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Data to Support Development of Geologic Framework Models for the Deep Borehole Field Test

Fuel Cycle Technology

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SPENT FUEL AND WASTE DISPOSITION

Data to Support Development of Geologic Framework Models for the Deep Borehole Field Test

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Acronyms

DBFT	Deep Borehole Field Test
DOE	Department of Energy
GFM	Geologic Framework Model
GIS	Geographic Information System
NMBGMR	New Mexico Bureau of Geology and Mineral Resources
RRCT	Railroad Commission of Texas
SDGS	South Dakota Geological Survey
SFWD	Spent Fuel and Waste Disposition

DATA TO SUPPORT DEVELOPMENT OF GEOLOGIC FRAMEWORK MODELS FOR THE DEEP BOREHOLE FIELD TEST

1. Introduction

This report summarizes work conducted in FY2017 to identify and document publically available data for developing a Geologic Framework Model (GFM) for the Deep Borehole Field Test (DBFT). Data was collected for all four of the sites being considered in 2017 for a DBFT site. Development of a GFM was planned to commence upon final selection of a GFM site. The primary data needed for development a GFM are obtained from boreholes within the region of interest. Borehole data can include the depth and thickness of geologic formations, lithologic variations within geologic units, the depth and characteristics of aquifers and the geochemistry of groundwater. Data collected from boreholes may also provide data on the location of faults and fracture zones. Boreholes are primarily for drilled for oil and gas exploration or groundwater resources. Borehole data is generally available from state agencies such as state geological surveys or regulatory agencies. Geophysical data is also useful to characterize basement features. Geophysical data can be used to identify and constrain the location of faults and shear zone that juxtapose rocks with different densities or magnetic properties. Geophysical data can also be used to identify the location and margins of igneous intrusions that intrude rocks with contrasting magnetic or gravity signatures.

A total of six sites were publically announced as potential candidate sites for the DBFT as the result of two solicitations issued by DOE (DOE 2015, 2016). The first solicitation led to consideration of two sites in North Dakota and South Dakota. DOE terminated consideration of both sites due to lack of local support. The second solicitation led to concurrent consideration of four additional sites in South Dakota, New Mexico and Texas, but consideration of these sites ended with termination of the DBFT project in May of 2017. The first site in South Dakota (in Spink County) was under consideration for a long enough period of time that we were able to complete a preliminary GFM based on borehole data obtained from the South Dakota Geological Survey (SDGS, 2016). Documentation of the development of this GFM is reported in Perry and Kelley (2016) and is reproduced in Sections 4 and 5 of this report.

A GFM, also referred to as a 3-D geologic model, would represent the geologic features of a DBFT site and serve as a data repository for (1) already existing geologic data relevant to a DBFT site as well as (2) data collected during the DBFT. The GFM would serve as a fundamental project tool to document and visualize the geologic features of the DBFT site and to document, manage and visualize data collected as part of the DBFT. As such, it would serve as a powerful tool to inform project participants, the public and other stakeholders about the geology of the site as well as the scientific and engineering outcomes of the DBFT.

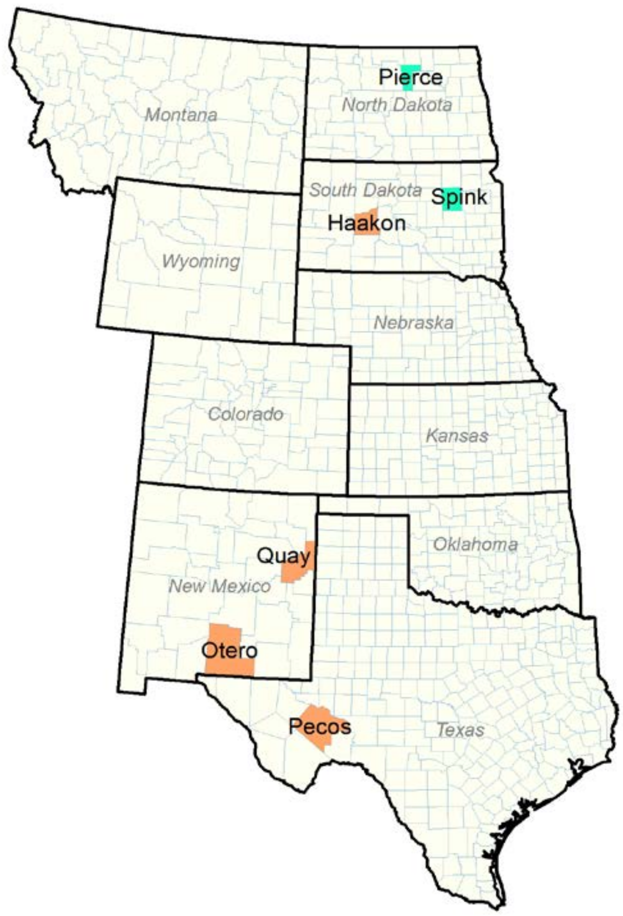

Figure 1-1. Map of counties where sites were considered for the DBFT. Counties in green were considered in response to the first DOE solicitation (DOE, 2015). Counties in orange were considered in response to the second solicitation (DOE, 2016).

2. Data Acquisition for Potential DBFT Sites – DOE Solicitation DE-SOL-0008071 (2015)

2.1 Pierce County, North Dakota

Data collection efforts during the period of consideration for the Pierce County site were focused on acquiring borehole locations and data within a 100 km-square-region centered on the proposed site (Figure 2-1). Borehole data was obtained from the Oil and Gas Division, Department of Mineral Resource of the North Dakota Industrial Commission (https://www.dmr.nd.gov/oilgas/). No further geologic or geophysical data was acquired and no GFM was completed for the Pierce County site.

