Hydrologic Science and Homestake: Research Possibilities

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Two example fundamental focus areas

(to be added to a long list of possibilities):

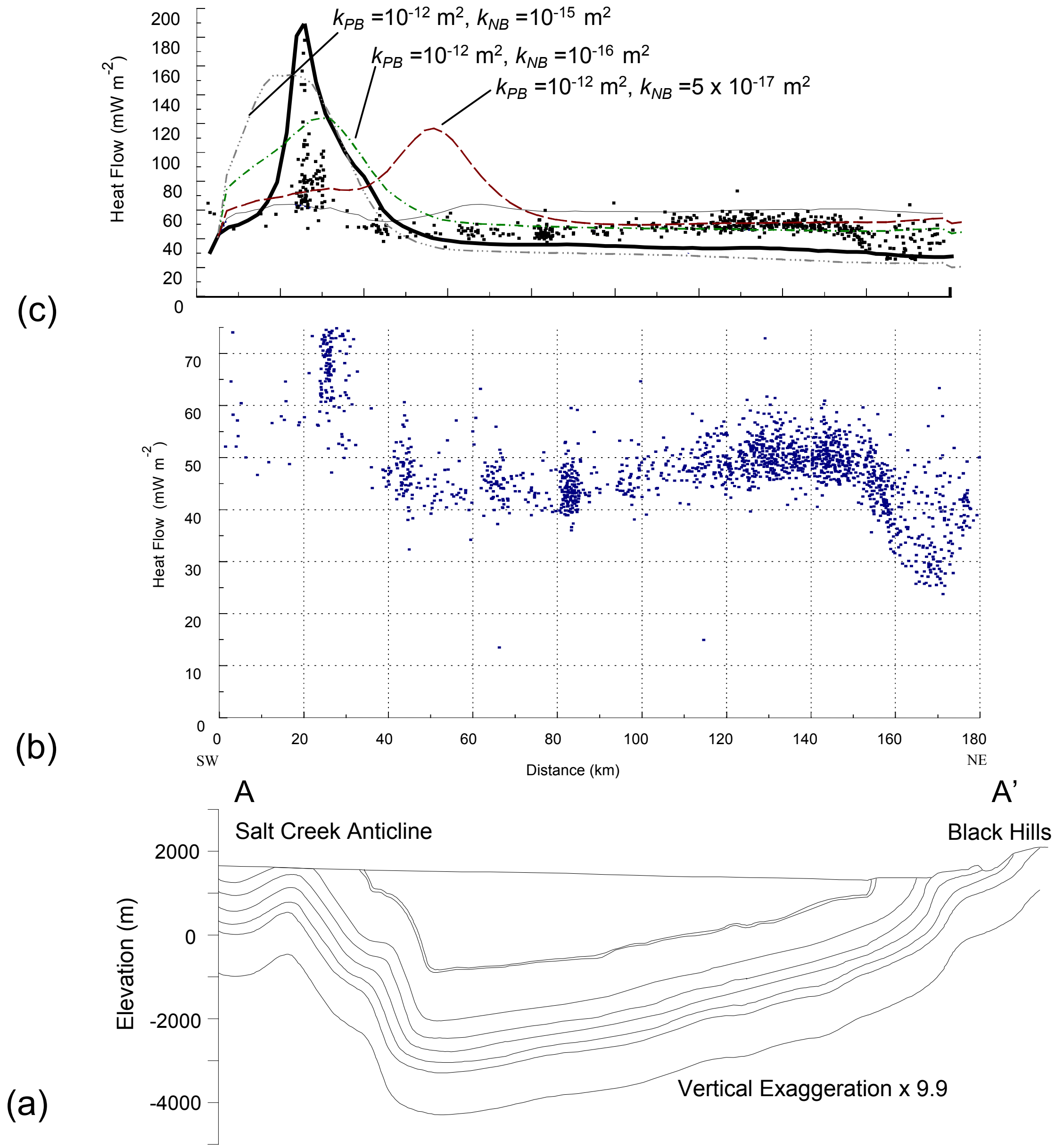
1) permeability and scales-of-evaluation

2) spatial and temporal variation of recharge and its interaction with subsurface groundwater flow

1. PERMEABILITY: SCALE-OF-EVALUATION

Permeability of crustal rocks may have different values depending on the scale at which it is evaluated. General quantitative or semi-quantitative relationships between permeability and scale do not exist.

