A Geothermal Investigation of 18 Bedrock Wells in Vermont

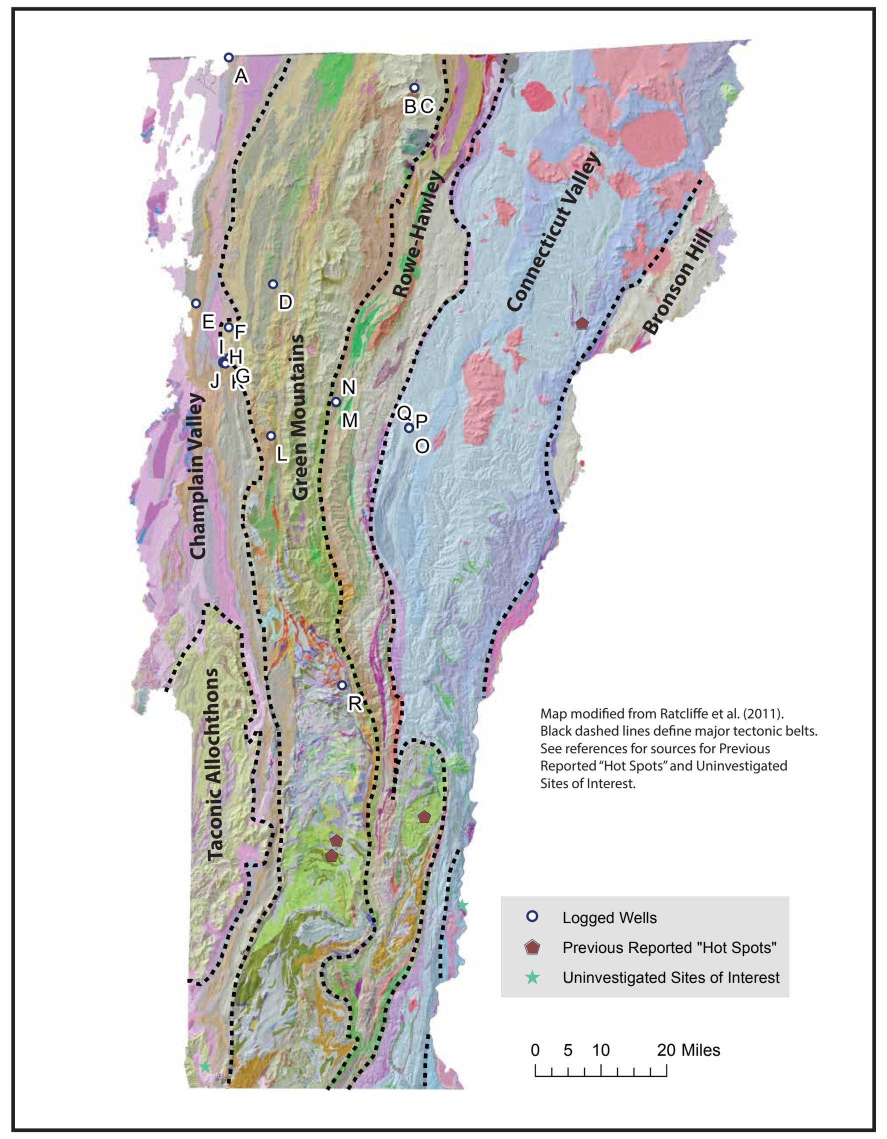
Nick Bachman, Dept. of Geology, Middlebury College, Middlebury, VT, 05753, nbachman@middlebury.edu
Jon Kim, Vermont Geological Survey, 1 National Life Dr., Davis 2, Montpelier VT 05620, jon.kim@state.vt.us
Ed Romanowicz, Center for Earth and Env. Science, SUNY at Plattsburgh, 101 Broad Street, Plattsburgh, NY 12901, romanoea@plattsburgh.edu