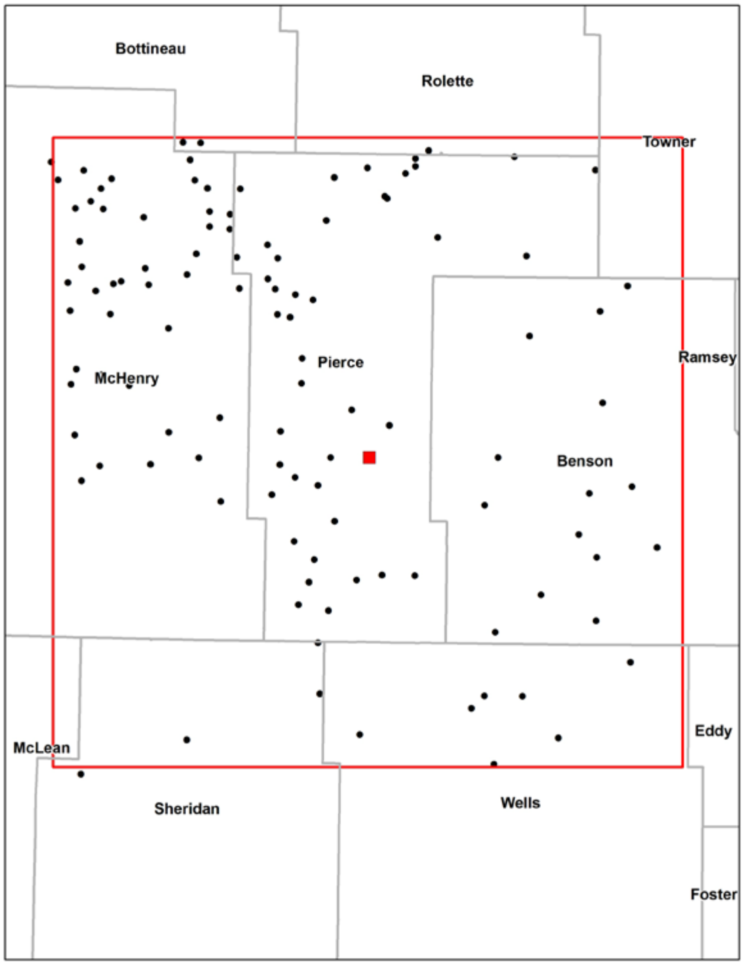

Figure 2-1. Location map of the proposed Pierce County DBFT site showing boreholes within a 100x100 km region of interest (red square) centered on the proposed site.

2.2 Spink County, South Dakota

Sections 4 and 5 of this report are taken from Perry and Kelley (2016) and are presented here to summarize our efforts in developing a GFM. These sections describe data gathering activities and the development of a preliminary GFM for the proposed Spink County site in South Dakota. The region encompassing Spink County lies in the north-central portion of the Benson Block in South Dakota (McCormick, 2010a), within the Great Plains Province.

3. Data Acquisition for Potential DBFT Sites - DOE Solicitation DE-SOL-0010181 (2016)

In late 2016, four teams were awarded contracts to explore the feasibility of siting a DBFT at four sites in South Dakota, Texas and New Mexico (Figure 1-1). The first phase of these awards was to demonstrate a successful partnership with the local communities to go forward with the competition until a final site for drilling was selected. For this reason, we made a decision to identify and gather geologic, geophysical and hydrologic data that could be used in creating a preliminary GFM but not to begin creating a GFM until a final DBFT site was selected. These data gathering efforts effectively ceased when the DBFT project was terminated by DOE in May 2017.

Given these constraints, the goals of this activity in FY17 were to:

- Identify and document publically available geologic and geophysical data for each of the four potential DBFT sites
- Attempt to obtain equivalent data from all four potential sites

All four potential sites were deemed acceptable in terms of Go/No Go criteria for geologic and hydrologic suitability described in the DOE solicitation. Because the contracts were still in a competitive phase at the time the project was terminated, we performed no further interpretations, evaluations or comparisons of site geology or hydrology. Our efforts focused only on gathering data that would be applicable to developing a GFM once a final site was selected.

Data for each of the four potential DBFT sites described below include depth to basement (contoured in meters), location of basement faults and location of boreholes (generally from oil and gas exploration or water wells). For a more detailed example, additional data for basement features are shown for the proposed Haakon County site in North Dakota, including basement terrane data and gravity and aeromagnetic data.

To help identify and constrain the data needed to begin development of a GFM for any of the potential sites, we defined a 100 km by 100 km “region of interest”. The size of these regions was considered large enough to include a sufficient number of boreholes to allow development of a GFM for any of the potential sites. The regions were also large enough to include information on the location of regional basement faults or shear zones as described in the performance parameters of the DOE solicitation.

3.1 Haakon County, South Dakota

The Haakon county site lies within the Great Plains Province to the east of the Black Hills uplift. Approximate depth to basement at the site is 1400 meters. In this report we use the Haakon County site as an example of the types of data that are publically and readily available and that could be used to create a preliminary GFM prior to any drilling activity for the DBFT. These data are shown in Figures 3-1 through 3-4 and include borehole data, depth to basement, basement terranes, basement faults and shear zones, and geophysical data such as aeromagnetic and gravity data. Similar data is available for the other three sites discussed below, although the data was not developed as completely due to termination of the project.

Basement depth data and borehole data was obtained from McCormick (2010a, 2010b) and SDGS (2016). Data for basement faults was obtained from McCormick (2010a). Geophysical data (aeromagnetic and gravity data for South Dakota) was obtained from Kucks and Hill (2002).

