Geological Background Pertinent to LR 254 & LR 147

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Opening Remarks

1. **I offer my sincere thanks to the Legislature, Nebraskans in general, and staff of Conservation and Survey Division.**
2. **It is laudable that citizens and elected officials are concerned about Nebraska's natural environment and natural resources.**
3. **In our representative democracy, citizens have rights to voice concerns and to formulate opinions.**
4. **I am a geologist. My job is only to provide facts about the local and regional geologic setting.**

Introductory Terminology

- aquifer: permeable body of Earth material that transmits (economic) quantities of (useable) water
- aquitard: comparatively lower-permeability body of Earth material that does not transmit useful quantities of water; the term confining layer is partially synonymous
- basement: old (Precambrian), deep, mostly crystalline rocks underlying the succession of sedimentary rocks in the interior of a continent
- hydraulic conductivity: rate of transmission of fluids through an Earth material (accounts for hydraulic gradient)
- microearthquake: earthquake with magnitude < 2
- subnormal pressure: pressure in a subsurface geologic layer is less than hydrostatic pressure of a column of water extending to the same depth

Induced seismicity

- earthquakes, typically very weak, related to human activity (deep wastewater injection, geothermal energy, large surface reservoirs, nuclear tests, mining, and even groundwater removal)
- can be an outcome of petroleum production, fluid disposal, and, much more rarely, hydraulic fracturing
- seismicity in injection-well settings is induced through: (a) introduction of mass, and (b) elevation of pore pressures
- only rarely can specific, single disposal wells be identified triggers for induced seismicity
- earthquake hazard associated with injection wells depends overall on volume of fluid injected over time (decades), proximity to faults, rates of occurrence and magnitude of historical earthquakes
- induced seismicity in cases of injection wells depends on a special set of circumstances: sites disposing into porous strata atop basement rocks with structures and/or critically stressed faults appear to be most problematic

sources: Rex Buchanan, Director, Kansas Geological Survey (personal communication), Ellsworth (2013, *Science* 341); Keranen et al. (2013, Geology 41: 699-702)

Stratigraphy in Laucomer #13-1 Well

base diagram: NOGCC

Hole Diameters (in.)
13.5
8.75
6.125

0

603

High Plains aquifer (0-208 ft)

aquifer confined below by strata of White River Group

Nebr. State Capitol

4 concentric layers of steel and concrete; surface casing set at 603 ft

5845 ft

Pierre Shale (1050-4432 ft; 3382 ft thick)

- ✓ fully 3382 ft in thickness
- ✓ studies indicate very low hydraulic conductivity of ~10^{-14} to 10^{-9} m/s* (e.g., Neuzil, 1993, *Water Res. Research* 29: 2007-2020)
- ✓ recognized by USGS as a regional *confining unit*, (part of their "Great Plains confining system") and definitely not an aquifer

Lower- to mid-Cretaceous strata (5260-5785 ft)

- ✓ 525 ft in thickness
- ✓ petroleum target in D-J Basin
- ✓ recognized by USGS as already containing saline water and brine across the entire region

perforations

6299
6300
6302

bridge plug and cement

injection zone in Spearfish Formation

- ✓ lies well more than 1600 ft above basement
- ✓ already contains saline waters (TDS >20,000 mg/l*)
- ✓ high porosity
- ✓ subnormally pressured

