The Blackfoot Volcanic Field, Southeast Idaho: A New Structural Paradigm for Hidden Geothermal Resources in the Northeastern Basin and Range*

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Abstract

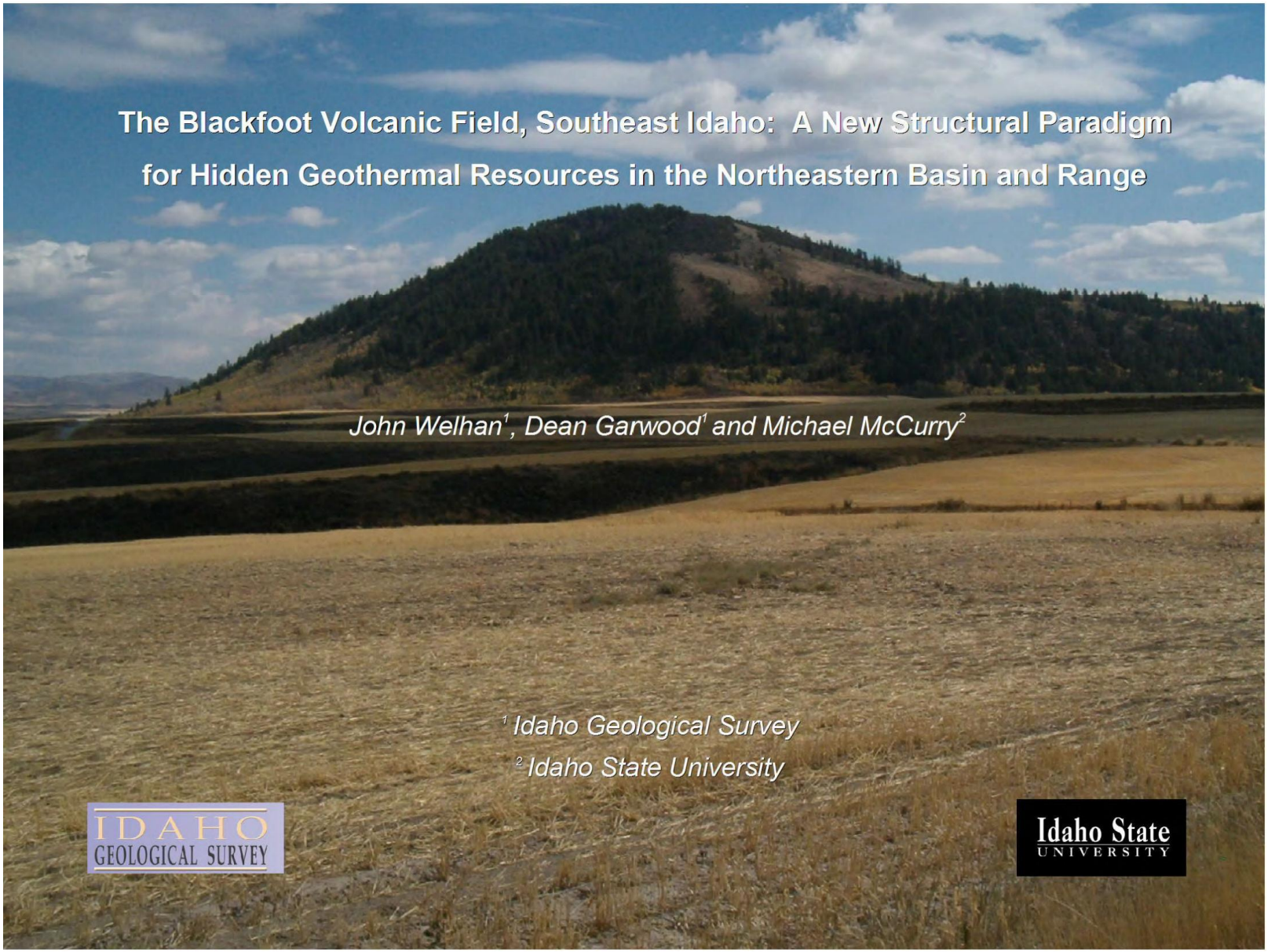
The Blackfoot volcanic field (BVF), located on the western margin of the Idaho-Wyoming overthrust belt in southeast Idaho, is a Quaternary bimodal volcanic province consisting of extensive basaltic lava flows and rhyolite lava domes in a north-trending Basin and Range graben whose Tertiary normal faults cross-cut west-dipping Cretaceous thrust faults. During the geothermal exploration boom of the 1970s and 80s, the BVF was considered to have high geothermal resource potential but interest waned after a 2.5 km-deep geothermal exploration well drilled near the 58 Ka China Hat rhyolite dome did not encounter temperatures above 100°C. The temperature information in that borehole, obtained from intermittent soundings during drilling, suggested that the volcanic heat source was already spent, possibly because of limited magma volume, rapid mid-crustal cooling or both. Recent re-examination of the petrology and geochemistry of BVF lavas (McCurry et al, 2012), however, suggests that a substantial magmatic heat source at depths of 12-14 km is not only likely but now appears to be necessary to explain the low-temperature geothermal activity and 3He and CO_2 gas fluxes that characterize the southern end of the BVF (Lewicki et al, 2012). Considering the region's geohydrology and structural setting, we propose a new paradigm for hidden geothermal resources where the overthrust belt and eastern Basin and Range merge. Based on the inferred depths and geometry of large-scale thrust faults in this area and the ubiquitous shows of high-temperature geothermal fluids encountered at depths of 3-5 km in wildcat wells east of the BVF, it is possible that fluids heated by a magmatic body at depths of 10-15 km beneath the BVF may rise and move eastward along one or more thrust faults (or along carbonate strata within the thrust sheets) to feed hidden geothermal reservoirs within the overthrust belt. The acidic nature of magmatically influenced fluids would contribute solution-enhanced porosity and permeability to the host thrust faults / sheets and could promote lateral migration well away from the BVF. Such a mechanism would also explain the presence of high-temperature brines reported in wildcat wells east of the BVF and suggests that the geothermal resource potential of this part of the Basin and Range and overthrust belt needs to be reconsidered. Both legacy information and new heat flow data collected for the National Geothermal Data System will be presented.