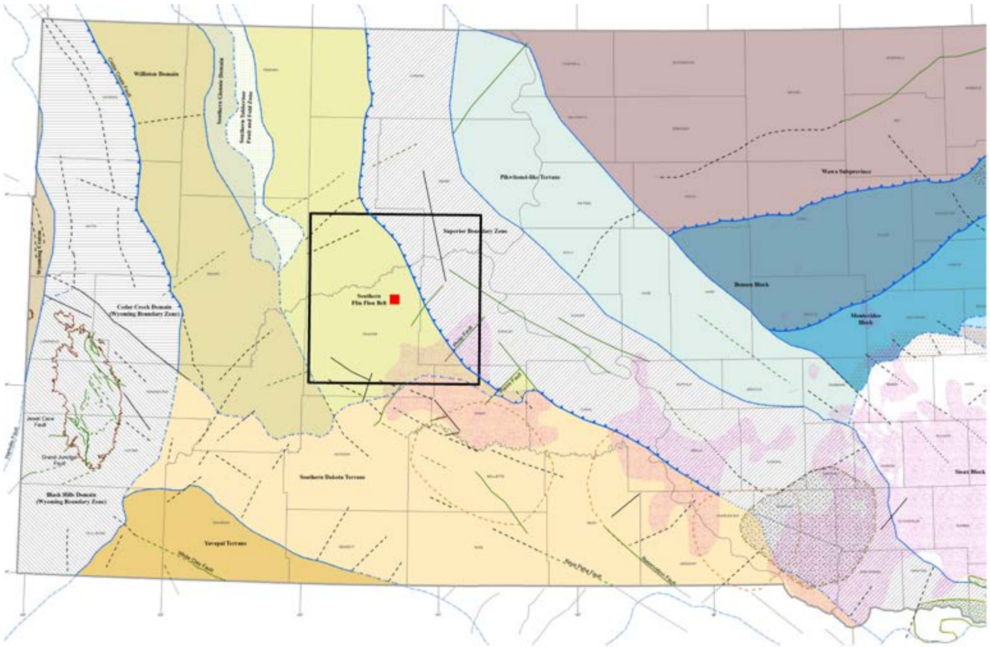

Figure 3-1. Basement terrane map of South Dakota from McCormick (2010a). Red square marks the location of the proposed DBFT site in Haakon County. The region outlined by the black square is a 100 by 100 km square that defines the preliminary region of interest for developing a GFM for the Haakon County site. The region of interest is consistent with performance measures regarding distance from basement faults and shear zones as well as the typical scales of individual basement terranes.

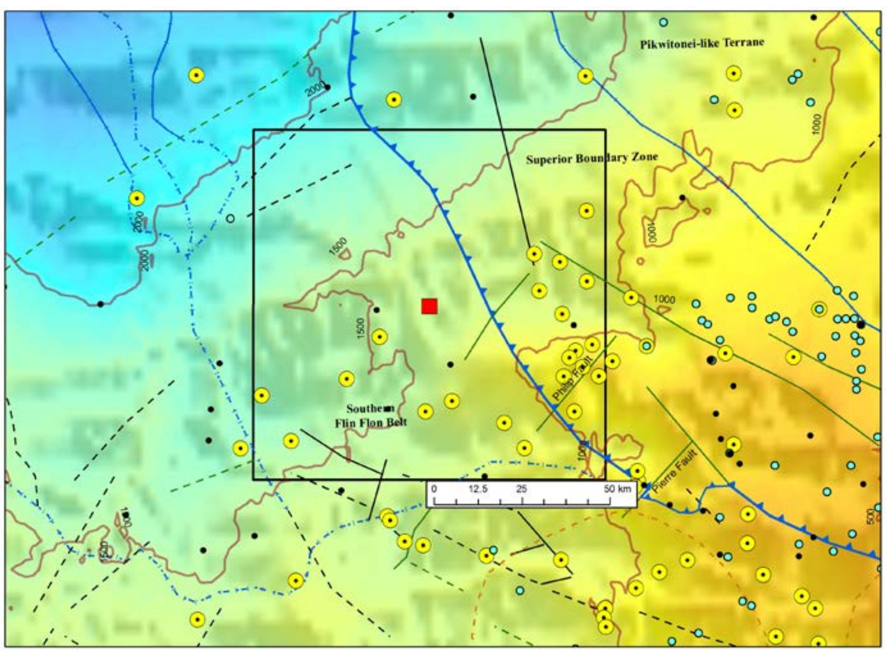

Figure 3-2. Haakon County site, boreholes and region of interest on depth-to-basement map (warm colors=shallower, cool colors=deeper; counter intervals in meters). Line segments are basement faults (for different types of faults and different levels of confidence in location) from McCormick (2010a; see also Figure 3-1). Boreholes: yellow circles with dots - intercepted basement; black circles - did not intercept basement (McCormick, 2010a): blue circles on eastern half of map – boreholes deeper than 100 meters from SDGS (2016).

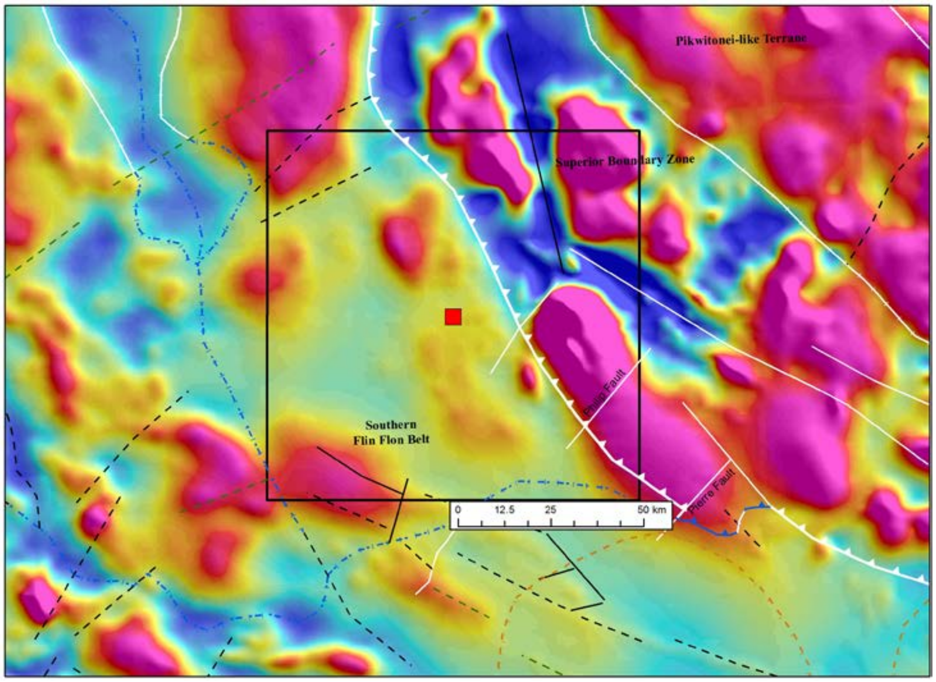

Figure 3-3. Aeromagnetic data for the Haakon County site and surrounding region. Warm colors indicate positive magnetic anomalies; cool colors indicate negative magnetic anomalies. Basement fault locations from McCormick (2010a).