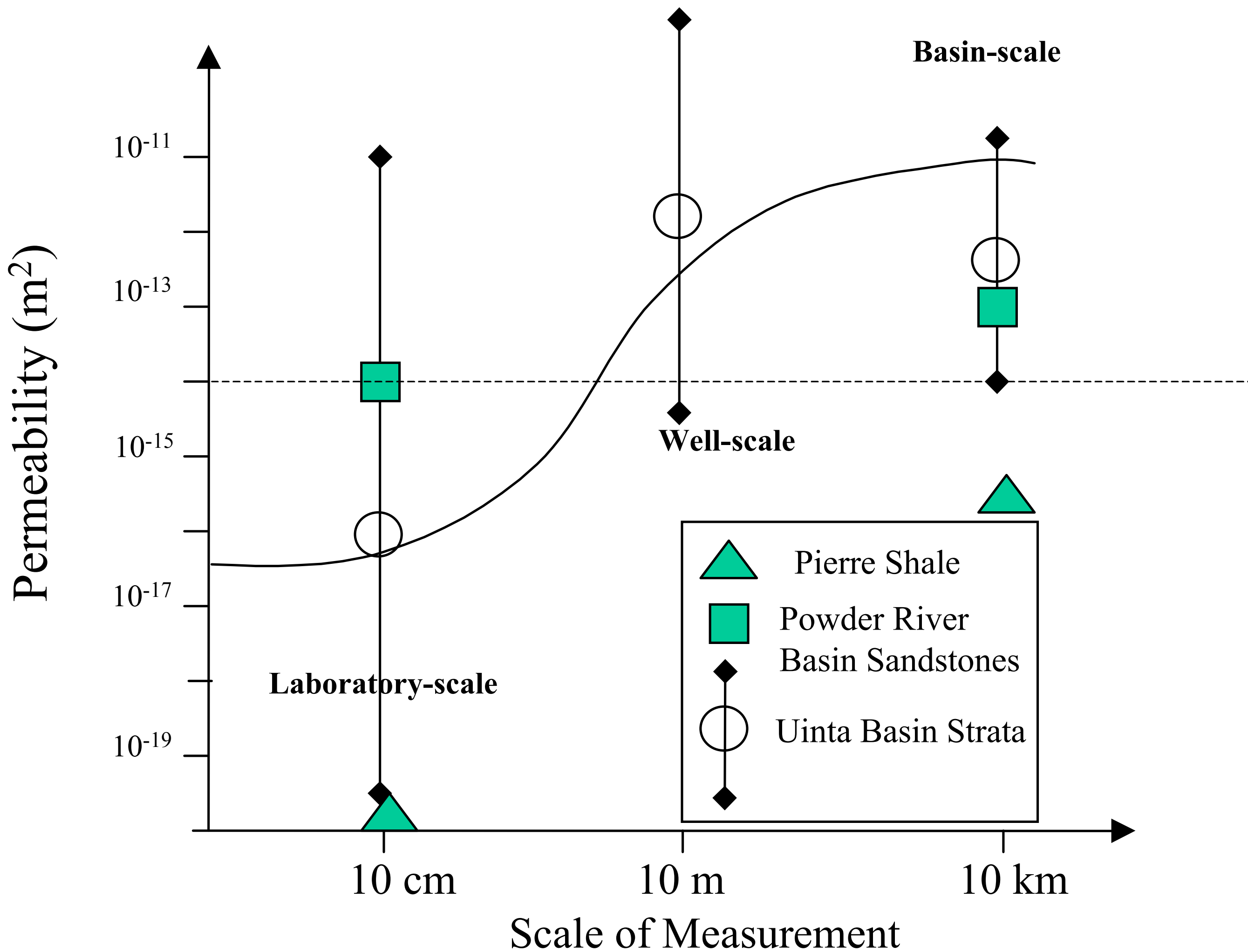
Regional-Scale Permeability of Powder River Basin, Including the Western Black Hills Area