Selected References

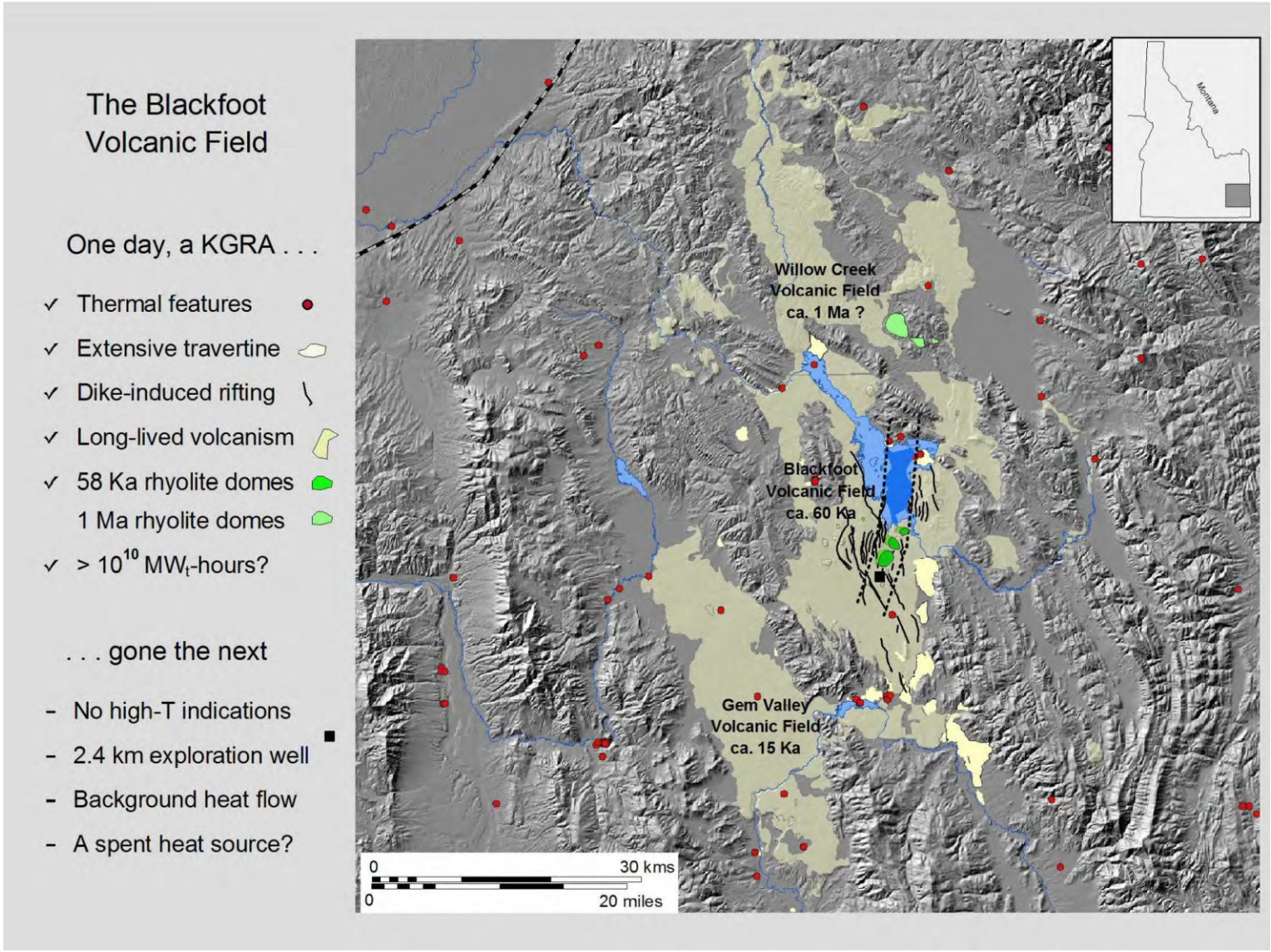
Dixon, J.S., 1982, Regional Structural Synthesis, Wyoming Salient of Western Overthrust Belt: AAPG Bulletin, v. 66/10, p. 1560-1580.

Lewicki, J.L., G.E. Hilley, L. Dobeck, T.L. McLing, B.M. Kennedy, M. Bill and B.D.V. Marino, 2012, Geologic CO2 input into groundwater and the atmosphere, Soda Springs, ID, USA; Chemical Geology, v.339, pp. 61-70.

Smith, R.L., and H.R. Shaw, 1979, Igneous-related geothermal systems, *in* L.J.P. Muffler, (ed.), Assessment of geothermal resources of the United States: U.S. Geological Survey Circular, Report # C 0790, p. 12-17.



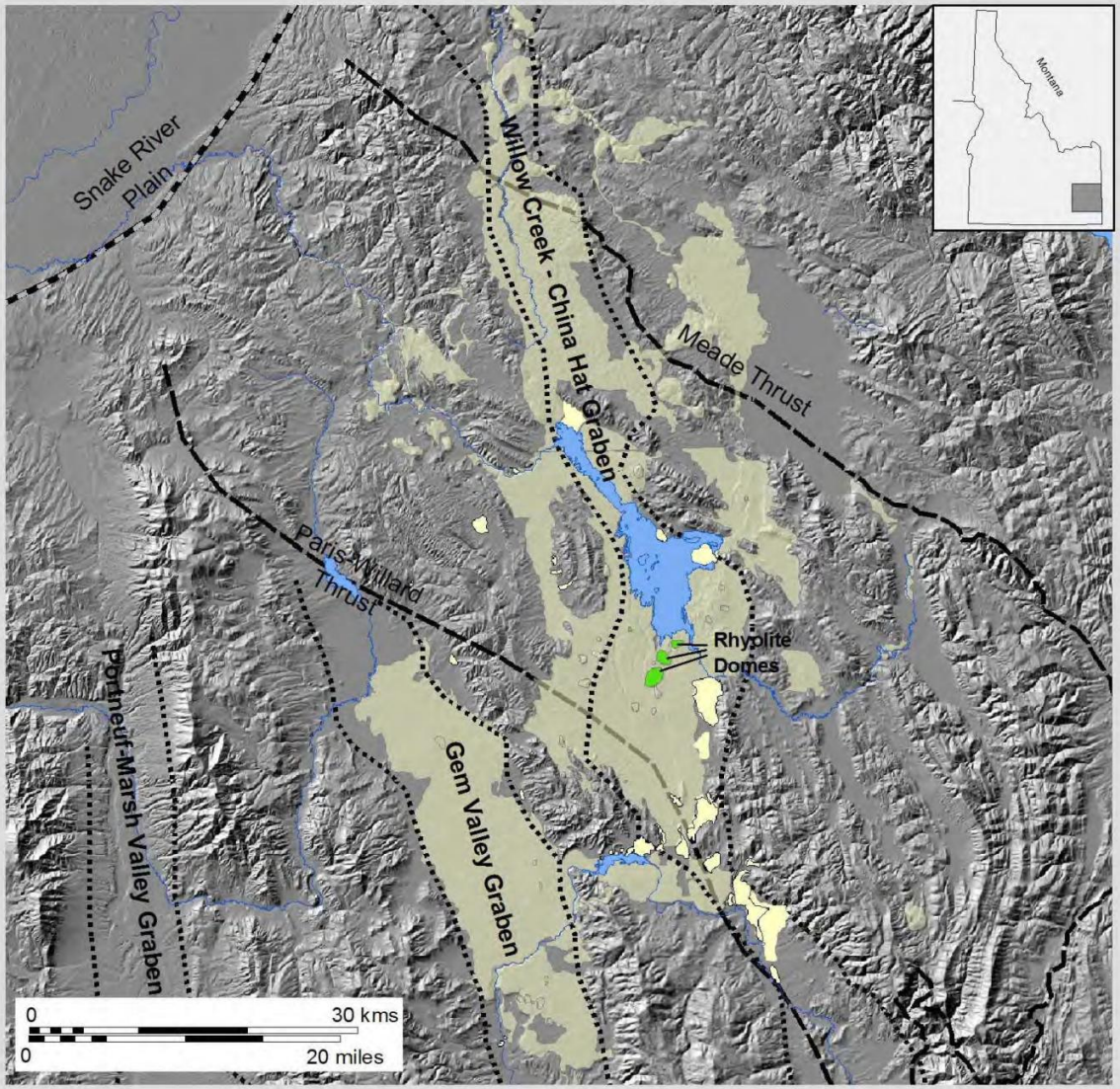
Presenter's notes: The BVF has confounded explorationists since it was designated a KGRA in the late 1970's.