Abstract

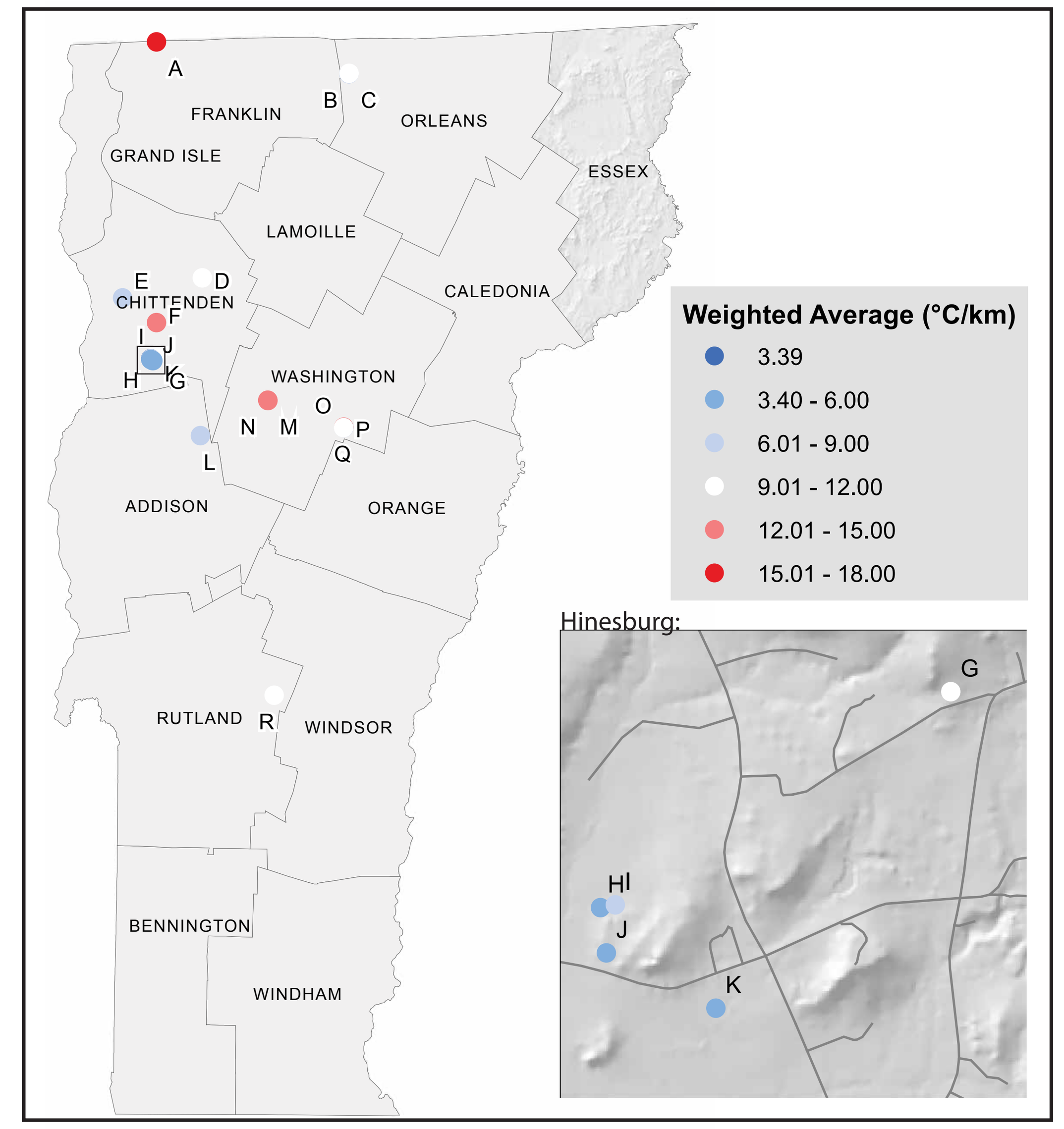
At present, the State of Vermont has not completed a thorough survey of the geothermal resources of its shallow subsurface. The lack of investigation is partly because the bedrock of Vermont is generally understood to be old, thick, and tectonically inactive, and thus "cold". Furthermore, a proper geothermal survey often relies on the existence of many deep, open wells from which Bottom Hole Temperatures (BHTs) can be collected and amassed to create a summary of geothermal potential (Shope et al., 2012). Deep, open wells are often the product of oil and gas exploration, which is practically absent in Vermont and makes such a large-scale survey impossible.

