A GIS DATABASE TO SUPPORT SITING OF A DEEP BOREHOLE FIELD TEST

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The US DOE Used Fuel Disposition Campaign is planning a demonstration of the deep borehole disposal concept by conducting a full-scale field test. To support the field test, we have created a geographic information system and database that contains geologic, geophysical, and other data related to site selection and site characterization activities. The database also contains information related to technical siting guidelines such as the depth to crystalline basement and the location of tectonic and volcanic features that could impact the long-term performance of a future disposal system. The database will be used as a tool to support high-level site selection at the national scale. It can also be populated with regional and local data to support final site selection decisions as well as site characterization once a site is selected. The GIS database is intended to support the DBH field test as well as siting and site characterization of a potential DBH disposal system if one is implemented in the future.

I. INTRODUCTION

Options for disposal of spent nuclear fuel and other high-level radioactive waste are being evaluated through research supported by the DOE Used Fuel Disposition Campaign (UFDC). These options include alternative host rocks (salt, shale, and crystalline rocks) for a mined geologic repository, as well as deep borehole (DBH) disposal in crystalline basement.[1] The DOE and UFDC began the process of implementing a full-scale DBH demonstration field test in late 2014.[2] The purpose of the field test will be to test the feasibility of engineering and monitoring deep boreholes, confirm the geologic conditions and controls in a deep borehole environment, test the safety and practicality of borehole sealing concepts, and test the processes and operations of deep borehole disposal and retrieval.[2]

The first steps in implementing a DBH field test include soliciting interest in hosting a site, selecting a site among several potential candidates, and characterizing the selected site. To support these efforts, we are applying a geographic information system (GIS) database that is designed to facilitate siting decisions and document site characterization data. The GIS allows visualization and qualitative and quantitative analysis of multiple data layers including information related to potential host rocks and siting guidelines.[3] We are currently focusing on using the GIS database to evaluate and document data related to siting of a DBH demonstration field test, but the same techniques can be used to site an DBH disposal system should one be implemented in the future.

At the national scale, the data provide a basis for comparison and understanding of the different geologic environments that would be considered for DBH site. These data are focused on the regional geologic setting, including depth to basement, the tectonic environment, and general ages and lithology of basement terranes.

II. DEEP BOREHOLE DISPOSAL CONCEPT

The conceptual design of a DBH disposal system is relatively simple. It specifies a large-diameter borehole to a depth of 5 kilometers, with the lower 3 kilometers located within crystalline basement rock and containing a waste emplacement zone and a system of borehole seals above the waste[4,5] (Fig. 1). Given this design concept, depth to basement of two kilometers or less is an important siting guideline that allows at least 3 kilometers of the DBH system to lie within crystalline basement rock.

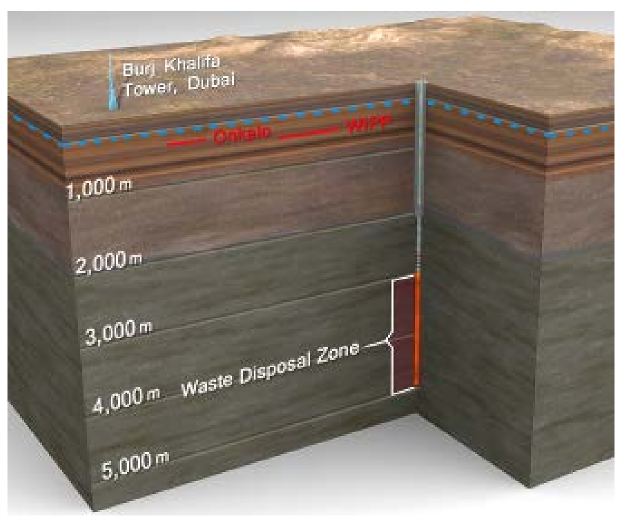

Fig. 1. Schematic illustrating the conceptual design of a deep-borehole waste disposal system in crystalline basement rock.

