Memorandum

To: Thad Kuntz, P.G.

From: Dennis McGrane, C.P.G., P.E. and Stephanie Ashley, G.I.T

Date: January 3, 2011

Project: 1352NPD02 Task 12

Subject: Brule Formation Fractures in NRD Priority Area 1 – Preliminary Results

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BACKGROUND

The Cooperative Hydrology Study (COHYST) is a geohydologic study of surface and ground water resources in the Platte River Basin of western Nebraska. The Hydrologic Unit and Aquifer Characterization Report (Cannia et al., 2006) describes hydrostratigraphic units used in the COHYST ground water model. Hydrostratigraphic Unit 8 includes the upper surface of the Brule Formation. The Brule Formation consists of low permeability siltstones, and claystones with minor thin sandstone beds (Sibray and Zhang, 1994). The principal source of ground water in the Brule are highly conductive secondary permeability zones. Many regions are not productive because secondary permeability zones are not present (Barrash and Morin, 1987).

The North Platte and South Platte Natural Resources Districts (NRD) provided LRE a map showing the spatial distribution of Brule Fracture zones mapped by Cannia (2006, File: layer8final.shp) which was reportedly used in the COHYST model. The NRD map shows "Brule Characterization Priority Areas." The NRD requested that Leonard Rice Engineers, Inc. (LRE) evaluate the occurrence and extent of Brule fractures within Priority Area 1. To do this, LRE was also asked to review previous research and compile geologic data from driller's logs within the area. This research is considered preliminary and may be updated when additional budget is available.

Sidney Draw Research

The most significant research into the distribution of Brule fractures was conducted by Morin and Barrash (1986), Barrash and Morin (1987), and Sibray and Zhang (1994) in the Sidney Draw area within Priority Area 1. These researchers used geologic logs, drill hole lost circulation zones, geophysical logs, and video and heat survey logs to identify and characterize Brule fracture networks.

Fracture Occurrence

At the Sidney Draw area, the major fracture zone (MFZ) consisting of one or more "layers" of fracture networks 0.08 to 2.2 meters in total thickness (Morin and Barrash, 1986). Fractures typically occurred in hard siltstone and claystone beds made up of "platy wafers." Some hard "claystone clasts" were crosscut with fracture networks. Pedotubules are common in claystone and siltstone, and contributed to secondary permeability. The pedotubules are up to 1.3 cm in diameter, and were filled with coarse silt or sand. Drill cores revealed horizontal fractures that were "genuine planes of secondary permeability (Barrash and Morin, 1987)." It was inconclusive whether fractures are laterally continuous from one hole to another. Barrash and Morin (1987) site previous researchers (Mollard, 1957; Alpay, 1973; Babcock, 1973) who believe tectonic joint sets may provide penetrative vertical conduits that hydraulically connect the fracture networks. Heat surveys suggest vertical movement of ground water from aquifers beneath the Brule.

LRE APPROACH

We initially examined approximately 264 well logs in the Brule Characterization Priority Area 1 from the Nebraska Department of Natural Resources database and the University of Nebraska, Lincoln database. The logs were previously identified by Cannia et al., 2006 as wells completed in the Brule Formation. Later, we examined an additional 91 wells from the state database. These included all of the wells in Priority Area 1 from the State Database that had not been previously examined.

The logs were examined online and data was entered into an Excel spreadsheet that included whether the Brule was fractured, depth to top and bottom of the Brule Formation, depth to top and bottom of the fractured zone, driller's description of the Brule, driller, depth to the top and bottom of the screen, what formation the well was screened in, lithology above the Brule Formation, whether or not the well fully penetrated the Brule Formation, and any available data on specific capacity or production. Most of the wells did not have most of this data available.

To evaluate fracture occurrence in the Brule, we used the following criteria and divided the wells into the following groups:

- **Fractured –** the log describes the Brule formation as fractured, broken, or as having pedotubules.
- Some Fractures – the log describes the formation as have fractured zones with some distinct zones of nonfractured Brule.
- **Probably Fractured –** The log lists areas of the Brule Formation as having lost circulation or no returns or the log does not indicate that the Brule is fractured, but the well is screened in and producing water from the Brule Formation.
- **Possibly Fractured –** The log does not indicate the Brule is fractured and there is no completion data for the well, but most of the well is drilled into the Brule Formation. If most of the well is in the Brule Formation, it is possibly producing from the Brule Formation and it is possible that the Brule is fractured. The drawback in this assumption is that the well may not be producing water. Many of the wells from the state database

do not provide information on use or production. They may have been test holes or monitoring wells that were not intended to produce water.

- **Not Fractured –** These are logs from monitoring wells drilled into the Brule that do not indicate that the Brule is fractured or test holes that never produced water. It also includes wells that were barely drilled into the Brule Formation, indicating that it did not produce water from the Brule in that area. This assumes that the drillers creating the logs would have included enough detail in their logs to mention fractures if fractures were present. In many instances, this may not be the case.