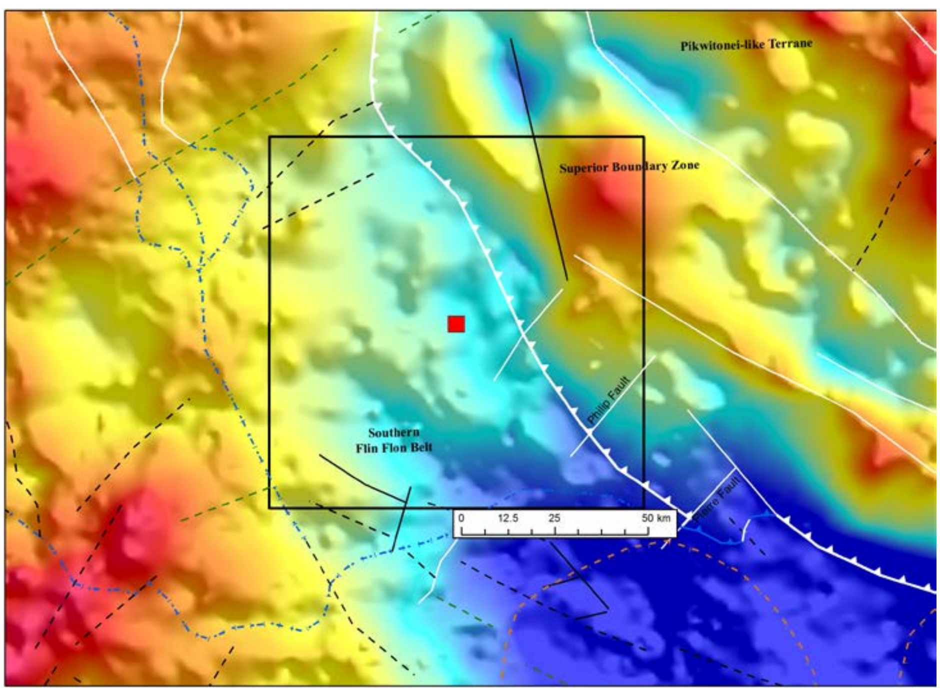

Figure 3-4. Isostatic gravity data for the Haakon County site and surrounding region. Warm colors indicate gravity highs, cool colors indicate gravity lows. Basement fault locations from McCormick (2010a).

3.2 Pecos County, Texas

The Pecos County site lies within a portion of the Central Basin Platform, an uplifted block that separates the Delaware Basin to the west and the Midland Basin to the east (Figure 3-5). Approximate depth to basement at the site is 1400 meters. Basement depth and borehole data were obtained from Ruppel (2009) and the RRCT (2016). Data for basement faults are from Ewing (1990) and are included in GIS data obtained from Ruppel (2009). Geophysical data (aeromagnetic and gravity data for Texas) is available from Bankey (2006).

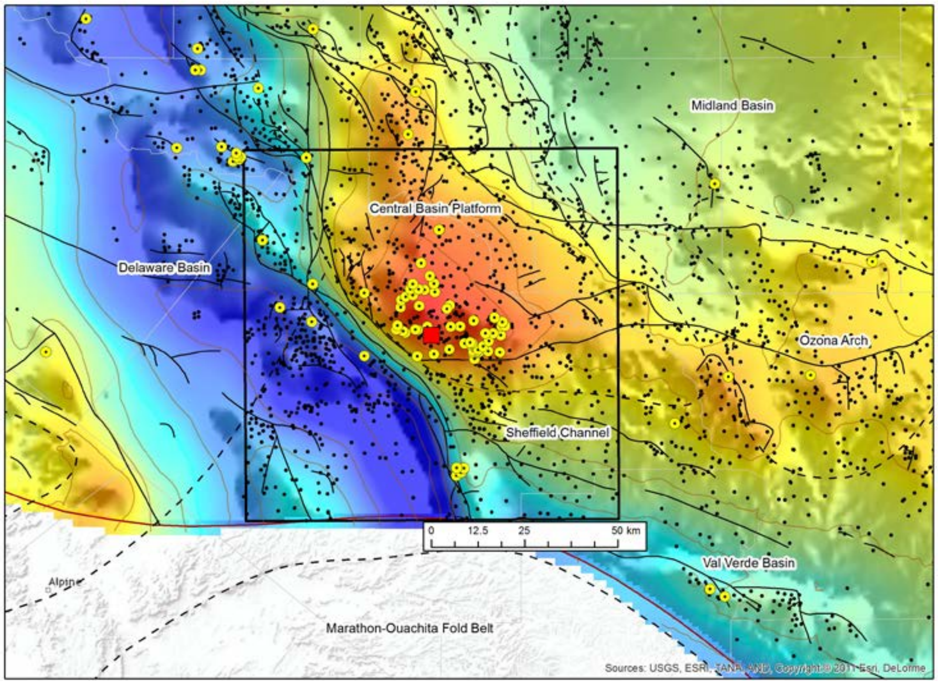

Figure 3-5. Pecos County site, boreholes and region of interest on a map of the depth to basement surface (warm colors=shallower, cool colors=deeper; counter intervals in meters). Line segments are basement faults (at different levels of confidence) from Ewing (1990) and were obtained as digital GIS data from Ruppel (2009). Boreholes: yellow circles with dots - intercepted basement, from Ruppel (2009); black circles – location of other boreholes from the RRCT (2017).

3.3 Quay County, New Mexico

The Quay County region of interest encompasses parts of New Mexico and Texas (Figure 3-6). The proposed site is on the uplifted Bravo Dome between the Dalhart Basin to the northeast and the Tucumcari Basin to the southwest. Approximate depth to basement at the site is 800-900 meters.

The basement depth data in New Mexico is from Broadhead et al. (2009). Depth to basement data for the Texas portion of the region is only readily available at the national scale. Data for well locations in New Mexico was obtained from NMBGMR (2017). Borehole location data in Texas was obtained from RRCT (2017). Note that these data only include borehole locations, not stratigraphic information from the boreholes. Obtaining this information would have required purchase of additional data from the RRCT. Locations of basement faults in New Mexico are from Broadhead et al. (2009). Geophysical data (aeromagnetic and gravity data for New Mexico) is available from Kucks et al. (2001).

