Geologic Site Model for the Deep Borehole Field Test – Capability Development

Fuel Cycle Technology

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Used Fuel Disposition Campaign

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USED FUEL DISPOSITION CAMPAIGN

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Acronyms

DBFT	Deep Borehole Field Test
DOE	Department of Energy
GFM	Geologic Framework Model
UFD	Used Fuel Disposition
US	United States
USGS	United States Geological Survey

GEOLOGIC SITE MODEL FOR THE DEEP BOREHOLE FIELD TEST – CAPABILITY DEVELOPMENT

1. Introduction

This report describes the development of a capability to create a geologic framework model (GFM) for the Deep Borehole Field Test (DBFT). A GFM, also referred to as a 3-D geologic model, will represent the geologic features of a DBFT site and will 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 will 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 will 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 project.

Because a DBFT site was not secured in FY16, this report will focus on the development of the techniques and tools needed to create a GFM for a future site. In order to understand and test the processes of importing geologic data, we incorporated into the model real data from an area in northeastern South Dakota. This area, centered on Spink County, encompasses the north-central portion of the Benson Block in South Dakota (McCormick, 2010a) and has many of the geologic attributes desired for a DBFT site, including crystalline basement at a depth of less than 2000 meters, lack of seismic activity and low geothermal heat flow (DOE, 2015).

When implemented for the DBFT site, the GFM will be developed in two basic steps. The first step will be to incorporate any existing geologic data from the appropriate region surrounding the site. This step will include incorporating stratigraphic data from existing borehole reports, as well as any subsurface information that can be derived from existing geologic maps, structural interpretations or geophysical surveys. The second step will be to incorporate data collected as part of the DBFT. The latter step will involve incorporation of lithologic variations within the crystalline basement rock, refinement of geologic and geophysical interpretations, fracture data, and incorporation of other types of data gathered during well logging and scientific and engineering tests conducted as part of the DBFT.

2. Software Evaluation

We evaluated several GFM software packages for use in creating a GFM for the DBFT site. The criteria for selection of software included:

1. Affordability, given current DBFT work package budgets.
2. Ability to import data and geologic features created or stored in ArcGIS 10, the GIS software that LANL has used extensively to create the Regional Geology GIS Database.
3. Capability to perform the functions we believe necessary to develop a successful GFM of the DBFT site.

Four software packages were evaluated with different amounts of rigor as part of the selection process:

1. RockWorks (RockWare, Inc., https://www.rockware.com/product/overview.php?id=164)
2. EarthVision (Dynamic Graphics, Inc., http://www.dgi.com/earthvision/evmain.html)

3. JewelSuite (Baker Hughes, Inc., http://www.bakerhughes.com/products-and-services/reservoir-development-services/reservoir-software/jewelsuite-reservoir-modeling-software)
4. Leapfrog (ARANZ Geo Limited, http://www.leapfrog3d.com)

All of the programs allow representation and visualization of basic geologic features such as stratigraphy, lithologic variations and faults in 3-D. All of the packages require a large investment of hands-on effort to achieve a reasonable level of proficiency and understanding of the software capabilities. For this reason, it is difficult to evaluate some of the more specialized functions without using the software for an extended period of time in a project environment. EarthVision and JewelSuite are used at LANL on projects other than UFD and we interviewed LANL users to understand their basic functionality. The cost of both of these packages (~$100,000) is prohibitive and we did not perceive a level of functionality over other packages that would justify the cost.

We chose RockWorks because it was affordable and appeared to provide all the functionality that we required for the DBFT. This has proven to be the case after several months of developing a simple GFM using real geologic data. Importantly, RockWorks allows us to interchange data with ArcGIS, which is the world standard for GIS software. A large amount of geologic data is available online as ArcGIS databases and features. The Regional Geology GIS database developed at LANL utilizes ArcGIS.

Rockworks has numerous capabilities that will be needed to document and visualize a DBFT site. The software is built around the concept of a borehole manager, which allows input of downhole data and is well-suited for the needs of the DBFT. Borehole data is managed in modules that include location (including depth and orientation), stratigraphy, lithology, fractures, water levels (aquifers) and well-construction/materials intervals. Date can be entered as depth point data, depth interval data, or time-series data, depending on the type of data (geochemical, geophysical, hydrologic lithologic, well-log, etc.). Data can be displayed as downhole striplog plots, cross-sections, or as part of 3-D visualizations.

