze and Kowallis, 2009). The Esplanade Sandstone changes laterally to the east to facies recognized as the Elephant Canyon Formation under the Kaiparowits Basin and Escalante Canyons areas. The Elephant Canyon is composed of an interbedded assemblage of red shale, red to brown siltstone, light-brown, fine-grained sandstone, and pink to red carbonates that were deposited on a marginal-marine, mud-flat environment (Blakey and Ranney, 2008; Hintze and Kowallis, 2009).

Following deposition of the Lower Permian marine rocks, the sea retreated to the west depositing the continental Cedar Mesa Sandstone and Hermit/Organ Rock Formation (figures 6 and 7), both of which are only known from drill hole data with one exception – a small exposure of Hermit Formation is found in excluded lands along the east flank of the Kaibab uplift in the southernmost part of the Grand Staircase area. Doelling and others (1989) described the Cedar Mesa Sandstone as white to light-brown, fine-grained, cross-bedded, eolian sandstone representing a large dune field, with minor interbeds of siltstone, red to green shale, and silty and cherty limestone. Irwin (1976) provided an isopach map of the Cedar Mesa across southwestern Utah, showing this unit generally thickens southward from a feature called the "Emery high" which occurs in southern Sanpete County. Stratigraphic sections published by Hintze and Kowallis (2009) show the Cedar Mesa strata under the Circle Cliffs, Escalante Canyons, and Kaiparowits Basin areas has a thickness that ranges from 800 to 1500 feet. Conformably overlying the Cedar Mesa Sandstone is a unit alternatively known as the Hermit or Organ Rock Formations (Doelling and others, 1989), consisting of red-brown shaly siltstone and sandstone deposited as a floodplain and channels in a fluvial setting (Blakey and Ranney, 2008; Hintze and Kowallis, 2009). This unit underlies most of the western half of the GSENM region, but it thins north and west; the maximum thickness of the Hermit Formation is about 600 feet (Hintze and Kowallis, 2009).

To the south in the Grand Canyon, the eolian Coconino Sandstone occurs between the Hermit and the overlying Toroweap Formation (figure 6); however, this unit thins to the north and is only present in the subsurface in the southern GSENM region (Hintze and Kowallis, 2009; Doelling and others, 2010). Another west to east transgressive-regressive cycle of the Late Permian sea deposited the Toroweap Formation over the Cedar Mesa Sandstone and Hermit-Organ Rock Formation strata. The Toroweap Formation ranges from 250 to 450 feet thick under the Grand Staircase area but pinches out east towards the Circle Cliffs uplift, Escalante Canyons, and the Kaiparowits Basin area. Transgressive beach sandstone makes up the lower 60 to 70 feet of the Toroweap Formation (Hintze and Kowallis, 2009).

Above the beach sandstone, the Toroweap consists of cliff-forming, yellowish-gray, cherty limestone, which is overlain by slope-forming, very fine to medium-grained sandstone with a few thin-bedded limestone and discontinuous gypsum beds.

In the subsurface of the Kaiparowits Basin and Escalante Canyons area, and outcrops on the crest of the Circle Cliffs uplift, the eolian White Rim Sandstone interfingers with, and overlies, the upper part of the Toroweap (Doelling and others, 1989). The White Rim was laid down as the Permian sea regressed to the west, and is composed of white, fine- to medium-grained, cross-bedded sandstone. Near its eastern pinchout along the Colorado and Green Rivers, the White Rim is known for its tar sand deposits exposed along the Circle Cliffs uplift. A period of erosion followed the deposition of the White Rim and the retreat of the Permian sea.

Unconformably overlying the Toroweap and White Rim is the Kaibab Formation (figure 6). The Kaibab is exposed in excluded lands of the Circle Cliffs uplift and along the east flank of the Kaibab uplift in the southernmost Grand Staircase area. According to Hintze (1988), the Kaibab thins from 280 feet under the western part of the GSENM region to an eastern pinchout near the Colorado River. This eastward thinning represents both depositional thinning and thinning due to post-Kaibab erosion. The Kaibab is the oldest unit exposed in the excluded lands occurring in T. 44 S., R. 4 W., on the west flank of Buckskin Mountain on the Kaibab uplift of the southernmost Grand Staircase area. The Kaibab is one of the primary oil-producing units at the Upper Valley field (map 5). At Upper Valley field, the lowermost Kaibab, termed the Gamma member in the subsurface, consists of a transgressive deposit of 100 feet or less of sandstone, sandy limestone, limestone, and dolomite, which is most sandy near this unit's eastern limits (Irwin, 1976). The middle (Beta in subsurface terminology) member of the Kaibab consists of up to several hundred feet of mostly cherty dolomite, but some cherty limestone is also present. Dolomitization has produced excellent leached and intercrystalline porosity in most of the Kaibab. The uppermost Kaibab (subsurface Alpha member) is a regressive unit composed of anhydrite, dolomite, and lesser amounts of shale and sandstone.

2.2.9 Triassic Rocks

The Triassic rocks of south-central Utah are represented by two formations, the Moenkopi and the Chinle in ascending stratigraphic order (figure 6), both of which are exposed in the GSENM region. These two formations were generally deposited in tidal-flat to flood-plain environments, although shallow seas occasionally spread eastward across the Triassic continental lowlands and deposited shallow-marine strata.

The Lower Triassic Moenkopi Formation is divided into as many as six members in southern Utah (Doelling and others, 1989); in ascending order they are the Timpoweap, lower red, Virgin Limestone, middle red, Shnabkaib, and upper red members. The Moenkopi strata lie unconformably over the Kaibab Formation. Like the underlying Permian strata, the Moenkopi Formation thickens to the west across south-central Utah, ranging from 300 feet thick in the east to over 1000 feet thick in the west (Koch, 1976; Hintze and Kowallis, 2009). As the Moenkopi thickens to the west, it shows increasing marine influence, and in Nevada, equivalent aged strata are completely marine in origin (Hintze and Kowallis, 2009). Doelling and others (1989) have mapped the Timpoweap as the lowest member of the Moenkopi. Doelling and others (1989) described the Timpoweap as consisting of 0 to 150 feet of dolomite, limestone, sandstone, chert breccia, siltstone, and, locally at the base, brecciated material derived from the underlying Kaibab Formation. The three unnamed red members all consist of interbedded red siltstone and fine-grained, rippled-bedded sandstone, with occasional gypsum veinlets. The middle member is the thickest, reaching up to 370 feet. The Virgin Limestone Member pinches out under the Kaiparowits Plateau, but to the north and west of the plateau, thickens gradually to over 200 feet. The Virgin Limestone is brackish-water to marine in origin and consists of calcareous sandstone, siltstone, and sandy limestone, which contains fragments of marine mollusks and crinoids in the thicker sections (Doelling and others, 1989). The Shnabkaib Member consists of up to 400 feet of interbedded reddish-brown, fine-grained sandstone, siltstone, and thin, greenish-gray gypsum beds. Whereas the fine-grained, red bed members of the Moenkopi are good petroleum reservoir seals with low permeability and porosity, the Timpoweap and Virgin Limestone Members are locally good reservoir units, which contain petroleum in places such as the Virgin (east of Zion National Park) and Upper Valley fields, and the Circle Cliffs tar sands.

A period of erosion during the Middle Triassic followed the deposition of the Moenkopi Formation and created an unconformity between the Lower Triassic Moenkopi and the overlying Upper Triassic Chinle Formation. Hintze and Kowallis (2009) reported the Chinle Formation ranges from 300 to 1050 feet thick across the GSENM region. The continental red bed deposits of the Chinle are divided into two members, the basal conglomeratic Shinarump Member and the overlying Petrified Forest Member (locally referred to as simply the upper member). The basal Shinarump Member consists of discontinuous channels cut 15 to 50 feet into the Moenkopi in the Circle Cliffs area, and it thickens to the west where it becomes a continuous deposit up to 220 feet thick of medium-grained, yellowish-gray sandstone and lenses of siltstone and pebble conglomerate (Doelling, 1975). Doelling (1975) described the upper, or Petrified Forest, member of the Chinle as varicolored interbeds of mudstone and friable muddy sandstone, with minor siltstone, conglomerate, and gypsum lenses. The upper Chinle, which reaches up to 350 feet thick, has low permeability and porosity that make it a good reservoir-sealing unit. On the other hand, the Shinarump Member has potential as a hydrocarbon reservoir and contains petroleum shows at exposures along the Circle Cliffs uplift. Following deposition of the upper Chinle Formation, a period of erosion extending a significant unconformity between the Chinle Formation and the overlying uppermost Late Triassic-Early Jurassic strata of the San Rafael Group.

2.2.10 Jurassic Rocks

A thick section of Jurassic rocks is exposed across south-central Utah and is comprised of up to 11 formations, all of which are not present everywhere under the GSENM and the GSEEL. The thickness of the Jurassic strata across southwestern Utah ranges from 1200 to 5500 feet and has been strongly affected by Jurassic and post-Jurassic periods of erosion. These formations, from oldest to youngest, are the Wingate-Moenave (Late Triassic-Early Jurassic in the lower section), Kayenta, Navajo, Page-Carmel, Entrada, Summerville-Curtis-Romana, and Morrison (figure 6).

The Wingate Sandstone interfingers with and is overlain by the slightly younger Moenave Formation (Doelling and others, 1989). These two units pinch out to the north and west (Hintze and Kowallis, 2009). In the Circle Cliffs, Escalante Canyons, and Kaiparowits Basin areas, the eolian, very fine to fine-grained Wingate Sandstone ranges from 230 to 350 feet thick (Hintze and Kowallis, 2009). In the Grand Staircase area, the 170 to 480-foot thick, fluvial to lacustrine Moenave Formation is composed mainly of reddish-brown siltstone, with lesser amounts of very fine grained sandstone and claystone.

Conformably overlying the Wingate-Moenave Formations is the Lower Jurassic Kayenta Formation, which thins to the north. The varicolored Kayenta is thickest to the west, reaching up to 1600 feet in the Grand Staircase area, and thins to only 400 feet thick at the Circle Cliffs uplift (Hintze and Kowallis, 2009). The mostly fluvial Kayenta Formation is predominantly medium-grained, thick-bedded sandstone with minor interbeds of siltstone, mudstone, and pebble conglomerate (Doelling and others, 1989). Some of the Kayenta sandstones show eolian influence, and rare lacustrine limestone beds can also be found. The ledgy weathering Kayenta commonly forms a distinct break between the massive, cliff-forming sandstones of the Wingate below and the Navajo Sandstone above.

The thick, eolian cross-bedded, Lower Jurassic Navajo Sandstone interfingers with and overlies the upper part of the Kayenta Formation (Doelling and others, 1989). The light-colored Navajo is composed of fine- to medium-grained sandstone that is weakly cemented with carbonate and iron oxide. It thickens westward, ranging from 1000 feet thick at the Circle Cliffs and Escalante Canyons areas, to 2000 feet thick in the Grand Staircase area. A period of erosion ensued after deposition of the Navajo and the J-1 unconformity separates the Navajo from the overlying Middle Jurassic Page Sandstone (Pipiringos and O'Sullivan, 1978).

The eolian Page Sandstone, which is similar in composition and grain size to the Navajo Sandstone, occurs in the Circle Cliffs, Escalante Canyons, and Kaiparowits Basin areas and thins to a narrow wedge to the northeast. The Middle Jurassic Carmel Formation, however, is a widespread unit that is commonly found overlying the Navajo Sandstone where the Page in not present or above the Middle Jurassic Temple Cap Formation farther to the west (Hintze and Kowallis, 2009). The Carmel occurs as a westward-thickening wedge of sediment that has a thin eastern edge, beginning near the Colorado and Green Rivers, and a thick western edge. The Carmel Formation was deposited in, and along the margins of, a shallow Middle Jurassic seaway that extended south from Canada through southern Utah (Blakey and Ranney, 2008; Hintze and Kowallis, 2009). The Carmel has been subdivided into as many as five members that contain sandstone, limestone, calcareous shale, siltstone, mudstone, gypsum, and salt beds (Doelling and others, 1989; Hintze and Kowallis, 2009). Limestone is most common in the lower part of the formation. The gypsum and salt beds are thicker and more abundant in the thicker, western portions of the formation, although some gypsum beds up to 35 feet thick are found in the thinner, eastern part of the formation near the Circle Cliffs uplift (Doelling, 1975).

The Entrada Sandstone conformably overlies the Carmel Formation, and is sometimes differentiated from the Carmel only by the lack of gypsum beds (Doelling, 1975). The Entrada is mostly made up of fine- to medium-grained sandstone with minor interbeds of siltstone and mudstone that were deposited in an arid coastal environment by water and wind processes. The main depocenter of the Entrada generally lay to the east of the Circle Cliffs uplift; it is absent west of the GSENM. The Entrada is relatively thin, 100 feet or less, near the Grand Staircase area, and thickens to as much as 1000 feet in the Circle Cliffs area (Hintze and Kowallis, 2009). The J-3 unconformity separates the Entrada from the overlying Curtis and Summerville Formations (Pipiringos and O'Sullivan, 1978; Doelling and others, 1989).

The Curtis and Summerville Formations (Romana in the Kaiparowits Basin area and to the east) are absent over most of the Grand Staircase area. A thin wedge of these two formations begins in the central portion of Garfield County and thickens to about 250 feet in the Circle Cliffs uplift (Hintze and Kowallis, 2009). The Curtis is composed of shallow-marine sandstone that records renewed transgression from the north of the Middle Jurassic sea. The Summerville is composed of alternating thin beds of sandstone, siltstone, mudstone, and minor gypsum that were deposited in arid, near-shore environments as the sea retreated (Doelling, 1975). Another unconformity separates the Middle Jurassic Curtis and Summerville strata from the overlying Upper Jurassic Morrison Formation.

The unconformity separating the Upper Jurassic Morrison Formation from the Middle Jurassic Curtis and Summerville Formations cuts progressively deeper in the section to the west of the Circle Cliffs, Escalante Canyons, and Kaiparowits areas. The Morrison is absent in the western Grand Staircase area and begins to develop in the subsurface in the eastern Kaiparowits Basin and thickens eastward continually to over 700 feet (Hintze and Kowallis, 2009). Varicolored mudstones, locally conglomeratic channel sandstones, and lacustrine limestone comprise the distinctive continental lithologies of the Morrison, which is best known for the uranium and abundant dinosaur fossils. The top of the Morrison is bounded by a significant unconformity that separates it from the overlying Cretaceous Cedar Mountain or Dakota Formations.

2.2.11 Cretaceous Rocks

In general, the Cretaceous strata beneath the GSENM region (figure 6) were deposited in a separate southern Utah basin bounded from the northern Utah Cretaceous basin by an east-west-trending salient that existed to the north. The rock record is unclear whether this salient lacks Cretaceous strata deposited across it or if it had some thin Cretaceous strata that were later eroded away. Since the strata in the southern basin cannot be physically correlated with those in the northern Utah Cretaceous basin, the southern basin has a different set of nomenclature for similar aged rocks (Hintze and Kowallis, 2009). In addition, the Cretaceous sediments deposited in the southern basin exhibit several lateral facies changes from east to west that add another layer of complexity to the nomenclature.

The Lower Cretaceous Cedar Mountain Formation are the oldest Cretaceous rocks in the region and is only exposed in excluded lands in the Kaiparowits Basin and the Escalante Canyons areas. It ranges in thickness from 0 to 50 feet. The Cedar Mountain typically consists of a basal conglomeratic unit and an upper assemblage of channel sandstones, overbank mudstones, and terrestrial carbonate horizons formed by lacustrine or pedogenic processes. An unconformity separates the Cedar Mountain from the overlying Lower- to Upper-Cretaceous Dakota Formation.

The unconformable nature of the basal contact of the Dakota Formation (more recently called the Naturita Formation) means that it can overlie rocks as old as the Early Jurassic Navajo Sandstone to rocks as young as the Early Cretaceous Cedar Mountain Formation (Hintze and Kowallis, 2009). The Dakota basin of southern Utah is asymmetrical with its steep western margin and depocenter near Cedar City and an eastern limb that gradually thins to a minimum in the northern portion of the GSENM. The thickest Dakota strata in the GSEEL in the northwestern part of the Grand Staircase area is about 750 feet, thinning east to less than 20 feet thick in the Circle Cliffs area. The Dakota Formation represents the interplay of fluvial and marine processes as the Cretaceous seaway transgressed from the southeast. The Dakota typically has a basal conglomeratic unit that is overlain by an interbedded assemblage of fluvial, coal bearing paludal, and shallow-marine facies. Generally, where the Dakota is at least 200 feet thick, coal deposits of minable thickness can be found in the formation (Alton coalfield). These thick Dakota coals may also be potential coalbed gas reservoirs. The Dakota Formation has been productive for petroleum under the Wasatch Plateau and in the Uinta Basin (Wood and Chidsey, 2015).

Conformably overlying the Dakota Formation is the Tropic Shale, which records the full incursion of the Cretaceous Western Interior Seaway into eastern Utah from both the south and the north. The Tropic is composed of gray marine shale and silty shale. Where present, the Tropic strata provide a good sealing unit for underlying potential petroleum reservoirs. The Tropic ranges from 300 to 1000 feet thick (Hintze and Kowallis, 2009).

The next Cretaceous units above the Tropic are the Tibbet Canyon and Smoky Hollow Members of the Straight Cliffs Formation (Hintze and Kowallis, 2009). These units are composed of nearshore marine sandstones and continental paludal and fluvial deposits that record a pulse of sediment that built out into the Cretaceous Seaway as a result of mountain building to the west. The Smokey Hollow Member is coal-bearing in excluded lands of the northern and southern parts of the Kaiparowits Basin area. Beneath the GSENM region, the Smoky Hollow and Tibbet Canyon Members are thickest in the west in excluded lands near Alton where they reach almost 600 feet, gradually thinning to the southeast, reaching about 300 feet thick in the Kaiparowits Basin (Hintze and Kowallis, 2009). Northward of the GSENM region, the Smoky Hollow and Tibbet Canyon Members were not deposited or were eroded away after deposition. Westward across the GSENM region, the upper members of the Straight Cliffs Formation disconformably overlie the Smoky Hollow and Tibbet Canyon Members (Hintze and Kowallis, 2009). The Blue Gate Member of the Mancos Shale is gray, marine shale deposited during westward transgression of the Cretaceous Seaway and is present only in the far northeastern part of the region.

Under the western part of the GSENM region, the Blue Gate passes laterally into the John Henry and Drip Tank Members of the Straight Cliffs Formation, a stacked sequence of nearshore marine sandstones and associated paludal and fluvial mudstone, sandstone, and coal, deposited where the sediment supply was able to keep up with rising sea level conditions. The Straight Cliffs Formation locally contains coal deposits with an aggregate thickness that reaches up to 100 feet, and thus may be prospective for coal and coalbed gas deposits.

The youngest Upper Cretaceous units are the Mesaverde Group strata, which include the Wahweap and Kaiparowits Formations in the GSENM region (Hintze and Kowallis, 2009). The Wahweap Formation ranges in thickness from 1000 to 1500 feet and consists of buff-colored interbeds of mudstone, siltstone, and conglomeratic sandstone. The Wahweap is exposed in excluded lands of the northern Grand Staircase and Kaiparowits Basin areas. The Kaiparowits Formation ranges from 2000 to 3000 feet consisting of a sequence of dark-gray, thin-bedded, arkosic sandstone (Doelling and others, 2010). However, in the excluded lands the Kaiparowits is only present in northernmost part of the Grand Staircase area.

2.2.12 Tertiary Rocks

The Paleocene-Eocene Claron Formation makes up the Pink Cliffs and the famous hoodoos of Bryce Canyon National Park. However, the Claron is not present in any of the GSEEL.

2.3 Structure

Generally, structural geologic features seen today within the GSENM region result from two phases (or styles) of deformation. Many of the folds that we see today in the Kaiparowits and Circle Cliffs areas began during the latter part of the Mesozoic (Jurassic-Cretaceous); initiated during the Sevier orogeny and later modified when compression of the region continued through the Laramide orogeny (Cretaceous-Tertiary). During mid-Tertiary, uplift of the Colorado Plateau was accompanied by basin and range extension which affected the western portions of the GSENM region resulting in the development of the Sevier and Paunsaugunt faults. The uplift of the Kaibab region and folding along the East Kaibab monocline accompanied initial formation of the Grand Canyon starting about 15 Ma (Doelling and others, 2010).

2.3.1 Grand Staircase Area

All strata in the Grand Staircase section of the GSENM region dip gently (mostly 2° to 4°) northward in a homocline that is warped and faulted (figure 3). Hence, the oldest rocks are generally exposed to the south and the youngest to the north. The strata are cut by many normal faults with displacements ranging to about 800 feet.

The Paunsaugunt fault, which extends from Arizona northward into central Utah, is the most significant of the Grand Staircase section faults. The fault is a high-angle normal fault, and the up-thrown block is to the east. The displacement decreases southward from about 800 feet near Willis Creek to less than 100 feet near Deer Spring Point. From there to the Arizona border it increases again to approximately 500 feet. The fault plane dips at various angles from 45° E. as a reverse fault to 45° W. Differential erosion of bedrock near the fault has resulted in reverse topography. Because west-side strata generally stand higher in elevation than the east side the outcrops of older rocks are exposed farther north on the upthrown block. The northern segment, outside the monument, shows evidence for surface rupture during Quaternary time, but movement along the southern segment during Quaternary is not apparent (Hecker, 1991).

The Johnson Canyon faults are present along the western part of the Grand Staircase area. These faults may be active, however, to date, associated earthquakes have registered very low on local seismographs (University of Utah Seismology Catalogs, 1986). Seismologists have not determined a link between movement on the Johnson Canyon faults and local earthquakes (Doelling and others, 2010).

Two major faults (Paria River faults), 0.75 to 0.25 miles apart, occur on each side of the Paria River just north of the abandoned Paria townsite. These form a graben or down-dropped block, the river generally flowing between them. Each exhibits a maximum displacement of about 250 feet. It is assumed these faults are not tectonic in origin, are shallow and die out not far beneath the surface. The strata on each side of the canyon are thought to be moving riverward due to gravity-induced sliding (Doelling and others, 2010).

The Kaibab uplift is present in the southeast corner of the area and consists almost entirely of excluded lands. It is expressed as a positive topographic feature known as Buckskin Mountain. The uplift is most easily recognized traveling southward along U.S. Highway 89 between the Paria turnoff and the deep cut through the Cockscomb as a whaleback. The uplift is connected and synchronous with the Grand Canyon uplift in Arizona. The axis of the uplift trends roughly north-south and is known as the Kaibab anticline. This anticline extends north to south completely across the monument, generally plunging northward. In the Buckskin Mountain part of the anticline, the east boundary of the uplift or east limb of the anticline (East Kaibab monocline as expressed by the Cockscomb) is steeply dipping and locally overturned. North of U.S. Highway 89, the Kaibab anticline is very subtle and gentle on both flanks and is bounded on the west by the Paria River syncline and on the east by the Hackberry Canyon syncline, both of which are also gentle, generally north-south-trending folds (Doelling and others, 2010).

The east boundary of the Grand Staircase area is the Cockscomb, the topographic expression of the East Kaibab monocline. It trends north-northeast from the south boundary of the area nearly to the north boundary and is paralleled by the Cottonwood Wash road. The rock strata dip abruptly eastward at angles ranging from 15° to slightly overturned. The structural relief across the monocline is about 5000 feet to the south and decreases gradually to the north end of the monument near Butler Valley. Locally, the monocline is faulted and strata are attenuated. It is the most magnificent structural feature in all of GSENM and the GSEEL (Doelling and others, 2010).

2.3.2 Kaiparowits Basin Area

Like the Grand Staircase section, strata in the Kaiparowits Basin section dip gently northward. Because of the displacement on the East Kaibab monocline, Cretaceous outcrops shift southward and dominate the Kaiparowits Basin section. The strata are composed of alternating hard and soft units as in the Grand Staircase area, but the cliffs are all subdivisions of the Gray Cliffs part of the Grand Staircase. Superimposed on the north-dipping homocline are several north-south-trending anticlines and synclines (figure 4). Most of these have gentle limbs, but a few form monoclines (Doelling and others, 2010).

The Kaiparowits Basin area is a structural basin topographically expressed as a high plateau. The deepest parts of the basin lie westward near the East Kaibab monocline. The strata gradually rise eastward. The Cretaceous rocks are cut off by erosion along Fiftymile Mountain (Straight Cliffs). West to east, from the East Kaibab monocline to the Straight Cliffs, the principal folds in the basin include the Coyote Creek-Blue Wash-Table Cliff syncline (deepest part of the Kaiparowits Basin), Tommy Canyon anticline, Wahweap syncline, Nipple Bench anticline, Warm Creek syncline, Smoky Mountain anticline, Last Chance syncline, Upper Valley anticline, Alvey Wash syncline, Rees Canyon anticline, and Croton syncline. Fewer of these folds are present to the north where the plateau-basin is narrower. The folds radiate out southward like the plications of a fan. Folds to the west trend southwesterly; folds to the east generally trend southeasterly (Doelling and others, 2010).

2.3.3 Escalante Canyons Area

The boundary between the Escalante Canyons and Kaiparowits Basin area is placed at the base of Fiftymile Mountain (Straight Cliffs). The Escalante Canyons area includes the Escalante monocline, a north-northwest-trending feature north of the town of Escalante that dips to the west. Several anticlines and synclines are superimposed on the gentle west limb of the Circle Cliffs uplift in the Escalante Canyons area. These include the Collet anticline and Red Breaks syncline to the north, and the Hurricane Wash syncline, Bridge anticline, and Fiftymile Creek syncline to the south. The Escalante River and its tributaries have cut deep canyons into the gentle west limb that are favorites for hikers. These deep canyons are the basis for the name of the Escalante Canyons area (Doelling and others, 2010).

2.3.4 Circle Cliffs Area

The dominant structural feature in the eastern GSENM region is the Circle Cliffs uplift (figure 5). It has a gentle southwest limb that extends from the Hole-in-the-Rock Road east-northeast to the axis of the uplift. The east limb of the uplift is the Waterpocket Fold, another steeply dipping monocline like the East Kaibab monocline. The Waterpocket Fold, however, is in Capitol Reef National Park. The core of the Circle Cliffs uplift is lined by the prominent vertical and magnificent red-brown or orange-brown cliffs of the Wingate Sandstone. These cliffs “circle” the uplift and are the basis for its name (Doelling and others, 2010). The core of the uplift exposes Permian and Triassic rocks within the GSEEL.

2.4 Geologic History

Nearly 275 million years of geologic history is revealed in the exposed rocks and paleontology of the GSENM region (Baars, 1972; Hintze and Kowallis, 2009). The oldest rocks record a time when the North American plate was situated such that the equator angled northeasterly from southern California and across the southeast corner of Utah. The region was a marginal marine lowland of streams, floodplains, and tidal flats. The sea lay to the west, but it occasionally spread eastward across the region, depositing limestone beds containing diverse shells, sponges, and other fossils between the red beds of sandstone and mudstone that were being deposited on adjacent lowlands. The Hermit, Toroweap, Kaibab, and Moenkopi Formations (Blakey and others, 1993; Blakey, 1996), which crop out in the Circle Cliffs and at Buckskin Mountain, record the events of the first 35 million years of exposed geologic history in the GSENM region. A missing record of nearly 20 million years separates the last record of the Permian Period from the Triassic Period in the GESNM region. Evidence for climatic regimes, environments of deposition, and other paleohistoric data are available only from the rocks that we currently see in the GSENM region, or only 43% of the 275-million-year interval (Doelling and others, 2010).

One might ask what happened during the remaining 57% of time. Strata may have been deposited only to be eroded before the next sequence was laid down. They may have been deposited or eroded in environments that differ from those recorded in the rocks that are present. Unfortunately, the missing intervals are generally not recorded in neighboring localities. Nevertheless, there is a wealth of information found in the 43% of the rocks that are present and much information remains to be gleaned from them (Doelling and others, 2010).

The final retreat of the Early Permian sea from southern Utah at the end of Kaibab Formation deposition marked the beginning of a period of significant erosion during the remainder of Late Permian time. Between the Permian and Triassic is known as the End-Permian Extinction or the Great Permian Extinction event, colloquially known as the Great Dying when up to 96% of all marine species and 70% of terrestrial vertebrate species becoming extinct.

The Upper Triassic rocks in the excluded lands of the Circle Cliffs area have remarkable specimens of petrified wood, including logs exceeding 90 feet in length. These logs represent conifer trees that were left as driftwood on river flood plains. Cellular organic tissues were replaced by silica derived from volcanic ashes which were deposited as part of the Chinle Formation (Dubiel, 1994). Fossils of other kinds of plants, fish, amphibians, and reptiles, tracks of early dinosaurs, and freshwater clam and gastropod shells also give hints about the environment and life in the region during Late Triassic time (Foster and others, 1999; Doelling and others, 2010).

Near the end of the Late Triassic, a period of 5 to 6 million years of non-deposition and erosion dominated the region and was followed in the latest Triassic and Early Jurassic by sand deposition as desert conditions prevailed. In the Escalante Canyons area this sand was initially deposited in a sand dune desert (Wingate Sandstone). The desert environment changed for a time and streams deposited sand in channels and overbank deposits on flood plains (Kayenta Formation). The desert climate returned and sand was again deposited in a huge area of sand dunes (Navajo Sandstone). In the Grand Staircase area, Triassic-Jurassic tidal flats (lower Moenave Formation) gradually changed to flood plains (upper Moenave and Kayenta Formations), and finally ended in a wind-blown sand environment (Navajo Sandstone). These mostly Lower Jurassic rocks form the Vermilion and White Cliffs in the Grand Staircase area and make up the walls of the canyon and tributary canyons of the Escalante River. Though generally devoid of fossils, these rocks commonly exhibit tracks of small to medium-sized dinosaurs (Hamblin, 1998).

Middle Jurassic time in the GSENM region is mostly represented by the Carmel and Entrada Formations. The Carmel was deposited near the south margin of a shallow sea that advanced into the area from the north. Carmel limestones contain marine mollusks, brachiopods, crinoids, coral, and algae. Desert sand dunes (beach and back-beach sands of the Entrada Sandstone) were deposited on Carmel sediments and limestones in the wake of the retreating Carmel sea. Another 3 to 5 million years elapsed between the time the Entrada sands were deposited and Upper Jurassic Morrison Formation sediments were laid down. In the Escalante Canyons area, the Morrison was deposited by northeast-flowing streams. The sluggish meandering and anastomosing streams of Morrison time developed broad flood plains. Dinosaurs roamed the GSENM region in profusion and “sloshed” across the streams and through the ponds and lakes that developed on the flood plain (Doelling and others, 2010).

Late Jurassic to early Tertiary compressive forces in the Earth’s crust formed high mountain ranges in western Utah and eastern Nevada which peaked in the Late Cretaceous. This mountain-building event is known as the Sevier orogeny. Simultaneously, an epicontinental sea spread to the foot of these mountains and inundated the GSENM region. The sea covered most of the interior of the North American continent from the Arctic Ocean to the Gulf of Mexico, dividing the continent into two parts. At its maximum extent, the sea stretched to the Cedar City area in southwest Utah, west of the GSENM. Sediments, provided by the erosion of the Sevier mountains, were carried eastward by rivers and streams to the sea. Dakota Formation sediments were deposited in coastal areas ahead of the encroaching sea. The Tropic Shale represents the muds deposited at the bottom of the sea, and the Straight Cliffs, Wahweap, and Kaiparowits Formations represent sediments deposited on a piedmont belt between the mountains and the sea after the sea retreated east of the GSENM region. The west part of the GSENM region was elevated before sediments were deposited during the transgressive and regressive stages of the epi-continental sea. In the west part of the GSENM region a good part of the Middle Jurassic and all Upper Jurassic rocks were removed by erosion before the Cretaceous sediments were deposited (figure 6) (Doelling and others, 2010).

The thickness, continuity, and broad temporal distribution of the Kaiparowits Basin stratigraphy provide opportunities to study the paleontology of Late Cretaceous time. Significant fossils, including marine and brackish-water mollusks, turtles, crocodilians, lizards, dinosaurs, fish, and mammals have been recovered from the Dakota, Tropic, Straight Cliffs, Wahweap, and Kaiparowits Formations in the GSEEL. These formations provide evidence of a diverse terrestrial vertebrate fauna, especially for mammals and dinosaurs, in the 20 million years after the retreat of the epicontinental sea. This sequence of rocks in the GSENM region contains one of the best and most continuous records of Late Cretaceous terrestrial life in the world (Kirkland and others, 1998; Eaton and others, 1999). The research on these strata is still in its earliest stages (Doelling and others, 2010).

Dinosaurs became extinct between Cretaceous and Tertiary time and changes in depositional environments followed. The Sevier mountains to the west were gradually removed by erosion by early Tertiary time and several large lakes occupied areas extending from southwestern Wyoming to southwestern Utah. The Claron Formation, which forms the Pink Cliffs at Powell Point and Bryce Canyon National Park, was deposited in a lake which covered much of the GSENM region (Doelling and others, 2010).

Much volcanic activity took place in central Utah in middle Tertiary time. Today, volcanic rocks cap the Aquarius Plateau and Boulder Mountain north of the GSENM region, but volcanic boulders litter benches in the north part of the Escalante Canyons area. All during the middle Tertiary, Utah and surrounding areas lay at low elevations, probably not far above sea level. A general rise of the landscape and tectonic activity (faulting) occurred in latest Cretaceous time and continues into the present. The Colorado Plateau uplift began about 65 Ma. About 15 Ma, normal faulting brought on by crustal extension (stretching) began in western Utah and enhanced the uplift of the Colorado Plateau region. This faulting formed grabens, horsts, and tilted fault blocks that form the north-south-trending basins and ranges in western Utah and Nevada. The GSENM region is located at the east edge of this basin-and-range faulting. The Johnson Canyon and Paunsaugunt faults are the easternmost of the basin and range faults. Although detailed fault and seismic studies are necessary, the Johnson Canyon and Paunsaugunt faults may be active and may relate to small earth tremors and earthquakes that have been experienced in the area (Doelling and Davis, 1989; University of Utah Seismology Catalog, 1986). The Grand Canyon uplift occurred simultaneously with the Colorado Plateau uplift and its specific effect extends into the monument area as the Kaibab uplift (Lucchitta, 1972; McKee and McKee, 1972). The Colorado Plateau is still rising. The Colorado River and its tributaries cut deep canyons into the landscape and into the colorful formations deposited in late Paleozoic and Mesozoic time. The basin-and-range faults continue to move and affect the Grand Staircase area. The unconsolidated fluvial and wind-blown deposits that are temporarily lodged in the hollows of the eroding formations, and on their way to the ocean, hold the secrets of the events of the last few million years and hold most of the evidence of human habitation for the last few thousand years (Doelling and others, 2010).

3.0 MINERAL EXPLORATION DESCRIPTION, PRODUCTION, AND OCCURRENCE

3.1 Leasable Minerals

3.1.1 Oil and Gas

Introduction

The plays described below are numbered to correspond with, generally follow the same boundaries as, and rely heavily on descriptions presented in the U.S. Geological Survey's (USGS's) 1995 National Assessment of United States Oil and Gas Resources (Beeman and others, 1996; Charpentier and others, 1996; Gautier and others, 1996). A number of the USGS plays have been subdivided into oil-and-gas-prone and carbon-dioxide-prone portions. The USGS originally included the Devonian through Pennsylvanian play reservoirs with the Proterozoic-sourced play, but in this report they are separated because the Devonian-Pennsylvanian depositional sequence contains both source and reservoir beds and can be considered a discrete play. In addition to the USGS-identified plays, new plays have been added for areas prospective for coal-bed gas. Some of the plays are hypothetical because they have no proven reserves or production history.

Only limited exploration and development for oil and gas has occurred within the GSEEL (map 4 and map 6). A total of 26 well locations were drilled within the excluded lands between 1928 and 2017 (map 4); most of the wells were drilled between 1952 and 1986. The last well drilled in the GSEEL was the Reese Canyon State 32-2 well (SW1/4SW1/4 section 34, T. 39 S., R. 5 E., SLBL&M, Kane County), an 11,911-foot dry hole (see discussion in Late Proterozoic/Cambrian Play section). As of 2018, there is only one producing oil field in the region, Upper Valley field, which was discovered in 1964 (map 5). Based on the cumulative oil production through 2017, which falls in the range of 25 to 50 million barrels, Upper Valley is classified as a medium-sized oil field. Only 15% of Utah's actively producing fields are larger than very small (1 to 10 million barrels of oil or 0.01 to 0.1 trillion cubic feet of gas). Thus, any new field discoveries in the GSEEL can be generally expected to be very small or smaller in size. Very small fields are not likely to attract large oil companies but may attract small or mid-sized petroleum companies.