Modeled Heat Flow

Observed Heat Flow

From McPherson et al., 2001



Effect of scale on permeability of rocks in 3 different sedimentary basins in the United States, including the Uinta Basin of Utah (Willett and Chapman, 1987), the Powder River Basin, Wyoming, and the Pierre shale in South Dakota (Bredehoeft et al, 1983; Nuezil, 1994). Dashed line at 10^{-14} m^2 indicates average crustal permeability inferred by Brace (1980). Error bars are associated with Uinta Basin rocks only.

•**Permeability** has already been evaluated for specific scales and parts of this typical intracontinental flow system, including both basins adjacent to the Black Hills. These permeability data are sparse in number and density, and limited to the basin- and lab-scales.

•Homestake provides the opportunity for acquiring a dense network of measurements, at all possible scales. More importantly, it provides the opportunity for making these measurements at depth and in situ.

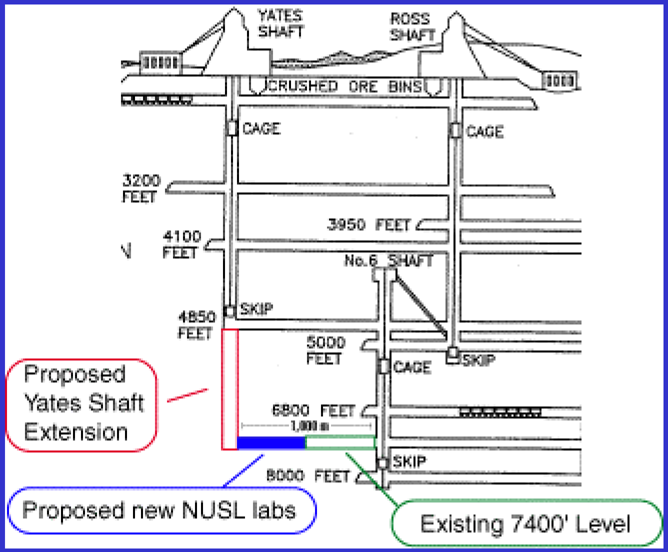
•Thousands of core-scale measurements may be accomplished using mini-permeameters, such as approaches taken by Tidwell and Wilson (1999a, 1999b).

•Incrementally larger-scale measurements could be undertaken stepwise by designing and completing conventional flow and/or tracer tests between different parts of the mine, including between shafts, and including pump tests induced in surface wells and monitored within different parts of the mine at depth.

•Similar studies regarding scaling effects on **hydraulic diffusivity and storage** could be designed and undertaken.

2. Relationship of Groundwater Flow to the Spatial and Temporal Variation of Recharge

•Evaluating recharge at the surface is straightforward through direct measurements.



•However, evaluating and characterizing hydrologic communication between subsurface groundwater and surface recharge is extremely difficult.

•For example, at the surface, many factors effect the spatial distribution of recharge, as well as the ratio of recharge to surface runoff, including:

- -surface elevation
- -surface geology (rock/soil types, local terrain variability, local and regional structural geology)
- -vegetation
- -climate

All of these aspects may be measured directly.

•Once water enters the subsurface, however, its fate is only generally understood, and can be tracked only by indirect methods and point measurements in wells.

•What is needed is a fundamental characterization of the relationship between subsurface groundwater flow and surface recharge.

Specifically, we need to identify and characterize:

(1) how subsurface groundwater flow responds to recharge,

(2) which factors most influence that response, and

(3) which subsurface factors influence the ratio of recharge to runoff.

