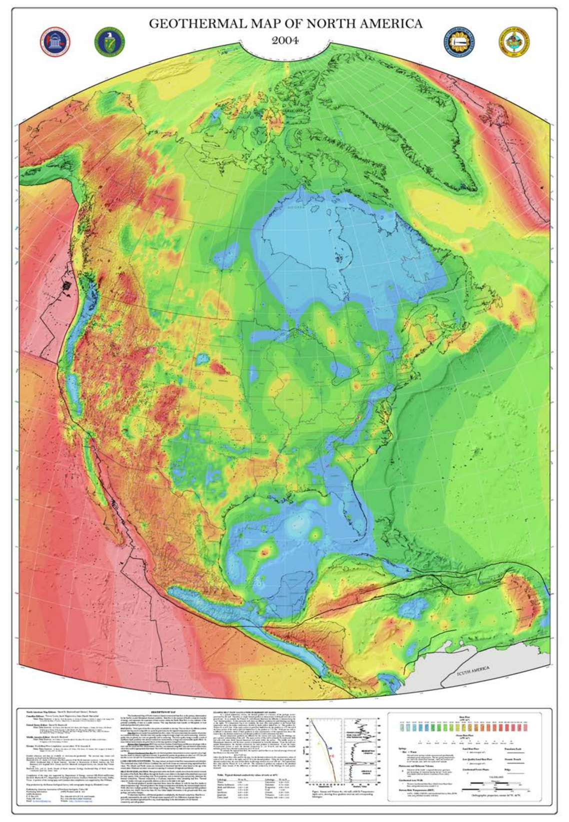
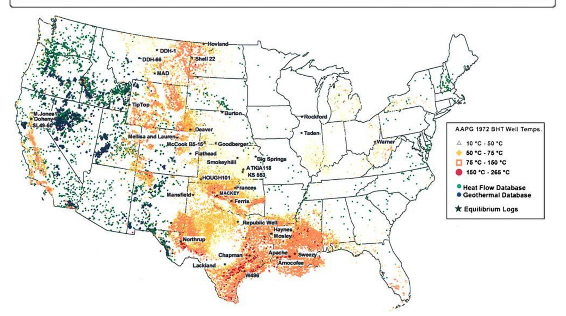
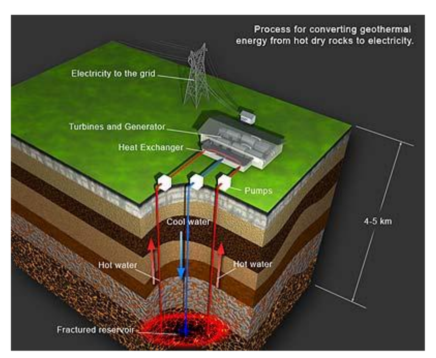
GEOTHERMAL ENERGY: TECHNOLOGY, GEOLOGIC SETTINGS, AND THE NATIONAL GEOTHERMAL DATA SYSTEM

Poster: M. Gale, L. Becker and J. Kim, 2013

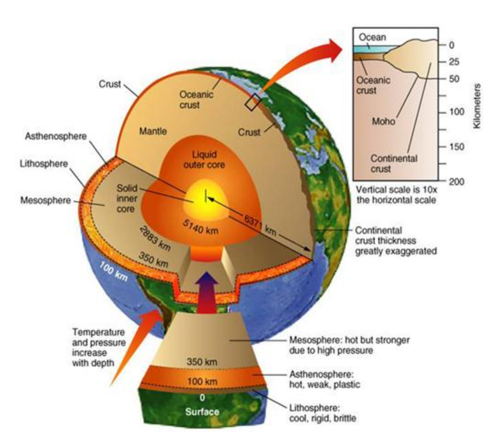




Figures 1 and 2: (1) Geothermal Map of North America showing heat flow and (2) bottom – hole well temperature points used to calculate geothermal gradients. Note only 2 well temperature data points in Vermont and low values for calculated heat flow.
Mean continental heat flow is 65 mW m^{-2};
Average heat flow values are: Proterozoic: 58.3+/-23.6 mW m^{-2};
Paleozoic sedimentary and metamorphic: 61.0+/-30.2 mW m^{-2};
Paleozoic igneous: 57.7 +/- 20.5 mW m^{-2}
Heat flow numbers from: Pollack et al., 1993, Heat loss from the earth's interior: analysis of the global data set: Revs. Geophys, 31, p.267-280.