Petroleum development potential is tied to the industry's varying interest in pursuing possible targets, the nature and size of those targets, the risk factors in success, available infrastructure (pipeline and roads), seismic acquisition and drilling costs, and oil and gas prices. Future leasing near BLM Wilderness Study Areas will likely also draw extensive scrutiny from environmental groups and thus have a dampening effect on industry interest in pursuing new leases and exploration drilling.

The resource occurrence and development potential rating system used in this study is presented in Appendix A at the end of this report. This rating system comes from the BLM Manual 3031 (illustration 3). The following sections provide a detailed description and assessment of the resource occurrence potential and development potential of the various plays defined in the GSEEL.

Late Proterozoic/Cambrian Play (USGS-2403)

Introduction

About one-third of the area of this hypothetical oil and gas play is in north-central Arizona and two-thirds is in south-central Utah within the Colorado Plateau and Transition Zone (Gautier and others, 1996). The play is hypothetical and highly speculative, based on the idea that the Upper Proterozoic Chuar Group sourced reservoir units within itself and in superjacent Paleozoic reservoirs, primarily the Cambrian Tapeats Sandstone. Measured thickness of the group in the eastern Grand Canyon ranges from 5370 to

6400 feet. Potential accumulations are associated with large Colorado Plateau structural traps. Boundaries for this play (maps 7) are poorly defined because so few boreholes have penetrated the Chuar; consequently, its regional occurrence and facies are poorly understood. Papers by Rauzi (1990), Allison (1997), Uphoff (1997), Seeley and Keller (2003), and Lillis (2016) provide additional information on this play.

Reservoirs

Drilling depths to potential accumulations are from 2000 to 13,000 feet for oil and from 6000 to 20,000 feet for gas. These units are probably underpressured and include numerous fine clastic (mostly siltstone) beds in the Chuar Group (if sufficiently fractured), the superjacent Tapeats Sandstone (a 150- to 400-foot-thick, cross-bedded beach deposit), and possibly other Paleozoic sandstones if extensive vertical migration has occurred. There have been significant petroleum shows in every Paleozoic system and also in Triassic strata in southern Utah. Multi-billion-barrel-size accumulations of hydrocarbons are present as tar sand deposits exposed at the surface in the Permian and Triassic strata of central and eastern Garfield County (Circle Cliffs and Tar Sand Triangle deposits). Their origin is a long-standing enigma; some explorationists suggest the Chuar Group may have been their source, but this hypothesis remains as only one of several possible explanations.

Source Rocks

The Walcott Member of the Chuar Group is the youngest member of the Kwagunt Formation. It is an organic-rich, gray to black mudstone and siltstone containing thin sequences of sandstone and stromatolitic, crypto-algal, pisolitic dolomite probably deposited in lacustrine to tidal-flat environments (Elston, 1989). Where measured, the 850- to 1100-foot-thick Walcott Member is the richest unit of the Chuar Group in terms of organic content. Total organic carbon (TOC; algal type) has been documented as high as 10% in the dark mudstones; 3% TOC is average for the source-rock component of the Walcott. Thermal maturity of the Chuar Group is partially within the assumed oil-generation window (an estimated vitrinite reflectance [Ro] equivalent range of 0.8 to 1.35%). Perhaps half of the mature source rock has an estimated Ro equivalent greater than 1.35% and has passed into the gas generative phase. Upper Paleozoic and Mesozoic outcrops in the play area have Ro values between 0.5 and 0.6%, indicating that they have not been deeply buried. In the Arizona part of the play, the top of the Chuar Group is probably at estimated Ro of 0.8 to 1.0%.

Depth to the top of the Chuar Group at the Utah-Arizona state line in the center of the play is about 13,000 feet, implying that Arizona is oil-prone and Utah is gas-prone. The Utah source beds are more mature, having been buried deeper in the Kaiparowits Basin area than in the Arizona Kaibab Plateau area. Chuar depths on the west side of the play in the southwestern portion of the GSENM region are relatively shallow, at about 5000 feet, due to the north-trending Kaibab uplift.

The Tidewater No. 1 Kaibab Gulch well (section 34, T. 42 S., R. 2 W., SLBL&M, Kane County), drilled in now excluded lands (map 4) penetrated 900 feet of dark-gray shale originally assigned to the Chuar Group, but Lillis (2016) places it in the Nankoweap Formation below the Chuar. Munger and others (1965) reported an abundance of carbonaceous material and associated plant-like spores. However, the analyses of well cuttings by the Utah Geological Survey suggest that these rocks would be poor sources of hydrocarbons (Chidsey, 1997).

Timing and Migration

Timing of generation and migration are two big unknowns in this play. The Laramide orogeny is suspected as being a reasonable time for generation, but questions remain. If migration occurred prior to the late Paleozoic uplifts or barriers, accumulations may be a long distance from the play area. If migration occurred after late Paleozoic and Laramide deformations, ample structural traps would be available. In addition, the presence of significant carbon dioxide in the Tapeats Sandstone in wells drilled in excluded lands on the Circle Cliffs uplift and the Rees Canyon anticline in the Kaiparowits Basin implies the region has undergone a natural flushing by carbon dioxide from volcanic areas to the north that appears to have pushed hydrocarbons to the south (figure 8) (Chidsey and others, 1998).

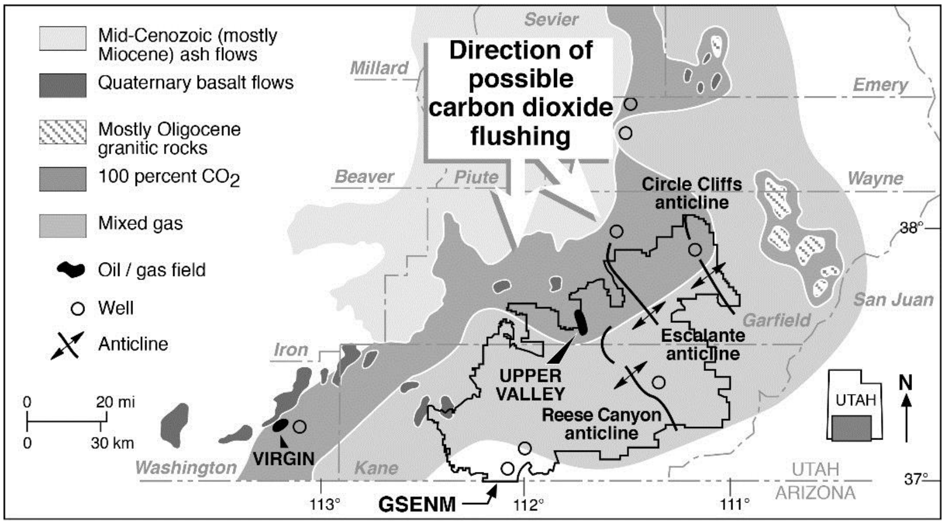


Figure 8. *Possible nature carbon dioxide flood from volcanic area to the north of the GSENM region may have flushed hydrocarbons out of Paleozoic reservoirs in anticlinal traps in south-central Utah. From Utah Geological Survey (1998).*

Traps

Stratigraphic traps (porosity and permeability pinchouts and major disconformities and angular unconformities) are also known to be present but are not necessary to make this play work. Within this play are numerous anticlines and monoclines. Very limited drilling of large anticlines has been unsuccessful to date, but many large anticlines are undrilled or not drilled to the lower Paleozoic and Precambrian. These structures are large enough to permit very large accumulations, however, only carbon dioxide and minor amounts of methane have been encountered to date. Graben-like structures in the basement could also trap hydrocarbons. The Bright Angel Shale is probably an excellent seal overlying the Tapeats. Other seals in the Paleozoic section include impermeable carbonates, fine-grained clastics, and evaporites.

Exploration, Development, and Production

Other than carbon dioxide tests, no hydrocarbon production has been recorded from this play anywhere in Utah or Arizona, and only five wells in the GSEEL have penetrated Proterozoic-Cambrian strata; Tidewater No. 1 Kaibab Gulch well discussed previously. The other wells were drilled in the 1990s to test the Proterozoic Chuar sediments in the Kaiparowits Basin, but encountered metasediments or metamorphic schist instead, indicating the Chuar play is more complex than previously thought. The Circle Cliffs No. 28-l Federal well (section 28, T. 33 S., R. 7 E., SLBL&M, Garfield County) drilled in 1994 on now excluded lands penetrated Precambrian metasediments and tested 5 million cubic feet of gas, which was nearly 100% carbon dioxide, from the Tapeats Sandstone before it was plugged and abandoned. The Rees Canyon State 32-2 well (section 34, T. 39 S., R. 5 E., SLBL&M, Kane County) was drilled in 1997, the last well in the GSEEL. The well penetrated Precambrian metasediments and tested the Cambrian Tapeats Sandstone and Muav Limestone. Initially petrophysical log analysis of these formations was reported as indicating significant gas shows and a major new gas discovery. Unfortunately, the operator Conoco plugged and abandoned the well after recovering only water and traces of hydrocarbon and non-hydrocarbon gas from drill-stem and production tests in the Tapeats and Muav. Conoco and the UGS re-evaluated the reservoir quality of Tapeats and Muav and the gas shows by independently analyzing the petrophysical logs. The petrophysical log analysis indicated that both formations are tight reservoirs, although both formations may have fracture porosity. After correcting the logs for the proper matrix density in the Tapeats Sandstone, the Tapeats had an average density porosity of 3 to 4% and much of the log neutron-density (gas effect) crossover was reduced. The remaining crossover likely reflected uneconomic gas zones because of low porosity. The Muav only had an average porosity of 1 to 3% and the high resistivity recorded on the logs probably reflect the resistivity of the rock. Thus, the gas shows in the Muav are considered meaningless (Sprinkel, 1997).

Occurrence and Development Potential

The Late Proterozoic/Cambrian Play remains hypothetical and unproven. If the Chuar is as good a source rock as believed, one would expect to find relic oil or seeps in this play; however, no Chuar seeps have been reported in the Grand Canyon or in the paleo-high areas, such as around the excluded lands in the Kaibab uplift. On the other hand, more than a dozen shows have been encountered in the Paleozoic section in Arizona west of longitude 112°. Some of the Cambrian penetrations in the play encountered only the Bright Angel Shale and Muav Limestone, but did not test the lower potential reservoir in the Tapeats Sandstone, thus exploration to the Chuar is extremely limited. Wells drilled in the 1990s to test the Precambrian Chuar sediments in the Kaiparowits Basin encountered metasediments and metamorphic schist, indicating the Chuar play is more complex than previously thought. Based on the above information, the Late Proterozoic/Cambrian play is assigned a low potential (L) for the occurrence of economic petroleum deposits, with C level of certainty for this potential (map 7). The GSEEL are prospective for carbon dioxide in the Tapeats Sandstone.

This Late Proterozoic/Cambrian Play is likely to remain a rank wildcat play into the foreseeable future. More details on the extent of the Chuar in Utah need to be worked out, probably via geophysical methods. The timing of petroleum generation, and the timing and direction of migration are problematic. The development potential of this play is low (L) because of its remoteness from pipeline and road infrastructure, specific targets are as yet undefined, high risk, and because it is the deepest and generally most expensive play to explore compared with the shallower play reservoirs (map 8). Some operators looking to explore the shallower reservoirs may be tempted to make stratigraphic tests to the basement if leases are available. No exploration for carbon dioxide in the GSENM region in Late Proterozoic/Cambrian play is expected since there is no market for that gas for the foreseeable future. Only one field in Utah, Greater Aneth in the southern Paradox Basin, uses carbon dioxide gas for enhanced oil recovery and it is supplied via a pipeline from McElmo Dome in southwestern Colorado.

Paleozoic Devonian-Mississippian Play (UGS-2108)

Introduction

The oil-and-gas-prone portion of the Paleozoic Devonian-Mississippian Play in the Colorado Plateau underlies the entire GSEEL region (map 9). It is based on the possibility that early-formed structural and stratigraphic traps may be preserved within the Devonian through Mississippian section (figure 7), sealed by interbedded or overlying shales and shaly carbonates, or faults, independent of the unconformity trapping system. The area of this play is restricted to the north and northwest by a carbon dioxide play where the carbon dioxide was generated by the igneous rocks of the Fishlake Plateau to the north (Montgomery, 1984).

Reservoirs

Potential reservoirs include dolomitized carbonate beds, in part reefoid or moundlike, of the Devonian Temple Butte and Elbert/Ouray Formations and the Mississippian Redwall Limestone. The Redwall tested oil at Upper Valley field (map 5). However, no information in the way of reservoir quality and specific facies is available on these potential reservoirs in the GSENM region.

Source Rocks

Potential source rocks for this play are unknown. Possible local source rocks include the Thunder Springs Member of the Mississippian Redwall Limestone. The organic-rich, marine Mississippian Chainman Shale, Mississippian-Pennsylvanian Manning Canyon Shale, and equivalent rocks occur far to the west of the play. These formations could provide a long-distance hydrocarbon source through several potential carrier formations. However, these rocks are immature to overmature (Sandberg and Gutschick, 1984). Finally, the dark marine shales and shaly carbonates of Pennsylvanian age to the east in the Paradox Basin could provide another long-distance source via carrier beds and faults.

Timing and Migration

Oil generation and migration from source rocks in the Chainman and Manning Canyon Shales probably began by Permian time and earlier in areas of thick Permian–Pennsylvanian basins, such as the Oquirrh basin of Utah and the Butte basin belt in eastern Nevada. Oil generation in potential local source rocks and those in the Paradox Basin probably began in Cretaceous time when the thick section of Cretaceous rocks associated with the Sevier orogeny and the Interior Seaway was deposited in the region.

Traps

Traps are pre-Tertiary folds and vertical fault blocks; sandstone and (or) carbonate stratigraphic traps; and zones of lateral porosity change and carbonate buildups. Seals are equivalent-aged Paleozoic shales, argillaceous carbonates, and rare evaporites that interfinger with and occur as lateral equivalents of the reservoir units.

Exploration, Development, and Production

In the GSEEL, nine wells have penetrated Redwall Mississippian strata, six of these drilled through the Devonian; within the current GSENM, two wells drilled through the Devonian and one to the Mississippian. Outside the GSENM and excluded lands, minor oil shows were recorded from the Redwall Limestone at the Tenneco Oil Company 1 Johns Valley Federal well (section 35, T. 35 S., R. 2 W., SLBL&M, Garfield County) in tests before the well was abandoned. One well in the Upper Valley field, which borders excluded lands (map 5), reportedly produced 17,000 barrels of oil in tests of the Redwall Limestone before being plugged back and completed in the Kaibab Formation (Sharp, 1976). The remaining wells testing this play in the region were plugged and abandoned without hydrocarbon shows. However, the minor production and a few shows indicate some potential for this play.

Occurrence and Development Potential

Since this play has actually seen some limited, non-commercial production bordering excluded lands, it has a moderate potential (M) for the occurrence of new economic petroleum accumulations, with a C level of certainty (map 9). Although most of the large, elongate anticlines in the Kaiparowits Basin and Grand Staircase areas have been drilled to the Devonian by one or two wells, their shear lengths (some over 20 miles) suggests that untested multiple culminations may be present.

As the shallower Permo-Triassic oil reservoirs continue to deplete at Upper Valley field, it is possible the operators may look to the deeper reservoirs to extend the life of that field by drilling at least to the Redwall Limestone. However, such drilling will not entail new disturbances since the existing wells in the field would simply be deepened. Should that successfully occur, it is likely that Devonian through Mississippian reservoirs will attract drilling attention on some of the undrilled, or sparsely drilled, structures in the play area. This area is believed to have a moderate (M) development potential because of existing well facilities and some evidence for potentially economic accumulations of oil (map 10).

Permo-Triassic Unconformity Play (USGS-2106)

Introduction

This Colorado Plateau play is a downdip extension of the tar sand deposits of south-central Utah. It is based on the assumption that oil migrated generally east and south to form the giant pools that were subsequently biodegraded into the tar sand deposits near the outcrop and heavy oil accumulations in the subsurface to the west. It is named the Permo-Triassic Unconformity Play (map 11) because all of the known accumulations, shows, and oil staining are associated with this unconformity (figure 6), either above or below. The oil and gas portion of this play is again bounded to the north and northwest by a carbon dioxide play that was generated by intrusion and extrusion of Fishlake Plateau volcanic rocks (Montgomery, 1984). Major accumulations of carbon dioxide were discovered in the Permian and Triassic section of the Escalante field just north of the GSENM (map 5).

Reservoirs

The tar sand and heavy oil accumulations are in the Permian White Rim Sandstone. All of the sandstones are eolian deposits that have excellent porosity and permeability. Thicknesses range from a pinchout edge to 300 feet. Downdip production has been recorded in Upper Valley field from the Timpoweap Member of the Triassic Moenkopi Formation and from the Permian Kaibab Limestone.

Production at Upper Valley field is from carbonate zones in the Beta Member of the Kaibab Limestone and the Timpoweap Member of the Moenkopi Formation. Cores indicate a variety of depositional environments including open marine subtidal, nearshore marine/intertidal, restricted marine/lagoon, and supratidal/microbial (algal mat) (Goolsby and others, 1988). Carbonate fabrics range from oolitic/skeletal grainstone to wackestone containing intergranular, vuggy, moldic, channel, intercrystalline, and fracture porosity types (Sharp, 1976, 1978). Dolomitization and brecciation have occurred in various degrees and forms.

Carbon dioxide-bearing Reservoirs at Escalante field include the eolian Permian Cedar Mesa Sandstone, shallow marine Toroweap Formation and Kaibab Limestone (Black Box Dolomite in the northeast part of the GSENM), and the tidal flat to marine Triassic Moenkopi and fluvial flood plain Chinle Formations.

Source Rocks

A wide variety of source rocks have been proposed for the tar sand deposits and, hence, the downdip accumulations. Among the most prominently mentioned are the Precambrian Chuar Group, Mississippian Chainman Shale, Pennsylvanian Paradox Formation, Permian Kaibab Limestone and Phosphoria Formation, and Triassic Moenkopi Formation. Oil analysis suggests two possible sources for the hydrocarbon production at Upper Valley. The pristane/phytane ratio versus canonical variable plot indicates a probable unknown Permian source whereas the aromatic versus saturated hydrocarbons plot suggests the oil may be more closely associated with a Mississippian Chainman Shale source (Sprinkel and others, 1997; Chidsey and others, 2007).

The thick sections of Paleozoic carbonate rocks in the region are the probable carbon dioxide source-rocks for the accumulation at Escalante field and elsewhere in the region. Metamorphism of marine carbonates by the heat of nearby igneous intrusive rocks likely generated the high concentrations of carbon dioxide found in the Escalante anticline. Carbon dioxide may also have been produced by the reaction of hot, acidized ground water with the carbonate rocks, or the heating of kerogen-bearing (source) rocks (Petroleum Information, 1984). Extensive Tertiary, volcanic rocks covering large areas of the High Plateaus implies intrusions of high-level Tertiary plutons. These plutons probably acted as heat sources.

Timing and Migration

Neither the time of generation nor migration is known, although most work suggests that final migration into the Tar Sand Triangle deposits of south-central Utah occurred after the Laramide orogeny. Igneous rocks are believed to have reacted with Paleozoic carbonate rocks at depth and created a pulse of carbon dioxide about 30 million years ago that flushed petroleum to the east and south from under the Fishlake Plateau (Montgomery, 1984; Chidsey and others, 1998; UGS, 1998), but the exact migration pathways are unknown.

Traps

Both structural and combination traps predominate even though the largest deposit, the Tar Sand Triangle deposit, is largely a stratigraphic trap. As the hydrocarbons migrated eastward and southward, existing structures (mostly Laramide in age) would have been charged, or filled with hydrocarbons, producing fields such as Upper Valley (map 5). In the case of Upper Valley field, the oil was pushed to the flank of the structure after charging of the reservoirs by regional hydrodynamic conditions (Sharp, 1976, 1978; Goolsby and others, 1988; Allin, 1990). Depths to the petroleum deposits range from less than 1000 to almost 8000 feet and seals are provided by shale beds as well as by reduction in permeability due to cementation

The trap for the carbon dioxide for Escalante field is the large, northwest-trending Escalante anticline which extends into the northern part of the GSENM and excluded lands near the town of Escalante.

Exploration, Development, and Production

This play has been the most explored in the GSENM region; 24 wells in the GSEEL and 21 wells in the former GSENM penetrated the Permo-Triassic reservoirs. Most of these scattered wells tested the crests of the structures rather than being located somewhat off the crest, as is the situation with the oil accumulation at the Upper Valley field. Thirty-seven Permo-Triassic wells have been drilled on the Upper Valley anticline in Upper Valley field; as of October 1, 2017, there were 20 producing oil wells. The medium-sized Upper Valley field (discovered in 1964) was Utah's eleventh largest oil producer in 2016 and has produced a total of 29 million barrels of oil as of October 1, 2017 (Utah Division of Oil, Gas and Mining, 2018).

In 1960 and 1961, wells drilled by Phillips Petroleum tested carbon dioxide from the Permian and Triassic rocks on the Escalante anticline. Mid-Continent drilled the Charger No. 1 well (section 29, T. 32 S., R. 3 E., SLBL&M, Garfield County) to a depth of 3443 feet within the structure in 1983. Gas flowed at a rate as high as 12.4 million cubic feet per day over an effective pay interval of 2000 feet (Montgomery, 1984). The gas from the Charger well is composed of 93-99% carbon dioxide, 1-6% nitrogen, and 0.4-0.7% methane (Moore and Sigler, 1987). Reserve estimates range from 1.5 to 4.0 trillion cubic feet of gas (Petroleum Information, 1984). However, tests performed on two wells in 1986 indicated a much smaller carbon dioxide reservoir.

Occurrence and Development Potential

This play is the most promising for future discoveries in the GSEEL. In spite of Upper Valley field, this play is very lightly explored considering the vastness of the region. However, until a better understanding of the regional hydrodynamic picture, oil migration timing, and source rocks questions are answered, the true petroleum occurrence potential of this play remains unclear. Since this play has production bordering excluded lands, it has a high potential (H) for the occurrence of new economic petroleum accumulations, with a D level of certainty (map 11).

This play has been the most successful within the GSENM region in the past, and despite unresolved play parameters and the remote nature of the area, it is assigned a high (H) rating for the development potential for new oil discoveries (map 12). The shut-in carbon dioxide wells of the Triassic Shinarump Member of the Chinle Formation and the Cutler Group along the Escalante anticline represent the best, albeit slim, chance for future development. However, since no market has developed in the past 35 years for the Escalante deposit, no exploration or development is anticipated for new carbon dioxide deposits in the GSEEL even though there are some structures of the same order of magnitude with the same stratigraphic section. As stated earlier, ample supplies of carbon dioxide are available from other states. Moreover, there are no planned carbon dioxide enhanced oil-recovery projects in Utah.

Cretaceous Sandstone Play (UGS-2107)

Introduction

This extension of an Upper Cretaceous conventional play in the Uinta-Piceance Province (Beeman and others, 1996; Charpentier and others, 1996; Gautier and others, 1996) includes the Upper Cretaceous units of south-central Utah. This play covers most of the excluded lands in the Kaiparowits Basin area and parts of the northern Grand Staircase area in the GSENM region (maps 13 and 14).

Reservoirs

The Straight Cliffs Formation consists of coalescing delta complexes derived from a westerly source. Permeable zones are present both in the delta front and in distributary channel sandstone bodies. In addition to the Straight Cliffs reservoirs, marine and deltaic sandstones of the Dakota Formation (more recently called the Naturita Formation), and the fluvial sands of the Cedar Mountain and Morrison Formations are also potential reservoirs.

Source Rocks

Mancos/Tropic Shale beds are potential source rocks for this play; however, because these beds thin and give way to sandstone, carbonaceous shale, and coal to the west, and since gas alone has been primarily produced, it is likely that the coals and carbonaceous shale that intertongue with the sandstone bodies are the source of gas.

Timing and Migration

Data on maturity of these rocks come from limited vitrinite reflectance data from the GSENM region and indicate that the Upper Cretaceous rocks are immature or just entering the oil generation window (Hucka and others, 1997).

Traps

Entrapment of gas in this play is related to structural closure on simple anticlinal folds and complexly faulted anticlines. Updip pre-faulting migration toward the depositional edge of some of the Cretaceous units may also have influenced accumulation. Discontinuous sandstone bodies in the deltaic complex also offer the possibility of stratigraphic trap accumulations. Depths range from 0 to more than 7000 feet.

Exploration, Development, and Production

By virtue of being shallow, the Cretaceous Sandstone reservoirs have been penetrated by all of the deeper tests in the GSENM region, resulting in 24 wells in excluded lands and 21 wells in the former GSENM in this play. All 37 wells drilled in Upper Valley field penetrated the Cretaceous Sandstone reservoirs without any mention of shows in these upper units; however, with the development attention focused on the Permo-Triassic reservoirs, the Cretaceous reservoirs may have been somewhat overlooked. The 1 Buck Knoll well (section 36, T. 37 S., R. 4.5 W., SLBL&M, Garfield County) about 6 miles west of excluded lands in the Grand Staircase area (map 4), was completed and abandoned in 1985 in the Permian Cedar Mesa Sandstone at a total depth of 10,119 feet. Cores and formation tests run on this well had weak oil shows in the Cedar Mesa Sandstone and Kaibab Limestone, the Moenkopi Formation, and the Dakota Formation. Between 2002 and 2004, Legend Energy drilled four wells to test mainly for coal-bed gas in the Dakota Formation in the Kane County west of the GSENM region. All four wells were plugged and abandoned and only one, the Pugh 8 (section 34, T. 38 S., R. 5 W., SLBL&M, Kane County), had a show of gas in the Dakota coals that were cored; no gas desorption data have been released. Based on the limited drilling results to date, the Dakota-Tropic interval of the northwestern portion excluded lands in the Grand Staircase area and the Kaiparowits Basin area have the best potential, albeit low.

Occurrence and Development Potential

The Cretaceous Sandstone Play has been lightly explored and this portion of the play is prospective for oil and gas covering a broad swath through the GSENM region. Undiscovered deposits are likely to be found in subtle structures and stratigraphic traps in untested portions of the play. Elsewhere in Utah this play has been mainly productive for gas, with minor amounts of associated oil. This play is rated low (L) for the occurrence potential of petroleum, with a certainty level of C (map 13). There is no potential for the occurrence of carbon dioxide in this play.

The potential for development of the Cretaceous Conventional play is low (map 14). Dampening interest in this play is its remoteness from established markets and pipelines and the questionable maturity of the source rocks to provide adequate hydrocarbon generation for economic accumulations. Any wells drilled to test deeper reservoirs would hopefully also test the Cretaceous section where penetrated.

Coal Bed Methane Play (UGS-2100)

Introduction

The coal-bed-gas play was defined by the UGS to cover potential reservoir areas of the coal-bearing Upper Cretaceous units of south-central Utah (map 15). The coal-bearing units in the GSENM region include the Dakota Formation and Straight Cliffs Formation (figure 6). The play area is very small in the excluded lands of the western Kaiparowits Basin and the northernmost part of the Grand Staircase.

Reservoirs

The coals of the Dakota and Straight Cliffs Formations were deposited by a series of coalescing delta complexes derived from a westerly source. Coal beds are generally developed in a 6- to 10-mile-wide band landward of the delta front sandstone bodies. Carbonaceous shale and sandstone that interfinger with the coal beds may also be charged with some coal-bed-derived gas. In the Kaiparowits coalfield of the Kaiparowits Basin area, the play is defined where the net coal thickness is greater than 10 feet and the coal beds are covered by 1000 to 6000 feet of overburden (Allison, 1997).

A few shallow coal beds from both the Dakota and Straight Cliffs Formations with less than 1000 feet of cover have been tested from coal exploration holes, and the methane content from these samples ranges from no methane up to about 13 cubic feet per ton (Doelling and others, 1979). These numbers are not encouraging, but deeper coal beds in the area may contain more methane. In 2002, Legend Energy drilled the Pugh 8 well (section 34, T. 38 S., R. 5 W., SLBL&M, Kane County) and cored two Dakota coal beds between 1203 and 1236 feet, and reported gas shows from these coals. The well was plugged and abandoned in early 2004, but no specific gas content data have been released.

Source Rocks

The reservoir coal beds are also sources for gas; the gas can either be thermogenic gas generated during increasing coalification, or biogenic gas that was generated by bacteria introduced by groundwater movement through the coal beds. Carbonaceous shale has also been shown to be a source of gas at the Drunkards Wash field in Carbon County, Utah (Lamarre, 2001). Available coal quality data indicate the coal in the GSENM region is mostly subbituminous in rank (Doelling and Graham, 1972; Kohler and others, 1998) and thus, would not have generated more than 50 to 100 standard cubic feet of thermogenic gas per ton (scf/ton) of coal. Limited desorption data from 14 samples from the Dakota and Straight Cliffs coals (one from Johns Valley, two from the Alton coalfield, and 11 from the Kaiparowits Plateau coalfield [Kaiparowits Basin area]) with less than 800 feet of cover have gas contents ranging from no gas up to 14 scf/ton of coal (Doelling and others, 1979) and average about 4 scf/ton. The deeper coals would need to have significantly higher gas contents to be economically attractive but given the subbituminous rank of the coal in these fields, the gas content will not likely be more than 100 scf/ton.

Timing and Migration

Limited vitrinite reflectance data from the Dakota and Straight Cliffs coals in the GSENM region indicate that the Upper Cretaceous rocks in this area are low rank (borderline subbituminous to bituminous), with vitrinite reflectance levels of less than 0.57%, and are therefore immature to just entering the oil generation window (Hucka and others, 1997). Initial thermogenic gas was possibly generated in the Eocene during maximum burial. Late-stage biogenic gas generation would have begun during uplift, cooling, and dissection during the late Pliocene and Pleistocene.

Traps

Coal-bed gas is held in the matrix of the coal by the hydrostatic pressure of the groundwater in the coal bed. Fractures in the coal beds, or cleats, allow the gas and water to be communicated to the well bore. Higher rank coals tend to have more closely spaced cleat development, but structure may enhance coal fracture development whereby better fracture networks are developed along fold axes and faults. Updip migration may also have influenced the accumulation of coal-bed gas deposits if the coal beds pinch out before they reach the surface. In areas with active hydrologic systems of recharge and groundwater flow, bacteria introduced by groundwater can generate secondary biogenic methane in the coal beds. Depths of the coal-bed reservoirs in this play range from 0 to about 6000 feet.

Exploration, Development, and Production

No coal-bed gas production has come from the GSENM region, and only limited exploration has taken place. Although coal beds of sufficient thickness are present in the GSENM region coal-bed gas play, the low rank of the coal and its corresponding low gas content makes the potential for coal-bed gas production low.

Occurrence and Development Potential

Most of the Coal Bed Methane Play with favorable potential based on net coal thicknesses greater than 10 feet and coal beds covered by 1000 to 6000 feet of overburden is located in the Kaiparowits Basin area where most of the lands are still included in the Kaiparowits National Monument; only a few relatively small tracts on excluded lands are within the play (map 15). As discussed above, no wells have discovered economic gas accumulations in the coal beds and the limited testing to date has resulted in discouraging gas content and show results. A similar gas play in central Utah has been mainly productive where gas has migrated from deeper basin sources. This play is rated low (L) for the occurrence potential of gas, with a certainty level of C (map 15). There is no potential for the occurrence of carbon dioxide in this play.

The potential for development of the Coal Bed Methane Play is low (map 16). As is the case for all oil and gas plays in the GSENM region, this play is also far from established markets and pipelines, there are no encouraging gas tests, and there is questionable gas maturity and gas content of the coals economic accumulations. Again, as with the Cretaceous Sandstone Play, any wells drilled to test deeper reservoirs should also test the Cretaceous coal beds where penetrated.

3.1.2 Coal

Description of Energy and Mineral Resources

Beds of coal thick enough to be mined commercially occur in the Cretaceous Dakota and Straight Cliffs Formations near the GSEEL of south-central Utah (Doelling and Graham, 1972; Doelling and others, 1989). The Dakota coals occur in the Alton coalfield, where only the far eastern side overlaps with the GSEEL, while the Straight Cliffs coals occur in the Kaiparowits Plateau coalfield, located in the north-central area and south-central area of the GSEEL; these various coal-bearing areas are shown on map 17. Local lenses and stringers of coal can be found in the Triassic Chinle Formation, but none are thick enough for commercial development.

Alton Coalfield

The coals of the Cretaceous Dakota Formation (more recently called the Naturita Formation) were deposited by a series of coalescing delta complexes derived from a westerly source. Coal beds are generally found in a 6- to 10-mile-wide band that developed landward of the delta-front sandstone bodies. The coals interfinger with carbonaceous shale and sandstone. Within the Alton field, the Dakota ranges from 140 to 400 feet thick, thinning to the east (inside the GSEEL area) and thickening to the west (outside the GSEEL area) (Doelling and others, 1989). The Alton field is separated from the adjacent (to the west) Kolob field (not within the GSEEL) by the Sevier fault zone, which drops strata to its west down by 1000 to 2000 feet. There are two commercial coal zones in the Dakota in the Alton field, the more prospective Smirl bed near the top of the formation, and the Bald Knoll bed near the base. These two coal zones are lenticular in nature and thin or split into thinner plies with intervening shale across the western Alton field. The upper, or Smirl, coal zone reaches up to 11 feet thick in the western GSEEL (eastern side of the Alton coal field) but is mostly less than a few feet thick in this area (Doelling and Graham, 1972), while the lower, or Bald Knoll, is about 3-4 feet (mostly uneconomic) in the GSEEL area (Bon and others, 2006).

The Dakota coals crop out along the southern and eastern margins of the Paunsaugunt Plateau. The coal-bearing strata generally dip less than 5 degrees to the north-northeast, although the dips may locally be greater near faults or along some monoclinal folds (Doelling, 1975). The 3000-foot cover line above the Dakota coals, the maximum depth for coal mining, usually conforms very closely to the Tertiary-Cretaceous contact at the base of the Claron Formation (Doelling, 1975). The area prospective for coal-bed gas would extend from 1000 to 5000 feet of cover. The 1000-foot cover line for the Dakota coals is approximately at the Tropic-Straight Cliffs contact, while the 5000-foot cover line would roughly coincide with the upper contact of the Claron Formation.

The coal in the Dakota Formation is generally of subbituminous B rank in the Alton coalfield (Bragg and others, 1997; see table 1). The sulfur content of these coals is somewhat variable, but averages about 1.2 percent, while the ash content is generally between 10 and 15 percent. These coal beds are as thick as, but lower in heat content, and higher in ash and sulfur content, than the coal beds mined from the Blackhawk Formation in the coalfields of central Utah.

Table 1. *Coal quality data for the Alton coalfield (modified from Bragg and others, 1997).*

Alton coalfield – Smirl coal zone quality (in weight percent except Btu/lb)

	Ash	**Sulfur**	**Moisture**	**Fixed Carbon**	**Volatile Matter**	**Btu/lb**
Mean	10.2	1.2	20.8	38.4	30.6	9113
Range	4.8 - 20.9	0.5 - 3.5	16.2 - 24.2	34.6 - 42.0	28.1 – 34.1	8069 – 9780
no. samples	8	8	8	8	8	8

Alton coalfield - Bald Knoll coal zone quality (in weight percent except Btu/lb)

	Ash	**Sulfur**	**Moisture**	**Fixed Carbon**	**Volatile Matter**	**Btu/lb**
Mean	14.2	1.1	25.2	33.4	27.2	7955
Range	10.2 - 18.2	0.6 - 1.6	24.4 - 25.9	29.7 - 37.2	26.7 – 27.7	7433 – 8477
no. samples	2	2	2	2	2	2

Doelling and Graham (1972) provided estimates of the coal resource down to a depth of 3000 feet for the entire Alton field. The GSEEL portion of the Alton coalfield lies mostly within the Bryce Point, Rainbow Point, and Cannonville quadrangles, with very small portions also in the Podunk Creek and Deer Springs Point quadrangles (Doelling and Graham, 1972). Some of the coal in the Rainbow Point and Deer Springs Point quads is surface minable (Doelling and Graham, 1972). Doelling and Graham (1972) estimated a coal resource within the Bryce Point quadrangle of 184 million tons of coal (54 million tons under less than 1000 feet of cover, 58 million tons under 1000-2000 feet of cover, and 72 million tons under 2000-3000 feet of cover). They also estimated a coal resource of 132 million tons in the Rainbow Point quadrangle (45 million tons under less than 1000 feet of cover, 46 million tons under 1000-2000 feet of cover, and 41 million tons under 2000-3000 feet of cover). Both estimates only include coal in the Bald Knoll bed, at the time, the Smirl bed was believed to be too thin to be economically mined. It should be noted that only the southeast corner of the Bryce Point quadrangle is within the GSEEL area, and only a portion of the Rainbow Point quadrangle is within the GSEEL. The coal resources in the other quadrangles mentioned above were not assessed by Doelling and Graham (1972). More recently, Bon and others (2006) studied the coal resource within 8 quadrangles in the southern Alton coalfield, but excluded the areas covered by the Grand Staircase-Escalante National Monument.

