United States
Department of the Interior
Bureau of Land Management

MINERAL REPORT

Mineral Potential Report
For
The Monticello Planning Area

Monticello Field Office

Encompassing Approximately 4.58 million acres
San Juan County, Utah

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SUMMARY AND CONCLUSIONS

This report assesses the mineral resource occurrence and development potential for the Monticello Planning Area (MtPA). The mineral resource potential is classified using the system outlined in Bureau of Land Management Manual 3031. The potential for development of each mineral resource in the MtPA is projected for the 15-year life of the Resource Management Plan (RMP) and is rated as high, moderate, or low. The conclusions regarding the mineral resources identified within the MtPA are summarized as follows:

Oil and Gas

Areas of high, moderate, and low potential for the occurrence of oil and gas have been identified for the MtPA. The northern and eastern sections of the MtPA correspond to USGS plays that have a high potential (H/D) for the occurrence of oil and gas. The remainder of the MtPA has a high occurrence potential (H), but a lower level of certainty (C to B) except for the Abajo Mountains, which has a low occurrence potential (L/B). Development of oil and gas is considered likely over the next 15 years for the areas with high occurrence potential.

A Reasonably Foreseeable Development Scenario for oil and gas (RFD) has been developed which predicts future oil and gas activity (see attached study). The baseline RFD scenario for the MtPA is summarized as follows:

- Existing surface disturbance for 1,135 active wells, 480 abandoned wells, and associated infrastructure is about 15,504 acres. This amounts to about 9.6 acres of surface disturbance per well.
- Future surface disturbance over the next 15 years for a projected 195 wells and infrastructure amounts to about 1,872 acres.
- During this period, 27 dry wells, 20 abandoned wells, and all 480 currently abandoned wells should be successfully reclaimed, making the total reclaimed surface area equal 5,059 acres.
- The total net surface disturbance for wells drilled in the MtPA over the next 15 years will equal roughly 12,317 acres.
- Future surface disturbance over the next 15 years for geophysical exploration (1,230 linear miles) amounts to about 2,236 acres. Reclamation of all these disturbed lands would be successful over the scope of 10 years.

Coal

Old coal mines and drill hole data suggest a high potential (H/D) for coal occurrence in the Cretaceous Dakota Sandstone in a small portion of the San Juan Coal Field southeast of Monticello, Utah. Other areas of the San Juan Coal Field are rated as having high occurrence potential, but with a C level of certainty (H/C). Due to the poor quality of the coal, development is considered unlikely over the next 15 years.

Potash and Salt

The Cane Creek Known Potash Leasing Area (KPLA), the Lisbon Valley KPLA, and the Gibson dome area are all rated as having a high (H/D) potential for potash and salt occurrence. The more expansive areas underlain by potash and salt also have a high (H) occurrence potential, but are rated as a C certainty. A combination of factors, including the high cost of extraction and easier to mine deposits outside the planning area, suggests that the development of these resources in the MtPA is unlikely over the next 15 years.

Tar Sand

There is a high potential (H/D) for tar sand occurrence in the White Canyon Designated Tar Sand Area. Due to high costs associated with hydrocarbon extraction from tar sands and the poor quality of the resource, development is considered unlikely over the next 15 years.

Uranium-Vanadium

There is a high potential (H/D) for the occurrence of uranium and vanadium deposits in historic mining areas. Where the Chinle and Morrison Formations are present outside of these areas, there is a moderate potential (M/C) for occurrence. With the current price of uranium at $29.00 per pound (May 9, 2005) and vanadium at an historic high price of over $25.00 per pound, it is likely that some of the existing mines will resume production in the next 15 years.

Copper

There is a high (H/D) potential for occurrence of copper in the MtPA in the White Canyon, Oljeto Mesa (Monument Valley), and Indian Creek uranium mining areas. Where the Chinle and Moenkopi Formations are present outside these areas, there is a low to moderate (L-M/C) potential for occurrence. The copper deposits throughout the MtPA are low-grade and sparse, making development unlikely over the next 15 years.

Placer Gold

There is a high (H) potential with D certainty for placer gold occurrence at previously mined sites, while the broader areas of alluvial deposits along the San Juan River, and Johnson and Recapture Creeks are rated as H/C to M/C. Some small-scale development is considered likely over the next 15 years.

Limestone

The identified limestone quarries in the MtPA have been characterized as H potential for the occurrence of limestone with D certainty. Elsewhere in the MtPA, the Honaker Trail Formation is characterized as H potential with C certainty for the occurrence of limestone. There is significant interest in limestone in southeastern Utah for a variety of reasons and development of this resource over the next 15 years is considered likely.

Sand and Gravel

Sand and gravel deposits are mostly associated with Quaternary sediments and are rated as high (H) potential with D certainty. Sand and gravel is an important commodity for a variety of uses and development is considered likely over the next 15 years.

Building Stone

Known sites of building stone production in the MtPA are rated as H potential for occurrence with a D level of certainty. Elsewhere, host formations have been classified as M potential and C certainty. The past production and continued demand for building stone in large, growing communities in the west makes its development likely in the next 15 years, particularly in the areas where there has been previous production.

Clay

Known clay sites in the MtPA have been classified as H potential for occurrence with D level of certainty. Elsewhere the favorable formations are rated as M potential with C certainty for the occurrence of bentonite. Based on past use, it is likely that there will be continued clay development over the next 15 years, particularly around those areas where there has been previous production.

1. INTRODUCTION

1.1 Purpose and Scope

The purpose of this Mineral Potential Report is to assess and document the mineral resource occurrence and development potential within the Monticello Planning Area (MtPA). The information provided in this report is based upon published data along with information from the U.S. Bureau of Land Management (BLM) Utah State Office, the BLM Monticello Field Office, Utah state agencies, and industry. No field studies were conducted. Identified mineral resources are classified according to the system found in BLM Manuals 3031 and 3060 (see section 5).

This report provides an intermediate level of detail for mineral assessment as prescribed in BLM Manual 3031 for planning documents. It has been prepared as a preliminary mineral assessment for use in preparing the Environmental Impact Statement (EIS) for the Monticello Field Office Area Resource Management Plan (RMP), as required by the National Environmental Policy Act. Mineral resource development projections provided in this report are for all lands within the MtPA. This report is not a decision document and does not present specific recommendations on the management of mineral resources.

1.2 Lands Involved and Record Data

The MtPA is located in southeastern Utah and encompasses the majority of San Juan County (Map 1). The MtPA is bounded by Canyonlands National Park to the north and west, the Utah-Colorado state line to the east, the Utah-Arizona state line to the south, and the Colorado River to the west. Map 2 shows locations of the current and pending federal leases within the MtPA.

There are approximately 4.58 million acres of land within the MtPA, of which, approximately 1.79 million acres of public land are administered by the BLM. The MtPA also encompasses lands where federal minerals underlie surface that is not administered by the BLM. These lands include the following:

- Certain areas of Glen Canyon National Recreation Area, totaling approximately 101,720 acres;
- Manti-LaSal National Forest totaling approximately 319,932 acres;
- Navajo Indian Reservation within the area known as the McCracken Extension, totaling approximately 51,610 acres;
- Indian Trust Lands, totaling approximately 1,080 acres;
- Split-estate lands with private surface, totaling approximately 55,390 acres.

The BLM has three minerals management categories: leasable, locatable, and salable. Leasable minerals are subject to disposal by lease under the authority of the Mineral Leasing Act of 1920, as amended (Map 2). A classification for leasable minerals such as a Designated Tar Sand Area (DTSA) and a Known Potash Leasing Area (KPLA) is an area where a potentially valuable deposit has been identified and where competitive leasing is required. Locatable minerals are subject to disposal by mining claim location under the authority of the Mining Law of 1872 (Map 3). Salable minerals are subject to disposal by contract sale or free use permit under the authority of the Materials Act of 1947 (Map 4). Community pits are designated on known deposits of salable minerals for the purpose of ensuring a supply of material by providing a superior right over subsequent claims or entries of the lands.

The descriptions of the important fluid and solid mineral resources found in the MtPA include discussions of the mineral deposits; summaries of the exploration, development and production of each mineral resource; classification of the potential for occurrence of each mineral throughout the planning area; and determination of whether development potential of the mineral resource is high, moderate, or low over the next 15 years.

1.3 Energy Policy Conservation Act (EPCA) Report

The Energy Policy Conservation Act (EPCA) report (DOE, 2003) is based on the USGS estimation of undiscovered, technically recoverable resources and on Energy Information Administration (EIA) reserve calculations. Although the main purpose of the EPCA report is to classify the availability of land for leasing and leasing stipulations, resources are also evaluated. The calculation of resources is primarily mathematical and estimates are provided on a basin-wide scale. Evaluating the USGS oil and gas plays and the individual well information within the planning area, as this mineral potential report does, provides a better basis for determining oil and gas potential.

In summary, the EPCA report estimates the volume of oil under all lands within the Paradox/San Juan basin, which includes lands in Utah, Colorado, New Mexico, and Arizona, ranges from 174 to 1,319 million barrels, with a mean estimate of 660 million barrels. The estimated volume of natural gas under all lands within the basin ranges from 41 to 64 trillion cubic feet, with a mean estimate of 52 trillion cubic feet. This EPCA report concludes that approximately 34% of the federal land in the Paradox/San Juan Basin is available for oil and gas leasing with standard stipulations, and includes 52% of the technically recoverable oil and 79% of the technically recoverable gas. The EPCA report also concludes that approximately 9% of the federal land in the basin is available for leasing with restrictions on oil and gas operations beyond standard stipulations, and includes 16% of the technically recoverable oil and 17% of the technically recoverable gas. In addition, approximately 57% of the federal land in the basin is not available for leasing, and includes 32% of the technically recoverable oil and 3% of the technically recoverable gas.

2. DESCRIPTION OF GEOLOGY

The geologic history of the MtPA involves a complex interplay of tectonic and structural developments from the Precambrian Era to the present, with the subsequent sedimentation patterns that resulted during that timeframe. While recognizing that intricate connections between the structural and stratigraphic history of the MtPA do exist, it is possible to separate the two sets of processes for ease of discussion. This section of the report reviews the formation of the pertinent stratigraphic units in the MtPA, followed by the structural history of the area. These discussions emphasize host formations for solid mineral resources in the MtPA and petroleum reservoirs, source rocks, and seals.

2.1 Stratigraphy

The geologic map for the MtPA (Map 5) illustrates the surface relationships of some of these rock formations. Some formations are not laterally continuous. Figure 1, a stratigraphic correlation chart for rocks of the Paradox Basin and vicinity, demonstrates some of the facies relationships that exist in the area. The stratigraphic evolution of the area, integrating those stratigraphic horizons that are important to petroleum generation and storage and that host solid minerals in the MtPA, is discussed below.

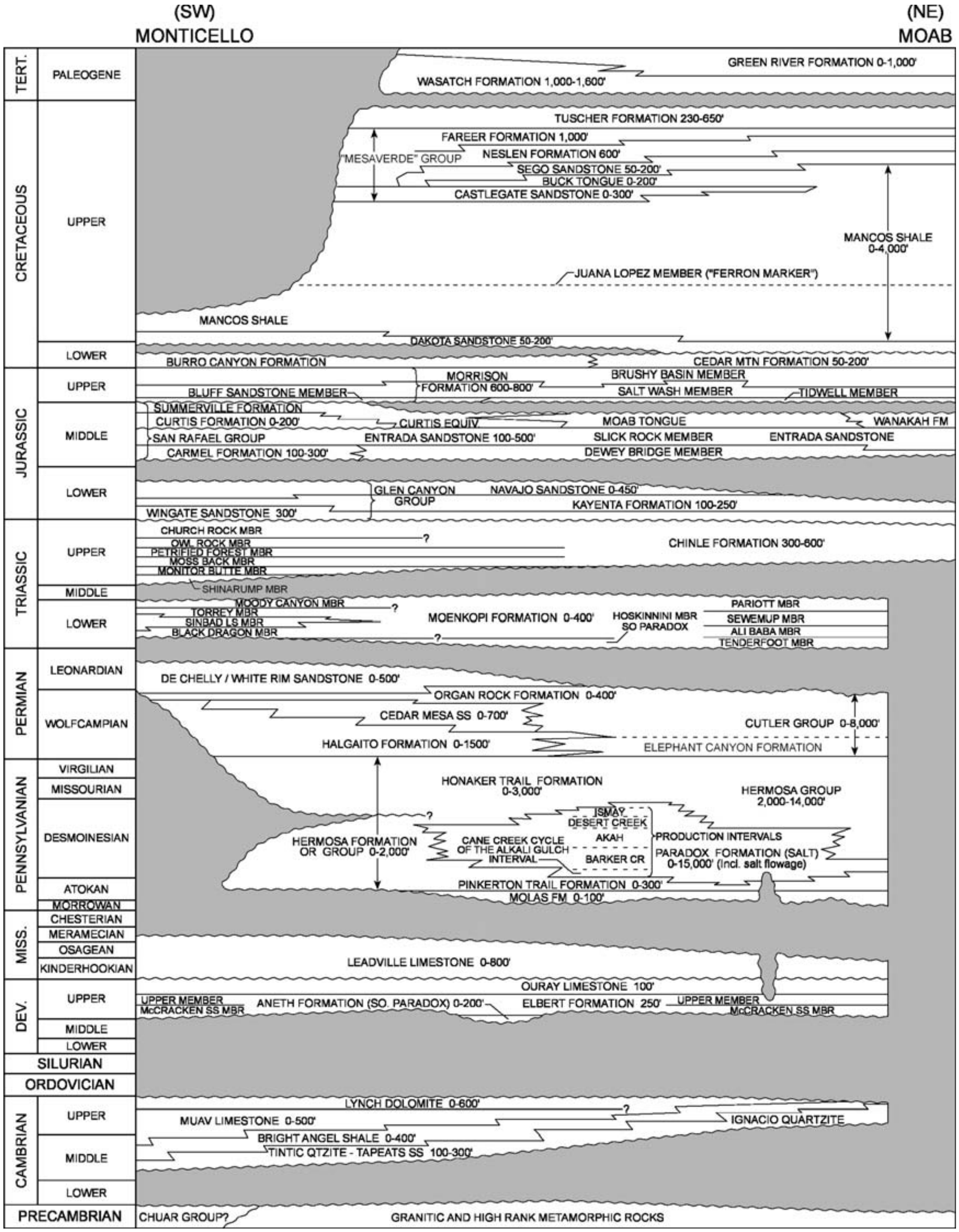

Figure 1. Correlation chart of geologic strata for the Paradox Basin and vicinity (modified from Molenaar, 1987).

2.1.1 Precambrian

Precambrian rocks underlie the MtPA, and based upon the composition of Precambrian rocks exposed in the Uncompahgre Plateau to the north, include metamorphic gneisses intruded by mafic and ultramafic rocks, diorites, and pegmatites. Precambrian rocks of approximately 1.7 billion years, intruded by 1.4 billion-year-old igneous rocks, are exposed in the core of the Uncompahgre Plateau (Dickerson and others, 1988; Willis and others, 1996). In general, these igneous and metamorphic rocks hold little potential for petroleum reservoirs or source rocks. However, clastic sequences within the Precambrian could have the potential to be both reservoirs and source rocks. As an example, the Precambrian Chuar Group, recognized on the Monument Upwarp in the southwestern part of the planning area, may be a potential source rock for hydrocarbons trapped in fractured Precambrian and basal Cambrian sandstones (Gloyn and others, 1995; Butler, 1996).

2.1.2 Cambrian

The basal Cambrian Tapeats Sandstone, if fractured, is a potential reservoir for hydrocarbons originating from the Precambrian Chuar Group (Gloyn and others, 1995; Butler, 1996). The Middle and Upper Cambrian formations, Bright Angel Shale, Mauv Limestone, and Lynch Dolomite all have very low permeability and are not known to be hydrocarbon source rocks or reservoirs (Hintze, 1988).

