Site Characterization in a Deep Borehole Field Test

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Abstract

The US Department of Energy Office of Nuclear Energy is embarking on a 5-year Deep Borehole Field Test (DBFT) to investigate the feasibility of the Deep Borehole Disposal (DBD) concept (Fig 1) by constructing and characterizing two boreholes in crystalline basement rock to a depth of 5 km [16,400']. The DBD concept for radioactive waste offers advantages, such as incremental construction and loading, and enhanced isolation by natural barriers at depth in the continental crystalline basement. Site characterization activities will include geomechanical (i.e., hydrofracture stress measurements), geological (i.e., core and mud logging), hydrological (i.e., packer-based pulse and pumping tests), and geochemical (i.e., fluids sampled in situ from packer intervals and extracted from cores) tests. Borehole-based characterization will be used to determine the variability of system state (i.e., stress, pressure, temperature, and chemistry) with depth, to constrain the disturbed rock zone (DRZ) surrounding the borehole, and to interpret material and system parameters for use in numerical site simulation. The effects of fluid density and geothermal gradients (e.g., thermohaline convection) on characterization goals will be investigated.

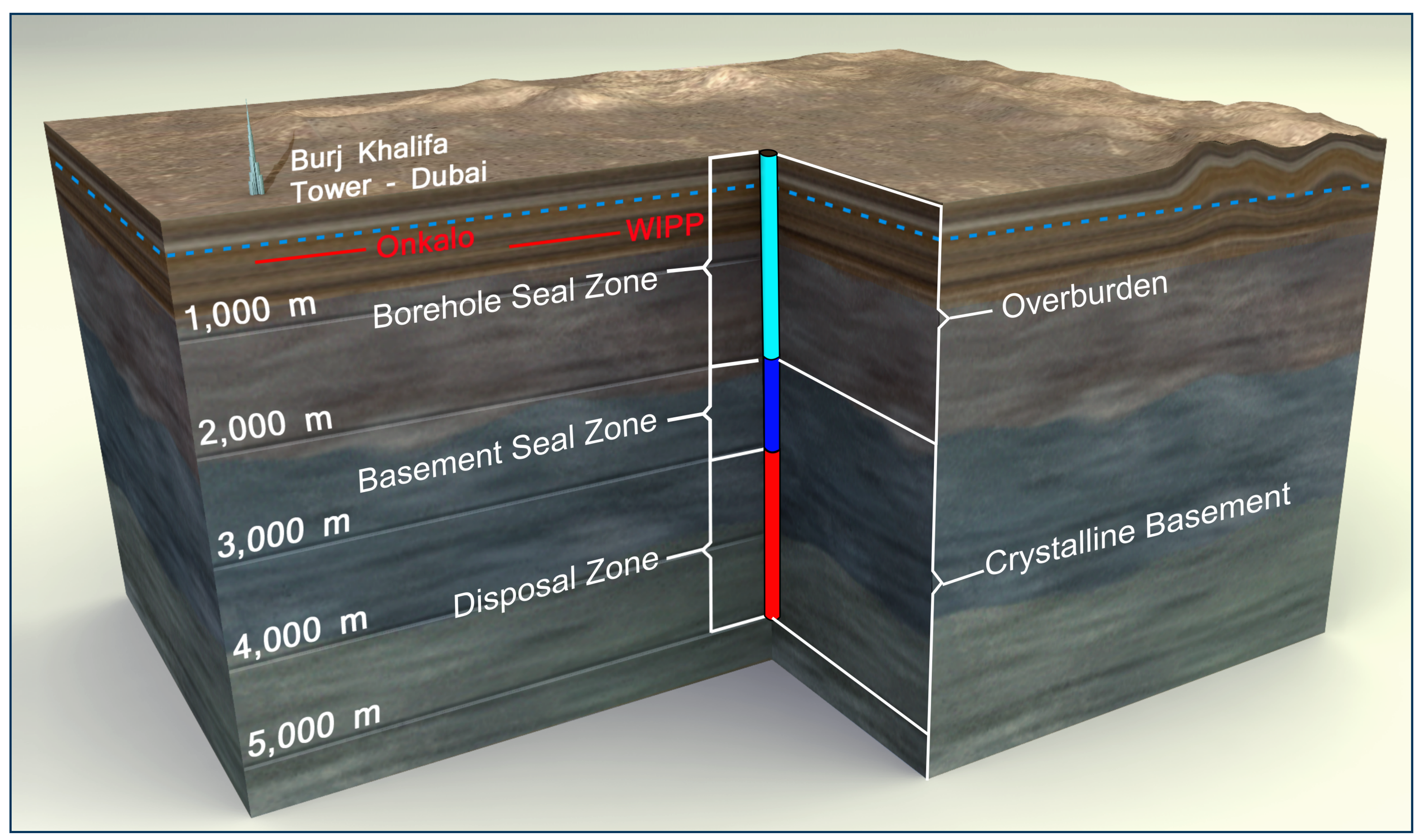

Figure 1: *Deep Borehole Disposal Concept. No radioactive materials or seals will be involved in the DBFT*

Deep Drilling

Deep drilling in crystalline basement is non-trivial, but significant advances have been made recently, which make possible the standard construction of large-diameter (≥ 43 cm [17"]) boreholes to depths of 5 km [16,400']. Table 1 lists some notable historic drilling projects in crystalline rock that