Upper Pennsylvanian-Lower Permian strata

- ✓ recognized by USGS as a regional *confining unit*

7265

7667

7904

9153
9155

7696

*aquifer materials might range 10^{-7} to 10^{-2} m/s in hydraulic conductivity

*TDS of seawater: ~30,000-40,000 mg/l; EPS advice on drinking water is <500 mg/l

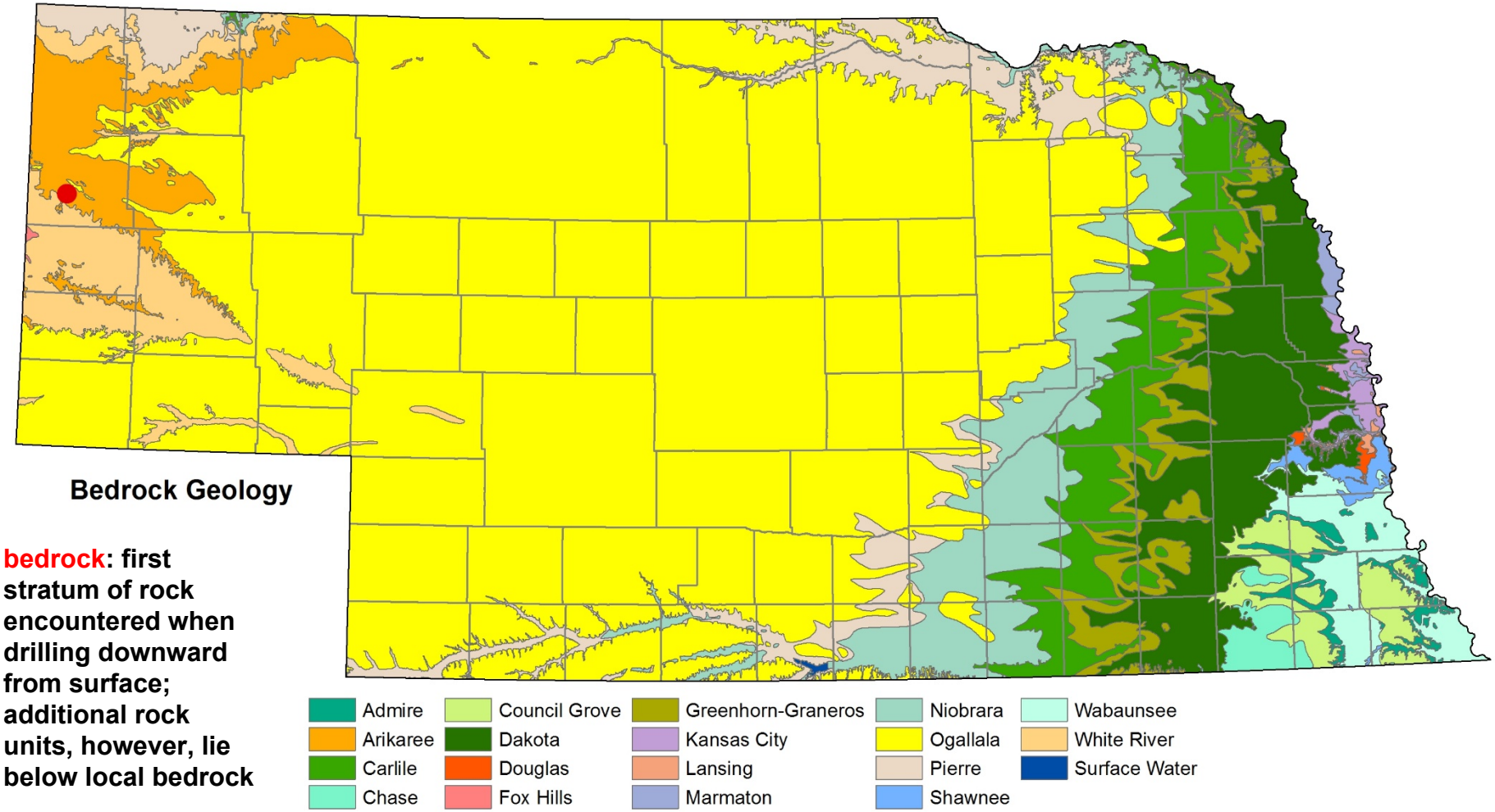
Borehole Stratigraphy

- ✓ fluid is not being injected into High Plains aquifer
- ✓ injection zone is more than a mile below the estimated base of the High Plains aquifer
- ✓ High Plains aquifer is confined below by strata of White River Group and, below those strata lies an aquitard nearly 4000 ft thick
- ✓ saline waters already exist in a zone more than 500 ft thick above the injection zone
- ✓ saline waters already exist in injection zone
- ✓ injected fluids should readily be accommodated in injected zone

CSD Testhole 10-B-77: Independent, Unbiased Assessment of Geology

- ✓ test hole is < 1 mi away from site
- ✓ in 1977, depth to water measured at 240 ft
- ✓ assumed with justification to be constant, base of High Plains aquifer was measured at 280 ft
- ✓ Arikaree Group strata to 280 ft depth, underlain by confining units
- ✓ groundwater in Arikaree Group may be more difficult to contaminate from surface spills because of its lithologic characteristics (somewhat finer-grained nature, local cementation, and other factors)

Bedrock Geologic Map



bedrock: first stratum of rock encountered when drilling downward from surface; additional rock units, however, lie below local bedrock

✓ **bedrock under site is Arikaree Group, which is merely a part of the strata making up the High Plains Aquifer**

✓ **deeper strata in which injection is to take place are not even represented on this map**

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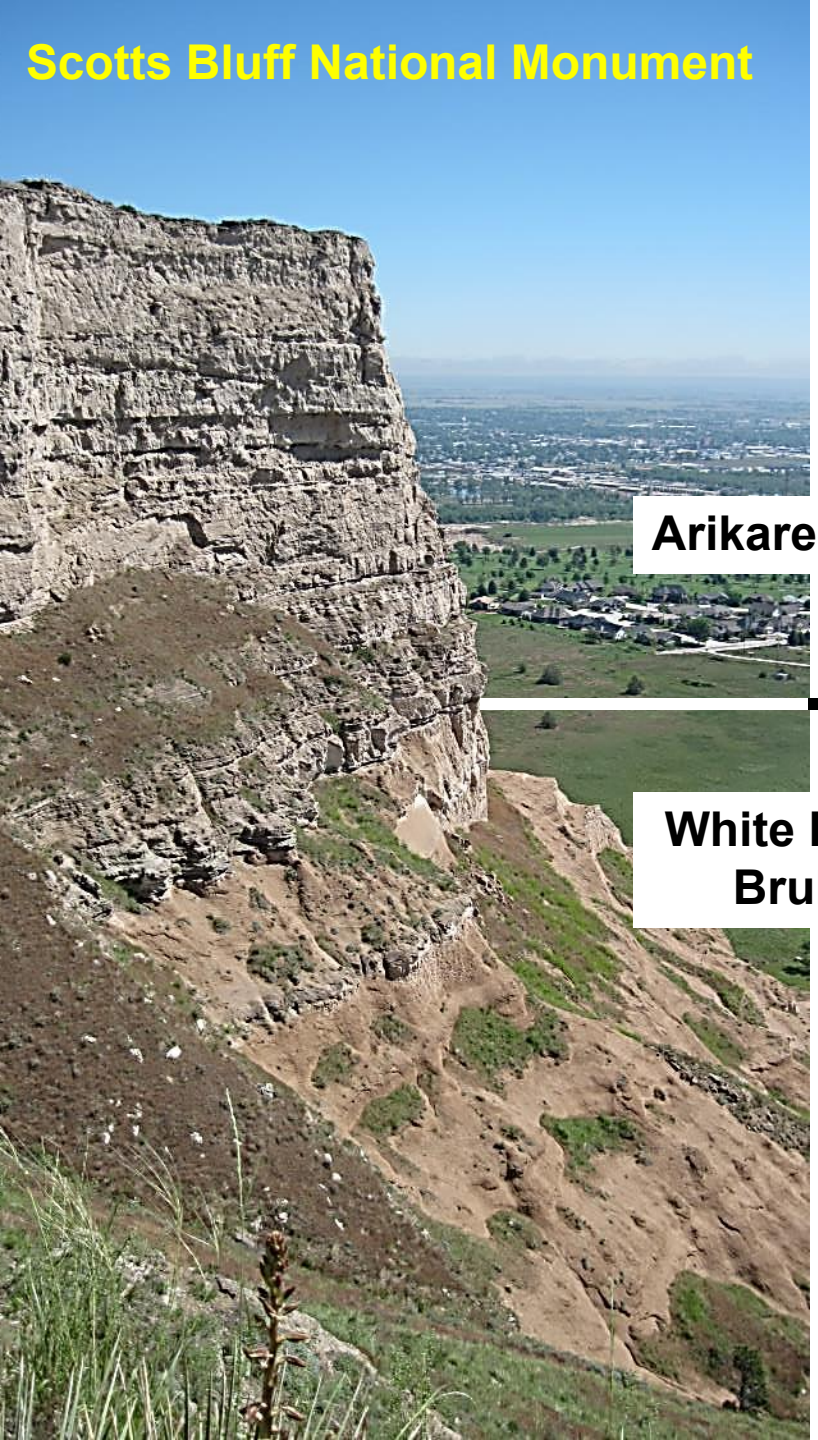
Scotts Bluff National Monument



