Circular 93

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Utah Geological Survey

Circular 93

A Preliminary Assessment of Energy and Mineral Resources within the Grand Staircase - Escalante National Monument

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CONTENTS

PREFACE

The purpose of this report is to provide a preliminary assessment of the energy and mineral resources in the newly created Grand Staircase - Escalante National Monument for two principal reasons. First, President Clinton directed the Bureau of Land Management to develop a management plan for the monument during the next three years. Information on the location, extent, size, and quality of various energy and mineral deposits needs to be available to the monument planners and the interested public to help determine how these resources will be incorporated into the management plan.

Second, about 176,000 acres of surface lands managed by the School and Institutional Trust Lands Administration (SITLA) for the benefit of Utah's school children are within the monument's boundaries and contain significant amounts of coal and other resources. The President, in proclaiming the monument's creation, promised to trade out the School Trust lands for comparable federal lands elsewhere, presumably in Utah. The Utah Geological Survey (UGS), hopes to conduct an inventory of resources on School Trust lands in the monument.

The summary information in this report gives what we believe is a reasonable initial overview of each of the different commodities present, although the amount and quality of data for each commodity varies. Do we have enough data for an in-holdings exchange to take place or even for an appraisal at this time? Probably not, if we need to be assured that the state gets fair and adequate compensation for its resources. An example using coal resources demonstrates just how accurate the assessment needs to be. Of the 62 billion tons of coal in the Kaiparowits coal field (which lies almost entirely within the monument) we calculate that at least 11.3 billion tons is recoverable. A one-percent increase in our coal recovery estimate amounts to more than 100 million tons of coal. At the current average price of $19.50 per ton of coal, the additional coal is worth nearly $2 billion, of which about $160 million in royalties would be paid.

Our preliminary calculation of recoverable coal on School Trust lands is 876 million tons. Each one-per cent change in our determination of recoverable coal on School Trust lands amounts to $170 million in value, worth nearly $14 million in royalties to the School Trust fund. Because we were so conservative in our calculations, the actual recoverable coal in the monument might be 50 percent higher than our base estimate, perhaps 16 billion tons in the monument, 1.3 billion tons on School Trust lands. The value of the recoverable coal on School Trust lands is at least $17 billion but could be $25 billion or more. Royalties to the School Trust fund thus could be from $1.4 billion to over $2 billion.

In order to adequately assess the recoverable coal resources on the School Trust lands in the monument, a team of geologists and mining engineers needs to prepare the equivalent of a operational mine plan for the entire Kaiparowits coal field. This would be a major effort requiring the team to map the continuity of each coal seam, determine lateral variations in thickness and vertical separation from other minable horizons, and to develop a plan that optimizes coal recovery. Given the massive size of the coal reserves and number of coal seams, we estimate such an undertaking could take a score of engineers and geologists three years to complete. However expensive that may seem, it's important to recognize that the entire cost of fully evaluating the potential of School Trust lands would be less than the additional royalties gained from a fraction of one percent increase in the amount of recoverable coal on School Trust lands.

Deposits of coal-bed gas, oil and gas, and alabaster are currently being developed inside the monument or appear to have strong potential to be developed. **The value of the known and potential energy and mineral resources of the Grand Staircase - Escalante National Monument at today's prices is between $223 billion and $330 billion.** This figure does not include values for tar sands, carbon dioxide reserves, or any of the other mineral deposits such as titanium, zirconium, uranium, or copper.

Coal	$221 billion - $312 billion
Coal-bed gas	$2 billion - $17.5 billion
Petroleum	$20 million - $1.1 billion
Minerals	$4.5 million - unknown

In our view, it is imperative that a detailed, combined geologic-engineering evaluation be conducted of the coal and other resources in the monument to ensure fair compensation for Utah's children. Without this, we risk leaving tens of millions of dollars of the children's money on the negotiating table. With it, we may be able to greatly enrich and protect their legacy.

M. Lee Allison
January 1997

SUMMARY

Since the designation of the Grand Staircase - Escalante National Monument by President Clinton on September 18, 1996, unresolved issues regarding the mineral value of state and federal lands within the monument have come to the forefront of debates. The monument extends across 1.7 million acres in Kane and Garfield Counties, Utah, and includes some of the most energy-rich lands in the lower 48 states. The U.S. Bureau of Land Management (BLM), the agency assigned to manage the monument, recently has begun a three-year program to formulate a management plan. Part of the management plan will likely focus on the disposition of more than 176,000 acres of Utah School and Institutional Trust Lands that are now monument in-holdings. SITLA controls mineral rights on more than 200,000 acres.

During President Clinton's proclamation speech, he addressed the issue of lands within the monument belonging to the school children of Utah. He stated to the effect that Utah's school children would not be denied the value held within these lands. Moreover, he directed the Interior Secretary to quickly move to trade the Utah School Trust lands within the monument for other federal lands or resources in Utah that are of comparable value. With the creation of the monument, mineral lands may have been effectively removed from consideration for mining, oil and gas exploration, etc. The purpose of this report is to review the present understanding of energy and mineral resources within the monument, qualitatively describe the resource potential for each known commodity, and propose plans to better assess these potential resources in order to help assure that Utah's school children receive fair and just compensation.

Coal in the Kaiparowits Plateau

The main mineral-resource issue is the enclosing of the Kaiparowits Plateau coal field within the monument boundary. The coal field is the largest in Utah, containing over 62 billion tons of coal in place (Hettinger and others, 1996). Using a resource assessment recently completed by the U.S. Geological Survey (USGS) and excluding resources considered unminable, the Utah Geological Survey (UGS) estimates that at a minimum, 11.36 billion tons of the coal resource are technologically recoverable from the entire field. Of this total, the UGS further estimated that some 870 million tons of this coal are technologically recoverable from Utah School Trust lands within the monument.

The Utah Office of Energy and Resource Planning (OERP) performed a preliminary valuation of coal lands in the monument and projected royalty and bonus bid revenues to the State of Utah and the Federal government. From this analysis, OERP determined that potential revenue to the State from recoverable coal could be $9.25 billion in present dollars over the life of mining. The U.S. Government would receive an equal amount. Revenue to the Utah School Trust could be an additional $1.54 billion. OERP also estimated that $65.15 million in present dollars could be realized as income by the State just from the proposed Smoky Hollow mine project of Andalex Resources over the proposed 30-year mine life. Of this total, OERP estimated that the Smoky

Hollow project would have generated some $17.97 million in income to the State School Trust.

Coal-bed Gas

Most of the Kaiparowits Plateau coal field has potential for development of Coal-bed methane gas, even though no definitive studies have been done to date. Based on research in other Utah coal fields and extrapolating to the Kaiparowits field, the UGS estimates that the coal beds of the Straight Cliffs Formation contain between 2.6 and 10.5 trillion cubic feet of methane.

Oil and Gas Potential

The monument contains all the elements necessary for major oil and gas accumulations: source rocks, reservoirs, and trapping mechanisms. Commercial deposits of oil have been discovered both within and along the margins of the monument at Upper Valley field. Although the characteristics of the monument and Kaiparowits basin as a whole are favorable for the accumulation of oil and gas, wildcat density is extremely sparse. Only 47 exploratory wells have been drilled within the monument, or an average of 57 square miles per well. The postulated reasons for this apparent lack of exploratory activity are: (1) inaccessibility, (2) lack of oil and gas pipelines, (3) low success rates, (4) the collapse of world oil prices in 1986 and a nationwide oversupply of natural gas, and (5) environmental concerns and restrictions. Although the exploration risk is high, the monument could contain major accumulations of oil based on the production history of Upper Valley field and geologic evidence.

Circle Cliffs Tar Sand

Solid hydrocarbons impregnate Triassic-age sandstone and siltstone along the flanks of the breached, Circle Cliffs anticline in the northeastern part of the monument. Known as tar sand, such deposits are essentially exhumed, fossil oil reservoirs where the lighter, more volatile fractions have been removed due to exposure. The entire west flank of the Circle Cliffs tar-sand deposit and a small part of the east flank is located in the monument. The remainder is within Capitol Reef National Park. Although there has been little recent commercial interest in extracting oil from the tar-sand deposits of the Circle Cliffs, researchers have estimated that as many as 550 million barrels of oil might be contained within tar sands of the monument.

Non-Fuel Minerals

Metallic mineral occurrences in the monument include gold, copper, manganese, titanium, zirconium, uranium, and vanadium. Most occurrences are small, low-grade, and have little development potential. Minerals such as titanium, zirconium, and vanadium, however, are considered "strategic and critical" and may have development potential within the monument. Uranium with associated copper plus trace amounts of cobalt occurs in the Shinarump Member of the Triassic Chinle Formation in the Circle Cliffs area of the northeastern section of the monument. About 75,000 pounds of U308 was reportedly produced from these deposits during the 1950s and 1960s. Vanadium associated with the uranium was produced as a byproduct. Anomalously radioactive outcrops of the Jurassic Morrison Formation have been noted on the east side of Fiftymile Mountain, suggesting the possibility that uranium minerals extend beneath the Kaiparowits Plateau.

Fossil, placer titanium-zirconium deposits occur in the Cretaceous Straight Cliffs Formation in a 40 to 50 mile-long-belt along the east side of the Kaiparowits Plateau. The deposits were never developed commercially because they are remote and because of problems associated with mining and beneficiation. However, the deposits are reportedly rich in rutile (titanium) and zircon (zirconium). Dow and Batty (1961) estimate that the aggregate size of 14 individual deposits is from 1 to 3 million tons of raw material.

Records obtained from the Utah Division of Oil, Gas and Mining indicate that five small mining operations are currently under permit in the monument. About 300 tons of alabaster, a fine-grained form of gypsum used for ornamental carvings, is quarried annually in four of these operations. The fifth is a suspended operation that mined petrified wood.

INTRODUCTION

Background

On September 18, 1996, by the authority vested through section 2 of the Antiquities Act of June 8, 1906 (34 Stat. 225, 16 U.S.C. 431), President Clinton established by proclamation the Grand Staircase-Escalante National Monument (Appendix A). The monument sets aside some 1.7 million acres, or about 2,700 square miles, in southern Utah to be protected for its scientific, historic, biologic, cultural, and scenic attributes. The proclamation cites examples of the attributes of the monument including: (1) exposed sedimentary rock layers that offer unobscured views of stratigraphy and geologic processes; (2) natural features like The Grand Staircase, White and Vermillion Cliffs, Paria Canyon, East Kaibab Monocline (The Cockscomb), Circle Cliffs, Waterpocket Fold, Escalante Natural Bridge, and Grosvenor Arch; (3) numerous archeological sites of the Anasazi and Fremont cultures; and (4) the variety of life zones from low-lying desert to coniferous forest.