2.1.3 Ordovician and Silurian

Ordovician and Silurian rocks are absent from the craton east of the Mesozoic thrust belt, which runs roughly northeast-southwest across Utah. If any Ordovician or Silurian strata were deposited in eastern Utah, extensive erosion during Devonian times removed them (Hintze, 1988).

2.1.4 Devonian

The oldest significant reservoirs in the MtPA are Devonian in age. The McCracken Sandstone Member of the Upper Devonian Elbert Formation was deposited, probably as transgressive sand bars, on a relatively stable continental shelf, adjacent to normal marine carbonates. Sea level fluctuations produced coarsening- and thickening-upward sequences that constitute the main reservoir intervals. The resulting dolomitic sandstones and sandy dolomites are the primary productive facies at the Lisbon Field, which is located in the northern portion of the MtPA. The fine- to medium-grained siliciclastic units containing the best porosities tend to be the reservoir units, while the supratidal and lagoonal dolomitic mudstones act as flow barriers and baffles. Coarser grained sandstones have their porosities occluded by dolomite and quartz cements (Cole and Moore, 1996).

2.1.5 Mississippian

The most prolific pre-Pennsylvanian reservoir in the MtPA is the Mississippian Leadville Limestone. Deposited on a shallow carbonate shelf under open-marine conditions, the Leadville Limestone is thickest in the northwestern part of the Paradox Basin, in southern Grand County. The Leadville Limestone is the second most productive oil and gas reservoir in southeastern Utah (Fouret, 1996; Gloyn and others, 1995). In general, reservoirs are developed in porous dolomites of the lower member, and dolomitized, crinoidal carbonate muds of the upper members. Sedimentation patterns, subaerial exposure, sea level fluctuations, and a complex diagenetic history created a variety of reservoir facies that will become better understood with continuing field production. Extensive subaerial exposure created a major unconformity at the top of the Leadville Limestone and was responsible for widespread reservoir development (Hintze, 1988). Permeabilities within all the Leadville reservoirs are enhanced by tectonic and solution-collapse fractures (Fouret, 1996).

2.1.6 Pennsylvanian

By far, the most prolific oil and gas reservoirs and source rocks of the MtPA exist within Pennsylvanian-age sediments. The Ismay and Desert Creek zones of the Paradox Formation have produced, and continue to produce, the majority of oil and gas in southeastern Utah (Chidsey and others, 1996b). The Blanding sub-basin of the Paradox Basin is confined within the MtPA. The structural development of the Blanding sub-basin will be discussed in more detail in the structural history section below.

Pennsylvanian sediments filled accommodation space created by the rapidly subsiding Paradox Basin. Thousands of feet of evaporates, carbonates, and black shales constituting the Hermosa Group contain the major reservoirs, source rocks, and evaporates, which act as lateral and top reservoir seals. Flowage of these evaporates formed prominent structural anticlines and fractures in overlying sediments, thereby creating ideal traps in reservoir-quality rocks. The Pennsylvanian strata are also host to halite, potash, and high quality limestone deposits in the MtPA.

The basal member of the Hermosa Group is the Pinkerton Trail Formation that disconformably overlies Mississippian carbonates. A suite of normal to restricted marine sediments, including limestones, dolomites, sandstones, siltstones, shales, and anhydrites, characterize this final formation deposited on the relatively stable continental shelf in the Paradox Basin. This unit varies from 0 to 150 feet thick (Hintze, 1988).

Although subsidence and evaporate deposition were initiated during sedimentation of the Pinkerton Trail Formation, these processes increased dramatically during deposition of the middle member of the Hermosa Group (Hintz, 1988). Early Pennsylvanian crustal movements along pre-existing faults created a stratigraphic-structural trough that extended through northwestern New Mexico, southwestern Colorado, and southeastern and central Utah. Thousands of feet of black shales and evaporates accumulated in the deeper portions of the Paradox Basin, while shallower areas around the basin perimeter were the sites of carbonate shelf sedimentation. Basin geometry and subsidence controlled the complex horizontal and vertical lithologic facies distributions. The deeper portions of the basin were bounded by deep, northwest-southeast-trending basement flexures. On the northeast side of these flexures, restricted flow of normal marine waters, often caused by marine regressions, and created deep, hyper-saline conditions ideal for the deposition of evaporitic facies (halite, anhydrite, and sylvite). Shallow-marine shelf conditions dominated the southwest sides of these flexures, creating ideal environments for carbonate facies deposition, primarily shelf carbonates and algal and bryozoan bioherms.

Depositional facies for both the Paradox Ismay and Desert Creek zones are laterally complex, and the vertical succession throughout Pennsylvanian time created multiple occurrences of carbonate reservoirs (Chidsey and others, 1996b). Transgressive events resulted in the deposition of organic-rich dolomitic muds and initiated the multiple, upward-shoaling events characteristic of the Paradox Formation. Repetitive sea-level fluctuations allowed black shales to be deposited during high stands when inflows of organic and detrital materials were highest and salinities were lowest. As normal seawater influx into the basin decreased in response to dropping sea levels, salinities increased, allowing the deposition of anhydrite, halite, and potash salts. Each evaporite cycle is comprised of a halite unit, which may or may not have an accompanying potash unit (Hite, 1960; Hite, 1968). The salt and potash deposits in this formation are commercial-sized, but undeveloped (Dames and Moore, 1978; Gloyn and others, 1995; Baars, 1973; Ritzma and Doelling, 1969).

As part of the carbonate cycles within the Paradox Formation, one interval, the Cane Creek interval, contains three clastic units that range up to 150 feet thick near the center of the Paradox Basin (Nuccio and Condon, 1996). The lowest unit, the “C” unit, consists of interbedded red siltstone and anhydrite. The middle “B” unit is comprised of black, organic-rich shales and dolomites. The upper “A” unit contains interbedded red siltstone and anhydrite. The Cane Creek interval, particularly the middle "B" unit, is rich in organic material with a total organic carbon (TOC) content of 3.96% and a vitrinite reflectance (Ro) value averaging 0.54, suggesting that the Cane Creek reservoirs are self-sourced. Wells within this interval produce oil and gas and have shown excessive reservoir overpressure (up to 6,500 psi at depths of 7,500 feet, with pressure gradients of approximately 0.85 psi/ft) that may be attributed to salt flowage (Popov and others, 2001). Most of the Cane Creek production occurs within the Moab Planning Area to the north of the MtPA; however, the extent of the fractured Cane Creek play appears to include some of the northern portion of the MtPA.

Four main cycles of middle Pennsylvanian deposition exist in the southeastern part of the Paradox Basin and may represent stratigraphic and facies relationships seen in the MtPA as well. These are the Barker Creek, Akah, Desert Creek, and Ismay intervals (Hintze, 1988). Hypersaline conditions were widespread during Akah deposition, resulting in thick sequences of evaporites. The other zones are composed of algal limestones associated with organic-rich dolomitic shales and mudstones.

Extensive examination of Ismay and Desert Creek cores from the Blanding Basin in San Juan County allowed Eby and others (2003) to develop a depositional facies scheme for the Paradox Formation in the MtPA. Seven depositional facies were identified from the upper Ismay zone, the interval in which the major reservoirs are found: 1) phylloid-algal mounds; 2) bryozoan mounds; 3) anhydrite salinas; 4) middle shelf environments; 5) inner shelf/tidal flat areas; 6) open marine regions; and 7) quartz dune sands (Eby and others, 2003). Only four depositional facies have been recognized in the Lower Desert Creek where reservoir intervals are also found: 1) phylloid-algal mounds; 2) proto-mounds/collapse breccias; 3) middle shelf environments; and 4) open marine areas. The Upper Ismay anhydrite salinas are not representative of reservoir rocks; however, all the other facies can be considered as potential reservoirs, depending upon porosity, permeability, and facies extent. By far, the algal and bryozoan mound build-ups are the major reservoir intervals for both the Upper Ismay and Lower Desert Creek (White and Kirkland, 1996). Outcrop analogues for these algal bioherms have been studied in detail along the San Juan River (Chidsey and others, 1996a). Similar algal mounds are potentially productive on the Monument Upwarp in the MtPA.

Within an open-marine setting, broad middle shelf areas developed within the Paradox Basin. Here, bioturbated limy and dolomitic mudstones formed in shallow, low-energy conditions and became sites for the development of various bioherms, dunes, and inner shelf/tidal flats (Hintze, 1988). Within the interiors of the middle shelf, evaporitic salinas developed with locally thick accumulations in Upper Ismay intra-shelf basins. These anhydritic basins were the ideal, high-salinity sites for evaporite precipitation, isolated from the flow of normal marine waters. Consequently, thick anhydrite accumulations formed contemporaneously with the clean carbonate units that developed around the peripheries of these salinas. The Paradox Formation's original depositional thickness is uncertain because of the great amount of internal deformation that has occurred due to the flowage of salt layers. However, in the Lisbon Valley area near the center of the Paradox Basin, the salt-bearing evaporite beds are in excess of 8,000 feet thick (Parker, 1981). Elsewhere in the MtPA, the unit varies from 2,000 to 5,000 feet thick (Hintze, 1988).

Overlying the Paradox Formation is the upper member of the Hermosa Group, the Honaker Trail Formation. Deposition of limestones signaled the end of the cyclic, evaporitic sequences, forty of which have been identified in recent years (Eby, D., Eby Petrographic, personal communication, August 2003). The influx of normal-marine waters into the Paradox Basin caused the basin to begin to fill with carbonates, which represent the final vestiges of marine deposition before the coarse clastics were shed from the Uncompahgre Uplift during the Permian. Gray fossiliferous limestone, with red-brown to brown sandstone, and gray, green, and red shale comprise the upper third of the formation. The lower two-thirds of the formation consists of gray limestone interbedded with black shale with thin anhydrite beds (Hite, 1978). At least some of the carbonates within the Honaker Trail Formation constitute high-calcium limestones that have potential for use in pollution abatement devices for coal-fired power generating plants, cement, and the generation of crushed stone (Reed, 1996). The Honaker Trail Formation varies from approximately 1,500 to 4,000 feet thick (Hintze, 1988).

2.1.7 Permian

The Upper Honaker Trail Formation has a transitional relationship with the overlaying non-marine clastics of the Permian Cutler Group. This transition zone, often called the Elephant Canyon Formation, is composed of fluvial, fluvial deltaic, and eolian sands (Cole and Moore, 1996). The Permian period initiated the onset of clastic deposition, a trend that persisted until modern times. Responding to the rapid rise of the Uncompahgre Uplift to the northeast, thousands of feet of coarse clastics were shed southwestward over thick sequences of carbonates, evaporites, and shales (Hintze, 1988). These clastic wedges, comprising the Cutler Group, were preserved in depositional geometries of alluvial fans, fan aprons, meandering and braided channels, tidal flat sands, and eolian deposits (Cole and Moore, 1996). As the ever-thickening wedge of Cutler clastics buried the organic shales of the underlying Paradox Formation, increasing temperature raised thermal maturity levels to optimal conditions for petroleum maturation and expulsion (Nuccio and Condon, 1996).

Although many clastic facies within the Cutler Group preserved and/or developed good reservoir characteristics, the most significant result of Cutler deposition was to provide a massive weight of sediments on top of the Paradox Formation evaporitic sequences. The resulting heat and pressure also caused the evaporites to flow ductilely to the west, away from the areas of maximum sediment loading. When the salt encountered buttresses in the form of northwest-southeast, basement-involved, fault blocks that had been reactivated during middle Pennsylvanian times, it was forced to flow upward into the overlying sediments. The resultant structures are northwest-southeast salt-cored anticlines, visible at the surface today, that contain numerous hydrocarbon-producing reservoirs. Salt flows carried with them organic-rich shale interbeds that are juxtaposed against Devonian and Mississippian reservoir rocks in the emergent horst blocks. Fracturing of these shale interbeds, such as the Cane Creek, enhanced reservoir permeabilities. Fracture intensity has subsequently been demonstrated to be greatest in the areas of maximum salt flowage (Nuccio and Condon, 1996).

The Cutler Group varies from 0 to more than 10,000 feet thick in the MtPA, with the thickest portion of the arkosic wedge being in the northeast (Gloyn and others, 1995). This group is not widely tested in the subsurface, mostly because the underlying Paradox Ismay and Desert Creek zones are the obvious reservoir targets. Gas production from Cutler sands and silts has occurred from structural traps adjacent to faulted salt anticlines. Within the northernmost part of the MtPA (Indian Creek area), the Cutler Group is undifferentiated, but to the south it is divided into various formations (Cole and others, 1996).

Where the Cutler Group is subdivided into formational units, these units, progressing from oldest to youngest, are the Halgaito Shale, Cedar Mesa Sandstone, Organ Rock Shale, and the DeChelly/White Rim Sandstone (Hintze, 1988; Gloyn and others, 1995). The Halgaito Shale is comprised of thin-bedded, reddish-brown to purple arkosic siltstones, sandstones, mudstones and conglomerates, interbedded with thin, gray limestones. The Elephant Canyon Formation identified in the northeast part of the MtPA is equivalent to, but a different facies than the Halgaito Shale found to the southwest. The Cedar Mesa Sandstone is exposed prominently in various places on the Monument Upwarp where it is approximately 800 feet thick. This interval is a white to pale-reddish-brown, fine-grained, cross-stratified, calcareous, near-shore marine sandstone that is transitional with a gypsiferous facies consisting of gypsum, shales, and sandstones. The Organ Rock Shale contains red, thin-bedded sandstones and shales with occasional limestone lenses. The uppermost White Rim Sandstone is composed of distinctly cross-bedded, lightcolored, non-marine sandstone. This sandstone unit is the host for several tar sand deposits in eastern Utah. The upper beds of the Cutler are truncated by a subtle angular unconformity (Lekas and Dahl, 1956). Sandstone lenses in the upper part of the group host small uranium-vanadium deposits (Weir and others, 1961).

2.1.8 Triassic

The Triassic-age sediments in the MtPA are characterized by thick, red, clastic sequences that were deposited in a range of near-shore environments (Gloyn and others, 1995). The Moenkopi Formation consists of chocolate-colored, fluvial, deltaic, and coastal deposits that include silty, micaceous shales interbedded with sandstones and limestones. One reservoir interval at the base of the Moenkopi, the Hoskinnini Member, hosts a tar sand deposit in White Canyon (Gloyn and others, 1995).

The Chinle Formation rests unconformably on the Moenkopi Formation. The Chinle Formation's depositional regime ranged from fluvial, floodplain, and lacustrine continental environments (Woodward-Clyde, 1982). This formation consists of red, brown, and gray sandstone; conglomerate; and red, purple, and green-gray mudstone (Hahn and Thorson, 2002). These deposits form distinctive upper and lower units that are respectively red and green in color. The Moss Back and Shinarump Members in this formation are host to a large number of uranium deposits that have supported small- to medium-sized mining operations in the past (Wood, 1968; Gloyn and others, 1995). Uranium ore deposits in the Shinarump Member can be found in the White Canyon area, while deposits in the Moss Back Member can be found in the Lisbon Valley, Inter-River and Cane Creek areas (Chenoweth, 1996).

2.1.9 Jurassic

Jurassic sediments in the MtPA were deposited in various continental environments, ranging from eolian (massive sandstone), to fluvial (interbedded sandstone, shale and siltstone), to lacustrine conditions (freshwater limestones). These sediments comprise the Glen Canyon Group, the San Rafael Group, and the Morrison Formation (Hintze, 1988).

<u>Glen Canyon Group</u>

The Jurassic Glen Canyon Group consists of the Wingate Sandstone, Kayenta Formation, and Navajo Sandstone. The Wingate Sandstone consists of massive, gray-orange to red-brown, eolian, cross-bedded sandstone. It overlies the Chinle Formation unconformably and varies from approximately 250 to 650 feet thick (Hintze, 1988).

