Basin is structurally folded into a westward-plunging syncline that trends roughly east-west. Note that the Bordeaux Fault, Pine Ridge Fault, and Toadstool Park Fault proposed by DeGraw (1969) are not presented on the State Geologic Map (**Figure 3.3-1**). The Toadstool Park Fault has been mapped at one location (T33N, R53W) and is estimated to have had approximately 60 feet of displacement (Singler and Picard 1980). The City of Crawford is located near the axis of the Crawford Basin. More recent fault interpretations by Hunt (1990) for northwest Nebraska are also shown on **Figure 3.2-12**, which include the Whetstone Fault, Eagle Crag Fault, Niobrara Canyon Fault, and Ranch 33 Fault in the vicinity of the Town of Harrison in Sioux County. The faults identified by Hunt (1990) all trend to the northeast-southwest, sub-parallel to the Pine Ridge Fault (**Figure 3.3-12**).

Diffendal (1994) performed lineament analyses on a mosaic of early Miocene synthetic-aperture radar images and largely confirmed known faults in the vicinity of Chadron. Lineaments in the radar image along Pine Ridge, located to the south of Chadron, are attributed to jointing or faulting and trend N40E and N50W (Diffendal 1982). Similar features were also noted west of Fort Robinson. Swinehart et al. (1985) report that these features are likely an extension of the Wheatland-Whalen trend in Wyoming (Hunt 1981; Wheeler and Crone 2001).

Former drilling activities at the Crow Butte Project identified a structural feature, referred to as the White River Fault, located between the CPF Class III permit area and the NTEA (**Figure 3.3-12**). Evidence of a fault was identified during the exploration drilling phase of the Crow Butte Project (Collings and Knode 1984). The fault is manifested in the vicinity of the NTEA as a significant northeast-trending, subsurface fold. The detailed kinematics of the White River Fault were investigated during preparation of the NTEA Petition for Aquifer Exemption. An extensive review of drilling and logging data determined that, while the White River Fault may cut the Pierre Shale at depth along with stratigraphically lower units, there is no evidence that a fault offsets the geologic contact between the Pierre Shale and overlying White River Group or individual members of the White River Group. This fault does not appear to be present in the vicinity of the MEA.

3.3.1.4 Seismology

National Seismic Hazard Maps and Risks

The USGS updated the National Seismic Hazard Maps in 2008, which includes changes in the methodology used to model potential seismicity in any given region (Petersen et al. 2008). Wheeler and Crone (2001) described Quaternary fault zones and their potential seismic activity. Their findings were used to develop the prior National Seismic Hazard Map. The revised maps incorporate new seismic, geologic, and geodetic information on earthquake rates and associated ground shaking. The maps supersede versions released in 1996 and 2002. The next update to the National Seismic Hazard Maps is scheduled for 2014.

The National Hazard Maps show the distribution of earthquake shaking levels that have a certain probability of occurring in the U.S. (**Figure 3.3-13**). The hazard rating ranges from the lowest hazard (0.4 %g) to the highest (64+ %g), with the City of Crawford area and the majority of Nebraska being located in a low hazard ranking level of 4 to 8 %g. The term "%g" is a unit of acceleration (movement of earth) measured in terms of gravity (g) (i.e., acceleration due to gravity). Peak acceleration (%g) refers to the maximum acceleration (movement) experienced

during a non-uniform earthquake event (i.e., starts off small, achieves a maximum, and then decreases).

The seismic hazard map for Nebraska (**Figure 3.3-14**), represents the %g with a 2 percent probability of exceedances in 50 years (USGS 2009a), meaning that in a given 50-year period, there is only a 2 percent chance of seismic shaking exceeding any given equivalent percentage of acceleration due to Earth's gravity. **Figure 3.3-14** also shows that the modeled peak acceleration due to seismic shaking in the City of Crawford area is very low: 6 to 8 %g for the majority of the immediate area and 8 to 10 %g in a much smaller area, meaning that the maximum shaking due to any given earthquake in the region during a 50-year period would be equivalent to only 10 percent or less of the force of gravity at Earth's surface. These estimates demonstrate that the Marsland and City of Crawford area are at the low end of the USGS's hazard ranking system for earthquake risks. Note that the differences between **Figures 3.3-13** and **3.3-14** as to the hazard ranking values are due to the use of different scales (i.e., 4 to 8 versus 6 to 8, respectively).