3. Development of Geologic Site Models

3.1 Data Needs and Sources

The goal of a GFM is to accurately represent the geology, hydrology and other key subsurface features of a site. Features that are typically included in a GFM include surface topography, stratigraphic relationships, structural features and relationships, fracture zones and aquifers. The availability of subsurface data for inclusion in the GFM is largely dependent on the existence and availability of data from regional and local boreholes.

Boreholes in the US are overwhelmingly drilled for either oil or gas or groundwater resources. Borehole data is generally available as downloadable online data from state agencies that manage and regulate oil and gas or water resources such as state departments of natural resources or state geologic surveys. Data from these sources has to be evaluated for accuracy of the borehole locations and the quality of interpretations of stratigraphy, which can vary by individual borehole.

Other data for a GFM that is necessary or desirable include a digital elevation model of the site and any published geologic or geophysical data pertaining to the site or region that can be logically incorporated into the model. These data include published surface geologic maps, cross-sections, structural interpretations and hydrologic interpretations.

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3.2 Model Development

In South Dakota, borehole data is available 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 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 (Figure 3-2). 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.

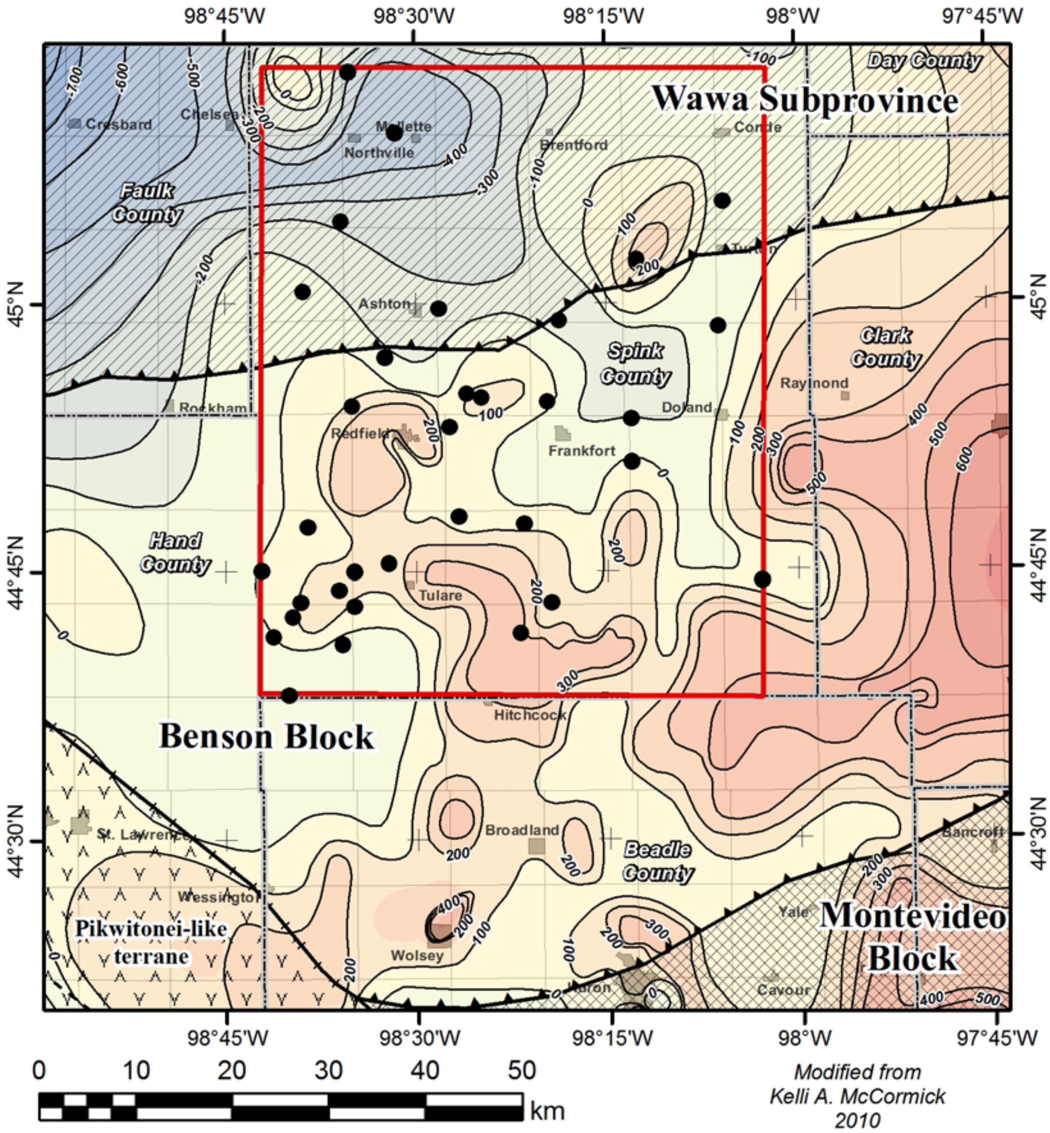

Figure 3-1. Map of crystalline basement surface elevation contours (feet relative to sea level) in the Benson Block region of northeastern South Dakota. Basement elevation contours are from McCormick (2010b) and are constrained by analysis and interpretation of over 7500 boreholes that both intersect or do not intersect Precambrian basement rocks. Area outlined in red is that of the GFM domain described in this report. The black symbols 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.

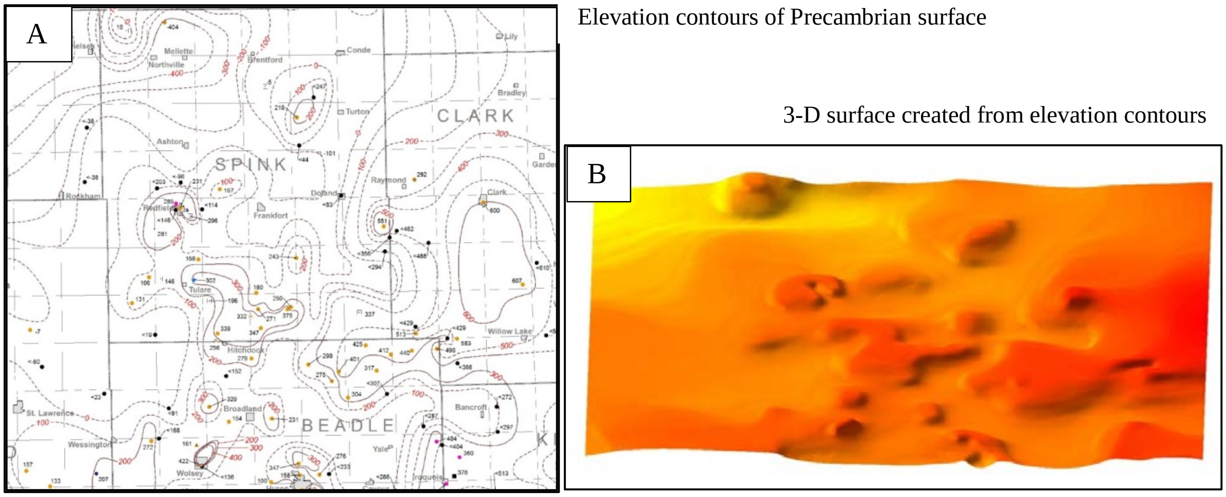

Figure 3-2. (A) Map of crystalline basement surface elevation contours in the Benson Block region of northeastern South Dakota from McCormick (2010b). (B) 3-D representation of the Precambrian surface created in ArcGIS from interpolation of the surface contours in (A).

4. Visualization of Site Geology and Borehole Data

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 4-1 through 4-3 show examples of different ways in which site data can be visualized and communicated and demonstrates some of the capabilities of the software. Figure 4-1 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 4-1 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 4-2 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 4-3 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.