The Kayenta Formation varies from 0 to 340 feet thick, thinning to the southeast (Hintze, 1988; Gloyn and others, 1995). It is a very fine to fine-grained, irregularly bedded, locally conglomeratic, fluvial sandstone, siltstone, and shale. It also contains beds of mudstone or lacustrine limestone (Gloyn and others, 1995). This formation is a favored source for local building stone.

The Navajo Sandstone varies from 0 to 1,250 feet thick (Hintze, 1988; Gloyn and others, 1995). This formation thins eastward and northward and intertongues with the underlying Kayenta Formation in southwestern Utah. It consists of massive, white and yellow, eolian sandstone. Beds and lenses of high-calcium limestone (+95% calcium carbonate) that are 1 to 10 feet thick and locally contain blue chert are also present (Gloyn and others, 1995). The carbonate units may have value for use in pollution abatement devices for coal-fired power generating plants and for producing cement (Gloyn and others, 1995). The

Lower Jurassic Navajo Sandstone is a thick, fine- to medium-grained, cross-bedded, quartzose, eolian sandstone. Although its reservoir characteristics are excellent for storing hydrocarbons, there is only one field to the north in the Moab Planning Area that produces from the Navajo Sandstone, suggesting that there are problems with trap and/or seal integrity.

San Rafael Group

The San Rafael Group includes the Carmel Formation, Entrada Sandstone, and Wanakah Formation (Hintze, 1988). The Carmel Formation, a non-reservoir unit, ranges from a calcareous sandstone to a marine gypsum, limestone, or shale (Gloyn and others, 1995). Overlying the Carmel Formation is the Entrada Sandstone, recognized overall as a non-marine, cross-stratified sandstone and siltstone that has good reservoir qualities. The Wanakah Formation, formally called the Curtis and Summerville Formations, ranges up to 200 feet thick (O'Sullivan, 1996). The lower part of the formation consists of thin-bedded red mudstone and gray and yellow sandstone, while the upper portion is a marine glauconitic sandstone (Gloyn and others, 1995).

Morrison Formation

The Jurassic Morrison Formation contains various members, some of which are hydrocarbon reservoirs, but not all are present in the MtPA. The Morrison Formation is also host to extensive uranium deposits. The Salt Wash Member, particularly in its upper part, is the most prolific uranium-producing horizon in the Morrison Formation, and hosts small to large uranium deposits in channel sandstones (Wood, 1968; Woodward-Clyde, 1982; Gloyn and others, 1995). This member consists of brown, lenticular, fluvial sandstone that is interbedded with red mudstone, with thin gray limestones at its base. It varies from 0 to 550 feet thick (Hintze, 1988). Locally, two members occur above the Salt Wash Member; they are the Recapture Creek Member and the Westwater Canyon Member, both composed of fluvial sandstone and mudstone. The youngest member of the Morrison Formation is the Brushy Basin Member, a recognized hydrocarbon reservoir in the Moab Planning Area to the north. However, this rock unit does not have potential as a hydrocarbon reservoir in the MtPA because it is exposed at the surface and incised by numerous canyons. It varies from 200 to 440 feet thick and consists of brown, bentonitic mudstone and brown, conglomeratic sandstone (Hintze, 1988). The bentonite was derived from voluminous amounts of volcanic ash that was carried to the depositional sites by north and northwesterly flowing paleo-streams (Turner-Peterson and others, 1986). Bentonite deposits in the Morrison have been mined locally for engineering applications.

2.1.10 Cretaceous

The Cretaceous sediments represent a sustained marine transgression across the Jurassic continental lowlands (Hahn and Thorson, 2002). Conglomerate, sandstone, mudstone, and coal were deposited in transitional regimes, while carbonaceous shale and minor limestone reflect deposition in marine environments. Cretaceous units are exposed at the surface and incised by numerous canyons in the MtPA, so they have little or no potential as oil and gas reservoirs.

Burro Canyon Formation

The Burro Canyon Formation is the basal Cretaceous unit found in the area and varies from 50 to 180 feet thick (Hintze, 1988). It consists of brown and gray fluvial sandstone and conglomerate in its lower half, while thin beds of dense gray limestone and variegated green and purple mudstone comprise its upper half (Gloyn and others, 1995). It interdigitates with the underlying Morrison Formation, but is unconformably overlain by the Dakota Sandstone.

Dakota Sandstone

The Dakota Sandstone varies from 30 to 150 feet thick and consists of brown and yellow fluvial sandstone and conglomerate as well as interbedded green, gray, and black mudstones (Hintze, 1988). Some of the sandstones are interbedded with siltstones, claystones, and thin coals. The coals have been produced in minor quantities in the San Juan Coal Field in southeastern San Juan County. The middle coal-bearing unit within the Dakota Sandstone contains four coal horizons in the Sage Plain area. These coals were commonly impure, bony, and discontinuous. The ash content reaches 30% in many of these coals and individual bed thicknesses range from 2 to 15 feet (Gloyn and others, 1995). Sandstone from this formation may also be locally suitable for building stone or aggregate for road construction and maintenance.

Mancos Shale

A thick interval of Mancos Shale, interbedded with gas-productive sandstones and sandy siltstones, overlies the Dakota Sandstone. The Mancos Shale is the youngest formation of Cretaceous age in the planning area and consists of gray thin-bedded fissle shale that is locally fossiliferous. The Mancos underlies much of northeastern San Juan County, but is typically not present south of Blanding and west of Comb Ridge (Gloyn and others, 1995).

2.1.11 Tertiary

No Tertiary sedimentary units occur within the MtPA. The only rocks of Tertiary age in the MtPA are laccolithic intrusions, which are exposed on the surface in the Abajo Mountains (Gloyn and others, 1995).

2.1.12 Quaternary

The various Quaternary deposits in the MtPA are landslides, eolian deposits, older alluvial deposits, and alluvium and colluvium. Sand and gravel that occur in the larger river channels and their associated high-level terrace deposits have been used to supply a variety of local road building and construction projects (Gloyn and others, 1995). Small placer-type gold deposits occur in the gravels of the San Juan and Colorado Rivers, as well as some of their tributaries.

2.2 Structural History

The underlying structural fabric of southeastern Utah was established by late Precambrian time; later tectonic reactivation along the basement faults simply modified the original orthogonal lineaments and associated faults. Approximately 1.7 billion years ago, two extensive, deep-seated rift systems developed, affecting what is now known as the Colorado Plateau region. One northwest-southeast trending rift system extends from Vancouver, British Columbia to southwestern Oklahoma, and is called the Olympic-Wichita Lineament. The second rift, called the Colorado Lineament, trends in a northeast direction from the Grand Canyon to Lake Superior, and appears to be offset along the Olympic-Wichita Lineament in a right-lateral sense. These two extensive rift systems intersect near Moab, Utah (Hintze, 1988).

Throughout the early Paleozoic, vertical movement occurred along basement-involved faults in the Paradox Basin region. In general, fault displacements were minor, although the vertical movement did influence local facies depositional patterns. As an example, reactivation of these faults during the Late Devonian created paleohighs on which offshore sand bars of the McCracken Sandstone Member formed, providing excellent petroleum reservoirs (Cole and Moore, 1996). Continued fault rejuvenations during the Mississippian were responsible for the topographic highs on which Leadville crinoidal bioherms became established, also creating excellent reservoirs (Fouret, 1996). The entire marine platform that had developed in the Paradox Basin region was subjected to regional uplift in the Late Mississippian, initiating a period of extensive subaerial erosion on the Mississippian carbonate surface. Surface and subsurface evidence for this extensive subaerial exposure is preserved in the Leadville Limestone karst features, breccias, and paleosols (Fouret, 1996).

The most significant structural activity controlling the deposition of source rocks, seals, and reservoirs in the Paradox Basin region occurred during the late Paleozoic through the Permian. The Uncompahgre Uplift to the northeast of the MtPA was activated concurrent with the structural sagging along the Precambrian basement fault and lineament shear zone, creating the Paradox Basin (Hintze, 1988). The Paradox Basin is a northwest-southeast-trending, oval-shaped feature, approximately 180 miles long and 100 miles wide that dominates most of the planning area (Merrell and others, 1979). Downwarping occurred along sub-parallel, northwest-southeast trending, northeast dipping, hingeline fracture zones that were initially sites of monoclinal folding. Rapid subsidence adjacent to the Uncompahgre Uplift produced extensional faults that attenuated the deepening eastern portion of the basin, creating its characteristic asymmetry. The faulting created fractures that enhanced Leadville Limestone reservoir permeabilities. Meanwhile, the deep trough section of the Paradox Basin, known as the Blanding sub-basin, became the locus of thick evaporite deposition that resulted from restricted marine circulation. The areal extent of the Paradox Basin is defined as the geographic extent of the salt deposits that are hosted in the Paradox Formation (Baars and Stevenson, 1981).

The thick accumulation of salts and evaporites in the Paradox Basin set in motion the key structural developments of the Pennsylvanian reservoirs. While the evaporites were being deposited in the deep basin, carbonate facies were forming on an adjacent shallower platform at the southwest margin of the basin (Chidsey and others, 1996b). The platform developed almost at sea level, so that any sea level fluctuations would either flood the basin or cut off the supply of seawater, thus isolating the basin from the open seaway. During lower sea level stands, intense evaporation occurred in the hot and dry climate of the middle Pennsylvanian, concentrating the salts to form brine. As the density of the brine increased, it sank to the bottom of the rapidly subsiding basin, where it was preserved. Multiple periods of sea level fluctuations caused both the accumulation of evaporites as well as carbonate facies that flourished during periods of sea level influx (Chidsey and others, 1996b). From a structural standpoint, it should be observed that the distribution of these facies mirrors the northwest-southeast structural fabric of the Paradox Basin.

The rapid uplift of the Uncompahgre Plateau resulted in the erosion of the exposed Precambrian and Paleozoic rocks (Hintze, 1988). Depositional thinning and stratigraphic pinchouts occur over the uplift in several formations, providing evidence for the timing of the upward movement. The position of the current Uncompahgre Plateau closely approximates the location of this ancestral Uncompahgre Uplift. With the rise of the ancestral Uncompahgre Uplift, a thick wedge of Cutler Group clastic sediments, in some areas reaching 10,000+ feet, was shed to the southwest onto the 5,000 to 8,000 feet of evaporites and shales in the deep, northeast trough of the Paradox Basin (Gloyn and others, 1995; Cole and others, 1996). The overburden pressure from this great thickness of sediments on the underlying evaporites induced ductile flow of the salt, which moved in a southwest direction, away from the thickest accumulations of Cutler sediments. Buried fault scarps along the northwest-trending basement faults acted as buttresses to the flow of salt, forcing it upward into the overlying strata and forming the salt anticlines of the Paradox Fold and Fault regions (Hintze, 1988).

The Paradox Fold and Fault Belt is characterized by high-angle, down-to-the-basin faults and non-piercement and complex piercement salt anticlines (Nuccio and Condon, 1996). The black, organic shales created mature source rocks that have, in some cases, been juxtaposed against Devonian and Mississippian reservoirs by salt diapirism. In fact, those areas of greatest salt flowage coincide with areas of maximum fracturing of overlying sediments.

Where the salt anticlines have breached the surface, collapsed or depressed surficial features were created by the dissolution of the salt deposits. Topographically, these anticlines are typically expressed as large elongate oval-shaped northwest-trending valleys where salt is commonly found at the surface or shallow depths (Nuccio and Condon, 1996). These valleys are enclosed by high walls and bounded by complex marginal structures and include Moab Valley, Spanish Valley, Lisbon Valley, Salt Valley, Fisher Valley, Sinbad Valley, Paradox Valley, and Castle Valley. The anticlines within the Paradox Fold and Fault Belt are prolific structural traps for hydrocarbons, and offer shallow accumulations of potash and salt. Pennsylvanian movement of the basement rocks and overlying sediments occurred along the pre-existing faults and lineaments. The relative movements controlled the location of shelf carbonates, provided topographic shoals for carbonate mound development, and created horst blocks that diverted the flow of salt upwards into the overlying sediments (Nuccio and Condon, 1996).

By the Triassic, the rate of salt flowage had slowed considerably. By the close of the Jurassic period, there was no longer an available supply of salt to continue the flowage, and the formation of salt anticlines ceased. Meanwhile, the Uncompahgre Plateau was eroded to a topographically low surface, allowing the deposition of the first Mesozoic sedimentary rocks across the uplift (Hintze, 1988).

The second significant structural event to affect the eastern Utah reservoirs was the Late Cretaceous to Early Tertiary Laramide Orogeny, involving compressional tectonism in western North American and associated rejuvenation of pre-existing structures. In many places, compressional forces dramatically altered the landscape by forming mountain ranges. In the Paradox Basin region, however, the pre-existing lineament and fault systems may have acted as buttresses, deflecting the lateral compression (Baars and Stevenson, 1981). The Laramide Orogeny in the Paradox Basin area caused large drape-fold anticlines with overturned eastern limbs, as well as enhancement of pre-existing structures such as the Monument Upwarp and smaller domes prevalent in the MtPA.

The Monument Upwarp, a broad, asymmetric anticline approximately 30 to 40 miles wide and 90 miles long, is one of the major structural features of the Colorado Plateau region. It was formed in response to the horizontal crustal compression during the Laramide Orogeny. At the northern end of the Monument Upwarp, the primary structural feature is a series of near-vertical faults that trend from west to east to northeast in an arcuate pattern (McDougall, 2000a). On the eastern side of the Upwarp is a second prominent structural feature, Comb Ridge monocline.

Beginning in the middle Tertiary, the entire Colorado Plateau area underwent uplift and regional tilting towards the north. To the northeast of the MtPA, the Uncompahgre Plateau is a northeast tilted fault block with thousands of feet of vertical relief. The process of incisement and erosion that continues today was set in motion following this last tectonic event. Large rivers, including the Colorado, San Juan, and Dolores Rivers, incised deeply into the uplifted plateau, creating the characteristic canyons of southeast Utah. Thousands of feet of sedimentary rocks were eroded, exposing both Paleozoic and Mesozoic sediments. In the area of the salt anticlines, groundwater dissolved the salt cores, leading to solution collapse along the anticlinal axes. The removal of those salts has created the elongated, northwest-trending valleys characteristic of the Salt Anticline physiographic province (Aubery, 1996).

Between 24 and 48 million years ago, igneous intrusions of the La Sal and Abajo Mountains occurred near the intersection of the Precambrian lineaments in eastern Utah, suggesting another impact of old, deep-seated structures (Hintze, 1988). The La Sal and Abajo igneous complexes intruded the basinal and fold belt sequences of southeastern Utah. Their emplacement was forceful and arched the overlying sedimentary sequence resulting in the formation of mantled domes, which have now been breached by erosion to expose their igneous cores. Similar features occur in adjoining portions of Colorado; all appear to be localized at the intersection of major Precambrian lineaments (Hintze, 1988).

3. DESCRIPTION OF ENERGY AND MINERAL RESOURCES

This section of the report describes the important fluid and solid mineral resources found in the MtPA. The resources included below are those that have a history of interest and development in the planning area and are relevant for planning purposes over the next 15 years. Although geologic host formations for other mineral resources may exist in the MtPA, their known occurrence is limited or insignificant. For example, there is minimal or no interest in the development of several minor resources present in the MtPA including coalbed methane, lode gold, manganese, humates, gypsum, barite, zeolites, crushed stone, collectable rocks and minerals, and low-temperature geothermal water. These resources are describe briefly here, but will not be further addressed in this report.

Coalbed methane development potential in the MtPA is very low or nonexistent. There are four coal horizons in the Dakota Sandstone, each separated vertically by 12 to 15 feet of shale and sandstone strata. Each coal horizon generally contains multiple lens-shaped beds of coal ranging from 2- to 15-feet-thick (Gloyn and others, 1995). Thus, the coal in the Dakota is generally thin and discontiuous and not usually thick enough to be an attractive reservoir. The coal is also of low rank, generally subbitumious C, and as such will not have generated any thermogenic gas. Any gas present will likely be late-stage biogenic gas. The coal is commonly impure or boney, with thinly interlaminated shale, and nearly everywhere contains 30% or more ash. Higher ash content reduces the gas carrying capacity of the coal. Furthermore, the coal horizons of the Dakota Sandstone are exposed around the margins of the Sage Plain plateau. Due to the flat topography of the plateau, the coal horizons are covered by only 35 feet or less of upper Dakota Sandstone and 100 feet or less of Mancos Shale strata (Doelling, 1972). Such shallow and disssected deposits of coal are likely to have lost any contained gas to the atmosphere.

