# Potential Seismicity Evaluation of the Griswold 2N-11HZ EOR project in 1N 66W Sec. 11, Weld County, Colorado

The Griswold EOR Unit is located in North-central Colorado within the Denver-Julesberg basin. The Denver-Julesberg basin is an asymmetrical Laramide aged basin elongated North to South (Exhibit 1). It is bound by the front range of the Rocky Mountains to the west on its steeply dipping limb with a gradually dipping eastern limb stretching nearly to the Kansas border. To the north it is bound by the Hartville Uplift in Wyoming and to the south by the Apishapa uplift and Las Animas Arch (Drake II, R.M. et al. 2012).

EOR injection followed by production is planned into the Cretaceous aged Niobrara chalk formation (82-87Ma) at this location. The structural setting during the time of Niobrara deposition was a foreland basin associated with the Sevier Orogeny. During this time, a shallow seaway existed connecting the Gulf of Mexico to the Arctic Ocean commonly referred to as the Western Interior Seaway (Longman, 2020).

Oxy has evaluated both the local and regional risks for the potential of inducing seismicity with this project and has concluded the risk to be low. Below are comments on the figures included in this evaluation that assist in this determination.

Exhibit 1: The Griswold EOR Unit sits above granitic basement rocks of Paleoproterozoic age shown in a light orange color on the map derived from aeromagnetic data interpretation (Sims, P.K., et al, 2001). The world stress data overlain on this map shows the current maximum stress state in this area to be NNW-SSE (http://www.world-stress-map.org/). The current tectonic stresses are extensional in nature as the North American Plate moves away from the Pacific Plate (Meldahl, 2011).

Exhibit 2: Surface geology map from Tweto, 1979 shows the Griswold Unit and the 12-mile radius sit within an area of Quaternary, Tertiary and Triassic sediments at surface. Faulting is present at surface approximately 11 miles west of the EOR injection site. Faulting further west in the Precambrian Granite formations concur with the regional uplift forming the front range of the Rocky Mountains.

Exhibit 3: Within the Niobrara formation there are numerous layer bound extensional faults as shown on a 3D seismic line through the 12-mile EOR radius. This fault system is contained within the Niobrara Formation and is not connected to the basement along this shear zone or within the 12-mile radius surrounding the Griswold EOR Unit. These faults are considered non-tectonic in origin (Bracken, 2020).

Exhibit 4: The current tectonic setting is extensional, which is accommodated in this area by a transtensional shear zone characterized by an extensional strike-slip duplex in the basement. The maximum stress runs perpendicular to the shear zone in the area therefore this fault is not critically stressed and presents a lower risk for induced seismicity

Exhibit 5: There are four identified historic seismic events within the 12-mile radius of the Griswold EOR Unit. These seismic events occurred from 1966-1967 and ranged from 3.5-5.3 magnitude. They are located in 1S66W, 2S66W, and 2S65W at a distance of approximately 8 miles from the injection location. These events have been attributed to wastewater injection directly into the Precambrian Basement at the Rocky Mountain Arsenal (Hsieh, P.A., Bredehoeft, J.D., 1981). The Griswold EOR Unit plans injection into the Niobrara formation followed by production so pressures will not remain elevated through time. This should lead to a decreased chance of induced seismicity.

KerrMcGee

Exhibit 6: The 2018 USGS Short Term Seismic Activity potential indicates that this area has less than a 1% chance of potentially minor-damage ground shaking in the Griswold EOR Unit AOI.

Exhibit 7: The 2018 USGS Long Term Seismic Hazard Potential indicates that the Griswold EOR Unit AOI falls within the lower hazard categories.

Exhibit 8: The Niobrara formation is approximately 3,900 feet above the Precambrian basement near to the Griswold Unit. The nearest well penetration with logs to the basement is the KMG 16-24i well drilled in 2016 approximately 9 miles to the northeast of the Griswold Unit. The large distance between the injection formation and the basement coupled with the lack of fault connection between the two units leads to a lowered risk of induced seismicity.

References:


Bracken, K. Mechanical stratigraphy and layer-bound normal faulting in the Upper Cretaceous Niobrara Formation, Wattenberg Field, Colorado. The Mountain Geologist, 2020.

Drake II, R.M., Brennan, S.T., Covault, J.A., Blondes, M.S., Freeman, P.A., Cahan, S.M., DeVera, C.A., and Lohr, C.D. Geologic Framework for the National Assessment of Carbon Dioxide Storage Resources- Denver Basin, Colorado, Wyoming, and Nebraska.

Hsieh, P.A., Bredehoeft, J.D. A reservoir analysis of the Denver earthquakes: A case of induced seismicity. Journal of Geophysical Research Volume 86, Issue B2. 10 February 1981, pp903-920.