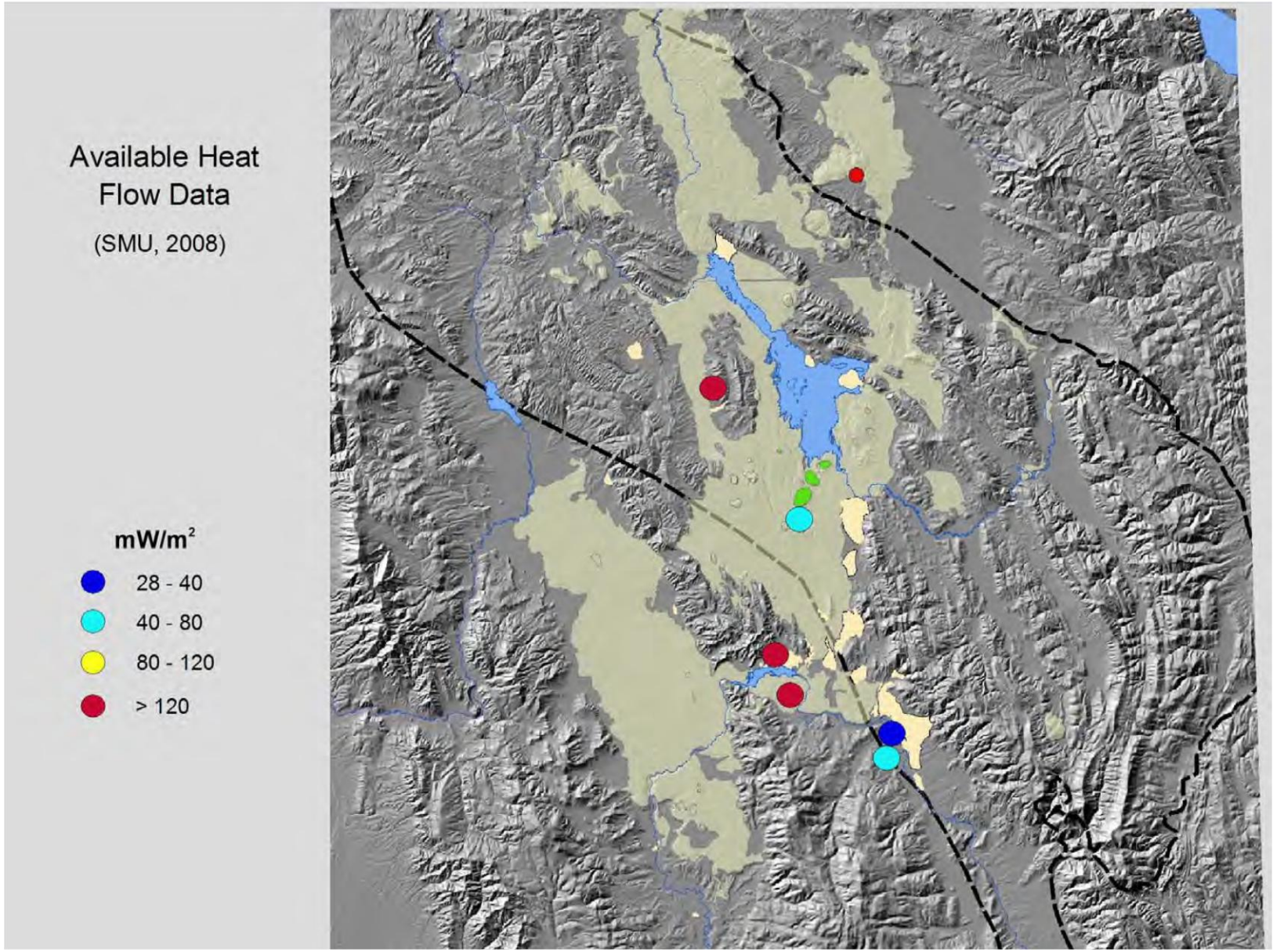
Presenter's notes: The BVF is part of a late Pleistocene volcanic complex that covers 1300 km^2, with 50-100 km^3 of basaltic lava that accumulated in a N to S sequence. It seems to have a lot going for it, most obviously the 58Ka rhyolite domes that led to the USGS's residual heat estimate that equals that of Newberry Crater. However, after 30 years of disappointing and inconclusive exploration evidence, including a 7800-foot GT exploration well just south of China Hat, consensus has moved toward the conclusion that the magma chamber may be too small to retain much heat.

The China Hat Rhyolite Magma: A Viable Heat Source

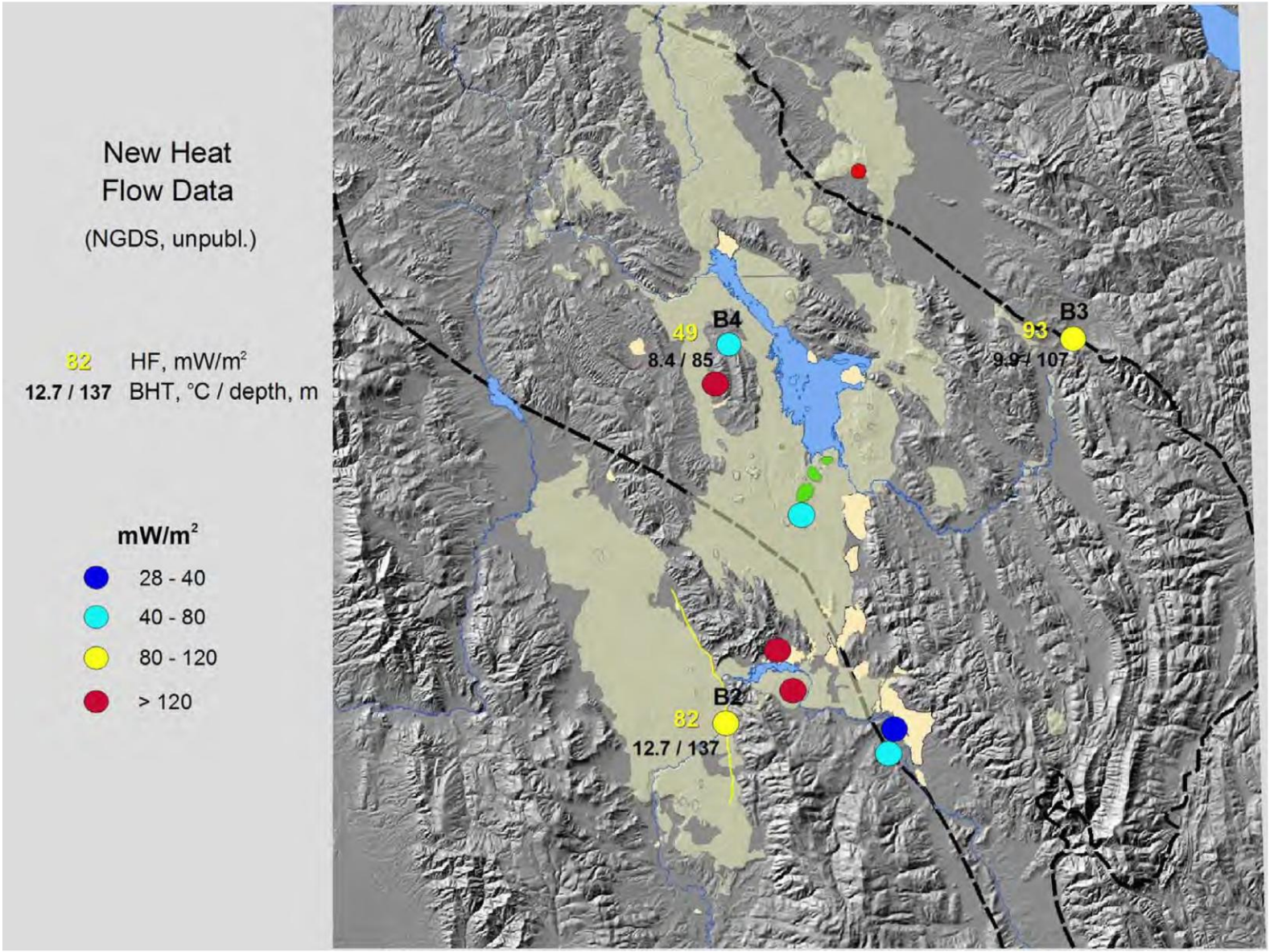
- ✓ v. strong ESRP affinities: mafic parental magma; upper 15 km of crust; extreme differentiation; large unerupted volume
- ✓ "topaz rhyolite" very rich in U, Th (e.g., $ThSiO_4$)
- ✓ thermobarometry: 760-810 °C, 13 km depth
- ✓ ≥4 wt. % H_2O, like many GB Quaternary rhyolites
- ✓ Magmatic ^3He, CO_2 flux
- ✓ heat flow masked by ground water advection or . . . ?



