

SEISMICITY EVALUATION

D90 ENERGY

Mutual EOR Project Seismicity Study - 004a-2022

To address COGCC Rule 803.g. (6), Created July 1, 2020

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August 29, 2022

PURPOSE:

D90 Energy is applying for a permit with the state of Colorado to reinject associated produced natural gas into the Niobrara Formation using the Mutual 0780 3-8H, an existing ~5000 feet horizontal well in the Niobrara shale for resource conservation and potential enhanced oil recovery (EOR).

As part of Rule 803.g. (6), the Commission requires a seismicity evaluation be provided. This report was commissioned to address the Mutual 0780 3-8H injection well and to ensure the injection well application complies with the standards in Rules **801.c** and **801.d**:

801.c. Class II injection wells will not be permitted in areas where they would inject into a formation which is separated from any Underground Source of Drinking Water by a confining formation with known open faults or fractures that would allow flow between the injection zone and Underground Source of Drinking Water within the Area of Review.

801.d. Injection zones will not be permitted within 300 feet in a vertical dimension from the top of any Precambrian basement formation.

The objective of the rule is to minimize the potential for an injection well to contaminate an underground source of drinking water or induce a seismic event that could impact public health, safety, and welfare or impact wildlife or the environment.

A seismicity evaluation is required for all proposed injection wells. A core component of the seismicity evaluation is to identify known seismic events or faults within the vicinity of the proposed injection facility that could increase the potential for seismic activity (or fluid migration). The Commission chose a 12-mile radius for the fault evaluation as a precautionary measure to ensure that all potential fault zones are identified and evaluated.

Under Rule 803.g. (6) Seismicity Evaluation an application for an injection well will include the following information:

- A. A geological and geophysical evaluation of known transmissive or sealing faults or shear zones within 12 miles of the injection well and the potential for induced seismicity.
- B. An exhibit of the historic seismic activity within 12 miles of the proposed injection well.
- C. An exhibit showing the potential for seismic activity within 12 miles of the proposed injection well.
- D. A wellbore diagram of the injection zone depicting the well's bottom hole location relative to the Precambrian basement.

This report will address the above topics.

METHODOLOGY:

As the proposed injection is a south to north oriented horizontal well contained within T7N, R80W, Sec 8, the operator has modified the radius of investigation to 12.5 miles originating from the center of Section 8. All maps in this report are consistent in showing the area of investigation of 12.5 miles (20,120 meters). The resultant area of investigation represents an area of 491 Square miles (1,272 sq km).

A. GEOLOGICAL OVERVIEW:

The North Park Basin is located in Jackson and Grand Counties in north central Colorado (Figure 1).

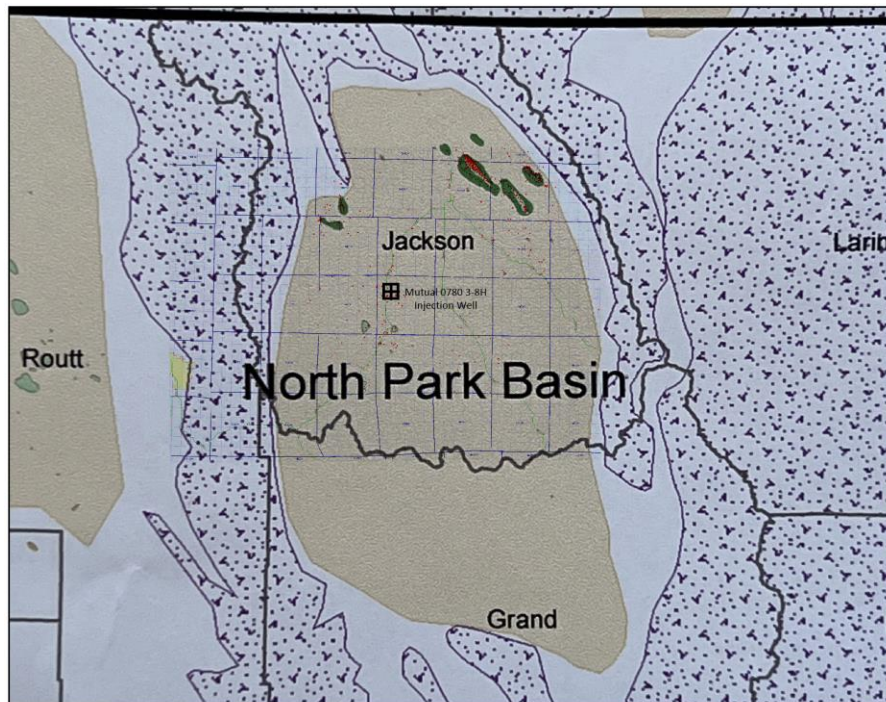


Figure 1. Location of project area within the North Park Basin

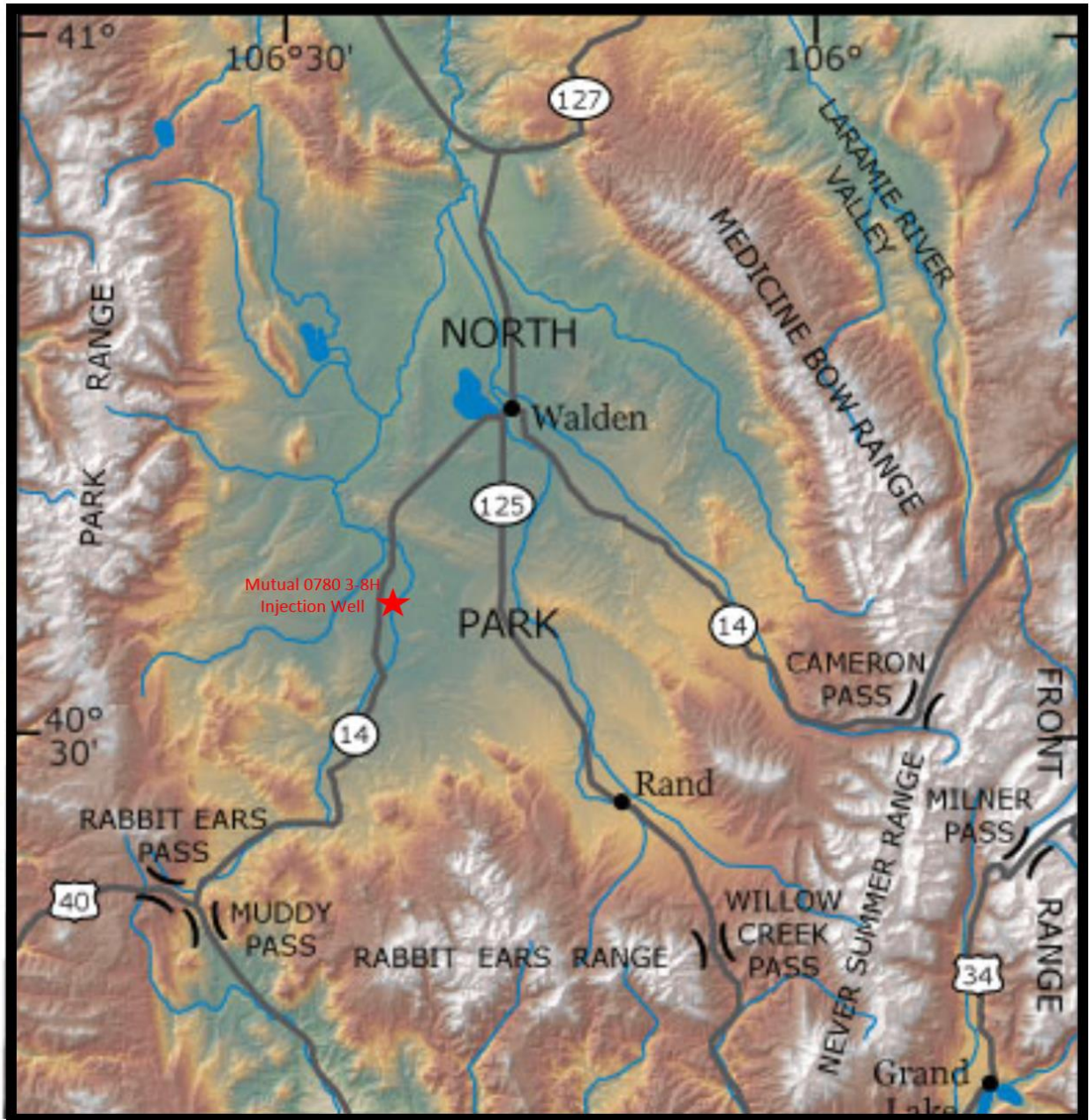


Figure 2: Physiography of North Park Basin, North-Central Colorado
 The red star indicates the location of the proposed D90 Mutual 0780 3-8H Injection well.