Over the past two years, Jon Kim of the Vermont Geological Survey and Ed Romanowicz of SUNY-Plattsburgh have collected high quality temperature data from 18 bedrock wells in Vermont. Though not as extensive, the Vermont data can be seen as more accurate for each location than BHT data because the entire well is surveyed and analyzed for temperature fluctuations. For each of the 18 wells, temperature and differential temperature charts were plotted and analyzed to determine the "true" geothermal gradient at each site. The differential temperature log is more sensitive to changes in temperature gradient than the temperature log and provides a more precise reference from which to calculate thermal gradients (Keys, 1989). For each well, transects with a differential temperature close to zero were selected to calculate a representative temperature gradient for each site. For 10 of the 18 wells, constant temperature gradients were interrupted by anomalous temperature fluctuations. For these 10 wells, two or three transects of constant gradient were aggregated and a weighted average was calculated.

Data continue to be collected and analyzed in order to gain a greater understanding of the complicated geologic and hydrogeologic setting of Vermont's shallow subsurface.



Well Name	Previously Calculated Gradients (°C/km)	Approximate Depth (meters)	Weighted Average (°C/km)	(C/100')	Percent Change Between Methods
A. Highgate Border	15.16	300	16.127	0.492	6.4
B. Jay Peak Well 12	10.82	250	8.132	0.248	24.9
C. Jay Peak Well 13	8.94	175	10.406	0.317	16.4
D. Spafford Well	10.77	340	11.275	0.344	4.7
E. Champlain College	7.02	320	7.308	0.223	4.1
F. 180 Desarno Rd. Well	13.81	400	13.600	0.415	1.5
G. Place Rd. East	10.54	180	10.377	0.316	1.5
H. Hinesburg Well 7797	9.01	90	3.395	0.103	62.3
I. Hinesburg Well 8609	7.03	175	6.365	0.194	9.5
J. Hinesburg Well 8608	5.64	180	5.689	0.173	0.9
K. Hinesburg Wainer 1	N/A	190	5.010	0.153	N/A
L. Norland	9.50	95	8.934	0.272	6.0
M. Harwood Union Well N	12.30	180	13.443	0.410	9.3
N. Harwood Union Well O	13.88	220	13.132	0.400	5.4
O. Berlin Well C	13.69	170	9.383	0.286	31.5
P. Berlin Well D	15.36	150	8.630	0.263	43.8
Q. Berlin Well A	14.85	185	12.182	0.371	18.0
R. Edgemont Condos	10.67	200	10.300	0.314	3.5



Method

Differential temperatures were calculated in Microsoft Excel using the equation:

$$[\ dT/dZ = (T_n - T_{n-1})/(Z_n - Z_{n-1})\ ]$$

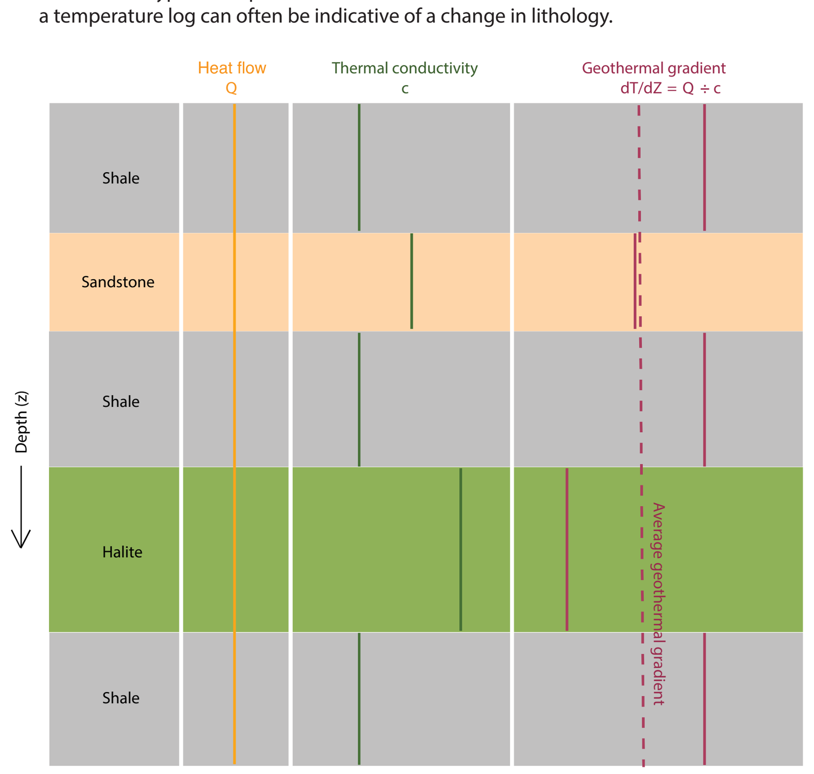
Where T = temperature and Z = depth below surface. The precision of the measurements are upwards of 0.1 degrees C and 0.1 meters. A first derivative of zero represents a linear relationship between temperature and depth. A linear relationship is expected in areas where there isn't any significant input from groundwater that would skew the otherwise constant relationship between depth and temperature in the earth's shallow subsurface. For 10 of the 18 wells, constant temperature gradients were interrupted by anomalous temperature fluctuations – assumedly associated with groundwater infiltration or some other non-geological control. For these 10 wells, two or three transects of constant temperature gradient were aggregated and a weighted average was calculated to describe the entire well.