Earthquake Magnitude and Intensity

Earthquakes release different amounts of energy and the strength of this energy can be measured by magnitude and intensity (CDERA 2009*)*. A comparison of the magnitude and intensity scales is shown in **Table 3.3-3** as well as the USGS abbreviated descriptions of the 12 levels on the Modified Mercalli (MM) scale. The Richter Scale is used to measure the magnitude of an earthquake and is a measure of the physical energy released or the vibrational energy associated with the earthquake. In general, earthquakes below 4.0 on the Richter scale do not cause damage, and earthquakes below 2.0 usually cannot be felt. However, earthquakes rated higher than 5.0 on the Richter Scale can cause damage. An earthquake of a magnitude 6.0 is considered strong, and a magnitude of 7.0 is considered a major earthquake.

The MM scale measures the intensity of an earthquake, and consists of 12 increasing levels of intensity that range from imperceptible shaking to catastrophic destruction (USGS 2009b). It is an arbitrary ranking by the USGS based on observed effects rather than mathematics.

For states in the U.S. that had reported earthquakes with a magnitude of 3.5 or greater from 1974 to 2003, the State of Nebraska had a total of eight (less than 0.05 percent of the total of 21,080 earthquakes occurring in the U.S; USGS 2009d). **Figure 3.3-14** is a seismic hazard map of Nebraska (USGS 2009e). A seismicity map of Nebraska that shows the distribution of earthquakes from 1990 to 2006 is shown on **Figure 3.3-15**.

The first significant earthquake recorded in Nebraska occurred on April 24, 1867, apparently centered near Lawrence, Kansas. It affected an estimated area of 301,159 square miles (mi^2) (780,000 square kilometers [km^2]) including much of Nebraska. Since 1867, there have been at least seven earthquakes of MM Intensity V or greater originating within Nebraska's boundaries. It is thought that the strongest earthquake in Nebraska occurred on November 15, 1877. The total area affected was approximately 138,996 mi^2 (360,000 km^2) including most of Nebraska. The most recent earthquake occurred on November 18, 2010 (depth of 3.1 miles [5 km]), approximately 15 miles (24.1 km) east-southeast of Columbus, Nebraska in Platte County, east central Nebraska (lat. 41.37N long. 97.07W). The magnitude of this earthquake was 3.3 on the Richter Scale. The epicenter was approximately 326 miles (525 km) east southeast of the City of Crawford.

Earthquakes along the Chadron and Cambridge Arches in Western Nebraska

The locations of the Chadron and Cambridge Arches in Nebraska are shown on **Figure 3.3-11**. Earthquakes that have occurred in Nebraska in the vicinity of the Chadron and Cambridge Arches from 1884 to 2009 are identified in **Table 3.3-4**. The MM Intensity of these earthquakes ranged from I to VI, with the majority between I and III. The strongest of these earthquakes centered in Dawes County (near Chadron) occurred July 30, 1934 with an intensity of VI. It affected an estimated area of approximately 23,166 mi^2 (60,000 km^2) in Nebraska, South Dakota, and Wyoming. This earthquake resulted in damaged chimneys, plaster, and china. An earthquake that occurred on March 24, 1938 near Fort Robinson had an intensity of IV; no additional information is available. An Intensity IV earthquake should be felt indoors by many and cause dishes, windows, and doors to be disturbed. An earthquake occurred on March 9, 1963 near Chadron and was reported to last about 1 second. It was not accompanied by any damage or noise and was not even noticed by many of the residents of Chadron. An earthquake occurred on March 28, 1964 near Merriman, the vibrations from which lasted about 1 minute and caused much alarm, but no major damage occurred. Books were knocked off shelves, and closet and cupboard doors swung open. On May 7, 1978, an earthquake with Intensity V occurred in southwestern Cherry County, also near the Chadron Arch. No major damage was reported from this earthquake.

