APPENDIX H

Seismology

ENERGY FUELS RESOURCES CORPORATION
PIÑON RIDGE MILL SITE

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Kleinfelder West, Inc.

SEISMOLOGY

1.0 Introduction

This section presents the results of the seismology investigation for the Piñon Ridge Mill site. Included in this section is a discussion of the local and regional faulting, historical seismicity, and ground motions, conducted by Kleinfelder West, Inc. (Kleinfelder) for Energy Fuels Resources, Inc. (EFR) in support of the mill license application.

2.0 Local and Regional Faulting

The site is located in the southwest region of Colorado near the Utah border. The faults of interest to the site include those in southwest Colorado and southeast Utah. The nearest mapped fault to the site is the Paradox Valley graben, located less than one kilometer from the site (USGS Quaternary fault database No. 2286). The U.S. Geological Survey (USGS, 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. Other than the inferred faults interpreted by the seismic survey, no faulting has been mapped by others crossing the proposed locations of the mill, ore pad, tailings impoundment, evaporation pond or office. Trench excavations of the late Quaternary surface soils overlying the buried faults demonstrated that the soils were laterally continuous and do not exhibit any late Quaternary fault activity.

Significant local and regional faults and their parameters within a radius of 100 km are listed in Table 1

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
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
Monitor Creek	30	48	Normal	N86W	< 0.2	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 1 shows assigned magnitudes of maximum credible earthquakes for some faults in Colorado. According to Figure 1, 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 shown in Table 1 have not been assigned any magnitudes, but, in general, the magnitudes are expected to be in the range of 4.5 to 5.

3.0 Historical Seismicity

An excellent discussion on the seismicity of Colorado has been presented by Sheehan et al., (2003). Figure 2 shows the seismicity of Colorado from 1870 to 1992 per Bott and Wong (1995). 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 project region has been characterized by either induced seismicity or natural earthquakes.

3.1 Induced Seismicity

Many of the earthquakes in Colorado, especially in the Paradox Valley region, have been 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 by the U. S. Bureau of Reclamation. To reduce the salinity in the Dolores River, the Bureau of Reclamation has installed as series of extraction wells to intercept saline saturated groundwater flowing from the Paradox Valley into the Dolores River. The Paradox Valley Unit includes nine shallow (10 to 100 m deep) brine extraction wells and a deep (total depth about 4.9 km) injection well as shown on Figure 3. 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 km. Since 1991, the Paradox Valley Unit has injected more than 4 x 10^6 m^3 of the brine, which has included more than 9 x 10^5 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 Paradox Valley Unit 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 km^2 of the Colorado Plateau

(Figure 3). Presently, the PVSN operates 15 stations; the two closest stations to the Paradox Valley Unit have three-component sensors and the remaining stations have only vertical-component sensors.

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 (RockTalk, 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. The secondary zone is located about 8 km to the northwest of the well.

3.2 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 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). Damages included 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 the 1960 earthquake near Ridgway, about 60 km southwest 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. Historical significant 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 July 2008 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 events for 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 July 2008. Appendix A at the end of the report presents the results of this search in a tabular form.

Based on the historical earthquake record and geologic studies in Colorado, an event of magnitude 6½ to 7¼ could occur somewhere in the state.

4.0 Ground Motions

Buildings and structures at the site can be designed using the International Building Code (IBC). Seismic design parameters presented in Tables 3 and 4 are based on the mapped values per 2006 IBC and can be used for the design of the buildings at the Piñon Ridge uranium mill facility. According to Section 1613 of 2006 IBC, mapped acceleration values (S_S and S_1) represent Maximum Considered Earthquake (MCE), defined as ground motions having 2 percent probability of exceedance in 50 years (return period of about 2,475 years). The site-modified spectral acceleration values (S_{MS} and S_{M1}) are based on mapped spectral acceleration values at 0.2 sec (S_S) and 1.0 sec (S_1) and the Site Class and can be computed as follows.