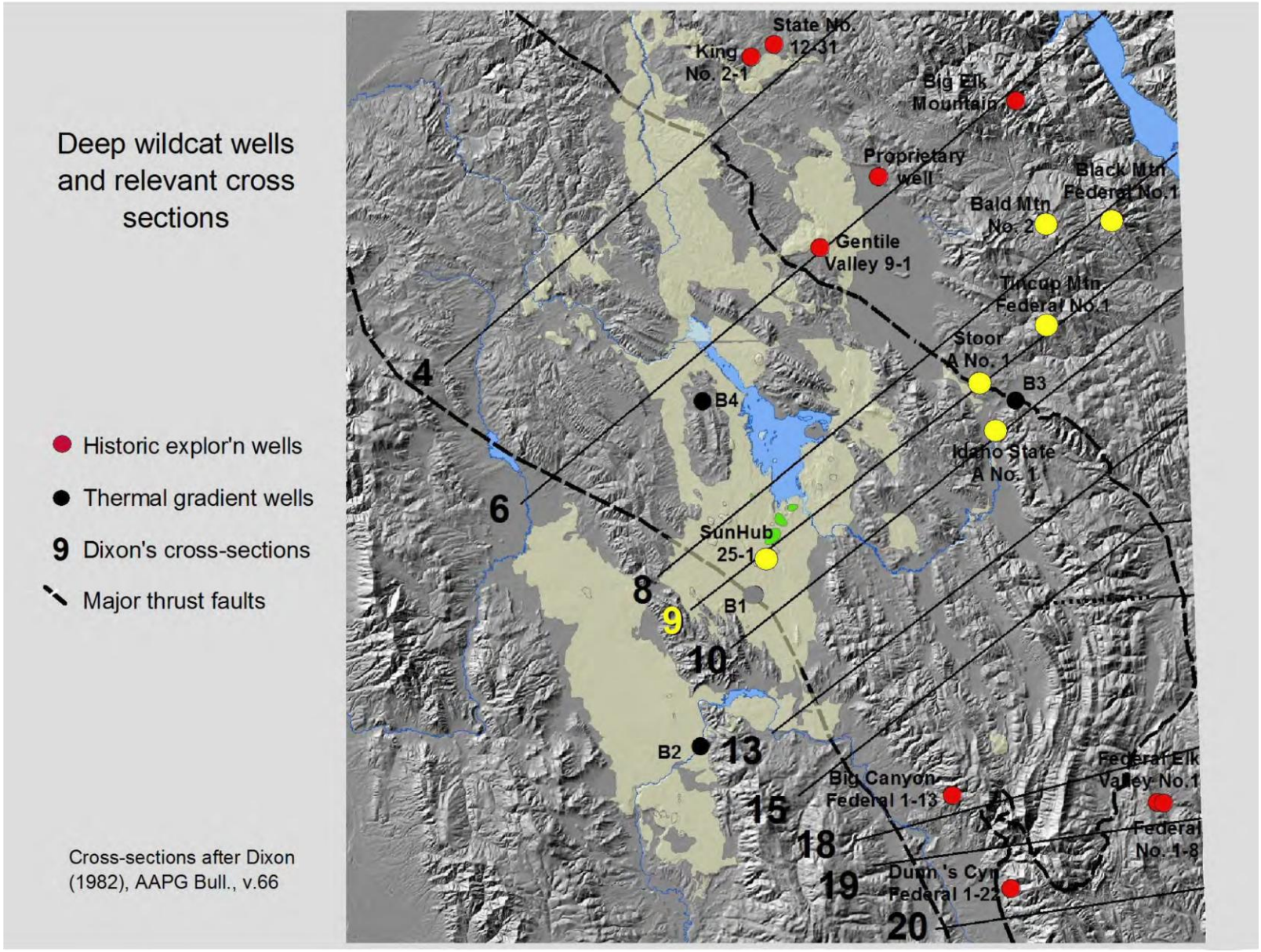
Presenter's notes: However, there is good evidence that the magma chamber remains a large and still-potent heat source for a geothermal resource located in the transition zone between the Basin & Range and the ID-WY thrust belt. The most direct corroboration of a still-active magmatic source of heat came last year with the discovery that the large CO_2 flux from the south end of the BVF includes a significant fraction of magmatic carbon and helium. So, if this geothermal system is still being fed by a high-T magmatic source, where is the heat?



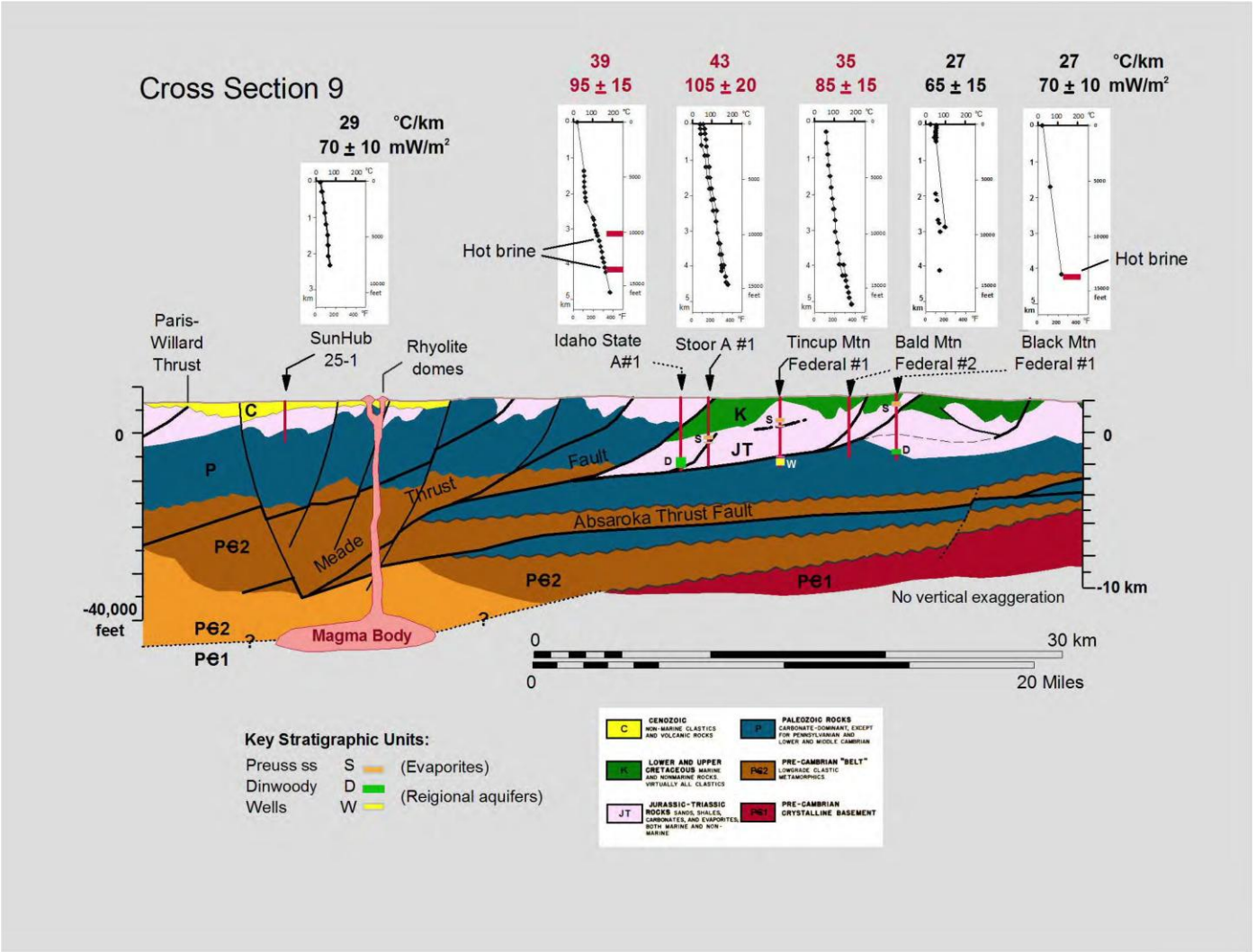
Presenter's notes: Unfortunately, available heat flow data in this region are sparse. The SMU database contains only a handful of reliable estimates and those show an odd distribution of high values in unusual locations. With additional funding from DOE's NGDS program, we completed three additional shallow thermal gradient wells...