III. GIS DATABASE TO ASSESS GEOLOGIC AND SITING ALTERNATIVES

The UDFC has supported the implementation of a spatial database to manage and analyze regional geologic information needed to support site screening and site evaluation activities.[3] The GIS database integrates geologic data for alternative host-rock formations and information that has been historically used for siting guidelines, both in the US and other countries, such as seismic hazard, population distribution and natural resources. These two types of information are fundamental to the eventual siting of a geologic disposal system for HLW. The database will allow analyses of the degree to which features related to siting guidelines and host-rock formations spatially overlap, thus providing information on the options available for HLW disposal in different regions of the US.

IV. PREFERRED SITING GUIDELINES FOR A DEEP BOREHOLE FIELD TEST

Siting guidelines for the DBH field test are intended to parallel those of a borehole disposal system in order to more realistically and fully test the DBH disposal concept. The goal is to site the field test in a geologic and hydrologic environment that is similar to that of a potential future disposal system. The siting guidelines are formulated to locate a site within a relatively stable and simple geologic environment with characteristics that would enhance the ability to predict long-term system performance.

The preferred technical siting guidelines for a DBH field test are as follows:[2,5]

- Less than 2 km (1.2 miles) depth to crystalline basement
- Not at or proximate to a strategic petroleum reserve site
- Not near an urban area
- Site area greater than 1 km^2 (about ½ square mile so that there is ample area for drilling operations)
- Distance greater than about 100 km (about 60 miles) to topographic slope of greater than 1º to avoid deep groundwater circulation
- Geothermal heat flux less than 75 mW/m^2
- Less than 2% probability within 50 years of peak ground acceleration greater than 0.16 g from a seismic event (generally indicative of area of tectonic stability)
- Distance to Quaternary age (< 2.6 million years ago) volcanism greater than 10 km (6.2 miles)
- Distance to Quaternary age faulting greater than 10 km (6.2 miles)
- No known major crystalline basement shear zones or major tectonic features
- Low density of petroleum drilling
- Lack of known existing surface or subsurface anthropogenic radioactive contamination

The strictest siting guideline is the depth to crystalline basement. The depth guideline is required in order to be consistent with the DBH conceptual design that requires a vertical length of least 3 kilometers within crystalline basement for the DBH disposal zone and seals system, while not exceeding the desired drilling depth of 5 kilometers (Fig. 1). The intent of the remaining guidelines is primarily to identify a site in a region of geologic and hydrologic stability and simplicity that minimizes potential interaction with human activities and population.

Nine of the guidelines are currently incorporated into the GIS database. These guidelines cover many of the technical aspects related to the long-term safety of a disposal system, but do not include other important siting considerations related to site logistics or public and political acceptance of a DBH disposal system.

Another important siting consideration not included in the guidelines is the type (lithology) of crystalline rock present at the DBH site. A homogeneous crystalline rock such as a granitic pluton is preferred compared to more heterogeneous and layered metamorphic rocks because of a higher likelihood of completing a successful borehole in rock with homogeneous physical properties and a lesser likelihood of encountering preferential groundwater pathways that could impact the performance of the disposal system.[5]

Siting guidelines for several DBH disposal concepts have been developed over the years beginning in the 1970s. In general, these guidelines are similar to those applicable to mined geologic repositories. Nirex[6] summarizes siting guidelines developed for several alternative DBH disposal concepts developed over the past several decades. Similar to the guidelines described in this paper, earlier guidelines emphasize siting of a DBH system in areas of geologic stability and hydrologic simplicity, while avoiding human activities and population.[7,8]

V. SITING DATA AT THE NATIONAL SCALE

The datasets included in the GIS database provide a framework for comparing potential DBH sites at the national scale against preferred siting guidelines. These include data for depth to crystalline basement, the location and nature of tectonic structures within crystalline basement, the distribution of surface exposures of crystalline rocks, topographic slope, the location of Quaternary faulting and volcanism, estimates of seismic hazard, the location of drilling related to petroleum production and exploration, and geothermal heat flow values. Much of these data are available online from