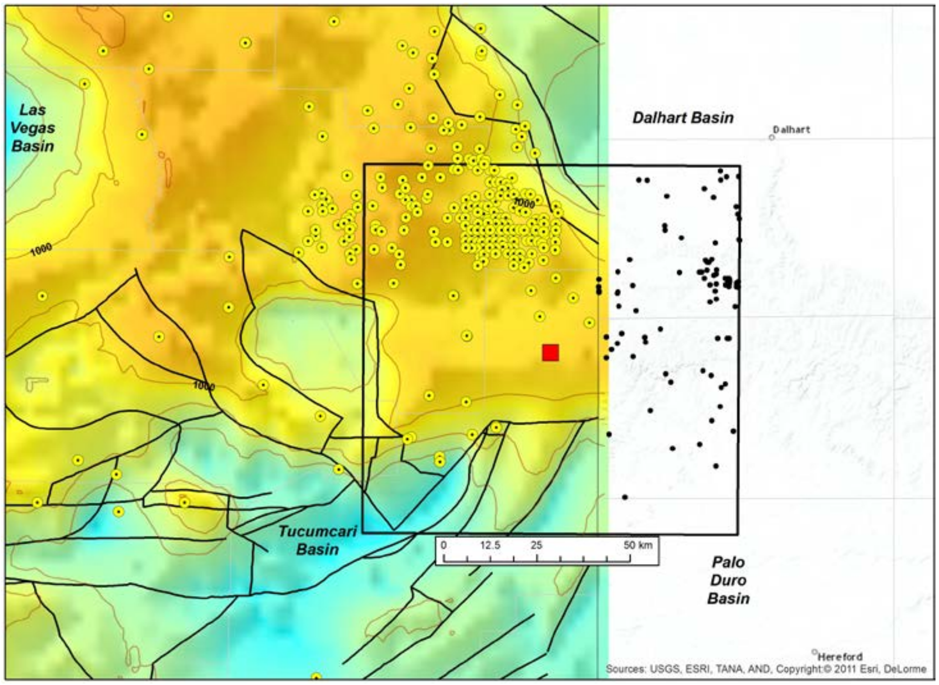

Figure 3-6. Quay County site, boreholes and region of interest on a map of depth to basement (warm colors=shallower, cool colors=deeper; counter intervals in meters). Line segments are basement faults from Broadhead (2009). Boreholes: yellow circles with dots - intercepted basement, from NMBGMR (2017); black circles – location of other boreholes from the RRCT (2017).

3.4 Otero County, New Mexico

The region of interest for the Otero County site also encompasses parts of New Mexico and Texas (Figure 3-7). The proposed site lies on the eastern edge of the Basin and Range Province and to the west of the Delaware Basin portion of the Permian Basin. Approximate depth to basement at the site is 1000 meters.

No basement depth data is readily available for the region that lies in Texas. Basement depth data from New Mexico is from Broadhead et al. (2009). Data for boreholes in New Mexico was obtained from NMBGMR (2017). Borehole location data in Texas was obtained from RRCT (2017). Note that these data only included borehole locations, not stratigraphic information from the boreholes. Obtaining this information would have required purchase of additional data from the RRCT.

Locations of basement faults in New Mexico are from Broadhead et al. (2009). Location of additional basement faults from the Permian Basin/Delaware Basin region of Texas and New Mexico are from Ewing (1990) and obtained as digitized data from Ruppel (2009). Geophysical data (aeromagnetic and gravity data for New Mexico) is available from Kucks et al. (2001).

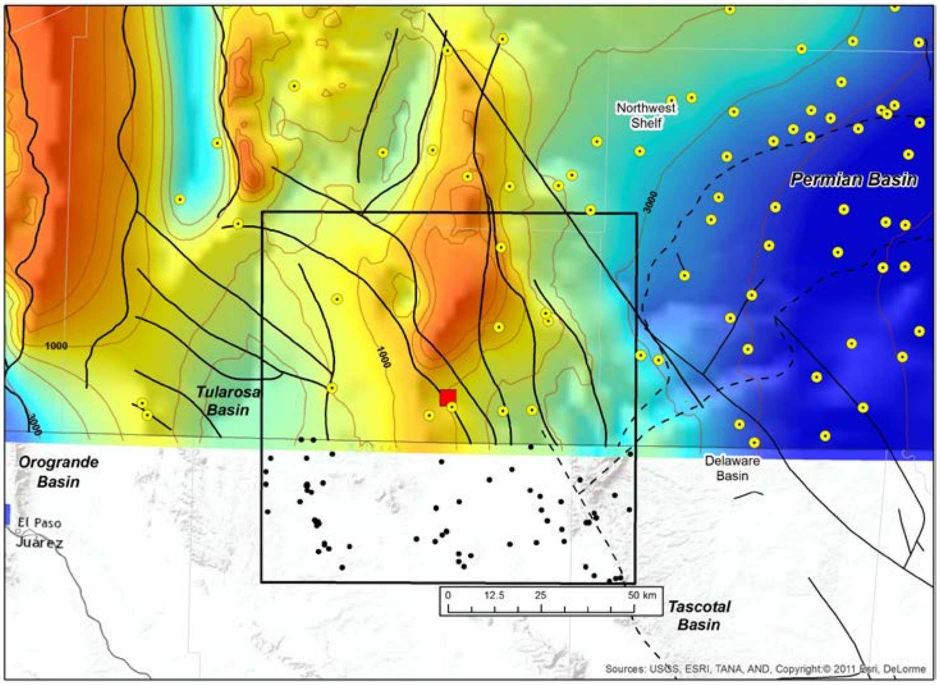

Figure 3-7. Otero County site, boreholes and region of interest on a map of depth to basement (warm colors=shallower, cool colors=deeper; counter intervals in meters). Line segments are basement from Broadhead (2009). Boreholes: yellow circles with dots - intercepted basement, from NMBGMR (2017); black circles – location of other boreholes from the RRCT (2017).

4. Previous Work – Data Acquisition and GFM Development for the Proposed Spink County Site

Borehole data from South Dakota is available from the SDGS through the Department of Environmental and Natural Resources website. The borehole data useful for constructing GFMs resides in two main online databases, the Lithologic Logs Database (primarily water wells) and the Oil and Gas Database. In north-central South Dakota, crystalline basement is relatively shallow and the sedimentary overburden relatively thin (~300 meters). Because this region does not lie within a deep sedimentary basin, oil and gas resources are not present, and only eleven boreholes for oil and gas exploration exist. In contrast, water wells for agricultural use are common, and over 1300 wells with depth exceeding 150 meters exist in the GFM area. We chose a subset of these wells that contain pertinent stratigraphic data to construct the GFM model described in this report (see Figure 3-1). In areas of the US with oil and gas resources, oil and gas boreholes would likely provide the primary basis for building a GFM.

