GEOLOGIC REPORT

Rev. 0 **Date: 06/09/09**

IN SUPPORT OF THE APPLICATION FOR A LICENSE FOR SOURCE MATERIAL MILLING

PIÑON RIDGE URANIUM MILL
Montrose County, Colorado

Submitted to:

Radiation Management Unit
Colorado Department of Public Health and Environment

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1.0 INTRODUCTION

Energy Fuels Resources Corporation (EFR) proposes to license, construct, and operate a conventional acid leach uranium and vanadium mill at the Piñon Ridge Mill site (the Site) in western Montrose County, Colorado. Site facilities will include an administration building, a 17-acre mill, tailing ponds totaling 90 acres, an 80-acre evaporation pond, a 5-acre ore storage pad, and an access road. The mill will process ore produced from mines within a reasonable truck-hauling distance. The mill will process up to 500 tons of ore per day but is designed to accommodate subsequent expanded production capacity of up to 1,000 tons per day. The expected operating life of the mill is 20 to 40 years.

The Piñon Ridge Mill is subject to regulation by the State of Colorado, and the mill license (Radioactive Source Material License) will be issued and administered by the Colorado Department of Public Health and Environment (CDPHE). The activities described in this document were performed by Kleinfelder as part of the geologic baseline characterization required for the Environmental Report (ER) in accordance with Section 3.8.8, Part 3, 6 CCR 1007-1 (Colorado Department of Public Health and Environment, 2001) and NUREG 1748 (NRC, 2003).

1.1 Site Location and Description

The proposed Piñon Ridge Mill (Site) is located in the Paradox Valley at 16910 Highway 90, approximately 14 miles west of Naturita in Montrose County, Colorado. The Site's legal description is the Southwest ¼ of the Southeast ¼ of Section 5, all of Section 8, the North ¼ of Section 17, and the Southeast ¼ of the Northwest ¼ of Section 17, Township 46 North, Range 17 West, of the New Mexico Principal Base and Meridian. The Site is located on both the Davis Mesa Quadrangle (1955/1994) and Bull Canyon Quadrangle (1954/1994) 1:24,000 United States Geological Survey (USGS) geologic/topographic maps. The general location map is presented in Figure 1.

The Site consists of 880 acres on the south side towards the eastern end of the Paradox Valley. Elevations across the Site range from approximately 6,020 feet above mean sea level (amsl) on the lower flank of Davis Mesa to the south to approximately 5,420 feet amsl near the center of Paradox Valley to the north. As shown in the site layout map, Figure 2, the majority of the site is relatively flat with less than 200 feet of relief from south to north and is crosscut by minor, ephemeral arroyos or washes.

The primary historic land use has been grazing. Land use adjacent to the Site includes mining, oil and gas exploration and production, timber harvesting, recreation, and grazing. Current and past mining activities have occurred to the southwest and southeast of the Site.

2.0 PURPOSE AND SCOPE

The purpose of this baseline report is to characterize the geology of the site for inclusion in the Environmental Report in accordance with CDPHE and NRC guidance (NRC, 2003). The baseline study includes a description of the regional geology, the local geologic stratigraphy, and structures, seismicity, and geologic hazards or conditions of potential concern at the Site. The scope included a literature review, aerial photograph interpretation, site reconnaissance and geologic mapping, subsurface exploration using trenching, geologic boreholes, and geophysical surveys, radiometric age dating, and data review and evaluation.

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3.0 METHODS

3.1 Geologic Mapping

Prior to the commencement of field reconnaissance and geologic mapping, a literature review was conducted in databases of the United States Geological Survey (USGS), the Colorado Geological Survey, the New Mexico Bureau of Mines and Mineral Resources, and other available public sources. In addition, aerial photographs of the area were obtained and reviewed to assist in the identification of larger scale geologic features.

Geologic mapping was conducted in August 2007 on a topographic base map using a scale of 1 inch = 200 feet and a contour interval of 2 feet. Geologic mapping was conducted according to those practices generally accepted by industry and outlined in Compton (1962) and Keaton (1984). Soils were classified according to the Unified Soil Classification System (USCS). The geologic mapping was conducted in accordance with the Geological Investigations Work Plan (Kleinfelder, 2007).

Supplemental geologic reconnaissance and mapping was conducted in December 2008 in the northern half of the Site and on the adjacent property to investigate potential sinkholes and karst features north of the Site. The investigation included field reconnaissance of an observed sinkhole north of the Site's boundary, field observations of multiple circular-shaped clearings observable in aerial photographs, and reconnaissance of the contact between the alluvial valley fill deposits to the south and the weathered surface of the Paradox member of the Hermosa Formation to the north. The work was conducted in accordance with Amendment No. 2, Geological Investigations Work Plan (Kleinfelder, 2008e).

3.2 Geophysical Surveys

A combined refraction and reflection geophysical survey was conducted in 2007 along three lines (S1 – west portion of the Site; S2 – central; and S3 – east) oriented roughly north-south across the site to detect bedrock faults, to determine if faults could be detected in the Quaternary deposits, and if any evidence could be obtained regarding groundwater in the area. The refraction and reflection system utilized an accelerated weight-drop source ("thumper") and a "land streamer" receiver array to produce 12-fold shallow reflection seismic and multi-fold refraction coverage along the three lines. The thumper used was a Gisco ESS-100 elastic wave generator capable of introducing 1,000 foot pounds of energy into the earth. Twelve receivers or geophones were spaced 32.8 feet apart along the land streamer or cable in a linear serial array 393.6 feet long. The seismic survey methodology and results are summarized in a technical report to Kleinfelder by Geological Associates (2007) and presented in Appendix A.

In addition, two pilot tests using different geophysical methods were conducted in February and March 2008 to further investigate an anomalous soil feature identified in the wall of Trench 2. Both pilot tests were conducted in the immediate vicinity of the soil feature. The first pilot test was conducted using electrical conductivity to determine if the method would be capable of detecting the soil feature. The survey covered an area approximately one acre in extent using a Geonics Ltd. EM-31 ground conductivity meter and a GSSI EMP-400 Profiler. The EM-31 samples to a depth of approximately 18 feet, while the EMP-400 instrument samples to a depth of approximately 6 feet. The soil feature did not have sufficient lateral contrast in soil properties to the surrounding materials to generate a mappable conductivity feature.

A second pilot study was undertaken using direct current (DC) resistivity and transient electromagnetic (TEM) methods to determine if the Paleozoic bedrock (top of bedrock below the

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soil) could be readily detected at depth. The DC resistivity soundings were acquired using an AGI miniSting resistivity meter and a Wenner electrode configuration. The TEM soundings were acquired with a Geonocs Protem 47D system and Protem high-frequency receiver. The pilot test was conducted in areas where the bedrock was relatively shallow at approximately 35 to 40 feet bgs based on nearby boreholes. Both the resistivity and TEM methods did detect the bedrock at about the expected depths and it was concluded that these methods, singly or in combination, would be suitable for detecting subsurface bedrock in areas of critical concern. The work was performed in accordance with the Work Plan for Additional Geophysical Investigations (Sunbelt Geophysics, 2008a). The results of the two pilot tests are provided in Appendix B (Sunbelt Geophysics, 2008b).

3.3 Trench Excavations

Exploration trenches 1, 2, and 3 were excavated and mapped in December 2007 over the areas of possible subsurface faults inferred from the seismic refraction and reflection surveys. The purpose of the trench excavations was to assess if fault rupture or displacement has occurred in the near-surface Quaternary deposits in those areas overlying the inferred faults. The trenches were excavated using a track-mounted excavator from 4 of 8 feet deep and from 600 feet (Trench 3) to 1,300 feet (Trench 1) in length. The vertical walls were scraped to expose soil layers and boundaries and were carefully examined for evidence of deformation and/or fault traces. Trench logs/maps were prepared at a scale of 1 inch = 5 feet. Selective soil and/or rock samples were collected from the trenches and sample locations were indicated on the logs and surveyed with a hand-held global positioning system. The trench mapping was completed in accordance with the Geological Investigations Work Plan (Kleinfelder, 2007)

During the trench mapping activities, organic samples were collected for radiocarbon analysis to help in establishing the ages of the surficial alluvial deposits. Samples were taken from the trench walls using a trowel or small scoop without being handled by bare hand and placed into double zip-lock plastic bags for storage in a cooler for preservation. Fragile samples were wrapped in aluminum foil for additional protection and placed inside the zip-lock bag. All sample containers were labeled with date, time, and depth collected. Sample descriptions were recorded in the field book and/or on the daily field report. The radiocarbon analysis methodology and results prepared by the Paleo Research Institute, Inc. are provided in Appendix C.