Longman, M.W., and Luneau, B.A. Revisiting the Upper Cretaceous Niobrara Petroleum System in the Rocky Mountain Region. Adapted from oral presentation given at 2019 AAPG Rocky Mountain Section Meeting, Cheyenne, Wyoming, September 15-18, 2019. DOI:10.1306/51635Longman2020

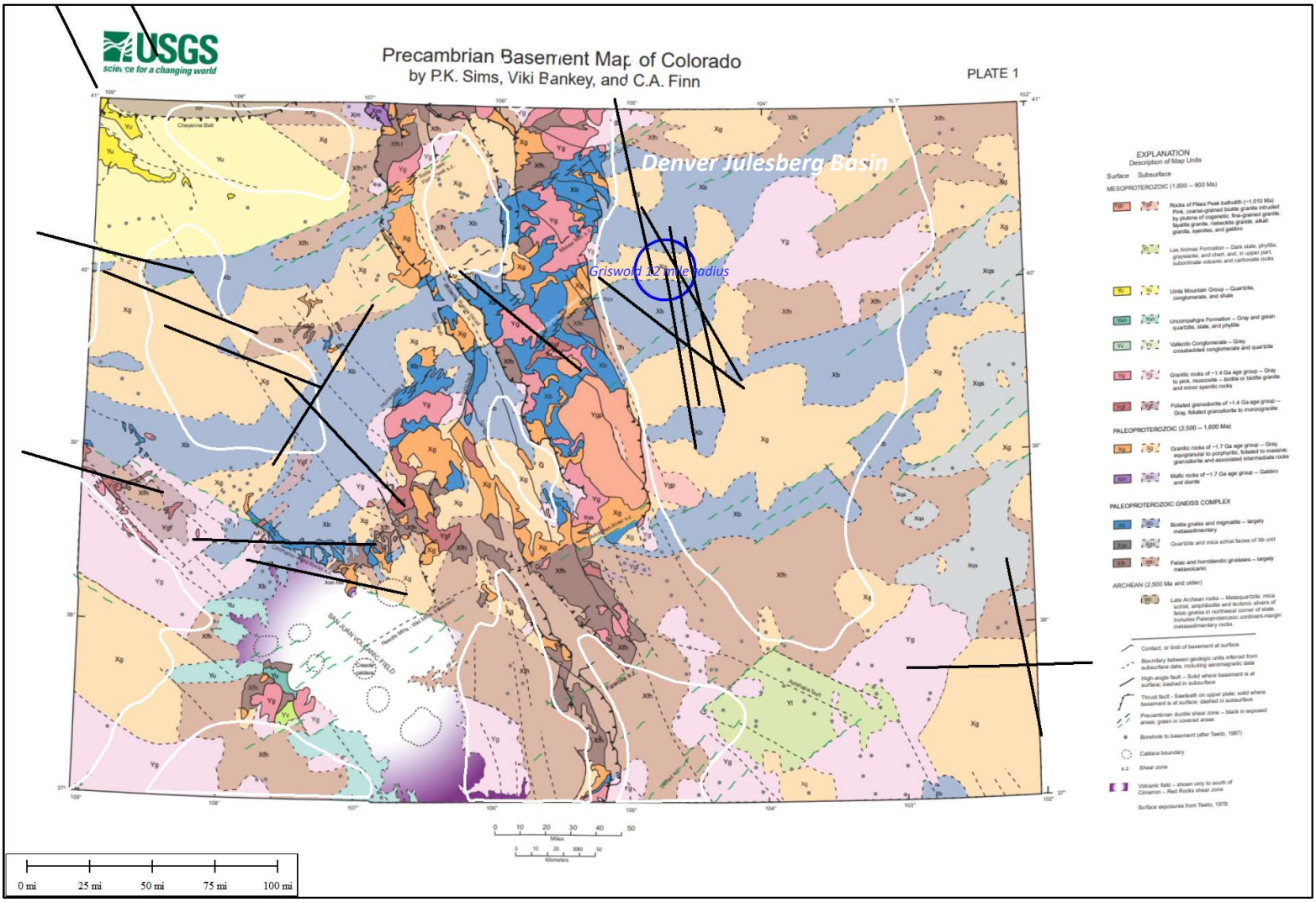
Meldahl, K.H., 2011, Rough hewn land: a geological journey from California to the Rocky Mountains: University of California Press, 296 pp.

Sims, P.K., Bankey, V., Finn, C.A. Preliminary Precambrian basement map of Colorado – A geologic interpretation of the aeromagnetic anomaly map. Open-File Report 2001-364, 2001. https://doi.org/10.3133/ofr01364

Tweto, Ogden. “MI-16 Geologic Map of Colorado.” Geologic. Miscellaneous Investigations. Denver, CO: Colorado Geological Survey, Department of Natural Resources, 1979. https://coloradogeologicalsurvey.org/publications/tweto-geologic-map-colorado-1979.

