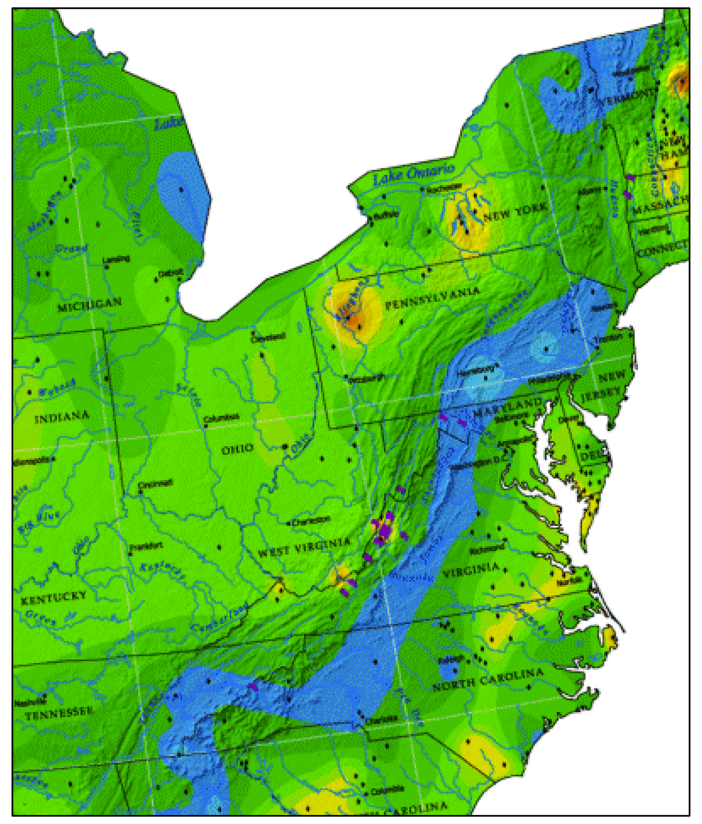
NEW TECHNIQUES FOR HEAT FLOW CALCULATIONS AND MAPPING TEMPERATURE-AT-DEPTH

Zachary Frone, David Blackwell, Joseph Batir, Junghyun Park, and Maria Richards

Geothermal Laboratory, Southern Methodist University, Dallas Texas 75275

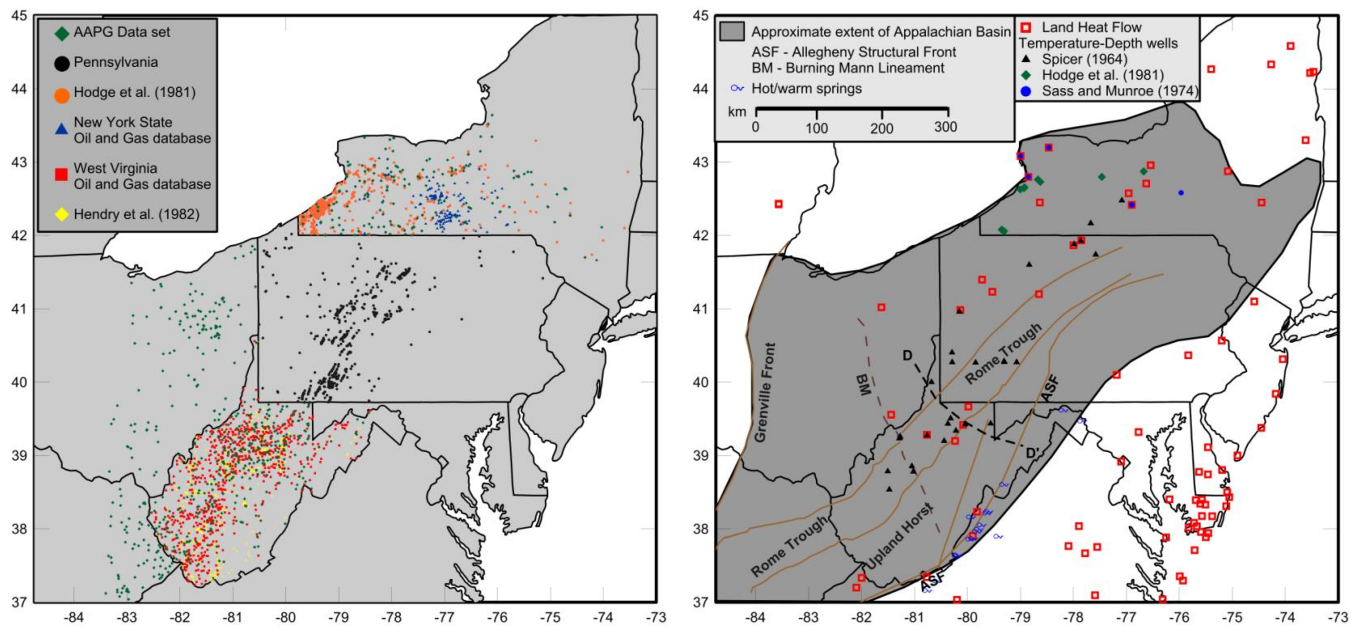
2004 Geothermal Map of North America



Important Features:

- Generally average stable continental values (45-55 mW/m^2)
- Low heat flow values east of Appalachian belt
- Higher heat flow areas in Pennsylvania and New York
- Very Low data density for this area (~90 data points)