Earthquakes occurring from 1992 through 2007 within 125 miles (201.2 km) of the City of Crawford, in Wyoming, and South Dakota are shown in **Table 3.3-5**. The Richter Scale measurements ranged from 3.0 to 3.8 for Wyoming and 2.5 to 4.0 for South Dakota. The MM Intensity values for Wyoming ranged from II to IV, with all but one of the total nine observations ranging from II to III. The MM Intensity values for South Dakota ranged from I to IV, with all but one of the total observations ranging from I to III. The most recent earthquake within the region occurred on November 19, 2011, in South Dakota with the epicenter located 30 miles (48.3 km) west-northwest of the City of Chadron. The earthquake had a magnitude of 2.8 with a depth of ~3.0 miles (4.9 km). The most recent earthquake in Wyoming occurred on November 19, 2011 and was located 69 miles (111.0 km) north of Jackson, Wyoming, a significant distance from the City of Crawford. It had a magnitude reading of 1.7 with a depth of ~1.0 mile (1.2 km).

Although the risk of major earthquakes in Dawes County and the State of Nebraska is low (Burchett 1990), some low to moderate tectonic activity has occurred (Rothe 1981). This tectonic movement is also suggested by geomorphic and sedimentation patterns during the Pleistocene (Rothe 1981), which reflect such movement. Previous seismic activity along the Cambridge Arch has been reported as possibly related secondary recovery of oil in the Sleepy Hollow oil field located in Red Willow County in southwest Nebraska (Rothe et al. 1981). However, deeper events suggest more recent low-level tectonic activity on the Chadron and Cambridge Arches.

Based on information discussed above, and the historical records for the proposed MEA in northwest Nebraska, no major effects would be expected from earthquakes on ISR activities in the MEA area.

3.3.1.5 Inventory of Economically Significant Deposits and Paleontological Resources

According to the Nebraska Oil and Gas Conservation Commission (NOGCC 2011) there was no oil and gas production in Dawes County between 2004 and 2010. There are no current applications for permits to drill in Dawes County. Two wells are currently producing in Sioux

Table 3.3-3 USGS Abbreviated Modified Mercalli (MM) Intensity Scale

Richter Magnitude	Modified Mercalli Scale	Description of MM Scale
1.0 – 3.0	I	Not felt except by a very few under especially favorable conditions.
3.0 – 3.9	II	Felt only by a few persons at rest, especially on upper floors of buildings.
	III	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.
4.0 – 4.9	IV	Felt indoors by many, outdoors by a few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
	V	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
5.0 – 5.9	VI	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
	VII	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
6.0 – 6.9	VIII	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
	IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
7.0 and higher	X	Some well-built wooded structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.
	XI	Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly.
	XII	Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly. Damage total. Lines of sight and level are distorted. Objects thrown into the air.

