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Used Fuel Disposition Campaign

Deep Borehole Field Test Site Evaluation

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Presentation Overview

- Deep Borehole Field Test (DBFT) Background
- Desirable Site Characteristics Feasibility
- Status of DBFT Site Selection and Evaluation
- Characteristics of Sites Considered

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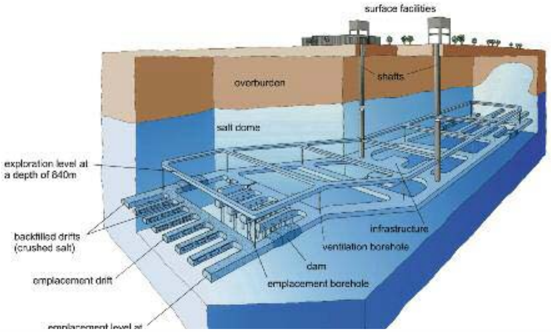
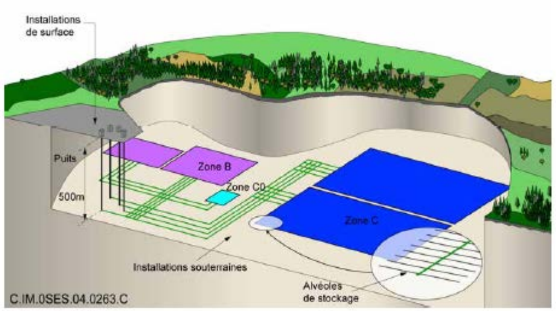
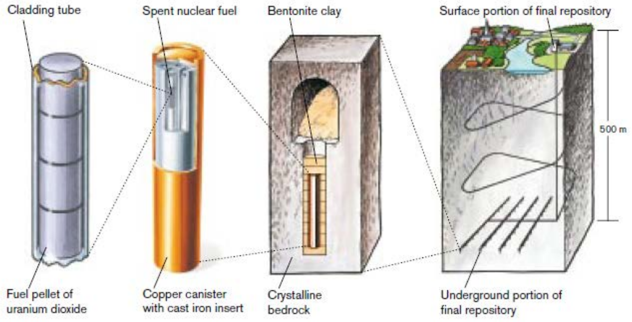
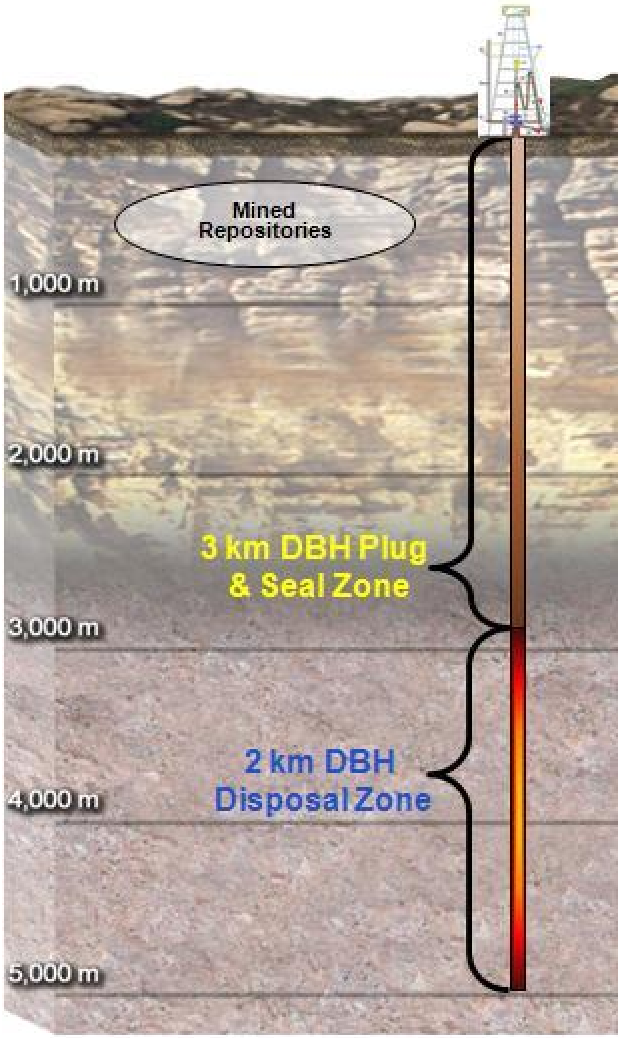
Deep Borehole Disposal Concept