Purpose and Scope

Since the establishment of the monument, issues regarding the mineral value of state and federal lands within the monument have come to the forefront of debates. The monument extends across 2,700 square miles in Kane and Garfield Counties, and includes the largest coal field in Utah. The monument also contains lands with probable oil and gas accumulations as well as other mineral commodities.

The BLM, the agency assigned to administer the monument, has begun a three-year program to formulate a management plan. Part of the management plan will likely focus on the disposition of nearly 176,000 acres of Utah School and Institutional Trust lands that are now within the monument. Recognizing their importance, President Clinton directed the Interior Secretary to act quickly to formulate plans to trade the Utah School Trust lands within the monument for other federal lands or resources in Utah that are of comparable value. The purpose of this report is to review the present understanding of energy and mineral resources within the monument, describe in general terms the resource potential for various commodities, and outline resource assessment objectives to help assure that Utah's school children receive fair and just compensation.

Location and Physiography

The monument is located within the Colorado Plateau physiographic province, near its western margin (figure 1). The Kaiparowits Plateau is centrally situated in the monument surrounded by the towns of Escalante, Henrieville, and Glen Canyon City. Doelling and Davis (1989) describe the region as characterized by a series of plateaus, buttes, and mesas that reflect the type and structure of the underlying geologic strata. The Grand Staircase is a broad feature which extends into the western half of the monument, and consists of a series of topographic benches and cliffs which, as its name implies, step progressively down in elevation from north to south. These step-like features include the Paria Terrace and the White and Vermillion Cliffs, which extend southward decreasing in elevation from the Paunsaugunt Plateau near Bryce Canyon (greater than 9,000 feet) to the Shinarump Flats (less than 5,000 feet).

The Kaiparowits Plateau covers approximately 1,650 square miles in the central part of the monument (figure 2). The feature is a broad structural basin, however, the topographic expression is that of a northward-tilted plateau (Doelling and Davis, 1989). The Kaiparowits Plateau merges to the north with the Aquarius Plateau, and to the northwest with the Paunsaugunt Plateau. Elsewhere, the edge of the Kaiparowits Plateau is defined by the outcrop of Cretaceous strata (Hettinger and others, 1996). The plateau is a dissected mesa that rises as much as 6,500 feet above the surrounding terrain. The landscape is defined by four sets of cliffs and benches that form a step-like topography between the Aquarius Plateau and Lake Powell (Sargent and Hansen, 1980). The Straight Cliffs form a prominent escarpment that extends northwest to southeast along the plateau's eastern flank; the escarpment is as high as 1,100 feet along Fiftymile Mountain (figure 2).

The monument, comprised mostly of BLM- and SITLA-administered lands, is bordered by several other federally administered land units. The Dixie National Forest lies to the north of the monument. The southern boundary abuts the Glen Canyon National Recreation area. Bryce Canyon National Park is located adjacent to the west of the monument and Capitol Reef National Park is adjacent to the east of the monument. About 275 square miles of School Trust Lands are scattered throughout the monument as in-holdings (figure 3).

GEOLOGY

Regional Structure

The Colorado Plateau is characterized by relatively flat-lying strata that have been locally offset and folded during vertical movements along north-south-oriented blocks in the earth's crust. These crustal movements, called tectonism, compressed and folded the overlying strata into many asymmetrical, or monoclinal, folds that have one gently dipping side and one steeply dipping side. This early compressional tectonism is referred to as the Laramide event. Later extensional tectonism caused the overlying strata along the west side of the monument to break along faults. Two structural features related to these tectonic events roughly define the eastern and western boundaries of the monument. Strata west of the north-south-trending Paunsaugunt normal fault (figures 2 and 4), near the western boundary of the monument, have dropped 2,000 feet (Doelling and Graham, 1972). The Circle Cliffs anticline, which has a steeply dipping eastern limb called the Waterpocket Fold and a gently dipping western limb, occurs at the eastern side of the monument (figure 4).

The generally northward-dipping strata of the monument area are structurally divided into two subareas by another major fold, the East Kaibab monocline (figure 2 and 4), which forms the prominent landform known as the Cockscomb. This structure, like the Circle Cliffs anticline, has a steeply dipping eastern limb and a gently dipping western limb. In addition to these three major structures, numerous smaller, but similar, folds are found in the monument area (figure 4). Beds throughout most of the monument are typically inclined less than 6 degrees; however, near the fold axes steeper dips can be found. For example, beds dip as many as 25 degrees along the western flank of the Escalante anticline, 30 degrees on the eastern limb of the John's Valley anticline, 45 degrees along the western limb of the Upper Valley anticline (Dutton monocline), and 80 degrees along the East Kaibab monocline (Hettinger, and others, 1996).

Strata within the Kaiparowits region, between The Cockscomb and the Straight Cliffs (figures 2 and 4), are inclined along numerous northerly trending folds that plunge into a deep central basin between the Kaibab uplift and the Rees Canyon anticline. Because of the overall basin structure, Cretaceous and younger rocks in the Kaiparowits region have been somewhat preserved from erosion more so than the surrounding regions. These rocks now comprise the Kaiparowits Plateau. Hettinger and others (1996) illustrated deformation of Cretaceous strata on a structure contour map of the Calico sequence boundary. The sequence boundary, which is nearly equivalent to the base of the Smoky Hollow Member of the Straight Cliffs Formation (described later), is 4,500-9,000 feet above sea level on outcrops surrounding the Kaiparowits Plateau (figure 2) and 2,000 feet above sea level in the subsurface of the Table Cliffs syncline (figure 4).

Permian through Jurassic Stratigraphy

The oldest exposed rocks in the region are Permian and crop out only along Kaibab Gulch southwest of The Cockscomb (figure 2). Exposed Permian units, from oldest to youngest, include the Hermit Shale, Coconino Sandstone, Toroweap Formation, White Rim Sandstone, and Kaibab Limestone (figure 5).

Triassic rocks are exposed in southern Kane County and include six members of the Moenkopi

Formation and two members of the Chinle Formation. The Moenkopi comprises the Timpoweap, Lower Red, Virgin Limestone, Middle Red, Shnabkaib, and Upper Red Members, all deposited in intertidal or shallow marine environments. The Shinarump Member of the Chinle Formation is a fluvial conglomeratic sandstone unit resting unconformably upon the Moenkopi Formation. The upper units of the Chinle are dominated by colorful mudstones and sandstones related to fluvial channel and overbank deposition.

Peterson (1988) places Jurassic sedimentary units into divisions bounded by unconformities or depositional surfaces where little intertonguing occurs. The Glen Canyon Group, consisting of the Wingate Sandstone, Moenave and Kayenta Formations, and the Navajo Sandstone, is the oldest of the Jurassic divisions. The Wingate and Navajo Sandstones are massive, wind-deposited (eolian) units separated by the Moenave and Kayenta Formations, which are water-lain (fluvial and lacustrine) in origin. The Glen Canyon Group sediments were apparently shed from a source region to the south and east and, therefore, become thicker to the west and northwest.

The Middle Jurassic San Rafael Group consists of the Page Sandstone, the Carmel Formation, the Entrada Sandstone, and the Romana Sandstone. The lower division (Page Sandstone and Carmel Formation) is primarily marine limestone and mudstone deposits, in the western part of the region. These deposits change laterally to the east and southeast to coastal sabkha deposits of mudstone and lenticular beds of gypsum. The Entrada Sandstone comprises the middle division and is separated into three members deposited in sabkha and eolian environments. The upper division consists of the Romana Sandstone which was deposited in marginal marine and eolian environments.

The Salt Wash and Tidwell Members of the Morrison Formation together form the lower division of the Upper Jurassic series. The Salt Wash Member consists of fluvial sandstone and conglomerate and very minor mudstone of lacustrine and flood-plain origin. The Tidwell Member represents dominantly lacustrine deposition with associated deposition on mudflats, in evaporative environments, and in small eolian dune fields.

The upper division of the Morrison Formation consists of the Brushy Basin Member in the northern Kaiparowits region, and the Fiftymile Member (a facies of the Brushy Basin) in the southern Kaiparowits. These units were deposited in a broad lowland containing mudflats, lakes, dune fields, and few streams. The Fiftymile Member represents an alluvial complex that gradually moved from southwest to northeast across the Kaiparowits region toward mudflat and lacustrine environments represented by the Brushy Basin Member.

Cretaceous and Tertiary Stratigraphy

As many as 7,500 feet of Upper Cretaceous strata and 3,000 feet of Tertiary strata underlie the Kaiparowits Plateau (Lidke and Sargent, 1983). Upper Cretaceous strata include, in ascending order, the Dakota, Tropic Shale, Straight Cliffs, Wahweap, and Kaiparowits Formations, and the lower part of the Canaan Peak Formation. The Dakota Formation, Tropic Shale, and Straight Cliffs Formation are exposed along the margins of the Kaiparowits Plateau but are buried by younger strata in the central region. Tertiary strata include the upper part of the Canaan Peak Formation, the Pine Hollow and Wasatch Formations, and the overlying volcanic rocks of the Mount Dutton Formation and Osiris Tuff.

Hettinger and others (1996) present the detailed stratigraphy of the Straight Cliffs Formation. The major coal beds of the Kaiparowits coal field are contained within the John Henry Member of the Straight Cliffs Formation (Late Cretaceous), that Shanley and McCabe (1991) term the Calico- and A-sequences. Peterson (1969b) formally divided the Straight Cliffs Formation, in ascending order, into the Tibbet Canyon, Smoky Hollow, John Henry, and Drip Tank Members (figure 6). The Calico and A-sequences contain all of the coal within the John Henry Member and the upper part of the Smoky Hollow Member. Peterson (1969a, b) interpreted the Tibbet Canyon and Smoky Hollow Members as a regressive stratigraphic succession consisting of shallow marine and beach deposits in the Tibbet Canyon Member and coal-bearing coastal plain strata and alluvial deposits in the Smoky Hollow Member. The John Henry Member is early

Coniacian to late Santonian in age (Eaton, 1991) and consists of coal-bearing continental beds that grade eastward into a vertical stack of nearshore marine strata (Peterson, 1969a, b). These shoreface sandstone bodies are the dominant lithology along the Straight Cliffs escarpment. Continental strata within the John Henry Member contain coal in the Lower, Christensen, Rees, and Alvey coal zones (figure 6) as defined by Peterson (1969a, b). The Drip Tank Member is constrained to a late Santonian or early Campanian age (Eaton, 1991) and consists of fluvial sandstone (Peterson, 1969a, b).