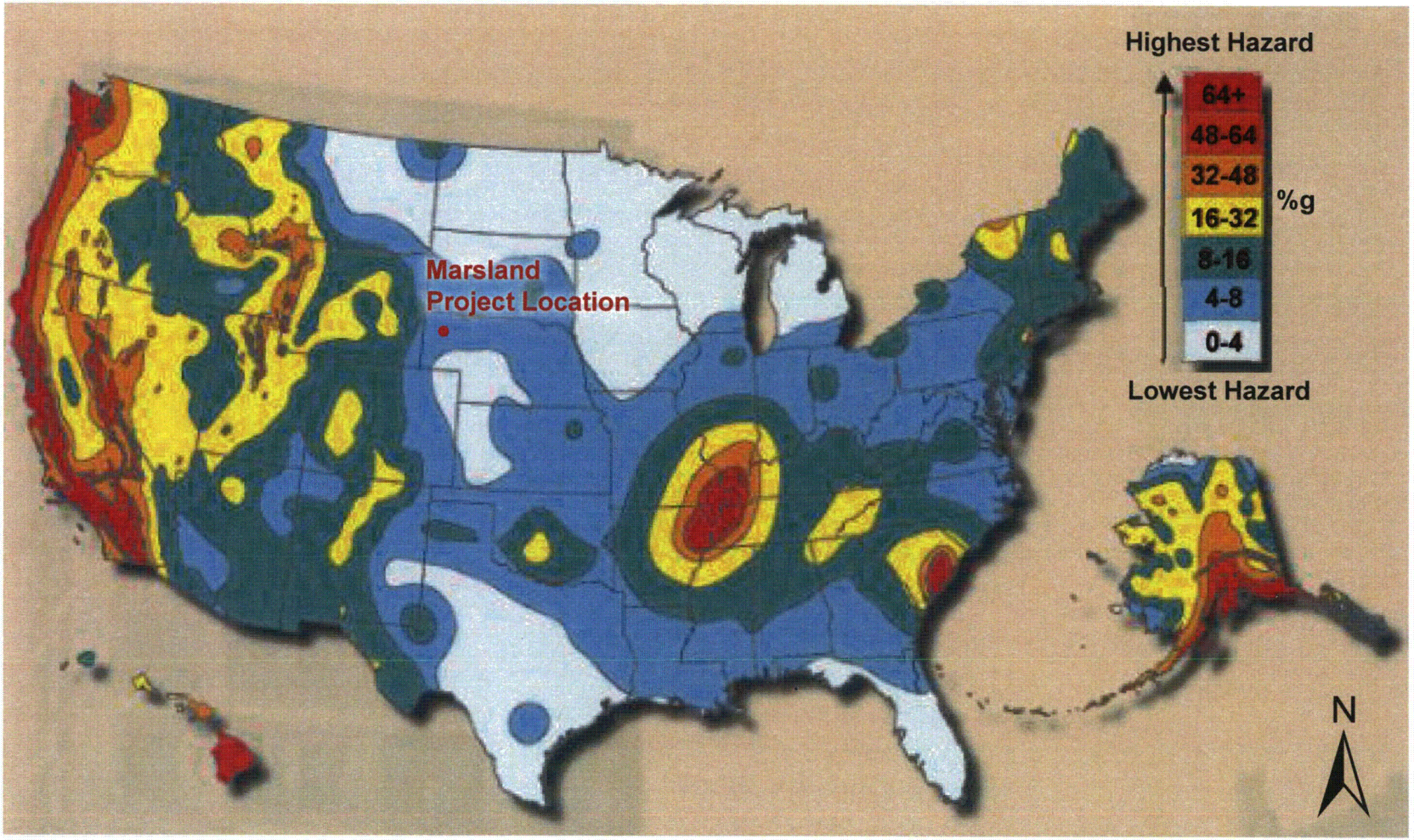
Source: FOO 2002

Table 3.3-4 Historical Earthquakes in Northwestern Nebraska in Close Proximity to the Chadron and Cambridge Arches (1884 – 2009)

Date	Location	Latitude	Longitude	Depth (km)[a]	Richter Magnitude[b]	Modified Mercalli Intensity [b]	Source
3/17/1884	North Platte, NE	41.133	100.75			IV	D
				--	--		
12/16/1916	Stapleton, NE	41.55	100.467	--	--	II-III	D
9/24/1924	Gothenberg, NE	40.95	100.133	--	--	IV	D
8/08/1933	Scottsbluff, NE	41.867	103.667	--	--	IV-V	D
7/30/1934	Chadron, NE	42.85	103	==	==	VI	D
3/24/1938	Fort Robinson, NE	42.683	103.417	--	--	IV	D
3/09/1963	Chadron, NE	42.85	103	--	--	II-III	D
3/28/1964	Merriman, NE	42.8	101.667	--	--	VII	D
5/7/1978	SW Cherry County, NE	42.26	101.95	--	--	V	E
3/06/1983	NE Sheridan, NE	42.96	102.2	--	--	III	E
1/01/1987	Crawford, NE	42.79	103.48	--	--	III	E
2/08/1989	Merriman, NE	42.8	101.6	--	--	IV	E
2/09/1989	39 Miles SE of White Clay, NE	42 41 21 38	101 54 00 32	5 (3.21 miles)	3.8	III	A
7/18/1990	7 miles SSE of Ord, NE	41 30 16 72 N	98 57 39 74 W	5 (3.21 miles)	3.0	II	A
9/30/1990	18 miles SE of Hyannis, NE	41 48 52 97 N	101 30 12 67 W	5 (3.21 miles)	3.0	II	A
8/26/1991	10 miles SE of Brownlee, NE	42 09 46 40 N	100 32 03 25 W	5 (3.21 miles)	3.4	II	A
2/20/1993	14 miles SE of Merriman, NE	42 49 48 00 N	101 27 44 36 W	5 (3.21 miles)	3.5	II - III	A
1/25/1994	5 miles ESE of Wood Lake, NE	42 37 36 39 N	100 08 25 90 W	5 (3.21 miles)	3.3	II	A

