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MASTER

**Analysis of Potential
Geothermal Resources and
Their Use: Lebanon Springs
Area, New York**

**New York State Energy
Research and Development
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ANALYSIS OF POTENTIAL GEOTHERMAL RESOURCES AND THEIR USE:
LEBANON SPRINGS AREA, NEW YORK

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ABSTRACT

This work was performed to determine the feasibility of using thermal waters at Lebanon Springs or elsewhere in the Capital District of New York as an energy source. To evaluate the area, geologic mapping of the Lebanon Springs, New York, to Williamstown, Massachusetts, area was conducted, and efforts made to locate additional thermal waters besides those already known. In addition to mapping, thermal gradients were measured in twenty-five abandoned water wells, and the silica contents and water temperatures of seventy-eight active domestic water wells were determined. Based on the results of that work, Lebanon Springs appears to be the first choice for a demonstration project, but further exploration may confirm that other areas with good potential exist. A preliminary economic analysis of possible uses in the Town of Lebanon Springs was made, and it was determined that a system combining groundwater heat pumps and a microhydroelectric plant could be applied to heating the Town Hall, Town Garage, and High School with significant savings.

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EXECUTIVE SUMMARY

The purpose of the Lebanon Springs study was to determine the feasibility of using warm waters at Lebanon Springs or elsewhere in the Capital District for energy purposes. During the course of the study, legal problems in obtaining rights to use the water of Lebanon Springs and with drilling in the vicinity of the springs were indicated by New York State ERDA attorneys. The exploration goal therefore became locating either warm wells or other warm springs.

Geologic work indicated the presence of two warm springs not previously described in Massachusetts, but no new warm springs were found in New York. Further exploration involved potential warm water wells that might indicate the presence of usable thermal waters. Seventy-eight domestic wells were checked for temperature and silica content. Both measurements were necessary because the actual temperature of water in the wells is often difficult to measure because of heat gains or losses in holding tanks and pipes. No wells were found which had temperatures comparable to Lebanon Springs, and the silica content results were consistent with low temperature water. The highest temperature well was 16°C in comparison with the 22°C temperature of Lebanon Springs. Abandoned domestic wells were located through advertising and literature search, and temperature gradients were measured in 25 wells. An area of over 200 square miles with temperature gradients from 2 to 3.5 times the average background gradient of 8.5°C/km was defined. The presence of this area of elevated gradients suggests the presence of a usable shallow heat resource.

The work demonstrated that: (1) active domestic wells can be used to locate warm areas; and (2) silica and temperature broadly correlate, i.e., either measurement may indicate warmth. While this knowledge is extremely useful for the broader exploration program, other warm waters in the area of interest that might be used as a demonstration project for the use of thermal waters as an energy source were not located. An area of potential interest occurs near Poestenkill based on temperature gradient data. The actual presence of warm water was not shown, however, and without additional work in that area, it is not recommended as a site with immediate potential use.

With no other warm water currently available in eastern New York State, it was concluded that even with the attendant difficulties the best site for a demonstration project was Lebanon Springs itself. This was discussed at a Lebanon Springs

town meeting in which New York State ERDA, DGC and RGJ & Associates participated. At this meeting, the purposes and background of the study were discussed and a preliminary economic analysis of possible uses was presented. It was concluded that if between 400 to 500 gpm are available from Lebanon Springs at a temperature of 72° F, with a head of 120 feet above the town buildings, a combination of heat pumps in the Town Garage, Town Hall, and high school and a microhydroelectric plant could save up to \$34,990 per year (adjusted for amortization of installation cost) at an installation cost of \$405,000. More detailed engineering, economic, and geologic analyses do not appear to be justified until uncertainties regarding the legal availability of the Lebanon Springs water are resolved. The sequence of steps which we recommend are: (1) Assure availability of the water; (2) Determine the actual flow of spring water that could be available for energy supply; (3) Make a detailed engineering-economic analysis; and (4) Design the systems.

SECTION 1
INTRODUCTION

INCEPTION

The research is based on a proposal by Dunn Geoscience Corporation (DGC) to New York State Energy Research and Development Authority (ERDA) called "Lebanon Spring Area Geothermal Exploration and Development" and dated June 20, 1979. A research contract dated July 26, 1979, between DGC and ERDA initiated the research.