During mapping of the trench face in Trench 2, an anomalous soil discontinuity feature was identified in the wall of the trench. Several supplemental investigations were undertaken to further understand the origin and extent of this soil discontinuity feature. Trenches 2a and 2b were excavated in May 2008 to expose and further investigate the feature; four boreholes were continuously sampled in October 2008 to depths from 72 to 92.5 feet below ground surface (bgs) to determine if the bedrock beneath the site showed evidence of karst or subsidence features; and additional geophysical surveys were conducted over this soil feature as discussed in Section 3.2. In total, the trenches totaled approximately 3,150 feet of linear excavation.

3.4 Boreholes

Several drilling programs were conducted at the Site for purposes of geotechnical characterization, groundwater characterization and monitoring, general site exploration, and water resources development. These included:

- Phase 1 geotechnical investigation (PR-series borings) consisting of 20 borings to develop the initial geotechnical characterization for the Site facilities (Appendix D);

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- Phase 2 geotechnical investigation (TB-, PB-, and GA-BH-series borings) consisting of 73 borings advanced jointly by Kleinfelder (Kleinfelder, 2008f) and Golder Associates, Inc. (Golder, 2008a) to support additional geotechnical characterization and design of the Site facilities;

- Nine groundwater monitoring wells (MW-series borings) drilled by subcontractors under Kleinfelder's supervision to provide sampling points for the baseline characterization of groundwater quality (Appendix D);

- Eighteen borings (EX-series borings) drilled under EFR supervision for geological characterization and as a preliminary phase of the water resources investigation (Appendix D);

- Three production wells and six observation wells (PW-series borings) installed by drilling subcontractors under Golder's supervision to investigate the available water resources for the proposed Site facilities (Golder, 2008b); and

- Four additional borings advanced by a drilling subcontractor under Kleinfelder's supervision to assess the stratigraphic discontinuity identified in Trench 2 (Appendix G).

Geotechnical and stratigraphic discontinuity drilling consisted of continuous core or hollow stem auger drilling to identify soil types, depth to bedrock, and evidence of recent fault movement or voids. These borings were generally advanced to depths of less than 100 feet. Coring in the bedrock was typically performed using wet coring methods. Samples of unconsolidated sediments were collected by split spoon sampling methods. Core samples were collected from borehole intervals selected by the rig geologist to be representative of lithologic units and stratigraphic/formational boundaries.

Groundwater monitoring wells, production wells, observation borings, and EX borings were drilled to depths of up to 1,020 feet using air rotary or down-the-hole hammer methods. Cuttings were collected from discrete intervals and logged by the rig geologist according to lithologic units and stratigraphic/formation boundaries. Representative samples were collected in chip trays for archival preservation.

4.0 RESULTS

4.1 Regional Geology

The Site is located in the Paradox Valley within the Canyonlands Section of the Colorado Plateau Physiographic Province (Cater, 1954). The Colorado Plateau Physiographic Province consists of a broad area covering parts of Utah, Colorado, New Mexico, and Arizona, and is dominated by largely horizontal stratigraphy and deeply incised drainages. It is characterized by mesas, plateaus, deep canyons, pediments, barren badlands, and mostly arid climatic conditions (Hunt, 1967).

Within the Colorado Plateau, the Paradox Valley lies in the eastern part of the ancestral Paradox Basin, a vast basin approximately 200 miles long (northwest-southeast) by 80 miles wide (northeast-southwest) (Figure 3). The Paradox Basin formed adjacent to the southwestern bounding faults of the Uncompahgre uplift as a complimentary faulted depression. Within this basin, thick beds of black shale, dolomite, anhydrite, and salt of the Paradox member of the

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Hermosa Formation were deposited in Pennsylvanian time some 300 million years ago as the ancestral Paradox Basin subsided and the ancestral Uncompahgre highland was elevated. Deposition of the Paradox member was thickest in the northeastern part of the ancestral basin near the present day Uncompahgre Plateau (Chenoweth, 1987).

Shortly after their deposition, the thick interbedded salt deposit of the Paradox Formation began to rise diapirically and flow plastically primarily along northwest trending faults in the basin floor (Chenoweth, 1987). The result was a series of northwest trending, elongated salt diapirs in present day east-central Utah and west-central Colorado. This broad region, termed the "Paradox fold and fault belt" by Kelley (1955), is distinctive in its structural features and origin. The rising salt cores resulted in a number of northwest-trending salt-cored anticlines and intervening synclines. The structures formed following deposition of the thick sediments in the basin during the Pennsylvanian through Permian periods roughly 320 to 250 million years ago.

As these geologic structures were forming, they influenced the depositional nature of the younger, post-Paradox and pre-Morrison formations deposited during the Late Pennsylvanian through Jurassic periods. The deposits immediately overlying the Paradox Formation in the region, the Honaker Trail and the Cutler Formations (Pennsylvanian/Permian), were tilted and thinned along the flanks of the rising salt diapirs. Upwelling of the salt continued through the Triassic period and into the Jurassic period but the process slowed as the salt supply from the adjacent synclines was largely depleted. Consequently, the overlying, younger formations were less affected by the salt movement as the diapirs stabilized. The formations were eventually covered by deposition of up to 5,000 feet of younger Late Jurassic and Cretaceous formations that were deposited across the upturned and truncated edges of the older formations (Chenoweth, 1987). Regional compression during the Laramide orogeny (Late Cretaceous to Paleogene time) accentuated these structures

Broad uplift of the Colorado Plateau during the middle to late Tertiary, roughly 38 million to 2 million years ago, resulted in erosion and increased groundwater circulation across the region that allowed groundwater to reach the upper parts of these salt diapirs through fractures and joints in the anticlines (Chenoweth, 1987). The resulting dissolution of the salt caused collapse and removal of the anticlinal crest. These dissolution features have been active during Quaternary time and may be active today. However, because they result from very gradual processes of salt dissolution, they are not likely capable of generating earthquakes.

The Paradox Valley is one of the largest of these collapsed salt anticlines in southwestern Colorado and southeastern Utah. The Paradox Valley obtains its name from the anomaly that the Dolores River crosses perpendicular to the valley axis, although there is no river coursing through the valley (Cater, 1955b). According to Chenoweth (1987), the Paradox Valley anticline probably began at the point where the antecedent Dolores River eroded a channel across the anticlinal crest. The canyon cut by the Dolores River exposed the salt to rapid dissolution and removal and collapse of the anticlinal crest began. The ancestral east and west Paradox creeks removed materials from both the core and the crest during the process of headward erosion. Cater (1970) has estimated that the upper surface of the salt core of the anticline in the Paradox Valley was at least 3,000 feet higher than the present day valley floor. The salt core in the Paradox Valley is exceptionally thick. An oil well drilled 1.5 miles north of Bedrock penetrated the base of the salt at 14,670 feet bgs (Chenoweth, 1987).

Structurally, the Paradox Valley is a graben formed by the collapsed and eroded anticline structure bounded on the northeast and southwest by a series of normal faults (Widmann, 1997). A regional geology map is presented in Figure 4; regional geologic cross-sections are presented on Figure 5. The oldest rocks exposed in the vicinity of the Site belong to the

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Paradox member of the Hermosa Formation (Cater, 1955a). These oldest rocks are found in the middle of the valley, while younger rocks of Triassic and Jurassic age bound the slopes on the southwest and northeast sides of the valley. Triassic-age rocks include the Moenkopi Formation and the Chinle Formation. Jurassic-age rocks include the Wingate Sandstone, the Kayenta Formation, the Navajo Sandstone, and the Morrison Formation (Cater, 1954). Uranium-vanadium deposits occur in numerous locations in the Salt Wash member of the Jurassic Morrison Formation. Holocene deposits of eolian sands and sheet wash are widely distributed on the valley floors, along the benches, and on top of the mesas (Cater, 1954).

Volcanic rocks do not occur within the region. The nearest volcanic rocks occur at the western margin of the San Juan volcanic field, which includes several calderas and is located approximately 60 miles east of the Site.