New Data



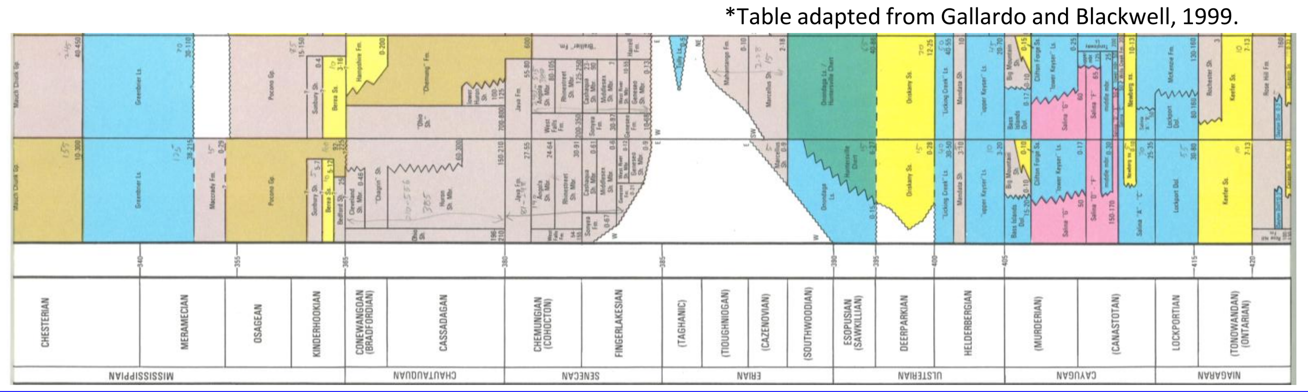
Conductivity Model

$$Q = K\frac{dT}{dz}$$

- Based on Correlation on Stratigraphic Units of North America (COSUNA) AAPG project
- Assumed continuous units
- Collected specific data on depth and thickness of Salina Unit (in Northeast)
- Used K values based on lithology averages for Paleozoic sediments

Rock Type	Thermal Conductivity*
Dolomite	4.4
Limestone	2.9
Sandstone	4.2
Shale	1.4
Unconsolidated Sediment	1.2
Evaporites	4.7
Conglomerate	4.0
Limestone/Shale	2.0
Coal	0.6
Chert	4.0