The North Park Basin is a Laramide age (80-55Ma) basin and encompasses an area of nearly 1600 square miles. The basin is bounded on the west by the Park Range; on the south by the Rabbit Ears Range and the east and north by the Never Summer and Medicine Bow Ranges (Figure 2).

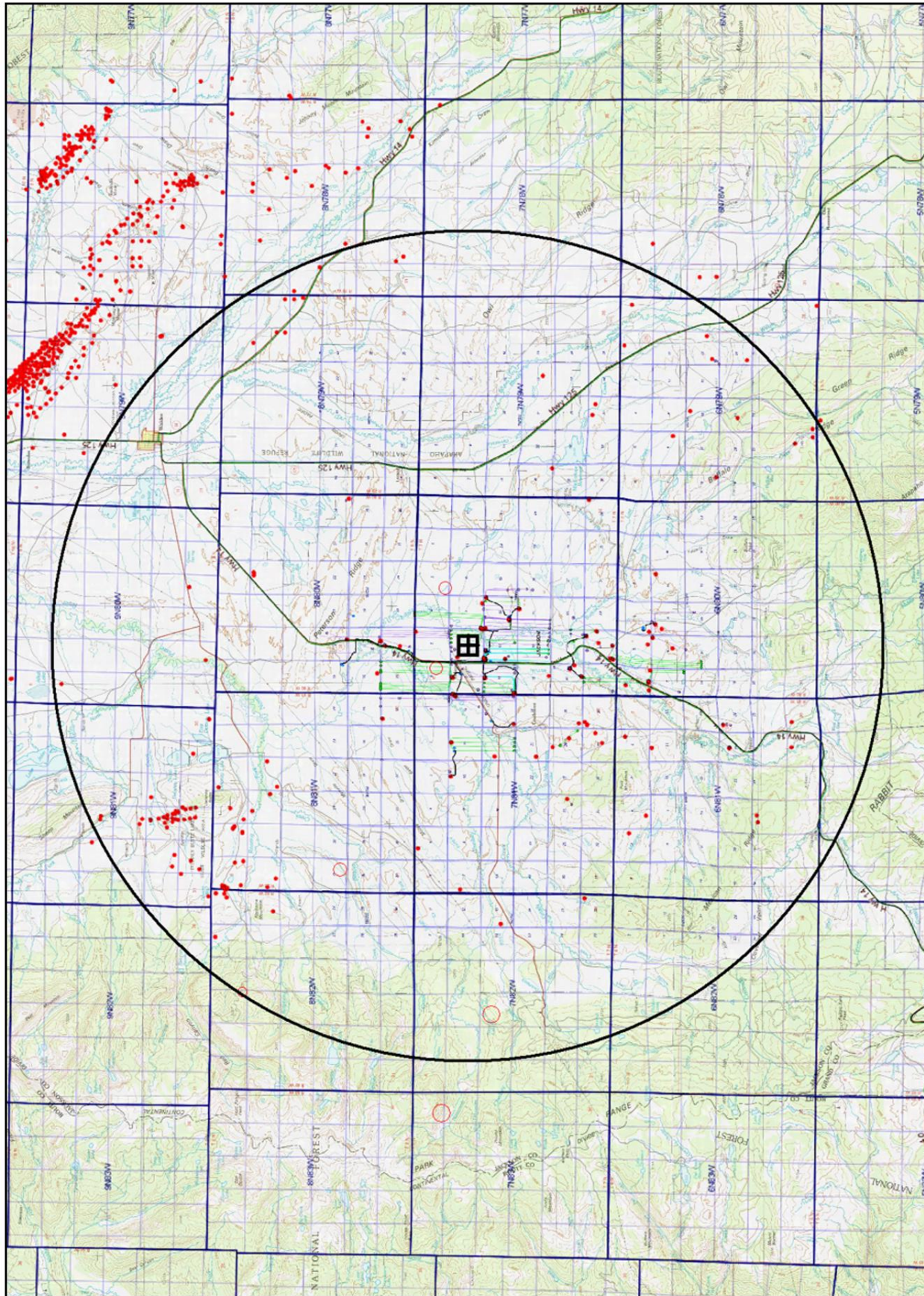


Figure 3. Topographic Map showing the vertical and horizontal well control of the area.
 Center of Section 8, T7N, R80W is shown by the symbol: 