have drilled to depths of at least 3 km [9,840'] (Figure 2). Traditional and enhanced geothermal exploration and development have been the primary targets at these depths, but notable geological exploration boreholes include the KTB, Kola, Cajon Pass, CCSD, and SAFOD projects.

Table 1: *Deep Borehole Drilling Projects in Crystalline Rocks*

Site	Location	Years	Depth to Crystalline [km]	Total Depth [km]	Diam* [inch]	Purpose
Kola	NW USSR	1970-1992	0	12.2	8½	Geologic Exploration + Tech.Development
Fenton Hill	New Mexico	1975-1987	0.7	2.9, 3.1, 4.0, 4.4	8¾, 9⅞	Enhanced Geothermal
Urach	SW Germany	1978-1992	1.6	4.4	5½	Enhanced Geothermal
Gravberg	Central Sweden	1986-1987	0	6.6	6½	Gas Wildcat in Siljan Impact Structure
Cajon Pass	Southern California	1987-1988	0.5	3.5	6¼	San Andreas Fault Exploration
KTB	SE Germany	1987-1994	0	4, 9.1	6, 6½	Geologic Exploration + Tech.Development
Soultz	NE France	1995-2003	1.4	5.1, 5.1, 5.3	9⅝	Enhanced Geothermal
CCSD	E China	2001-2005	0	2, 5.2	6	Geologic Exploration
SAFOD	Central California	2002-2007	0.8	2.2, 4	8½, 8¾	San Andreas Fault Exploration
Basel	Switzerland	2006	2.4	5	8½	Enhanced Geothermal

* borehole diameter at total depth

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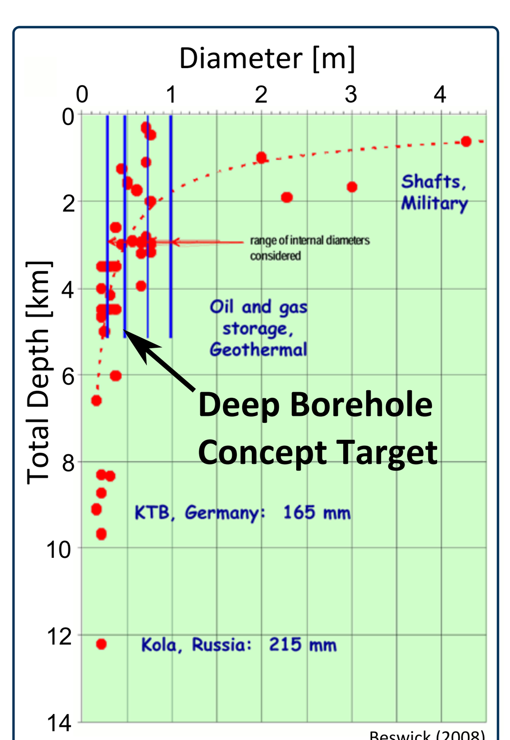

Figure 2: *Borehole diameter vs. depth in crystalline rock*

Why Deep Boreholes?

The DBD concept and the DBFT include boreholes penetrating at least three km into the crystalline basement, where groundwater is hypothesized to be old and chemically reduced (i.e., isolated from the atmosphere). Permeability of the rock is hypothesized to decrease to a regional minimum at depth, and the salinity of the groundwater is hypothesized to increase with depth. The higher density of the deep fluid stabilizes it, relative to less saline meteoric water.