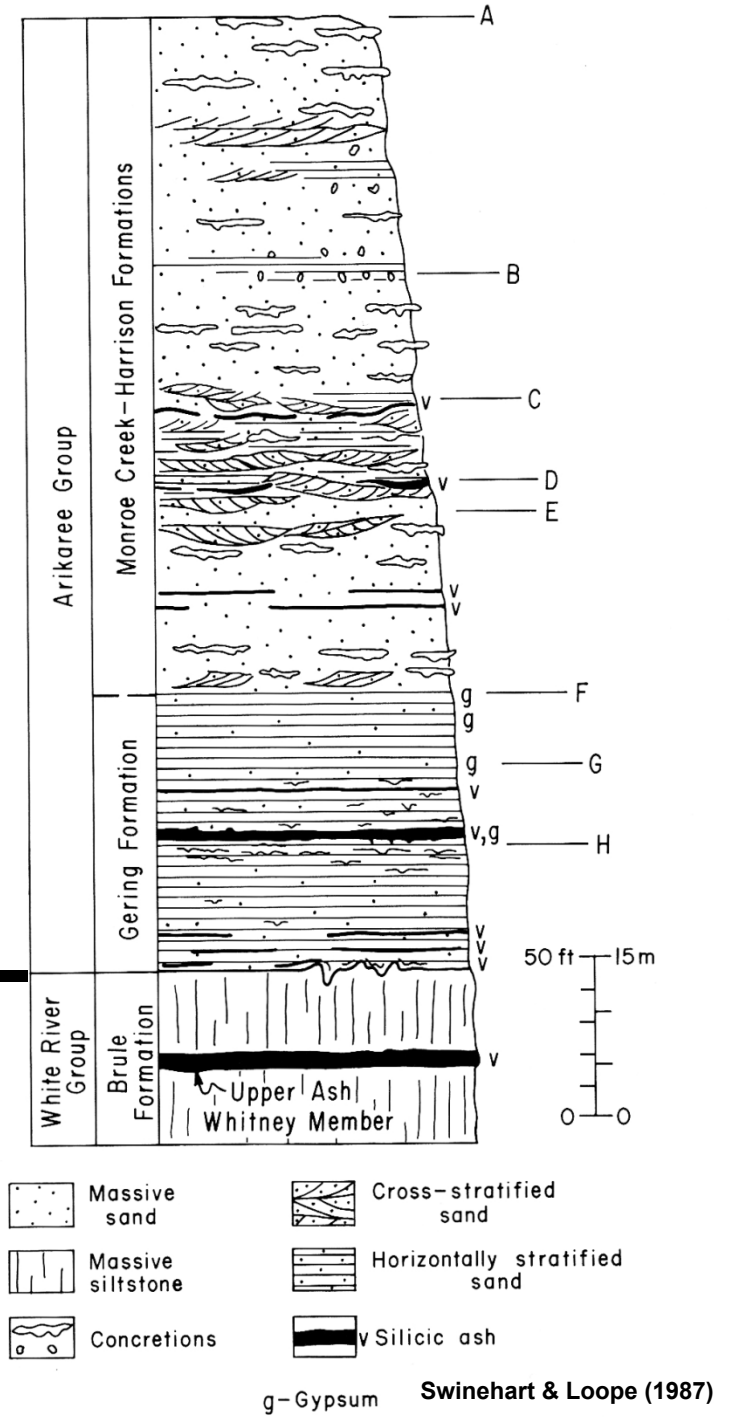
fluvial and eolian sandstones

Arikaree Group

fluvial sandstones

White River Gp.
Brule Fm.

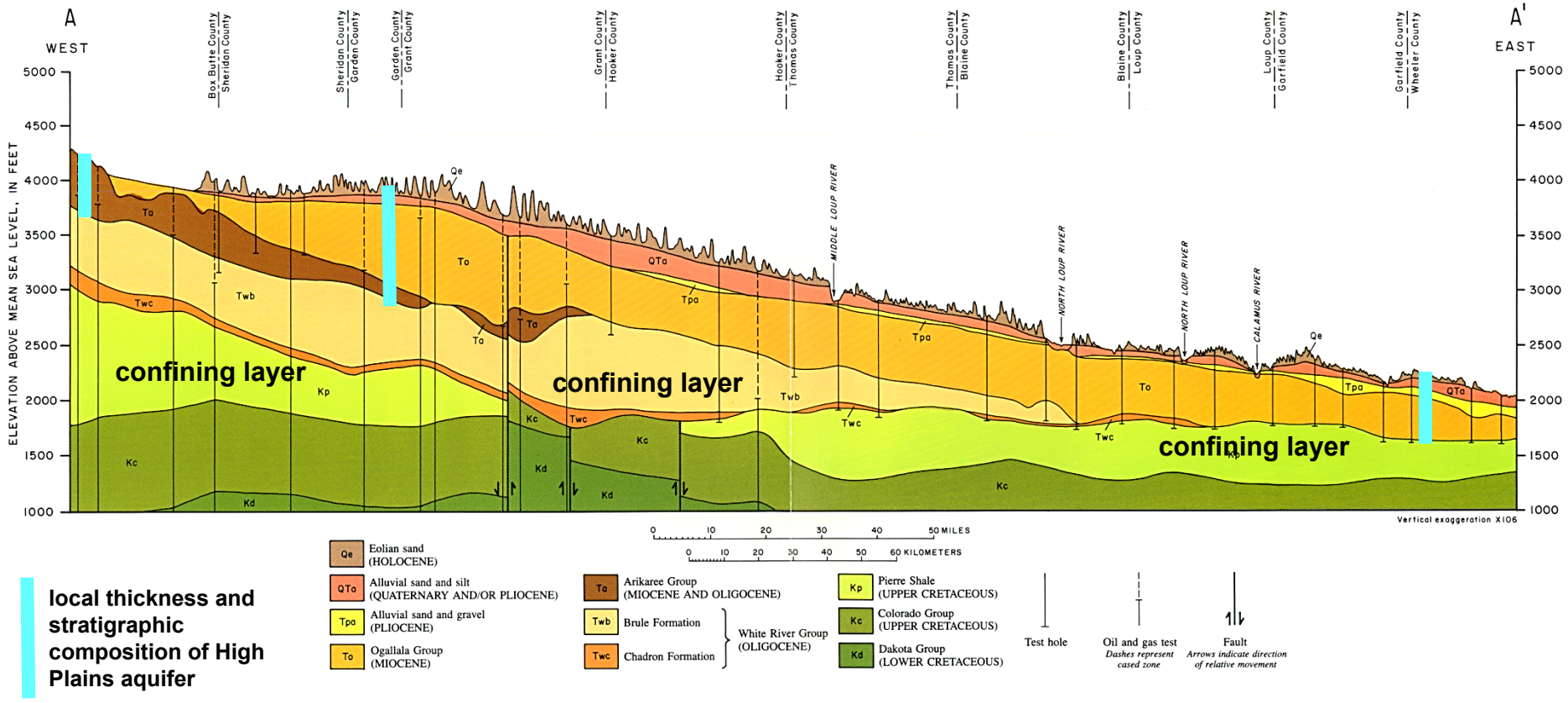
volcaniclastic siltstones



Swinehart & Loope (1987)

West-East Geologic Cross-Section, Nebraska Sand Hills

Box Butte Co. **Wheeler Co.**



local thickness and stratigraphic composition of High Plains aquifer

- ✓ **thickness, composition, and characteristics of High Plains aquifer vary markedly from place to place**
- ✓ **aquifer is comparatively thinner in vicinity of site than in areas to east**
- ✓ **<u>injection is to occur *far below* the lowermost strata represented in this diagram (those in green)!</u>**