We began development of the GFM by identifying publications that describe the geology and stratigraphy of Spink County, South Dakota (e.g., Tomhave, 1997). The southern Portion of Spink County lies within the Benson Block, a Precambrian basement terrain composed primarily of granitic plutons (McCormick, 2010a). We downloaded the database of Spink County water wells from the Lithologic Logs database at the South Dakota Department of Environment and Natural Resources website. Of the 1300 water wells in the database, we screened out all of those with depths of less than 700 feet, eliminating shallow water wells for residential use and wells for septic tanks. The remaining wells ranged in depth from 700 to greater than 1000 feet. From this population we identified 33 boreholes that according to well logs penetrated the Dakota Sandstone. These boreholes define the extent of the model domain. The Dakota Sandstone is the formation that lies immediately above the top of the Precambrian crystalline basement and is a regional aquifer for agricultural use. In addition, five of the boreholes penetrated in the crystalline basement. As a group these boreholes provide adequate coverage of the GFM domain (Figure 3-1), which allows a reasonably constrained interpolation of the top of the Dakota Sandstone within the area of the model domain (see Figures in Section 4).

The components included in this example GFM are (1) the borehole data, including location, borehole depth and formation data, downloaded from the South Dakota Department of Environmental and Natural Resources, (2) a digital elevation model (to represent the Earth's surface) obtained from the USGS, and (3) 3-D representations of the top surfaces of the Dakota Sandstone and the crystalline basement. The data from the boreholes was appropriately formatted in a spreadsheet and imported directly into the GFM software. The crystalline basement surface was created in ArcGIS using GIS data created by McCormick (2010b) and downloaded from the South Dakota Department of Environmental and Natural Resources. The elevation contours of the Precambrian basement surface were interpolated in ArcGIS to create a continuous 3-D surface grid. This grid was then imported into the GFM. In a similar manner, the elevations of the top of the Dakota Sandstone obtained from the 33 boreholes were interpolated in ArcGIS to create a 3-D surface grid that was then imported into the GFM. This same interpolation can be performed within the RockWorks GFM software, but we used ArcGIS in this case for convenience.

Primarily because we were testing the GFM capability by importing datasets and creating simplified models, we generalized the sedimentary stratigraphy of the model domain by combining all sedimentary units above the Dakota Sandstone as “shale”. These rocks include surficial deposits and glacial deposits, several major shale formations (Pierre, Niobrara, Carlisle, Graneros) and the Greenhorn Limestone. We were more interested in the Dakota Sandstone because it directly overlies the Precambrian basement in most of the model domain and is a significant regional aquifer for agricultural use.

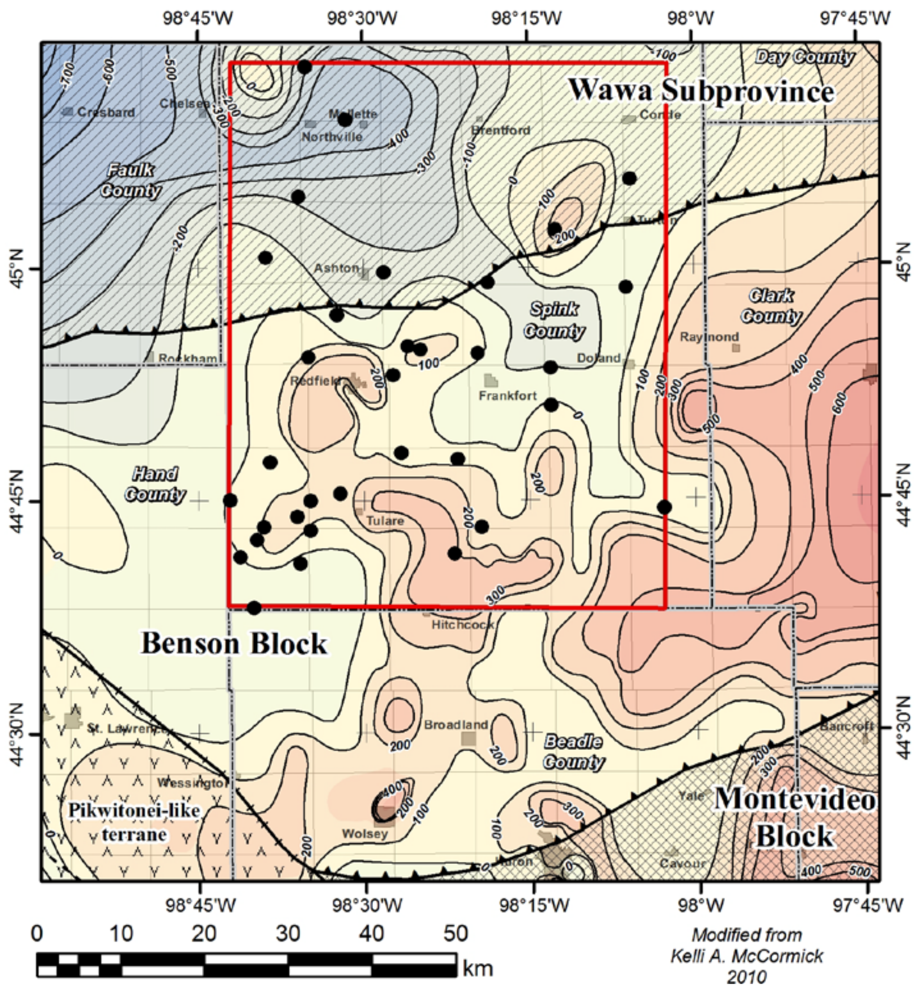

Figure 4-1. Map of crystalline basement surface elevation contours (feet relative to sea level) in the Benson Block region of northeastern South Dakota. Basement elevation contours are from McCormick (2010b) and are constrained by analysis and interpretation of over 7500 boreholes that both intersect or do not intersect Precambrian basement rocks. Area outlined in red is that of the GFM domain described in this report. This domain corresponds closely to the area of Spink County. The solid black circles within the domain are the locations of a subset of boreholes that penetrate the Dakota Sandstone. Five of these boreholes also penetrate the Precambrian surface.

5. Previous Work – Visualization of Site Geology for the Proposed Spink County Site Using a GFM

A GFM supports the DBFT in two fundamental ways. First, it provides a **data repository** for all geologic data relevant to the DBFT site and for data collected as part of the DBFT. Second, it provides a tool for **visualization** of the geology of the site and of DBFT test data that can be incorporated into the GFM, such as borehole logging results, lithologic variations, fracture zones, aquifers and the downhole locations of samples and tests. For certain tests, the test results could be incorporated for 3-D display as part of the GFM. The GFM software allows for management and visualization of borehole data collected as point data (specific depth), interval data (depth interval) or time-interval data (time series). The GFM software provides numerous options for visualizing data to best suit the needs of the project and stakeholders.