THE KAIPAROWITS PLATEAU COAL FIELD

History of Mining and Exploration

Coal in the Kaiparowits Plateau region was first mined by settlers in the late 1800s near the town of Escalante, and small mines produced coal for local needs until the early 1960s. Coal investigations were first reported in the Kaiparowits Plateau by Gregory and Moore (1931), but it was not until the early 1960s that energy companies expressed interest to commercially develop coal in the region. As many as 23 companies acquired coal leases, and drilled about 1,000 coal test holes (Doelling and Graham, 1972). Plans made in 1965 to develop a 5,000-megawatt coal-burning power plant were revised in the mid 1970s to a construct only 3,000-megawatt generating plant after controversy over environmental issues. Construction plans were finally discontinued because of government action and pending lawsuits over environmental concerns (Sargent, 1984). In the latter part of the 1980s, Andalex Resources began formulating plans to mine underground and ship up to 3.5 million tons of coal annually from their leasehold in the southern part of the Kaiparowits coal field. Environmental analyses for the proposed mine, required as part of the permitting process, were underway at the time of the proclaiming of the monument.

The U.S. Geological Survey (USGS) recently performed an assessment of coal resources in the Kaiparowits Plateau coal field as part of a national coal availability assessment (Hettinger and others, 1996). The USGS study builds on the classic study of the Kaiparowits Plateau coal field by the UGS (Doelling and Graham, 1972) and is based on data from geologic mapping, outcrop measurements of stratigraphic sections, and drilling that has been conducted in the region since the late 1960s. Although the distribution of coal was well documented on outcrop (Doelling and Graham, 1972), coal distribution in the subsurface remained largely unknown due to the proprietary status of company data. Recently released company drill-hole data and drilling by the USGS provided new insight into the subsurface aspects of these coals. Using a Geographic Information System, the USGS integrated these new data with existing published geologic data to construct coal correlation charts and maps that illustrate coal distribution in the Kaiparowits Plateau, and to calculate coal resources (Hettinger and others, 1996).

Coal Resources

Table 1. Coal resources in the Kaiparowits Plateau coal field (billions of short tons) compiled by the Utah Geological Survey from Hettinger and others (1996).

RESOURCE CATEGORY	FEDERAL	PRIVATE	STATE	TOTAL
Resources in-place	57.2	0.3	4.8	62.3
Estimated minable	20.88	0.11	1.75	22.74
Estimated recoverable	10.44	0.05	0.87	11.36

Hettinger and others (1996) estimate that some 62.3 billion tons of original coal resources are contained in the Kaiparowits coal field (table 1). They define original resource as including all coal beds greater than one foot thick. None of the resource is minable by surface methods. Moreover, the total original resource estimate does not reflect geologic, technological, land-use, and environmental restrictions that may affect the availability and the recoverability of the coal. At least 32 billion tons of coal are unlikely minable under current conditions because the coal beds are either too deep (greater than 3,000 feet), too thin (less than 3.5 feet thick), inclined at more than 12, or in beds that are too thick (greater than 14 feet thick) to be completely recovered in underground mining using existing mining machinery. The estimated balance of 30 billion tons of minable coal resources does not reflect land-use or environmental restrictions, does not account for coal that would be bypassed due to mining of adjacent coal 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. Although all of these factors will reduce the amount of coal that could be recovered, insufficient data are available to estimate recoverable coal resources. Using Hettinger and others' (1996) summary, the UGS feels that an additional 7.5 billion tons within seams 3.5 to 6 feet thick are not minable because they are too thin for current longwall operations in Utah. This leaves 22.74 billion tons minable throughout the field. Applying a conservative recovery factor of 50 percent to the minable resource leaves about 11.37 billion tons as recoverable. Other underground coal mines in Utah recover 60 to 80 percent of the minable resource. Studies of coal resources in the southeastern Appalachians have shown that less than 10 percent of the original coal resource, in the areas studied, could be mined economically at today's prices (Rohrbacher and others, 1994). Given that much of the Appalachian coal was in thin beds and was mined with much lower efficiency methods than are currently available, the 10 percent recovery should be considered an unrealistically low minimum recovery factor in the Kaiparowits coal field. Moreover, if longwall technology is redesigned allowing coal seams to be mined that are thicker than 14 feet and mining occurs deeper than 3,000 feet, then minable resources could be greater, perhaps 50 percent higher.

The Utah Office of Energy and Resource Planning (OERP) performed a preliminary analysis of the potential value of coal in the Kaiparowits Plateau coal field (Appendix B). Total coal value of 11.36 to 16 billion tons of coal, at todays price, is $221 - 312 billion. Their analysis showed that if the Kaiparowits resource were mined, the royalties on this coal to the State of Utah may approach $9.25 billion. Bonus bids and royalties on federal lands are shared equally with the state. The royalties on coal on Utah School and Institutional Trust Lands may approach $1.54 billion.

Coal Resources on School and Institutional Trust Lands

The Utah School and Institutional Trust Lands Administration (SITLA) asked the UGS to report on coal resources on Trust Lands in the Kane County portion of the Kaiparowits coal field. Following President Clinton's designation of the monument, which included all of the Kaiparowits coal field outside of national forest lands, SITLA requested that the UGS augment the previous study by also estimating coal resources on Trust Lands in the Kaiparowits coal field of Garfield County. The Trust Lands of concern generally comprise sections 2, 16, 32, and 36 in Townships 34 to 42 South, Ranges 2 West to 5 East. Data for the study were taken mostly from Blackett (1995) who summarized published measured sections from outcrops, and presented drill-hole data from confidential files. Some data points were taken from Hettinger and others (1996). The results of these two efforts, which were summarized in two unpublished UGS Technical Reports, are presented in this section and in Appendix C.

In addition to the data contained in Blackett (1995), which includes coal intercepts from more than 170 drill holes and several hundred measured sections, data from 32 additional exploratory holes, drilled on Trust Lands, and published measured sections were also compiled for the two Technical Reports. Geophysical logs from the drill-hole files were interpreted for coal intercepts and the intercepts were entered into the original database. Total coal penetrated by the drill holes was used as a basis for preparing maps showing contours of total coal within the Straight Cliffs Formation. In the Garfield County part of the coal field, five data points (three drill holes and two measured sections) from the USGS study (Hettinger and others, 1996) were included as well as three drill holes from other sources. The database used to generate the isopach contours included 217 drill holes and 28 outcrop measurements. Total coal was mapped using gridding and contouring computer software that manages irregularly spaced data. Several iterations of total coal contour maps were made using the inverse distance weighting method. The few erroneous data points found during the contouring were discarded from the data set, the data were re-gridded, and the contours were re-plotted.

Figure 7 shows contoured total coal thickness in the Straight Cliffs Formation to the erosional limits on the east, west, and south sides of the Kaiparowits field. Thickness contours depict the main coal resource trending northwest to southeast, in an 18-mile-wide belt parallel to the Cretaceous paleo-shoreline (documented for example by Peterson, 1988; and in Nations and Eaton, 1991). Much natural burning of coal seams has taken place mainly in the southeastern part of the Kaiparowits field where the coal beds are exposed along narrow ridges. Appendix C lists a section by section summary of coal resources based on thickness contours shown on figure 7. Listed are locations of the Trust Land sections, estimated acreage, estimated coal thickness, and total tons of coal in place. The last column notes those sections where resources are demonstrated by drilling, where the resource might be naturally burned, or where the presence of the resource is questionable due to erosion.

The UGS calculated that roughly 4.45 billion tons of coal resources lie in-place on SITLA lands within the Kaiparowits coal field of Garfield and Kane Counties. Of this total, the UGS estimated that 2.38 billion tons may be considered demonstrated reserves in relatively close proximity to drill holes. This estimate includes all coal seams of one-foot thickness or greater. Hettinger and others (1996) estimated that 4.8 billion tons of coal resource are contained on SITLA lands in the Kaiparowits Plateau field. Using the same criteria and recovery factor as previously stated, the UGS estimates that 876 million tons to 1.3 billion tons of coal are recoverable from Trust Lands.

Sulfur Content of Kaiparowits Coal

Sulfur content of the coal in the Kaiparowits coal field is variable, but generally low, averaging less than 1.0 percent. Coal beds in the Smoky Hollow area, near the proposed Andalex mine, are particularly low in sulfur, averaging 0.45 percent. Data taken from the UGS coal quality database and information from Andalex Resources, are summarized below:

Area/seam	No. Samples	Avg. Sulfur %
Alvey zone	25	0.86
Christensen zone	31	1.02
Henderson zone	15	0.87
Rees zone	11	0.79
Warm Springs mine	42	0.45

This range of in-ground sulfur contents appears similar to the range of sulfur contents found in the Book Cliffs and Wasatch Plateau coal fields of Utah which typically produce coal ranging from 0.44 to 0.71 percent. Such low-sulfur coals have been in high demand in recent years, particularly since 1994 with the implementation of the sulfur emissions portion of the Federal Clean Air Act of 1990. While overall U.S. coal usage has increased at 2 to 3 percent in recent years, demand for Utah's low-sulfur coal has grown annually at a rate of about 10 percent since 1994. This reflects the switching by electric utilities from higher sulfur content eastern U.S. coal to lower sulfur western U.S. coal. New and growing market demand for low-sulfur coal has prompted Andalex Resources to pursue mining of the low-sulfur Kaiparowits coal. Washing of the coal, as is done with some of the Book Cliffs and Wasatch Plateau coals, would further reduce the sulfur content of the Kaiparowits coals.

Coal-bed Gas Resources

The major coal deposits and associated coal-bed gas within the monument occur in the John Henry Member of the Straight Cliffs Formation. As mapped by Hettinger and others (1996), the net coal thickness in the John Henry Member ranges from zero along the eastern and western edges of the Kaiparowits Plateau to as much as 150 feet thick in the center of the plateau. Within the monument, coal beds are found at the surface around the margins of the Kaiparowits Plateau and extend into the subsurface to depths of nearly 6,000 feet. Based on general industry guidelines, areas considered prospective for coal-bed gas have at least 10 feet of coal (net thickness) which is found at depths between 1,000 and 6,000 feet. The area prospective for coal-bed gas within the monument is primarily covered by seven 7.5 minute quadrangles; Butler Valley, Canaan Peak, Death Ridge, Fourmile Bench, Horse Mountain, Petes Cove, and Ship Mountain Point (figure 8). The deep coal resources for these seven quadrangles, as determined by Hettinger and others (1996), is summarized in table 2 along with an estimated range of potential gas resources. The gas contents for the deeper coal resources in the monument were estimated to range from 100 to 400 cubic feet per ton, based on the range of gas contents seen elsewhere in deep Utah coals. Actual desorption tests by the UGS of five shallow John Henry Member coals, from depths of less than 800 feet, only contained as much as seven cubic feet of gas per ton of coal (Sommer and others, 1993). However, other productive fields in the state also show low gas contents in shallow coal beds. The deeper John Henry Member coals of the monument are estimated to contain in-place coal-bed gas resources ranging from 2.6 to 10.5 trillion cubic feet, assuming gas contents ranging from 100 to 400 cubic feet per ton. Considering a recovery factor of 67 percent, and current market prices of $1.20 to $2.50 per thousand cubic feet, the coal-bed gas could be worth from $2 billion to $17.5 billion.