(Old) Geologic Cross Section Trending Near (*Not Through*) Site

(Condra et al., 1950, Nebr. Geol. Survey Bull. 13A)

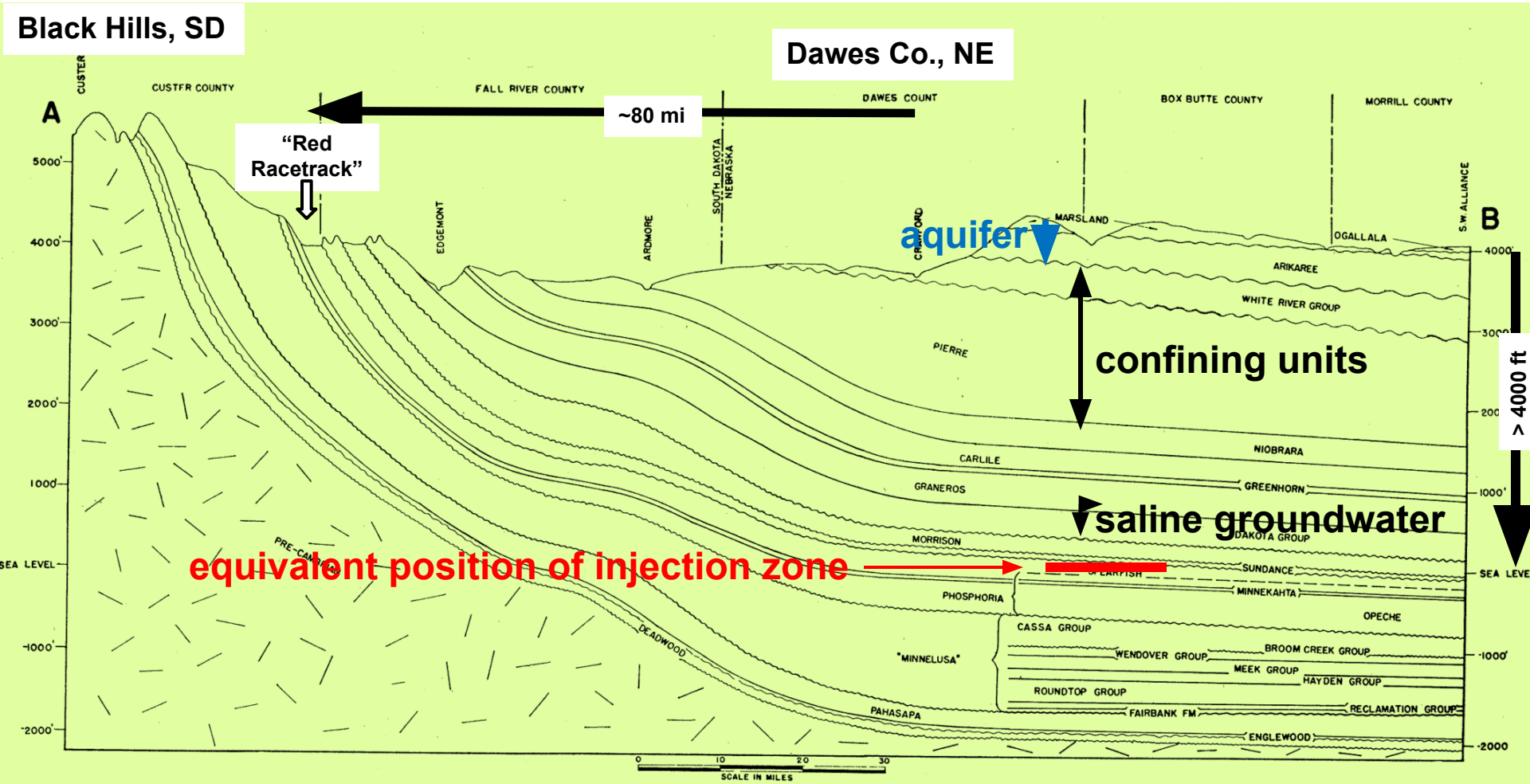
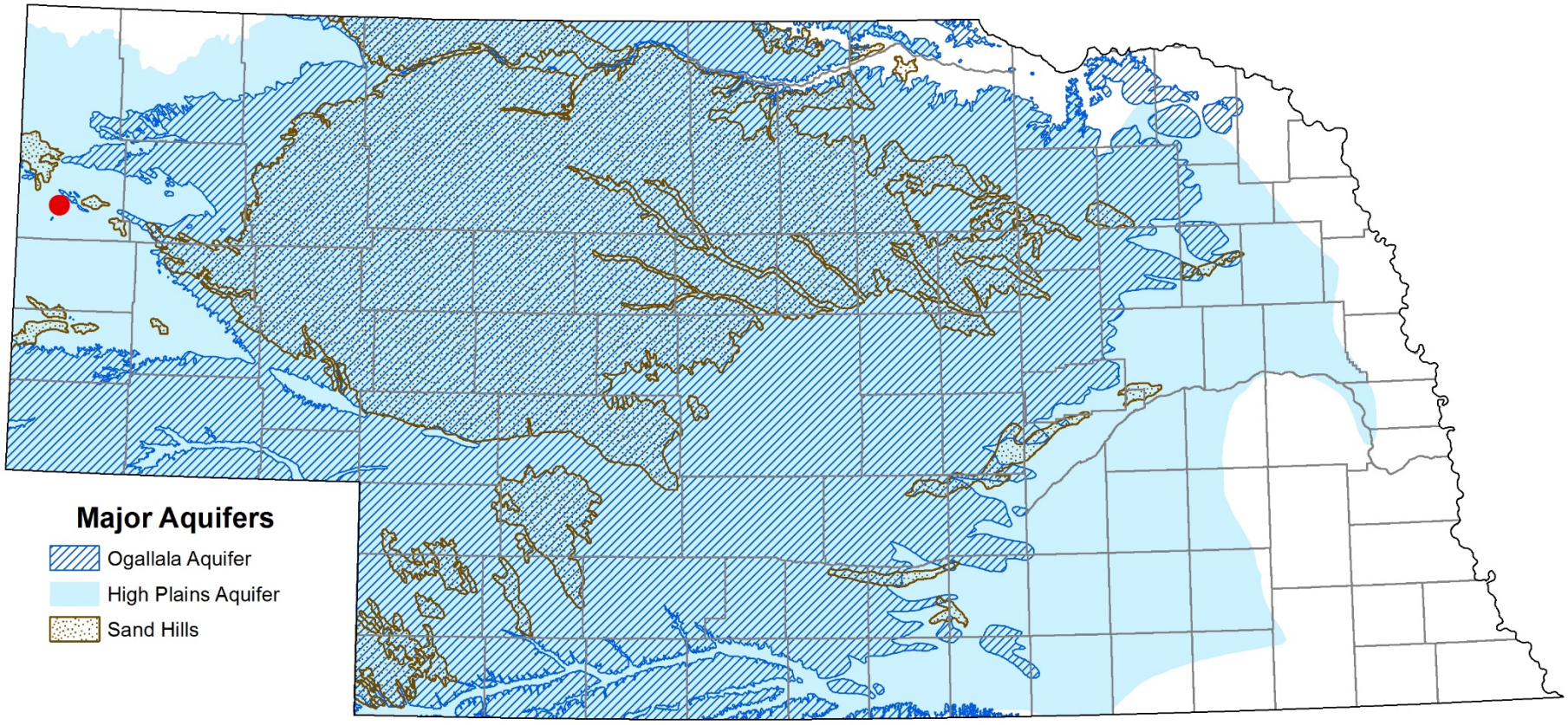


Figure 13.—Geologic profile section A-B from the vicinity of Custer, South Dakota, to a point about 10 miles southwest of Alliance, Nebraska. (See Figure 1 for location of profile section.)