Presenter's notes:...which confirmed that the shallow thermal regime in this crustal environment is strongly influenced by local geohydrologic conditions. Well B2's HF is not representative of the conductive HF in Gem Valley because it reflects warm waters that upwell to shallow levels along the East Gem Valley fault. This result suggests that a similar mechanism is responsible for the elevated HF seen near B4, which we interpret to be more representative of the local conductive situation in that area.



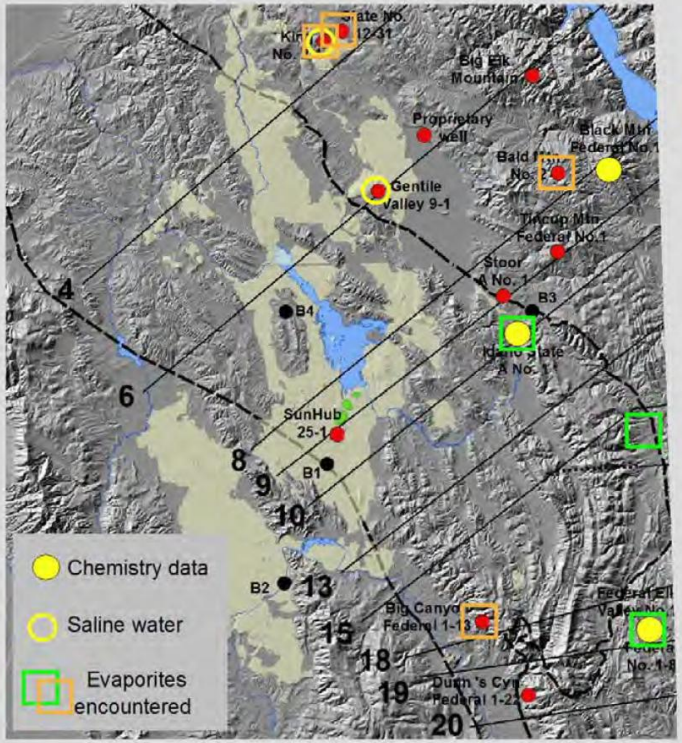
Presenter's notes: Because the shallow heat flow results did not clarify the regional picture, we've had to rely on what thermal data could be gleaned from historic records of deep drilling in the area. For the sake of time, I will not belabor you with details on every well for which we have data...



Presenter's notes:...except to point out that we see very similar patterns wherever we look. The only deep well in the China Hat graben has background HF whereas several wells in the overthrust belt encountered high temperatures. Regardless of which cross section we look at, we see similar patterns:

- 150 - 200°C @ 3 - 5 km
- Hot fluids only in Jurassic & older rocks
- Wells, Twin Creek and Dinwoody Fms are important players
- Saline fluids observed in several wells

Available Fluid Chemistry Data from Drill Stem Test Intervals



Idaho State A #1 9/4/1981

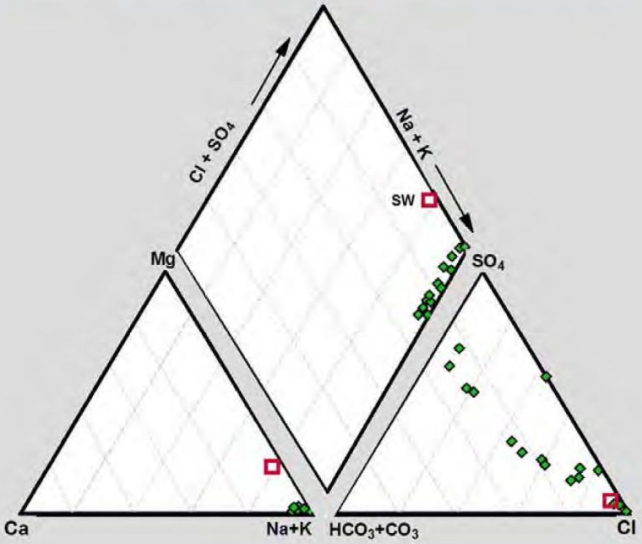
Depth, ft	DST #	Tmax, °C	TDS, mg/l	Brine Type
10112-10119	Evans	126	69920	Sodium-chloride-sulfate
13178-13241	4	148	25950	
13178-13241	bottom	n.a.	320809	

Black Mtn Federal #1 4/13/1977

Depth, ft	DST #	Tmax, °C		Brine Type
13554-13703	3	116	23402	Sodium-chloride-sulfate
13554-13703	4	n.a.	23671	

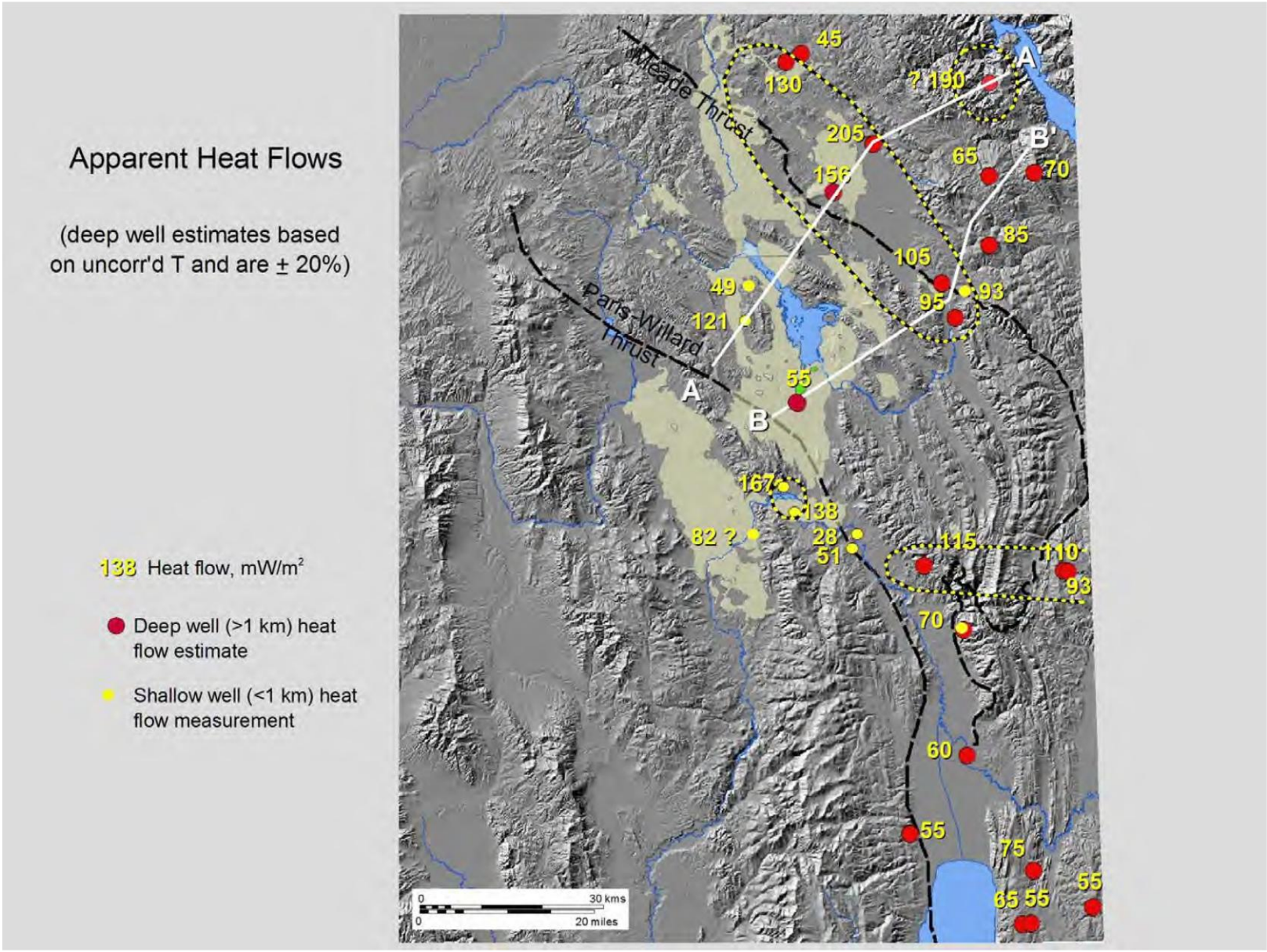
Elk Valley #2 Federal 1-8 3/28-30/1978

Depth, ft	DST #	Tmax, °C		Brine Type
11385 - 11487	4	149	11600	Sodium-sulfate-chloride
11645 - 11884	5	114	20567	