Table 2. Coal-bed Gas Resources of the Grand Staircase-Escalante National Monument.

QUADRANGLE	**IN-PLACE COAL RESOURCES (millions of tons)**				**IN-PLACE GAS RESOURCES**	
	Depth Range (ft)				**(in millions of cubic feet)**	
	1,000-2,000	**2,000-3,000**	**3,000-6,000**	**TOTAL**	**100 cu ft/ton**	**400 cu ft/ton**
Bulter Valley	89.1	1,002.4	19.4	1,110.9	111,090	444,360
Canaan Peak	189.0	1,204.9	1,581.3	2,975.2	297,520	1,190,080
Death Ridge	4,088.4	1,534.0	0.1	5,622.5	562,250	2,249,000
Fourmile Bench	427.9	2,129.3	0.0	2,557.2	255,720	1,022,880
Horse Mountain	840.4	4,371.8	676.6	5,888.8	588,880	2,355,520
Petes Cove	4,479.6	891.2	0.0	5,370.8	537,080	2,148,320
Ship Mtn Point	1,678.4	1,064.2	0.0	2,742.6	274,260	1,097,040
TOTAL	11,792.8	12,197.8	2,277.4	26,268.0	2,626,800	10,507,200

Further Coal Resource Assessments Needed

The coal-bed gas resources presented for the monument in this report are simply estimates. There are adequate data available to identify the presence and location of thick, deep coal deposits, however there are no good measurements of the gas content contained in the deep John Henry Member coals of the Kaiparowits Plateau coal field. To prove the presence, or absence, of coal-bed gas requires that some deep core samples be taken for desorption and isotherm studies. Further, the presence of significant gas volumes in coal beds does not always translate to an economically producible field. There are approximately 37 School Trust sections of land regularly spaced within the monument area prospective for coal-bed gas. Test wells drilled and cored on perhaps a dozen or more of these sections would probably provide an adequate data set to test for the presence of significant gas volumes in the coal beds. If significant gas was found in the deep John Henry Member coals, several five-spot patterns of test wells may need to be drilled on two or three widely-spaced sections to test the productive capacity of the coals, and see if they can be successfully dewatered.

OIL AND GAS POTENTIAL

The monument contains all the elements necessary for major oil and gas accumulations: source rocks, reservoirs, and trapping mechanisms. Commercial deposits of oil have been discovered both within and along the margins of the monument at Upper Valley field (figure 4). Although the characteristics of the monument and Kaiparowits basin as a whole are favorable for the accumulation of oil and gas, wildcat density is extremely sparse. Only 47 exploratory wells have been drilled within the monument or an average of 57 square miles per well. The postulated reasons for this apparent lack of exploratory activity are: (1) remoteness, (2) lack of oil and gas pipelines, (3) low success rates, (4) the collapse of world oil prices in 1986 and a nationwide oversupply of natural gas, and (5) environmental concerns.

However, during the 1990s the Kaiparowits basin and surrounding areas (including the monument) have gained the attention of the petroleum industry as two play concepts developed: (1) Precambrian-source oil and (2) hydrodynamically displaced oil (where the fluid-potential gradient is such that the flow of water is directed down dip barring the up-dip movement of oil). As a result, 141,068 acres of federal land and 49,104 acres of School Trust Lands within the monument are under lease for oil and gas exploration. Seismic data acquisition and drilling activity have increased; several additional wells are in the planning stage either within or near the borders of the monument.

Industry representatives reported attempts to lease an additional 60,000 acres of BLM lands by oil companies in 1996, were denied by the BLM. BLM officials state that those lands falling within H.R. 1500 (Utah BLM Wilderness Act of 1989) were held pending resolution of the Act. Lease applications within the monument but outside of H.R. 1500 were issued. Following creation of the monument, all applications pending were rejected.

Analogous accumulations of oil and gas in terms of source, reservoirs, and trapping mechanisms are found elsewhere in the U.S. and other oil-producing countries. Although the risk of failure is high, the monument could contain major accumulations of oil based on the production history of Upper Valley field and geologic evidence presented in this section.

Source Rocks

Known source rocks in the Precambrian, Mississippian, and Permian are present south, west, and north of the monument. Carrier formations and major faults can provide migration pathways through which oil and gas generated from these source rocks could have migrated into reservoirs and traps in the monument. In addition, potential source rocks within the monument may also provide local hydrocarbon-generating capabilities.

Precambrian Chuar Group

The Proterozoic (Precambrian) Chuar Group of the Grand Canyon Supergroup exposed in the Grand Canyon represents the greatest untested source of hydrocarbons in the monument (figure 9). These outcrops have been evaluated by Reynolds and others (1988), Palacas and Reynolds (1989) Cook (1991); and Lillis and others (1995). The Chuar Group consists of 14,000 feet of unmetamorphosed rocks deposited in a basin 950 to 800 million years ago (Ma). Organic material flourished in depositional environments which included nearshore marine, lacustrine, paludal, and coastal plain (Reynolds and Elston, 1986; Reynolds and others, 1988).

During the creation of the Late Proterozoic western margin of North America, the Chuar deposits were broken into blocks by high-angle, down-to-the west, extensional normal faults (Huntoon, 1971). The duration of the event represented by the "Great Unconformity" between the Cambrian Tapeats Sandstone and underlying Precambrian in the Grand Canyon was about 250 million years. The Chuar and its potential source rocks were preserved in northeast-tilted blocks along north-south-trending rift or normal faults observed today in the eastern Grand Canyon. Figure 4 indicates the maximum extent of Chuar "fairway" in the subsurface based on limited well control and outcrops (Chidsey and others, 1990; Rauzi, 1990; and Utah Geological Survey, 1991). This fairway encompasses essentially all of the monument. However, it is important to note that the fairway is likely broken up into blocks similar to those observed in the Grand Canyon and preservation of Chuar source rocks would be limited. Only seismic data and additional drilling can define the presence of these blocks. If Chuar is present, then a local Precambrian hydrocarbon source is provided, whereas a long distance migration is required from Chuar rocks known to exist in the Grand Canyon.

Work by Reynolds and others (1988), Palacas and Reynolds (1989), and Cook (1991) indicate that the Walcott Member of the Kwagunt Formation within the Chuar Group contains over 680 feet of dark-gray to black mudstone, shale, and siltstone deposited in a shallow lacustrine environment where abundant planktonic microbiota created reducing conditions (Reynolds and Elston, 1986; Reynolds and others, 1988). These rocks are organic rich, over 4.7 percent total organic carbon (TOC), and maturity assessments (Rock-Eval pyrolysis) place them in the principal oil-generating window (table 3).

Table 3.Source-rock characteristics of the Walcott Member, Kwagunt Formation of the Precambrian Chuar Group, eastern Grand Canyon, Arizona (Palacas and Reynolds, 1989) and the Tidewater No. 1 Kaibab Gulch well, Grand Staircase - Escalante National Monument, Utah.

Location	TOC (%)	S1 (mg HC/g rock)	S2 (mg HC/g rock)	HI (mg HC/g TOC)	OI (mg CO2/g TOC)	PI S1/S1+S2	Tmax (C)	CEOM (ppm)	EH (ppm)	RO (%)
Grand Canyon	4.7	2.15	9.60	204	17	0.18	441	4,900	3,200	0.76
1 Kaibab Gulch	0.92	0.14	0.38	41	110	0.27	438	-	-	-

Explanation: TOC - total organic carbon, S1 - volatile or free hydrocarbons, S2 - pyrolytic hydrocarbons, HI - hydrogen index, OI - oxygen index, PI - production index, Tmax - temperature corresponding to the maximum of hydrocarbon generation (level of thermal maturity), CEOM - chloroform extractable organic matter, EH - extractable hydrocarbons, Ro - vitrinite reflectance.

The Tidewater No. 1 Kaibab Gulch well (section 34, T. 42 S., R. 2 W., Salt Lake Base Line, Kane County), drilled in 1956, is inside the monument (figure 4). This well penetrated 900 feet of dark-gray shale assigned to the Chuar Group (figure 10). Munger and others (1965) reported an abundance of carbonaceous material and associated plant-like spores. However, the analyses of well cuttings by the UGS suggest that these rocks would be poor sources of hydrocarbons (table 3). Possible explanations for the poor source-rock characteristics of the section encountered include: (1) that the rocks belong to some other formation within the Grand Canyon Supergroup (figure 9), (2) the rocks penetrated are a part of the Chuar not containing source rocks, or (3) depositional conditions of the Chuar basin at this locale was not conducive to the development of source rocks.

Uphoff (1997) calculated source-rock volumetrics for a 150 square mile area within the monument along the north-northwest-trending axis of the Kaiparowits basin. This represents a conservative sized area and considerably larger area would be expected to contain Chuar source-rocks. Using a source-rock thickness of 160 feet, an average total organic carbon (TOC) content of 4 percent, and a hydrogen index of 200 mg HC/g TOC, the calculated total volume of hydrocarbons generated was 2,700 million barrels (Uphoff, 1997). When applying an entrapment rate of 10 percent, equal to the typical success rate for exploratory wells, potential trapped oil in-place could be 270 million barrels or more within the monument from this source alone. Using a 20 percent oil-recovery factor and a value of $20 per barrel, the value of this oil would be $1.08 billion. At the low end of oil-reserve potential, at least one million barrels of oil worth $20 million are likely to be recovered from further development of Upper Valley field and from discoveries of oil generated from source rocks other than Precambrian.