Design of possible research studies include four fundamental components:

(1) *Detailed 3-dimensional geological characterization*

Characterization of all strata that the mine penetrates, from the surface to maximum depth and lateral extent (see schematic above), including assessment of relative rock properties such as lithology, facies or depositional environment description, porosity, permeability, thermal properties, etc. Relevant rock properties for other scientific studies, e.g., mechanical and elastic rock properties for fracture or deformation studies, could also be made in tandem with the hydrogeologic characterization.

(2) *Continuous measurements of relevant processes*

Instrumentation could be installed in all parts of the mine, especially the portions that are adjacent to maximum depth extent and lateral extents of the mine. Most important aspects include fluid flow/moisture content measurements, temperature measurements, and chemical evolution, including isotopic aspects. Detailed precipitation, runoff, recharge and climate information must be measured continuously at the surface.

(3) *Comparison or tracking of correlation between subsurface conditions and surface conditions*

Continuous histories of surface through subsurface data will be recorded. Conceptual models will be developed based on correlations between conditions at the surface responses in the subsurface. Linking of specific recharge areas to different portions or flowpaths may be possible using isotopes or other tracers, given the great lateral extent of the mine. Tracking of recharge:runoff ratios as a function of seasonal climatic variation, and climatic variation over the longer term, will be sought. Anthropogenic changes to the geological/hydrological regime, including the presence of the mine and its effect on the regional hydrologic regime, must be accounted for in these analyses. Additionally, factors and possible changes to the geological environment associated with other scientific studies, including physics and geological research, must also be tracked and evaluated for possible hydrologic effects. At this time, the mine is in place, including necessary infrastructure for access to all parts of the mine. Maintaining this full access after the mine ceases ore-mining operations is critical for the studies proposed inasmuch as maximum spatial coverage is necessary.

(4) *Modeling Studies*

Conceptual models of recharge and subsurface flow response will be developed, based on observations of data and their evolution over the long term. Hypotheses will be developed and tested using new experiments and data in addition to detailed mathematical models of the hydrogeologic evolution. For example, numerical models of fully coupled fluid and heat flow will be appropriate. Additional models including chemical and mechanical processes may also be applicable.

Other Hydrogeologic Issues

1) Hydrothermal System Characterization - Homestake as well as the general case
2) Controls on ore deposition -- Homestake as well as the general case
3) Fractures and fluid pressures
4) Fracture propensity: fracture propensity vs. stress-state and changes to stress-state incurred by mine perturbation
5) Fracture flow: detailed mapping of fractures and their effects on the local flow field may be measured, perhaps providing an opportunity to characterize effective conductivity changes at different scales
6) Seismology and hydraulic properties: Can seismic activity and fluid pressures be correlated?
7) Reactive transport - with the detailed geology and hydrothermal chemistry of the mine detailed by Homestake Mining Corporation: are predictive models of fluid flow and reactive transport consistent with observed conditions?
8) Geologic CO_2 Sequestration

Facilitating Hydrologic Science Research at Homestake: Should We Try to Implement Homestake as a CUAHSI "Long Term Hydrologic Observatory"?

•CUAHSI is the "Consortium of Universities for the Advancement of Hydrologic Science," sponsored by the NSF with funding in place (award was made during the past 3 months).

•CUAHSI is still forming, with 20-30 universities on board so far, in addition to representatives from the DOE and USGS.

•One component of the CUAHSI program of infrastructure is a network of Long-Term Hydrologic Observatories (LTHO).

Purpose of the LTHOs

•"What should a network of LTHOs accomplish? It should provide a set of venues at which scientists, either individually or in teams, can come to perform experiments that add to the understanding of hydrologic processes that are pertinent in the solution of significant problems that are being or will be faced by humankind of this and the next few generations."

•"Each LTHO should be a geographic entity in which basic background data are routinely collected and readily made available so that the scientific community can understand the workings of the hydrologic and related components of the entity to the extent that experiments can be conceived, designed, and executed in an efficient and effective manner."