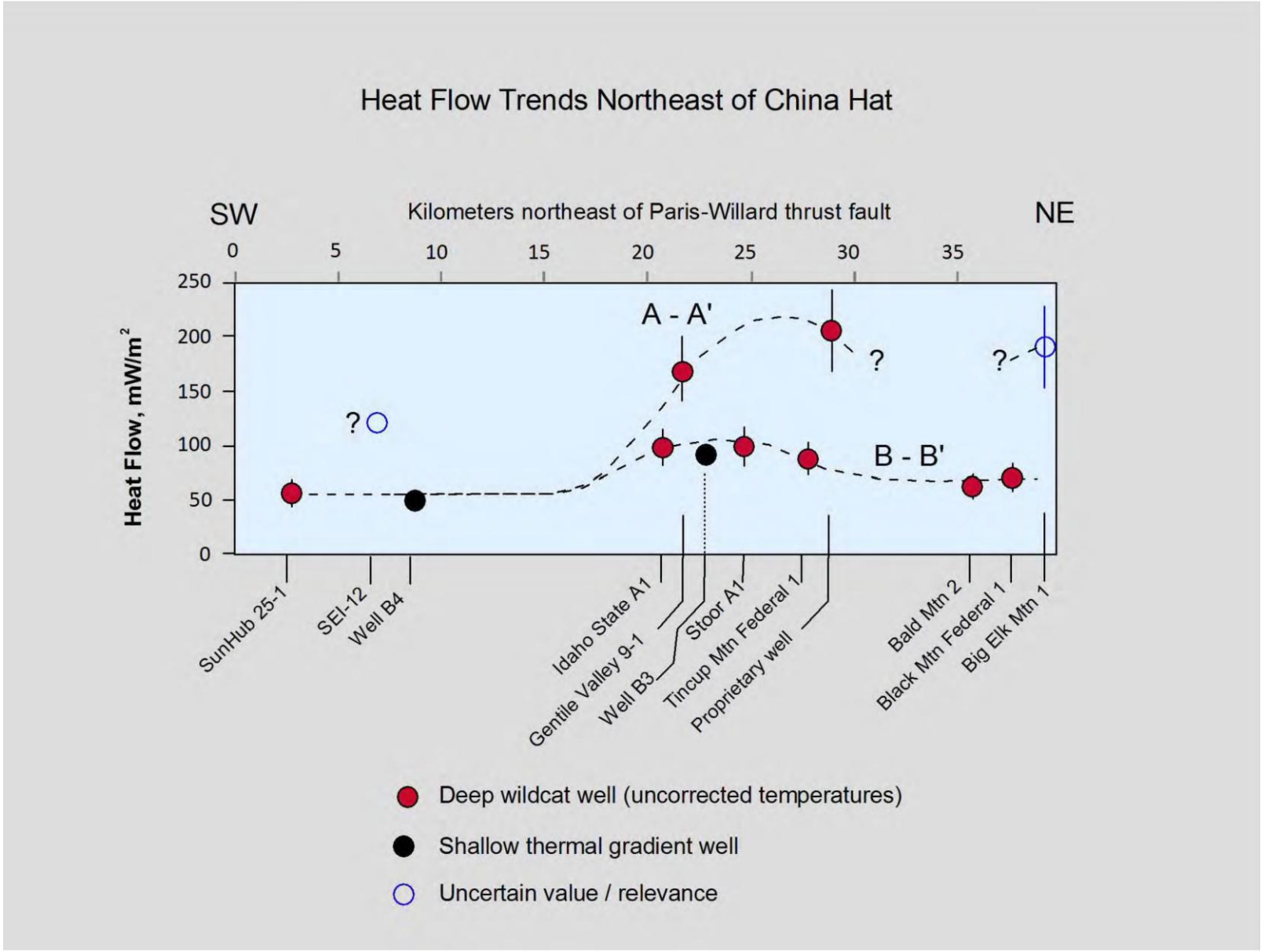


Dissolution of Evaporite Minerals

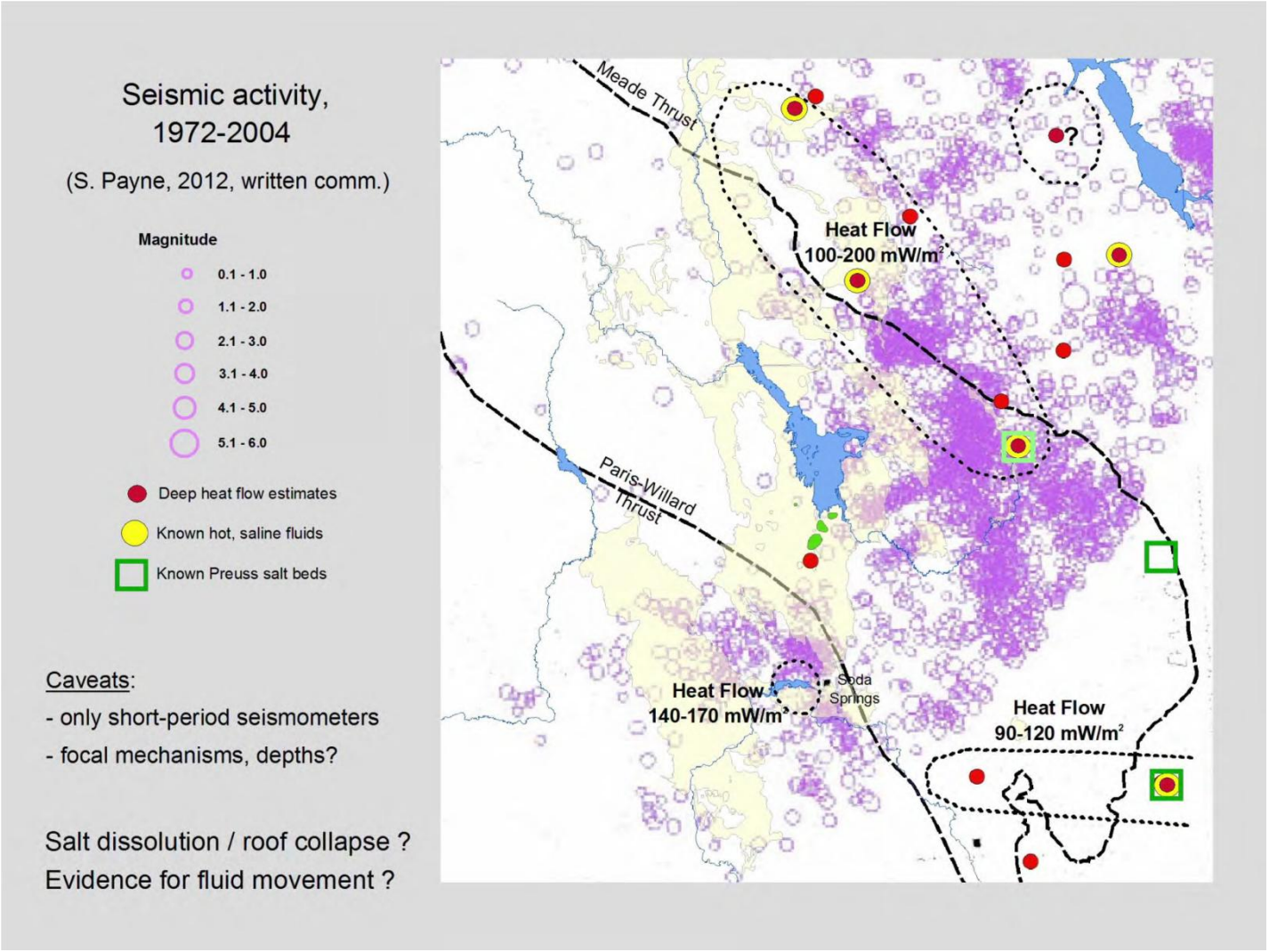
Presenter's notes: We have eighteen major-ion chemical analyses from several DST reports in three deep wells (yellow symbols). What jumps out is the brackish to very saline nature of these fluids, varying from 2/3 of seawater density up to 10x seawater density. All the chemical data show a surprisingly uniform composition pattern that indicates these salts are derived from dissolution of massive amounts of halite and anhydrite such as are found in the Preuss SS, where thick halite beds are encountered (green squares) and anhydritethat occurs throughout the stratigraphic column in several wells (orange squares).