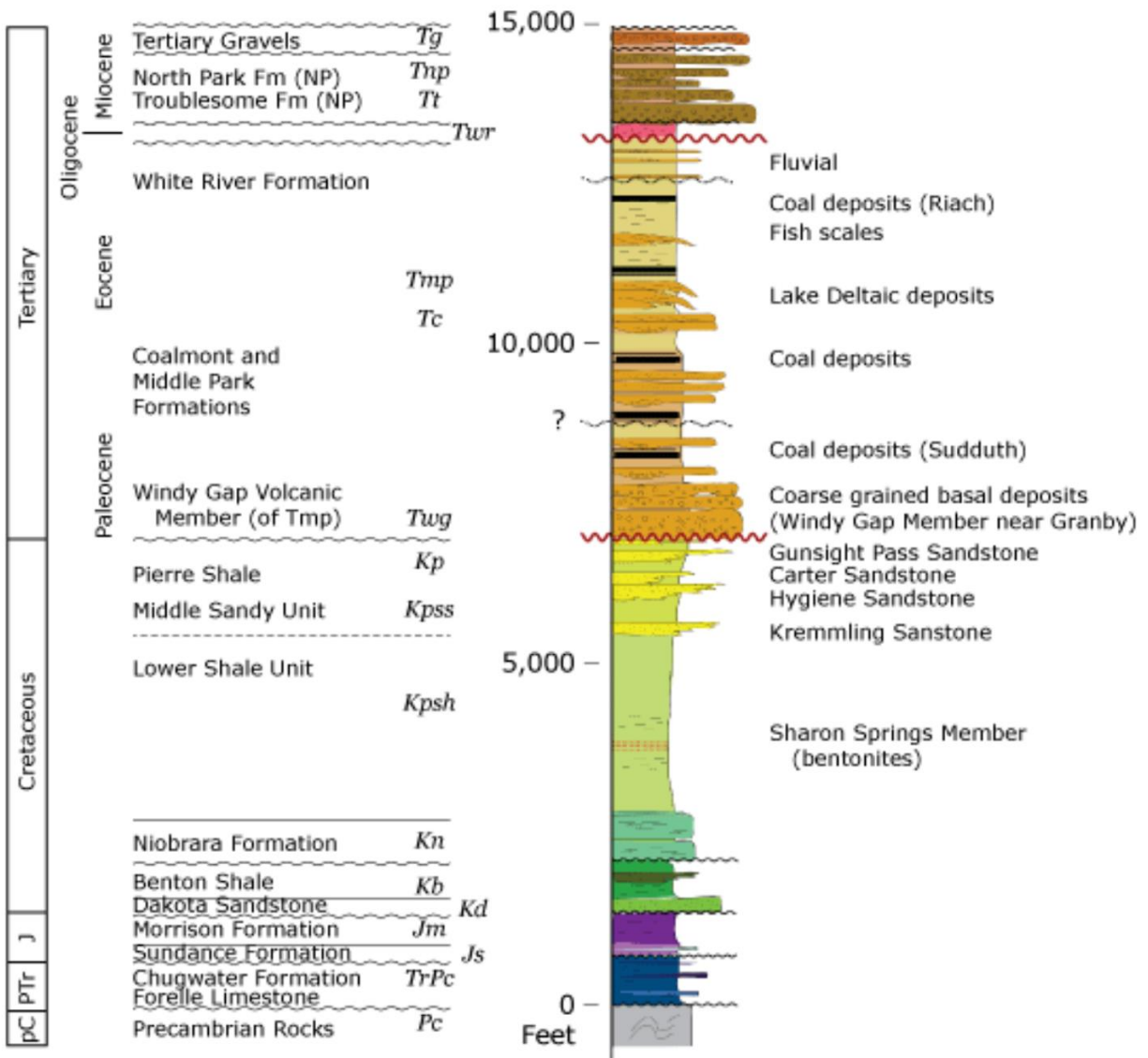


Figure 4. Generalized composite stratigraphic section from North Park and Middle Park Basins (USGS)

The Stratigraphy of the North Park Basin is summarized in Figure 4. A sedimentary section of up to 15,000 feet is overlain on top of Precambrian crystalline basement. The oldest rocks in the basin consist of the Triassic age Chugwater formation. Sedimentary rocks of Triassic, Jurassic, Cretaceous and Tertiary ages are present in the basin.

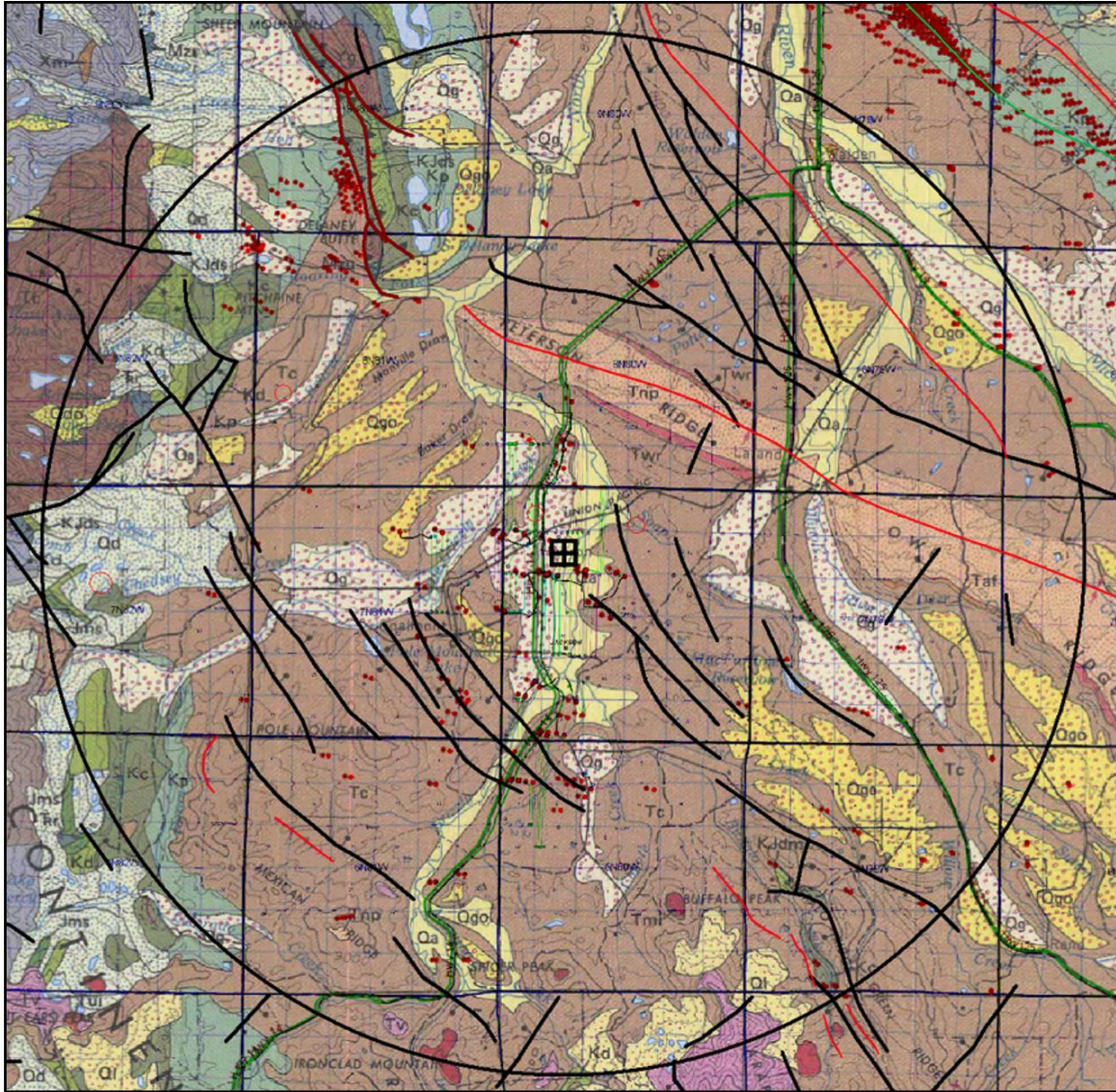


Figure 5a. 1:250,000 USGS Geologic Map of North Park Basin, Jackson County, Colorado. Black Circle represents 12.5 mile radius of investigation from center of T 7N, R80W, section 8.

The Tectonic history of the basin is primarily one of E-W compression during the Laramide Orogeny (80-55 Ma). This compression is responsible for the formation of the generally N-S trending uplifts bounding the east and west sides of the basin. This E-W principle stress direction has formed antithetic fault patterns which dominate the basin in a NW-SE direction and to a lesser extent, NE-SW direction. These faults are primarily normal in nature and are thought to extend from surface to Basement. Figure 5 shows a portion of the 1:250,000 USGS Geological map of the area showing the surface units and main structural features present in the area:

- Black Lines- Normal faults Brown Lines- Reverse faults
- Red Lines- Synclinal trends Green Lines- Anticlinal trends

USGS mapping of the area reveals a dominant fault pattern consisting of NW-SE trending normal faults (Figures 5, 6 and 7). These faults are mapped as being 2-8 miles in length and verging primarily to the SW. North of the Peterson/Owl Ridge the faults are mapped as being longer in length (6-20 miles).

The Mutual 0780 3-8H borehole is mapped to be within 0.96 miles (1.55 km) and 1.53 miles (2.46 km) of the closest faults to the north and east. To the south and west, the borehole is mapped to be 3.49 miles (5.62 km) from the nearest fault.