Minor non-commercial deposits of lode gold occur in the Tertiary intrusives of the Abajo Mountains (Witkind, 1964; Gloyn and others, 1995). A small number of manganese deposits are found in Jurassic and Cretaceous sedimentary rocks along the Lisbon Valley fault system, which is mostly north of the MtPA (Baker and others, 1952; Weir and Puffet, 1981; Gloyn and others, 1995). No recent exploration activity for manganese in the MtPA is known and the potential for discovery of any economic deposits is minimal. Weathered coal and carbonaceous shales and mudstones of the Cretaceous Dakota Sandstone have potential for sale as humate, a natural soil conditioner (Gloyn and others, 1995). However, no known humate exploration has taken place in the MtPA and development potential is considered very low. Gypsum can be found throughout the MtPA in the Pennsylvanian Paradox Formation, the Permian Cedar Mesa Sandstone, and the Triassic Moenkopi Formation (Gloyn and others, 1995). However, gypsum is a very low unit value commodity and generally must be located close to existing wallboard plants to be economical. Therefore, development potential of gypsum in the MtPA is very low. A small amount of barite was reported as a gangue mineral associated with uranium-vanadium-copper mineralization at a mine in the west-central part of the MtPA (Trites and Chew, 1955). However, these occurrences are insignificant compared to Nevada's large bedded barite deposits. Minor zeolite deposits are known to be contained in the Brushy Basin Member of the Morrison Formation and speculative potential exists for zeolite production in the MtPA (Gloyn and others, 1995). However, high-purity zeolites have not yet been found and the zeolite industry continues to be very small.

Stone suitable for commercial crushing operations must occur in large quantities, possess adequate compressive strength, break into uniform equidimensional clasts without excessive fines, and be chemically inert when mixed with cement (Gloyn and others, 1995). Rocks suitable for crushing in the MtPA include limestones in the Pennsylvanian Hermosa Group Honaker Trail Formation and the Jurassic Navajo Sandstone (Ritzma and Doelling, 1969), as well as the well-indurated sandstones and conglomerates of the Cretaceous Dakota Sandstone and Burro Canyon Formation. Although LR 2000 records (BLM, 2004) indicate there has been only one authorization for 50 cubic yards since 1989, this resource could become more significant as suitable sand and gravel resources are exhausted. In any event, need for crushed stone in the next 15 years is anticipated to be insignificant.

Collectable rocks and semi-precious gemstones present in the MtPA include petrified wood containing opal and agate, chalcedony, garnet, azurite and malachite. Petrified wood is found scattered throughout the MtPA, hosted in the Jurassic Morrison and Triassic Chinle Formations. Deep red to black pyrope garnets have been recovered from volcanic vent deposits of the Mule Ear and Moses Rock occurrences near Mexican Hat. The amount of garnet material known to be present in this area is so small that commercial extraction is unlikely (Gloyn and others, 1995). None of the above-mentioned collectable materials have been, or are expected to be, produced in large quantities and are not further discussed in this report with regard to their potential for occurrence and foreseeable development.

Low-temperature geothermal waters, at temperatures between 20 and 36°C (68 to 97°F) have been recorded from several springs and wells in the MtPA; this includes the Warm Springs Canyon geothermal area identified by the USGS. Because the MtPA is situated within the Colorado Plateau geologic province, where heat-flow through the earth's crust is generally low, no high-temperature geothermal resources would be expected within reasonable drilling depths (Gloyn and others, 1995). There is potential for direct use of low-temperature geothermal water for space heating of buildings, but no such development in the MtPA exists or is expected.

3.1 <u>Leasable Minerals</u>

3.1.1 Oil and Gas

As described in the 1995 National Assessment of United States Oil and Gas Resources (Gautier and others, 1996), the U.S. Geological Survey (USGS) has delineated a number of oil and gas plays, both structural and structural-stratigraphic, in the Paradox Basin Province. These plays incorporate the source rocks, reservoirs, structures, and tectonic history previously discussed in the geology section of this report. Oil and gas plays of the Paradox Basin that occur in the MtPA are the Buried Fault Block play (2101), the Porous Carbonate Buildup play (2102), the Fractured Interbed play (2103), the post-Mississippian Salt Anticline Flank play (2105), and the Permo-Triassic Unconformity play (2106). A sixth hypothetical play also occurs in the MtPA, the Late Proterozoic (Chuar-sourced) Lower Paleozoic play (2403).

Map 6a shows the extent of the Buried Fault Block play (2101) in the MtPA and those oil and gas fields that produce from reservoirs in this play (Huffman, 1996). Development of these carbonate reservoirs occurred before salt flowage began. Deep, northwest-trending faults were reactivated during Pennsylvania times, elevating the Mississippian and Devonian carbonates above sea level and subjecting them to subaerial erosion and chemical alteration, thereby creating the porosity and permeability to classify them as excellent reservoirs. Basement faulting associated with Pennsylvanian salt movement caused the juxtaposition of black, organic-rich shales against the Devonian and Mississippian reservoirs, primarily the McCracken Sandstone Member of the Elbert Formation and the Leadville Limestone, respectively. Hydrocarbons were able to migrate across those normal faults into the adjacent carbonate and clastic reservoirs. The seals for these traps are the Pennsylvanian Paradox Formation evaporites that overlie the carbonate reservoirs or are in fault communication with them. The largest of the six oil and gas accumulations in this play is the Lisbon field, which contains approximately 43 million barrels of oil and 250 billion cubic feet of natural gas.

Despite the fact that all the elements are present in the area to create superior hydrocarbon accumulations (reservoir quality, traps, seals, source rocks, thermal maturity, and migration history), the complex tectonic history of the Paradox Basin has altered most of these elements in some manner or another in various locations. For example, late-stage diagenetic fluids have occluded porosity, traps have been breached by regional uplifts, seal integrity has been destroyed by Laramide fault movement, the thermal maturity of some source rocks has passed through the hydrocarbon window due to deep burial, and the timing of migration has been too early or too late to fill viable traps. The complexity in reservoir development may explain the scarce number of Paleozoic fault block reservoirs identified in this area to date.

The Porous Carbonate Buildup play (2102) (Map 7a) is the primary play type of the Paradox Basin in the MtPA (Huffman, 1996). Most of the developed fields in this play are located in the Blanding sub-basin and produce oil from Pennsylvanian Hermosa Group algal mounds in stratigraphic or combination traps. The largest oil field in Utah, the Greater Aneth field, is developed in this play. Source rocks are the Pennsylvanian interbeds of organic-rich dolomitic shales and mudstones that commonly range from 1% to 5% total organic carbon. Seals include overlying evaporites and impermeable shales and carbonates. Most of the fields that produce in this play outside the Blanding sub-basin are small in size and produce from 1 to 3 million barrels of oil. High resolution, three-dimensional (3-D) seismic surveys have been successful in identifying unexplored algal buildups.

The organic-rich, black dolomitic shales and mudstones of the Fractured Interbed play (2103) (Map 8a), which contain total organic carbon contents of up to 20% (average of 1% to 5% in most cases), are the source rocks for most of the oil and gas in the Paradox Basin (Huffman, 1996). The Cane Creek Shale discoveries north of the MtPA, many of which have been developed with horizontal drilling, are found in this play. Additionally, there are other organic shales in the play, notably the Chimney Rock, Gothic, and Hovenweep Shales, which may provide additional drilling targets for hydrocarbon accumulations. The presence of abundant fractures within the Paradox Formation clastic or carbonate interbeds are essential for the successful development of this play.

The Salt Anticline Flank play (2105) (Map 9a) occurs along the flanks of the northwest-trending salt anticlines typical of the greater Paradox Fold and Fault Belt (Huffman, 1996). Salt diapers or pillows of Paradox Formation salts formed after overburden loading by the Cutler Group clastics caused those salts to flow to the west until they were forced upward into overlying sediments by northwest-trending horst blocks. The overlying sediments, which include the carbonate and clastic reservoirs in the upper part of the Hermosa Group and Cutler Group, were arched upward into anticlinal structures. Organic-rich black dolomitic shales of the Hermosa Group are the source rocks and are, therefore, commonly in contact with the reservoir rocks. Extensive fracturing along the anticlines can also provide fault conduits from source rocks to reservoirs.

The Permo-Triassic Unconformity play (2106) (Map 10a) is a downdip play extending west from the tar sand deposits of south-central Utah (Huffman, 1996). The hypothesis behind this play is that oil migrated in an eastward direction to form large accumulations that were biodegraded into both tar sand deposits near the outcrop as well as heavy oil accumulations in the subsurface to the west. All of the known tar sand accumulations, heavy oil shows, and oil staining are found either above or below this unconformity. Source rocks and migration pathways are not fully understood at this time. Reservoirs for both tar sands and heavy oil accumulations are in the Permian White Rim Sandstone, with downdip production from the White Rim and DeChelly Sandstones of the Paradox Basin. These eolian sandstones have excellent reservoir porosities and permeabilities. Reservoir thicknesses can vary from a few feet to several hundred feet. This play is lightly explored and contains no developed oil and gas fields in the MtPA.

Although not delineated as a Paradox Basin play, the USGS has also defined a hypothetical play called the Late Proterozoic (Chuar-sourced) and Lower Paleozoic play (2403) (Map 11a) (Butler, 1996). This highly speculative oil and gas play presumes that the Chuar Group is both the source and reservoir rock. One member of the Chuar Group consists of organic-rich, black mudstone and siltstone that has a measured total organic carbon content of up to 10%. The Chuar Group has to have undergone sufficient thermal maturity to place it within the assumed oil-generation window. Vitrinite reflectance data from the Chuar Group indicate values derived from both the oil and gas generative phases. Siltstones and sandstones, possibly fractured and probably underpressured, have the potential to store hydrocarbons if vertical migration has occurred. Structural elevation of areas such as the Monument Uplift would be possible reservoir enhancements for hydrocarbon traps involving the Chuar Group in the MtPA. Very few wells have penetrated the Chuar Group in Utah. In Kane County, one well encountered hydrocarbon shows in the Chuar Group at a depth of about 5,900 feet, prompting the permitting of additional Chuar tests (Butler, 1996).

3.1.2 Coal

Coals of the San Juan Coal Field in the eastern part of the MtPA (Map 12a) were mined for several decades for local consumption. The coal in this field occurs in the Cretaceous Dakota Sandstone. The middle coal-bearing unit within the Dakota Sandstone, which is 45 to 122 feet thick, contains four coal horizons in the Sage Plain area. These coals were commonly impure, ashy, boney, and discontinuous. The ash content for these coals reaches 30% or more and sulfur content averages around 1.8%. The coal beds in this area have individual thicknesses ranging from 2 to 15 feet (Gloyn and others, 1995).

3.1.3 Potash and Salt

Potash (potassium-bearing) deposits in the MtPA are comprised primarily of sylvite (potassium chloride) and carnallite (hydrated potassium magnesium chloride) found exclusively in the Pennsylvanian Paradox Formation. Within the saline facies, the area of potash mineralization is limited to the deeper portion of the Paradox Basin encompassing approximately 2,800 square miles (Map 13a) (Dames and Moore, 1978). However, the saline facies extends beyond the limit of potash mineralization. Estimated known resources of potassium oxide (K_2O) are 254 million tons, while inferred resources are estimated at an additional 161 million tons. These estimated and inferred resources are based on subsurface mining with minimum potash bed thickness of 4 feet, a minimum K_2O grade of 14%, and a cutoff depth of 4,000 feet (Lewis, 1965; Patterson, 1989; Gloyn and others, 1995). However, solution minable resources are much greater.

According to Hite (1960), there are 29 evaporite cycles in the Paradox Basin. Of these, 18 cycles contain potash, but only 11 cycles are potentially valuable. Undeformed potash-bearing intervals average 20 feet in thickness, but can range up to 100 feet. The thickness of the potash intervals varies in proportion to the thickness of the accompanying halite and anhydrite beds. The original undeformed evaporate sequence ranged from 0 to 7,000 feet thick, progressing from the Paradox Basin's margins to its depositional center. Diapiric structures have created sections of salt up to 14,000 feet thick, but flowage has destroyed the continuity of the potash-bearing layers (Hite, 1964). Conversely, salt anticlines in the Paradox Fold and Fault Belt have produced thickening, wherein the continuity of the near-surface potash layers have not been disrupted.

Most of the interest in potash and salt deposits in the Paradox Basin has been concentrated in the fold and fault belt. Salt anticlines in this area are attractive targets for potash deposits because they are characterized by structurally thickened salt cores where potash beds are relatively close to the surface. In many cases, salt flow was extensive and actually pierced through the overlying sediments to form salt anticlines (Hite, 1960). The anticlinal structures are either simple or diapiric. The simple structures show relatively little movement of the salt except for where small drag folds have been encountered. These small folds are confined within the individual halite beds and do not disrupt the continuity of the potash horizons. The diapiric structures contain tremendously expanded sections of salt, up to 13,000 feet thick, but continuity of potash deposits is destroyed by the salt flow.

The Moab Salt Company's Cane Creek mine, located in Grand County just north of the San Juan County line and the MtPA, is the only development of potash (sylvite) and by-product salt (halite) in the Paradox Basin. The salt beds of this mine are found in simple anticlinal structures near the surface, thickened by folding (Gloyn and others, 1995). Both sylvite and carnallite occur in varying portions throughout most potash deposits, but sylvite, with a higher weight percent of potassium, is dominant in those horizons under economic consideration (Hite, 1960; Dames and Moore, 1978; Gloyn and others, 1995).

In addition to the commercial deposits found in Grand County's Cane Creek area, other potentially valuable deposits are known to occur in the MtPA. These include the Lisbon Valley and Gibson Dome areas (Gloyn and others, 1995). In 1960, the USGS classified the Cane Creek and the Lisbon Valley areas as Known Potash Leasing Areas (KPLAs). A KPLA is designated where valuable deposits of potash are known to exist. There also appears to be sufficient data available to indicate that the Gibson Dome area qualifies as a KPLA.

3.1.4 Tar Sand

Tar sand contains heavy hydrocarbon residues such as bitumen, tar, or degraded oil that has lost its volatile components. Hydrocarbons can be liberated from tar sands by heating and other processes. Tar sand in the MtPA has been identified in the White Canyon Designated Tar Sand Area (DTSA), which extends over 10,000 acres in the western portion of the MtPA (Map 14a). This DTSA was established by the Department of Interior's Order of January 21, 1981 (46 Federal Register 6077). The oil-saturated Hoskinnini Member of the Triassic Moenkopi Formation, which hosts the deposit, is exposed on the sides of an isolated mesa in Long, Short, and Fort Knocker Canyons. The deposit is roughly 80 feet thick and is estimated to contain 12 to 15 million barrels of oil in place (McDougall, 2000b). From the research done to date, it appears that the tar sands in the White Canyon DTSA are low-grade and fractured.

A second deposit of tar sands in the MtPA occurs in the Mexican Hat area. These deposits are minor compared to the White Canyon area and are found in the Pennsylvanian Honaker Trail Formation. Ritzma (1979) classified the Mexican Hat occurrences as medium to small and estimated the contained oil at 0.4 to 0.5 million barrels.

3.2 Locatable Minerals

3.2.1 Uranium-Vanadium

An important locatable commodity in the MtPA is sediment-hosted uranium. It is usually found intimately associated with vanadium and sometimes copper because of the elements' mutual chemical affinities. The deposits are dominantly of the tabular roll-front-type (Adler and Sharp, 1967; Fisher and Julliand, 1986). Hosts of the uranium-vanadium resource include the Cedar Mesa Sandstone of the Permian Cutler Formation, the Moss Back and basal Shinarump Conglomerate Members of the Triassic Chinle formation, and the Salt Wash Member of the Jurassic Morrison Formation (Map 15a).