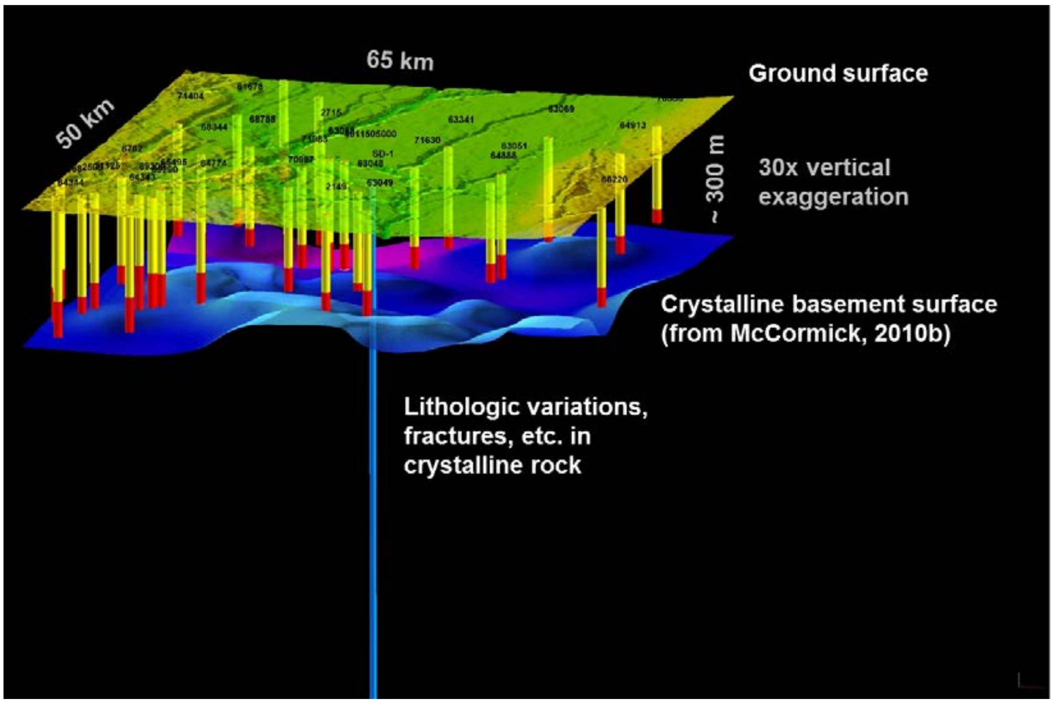

Figure 4-1. GFM visualization of the crystalline basement surface, regional boreholes with simplified stratigraphy and a hypothetical deep borehole. Extent of the GFM corresponds to the model domain outlined in red in Figure 3-1. Vertical exaggeration is 30. Red intervals in the boreholes indicate Dakota Sandstone, yellow intervals indicate undifferentiated shale.

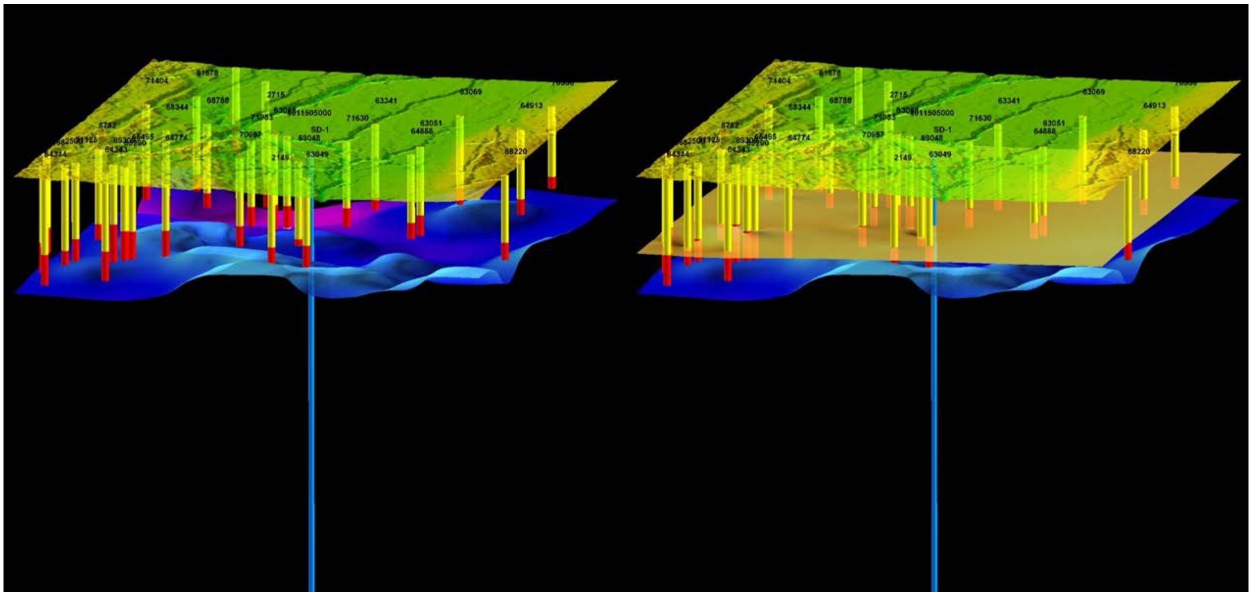

Figure 4-2. Same visualization as in Figure 4-1 except frame on the right includes the top surface of the Dakota Sandstone rendered in tan-yellow. The two frames demonstrate how model elements can be switched on or off to visualize and communicate different components of the model.