According to the BLM Kanab Field Office Coal Unsuitability Report, all coal in the Alton field in the GSEEL is within an area identified as unsuitable for surface mining due to its proximity to Bryce Canyon National Park (map 18)

Kaiparowits Plateau Coalfield

The coals of the Cretaceous Straight Cliffs Formation were deposited by a series of coalescing delta complexes derived from a westerly source. Coal beds are generally found in a 6- to 10-mile-wide band that developed landward of the delta-front sandstone bodies. The coals interfinger with carbonaceous shale and sandstone. The coal beds of the Straight Cliffs Formation are thicker and more numerous on the eastern side of the Kaiparowits coalfield near Escalante and thin to the west. In the Escalante area, the Alvey, Rees, and Christensen coal zones, in descending order, are well developed, while in the western part of the field only the lowermost coal zone is present (Doelling, 1975). The total coal thickness in the Straight Cliffs Formation is greatest along the axis of the Kaiparowits basin and thins toward the eastern and western edges (Hettinger and others, 1996). Individual coal beds in the Straight Cliffs Formation range in thickness from 1 foot up to 30 feet (Doelling, 1975).

The Straight Cliffs coals are exposed on the eastern and western margins of the Kaiparowits basin in the Escalante and Tropic areas respectively. The coals get progressively deeper towards the axis of the basin, reaching a maximum depth of slightly over 6000 feet in the center of the basin within a northern and southern area of the GSEEL (Hettinger and others, 1996). The coal down to a depth of 3000 feet is potentially minable, while the coal between 1000 and 6000 feet deep could be prospective for coal bed gas.

The rank of the coal decreases from high volatile C bituminous to subbituminous B moving from south to north along the Kaiparowits Plateau field; sulfur content also increases to the north (Kohler and others, 1998). Hettinger and others (1996) includes several analyses of coal quality from various sites and beds within the Kaiparowits coalfield, summarized in table 2. While the ash and sulfur levels of these average Straight Cliffs coal analyses are similar to those for coal currently mined from the Blackhawk Formation in central Utah, the moisture content is considerably higher and the heat content somewhat lower.

Table 2. *Coal quality data for the Kaiparowits Plateau coalfield (modified from Hettinger and others, 1996).*

Straight Cliffs Formation – all coal zones quality (in weight percent except Btu/lb)

	Ash	Sulfur	Moisture	Fixed Carbon	Volatile Matter	Btu/lb
Mean	10.0	1.0	12.3	39.4	38.3	10,157
Range	2.3-29.9	0.3-2.3	5.0-20.5	24.9-48.7	27.9-50.7	6962-12477
no. samples	95	95	95	95	95	18

The USGS has estimated the total coal resource within Kaiparowits Plateau coalfield (Hettinger and others, 1996). The USGS's estimate was not made on individual beds but on the total net coal in the Straight Cliffs Formation, so it is difficult to establish how much of this coal is actually minable; however, the size of the estimate indicates the coal resource is significant. According to Hettinger and others (1996), the Kaiparowits Plateau contains an original resource of 62 billion tons of coal in the ground (this includes all beds greater than 1 foot thick). None of the resource was identified as being recoverable from surface mining. At least 32 billion tons of coal are unlikely to be mined because the coal beds are either too deep, too thin, or inclined at more the 12 degrees, or in beds that are too thick to be completely recovered in underground mining. The estimated balance of 30 billion tons of coal resource does not reflect land use or environmental restrictions, does not account for coal that would be bypassed due to mining of adjacent beds, does not consider the amount of coal that must remain in the ground for roof support, and does not take into consideration the continuity of beds for mining. Studies from central Utah coalfields (Tabet and others, 1999; Quick and others, 2004; Quick and others, 2005) indicate that only about 30 percent of the original minable coal in the ground can ultimately be recovered by underground mining, thus the recoverable coal from part of the Kaiparowits Plateau field is estimated at about 9 billion tons.

Table 3 lists the total identified coal resource, in all coal beds (29 billion tons, beds greater than 1 foot thick and under less than 3000 feet of cover), for townships adjacent and within the GSEEL areas (Hettinger and others, 1996). However, the GSEEL boundaries do not follow township boundaries, so to estimate the coal resource specifically within the GSEEL area, the percent of the township that overlaps with the GSEEL was calculated and this percent was applied to the total resource within the township (table 3). Using this estimation method, 11 billion tons of coal are located within the GSEEL areas of the Kaiparowits Plateau (table 3). In order to estimate the potential recoverable coal resources, a 21% discount factor was applied, based on several mining criteria analyzed by Kohler and others (undated), leaving a potential recoverable coal resource of 2.4 billion tons within the GSEEL areas of the Kaiparowits coalfield.

Table 3. *Original identified coal resource for the Kaiparowits Plateau coalfield within and adjacent to the GSEEL by depth of cover and township (in millions of tons; modified from Hettinger and others, 1996).*

Township	**Area of Twn within GSEEL**	**Identified Coal Resource within Twn[1]**	**Percent of GSEEL within Twn**	**Estimated identified coal resource within GSEEL**	**Estimated recoverable coal resource within GSEEL (21% of total resource)[2]**
35S-1E	SE corner	399.4	8.7%	34.6	7.3
35S-2E	southern half	2.1	54.6%	1.1	0.2
36S-1W	SW corner	268.4	21.0%	56.3	11.8
36S-2E	Entire twn	1,415.2	100.0%	1,415.2	297.2
36S-3E	West half	270.9	30.8%	83.5	17.5
37S-1W	Small strip on west side	311.6	17.6%	54.9	11.5
37S-2E	NW corner and east half	4,186.2	43.1%	1,804.3	378.9
37S-3E	West half	1,090.5	43.0%	468.7	98.4
38S-1W	SW large area	31.5	23.9%	7.5	1.6
38S-3E	NW corner and east half	3,561.5	31.8%	1,131.1	237.5
39S-3E	Small sliver on east side	4,579.4	1.8%	81.5	17.1
39S-4E	Most of Twn	2,389.8	78.7%	1,880.1	394.8
39S-5E	SW corner	2,487.7	16.8%	417.4	87.7
40S-3E	Sliver on south and east side	3,076.4	5.9%	181.5	38.1
40S-4E	Most of Twn	243.9	94.2%	229.7	48.2
40S-5E	NW and SE corners	873.8	43.9%	383.2	80.5
40S-6E	Southern half	87.5	43.4%	38.0	8.0
41S-3E	Most of Twn	1,379.3	83.1%	1,145.6	240.6
41S-4E	Most of Twn	1,568.5	92.5%	1,450.4	304.6
41S-5E	NE corner	567.0	25.6%	145.2	30.5
41S-6E	Northern half	2.4	42.9%	1.0	0.2
42S-2E	Northern half	72.4	65.6%	47.5	10.0
42S-3E	Entire Twn	335.2	100.0%	335.2	70.4
42S-4E	Northern half	69.5	72.1%	50.1	10.5
42S-5E	NW corner	0.1	24.9%	0.0	0.0
43S-3E	Northern strip	21.0	14.0%	2.9	0.6
Total		**29,291**		**11,447**	**2,404**

[1]From Hettinger and others, 1996; coal beds >1 ft thick and under <3000 ft cover

[2]Based on similar calculations from Kohler and others, undated

Mineral Exploration, Development, and Production

Despite the large coal resources present in the southern Utah coalfields, virtually no coal production has occurred in the GSEEL areas. Hundreds of coal exploration holes were drilled in the late 1960s and 1970s in the Alton and Kaiparowits Plateau coalfields, when a major national effort was made to increase coal-fired power generation.

All historic small coal mines and prospects in the Alton field are located south of the town of Alton, west of the GSEEL areas (up to 14 small mines). In 2011, Alton Coal Development opened a surface mine on private land and has since mined nearly 4.0 million tons of coal from the Smirl bed and a minor amount of coal (~45,000 tons) from a small underground mine. Future plans call for the mine to include surrounding federal lands and produce roughly 2 million tons a year. Besides measured sections on outcrop and several exploratory drilling, no coal mines or prospects were ever developed on the eastern side of the Alton coal field in the GSEEL area.

Thirteen small historic coal mines and about 4 prospects accessed the Kaiparowits Plateau coalfield within the GSEEL area, all of which produced less than 25,000 tons total (table 4) (Doelling and Graham, 1972). All of these small mines were developed to provide fuel for local heating and domestic use. Coal mining apparently began in the late 1800s, but no coal mine has been active in the Kaiparowits since the early 1970s. Starting in the 1960s, several energy companies expressed interest in commercially developing coal in the region to supply a proposed coal-fired power plant. As many as 23 companies acquired coal leases and drilled about 1000 coal test holes (Doelling and Graham, 1972) (map 17 and see historic leases on map 1). However, the power plant was never developed.

In the latter part of the 1980s, Andalex Resources began formulating plans to mine underground and ship up to 2.5 million tons of coal annually from their leasehold in the southern part of the Kaiparowits coalfield (most of which is in the GSEEL area, map 17). Environmental analyses for the proposed mine, required as part of the permitting process, were underway at the time the Grand Staircase-Escalante National Monument was named.

Table 4. *Past coal mines and prospects in the Kaiparowits Plateau coalfield in the GSEEL area (Doelling and Graham, 1972).*

Mine	UTM-E (NAD27)	UTM-N (NAD27)	Dates of Operation
Alvey	444310	4171885	1920-1962, 1952-1961
Schow	443755	4174305	1893-1930
Christensen	442735	4174270	1893-1930
Richards	443380	4174395	1913-1928
Shurtz	443545	4174295	1913-1928
Winkler	444215	4171630	Unknown
Spencer 1	448690	4114850	1913
Spencer 2	448780	4114940	Unknown
Warm Spring	452760	4117890	1971
Bryce Canyon	418900	4111120	1939-1970?
Davis	416230	4165740	1952-1953
Pollock	416305	4165940	1920s
Shakespear	413530	4168630	1952-1963?
Prospect 1	444465	4173625	Unknown
Prospect 2	444465	4173685	Unknown
Prospect 3	458240	4127670	Unknown
Prospect 4	452220	4113730	Unknown

Potential for the Occurrence and Development of Coal Resources

Substantial past coal exploration drilling in both the Alton and Kaiparowits Plateau coal fields has been sufficient to meet BLM requirements to delineate Known Recoverable Coal Resource Areas (KRCRA). The areas within each field that have thick, shallow coal have all been rated high (H) for occurrence potential with a D level of certainty (map 17). The deeper and thinner parts of each coal field have been rated as high (H) for occurrence potential, but with a C level of certainty (map 17).

The Alton coalfield within the GSEEL area contains coal beds greater than 4 feet thick and that are under less than 3000 feet of cover, including a small area under less than 200 feet of cover potentially suitable for surface mining. However, despite the presence of several exploratory drill holes, no historic coal mining has occurred in the Alton coalfield within the GSEEL area. In addition, the area of the Alton coalfield in the GSEEL has been declared by the BLM as unsuitable for surface mining (and/or surface disturbance related to underground mining) due to its proximity to Bryce Canyon National Park. These declarations can change, but due to the mostly thinner nature of the coal beds, it is believed that development in this area is low (map 18).

Significant coal resources, with beds thicker than 4 feet and under less than 3000 feet of cover, are in the Kaiparowits Plateau coalfield. Nearly 1000 exploratory holes have been drilled to define the resource. In addition, several small historic mines produced minor amounts of coal in the early 1900s. Therefore, the coal resources of the Kaiparowits Plateau within the GSEEL areas are rated high (H) for development potential, except within Wilderness Study Areas (WSAs), where the development potential is rated as low (L) (map 18).

As the low-cost coal resources of the Book Cliffs and Wasatch Plateau coalfields of central Utah become ever more depleted over the next 15 years, it is possible that companies could look to non-traditional areas (e.g., Kaiparowits) to meet possible future coal demand (e.g., if an export market is established). However, the lack of current infrastructure in the area and the potential long transportation routes to market, will make this area challenging to develop in the current low-coal demand environment.

3.1.3 Tar Sands

Description of Energy and Mineral Resources

Tar sands are sedimentary deposits, typically sand or sandstones, containing viscous bitumen. Tar sands require processing beyond conventional methods, and the bitumen, or tar, must have a viscosity of 10,000 centipoises or greater to classify as a tar sand. Tar sands are thought to originate as typical crude oil reservoirs, which are subsequently exhumed by erosion. Exposure of the crude oil to near-surface or atmospheric conditions allows release of volatiles and biodegradation, causing the high viscosity of the bitumen. On federal lands, tar sands can only be leased within areas designated as a Special Tar Sand Area (STSA). Within STSAs oil and gas leases can be converted to combined hydrocarbon leases to allow development of tar sand as per the Combined Hydrocarbon Leasing Act. At present, there are 34 suspended oil and gas leases and one pending application for a combined hydrocarbon lease conversion, which are wholly or partially within the GSEEL.

The Circle Cliffs STSA overlaps some of the northeastern GSEEL, and covers the Circle Cliffs tar sand deposit (map 19). The deposit is exposed in a doubly-plunging, northwest trending, breached anticline. The core of the anticline, which exposes Triassic Moenkopi Formation and Permian rocks, is about 30 miles long and 10 miles wide. The northeast limb is steep, with dips ranging from 25º to near vertical, and the southwest limb dips gently at a few degrees (Ritzma, 1980). Some faulting is present in the core of the anticline.

The bitumen occurs primarily within the Torrey Member of the Triassic Moenkopi Formation, but also, to a lesser degree, in the Moody Canyon Member of the Moenkopi Formation, the Shinarump Member of the Triassic Chinle Formation, the Permian Kaibab Limestone, and the Permian White Rim Sandstone (Ritzma, 1980). Ritzma (1980) reported that over 99% of the tar sand resource is within the Moenkopi Formation, and 95% of the resource is within the Torrey Member. The Torrey Member includes sandstone and siltstone; impregnated zones are variably saturated and range from a few feet to nearly 300 feet thick in a few areas. Wood and Ritzma (1972) included results from 12 tar sand samples from the Moenkopi Formation, Shinarump Member of the Chinle Formation, and the Kaibab Limestone within the Circle Cliffs deposit. Tar content in the samples ranged from 0.7% to 27% and averaged 6.5%; API gravity ranged from -11.1 to 6.8 and averaged -3.0.

Ritzma (1980) estimated an in-place resource of 1.3 billion barrels of bitumen in the deposit; 860 million barrels in the east flank and 447 million barrels in the west flank. Most of the east flank of the deposit is within Capitol Reef National Park and outside the GSEEL. Allison (1997) estimated that up to 550 million barrels of bitumen were within the former GSENM, suggesting that the in-place resource within the GSEEL is less than 550 million barrels. Notably, Ritzma (1980) observed that the fine-grained nature of most of the host rocks could create difficulty in bitumen extraction.

Mineral Exploration, Development, and Production

Allison (1997) suggested that interest in the Circle Cliffs tar sands may have started in the 1920s, when the Ohio Oil Company drilled for oil in the area. However, to date, little substantial exploration or development of the deposit has occurred. A sampling of some of the limited work on the deposit follows. Wood and Ritzma (1972) collected and analyzed twelve samples of the Circle Cliffs deposit as part of an effort to evaluate the bitumen of several tar sand deposits in Utah. Ritzma (1979), working on behalf of the Utah Geological and Mineral Survey, prepared a map of tar sands in Utah that included the Circle Cliffs and followed that up with a focused report on the Circle Cliffs deposit (Ritzma, 1980) that included a more detailed map of the deposit and a simple resource estimate. Some limited characterization of the Circle Cliffs bitumen has occurred in the interim (e.g., Shepherd and others, 1986; Bukka and others, 1994).

Potential for the Occurrence and Development of Energy and Minerals

The occurrence potential for tar sand is rated as high (H) with a certainty of D at known prospects or occurrences (map 19). The rating is high (H) with a certainty of C where tar sands have been mapped at the surface, and a certainty of B is assigned to areas where tar sands are projected to be in the subsurface (map 19). Development of the tar sand deposits in the GSEEL is unlikely given minimal past development of Utah tar sands and lack of specific past interest in the Circle Cliffs deposit.

3.2 Locatable Minerals

3.2.1 Introduction

Five recognized metal mining districts at least partially overlap with the GSEEL. In decreasing order of production value these districts are the Circle Cliffs U-V-Cu district, Paria West Mn district, Cannonville Pb district, Paria East U district, and the Kaiparowits Ti-Zr area. Only the Circle Cliffs district has appreciable production and most of this production is from outside of the GSEEL. None of the individual U-V-Cu mines on the GSEEL have more than a small amount of production.

The locatable metal deposits of consequence found in the GSEEL are sandstone-hosted U, V, and Cu. These deposits have a variety of locally anomalous trace metals including Pb, Zn, Mo, Co, Ni, Li, Ag, and Mn. However, none of these minor metals have been shown to reach economic concentrations and even Cu has rarely been recovered from the deposits mined in the past. Because many of the ore deposits are polymetallic, they will be discussed below by deposit type rather than by individual mineral commodity.

Several Ti-Zr-bearing heavy mineral occurrences are known in the Kaiparowits district. The deposits are fossil beach placers in the John Henry Member of the Late Cretaceous Straight Cliffs Formation. While these paleoplacers have never been exploited, they have been repeatedly explored and one deposit has a drill defined inferred subeconomic resource.

One small mine in the Paria West district produced a nominal amount of Mn ore during a period of high Mn demand from 1941 to 1944 during World War II. The Manganese King Mn nodules occur near the middle of the Petrified Forest Member of the Triassic Chinle Formation.

Locatable industrial mineral deposits in the GSEEL include gypsum, silica and industrial sand, and high-calcium limestone. High-calcium limestone is discussed in conjunction with crushed stone in the salable minerals section.

3.2.2 Uranium, Vanadium, Copper, and Minor Associated Metals

Description of Mineral Resources

Utah is the second leading Cu producing state and ranks third in U production. With the harnessing of atomic energy at the close of World War II, the U.S. Atomic Energy Commission (AEC) launched a drive to discover new sources by offering bonus payments. Widespread prospecting generated by the bonus program led to the recognition of previously unrecognized areas such as those in the Circle Cliffs and Paria East districts of the GSEEL (Doelling, 1975; Doelling and others, 1989). The quest for uranium reached its climax in the mid- to late-1950s and then declined over the next decade. The bonus program was so successful the Atomic Energy Commission had a surplus of fuel, bonus payments were dropped, U prices were fixed, and exploration and development wound down. In the early 1960s, mining continued on some defined U-V reserves and, as these operations ran out of ore, the mines closed. In the mid-1960s, plans for nuclear electrical generation plants in the United States and elsewhere stimulated a new period of property acquisition and exploration; however, the areas prospected in the GSEEL were not competitive with low cost structure of world U production and by the late 1970s exploration and development activity in the area had all but ceased (Doelling, 1975; Doelling and others, 1989).

The only significant U-V-Cu host in the GSEEL is the Shinarump Member of the Late Triassic Chinle Formation, primarily in the Circle Cliffs mining district of Garfield County (map 20). The Circle Cliffs district is geologically situated in the Waterpocket fold section of the Colorado Plateau. The district's mines flank the doubly plunging, north-northwest-trending Circle Cliffs anticline. The west limb of the fold dips gently (5° to 10°) west and the eastern limb, known as the Waterpocket fold, dips more steeply (10° to 35°) to the east. The anticline plunges gently to the northwest and southeast. The exposed rocks range from Permian, in the eroded core of the fold, to Cretaceous around the rim (Doelling, 1975).

The bulk of the Circle Cliffs' U-V ±Cu prospects and production in the GSEEL is associated with the Upper Triassic Chinle Formation, although there are also U-V occurrences in the Upper Jurassic Morrison

Formation in the district east of the GSEEL. The Triassic-hosted ores are primarily in the basal Shinarump Conglomerate Member of the Chinle Formation channels, especially where its channels have cut down into the underlying Moenkopi Formation. These Shinarump channels snake northward across the district. Mineralized areas are generally small and highly irregular; they occur where U-bearing solutions in the channel aquifers were impeded by zones of low permeability and porosity along the channels margins or where reducing conditions existed (Doelling, 1975).

The U, V, and Cu deposits belong to two closely related ore deposit models: sandstone U (USGS Model 30c) and sediment-hosted Cu (USGS Model 30b) (Cox and Singer, 1968). These two deposit types are geologically very similar and differentiated by their primary economic commodity. The sandstone U deposits are far more prevalent and economically important in the GSEEL than the sediment-hosted Cu deposits which have had only one nominal producer. The primary ore and sulfide minerals in these deposits include uraninite, roscoelite, chalcopyrite, bornite, chalcocite, pyrite, marcasite, sphalerite, and galena (Doelling, 1975). Both deposit types may have a diverse array of associated trace metals including V, Pb, Zn, Mo, Co, Ni, Li, Ag, and Mn. The Colt Mesa Cu mine, for example, has erratically high levels of Co as well as recorded cobalt minerals bieberite and erythrite (cobalt bloom) (Collins, 1975).

Outside of the Circle Cliffs district, several small U-V prospects without production occur in the Kaiparowits (two), Paria East (one), and Paria West districts (one) (map 20). Two small Cu prospects are located in the Cannonville district and one at Jodies Knoll. These prospects are inconsequential and not discussed further.

Mineral Exploration, Development, and Production

The Circle Cliffs U-V-Cu district is the only notable producer in the GSEEL. Uranium production values account for an estimated 90% of the district's values. Vanadium is a common byproduct in the sandstone U deposits and has accounted for nearly all of the remaining production values. The ore grade from the U deposits ranged from 0.05 to 0.3% U_3O_8, 0.01 to 1.01% V_2O_5, and 0.5 to 3% Cu and probably averaged about 0.2% U_3O_8 and 0.1% V_2O_5 by selective underground mining. Some of the U mills operating during the years of GSEEL U production were duel circuit operations that recovered both U and V, but not Cu. Consequently, the district has produced modest V as a byproduct of the U mines. The largest operation within the GSEEL is the Centipede U-V ±Cu mine (map 20) having produced just 1600 tons of ore averaging a modest 0.18% U_3O_8 and 0.06% V_2O_5. All of the other U-V producers in the GSEEL are significantly smaller. The known U-V deposits are generally small, irregular, and low grade, and the potential for finding undiscovered larger, higher-grade deposits in the GSEEL is unfavorable.

The standalone Colt Mesa Cu mine (map 21) had nominal Cu production in the 1970s (Doelling, 1975). The copper generally occurs as malachite, azurite, bornite, and chalcopyrite in discontinuous zones generally 1 to 6 ft thick in basal, massive, medium-grained sandstones of the Shinarump (Collins, 1975; Allison, 1997). The host sandstone has tiny bits of coal interspersed throughout. The associated trace metals at the mine (Pb, Zn, Mo, Co, Ni, Li, Ag, and Mn) have high, but very erratic metal values. The Colt Mesa Cu mine had minor Cu production at a grade of about 3% Cu (Collins, 1975; Doelling, 1975). However, it is unique because of its locally strongly anomalous associated metal values, most notably Co. These erratic high values are likely to attract attention during times of high prices for these metals. Uranium mines in the GSEEL containing significant Cu values include the Blue Bird, Black Widow, Hot Shot, and Yellow Jacket (Allison, 1997).

Potential for the Occurrence and Development of Minerals

The occurrence potential for U-V-Cu deposits in the GSEEL is rated as high (H) with a certainty of D at known sites of past U-V or Cu mines and prospects and moderate (M) with a certainty of B if the

Shinarump Member of the Late Triassic Chinle Formation is present (map 20). The potential for the occurrence of U-V-Cu deposits is rated as low (L) with a certainty of A if the Chinle Formation is present without the Shinarump Member or in the Salt Wash Member of the Late Jurassic Morrison Formation (map 20).

3.2.3 Titanium and Zirconium

Description of Mineral Resources

Roughly 90% of the U.S. Ti concentrate production comes from large Georgia and Florida open pit mines. These concentrates are used to produce TiO2 pigment for paint, paper, and plastics, with some used for welding-rod coatings and manufacturing carbides, chemicals, and Ti metal. The primary uses of Zr are ceramics, foundry sand, opacifiers, and refractories. Hafnium (Hf) is typically contained in zircon at a ratio of about 50:1 Zr to Hf and the leading use of Hf is in superalloys (U.S. Geological Survey, 2018).

The Kaiparowits district spans the Garfield-Kane County line along the Straight Cliffs, south of Escalante (map 21). The prospects are on a plateau with steep-walled, incised canyons and the area is undeveloped. The district has no recorded production but encompasses at least 14 Cretaceous Ti-Zr paleoplacers, three small U ±V occurrences, and a Mn prospect. The Mn and U-V occurrences are of no consequence. The Ti-Zr paleoplacers were discovered in the 1950s, probably by prospectors during the uranium exploration boom. The Ti-Zr occurrences have been repeatedly staked, examined, and abandoned by a series of prospectors and junior companies primarily driven by periodically high Ti-Zr prices prior to the area's inclusion in the GSENM in 1996. Most of the exploration focus was on the Escalante (Calf Canyon – Dave Canyon) and the Mann Ti-Zr deposits in the late 1980s and mid-1990s (Dow and Batty, 1961; Gloyn and others, 1997).

A series of at least 14 Ti-Zr deposits lie on a 30 to 35-mile-long, north-northwest-trending belt extending from about 10 miles southwest of Escalante to the middle of Kane County (Allison, 1997). These paleoplacers occur in the John Henry Member of the Upper Cretaceous Straight Cliffs Formation. This formation records a series of transgressive and regressive marine sandstones interbedded with non-marine siltstone, fine-grained sandstone, carbonaceous shale, and coal. The source area for the Straight Cliffs Formation sandstones was to the southwest with open water to the northeast (Gloyn and others, 1997). The better paleoplacers developed in beach swash zones during regressive phases. The Straight Cliffs Formation has been folded into a series of open, upright, north-northwest-trending anticlines and synclines (Doelling, 1975; Doelling and others, 1989). The northern Garfield County occurrences are between the Alvey and Christensen coal seams and the southern Kane County occurrences are lower in the John Henry Member below the Christensen coal seam, indicating the presence of multiple heavy mineral horizons (Gloyn and others, 1997).

The heavy mineral concentrations generally occur in small, red-brown, elongate lenses from 3 to 15 ft thick, 100 to 300 ft wide, and 300 to 3500 ft long. The iron-rich cement may cause the deposits to weather as low, resistant ridges. Heavy minerals in the deposits include the Ti phases rutile, ilmenite, leucoxene, and titanite (sphene); and the Zr phases zircon, brookite, and anatase. Hematite, quartz, calcite, garnet, staurolite, and minor allanite, monazite, apatite, tourmaline, aluminosilicates, chromite, and gahnite are also reported from the deposits (Gloyn and others, 1997). Because zircon may be colorless, the highest Zr grades may not occur in the darkest beds. Virtually no magnetite is present in the deposits, but the deposits do contain an unusual, magnetic ilmenite-hematite mineral that has been mistaken for magnetite. This magnetic Ti-bearing mineral may require a more complex metallurgical process to recovery a saleable Ti product (Force, 2000; Force and others, 2001). The deposits have a weak magnetic expression due to the ilmenite-hematite phase and are also weakly radioactive due to the presence of the Th phase monazite in the deposits. These Ti-Zr deposits belong the shoreline placer Ti deposit model (USGS Model 39c; Cox and Singer, 1986).

Mineral Exploration, Development, and Production

The best studied deposits fall in two distinct areas; the Escalante deposit to the north in Garfield County and the Mann, Sargent, and U-429 deposits to the south in Kane County (map 21). The only prospect that has had enough drilling done on it to provide any type of reliable grade-tonnage information is the Mann (Longshot) deposit. This paleoplacer has a subeconomic inferred resource of 300,000 tons at an average grade of 9.6% TiO_2 and 3% ZrO_2. Hafnium (Hf) and minor concentrations of Th, Nb, Ta, U, W, Y, and possibly Au have also been reported from the deposits. The Escalante deposit to the north is not nearly as well delineated but is believed to present a potentially somewhat larger (300,000 to 600,000 tons) and potential slightly better grade deposit (Gloyn and others, 1997).

The Mann mineral inventory is only a fraction of the size of the average shoreline placer Ti deposit but is slightly above average grade. The average tons and grade for the shoreline placer Ti model (USGS Model 39c) is about 96 million tons at 2.54% TiO_2 and 0.9% ZrO_2 (Cox and Singer, 1986). Consequently, the drill defined Mann deposit is over three times the average model grade, but at less than a third of one percent the average model size. Well over a hundred of these Cretaceous Ti-Zr paleoplacer deposits are reported in the western U.S. (Dow and Batty, 1961; Houston and Murphy, 1977). Dow and Batty (1961) give the average weighted grade for about 80 of these deposits at 6.95% TiO_2, 0.99% ZrO_2, 22.8% Fe, and 0.03% ThO_2. So, the Kaiparowits Ti-Zr deposits are above this paleoplacer average in Ti and Zr. U.S. Bureau of Mines studies (Dow and Batty, 1961) report recoveries from beneficiation tests in the Kaiparowits district deposits showing modest recoveries of 41.2-61% for TiO_2 and better recoveries 76-77.8% for ZrO_2. Despite the widespread occurrence of these Ti-Zr paleoplacers in the western U.S. and the moderate grade present, we can find no reports of production from any of the deposits.

The Mann deposit is some 45 miles by mostly gravel and dirt road south of Escalante (map 21). In contrast, the Escalante deposit is better situated being only about 10 gravel and dirt road miles southwest of Escalante.

Potential for the Occurrence and Development of Minerals

The potential for the occurrence of Ti-Zr paleoplacer deposits in the GSEEL is rated as high (H) with a certainty of D at known prospects and low (L) with a certainty of A elsewhere in the John Henry Member of the Upper Cretaceous Straight Cliffs Formation in the Kaiparowits district (map 21).

3.2.4 Manganese

Description of Mineral Resources

The Paria West mining district lies about 25 miles east-northeast of Kanab in south-central Kane County. Manganese mineralization was initially discovered in 1908, but production didn't begin until World War II when the district became a small Mn producer (Buranek, 1945). The Manganese King mine is the only productive mine in the district (map 21).

The Paria West district is situated in the Grand Staircase section of the Colorado Plateau (map 21). The district contains both Mn and U prospects, but only Mn has had production. Both the Mn and U ores are hosted in very shallowly north dipping (3º to 15°) Upper Triassic Chinle Formation. The Manganese King ores occur in the middle part of the Petrified Forest Member. The section consists of a lower bentonitic mudstone that grades upward into a dark manganiferous shaley mudstone, which is overlain by a calcareous, rhyolitic (?) tuff and sandy limestone. The Mn occurs primarily as botryoidal nodules up to several inches in diameter in the top few feet of the dark shaly mudstone (USGS Model 34b; Cox and Singer, 1986). The larger nodules usually have better Mn grades. The main ore minerals are psilomelane and lesser pyrolusite and earthy black Mn wad. Barite and calcite crystals and veinlets occur within the clayey ore zone (Baker and others, 1952). The nodules contain slightly over 50% Mn (Buranek, 1945), but the in-place grades are only about 7-10% Mn.

Manganese is also found at the Van Hamet prospect located a few miles southeast of Escalante. The manganese here occurs as lenticular pods and concretions in sandstone of the Jurassic Carmel Formation. The pods are up to 1 foot thick and scattered in an area of 100 by 250 feet. Select samples can grade as much as 15-27% Mn (Doelling, 1975; Allison, 1997).

Mineral Exploration, Development, and Production

The Mn ore at the Manganese King mine in the Paria West district was extracted by a series of short tunnels and small surface cuts in the 1940s. A total of just 191 tons of Mn nodules were shipped (Havens and Agey, 1949; Doelling and Davis, 1989). No notable work has been done on the Manganese King mine or Van Hamet property since the 1940s.

Potential for the Occurrence and Development of Minerals

The Manganese King is a small mine, with minimal production, and a thin low-grade ore zone. The potential for the occurrence of Mn deposits in the GSEEL is rated as high (H) with a certainty of D at the Manganese King mine and Van Hamet prospect (map 21).

3.2.5 Gypsum

Description of Mineral Resources

Gypsum and anhydrite are both calcium sulfate minerals that most commonly precipitate via evaporative processes in restricted marine basins. Gypsum, the more relevant commercial product, is a hydrous form of calcium sulfate ($CaSO_4 \cdot 2H_2O$), and anhydrite is the anhydrous form ($CaSO_4$). In the U.S., gypsum is primarily used to produce wallboard and plaster products, but it is also used in cement production, for agricultural purposes, and other applications (Crangle, 2018). Doelling and others (1989) noted that most subsurface calcium sulfate deposits are anhydrite, but are converted to gypsum nearer to the surface by weathering. In semiarid climates such as the GSEEL, hydration often reaches less than 40 feet below the surface.

Rock gypsum is the most common form of gypsum, and is an aggregation of gypsum crystals often interbedded with carbonates, mudstone, and/or siltstone. Rock gypsum tends to have a massive or granular appearance, but can also be nodular, laminated, or bedded. Other varieties of gypsum include alabaster, selenite, and satin spar. Alabaster tends to be compact, massive, and finely crystalline, and commercial gypsum deposits often consist of rock gypsum and alabaster. Selenite is a term for large euhedral crystalline gypsum and satin spar is a fibrous variety of gypsum often found in fractures (Sharpe and Cork, 2006). Sharpe and Cork (2006) noted that impurities in gypsum deposits commonly range from 10% to 15% and are typically carbonates, clay, anhydrite, and soluble salts. Of those contaminants, soluble salts are generally the most deleterious for gypsum applications and are tolerated in the lowest amounts. Suitability of a particular gypsum deposit depends on the types and amount of impurities, potential applications, and market dynamics. Gypsum processing can be limited to grinding and sizing, but gypsum may also be calcined or dead burned depending on end use (Sharpe and Cork, 2006).

Gypsum occurrence potential within the GSEEL is found in the Winsor and Paria River Members of the Jurassic Carmel Formation, the Shnabkaib Member of the Triassic Moenkopi Formation, and the Toroweap Formation (map 22). Descriptions of the Winsor and Paria River Members in the GSEEL area note gypsum beds in most parts of the area (Doelling and Willis, 1999; Doelling and Willis, 2006; Doelling, 2008; Biek and others, 2015). Doelling (2008) reported a gypsum bed about 40 feet thick in the Paria River Member and Biek and others (2015) noted that the lower part of the Paria River Member includes gypsum beds with minor shale up to 80 feet thick. Doelling (1975) included information from some measured sections of the Carmel Formation in the GSEEL: in section 16, T. 36 S., R. 4 E., a 119-feet-thick sequence included 42 feet of gypsum with the thickest relatively pure gypsum bed being 13 feet thick; and in T. 37 S., R. 5 E., a 125-feet-thick sequence included 59 feet of gypsum with the thickest relatively pure gypsum bed being 28 feet thick. Although, there are no analytical data from within the GSEEL, Zelten (1987) collected eight samples of gypsum from the Carmel Formation west of the GSEEL that averaged 92.7% $CaSO_4$. However, the member that these samples were collected from is unspecified. Some of the gypsum in the Carmel Formation in the GSEEL occurs as alabaster, and Allison (1993) noted that alabaster in the area has a reputation of being some of the best in the country for sculpting. Some of the alabaster has been mined and locations of the mines indicate that the alabaster occurs in the Winsor Member of the Carmel Formation. Descriptions of the Shnabkaib Member note bedded gypsum up to 6 feet thick (Doelling, 2008). The upper part of the Toroweap Formation reportedly contains gypsum beds thicker than 3 feet (Doelling and others, 1989). Doelling and others (1989) noted that gypsum from the Shnabkaib Member and Toroweap Formation appeared to be less pure than gypsum from the Carmel Formation.