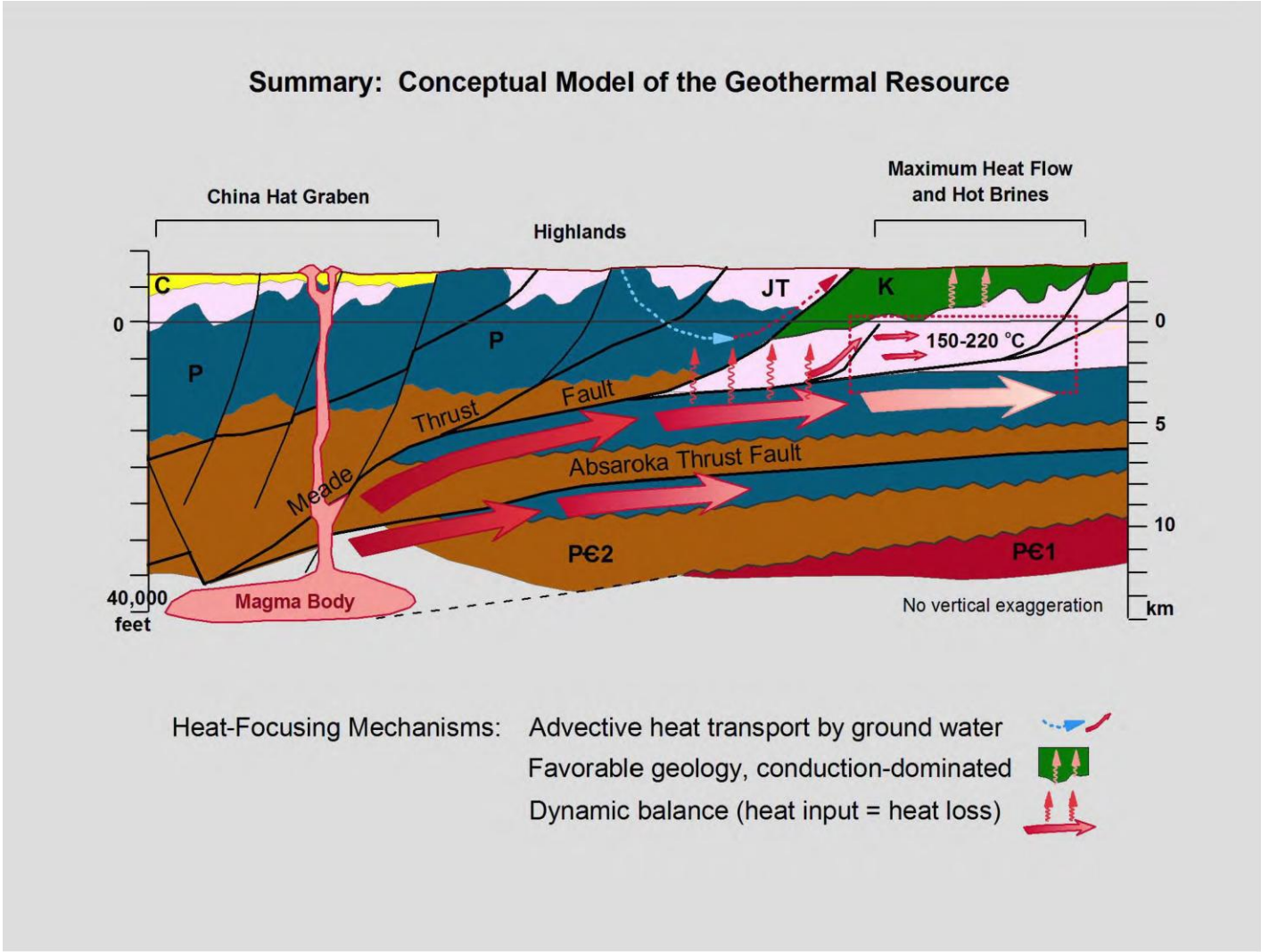
Presenter's notes: Putting it all together, the available heat flow estimates define three areas that have HF in excess of 100 mW/m^2. A possible fourth area is defined by a single record in IDWR's DB of thermal wells, so I remain skeptical until this is corroborated. Looking along two transects...



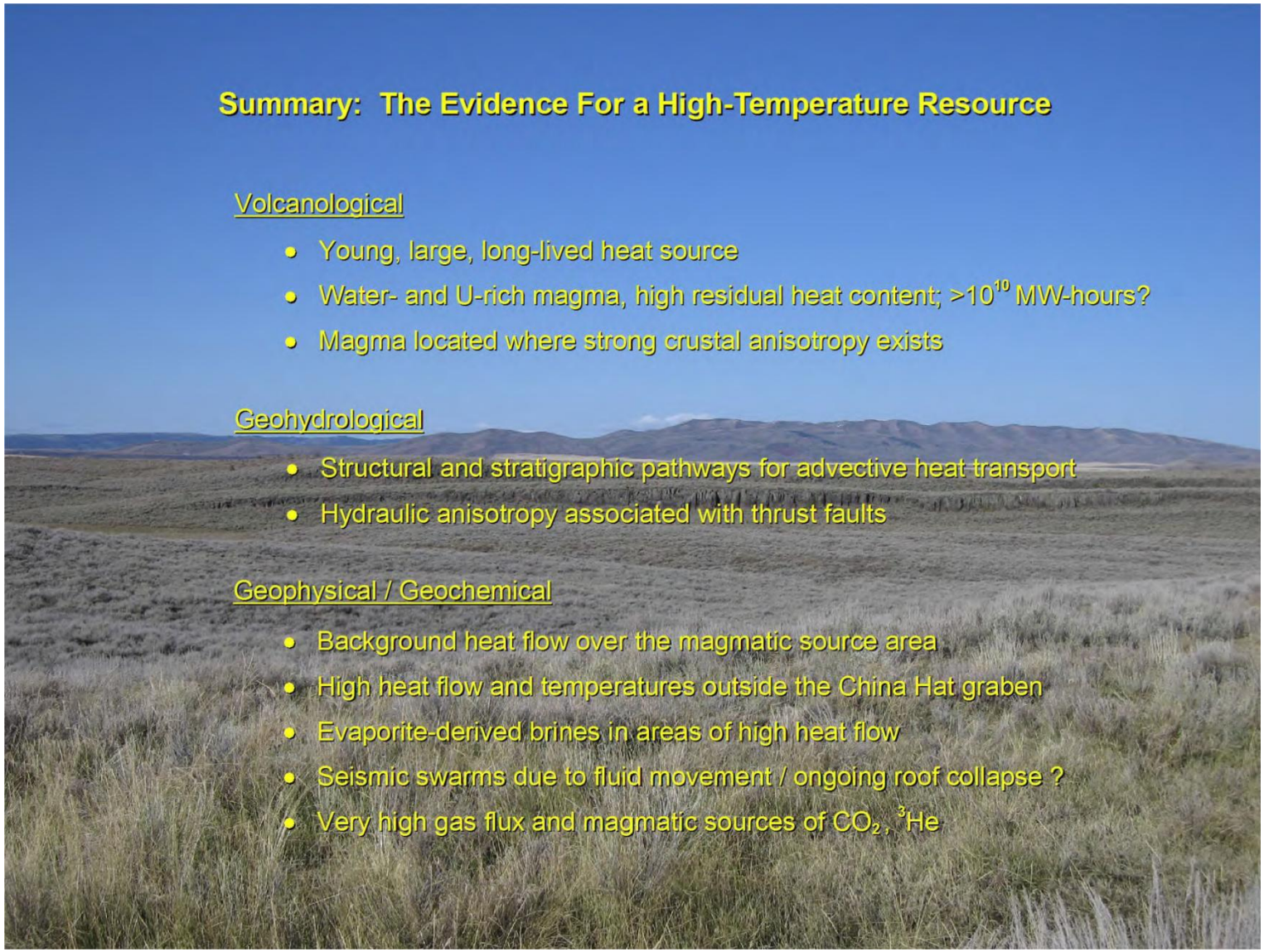
Presenter's notes:...we see HF over the China Hat graben is low then rises over a 10 km-wide belt east of the graben before falling back to background levels farther to the east. As I have mentioned, two values plotted here are considered uncertain and unrepresentative of deep HF.