$S_{MS} = F_a S_S$

$S_{M1} = F_v S_1$

S_S = mapped acceleration value at 0.2 sec

S_1 = mapped acceleration value at 1.0 sec

Where, F_a and F_v are estimated from 2006 IBC Tables 1613.5.3(1) and 1613.5.3(2)

Based on the results of our field investigations, the site can be classified as Site Class D per Table 1613.5.2 of the 2006 IBC. Site Class D is defined as a stiff soil profile with average shear wave velocities between 600 ft/s and 1,200 ft/s, average SPT N-value between 15 and 50, or average undrained shear strength (S_u) between 1,000 and 2,000 psf within the upper 100 feet. The mapped acceleration values were calculated using the Java calculator for Site Class D at the USGS website

(http://earthquake.usgs.gov/research/hazmaps/design/). The Design Earthquake (DE) spectral acceleration values, taken as two-thirds of MCE (S_{DS} = 2/3 S_{MS}; S_{D1} = 2/3 S_{M1}), are presented in Table 4. It should be noted that mapped IBC values are based on 2002 USGS National Seismic Hazard Maps. The acceleration values obtained from the USGS website are based on probabilistic seismic hazard analysis (PSHA). Deaggregation or disaggregation is a common practice in a PSHA to break the hazard back down into its contributions from different magnitude and distance pairs to provide insight into what events are the most dominant to the hazard at a given ground motion level (Bazzurro and Cornell, 1999). An interactive deaggregation website by the USGS (http://eqint.cr.usgs.gov/deaggint/2002/index.php) was used to assess the mode (the most common) values of dominant earthquake magnitude and distance for this site. The mode magnitude and distance for the MCE acceleration values are listed in Tables 3 and 4.

Table 3
Seismic Design Parameters for the MCE

Parameter	Value
Mapped spectral acceleration at short period, S_S	0.252g
Mapped spectral acceleration at 1 second, S_1	0.062g
Site Class	D
Site Coefficient, F_a	1.598
Site Coefficient, F_v	2.4
Site-modified spectral acceleration at short period, S_{MS}	0.403g
Site-modified spectral acceleration at 1 second, S_{M1}	0.150g
Peak Ground Acceleration, PGA	0.161g
Earthquake Magnitude, M (Mode value)	4.8
Earthquake Distance (Mode value)	15.5 km

Table 4
Seismic Design Parameters for the DE

Parameter	Value
Design spectral acceleration at short period, S_{DS}	0.269g
Design spectral acceleration at 1 second, S_{D1}	0.100g
Peak Ground Acceleration, PGA	0.107g
Earthquake Magnitude, M (Mode value)	4.8
Earthquake Distance (Mode value)	15.5 km

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APPENDIX A

Date	Latitude	Longitude	Magnitude
10/11/960	38.300	-107.600	5.50
12/11/1962	39.364	-110.415	3.4
4/24/1963	39.439	-110.329	3.30
8/1/1963	39.300	-109.100	3.70
12/24/1963	39.555	-110.325	3.00
1/14/1965	39.445	-110.352	3.30
6/27/1965	39.509	-110.378	3.10
6/29/1965	39.498	-110.389	3.20
7/18/1965	39.500	-109.900	3.10
1/23/1966	36.900	-107.300	4.60
7/30/1966	39.444	-110.362	3.10
9/4/1966	38.300	-107.600	4.20
1/12/1967	38.979	-107.506	4.40
1/16/1967	37.672	-107.860	4.10
2/5/1967	39.549	-110.097	3.00
2/15/1967	39.272	-110.371	3.40
4/4/1967	38.318	-107.754	4.50
10/25/1967	39.471	-110.351	3.20
10/25/1967	39.460	-110.341	3.10
6/2/1968	39.208	-110.450	3.30
6/23/1968	39.314	-107.409	3.80
2/3/1970	37.918	-108.311	4.00
2/21/1970	39.488	-110.345	3.10
4/21/1970	40.002	-109.079	3.20
1/7/1971	39.486	-107.307	4.30
11/12/1971	38.914	-108.678	4.00
1/30/1975	39.270	-108.646	4.40
9/24/1977	39.309	-107.311	4.00
5/29/1978	39.275	-107.322	3.00
3/19/1979	40.044	-108.860	4.10
4/11/1979	37.887	-110.973	3.50
4/30/1979	37.884	-110.982	3.60
6/16/1979	37.861	-110.905	3.00
6/22/1979	37.901	-110.950	3.10
7/25/1979	37.592	-110.592	3.10
10/23/1979	37.891	-110.933	3.10
9/10/1981	37.497	-110.560	3.17
5/3/1983	38.306	-110.632	3.19
8/14/1983	38.359	-107.402	3.40
12/15/1983	37.580	-110.513	3.01
4/22/1984	39.281	-107.190	3.10
5/3/1984	39.304	-107.253	3.00
5/14/1984	39.322	-107.228	3.20
6/12/1984	39.143	-107.394	3.00
12/6/1985	38.841	-109.041	3.12
5/14/1986	37.271	-110.309	3.35
8/18/1986	38.914	-107.087	3.00
8/22/1986	37.453	-110.529	3.36
8/26/1986	38.900	-107.041	3.10