Mineral Exploration, Development, and Production

Three small, inactive surface mines within the GSEEL have a history of gypsum production. All three of the mines produced alabaster for sculpting purposes. Alabaster for sculpting generates a somewhat more valuable product than gypsum mined for most other applications. The three mines are Butler Valley Quarries, Long Gulch II, and Low Down 1. Incomplete records from the Utah Division of Oil, Gas and Mining (DOGM) indicate that the Butler Valley Quarries produced nearly 1400 tons of material between 1994 and 2005. Although DOGM records are somewhat unclear, Long Gulch II may have produced around 29 tons between 1995 and 1999 and Low Down 1 may have produced about 25 tons between 1994 and 1999. In early 2018, a new claim, known as Berry Patch #1, was staked covering the area of the Butler Valley Quarries in sections 35 and 36, T. 38 S., R. 1 W.

Potential for the Occurrence and Development of Minerals

The potential for the occurrence of gypsum is rated as high (H) with a certainty of D at known mines and prospects (map 22). Occurrence potential of mapped exposures of gypsum-hosting members of the Carmel Formation are rated as high (H) with a certainty level of C. Occurrence potential for gypsum in the Shnabkaib Member of the Moenkopi Formation and Toroweap Formation is rated as moderate (M) with a certainty of C. Available information and past production suggests that the quality and quantity of gypsum in the Carmel Formation is likely superior to the Moenkopi and Toroweap Formations. Some development and production of gypsum is possible in the GSEEL in the future, but would likely be limited to extraction for sculpting alabaster. Development of gypsum for more typical construction purposes is unlikely given the remoteness of the area and lack of infrastructure. Other gypsum resources are widespread throughout Utah.

3.2.6 Silica and Industrial Sand

Description of Mineral Resources

Silica and industrial sand sourced from sand, sandstone, and quartzite is used in a variety of industrial applications. Common applications include hydraulic-fracturing sand (frac sand) and other oilfield uses, foundry sand, glass-making sand, fillers, and others (Herron, 2006; Dolley, 2018a). Specifications for industrial sand vary by application, but can include grain size, grain shape, and low thresholds of certain contaminants. Generally, SiO_2 content should be 95% or above for economic silica deposits (Herron, 2006).

Silica occurrence potential in the GSEEL is found within the Jurassic Navajo Sandstone and eolian sand and dune deposits (map 23). The Navajo Sandstone is a massive, cliff-forming, cross-bedded sandstone. In the region of the GSEEL, it ranges in thickness from about 550 to 1700 feet, and generally thickens to the west (Doelling and Willis, 1999; Doelling and Willis, 2006; Doelling, 2008). Eight samples collected from the Navajo Sandstone within the immediate area of the GSEEL range from about 93.7% to 97.0% SiO_2, and average 95.7% SiO_2 (Brown and Hannigan, 1986; Corbetta, 1986). Brown and Hannigan (1986) concluded that the Navajo Sandstone was suitable for use in "ordinary, colored container glass." Eolian sand and dune deposits, often proximal to Navajo Sandstone exposures, range in thickness, but can reach up to 100 feet thick (Doelling and Willis, 2006; Doelling, 2008). Three samples of eolian sand were collected south of the GSEEL in Kane County and the SiO_2 contents were 93.3%, 95.2%, and 95.6% (Rupke and Boden, 2013).

Mineral Exploration, Development, and Production

No known production, development, or exploration for silica or industrial sand has occurred within the GSEEL. Available samples of the Navajo Sandstone in the area of the GSEEL were collected by the U.S. Bureau of Mines as part of an effort to evaluate mineral resources within BLM Wilderness Study Areas (Brown and Hannigan, 1986; Corbetta, 1986). Samples of eolian sand from an area south of the GSEEL were collected by Rupke and Boden (2013) as part of an evaluation of potential frac sand resources in Utah.

Potential for the Occurrence and Development of Minerals

The potential for the occurrence of silica is rated as high (H) with a certainty of C within the Navajo Sandstone and eolian dune and sand deposits (map 23). Any substantial development of silica resources is unlikely due to the remoteness of the area and lack of infrastructure. The units with potential are abundant and widespread beyond the GSEEL.

3.3 Salable Minerals

3.3.1 Sand and Gravel

Description of Mineral Resources

Sand and gravel in unconsolidated deposits is the most common source of construction aggregate and is commonly used in concrete, road base, asphalt, fill, and other applications. Sand and gravel is a low unit value commodity, but in most regions has a high cumulative value due to the large volumes consumed. Because of low unit value and substantial transportation costs, material is ideally sourced close to its area of use. In 2017, the average domestic price of a ton of sand and gravel was about $8 (Willett, 2018a). In Utah, sand and gravel is commonly sourced from alluvial and lacustrine deposits.

Several types of Quaternary unconsolidated deposits have sand and gravel occurrence potential in the GSEEL (map 24). The dominant bedrock lithologies in the area, such as mudstone or friable sandstone and siltstone, are not ideal sources for high quality material, but Doelling and others (1989) noted that some good deposits are present. The Utah Department of Highways (UDOH) prepared a materials inventory of aggregate sources for Garfield and Kane Counties in an undated report from the late 1960s (?), and the report gives general information on the suitability of various unconsolidated deposits. UDOH (undated) suggested that alluvial deposits from stream channels and washes are generally only considered a source of borrow material; however, many of the known sand and gravel quarries are within these alluvial deposits. UDOH (undated) indicated that pediment and terrace deposits are the principle sources of gravel, but the gravel derived from these deposits may or may not meet wear and soundness specifications for certain applications. They also identified eolian sand as a potential source of borrow.

Below are descriptions modified from Doelling (1975) of some specific areas within the GSEEL that have sand and gravel potential:

Kitchen Corral Wash—An extensive old river terrace deposit is just east of and parallel to this wash near U.S. Highway 89. Two pits, one south of the highway and one north, have been opened in the deposit. The exposed gravel is 20 to 40 feet thick and it is well cemented in places. The gravel is graded and very few cobbles exceed 3 inches in diameter. The clasts are subrounded to round quartzite (60%), limestone (30%), and sandstone (about 10%) with a few scattered conglomerate boulders. A pit south of the highway was inventoried by UDOH, but that small area is almost mined out. By far, the largest reserve is in the old terrace north of the highway in section 23, T. 42 S., R. 3 W. The test data on material from both pits are good. The sand and gravel from this old river terrace deposit is suitable for use in concrete and bituminous mixtures.

Adjacent to the Paria River—The Paria River also has river terrace deposits near U.S. Highway 89. Auger holes have proven at least 11 feet of gravel, mostly subrounded to rounded quartzite pebbles and cobbles. UDOH inventoried one pit and three potential material sites along the wash. Test data indicate that the sand and gravel meet specifications as aggregate in concrete and bituminous mixtures. The listed reserves at the 4 sites are very conservative; probably millions of cubic yards are present along the length of the old river terrace.

Doelling (1975) also described gravel deposits along Wahweap Creek, noting extraction already occurring near Big Water. He described the gravel as well-sorted, mainly quartzite, and a minimum of 12 feet thick. The gravel also meets specifications for use in concrete and asphalt. However, these deposits are primarily mined south of the GSEEL where they are closer to development.

Mineral Exploration, Development, and Production

Production of sand and gravel has occurred within the GSEEL, but volumes are limited and exact tonnages of extracted material are unknown. The largest known quarries exist along the Paria River drainage and Kitchen Corral Wash near U.S. Highway 89.

Potential for the Occurrence and Development of Minerals

The potential for the occurrence of sand and gravel deposits is rated as high (H) with a certainty level of D at known sites of past and present sand and gravel pits, quarries, and prospects (map 24). Elsewhere in the GSEEL, mapped stream alluvium, pediment deposits, terrace deposits, and alluvial gravel deposits are rated high (H) with a certainty level of C based on past extraction and reported potential. Colluvial, eolian, and other unconsolidated deposits are rated as moderate (M) with a certainty of C. Future development will most likely occur at favorable locations within a short distance of major roads.

3.3.2 Crushed Stone and High-Calcium Limestone

Description of Mineral Resources

Crushed stone is commonly used for construction aggregate (Willett, 2018b) and is typically extracted from geologic units containing rocks with high compressive strength. Rock types suitable for crushed stone often include limestone, dolomite, granite, and traprock (often basalt). In the U.S. in 2017, most crushed stone (70%) was sourced from carbonate rocks (limestone and dolomite) (Willett, 2018b). Because crushed stone is a low unit-value commodity, it is typically surface mined at low stripping ratios. Willett (2018b) estimated that the average cost of a ton of crushed stone in 2017 was about $10. The particular attributes of crushed stone mined in a given area are affected by the overall availability of crushed stone and types of local end uses. High-calcium limestone usually refers to limestone that has a 95% or higher $CaCO_3$ content, and it is used in a variety of applications. In Utah, high-calcium limestone is used primarily for lime and cement production, but it is also used for flue-gas desulfurization and rock dust in the coal mining industry (Boden and others, 2016). This section combines crushed stone and high-calcium limestone because the geologic units with crushed stone potential are coincident with those units that have potential for high-calcium limestone. While crushed stone is generally considered a salable mineral, high-calcium limestone is often locatable. As noted above, carbonates (most commonly limestone) are the most utilized type of crushed stone.

The dominant lithologies exposed in the GSEEL, such as friable sandstone, siltstone, and shale, are generally unsuitable for crushed stone, but there are a few Jurassic, Triassic, and Permian units in the area that have potential for crushed stone and contain limestone (map 25). Units with potential include the Paria River Member, Co-op Creek Limestone Member, and Judd Hollow Tongue of the Jurassic Carmel Formation; the Timpoweap Member of the Triassic Moenkopi Formation; the Permian Kaibab Formation; and the Permian Toroweap Formation. No testing data are available describing these units' suitability for crushed stone; however, near St. George, Utah, the Kaibab Formation is being mined for crushed stone. Unit descriptions for the Kaibab and Toroweap Formations imply the most potential, indicating that cliff-forming limestone beds are present within these units, but their exposures in the GSEEL are limited (Doelling and Willis, 2006; Doelling, 2008). However, these units are also reported to be cherty, which can be disadvantageous for certain crushed stone applications. Available analytical data suggest that potential for high-calcium limestone is limited. Within the GSEEL, several limestone samples from the Moenkopi Formation were tested for acid insoluble content. Of 27 samples, only three were below 5%, and those were only slightly below 5%. Maximum allowable insolubles for high-calcium limestone is 5%, but should generally be lower than 5%. Most of the Moenkopi samples were collected in T. 42 S., R. 3 W., and T. 42 S., R. 2 W. (Hodgson, 1974; Tripp, 2005). Samples of the Carmel Formation collected elsewhere, but within Kane County, indicate that it is too high in SiO_2 (typically 10% or more) and other impurities to meet high-calcium limestone specifications (Zelten, 1987; Doelling and others, 1989). No analytical data are available for the Kaibab and Toroweap Formations, but, as noted above, descriptions indicate that they are cherty (Doelling and Willis, 2006; Doelling, 2008).

Mineral Exploration, Development, and Production

No known production of crushed stone or high-calcium limestone has occurred in the GSEEL. Hodgson (1974) evaluated multiple deposits, including one in the GSEEL, to identify limestone for use at the Kaiparowits Power Plant in Arizona. Exposures of the Moenkopi Formation along U.S. Highway 89 were among the evaluated deposits and, as previously noted, several samples were collected in the area. Ultimately, other targets were preferred on the basis of quality and quantity of stone. We are aware of no other exploration for crushed stone or limestone within the GSEEL.

Potential for the Occurrence and Development of Minerals

The occurrence potential of crushed stone and high-calcium limestone in the GSEEL varies slightly depending on geologic unit (map 25). Because the Kaibab and Toroweap Formations include massive beds of limestone we assigned a high (H) occurrence potential with a certainty of C for crushed stone. Although the other units each possess some limestone, the varied lithologies found within the units, as implied by available descriptions, do not suggest ideal conditions for uniform, high-quality, crushed stone deposits. So for most units we assigned a moderate (M) occurrence potential with a certainty of C for crushed stone. Available analytical data and geologic descriptions suggest moderate (M) occurrence potential with a certainty of C for all units in regards to high-calcium limestone. Given the lack of past production of either commodity, future development will probably be minimal.

3.3.3 Building Stone

Description of Mineral Resources

A succinct and simple definition of building stone is difficult, but, for this evaluation, building stone includes (but is not necessarily limited to) decorative stone, ornamental stone, fieldstone, flagstone, landscape rock, and dimension stone. Decorative and ornamental stone are broad terms that are not consistently defined, but generally include rock used in architectural decoration, often on the basis of its color, texture, and general appearance. Fieldstone, a type of decorative stone, is rock gathered without extensive quarrying, and includes landscape rock. Flagstone, also a type of decorative stone, is thin, irregular slabs used for a variety of applications, but generally requires stone that breaks easily along planes in one direction (Austin and others, 2006). Dimension stone is typically the most valuable building stone and has been cut or finished to specific shapes and sizes (Mead and Austin, 2006). However, flagstone is considered the most important building stone product in Utah (Boleneus, 2008). Quarries in the region tend to be small and most make use of manual labor for splitting, sorting, and stacking the building stone. Many operators combine manual labor with some level of mechanization, but drilling and blasting are rarely used (Boleneus, 2008). The price of building stone is widely variable depending on its end use (Dolley, 2018b).

Although no known production of building stone has come from the GSEEL, there is some building stone resource potential, particularly from the Moenkopi Formation (map 26). Both Doelling (1975) and Doelling and others (1989) reported that the thin- to medium-bedded, fine-grained sandstone of the Moenkopi Formation produces good flagstone. Boleneus (2008) commented on the wide importance of the Moenkopi Formation as an important source of building stone in southern Utah, and Doelling (1975) also noted that some of the Moenkopi rock has ripple marks and mud cracks, which adds to the aesthetic of a potential product.

While the Moenkopi Formation is probably the most significant potential source for building stone in the GSEEL, a few other geologic units have potential as well. Historically, small amounts of the Co-op Creek Member of the Carmel Formation were used as dimension stone in Kane County (Doelling and others, 1989). Doelling (1975) discussed rock known as "clinker," which is rock that has been altered due to spontaneous burning of coal seams. Clinker rock has been melted, to some degree, and produces decorative stone of a variety of colors. A few small clinker pits are located immediately west of the GSEEL in the Dakota Formation (Boleneus, 2008) and possibly the Tropic Shale. In some areas, often in the vicinity of faults or springs, sandstone from the Jurassic Navajo Sandstone and Shinarump Member of the Triassic Chinle Formation are known to have laminae or bands of iron oxide or limonite. Sandstones with these colorful features are known as picture rock (Doelling and others, 1989), which is used for a variety of different decorative purposes.

Mineral Exploration, Development, and Production

No known production of building stone has come from the GSEEL. Adjacent to the southwest corner of the GSEEL, flagstone is produced from the Moenkopi Formation at the Moenkopi Moca mine, and, based on incomplete DOGM records, annual production has ranged from about 300 to 1800 tons per year for the last decade. About two miles west of the Moenkopi Moca, a community pit is present in the Shinarump Member of the Chinle Formation. Also west of the GSEEL, a few clinker-producing quarries are located in the Dakota Formation and possibly the Tropic Shale.

Potential for the Occurrence and Development of Minerals

Potential for occurrence of building stone in the Moenkopi Formation is rated high (H) with a certainty of C, based on production of Moenkopi Formation elsewhere (map 26). Other host formations with building stone occurrence potential are rated as moderate (M) with a certainty of C. Although some future development of building stone in the GSEEL is possible, it will likely be limited given absence of past production.

3.3.4 Clay

Description of Mineral Resources

Clay has a wide range of uses and applications, and is generally defined as fine-grained, naturally occurring, earthy, argillaceous material (Grim, 1953). Clays are also geologically diverse and deposits are commonly a result of weathering, diagenesis, metamorphism, hydrothermal alteration, or sedimentary processes (Harvey and Murray, 2006). For example, bentonite is most often formed by alteration of volcanic ash or tuff (Eisenhour and Reisch, 2006), but common clay has several sources including glacial clay, alluvium, soil, loess, shale, and weathered rock (Keith and Murray, 2006). Clay is often categorized by its composition (Harvey and Murray, 2006), which typically determines its end use. Utah has significant clay resources, and currently bentonite, common clay, and high-alumina clay are produced in Utah (Boden and others, 2016). Uses for Utah's bentonite include drilling and environmental applications, and significant uses of common clay and high-alumina clay include brick and cement manufacture. Some shale in Utah is also extracted to produce lightweight aggregate (Boden and others, 2016).

Several geologic units within the GSEEL have resource potential for clay (map 27) in beds of mudstone, claystone, and shale that are commonly interbedded with other lithologies, most commonly, sandstone and/or siltstone. Past producing units within the GSEEL include the Cretaceous Dakota Formation and possibly the Cretaceous Tropic Shale. The Dakota Formation includes several claystone, mudstone, and shale beds that are interbedded with sandstone and conglomerate. In some areas, the clay beds have a typical bentonitic "popcorn" texture (Doelling, 1975). At the American Mud and Chemical Corporation deposit in section 13, T. 37 S., R. 3 W., bentonite was produced from an 11-feet-thick bed. In other parts of Garfield County, northeast of the GSEEL, the Dakota Formation is known to possess clay suitable for high- and super-duty refractory applications (Van Sant, 1964). The Tropic Shale, which varies in thickness up to 1000 feet, includes several shale and mudstone intervals, and also smectitic ash beds throughout the formation (Biek and others, 2015). Doelling and others (1989) concluded that some of these beds would be suitable as lining material for canals or reservoirs, and Robison (1966) reported that a small amount of bentonite was produced from the Tropic Shale just north of the GSEEL in section 25, T. 36 S., R. 3 W.

Doelling and others (1989) reported that the Chinle Formation includes mudstone and claystone beds from 9 to 81 feet thick in the Chinle Formation, and some have developed a bentonitic texture on exposed surfaces. They also noted that clay horizons in the Straight Cliffs Formation would be suitable as lining material, and Van Sant (1964) tested a thin bed (2 feet thick) of the formation a few miles north of the GSEEL, concluding that it might be suitable for bricks and low-duty refractory. Doelling (1975) noted that the Jurassic Morrison and Carmel Formations may also have clay potential. Mudstone in the Morrison is commonly bentonitic in the region of the GSEEL (Doelling and Willis, 2006), and bentonite has been extracted from the Morrison Formation in southeast Utah.

Analytical data from the U.S. Geological Survey's National Geochemical Database suggest that the Morrison Formation, Chinle Formation, and Tropic Shale may also have potential for high alumina shale. Six samples from these formations collected outside of, but proximal to, the GSEEL showed about 19 to 21% Al_2O_3 content.

Mineral Exploration, Development, and Production

Minor clay production has come from the GSEEL. Robison (1966) reported that 4000 tons of bentonite was produced at the American Mud and Chemical Corporation deposit for use in the Glen Canyon Dam project. A 120 ton-per-day mill was present at the location, and the deposit yielded 80 to 105 barrels of gel per ton of ore. Last production at the deposit was 1960, and the mill was dismantled (Robison, 1966; Doelling, 1975). Van Sant (1964) noted that the bentonite was used for drilling mud, canal sealing, and for bonding molding sand.

According to UMOS, a small amount of clay may have been produced at the Bulldog Pit in section 9, T. 37 S., R. 3 W., from the Tropic Shale or alluvial clay, but few details are available on this quarry. Van Sant (1964) reported on the Jell claims in section 15, T. 35 S., R. 2 E., as part of a statewide study of refractory clay deposits. Samples collected and tested at the Jell claims from a 2.5-feet-thick claystone bed within Dakota Formation suggest that it is a low-duty refractory clay.

Potential for the Occurrence and Development of Minerals

The potential for the occurrence of clay deposits is rated as high (H) with a certainty level of D at known sites of past clay mines and prospects (map 27). Elsewhere in the GSEEL, where clay-bearing host formations are present, the potential for occurrence is rated high (H) with a certainty level of C. An exception is the Carmel Formation which we rated as moderate (M). Significant development of clay resources in the GSEEL is unlikely given the remoteness of the area and lack of infrastructure. Limited extraction could potentially occur for local purposes.

3.3.5 Humate

Description of Mineral Resources

Humate is derived from plant debris associated with carbonaceous shales or coals that were deposited in a swampy, continental environment (Tabet, 2006). It contains salts or esters of humic acid that form from the decay and weathering of carbonaceous material. The most desirable feature of humate is its humic acid content, which is used to enhance soil productivity (Jackson, 1983). Other, lesser uses of humate include neutralization of acid wastewater through the formation of insoluble humic acids and the removal of heavy metals by chelation or precipitation in insoluble humate. In the GSEEL, humate deposits are found within the outcrop of the Cretaceous Dakota and Straight Cliffs Formations (map 28), which contain several thick intervals of carbonaceous shale and shaly coal.

Mineral Exploration, Development, and Production

No known exploration or development activities for humate have occurred in the GSEEL. The areas underlain by humate are remote from rail and road transport and potential markets.

Potential for the Occurrence and Development of Energy and Minerals

The potential for the occurrence of humate deposits is rated as high (H) with a certainty of C where the humate-bearing host formations of the GSEEL are present (map 28). Development of humate deposits is unlikely because better deposits with closer access to transport and market are available elsewhere in Utah. Thus, no exploration and development activities for humate are expected in the GSEEL.

4.0 REASONABLE FORESEEABLE DEVELOPMENT POTENTIAL

4.1 Oil, Gas, and Coal Bed Methane

4.1.1 Past Leasing, Exploration, and Development Activity

The recent extended period of low drilling activity in the GSENM region makes it difficult to use historic data to predict the future. However, looking only at those years when most of the drilling took place (1952-1986) indicates 24 wells in the GSEEL and 21 wells in the former GSENM over a 65-year period for a rate of a little over one well every two years. From 1952 through 1986, the number of wells drilled per year varied from none to two wells per year in the GSEEL and from none to two wells in the former GSENM. During the development of the Upper Valley field (1965 through 1972), five wells were drilled in the GSEEL and 11 wells in the former GSENM, an average of about 2.3 wells per year for the combined region. Future drilling is impossible to predict. If a new discovery occurs in the region, in the excluded lands or nearby, then drilling activity would likely increase. Three wells were drilled in the GSEEL in the 1990s (discussed earlier); no wells have been drilled in the region near the GSENM since 1995.

What historic drilling rates do not account for is whether increased demand for petroleum or advances in drilling and seismic technology and reservoir characterization make parts of the GSENM region and the GSEEL more attractive targets in the near future than they were in the recent past. One such new development is the improvements in horizontal drilling techniques, which allow companies to test the crest and both limbs of an anticlinal structure from one well location. A second new technological development is the improvement in seismic data acquisition and interpretation that allows 3-D visualization of reservoirs and potential hydrocarbon accumulations. In light of the improved exploration technologies and understanding of petroleum systems, future drilling in the GSENM region will be based on individual petroleum plays rather than for the region as a whole.

Availability of lands for oil and gas leasing will be a major factor in determining the level of future exploration/development in the GSEEL areas. Prior to the designation of the GSENM, nearly 114,000 acres of federal land was leased for oil and gas (map 1). In addition, 33,000 acres of previously state land was also leased. This significant acreage under lease before the original monument designation indicates that companies had at least some interest in developing these areas, despite the fact that only minor exploration had taken place in the past.

4.1.2 Summary of Reasonably Foreseeable Developments

There are five requirements necessary for oil and gas accumulations to occur: (1) source rocks, (2) reservoir rocks (porosity and permeability), (3) seal, (4) trap, and (5) perfectly timed hydrocarbon migration. If all these criteria are not met, the hydrocarbons will not be present at a drilling target. With the exception of the Permo-Triassic Unconformity Play (USGS-2106), within the GSENM area and the GSEEL, the plays described in the earlier sections as presently understood lack one or more of these requirements for hydrocarbon accumulations. Thus, foreseeable development in these plays in the future is unlikely barring any new discoveries elsewhere in the region.

When the Cretaceous conventional sandstone and coal bed gas plays are considered together, there are four oil and gas plays covering the GSENM region. While it is possible that one deep well could test all four stratigraphic intervals, extending from the Cretaceous plays at the surface to the Late Proterozoic/Cambrian at the bottom, these plays were not analyzed as one group in this report.

In spite of their partial spatial overlap, each play was analyzed separately because the overall differences in the nature and extent of their reservoirs, and the differences in timing of hydrocarbon generation and migration from their source rocks mean that petroleum deposits in each play reservoir may not necessarily be vertically superimposed. Thus, other than the Cretaceous plays, each play is considered as an individual target that will have separate, spatially isolated hydrocarbon accumulations that will need to be discovered on a play-by-play basis. Only one play has high development potential, and despite the remoteness of the area and poorly defined targets for petroleum accumulations in some plays, it is possible that new exploration wells drilled in the excluded lands could find a new small field.

Table 5 below summarizes the expected number of wildcat and development wells that could be drilled for oil and gas in each of the plays in the GSEEL over the next 15 years, which is highly speculative and optimistic. No new wells for carbon dioxide are expected. Most companies exploring in Utah will focus their efforts in the Uinta Basin of eastern Utah, which have high rates of success and well-established infrastructure.

Table 5. *Summary of petroleum development potential and estimated number of wells drilled in the next 15 years for each play in the GSEEL.*

Play Name	**Occurrence Potential**	**Development Potential**	**New Wells**
Late Proterozoic/Cambrian play	low	low	0
Devonian-Mississippian play	moderate	moderate	1
Permo-Triassic unconformity play	high	high	12
Combined Cretaceous plays	low	low	1
Total New Exploration Wells			**4**
Total New Development Wells (1 small field)			**10**
GRAND TOTAL EXPECTED WELLS			**14**

Before any projected drilling takes place, additional seismic exploration might be expected to help pinpoint structural and stratigraphic traps, identify potential petroleum deposits, and focus drilling in the hope of reducing dry holes and unnecessary environmental disturbances. Only a small amount of seismic exploration has been carried out in the GSENM region (map 6). To cover the GSEEL areas that have moderate or high potential could entail shooting and collecting perhaps 500 miles of seismic data.

4.1.3 Expected Disturbance from Oil and Gas

The expected level of disturbance from the 14 oil and gas wells (4 exploration and 10 from development of a newly discovered very-small-sized field) that could be be drilled in the GSEEL in the next 15 years was determined using some reasonable assumptions about a generic well site and access needs. Each well pad was estimated to comprise 3 acres, or a square area roughly 361 feet on a side. Based on an analysis of the network of existing roads, it was estimated that to reach each new well site would require an average of 5 miles of new road to be constructed, and the new roads would disturb a path almost 33 feet wide. Thus, each mile of new road would disturb 4 acres. An estimate of the total surface disturbance for all 14 new wells is as follows:

14 oil and gas well pads at 3 acres each = 42 acres, plus 5 miles of new roads at 4 acres/mile = 280 acres.

Thus, the total surface disturbance for the 14 new wells would be 322 acres, or about 23 acres per well.

The disturbance involved with shooting and collecting up to 500 line miles of seismic data would likely be split between buggy-mounted and helicopter data acquisition methods. Assuming that buggy-mounted drill rigs could be used to acquire half the seismic data, and that the other half required heliportable drilling rigs, means that there would be 250 line miles of each type of disturbance. Buggy-mounted seismic data acquisition generally disturbs 1.2 acres per mile, whereas helicopter-acquired data only disturbs 0.007 acres per mile according to recent BLM environmental assessments (i.e., Veritas and Western Geco Uinta Basin projects) for similar seismic projects elsewhere in Utah. Thus, acquiring 500 miles of seismic data in the portion of the excluded lands prospective for petroleum would entail a total disturbance of 302 acres of the surface (300 acres for buggy-mounted data and 2 acres for helicopter data). Combining the seismic disturbance with the drilling disturbance means that exploration and development for oil and gas in the GSEEL during the next 15 years could be about 624 acres of the surface. Since reclamation of all of the seismic disturbance and about 70% of the exploration well disturbance is expected to occur during the planning period, about 527 acres of surface disturbance will be reclaimed during the planning horizon, leaving a net disturbance from oil and gas during the next 15 years of 97 acres.

4.2 Coal

The Alton coalfield within the GSEEL area contains coal beds greater than 4 feet thick and that are under less than 3000 feet of cover, including a small area under less than 200 feet of cover potentially suitable for surface mining. However, despite the presence of several exploratory drill holes and the presence of historic federal coal leases, no historic coal mining has occurred in the Alton coalfield within the GSEEL area. In addition, the area of the Alton coalfield in the GSEEL has been declared by the BLM as unsuitable for surface mining, as well as surface disturbance related to underground mining, due to its proximity to Bryce Canyon National Park. These declarations can change, but due to the mostly thinner nature of the coal beds, it is believed that development in this area is low.

Up to 9 billion tons of potentially recoverable coal (not all in the GSEEL area), with beds thicker than 4 feet and under less than 3000 feet of cover, are in the Kaiparowits Plateau coalfield. Nearly 1000 exploratory holes have been drilled to define the resource. In addition, several small historic mines produced minor amounts of coal in the early 1900s and 39,168 acres of federal land were previously leased for coal. Therefore, the coal resources of the Kaiparowits Plateau within the GSEEL areas are rated high for development potential, except within Wilderness Study Areas, where the development potential is rated as low.

In the latter part of the 1980s, Andalex Resources began formulating plans to mine underground and ship between 3.5 and 5.5 million tons of coal annually from their leasehold, termed the Warm Springs lease and Smokey Hollow mine, in the southern part of the Kaiparowits coalfield. Seventeen separate but adjacent federal leases were controlled by the company and comprised 34,498 acres. The company also obtained three leases on adjacent state land for an additional 1920 acres, with options to obtain another four leases from the state for an additional 2610 acres—for a total of 39,028 acres (some of which is outside the GSEEL area) (map 17). Over 200 exploratory drill holes covered the area and were sufficient to consider over 90% of the coal as "demonstrated" resource. The total recoverable resource in multiple coal beds for the leased area was estimated at over 800 million tons, and the recoverable reserve (at 1996 mining methods and economics) was estimated at 248 million tons (all data from company reports archived at UGS). Mining conditions and geology on the lease are good to excellent with thick coal seams, consistent favorable overburden depths, and no significant faulting, water, or methane. Original mine plans called for the production of 182 million tons of coal over a 35-year period from approximately 10,000 acres of the leasehold area; 3.5 million tons a year for the first five years, then ramping up to 5.5

million tons for the next 30 years (all data from company reports archived at UGS). Production would mainly be from longwall equipment with more minor amounts via continuous miner. Surface facilities for the underground mine were estimated to disturb less than 45 acres and would have been accessed via 21 miles of the Warm Creek country dirt road, which would have needed improvement.

Environmental analyses for the proposed Smokey Hollow mine, required as part of the permitting process, were underway at the time the Grand Staircase-Escalante National Monument was named.

If development for coal were to occur in the GSEEL, it would most likely happen at the same location as the proposed Smokey Hollow mine. It is envisioned that development would mirror the original Andalex plan comprising an underground mine covering roughly 10,000 acres, with surface facilities disturbing less than 45 acres. The access road would need improvement, resulting in new disturbance along a roughly 21-mile corridor.

Demand for coal in Utah and surrounding states is currently low as several coal-fired power plants have shut-down or converted to natural gas generation. Current Utah coal mines, with easy access to transportation hubs, supply the in-state demand, with only minor shipments going out of state. However, just recently, Utah coal operators have seen an increase in demand for coal from Asian markets. This increased foreign demand could generate interest in coal production opportunities outside the traditional coal producing areas of the state.

5.0 REFERENCES

Allin, D.L., 1990, Colorado Plateau sub-surface water flow key: Oil and Gas Journal, v. 88, no. 30, p. 52–54.

Allin, D.L., 1993, Upper Valley, in Hill, B.G., and Bereskin, S.R., editors, Oil and gas fields of Utah: Utah Geological Association Publication 22, nonpaginated.

Allison, M.L., 1997, A preliminary assessment of energy and mineral resources within the Grand Staircase-Escalante National Monument: Utah Geological Survey Circular 93, 36 p., 4 appendices.

Austin, G.S., Barker, J.M., and Lardner, S.C., 2006, Decorative stone, in Kogel, J.E., Trivedi, N.C., Barker, J.M., and Krukowski, S.T., editors, Industrial minerals and rocks—commodities, markets, and uses, 7th edition: Society for Mining, Metallurgy, and Exploration, Inc., p. 893-906.

Baars, D.L., 1972, Red Rock Country—the geological history of the Colorado Plateau: Garden City, New York, Doubleday, 264 p.

Baker, A.A., Duncan, D.C., and Hunt, C.B., 1952, Manganese deposits of southeastern Utah; Part 2, Manganese deposits of Utah: U.S. Geological Survey Bulletin 979-B, 157 p.

Beeman, W.R., Obuch, R.C., and Brewton, J.D., 1996, Digital map data, text, and graphical images in support of the 1995 national assessment of United States oil and gas resources: U.S. Geological Survey Digital Data Series DDS-35, CD-ROM.

Bereskin, S.R., McLennan, J.D., Chidsey, T.C., Jr., and Nielsen, P., 2015, Hydrocarbon reservoir potential of the Mississippian Chainman Shale, western Utah: Utah Geological Survey Miscellaneous Publication 15-4, 30 p., 5 appendices.

Biek, R.F., Rowley, P.D., Anderson, J.J., Maldonado, F., Moore, D.W., Hacker, D.B., Eaton, J.G., Hereford, R., Sable, E.G., Filkorn, H.F., and Matyjasik, B., 2015, Geologic map of the Panguitch 30’ x 60’ quadrangle, Garfield, Iron, and Kane Counties, Utah: Utah Geological Survey Map 270DM, scale 1:62,500.

Blakey, R.C., 1996, Permian eolian deposits, sequences, and sequence boundaries, Colorado Plateau, in Longman, M.W., and Sonnenfield, M.D., editors, Paleozoic systems of the Rocky Mountain region, USA: Rocky Mountains Section, Society for Sedimentary Geology, p. 405–426.

Blakey, R.C., Basham, E.L., and Cook, M.J., 1993, Early and Middle Triassic paleogeography of the Colorado Plateau and vicinity, in Morales, M., editor, Aspects of Mesozoic geology and paleontology of the Colorado Plateau: Museum of Northern Arizona Bulletin 59, p.

Blakey, R., and Ranney, W., 2008, Ancient landscapes of the Colorado Plateau: Grand Canyon, Grand Canyon Association, 156 p.

Boden, T., Krahulec, K., Vanden Berg, M., and Rupke, A., 2016, Utah’s extractive resource industries 2015: Utah Geological Survey Circular 123, 33 p.

Boleneus, D.E., 2008, Building stone quarries and yards, Utah and parts of Arizona, Idaho, Montana, Washington, and Wyoming: Utah Geological Survey Open-File Report 521, variously paginated.

Bon, R.L., Quick, J.C., Wakefield, S.I., Hucka, B.P., and Tabet, D.E., 2006, The available coal resources for eight 7.5-minute quadrangles in the Alton Coalfield, Kane County, Utah: Utah Geological Survey Special Study 118, 23 p.

Bragg, L.J., Oman, J.K., Tewalt, S.J., Oman, C.L., Rega, N.H., Washington, P.M., and Finkelman, R.B., 1997, U.S. Geological Survey coal quality (COALQUAL) database- version 2.0: U.S. Geological Survey Open-File Report 97-134, CD-ROM.

Brown, S.D., and Hannigan, B.J., 1986, Mineral investigation of a part of the Paria-Hackberry Wilderness Study Area (UT-040-247), Kane County, Utah: U.S. Bureau of Mines Mineral Land Assessment 34-86, 25 p.

Buranek, A.M., 1945, Notes on the Manganese King property near Kanab, Kane County, Utah (includes the Johnson manganese deposit): Utah Department of Publicity and Industrial Development Circular 33, 11 p.