Table 3.3-5 Earthquakes in Wyoming and South Dakota Within 125 miles of City of Crawford, NE (1992 – 2009)

Date	Location	Latitude	Longitude	Depth (km)[a]	Richter Magnitude[b]	Modified Mercalli Intensity[b]	Source
WYOMING							
8/29/2004	10 miles NW of Douglas, WY	42 54 05 38 N	105 30 33 39 W	5 (3.1 miles)	3.8	III	A
2/15/2004	12 miles N of Douglas, WY	42 56 27 51 N	105 24 12 32 W	10 (6.2 miles)	3.5	II - III	A
4/09/1996	5 miles SE of Redbird, WY	43 03 43 28 N	104 05 54 17 W	5 (3.1 miles)	3.7	III	A
12/13/1993	9 miles SW of Esterbrook, WY	42 20 11 47 N	105 30 04 15 W	5 (3.1 miles)	3.5	II - III	A
10/10/1993	26 miles W of Esterbrook, WY	42 25 25 99 N	105 52 21 90 W	5 (3.1 miles)	3.7	III	A
7/23/1993	18 miles WNW of Esterbrook, WY	42 28 34 03 N	105 42 18 29 W	5 (3.1 miles)	3.7	III	A
6/30/1993	15 miles N of Douglas, WY	42 59 02 58 N	105 22 48 50 W	5 (3.1 miles)	3.0	II	A
2/24/1993	11 miles SE of Wright, WY	43 42 46 50	105 17 20 18 W	0	3.6	III	A
11/02/1992	3 miles SE of Lusk, WY	42 44 49 37 N	104 53 22 98 W	5 (3.1 miles)	3.0	II	A
SOUTH DAKOTA							
2/07/2007	1 mile SW of Owanka, SD	44 01 56 13 N	102 34 47 35 W	5 (3.1 miles)	3.1	II	A
5/25/2003	35 miles E of Pine Ridge, SD	43.08 N	101.84 W	5 (3.1 miles)	4.0	IV	B
5/03/1996	18 miles NW of Ardmore, SD	43 02 32 88 N	104 01 11 30 W	5 (3.1 miles)	3.1	II	A
2/06/1996	8.3 miles NW of Hill City, SD	43 58 52 67 N	103 43 41 52 W	5 (3.1 miles)	3.7	III	A
3/20/1994	3 miles SW of Hot Springs, SD	43 23 51 02 N	103 29 57 16 W	5 (3.1 miles)	2.3	I	A