Exhibit 1

# Geologic Assessment: Regional



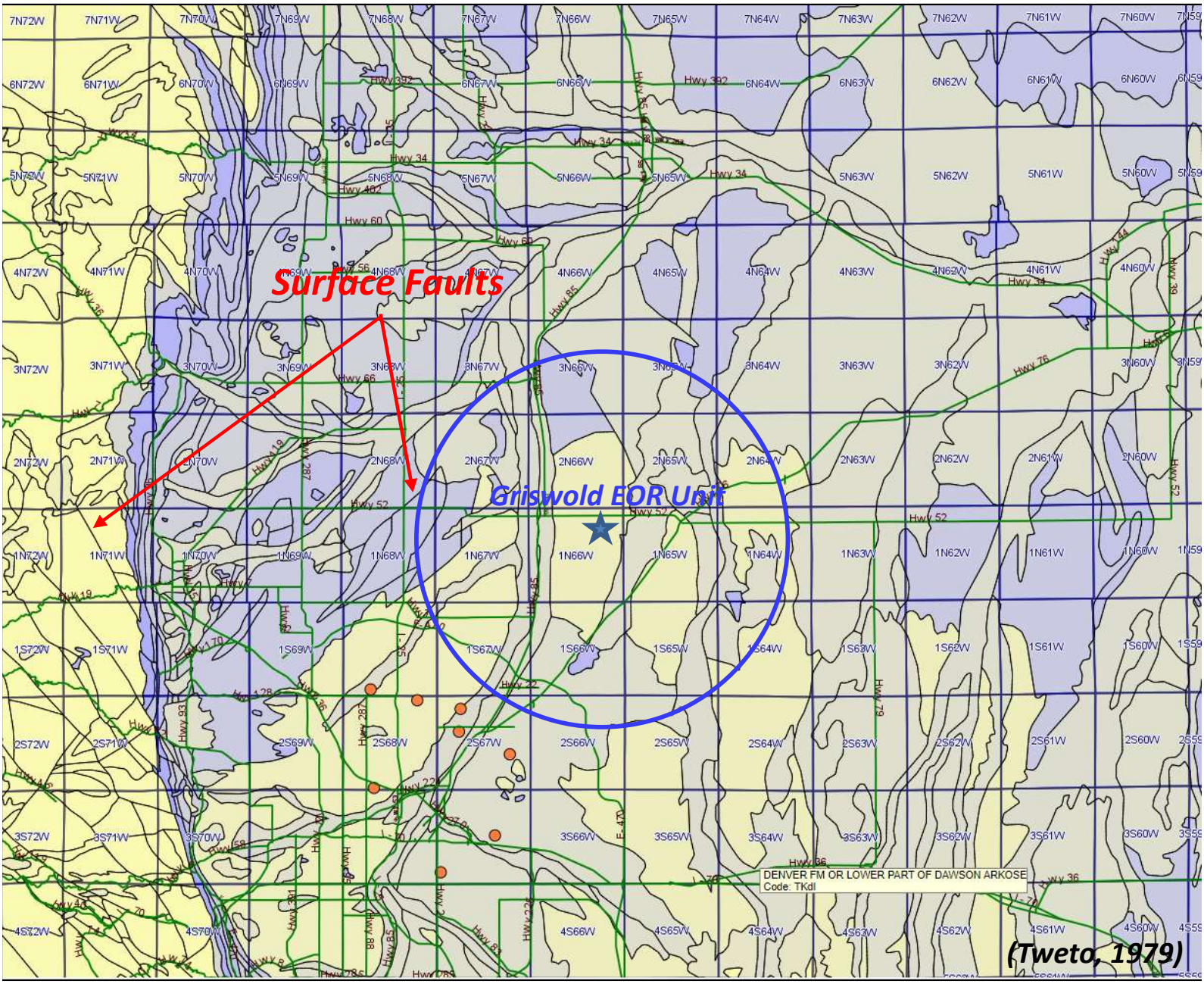

**USGS Precambrian Basement Map of Colorado:**
[USGS Open-File Report 01-0364: Preliminary Precambrian Basement Map of Colorado -- A Geologic Interpretation of the Aeromagnetic Anomaly Map]

**World Stress Map:**
http://www.world-stress-map.org/

KerrMcGee

Exhibit 2

# Geologic Assessment: Structure




TKdl Denver Formation or Lower Part of Dawson Arkose – Arkosic sandstone, shale, mudstone, conglomerate, and local coal beds

Qg Gravels and Alluviums (Pinedale and Bull Lake AGE) Includes Broadway and Louviers Alluviums