"A geothermal system is any localized geologic setting where portions of the Earth's thermal energy may be extracted from a circulating fluid and transported to a point of use.
A geothermal system includes fundamental elements and processes, such as fluid and heat sources, fluid flow pathways, and a caprock or seal, which are necessary for the formation of a geothermal resource." USGS



Data on the Earth's Interior

	Thickness (km)	Density (g/cm³) Top	Bottom	Types of rock found
Crust	30	2.2	—	Silicic rocks.
		—	2.9	Andesite, basalt at base.
Upper mantle	720	3.4	—	Peridotite, eclogite, olivine, spinel, garnet, pyroxene.
		—	4.4	Perovskite, oxides.
Lower mantle	2,171	4.4	—	Magnesium and silicon oxides.
		—	5.6	
Outer core	2,259	9.9	—	Iron+oxygen, sulfur, nickel alloy.
		—	12.2	
Inner core	1,221	12.8	—	Iron+oxygen, sulfur, nickel alloy.
		—	13.1	
Total thickness	6,401			

NEAR SURFACE SYSTEMS

TECHNOLOGY

Comparing the Cost of Heating Fuels
March 2011

Type of Energy	BTU/unit	Adj Effic	$/unit	$/MMBtu
Fuel Oil, gallon	138,200	80%	$3.62	$32.70
Kerosene, gallon	136,600	80%	$3.98	$36.43
Propane, gallon	91,600	80%	$3.39	$46.29
Natural Gas, therm	100,000	80%	$1.55	$19.40
Electricity, kwh	3,412	100%	$0.15	$43.46
Geothermal, kwh	3,412	400%	$0.15	$10.87
Wood, cord (green)	22,000,000	60%	$180.00	$13.64
Pellets, ton	16,400,000	80%	$247.00	$18.83

Note: MMBtu equals 1 Million Btus

Cost Comparison Chart (above) from Green Mountain Geothermal, LLC (http://www.vermontgeo.com/) based on Vermont Public Service Dept monthly fuel price reports

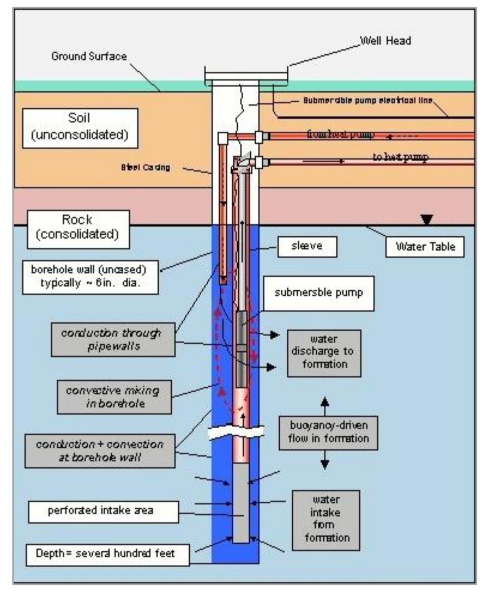


Figure 3. Standing Column Well Configuration: Conduction with borehole wall; see thermal conductivity tables below.
Image from Geo4VA (http://www.geo4va.vt.edu/A2/A2.htm#A2sec1): Virginia Tech, VA Dept. of Mines, Minerals, & Energy and VA State Energy Office

