Connecticut Geothermal Energy Project:
Inferred Temperature at 4 Km Depth
2013

About This Map

The Connecticut and Massachusetts Geological Surveys collaborated on a National Geothermal Data Project funded by the US Department of Energy through the Association of American State Geologists. The goal was to develop information to assist in locating deep geothermal resources and provide data for better design of Enhanced Geothermal Systems in bedrock and unconsolidated sediments. Bedrock units suspected capable of producing radiogenic heat at depth were the primary focus of this study. Additional bedrock units were analyzed to provide a regional view of the geothermal potential across the State. A total of 55 bedrock units were targeted and 242 samples were collected for this study

This map shows the location of surface outcrop samples for which temperature at 4 km is inferred. Direct measurements of thermal conductivity and density were obtained along with geochemical analyses of the samples. This data was then used to calculate heat production values, inferred heat flow values and inferred temperature at 4 km depth. With knowledge of surface temperature (T_0) in ^{0}C, heat production (A) in μW/m³, thermal conductivity (K) in W/m/^{0}K, and heat flow (Q) in mW/m², the temperature at any depth (T_z) can be approximated by:

$$T_z = T_0 + Q/K \times (z - z_0) - A/2K \times (z - z_0)^2$$ *(Philpotts and Ague, 2008)*

A near surface temperature of 11.0 ^{0}C is the average from over 844 well temperature measurements in Massachusetts. This is consistent with well water temperature measurements made in Connecticut. The thermal conductivity is measured directly on polished slabs of the sample using a C-Therm TCi Thermal Conductivity meter, which utilizes the modified transient plane source technique. The standard error for these measurements is typically within ±0.14 W/m/^{0}K (~5%) and measurements on National Institute of Standards (NIST) standards are within 0.06 W/m/^{0}K. The thermal conductivity of a few samples have been estimated from their chemical composition. Heat production is calculated from the chemical composition and measured density (D) of the samples.

$$A = ((K_2O) \times 0.0297) + (U \times 0.0967) + (Th \times 0.0263)) \times D$$

The concentration of K_2O, U, and Th are determined by X-ray Fluorescence Spectroscopy (XRF) following modifications of the methods of Norrish and Chappel (1967) outlined in Rhodes and Vollinger (2004). The lower limits of detection are 0.001 weight percent for K_2O and 0.3 ppm for both U and Th. Results for standard rocks are typically within ±0.04 weight percent for K_2O and ±0.4 ppm for U and Th.

Heat flow is estimated from heat production, which for New England is approximated by:

$$Q = A \times 7.506 + 33.1$$ *(Birch et al., 1968; Roy et al., 1968)*

Results from studies in Maine plutons (Decker, 1987) are consistent with this relationship within a variance of ±15%. However, if heat-producing layers are less than 7.5 km in thickness their temperatures may be over estimated. Conversely, if these heat-producing layers exceed 7.5 km in thickness their temperatures may be under estimated.

References

Birch, F., Roy, R.F. and Decker, E.R., 1968. Heat flow and thermal history in New England and New York. In *Studies in Appalachian Geology; Northern and Maritime,* eds., E-an Zen, W.S. White, J.B. Hadley, and J.B. Thompson, Interscience Publishers, New York, pp.437-452.

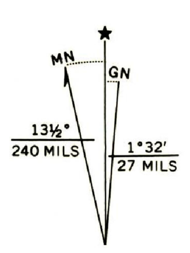
Decker, E.R., 1987. Heat flow and basement radioactivity in Maine: First-order results and preliminary interpretations, *Geophysical Research Letters,* v.14, pp.256-259.

Norrish, K., and Chappell, B.W., 1967. X-Ray fluorescence spectroscopy. In Zussman, J., ed., *Physical Methods in Determinative Mineralogy.* Academic Press, London, pp. 161-214.