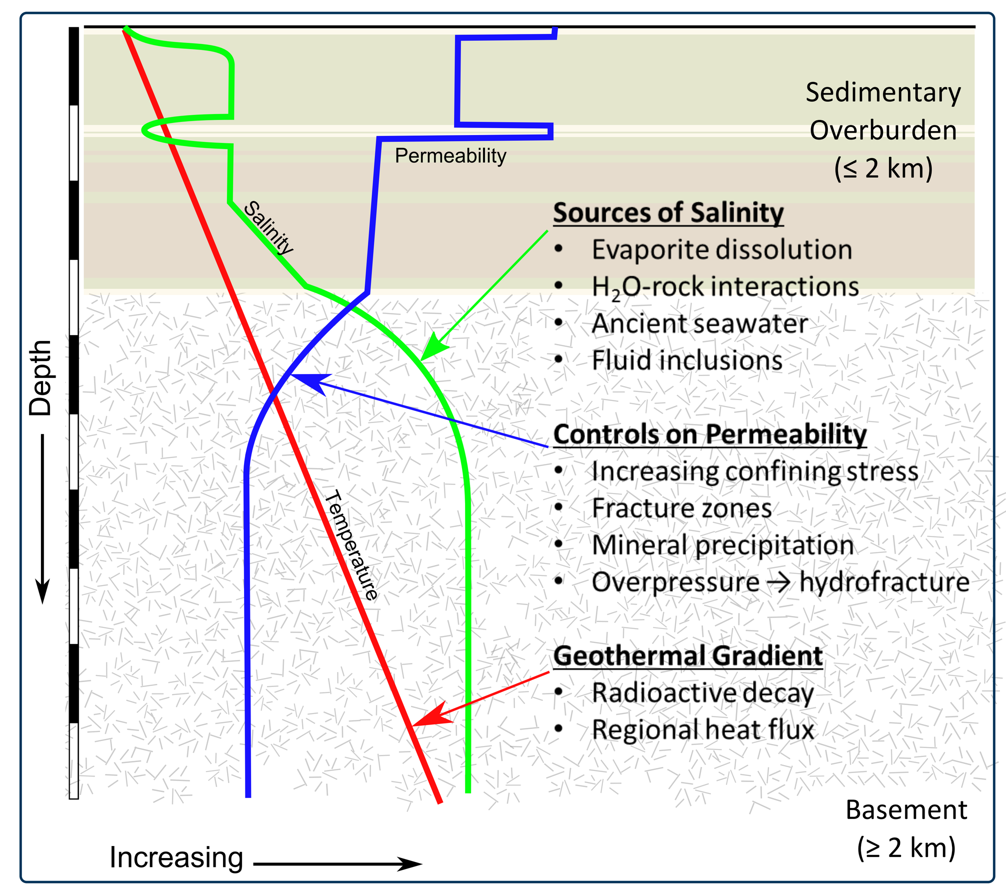

Figure 3: *Conceptual profiles of permeability, salinity and temperature*

One DBFT goal is to evaluate geochemical evidence to assess if the deep crystalline basement has been isolated for a long period, and therefore would be suitable to provide isolation of radioactive waste for a long period of time. Such evidence places a focus on mimimizing and quantifying contamination of fluid samples.

The primary pathway to the biosphere from depths of 3 to 5 km may be the DRZ surrounding the borehole. For future DBD sites, the borehole will be sealed with cement and bentonite.

Another DBFT goal is to evaluate current capability to perform in situ tests using generally off-the-shelf methods to constrain the profiles shown in Figure 3.