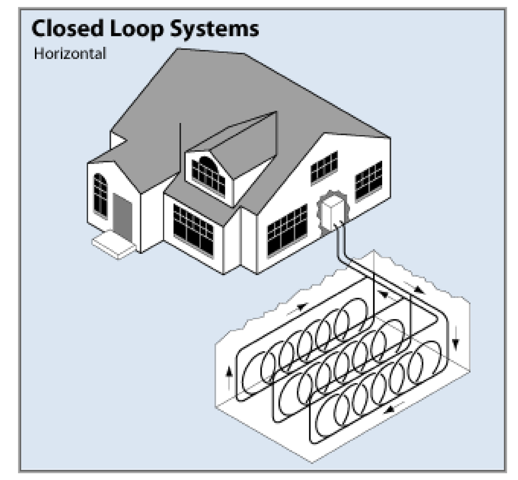


Figure 4. Closed loop system

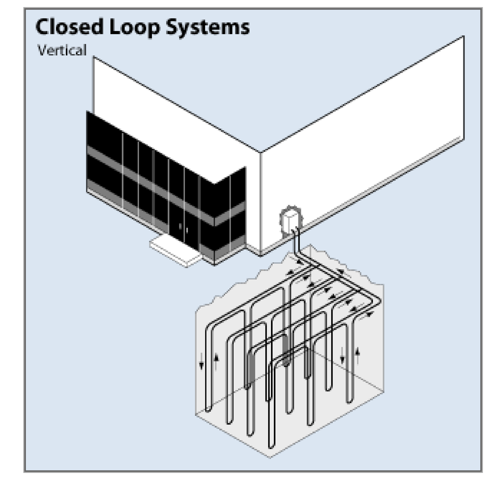


Figure 5. Closed loop system.

Figures 4,5,6. In a closed loop, water is circulated either horizontally (4) or vertically (5) in unconsolidated materials (4 or 5). In an open loop system (6) water may be discharged.back into the borehole or elsewhere. Figures 4-7 from: Luce, Ben, 2011, Heating Your Home or Business in Vermont with a Geothermal System, Northeast Vermont Development Association.

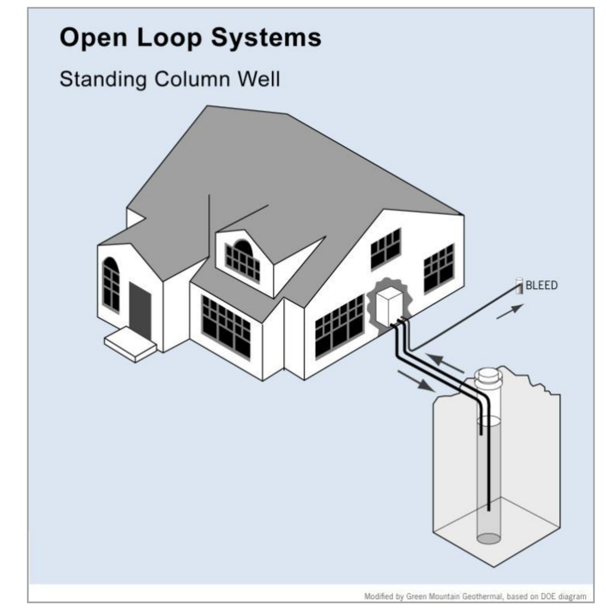


Figure 6. Standing column well; open loop system.

Schematic Diagram of an Open Loop Geothermal System in Heating Mode

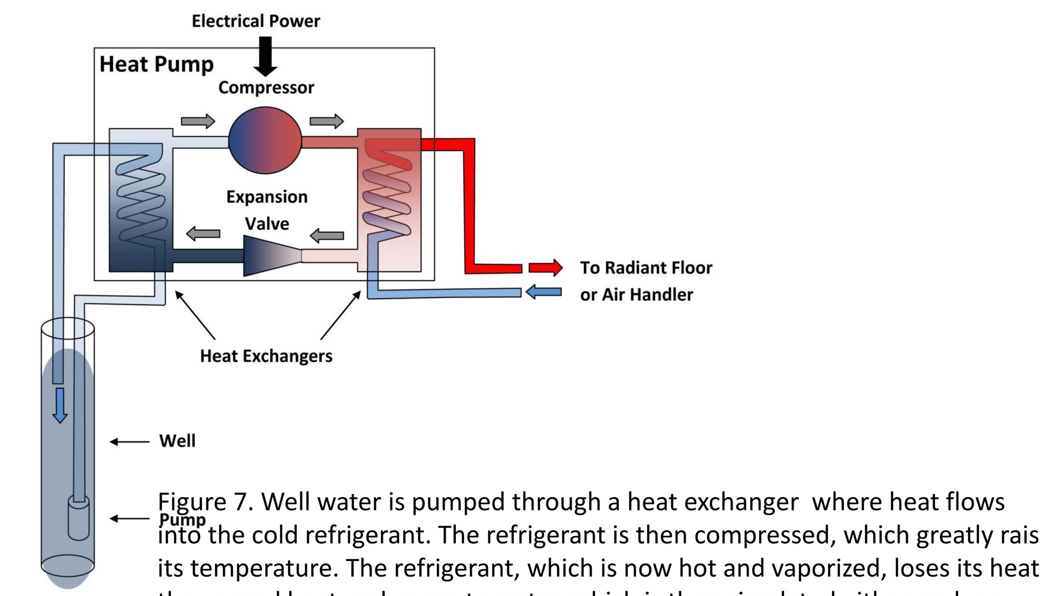


Figure 7. Well water is pumped through a heat exchanger where heat flows into the cold refrigerant. The refrigerant is then compressed, which greatly raises its temperature. The refrigerant, which is now hot and vaporized, loses its heat in the second heat exchanger to water, which is then circulated either under a radiant floor or into an air handler.