Bukka, K., Miller, J.D., Hanson, F.V., and Oblad, A.G., 1994, Characterization of Circle Cliffs oil sands of Utah: Fuel Processing Technology, v. 38, iss. 2, p. 111-125.
Charpentier, R.R., Klett, T.R., Obuch, R.C., and Brewton, J.D., 1996, Tabular data, text, and graphical images in support of the 1995 national assessment of United States oil and gas resources: U.S. Geological Survey Digital Data Series DDS-36, CD-ROM.
Chidsey, T.C., Jr., 1997, Oil and gas potential, in Allison, M.L., compiler and Blackett, R.E., editor, A preliminary assessment of energy and mineral resources within the Grand Staircase-Escalante National Monument: Utah Geological Survey Circular 93, p. 13–25.
Chidsey, T.C., Jr., Sprinkel, D.A., and Allison, M.L., 1998, Hydrocarbon potential in the Grand Staircase-Escalante National Monument, southern Utah [abs.]: American Association of Petroleum Geologists Annual Convention Extended Abstracts, v. I, p. A122.
Chidsey, T.C., Jr., DeHamer, J.S., Hartwick, E.E., Johnson, K.R., Schelling, D.D., Sprinkel, D.A., Strickland, D.K., Vrona, J.P., and Wavrek, D.A., 2007, Petroleum geology of Covenant oil field, central Utah thrust belt, in Willis, G.C., Hylland, M.D., Clark, D.L., and Chidsey, T.C., Jr., editors, Central Utah—diverse geology of a dynamic landscape: Utah Geological Association Publication 36, p. 273–296.
Collins, G.M., 1975, Geology and geochemistry of the Colt Mesa copper deposit, Circle Cliffs, Utah: Salt Lake City, University of Utah M.S thesis, 52 p.
Cook, D.A., 1991, Sedimentology and shale petrology of the Upper Proterozoic Walcott Member, Kwagunt Formation, Chuar Group, Grand Canyon, Arizona: Flagstaff, Northern Arizona University, M.S. thesis, 158 p.
Corbetta, P.A., 1986, Mineral investigation of a part of the Scorpion Wilderness Study Area (UT-040-082), Garfield County, Utah, and North Escalante Canyon (V) Instant Study Area, Kane County, Utah: U.S. Bureau of Mines Mineral Land Assessment 59-86, 9 p.
Cox, D.P., and Singer, D.A., 1986, Mineral deposit models: U.S. Geological Survey Bulletin 1693, 379 p.
Crangle, R.D., 2018, Gypsum, in U.S. Geological Survey, mineral commodity summaries: Online, https://minerals.usgs.gov/minerals/pubs/commodity/gypsum/mcs-2018-gypsu.pdf, accessed March 2018.
Doelling, H.H., 1975, Geology and mineral resources of Garfield County, Utah: Utah Geological and Mineral Survey Bulletin 107, 175 p.
Doelling, H.H., 2008, Geologic map of the Kanab 30’ x 60’ quadrangle, Kane and Washington Counties, Utah, and Coconino and Mohave Counties, Arizona: Utah Geological Survey Miscellaneous Publication 08-2DM, scale 1:100,000.
Doelling, H.H., Blackett, R.E., Hamblin, A.H., Powell, J.D., and Pollock, G.L., 2010, Geology of Grand Staircase-Escalante National Monument, Utah, in Sprinkel, D.A., Chidsey, T.C., Jr., and Anderson, P.B., editors, 2010, Geology of Utah’s parks and monuments (third edition): Utah Geological Association and Bryce Canyon Natural History Association, p. 193–235.
Doelling, H.H., Davis, F.D., and Brandt, C.J., 1989, The geology of Kane County, Utah: Utah Geological Survey Bulletin 124, 192 p.
Doelling, H.H., and Graham, R.L., 1972, Southwestern Utah coal fields—Alton, Kaiparowits Plateau and Kolob-Harmony: Utah Geological and Mineralogical Survey Monograph 1, 333 p.
Doelling, H.H., Smith, A.D., and Davis, F.D., 1979, Methane content of Utah coals, in Smith, M., editor, Coal studies: Utah Geological and Mineral Survey Special Studies 49, p. 1–43.
Doelling, H.H., and Willis, G.C., 1999, Interim geologic map of the Escalante and Parts of the Loa and Hite Crossing 30’ x 60’ quadrangles, Garfield and Kane Counties, Utah: Utah Geological Survey Open-File Report, scale 1:100,000.
Doelling, H.H., and Willis, G.C., 2006, Geologic map of the Smoky Mountain 30’ x 60’ quadrangle, Kane and San Juan Counties, Utah, and Coconino County, Arizona: Utah Geological Survey Map 213, scale 1:100,000.

Dolley, T.P., 2018a, Sand and gravel (industrial), in U.S. Geological Survey, mineral commodity summaries: Online, https://minerals.usgs.gov/minerals/pubs/commodity/silica/mcs-2018-sandi.pdf, accessed March 2018.
Dolley, T.P., 2018b, Stone (dimension), in U.S. Geological Survey, mineral commodity summaries: Online, https://minerals.usgs.gov/minerals/pubs/commodity/stone_dimension/mcs-2018-stond.pdf, accessed March 2018.
Dow, V.T. and Batty, J.V., 1961, Reconnaissance of titaniferous sandstone deposits of Utah, Wyoming, New Mexico, and Colorado: U.S. Bureau of Mines Report of Investigations 5860, p. 52.
Dubiel, R.F., 1994, Triassic deposystems, paleogeography, and paleoclimate of the Western Interior, in Caputo, M.V., Peterson, J.A., and Franczyk, K.J., editors, Mesozoic systems of the Rocky Mountain region, USA: Denver, Rocky Mountain Section, Society for Sedimentary Geology, p. 133–168.
Eaton, J.G., Cifelli, R.L., Hutchison, J.H., Kirkland, J.I., and Parrish, J.M., 1999, Cretaceous vertebrate faunas from the Kaiparowits Plateau, south-central Utah, in Gillette, D.D., editor, Vertebrate paleontology in Utah: Utah Geological Survey Miscellaneous Publication 99-1, p. 345–354.
Elston, D.P., 1989, Grand Canyon Supergroup, northern Arizona—stratigraphic summary and preliminary paleomagnetic correlations with parts of other North American Proterozoic successions, in Jenney, J.P., and Reynolds, S.J., editors, Geologic evolution of Arizona: Arizona Geological Society Digest, V. 17, p. 259–272.
Foster, J.R., Titus, A.L., Winterfeld, G.F., Hayden, M.C., and Hamblin, A.H., 1999, Paleontological survey of the Grand Staircase–Escalante National Monument, Garfield and Kane Counties, Utah: Utah Geological Survey unpublished report to the Bureau of Land Management, 40 p.
Force, E.R., 2000, Titanium mineral resources of the Western U.S.―an update: U.S. Geological Survey Open-File Report 00-442, p. 37.
Force, E.R., Butler, R.F., Reynolds, R.F., and Houston, R.S., 2001, Magnetic ilmenite-hematite detritus in Mesozoic-Tertiary placer and sandstone-hosted uranium deposits of the Rocky Mountains: Economic Geology, vol. 96, p. 1445-1453.
Eisenhour, D., and Reisch, F., 2006, Bentonite, in Kogel, J.E., Trivedi, N.C., Barker, J.M., and Krukowski, S.T., editors, Industrial minerals and rocks—commodities, markets, and uses, 7th edition: Society for Mining, Metallurgy, and Exploration, Inc., p. 357–368.
Gautier, D.L., Dolton, G.L., Takahashi, K.I., and Varnes, K.L., 1996, 1995 National assessment of United States oil and gas resources: U.S. Geological Survey Digital Data Series DDS-30, CD-ROM.
Goolsby, S.M.L., Dwyff, L., and Fryt, M.S., 1988, Trapping mechanisms and petrophysical properties of the Permian Kaibab Formation, south-central Utah, in Goolsby, S.M.L., and Longman, M.W., editors, Occurrence and petrophysical properties of carbonate reservoirs in the Rocky Mountain region: Rocky Mountain Association of Geologists Guidebook, p. 193–210.
Grim, R.E., 1953, Clay mineralogy: New York, McGraw-Hill, 384 p.
Gloyn, R.W., Park, G.M., Reeves, R.G., 1997, Titanium-zirconium-bearing fossil placer deposits in the Cretaceous Straight Cliffs Formation, Garfield and Kane Counties, Utah, in Learning from the land―Grand Staircase-Escalante National Monument Science Symposium Proceedings: Salt Lake City, Bureau of Land Management, p. 293–303.
Hamblin, A.H., 1998, Mesozoic vertebrate footprints in the Grand Staircase–Escalante National Monument, Utah: Journal of Vertebrate Paleontology, v. 18, supplement to no. 3, p. 48A.
Harvey, C.C., and Murray, H.H., 2006, Clay—an overview, in Kogel, J.E., Trivedi, N.C., Barker, J.M., and Krukowski, S.T., editors, Industrial minerals and rocks—commodities, markets, and uses, 7th edition: Society for Mining, Metallurgy, and Exploration, Inc., p. 335–342.
Havens, R. and Agey, W.W., 1949, Concentration of manganese ores from Piute and Kane Counties, southern Utah: U.S. Bureau of Mines Report Investigation 4551, 9 p.
Hecker, S., 1993, Quaternary tectonics in Utah with emphasis on earthquake-hazard characterization: Utah Geological Survey Bulletin 127, 2 pts.

Herron, S., 2006, Industrial sand and sandstone, in Kogel, J.E., Trivedi, N.C., Barker, J.M., and Krukowski, S.T., editors, Industrial minerals and rocks—commodities, markets, and uses, 7th edition: Society for Mining, Metallurgy, and Exploration, Inc., p. 815-832.

Hettinger, R.D., Roberts, L.N., Biewick, L.R., and Kirschbaum, M.A., 1996, Preliminary investigations of the distribution and resources of coal in the Kaiparowits Plateau, southern Utah: U.S. Geological Survey Open-File Report 95-539, 72 p., 1 plate.

Hintze, L.F., and Kowallis, B.J., 2009, Geologic history of Utah: Brigham Young University Geology Studies Special Publication 9, 225 p.

Hodgson, D.L., 1974, 1974 limestone exploration for the Kaiparowits Project: Unpublished report for Arizona Public Service during the planning for the Kaiparowits Power Plant, variously paginated.

Houston, R.S., and Murphy, J.F., 1977, Depositional environment of Upper Cretaceous black sandstones of the western interior: U.S. Geological Survey Professional Paper 994-A. 29 p.

Hucka, B.P., Sommer, S.N., and Tabet, D.E., 1997, Petrographic and physical characteristics of Utah coals: Utah Geological Survey Circular 94, 80 p., 10 appendices, 1 diskette.

Irwin, C.D., 1976, Permian and Lower Triassic reservoir rocks of central Utah, in Hill, J.G., editor, Geology of the Cordilleran Hingeline: Rocky Mountain Association of Geologists Guidebook, p. 193–202.

Jackson, A. L., 1983, Humates and their development at Harley Dome: Utah, Grand Junction Geological Society—1983 Field Trip, p. 17-19.

Keith, K.S., and Murray, H.H., 2006, Common clays and shale, in Kogel, J.E., Trivedi, N.C., Barker, J.M., and Krukowski, S.T., editors, Industrial minerals and rocks—commodities, markets, and uses, 7th edition: Society for Mining, Metallurgy, and Exploration, Inc., p. 369–371.

Kirkland, J.L., Lucas, S.G., and Estep, J.W., 1998, Cretaceous dinosaurs of the Colorado Plateau, in Lucas, S.G., Kirkland, J.I., and Estep, J.W., editors, Lower and Middle Cretaceous terrestrial ecosystems: New Mexico Museum of Natural History and Science Bulletin 14, p. 79–90.

Koch, W.J., 1976, Lower Triassic facies in the vicinity of the Cordilleran Hingeline—western Wyoming, southeastern Idaho and Utah, in Hill, J.G., editor, Geology of the Cordilleran Hingeline: Rocky Mountain Association of Geologists Guidebook, p. 203–217.

Kohler, J.F., Nielson, R.M., and Perkes, S., undated, Technical Report: Preliminary Assessment of the Coal Resources in the Grand Staircase-Escalante National Monument, Kane and Garfield Counties, Utah: Unpublished BLM report. 23 p.

Kohler, J.F., Quick, J.C., and Tabet, D.E., 1998, Variations in the chemistry of Upper Cretaceous, Straight Cliffs Formation coals, in Hill, L.M., editor, Learning from the land—Grand Staircase-Escalante National Monument science symposium proceedings, November 4-5, 1997: U.S. Bureau of Land Management, p. 307–320.

Lamarre, R.A., 2001, The Ferron play—a giant coalbed methane field in east-central Utah: presented October 16, 2001 at the IPAMS 2001 Coalbed Methane Symposium, Denver, Colorado.

Lessentine, R.H., 1965, Kaiparowits and Black Mesa Basins—stratigraphic synthesis: American Association of Petroleum Geologists Bulletin, v. 49, no. 11, p. 1997–2019.

Lillis, P.G., 2016, The Chuar petroleum system, Arizona and Utah, in Dolan, M.P., Higley, D.K., and Lillis, P.G., editors, Hydrocarbon source rocks in unconventional plays, Rocky Mountain Region: Rocky Mountain Association of Geologists Guidebook, p. 79–136.

Lucchitta, I., 1972, Early history of the Colorado River in the Basin and Range Province: Geological Society of America Bulletin v. 83, p. 1933–1948.

McKee, E.D., and McKee, E.H., 1972, Pliocene uplift of the Grand Canyon region—time of drainage adjustment: Geological Society of America Bulletin, v. 83, p. 1923–1932.

Mead, L., and Austin, G.S., 2006, Dimension stone, in Kogel, J.E., Trivedi, N.C., Barker, J.M., and Krukowski, S.T., senior editors, Industrial minerals and rocks—commodities, markets, and uses, 7th edition: Littleton, CO, Society for Mining, Metallurgy, and Exploration, Inc., p. 907-923.

Montgomery, S.L, 1984, Kaiparowits Basin—an old frontier with new potential: Petroleum Frontiers, v. 1, no. 1, p. 4–25.

Moore, BJ., and Sigler, S., 1987, Analyses of natural gases, 1917-1985: U.S. Bureau of Mines Information Circular 9129, p. 952.
Petroleum Information, 1984, Carbon dioxide gas origins—high temperature cookery in south-central Utah: Rocky Mountain Region Report, June 7, 1984, section 1, p. 7–9.
Pipiringos, G.N., and O'Sullivan, R.B., 1978, Principal unconformities in Triassic and Jurassic rocks, western interior United States—a preliminary survey: U.S. Geological Survey Professional Paper 1035-A, 29 p.
Quick, J.C., Tabet, D.E., Hucka, B.P, and Wakefield, S.I., 2004, The available coal resource for eight 7.5-minute quadrangles in the southern Emery coalfield, Emery and Sevier Counties, Utah: Utah Geological Survey Special Study 112, 37 p.
Quick, J.C., Tabet, D.E., Hucka, B.P, and Wakefield, S.I., 2005, The available coal resource for nine 7.5-minute quadrangles in the southern Wasatch Plateau coalfield, Emery, Sanpete, and Sevier Counties, Utah: Utah Geological Survey Special Study 114, 1 CD-ROM.
Rauzi, S.L., 1990, Distribution of Proterozoic hydrocarbon source rock in northern Arizona and southern Utah: Phoenix, Arizona, Arizona Oil and Gas Conservation Commission Special Publication 5, 38 p., map scale 1:500,000.
Ritzma, H.R., 1979, Oil-impregnated rock deposits of Utah: Utah Geological and Mineral Survey Map 47, scale 1:1,000,000.
Ritzma, H.R., 1980, Oil-impregnated sandstone deposits, Circle Cliffs Uplift, Utah, in Picard, M.D., editor, Henry Mountains Symposium: Utah Geological Association Publication 8, p. 343-351.
Robison, R.A., 1966, Geology and coal resources of the Tropic area, Garfield County, Utah: Utah Geological and Mineralogical Survey Special Studies 18, 47 p.
Rupke, A.L., and Boden, T., 2013, Frac sand potential on selected SITLA lands: unpublished report prepared for SITLA by the Utah Geological Survey, variously paginated.
Sandberg, C.A., and Gutschick, 1984, Distribution, microfauna, and source-rock potential of Mississippian Delle Phosphatic Member of Woodman Formation and equivalents, Utah and adjacent states, in Woodward, J., Meissner, F.F., and Clayton, J.L., editors, Hydrocarbon source rocks of the Greater Rocky Mountain region: Rocky Mountain Association of Geologists Guidebook, p. 135–178.
Seeley, J.M., and Keller, G.R., 2003, Delineation of subsurface Proterozoic Unkar and Chuar Group sedimentary basins in northern Arizona using gravity and magnetics—implications for hydrocarbon source potential: American Association of Petroleum Geologists Bulletin, v. 87, no. 8, p. 1299–1321.
Sharp, G.C., 1976, Reservoir variations at Upper Valley field, Garfield County, Utah, in Hill, J.G., editor, Geology of the Cordilleran Hingeline: Rocky Mountain Association of Geologists Guidebook, p. 325–344.
Sharp, G.C., 1978, Upper Valley, in Fossett, J.E., editor, Oil and gas fields of the Four Corners area: Four Corners Geological Society Guidebook, v. II, p. 709–711.
Sharpe, R., and Cork, G., 2006, Gypsum and anhydrite, in Kogel, J.E., Trivedi, N.C., Barker, J.M., and Krukowski, S.T., senior editors, Industrial minerals and rocks—commodities, markets, and uses, 7th edition: Littleton, CO, Society for Mining, Metallurgy, and Exploration, Inc., p. 519-540.
Shepherd, R.A., Kiefer, W.S., and Graham, W.R.M., 1986, Characterization of Circle Cliffs tar sands—1. Application of the FT-i.r. Technique to mineral matter: Fuel, v. 65, iss. 9, p. 1261-1264.
Sprinkel, D.A., Castaño, J.R., and Roth, G.W., 1997, Emerging plays in central Utah based on a regional geochemical, structural, and stratigraphic evaluation [abs.]: American Association of Petroleum Geologists Bulletin Annual Convention, Official Program with Abstracts, v. 6, p. A110.
Stokes, W.L., 1987, Geology of Utah: Utah Geological and Mineral Survey and Utah Museum of Natural History, Salt Lake City, Utah, 280 p.
Tabet, D.E., 2006, Mineral potential report for the Kanab Planning Area, Kanab Field Office: report prepared for U.S. Bureau of Land Management, 87 p.

Tabet, D.E., Quick, J.C., Hucka, B.P., and Hanson, J.A., 1999, The available coal resources for nine 7.5-minute quadrangles in the northern Wasatch Plateau coalfield, Carbon and Emery Counties, Utah: Utah Geological Survey Circular 100, 46 p.

Tripp, B.T., 2005, High-calcium limestone resources of Utah: Utah Geological Survey Special Study 116, 83 p.

University of Utah Seismology Catalog, 1986, Earthquake data, 1979 to February 1986: University of Utah, Department of Geology and Geography.

Uphoff, T.L., 1997, Precambrian Chuar source rock play—an exploration case history in southern Utah: American Association of Petroleum Geologists Bulletin, v. 81, no. 1, p. 1–15.

U.S. Geological Survey, 2018, U.S. Geological Survey minerals information: Online, https://minerals.usgs.gov/minerals/pubs/commodity/ , accessed March 2018.

Utah Department of Highways, undated, Materials inventory—Piute, Wayne, Garfield, and Kane Counties: Utah State Department of Highways, Materials and Research Division, Materials Inventory Section, 33 p.

Utah Division of Oil, Gas and Mining, 2018, Oil and gas summary production report by field, September 2017: Online, https://oilgas.ogm.utah.gov/oilgasweb/publications/monthly-rpts-by-fld.xhtml, accessed April 2018.

Utah Geological Survey, 1998, Energy news—new study suggests gas deposits in Grand Staircase may have been moved by CO2: Utah Geological Survey, Survey Notes, v. 31, no. 1, p 8.

Van Sant, J.N., 1964, Refractory-clay deposits of Utah: U.S. Bureau of Mines Information Circular 8213, 176 p.

Welsh, J.E., and Bissell, H.J., 1979, Chapter Y – Utah, in The Mississippian and Pennsylvanian (Carboniferous) systems in the United States: U.S. Geological Survey Professional Paper 1110-M-DD, p. Y1–Y35.

Willett, J.C., 2018a, Sand and gravel (construction), in U.S. Geological Survey, mineral commodity summaries: Online, https://minerals.usgs.gov/minerals/pubs/commodity/sand_&_gravel_construction/mcs-2018-sandc.pdf, accessed March 2018.

Willett, J.C., 2018b, Stone (crushed), in U.S. Geological Survey, mineral commodity summaries: Online, https://minerals.usgs.gov/minerals/pubs/commodity/stone_crushed/mcs-2018-stonc.pdf, accessed March 2018.

Wood, R.E., and Ritzma, H.R., 1972, Analyses of oil extracted from oil-impregnated sandstone deposits in Utah: Utah Geological and Mineralogical Survey Special Studies 39, 19 p.

Wood, R.E., and Chidsey, T.C., Jr., 2015, Oil and gas fields map of Utah: Utah Geological Survey Circular 119, scale 1:700,000.

Zelten, J.E., 1987, Mineral investigation of eleven Wilderness Study Areas adjacent to Zion National Park, southwestern Utah: U.S. Bureau of Mines Mineral Land Assessment 77-87, 55 p.

APPENDIX A. MINERAL OCCURRENCE POTENTIAL CLASSIFICATION SYSTEM (from BLM Manual 3031, illustration 3)

Potential for Occurrence

H: The geologic environment, the inferred geologic process, the reported mineral occurrences and/or valid geochemical/geophysical anomaly, and the known mines or deposits indicate high potential for accumulation of mineral resources. The known mines and deposits do not have to be within the areas that is being classified, but have to be within the same type of geologic environment.

M: The geologic environment, the inferred geologic process, the reported mineral occurrences or valid geochemical/geophysical anomaly indicates moderate potential for accumulation of mineral resources.

L: The geologic environment and the inferred geologic process indicate low potential for accumulation of mineral resources.

O: The geologic environment, the inferred geologic process, and the lack of mineral occurrences do not indicate potential for accumulation of mineral resources.

ND: Mineral potential is not determined due to the lack of useful data. This notation does not require a level of certainty qualifier.

Certainty of Occurrence

A: The available data are insufficient and/or cannot be considered as direct or indirect evidence to support or refute the possible existence of mineral resources within the respective area.

B: The available data provide indirect evidence to support or refute the possible existence of mineral resources.

C: The available data provide direct evidence but are quantitatively minimal to support or refute the possible existence of mineral resources.

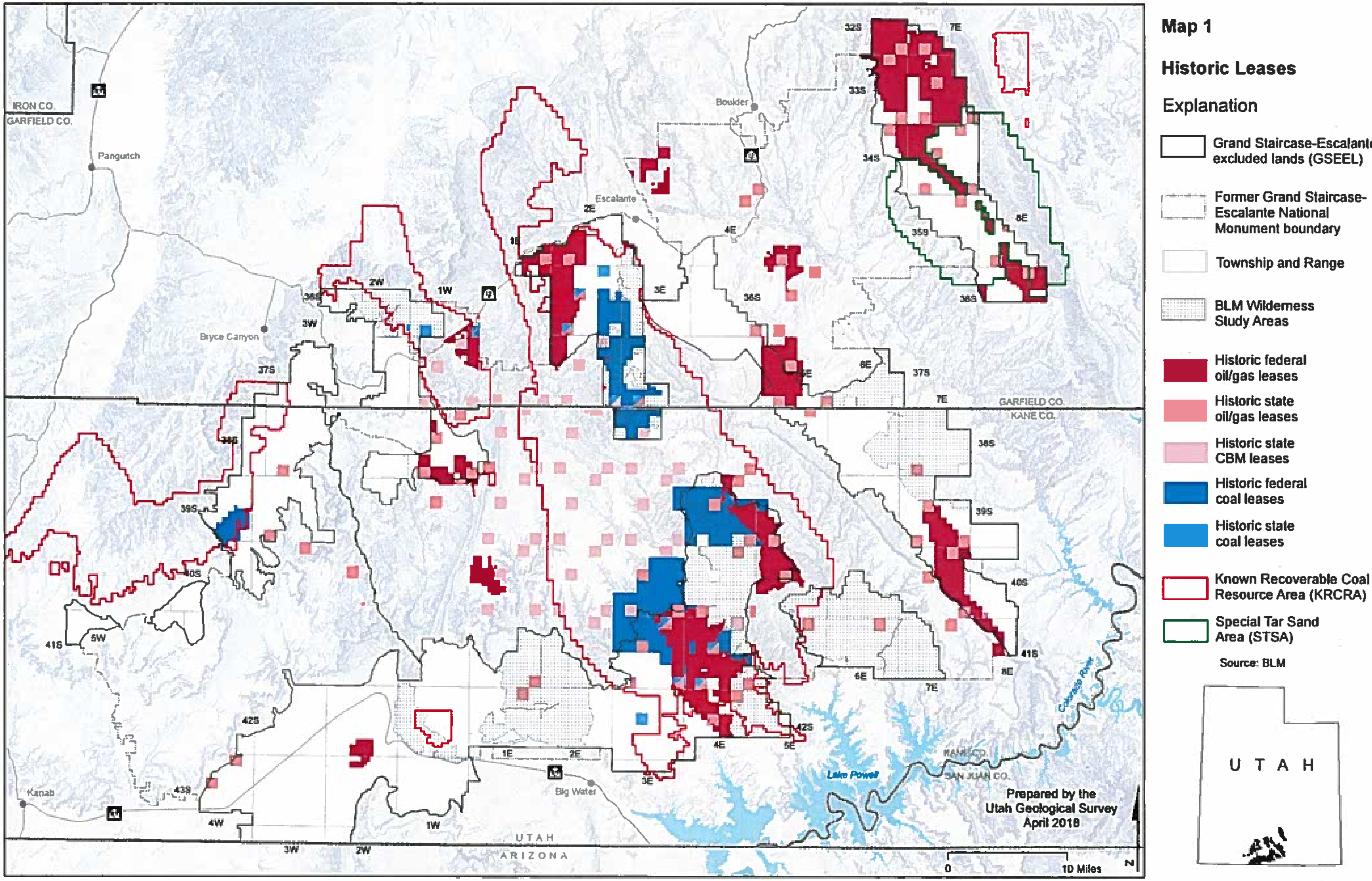
D: The available data provide abundant direct evidence and indirect evidence to support or refute the possible existence of mineral resources.

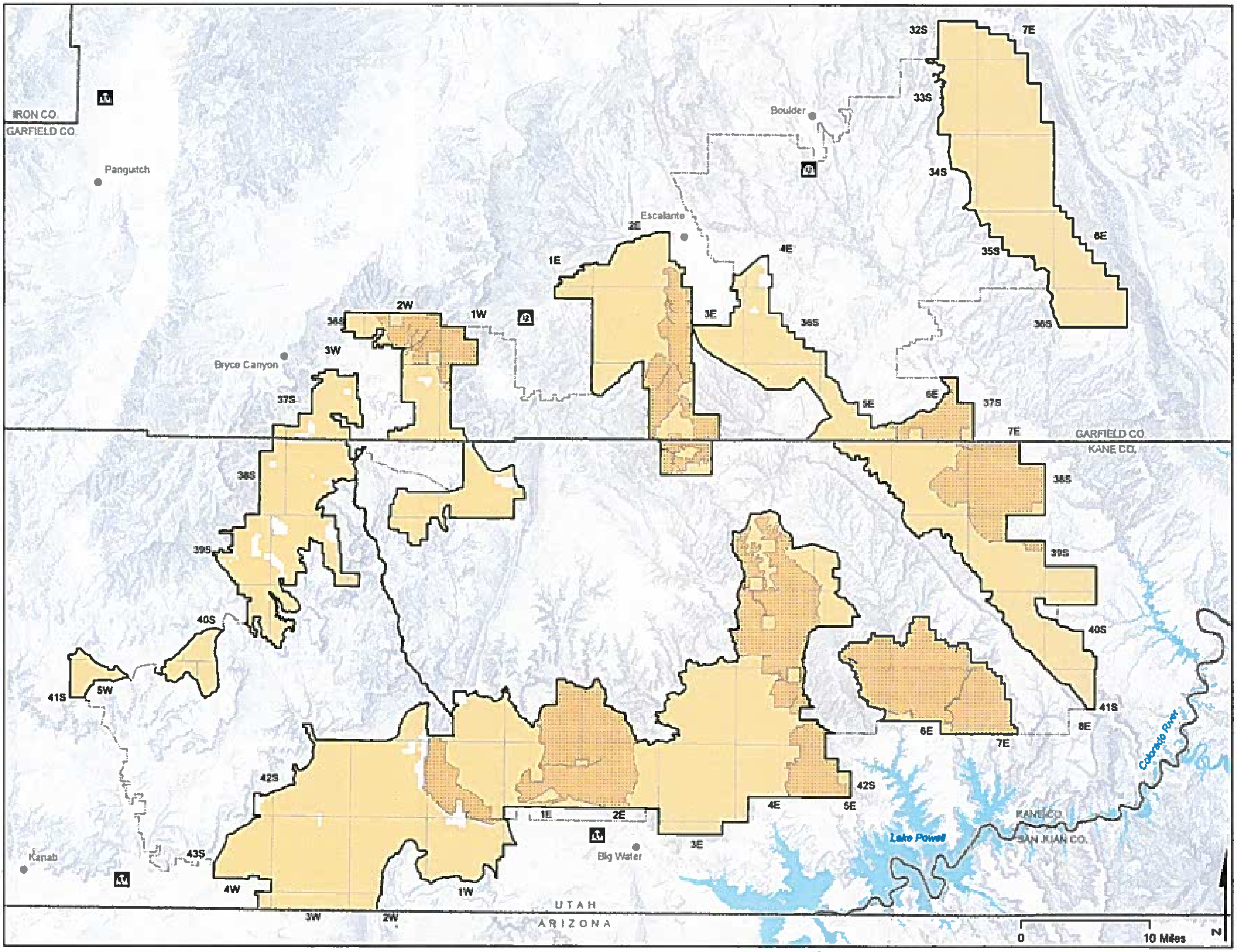
NONE: No data exist to prove or disprove the existence of economic deposits of petroleum or carbon dioxide in the play area reservoirs.

(Note: the determination of "no potential (O)" for specific commodities implies O/D.)

APPENDIX B. OIL AND GAS FIELD-SIZE CLASSIFICATION

Field Size	**Gas, trillion cubic feet** (ULTIMATE RECOVERY)	**Oil, millions of barrels** (ULTIMATE RECOVERY)
Giant	>5 to 50	>500 to 5,000
Major	>1 to 5	>100 to 500
Large	>0.5 to 1	>50 to 100
Medium	>0.25 to 0.5	>25 to 50
Small	>0.1 to 0.25	>10 to 25
Very Small	>0.01 to 0.1	>1 to 10
Tiny	>0.001 to 0.01	>0.1 to 1
Insignificant	≤ 0.001	≤ 0.1


Map 1
Historic Leases
Explanation
Grand Staircase-Escalante excluded lands (GSEEL)
Former Grand Staircase-Escalante National Monument boundary
Township and Range
BLM Wilderness Study Areas
Historic federal oil/gas leases
Historic state oil/gas leases
Historic state CBM leases
Historic federal coal leases
Historic state coal leases
Known Recoverable Coal Resource Area (KRCRA)
Special Tar Sand Area (STSA)
Source: BLM
UTAH
IRON CO.
GARFIELD CO.
Panguitch
Boulder
Escalante
Bryce Canyon
KANE CO.
Kanab
Big Water
Lake Powell
Colorado River
SAN JUAN CO.
UTAH
ARIZONA
Prepared by the
Utah Geological Survey
April 2018
0
10 Miles
N



Map 2

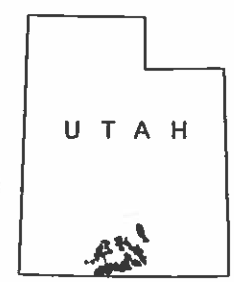
Surface Management

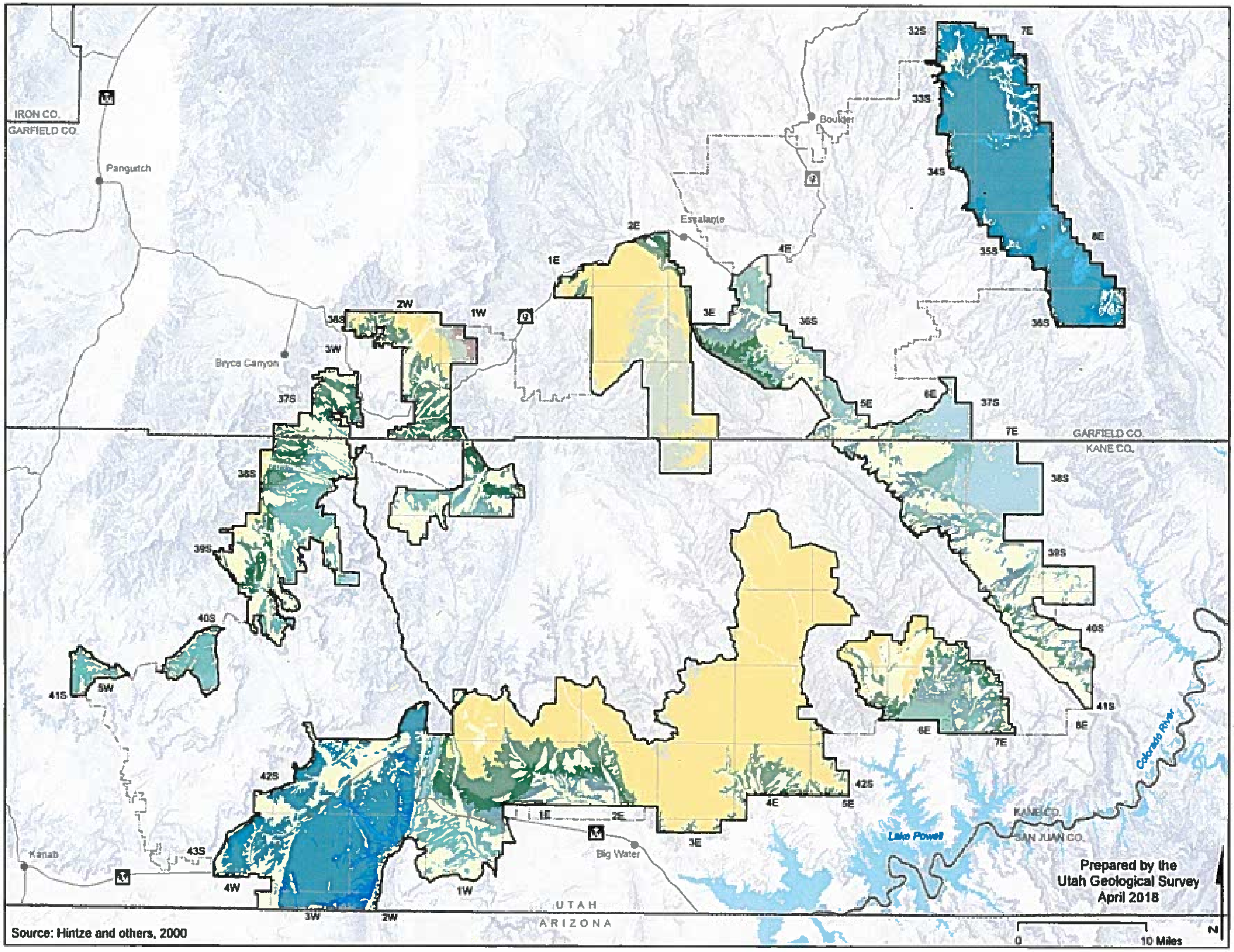
Explanation

- Grand Staircase-Escalante exluded lands (GSEEL)
- Former Grand Staircase-Escalante National Monument boundary
- Township and Range
- BLM Wilderness Study Areas
- BLM
- Private

Prepared by the
Utah Geological Survey
April 2018

Source: BLM; SITLA; Utah AGRC





Source: Hintze and others, 2000

Map 3

Geologic Map of Grand Staircase-Escalante Excluded Lands

Explanation

Grand Staircase-Escalante excluded lands (GSEEL)