Mississippian Formations

The Mississippian Redwall Limestone is a proven producer of oil within the Kaiparowits basin (figure 9). There are three possible Mississippian sources for this production: (1) the Chainman Shale of the eastern Great Basin, (2) the Manning Canyon Shale of north-central Utah, and (3) the Thunder Springs Member of the Redwall Limestone of southern Utah. The Chainman Shale generates the oil in several fields in Railroad Valley Nevada (Poole and Claypool, 1984). This formation and its equivalents extend into western Utah and could provide a long-distance hydrocarbon source through several potential carrier formations. The Manning Canyon Shale is rich in organic material though little work has been published pertaining to its source-rock potential. Oil from this formation would also require a long-distance migration to have accumulated in the monument. However, the Thunder Springs Member of the Redwall Limestone provides a possible local source. In 1990, Beard Oil Company drilled the Tanner 1-27 well (section 27, T. 28 S., R. 3 E., Salt Lake Base Line) near the town of Loa in Wayne County. Well cuttings indicated characteristics of source rocks in the Thunder Springs Member (verbal communication, Martin Pruatt, Beard Oil Company, 1990). A drill-stem test of the Redwall in this well, however, recovered only muddy and gassy water.

Permian Formations

Oil collected form the Permian Kaibab Limestone reservoir at Upper Valley field was geochemically analyzed and correlated with known genetic oil families in north-central Utah (Sprinkel and Castaño, 1997). This geochemical correlation indicates a Permian source, probably the organic-rich shale of the Phosphoria or Park City Formations in the Uinta or Oquirrh basins to the north. These formations have long been recognized as having source rocks (Maughan, 1984). Again, a long-distance migration is required to develop oil accumulations in the monument from these rocks. Oil may also be derived from an unrecognized local Permian source, possibly the Hermit Formation (figure 9).

Other Possible Source Rocks

Several other sources of oil could be derived from formations outside the monument through long-distance migration in carrier beds or along major faults. The Devonian Pilot Shale in the eastern Great Basin is recognized as a petroleum source rock although no production of Devonian oil is known in Utah (Sandberg and Poole, 1975). All fields which produce oil and gas from the Pennsylvanian Paradox Formation in the Paradox basin of southeastern Utah and southwestern Colorado were source from cyclic, black, organic-rich shales within the formation (Hite and others, 1984). Oil migrating from the basin could account for numerous live oil shows in the Permian Cedar Mesa Sandstone penetrated by several wells within the monument.

Potential Reservoirs

Potential reservoirs that may contain significant quantities of hydrocarbons in the monument are the Precambrian Chuar Group, Cambrian Tapeats Sandstone, Mississippian Redwall Limestone, Permian Kaibab Formation, and Timpoweap Member of the Triassic Moenkopi Formation (figure 9). The latter three are productive at Upper Valley field. Other potential reservoirs include the Cambrian Muav Limestone, Devonian Temple Butte Limestone, and Permian Cedar Mesa Sandstone and Toroweap Formation.

Chuar Group

The Chuar Group in the Grand Canyon crops out as a 5,370-foot-thick succession of very-fine-grained siliciclastic rocks composed of thin sequences of sandstone with stromatolitic and cyrptalgal carbonate (Reynolds and others, 1988). Cuttings from the Tidewater No. 1 Kaibab Gulch well contain fine-grained, well-sorted quartzarenites. These sandstones consist predominately of monocrystalline quartz; feldspar is almost entirely leached from the rock. Cementing agents include silica (the dominant agent), and minor amounts of anhydrite, dolomite, and pore-lining clay. Moderate compaction has occurred.

These rocks have low porosity and permeability. Pervasive silica over-growths have greatly reduced the original intergranular porosity and the size of interconnecting pore throats. What porosity remains is mainly secondary in origin, resulting from leaching of unstable framework grains. For these units to contain oil, porosity and permeability must be enhanced by significant fracture development.

Tapeats Sandstone

Outcrops of the Cambrian Tapeats Sandstone in the Grand Canyon consist of coarse- to medium-grained feldspathic and quartzarenite (Middleton, 1989). These sandstones were deposited initially in a braided stream setting (Middleton and Elliot, 1990). Widespread progradation of the sea resulted in shallow marine to shoreface deposition of blanket sands over the underlying coastal plain (Middleton and Elliot, 1990). These sandstones are 200 to 300 feet thick in the Kaiparowits basin. The Tapeats is locally absent due to the presence of Precambrian "islands" which can be observed along the Colorado River in the Grand Canyon. This situation is also likely to be present within the monument.

Cuttings from Tapeats in the Tidewater No. 1 Kaibab Gulch well contain white, fine-grained, well-sorted quartzarenites. 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.

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. Porosity values of apparent permeable beds range from 7 percent in the BHP Circle Cliffs No. 28-1 Federal well (section 28, T. 33 S., R. 7 E., Salt Lake Base Line, Garfield County) to as high as 13 percent in the Tidewater No. 1 Kaibab Gulch well (Uphoff, 1997). The pink, dolomitic and green-gray, glauconitic sandstones have low effective porosity and permeability in the cuttings evaluated.

Redwall Limestone

The Mississippian Redwall Limestone in the Kaiparowits basin is a widespread, 500- to 1,200-foot-thick, dense, crystalline dolomite and limestone containing varying amounts of chert (Doelling, 1975; Doelling and others, 1989). The Redwall was deposited in an open-marine environment on the cratonic shelf east of the Cordilleran geosyncline. The formation thins and becomes more dolomitic to the southeast (Montgomery, 1984).

The Redwall is equivalent to the Leadville Limestone in the Paradox basin where it is the main oil reservoir in the Lisbon field. Bordering the monument, the Redwall produced 17,000 barrels of oil from one well in Upper Valley field (Sharp, 1976). As a potential reservoir, the Redwall exhibits intergranular, vuggy, and cavernous porosity (Doelling, 1975). After deposition, the upper part of the formation was subjected to subaerial erosion and solution resulting in the development of a karst topography (Doelling, 1975; Doelling and others, 1989). Fracturing and solution brecciation are also present (Montgomery, 1984).

In an oil reservoir with a karst overprint, production come from a heterogenous combination of fractures, vugs, and caves. Horizontal drilling can be used to intersect more fractures and overcome reservoir heterogeneity. This technique greatly increases the chance of drilling success and production rates in reservoirs with karst topography. Therefore, the Redwall is a good candidate for horizontal drilling.

Kaibab Limestone

The Permian Kaibab Limestone is the major oil-producing reservoir within the monument. The Kaibab is fairly widespread throughout the monument, ranging in thickness from 100 to 370 feet (Hintze, 1988). The reservoir portion of the formation consists of skeletal, bioturbated, glauconitic, sandy, dolomite grainstone (Sharp, 1978). Chert nodules are abundant. The Kaibab was deposited in a shallow, open-marine environment.

In Upper Valley field, there are two zones affected by facies changes and diagenetic alteration (Sharp, 1976; 1978). Similar conditions should also be present in some other areas of the monument. Fracturing due to solution brecciation and tectonic folding enhances porosity and permeability in the upper Kaibab. Porosity ranges from 16 to 18 percent and the maximum permeability is 300 millidarcies (md) with an average of 100 md (Sharp, 1978; Allin, 1993).

Timpoweap Member of the Moenkopi Formation

The Timpoweap Member of the Triassic Moenkopi Formation also produces oil within the monument. Though not as prolific a producer or as widespread as the Kaibab, the Timpoweap is a viable potential reservoir. The Timpoweap ranges in thickness from 20 to 150 feet (Doelling and others, 1989). The reservoir portion of the Timpoweap consists of oolitic and skeletal, grain-supported dolomites, algal mat dolomites, and calichefied dolomites (Sharp, 1976). These dolomites were deposited in open-shallow marine, intertidal and restricted-shallow marine, and supratidal environments.

In Upper Valley field, like the Kaibab, the Timpoweap produces oil from two zones which are also affected by rapid facies changes and diagenetic alteration (Sharp, 1976, 1978). These conditions are similar to those in the Kaibab and should exist to a greater extent than the Kaibab over much of the monument. An unconformity separates the two zones. Diagenesis and fracturing related to subaerial exposure at the unconformity are responsible for the creation and destruction of porosity and permeability in the lower reservoir (Sharp, 1976). Porosity averages 8 percent, permeability ranges from 2.5 to 141 md (Sharp, 1976).

Trapping Mechanisms

During the Laramide Orogeny (Late Cretaceous and Early Tertiary) the high-angle normal faults created during the Precambrian underwent reverse movement forming numerous surface anticlines and monoclines observed within the Kaiparowits basin and surrounding region (figure 4). These basement- or Chuar-cored structures are the potential localities for both Precambrian-source and hydrodynamically displaced oil. The monument contains at least 24 major structures, many tens of miles long (figure 4). Numerous subsidiary closures, analogous to those which produce hydrocarbons along the Moxa arch in the Green River basin of southwestern Wyoming, are likely to be present along these structures. Only three wells have penetrated through the Cambrian Tapeats Sandstone and into Precambrian rocks on major anticlines in the monument. Although these wells were dry, other closures probably on the anticlines, remain untested. The depth to the Precambrian ranges from 5,000 to 10,000 feet in the monument.

Precambrian-Source Oil

Precambrian-source oil is most likely trapped in sandstone reservoirs of the Chuar Group or in the Tapeats Sandstone (figure 11). The trapping mechanisms for Precambrian oil in the Chuar include: (1) updip sandstone pinchouts, (2) normal or reverse faults, (3) the angular unconformity, and (4) fracture zones. Identification of these types of traps would require numerous, high-quality seismic records and are considered the type of drilling targets with the highest risk of failure.

The more likely drilling target is the Tapeats Sandstone along the major anticlines and associated subsidiary closures. Oil trapped in Tapeats structures could have been sourced from the Chuar, where it is in direct contact on preserved rift blocks. The Tapeats could have also served as a carrier bed from Chuar to structural traps elsewhere. The Cambrian Bright Angel Shale directly above the Tapeats is a 250- to 450-feet-thick series of interbedded micaceous shale and sandstone (Uphoff, 1997). The Bright Angel Shale has hydraulically sealed the Tapeats from the overlying Paleozoic section (Huntoon, 1977). Modeling of the Kaiparowits basin by Uphoff (1997) determined qualitatively a range of generation-migration timing. According to this model, hydrocarbon generation from Chuar source rocks began in the Early-Middle Cretaceous (100-150 Ma) and continued until mid-Tertiary (30-40 Ma). This oil-generating window overlaps the Laramide Orogeny thereby making all the structures in the monument potential targets for Precambrian-source oil. The combination of source, migration timing, reservoir quality, structure, and seal define the virtually untested Tapeats Sandstone as a prime candidate for exploratory drilling.