Small uranium-vanadium deposits are found in the fluvial sandstone and mudstone of the Cedar Mesa Formation which is part of the Permian Cutler Group, as evidenced by historic mining production in the northern part of the MtPA (Gloyn and others, 1995). Uranium-vanadium mineralization occurs in the Cutler in the Lisbon Valley mining area, where the Moenkopi Formation is absent and the Chinle Formation lies unconformably on the Cutler as a result of the growth of the Lisbon Salt Anticline during the Early Triassic. The unique stratigraphic relationships in Lisbon Valley area are not known to occur elsewhere in the MtPA. Uranium deposits in the Cutler Group are also found in the Indian Creek mining area (Chenoweth, 1996).

The basal Shinarump Conglomerate Member of the Triassic Chinle Formation is host to numerous copper-uranium deposits, especially in the White Canyon mining area where the Cu:U_3O_8 ratio is as high as 13:1 and copper grades range up to 1-2% (Johnson and Thordarson, 1959). Deposits in the White Canyon mining area vary from a few to more than 600,000 tons and average 0.29% U_3O_8. These deposits typically occur in a series of westerly-trending Shinarump fluvial channels, known as the Elk Ridge-White Canyon channel system, which are incised into the subjacent Moenkopi Formation (Chenoweth, 1996; Thadden and others, 1964). The Shinarump Member was also a host in the Oljeto Mesa (Monument Valley) mining area (Johnson and Thordarson, 1959).

The Moss Back Member of the Triassic Chinle Formation consists of a thick, basal, fluvial lenses composed of coarse-grained sandstone interbedded with mudstone and pebble conglomerates, as well as podiform zones of carbonized vegetal trash. In the Lisbon Valley area, on the northern border of the MtPA, some of the largest, high-grade uranium-vanadium ore bodies have been mined. Deposits in this area range from 500 to 1,500,000 tons and the average grade of the mined ore was 0.37% U_3O_8 and 0.34% V_2O_5 (Gloyn and others, 1995). The deposits often comprise tabular bodies elongated parallel to the trend of the paleo-channel host that are incised into the underlying Moenkopi Formation (Chenoweth, 1996). Uranium deposits in the Inter-river, Cane Creek, White Canyon, and Indian Creek regions are also contained within the Moss Back Member of the Chinle Formation (Gloyn and other, 1995).

The Salt Wash Member of the Jurassic Morrison Formation generally tends to host deposits having larger reserves and higher grades and that are more closely clustered than those occurring in other formations (Chenoweth, 1981; Johnson and Thordarson, 1959). Past production from the Salt Wash Member was located in the Cottonwood Wash, Montezuma Canyon, and Dry Vally mining areas (Chenoweth, 1996; Sprinkel, 1999).

All of the preceding units were deposited in river-fed swampy continental environments where plant life was common. Although the formations are dominantly shale (low-energy muds), it is the sandstone and conglomerate units (high energy fluvial channel deposits) in each that host the uranium-vanadium mineralization. Uraniferous fluids, migrating predominantly through the higher permeability sandstones, precipitated uranium minerals when they encountered various types of reductants within the sandstone units. These chemical immobilizers consisted largely of reducing intra-formational waters and organic debris that sometimes included tree logs and branches (Johnson and Thordarson, 1959).

Regionally, remaining recoverable reserves are estimated at 4.2 million tons of ore in the Four Corners Region. Approximately 57% of these reserves are hosted in the Morrison Formation, 39% in the Chinle Formation, and 4% in the Cutler Group (Johnson and Thordarson, 1959; Gloyn and others, 1995).

3.2.2 Copper

Blanket-like deposits of disseminated chalcocite and its oxidation products, malachite and azurite, are hosted by late Paleozoic to Mesozoic redbed sequences throughout the southwest (Hahn and Thorson, 2002). In the MtPA, copper mineralization has been observed primarily in the Triassic Chinle and Moenkopi Formations (McFaul, 2000). These observed copper occurrences have been associated with uranium deposits in several areas including the White Canyon, Oljeto Mesa (Monument Valley), and Indian Creek mining areas (Map 16a). In the Indian Creek area, the Permian Cutler Group consists of deposits representing a transition zone between fluvial rocks to the east and marine rocks to the west. Small uranium-copper deposits are found in this transition of the Cutler Formation, as well as in the overlying Moenkopi Formation.

3.2.3 Placer Gold

Placer gold mining in the MtPA has occurred sporadically along the Colorado and San Juan Rivers and their respective tributaries since the late 1800s (Map 17a). Along the Colorado River, the native metal occurs in alluvial bars and has been found in high level terraces as much as 200 feet above the present river. The gold occurs as diminutive thin flakes averaging less than 0.1 millimeters (Butler and others, 1920). The gold grades of historical placer operations ranged from 0.03 to 0.05 ounces per cubic yard (Gloyn and others, 1995).

Placer gold deposits in San Juan River gravels were discovered in 1879 and extend from the mouth of Montezuma Creek to the confluence of the Colorado River (Johnson, 1973). The gold occurs primarily as fine flakes and “flour” in thin clayey layers in the present day river gravels and in older, higher level terrace gravels (Ritzma and Doelling, 1969). In addition to the Colorado and San Juan Rivers, placers have also been located in the Abajo Mountains along Johnson Creek and Recapture Creek (Johnson, 1973; UGS, 2003).

3.2.4 Limestone

High-quality limestone deposits in the MtPA are mostly hosted in the Pennsylvanian Honaker Trail Formation (Map 18a) (Gloyn and others, 1995). Four lenses or beds, each 1 to 3 feet thick, are observed in the San Juan River canyon west of Mexican Hat, while similar beds are exploited at the nearby Holliday Construction quarry northeast of Mexican Hat (Ritzma and Doelling, 1969). A 7- to 10-foot-thick bed containing 97% calcium carbonate and less than 1% magnesium carbonate has also been reported in the Honaker Trail Formation at a 200- to 300-acre site located southeast of Mexican Hat. Additionally, studies from a site on the Navajo Indian Reservation in the southern portion of the MtPA show that limestone in this formation may be utilized for producing high quality burned lime, cement rock, and rock dust (Ritzma and Doelling, 1969). Outcrops of the Honaker Trail Formation also occur in the northwest portion of the MtPA along the Colorado River and its tributaries, but development in this area is considered unlikely.

3.3 Salable Minerals

3.3.1 Sand and Gravel

Sand and gravel deposits are mostly associated with unconsolidated Quaternary sediments (Map 19a). Important sand and gravel deposits occur along the San Juan River, surrounding the Abajo Mountains, and near the town of Blanding. Sand and gravel along the San Juan River occurs as alluvial bars and terraces. The alluvium consists of moderately to well-sorted sand and gravel. Gravel is comprised chiefly of metamorphic rock fragments transported from the San Juan Mountains in Colorado. The material is high quality due to its hardness and is suitable for most uses including concrete aggregate. Sand and gravel deposits surrounding the Abajo Mountains occur primarily as pediments. Gravel in the pediments is comprised of diorite and quartz diorite rock derived from the Abajo Mountain intrusive complex. This material is softer and not as suitable for concrete aggregate. Less important sources of sand and gravel include eolian sands derived from the Entrada Sandstone and the Glen Canyon Group, alluvium along tributaries to the major rivers, colluvium, and talus.

3.3.2 Building Stone

The attributes of sandstone for use as a high quality building stone include well-cemented formations that exhibit uniform thin bedding; large slab size with few joints or fractures; and attractive color, texture, and color banding (Gloyn and others, 1995). Such sandstone is usually referred to as flagstone or dimension stone and is present in the Triassic Moenkopi Formation, the Triassic Chinle Formation, the Jurassic Kayenta Formation, the Jurassic Morrison Formation, and the Cretaceous Dakota Sandstone and Cedar Mountain Formation (Atwood and Doelling, 1982) (Map 20a). In addition, the granites of the Abajo and La Sal Mountains could have building stone potential (Gloyn and others, 1995).

3.3.3 Clay

Bentonite and bentonitic clays swell when saturated with water and can be used as a natural sealant for reservoirs, stock ponds, ditches, and landfill linings. Several geologic units have potential for bentonite production in San Juan County: the Triassic Petrified Forest and Monitor Butte Members of the Chinle Formation, the Cretaceous Brushy Basin and Westwater Canyon Members of the Morrison Formation, and the Cretaceous Mancos Shale (Map 21a) (Gloyn and others, 1995). Bentonite is ubiquitous in the Petrified Forest and Monitor Butte Members of the Chinle Formation throughout the MtPA, but the thickness and purity of the bentonite is quite variable. The bentonite in the Petrified Forest Member along the Chinle Creek southeast of Mexican Hat is roughly 40 feet thick. Triassic bentonite deposits can also be found near Monument Valley, Clay Hills and Comb Ridge (Gloyn and others, 1995).

The upper portion of the Brushy Basin Member of the Jurassic Morrison Formation is largely comprised of clay derived from altered volcanic ash. Samples from this unit in the Lisbon Valley north of the MtPA have a measured bentonite content exceeding 90% (Gloyn and others, 1995). Samples taken from the undifferentiated Brushy Basin at Montezuma Creek also averaged more than 90% bentonite.

Other clay types are also found in the MtPA, such as fireclay and common brick making clays. However, these deposits are poorly explored and development potential is low.

4. MINERAL EXPLORATION, DEVELOPMENT AND PRODUCTION

4.1 Leasable Minerals

4.1.1 Oil and Gas

The locations of both active and inactive oil and gas fields throughout the entire MtPA are shown in Map 22. Table 1 presents the cumulative production amounts for these fields. All field statistics mentioned below, including producing formation, discovery date, and the number of active wells, are those reported by the Utah Division of Oil, Gas and Mining as of December 2003 (DOGM, 2004). Map 23 delineates the reported locations of all oil and gas wells, including dry holes, which have been drilled in the MtPA.

As shown in Map 22, the production of oil and gas in the MtPA has primarily occurred in the eastern portion of the planning area. A large area of concentrated oil and gas fields occurs in the southeastern portion of the MtPA within the Blanding sub-basin region of the Paradox Basin. Operations also occur in the northeastern portion of the MtPA in the Lisbon Valley area of the Paradox Fold and Fault Belt. This area is also referred to as the Lisbon-Big Flat Hinge area. Although limited, some oil and gas production has occurred outside these two distinct areas at single well locations as shown in Map 23.

Aspects of certain oil and gas fields, encompassed by the two distinct producing areas in the MtPA, are discussed to highlight their general characteristics and history of resource development. Details include first discoveries, drilling and completion techniques, and technologies used for exploration and discovery of the oil and gas resources in the areas. Drilling and exploration activities over the past 15 years are also discussed, followed by drilling and exploration activities in the remaining areas of the MtPA.

Paradox Fold and Fault Belt Area

The Paradox Fold and Fault Belt, located in the northern part of the MtPA, encompasses only five oil and gas fields: 1) Lisbon, which straddles the northern MtPA border; 2) Lightning Draw; 3) Lightning Draw SE; 4) Wildcat; and 5) Paiute Knoll (Map 22). Production from the Devonian McCracken Sandstone Member of the Elbert Formation first occurred in the Lisbon field, which was discovered in 1960 with the completion of the Pure Oil Lisbon No. 1 NW Lisbon well. Drilled to a depth of 8,442 feet, this well produced 587 barrels of oil per day from the McCracken reservoir. Later, uphole testing in the Mississippian Leadville Limestone resulted in the discovery of a giant oil and gas accumulation, which has resulted in approximately 90% of the oil produced from the Leadville Limestone.Both oil and gas filled the Leadville structure almost to the structural spill point and has produced a reported 51,076,593 barrels of oil and 761,560,184 thousand cubic feet (Mcf) of gas. Both the McCracken and Leadville reservoirs contain high concentrations of hydrogen sulfide (H_2S), as well as nitrogen, carbon dioxide, sulfur, and helium.

Two separate structures, one shallow with surface expression and one deep, exist in the Lisbon Valley area. A combination of subsurface geologic mapping and seismic surveys were employed to identify the deeper structure, which turned out to be a faulted anticline that trapped hydrocarbons in both the McCracken Sandstone and Leadville Limestone reservoirs. The shallow structure, the Lisbon Valley – Dolores salt anticline, is one of the northwest-southeast trending anticlines and synclines characterizing the Paradox Fold and Fault Belt. This particular structure, which affects the Pennsylvanian Paradox Formation and trapped hydrocarbons in the Paradox reservoir, was identified in the Lisbon Valley area by surface geologic mapping. The folding and faulting that affected the Leadville, McCracken, and Paradox traps occurred separately, causing the structural crests of the three anticlinal reservoirs to be out of alignment.

Table 1. Monticello Planning Area oil and gas field statistics as of December 31, 2003