4.2 Site Geology

The Site is located along the south side of the eastern end of Paradox Valley. The site geology observed during the course of these investigations is consistent with that reported in the literature by others (Cater, 1954, 1955b: Nuccio and Condon, 1996; Widmann, 1997). The Paradox Valley is a graben formed by the collapse and erosion of an anticline with an intrusive salt and gypsum core bounded on the northeast and southwest by a series of normal faults. The south-southwest part of the Site is underlain by bedrock along the lower flank of Davis Mesa. As shown in Figure 5, rocks exposed south of the Site on Davis Mesa include the Triassic Chinle Formation, the Jurassic Wingate Formation, Kayenta Formation, Entrada Formation, Summerville Formation, and the Salt Wash and Brushy Basin members of the Morrison Formation.

The majority of the Site is directly underlain by late Quaternary deposits of fine-grained alluvium and eolian (wind-blown) deposits with intermixed gravelly alluvial stream channel deposits. These sediments overlie the sandstone and siltstone of the Chinle Formation, sandstone of the Wingate Formation, and the shales and evaporites of the Hermosa Formation. The Hermosa Formation forms the core of the salt diapir that runs the length of the valley. Minor alluvial stream deposits are confined to the ephemeral arroyo or wash channels that drain across the site and terminate near the middle of the valley north of the site. The surficial geology of the Site is presented in Figure 6. The location of the seismic survey lines, trenches, and selected borings are shown in Figure 7. Geologic cross-sections across the Site are presented in Figures 8 and 9.

4.2.1 Surficial Geology - Quaternary Sediments

The majority of the Site is located on the floor of the Paradox Valley and is underlain by deposits of unconsolidated late Quaternary eolian (wind blown) and alluvial sediments. Because the deposits are derived from the surrounding sandstone and shale bluffs, they are primarily fine-grained mixtures of sand, silt, and clay with occasional gravel interbeds. The Quaternary valley fill materials identified in the geotechnical boreholes consisted primarily of light brown to brown interbedded silty sand (SM) and sandy silt (ML) with occasional interbeds of sandy and silty clay and lean clay (CL). Fine to coarse gravel and cobble-sized materials occur in discontinuous layers and lenses in the sediments or may be intermixed with the finer-grained sediments. The coarser alluvial material represents alluvial detritus deposited as sheet wash or in small channels similar to the channel deposits on the surface today. Some of the beds were weakly to moderately cemented with calcareous material.

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The thickness of the Quaternary deposits varies across the site. The alluvial sediments pinch out against the bedrock to the south, thicken up to 140 feet thick beneath the mill and Tailing Cells A and B, and thin to the north near the center of the valley where the Hermosa Formation surfaces.

The Site is covered by an eolian deposit of light brown to brown fine-grained sand (Unit E(cs)c-s in Figure 6) with silt and clay. Laboratory test results of this material sampled from geotechnical boreholes classified this material as silty sand (SM) and sandy silt (SM). Minor alluvial stream deposits of loose sand (Units A(s)c-g; A(s)m-g, A(s)m-b; A(s)c-s) intermixed with clay to boulder size fragments occur along ephemeral stream or wash channels that drain across the Site from south to north. In the northern portion of the Site and outside the footprint of the facilities, the channels occasionally transition into alluvial floodplain deposits of fine-grained sand with intermixed gravel, silt, and clay (Units A(fp)c-c, A(fp)m-p). Alluvial fans (Unit A(f)m-b) draining from the adjacent mesa occur along the margins of the slopes southwest of the Site. Colluvial soils (Unit C(sw)m-b) cover areas of the bedrock along the southwest part of the Site. An area containing residual soils developed over the Paradox member of the Hermosa Formation (Unit R(w)m-b/LS) was mapped on the northeast portion of the site. Within the Site boundary, areas of man-made fill are shown as Units F(u)c-s, F(u)m-g, and F(u)m-k. The Unit F(u)m-g was mapped along State Highway 90. Units F(u)c-s and F(u)m-k were limited to small berms built across the dry washes to collect runoff. Adjacent to the southeast corner of the Site boundary is Unit F(u)m-k, which represents overburden from the Cotter mine.

The soils at the surface of the Site are classified by the NRCS Web Soil Survey (USDA, 2008) as Barx, Vananda, Begay, Mikim, Paradox, and Gypsiorthids Series. The majority of the soils (71.6 %) are classified as fine sandy loam (USDA, 2008) with typical hues in the 5YR (middle of the yellow-red hue) range (MacBeth, 2000). The USDA (2008) and USACE (2006) literature did not identify hydric soils as being present at the Site. Hydric soils are those soils formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part of the soil horizon. A more complete description of soils at the Site from an agronomic perspective is presented in the Soil Survey (Kleinfelder, 2009a).

Three trenches were excavated and mapped in December 2007 to characterize and to evaluate the potential surface fault rupture related to faults inferred by the shallow seismic refraction and reflection surveys. As shown in Figure 7, Trenches 1 and 3 were excavated in the vicinity of the proposed mill location and Trench 2 was excavated in the proposed tailing cells area. Geologic maps of the trench walls are presented in Appendix E. The results of the trench mapping demonstrated that the late Quaternary soil layers were laterally continuous over the Site and undisturbed by any surface fault displacement over the inferred faults.

Five soil units were identified in the trenches. The soil units exposed were assigned Soil Units 1 (oldest) through 5 (youngest). All of the units were laterally continuous and are relatively uniform in thickness across the length of the trenches, except for a localized soil discontinuity feature identified in Trench 2 and mapped as Soil Unit 3 (this soil feature is discussed in more detail below). Nomenclature assigned to the stratigraphy exposed in the trenches was based primarily on the identification of carbonate soil horizons in Soil Units 1 and 2. These soil units contain the primary carbonate marker horizons and consist of a stage II to II+ carbonate accumulation in a clay and/or silty fine-grained sand matrix.

The soil units are described below from the oldest (bottom of the trench) to the youngest (top of the trench or surface layer):

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Soil Unit 1 - reddish-brown to light reddish-brown silt to clay (ML/CL), dry, very stiff, massive, with the upper surface cemented to stage II soil calcium carbonate accumulation (Machette, 1985) and particles fining upward. The contact between the Soil Unit 1 and the overlying Soil Unit 2 appears to be an erosional/depositional contact. The top of Soil Unit 1 was observed in Trenches 1 and 2 only at a maximum depth of approximately 5 feet. The bottom of Soil Unit 1 was not observed in the trenches. Its projected soil age is mid-Pleistocene based on the buried stage II soil calcium carbonate development. The Soil Unit was laterally continuous, and evidence of faulting was not observed in this soil unit.

Soil Unit 2 - light reddish-brown, silty clay to silty fine sand (SM/CL), dry, stiff to dense, massive, also with the upper surface cemented to stage II+ soil calcium carbonate accumulation (Machette, 1985) and traces of sub-rounded gravel with particles fining upward. Locally, the unit contained gravelly lenses and beds. Soil Unit 2 was observed to be laterally continuous throughout the trenches up to a maximum thickness of approximately 7.5 feet with the exception of a funnel-shaped stratigraphic discontinuity that truncated the unit at the north end of Trench 2 in the vicinity of Trench Station 550 (see Figure 18 in Appendix D). This feature is identified as Soil Unit 3. Soil Unit 2 resumes laterally on either side of this feature with no indication of deformation, vertical offset, or shear structures typical of faulted soils.

Soil Unit 3 - brown silty fine sand (SM), dry, medium-dense, massive with traces of angular gravel and broken carbonate soil aggregates. Soil Unit 3 was a localized funneled-shaped deposit observed in Trench 2 only. Its width at the top of the unit was approximately 15 feet narrowing rapidly to the bottom of the trench. Its overall thickness was approximately 5 feet. The surface of Soil Unit 3 is truncated by and overlain by Soil Unit 4. This feature appears to be a result of surficial processes such as channel erosion and backfilling or bioturbation rather than a bottoms-up geologic process such as karst subsidence or fault rupture, as discussed below.