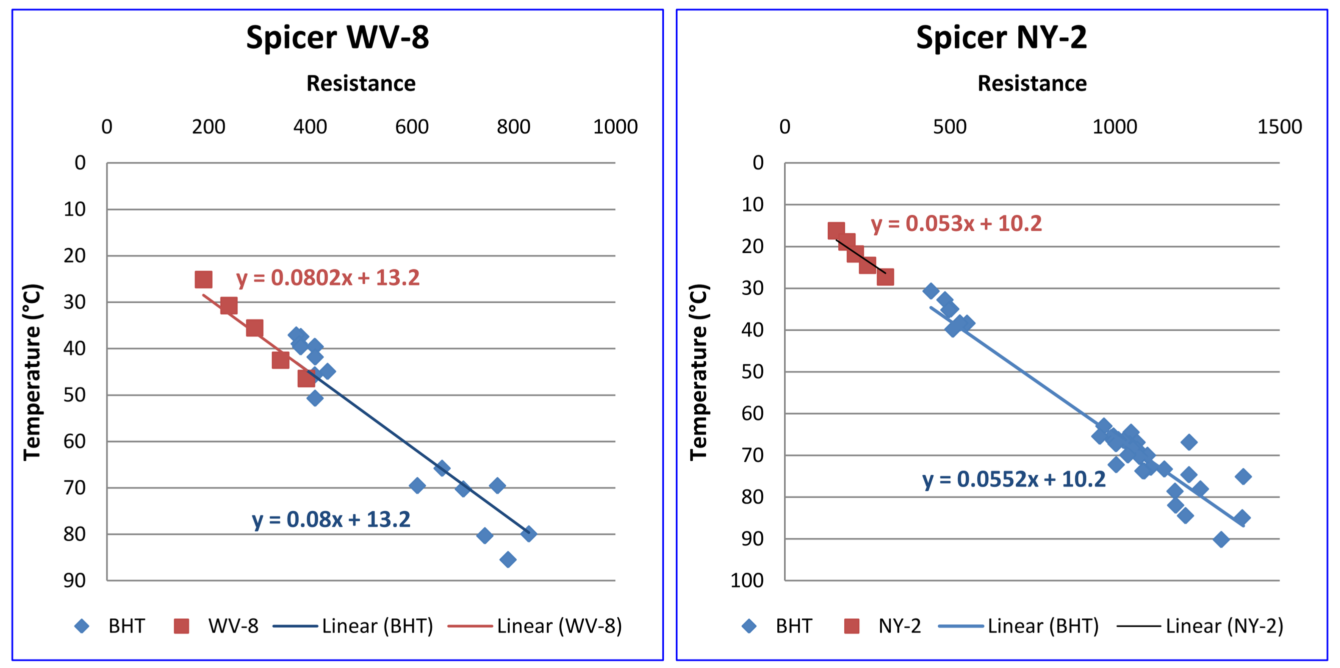
*Table adapted from Gallardo and Blackwell, 1999.



ABSTRACT

The results from a new geothermal resource assessment of the United States, including for the first time detailed data for much of the eastern US, are summarized along with the techniques used to accomplish the assessment. Bottom hole temperature (BHT) data were incorporated in the eastern US, where conventional heat flow data is sparse, using BHT corrections and calculated conductivities from a regional lithology model; comparing results to overlapping conventional heat flow and BHT data for error calibration. A total of 5,000 points are now available in the northeast as opposed to the 1,000 used to produce the 2004 Geothermal Map of North America. Where neither heat flow or BHT data were not available, geophysical data (regional gravity and magnetics) were used as an ancillary predictor to the process for areas with sedimentary cover. The effectiveness of that process is demonstrated. This study uses the new heat flow data to improve the calculated heat in place to 10 km for the US. Based on the preliminary results from this work, the Appalachian Basin may contain some of the most favorable potential targets for EGS geothermal exploration in the eastern 1/3 of the United States and especially in eastern West Virginia, where temperatures of at least 150˚C are predicted at a depth of 4.5 km in localized areas.