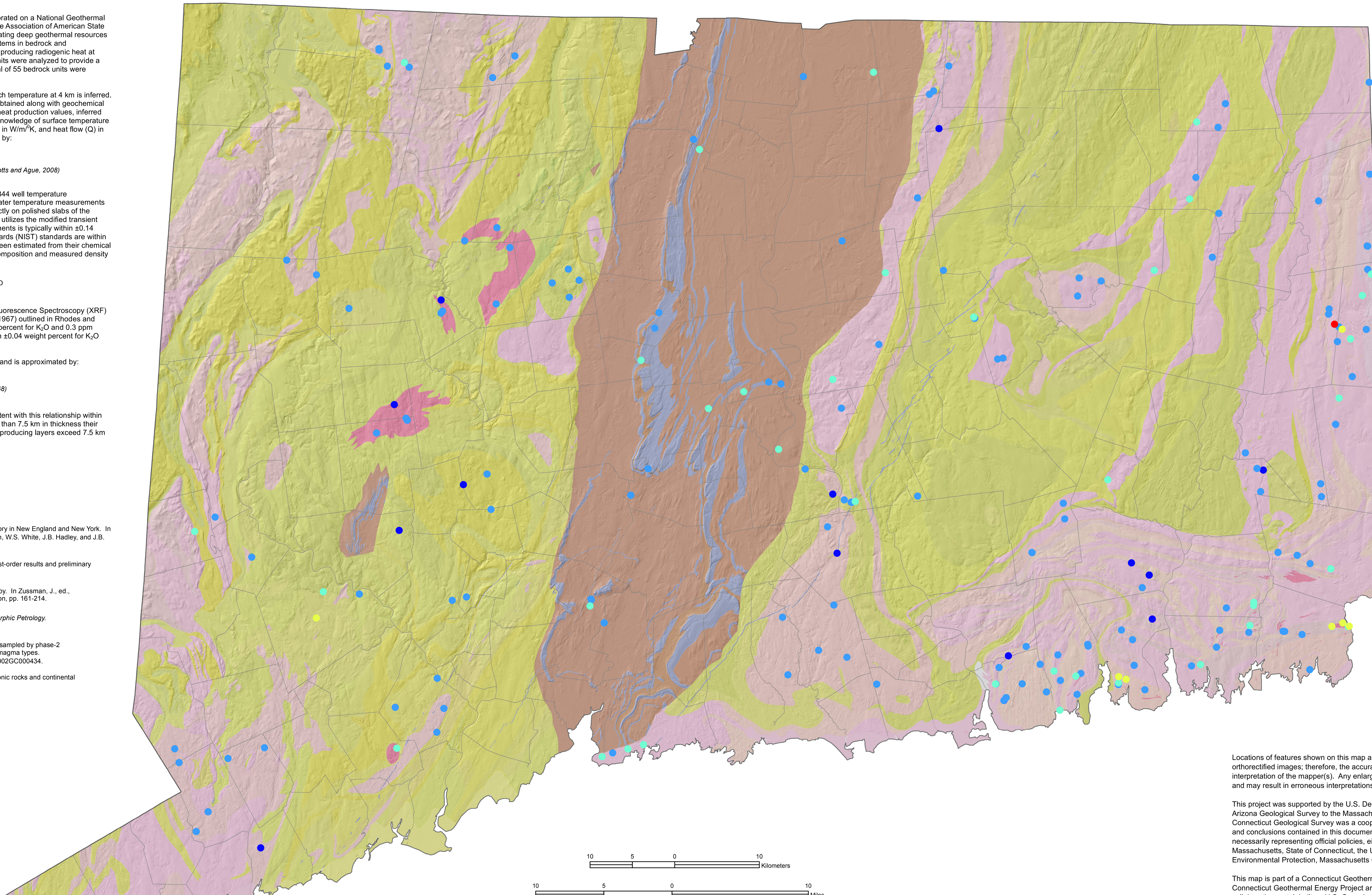
Philpotts, A.R. and Ague, J.J., 2008. *Principles of Igneous and Metamorphic Petrology.* Cambridge University Press, pp.6-13.

Rhodes, J.M., and Vollinger, M.J., 2004. Composition of basaltic lavas sampled by phase-2 of the Hawaii Scientific Drilling Project: Geochemical stratigraphy and magma types. *Geochemistry, Geophysics, Geosystems,* v.5, Q03G13, doi: 10.1029/2002GC000434.

Roy, R.F., Blackwell, D.D., and Birch, F., 1968. Heat generation of plutonic rocks and continental heat flow provinces. *Earth and Planetary Science Letters,* v.5, pp.1-12.