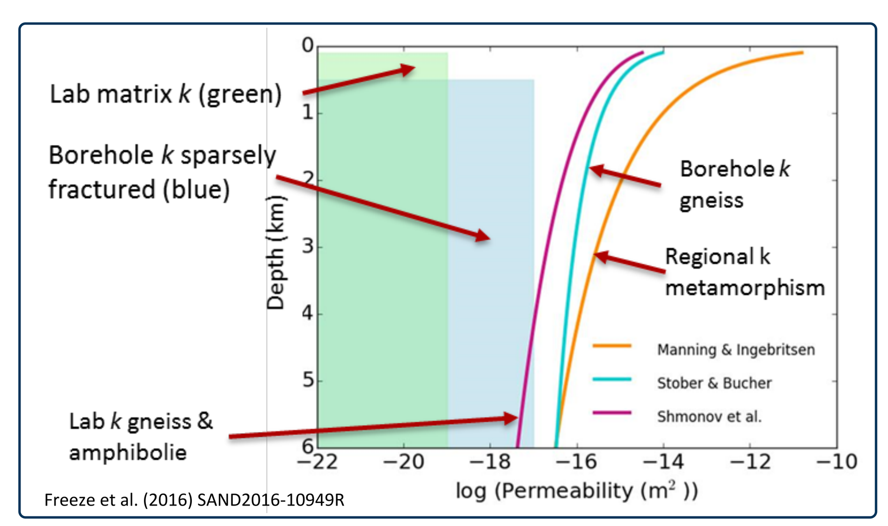

Figure 4a: *Generalized permeability trends with depth*

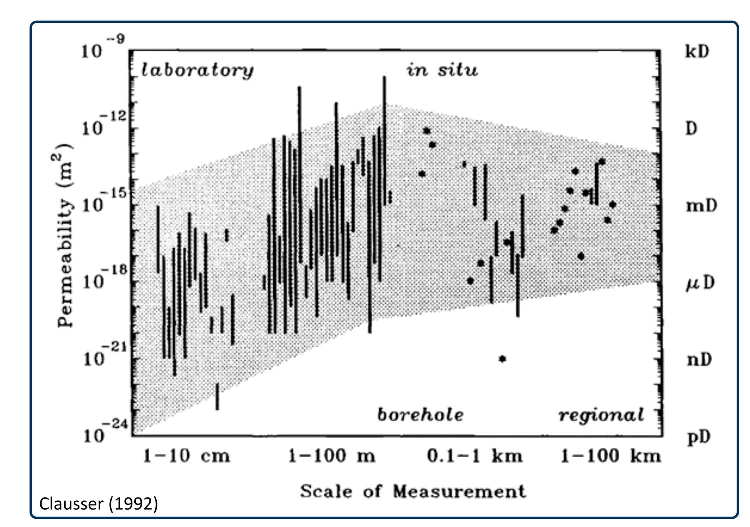

Figure 4b: *Permeability trends with scale*

Supporting Data

Hydraulic parameters estimated from cores tend to be associated with the lowest observed permeabilities ($<10^{-19}$ m^2). Fractures are the primary source of permeability in crystalline rocks and recovered cores will preferentially sample intact unfractured rock (Figures 4a & b). Observations also indicate permeability tends to increase as the observation scale increases, with the largest observations coming from interpretation of regional metamorphism, heat-flow, and dam impoundment phenomena (Manning & Ingebritsen 1999).

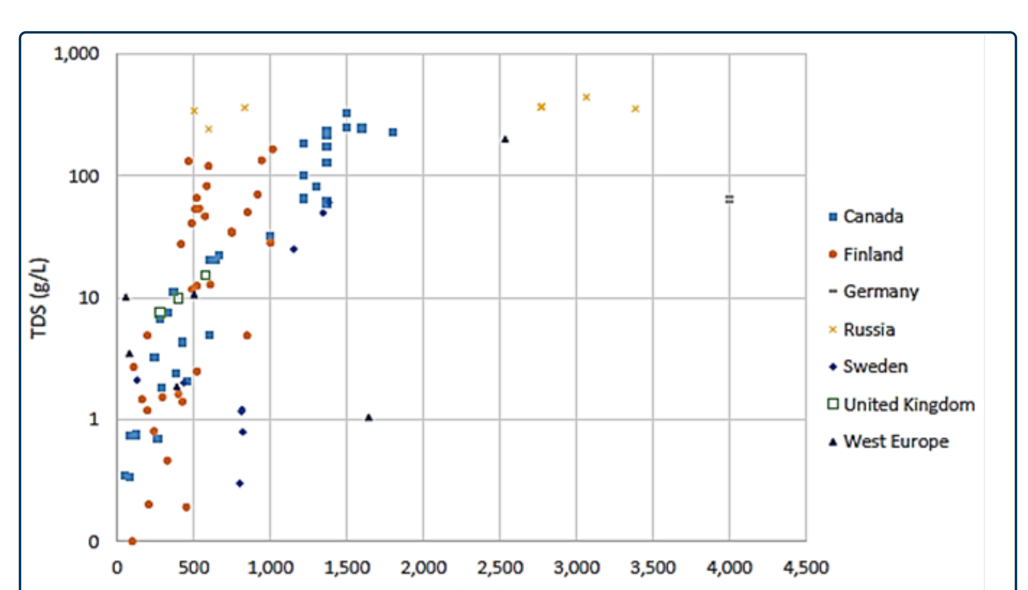

Figure 5: *Salinity trends with depth*

Geochemical data (Figure 5) show a general trend of increasing total dissoved solids (TDS) with depth. At depths below 1.5 km, most boreholes encounter water with a salinity greater than seawater (approximately 30 g/L).