UNCONSOLIDATED MATERIALS AND WATER SUPPLY

Figures 8-12. Surficial materials and depth to bedrock support the search for higher yield shallow sources of mean annual temperature water.
This results in lower drilling costs, adequate supply for heat exchange, and discharge and energy storage areas.
The map and cross-section (Fig. 8) show shallow water supply, sand of adequate thickness and depth, and likely ease of excavation for a horizontal closed loop system.

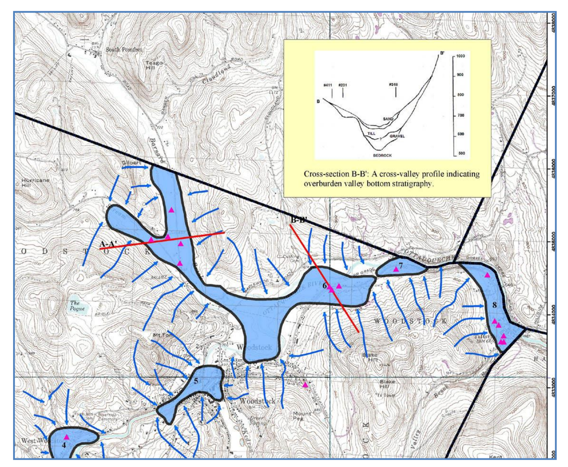


Figure 8. Shallow aquifers, recharge and cross-section inset. (DeSimone, 2007)

Figure 9. Contact of bedrock and sand; where surficial materials are thin, a standing column system is needed. Figure highlights the site specific nature of technology choices.

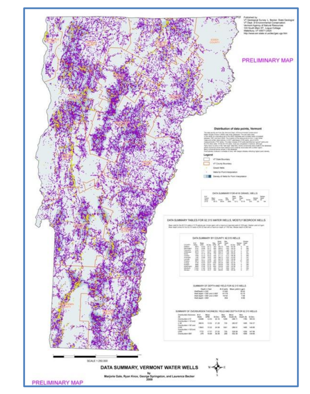
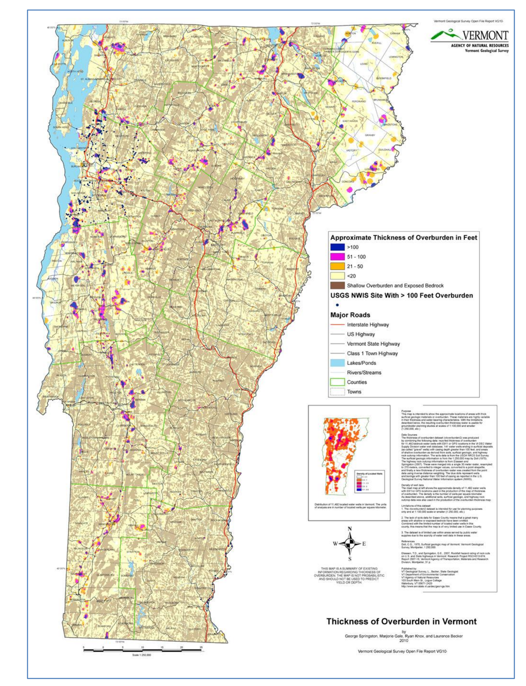


Figure 10. Water supply data provides yield and depth input for each site. Higher yield wells are favorable.

Figure 11.
Overburden Thickness Map (Springston et al., 2010). Thicker overburden may support unconsolidated materials for horizontal and vertical closed loop technologies.
Thicker overburden requires casing for vertical open loop bedrock technologies, adding additional cost.



Sands and gravels are an example of surficial deposits in Vermont.