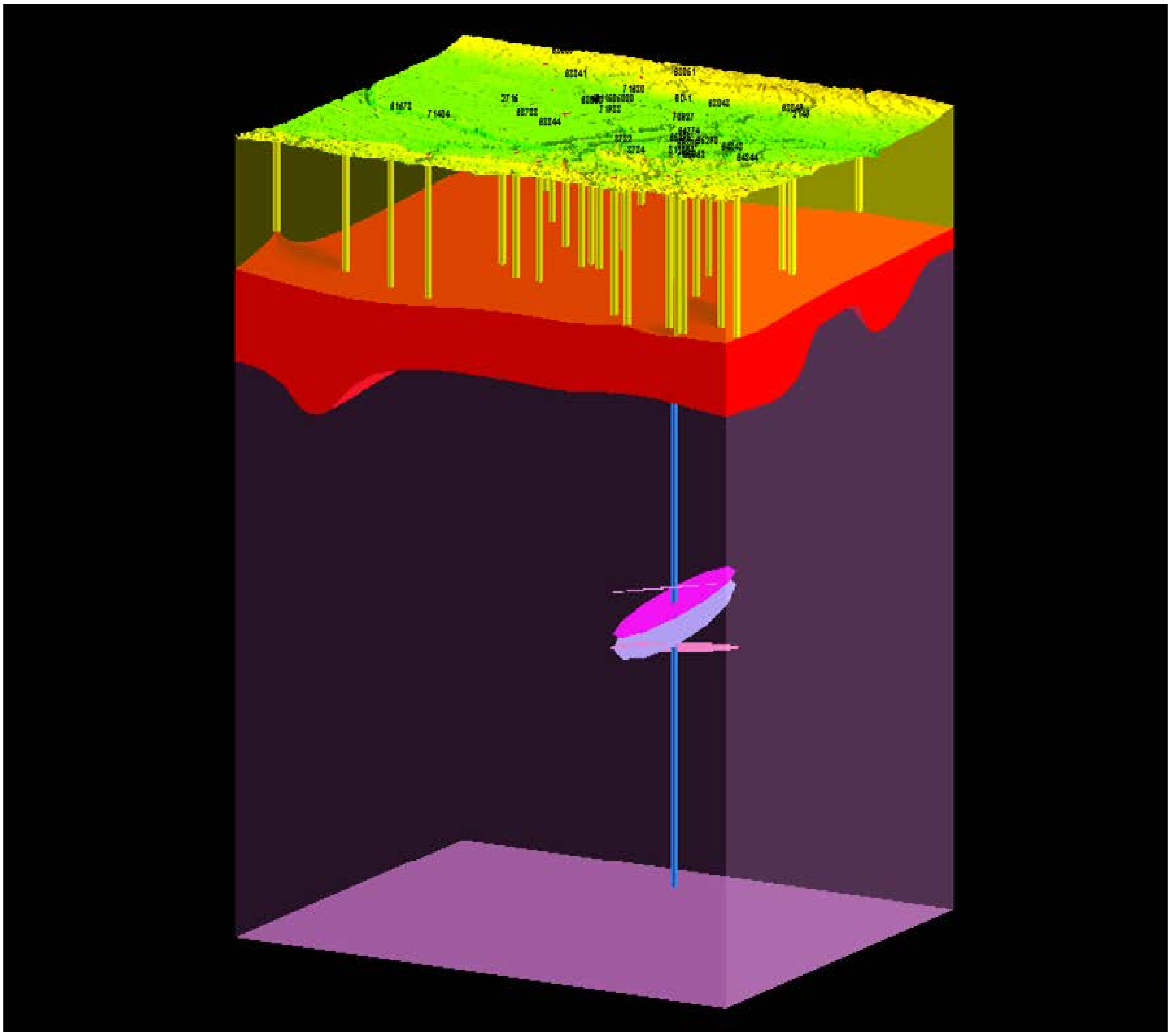

Figure 4-3. Block diagram view of boreholes, sedimentary overburden and crystalline basement. The Dakota Sandstone is rendered solid red to emphasize thickness variations due to the topography of the basement surface. The deep borehole (blue) includes examples of hypothetical intersected fractures with different orientations.

5. Summary

We have developed a simple GFM for a hypothetical DBFT site using actual data from a small region in the Benson Block of South Dakota. This capability development has allowed us to test the processes of identifying appropriate geologic data and incorporating these data into the GFM. We explored alternative ways of creating geologic surfaces for the GFM and the visualization capabilities of the software. Alternative visualizations of the geologic data can be created with the GFM software depending on what the project wants to communicate or emphasize to project or external audiences.

Overall, 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 for a variety of projects needs and stakeholders. The GFM capability is an additional tool, in combination with the Regional Geology GIS Database, which can be utilized by the UFD Campaign to support a variety of future site evaluations and site testing and characterization activities.

6. References

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