ANALYSIS

Figure 1 shows the location of wells within NRD Priority Area 1. Wells with fractures and wells probably and possibly fractured agree with areas outlined by Cannia et al., 2006. Some areas mapped by Cannia (2006) exist outside the Priority Area 1 which suggests that fractured Brule is not limited to NRD Priority Areas.

Figures 2 shows the number of wells in fractured and nonfractured Brule in each depth category. For these graphs, wells with fractures, some fractures, or clearly screened in the Brule Formation were included as fractured. Many of the well logs simply listed "Brule" or "Brule Formation." Wells without fractured mentioned in the logs and no information on use, production, or well screen were included in the nonfractured category. The figure shows that most wells are less than 150 feet and do not encounter fractures.

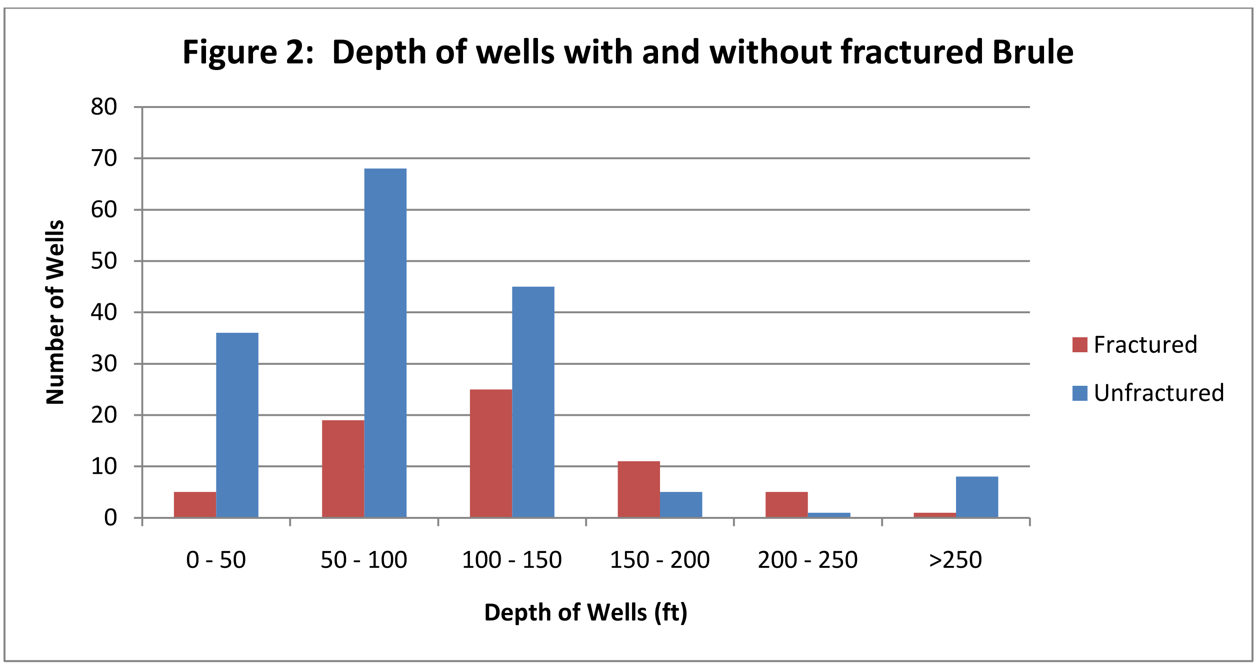
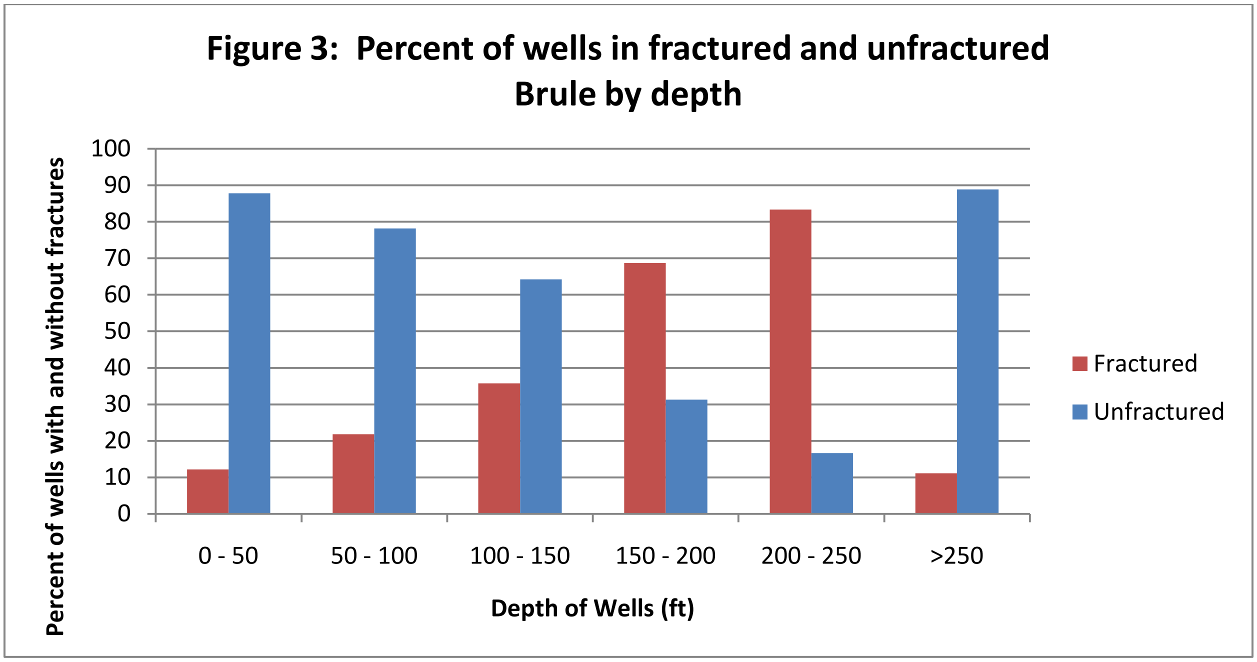