Unless there are soluble evaporite deposits available nearby, high salinity is typically associated with water that has been in equilibrium with rocks for a long period of time. Increased liquid density with depth resists buoyancy, preventing deep saline water from mixing with overlying, dilute water.

What are We Testing in the Deep Borehole Field Test?

The goals of the Characterization Borehole (CB) are to:

1. Construct a straight 21.6 cm [8.5"] borehole to 5 km;
2. Perform in situ hydraulic and tracer testing via packers in the crystalline basement (3 to 5 km);
3. Collect natural tracer geochemical profiles (e.g., He, Ar);
4. Collect depth profiles of physical and geochemical properties of the solution (e.g., density, temperature), and major ions;
5. Characterize a site somewhat representative of the guidelines for a Deep Borehole Disposal Site.

Data collection in the CB is divided into several phases:

1. Sampling during drilling (cores, drilling fluid, exsolved gases, cuttings, and rock flour);
2. Testing during drilling (wireline packer fluid sampling and hydrofracture stress measurements);
3. Borehole geophysics (standard environmental and oilfield wireline logs, borehole imaging logs);
4. Flowing borehole log (estimate location and magnitude of flowing fractured zones);
5. Testing after drilling (workover-rig based packer testing: hydraulic, geochemical, and geomechanical);
6. Sampling after drilling (high-permeability zones will have formation fluids pumped to the surface).

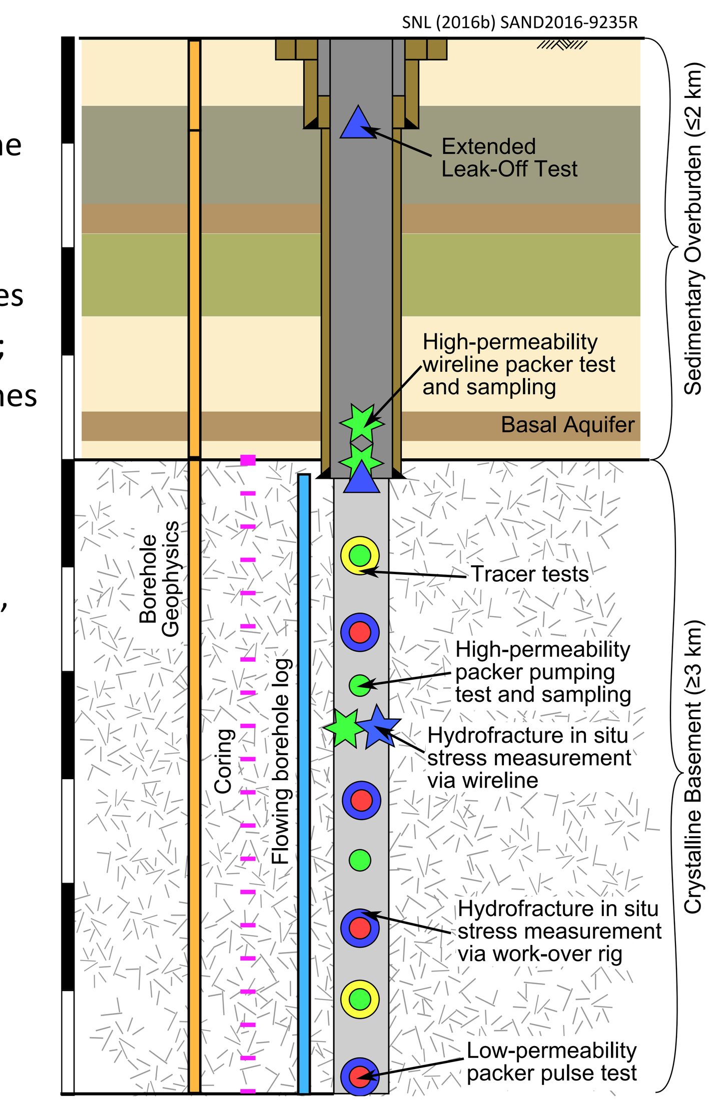

Figure 6: *DBFT Characterization Schematic*

Figure 6 illustrates nominal tests to be conducted during drilling (polygons) and after drilling (circles) of the Characterization Borehole (first borehole) in the DBFT. A second larger-diameter Field Test Borehole will include minimal testing, focusing instead on surface and downhole test package handling (SNL, 2016a).