BEDROCK, WATER WELL TEMPERATURES AND WELL LOG DATA

Figures 12-16. The Vermont Geological Survey has been collecting data and contributing to the National Geothermal Data System for the past 3 years.
The funds from the Dept. of Energy and the Association of American State Geologists support investigations for commercial Enhanced Geothermal Systems (EGS) which could be developed in deep bedrock. Advances "are needed in site characterization, reservoir creation, wellfield development and completion, and system operation, as well as improvements in drilling and power conversion technologies. " (US DOE, 2008)

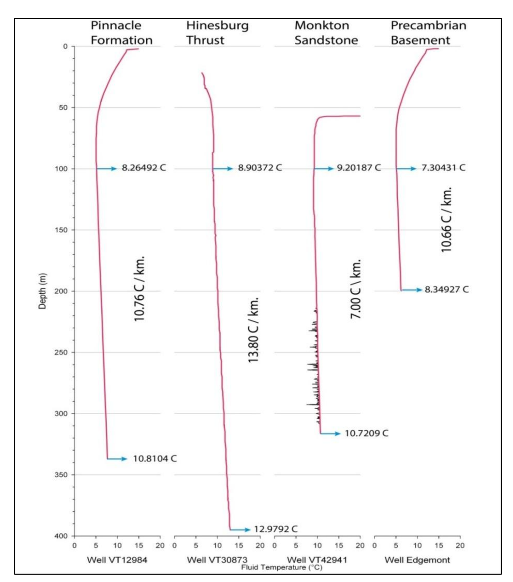


Figure 12.

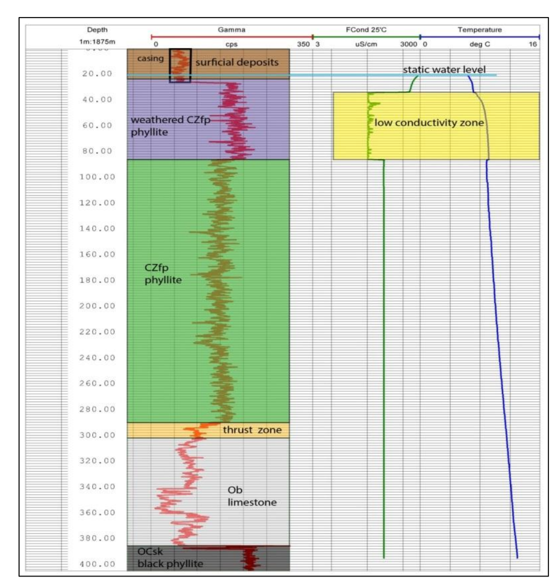


Figure 13.

Figures 12 & 13. Temperature data is being collected in accessible deep water wells. This data is used to investigate temperature gradients and well profiles. Minimum temperatures of 150°C are required for commercial geothermal systems and well data suggest that depths would need to significantly exceed 5 km if there are no other mitigating factors. Factors which may enhance a site's temperature include thick (3 km)layers of insulating sedimentary rock (low thermal conductivity) over a radiogenic rock such as granite (ie SE Australia).

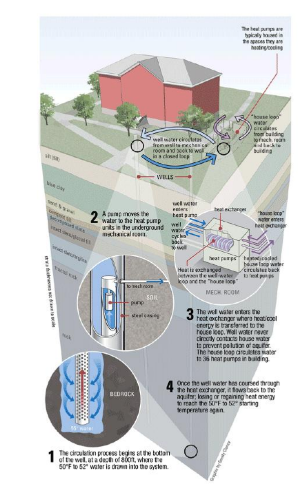


Figure 14. Drilling in the Monkton Fm at Champlain College for a standing column (shallow) geothermal system.

Hinesburg Thrust

ENHANCED GEOTHERMAL SYSTEMS (EGS)

DEEP BEDROCK (4-6.5 km), RADIOGENIC HEAT PRODUCTION AND MODELS

Site characterization from DOE:
- Temperature gradients and heat flow
- Lithology and radioactivity
- Fluids/geochemistry
- Geologic history
- Seismic activity
- Proximity to transmission lines
- Land availability
- Demographics

VGS Approach:
Geologic Domains
Thermal Conductivity Samples
Uranium, Thorium, Potassium
Temperature Data
Transmission Lines

Figure 15. Bedrock map with transmission lines helped guide a sampling plan.