Figure 3 shows the percentage of fractured or nonfractured wells at each depth category. The deeper the well, the higher likelihood it contains fractured Brule. The highest percentage of wells with evidence of fractures occurs between 150 and 250 feet where 69 – 82 percent of the

Brule wells are fractured. This suggests that there is a high (approximately 75 percent) probability of encountering fractures if the wells are drilled that deep.



Figures 4a - 4c show the elevations of the top of the fractured zone in the wells with fractures and possible factures with the elevations of the bottom of the wells that did not contain fractures. The data shows that the bottom of wells without fractures are generally higher than nearby wells with fractures which spatially supports the theory that fractures are depth dependent.

Brule Fracture Extent

The extent of Brule fractures is not well defined. Cannia (2006) models fractured Brule (Hydrostratigraphic Unit 8) in isolated areas in the vicinity of Pumpkin Creek, Lodge Pole Creek, Sidney Draw and parts of the North Platte River Valley (Cannia, 2006, Figure 25). However, researchers at the Sidney Draw site do not state that the location of fractures should be limited to beneath drainages. Geologic log data suggest that the location of Brule fractures is structurally or related to depositional characteristics. Figure 5 shows the contoured elevation of Brule fracture zones generally decrease from west to east which is consistent with the surface elevation and dip of the formation (Swinehart, 1985).

The contoured top of Brule fractures in Figure 5 resembles a series of structural anticlines and synclines. Cross section A-A’ shows fractures in the shape of either folded bedding or possibly related to longitudinal dune deposition. Based on our limited literature search, we did not find any references to NE-SW structural folding other than possible joint sets. If a dune feature, the crest height of a particular dune would be approximately 150 feet high with a crest-to-crest spacing of approximately 3 miles. Based on a limited Web-search, we learned that crest-to-crest spacing of longitudinal dunes can vary between 150 meters and 3.3 km, with heights between 2 -

300 m (http://ag.arizona.edu/~lmilich/dune.html). Therefore, it is plausible that fracture zones are related to dune deposition.

Figure 5 also shows areas of high fracture density within the structurally low areas. During longitudinal dune formation, fine-grained deposition occurs in the trough or “slack” between dunes. Dune slacks are ideal habitat for worms, the source of pedotubles. Subsequent burial and fracturing associated with tectonic forces likely created a hydraulic connection between fracture zones and surrounding aquifers. This interpretation is consistent with other researchers (Russel, 1929: White, 1961: and Beaty, 1975) as described by Barrash and Morin (1987). It also suggests that the location of fracture zones should not be constrained to existing drainages. We emailed Dr. Barrash who is now at Boise State University to gain his opinion of our work. Dr. Barrash is willing to discuss the occurrence of Brule fractures, but we had not done so at the time of this memo.

PRELIMINARY CONCLUSIONS

Based on our limited literature search and review of over 350 geologic logs within the NRD Priority Area 1, we conclude:

- Brule fractures typically occur in hard, brittle, narrow, discontinuous, claystone and siltstone layers.
- The likelihood of encountering a fracture zone increases with depth until approximately 250 feet.
- Approximately 75 percent of wells completed between 150 and 250 feet encounter fractures.
- Multiple fractures zones can occur in a single well. Whether a fracture zone produces water likely depends on whether it is hydraulically connected to other fracture zones or recharged through near-vertical joint sets. The location of vertical joints could be evaluated using aerial imagery.
- Fractured Brule likely extends beyond areas previously mapped by Cannia, et al., 2006 and Priority Areas defined by the NRD and may be associated with structural folding or dune development.