High Plains Aquifer and Associated Features



✓ **site is underlain by High Plains Aquifer**

✓ **site is not atop that aquifer's most important part ("Ogallala aquifer") and it is not within Sand Hills**

✓ **<u>injection is to occur *far below* level of aquifer</u>**

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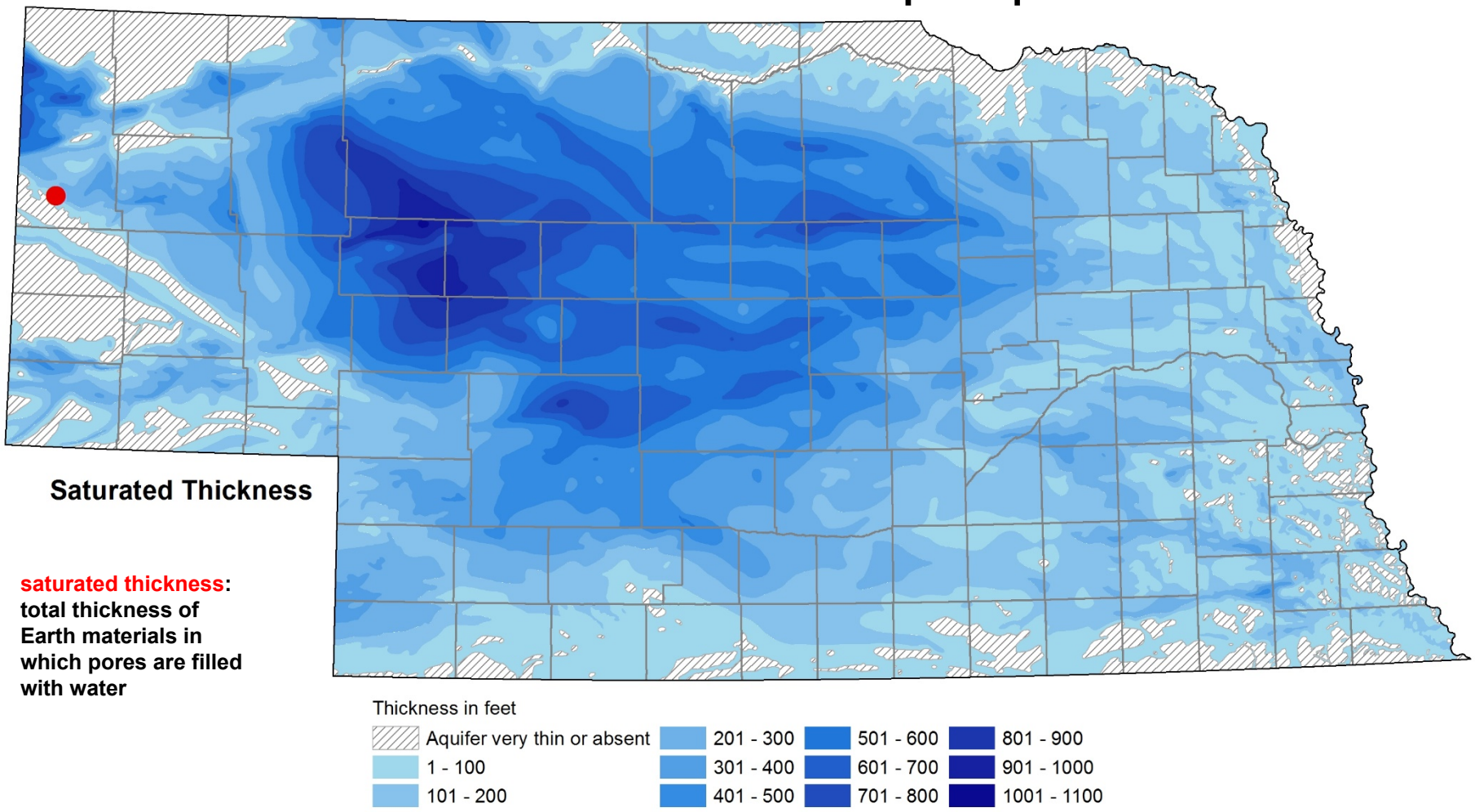
Saturated Thickness of Principal Aquifer



saturated thickness: total thickness of Earth materials in which pores are filled with water

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- ✓ abundant groundwater does not exist everywhere in Nebraska
- ✓ site is near an area where High Plains aquifer is thin or absent
- ✓ site is far from area of maximum saturated thickness of aquifer
- ✓ injection is to occur *far below* level of aquifer