Former Grand Staircase-Escalante National Monument boundary

Township and Range

Map Symbols

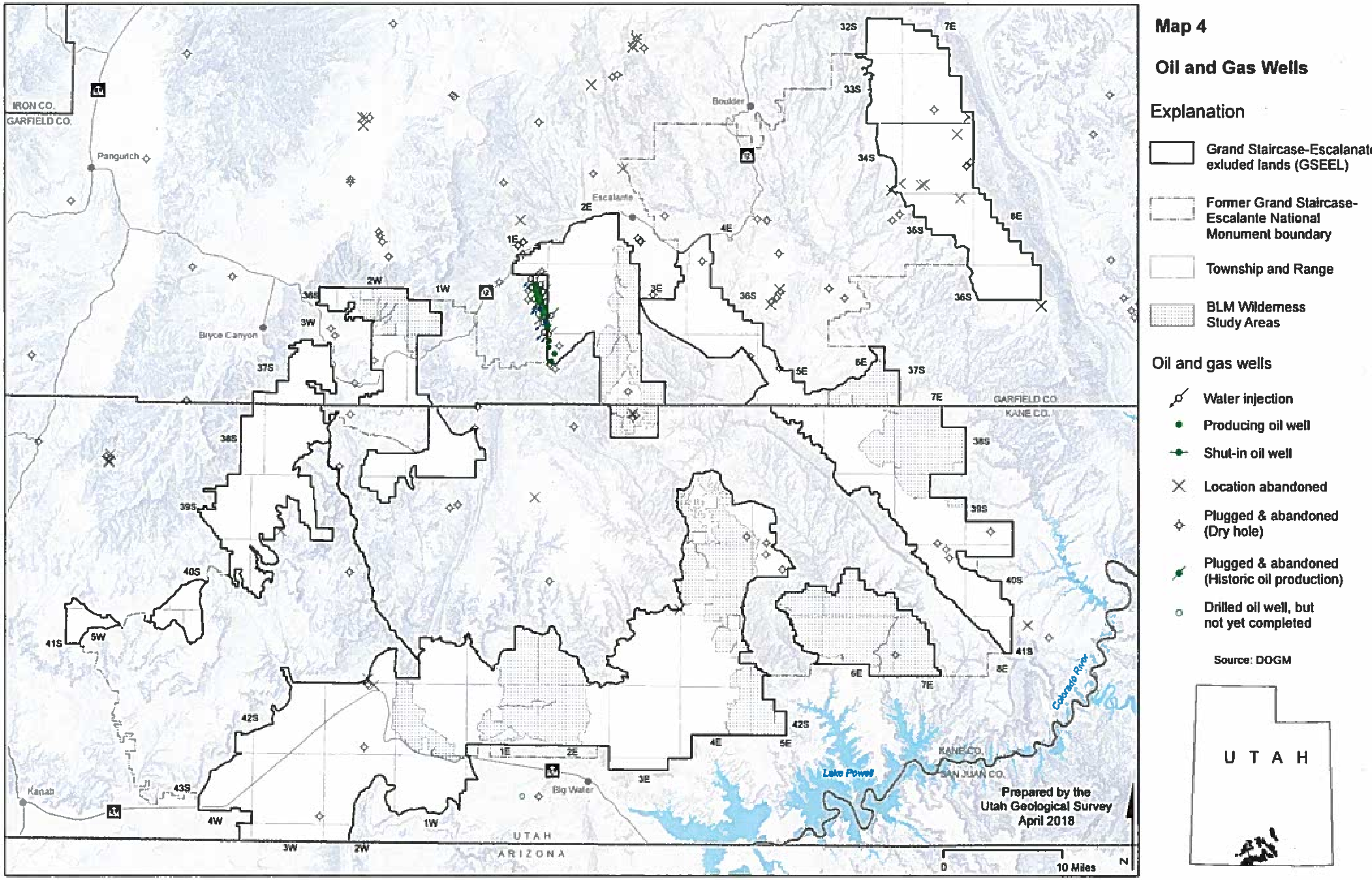
Quat
- Q – Surficial Deposits

Cretaceous
- Kk – Kaiparowits Fm
- Kw – Wahweap Fm
- Ks – Straight Cliffs Fm
- Kt – Tropic Sh
- Kdcm – Dakota-Cedar Mtn Fms

Jurassic
- Jm – Morrison Fm
- Jms – Morrison-Summerville Fms
- Jr – Romana Ss
- Je – Entrada Ss
- Jc – Carmel Fm
- Jp – Page Ss
- Jn – Navajo Ss
- Jk – Kayenta Fm
- Jw – Wingate Ss
- JTm – Moenave Fm

Triassic
- Tc – Chinle Fm
- Tm – Moenkopi Fm

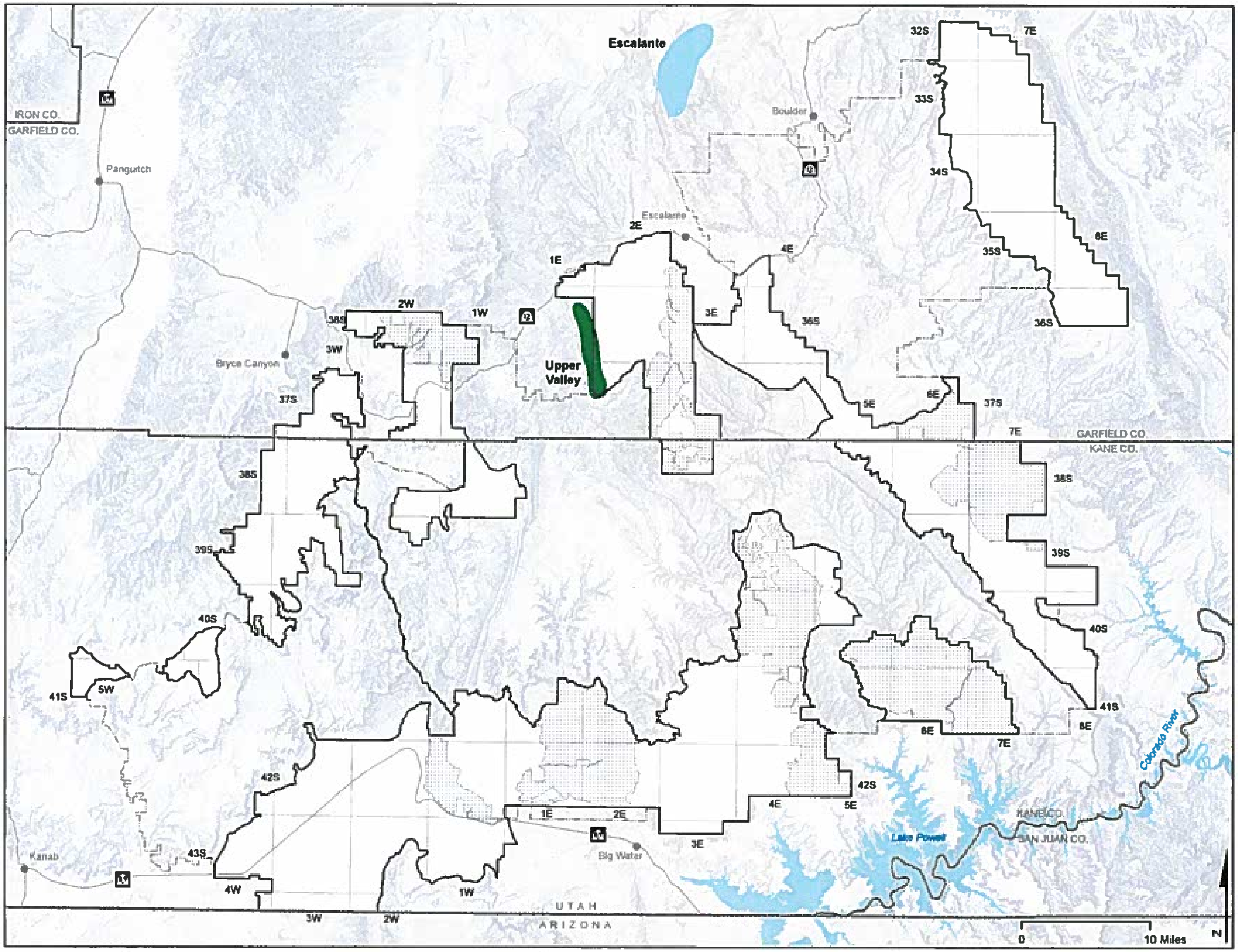
Permian
- Pu – Permian, undivided
- Pk – Kaibab Fm
- Pt – Toroweap Fm
- Ph – Hermit Fm



Map 4
Oil and Gas Wells
Explanation
Grand Staircase-Escalanate exluded lands (GSEEL)
Former Grand Staircase-Escalante National Monument boundary
Township and Range
BLM Wilderness Study Areas
Oil and gas wells
Water injection
Producing oil well
Shut-in oil well
Location abandoned
Plugged & abandoned (Dry hole)
Plugged & abandoned (Historic oil production)
Drilled oil well, but not yet completed
Source: DOGM
UTAH
IRON CO.
GARFIELD CO.
Panguitch
Bryce Canyon
Escalante
Boulder
Kanab
Big Water
Lake Powell
Colorado River
GARFIELD CO.
KANE CO.
KANE CO.
SAN JUAN CO.
UTAH
ARIZONA
32S
33S
34S
35S
36S
37S
38S
39S
40S
41S
42S
43S
5W
4W
3W
2W
1W
1E
2E
3E
4E
5E
6E
7E
8E
Prepared by the Utah Geological Survey April 2018
0
10 Miles
N

Map 5

Oil and Gas Fields



Explanation

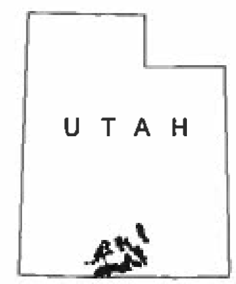
- Grand Staircase-Escalante excluded lands (GSEEL)
- Former Grand Staircase-Escalante National Monument boundary
- Township and Range
- BLM Wilderness Study Areas

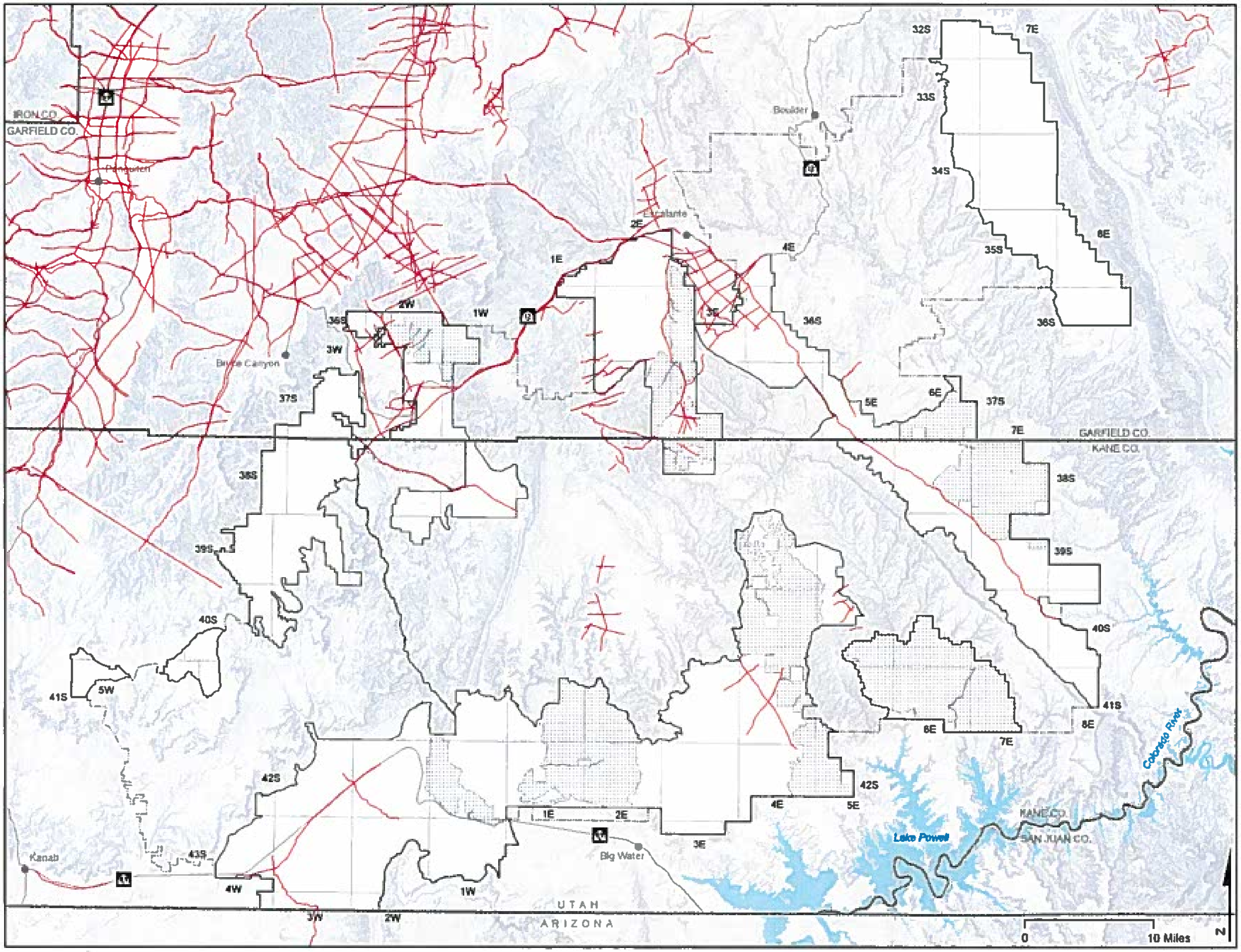
Oil and gas fields

- Oil field
- Carbon dioxide field

Prepared by the
Utah Geological Survey
April 2018

Source: DOGM; Wood and Chidsey, 2015





Map 6

Geophysical Surveys

Explanation

Grand Staircase-Escalante exluded lands (GSEEL)

Former Grand Staircase-Escalante National Monument boundary

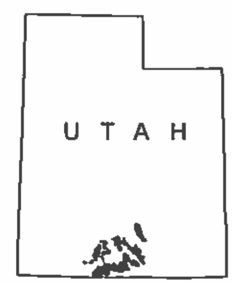
Township and Range

BLM Wilderness Study Areas

2D seismic survey lines

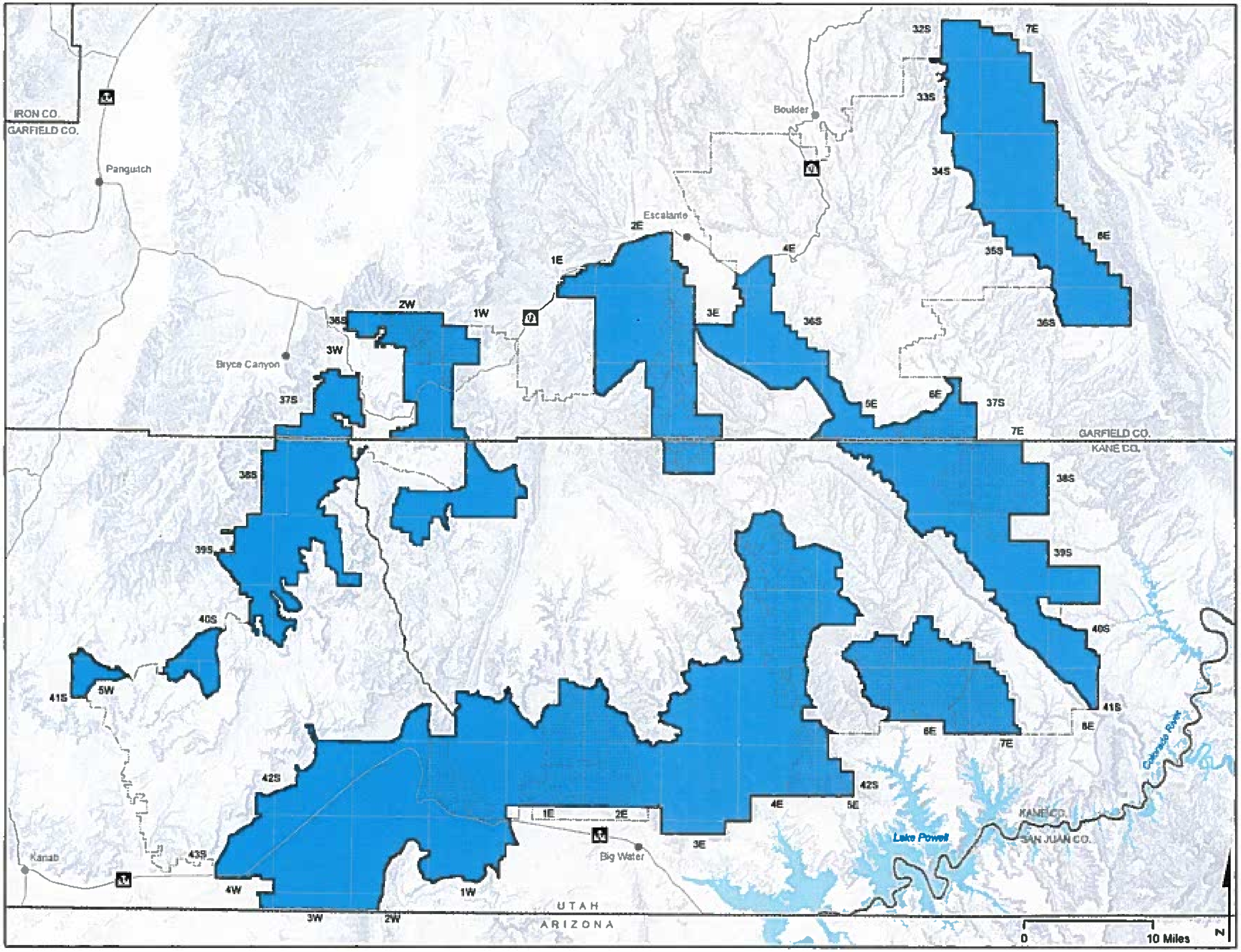
Prepared by the
Utah Geological Survey
April 2018

Source: Seismic Exchange, Inc.



Map 7

Late Proterozoic and Lower Paleozoic (2403) Play - Occurrence Potential



Explanation

Grand Staircase-Escalanate excluded lands (GSEEL)

Former Grand Staircase-Escalante National Monument boundary

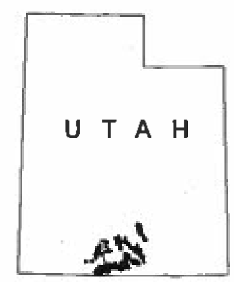
Township and Range

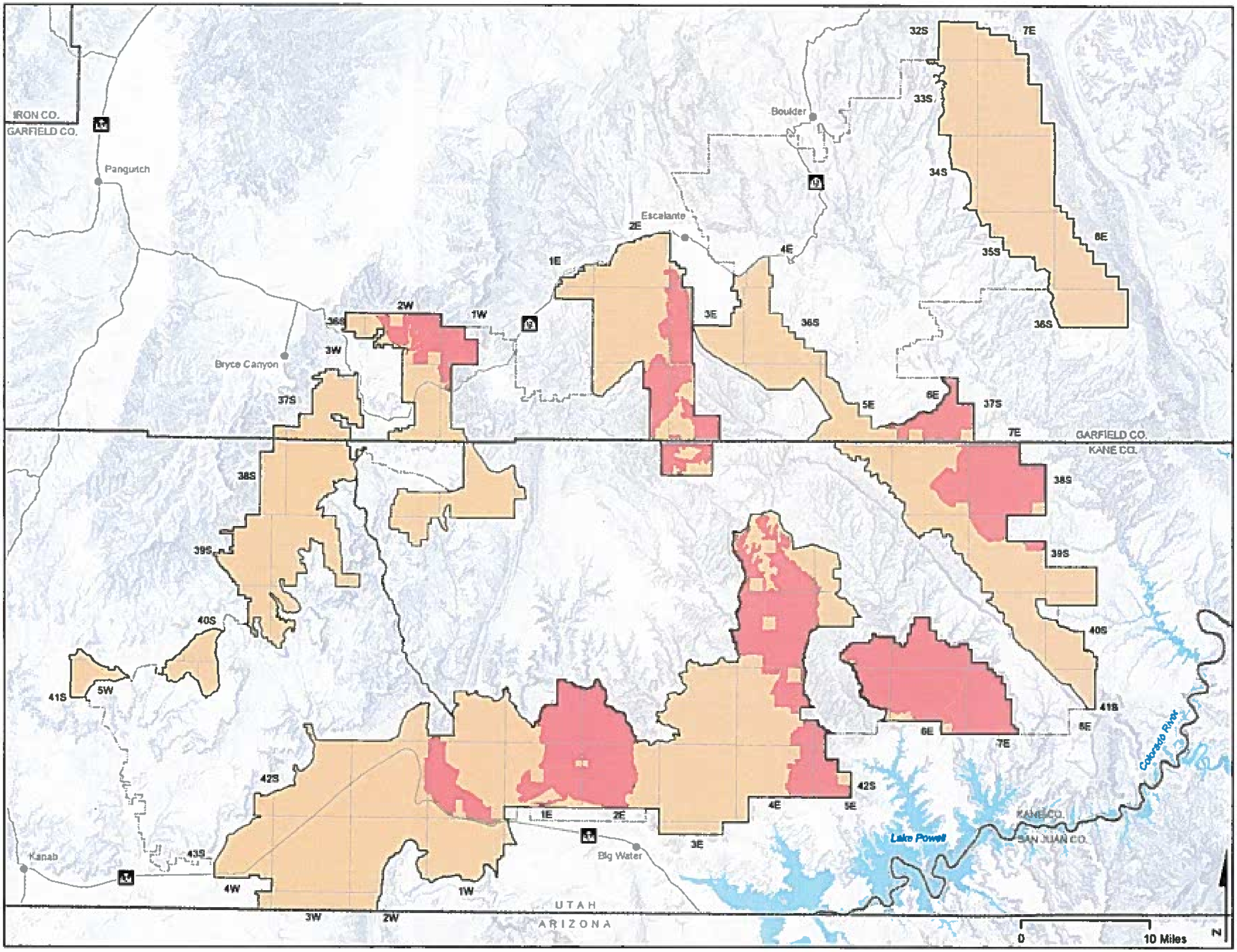
BLM Wilderness Study Areas

Oil and gas play (Low/C)

Prepared by the
Utah Geological Survey
April 2018

Play boundary source:
UGS; Charpentier et al., 1996





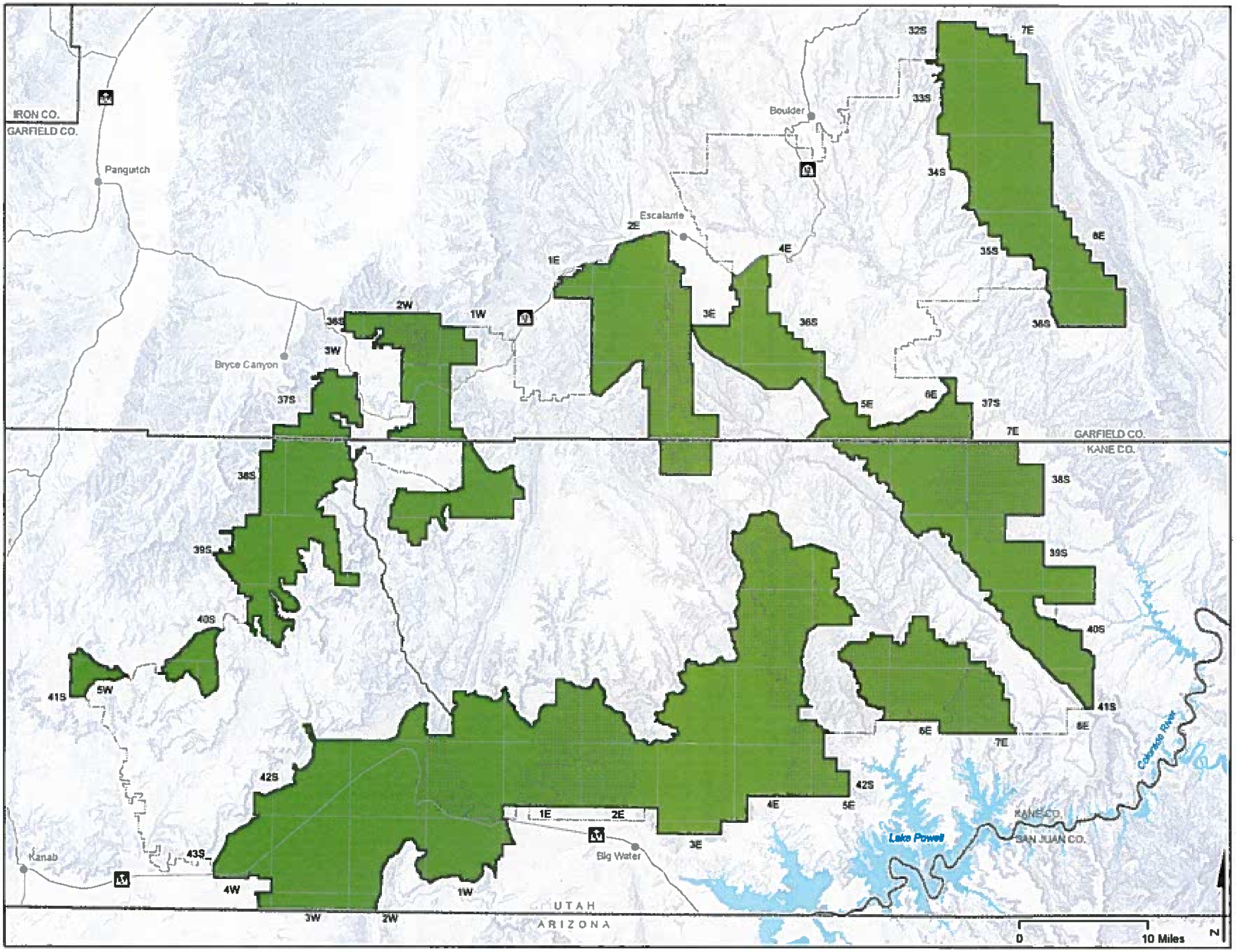
Map 8

Late Proterozoic and Lower Paleozoic (2403) Play - Development Potential

Explanation

- Grand Staircase-Escalante excluded lands (GSEEL)
- Former Grand Staircase-Escalante National Monument boundary
- Township and Range
- Restricted land (WSAs) - Low
- Oil and gas play - Low

Prepared by the
Utah Geological Survey
April 2018



Map 9

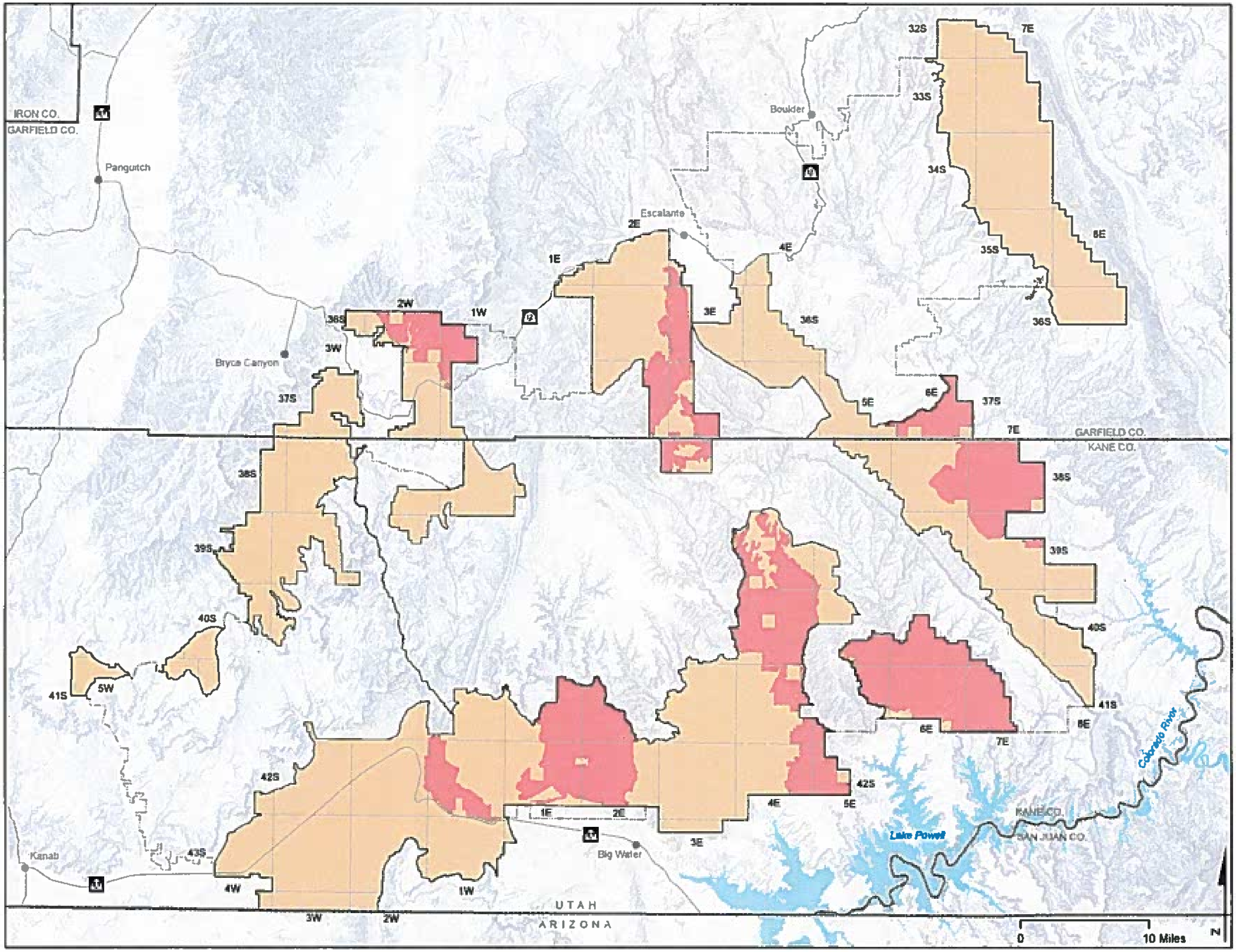
Paleozoic Devonian through Mississippian (2108) Play - Occurrence Potential

Explanation

- Grand Staircase-Escalante excluded lands (GSEEL)
- Former Grand Staircase-Escalante National Monument boundary
- Township and Range
- BLM Wilderness Study Areas
- Oil and gas play (Moderate/C)

Prepared by the Utah Geological Survey April 2018

Play boundary source: UGS



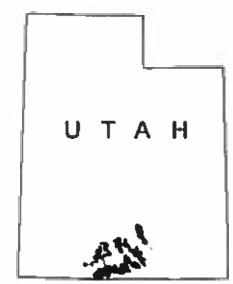
Map 10

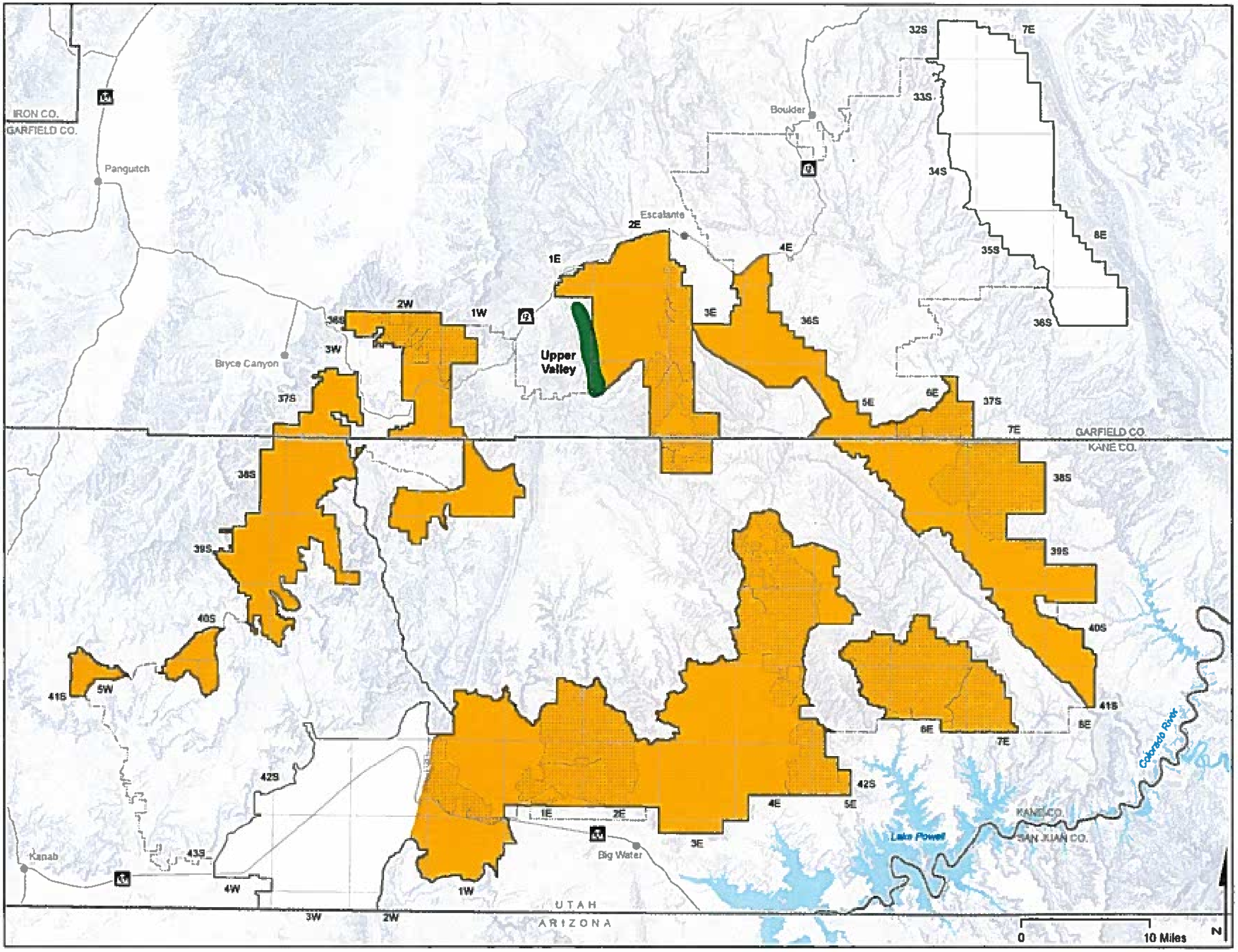
Paleozoic Devonian through Mississippian (2108) Play - Development Potential

Explanation

- Grand Staircase-Escalante excluded lands (GSEEL)
- Former Grand Staircase-Escalante National Monument boundary
- Township and Range
- Restricted land (WSAs) - Low
- Oil and gas play - Moderate

Prepared by the Utah Geological Survey
April 2018





Map 11

Permo Triassic Unconformity (2106) Play - Occurrence Potential

Explanation

Grand Staircase-Escalante excluded lands (GSEEL)

Former Grand Staircase-Escalante National Monument boundary

Township and Range

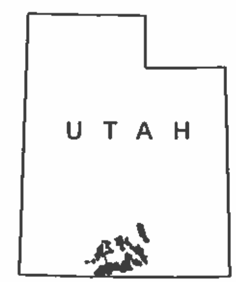
BLM Wilderness Study Areas

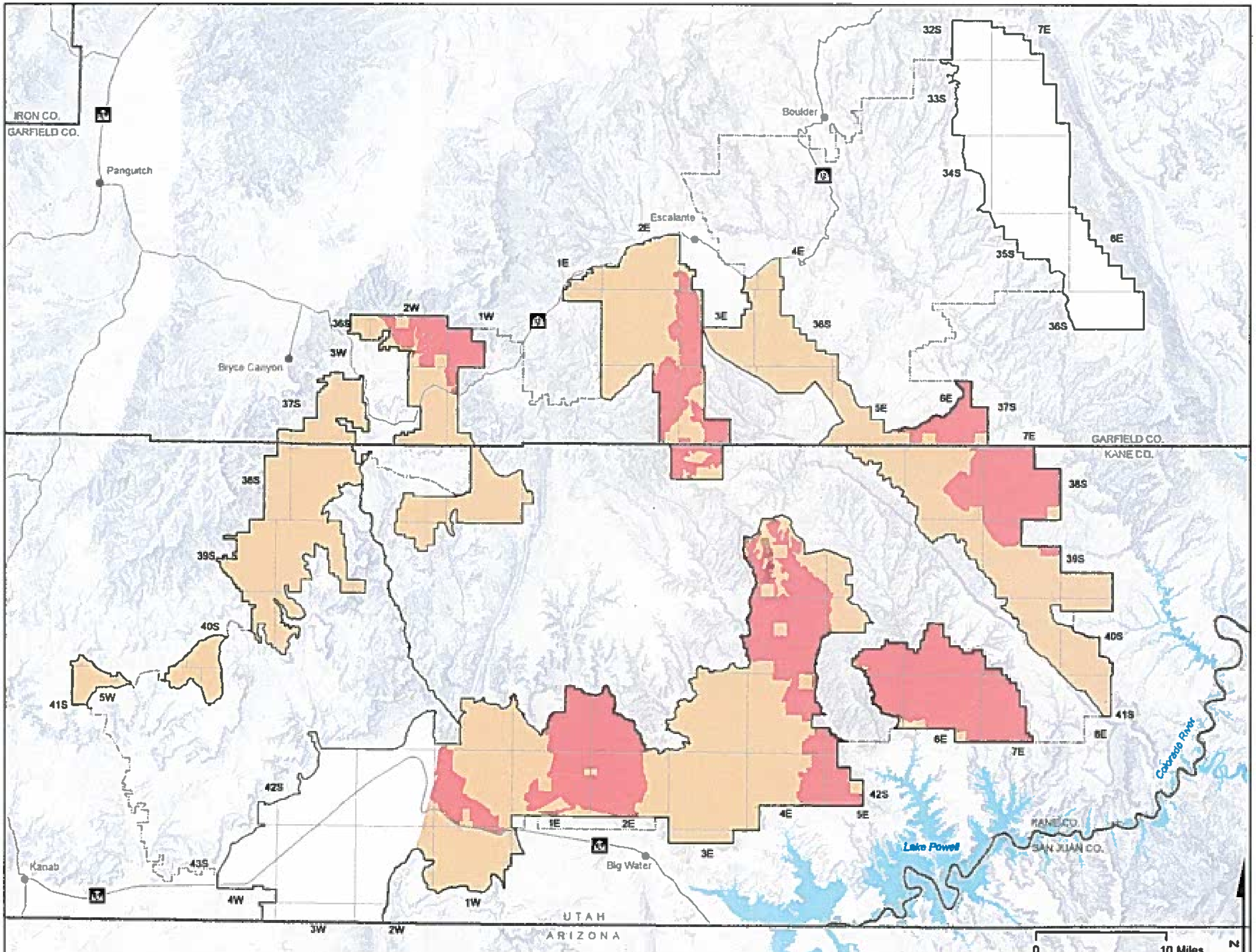
Oil field

Oil and gas play (High/D)