Future Work

We recommend that the NRD further evaluate the origin and extent of Brule fractures by:

- Conducting additional literature research on possible fracture occurrences including dune deposition or structural folding.
- Contact Dr. Barrash at wb@cgiss.boisestate.edu who conducted earlier work in Sidney Draw to learn more about his research and theories.
- Evaluating more geologic logs located beyond the Priority Areas.

- Obtaining geophysical data reportedly available from the University of Nebraska, Lincoln.
- Analyzing aerial imagery to determine if the location of vertical joint sets contributes to the location and density of high capacity wells.

Once these tasks are conducted, the NRD will be better able understand the occurrence of fractured Brule, and how to model it in ground water models such as COHYST.

Glossary

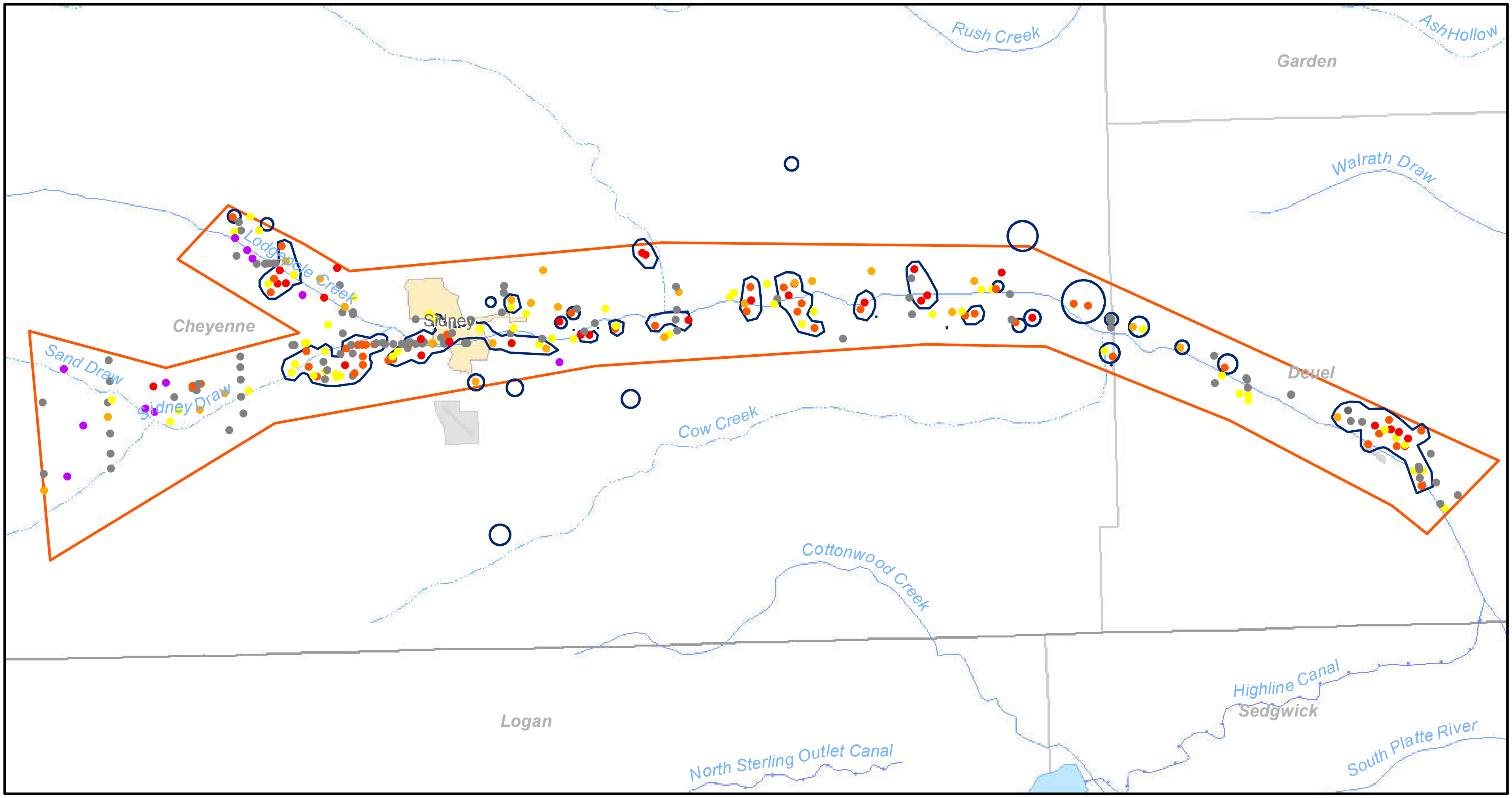
Barrash, Warren and Morin, Roger, 1987. Hydrostratigraphy and distribution of secondary permeability in the Brule Formation, Cheyenne County, Nebraska. Published in the Geological Society of America Bulletin, V. 99. P. 445-462, October, 1987.