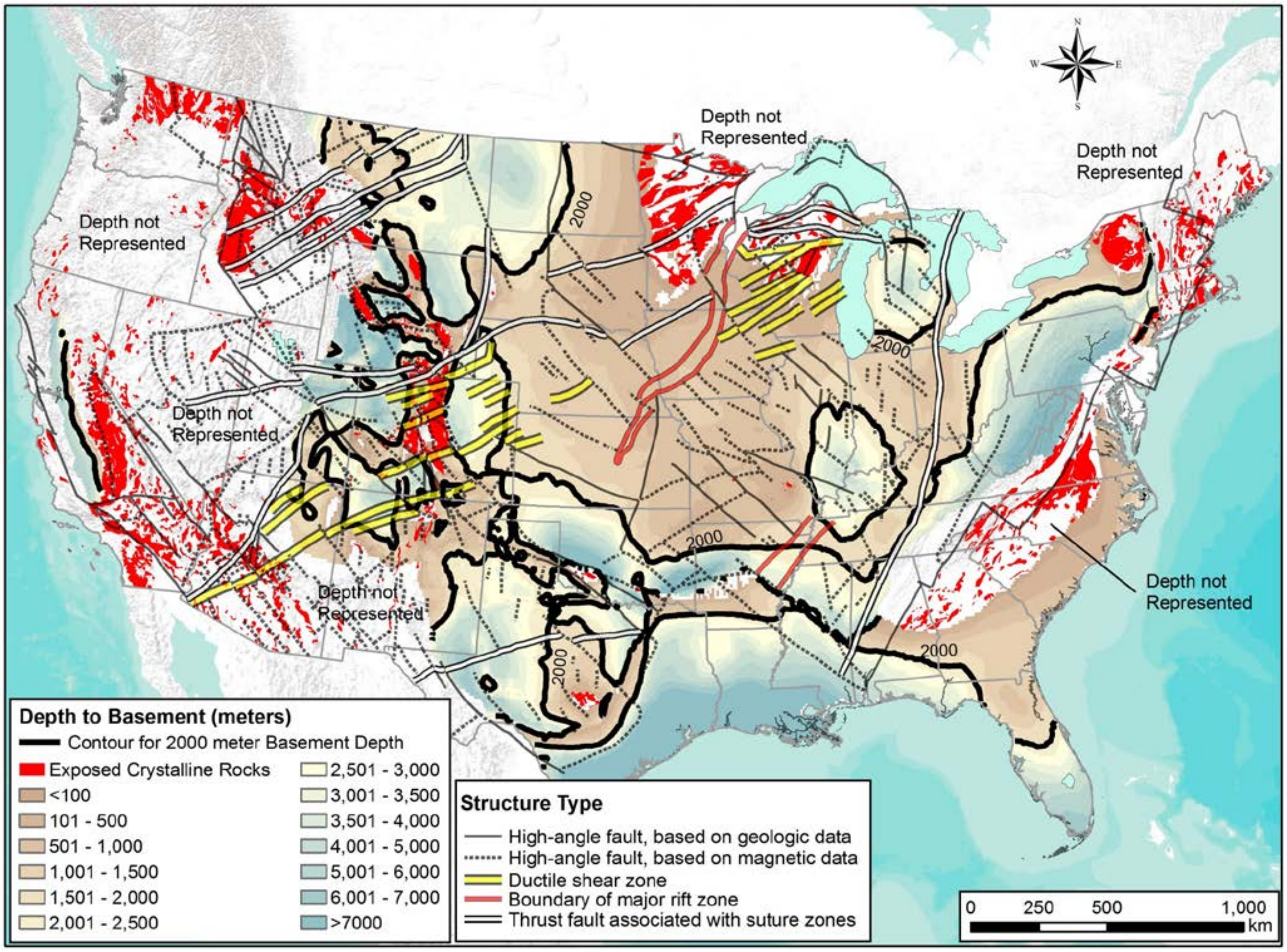

Fig. 2. Shaded contour map for the depth to crystalline basement in the US. Surface exposures of crystalline (granitic) rock are shown in red. The heavy black line is the 2000 meter contour line for depth to crystalline basement. The tan to brown shaded areas contained within the 2000 meter contour have crystalline basement that lies at a depth of less than 2000 meters. Yellow to green shading represents sedimentary basins with basement depth of greater than 2000 meters. Depth to crystalline basement is not represented for the tectonically active regions of the western US because the depth is variable over short distances due to Cenozoic faulting. Depth to basement data was derived from sediment thickness data provided courtesy of the SMU Geothermal Laboratory. The overlay of basement structures is from Sims et al.[9]

sources such as the United States Geological Survey or from university sources such as the Southern Methodist University (SMU) Geothermal Laboratory.