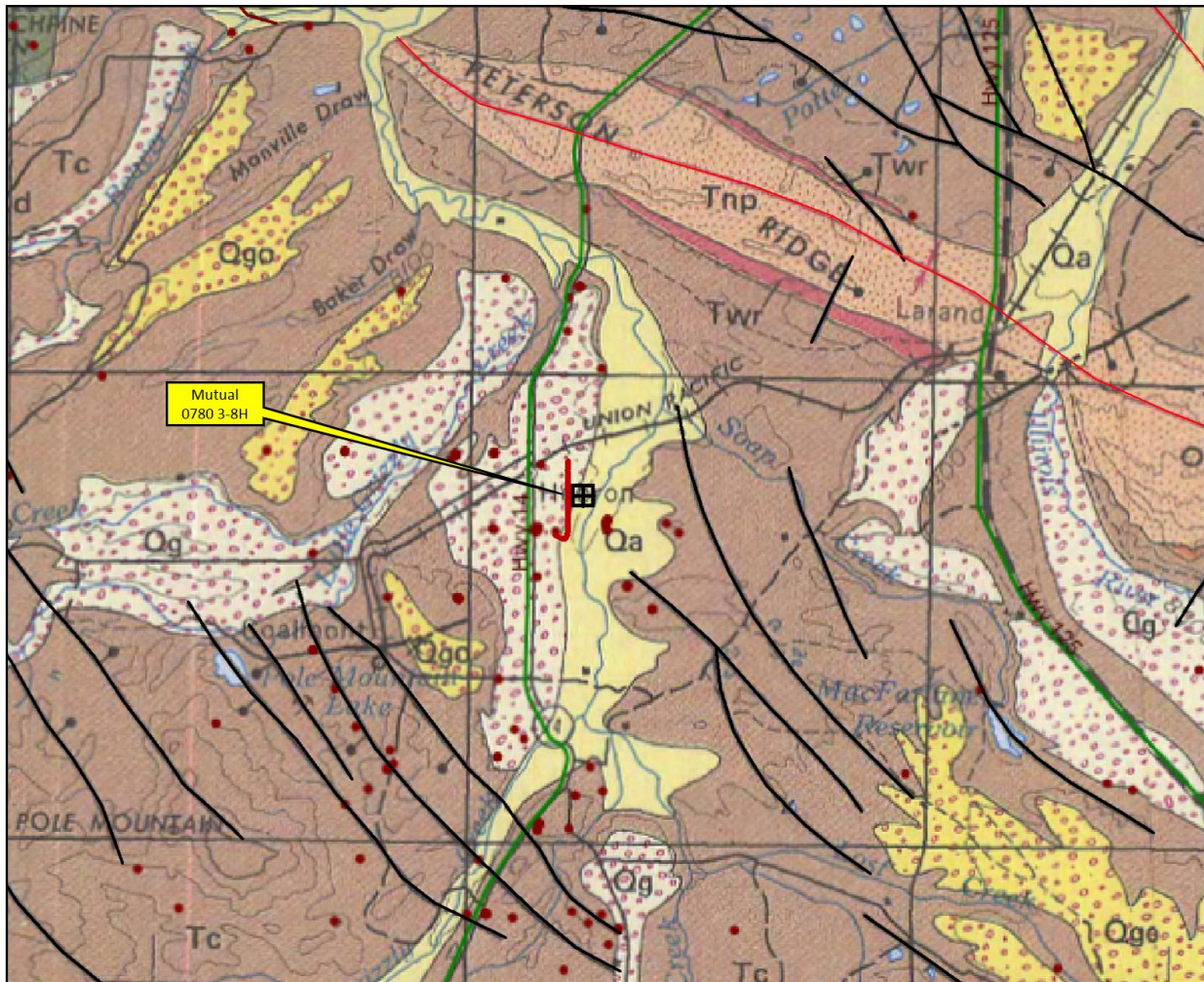


Figure 5b. Close-up of the proposed Mutual 0780 3-8H injection well in relation to USGS mapped faulting and structural elements.

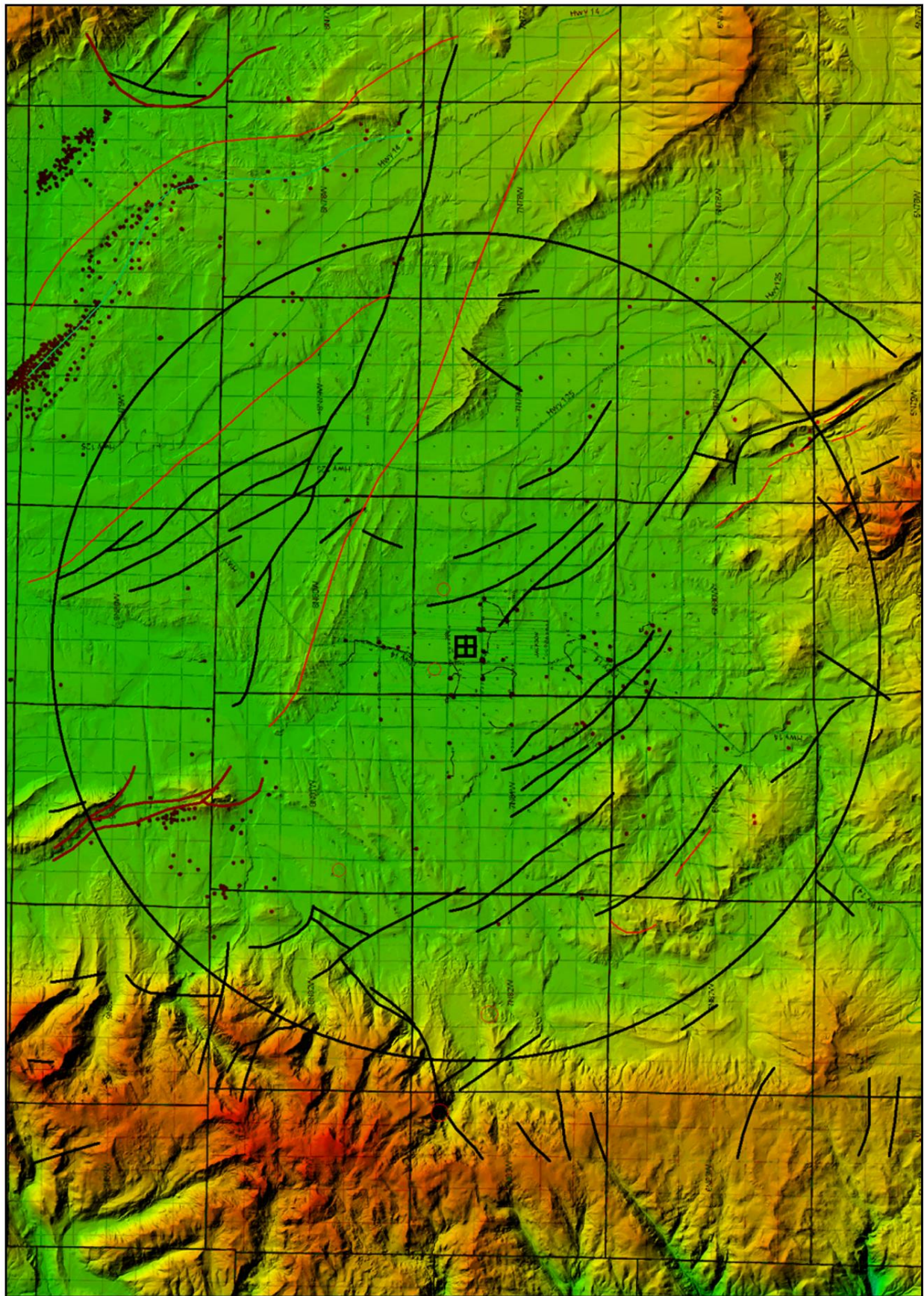


Figure 6. Digital Elevation Model showing the main structural features of the area.