Cannia, James, Woodward, Duane, and Cast, Larry, February 24, 2006. Cooperative Hydrological Study COHYST Hydrostratigraphic Units and Aquifer Characterization Report.

Kuntz, Thad. November 6, 2010. Brule Fracture Spatial Characterization Study. Figure 1 - Map of Brule Characterization Priority Areas and Approximate Brule Fracture Locations (From Cannia, 2006, File name: layer8final.shp.).

Morin, Roger, and Barrash, Warren, 1986. Defining Patterns of Ground Water and Heat Flow in Fractured Brule Formation, Western Nebraska, Using Borehole Geophysical Methods. U.S. Geological Survey, Denver, Colorado 80225 and Conservation and Survey Division, University of Nebraska – Lincoln, Panhandle Research and Extension Center, Scottsbluff, Nebraska 69361

Sibray, Steven and Zhang, You Kuan, 1994. Three-Dimensional Modeling of Hydraulic Behavior of a Highly Conductive Secondary Permeability Zone in the Brule Formation. Proceedings for the 1994 Groundwater Modeling Conference, August 10-12, 1994, Colorado State University, Ft. Collins, Colorado. Sponsored by the Department of Civil Engineering Groundwater/Environmental Hydrogeology Program, CSU in cooperation with the International Ground Water Modeling Center, Colorado School of Mines, Golden, Colorado.



Substantial efforts have been made to accurately compile GIS data and documentation. Accuracy is not guaranteed. This product is for reference purposes only and is not to be construed as a legal document or survey instrument.

Wells with data in Area 1

- Fractured
- Some Fractures
- Probably Fractured
- Possibly Fractured
- Not Fractured
- Previously mapped areas of fractured Brule (Cannia et al., 2006)
- Brule Characterization Priority Area 1 (per T. Kuntz)

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Figure 1
Location and Grouping of Wells in Area 1

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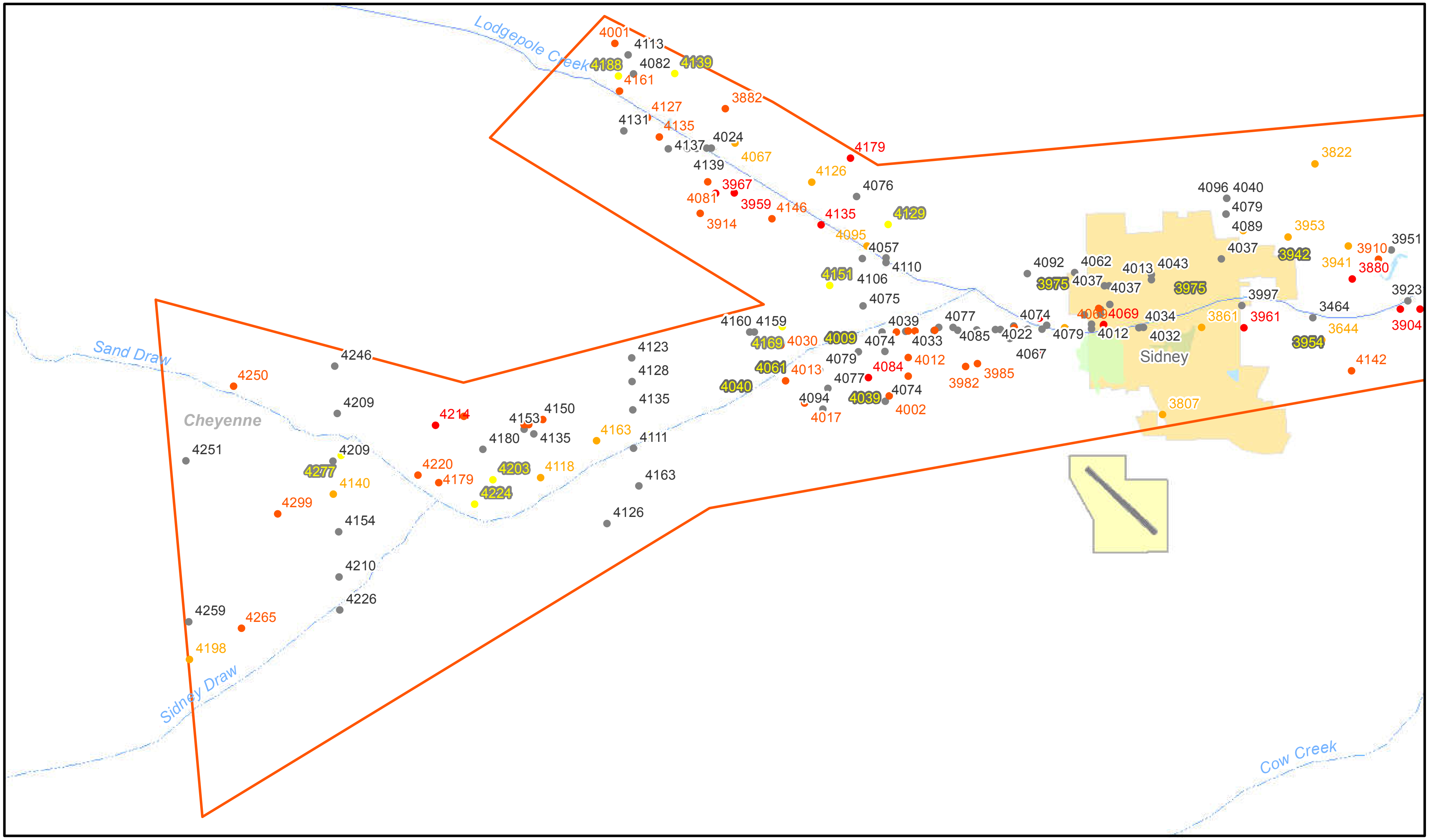