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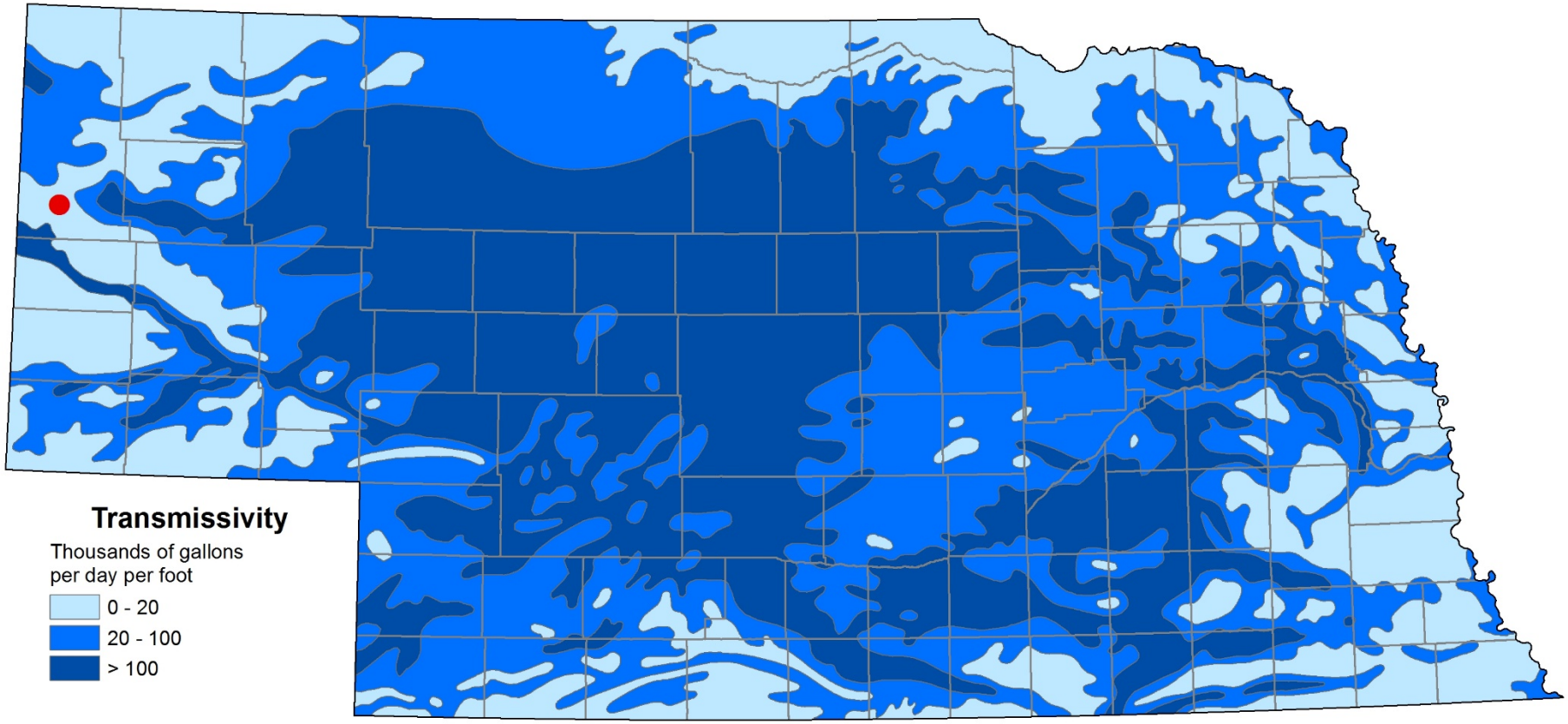
Transmissivity of Principal Aquifer



transmissivity: rate of groundwater flow through a given width of aquifer having a given saturated thickness

✓ **site lies within an area of low transmissivity of High Plains aquifer**

✓ **injection is to occur *far below* level of aquifer**

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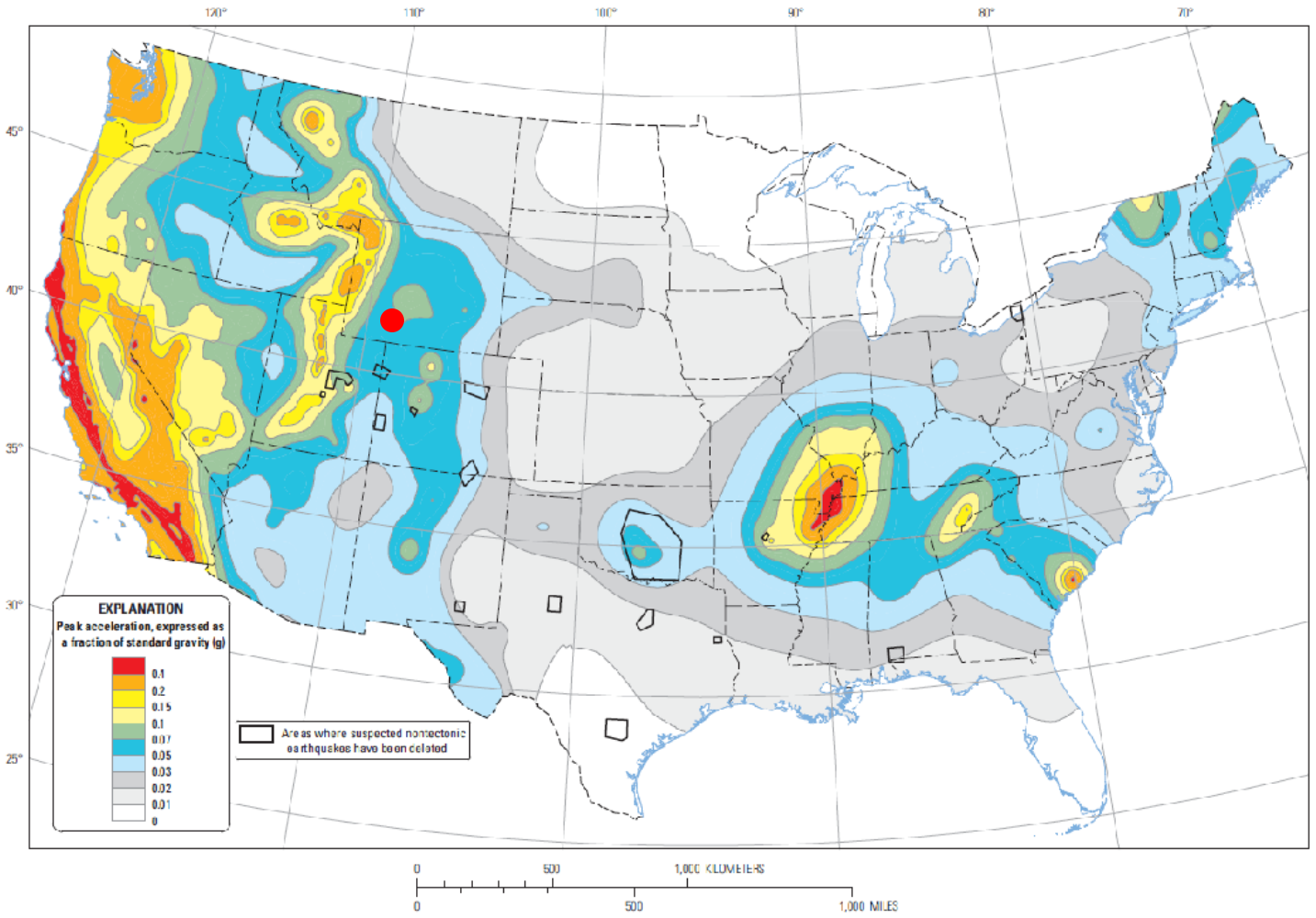
USGS Earthquake Hazard Map: Estimated 10% Probability of Exceedance in 50 yrs of Peak Acceleration Due to Shaking of 0.03-0.05 g*