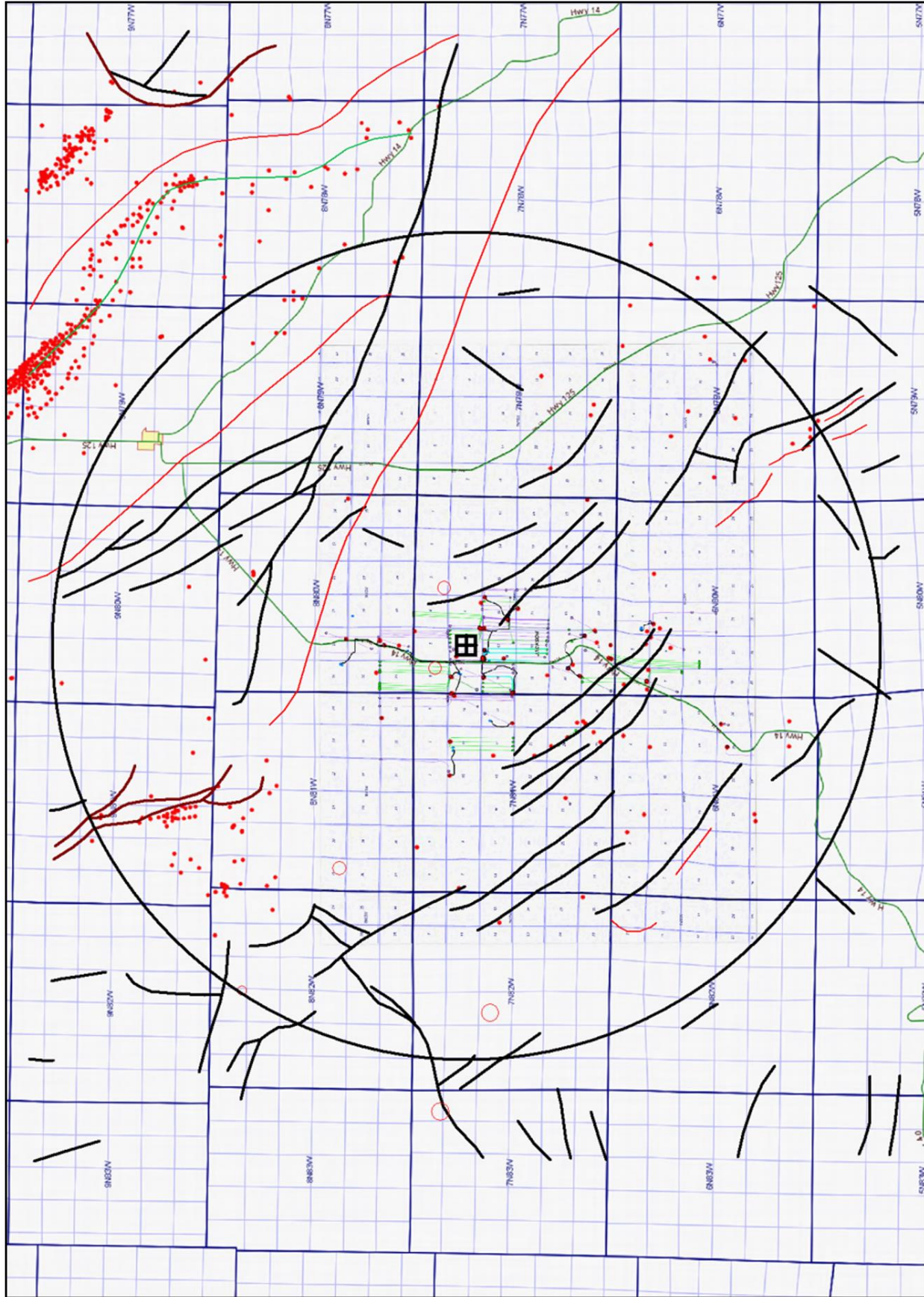


Figure 7. Radius of investigation showing well control and the main structural features of the area.

B. HISTORIC SEISMIC ACTIVITY

Figure 10. Tabulation of Earthquakes within 15 miles of Injection Well

	Date	Depth (Miles)	Magnitude	Dist from Inj Well (Miles)
Earthquake 1	6/21/2018	1.03	2.70	1.88
Earthquake 2	7/3/2018	2.17	2.60	1.14
Earthquake 3	7/26/2019	2.24	2.00	7.80
Earthquake 4	10/1/2005	3.11	3.90	11.18
Earthquake 5	7/14/2022	2.62	1.70	12.44
Earthquake 6	2/7/2000	3.11	3.00	14.12

In recorded history, there have been 5 documented earthquakes within a 12 mile radius of the proposed injection well Mutual 0780 3-8H. The closest of these earthquakes (#2) to the proposed injection well occurred on 7-3-2018 at a distance of 1.88 miles (3.02 km) from the center of section 8. This quake registered a magnitude of 2.6 at a depth of 2.17 miles (3.5 km) and was preceded by another quake (#1) two weeks earlier, a distance of 1.88 miles (3.02 km) away measuring a magnitude of 2.7 at a depth of 1.03 miles (1.66 km).

The other recorded quakes in the vicinity measured 7.80, 11.18, 12.44 and 14.12 miles distant respectively and ranged in magnitudes from 1.7 to 3.9.

A map of known historical earthquakes is shown in Figures 8 and 9.

A table documenting the earthquake details is shown above in Figure 10.

As a matter of comparison the following table shows the historical earthquakes within a 12 mile radius of downtown Denver:

Tabulation of Earthquakes within 12 miles of Capitol in Denver

	Date	Depth (Miles)	Magnitude
Earthquake 1	4/10/1967	3.10	4.30
Earthquake 2	4/27/1967	3.10	4.50
Earthquake 3	9/18/1982	3.10	2.80
Earthquake 4	4/2/1981	4.97	4.30
Earthquake 5	2/25/1984	3.10	2.50
Earthquake 6	3/11/1982	3.10	2.80
Earthquake 7	11/27/1967	3.10	5.20
Earthquake 8	9/16/1981	3.10	2.10
Earthquake 9	2/16/1965	3.10	3.00
Earthquake 10	11/8/1989	1.55	2.50
Earthquake 11	9/29/1965	3.10	3.50
Earthquake 12	11/21/1965	3.10	3.80
Earthquake 13	6-10 1978	12.42	2.90
Earthquake 14	3/24/1981	3.10	2.80

It is interesting to note the greater number and magnitude of quakes suggesting that North Park basin is more stable than the Denver area in terms of seismic activity.