Soil Unit 4 - reddish-brown, clayey silty sand to fine sand (SM/SP), moist, medium-stiff, and massive eolian cover sand deposits. A thin soil A-Horizon with plant root systems has developed in the upper part of this unit. Soil unit 4 was observed in each trench at a maximum thickness of approximately 5 feet. The contact between the underlying Soil Unit 2 and Soil Unit 4 was an erosional/depositional surface. Locally, Soil Unit 4 filled eroded channel-like depression cut into Soil Unit 2. Based on Archaic age artifacts found on the surface of the Site, Soil Unit 4 is projected to be at least 2,000 years old and possibly as much as 11,000 years in age (ERO Resources, 2007).

Soil Unit 5 - reddish-brown to dark brown, clayey to fine sand (SM/SP), moist, soft, clay and sand is an interbedded sheet flow deposit. Soil Unit 5 overlies the soil A-Horizon of Soil Unit 4 and was observed in Trench 1 only at a maximum thickness of 1.5 feet. Because Soil Unit 5 overlies the soil A-horizon of Soil Unit 4. Soil Unit 5 is believed to be contemporary in age.

To date the age of the soils, charcoal and root tissue samples were collected from Soil Unit 2 in Trench 1 using accelerated mass spectrometry (AMS) radiocarbon age dating techniques. In addition, bulk soil samples from Soil Units 2, 3, and 4 in Trench 2 were collected and submitted for macro-floral remains search and radiometric dating. The dates varied from modern to 4,035 ±15 years before present and it was concluded that the samples did not appear to be indicative of the primary depositional ages of the soil units (Appendix C). The dates may be used as minimum limiting dates documenting the age of plants that occupied the soils during the past,

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but probably have no relationship to the primary depositional age of the soil units in which they occur. Kleinfelder observed very little in terms of megascopic samples in the trenches that could potentially represent the soil units in a primary context. The soil units are thought to be much older than the radiometric ages reported based on relative indices, including thickness of the eolian deposits of Soil Unit 4, the occurrence of Archaic age artifacts on the surface of Soil Unit 4 (ERO Resources, 2007), and the thickness of calcium carbonate accumulations observed in Soil Units 1 and 2. These facts suggest that Soil Unit 2 may be Sangamon age (75,000 to 125,000 years before present), or mid- to late-Pleistocene equivalent age based on the relative duration of soil stability required to produce a stage II to II+ carbonate accumulation, the truncation of the upper surface of this unit, and the geo-archeological context of artifacts found on the surface of the site.

Additional investigations were conducted to more fully assess the lateral extent and the origin of the stratigraphic soil discontinuity feature identified in Trench 2. The investigations included completion of pilot tests (February/March 2008) using electromagnetic ground conductivity survey and transient electromagnetic soundings and/or direct electrical surveys, excavation of two additional trenches (May 2008) to examine the feature's lateral extent, and drilling of four boreholes (October 2008) to assess if the bedrock below the feature showed signs of dissolution processes. The locations of the additional trenches and the four borings are provided in Figure 10.

Geophysical Pilot Tests - The two pilot geophysical surveys conducted by Sunbelt Geophysics (Appendix B) were conducted to determine if: 1) shallow conductivity surveys could readily detect the soil feature and then be used to map this and similar features without extensive trenching, and 2) deeper bedrock features could be detected using direct current (DC) resistivity and transient electromagnetic (TEM) methods. The near-surface ground conductivity survey was conducted directly over the soil feature. No subsurface expression of the soil feature was found in the ground conductivity survey. It was concluded that the soil feature observed in the trench did not have sufficient lateral contrast in soil properties to generate a recognizable conductivity feature. The DC resistivity and TEM methods showed these methods to be effective in assessing the continuity of the underlying bedrock surface. The survey did not reveal any voids in the bedrock surface indicative of dissolution or collapse.

Trenching - Trenches 2-B and 2-C were excavated approximately 40 feet to the east and west of the feature. The trenches were aligned generally north to south on the east (Trench 2-B) and west (Trench 2-C) side of Trench 2 and perpendicular to the axis of the faults inferred from the seismic surveys conducted across the Site. The trenches were excavated to depths ranging from 8 to 12 feet with benched 4-foot riser and tread configurations. The trenches were logged continuously with the same guidelines used for Trenches 1 through 3. The results of the additional trench mapping are presented in a Kleinfelder Technical Memorandum (2008a) included in Appendix F.

No evidence of the anomalous soil discontinuity feature was found in Trenches 2-B and 2-C, indicating that the feature is localized and not indicative of large-scale geologic dissolution processes. The feature itself had no expression on the ground surface and was only observable in the face of Trench 2. The soil feature is truncated by and overlain by Soil Unit 4, indicating that it formed prior to deposition of Soil Unit 4. In Trench 2-B, the base of uppermost Soil Unit 5 had eroded or channeled through the upper Soil Unit 2 carbonate horizon into the lower Soil Unit 1 carbonate horizon. This was similar to the soil relationships observed in the stratigraphic discontinuity feature in Trench 2. Trench 2-B was excavated to 12 feet in this zone to show that the younger soils did not fully

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penetrate the lower Soil S-1 carbonate horizon. Based on these observations, Kleinfelder concludes that the occurrence of the younger soils penetrating the carbonate horizons is not the result of a bottoms-up phenomenon such as dissolution or fault rupture, but is likely related to surficial processes such as erosion or channel development and backfilling.

Boreholes - Four boreholes were advanced into the underlying bedrock in the immediate vicinity of the anomalous soil feature. The soil was continuously sampled from the surface to bedrock using a dry core barrel; a HQ rock core barrel was used to sample the bedrock. As shown in Figure 10, boring GB-1 was located 160 feet north of the feature near the north end of Trench 2, boring GB-2 was located over the feature, boring GB-3 was located 40 feet south of the feature, and boring GB-4 was located 465 feet south of the feature near the south end of Trench 2. Boreholes GB-1, GB-2, and GB-3 encountered silty sand and sandy silt alluvial materials to depths of 26 to 37 feet bgs underlain by bedrock of light green claystone transitioning at depth to brown clay and gypsum bedrock of the Hermosa Formation. The uppermost geology in GB-4 was similar to the others boreholes except it encountered yellow brown weathered claystone at depth. The bedrock encountered in GB-2, which was drilled directly over the anomalous soil feature, was similar to that found in the other boreholes. The continuity of the bedrock beneath the soil feature of interest indicates that the area is not underlain by a larger-scale sinkhole. Indications of subsidence, dissolution, or faulting were not observed in the drill cores as described in a Kleinfelder Technical Memorandum (2009c) included in Appendix G.

Based on the results of these additional investigations, the anomalous soil feature most likely appears to be related to surficial geologic processes, such as channel erosion and backfilling, and does not appear to present a concern to the design or construction of the facility.

4.2.2 Bedrock Geology

Outcrops are limited to the southwest part of the Site along the slopes of Davis Mesa (Figure 6). Rocks exposed in this area of the Site include interbedded siltstone, sandstone, shale, and conglomerate of the Triassic Chinle Formation and sandstone of the Jurassic Wingate Formation. Rocks encountered in drill holes below the unconsolidated Quaternary sediments include the Moenkopi, Chinle, and Wingate Formations underlain by the Pennsylvanian Paradox member of the Hermosa Formation (Figures 8 and 9). The Cutler Formation was not penetrated in any of the boreholes and appears to be absent at the Site. The weathered surface of the Hermosa Formation is exposed in the valley floor north of the Site.

The south end of the Site contains a sequence of buried bedrock from oldest (lowermost unit) to youngest (uppermost unit) that includes the Paradox member of the Hermosa Formation, the Moenkopi Formation, the Chinle Formation, and the Wingate Formation. To the north beneath the Site, the Wingate, Chinle, and Moenkopi Formations do not occur and the Hermosa Formation directly underlies the Quaternary sediments. The absence of the Moenkopi, Chinle, and Wingate Formations towards the axis of the valley is a result of the uplift of the salt diapir, collapse due to subsequent dissolution of the underlying evaporates, and erosion of the sedimentary rock, which is characteristic of the entire Paradox Valley.

The Paradox member of the Hermosa Formation consists of interbedded dark brown to dark gray to black shale, white to dark gray anhydrite, white to gray gypsum with minor amounts of carbonaceous limestone, siltstone, and sandstone. Occasionally, the cuttings had a strong sulfur odor. The Paradox member underlies the entire Site at depth and is exposed at or near

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the surface in the floor of the Paradox Valley north and northwest of the Site. All known surface occurrences of the Paradox member are the exposed remnants of the salt diapirs and the beds are typically highly folded and contorted. The undisturbed thickness of the member is not known (Cater, 1954). At depth, Cater (1954) reports that more than half the formation is composed of rock salt, although none of the boreholes encountered rock salt at the Site. The Paradox member does not contain groundwater at the Site.