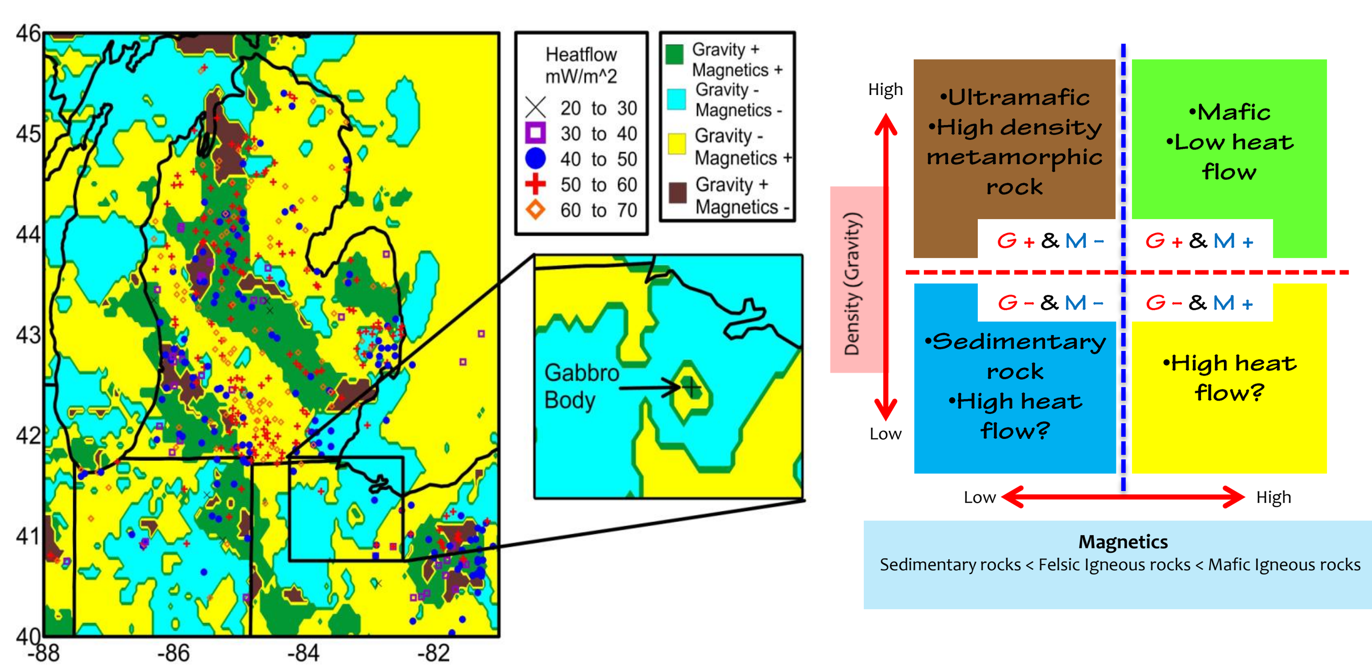
Error for Heat Flow Calculations



Bullard Plots of BHT data in the area of Spicer equilibrium temperature depth wells. The slope of a Bullard plot is heat flow. In this case it is in W/m^2 and the constant is the surface temperature.