9/3/1986	38.912	-107.090	3.50
9/18/1986	38.937	-107.116	3.20
9/18/1986	38.925	-107.086	3.40
11/7/1986	37.434	-110.299	3.85
11/19/1989	38.055	-107.767	3.00
6/25/1991	37.194	-110.355	3.10
8/2/1991	37.818	-110.111	3.38
2/24/1993	37.753	-109.315	3.13
5/13/1993	37.728	-109.281	3.12
6/3/1993	36.965	-110.356	3.68
10/14/1993	38.312	-109.785	3.59
5/12/1994	37.016	-110.363	3.00
9/13/1994	38.151	-107.976	4.60
9/26/1994	38.931	-107.484	3.10
1/1/1995	38.871	-107.448	3.00
12/15/1997	38.319	-109.080	3.22
4/10/1998	38.268	-108.827	3.00
5/8/1998	38.317	-109.102	3.03
6/3/1999	38.262	-108.940	3.62
7/6/1999	38.276	-108.879	3.73
5/27/2000	38.301	-108.881	4.41
8/9/2001	39.660	-107.378	4.00
11/5/2001	38.851	-107.384	3.40
12/4/2001	38.813	-107.374	3.10
3/30/2002	38.853	-107.386	3.1
6/3/2002	38.907	-107.418	3.3
6/6/2002	38.326	-108.941	3.03