Prepared by the Utah Geological Survey April 2018

Play boundary source: Charpentier and others, 1996; UGS





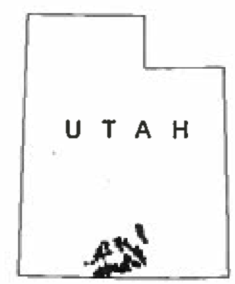
Map 12

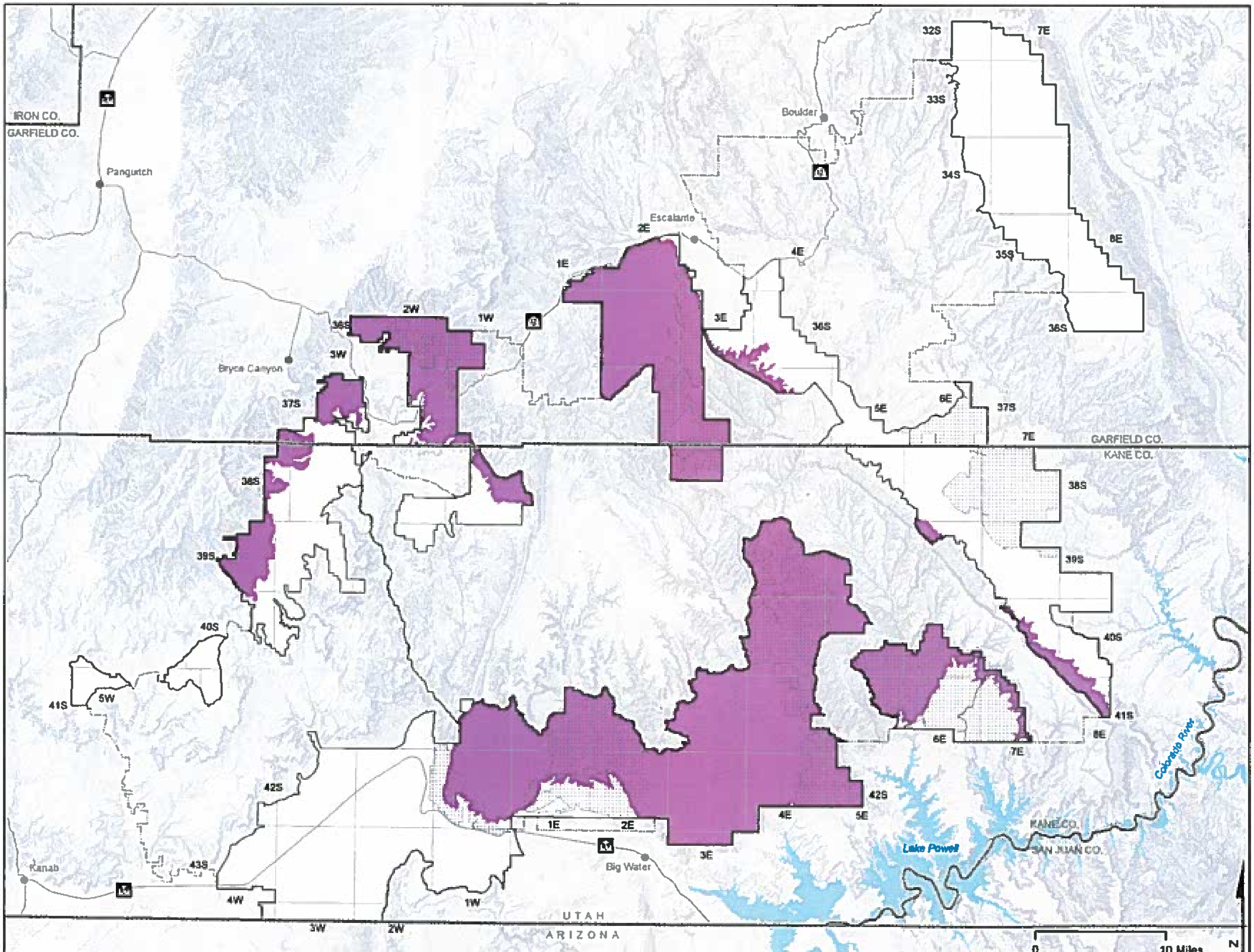
Permo Triassic Unconformity (2106) Play - Development Potential

Explanation

- Grand Staircase-Escalante excluded lands (GSEEL)
- Former Grand Staircase-Escalante National Monument boundary
- Township and Range
- Restricted land (WSAs) - Low
- Oil and gas play - High

Prepared by the
Utah Geological Survey
April 2018





Map 13

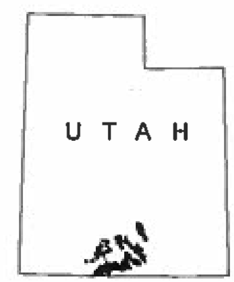
Cretaceous Conventional (2107) Hypothetical Play - Occurrence Potential

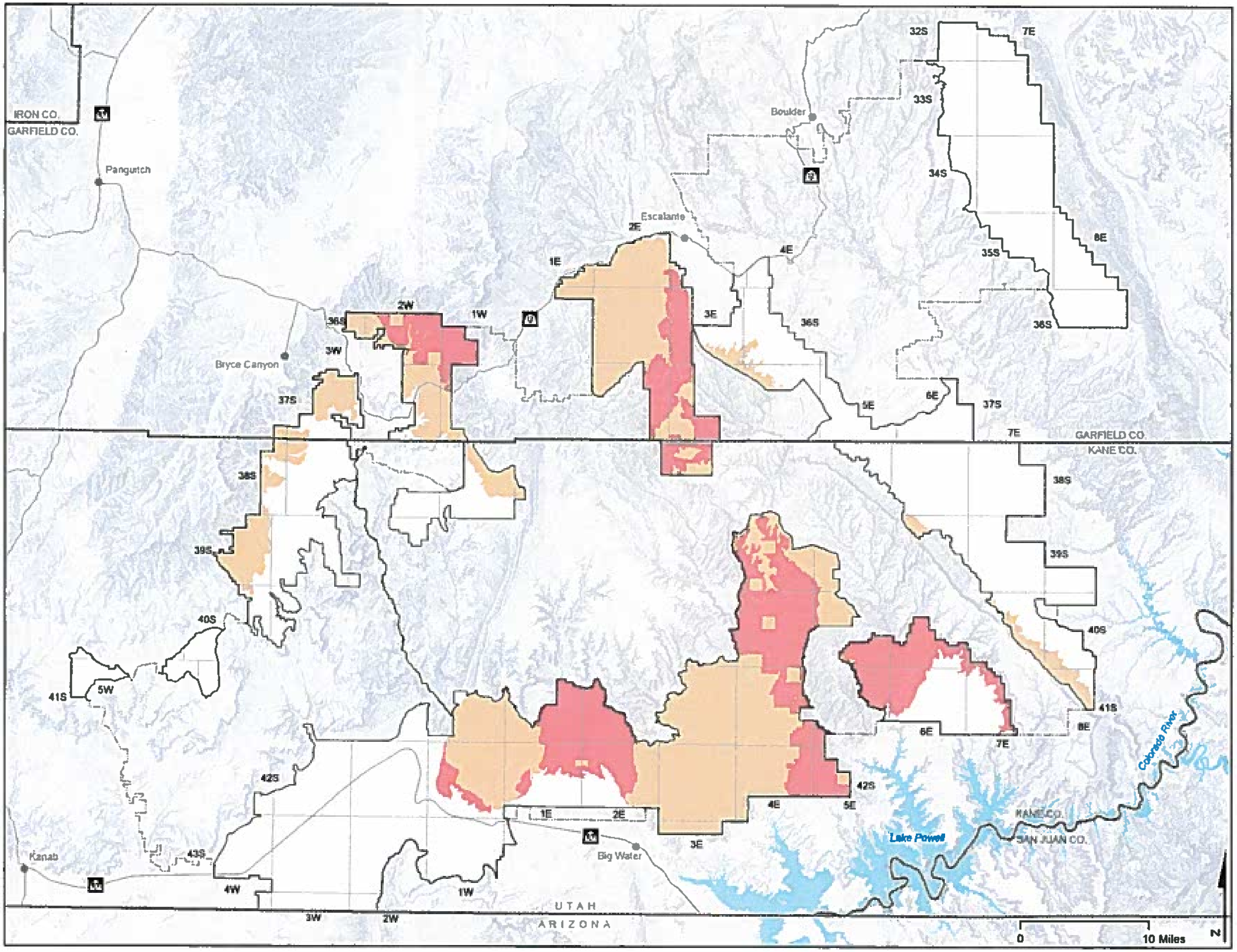
Explanation

- Grand Staircase-Escalante excluded lands (GSEEL)
- Former Grand Staircase-Escalante National Monument boundary
- Township and Range
- BLM Wilderness Study Areas
- Oil and gas play (Low/C)

Prepared by the
Utah Geological Survey
April 2018

Play boundary source: UGS





Map 14

Cretaceous Conventional (2107) Hypothetical Play - Development Potential

Explanation

Grand Staircase-Escalante excluded lands (GSEEL)

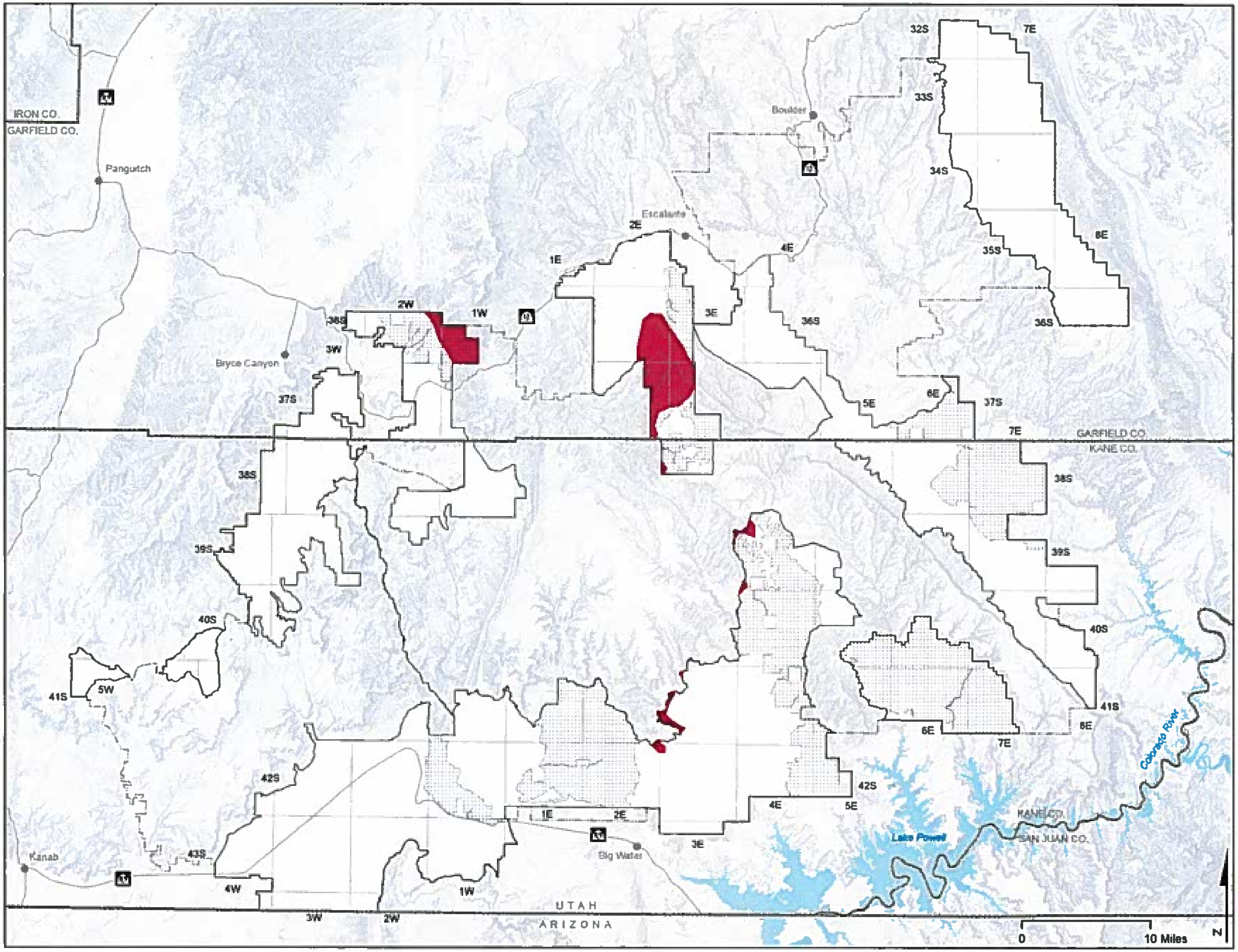
Former Grand Staircase-Escalante National Monument boundary

Township and Range

Restricted land (WSAs) - Low

Oil and gas play - Low

Prepared by the Utah Geological Survey
April 2018



Map 15

Coal Bed Methane (2100) Play - Occurrence Potential

Explanation

Grand Staircase-Escalante excluded lands (GSEEL)

Former Grand Staircase-Escalante National Monument boundary

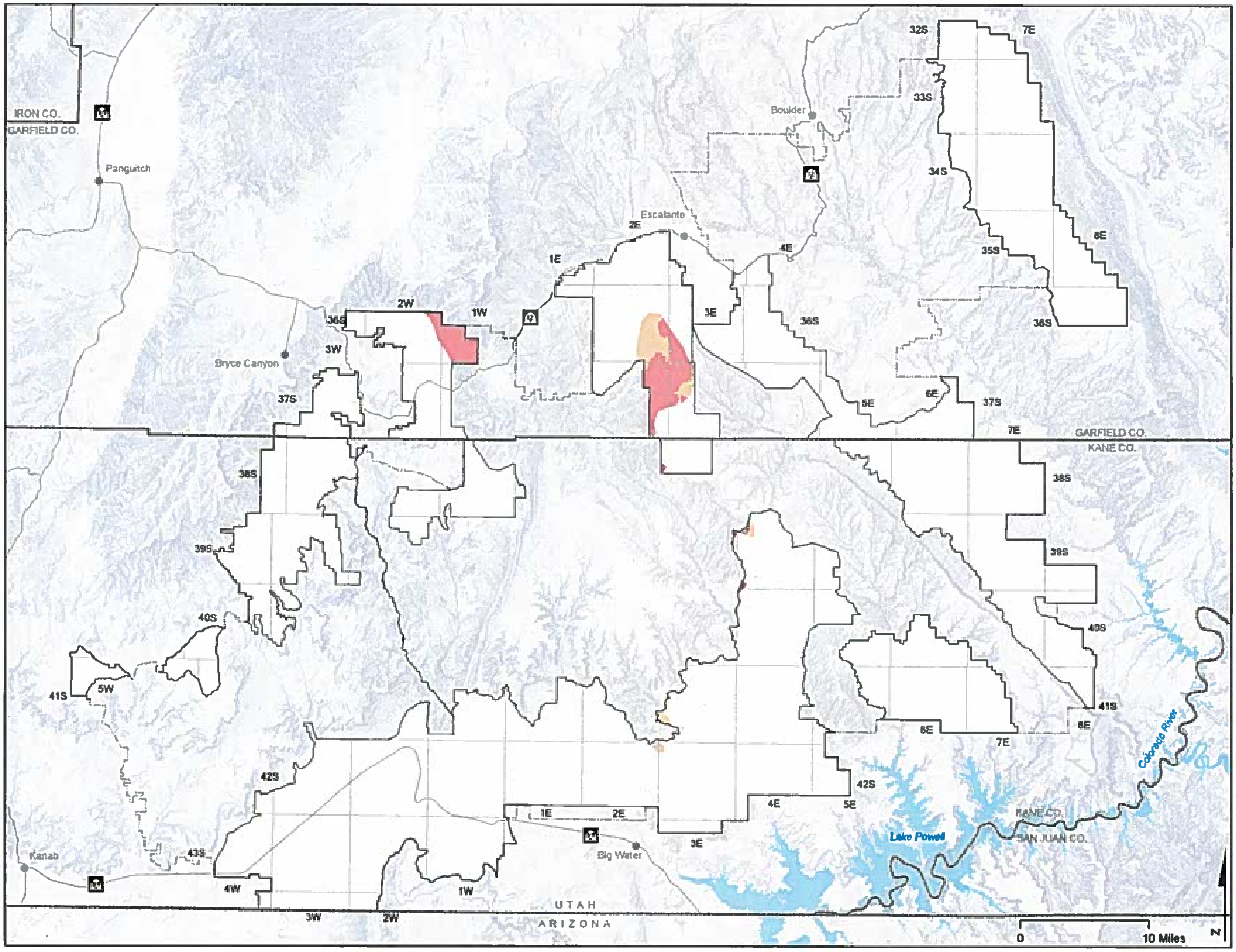
Township and Range

BLM Wilderness Study Areas

CBM play (Low/C)

Prepared by the
Utah Geological Survey
April 2018

Play boundary source:
Allison, 1997



Map 16

Coal Bed Methane (2100) Play - Development Potential

Explanation

Grand Staircase-Escalante excluded lands (GSEEL)

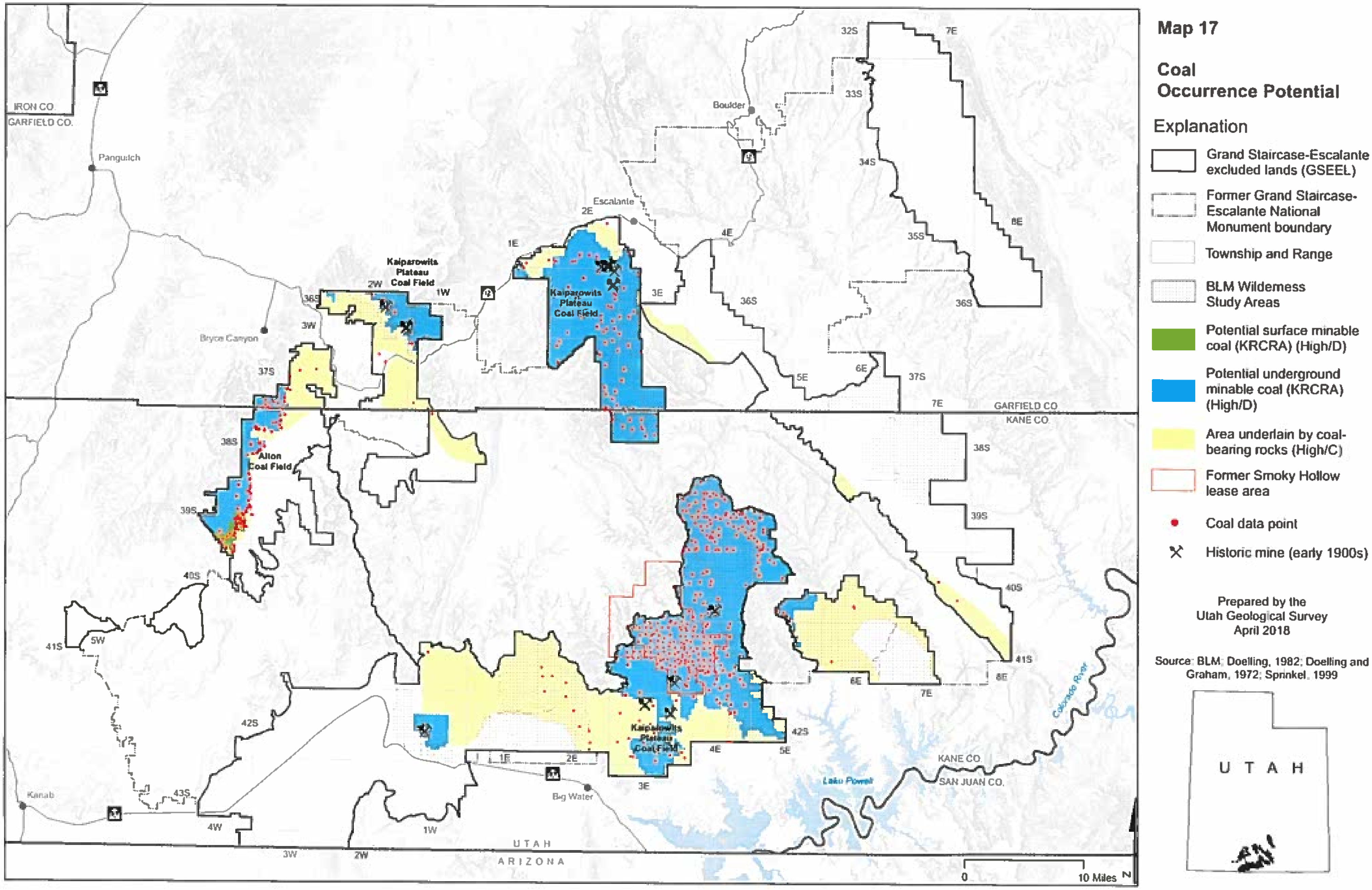
Former Grand Staircase-Escalante National Monument boundary

Township and Range

Restricted land (WSAs) - Low

CBM play - Low

Prepared by the Utah Geological Survey
April 2018

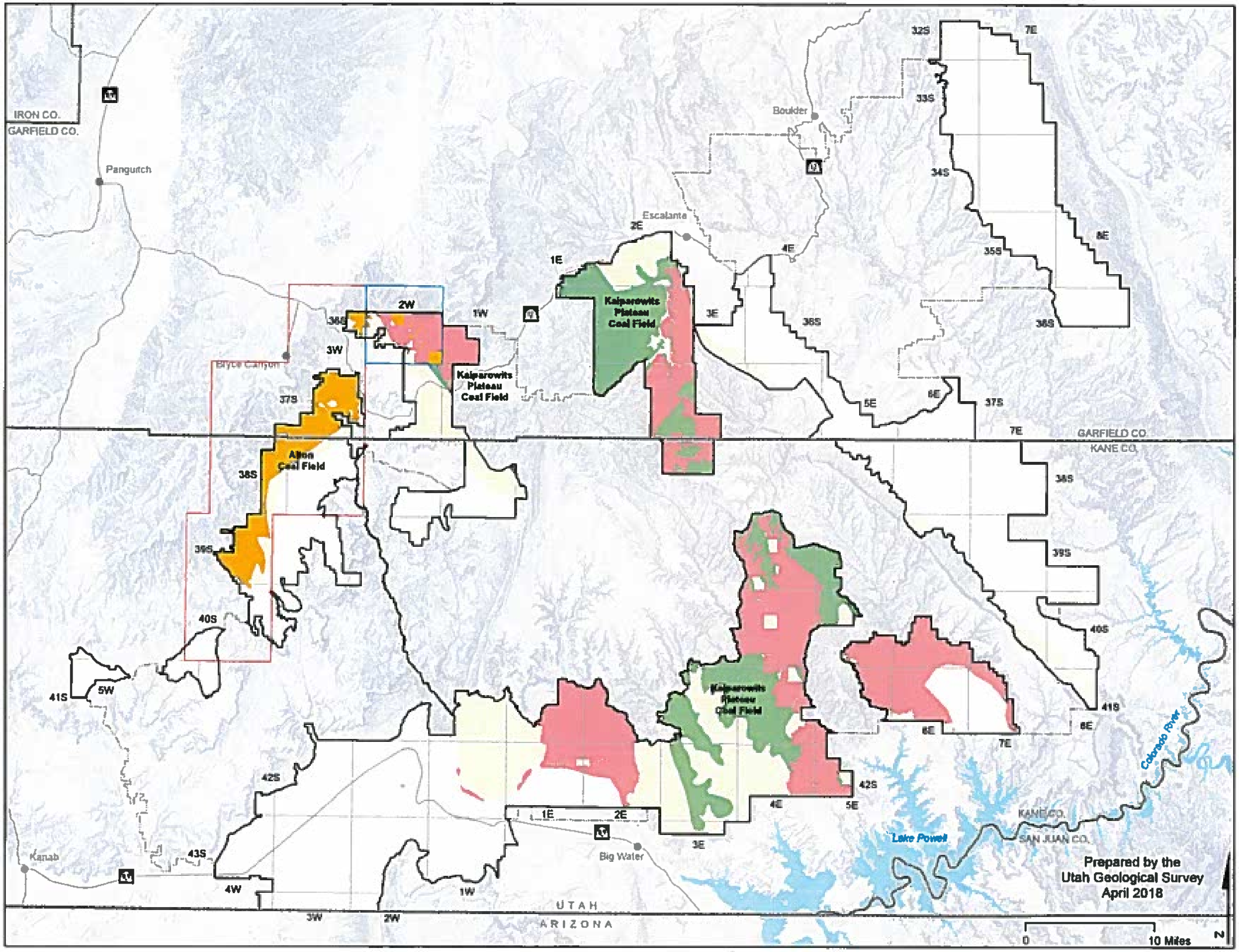


Map 17
Coal Occurrence Potential
Explanation
Grand Staircase-Escalante excluded lands (GSEEL)
Former Grand Staircase-Escalante National Monument boundary
Township and Range
BLM Wilderness Study Areas
Potential surface minable coal (KRCRA) (High/D)
Potential underground minable coal (KRCRA) (High/D)
Area underlain by coal-bearing rocks (High/C)
Former Smoky Hollow lease area
Coal data point
Historic mine (early 1900s)
Prepared by the Utah Geological Survey April 2018
Source: BLM; Doelling, 1982; Doelling and Graham, 1972; Sprinkel, 1999
UTAH
IRON CO.
GARFIELD CO.
Panguitch
Bryce Canyon
Boulder
Escalante
Kaiparowits Plateau Coal Field
Alton Coal Field
GARFIELD CO
KANE CO
KANE CO.
SAN JUAN CO.
Lake Powell
Colorado River
Kanab
Big Water
UTAH
ARIZONA
0
10 Miles
N

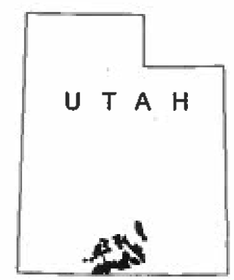
Map 18

Coal Development Potential

Explanation

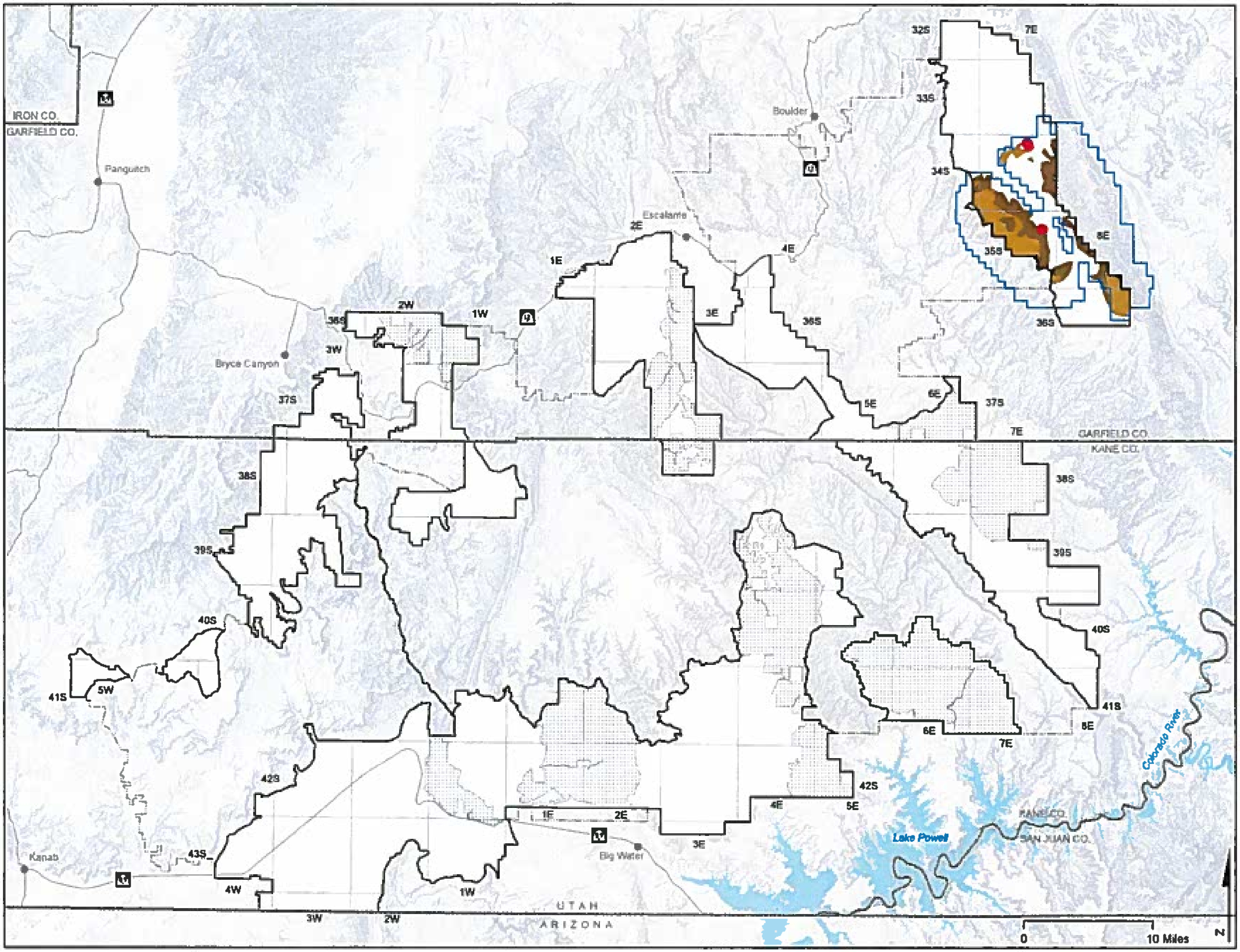


- Grand Staircase-Escalante excluded lands (GSEEL)
- Former Grand Staircase-Escalante National Monument boundary
- Township and Range
- Lands identified by the BLM as unsuitable for surface mining and surface distrubance related to underground mining
- Lands identified by the BLM as unsuitable for surface mining
- Restricted land (WSAs) - Low
- Lands unsuitable for surface disturbance - Low
- Coal area with beds >4 ft thick and <3000 ft deep - High
- Area underlain by coal-bearing rocks - Low



Map 19

Tar Sand Occurrence Potential

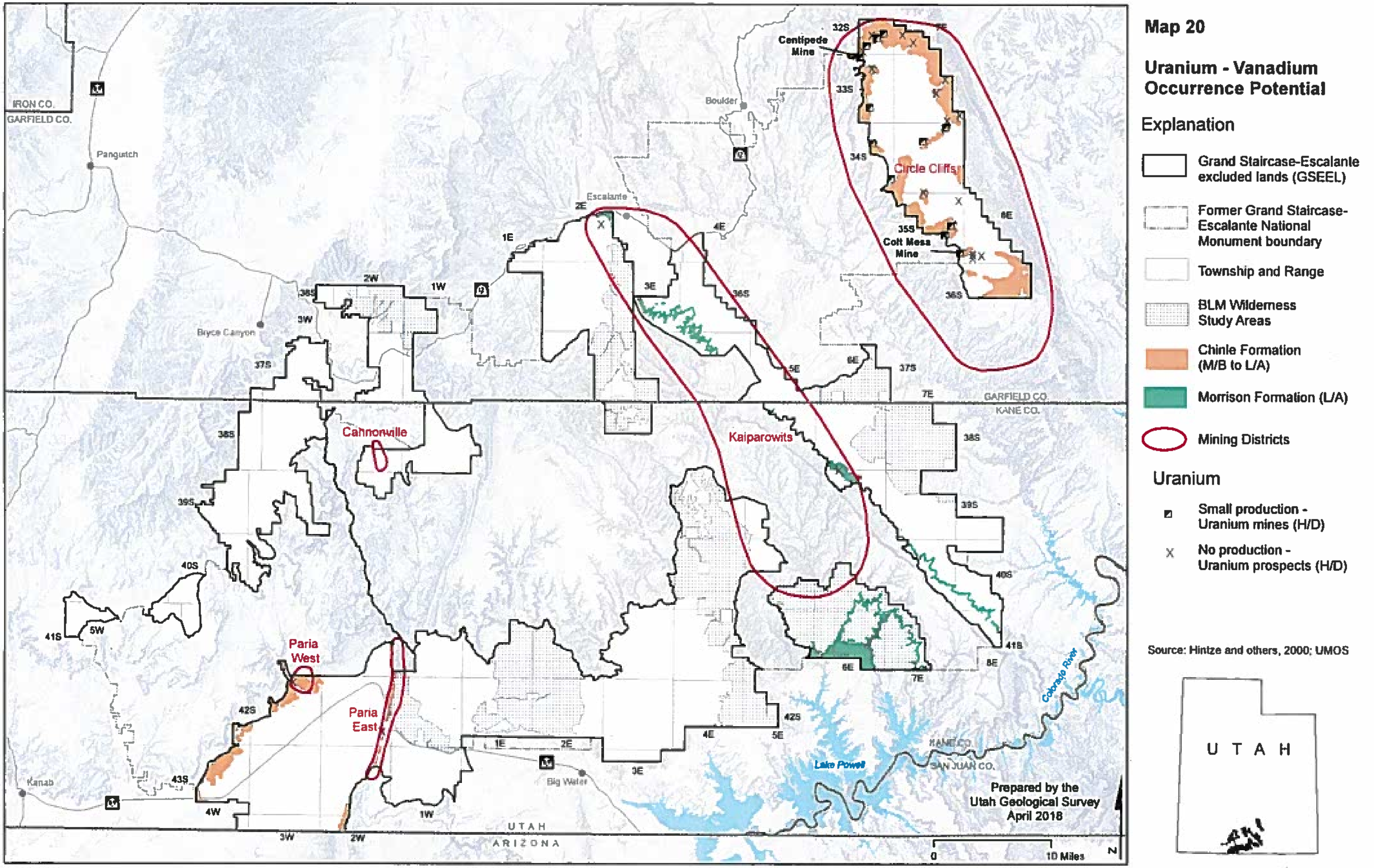


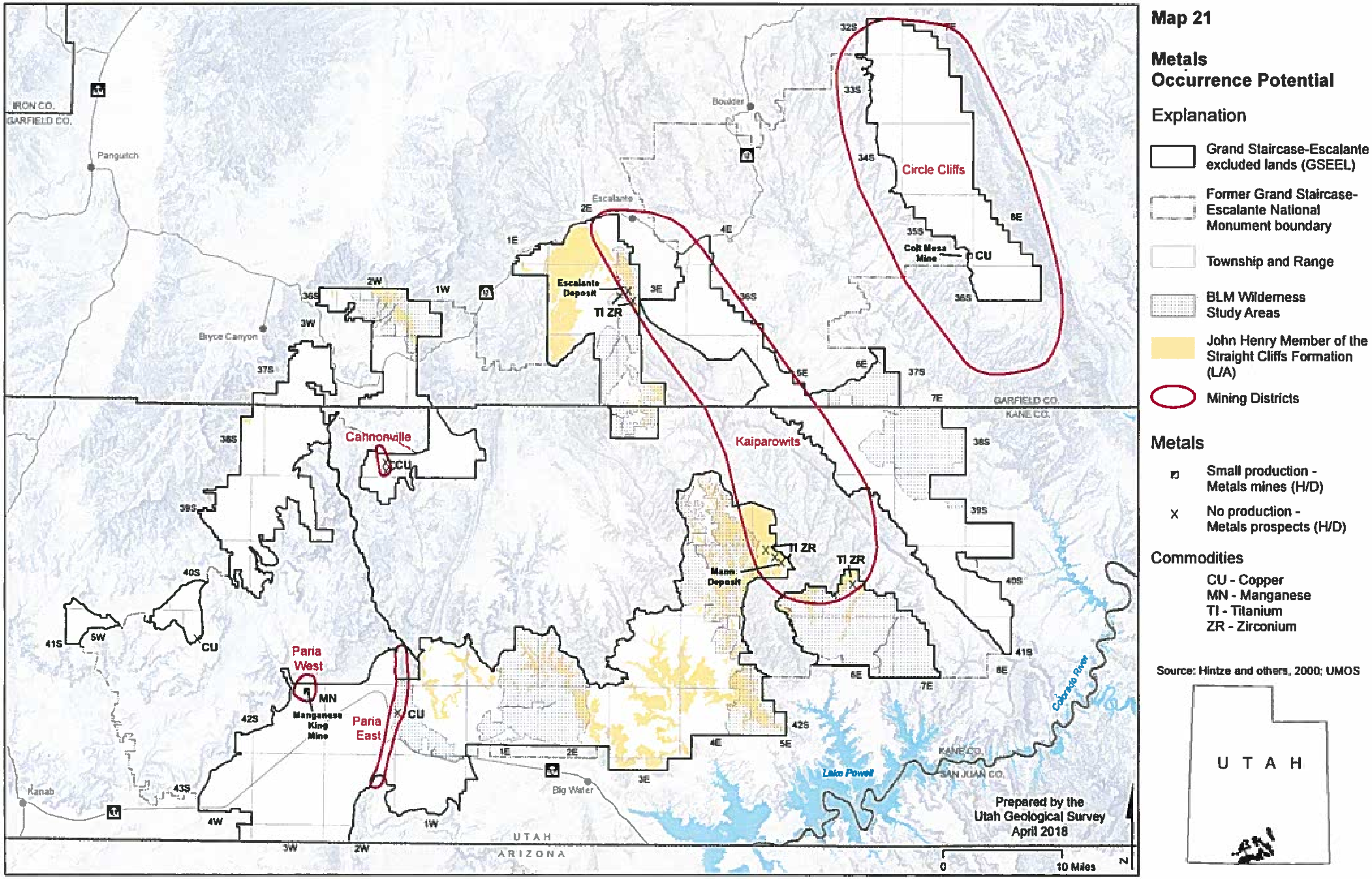
Explanation

- Grand Staircase-Escalante excluded lands (GSEEL)
- Former Grand Staircase-Escalante National Monument boundary
- Township and Range
- BLM Wilderness Study Areas
- Special Tar Sand Area (STSA)
- Tar Sand prospect or occurrence (H/D)
- Tar sand outcrop (H/C)
- Area likely underlain by tar sand (H/B)