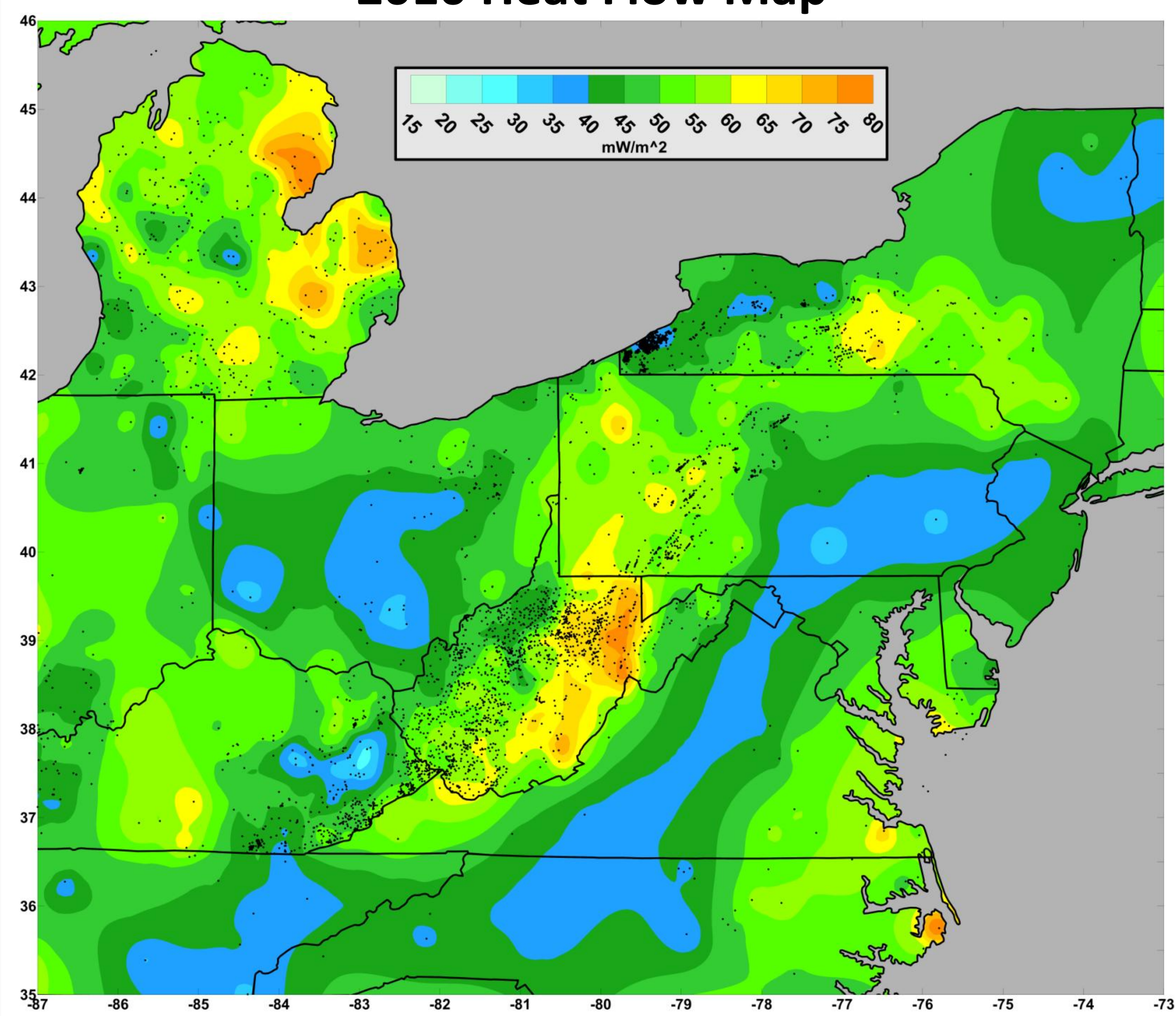
Well	Slope of Trendline	error	% error	BHT	error	% error	n	Abs. difference (slope-BHT)
WV-8	80.2	9	11.2	80.0	6.2	7.8	17	0.2
NY-2	55.2	4.3	7.8	55.2	2	3.6	40	0
		n=29	Average % error			Average % error		Average Difference
For New York, Pennsylvania and West Virginia			5.6			9.0		4.6