Figures 5-1 through 5-3 show examples of ways in which site data can be visualized and communicated and demonstrates some of the capabilities of the software. Figure 5-1 is a visualization of geologic surfaces, borehole locations and borehole stratigraphy. Vertical exaggeration is 30. As described in the previous section, the stratigraphy displayed in the boreholes is simplified to show the depth interval for the Dakota Sandstone (red) and for undivided shale (yellow). The lower surface (blue-purple) is the top of the Precambrian crystalline basement surface showing the elevation relief of the surface. (McCormick, 2010b). Figure 5-1 illustrates that the boreholes penetrate the Dakota Sandstone but few intersect the underlying basement. Note that the ground surface has been rendered partially transparent to allow a view of the borehole locations. A hypothetical deep borehole has been added to the model (in blue) and the labeling indicates that basement features such as lithologic variations and fracture zones can be represented in a real site model. 3-D visualizations in RockWorks can be converted to video files to display animated rotations or other specialized visualizations for presentations and web use.

Figure 5-2 is a similar view of the geologic surfaces showing how different features can be turned on or off to suit the purpose of the visualization. In this case, the surface of the Dakota Sandstone is displayed in the right frame. Note that the Dakota surface closely corresponds to the Dakota/shale boundary in the boreholes since it was created by interpolating the altitude of this boundary at the different borehole locations.

Figure 5-3 is a variation of the previous two figures and shows a block diagram of the site geology including the shales units (transparent yellow to allow view of boreholes), the Dakota Sandstone (solid red) and the crystalline basement (transparent pink, to allow view of hypothetical deep borehole) to a depth of approximately 1200 meters. A reference frame showing a depth scale was not included in these visualizations to simplify them for their intended purpose of creating animated rotations of the GFM. The Dakota Sandstone was rendered as solid red to emphasize thickness variations as it is of interest as a regional aquifer. Lastly, we populated a few hypothetical fractures within the crystalline basement in order to understand how fractures are input into the GFM. Fracture parameters in the model include orientation, dip, radius and aperture. Individual fractures could be displayed on a color scale to indicate aperture, flow rate or other fracture variables.

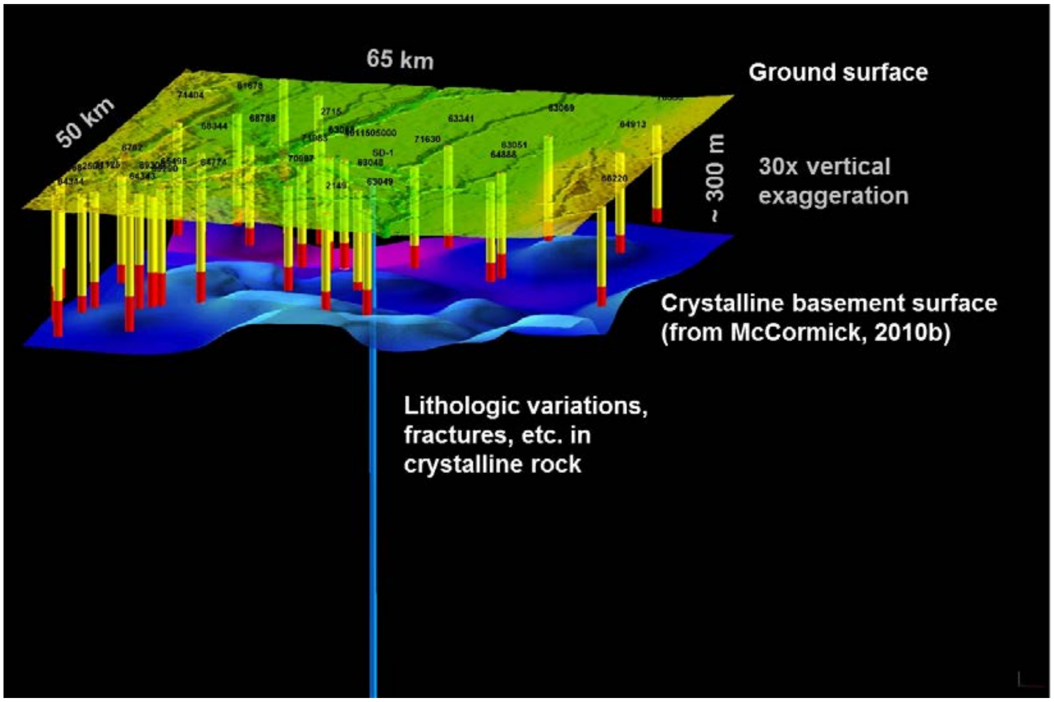

Figure 5-1. GFM visualization of the crystalline basement surface, regional boreholes with simplified stratigraphy and a hypothetical deep borehole (blue). Extent of the GFM corresponds to the model domain outlined in red in Figure 4-1. Vertical exaggeration is 30x. Red intervals in the boreholes indicate Dakota Sandstone, yellow intervals indicate undifferentiated shale.