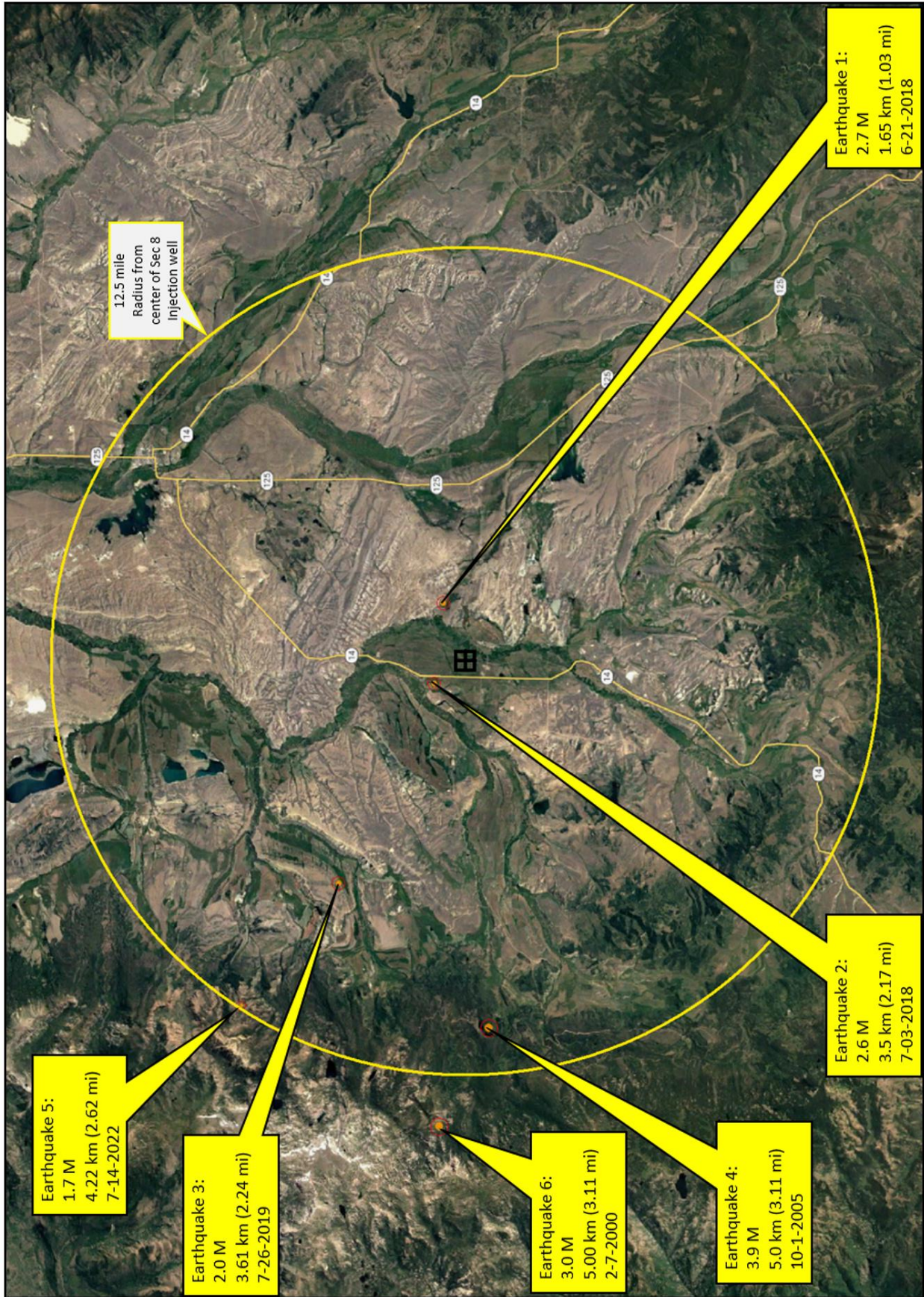


Figure 8. Aerial imagery showing radius of investigation along with historic earthquake activity

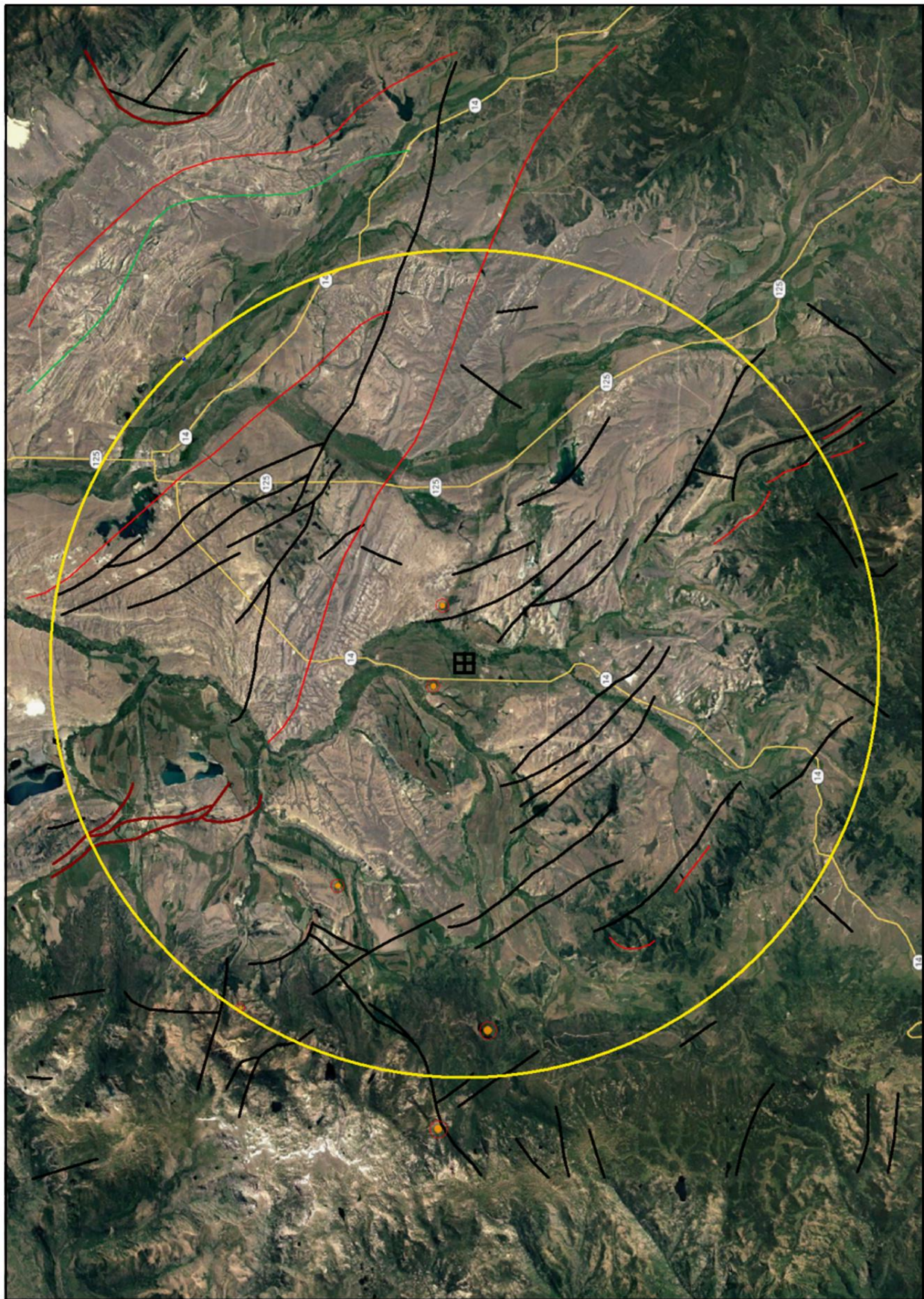


Figure 9. Aerial imagery showing historic earthquake activity and main structural features.

C. POTENTIAL SEISMIC ACTIVITY

Under Rule 803.g. (6).C, operators are required to submit an exhibit demonstrating potential for seismic activity within a 12 mile radius of the proposed injection well site. The operator has researched the USGS Seismic Hazard Map database and the results are discussed in this section.

Within the USGS Seismic Hazard Map data, the most recent short-term and long-term maps for the continental United States were selected, which identify two statistical measures of “potential” for seismic activity:

1. The short-term probability of at least a “minor” earthquake occurring (Figure 11).
2. Areas with at least a 2% peak ground acceleration probability within 50 years (Figure 12).