APPROXIMATE MEAN DECLINATION, 2013



Scale 1 : 250,000

one inch equals approximately 4 miles

Bedrock Lithology

- Granite
- Granitic Gneiss
- Mafic Igneous rocks
- Metamorphic rocks (undivided)
- Sedimentary rocks

Temperature (^{0}C) at 4 km Depth	Number of Samples
>150	1
125 - 150	0
100 - 125	7
75 - 100	43
50 - 75	173
<50	18
Sample Total	242

Sources

Hillshade base was produced by the University of Connecticut, College of Agriculture and Natural Resources, Center for Land Use Education and Research (CLEAR). It is derived from point elevation data captured during the year 2000 using Light Detection And Ranging (LiDAR) technology. Note, the 2000 LiDAR data for Connecticut is incomplete, necessitating interpolation in some areas. See http://cteco.uconn.edu/data_guides.htm for further information. This data is available for download at www.ct.gov/deep/gisdata

Geologic units are generalized from the Bedrock Geological Map of Connecticut, Rodgers (1985)

Field sampling by T.K. Gagnon, R. Steinen, G.C. Koteas and A. Ryan (2010-2012).

Sample preparation and lab analyses by G.C. Koteas, R. Weiss, S. Adams, C. League, M. Vollinger, M. Mnich and B. Leighton at the University of Massachusetts (2010-2012).

Digital cartography and editing by T.K. Gagnon, M.A. Thomas, J.M. Rhodes, S.B. Mabee, L.C. Belliveau (2013).

Connecticut Geothermal Energy Project: Inferred Temperature at 4 km Depth

By: T.K. Gagnon[1], G.C. Koteas[2], R.P. Steinen[1], A. Ryan[3], and M.A. Thomas[1]

Author Affiliations: [1] Connecticut Geological Survey, Connecticut Department of Energy and Environmental Protection, 79 Elm Street, Hartford, CT 06106, Email: deep.ctgeosurvey@ct.gov, [2]Norwich University, 158 Harmon Drive, Norwich, VT 05663, [3]University of British Columbia, 6339 Stores Road, Vancouver, BC U6P-1Z4 Canada

Comments to Map Users

Locations of features shown on this map are not surveyed, but are determined by GPS and verified using orthorectified images; therefore, the accuracy of feature locations depends on the scale of the mapping and the interpretation of the mapper(s). Any enlargement of this map could cause misunderstanding in the detail of mapping and may result in erroneous interpretations. Site specific conditions should be verified by field checking.

This project was supported by the U.S. Department of Energy through a subcontract award granted by the Arizona Geological Survey to the Massachusetts Geological Survey under award number MA-EE0002850. The Connecticut Geological Survey was a cooperative partner in the project for investigations in Connecticut.The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing official policies, either expressed or implied, of the U.S.Government, Commonwealth of Massachusetts, State of Connecticut, the University of Massachusetts, the Connecticut Department of Energy and Environmental Protection, Massachusetts Geological Survey, or the Connecticut Geological Survey.

This map is part of a Connecticut Geothermal Energy Project Map Series. All data and mapping products of the Connecticut Geothermal Energy Project are available through www.stategeothermaldata.org, a 50 State collaborative portal, built on U.S. Geosciences Information Network (USGIN) protocols and standards, and hosted by the Arizona Geological Survey.

Citation: Gagnon, T.K., Koteas, G.C., Steinen, R.P., Ryan, A., Thomas, M.A., 2013. Connecticut Geothermal Energy Project: Inferred Temperature at 4 km Depth. Connecticut Geological and Natural History Survey, Miscellaneous Map MM-2013-05. Scale 1:250,000. 1 sheet. Adobe PDF.

This map and other Connecticut Geological and Natural History Survey Publications are available at www.ct.gov/deep/geology

Acknowledgements

Special thanks are extended to J. Michael Rhodes and Stephen B. Mabee of the University of Massachusetts, and the Massachusetts Geological Survey for the conceptual design of the geothermal data collection and mapping project. The Association of American State Geologists and the Arizona Geological Survey were instrumental in bringing this U.S. Department of Energy program to the State Surveys.

Connecticut Geological Survey
Department of Energy & Environmental Protection
79 Elm Street, Hartford, CT 06106
deep.ctgeosurvey@ct.gov
www.ct.gov/deep/geology