Because the Hermosa Formation is composed of evaporites that are prone to dissolution and karst development from groundwater, additional investigations and mapping were conducted along the north and east margins of the Site where the Hermosa Formation is near the surface or is exposed. The area covered in these additional investigations is shown in Figure 10. A single sinkhole was identified in the weathered surface of the Hermosa Formation just north of the Site boundary (Figures 6 and 10). The sinkhole was approximately 5 feet in diameter and 4 feet deep with halite (salt) intermixed with soil in the walls. Kleinfelder conducted aerial photography analyses of the northern part of the Site and adjacent areas and identified numerous circular features northeast of the Site (see Figure 10) that were potentially related to sinkholes or karst dissolution in the Hermosa sedimentary or evaporite rocks. The locations of these features were recorded in GPS coordinates and observed in the field. Thirty five of the circular features identified in the aerial photography analysis were assessed. These circular features consisted of either circular- shaped clearings surrounded by sage brush or small soil mounds populated by strong cryptogamic soil development; they were not indicative of surface dissolution.

Additional surface reconnaissance was also conducted along the northeastern boundary of the Site to identify the general area underlain by the Hermosa Formation to the north and the alluvial sediments to the south in order to determine if sinkhole features could be associated with the surficial geology. As shown in Figure 6, the cross-hatched area along the northeastern boundary of the Site depicts the Hermosa Formation exposed at the surface as outcrops of weathered gypsum {R(w)c-g/GY} or limestone {R(w)m-b/LS} or covered by a thin veneer of eolian deposits as indicated by the residual gypsum or limestone clasts observed on the surface. The area south of this cross-hatched area is underlain by the alluvial sediments that thin to the north along this contact. Based on this surface reconnaissance, the single sinkhole identified north of the Site is within the area underlain by the Hermosa Formation. No sinkholes features were identified in the alluvial sediments along and to the south of this contact.

The Triassic Moenkopi Formation overlies the Hermosa Formation and consists of three members, however, only the upper member has been identified in boreholes at the Site. The upper member consists of interbedded sandstone, siltstone, and mudstone. The color varies from light gray to buff to brown and reddish-brown. In general, the sandstone is very fine grained to fine grained. The top of the Moenkopi is occasionally recognizable by a clayey paleosol. Based on data from the boreholes at the Site, the Moenkopi is up to 200 feet thick beneath the western part of the Site and thins to the east. The Moenkopi and Chinle Formations do not occur north of the buried fault zone defined by faults #4, #5, and #6 (see Figures 7, 8, and 9).

The Upper Triassic Chinle Formation overlies the Moenkopi Formation beneath the Site and consists of interbedded red to orange-red siltstone and fine-grained sandstone with interbeds of reddish-brown shale and pebbly conglomerate. The Chinle appears to be up to 400 feet thick in the boreholes at the Site.

The Jurassic Wingate Formation overlies the Chinle Formation and is a fine-grained, massive, light brown to buff colored sandstone composed of well-sorted quartz sand. The Wingate

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Formation was deposited in an eolian environment. Its presence is limited to the southwestern part of the Site along the slopes of Davis Mesa. The Wingate Formation attains a maximum thickness of 325 feet in the Davis Mesa Quadrangle (Cater, 1955b).

4.3 Structure

The Site is located within the graben that forms the Paradox Valley. The Paradox Valley graben is a collapse feature at the crest of a salt-cored anticline that formed over millions of years in response to long-term salt migration and dissolution from beneath the area and to erosion of the overlying sediments (Figures 4 and 5). In general, the faults are downthrown towards the interior of the valley, but several are antithetic. These bounding faults are present in the bedrock underlying the southwest corner of the Site along the flanks of Davis Mesa. The faults trend to the northwest, appear to be normal, and down-thrown to the northeast or southwest, may dip to the north or south, and become listric at depth. This series of faults is mapped as concealed beneath Quaternary deposits by Cater (1954, 1955a, 1955b), Cater and others (1955), and Withington (1955). Those concealed beneath Quaternary deposits appear to dip steeply to the north.

Based on seismic reflection and refraction surveys, this same general fault trend is inferred in the buried bedrock surface beneath the Site as shown in Figure 7. However, from south to north, each successive fault block may not be downthrown lower than the contiguous block to the south. Therefore, a normal stair-step profile is unlikely and covered bedrock highs may exist at more than one location. A contour map of the top of bedrock is presented in Figure 11. The contour map was generated by identifying the depth of the alluvium/bedrock contact for a number of boreholes across the Site and using a GIS program to develop the contours. The contour map shows that the bedrock surface slopes downward to the north, being somewhat steeper along the base of Davis Mesa and becoming less steep towards the valley. There appears to be a buried trough or channel on this surface that runs northerly through the middle of the Site. The surface is characterized by some local highs of a few tens of feet but there does not appear to be any large linear northwesterly trends indicative of significant fault displacement of the bedrock surface. The Quaternary sediments appear to have been deposited over a somewhat irregular and eroded bedrock surface.

The seismic surveys conducted in 2007 and subsequent exploration drilling in 2008 identified six primary buried faults as shown in Figure 7 and illustrated on the geologic cross-sections in Figures 8 and 9. In addition, in the north part of the Site, several other small, closely spaced faults in the Hermosa Formation were inferred from the seismic survey profiles. Interpretation of the relative displacement on the faults was based primarily on the data from the drill holes. Geophysical data were also analyzed for the relative displacements across the faults, but because the seismic reflection profiles show velocity contrasts and several stratigraphic layers may have similar seismic velocities, the fault displacement data presented in the cross-sections in Figures 8 and 9 relied primarily on the visual stratigraphic data from the borehole logs. The depths to the contacts were projected on to the cross-sections making it difficult to accurately calculate the amount of displacement on these faults. Relative amounts of displacement along the faults also appear to vary from east to west with some rotation (scissors displacement) possible on one or more of the fault. From south to north, the six major inferred faults have been labeled as follows:

- Fault #1 – lying near the foot of Davis Mesa and trending WNW-ESE, normal fault upthrown to the north.

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- Fault #2 – lying under the footprint of the future mill and trending WNW-ESE, upthrown to the south.

- Fault #3 – lying under the southwest part of Tailing Cell 1A and trending WNW-ESE with the north side upthrown.

- Faults #4, #5, and #6 – closely spaced and lying under Tailing Cells B and C, likely en echelon with displacement up to the north and probably dipping steeply to the south. These faults are most likely shear zones between the more plastic Hermosa core of the anticline and the more rigid Mesozoic sediments on the flanks. The depth of the alluvium was deeper in this zone and the reflector seen in the seismic logs was missing across this zone indicative of a zone of weakness. It is possible that this zone may have been preferentially eroded prior to deposition of and backfilling by the Quaternary sediments. Trenches 2, 2b, and 2c were excavated over this buried bedrock fault zone and did not show any disturbance of the overlying late Quaternary sediments (Figure 7).

The pattern of faulting in the buried bedrock formations is consistent with the structural development of the Paradox anticline and the subsequent dissolution and collapse of the salt core. Aerial photograph interpretation of the part of the Site underlain by the alluvial sediments and the buried faults did not reveal any lineaments or surface expressions typical of surface deformation from faulting. The extensive trench mapping conducted in December 2007 (Trenches 1 ,2, and 3) and May 2008 (Trenches 2b and 2c) in the late Quaternary soil deposits overlying the buried faults showed no evidence of displacement of the soil layers, indicating an absence of post-depositional or late Quaternary surface faulting. The detailed geologic logs of the trench excavations are presented in Appendix E. In addition, Appendices A, F, and G contain additional details of geological investigations addressing the local geology and structural features.