2018 One-Year Model

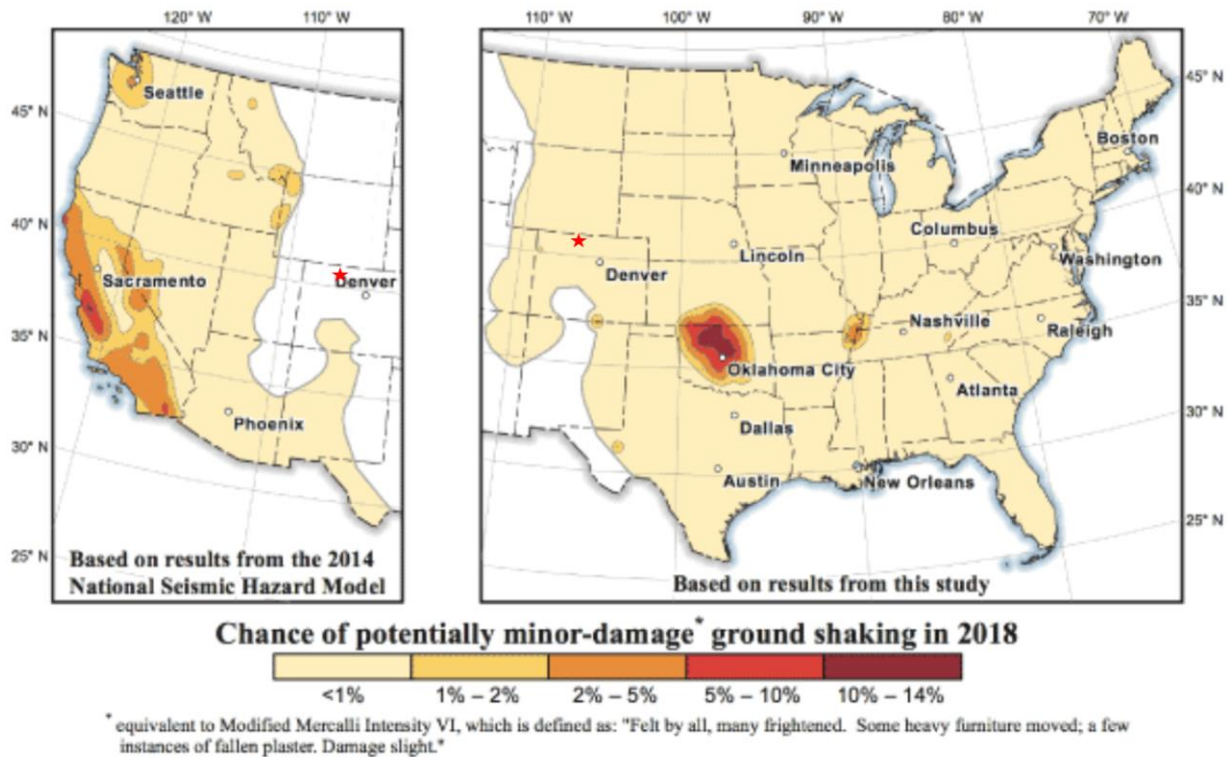


Figure 11: Map showing the Chance of potentially minor-damage ground shaking events in 2018 (last year available). The red stars ★ indicate the location of the North Park project where the chance is less than 1%. (Published by the USGS)

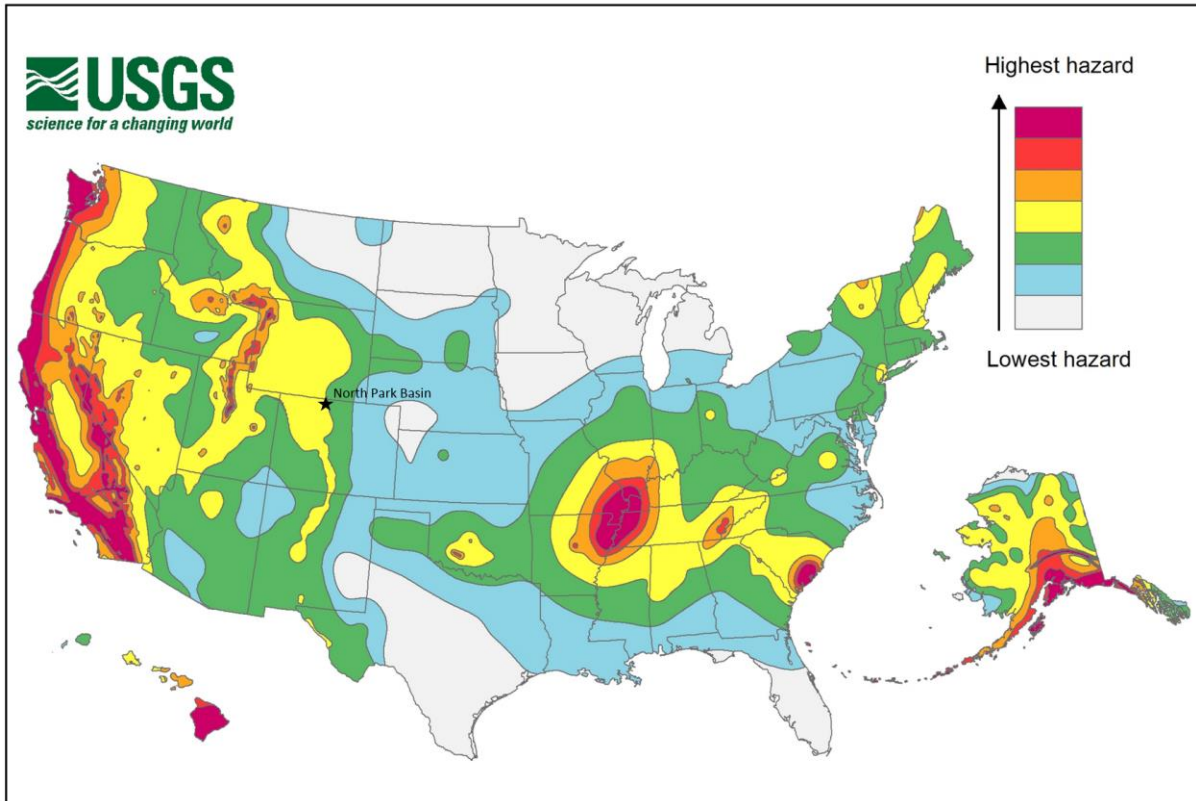


FIGURE 12: Earthquake hazard map showing peak ground accelerations having a 2 percent probability of being exceeded in 50 years, for a firm rock site. The map is based on the most recent USGS models for the conterminous U.S. (2018), Hawaii (1998), and Alaska (2007). The models are based on seismicity and fault-slip rates, and take into account the frequency of earthquakes of various magnitudes.

In addition to USGS Seismic Hazard Map data, the operator has reviewed The Quaternary Fault and Fold Database compiled by the USGS, Geologic Hazards Science Center (Figure 13). This data contains the results of thousands of scientific assessments of faults and associated folds in the United States that demonstrate geologic evidence for coseismic surface deformation in the Quaternary (the past 1,600,000 years). The Quaternary Fault and Fold Database includes information on the age of the most recent coseismic surface deformation, relative rates of activity, fault geometry, sense of movement, and citations of pertinent literature. Much of the information in the database is based on paleoseismology, which is the geologic study of prehistoric earthquakes. Paleoseismology combines well-established geologic practices such as trenching with archeological-style analysis to determine the time and magnitude of ancient earthquakes. These studies extend the historical earthquake record by hundreds of thousands of years and are indispensable in calculating future seismic hazard posed by the thousands of faults in the United States. Figure 13 demonstrates that no Quaternary age faults have been mapped in the area of the proposed injection well.