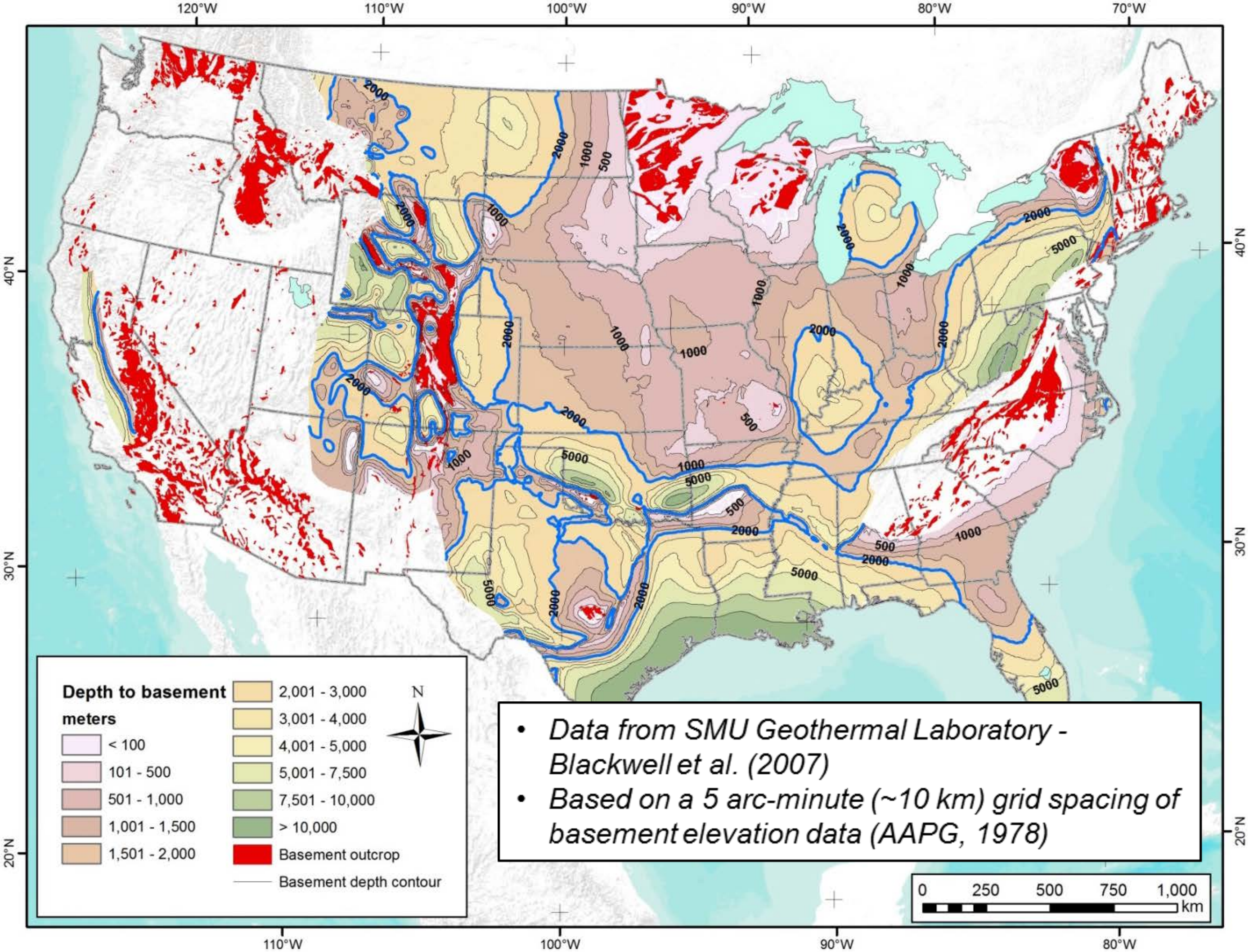








Depth to Basement – National Scale



- *Data from SMU Geothermal Laboratory - Blackwell et al. (2007)*
- *Based on a 5 arc-minute (~10 km) grid spacing of basement elevation data (AAPG, 1978)*