SOURCE: SD 2008

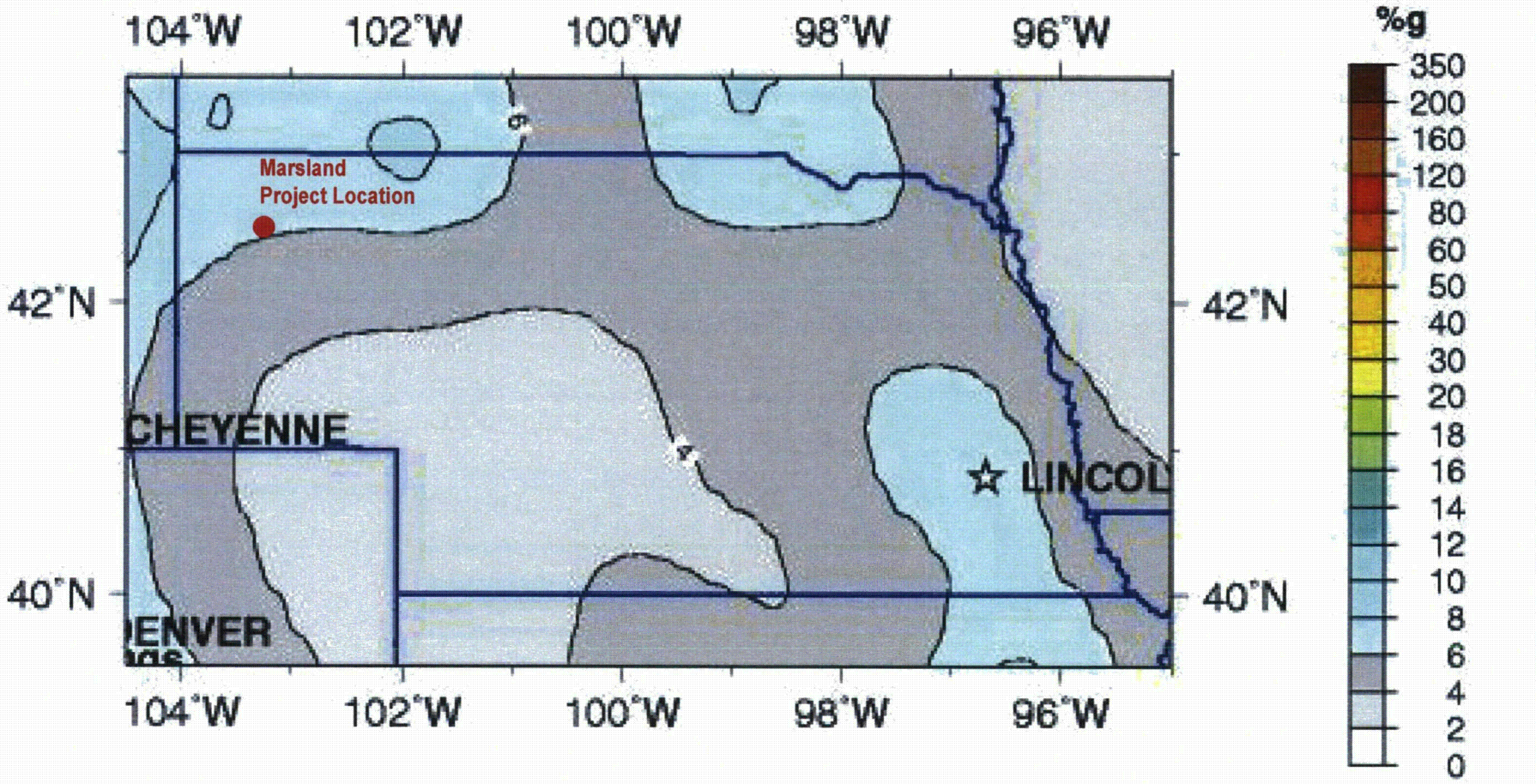
CROW BUTTE RESOURCES, INC.

FIGURE 3.3-13
EARTHQUAKE HAZARD RANKING IN THE U.S.

PROJECT: CO001636.00001 MAPPED BY: JC CHECKED BY: JEC

ARCADIS
630 Plaza Drive, Ste. 100
Highlands Ranch, CO 80129
P: 720-344-3500 F: 720-344-3535
www.arcadis-us.com

K:\CBR_Projects\CO001636_Marsland\3_IMAGES\Illustrator\ER Figure 3_3-13 Earthquake Hazard Ranking in the US.ai @11/03/2011



Peak Acceleration (%g) with 2% Probability of Exceedance in 50 Years
Site: NEHRP B-C boundary
National Seismic Hazard Mapping Project (Peterson, M.D. 2008)