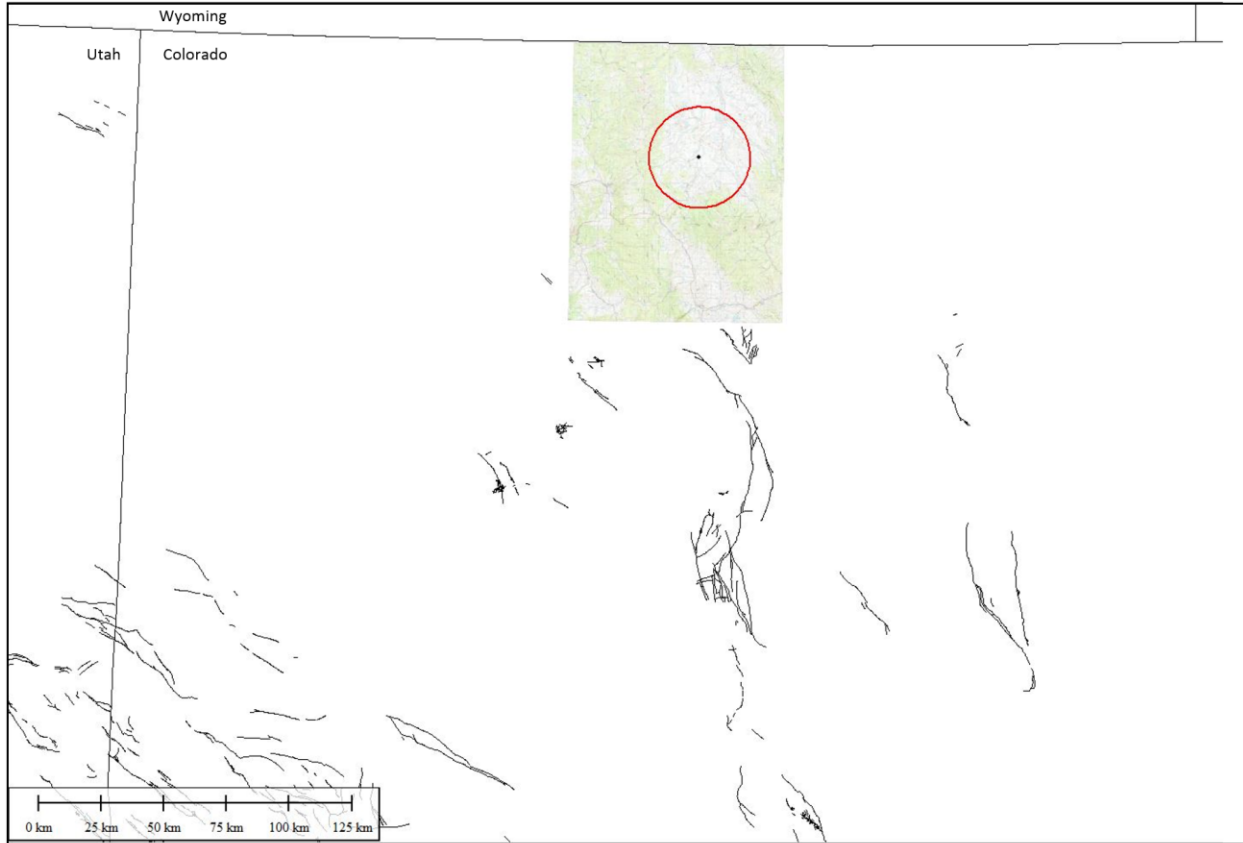
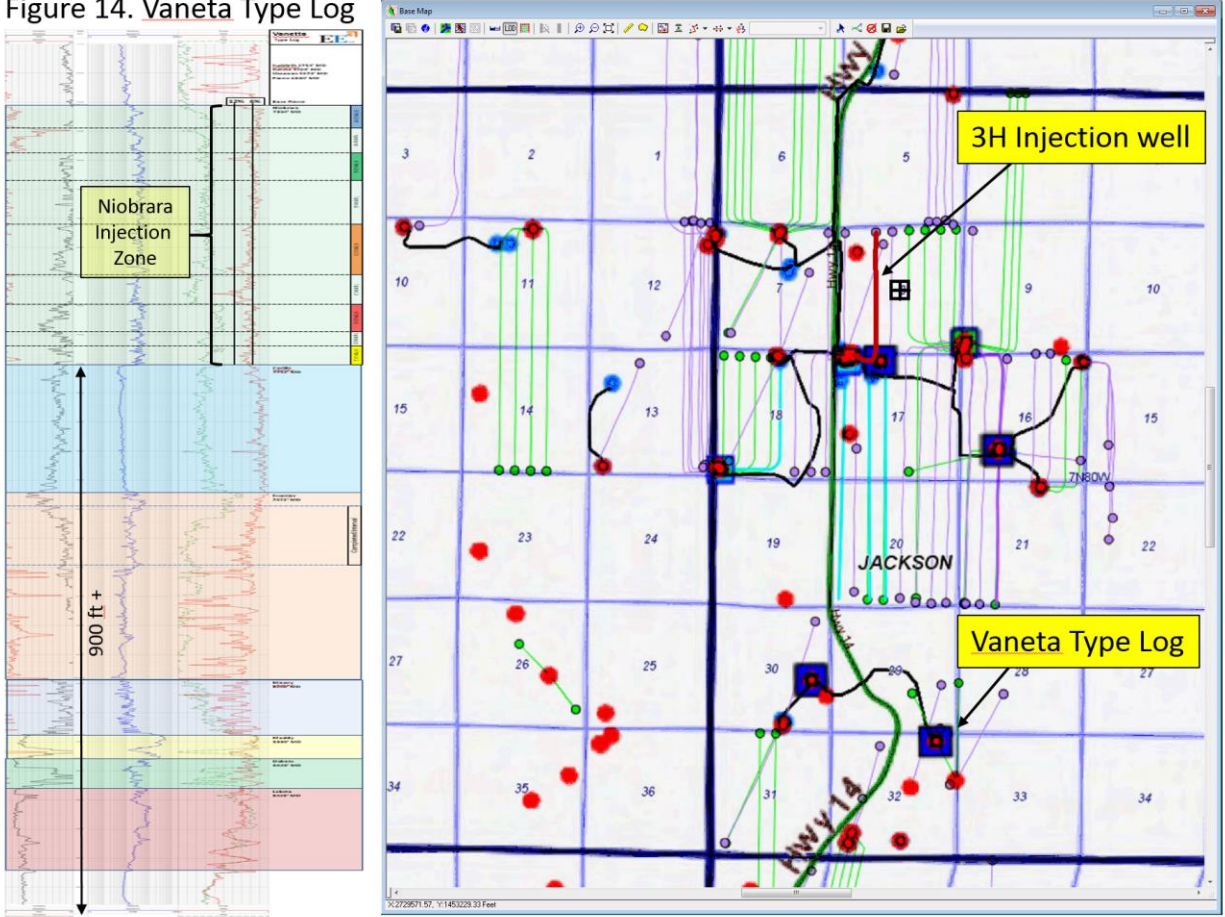


Figure 13. Map showing the Quaternary faults thought to have recent activity in the State of Colorado. The red circle indicates the 12.5 mile radius around the proposed Injection Well. Compiled by the U.S. Geological Survey, Geologic Hazards Science Center.

D. RELATIONSHIP TO BASEMENT

The deepest penetration of a vertical well in the area is the EOG Resources Inc. Vaneta 1-32D. The Vaneta well is approximately 3.5 miles SSE of the proposed Mutual 0780 3-8H injection well. This well (Figure 14) shows the position of the proposed Niobrara injection zone in relation to the deepest penetrated formation, the Morrison formation. Below the Morrison FM lie unknown thicknesses of Jurassic Entrada, Sundance and Triassic Chugwater sequences believed to rest unconformably on Crystalline Basement. A known thickness of 900 feet plus an estimated 4-500 feet of additional undrilled section are believed to separate the Niobrara injection zone from the Basement. Additionally, Shales of the Carlisle and Mowry Formations provide further effective barriers for fluid migration.

Figure 14. Vaneta Type Log



SUMMARY

The North Park basin and specifically the Mutual 0780 3-8H proposed injection site appears to be situated in an area of relatively low seismicity.

USGS mapping of Quaternary age faulting along with short-term and long-term probability maps confirm an area of low seismicity and potential.

Although the area has experienced earthquakes in the recent past, these have been quite minimal in magnitude.