Geophysics/Heat Flow Comparison



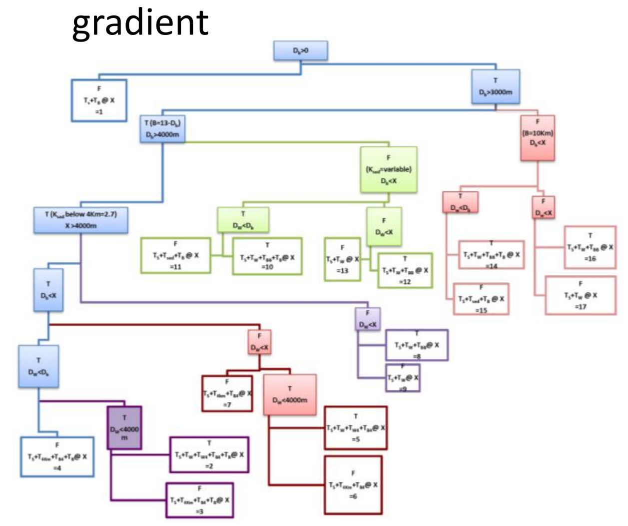
The combined gravity and magnetic maps in the Midcontinent area with a focus on Michigan and Ohio. The location of a gabbroic basement sample discussed by Ryder et al. (2008) is highlighted in the subset map, corresponding to overlap of positive gravity and magnetics values. The small dot on the map would normally be considered a gridding remnant, but with corresponding basement data it is confirmed. In general there are correlations from strong positive anomalies and strong negative anomalies to low and high heat flow, respectively.