Field Name	DOGM Field Number	Field Type	Producing Formation	Status	Year Disc.	Active Wells	Cumulative Oil Production	Cumulative Natural Gas Production	Cumulative Water Production
Akah	275	Oil	Ismay	Active	1958	2	526,222	494,661	2,033,332
Alkali Canyon	280	Gas	Desert Creek	Abandoned	1965	0	3,919	40,085	1,297
Alkali Point	481	Gas	Ismay	Inactive	1987	2	342	163,765	17
Anido Creek	285	Oil	Ismay	Abandoned	1958	0	612,082	424,388	718,051
Bannock	287	Oil	Ismay	Active	1989	1	216,855	755,978	30,279
Black Bull	297	Oil	Desert Creek	Active	1992	1	50,584	247,352	694
Bluff	295	Oil	Desert Creek	Active	1956	8	1,668,207	3,693,619	126,624
Bluff Bench	300	Oil	Ismay-Desert Crk	Abandoned	1957	0	14,531	4,593	13,762
Boundary Butte	305	Oil	Ismay-Desert Crk	Active	1947	25	5,448,763	13,218,702	23,205,666
Branford Canyon	310	Oil	Ismay	Active	1983	2	50,204	363,923	54,199
Broken Hills	315	Oil	Ismay-Desert Crk	Active	1959	1	143,692	86,193	209,360
Bronco	312	Gas	Desert Creek	Active	1992	1	4,471	109,386	138
Bug	320	Oil	Desert Creek	Active	1980	7	1,622,455	4,483,368	3,181,467
Caballo	736	Gas	Ismay	Active	1987	1	11,042	427,759	2,312
Cactus Park	484	Gas	Honaker Trail	Inactive	1987	1	0	3,500	354
Cajon Lake	730	Oil	Ismay-Desert Crk	Inactive	1988	1	40,197	166,571	10,778
Cajon Mesa	326	Oil	Desert Creek	Active	1992	1	126,073	663,259	14,997
Casa Mesa	489	Oil	Ismay	Abandoned	1986	0	3,370	5,252	13,573
Cave Canyon	323	Oil	Ismay	Active	1984	10	2,389,346	3,875,293	3,763,167
Cherokee	324	Gas	Ismay	Active	1987	3	182,464	3,667,068	3,358
Chinle Wash	325	Gas	Ismay-Desert Crk	Abandoned	1957	0	5,611	2,737,772	87,575
Clay Hill	327	Oil	Desert Creek	Active	1978	3	985,080	1,389,250	216,241
Cleft	330	Oil	Akah	Abandoned	1963	0	3,537	1,031	5,821
Cone Rock	335	Oil	Akah	Abandoned	1959	0	133	0	2
Cowboy	340	Oil	Ismay	Active	1968	2	217,367	41,045	16,229
Dead Man Canyon	345	Gas	Ismay	Active	1983	3	21,380	1,093,684	5,460
Deadman-Ismay	346	Gas	Ismay	Active	1987	3	785,000	12,190,488	152,708
Desert Creek	350	Oil	Desert Creek	Active	1956	8	2,030,862	1,715,012	313,736
Gothic Mesa	355	Oil	Ismay-Desert Crk	Active	1956	8	1,941,156	1,277,313	362,046
Grayson	360	Oil	Ismay	Abandoned	1957	0	5,777	4,876	2,220
Greater Aneth	365	Oil	Desert Creek-Ismay	Active	1956	482	432,914,670	378,829,790	1,348,164,582
Hatch	370	Oil	Desert Creek	Abandoned	1958	0	15,148	40,891	0
Hatch Point	367	Oil	Ismay	Inactive	1993	1	4,607	10,731	259
Heron	447	Oil	Ismay	Inactive	1991	1	237,321	402,860	36,957
Hogan	375	Oil	Ismay	Abandoned	1961	0	756	775	98
Horse Canyon	448	Oil	Desert Creek	Active	1998	1	149,247	174,075	8,707
Ismay	380	Oil	Ismay	Active	1956	10	10,863,672	17,504,794	11,229,950
Kachina	379	Oil	Ismay	Active	1987	5	2,547,419	2,236,280	13,466,362
Kiva	381	Oil	Ismay	Active	1984	5	2,610,110	3,739,168	14,376,896
Lightning Draw	742	Oil	Ismay	Abandoned	1988	0	2,039	9,178	1,674
Lightning Draw SE	743	Oil	Ismay	Inactive	1980	2	0	0	0
Lisbon*	385	Gas	McCracken/Leadville	Active	1961	23	51,076,593	761,560,184	49,512,009
McCracken Spring	402	Oil	Ismay	Active	1987	3	403,288	1,947,709	13,031
McElmo Mesa	405	Oil	Ismay	Inactive	1965	0	2,219,175	2,927,239	6,122,732
Mexican Hat	410	Oil	Honaker Trail	Active	1908	81	278,007	1,547	692
Monument	403	Oil	Desert Creek	Active	1991	2	117,009	565,834	11,692
Mustang Flat	415	Gas	Ismay	Active	1982	8	773,299	16,349,062	19,344
Navajo Canyon	488	Oil	Ismay	Active	1977	1	39,049	25,441	6,189
Piute Knoll	425	NA	Ismay	Inactive	1972	1	0	0	0
Patterson Canyon	420	Oil	Ismay	Active	1974	9	1,070,208	2,595,522	1,563,740
Rabbit Ears	430	Oil	Ismay	Abandoned	1967	0	54,068	154,717	641,817
Recapture Creek	435	Oil	Ismay-Desert Crk	Active	1925	5	2,206,281	3,716,864	358,308
Recapture Pocket	437	Oil	Desert Creek	Active	1987	3	176,538	324,275	40,467
River Bank	440	Oil	Ismay	Abandoned	1967	0	1,396	8,774	376
Road Canyon	401	Oil	Desert Creek	Active	1988	1	23,363	41,971	8,126
Rockwell Flat	445	Oil	Ismay	Abandoned	1967	0	624,235	518,812	4,191,806
Runway	446	Oil	Desert Creek	Active	1990	3	852,406	2,950,738	31,511
Shumway Point	486	Gas	Ismay	Active	1987	1	239	69,353	14
Soda Spring	741	Oil	Desert Creek	Abandoned	1989	0	3,657	9,303	5,453
Squaw Canyon	460	Oil	Ismay-Desert Crk	Active	1980	2	342,977	888,253	21,468
Tin Cup Mesa	465	Oil	Ismay	Active	1982	10	2,461,650	3,634,276	8,679,678
Tohonadla	470	Oil	Ismay-Desert Crk	Active	1956	4	2,258,444	921,663	915,653
Tower	476	Oil	Desert Creek	Abandoned	1994	0	10,064	3,848	20,447
Turner Bluff	475	Oil	Ismay-Desert Crk	Active	1957	9	920,213	754,089	560,058
Ucolo	477	Gas	Honaker Trail	Abandoned	1981	0	78,621	1,081,490	4,169
Wild Stallion	478	Gas	Ismay-Desert Crk	Active	1989	1	1,479	376,692	107
Yellow Rock	485	Oil	Ismay	Abandoned	1964	0	18,205	11,258	194,509
Totals						**768**	**534,466,175**	**1,257,732,642**	**1,494,754,344**

*Partially located in the Moab Planning Area to the north

Source: Utah Division of Oil, Gas and Mining (DOGM), 2004

In addition to the Leadville Limestone and McCracken Sandstone, oil and gas accumulations have also been recorded in the Paradox and Hermosa intervals, but no economic production has occurred in the Lisbon field from these uphole zones.

The Lightning Draw field, discovered in 1988 and now abandoned, produced 2,039 barrels of oil and 9,178 Mcf of gas from the Cane Creek fractured shales. No production of either oil or gas was reported for the shut-in Lightning Draw SE and Paiute Knoll fields. Reported production for the Wildcat field was 351,521 barrels of oil and 6,275,905 Mcf of gas. One new gas well (the Federal 1-31) was recently completed in the Lightning Draw SE field in NWSW, T. 30 S., R. 24 E., Sec. 31, and one well is currently being worked over. Development plans include construction of a pipeline connecting these wells to the existing gathering line and the Lisbon gas processing facility.

Hydrogen sulfide (H_2S) and helium have also been produced from the Lisbon field. In the mid-1990s, the then operator of the Lisbon gas plant, Unocal, installed a sulfur extraction unit from the H_2S waste stream. Molten sulfur was marketed from the plant until the spring of 2003 when a saturated sulfur market caused the closure of the uneconomic extraction operation. The current Lisbon Unit and gas plant operator, Tom Brown, Inc. (TBI), requested and received approval for a sulfur reinjection well. As of May 2003, TBI began reinjecting their H_2S waste gas back into the Leadville reservoir. The sulfur extraction unit will be deactivated and sold when operations are complete. The Lisbon gas plant upgrade also included the installation of a helium extraction unit from which helium is being extracted and marketed under a BLM helium contract (E. Jones, BLM Moab Field Office, verbal communication, June 2004).

Blanding Basin Area

Oil and gas were first discovered in the Blanding Basin area of the MtPA at Boundary Butte in 1948. Subsequent geophysical work on adjacent Navajo Indian land resulted in the 1956 discovery of the Greater Aneth field (Map 22), which produces from algal bioherms in the Desert Creek zone of the Paradox Formation, with some minor production from the Ismay zone. The Greater Aneth field has produced 432,914,670 barrels of oil and 378,829,790 Mcf of gas from this giant, fluid-expansion and solution gas drive, stratigraphic reservoir. There are currently 482 active wells in the field.
Other field discoveries followed quickly. Bluff field was found in 1956 as a result of mapping and seismic work. The discovery well was drilled to a depth of 8,762 feet, but completed from algal mounds in the Desert Creek and Ismay zones. This field has produced 1,668,207 barrels of oil and 3,693,619 Mcf of gas. Recapture Creek field, also discovered in 1956, has produced 2,206,281 barrels of oil and 3,716,864 Mcf of gas from Ismay and Desert Creek bioherms by means of solution gas expansion with a weak water drive.

There are a host of other Ismay and Desert Creek reservoirs in the Blanding sub-basin. Some of the larger producers include Bug, Cave Canyon, Cherokee, Deadman, Kachina, Ismay, Kiva, Mustang Flat, and Tin Cup Mesa fields (Table 1).

Monument Upwarp Area

Compared with the previously described areas, exploration drilling and completion of producing wells on the Monument Upwarp has been sparse (Map 23). Despite over 150 exploratory wells drilled in this area, only two fields have been established. These two fields, the Mexican Hat field and the Lime Ridge field, are located in the south-central portion of the MtPA. The Mexican Hat field has produced 278,007 barrels of oil and 1,547 Mcf of gas from the Pennsylvanian Honaker Trail Formation. Discovered in 1908 at depths less than 300 feet, this field was developed with 81 shallow wells. The Lime Ridge field produced 1,500,000 Mcf of mostly carbon dioxide from small bioherms in the Ismay, Desert Creek, and Akah cycles of the Pennsylvanian Paradox Formation (Riggs, 1978). The one well in this field is located in Section 28, T. 40 S., R. 20 E. on the Lime Ridge anticline. This field also had a significant gas show from the Mississippian Leadville Limestone.

Other representative activities on the Monument Upwarp include tests at the Nokai Dome in the southwest portion of the MtPA. One early well, the Skelly Oil Nokai Dome No. 1 located in section 27, T. 40 S., R. 12 E., encountered a show of oil and gas in the Triassic Shinarump Member of the Chinle Formation. Another well, the Forest Oil Corporation No. 31-1, had a show of gas in Pennsylvanian sediments (McDougall, 2000c). One of six exploratory wells drilled in 1992 in the west central portion of the MtPA, also had a significant show of oil and/or gas in the Ismay zone of the Paradox Formation. Casing was set on this well, the Ampolex Texas, Inc. Federal 22-5, which is located in section 5, T. 34 S., R. 15 E., but the completion attempt was unsuccessful and no production was established (McDougall, 2000b).

4.1.2 Coal

Coal activity in the 530,000-acre San Juan Coal Field has been limited to four areas: 1) exposures of Dakota Sandstone along Recapture and Johnson Creeks in Townships 35 and 36, Ranges 22 and 23; 2) an area near Monticello where several openings had been reported; 3) prospect holes located near section 22, T. 34 S., R. 26 E., including the Crepo Mine, with a bulldozed outcrop in section 26, T. 34 S., R. 25 E. representing the best showing in the field; and 4) several pits opened in an area located along Piute Creek, including the Rasmussen mine located in section 35, T. 33 S., R. 26 E. (BLM, 1985) (Map 12a). Reported activities primarily occurred prior to 1929, with insignificant production. All mines and prospects have been closed in this area since 1971 (BLM, 1985).

During the late 1970s, the energy crisis prompted renewed interest in domestic coal deposits and AMAX Coal and Arjay Petroleum drilled several exploration holes across the Sage Plain and near Eastland, Utah (Gloyn and other, 1995). Arjay Petroleum estimated that 77 million tons of coal may be recoverable by surface mining in their exploration area, but development is limited by poor coal quality and lack of rail transportation (Wilson and Livingston, 1980).

4.1.3 Potash and Salt

Potash deposits in the Paradox Basin were initially discovered during the exploration for oil and gas between 1924 and 1944. Based on these initial discoveries, further potash exploration concentrated in Cane Creek and Lisbon Valley, and contributed to the classification of these areas as Known Potash Leasing Areas (KPLAs) in 1960 (Hite, 1960). A portion of the Cane Creek and Lisbon Valley KPLAs occur within the northern part of the MtPA (Map 13a). The Cane Creek mine in the Cane Creek KPLA is the only development currently producing potash and salt. The actual mine is located just north of the MtPA boarder in the Moab Planning Area. Production has been through solution mining of Paradox salt units 5 and 9. The Moab Salt Company projects a remaining mine life of roughly 20 years.

Oil and gas drilling data in the Gibson Dome area has also contributed information on potash deposits (Map 14a). In addition, a borehole was drilled in the 1980s by the U.S. Department of Energy for the purpose of evaluating the salt structure in the Gibson Dome area as a potential repository for high-level nuclear waste. This borehole encountered potentially valuable potash-bearing zones (Woodward-Clyde Consultants, 1982; Merrell and others, 1979; Dames and Moore, 1978).

4.1.4 Tar Sands

There has been no exploration or production activity regarding the tar sand deposits located in the White Canyon Designated Tar Sand Area (BLM, 2004).

4.2 Locatable Minerals

4.2.1 Uranium-Vanadium

Although uranium deposits in the MtPA were mined for over 90 years, first for their radium content and then for their vanadium co-product, it was the "Uranium Boom" beginning in the late 1940s that lead to large-scale extraction in the early 1950s (Chenoweth, 1996). In the late 1970s, the area was still being explored by drilling to decipher the configuration of existing deposits and delineate new discoveries. Some mines in the White Canyon mining area did not close until 1987-1988 (Chenoweth, 1996). The last mines closed in 1990 due to declining economics brought on by socio-political factors, international oversupply, and competition from lower cost producers.

Sediment-hosted uranium deposits of the classic sandstone roll-front type are prolific in the MtPA (Map 15a). The greatest amount of production has occurred from the Salt Wash Member of the Jurassic Morrison Formation, and the Moss Back and Shinarump Conglomerate Members of the Triassic Chinle Formation. Lesser production has occurred from the Permian Cutler Group. Mines developed in the Chinle Formation produced 92% of the ore between the early 1950s and the mid-1960s. However, by the mid-1970s, production from the Morrison Formation overtook and slightly exceeded that of the Chinle, $600 million vs. $500 million, respectively. Table 2 provides a summary of historic mining production in the MtPA.

Table 2. Historical uranium/vanadium production in the Monticello Planning Area

Area	Average Ore Grade		Pounds of Production		Estimated Reserves - Pounds of U_3O_8	Development Potential
	% U_3O_8	% V_2O_5	U_3O_8	V_2O_5		
Lisbon Valley Area*	0.30 - 0.37	0.34 - 0.40	79,560,000	534,000	3,500,000	High
Combined White Canyon Area	0.25 - 0.30	0.04	11,069,000	216,000	2,000,000+	High to Moderate
Interriver, Cane Creek, Indian Creek Areas*	0.20 - 0.22	1.50 - 2.00	3,276,000	195,000	unknown	Moderate
Dry Valley Area	0.20	1.00 - 1.70	1,525,000	12,662,000	1,000,000	High
Cottonwood Wash Area	0.15 - 0.20	0.96 - 1.70	896,000	5,664,000	300,000	High
Oljeto Mesa Area (Monument Valley)	0.25 - 0.30	0.65	323,000	533,000	unknown	Moderate
Montezuma Canyon Area	0.16	0.60	88,000	775,000	unknown	High
Bluff-Butler Wash Area	unknown	unknown	53,000	--	unknown	Moderate
Abajo Area	unknown	unknown	7,000	1,000	unknown	Moderate
Ucolo Area	0.15	1.50 - 2.00	unknown	unknown	3,000,000	High

*Includes production from the Moab Planning Area to the north

Source: Gloyn and others, 1995; Chenoweth, 1996; Gloyn, 2004

There are seventeen uranium-vanadium mining areas within the MtPA (Map 15a) (Gloyn, 2004). The most significant ones are described below. The Cottonwood Wash mining area is centered at the junction of Cottonwood and Brushy Basin Washes, just west of Blanding, Utah. Ore deposits were discovered in this area in 1931, and were mined from the Salt Wash Member of the Morrison Formation until the mid-

1980s. Some 55 properties produced over 350,000 tons of ore that averaged 0.15% U_3O_8 and 0.96% V_2O_5 (Chenoweth, 1996). Actual product production equaled about 896,000 pounds of U_3O_8 and 5,664,000 pounds of V_2O_5 (Gloyn and others, 1995). Reserves in this area are estimated at 300,000 pounds of U_3O_8 (Gloyn, 2004). There are currently no mining permits filed with DOGM for this area.

The Montezuma Canyon mining area includes deposits on the sides of Montezuma Canyon and its tributaries, east of Blanding, Utah. Claims in this area were first staked in 1914-1915, also in the Salt Wash Member of the Morrison Formation, with intermittent mining starting in the late 1940s and ending in the mid-1980s. Sixty-eight properties produced about 109,000 tons of ore that averaged 0.16% U_3O_8 and 0.60% V_2O_5 (Chenoweth, 1996), equating to 88,000 pounds of U_3O_8 and 775,000 pounds of V_2O_5 (Gloyn and others, 1995). Currently, only one mine in the Montezuma Canyon area, the Dusty Mine, has a permit registered with DOGM; however, it is listed as inactive.