Preferred Site Geologic Conditions

- **Geohydrological Considerations**
  - No large-scale connected pathways from depth to aquifer systems
    - *No through going fracture/fault/shear zones that provide fast paths*
    - *No structural features that provide potential connective pathways*
  - Low permeability of crystalline basement at depth
    - Urach 3: (Stober and Bucher, 2000; 2004)
      - *~10-19 m^2 (intact rock); ~10-14 to 10-17 m^2 (bulk: parallel to or across shears)*
      - *Decreasing with Depth*
  - Evidence of ancient, isolated nature of groundwater
    - *Salinity gradient increasing downward to brine at depth (Parks et al., 2009)*
      - Limited recharge/connectivity with surface waters/aquifers
      - Provides density resistance to upward flow
    - *Major element and isotopic indication of compositional equilibration with rock*
      - Crystalline basement reacting with water (Stober and Bucher, 2004)
      - Ancient/isolated groundwater
        - *Ages – isotopes, paleoseawater (Stober and Bucher, 2000)*
        - *Radiogenic isotopes from atmosphere lacking: ^{81}Kr, ^{129}I, ^{36}Cl*
        - *Radiogenic isotopes/ratios from rock: ^{81}Kr, $^{87}Sr/^{86}Sr$; $^{238}U/^{234}U$*
        - *Noble gases (^{4}He, Ne) & stable isotopes (^{2}H, ^{18}O) compositions from deep water: (e.g., Gascoyne and Kamineni, 1993)*

Preferred Site Geologic Conditions (Continued)

- **Geochemical Considerations**
  - Reduced, or reducing, conditions in the geosphere (rock and water system)
    - *Crystalline basement mineralogical (and material) controls*
      - Magnetite-hematite buffer low oxygen potential
        - *Oxides equilibria => T-low ƒO2 paths (e.g., Sassani and Pasteris, 1988; Sassani, 1992)*
      - Biotite common Fe+2 phase (Bucher and Stober, 2000)
      - Lacking reductants, deep groundwater can be reduced if isolated
        - *Rock-reacted fluid compositions – water sink (Stober and Bucher, 2004)*
        - *More rock dominated at depth (Gascoyne and Kamineni, 1993)*
      - Steels in borehole will provide reducing capacity (H2 source)
  - Stratification of salinity – increasing to brine deep in crystalline basement
    - *Canadian Shield salinity increases with depth to ~350 g/L TDS; (Gascoyne and Kamineni, 1993; Parks et al., 2009)*
      - More Ca-rich brines with further reaction with deeper rock
    - *Urach 3, Germany, ~70- g/L TDS NaCl brine (Stober and Bucher, 1999; 2004)*
  - Subset of waste forms and radionuclides are redox sensitive
    - *Lower degradation rates*
    - *Lower solubility-limited concentrations*
    - *Increased sorption coefficients*
  - Higher salinity
    - *Density gradient opposes upward flow*
    - *Reduces/eliminates colloidal transport*

Deep Borehole Field Test Status
Acquisition of Site and Services

- **Request for Information Solicited Input and Interest**
  - from States, local communities, individuals, private groups, academia, or any other stakeholders who were willing to host a DBH Field Test
  - Posted via Federal Business Opportunities (FedBizOps, www.fbo.gov) on ***October 24, 2014***
  - Responses of interest received on December 8, 2014 (45 days)
- **Sources Sought and Draft Request For Proposal (RFP)**
  - Posted on FedBizOps on April 7, 2015
  - Public Feedback received on May 5, 2015
- **Final RFP (Solicitation Number DE-SOL-0008071)**
  - Pre-solicitation notice posted on June 22, 2015
  - Final RFP posted on FedBizOps on July 9, 2015
  - Proposals received September 23, 2015
- **The DOE Awarded Contract to the Team Led by Battelle Memorial Institute**
  - Early ***January 2016*** Award
    - *Schlumberger, Solexperts, others*
    - *Pierce County North Dakota Site*
      - Local community opposed the DBFT being sited there
  - DOE and Battelle team are in process of finding a new site
    - *Public meetings have been held in Spink County, South Dakota*

North Dakota Pierce County Site Geologic Characteristics – No Longer a Candidate for DBFT