✓ earthquake hazard in vicinity of site is low, as estimated by USGS

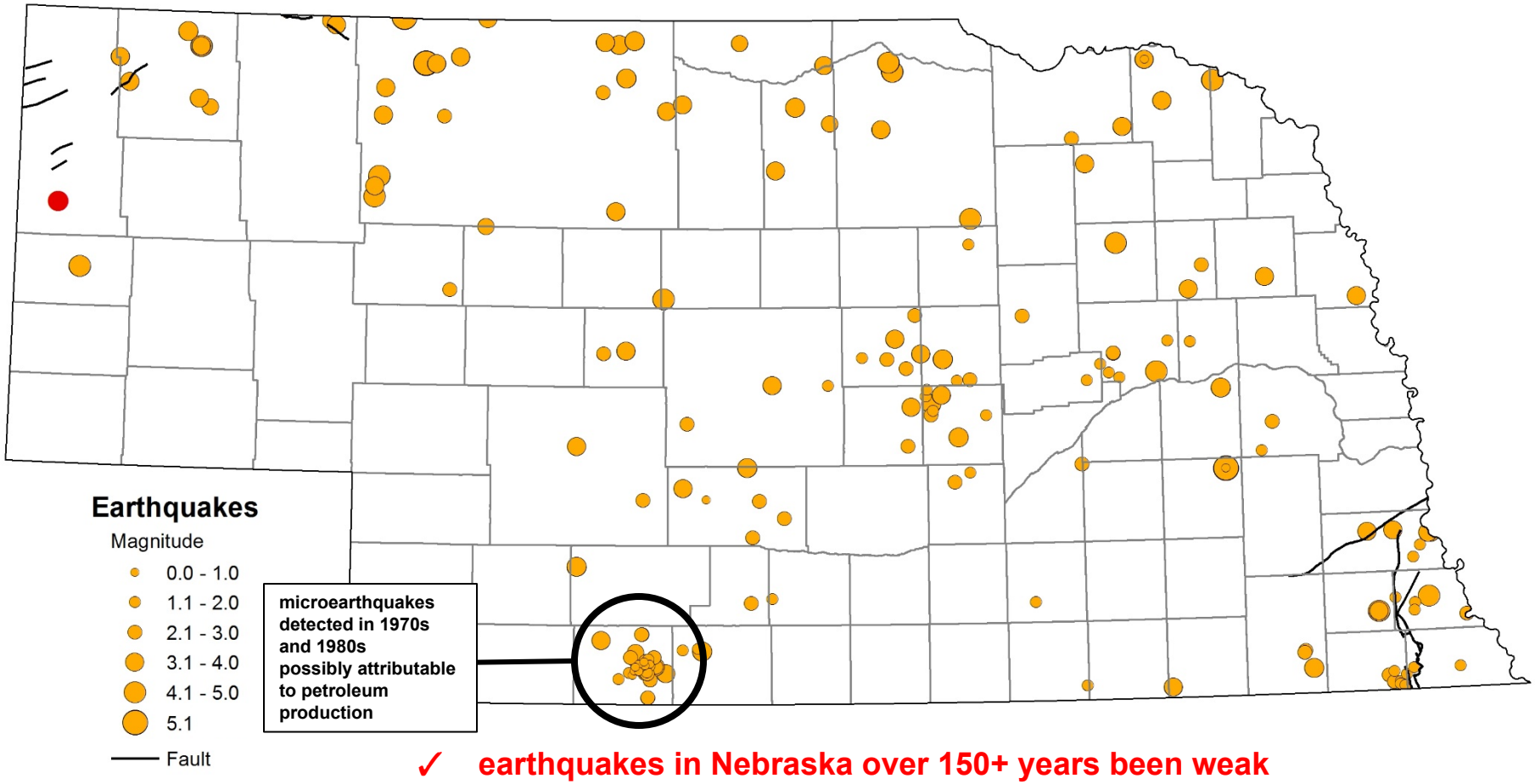


Ten-percent probability of exceedance in 50 years map of peak ground acceleration

*0.03-0.05 g would barely be felt by a fraction of the population; this range of acceleration would not normally cause damage

http://earthquake.usgs.gov/hazards/

Historic Earthquakes and Mapped Faults in Nebraska



- ✓ earthquakes in Nebraska over 150+ years been weak and have, in effect, caused no significant damage
- ✓ site is not atop a known fault mapped at the surface
- ✓ little seismic activity in vicinity of site

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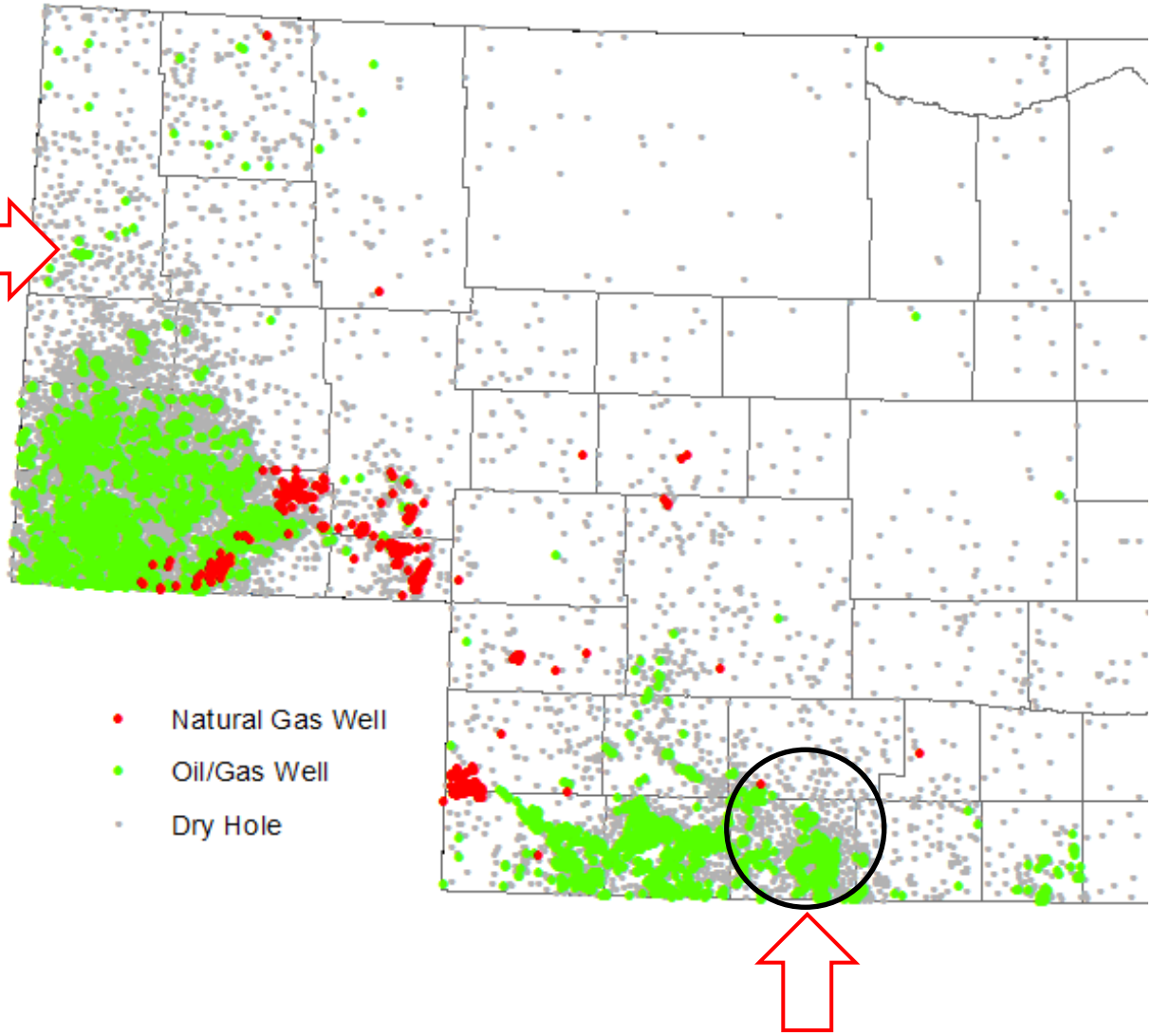
Distribution of Petroleum Wells in Nebraska