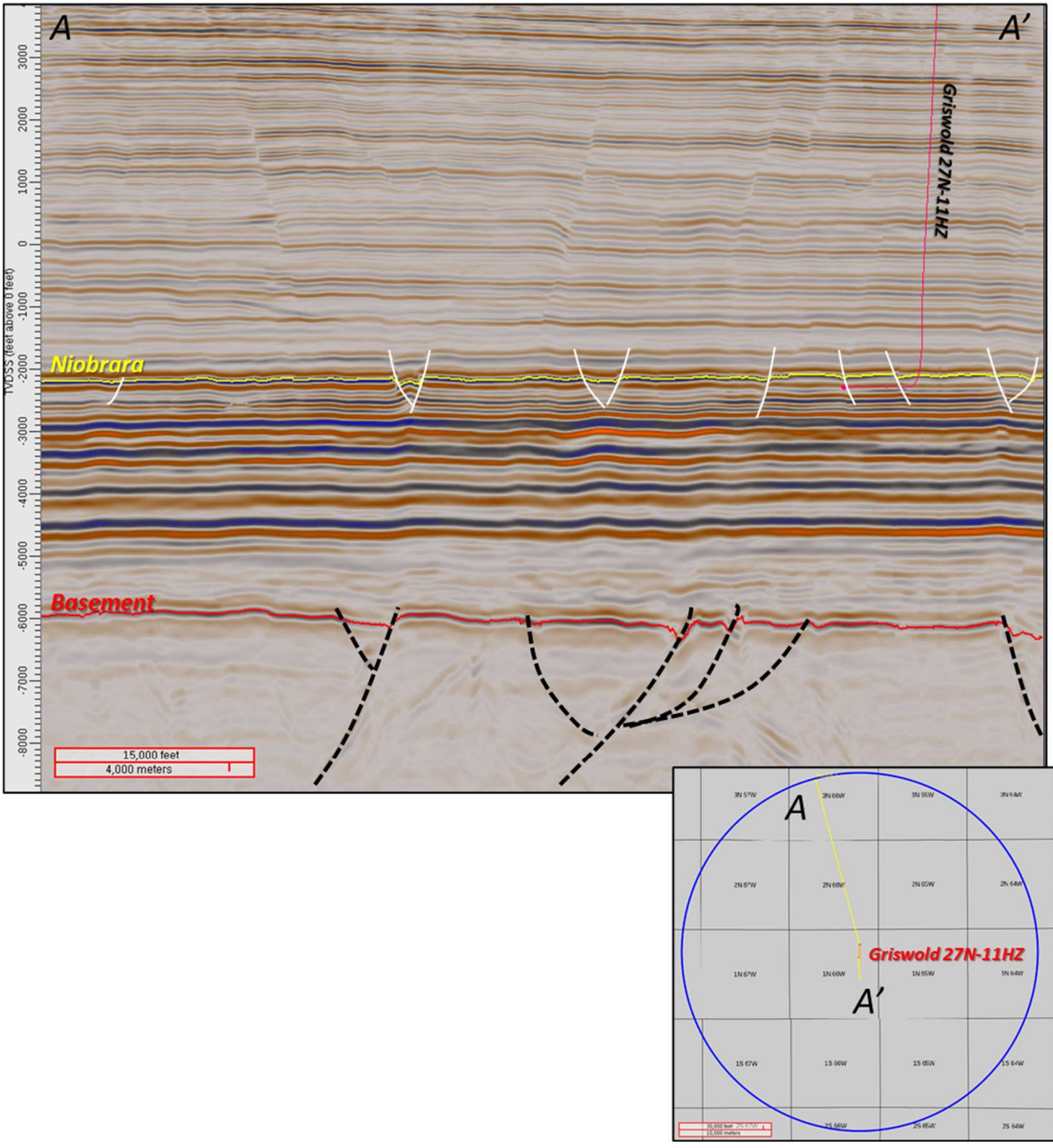
Klf Laramie Formation and Fox Hills Sandstone

TRPII Lykins Formation and Lyons Sandstone

Xg GRANITIC ROCKS OF 1,700 M.Y. AGE GROUP (AGE 1,650-1,730 M.Y.) Includes Boulder Creek, Cross Creek, Denny Creek , Kroeknke, Browns Pass, Powderhorn, Pitts Meadow, Bakers Bridge, and Tenmile Granites, Quartz Monzonites, or Granodiorites; also, unnamed granitice rocks