Uranium-vanadium deposits in the Lisbon Valley mining area, also called the Big Indian area, produced 79,560,000 pounds of U_3O_8 and 534,000 pounds V_2O_5; the most in southeastern Utah (Gloyn and others, 1995). This area, along with most of its associated ore deposits, lay in the Moab Planning Area. Only the southeastern portion of the area is located in the MtPA. These deposits are found in both the Triassic Chinle Formation and the Permian Cutler Group and average 0.37% U_3O_8 and 0.34% V_2O_5 (Chenoweth, 1996). Reserves in this area are estimated at 3.5 million pounds of U_3O_8, but again, most of this is in the Moab Planning Area (Gloyn, 2004). Only one mine in the MtPA portion of the Lisbon Valley area has a permit registered with DOGM; it is also listed as inactive.

Triassic Chinle Formation outcrops in the northwestern part of the MtPA are often referred to as the White Canyon mining area, but can also be separated into several smaller areas including: Red Canyon, White Canyon/Fry Canyon, Deer Flat, Elk Ridge, and the southern section of Indian Creek (Gloyn, 2004). About 11,069,000 pounds of U_3O_8 and 216,000 pounds of V_2O_5 have been produced from this group of mining areas (Gloyn and others, 1995). Uranium grades average about 0.25% to 0.30% U_3O_8, but vanadium grade is much lower, averaging only about 0.04% V_2O_5 (Gloyn and others, 1995). In addition, ore from the White Canyon area contains from 0.3% to 1.3% copper (Chenoweth, 1990, 1993). The Red Canyon section of this area contains an estimated 2 million pounds of U_3O_8, while reserves for other areas are unknown (Gloyn, 2004). One mine in the White Canyon area has a registered permit with DOGM; it is classified as being in its final stages of reclamation.

The Ucolo and Dry Valley mining areas hold significant reserves of uranium-vanadium in the Jurassic Morrison Formation, roughly 3 million pounds of U_3O_8 in the Ucolo area and 1 million pounds in Dry Valley. Ucolo ore deposits average 0.15% U_3O_8 and 1.5-2.0% V_2O_5, and Dry Valley deposits average 0.20% U_3O_8 and 1.0-1.7% V_2O_5 (Gloyn, 2004). Past production in the Dry Valley area totaled 1,525,000 pounds of U_3O_8 and 12,662,000 pounds of V_2O_5 (Gloyn and others, 1995). Three mines in the Ucolo area have registered permits; two of which are being reclaimed and one listed as inactive. Only one permitted mine is located in the Dry Valley area, but it is listed as inactive.

4.2.2 Copper

Copper production in the MtPA was often associated with uranium mining (Map 16a). The White Canyon, Red Canyon, Deer Flat, and Elk Ridge mining areas were the location of copper production in the late 1940s and early 1950s. In August 1949, the Vanadium Corporation of America (VCA) constructed a mill for processing uranium/vanadium ore, which included some copper content. VCA's attempt to recover copper at the mill, primarily in 1953, was not successful, and the mill closed at the end of that year (Chenoweth, 1993). Other areas for copper occurrence in the MtPA are in the Oljeto Mesa (Monument Valley) and Indian Creek mining areas. Both areas contain limited prospects, and no mining has developed. The most significant copper mining has been in the Lisbon Valley area, which lies in the Moab Planning Area to the north.

4.2.3 Placer Gold

Historical placer operations in the MtPA were small scale; so most of the gold production was not reported. Due to the fine flaky mode of the gold and difficulty in its recovery, most of these historical operations were not economic (Butler and others, 1920; UGMS, 1966; Johnson, 1973). Also, historical placer sites along the Colorado River are now under Lake Powell (Map 17a) (UGS, 2003).

Currently, there is little production of placer gold from the MtPA. One small placer operation is currently located below the dam on Recapture Creek near Blanding. Recently, the BLM Monticello Field Office (T. McDougall, BLM, verbal communication, 2004) has accepted a proposal to conduct gold exploration on a site in Johnson Creek.

4.2.4 Limestone

Limestone operations in the MtPA include the active Lime Ridge quarry operated by Holliday Construction, and the inactive Moon No. 4 quarry that was operated by Western Industrial Minerals (Map 18a). Both these operations were permitted on State lands near Mexican Hat. Recent production (1998 through 2003) at the Lime Ridge site has been reported at approximately 29,000 tons (DOGM, verbal communication, 2004).

Exploration and proposed development of chemical quality limestone has also occurred in the MtPA in the past. Dames and Moore, Inc., under a contract to the Arizona Public Service Company, conducted substantial exploration for high-calcium limestone in the middle to late 1970s. These efforts resulted in the identification of a massive 7- to 10-foot-thick bed of limestone in the Pennsylvanian Honaker Trail Formation approximately 13 miles northeast of Mexican Hat on Lime Ridge. The deposit is comprised of 97% calcium carbonate with less than 1% magnesium carbonate and is amenable to simple quarrying techniques (Gloyn and others, 1995). The limestone was to be used to control emissions of sulfur dioxide, nitrogen oxides, and particulates at coal-fired power generation plants in New Mexico and Arizona. In 1986, the Environmental Lime Corporation submitted a proposal to the BLM regarding a project, located northeast of Mexican Hat, to produce 1,100 tons per day of high-calcium limestone for the Four Corners Power Plant located in New Mexico, but no work was ever carried out on this project. In 1994, the Navajo Nation drilled core samples on claims located in section 4, T. 41 S., R. 20 E., to ascertain whether high-calcium limestone was present and if it could be used for proposed sulfur dioxide scrubbers/absorbers at the Navajo Generating Station located at Page, Arizona.

4.3 <u>Salable Minerals</u>

4.3.1 Sand and Gravel

Sand and gravel development is largely driven by the need to find suitable material for public works projects including local and state road projects and community development. Because sand, gravel, and other construction aggregates are generally the lowest priced of all mined mineral products, transportation costs from the pit to the point of end use are a large part of the cost to consumers. As such, even short transportation distances can adversely affect the cost of the final product, and it is imperative that sand and gravel sources be located as close as possible to the point of use and major roadways. For this reason, the sand and gravel industry is widely dispersed across Utah, aligned along roadways, and near population centers.

A review of LR 2000 records indicates that since 1989 there have been 57 authorizations made by the BLM for mining of sand and gravel in the MtPA for a cumulative total of 1.9 million cubic yards (BLM, 2004). Production has primarily occurred in the eastern and southern portion of the MtPA, from alluvial deposits located along the San Juan River and from pediments in the vicinities of Blanding and Monticello (Map 19a). The main producers are the Utah Department of Transportation and the County Highway Department.

4.3.2 Building Stone

Building stone production in the MtPA has primarily occurred from the Cretaceous Dakota Sandstone at quarries located southeast of Blanding (DOGM, verbal communication, 2004). Production has also occurred from operations in the Jurassic Kayenta and Triassic Moenkopi and Chinle Formations (Map 20a). Since 1989, there have been 7 authorizations made by the BLM for mining building stone for a cumulative total of approximately 130 tons (BLM, 2004). However, most of the production in the MtPA occurred on unpatented mining claims, six of which are recorded with the BLM, so no production figures are available.

4.3.3 Clay

Small-scale mining of bentonite for local engineering purposes has occurred in the MtPA. In 1977, the Butterfield mine near the town of Aneth, about 9 miles southeast of Montezuma Creek, produced about 5,000 cubic yards of bentonitic clays from the Brushy Basin Member of the Jurassic Morrison Formation (Gloyn and others, 1995). This mine may have produced in other years as well. Two other mine sites located in the southwest portion of the MtPA, in sections 6 and 7, T. 39 S., R. 15 E. (Map 21a), have produced bentonitic clay from the Triassic Chinle Formation. Uses of the bentonite include reservoir, ditch, and landfill lining. Since 1989, the LR 2000 records indicate that six BLM authorizations have been issued for 550,000 cubic yards of clay (BLM, 2004).

5. POTENTIAL FOR OCCURRENCE AND DEVELOPMENT OF ENERGY AND MINERAL RESOURCES

The mineral resource potential of the MtPA is classified using the system outlined in Bureau of Land Management Manual 3031. Under this system, occurrence potential ratings are strictly based on the geologic likelihood of the mineral to be present in the area and do not address the economic feasibility of development of the resource. These ratings address the accumulation of mineral resources and certainty of data as follows:

Level of Potential Ratings:

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

L. The geologic environment and the inferred geologic processes indicate low potential of accumulation of mineral resources.

M. The geologic environment, the inferred geologic processes, and the reported mineral occurrences or valid geochemical/geophysical anomaly, and the known mines or deposits indicate moderate potential for accumulation of mineral resources.

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

ND. Mineral potential not determined due to lack of useful data.

Level of Certainty Ratings:

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

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

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

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

The potential for development of each mineral resource in the MtPA is projected for the life of the Resource Management Plan (RMP), which is 15 years, and is rated as high, moderate, or low. The likelihood for development is based on communication with industry experts and government officials familiar with the specific resources, current or past activities in the area, as well as considerations such as mineral occurrence potential, historic development, commodity price and demand, and other factors as described. The projected development may be directly affected by planning decisions that restrict or preclude mineral exploration and/or development activity. The development rating is also affected by the status of the land in which the commodity is found. Resources found in National Parks, National Monuments, Recreational Areas, Wilderness Areas, and Wilderness Study Areas are generally not available for mineral development, except in a few areas where there may be valid existing rights. For that reason, these areas are considered to have a low development potential.

5.1 Leasable Minerals

5.1.1 Oil and Gas

The potential for occurrence of hydrocarbon resources in the MtPA is based on the previously discussed geology of the area, as well as the historic exploration and production activities. Maps 6a, 7a, 8a, 9a, 10a, and 11a portray the oil and gas occurrence potential for each individual play in the MtPA. Map 24a represents an aggregate of the occurrence potential of the individual plays.

In total, the U.S. Geological Survey (USGS) has identified six oil and gas plays in the MtPA (Gautier and others, 1996). The Buried Fault Black play (2101) is located in the northern part of the MtPA, in the Paradox Fold and Fault Belt. This play contains one of Utah’s large producing fields, the Lisbon field, and is rated as having a high (H) occurrence potential with a D level of certainty (Map 6a). The Porous Carbonate Buildup play (2102) contains the most oil and gas fields in the MtPA, including the largest producing oil field in Utah, the Greater Aneth field. The southeastern portion of this play, where all current oil and gas fields are located, is rated as H occurrence potential with a D level of certainty (Map 7a). The northwestern portion of this play, on the Monument Upwarp, is rated as H occurrence potential with a C level of certainty. No fields are located in this portion of the play, but there is potential for future discovery. The portion of this play around the Abajo Mountains is rated as low (L) occurrence potential with a C level of certainty. This area has been intruded by Tertiary igneous rocks, making oil and gas accumulations unlikely. Only one oil or gas field is located in the Fractured Interbed Play (2103), the now abandoned Kane Creek field. The northern part of this play is rated as high (H) occurrence potential with a D level of certainty, since fractured reservoirs are known to exist in this area (Map 8a). The western and southern portions of this play are rated as H occurrence potential with a C level of certainty, except around the Abajo Mountains, which is rated as L occurrence potential with C certainty. The Salt Anticline Flank play (2105), also located in the northern portion of the MtPA, is rated as H occurrence potential with a D level of certainty since it contains a few small fields with the potential for the discovery of others (Map 9a). The Permo-Triassic Unconformity play (2106) is rated as H occurrence potential with a C certainty (Map 10a). No oil or gas fields have been discovered in this play. The Late Proterozoic (Chuar-sourced) and Lower Paleozoic play (2403) is located in the southwest corner of the planning area and is rated as H occurrence potential with only a B level of certainty, since this play is only speculative (Map 11a).

Supply and demand for energy will drive the development of fossil fuels in the future. The forecast for energy needs in the next 15 years will require adequate supplies of hydrocarbons and other energy sources. The demand for natural gas alone is estimated at 30 trillion cubic feet in 2020 by most oil and gas associations (Wray and others, 2001). The demand for new sources of energy will impact the development of fossil fuels in the MtPA. Higher energy prices will encourage exploration programs and development activities. Oil and gas development will be further advanced through a better understanding of reservoir accumulations and depletions and technological advances in the areas of seismic acquisition, drilling and completion techniques, as well as secondary and tertiary recoveries. The development of these mineral resources will be balanced against the available pipeline and infrastructure to support marketing these resources. Although fluctuations in development of fossil fuels should be expected, the overall trend in activity over the next 15 years is projected to be an upward one.

The potential for future oil and gas exploration and development in the MtPA over the next 15 years is based on the history and extent of development in the area, consultation with petroleum companies actively studying fields and plays in the MtPA, and discussions with state and federal agencies familiar with activities in the area (see separate oil and gas Reasonably Foreseeable Development document). Based on these factors, potential for oil and gas exploration and development in the Paradox Fold and Fault Belt and Blanding Basin areas of the MtPA is considered high (Map 24b). Less activity is expected in western areas of the MtPA on the Monument Upwarp, and development potential is rated as moderate. The potential for exploration and development around the Abajo Mountains, within national parks or monuments, within wilderness study areas, or within other protected lands, is considered low.

Hydrogen sulfide, sulfur, helium, and carbon dioxide have been produced as a byproduct of oil and gas production in the Lisbon field. Production of these commodities will continue to be produced as a byproduct of oil and gas production as long as facilities exist at the Lisbon gas plant for recovery.

5.1.2 Coal

As shown on Map 12a, the area underlain by the Dakota Sandstone is rated as H potential and C certainty for occurrence of coal in the San Juan Coal Field. A small area southeast of Monticello is considered as H occurrence potential and D certainty. Drill hole data indicate the presence of significant coal beds in this area.

Only two small mines have operated in this area in the past, both of which have been closed since the late 1920s. In addition to the lack of historical activity, the poor quality of the coal in the area does not support development (Map 12b). Analyses of these coals indicate that they have high moisture, ash, and sulfur contents; the individual coal beds rarely exceed 15 feet thick; and the average heat content is only 7,162 Btu/lb, making them less desirable for mining than other coals in the state with higher heat values. Therefore, development potential for coal in the next 15 years is considered low.

5.1.3 Potash and Salt

Potash and salt deposits are hosted by the Pennsylvanian Paradox Formation in a thick series of cyclic evaporates. As shown on Map 13a, the two Known Potash Leasing Areas (KPLAs) in the MtPA and the Gibson dome area are rated, for both potash and salt, as H occurrence potential with D certainty. The area of known potash and salt deposits, which underlies a 2,800-square-mile area of the Paradox Basin's deeper northeastern half, is rated as H occurrence potential with C certainty for both commodities. The salt deposits occur in a broader area of the basin and are rated as H occurrence potential with C certainty.

Development potential for both potash and salt in the MtPA is considered low (Map 13b). The Moab Salt Company's Cane Creek Mine, the sole producer of potash and byproduct salt in the region, is located just north of the MtPA. This mine is located on the crest of the Cane Creek Anticline within the Paradox Basin Fold and Fault Belt and extracts the minerals through solution mining processes from a non-diapiric salt structure. Production of potash and salt is likely to continue at the Cane Creek Mine. Mine operations have been confined to state land where there are sufficient reserves to meet the demand for the next 15 years. Therefore, mining operations are not expected to expand on to adjacent federal land within the small section of the Cane Creek KPLA located in the MtPA.

The Lisbon Valley potash deposits are also classified as a KPLA. In the 1960s, underground mining operations were contemplated; however, the complex folding of the potash beds stopped the exploration program (Merrell and others, 1979). This diapiric salt structure consists of complex folding and faulting that preclude, or complicate, the application of underground and solution mining techniques (Dames and Moore, 1978). In addition, there are development complications due to the remoteness of the area from railroad and water. Therefore, development of the potash and salt resources within the Lisbon Valley KPLA is considered unlikely in the next 15 years.

Gibson Dome is a simple salt structure similar to the Cane Creek structure. Although Gibson Dome has notable potash deposits, there has been no interest expressed in their development. This could be attributed to the remoteness of the area to a railroad, the lack of availability of water, proximity to Canyonlands National Park, and the competition from lower cost producers in New Mexico, Canada, and the Great Salt Lake. Therefore, potash development in the Gibson Dome area is not considered likely during the next 15 years.