6/20/2002	38.908	-107.416	3.6
8/24/2002	38.92	-107.481	3.2
9/10/2002	38.789	-107.412	3.3
11/26/2002	38.904	-107.448	3.1
8/8/2003	38.907	-107.458	3.4
4/15/2004	38.87	-107.35	3.1
9/19/2004	38.853	-107.358	3.5
10/11/2004	38.825	-107.425	3.3
11/7/2004	38.2453	-108.911	4.09
11/13/2004	38.875	-107.497	3.2
4/30/2005	38.918	-107.393	3.1
5/2/2005	38.795	-107.393	3.2
5/13/2005	38.835	-107.372	3.3
5/30/2005	38.889	-107.474	3.3
6/8/2005	38.953	-107.527	3.5
7/25/2005	38.831	-107.415	3.1
2/10/2006	39.592	-107.439	3.8
11/21/2006	38.171	-108.004	3.3
5/19/2007	38.932	-107.536	3.3
11/5/2007	38.807	-107.206	3.2
11/17/2007	38.855	-107.315	3.4
12/2/2007	38.852	-107.312	3.3
5/9/2008	39.092	-107.364	3.1
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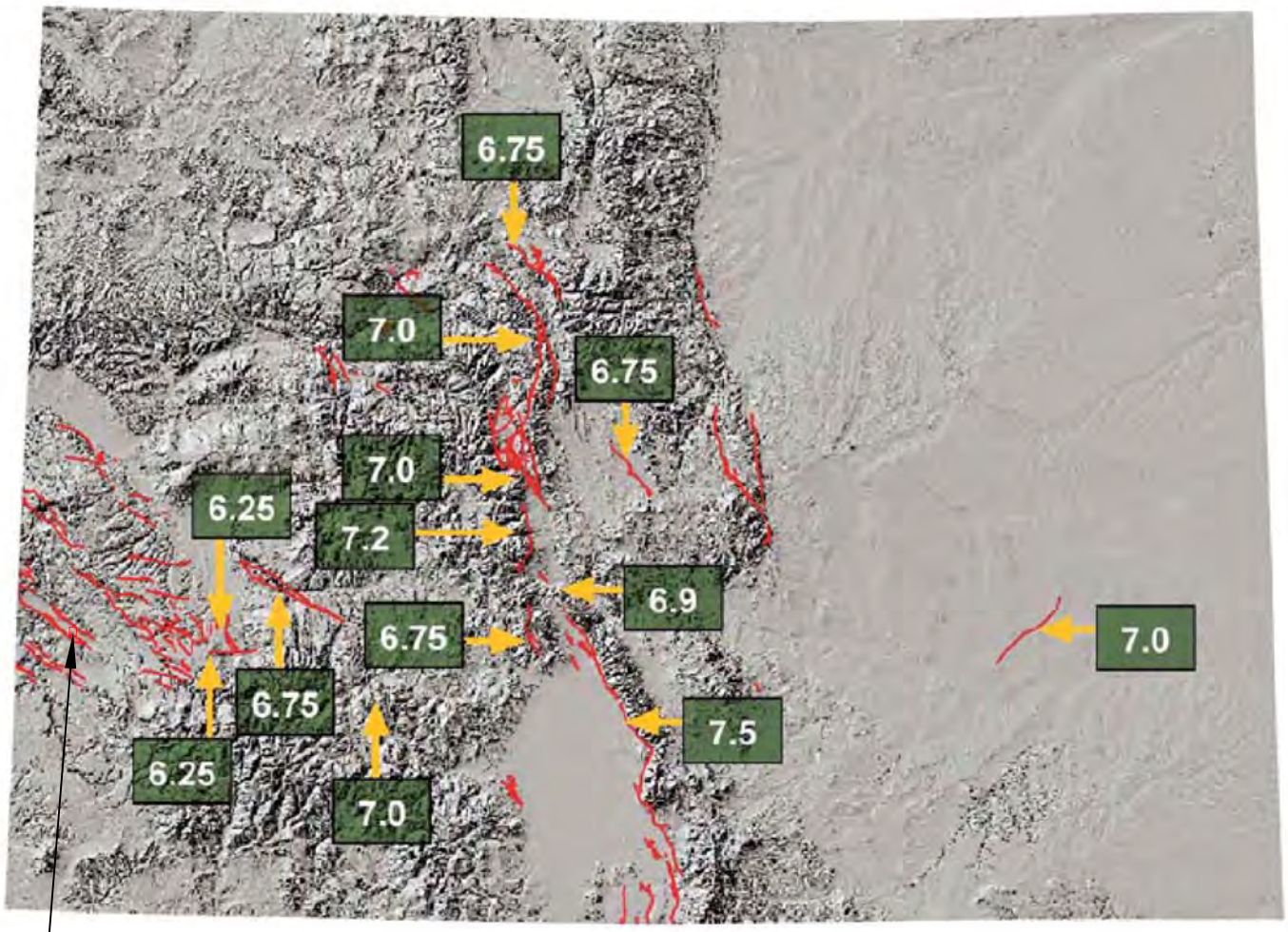
6/6/2008	37.3588	-109.458	3.62