4.4 Seismicity

According to the Colorado Geological Survey, more than 500 earthquake tremors have occurred in Colorado since 1867 (Colorado Geological Survey, 2002) (Figure 12). The largest known earthquake in Colorado was the November 8, 1882 earthquake, whose size and location remain uncertain (Sheehan et al., 2003). The 1882 earthquake had an estimated moment magnitude of 6.6 ± 0.6 and was located somewhere in north-central Colorado (Spence et al., 1996). The 1882 earthquake damaged the power plant in Denver and cracked buildings in Boulder. However, most of the earthquakes in Colorado have been due to induced seismicity caused by human activities. The best known examples are those induced by the disposal of waste fluids at the Rocky Mountain Arsenal near Denver and secondary oil recovery in western Colorado at the Rangely oil field (Sheehan et al., 2003). The injection of salty water in the Paradox Valley, approximately nine miles west of the Site, by the Bureau of Reclamation has also generated more than 3,000 minor earthquakes since the beginning of injection process in 1995 with some earthquakes as large as magnitude 4.3 in May 2000 (Colorado Geological Survey, 2002).

4.4.1 Local and Regional Faulting

Geological studies in Colorado have discovered about 100 faults that moved during the Quaternary Period (past 2 million years ago). As shown in Figure 12, most of the known or suspected Quaternary faults displaced middle to early Quaternary deposits (approximately past 130,000 to 2 million years old). A few faults have displacement of late Quaternary deposits

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(approximately the past 130,000 years). The Sangre do Cristo fault, which lies at the base of the Sangre de Cristo Mountains along the eastern edge of the San Luis Valley, and the Sawatch fault, which runs along the eastern margin of the Sawatch Range, are two of the most prominent potentially active faults in Colorado. These faults are in the middle part of the State and lie approximately 150 miles east of the Site.

The Site is located in the broad Colorado Plateau in southwest region of Colorado near the Utah border and in the southeast part of the Paradox Basin, also known as the Paradox Fold and Fault Belt. The faults of interest to the Site include those in southwest Colorado and southeast Utah. The nearest mapped faults to the Site are associated with the Paradox Valley graben, trending roughly parallel to the base of Davis Mesa along the southern edge of the Site (USGS Quaternary fault database, No. 2286, 2008) in the bedrock. The USGS (USGS, 2008) Quaternary fault and fold database reports the Paradox Valley graben as having movement as recently as Quaternary; however, no evidence of Holocene-age movement has been documented for these faults. Because these faults formed in response to the diapiric deformation of salt at depth rather than tectonic deformation, these faults are classified as Class B by the USGS. The USGS classifies faults according to three categories – A, B, or C. Class A faults show geologic evidence as being a Quaternary-age fault of tectonic origin. Class C faults show no evidence of Quaternary deformation. Class B faults are those that exhibit geologic evidence of Quaternary deformation, but either (1) the fault might not extend deeply enough to be a potential source of significant earthquakes, or (2) the available geologic evidence is too strong to confidently assign the feature to Class C (no evidence of Quaternary-age deformation) or not strong enough to assign it to Class A (evidence of Quaternary-age fault of tectonic origin).

Significant local and regional faults and their parameters within a radius of 100 km are listed in Table 1 (USGS, 2008). The system nearest the Site is the Paradox Valley graben system. The State of Colorado Earthquake and Fault Map (Figure 12) classifies the Paradox Valley graben system as displacing middle to early Quaternary deposits (approximately 130,000 to 2 million years old); it is not recognized as a fault with displacement of late Quaternary deposits. The faults associated with the graben system have been mapped in the exposed bedrock along the flanks of Davis Mesa to the south of the Site. This same system is believed to extend beneath the Site based on the results of the seismic surveys and through lithologic logging of the boreholes beneath the Site. These bedrock faults are buried beneath the Quaternary deposits. Extensive trenching of the late Quaternary deposits overlying the location of these buried fault traces demonstrated that the deposits are laterally continuous and do not show any evidence of faulting. Based on this evidence of undisturbed deposits, the age of the undisturbed soil horizons, and the general diapiric origin of the graben system, the buried faults are considered to be non-capable faults.

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Table 1
Significant Faults

Fault Name	Length (km)	Distance from Site (km)	Fault Type	Strike Angle	Slip Rate (mm/yr)	Recent Deformation
Paradox Valley graben	56	< 1	Normal	N46W	< 0.2	Quaternary
Big Gypsum Valley graben	33	28	Normal	N54W	< 0.2	Quaternary
Unnamed at northwest end of Paradox Valley	5	30	Normal	N2W	< 0.2	Quaternary
Atkinson Mesa	41	30	Normal	N63W	< 0.2	Quaternary
Pinto Mesa	20	34	Normal	N43W	< 0.2	Quaternary
Sinbad Valley graben	32	35	Normal	N50W	< 0.2	Quaternary
Lisbon Valley	38	37	Normal	N47W	< 0.2	Quaternary
Pine Ridge	6	36	Normal	N72W	< 0.2	Quaternary
Dolores	15	40	Normal	N67W	< 0.2	Quaternary
Pine Mountain	30	45	Normal	N52W	< 0.2	Quaternary
Monitor Creek	30	48	Normal	N86W	< 0.2	Quaternary
Roubideau Creek	26	48	Normal	N74W	<0.2	Latest Quaternary
Shay graben	40	50	Normal	N66E	< 0.2	Quaternary
Moab and Spanish Valley	68	50	Normal	N52W	< 0.2	Quaternary
Ridgeway	24	70	Normal	N87E	< 0.2	Quaternary
Log Hill Mesa graben	10	80	Normal	N32W	< 0.2	Late Quaternary
Busted Boiler	18	80	Normal	N5W	< 0.2	Late Quaternary
Red Rocks	38	90	Normal	N59W	< 0.2	Quaternary
Needles	29	95	Normal	N10E	< 0.2	Latest Quaternary

Some of the potentially active faults in Colorado have been assigned maximum credible earthquakes based on the length of the fault, age of the latest movement, and recurrence interval of the past earthquakes. Figure 13 shows assigned magnitudes of maximum credible earthquakes for the more significant faults in Colorado. For those nearest to the Site, the Busted Boiler fault and the Ridgway fault have been assigned magnitude 6.25. The Red Rocks fault has been assigned magnitude 6.75. The faults closer to the site in Table 1 have not been assigned any magnitudes. The Paradox Valley is located within the northeast part of the Paradox Basin and because the faults in the Paradox Basin generally result from very gradual processes of salt dissolution and flow, they are not likely capable of generating large earthquakes. Kirkham and Rogers (1981) estimated the possible maximum earthquake from these features to be about magnitude 5 (DOE, 2008).

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4.4.2 Historical Seismicity

The historical seismicity of Colorado from about 1867 to 2007 is shown in Figure 12. The seismicity of Colorado has been characterized as being low to moderate (Kirkham and Rogers, 1981) partly due to the lack of adequate seismographic coverage in the state and the relatively few sizable earthquakes that have occurred in the historical and more recent record. Seismicity of the Site has been characterized by induced seismicity and natural earthquakes.

4.4.3 Induced Seismicity

Many of the earthquakes in Colorado, especially in the Paradox Valley region, have been caused by induced seismicity. The best known examples of induced seismicity in Colorado are those induced by the disposal of waste fluids at the Rocky Mountain Arsenal near Denver and secondary oil recovery in western Colorado at the Rangely oil field (Sheehan et al., 2003). Induced seismicity in the region near the site is primarily due to the deep injection of saline water in the Paradox Valley Unit (PVU) by the U. S. Bureau of Reclamation. To reduce the salinity in the Dolores River, the Bureau of Reclamation has installed a series of extraction wells to intercept saline saturated groundwater flowing from the Paradox Valley into the Dolores River. The PVU includes nine shallow (10 to 100 meters deep) brine extraction wells and a deep (total depth about 4.9 kilometer) injection well as shown on Figure 14. The saline water is extracted from the shallow wells and then injected under high pressure into the deep well between the depths of 4.3 to 4.8 kilometers. Since 1991, the PVU has injected more than 4 million cubic meters of the brine, which has included more than 900,000 tons of salt, into deep Paleozoic and Pre-Cambrian strata (Ake et al., 2005).

Recognizing that deep, high-pressure injection could induce local earthquakes, the PVU installed the Paradox Valley Seismic Network (PVSN) and began monitoring the local, pre-injection seismicity starting in 1985. The PVSN has operated continuously since 1985 and covers an area of about 5,500 square kilometers of the Colorado Plateau. Presently, the PVSN operates 15 stations; the two closest stations have three-component sensors and the remaining stations have only vertical-component sensors (see Figure 14).