Each temperature gradient was calculated by creating a data series in Microsoft Excel consisting of temperature (y-axis) and depth (x-axis) for each transect that was determined to have a differential temperature of zero, implying a linear relationship between temperature and depth. For each transect, a trend line was fitted to determine the slope of the line. The coefficient of the slope could then be scaled to display the temperature gradient in degrees celcius per kilmometer and degrees celcius per 100 feet. The dashed lines on the charts for each well signify where transects were calculated.

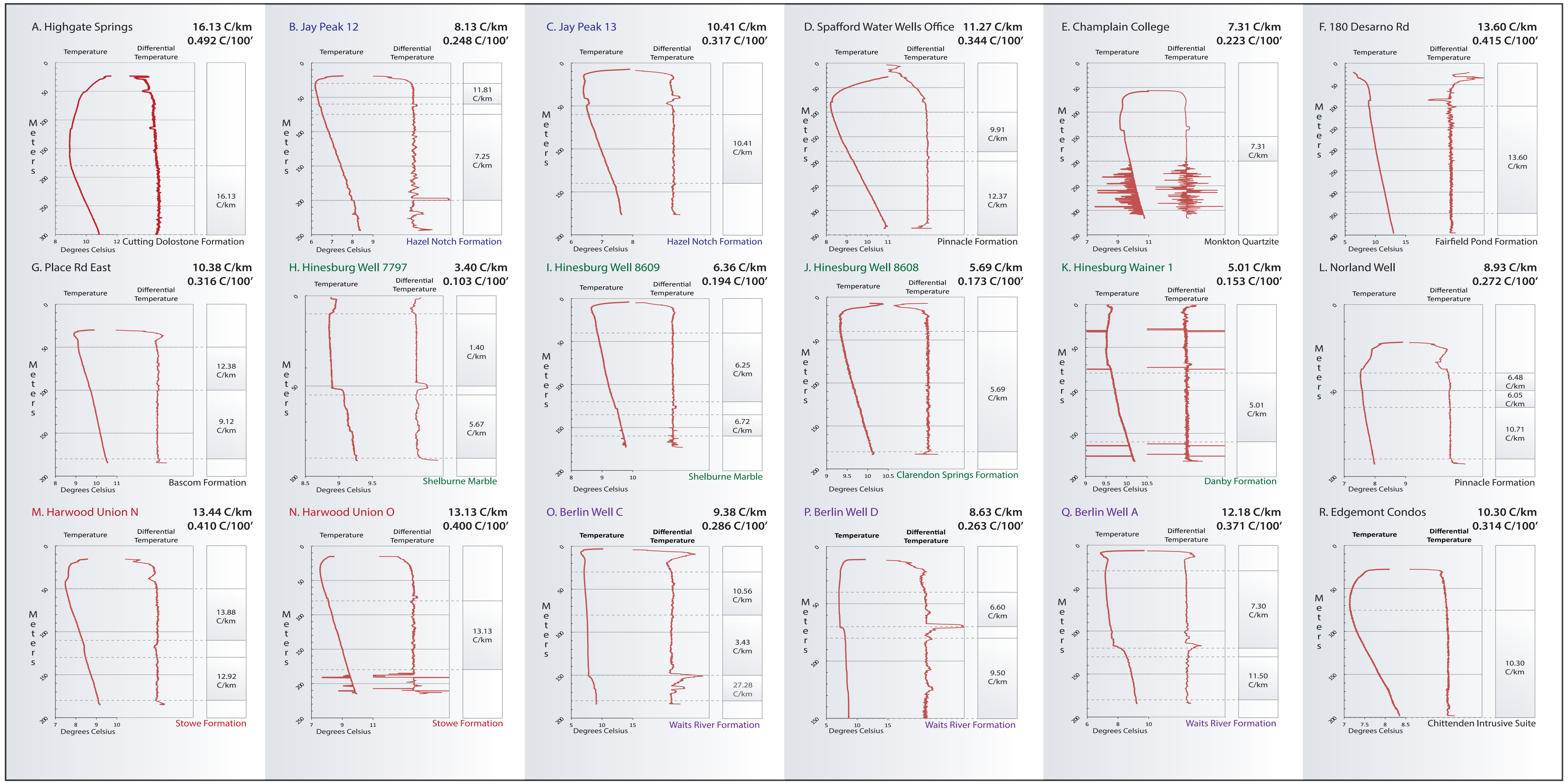
Left: Ed Romanowicz checking tension on the cable at the Altona Flats well field near Plattsburgh, New York.
Right: Dave Franzi inspecting the full logging set-up.