- **Overburden is the Eastern Limb of Williston Basin Sedimentary Sequence**
  - Fluids are fairly concentrated brines in lower aquifers (>100,000 mg/L salinity)
    - *Higher Br/Cl; lower Na/Cl; stable isotopes suggest older seawater, higher rock-water interactions (Grasby and Chen, 2005)*
  - Aquitards included in the deeper portion of the sequence
  - Depth to Basement ~1740 m
- **Crystalline Basement is ~2,700 ma Superior Craton Rocks**
  - Gneissic (metamorphic granitic rocks) to granite tonalite
  - Analogous Canadian Shield rocks exposed in Manitoba/Ontario
- **Stable and Ancient**
- **Few Large Scale Structures**
  - Near boundary of gneissic-granite terrains in Superior Craton
- **Resource Potential >100 km West (Bakken Fmn: Oil)**
- **Boundary Conditions Suggest Ancient Brines at Depth Likely in Crystalline Basement**
- **Canadian Studies Viewed Corresponding Geology Favorable**
  - Superior Craton below Williston Basin sediments (Brunskill, 2006; Brunskill and Wilson, 2011)

South Dakota Spink County Site Geologic Characteristics – Current Candidate for DBFT

- **Overburden is a Shallow Arch Sedimentary Sequence**
  - Glacial sediments in upper 100's feet; Mesozoic sedimentary sequence below
  - Dakota formation (an aquifer of mostly sandstone with some shale stringers) water is somewhat brackish (~2000 mg/L TDS) or fresher
    - *To west, lower formations pinch out and have flow up into Dakota*
    - *Lies on top of crystalline basement rocks*
  - Depth to crystalline basement ~350 m (Tomhave, 1997)
    - *Large thickness of crystalline basement above 2 km cutoff*
- **Crystalline Basement is Superior Craton Rocks**
  - Benson block of the Mississippi Valley River Subprovince
  - Gneissic terrain with granites
  - Most contacts in BH are granite (McCormick, 2010)
    - *~2,600 Ma plutons, (Schmitz et al., 2006)*
  - Analogous rocks near surface/exposed in east and MN
  - Stable and Ancient
- **Few Large Scale Structures ~ 20 km Away (Dips ~30° N-NW)**
  - Great Lakes Tectonic Zone to North (Wawa Subprovince)
  - Suture zones to South (Montevideo Block)
  - Mafic dikes in MN (~2070 Ma; Chandler et al., 2007)
- **No Local Resource Potential**
- **Boundary Conditions Suggest Ancient Brines at Depth are Possible**