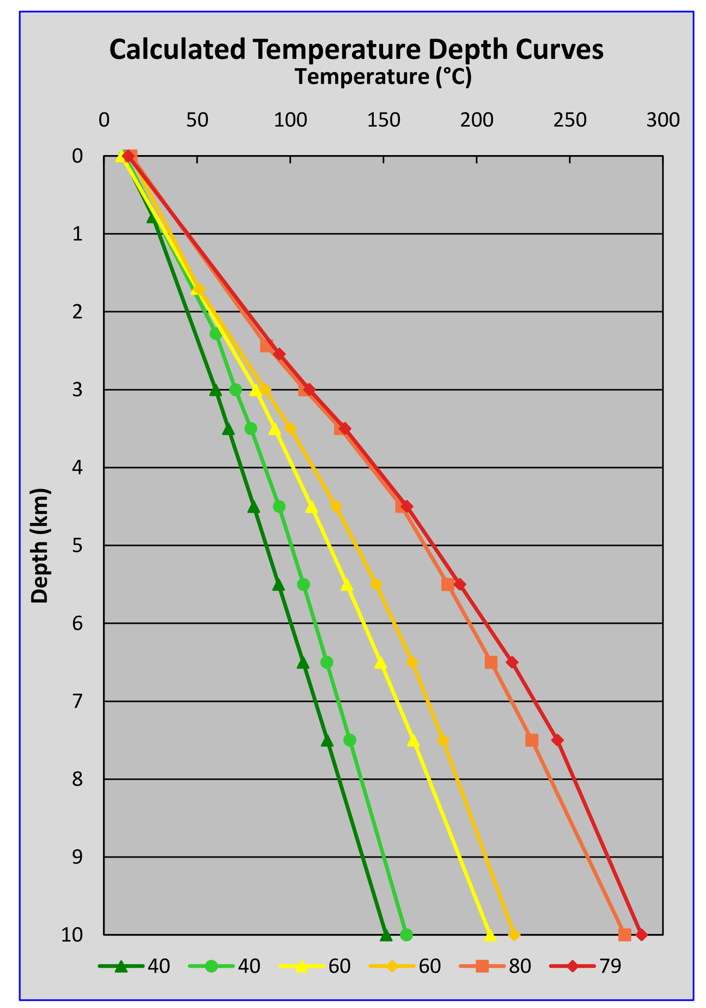
2010 Heat Flow Map



Temperature Calculations

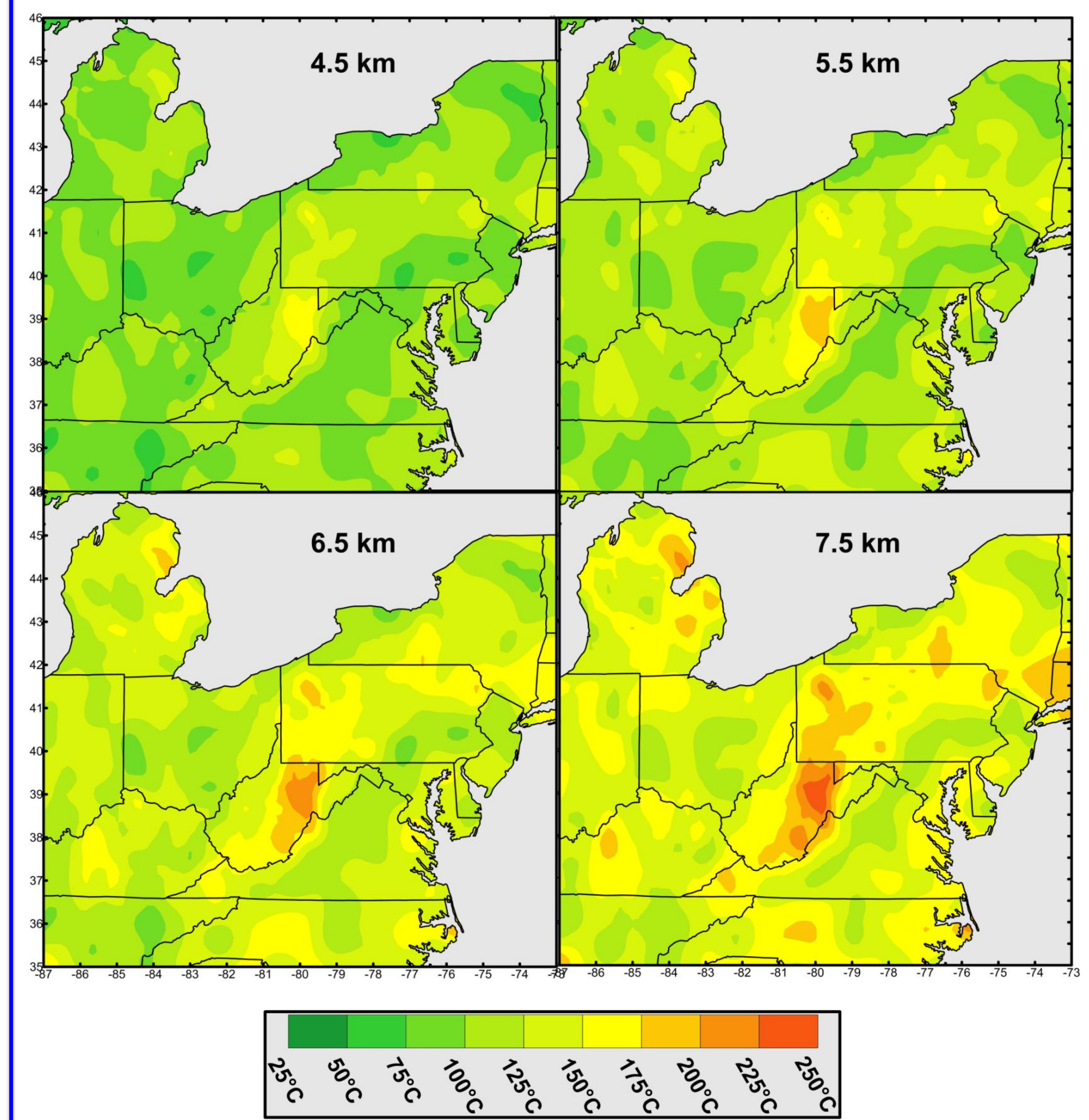
- Temperatures calculated at each data point
- Calculations take into account:
  - BHT
  - Heat flow
  - Conductivity
  - Sediment heat production
  - Basement heat production
  - Mantle heat flow
- Not an extrapolation of the gradient





Curve name corresponds to the heat flow for that well.

Temperature Maps



Future Work

- Collect well temperature data, well cores, and more detailed stratigraphy
- Comparison of BHT data with new high quality heat flow data
- Examine and more precisely define the correlation between gravity and magnetic anomalies and heat flow measurements

References

AAPG, American Association of Petroleum Geologist, CSDE, COSUNA, and Geothermal Survey Data_Rom, 1994.

AAPG, Correlation of Stratigraphic Units of North America Project, The American Association of Petroleum Geologists, 1985.