Hydrodynamically Displaced Oil

Potential reservoirs, such as the Redwall Limestone, Kaibab Limestone, the Timpoweap Member of the Moenkopi Formation, and others, are present along the same Laramide structures that have Tapeats potential. However, many of the structures have been drilled through the upper and middle Paleozoic section, and all have been barren of hydrocarbons.

Unlike the sealed Tapeats Sandstone, the rest of the Paleozoic and Mesozoic rocks have been subjected to freshwater flushing. Work by Goolsby and others (1988) and Tripp (1993) suggest hydrologic conditions have had a great impact on trapping of hydrocarbons over large areas of the western Colorado Plateau. Allin (1990) stated that most of the crests of major structures on the western Colorado Plateau once contained hydrocarbons.

During the Pleistocene, deep dissection of the Colorado Plateau changed the original hydrodynamic picture (Allin, 1990, 1993). Much of the trapped oil was probably lost to the Colorado River drainage. The hydrodynamic drive shifted generally to the southwest, moving crustally trapped oil back down the western flanks of the Laramide structures and washing away the lighter hydrocarbon fractions by the influx of fresh water (Allin, 1990). This phenomenon is observed at Upper Valley field where the hydrodynamic drive has offset oil to the western flank and the southern plunge of the structure. The oil/water contact in all zones is tilted S. 45 W. and appears curvilinear, concave down, due to a decrease in oil gravity (Sharp, 1978). Very little solution gas remains in the oil.

Most wildcat wells in the monument have been drilled on the crests of the major structures. Because of the hydrodynamic drive in the region, the potential traps on the flanks of the structures remain to be tested. Oil fields similar to Upper Valley have been discovered in Wyoming and California. Studies of these areas and methods used in their evaluation can help to determine the location of hydrodynamically-displaced oil in the monument.

Exploration and Development

Forty-seven wildcat wells have been drilled within the monument; 24 in Garfield County and 23 in Kane County, respectively. Petroleum shows have been found in Triassic, Permian, Pennsylvanian, Mississippian, Devonian, and Cambrian age rocks (Doelling, 1975). These shows were in the form of petroleum recovered from drill-stem or production tests in wells and live oil stains or bitumen in drilling cuttings. Sixty-three percent of the wells drilled in the monument tested only the Permian section, the Kaibab Limestone being the main target. Just five wells tested the Mississippian and Devonian sections, and only three penetrated the Precambrian.

Drilling History

The large surface anticlines within the monument sparked the interest of wildcatters in the early days of petroleum exploration in the West. The first well in the monument was drilled on the large Circle Cliffs anticline by the Ohio Oil Company in 1921. The No. 1 Circle Cliffs (section 25, T. 34 S., R. 7 E., Salt Lake Base Line) penetrated the Mississippian Redwall Limestone (figure 4), but no shows of oil or gas were reported and the well was plugged after reaching a total depth of 3,212 feet. In 1930, Midwest Exploration Company tested the Butler Valley anticline along the north plunge of the Kaibab uplift in the center of the Kaiparowits basin (now part of the monument). The No. 1 Parry well (section 14, T. 39 S., R. 1 W., Salt Lake Base Line) reached a total depth of 4,436 feet in the Permian Cedar Mesa Sandstone. Although good shows of oil were encountered in the Kaibab Limestone and Toroweap Sandstone, the well was abandoned (Montgomery, 1984). No other exploratory wells were drilled in the monument for the next 20 or so years.

Seven wildcats were drilled in the area which is now the monument the 1950s. In 1954, Hunt Oil Company drilled the second well on the Circle Cliffs anticline, the No. 1 Government (section 24, T. 34 S., R. 7 E., Salt Lake Base Line), which reached a total depth of 5,620 feet in the Bright Angel Shale above the Tapeats Sandstone. The well was plugged with no shows reported. The Tidewater Gulch No. 1, discussed earlier, was drilled in 1956 to a total depth of 6,253 feet. Several shows of oil were reported throughout the Cambrian section. A drill-stem test of the Tapeats Sandstone recovered 270 feet of gas-cut mud.

The greatest flurry of exploration activity took place during the 1960s and 1970s, when 32 wells were drilled in the area that is now the monument. In 1977, considerable interest was sparked by the reported Kaibab oil discovery in the Houston Oil and Minerals No. 11-9 Relsihen Federal well (section 9, T. 38 S., R. 3 E., Salt Lake Base Line). Drilled as a 10,285 foot Mississippian test on the Rees anticline in the center of the monument, this well only pumped one barrel of oil per day and was abandoned as non-commercial (Montgomery, 1984).

Only three wells were drilled in the 1980s but interest was renewed in 1994 with two wildcats designed to test the Precambrian-source oil play. On the Paria Plateau along the southern Kaibab uplift, Burnett Oil Company drilled the No. 1-36 Kaibab well (section 36, T. 43 S., R. 3 W., Salt Lake Base Line) to a total depth of 5,362 feet. The Precambrian was penetrated at 4,780 feet after which 585 feet of sedimentary rocks, possibly the Dox Sandstone, were penetrated (verbal communication, David Allin, 1997). The Tapeats Sandstone measured 106 feet thick, and although some shows were reported, the well was abandoned without any tests. The other well drilled in 1994, the BHP Petroleum No. 1-28 Federal (discussed earlier) on the Circle Cliffs anticline, reached a total depth of 6,185 feet. The Precambrian was penetrated at 6,130 feet but consisted of phyllite; no sedimentary rocks were encountered. The Tapeats measured 212 feet thick and contained bitumens. The presence of bitumens implied the Tapeats received a hydrocarbon charge prior to the influx of CO2 (Uphoff, 1997). The well was plugged after the CO2 tests.

Upper Valley Field

The Upper Valley field was discovered in 1964 when Tenneco Oil Company drilled the No. 2 Upper Valley Unit well (section 13, T. 36 S., R. 1 E., Salt Lake Base Line) near the monument's north-central boundary. That well pumped 300 barrels of oil per day out of the Kaibab Limestone along the flank of the north-northwest-trending part of the Upper Valley anticline (figure 4). The productive area covered 3,350 acres with an average net pay thickness of 75 feet (Sharp, 1978; Allin, 1993). The trapping mechanism and reservoir characteristics were described in previous sections and are summarized in detail by Campbell (1969), Peterson, (1973), Sharp (1976, 1978), Montgomery (1984), and Allin (1990, 1993).

The Upper Valley field has produced 25,144,770 barrels of oil, ranking it as the ninth-largest oil field in Utah in terms of total production (Utah Division of Oil, Gas and Mining, 1996). Citation Oil & Gas Corporation is the current operator of the 22 active wells in the field. Five of these wells lie within the monument and accounted for nearly 27 percent of the field production in September 1996, and 10 percent of the total cumulative field production (table 4) (Utah Division of Oil, Gas and Mining, 1996). In total, the monument wells would be ranked as the eighteenth-largest field in Utah in terms of cumulative production.

Table 4. Oil and water production from the Grand Staircase - Escalante National

Monument portion of Upper Valley field as compared to the field as a whole (Utah Division of Oil, Gas and Mining, 1996).

Location	Active Wells	Monthly Production (bbls)		Cumulative Production (bbls)		Field Production (%)	
		Oil	Water	Oil	Water	Monthly	Total
Within Monument	5	5,544	185,790	2,472,951	48,325,057	26.9	9.8
Outside Monument	17	15,059	686,040	22,671,819	307,536,233	73.1	90.2
Total Upper Valley	22	20,603	871,830	25,144,770	355,861,290	100.0	100.0

In addition to the producing wells, there are two water injection wells within the monument. These wells are part of a 10-well peripheral waterflood program begun in 1969 by the field operators and designed as a secondary recovery program. Over 10 million barrels of produced water are injected annually back into the reservoir to maintain pressure and increase oil recovery.

The Upper Valley field as designated by the Utah Division of Oil, Gas and Mining includes about 2,000 acres within the monument (figure 12). The federally-recognized Upper Valley Federal Unit includes about 1,840 acres within the monument. These areas include access roads, tank batteries, gathering systems, and other maintenance facilities necessary to operate this large field. As there are no oil or gas pipelines in the region, all of the oil is trucked 300 miles to refineries in Salt Lake City.

Sharp (1978) estimated the ultimate recovery from Upper Valley field as about 21 million barrels of oil. Allin (1993) estimated the ultimate recovery as 25 million barrels of oil. That amount was exceeded in 1996 and monthly production continues to average more than 20,000 barrels of oil. Tertiary recovery techniques and new technologic advances in enhanced oil recovery should help maintain Upper Valley field as a major contributor to oil production in Utah.

Carbon Dioxide

Carbon dioxide (CO2) is present in many large anticlines throughout the Colorado Plateau. Closest CO2 production to the monument is in the McElmo Dome field in southwestern Colorado, where gas is transported via a 502-mile pipeline to west Texas for enhanced oil-recovery programs. The gas is also piped to southeastern Utah for the state's only CO2-enhanced oil-recovery operation at Greater Aneth field.

In 1960 and 1961, wells drilled by Phillips Petroleum tested CO2 from Permian and Triassic rocks on the large, northwest-trending Escalante anticline which extends into the northern part of the monument near the town of Escalante (figure 4). Mid-Continent drilled the Charger No. 1 well (section 29, T. 32 S., R. 3 E.) to a depth of 3,443 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 2,000 feet (Montgomery, 1984). Reservoirs in this well include the Permian Cedar Mesa Sandstone, Toroweap Formation, Kaibab Limestone (Black Box Dolomite in the northeast part of the monument), and the Triassic Moenkopi and Chinle Formations. The gas from the Charger well is composed of 93 to 99 percent CO2, 1 to 6 percent nitrogen (N2), and 0.4 to 0.7 percent methane (CH4) (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 CO2 reservoir.

The thick sections of Paleozoic carbonate rocks in the region are the probable CO2 source-rocks. Metamorphism of marine carbonates by the heat of nearby igneous intrusive rocks likely generated the high concentrations of CO2 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 and parts of the Kaiparowits basin implies intrusions of high-level Tertiary plutons. These plutons probably acted as heat sources. The modern heat flow in the region ranges between 1.5 and 2.5 heat flow units (Lachenbruch and Sass, 1980).

The Upper Valley anticline, situated a few miles to the west and parallel to the Escalante anticline (figure 4), contains some accumulations of CO2 trapped as a gas cap above the oil reservoir. On the Circle Cliffs anticline, a drill-stem test of the Tapeats Sandstone in BHP's Circle Cliffs No. 28-1 Federal well had an initial flow rate of 5.0 million cubic feet of gas per day, and contained no water. The gas was composed of 98 percent CO2 and 1.5 percent nitrogen (Uphoff, 1997).