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References

1. AAPG, 1978, Basement map of North America: Am. Assoc. Petroleum Geologists, scale: 1:5,000,000.
2. Blackwell, D.D., P. Negraru, and M. Richards, 2007. Assessment of the enhanced geothermal system resource base of the United States, Natural Resources Research, DOI 10:1007/s11053-007-9028-7.
3. Brunskill, B. (2006): Discussion of an option for geological storage of used nuclear fuel beneath the Williston Basin of southern Saskatchewan; in Summary of Investigations 2006, Volume 1, Saskatchewan Geological Survey, Sask. Industry Resources, Misc. Rep. 2006-4.1, CD-ROM, Paper A-4, 8p.
4. Brunskill, B. and Wilson, M., 2011, The Geological Disposal of Spent Nuclear Fuel Beneath Sedimentary Basins, Waste Management, Decommissioning and Environmental Restoration for Canada's Nuclear Activities, September 11-14, 2011.
5. Bucher K, Stober I (2000) Hydrochemistry of water inthe crystalline basement. In: Hydrogeology of Crystalline Rocks (eds Stober I, Bucher K), pp. 141-75. Kluwer Academic Publishers, Dordrecht.
6. Chandler et al., 2007, Penokean tectonics along a promontory-embayment margin in east-central Minnesota, Precambrian Research 157 (2007) 26–49.
7. DOE (US Department of Energy), 2014. Request for Information (RFI) – Deep Borehole Field Test. Solicitation Number DE-SOL-0007705, US Department of Energy Idaho Operations Office: Idaho Falls, ID.
8. DOE (US Department of Energy), 2015. Request for Proposals (RFP) – Deep Borehole Field Test. Solicitation Number DE-SOL-0008071, US Department of Energy Idaho Operations Office: Idaho Falls, ID.
9. Gascoyne, M. and Kamineni, D. C. (1993) The hydrogeochemistry of fractured plutonic rocks in the canadian shield. In: Hydrogeology of Hard Rocks, 440- 449. Banks, S. B. and Banks, D. (editors) Geol. Survey of Norway: Trondheim.
10. Grasby and Chen, 2005, Subglacial recharge into the Western Canada Sedimentary Basin—Impact of Pleistocene glaciation on basin hydrodynamics, Geological Society of America Bulletin 117.3-4: 500-514, 2005.
16. McCormick, 2010, Precambrian Basement Terrane of South Dakota, Bulletin 41, Geological Survey Program, University of South Dakota, Vermillion, SD, 37 pp.
17. Park, Y.-J., E.A. Sudicky, and J.F. Sykes (2009), Effects of shield brine on the safe disposal of waste in deep geologic environments, Advances in Water Resources 32: 1352-1358.
18. Sassani, D.C., 1992. Petrologic and Thermodynamic Investigation of the Aqueous Transport of Platinum-Group Elements During Alteration of Mafic Intrusive Rocks, Ph.D. Dissertation, Washington University, St. Louis, University Microfilms.
19. Sassani, D.C., and Pasteris, J.D., 1988. Preliminary investigation of alteration in a basal section of the southern Duluth Complex, Minnesota, and the effects on the sulfide and oxide mineralization, in G. Kisvarzanyi and S.K. Grant, eds., North American Conference on Tectonic Control of Ore Deposits and the Vertical and Horizontal Extent of Ore Systems, Proceedings Volume, University of Missouri-Rolla, 280-291.
20. Schmitz et al., 2006, High-precision U-Pb geochronology in the Minnesota River Valley subprovince and its bearing on the Neoarchean to Paleoproterozoic evolution of the southern Superior Province, Geological Society of America Bulletin, v. 118 no. 1-2 p. 82-93.
21. Stober I, and Bucher K (1999) Origin of salinity of deep groundwater in crystalline rocks, Terra Nova, 11, 181-185.
22. Stober I, and Bucher K (2000) Hydraulic Properties of the upper Continental Crust: data from the Urach 3 geothermal well. In: Hydrogeology of Crystalline Rocks (eds Stober I, Bucher K), pp. 53-78. Kluwer Academic Publishers, Dordrecht.
23. Stober I and Bucher K (2004) Fluid sinks within the earth's crust. Geofluids 4(2): 143–151.
24. Tomhave, 1997, Geology of Spink County, South Dakota, Bulletin 38, Geological Survey Program, University of South Dakota, Vermillion, SD, 37 pp
25. Vaughn, P. B.W. Arnold, S.J. Altman, P.V. Brady & W. Gardner, 2012. Site Characterization Methodology for Deep Borehole Disposal. SAND2012−7981. Albuquerque, NM: Sandia National Laboratories.

References (Continued)