Wells with data in Area 1

- Fractured - with depth to fractures (in red)
- Some Fractures - with depth to fractures
- Probably Fractured - wtih depth to top of Brule (in orange)
- Possibly Fractured - with depth to top of Brule (in yellow)
- Not Fractured - with depth to bottom of well (in gray)
- Brule Characterization Priority Area 1 (per Thad Kuntz)

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Figure 4a

Top of Brule Fractures
(Central Portion of Area 1)

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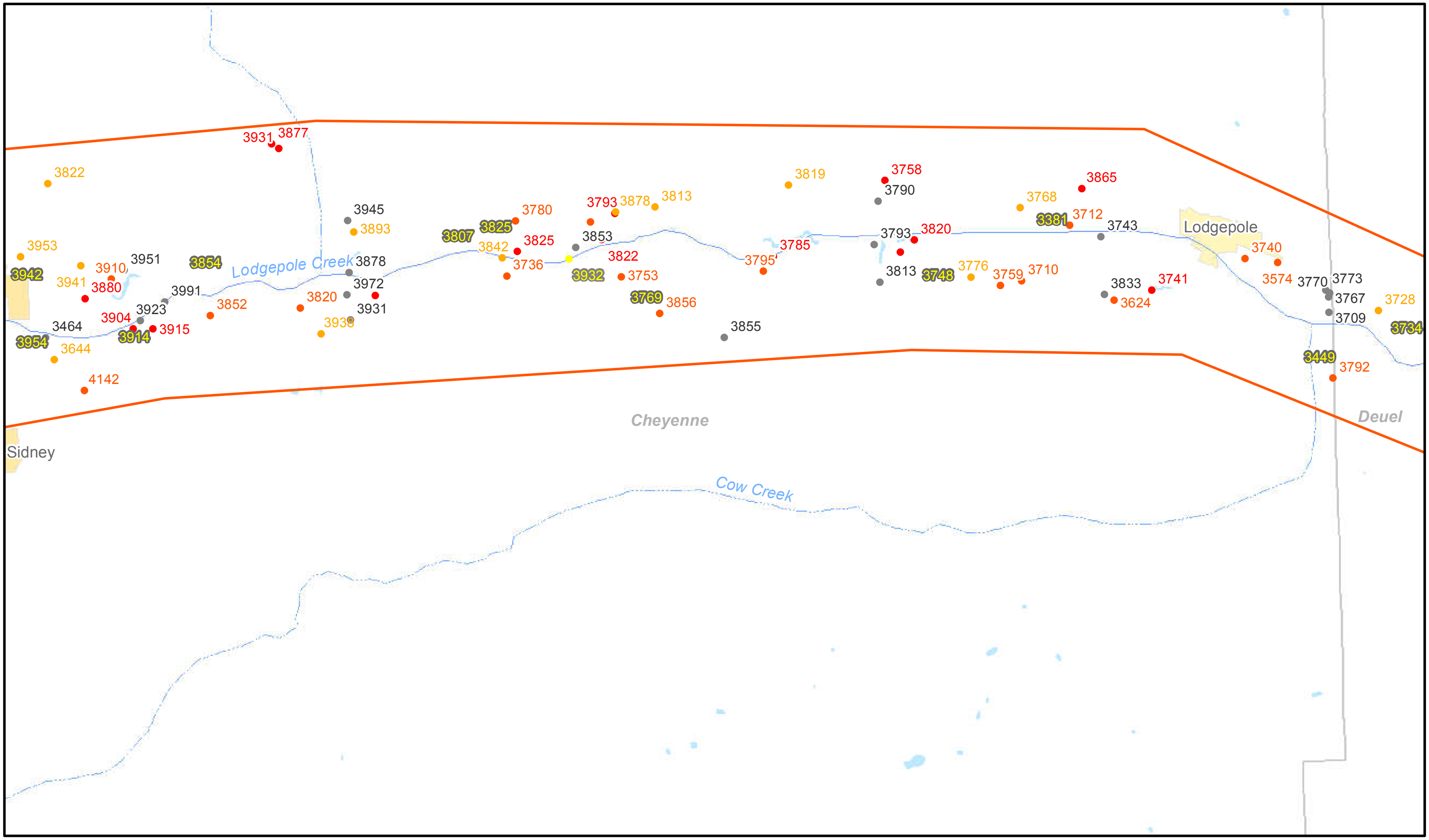