The injection has induced over 4,000 surface-recorded seismic events since the beginning of injection process in 1991 and more than 3,000 surface-recorded events since the beginning of continuous injection process in 1995 with some earthquakes as large as magnitude 4.3 in May 2000 (Colorado Geological Survey, 2002; Ake et al., 2005). More than 99.9% of the 4,000 events have magnitudes less than magnitude 2.0 and were not felt at the surface (Ake et al., 2005). The seismicity rate was much higher in the initial phases of injection with an average rate of surface recorded seismic events of about 82 per month with a peak of 172 events in January 1999. Due to this, the Bureau of Reclamation modified their injection strategy in July 1999 with 20 days of shutdown every six months. However, this did not result in reducing the seismic events to an acceptable level. In June 2000, the Bureau of Reclamation modified their strategy again to reduce the pumping rate, which resulted in significant reduction in induced seismicity to about 9 events per month with no event greater than magnitude 2.8. According to Ake et al. (2005), the induced seismicity at the Paradox Valley Unit is closely related to the injection rate. The primary seismic zone (95% of the events) is an asymmetric zone surrounding the deep injection well with the maximum radial distance of about 3 km (see Figure 14). The secondary zone is located about 8 km to the northwest of the well. By understanding the relationship between small earthquakes and injection parameters (in particular injection rate), the operations at the PVU have been modified to minimize the likelihood of future larger, damaging earthquakes (Ake et al., 2002).

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4.4.4 Natural Earthquakes

According to the USGS, more than 400 earthquake tremors of magnitude 2.5 or higher have occurred in Colorado since 1870. The largest known earthquake in Colorado was on November 8, 1882, but its exact size and location remain uncertain (Sheehan et al., 2003). The 1882 earthquake had estimated moment magnitude of 6.6 ± 0.6 and was located somewhere in north-central Colorado (Spence et al., 1996). This tremor damaged the power plant in Denver and cracked buildings in Boulder.

The largest known natural earthquake in the vicinity of the Site was magnitude 5.5 in 1960 earthquake near Ridgway, about 60 km northeast of the Site (Sheehan et al., 2003; Blume and Sheehan, 2003). Several earthquakes of magnitude 4 or higher have occurred in this region with the most recent one being a magnitude 4.1 on November 7, 2004, located west of Montrose. Significant historical earthquakes in the region are tabulated in Table 2.

Table 2
Significant Historic Earthquakes in the Region

Date	Location	Magnitude	Intensity
1913, Nov. 11	Ridgway area	--	VI
1944, Sep. 9	Montrose/Basalt	--	VI
1960, Oct. 11	Montrose/Ridgway	5.5	V
1966, Jan. 23	CO-NM border near Dulce, NM	5.5	VII
1966, Sep. 4	Near Montrose	4.2	--
1967, Jan. 12	East of Grand Junction	4.4	--
1967, Apr. 4	Near Montrose	4.5	--
1971, Nov. 12	South of Grand Junction	4.0	--
1994, Sep. 14	Southwest of Montrose	4.6	--
2000, May 27	West of Montrose	4.4	--
2004, Nov. 7	West of Montrose	4.1	--
Reference: Earthquake Subcommittee - Colorado Natural Hazards Mitigation Council ANSS Earthquake Catalog			

Kleinfelder performed a search of historical earthquakes greater than magnitude 3 within a radius of 200 km from the site. The search has been performed using the catalog maintained by Advanced National Seismic System (ANSS). The composite catalog covers a period from 1898 to the present and is a world-wide earthquake catalog, which is created by merging the master earthquake catalogs from contributing ANSS member institutions and then removing duplicate records of the same event. The member institutions include several regional and national seismic networks (http://www.ncedc.org/anss/cnss-detail.html). This search resulted in approximately 101 events within the search area between 1898 and now. The results are provided in Appendix H.

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Based on the historical earthquake record and geologic studies in Colorado, an event of magnitude 6½ to 7¼ could occur somewhere in the State (Colorado Earthquake Hazard Mitigation Council, 2008). However, as stated above, the region where the Site is located is characterized by very gradual processes of salt dissolution and flow and is not likely to experience large earthquakes.

4.4.5 Ground Motions

Ground motion parameters, in terms of peak ground acceleration (PGA) and/or spectral acceleration, are used to design earthquake-resistant structures. Guidelines from the seismic design criteria of the 2006 International Building Code (IBC), which are based on the National Seismic Hazards Maps by the USGS, were used to obtain these parameters. Ground motion parameters obtained from the 2006 IBC for the design of the structures are presented in more detail in Appendix H. Under IBC guidelines, the Maximum Considered Earthquake (MCE) is defined as an event having a 2 percent chance in 50 years of occurring (return period of 2,475 years). The PGA associated with the MCE for the site is 0.161g, where "g" is the acceleration of gravity. The most likely earthquake to produce these motions is projected to have a magnitude of about 4.8 at a distance of 15.5 km (9.6 miles) from the Site.

The mill buildings, tailings facilities, and other structures will be designed to meet or exceed the construction requirements for the IBC design earthquake, which is defined as 2/3rds of MCE or a PGA of 0.107g. The facilities will also meet or exceed the seismic design requirements specified in the Uniform Building Code, which is the code currently used by Montrose County.

4.5 Groundwater

On-site investigations of the groundwater have been undertaken to characterize the groundwater across the Site and to identify potential groundwater resources at the Site. A baseline groundwater characterization and monitoring program was initiated in the last quarter of 2007 and is ongoing. Results have been documented in five quarterly reports to date (Kleinfelder, 2008b, 2008c, 2008g, 2008h, and EFR, 2009). The groundwater monitoring program involved the drilling and installation of nine monitoring wells. Of these, four wells (MW-5, MW-6, MW-7, and MW-8B) have sufficient groundwater to monitor on a quarterly basis. The completion of monitoring wells ranged in total depth from 30 feet bgs at MW-1 to 485 feet bgs at MW-6. Figure 7 shows the location of the nine monitoring wells.

Golder has undertaken an investigation of the water resources at the Site and has developed a conceptual hydrogeologic model (Golder, 2008c). Golder's groundwater investigations at the Site have concluded that the primary water-bearing strata are associated with the Triassic Chinle and Moenkopi Formations, which lie beneath the southwestern part of the site, near the Davis Mesa. The Chinle Formation within the Paradox Valley is composed of reddish or orange siltstone with layers of sandstone and limestone pebbles. In places, the lower section of the Chinle formation contains quartz conglomerates, which are of interest hydrologically due to their ability to store and transmit groundwater. The Moenkopi formation has characteristics similar to the overlying Chinle formation. The Moenkopi formation contains arkosic beds that may contain and conduct water (Cater 1954, 1955).

Based on the on-site groundwater investigations by Golder (2008c), the only known groundwater occurrences within the Site are close to the contact between the Chinle and Moenkopi Formations, and close to the contact between the Moenkopi and Hermosa Formations. Groundwater at the Moenkopi/Hermosa contact was documented at two locations

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(MW-6 and MW-8B) and is likely the result of groundwater flow through fractures from the Moenkopi and Chinle contact to the top of the Hermosa Formation. The Hermosa Formation acts as a confining layer to further downward migration of groundwater. At most locations across the site, groundwater does not occur at depths below the Chinle/Moenkopi contact. Several holes were drilled at depths beyond this contact. For example, EX-08-06 was drilled to a total depth of 1,020 feet bgs, EX-08-05 was drilled to a total depth of 880 feet bgs, and EX-08-04 was drilled to a total depth of 800 feet bgs. In these boreholes, no groundwater was encountered below the Chinle/Moenkopi contact.

Regionally, the Navajo Sandstone is recognized as the primary water-yielding unit. However, this unit was is not present within the study area. According to geologic maps published by the USGS (Cater 1954, 1955), the Navajo Sandstone outcrops approximately two miles west of the Site.

The presence of groundwater and the configuration of the potentiometric surface in the local aquifer at the Chinle-Moenkopi contact are influenced by the following factors:

- Proximity to the Davis Mesa, which acts as a recharge source for the local aquifer,
- Numerous faults run parallel to the Davis Mesa; these faults may act as conduits to flow and affect groundwater flow from the Davis Mesa towards the center of the valley, and
- Uplifted sediment and evaporites of the Hermosa Formation, which acts as an aquitard. The Hermosa Formation truncates the Chinle and Moenkopi Formations near the center of the valley.