Backup Slides

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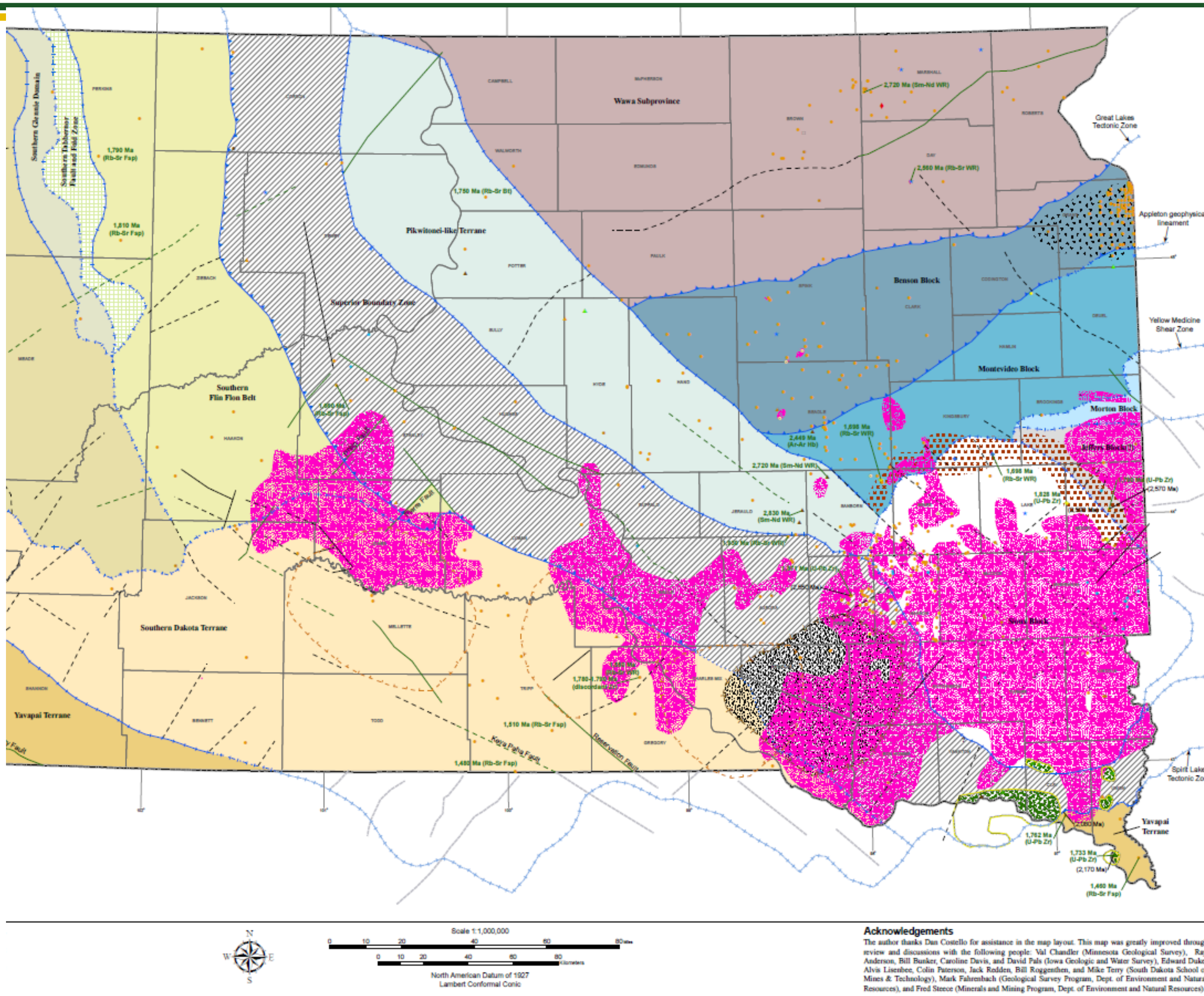
Terrane Map of the Precambrian Basement of South Dakota (Plate 1 – McCormick, 2010)