Although the Circle Cliffs deposit may be of the same order of magnitude as the Escalante deposit, this and other potential CO2 resources in the monument will likely remain undeveloped. Ample supplies of CO2 are available from other state states. Moreover, there are few planned CO2-enhanced oil-recovery projects in Utah.

Further Oil and Gas Resource Assessments Needed

The evaluation of potential petroleum resources presented for the monument in this report are based on a very limited amount of information. To prove the presence or absence of Precambrian-source and hydrodynamically displaced oil would require the following: (1) acquire new and compile existing seismic data, conduct a thorough interpretation of the data, and construct detail maps defining the extent of Chuar source rocks as well as the locality of rift fault blocks where Chuar could be preserved; (2) produce detailed structural contour maps for each potential reservoir to identify subsidiary closures along major anticlines; (3) conduct additional typing of produced oils and matching of those oils to known or potential source rocks in the monument and surrounding regions; (5) model the basic source rock parameters of these formations to determine, qualitatively, hydrocarbon generation-migration timing; (6) calculate petroleum volumetrics for each of the potential rocks; and (7) further refine the hydrodynamic characteristics of the Kaiparowits basin to determine the most likely locations of displaced oil along the major structures.

In the final analysis, however, Precambrian-source and hydrodynamically displaced oil in the monument can only be proved by drilling exploratory wells and using state-of-the-art techniques to develop any petroleum resources discovered. Three unsuccessful wells penetrating the Precambrian and another 44 plugged wells in shallower targets cannot be used alone to rule out the possibility of major petroleum accumulations in the monument.

TAR-SAND RESOURCES OF THE CIRCLE CLIFFS AREA

The Circle Cliffs tar-sand deposit, located in T. 33 through 36 S., R. 6 through 9 E., central Garfield County, is in the eastern part of the monument (figure 13). The deposit is entirely contained within the monument and Capitol Reef National Park and is about 40 miles south-southeast of the park's visitors' center. Access to the area is by the Burr Trail road from either Capitol Reef National Park or the town of Boulder. In 1981 the Federal government designated the Circle Cliffs deposit a Special Tar Sand Area (STSA) in accordance with the Combined Hydrocarbon Leasing Act. This designation as an STSA permits development of the tar-sand resource by allowing conversion of oil and gas leases to combined hydrocarbon leases within the STSA.

Tar sands is a catch-all term which includes asphaltic sandstone, bituminous sandstone, pitch rock, oil-impregnated sandstone, heavy-oil sand, and oil sand. The U.S. Department of Energy defines tar sands as any rock (other than coal, oil shale, or gilsonite) that contains oil with a gas-free viscosity greater than 10 Pascal seconds, or 10,000 centipoise, at original reservoir temperatures. Tar sands are the result of oil-migration from source rocks, accumulation in reservoir rocks, and subsequent degradation over time with exposure to oxygenated ground water, bacteria, and other nutrients. Conventional oil-field techniques cannot recover the oil in tar sands because it has little mobility at reservoir conditions. Processes developed to liberate hydrocarbons from tar sand usually involve crushing and washing the mined material using hot water, steam, or chemical solvents.

Active interest in the Circle Cliffs tar-sand deposits might have started as early as the 1920s, when the Ohio Oil Company, undoubtably encouraged by the oil shows in the Moenkopi Formation, drilled the first test near the axis of the structure. There is no known development of the tar sands deposits, although there have been applications made to the BLM for combined hydrocarbon leases.

The Circle Cliffs is a large, breached anticline that is approximately 9 miles wide and 30 miles long with a steep eastern flank, the Waterpocket Fold, and a shallow dipping west flank. The structure trends north-south and is distinctly asymmetrical. The structural axis of the anticline is located along the eastern boundary of the monument. Davidson (1967) indicated an anticlinal closure of about 1,200 feet. Only minor faulting, with displacement from a few feet to more than 100 feet, is associated with the anticline, mostly west of the anticlinal axis. The breached part of the anticline is marked by a topographic depression with isolated buttes and mesas standing as erosional remnants more than 300 feet above the floor of the depression.

Blakey (1977) and Ritzma (1980) described the tar sands of the Circle Cliffs as contained in low-porosity sandstones in the upper part of the Torrey and Moody Canyon Members of the Moenkopi Formation. These deltaic and fluvial sandstones range from 3 to 90 feet thick and are repeated in the vertical section. Normally the rocks are brownish red, but because of oil saturation, the rocks can be light grayish red to light gray to light yellow. Thickness of the oil-saturated rock ranges from a few feet on the margins of the deposits to over 200 feet. Oil apparently migrated to the structurally highest part of the trap within sandstones of the Moenkopi Formation. The deposit shows evidence of hydrodynamic offset; the thickest section of oil-saturated rock is offset from the crest of the anticline. Upward movement of the oil was stopped by less permeable layers of rocks in the Moenkopi Formation. The oil was eventually exposed to oxygenated meteoric water that carried bacteria into the reservoir. This resulted in biodegradation, loss of volatiles, and oxidation of the lighter oil fractions, increasing the gravity and viscosity of the residue. Eventually the anticline was breached by erosion dividing the deposit into the western and eastern flanks (Ritzma, 1980). The entire western flank and a small part of the eastern flank of the deposit are within the monument.

Since no study has systematically evaluated all possible sources of the oil accumulation in the Circle Cliffs, the origin of the oil is uncertain. Proposed sources for the oil include the Lower Triassic Sinbad Limestone Member of the Moenkopi Formation, the Lower Permian Kaibab Formation, and Paleozoic rocks (Blakey, 1977; Ritzma, 1980). Sanford (1995) suggests that, in addition to the Moenkopi and Kaibab Formations, potential source rocks include the Precambrian Chuar Group and the Paleozoic Toroweap Formation. Many wells that penetrate the Moenkopi Formation in central Utah record some type of oil show in the Moenkopi Formation. Free oil shows in cores, on drill-stem tests, during drilling, on wire line tools, and on completion attempts are common from the Moenkopi Formation throughout central Utah, suggesting a long migration path (Mitchell and others, 1989).

Ritzma (1980) estimated in-place tar-sand resources of 1.3 billion barrels (447 million barrels on the western flank and 860 million barrels on the eastern flank) for the Circle Cliffs deposit. Samples analyzed have yielded 5.0 to 27.0 percent oil. Based on Ritzma's (1979) estimate, in-place tar-sand resources for the part of the Circle Cliffs deposit inside the monument could be as much as 550 million barrels of oil.

NON-FUEL MINERALS AND MINING

Various types of metallic-mineral deposits are known to be present in the monument (figure 14). Most of these are small and low-grade with an uncertain likelihood of significant development. However, several areas contain known or potential deposits that might be of developable size and grade. Several of these deposits contain minerals or commodities, such as rutile and zirconium, that are considered to be strategic and critical minerals. Minor occurrences of other minerals such as manganese, copper, and uranium are also present in the monument but are probably not commercial quality due to low, often sub-economic grades and limited tonnage.

Manganese

Manganese was mined in the 1940s from the Manganese King Mine on the north side of Kitchen Corral Wash west of The Cockscomb (figure 14). The manganese deposits occur in the middle part of the Petrified Forest Member of the Chinle Formation. Manganese is contained over a stratigraphic thickness of 17 feet but most is concentrated in a 6- to 12-inch-thick-zone (Doelling and Davis, 1989). The occurrences can be traced laterally for about 1,000 feet. Total production was about 300 to 400 tons of ore containing 40 percent manganese. Descriptions of the deposit, workings, and history of production are presented in Buranek (1945), Havens and Agey (1949), Baker and others (1952), and Doelling and Davis (1989).

Manganese is also found at the Van Hamet prospect located a few miles southeast of Escalante (figure 14). The manganese 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 100 by 250 feet. Select samples are low grade, only 15 to 27 percent manganese (Doelling, 1975).

Uranium-Vanadium

Uranium deposits or prospects with associated vanadium or copper are present in several areas within the monument. The deposits and prospects occur in either the Triassic Moenkopi and Chinle Formations or the Jurassic Morrison Formation. The Triassic-hosted occurrences are in the extreme northeast portion of the monument in Circle Cliffs area and in the southwestern part of the monument near The Cockscomb. The Jurassic-hosted occurrences are in the east-central part of the monument along Fiftymile Bench. Additional Jurassic-hosted deposits are present immediately east of and outside of the monument along the eastern flank of the Circle Cliffs anticline. Most of the prospects are small and the only mines that produced more than 200 pounds of U_3O_8 were in Triassic host rocks in the Circle Cliffs area.

Triassic-hosted Deposits

At least 29 uranium prospects containing subordinate copper as well as seven copper mines and prospects are present in the portion of the Circle Cliffs uplift within the monument (figure 15). The deposits occur mostly in and adjacent to channels in the Shinarump Member of the Chinle Formation in either basal sandstones and conglomerates of the Shinarump or in sandstones or siltstones of the underlying Moenkopi Formation. Nearly 85 percent of the estimated 75,000 pounds of uranium produced in the Circle Cliffs area came from the Rainy Day, Horsehead, and Centipede mines (Doelling, 1975; Utah Geological Survey, unpublished file data). The Rainy Day mine is outside of the monument. Although vanadium generally is not important in Chinle-hosted deposits, an estimated 35,000 to 37,000 pounds of V_2O_5 were produced from the Circle Cliffs area, almost all from the Rainy Day mine (Doelling, 1975). Typical grades for most of the deposits are from 0.05 to 0.20 percent U_3O_8 and 0.5 to 3.0 percent copper. Anomalous amounts of lead, zinc, cobalt, nickel, molybdenum, silver and yttrium are associated with some of the deposits often as sulfides or secondary oxides forming a halo around or above the uranium mineralization. Of the associated elements, only copper is sufficiently abundant to be considered a by-product of uranium mining. Most previous exploration for Chinle-hosted deposits in the Circle Cliffs area has not extended more than a few hundred feet beyond the outcrop. Additional resources may lie along western extensions of channels containing the Centipede and Horsehead mines, but the expected uranium grade would still be only 0.10 to 0.20 percent U_3O_8.

Doelling and Davis (1989) reported four areas of anomalous radioactivity in the Chinle Formation in the Cockscomb-Buckskin Mountain area (figure 15). Surface cuts and short adits have been used to explore these areas but no uranium minerals were identified. Most occurrences are in iron-oxide stained, commonly bleached, sandstones of the Shinarump or Monitor Butte Members of the Chinle Formation close to the contact with the underlying Moenkopi Formation.