V.A. Depth to Crystalline Basement and Basement Structure

Among the most important data related to DBH siting are those related to the nature of crystalline basement itself, including depth, presence of basement structure, and basement lithology. Depth to basement and basement structures are represented in Fig. 2. The key information obtained from the depth to basement map is the identification of regions of the US with basement at a depth of less than 2000 meters, including crystalline rocks exposed at the surface, shown in Fig. 2 in red. An extensive region of the central US (enclosed within the heavy black contour lines of Fig. 2) overlies relatively shallow crystalline basement as does a region of the southeastern US. Areas where the depth to basement is not represented generally represent areas of structural complexity where the basement depth varies over short distances due to faulting (western US) or where the depth is very shallow near surface exposures of granitic crystalline rocks (middle and eastern US).

Crystalline basement contains structural features whose nature and location can be interpreted through a combination of geophysical and geologic data.[9] These structures generally represent suture or shear zones that formed during or following continental collision or accretion. In some cases, the exact boundaries of the structural zones are uncertain and their width may exceed

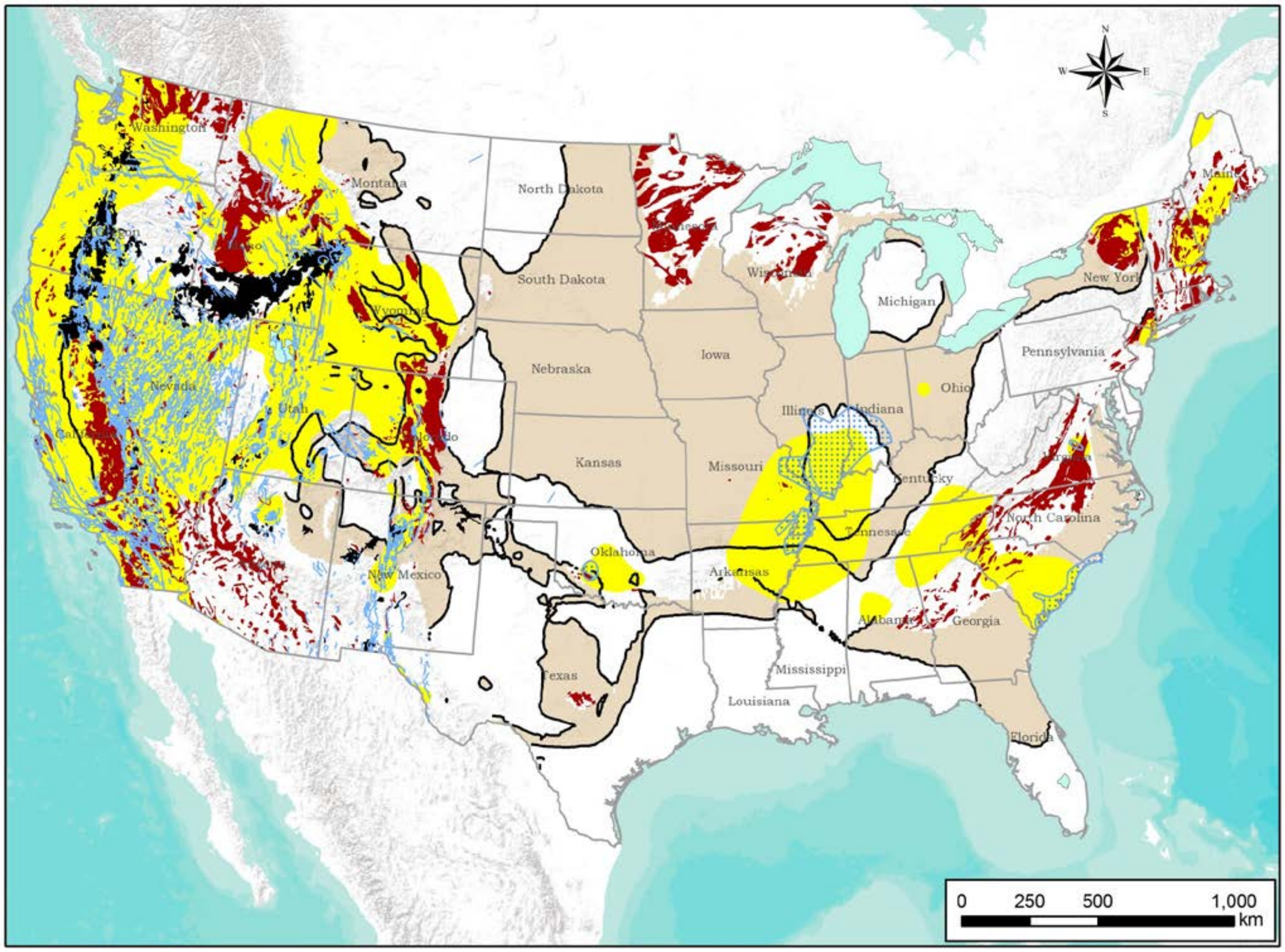

Fig. 3. Map displaying extent of crystalline basement in (tan shading) the contiguous US at a depth of less than 2000 meters. Included within this classification are exposed crystalline ("granitic") rocks at the surface. Also shown are the distribution of Quaternary faulting, volcanism, and seismic hazard (yellow shading = 2% probability of exceeding 0.16 g in 50 years), which indicate areas of recent tectonic activity in the US.