Heat Flow and Thermal Conductivity

The graphic below demonstrates how the geothermal gradient of a transect can be used to calculate the thermal conductivity of a rock formation if a constant heat flow is known. Certain rock types have particular thermal conductivities associated with them. "Kinks" in a temperature log can often be indicative of a change in lithology.



10/2011 This documented was inspired by Figure 9.1 of Bjørlykke (2010) (Springer). Petroleum Geoscience
Railsback's *Petroleum Geoscience and Subsurface Geology*



Discussion

Among the 10 wells with multiple transects, dissimliar temperature gradients within the same well are often apparent. These varying temperature gradients may represent changes in lithology as well as changes in the hydrological setting. For these wells, the weighted average may not give the best indication of the geothermal regime at depth. However, if coupled with more geophysical data, conclusions about changes in bedrock and water sources could certainly be reached. For many of these wells. More geophysical data has been collected by Jon Kim and Ed Romanowicz, but not analyzed. Measurements on conductivity (a proxy for dissolved species), gamma radiation (indicator of natural radioactivity), and well diameter (using a caliper tool) have been recorded at all of the sites.

In Hinesburg, research and analysis continue in order to help the town better undestand its water resources. On well H (Hinesburg 7797), note the jump in temperature just below 50 meters. Though relatively deep, this "jump" is associated with an influx of warmer water that is presumed to connected to surface water. Well H was logged in late May. If it was logged during the winter the jump may not be apparent and if it was logged in late summer, the jump may be much larger.

"Previously Calculated Gradients"

Jon Kim of VGS calculated preliminary temperature gradients for each of the 18 wells from depths of 50 -100m to the bottom of each well . The last column in the table above displays the percent difference between the two methods. Some of the wells showed minimal change between the two methods while others, such as Hinesburg Well 7797 and Berlin Well D, changed significantly.

References

Brophy, Gerald P. "Geothermal Resource Assessment of the New England States." Rep. no. DE83 010022. Amherst, MA: Department of Energy, 1982. Print.

Keys, W. S. Borehole Geophysics Applied to Ground-water Investigations. Washington, D.C.: U.S. Dept. of the Interior, U.S. Geological Survey, 1990. Print.

Railsback, L. B. "Heat Flow, Thermal Conductivity, Geothermal Gradient, and Subsurface Temperatures." Petroleum Geoscience and Subsurface Geology. University of Georgia, Athens, GA, Oct. 2011. Web. July 2014.

Ratcliffe, N.M., Stanley, R.S., Gale, M.H., Thompson, P.J., and Walsh, G., 2011, Bedrock Geologic Map of Vermont: U.S. Geological Survey Scientific Investigations Map 3184, 3 sheets, scale 1:100,000.

Renner, J. L., and Tracy L. Vaught. "Geothermal Resource Assessment of the Eastern United States." Rep. no. DOE/ET/28373-T2. Arlington, VA: Department of Energy, 1979. Print.

Shope, Elaina N. "Geothermal Resource Assessment: A Detailed Approach to Low-Grade Resources in the States of New York and Pennsylvania." 37th Stanford Geothermal Workshop (2012): n. pag. Print.

Geographic data from the Middlebury College Geography Department and the Vermont Geological Survey