Wells with data in Area 1

- Fractured - with depth to fractures (in red)
- Some Fractures - with depth to fractures
- Probably Fractured - wtih depth to top of Brule (in orange)
- Possibly Fractured - with depth to top of Brule (in yellow)
- Not Fractured - with depth to bottom of well (in gray)
- Brule Characterization Priority Area 1 (per Thad Kuntz)

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Figure 4b

Top of Brule Fractures
(Central Portion of Area 1)

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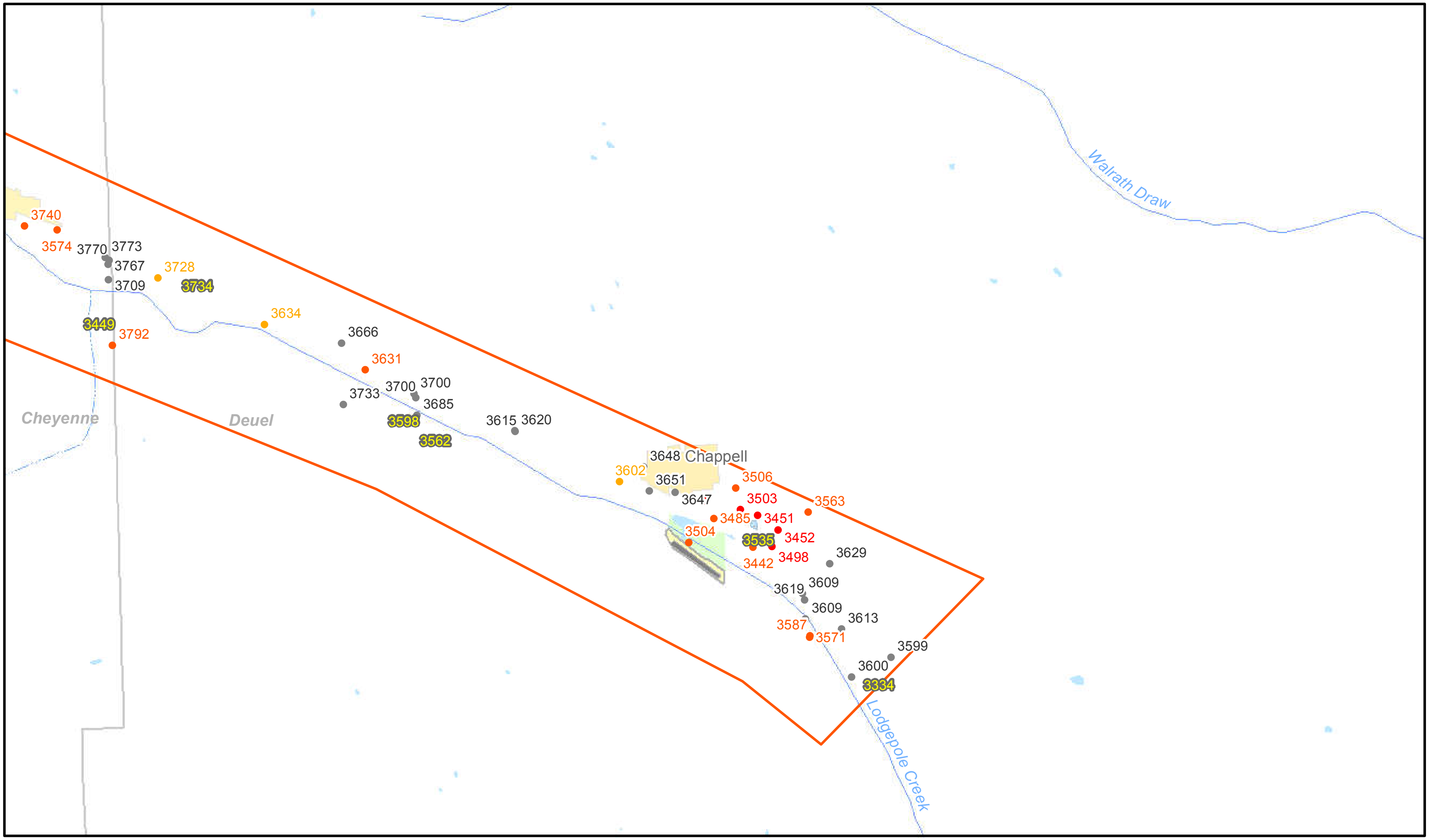