The development of salt, independent of potash, is also not likely over the next 15 years because extraction costs are high due to the depths of the salt beds and the abundance of this material produced from other low cost operations.

5.1.4 Tar Sands

The White Canyon Designated Tar Sand Area (DTSA), along with smaller tar sand deposits near Mexican Hat, have been characterized as H occurrence potential with D certainty (Map 14a). Compared with the oil and gas resources throughout the MtPA that can be extracted with modern drilling and pumping methods, tar sand extraction requires higher cost mining techniques such as open pits and associated earth-moving and reclamation activities.

Ritzma and Doelling (1969) stated that the Hoskinnini Member in the White Canyon tar sand deposit is "lightly" saturated with oil and that a reconnaissance assessment of the deposit indicates that it is not of commercial significance. Furthermore, strong jointing reported in the Moenkopi Formation, as well as in stratigraphically lower rocks, may prevent in situ thermal recovery of oil, while heavy overburden makes it unfavorable for surface mining methods. There are no leases in the White Canyon DTSA and little or no interest has been shown by industry in the past. For these reasons, development potential is considered low over the next 15 years (Map 14b); however, speculative potential for development exists beyond this time.

5.2 <u>Locatable Minerals</u>

5.2.1 Uranium-Vanadium

Uranium mining has taken place over much of the planning area (Chenoweth, 1996). Production was primarily from the following stratigraphic units in decreasing order: the Salt Wash Member of the Jurassic Morrison Formation, the Moss Back Member and the Shinarump Conglomerate Member of the Triassic Chinle Formation, and the Permian Cutler Group.

As shown on Map 15a, the designated mining areas (Gloyn, 2004) within the MtPA are rated as H occurrence potential with D certainty. Outside these areas, the aerial extent of the Jurassic Morrison and Triassic Chinle Formations has been classified as M occurrence potential with C certainty for uranium and vanadium. As previously discussed, mineralization in the Permian Cutler Group has been attributed to migration from the Chinle in the Lisbon Valley area where the Cutler sits directly below the Chinle, and the Moenkopi is absent. Outside this one area, mineralization in the Cutler is not expected.

The last uranium mines in the region closed in 1990 due to declining commodity prices. The local mine closures were part of a national and international trend in which the high level of domestic uranium mining and exploration that commenced in the late 1940s and early 1950s underwent an abrupt drop in the early 1980s. The drop in uranium demand was due to a number of factors including excess of international inventories; competition from higher-grade, readily accessible Canadian and Australian uranium deposits; low-cost domestic extraction by solution mining; the recovery of uranium as a by-product of other commodities; and an accompanying decline in the price of vanadium, which was an important by-product or co-product in a significant number of mines within the planning area.

It is estimated that a price of $20.00 to $30.00 per pound would probably be required to revive uranium mining from existing reserves in the Paradox Basin, while a price of $30.00 to $40.00 per pound would be necessary to stimulate new exploration and development (Energy Information Administration, 1999). The spot price for U_3O_8 is currently at $29.00 per pound (May 9, 2005), and prices could slowly increase in years to come (Ux Consulting Company, LLC, 2005). In addition, the price of vanadium has sky rocketed in recent months to an all time high of over $25.00/lb. At this price, vanadium would be sought after as a co-product, and possibly the primary metal, particularly because of the relatively high ratio of vanadium to uranium in most of the Salt Wash deposits in the area. Based on these recent prices and with current interest greatly increasing, it is reasonable to suggest that development of existing reserves is likely in the next 15 years. Development potential is highest for the Red Canyon, Deer Flat, Cottonwood Wash, Monezuma Canyon, Lisbon Valley, Dry Valley, and Ucolo mining areas where known reserves are significant (Table 2) (Map 15b). Development potential is moderate for the White Canyon-Fry Canyon, Oljeto Mesa (Monument Valley), Comb Ridge, Bluff-Butler Wash, Elk Ridge, Abajo, Indian Creek, Lockhart Canyon, Lower Cane Creek, and Inter-river areas, while development potential is low for host formations outside designated mining areas.

5.2.2 Copper

As previously discussed, host formations of disseminated copper deposits in the MtPA include the Triassic Moenkopi and Chinle Formations, and this mineralization is commonly associated with uranium deposits. Based on available information, there is H potential for occurrence with a D level of certainty for redbed-type disseminated copper deposits in the Triassic Chinle in the White Canyon, Oljeto Mesa (Monument Valley), and Indian Creek uranium mining areas (Map 16a). Occurrences in the Moenkopi are limited to just a few uranium mines in the White Canyon area. Therefore, because this is an isolated copper deposit, the Moenkopi in this area is rated as M occurrence potential with C certainty, while other exposures of Moenkopi are rated L occurrence potential and C certainty.

The only attempt to produce redbed-type disseminated copper in the MtPA occurred in the early 1950s and was associated with uranium production. No development of these type copper deposits has occurred since, even in times of favorable copper prices. These low-grade copper deposits have been uneconomically produced in association with uranium in a few cases. Even with the increase in uranium prices, copper development potential throughout the MtPA is considered low for the next 15 years (Map 16b).

5.2.3 Placer Gold

The placer gold sites shown on Map 17a have H potential for occurrence with D certainty level, given that gold has been produced at these locations. Alluvial deposits along the San Juan River, from the mouth of Montezuma Creek to Lake Powell are considered to have H potential for occurrence with C certainty level, as are deposits along Johnson and Recapture Creeks in the Abajo Mountains north of Blanding.

Only small sporadic extraction activities have taken place in the MtPA since the late 1980s. As previously discussed, because of the fine flaky mode of the gold and difficulty in its recovery, most operations have not been commercially successful (Butler and others, 1920; Chatman, 1987; UGMS, 1966; Johnson, 1973). However, one small placer operation, currently located below the dam on Recapture Creek near Blanding, is projected to continue at existing levels. In 2004, the BLM Monticello Field Office also accepted a Notice of Intent to conduct gold exploration on a small site in Johnson Creek consisting of a few backhoe trenches. The ongoing operation and the recent proposal indicate a high potential that some small-scale development is likely over the next 15 years in these two areas (Map 17b). Other areas are assigned a moderate to low development potential.

5.2.4 Limestone

Limestone occurrences in the MtPA have been identified in the Pennsylvanian Honaker Trail Formation. The identified limestone sites in the MtPA have been characterized as H potential for the occurrence of limestone with D certainty level (Map 18a). Elsewhere in the MtPA, the Honaker Trail Formation is characterized as H potential with C certainty for the occurrence of limestone.

The Holliday Construction Lime Ridge quarry is an active operation located on state land. An area also considered likely for development is a 200 to 300 acre site occurring on 60 claims and located 13 miles northeast of Mexican Hat on Lime Ridge. In 1976, on what were then only two claims, a massive 7- to 10-foot thick bed of high calcium limestone was identified in the Pennsylvanian Honaker Trail Formation at this site (Gloyn and others, 1995). This material was identified to provide a source of high-calcium limestone for the sulfur dioxide scrubbers/absorbers at the Four Corners Power Plant. There are a number of other coal-fired power generation plants in the Four Corners region that could utilize limestone produced from the Lime Ridge site. These include the San Juan Generation Station operated by Public Service Company of New Mexico and the Navajo Generating Station operated by the Salt River Project. Therefore, limestone development on Lime Ridge is considered likely, or high, in the next 15 years (Map 18b).

Interest has also been expressed in a deposit that extends into the MtPA within section 29, T. 30 S., R. 25 E. Cotter Corporation's Papoose Mine currently produces high-calcium limestone (95% calcium carbonate) from this deposit north of the MtPA (Reed, 1996). The Papoose Mine is expected to continue on state land with reserves estimated at about 6 million tons. Based on a current production rate of about 25,000 tons per year, it is unlikely that the operation will extend onto adjacent federal land in the foreseeable future. Therefore, development of limestone on federal land in this area is unlikely in the next 15 years.

5.3 Salable Minerals

5.3.1 Sand and Gravel

Sand and gravel deposits are mostly associated with Quaternary sediments. All these deposits are rated as H potential and D certainty for the occurrence of sand and gravel (Map 19a). Deposits located within 3 miles of a road are rated as having a high development potential, whereas deposits located further from roads have a moderate development potential (Map 19b).

One of the major uses of sand and gravel is for road maintenance, even in remote areas of the MtPA. However, due to transportation costs, most production has occurred in proximity to road infrastructure, communities, and specific points of use. It is anticipated that these factors will continue to be important in the future. Therefore, most development in the next 15 years is likely in areas where sand and gravel deposits have been previously utilized; specifically, the important sand and gravel deposits along the San Juan River and deposits derived from the Abajo Mountains.

5.3.2 Building Stone

Well-cemented, attractively colored, uniformly bedded sandstones that break into large slabs are prospective sources of building stone. These sandstones are known to occur in the Triassic Moenkopi and Chinle Formations, the Jurassic Kayenta and Morrison Formations, and the Cretaceous Dakota Sandstone. Known sites of building stone production in the MtPA are rated as H potential for occurrence with a D level of certainty (Map 20a). Elsewhere, the formations have been classified as M occurrence potential and C level of certainty. The past production and continued demand for building stone in the growing communities in the west makes its development likely in the next 15 years, particularly in the general areas where there has been previous production (Map 20b).

5.3.3 Clay

The upper portion of the Brushy Basin Member of the Morrison Formation is largely comprised of clay derived from altered volcanic ash. Other formations that host claystones containing bentonite occur in the Petrified Forest and Monitor Buttes Members of the Triassic Chinle Formation, and the Westwater Canyon Member of the Jurassic Morrison Formation. Given available information, known clay sites in the MtPA have been classified as H potential for occurrence with D certainty level (Map 21a). Elsewhere the favorable formations are rated as M potential and C certainty for the occurrence of bentonite. Based on past use, it is likely that there will be continued development over the next 15 years in the MtPA of clay resources for engineering applications such as reservoirs, oil and gas reserve pits, and livestock ponds, particularly around those general areas of previous production (Map 21b).

6. REASONABLY FORESEEABLE DEVELOPMENT

This section presents the projected development scenarios for those resources in the MtPA that are considered likely to be developed over the next 15 years. These resources are oil and gas, uranium-vanadium, placer gold, limestone, sand and gravel, building stone, and clay.

6.1 Leasable Minerals

6.1.1 Oil and Gas

Refer to the separate oil and gas Reasonably Foreseeable Development (RFD) document. The baseline RFD scenario for the MtPA is summarized as follows:

- Existing surface disturbance for 1,135 active wells, 480 abandoned wells, and associated infrastructure is about 15,504 acres. This amounts to about 9.6 acres of surface disturbance per well.
- Future surface disturbance over the next 15 years for a projected 195 wells and infrastructure amounts to about 1,872 acres.
- During this period, 27 dry wells, 20 abandoned wells, and all 480 currently abandoned wells should be successfully reclaimed, making the total reclaimed surface area equal 5,059 acres.
- The total net surface disturbance for wells drilled in the MtPA over the next 15 years will equal roughly 12,317 acres.
- Future surface disturbance over the next 15 years for geophysical exploration (1,230 linear miles) amounts to about 2,236 acres. Reclamation of all these disturbed lands would be successful over the scope of 10 years.

6.2 Locatable Minerals

6.2.1 Uranium and Vanadium

It is estimated that a price of \$20.00 to \$30.00 per pound would probably be required to revive uranium mining from existing reserves in the Paradox Basin, while a price of \$30.00 to \$40.00 per pound would be necessary to stimulate new exploration and development (Energy Information Administration, 1999). The spot price for U_3O_8 is currently at \$29.00 per pound (May 9, 2005), and prices could slowly increase in years to come (Ux Consulting Company, LLC, 2005). In addition, the price of vanadium has sky rocketed in recent months to an all time high of over $25.00/lb. At this price, vanadium would be sought after as a co-product, and possibly the primary metal, particularly because of the relatively high ratio of vanadium to uranium in most of the Salt Wash deposits in the area. Based on these recent prices and with current interest greatly increasing, it is reasonable to suggest that development of existing reserves is likely in the next 15 years. The existing infrastructure is already in place, such as mine facilities, roads, and the White Mesa mill, which is currently in operating condition. There would be some need for road maintenance and improvement; however, most mining activity will occur in previously disturbed areas within historical mining districts. Some development and exploration drilling may occur to define the extent of known deposits and to test favorable areas within mining districts. New surface disturbance from this activity is estimated to average 20 acres per year for a total of 300 acres over the life of the plan.

6.2.2 Placer Gold

The existing small placer gold mining operation in Recapture Creek will continue to operate for some period during the next 15 years. This operation consists of excavation of gravel utilizing a small dozer and front-end loader, screening, concentrating with a sluice box system, and settling ponds. Total acreage of surface disturbance associated with the operation over the next 15 years is anticipated between 5 and 10 acres. The BLM Monticello Field Office has recently accepted a Notice of Intent to Conduct Exploration consisting of a few backhoe trenches on a small site in Johnson Creek. If testing is favorable then a second small-scale operation, similar to the Recapture Creek operation, can be expected.

6.2.3 Limestone

The primary area for future limestone development is a 200 to 300 acre site on Lime Ridge. Based on previous project proposals, additional drilling can be expected with the possibility of a quarry operation and screening facility. The operation would likely be similar to the Cotter operation located in Lisbon Valley. That operation consists of an open pit mine involving drilling, blasting, and a front-end loader for ore removal to a jaw crusher. The product goes over a ½-inch screen to remove fines and then is stacked for delivery (Gloyn and others, 1995; Reed, 1996). Production at this site is estimated from 20,000 to 30,000 tons per year. Total surface disturbance for the mine and facilities over the next 15 years is estimated to be 20 to 50 acres.

6.3 <u>Salable Minerals</u>

6.3.1 Sand and Gravel

Development of sand and gravel deposits in the MtPA is anticipated to occur over the next 15 years, primarily in proximity to travel corridors and communities where these commodities will be used for maintenance and building purposes. A review of BLM's LR 2000 records indicates that in the last 15 years, there have been 57 authorizations made for mining of sand and gravel in the MtPA for a cumulative total of 1.9 million cubic yards (BLM, 2004). This would amount to about 4 permits per year for the next 15 years and an average of 127,000 cubic yards per year. Surface disturbance is estimated from 2 to 10 acres for each authorization for mining and access, resulting in roughly 24 acres of surface disturbance per year for a total of 360 acres over the life of the plan. Map 19a shows those areas where historic production has occurred, and it is projected that these areas will continue to see most of the new production over the next 15 years.

6.3.2 Building Stone

There have been 7 authorizations for the mining of building stone in the MtPA given by the BLM in the last 15 years for a cumulative production total of approximately 130 tons (BLM, 2004). However, most of the production in the MtPA has occurred on unpatented mining claims, 6 of which are recorded with the BLM. This averages to just one authorization every year over the past 15 years. Based on this average, it is projected that approximately 15 authorizations will be given for the recovery of building stone in the MtPA over the next 15 years. Each authorization will involve a quarry operation utilizing drilling, breaking, loading, and hauling. Total surface disturbance for an operation is estimated from 5 to 10 acres, equating to roughly 113 acres of disturbance over the next 15 years. Map 20a shows those areas where historic production has occurred, and it is projected that these areas will continue to see most of the new production.

6.3.3 Clay

The exploration and production of clay in the MtPA since 1989 has reportedly occurred under 6 separate authorizations totaling 550,000 cubic yards of clay (BLM, 2004). This averages just less than 1 authorization and 92,000 cubic yards every two and a half years over the past 15 years. It is projected that another 6 authorizations will be given for exploration and mining of clay over the next 15 years. A typical operation consists of surface mining with a front-end loader and a truck for haulage. Surface disturbance for each authorization is estimated from 1 to 5 acres, equating to roughly 18 acres of disturbance over the next 15 years. Map 21a shows those areas where historic production has occurred, and it is projected that these areas will continue to see most of the new production over the next 15 years.

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