Uranium mineralization also occurs in the Kayenta Formation at the Radiance Group southeast of The Cockscomb (figure 15). Workings consisted of several adits and inclines later destroyed by mining of sandstone for highway construction (Doelling and Davis, 1989). The mineralization consists of secondary uranium and copper minerals coating fractures in the Kayenta Formation. About 173 pounds of uranium were produced from ores containing 0.15 to 0.25 percent U3O8. The remaining resource, if any, is probably small (Doelling and Davis. 1989)

Potential for Chinle-hosted deposits in other parts of the monument is thought to be low (Dubyk and Young, 1978).

Jurassic-hosted Deposits

Within the monument, the Morrison Formation is exposed as a narrow zone along The Cockscomb, as a slightly broader zone along Fiftymile Bench below the Straight Cliffs, and as a yet broader zone along the southern edge of the Kaiparowits Plateau. Anomalous radioactivity has been detected along a 3- to 4-mile-long-zone along the eastern side of Fiftymile Mountain. A small adit (Steele prospect at Cat Pasture) is driven in a sandstone channel in the Morrison Formation here (figure 15). Samples from this prospect contained 0.014 and 0.033 percent U3O8 but only minor vanadium (Utah Geological Survey, unpublished file data). Doelling and Davis (1989) believe a substantial tonnage of very low-grade uranium (0.01 to 0.05 percent U3O8) could be found at Cat Pasture (figure 15).

Peterson and others (1982) identified two additional areas thought to be favorable for Morrison-hosted uranium deposits based on depositional environment, thickness, and structure. These two areas are near Fiftymile Point and Carcass Canyon (figure 15). Although these two areas have favorable geology, no uranium has yet been identified.

Zirconium-Titanium

A number of heavy mineral fossil placer deposits are present in the John Henry Member of the Cretaceous Straight Cliffs Formation within the central portion of the monument. The deposits are undeveloped at present due to their remote location, and due to problems associated with producing a mineral concentrate. However, these placer deposits represent a significant zirconium-titanium resource that could be potentially commercial.

The deposits occur in a 40- to 50-mile-long-belt extending from just south of Escalante (Dave Canyon) to the middle of Kane County (Sunday Canyon, figure 14). The northern occurrences are between the Alvey and Christensen coal seams and the southern occurrences are below the Christensen coal seam, suggesting the presence of multiple heavy mineral horizons.

The deposits are fossil beach placers containing variable amounts of zircon, ilmenite, magnetite, rutile, monazite, and some silicates. The heavy-mineral horizons are from 4 to 15 feet thick, and as much as 400 feet wide and 1,500 feet long. The deposits are "high grade," contain from 18 to 45 percent "ilmenite-equivalent," 4 to 14 percent zircon, and 1 to 4 percent monazite. Recent work indicates that from 10 to 50 percent of the titanium is contained in the mineral rutile (Carpco Inc., 1987). Rutile is considered to be a strategic and critical mineral and sells for about $600 per ton. Zircon is also a stockpiled critical and strategic mineral and sells for $350 to $400 per ton. The deposits are high grade (20 to 60 percent) when compared to recent heavy-mineral, beach placers that typically contain only 10 to 15 percent heavy minerals.

At least 14 individual deposits are known within the Ti-Zr belt within the monument (figure 14) with an estimated aggregate size of from 1.04 million tons (Dow and Batty, 1961) to 3.06 million tons (Mountain States Resources, 1988). Because of problems associated with producing a salable concentrate, the economic viability of the deposits is uncertain.

Gold

Anomalous gold values are reported for Permian to Jurassic sedimentary rocks over much of southeastern Utah, particularly in the Chinle and Wingate Formations and in the Navajo Sandstone (Butler and others, 1920; Gregory and Moore, 1931; Phillips, 1985). Lawson (1913) reported several early attempts to mine the gold in the Chinle Formation at Paria by hydraulic methods. All were unsuccessful.

Copper, Lead and Zinc

Copper, often with associated lead, zinc, and silver, occurs in sedimentary host units in four separate areas within the monument (figure 14). The Rock Springs, Ridge Copper, and Bullet Shaft deposits are located south of Kodachrome Basin. These deposits lie on the east side of the north-plunging Kaibab anticline (Kaibab Uplift) and occur in the Jurassic Thousand Pockets Tongue of the Page Sandstone. Workings consist of surface pits, shallow shafts, and short adits. The ore occurs as irregularly shaped pods a few feet in length, nodules, and impregnations in sandstone. The Ridge Copper and Bullet Shaft were mined for copper but the Rock Spring deposit was mined mostly for lead (Doelling and Davis, 1989).

Copper, lead, and zinc are associated with a number of uranium deposits in the Circle Cliffs area. Uranium mines containing significant copper values include the Blue Bird, Black Widow, Yellow Jacket, Hot Shot, Sneaky, and Rainy Day mines In addition, a number of mines and prospects contain mostly copper with little or no associated uranium. In both the copper and uranium-copper mines, the copper occurs as malachite, azurite, bornite, and chalcopyrite in discontinuous zones generally 1 to 3 feet thick in basal sandstones of the Shinarump and in the uppermost Moenkopi Formation. Trace amounts of cobalt and molybdenum are associated with these deposits.

Copper mineralization is found along a zone extending 12 miles northward from the Arizona border along the East Kaibab monocline. The mineralization is associated with fractures subparallel to regional folds. Copper oxide minerals with some associated sulfide minerals occur in fractures in the Jurassic Navajo Sandstone and Moenave Formation, and in the Triassic Shinarump Member of the Chinle Formation. Most mineralized fractures are small, extending only a few feet along strike, with the largest extending for several hundred feet. Prospects include Copper Cliff and Hattie Green, where Doelling and Davis (1989) reported several pits, adits, and small stockpiles of material they suspect were shipped for test smelting.

Copper-silver mineralization is found at Jodies Knoll near Montezuma. Mineralization is present as weak malachite and iron oxide staining in the Thousand Pockets Tongue of the Jurassic Page Sandstone. The mineralization is exposed over an area 400 to 500 feet long but is very erratic (Davis and Doelling, 1989).

Industrial and Construction Materials

Because there has been negligible production of industrial mineral materials within the monument, and because these materials are widely available in commercial operations elsewhere, we describe them briefly here. Industrial and construction materials in the monument include sand and gravel, limestone, gypsum, building stone, clays, and glass sand. Sand and gravel deposits used for concrete and road construction are located adjacent to the Paria River and Wahweap Creek drainages in the western and southern parts of the monument. No limestone deposits in the monument have produced material for industrial applications, although several formations, ranging in age from Permian to Tertiary and exposed in the western part, contain limestone of possible commercial quality and quantity. Likewise, rock units exposed in the western part of the monument, particularly units in the Moenkopi, Moenave, and Carmel Formations, have historically provided building stone for local uses. Gypsum is abundant in the Moenkopi and Carmel Formations inside the monument, but no deposits have been developed. Clay units occur throughout the exposed stratigraphic section particularly in the Chinle and

Dakota Formations, and in the Tropic Shale. Sand for industrial uses is also widespread throughout the monument, however, the only unit investigated has been the Navajo Sandstone (Doelling and Davis, 1989).

Mining Activity

There are five small mining operations currently permitted within the monument according to records at the Utah Division of Oil, Gas and Mining. Four of the operations are active quarries for alabaster. The fifth is a suspended operation that supplied petrified wood. The operators of the quarries primarily gather material that weathers out of the rock rather than actively quarrying the materials. One of the alabaster quarries lies on both federal and School Trust lands. The alabaster is reputed to be among the best available in the country for sculpting purposes. Annual production is about 300 tons and the wholesale price is $500 per ton ($150,000 per year). The retail price is approximately $2,500 per ton. Individual large pieces can sell for $2,000 to $6,000 each (Brad Orrin, verbal communication, 1996). Over a 30-year period, these quarries should generate $4.5 million in production.

Further Non-Fuel Mineral Resource Assessments Needed

Additional surface mapping in conjunction with a limited drilling program at the Manganese King mine would refine the estimates of the size and grade of the remaining manganese resource estimated by Buranek (1945) at 20,000 tons.

There is little information on the uranium resources down dip on the western side of the Circle Cliffs uplift. Additional uranium resources are likely along the western continuations of Shinarump channels hosting the Centipede and Horsehead mines. Drilling (less than 300 feet) would be required to discover and evaluate the uranium mineralization which would most likely be small (less than 3,000 to 4,000 tons) and low grade (0.10 to 0.20 percent U_3O_8).

The size, extent and grade of the titanium-zirconium placers are not well defined. The extents of exposed occurrences are not adequately known and the size and grade of the expected "blind" occurrences are purely speculative. Additional surface mapping, extensive sampling and some drilling would be required to determine the tonnage, grade and rutile/ilmenite ratios of the known occurrences. Stratigraphic studies, surface geophysical surveys, and drilling would be required to determine the subsurface extent of deposits.

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APPENDIX A: Presidential proclamation

APPENDIX B: Summary of the coal resource of Kaiparowits Plateau and its value

APPENDIX C: Summary of coal resources on School and Institutional Trust Lands, Kaiparowits Plateau coal field, Kane and Garfield Counties.

APPENDIX D: Authorized Federal Oil and Gas Leases in the monument

Request PDF | BroadScale Assessment of Rangeland Health, Grand Staircaseâ€“Escalante National Monument, USA | Over a 3-yr period, the qualitative assessment protocol "Interpreting Indicators of Rangeland Health" was used to evaluate the status of three | Find, read and cite all the research you need on ResearchGate.Â Dominant overstory plants in Pâ€“J ecosystems in GSENM are Colorado pinyon (Pinus edulis) and Utah juniper (Juniperus osteosperma) with a diverse understory community across the nine ecological site types that occur within the monument (Miller, 2009). A relict 142 ha mesa, No Man's Mesa, located in the southwestern GSENM served as an ungrazed control landscape for our study (Fig. The Grand Staircaseâ€“Escalante National Monument (GSENM) is a United States national monument that originally designated 1,880,461 acres (7,610 km2) of protected land in southern Utah in 1996. The monument's size was later reduced by a succeeding presidential proclamation in 2017. The land is among the most remote in the country; it was the last to be mapped in the contiguous United States.

The purpose of this report is to provide a preliminary inventory of the paleontological resources within the newly created Grand Staircase-Escalante National Monument for two principal reasons. First, in establishing the monument, President Clinton proclaimed the opportunities for scientific study, expounding at length on the paleontological resources and sites. He directed the U.S. Bureau of Land Management to develop a management plan for the monument within three years.