If the basement is low-permeability, low-porosity crystalline rock, collecting uncontaminated samples will be challenging. Additional efforts focus on using tracers from small fluid samples extracted rom cores to make the case for long isolation. These analytes include:

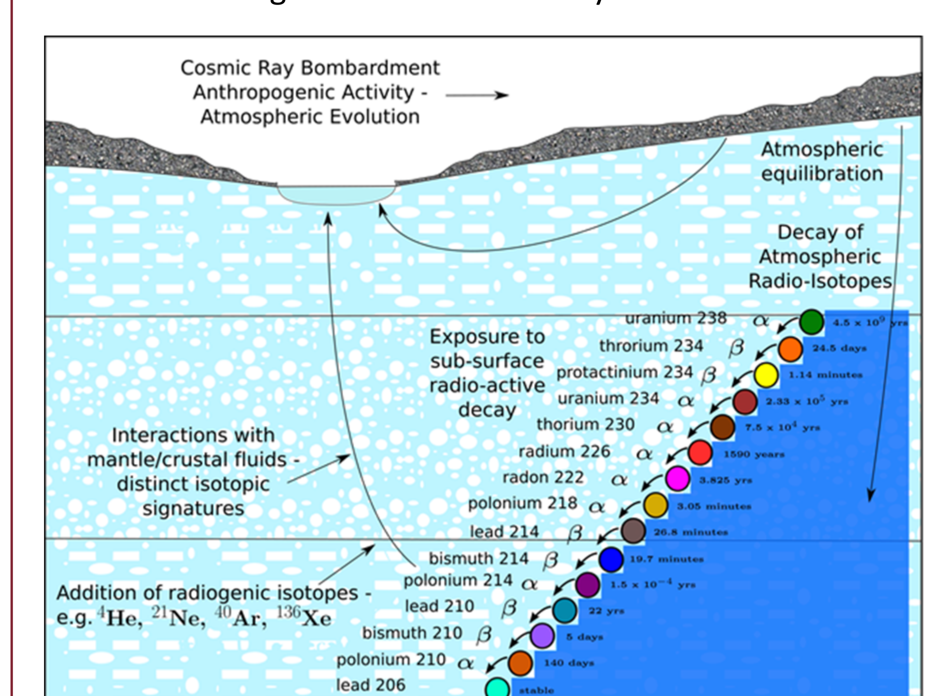

Figure 7: Noble Gas Natural Tracers of Interest in DBFT

1. Stable water isotopes
2. Helium (U and Th alpha decay - Figure 7)
3. Major anion/cation levels and ratios.

Helium-4 is generated in situ from decay of radioactive uranium and thorium. Helium is a small, inert molecule which is often used to detect leaks in gas plumbing systems.

Comparison of ^{4}He generation (estimated from spectral gamma logs) with 4He seen in preserved core samples will be used to estimate the balance of diffusive and advective transport of helium.

Deep Borehole Field Test (DBFT) in 2017

The US Department of Energy (DOE) Office of Nuclear Energy issued a Request for Proposals for teams and candidate sites to potentially implement the DBFT. In 2017 DOE will award up to five contracts to teams and their proposed sites to begin the DBFT project. The initial phase will focus on each team's public outreach and stakeholder involvement plans to build local and state acceptance of the project. This is followed by a phase for acquisition of all needed permits. Only after these phases, would the development of the detailed drilling and testing plans become the focus. The DBFT project will include drilling and completing two boreholes and is expected to take five years to complete (2017-2021).

DBFT References

(other references found in SNL DBFT reports)

Freeze G., E. Stein, L. Price, R. MacKinnon, J. Tillman, 2016. *Deep Borehole Disposal Safety Analysis.* SAND2016-10949R.

SNL, 2016a. *Deep Borehole Field Test Conceptual Design Report.* SAND2016-10246R.

SNL, 2016b. *Deep Borehole Field Test Laboratory and Borehole Testing Strategy*. SAND2016-9235R.

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