Prepared by the
Utah Geological Survey
April 2018

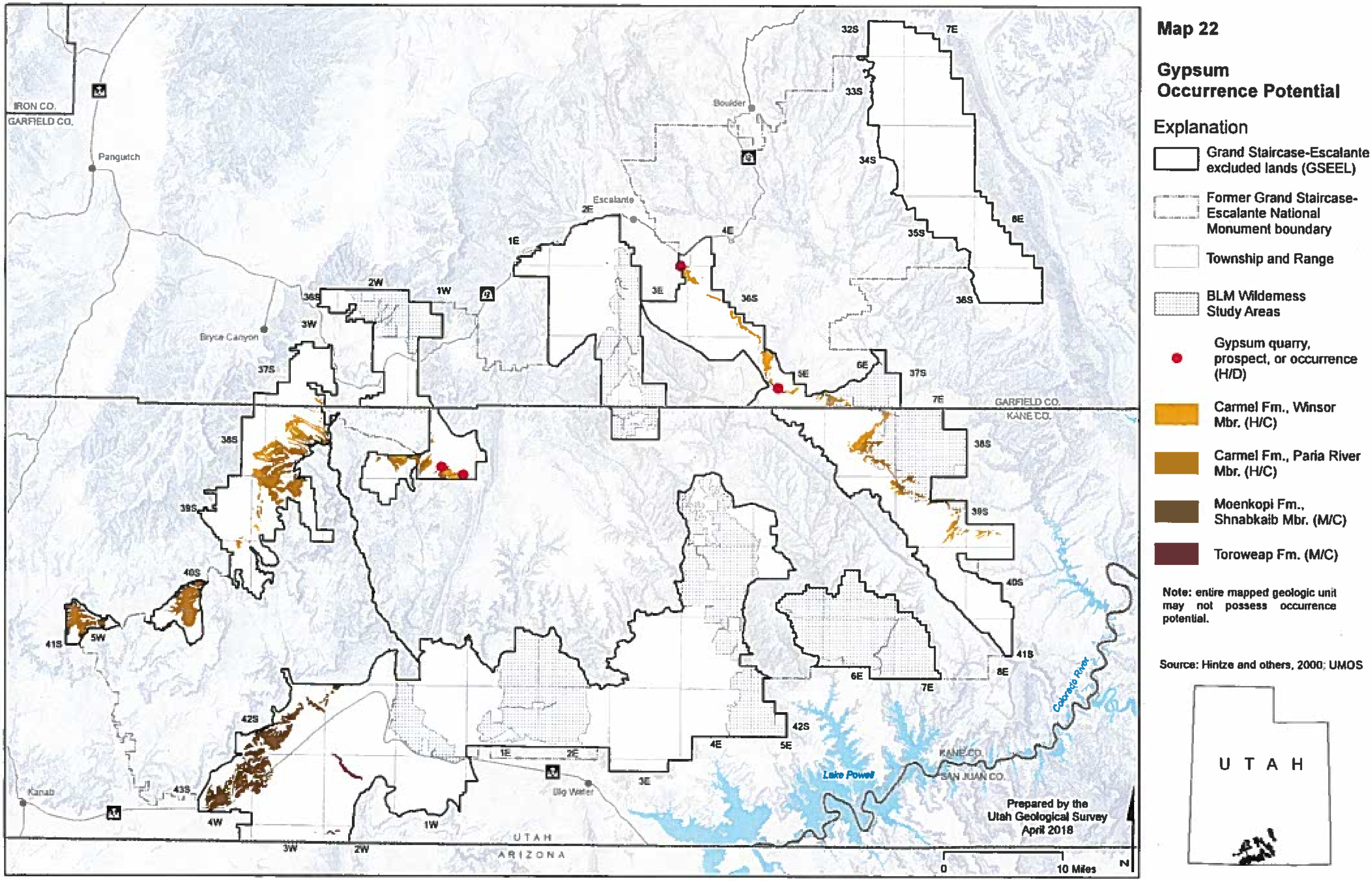
Source: Ritzma, 1979

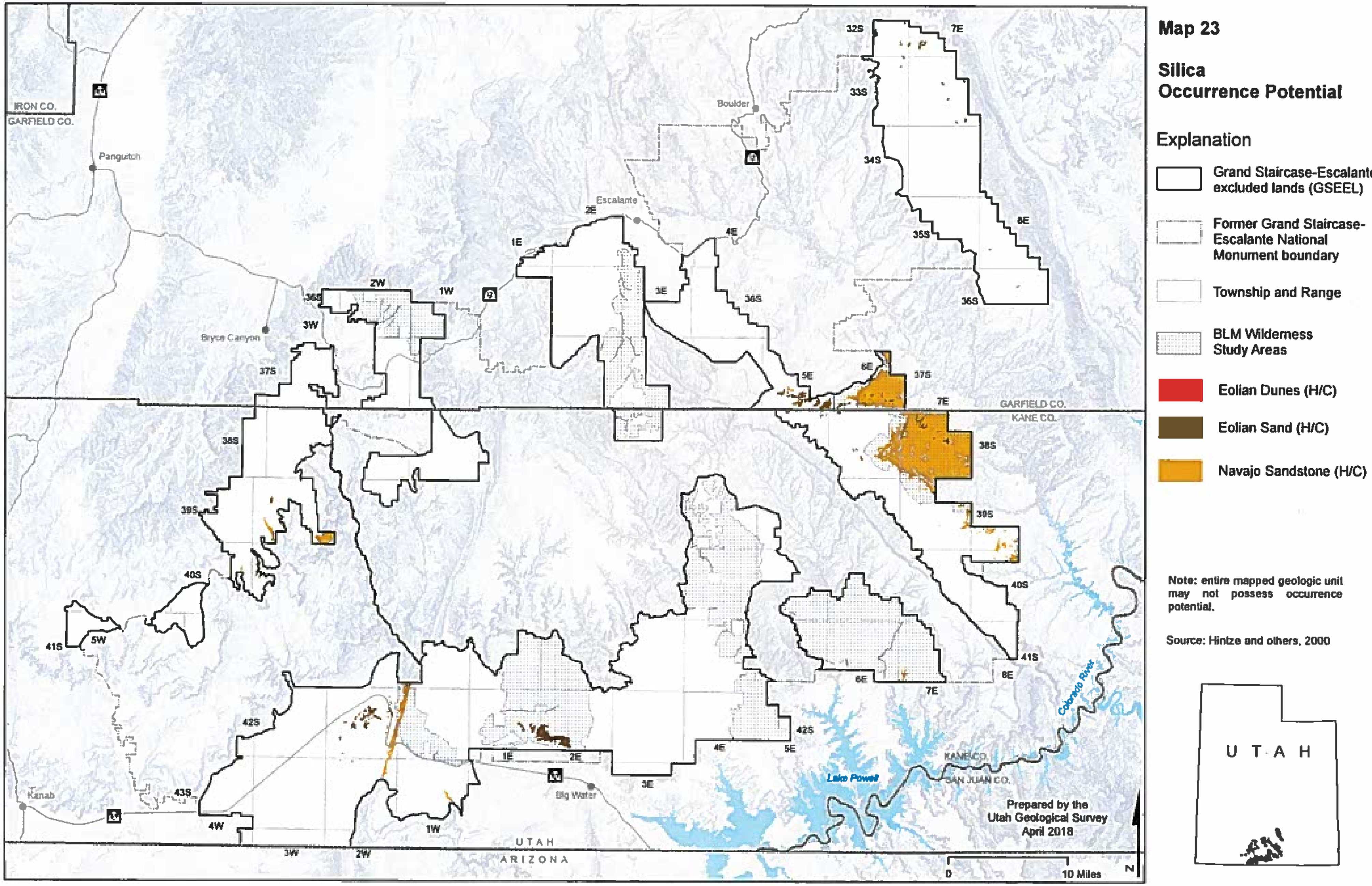

Map 20
Uranium - Vanadium Occurrence Potential
Explanation
Grand Staircase-Escalante excluded lands (GSEEL)
Former Grand Staircase-Escalante National Monument boundary
Township and Range
BLM Wilderness Study Areas
Chinle Formation (M/B to L/A)
Morrison Formation (L/A)
Mining Districts
Uranium
Small production - Uranium mines (H/D)
No production - Uranium prospects (H/D)
Source: Hintze and others, 2000; UMOS
UTAH
Prepared by the Utah Geological Survey April 2018
0
10 Miles
N
Circle Cliffs
Kaiparowits
Cannonville
Paria West
Paria East
Centipede Mine
Colt Mesa Mine
IRON CO.
GARFIELD CO.
KANE CO.
SAN JUAN CO.
Panguitch
Boulder
Escalante
Bryce Canyon
Kanab
Big Water
Lake Powell
Colorado River
UTAH
ARIZONA

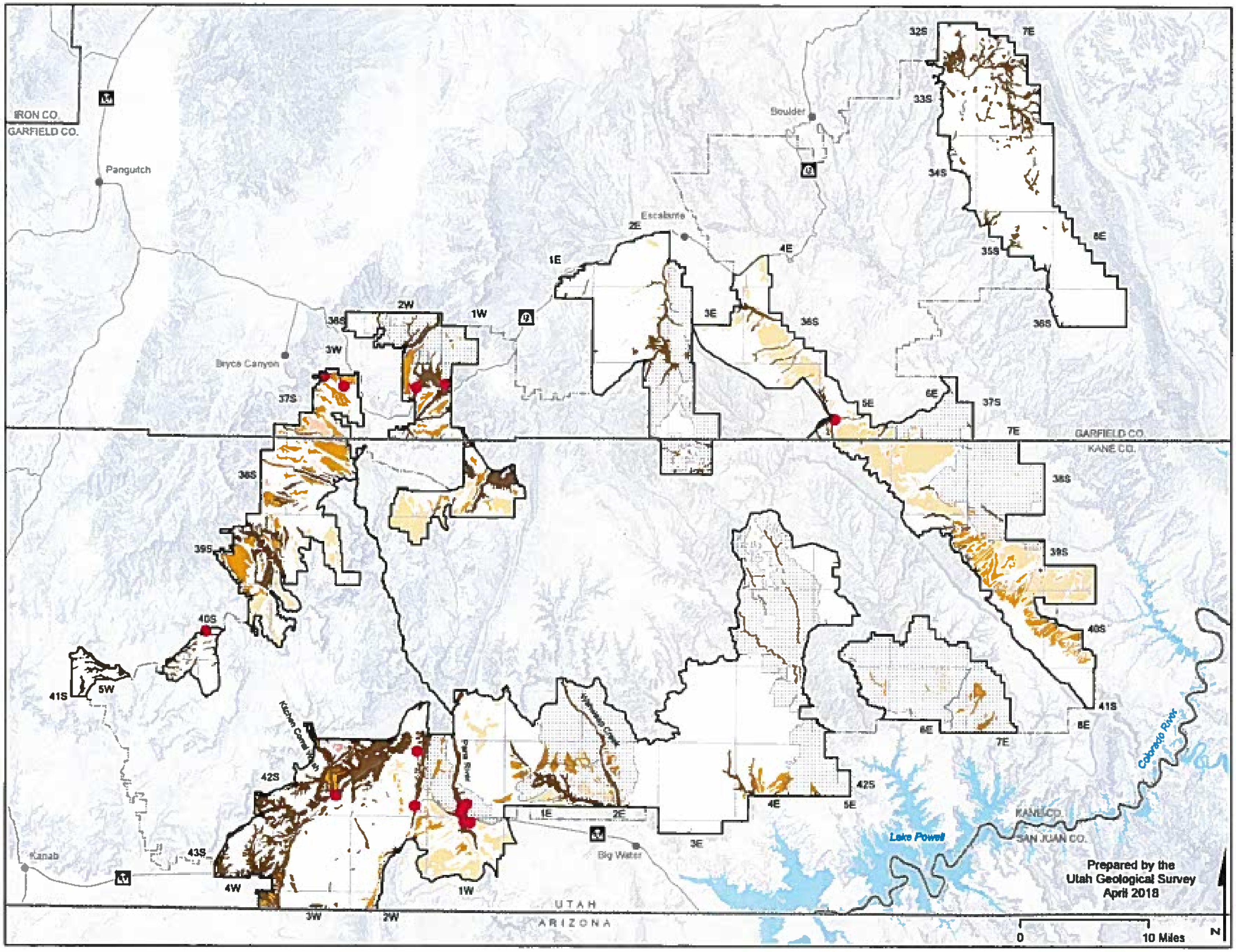

Map 21
Metals Occurrence Potential
Explanation
Grand Staircase-Escalante excluded lands (GSEEL)
Former Grand Staircase-Escalante National Monument boundary
Township and Range
BLM Wilderness Study Areas
John Henry Member of the Straight Cliffs Formation (L/A)
Mining Districts
Metals
Small production - Metals mines (H/D)
No production - Metals prospects (H/D)
Commodities
CU - Copper
MN - Manganese
TI - Titanium
ZR - Zirconium
Source: Hintze and others, 2000; UMOS
U T A H
Circle Cliffs
Kaiparowits
Cannonville
Paria West
Paria East
Escalante Deposit
Colt Mesa Mine
Manganese King Mine
Mann Deposit
TI ZR
CU
MN
Boulder
Escalante
Panguitch
Bryce Canyon
Kanab
Big Water
IRON CO.
GARFIELD CO.
KANE CO.
SAN JUAN CO.
Lake Powell
Colorado River
UTAH
ARIZONA
Prepared by the Utah Geological Survey April 2018
0
10 Miles
N

Map 22

Gypsum Occurrence Potential




Map 23
Silica Occurrence Potential
Explanation
Grand Staircase-Escalante excluded lands (GSEEL)
Former Grand Staircase-Escalante National Monument boundary
Township and Range
BLM Wilderness Study Areas
Eolian Dunes (H/C)
Eolian Sand (H/C)
Navajo Sandstone (H/C)
Note: entire mapped geologic unit may not possess occurrence potential.
Source: Hintze and others, 2000
UTAH
Prepared by the Utah Geological Survey April 2018
0
10 Miles
N
IRON CO.
GARFIELD CO.
KANE CO.
SAN JUAN CO.
UTAH
ARIZONA
Panguitch
Bryce Canyon
Boulder
Escalante
Kanab
Big Water
Lake Powell
Colorado River



Map 24

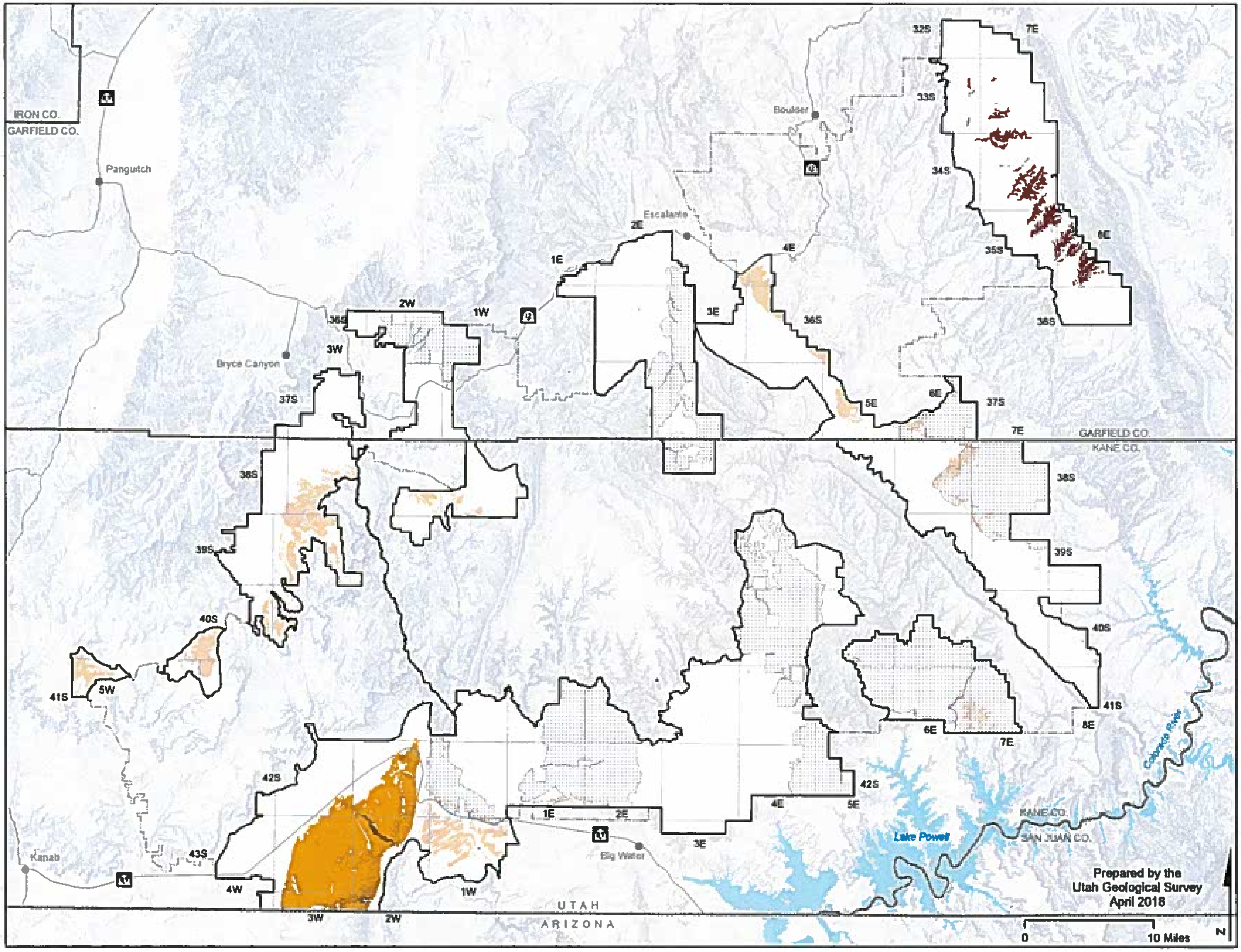
Sand and Gravel Occurrence Potential

Explanation

- Grand Staircase-Escalante excluded lands (GSEEL)
- Former Grand Staircase-Escalante National Monument boundary
- Township and Range
- BLM Wilderness Study Areas
- Sand and gravel quarry or occurrence (H/D)
- Alluvium (H/C)
- Terrace or pediment deposit (H/C)
- Mixed alluvium and colluvium (M/C)
- Colluvium (M/C)
- Eolian and mixed eolian and alluvial deposits (M/C)
- Other unconsolidated deposits (alluvial fans, talus, etc.) (M/C)

Note: entire mapped geologic unit may not possess occurrence potential.

Source: Hintze and others, 2000; UMOS



Map 25

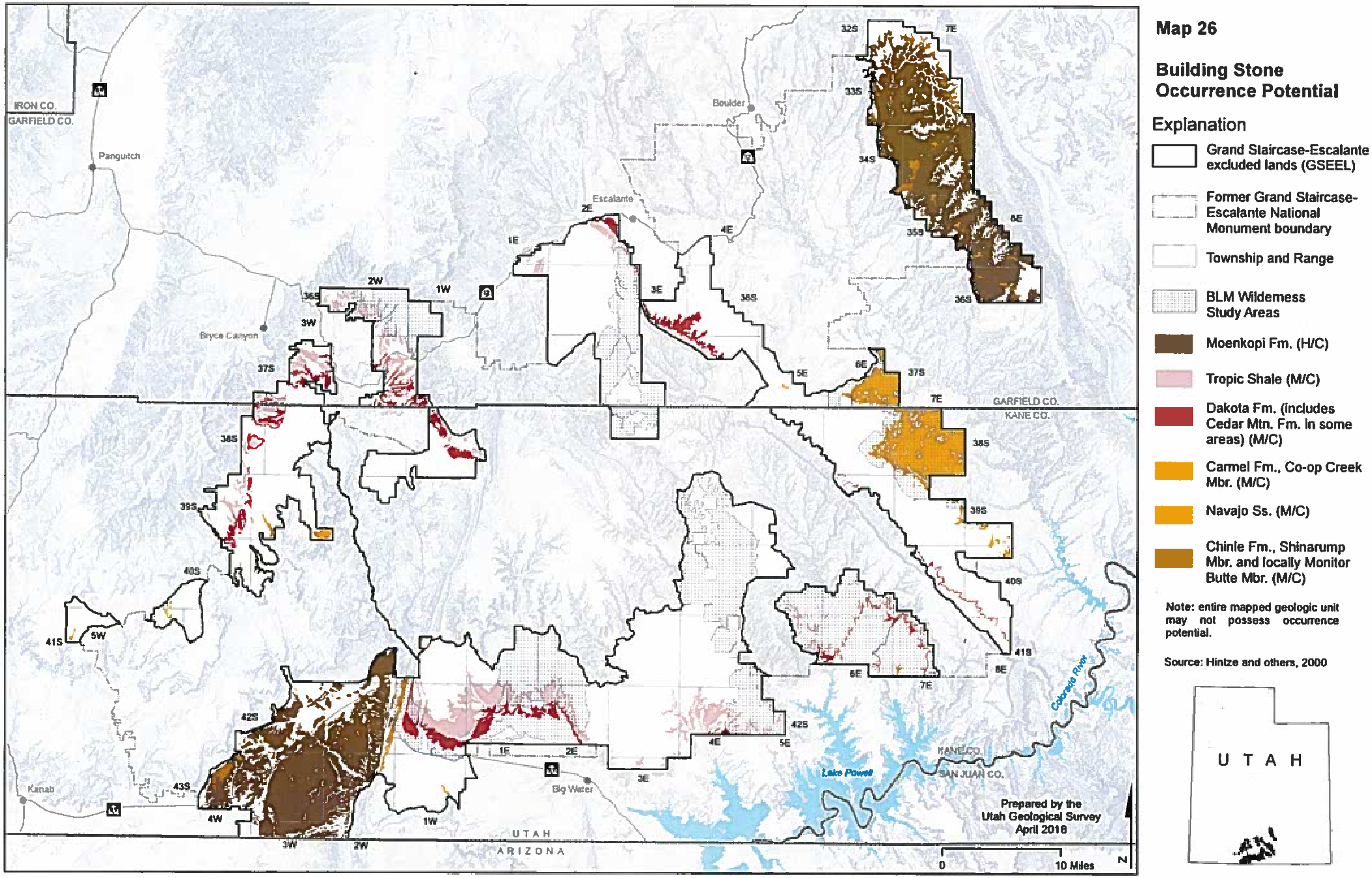
Crushed Stone & High-Calcium Limestone Occurrence Potential

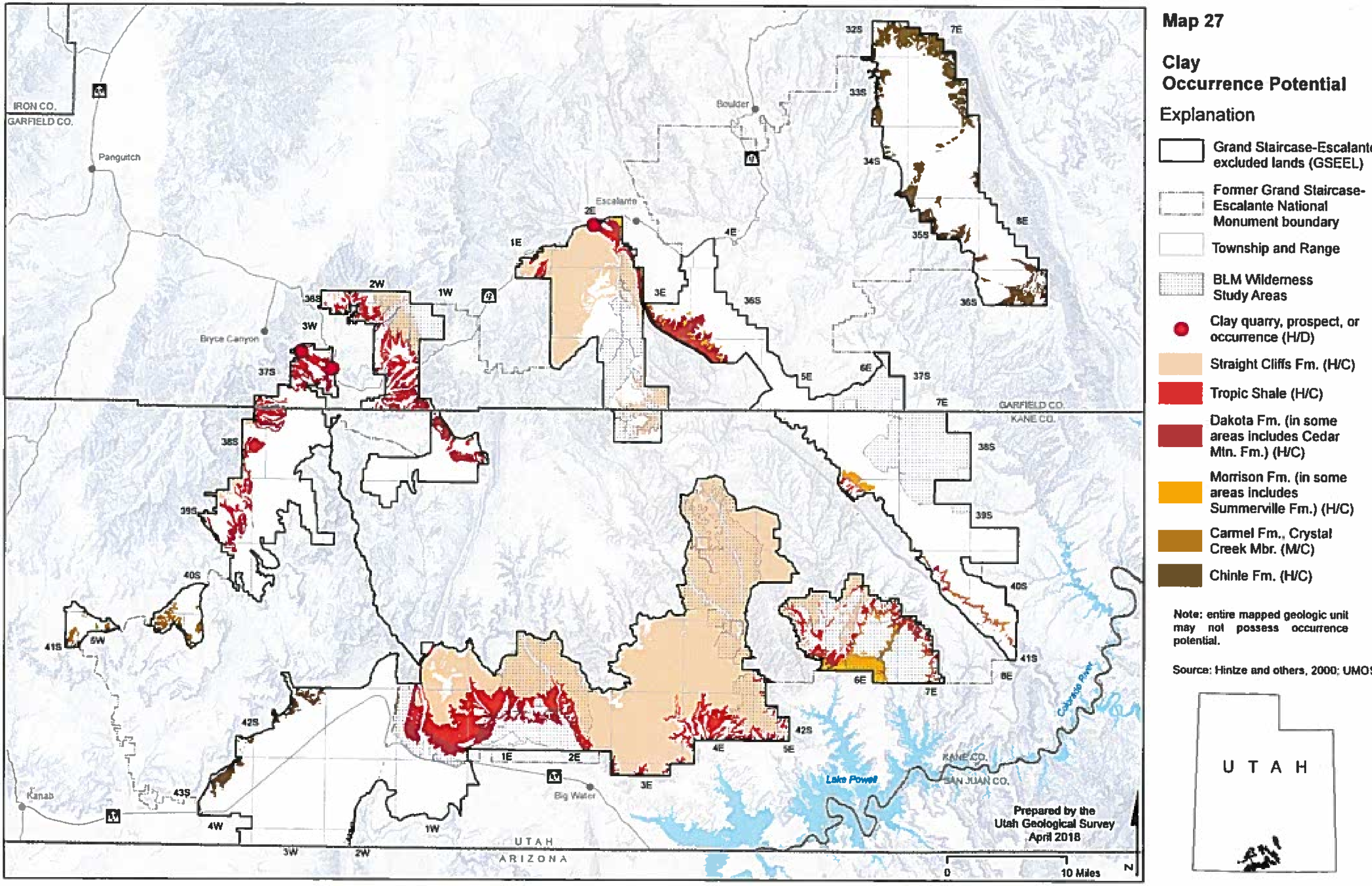
Explanation

- Grand Staircase-Escalante excluded lands (GSEEL)
- Former Grand Staircase-Escalante National Monument boundary
- Township and Range
- BLM Wilderness Study Areas
- Carmel Fm. (limestone-bearing members) (M/C)
- Moenkopi Fm., Timpoweap Mbr. (M/C)
- Kaibab Fm. (Crushed Stone - H/C; High-Calcium Limestone - M/C)
- Toroweap Fm. (Crushed Stone - H/C; High-Calcium Limestone - M/C)
- Permian Fms. (M/C)

Note: entire mapped geologic unit may not possess occurrence potential.

Source: Hintze and others, 2000

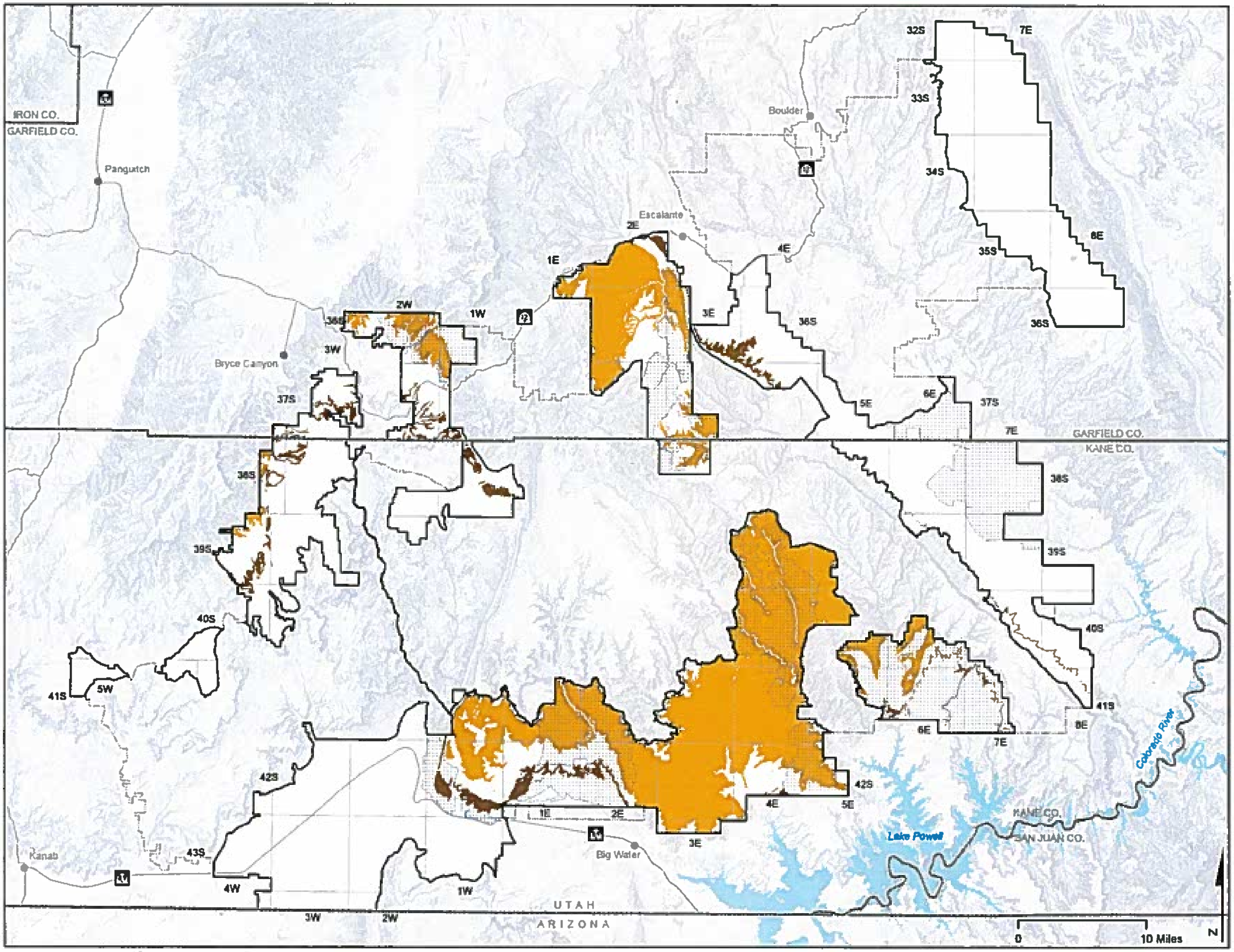

Map 26
Building Stone Occurrence Potential
Explanation
Grand Staircase-Escalante excluded lands (GSEEL)
Former Grand Staircase-Escalante National Monument boundary
Township and Range
BLM Wilderness Study Areas
Moenkopi Fm. (H/C)
Tropic Shale (M/C)
Dakota Fm. (includes Cedar Mtn. Fm. in some areas) (M/C)
Carmel Fm., Co-op Creek Mbr. (M/C)
Navajo Ss. (M/C)
Chinle Fm., Shinarump Mbr. and locally Monitor Butte Mbr. (M/C)
Note: entire mapped geologic unit may not possess occurrence potential.
Source: Hintze and others, 2000
UTAH
Prepared by the Utah Geological Survey April 2018
0
10 Miles
N
IRON CO.
GARFIELD CO.
KANE CO.
SAN JUAN CO.
Panguitch
Bryce Canyon
Escalante
Boulder
Kanab
Big Water
Lake Powell
Colorado River
UTAH
ARIZONA



Map 27
Clay
Occurrence Potential
Explanation
Grand Staircase-Escalante excluded lands (GSEEL)
Former Grand Staircase-Escalante National Monument boundary
Township and Range
BLM Wilderness Study Areas
Clay quarry, prospect, or occurrence (H/D)
Straight Cliffs Fm. (H/C)
Tropic Shale (H/C)
Dakota Fm. (in some areas includes Cedar Mtn. Fm.) (H/C)
Morrison Fm. (in some areas includes Summerville Fm.) (H/C)
Carmel Fm., Crystal Creek Mbr. (M/C)
Chinle Fm. (H/C)
Note: entire mapped geologic unit may not possess occurrence potential.
Source: Hintze and others, 2000; UMOS
UTAH
IRON CO.
GARFIELD CO.
Panguitch
Bryce Canyon
Escalante
Boulder
KANE CO.
SAN JUAN CO.
Lake Powell
Colorado River
Big Water
Kanab
UTAH
ARIZONA
Prepared by the
Utah Geological Survey
April 2018
0
10 Miles
N

Map 28

Humate Occurrence Potential



Explanation

- Grand Staircase-Escalante excluded lands (GSEEL)
- Former Grand Staircase-Escalante National Monument boundary
- Township and Range
- BLM Wilderness Study Areas
- Dakota Formation (H/C)
- Straight Cliffs Formation (H/C)

Prepared by the
Utah Geological Survey
April 2018

Note: entire mapped geologic unit may not possess occurrence potential.

Source: Hintze and others, 2000