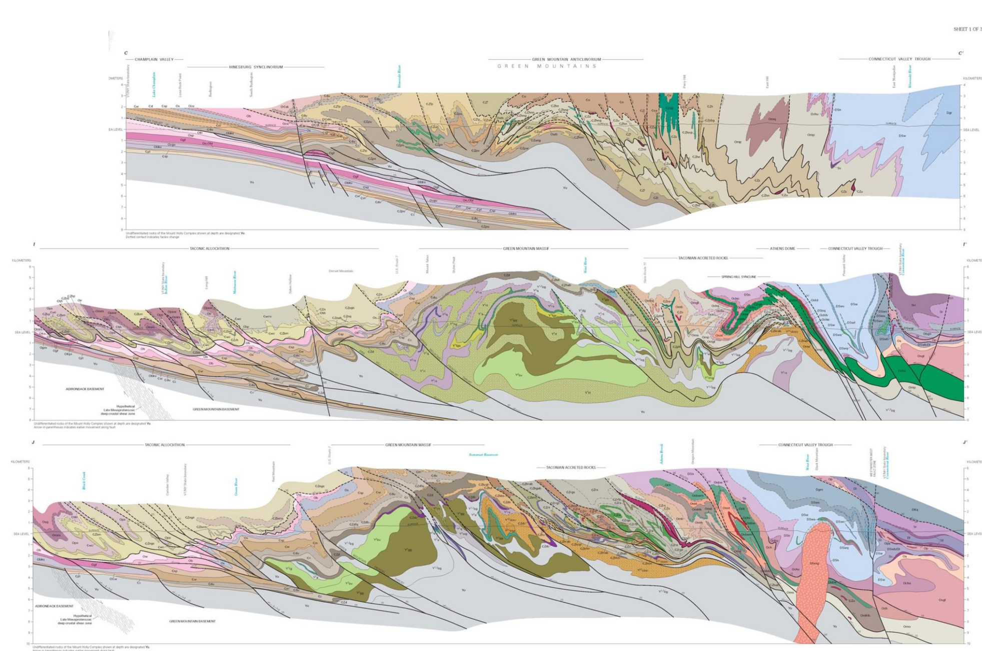
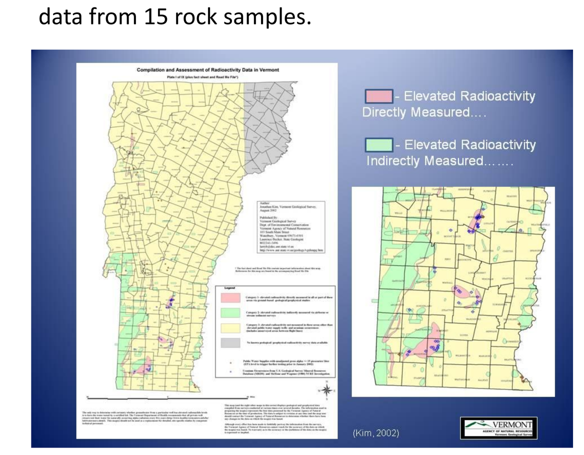


Figure 16. Cross-sections through geographic/geologic domains of preliminary interest:
NW VT – C-O shales, dolomites, limestones, quartzite over Precambrian bedrock
SW VT/Taconic Allochthons - Slates capping C-O cover rocks over Precambrian basement
Eastern VT/CT Valley – Exposed granite; S-D sandy marble and phyllites over granitic rocks
Green Mountains – Precambrian and basement overlain by C-O schists and phyllites

SiteLocName	SampleDensity(g/cc)	SaturatedSampleConductivity	DrySampleConductivity	GeologicFmName
Swanton Quarry (SLC)|Swanton	2.03	2.37	2.01	Iberville Shale/ls
Crosstown Rd|Berlin	2.69	3.79	3.04	Waits River Sandy marble
Camara Slate	1.97	1.78	1.42	Mettawee Grey slate
Barre Granite	2.58	3.18	2.89	NH Plutonic Suite granodiorite
Rte 100, Waterbury	2.58	1.75	1.54	Ottauquechee Black phyllite
Rte 7, Shelburne	2.82	4.89	4.72	Winooski Dolostone

Figure 18. Representative thermal conductivity data measured at 1350 psi and 20°C by SMU. Units are W/m/K. We have collected 40 representative rock samples from Vermont for analysis. Rocks are cut into 1" X 1.5" plugs with parallel ends and run both dry and saturated at slightly elevated pressures.

Figure 17. Radioactive decay of uranium, thorium and potassium contribute to heat production.
If a rock's density p and its concentrations in ppm of uranium, thorium, and potassium are known, its radiogenic heat generation rate can be determined.
We are collating existing data and collecting new data from 15 rock samples.



Slate

Limestone

Gneiss

VERMONT
AGENCY OF NATURAL RESOURCES
Vermont Geological Survey