Wells with data in Area 1

- Fractured - with depth to fractures (in red)
- Some Fractures - with depth to fractures
- Probably Fractured - wtih depth to top of Brule (in orange)
- Possibly Fractured - with depth to top of Brule (in yellow)
- Not Fractured - with depth to bottom of well (in gray)
- Brule Characterization Priority Area 1 (per Thad Kuntz)

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Figure 4c

Top of Brule Fractures

(Central Portion of Area 1)

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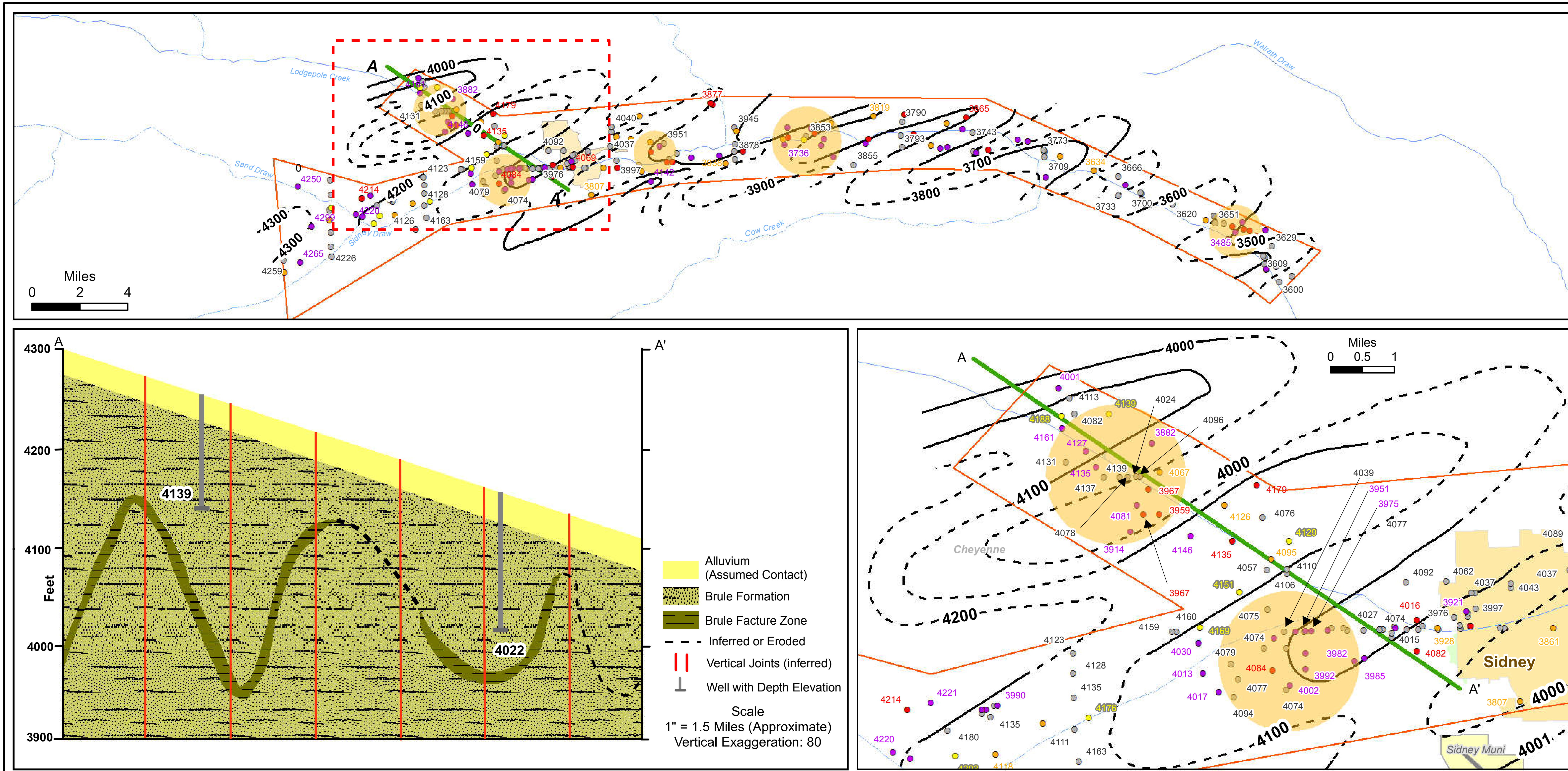

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Selected Wells in Area 1

- Fractured - with depth to fractures (in red)
- Some Fractures - with depth to fractures (in red orange)
- Probably Fractured - wtih depth to top of Brule (in orange)
- Possibly Fractured - with depth to top of Brule (in yellow)
- Not Fractured - with depth to bottom of well (in gray)

- Brule Characterization Priority Area 1 (per Thad Kuntz, NP and SP NRD)
- Fractured Zone Contact
- Inferred or Eroded
- Cross Section A - A'
- High Facture Density

Figure 5
Top of Brule Fractures

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