Exhibit 3

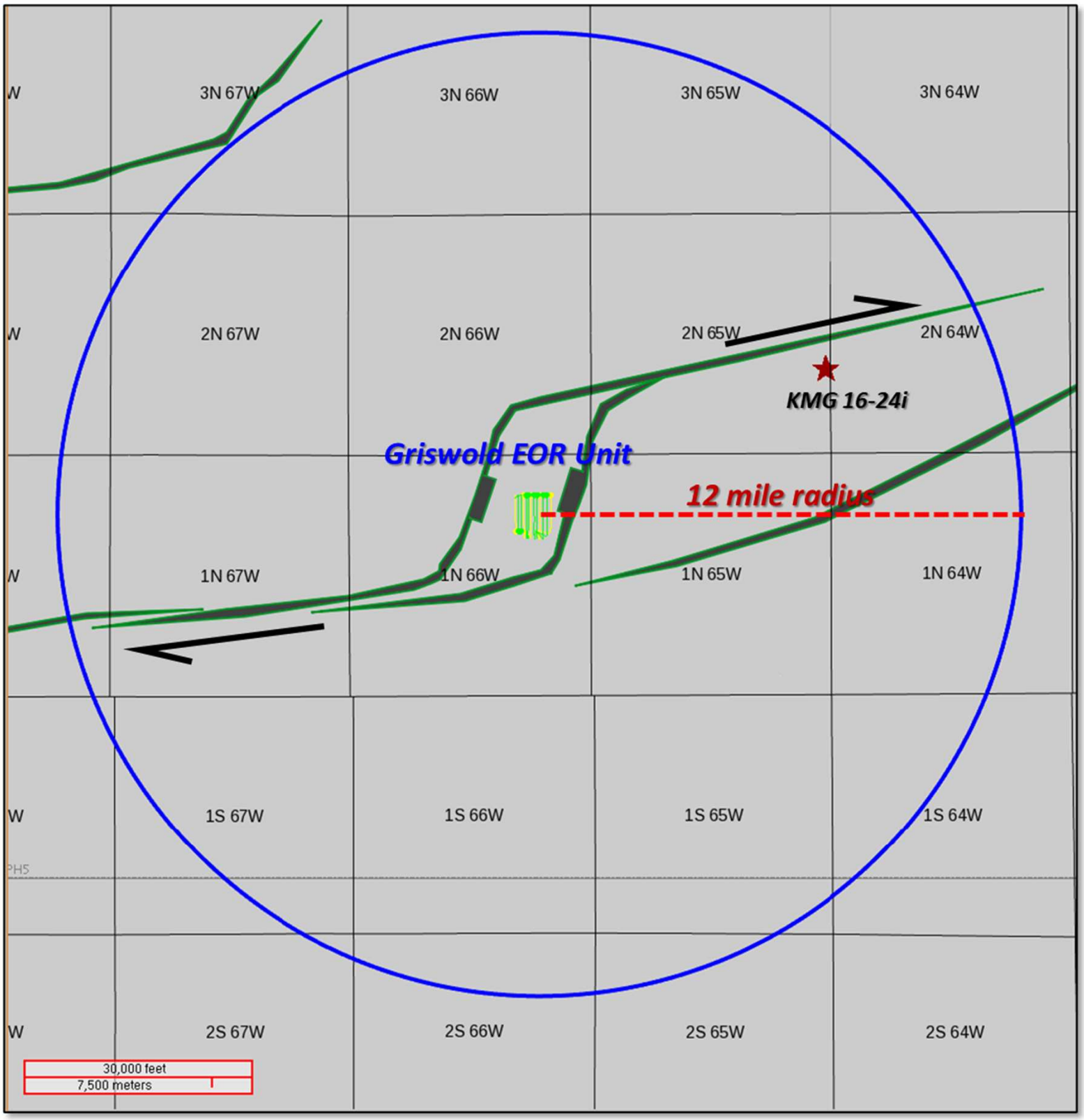
# Geologic Assessment: Seismic Line




KerrMcGee

Exhibit 4

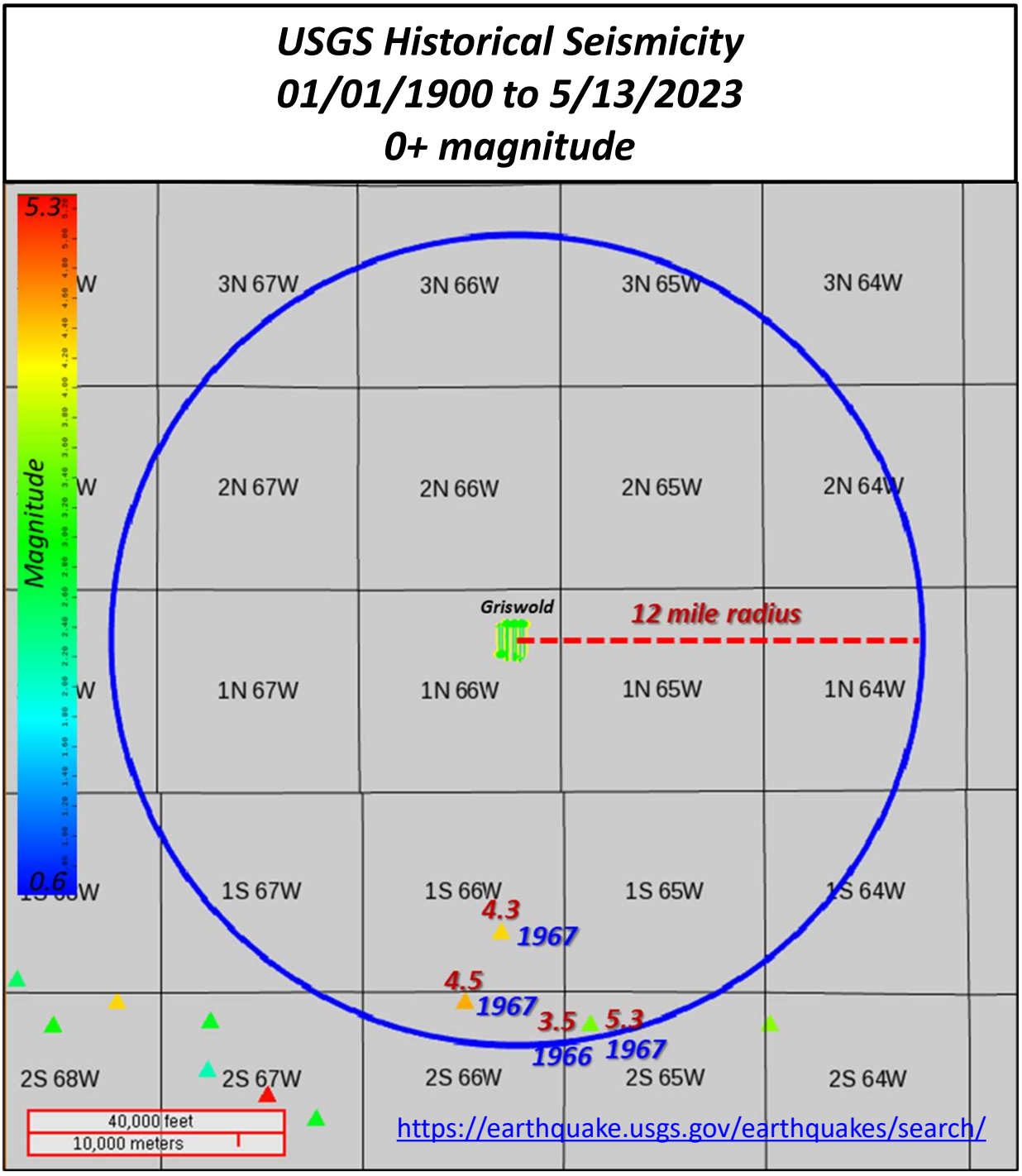
# Geologic Assessment: Local Basement Faulting