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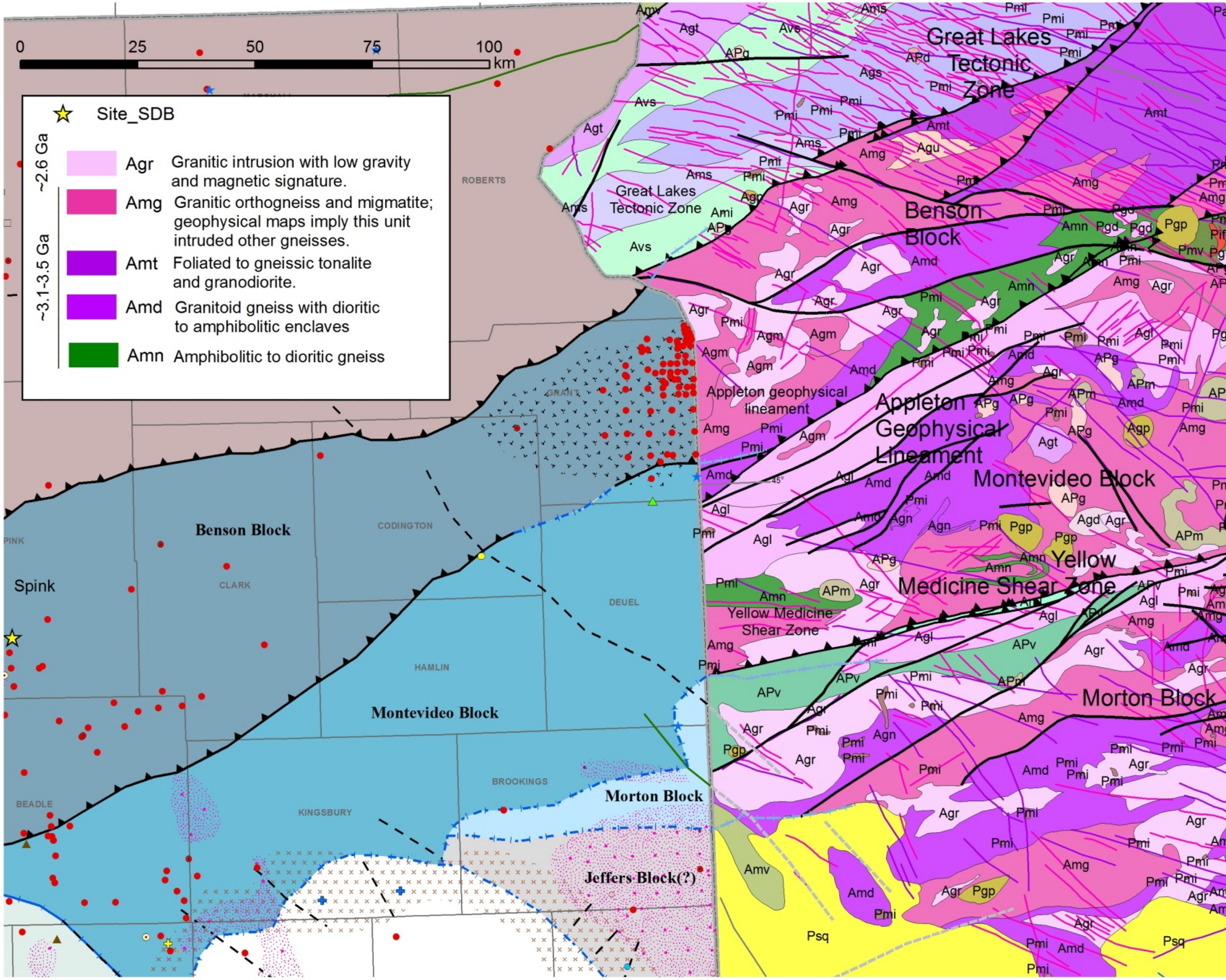
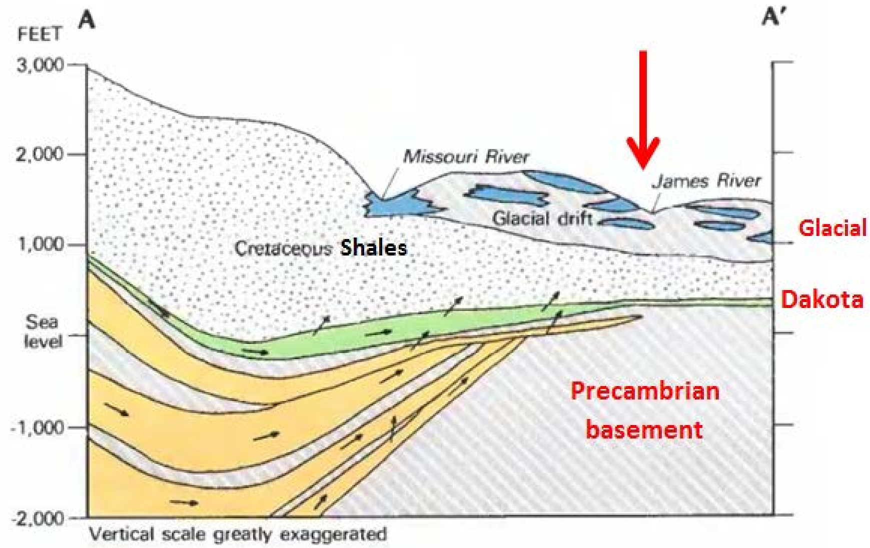
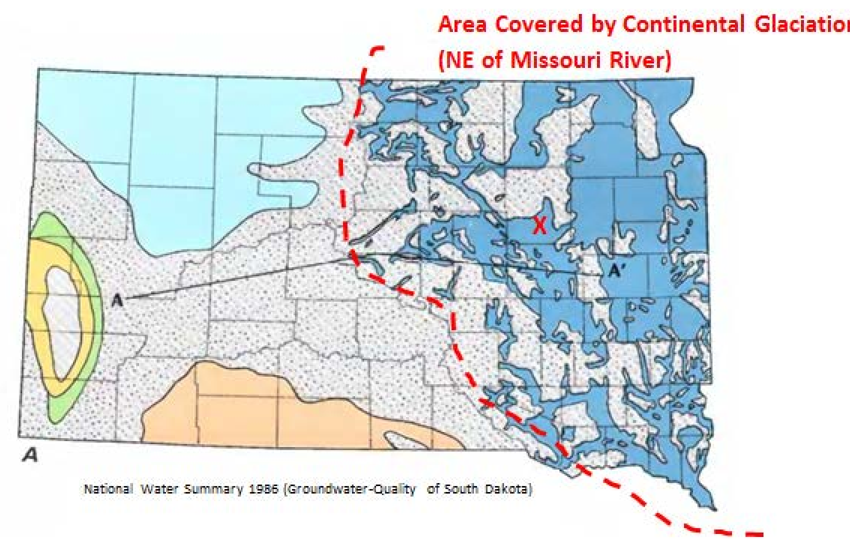