The potentiometric surface of the aquifer slopes from the Davis Mesa towards the center of the valley to the northeast. The slope is affected by recharge from the Davis Mesa, local topography, and faulting. Groundwater elevations are shown on cross-sections in Figures 8 and 9.

The southwestern boundary of the local aquifer is assumed to coincide with the alignment of the crest of the Davis Mesa. The assumption is supported by the observation that numerous faults paralleling the mesa likely act as conduits for aquifer recharge, thus elevating water levels beneath the mesa. Additionally, aquifers, especially in recharge areas, tend to form subdued replicas of the surface topography. Therefore, the crest of the mesa likely acts as a no-flow boundary.

The northwestern boundary of the aquifer is defined by the salt dome that truncates the Chinle and Moenkopi Formations. During drilling, no groundwater was encountered in boreholes EX-08-02 through EX-08-04, EX-08-23, and MW-1 through MW-4. Following drilling, a small amount of groundwater (i.e., less than a foot of water) has occasionally been observed in MW-2 and MW-3, but recharge following purging is extremely slow, sometimes as long as several months. Additionally, the water level in MW-3 is approximately 200 feet higher than the water levels in MW-8B, MW-9, and EX-08-22, suggesting that this water occurrence is perched or connate water and not connected to the aquifer encountered elsewhere on the Site. The limits of the Chinle and Moenkopi aquifer are shown on Figures 8 and 9.

The local aquifer present in the Chinle and Moenkopi Formations has an estimated 5-year sustained pumping rate ranging from 100 to 175 gallons per minute for the Site. Although the permeability of the aquifer is high, in the range of 10^{-3} cm/s, the aquifer's limited thickness may curtail attainment of higher groundwater production rates (Golder, 2008c).

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4.6 Geologic Hazards

Geologic hazards of potential interest to the site include slope instability, flooding, erosion, karst or dissolution features, faulting, seismicity, liquefaction, and soil instability. Each geologic hazard is discussed below:

Slope Instability - Natural slope gradients across the majority of the Site are gentle and are not susceptible to mass movement. Steeper slopes, which are over 1,000 feet from the mill facility, on the southwest corner of the Site appear to be bedrock controlled and show no evidence of past mass movement. Any development or cuts into these bedrock exposures may need to account for fractures and areas of weakness in the rock in the design. According to Strauss (1982), the large landslide block one half mile southeast of Site appears to be related to block movement on weaker units at depth (i.e., Paradox member of the Hermosa Formation) and are not of concern to the Site.

Flooding and Headward Erosion - Minor flood hazards may exist in the small drainages on the southwest corner of the Site where the alluvial fan deposits are present and the drainages emerge from Davis Mesa. However, because these drain relatively small headwater areas, it is unlikely that long sustained periods of flooding will occur along these drainages. Engineering control of the drainages will provide needed protection to the facilities. Several of the active channels exhibited headward erosion: the mill and tailing facilities have been sited to avoid these channels. These minor hazards are readily mitigated by implementation of engineering controls (e.g., diversion, soil stabilization, rip rap) of the surface drainages across the Site (Kleinfelder, 2009b).

Karst - No evidence of karst subsidence or active dissolution was observed within the boundaries of the Site. A sinkhole was observed north of the Site boundary (Figure 6), approximately one-half a mile north of the evaporation pond area. This sinkhole is localized and, at the surface, is approximately 5 feet in diameter and 4 feet deep. As confirmed by additional geologic reconnaissance and mapping, no other evidence of sinkhole development was identified within the boundaries of the Site or in the adjacent areas.

Faulting - The Site is located near fault traces of the Paradox Valley graben system. The U.S. Geological Survey (2008) Quaternary fault and fold database reports the Paradox Valley graben as having movement as recent as Quaternary; however, no evidence of Holocene age movement has been documented for these faults. Because these faults formed in response to the diapiric deformation of salt at depth rather than tectonic deformation, these faults are classified as “Class B” by the USGS. In addition, the geologic investigations including aerial photograph interpretation and extensive trenching excavations demonstrated that the late Quaternary soils overlying the buried faults at the Site were not disturbed or displaced, indicating an absence of surface faulting. The faults at the Site are judged to be non-capable according to the Criterion 4E of 6CCR 1007-1, Part 18.

Seismicity – Ground motion parameters obtained from the 2006 IBC for the design of the structures indicated there is a 2 percent chance in 50 years that the site can experience a peak ground acceleration equal to or greater than 0.16g. In addition, the most likely earthquake to produce these motions will have a magnitude of about 4.8.

Liquefaction - In conjunction with the ground-shaking potential of a large magnitude earthquake, certain areas may possess a potential for liquefaction. Liquefaction is a phenomenon whereby loose, saturated, granular soil deposits lose a significant portion of their shear strength due to excess pore water pressure buildup resulting from dynamic loading, such as that caused by an

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earthquake. Among other effects, liquefaction can result in densification of such deposits causing settlements of overlying layers after an earthquake as excess pore water pressures are dissipated. Horizontally continuous liquefied layers may also have the potential to spread laterally where sufficient slope or free-face conditions exist. The primary factors affecting liquefaction potential of a soil deposit are: (1) level and duration of seismic ground motions; (2) soil type and consistency; and (3) depth to groundwater. Based on the surface and subsurface observations of the deep groundwater conditions (absence of shallow groundwater), liquefaction of Site soils during an earthquake event is not likely.

Collapsible Soils - The presence of collapsible soils within the upper layers of overburden soils was identified as an issue to be addressed during construction and operation of the facility (Kleinfelder, 2008e). Collapse potential can be mitigated by removal of some of the collapsible soils and creating a relatively impermeable compacted soil layer beneath the proposed facility. This can be accomplished by moisture conditioning the on-site soils and replacement as compacted engineered fill. Conventional spread footing foundations placed on the compacted engineered fill could then be used for support of mill structures, equipment, and slabs.

5.0 CONCLUSIONS

The Site has been extensively investigated through a review of the available literature, aerial photograph interpretation, drilling and logging of 127 boreholes for purposes of geologic, hydrologic, and geotechnical characterization, excavation and mapping of approximately 3,150 feet of trenches, seismic refraction and reflection surveys totaling approximately 18,500 feet in length, and geologic mapping of the Site at a scale of one inch to 200 feet, and reconnaissance of the area surrounding the Site. Based on an evaluation of the results of these investigations, the Piñon Ridge Mill site is suitable for development of the uranium mill facilities and for long-term (1,000+ years) containment of the byproduct.

The area beneath the proposed location of the evaporation ponds is underlain by Quaternary eolian and alluvial deposits, which are underlain by shales and evaporites of the Hermosa Formation. Neither of these units contains groundwater. The area of the proposed tailing cells is underlain by the similar Quaternary deposits. This area is directly underlain by siltstones and sandstones of the Triassic Chinle Formation. The only groundwater identified in the subsurface was in the southern part of the site along a zone that parallels the base of Davis Mesa at a depth of over 300 feet below the ground surface and near the contact between the Chinle and Moenkopi Formations.

A series of northwest trending buried bedrock faults was inferred from the seismic surveys and from the boreholes. These faults are likely part of the Paradox Valley graben system that formed as a result of the large scale salt diapirism and the collapse of the graben that formed Paradox Valley. Field investigations from mapping of the trench excavations, geologic mapping, and aerial photograph interpretation demonstrated that these buried faults have no surface expression, do not displace the overlying late Quaternary deposits, and are therefore considered non-capable. The seismic risk in this part of Colorado is limited because most of the faults in the area are caused by the diapiric movement of the salt rather than deep seated tectonic movement, or they are induced by human activity from the Paradox Valley Unit Project and being controlled by limiting the injection rate of the fluids.

The land surface within the Site boundaries appears to be geomorphically stable with no evidence of karst development at the surface. Investigations of the land surface to the north of the Site found a localized sinkhole in the weathered soils of the Hermosa Formation exposed in the valley floor. Additional investigations in this area showed this feature to be limited in its

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extent; no other karst features were identified in this area. In addition, no landslides or mass movements were identified south of the Site boundaries along the slopes of Davis Mesa.

The other geologic hazards of concern, collapsible soils, flooding, and headward erosion are present to some degree. However, any impacts to the facilities can be readily mitigated by sound engineering practices in the design, construction, and maintenance of the facilities.

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