Presenter's notes: One more piece of evidence is worth noting. The Idaho National Laboratory's dataset on seismic epicenters in SE Idaho covers a portion of our study area and defines a large area of concentrated microseismicity, mostly < M3, including a major swarm of hundreds of micro-events in 1992 located directly NE of the Blackfoot Reservoir. Unfortunately, the INL's seismometers are short-period instruments with insufficient resolution to identify focal mechanisms, but Suzette Payne has suggested that some events have seismic signatures suggestive of fluid involvement of some kind. The Preuss salt beds are also thickest in the area of concentrated microseismicity and, coupled with the evidence for dissolution of salt, it is possible that the observed seismicity reflects ongoing roof collapse within the salt sequences in response to the dissolution of massive volumes of salt by the migrating hydrothermal fluids.

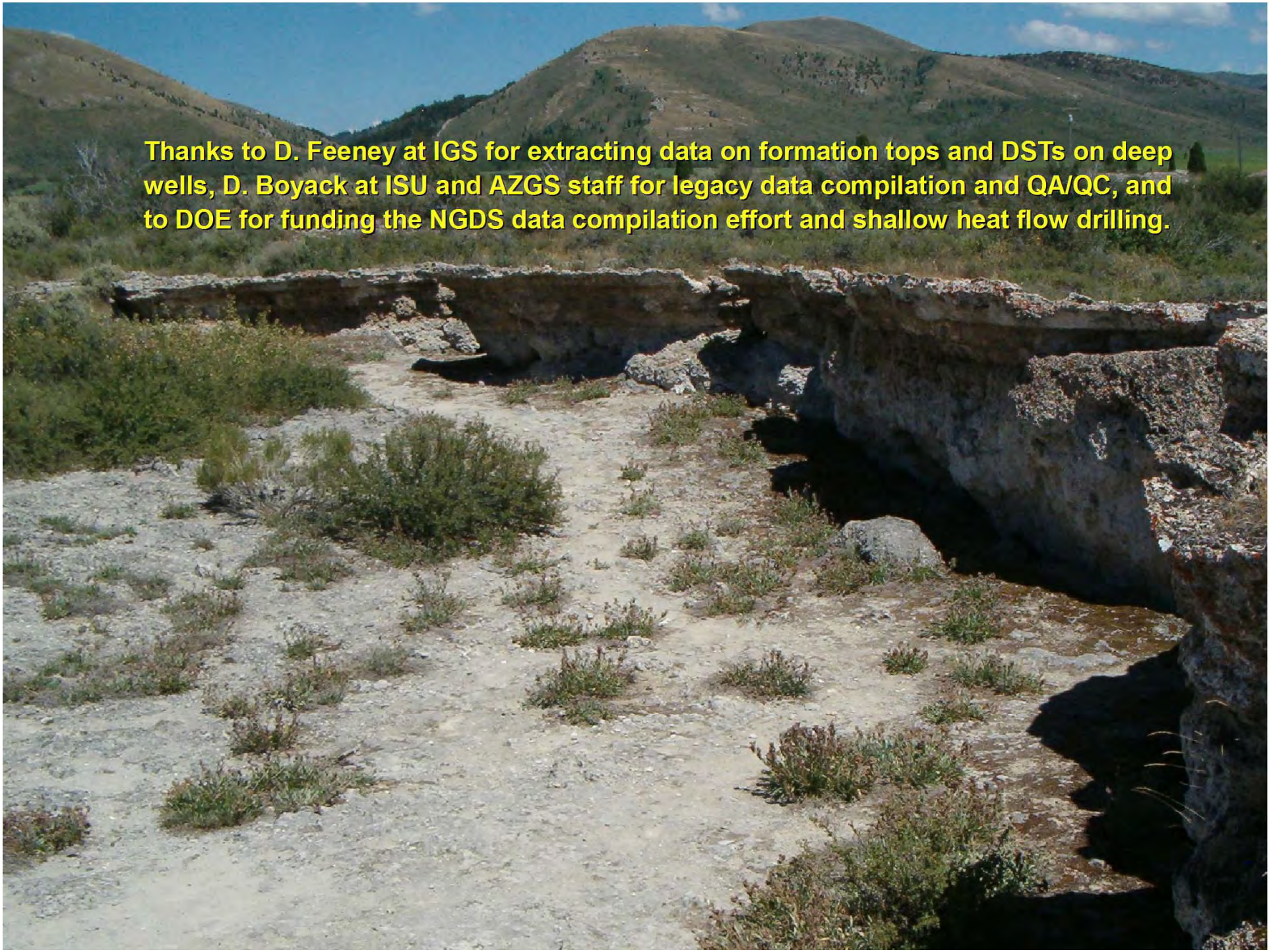


Presenter's notes: Our conceptual model is based on this magmatic heat source is located near the intersection of two major thrust faults allowing heat to be transported away to the east as it rises along these structures. A growing body of evidence indicates that old thrust faults can impose significant regional hydraulic anisotropy on the subsurface. The distribution of hot fluids in stratigraphic reservoirs to the east of the China Hat graben indicates that the movement of hydrothermal fluids and heat follows this anisotropy into shallower zones, a process possibly enhanced by dissolution of soluble phases, such as sedimentary halite and anhydrite. Whether these fluids move directly to the east and concentrate surface heat flow by mechanisms such as those depicted or whether they follow a more convoluted path then flow northward in a direction defined by this heat flow maximum remains to be seen.



Presenter's notes: The volcanologic evidence is compelling that a significant heat source feeds this geothermal prospect and that heat transport is occurring primarily by advective movement into Jurassic and Paleozoic sediments of the adjacent thrust belt. Potentially large volumes of hot brine up to 220°C exist in these sedimentary reservoirs at depths of 3 to 5 km. What remains to be determined is whether they occur in reservoir rocks of sufficient permeability and porosity to make this a viable high-temperature resource.

Presenter's notes: Need more core and brine data, possibly via collaboration with entities that have more data on these wells and rocks than we've been able to uncover. Resistivity surveying would be ideally suited to identifying depths and spatial extents of the saline fluid reservoirs and locating drilling targets. And it is none too soon to commence preliminary modeling investigations to constrain some of the basic process controlling regional advective heat transport and the interplay between magmatic heat output and flow system dynamics and to identify testable geohydrologic hypotheses that can be tested with exploratory drilling.


Thanks to D. Feeney at IGS for extracting data on formation tops and DSTs on deep wells, D. Boyack at ISU and AZGS staff for legacy data compilation and QA/QC, and to DOE for funding the NGDS data compilation effort and shallow heat flow drilling.


Questions?
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