Rerference: Widmann et al., (1998)

SITE LOCATION

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MAGNITUDE OF MAXIMUM CREDIBLE EARTHQUAKES IN COLORADO

PIÑON RIDGE PROJECT
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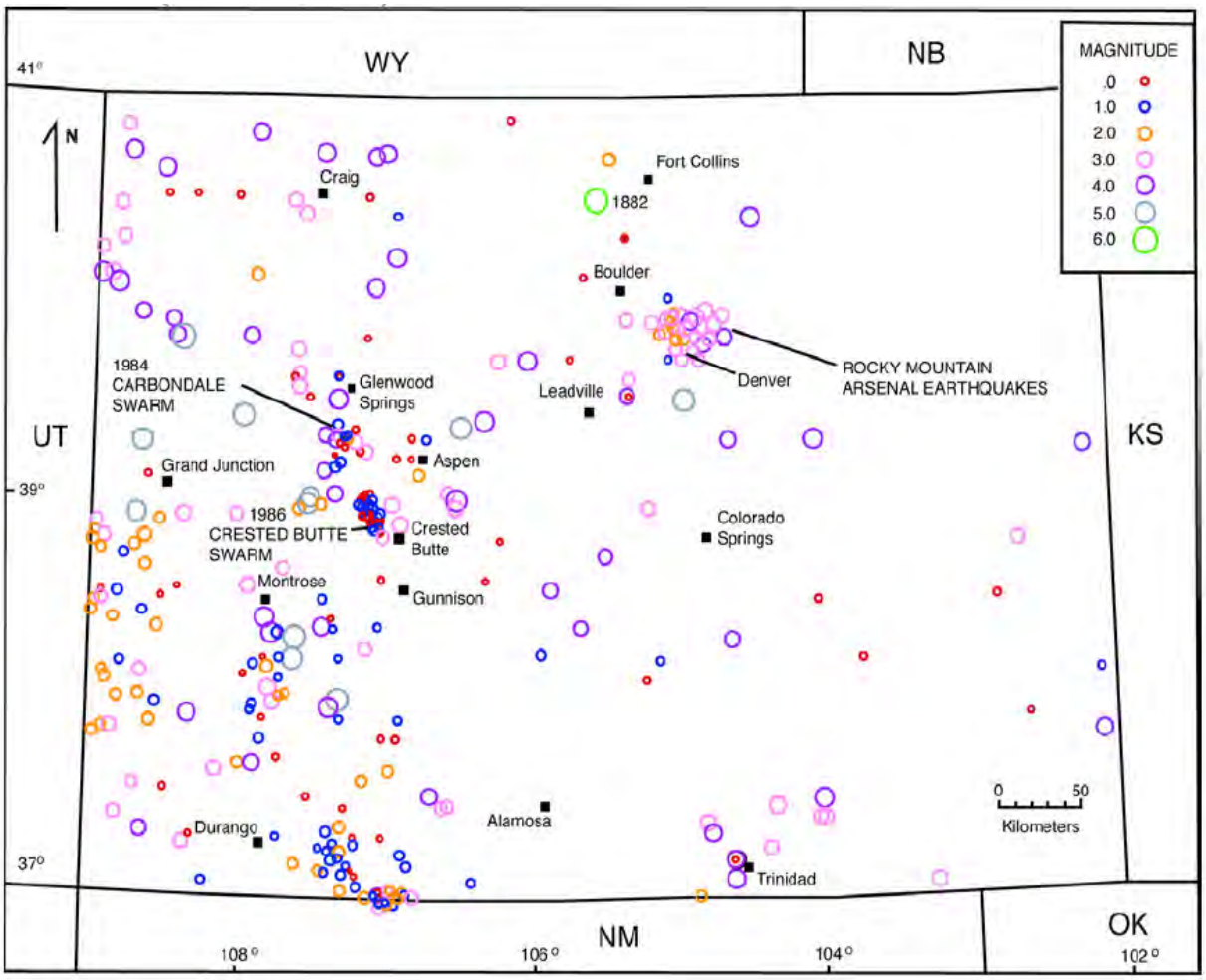
FIGURE	1