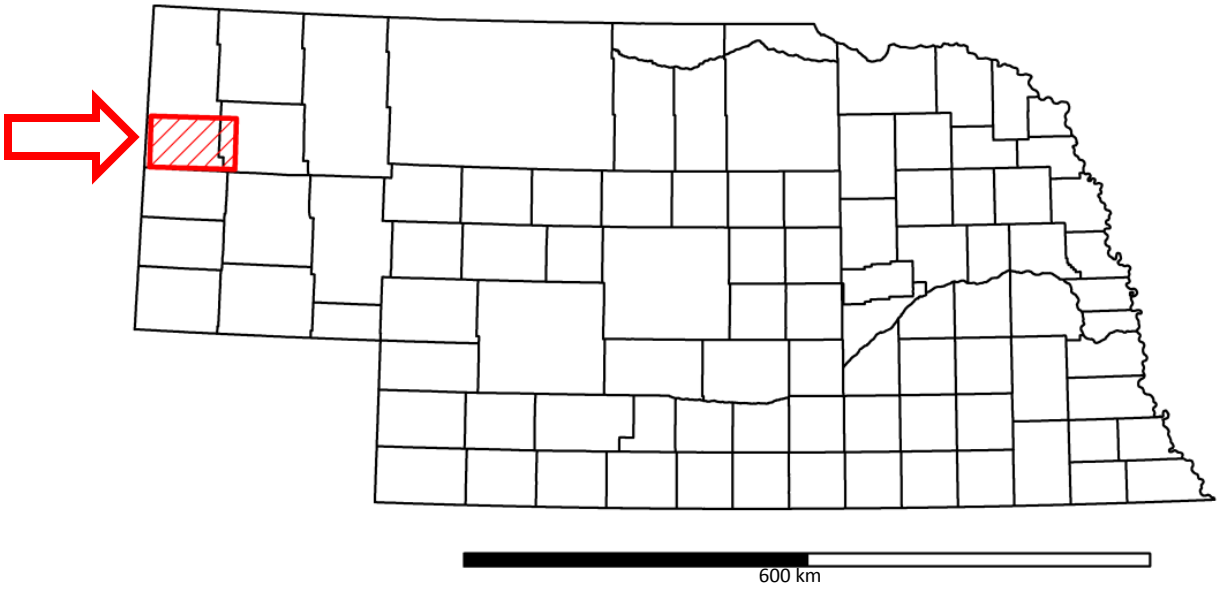
area of interest in today's discussion



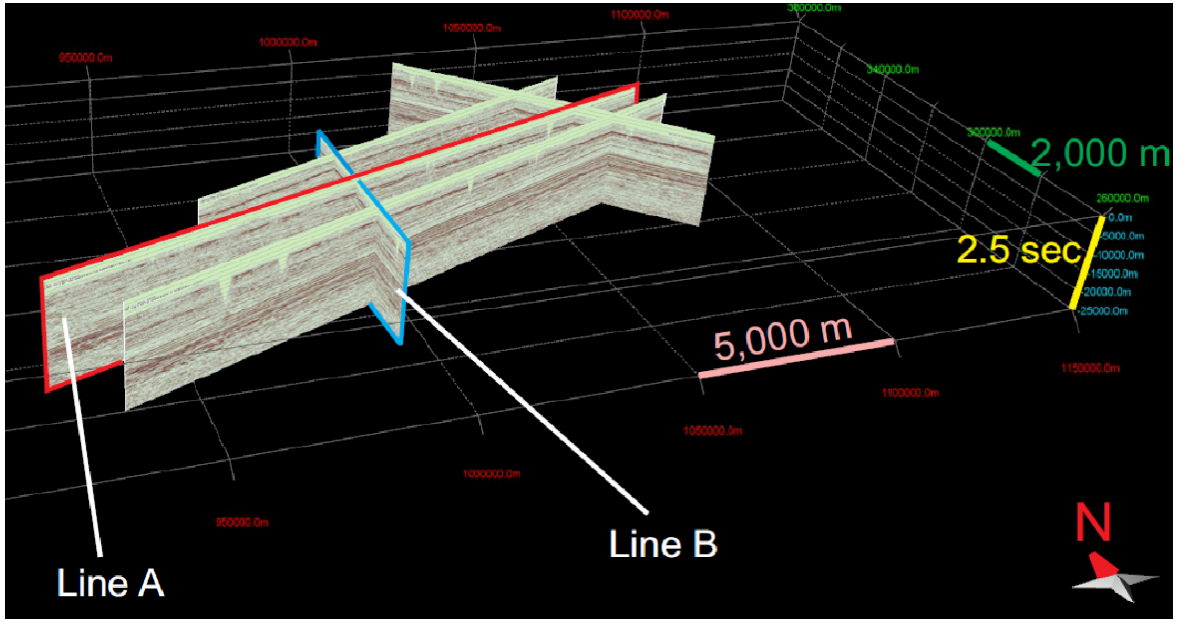
area highlighted in previous map

data source: NOGCC

Seismic Dataset for Southern Sioux County



seismic reflection: geophysical technique that employs artificial seismic energy source to send seismic waves into Earth's crust; reflection and refraction of these seismic waves by strata at depth provide a "picture" of the crust's structure when processed with computer software



West-East Seismic Line Across Southern Sioux County

- ✓ strata (incl. Spearfish Formation) are identifiable with use of well logs; the formation lies well above basement rocks
- ✓ geologic structure is very gentle
- ✓ a few faults (red) can be interpreted in subsurface, but these faults do not extend to High Plains aquifer or to surface; one fault is limited to basement rocks
- ✓ none of the interpreted faults extends through, or even near, Spearfish Formation