KerrMcGee

Exhibit 5

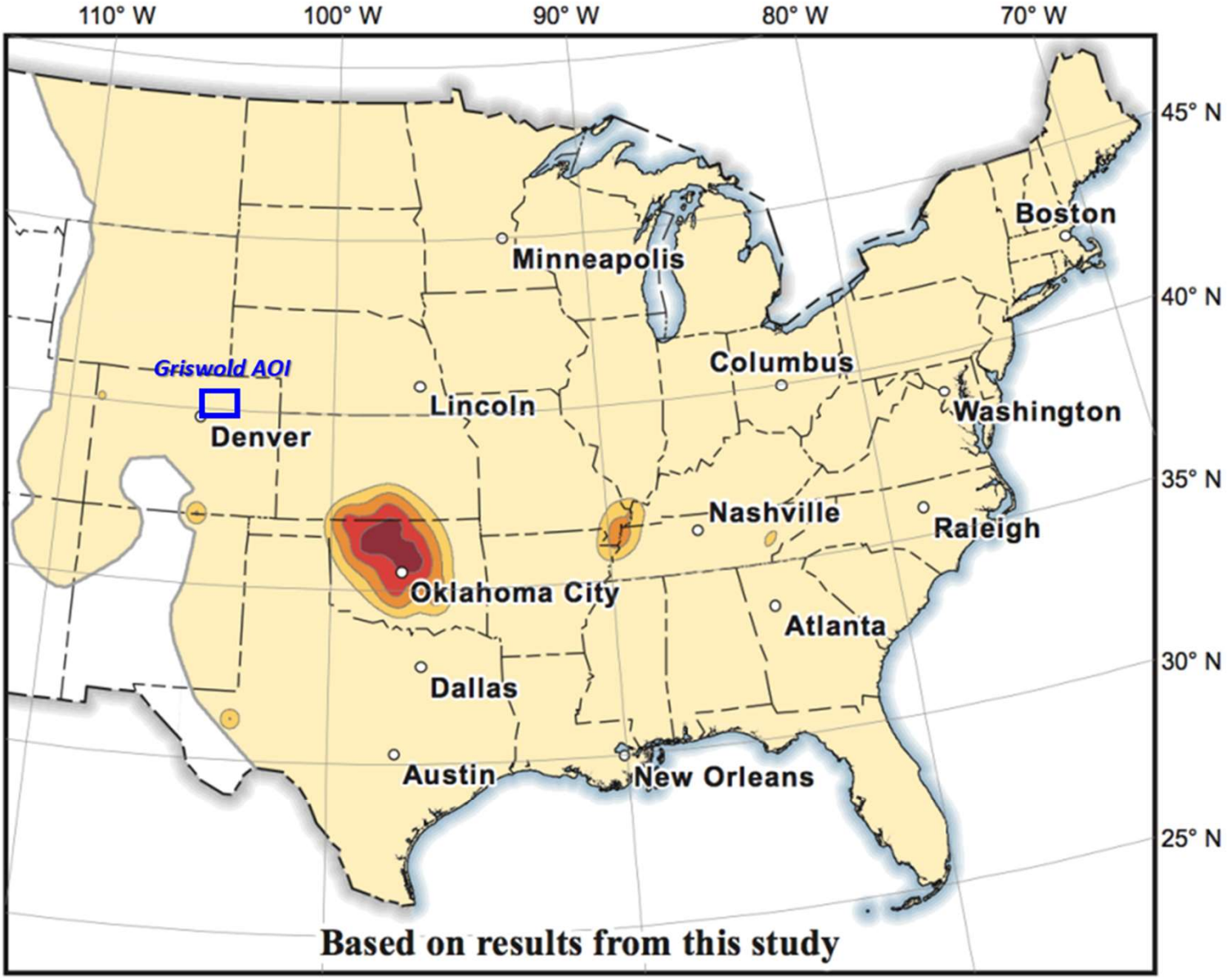
# USGS Seismicity within 12 Mile Radius




KerrMcGee

Exhibit 6

# 2018 Short Term Seismic Hazard Potential




**Chance of potentially minor-damage* ground shaking in 2018**