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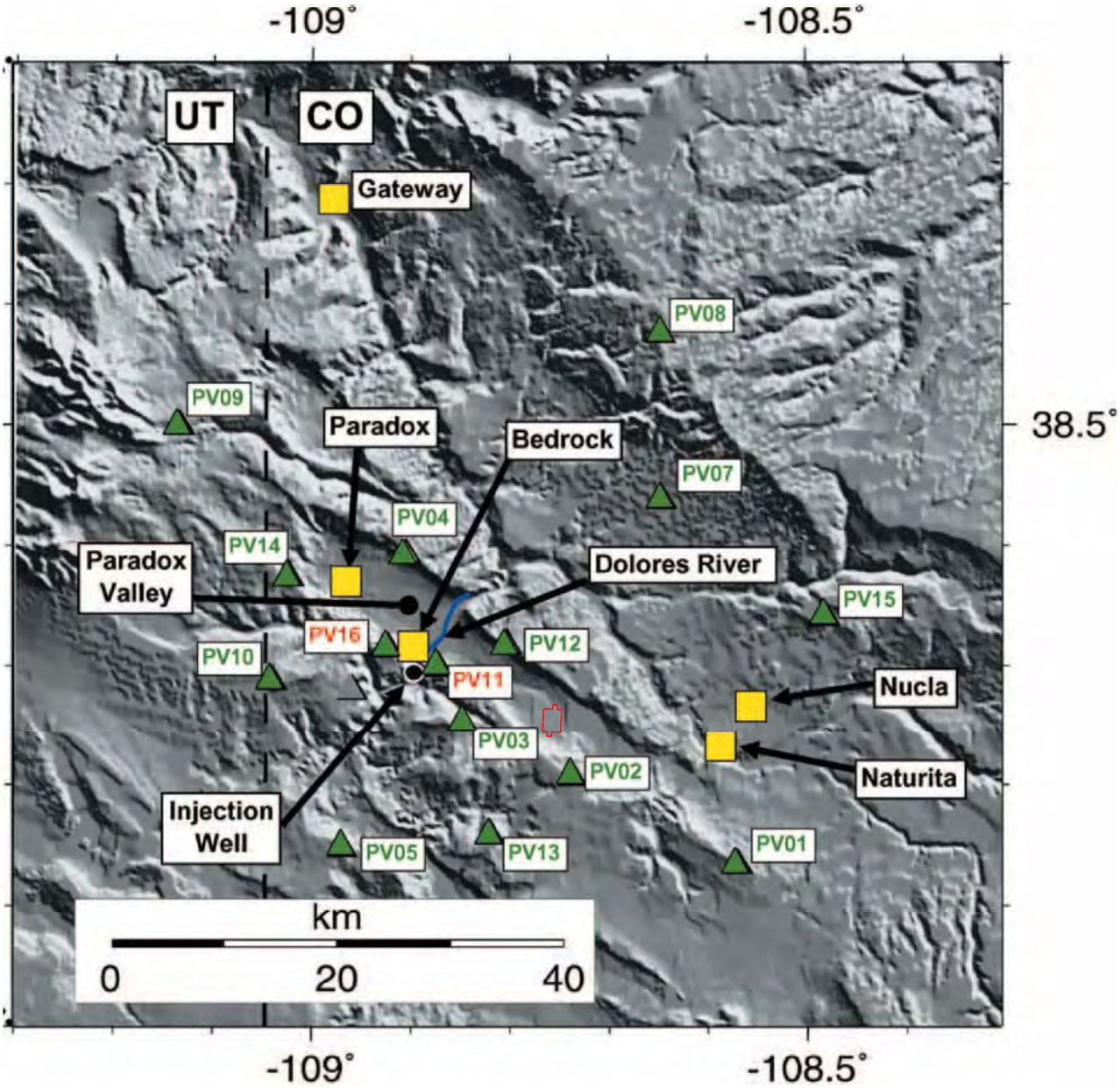
DRAWN: JULY 2008	**APPROVED BY_AKK**	**PROJECT NO. 83088**	



EXPLANATION

- Injection Well
- Local Municipalities
- Seismic Network
  - -vertical-only stations green lettering
  - -3-component stations red lettering
- Dolores River
- Approximate Piñon Ridge Property Boundary

Reference:
Ake et al. (2005)

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PARADOX VALLEY UNIT LOCATIONS OF WELLS AND SEISMIC NETWORK

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FIGURE	3