several tens of kilometers at major terrane boundaries.[10] Basement structures indicate areas of crustal complexity that could present drilling difficulties or impact post-closure disposal system performance due to relatively permeable pathways for groundwater flow.[5]

V.B. Tectonic Stability

Data layers for potential siting guidelines can be combined on a single map to provide better insight on potential siting opportunities and challenges. For example, the distribution of Quaternary faults, volcanism and strong seismic ground motion hazard approximate the "tectonically active" regions of the US (Fig. 3). Tectonic activity on the continental scale is dominated by the tectonic activity in the western US. The western US also has the highest elevations and topographic relief due to tectonic uplift over the last 100 million years. The major tectonically active areas in the eastern US are the New Madrid and Charleston regions. Large regions of the US mid-continent are tectonically stable with no evidence of significant tectonism in the past several hundred million years.

VI. SITING DATA AT SUBREGIONAL, STATE AND LOCAL SCALES

Data for siting guidelines applied at the national scale will provide a high-level screening tool to indicate whether a potential DBH site is clearly unsuitable for further consideration (e.g. a depth to basement of more than 2 kilometers). This initial screening will not be sufficient to make final siting decisions among the remaining sites that meet the initial siting guidelines. A final siting decision for the DBH field test will depend on acquiring additional (but existing) geological, geophysical