| <1% | 1% – 2% | 2% – 5% | 5% – 10% | 10% – 14% |
|---|---|---|---|---|

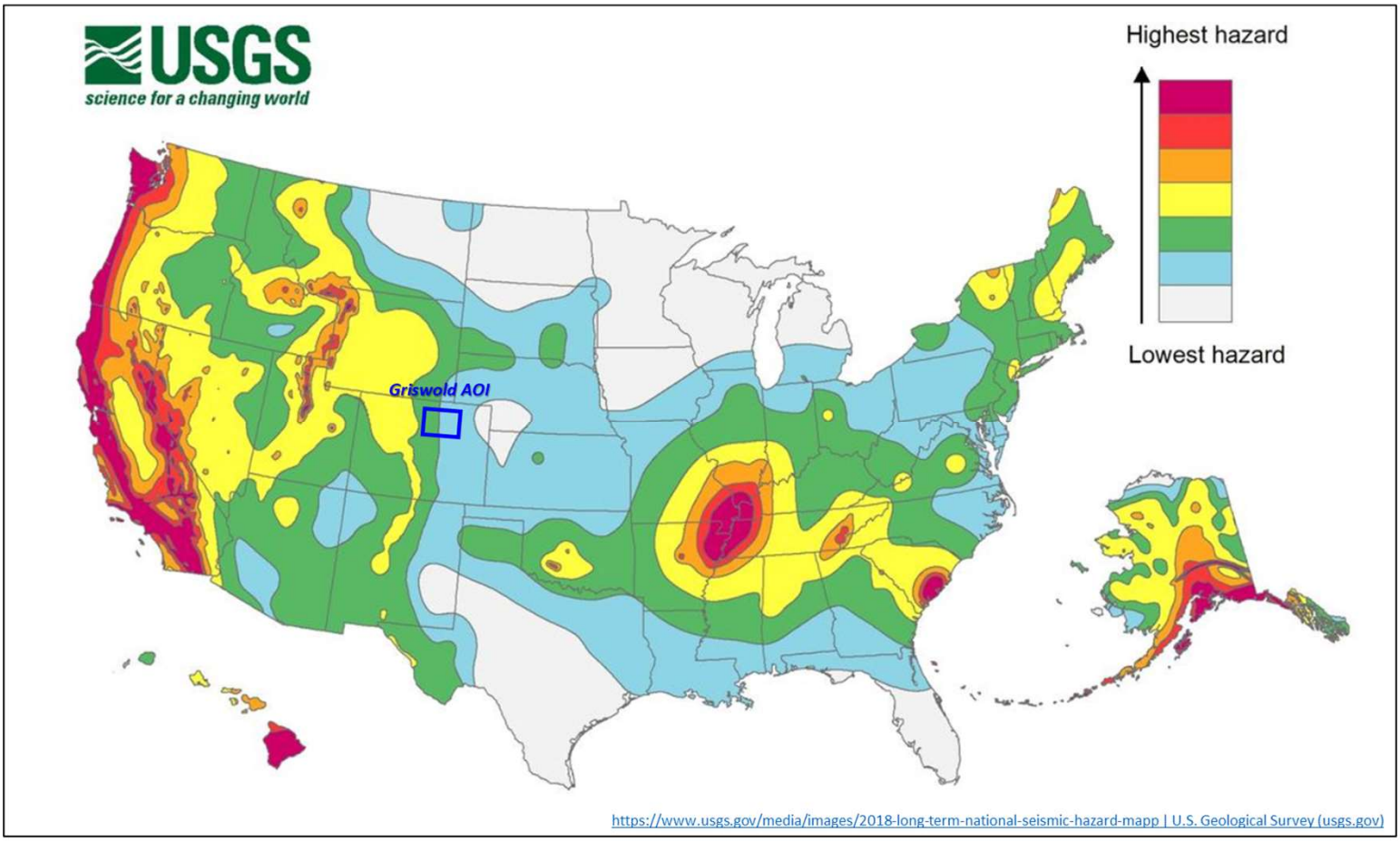
* equivalent to Modified Mercalli Intensity VI, which is defined as: "Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight."