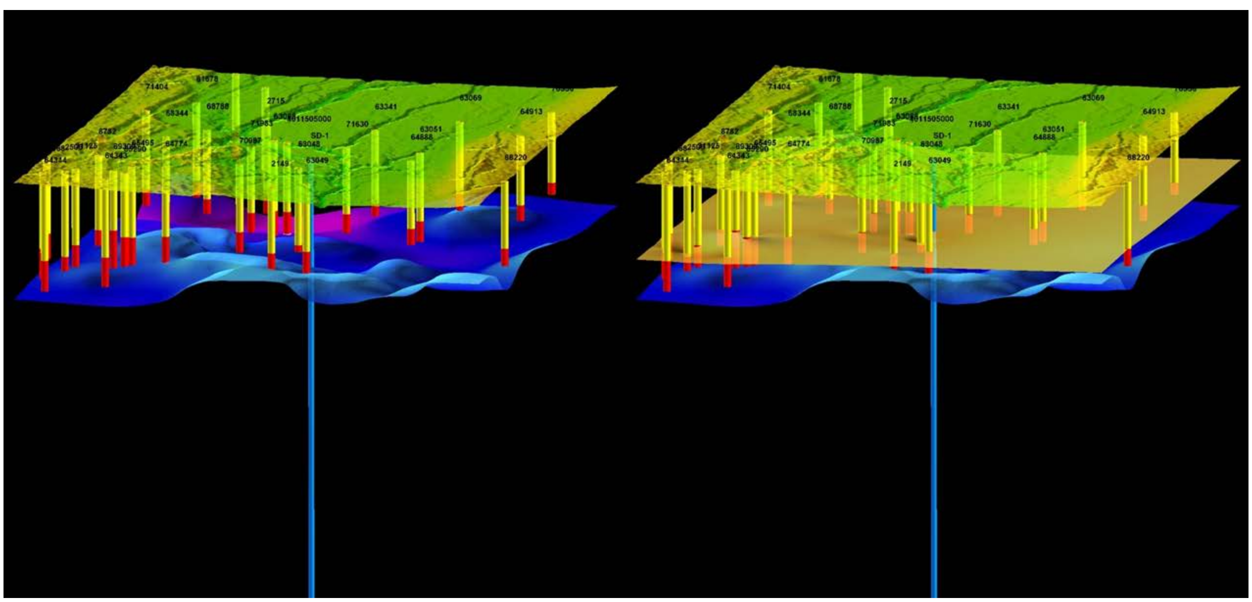

Figure 5-2. Same visualization as in Figure 5-1 except frame on the right includes the upper surface of the Dakota Sandstone rendered in tan-yellow. The two frames demonstrate how model elements can be turned on or off to visualize and communicate different components of the model.

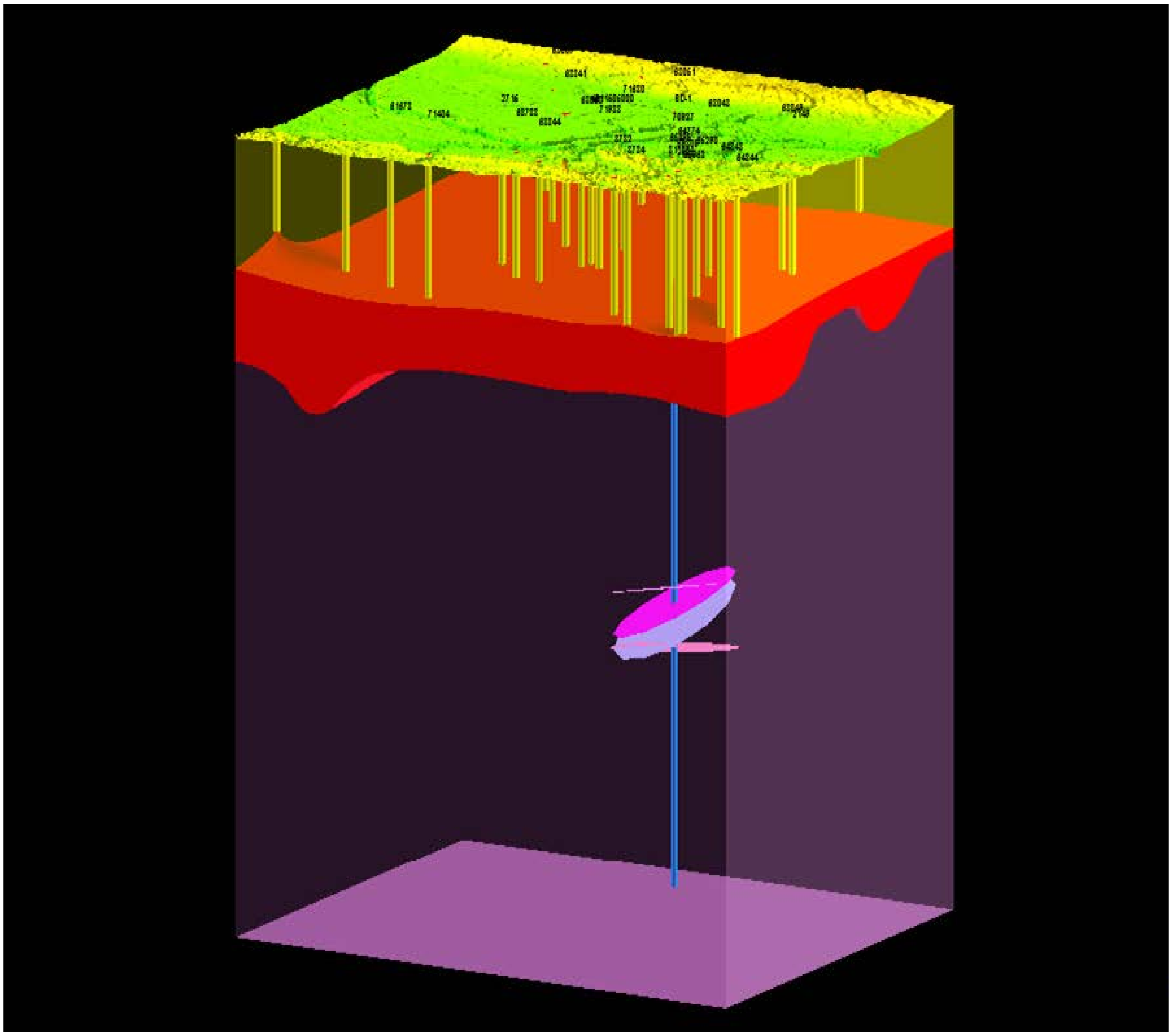

Figure 5-3. Block diagram view of boreholes, sedimentary overburden and crystalline basement. The Dakota Sandstone is rendered solid red to emphasize thickness variations due to the topography of the basement surface. The deep borehole (blue) includes examples of hypothetical intersected fractures with different orientations.

6. Summary

Six sites in North and South Dakota, New Mexico and Texas were considered for a DBFT in 2016 and 2017. The eventual goal of the work reported here was to build a GFM for the DBFT site once a final site was selected. Development of the GFM begins by collecting publically available geologic, hydrologic and geophysical data for the region of interest and incorporating appropriate data into the GFM software. Once work begins at the site, additional site data and data collected from the DBFT borehole would be incorporated into the GFM.

The GFM serves as a tool to document site and test data, manage data collected as part of the DBFT and visualize the site and test data to suite a variety of project and stakeholder needs. The geologic and hydrogeologic units documented within the GFM would serve as the basis for creating numerical grids of the DBFT site for the purpose of developing flow and transport models. The GFM is also a tool that can be utilized by the UFD Campaign to support a variety of future site evaluations and site testing and characterization activities.

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