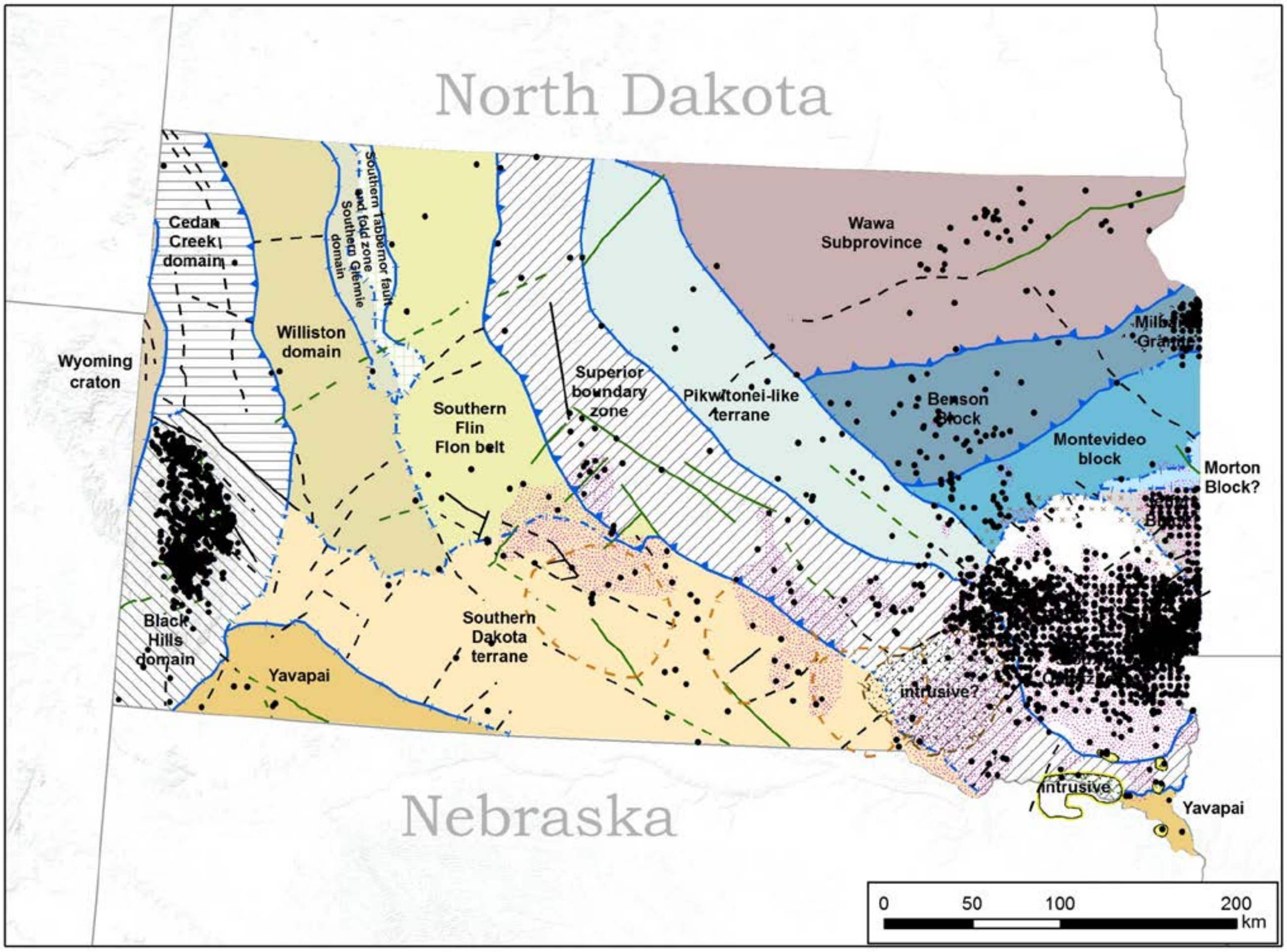

Fig. 4. Basement terrane and structure map of South Dakota.[10] Solid black circles represent the location of boreholes that penetrated Precambrian basement rocks. Granite was the most common lithology encountered within the crystalline basement.

and borehole data at the more local scale that can be used to differentiate among the remaining candidate sites.

A recent example of mapping the characteristics of crystalline basement at the more local (state) scale was provided for the state of South Dakota using borehole and geophysical data[10] (Fig. 4). The borehole database used in the study consisted of 4830 boreholes that intersected Precambrian basement rock. The most common rock encountered in the crystalline basement was granite. We assume that the boreholes only penetrated the uppermost portion of the crystalline basement and it is therefore possible that the lithology could change in a borehole that penetrates several kilometers of basement rock

As a whole, the maps at this scale probably provide the best overall balance between broad coverage and useful information about terrane boundaries, crustal structure, and terrane lithology.

Local data from nearby deep boreholes would provide some of the best information for understanding basement characteristics at a candidate site for a DBH field test or DBH disposal site. In every case, it would be necessary to review all available local data related to geology, hydrology and geophysics when comparing potential candidate sites.

VII. CONCLUSIONS

A GIS database is being applied to support siting of a DBH field test. The database contains information on most of the preferred siting guidelines identified in an RFI published by DOE in October 2014.[2] The datasets can be combined to show at a national scale how candidate sites for a DBH field test meet the siting guidelines. Data at a more local scale, along with other types of siting considerations, would be necessary to compare the potential candidate sites for final selection of a field test site. Ideally, already existing data would include information from regional boreholes, geophysical surveys, and hydrologic and geologic studies that could shed light on crustal processes and features. These data would be used in a comparative way to help choose between alternative DBH test sites. The methods used, including the further development of the GIS database, would be applicable to a future siting of one or more deep borehole disposal systems.

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