https://d9-wret.s3.us-west-2.amazonaws.com/assets/palladium/production/s3fs-public/atoms/files/ProbDamageEQ_2018-1.pdf

KerrMcGee

Exhibit 7

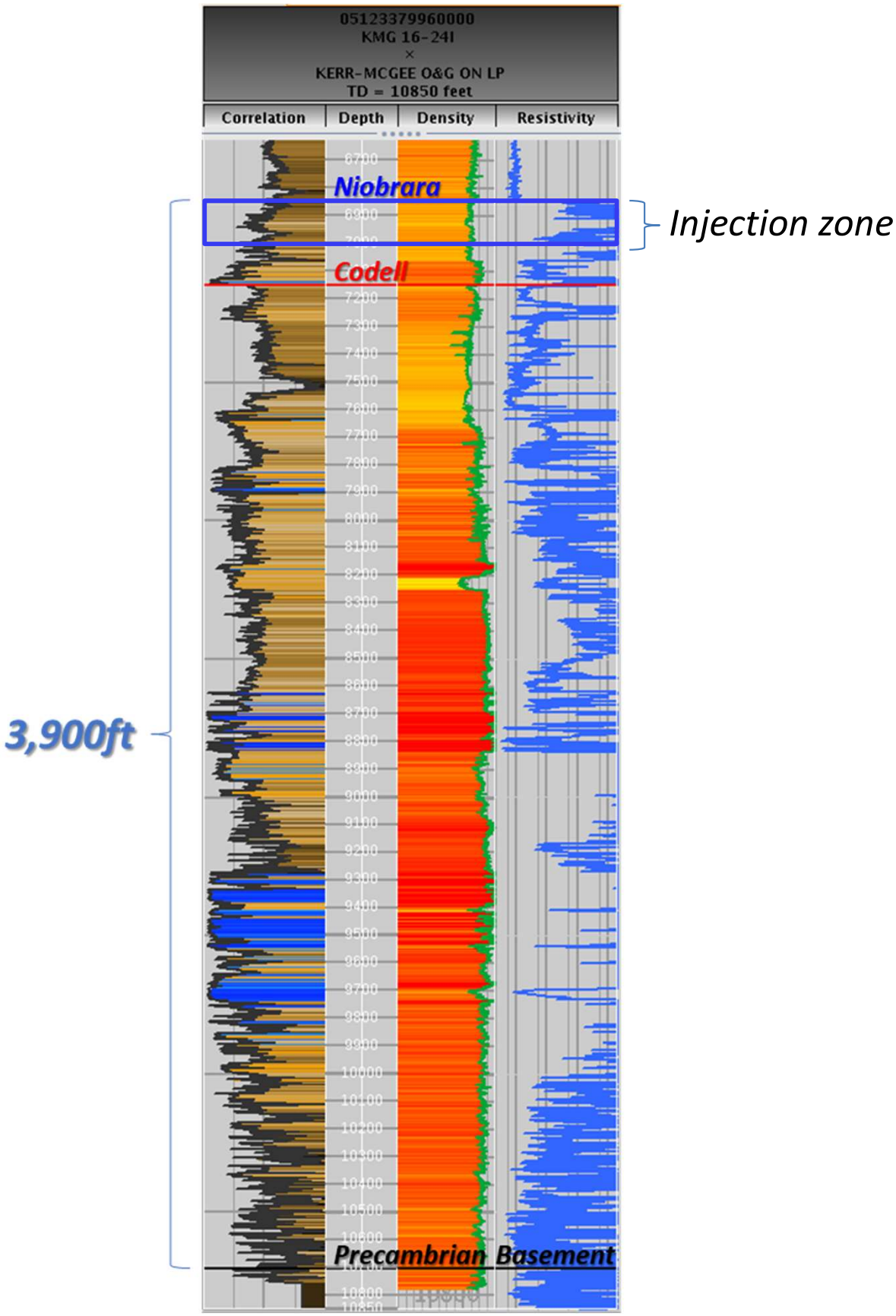
# 2018 Long Term Seismic Hazard Potential




KerrMcGee

Exhibit 8

# Depth to Basement Well Log




KerrMcGee