SOURCE: USGS 20009a

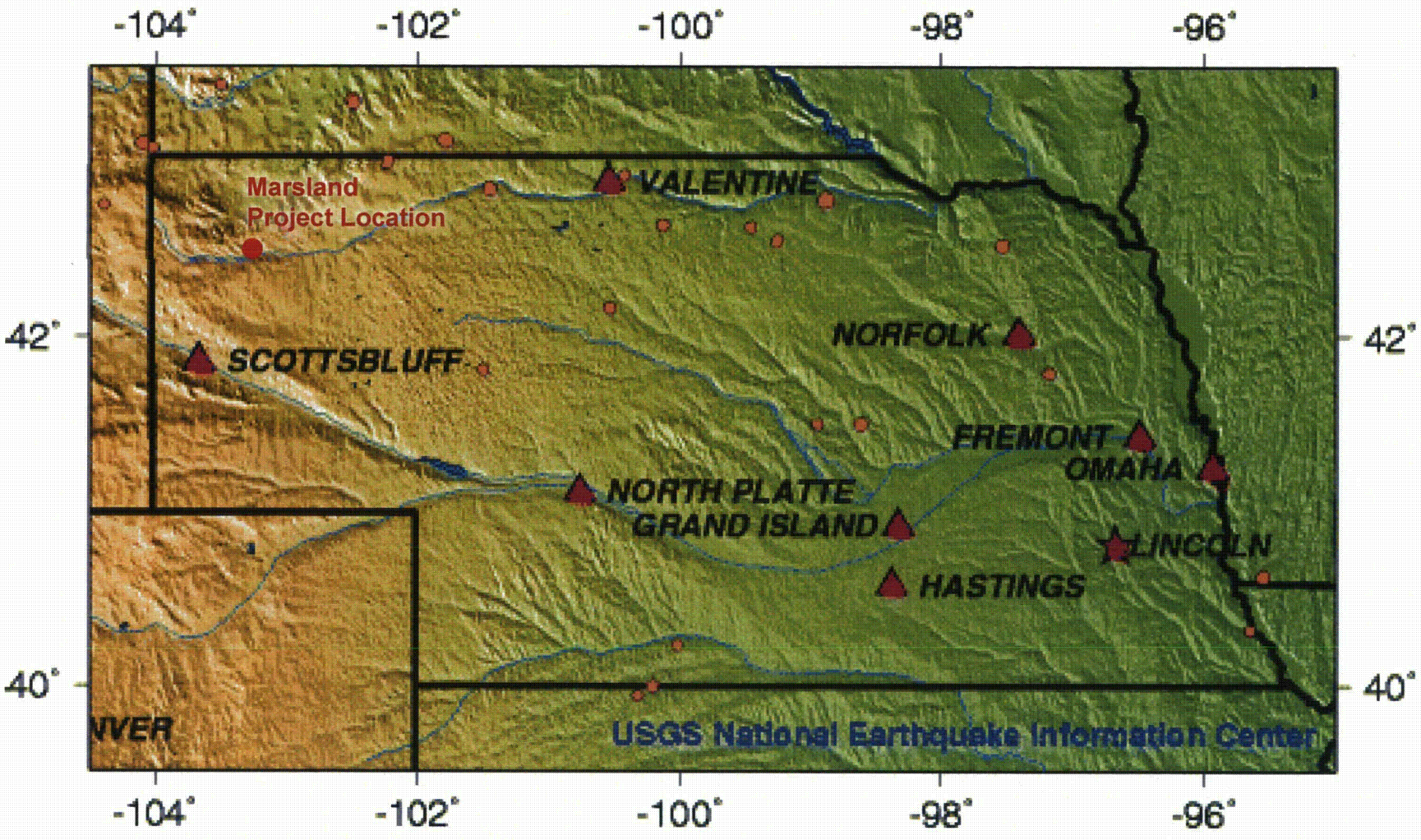
N

CROW BUTTE RESOURCES, INC.

FIGURE 3.3-14
SEISMIC HAZARD MAP
FOR NEBRASKA (2008)

PROJECT: CO0016 6.00001 MAPPED BY: JC CHECKED BY: LW

ARCADIS
630 Plaza Drive, Ste. 100
Highlands Ranch, CO 80129
P: 720-344-3500 F: 720-344-3535
www.arcadis-us.com



Depth is in kilometers.
Purple Triangles: Cities
Purple Star: Capital City
Circles: Earthquakes (color represents depth range)
Earthquake locations are from the USGS/NEIC PDE catalog

SOURCE: USGS 2009e

N

CROW BUTTE RESOURCES, INC.

FIGURE 3.3-15
SEISMICITY OF NEBRASKA
1990-2006

PROJECT: CO001636.00001 MAPPED BY: JC CHECKED BY: JEC

ARCADIS
630 Plaza Drive, Ste. 100
Highlands Ranch, CO 80129
P: 720-344-3500 F: 720-344-3535
www.arcadis-us.com

K:\CBR_Projects\CO001636_Marsland\3_IMAGES\Illustrator\ER Figure 3_3-15 Seismicity of Nebraska 1990-2006.ai @ 11/04/2011