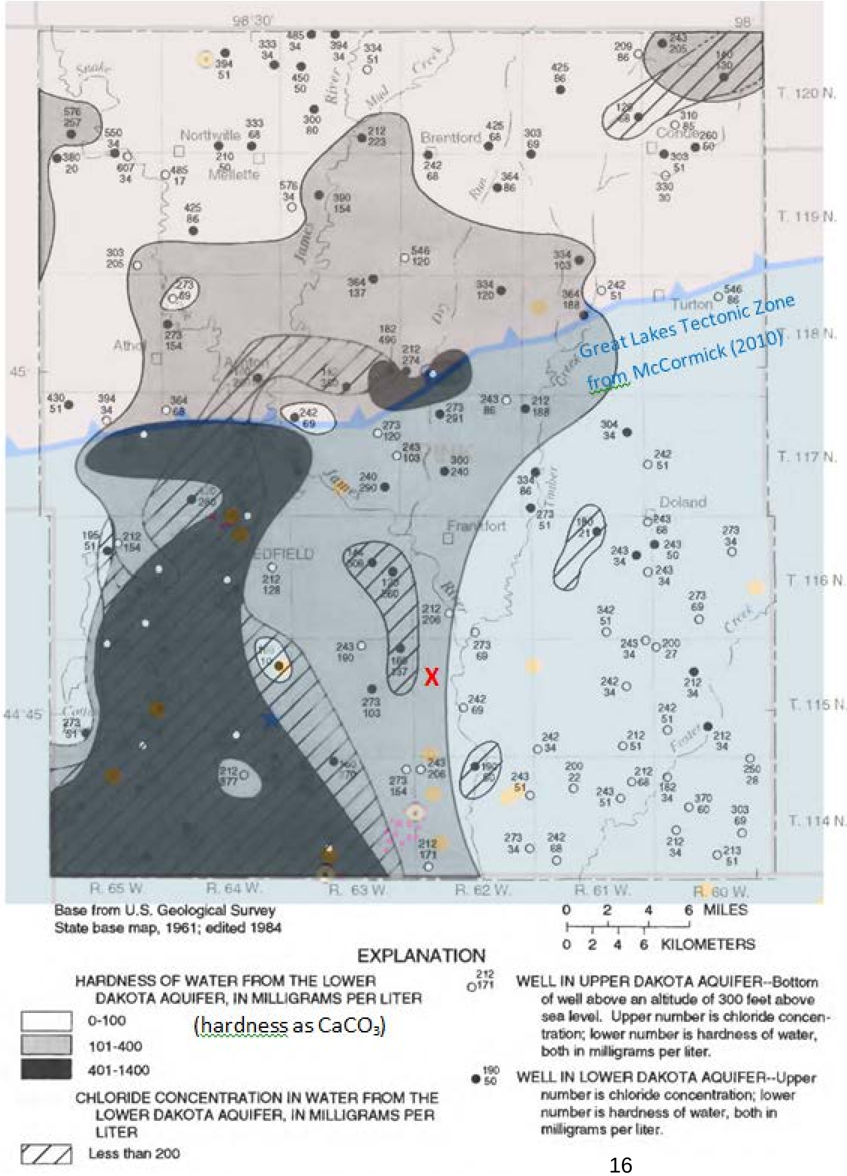
South Dakota Site Geology

- **Generalized hydrologic cross-section across SD (arrow indicates ~Spink County site)**
- **Plan view of aquifers in SD (X indicating ~Spink County site).**
- **Dakota (Newcastle in western SD) formation is lowermost aquifer at site (thin green unit in cross-section).**
  - Lower formations (yellow in cross section) pinch out just west of site. Where lower formations pinch out between Dakota Fm. and Precambrian basement, flow is up from lower units into Dakota Fm.
- **Most other Cretaceous units above the Dakota are shales (with minor limestone) and are typically considered impermeable (stippled area in map and cross section).**





Aquifer Salinity



Water Resources of Spink County South Dakota (USGS WRIR 96-4056), 1996
with overlay of basement terrane from McCormick (SDGS Bulletin 41), 2010