Blackwell, D. D., Maria Richards, Joseph Batir, Zachary Frone, and Junghyun Park, New Geothermal Resource Map of the Northeastern US and Technique for Mapping Temperature at Depth, GRC Transactions, v. 34, submitted, 2010.

Blackwell, D. D., and Richards, M. 2004. Geothermal map of North America. Am. Assoc. Petroleum Geologist (AAPG), 1 sheet, scale 1:6,500,000.

Blackwell, David D., Petru T. Negraru and Maria C. Richards, 2007. Assessment of the Enhanced Geothermal System Resource Base of the United States, *Natural Resources Research,* Springer Netherlands, v 15/4, *283-308, DOI 10.1007/s11053-007-9028-7.*

Gallardo, J. and D.D. Blackwell, Thermal structure of the Anadarko Basin, Oklahoma, *Bull. Amer. Assoc. Petrol. Geol.*, 83, 333-361, 1999.

Harrison, WE., Luza, KV., Prater, M.L., and Cheung, PK., 1983. Geothermal resource assessment in Oklahoma, Oklahoma Geological Survey Special Publication SP 83-1, 42 p., 1983.

Hendry, R., K. Hilfiker, D. Hodge, P. Morgan, C. Swanberg, and S. S. Shannon, Jr., Geothermal Investigations in West Virginia, Los Alamos National Laboratory, LA-9558-HDR, 57 pp., 1982.

Hodge, D. S., R. De Rito, K. Hilfiker, P. Morgan, and C. A. Swanberg, Investigations of low-temperature geothermal potential in New York State, Los Alamos National Laboratory, LA-8960-MS, 74 pp., 1981.

PA-O/G, 2009, Department of Environmental Protection: Oil and Gas Division, www.dep.state.pa.us

Perry, L. D., and J. K. Costain, Heat flow in western Virginia and a model for the origin of thermal springs in the folded Appalachians, J. Geophys. Res., 84, 6875-6883, 1979.

Ryder, R.T., Crangle, R.D., Jr., Trippi, M.H., Swezey, C.S., Lentz, E.E., Rowan, E.L., and Hope, R.S., 2009, Geologic cross section *D–D'* through the Appalachian basin from the Findlay arch, Sandusky County, Ohio, to the Valley and Ridge province, Hardy County, West Virginia: U.S. Geological Survey Scientific Investigations Map 3067, 2 sheets, 52-p. pamphlet.

Ryder, R.T., Swezey, C.S., Crangle, R.D., Jr., and Trippi, M.H., 2008, Geologic cross section *E–E'* through the Appalachian basin from the Findlay arch, Wood County, Ohio, to the Valley and Ridge province, Pendleton County, West Virginia: U.S. Geological Survey Scientific Investigations Map 2985, 2 sheets, 48-p. pamphlet.

Sass, J.H., and R.J. Munroe, Basic Heat flow Data from the United States, U. S. Geol. Surv. Open-File Report, 74-9, 1974.

Shumaker, R.C., Wilson, T.H., Basement structure of the Appalachian foreland in West Virginia: Its style and effect on sedimentation, in van der Pluijm, B.A., and Catacosinos, P.A., eds., Basement and Basins of Eastern North America: Boulder, Colorado, Geological Society of America Special Paper 308, 1996.

SMU Heatflow Database, http://smu.edu/geothermal/georesou/usa.htm.

Spicer, H. C., 1964, A compilation of deep Earth temperature data: USA 1910-1945: U.S. Geological Survey Open-File Report 64-147.

Tester, J. W., Anderson, B., Batchelor, A., Blackwell, D., DiPippo, R., Drake, E., Garnish, J., Livesay, B., Moore, M.C., Nichols, K., Petty, S., Toksoz, N., Veatch, R., Augustine, C., Baria, R., Murphy, E., Negraru, P., Richards, M. 2006. The future of geothermal energy: Impact of enhanced geothermal systems (EGS) on the United States in the 21st century. Massachusetts Institute of Technology, DOE Contract DE-AC07-05ID14517 Final Report, 374 p.