PERSONNEL

The Principal Investigator was J. R. Dunn with review by W. E. Cutcliffe and J. R. Young. M. R. Sneeringer coordinated the field work which was done primarily by D. P. Fenno and S. A. Chisick. G. M. Banino handled financial coordination. Richard G. Jacques Associates did the preliminary engineering analysis with C. A. Hall the Principal Investigator working with J. Ward and R. G. Jacques. Dr. B. Krakow was coordinator of the project for ERDA and was closely involved throughout the research.

PURPOSES

Purposes of the Research were as described in the June 20, 1979 proposal:

Research and Exploration

Determine the cause of the thermal springs at Lebanon Springs, New York, viz.

- deep circulation of waters (approximately 5,000 ft.) along a fault zone in the presence of a normal geothermal gradient,
or
- shallower circulation (approximately 1,000 - 3,000 feet) of waters along a fault zone in the presence of an above average geothermal gradient.

Define the probable distribution and magnitude of the warm water resource as well as the economic feasibility of using it.

Indicate the best site to install a demonstration heat exchange system, viz.

- the known thermal spring at Lebanon Springs; or
- an "offset" well near the Lebanon Springs; or
- another existing thermal well or spring found during this project which has less attendant logistical problems than Lebanon Springs does at present.

Engineering

An initial investigation of the site to be made to determine the economic feasibility of developing a favorable site as an energy source for a greenhouse complex (or for other purposes).

The purposes were weighted somewhat differently in the course of the project because of legal difficulties. First, there was no assurance of access to the existing spring even though permission was given to make measurements. Second, although the thermal waters could probably be tapped by drilling near the existing spring, the possibility that such drilling could affect the spring was finally considered to be too great and could cause problems. This caused the efforts to shift more toward geologic exploration, i.e., to stress trying to locate an alternate source of warm water either in existing wells or thermal springs.

The final purpose of the work was thus directed toward defining the situation for the Town of Lebanon Springs so that further steps could be taken to develop the existing spring.

SECTION 2

GEOLOGIC MAPPING

PREVIOUS GEOLOGIC WORK

Bitter controversy and considerable debate for 150 years surrounds the exceedingly complex structural and stratigraphic relations of the Taconics area in which Lebanon Springs is located. The severity of the conflict is shown in a short review in Appendix B.

The purposes of the present geologic mapping were to (1) try to understand the causes of the Lebanon Springs thermal waters, (2) determine if other thermal waters occur in the area or if conditions in which thermal waters are found are duplicated so that other sites could possibly be tested, and (3) become familiar with the details of the geology and physiography of the area.

Mapping was conducted primarily by S. A. Chisick in the Fall of 1979 using 7½ minute, 2" = 1 mile, U.S.G.S. topographic maps as base maps. Geologic mapping consisted of locating outcrops of various rock types, plotting their locations on the topographic maps along with such data as rock identification, rock formation, and structural information. Mapping was conducted along the so-called Taconic thrust fault between Lebanon Springs and Williamstown, Massachusetts. Although mapping was concentrated in New York, mapping the Williamstown area was considered important, because knowledge of its geology would be of value for understanding the nature of the thermal springs of the Lebanon Springs area as well as the potential for other thermal waters.

Plates 1 - 8 in Appendix A are copies of the geologic maps. A detailed description of the geologic units mapped is also in the appendix. The maps are reduced from 1:24,000, 7½ minute quadrangles on which the original mapping was done. Copies of the full size maps are available in event that more detail is required.

GEOLOGIC HISTORY AND STRATIGRAPHY

Upper Cambrian through Middle Ordovician rocks are exposed in New York and contiguous Vermont, Massachusetts and Canada in a narrow belt which circumscribes the Adirondacks, extends into the Champlain Valley and farther east abuts against

the Green Mountains of Vermont and the Berkshire Mountains of Massachusetts. These rocks are exposed in the Mohawk, northern Hudson, southern Champlain, Williamstown, Berlin, Canaan, and North Petersburg-Hoosick Valley in the Valley and Ridge Physiographic Province. Rocks of equivalent age have been recognized in the subsurface in New York to the south of the Mohawk Valley. In Orange and Dutchess Counties, New York, these Upper Cambrian through Middle Ordovician rocks are exposed again. Collectively these rocks are called the Beekmantown Group but may be known locally as the Stockbridge, Wappinger, and Copake Groups and are largely dolomites.

The Beekmantown Group is underlain by Upper Cambrian sandstone and orthoquartzites (Potsdam Formation) which unconformably overlie Proterozoic igneous and metamorphic rocks of the Adirondack, Green, and Berkshire Mountains. In turn, the Beekmantown is unconformably overlain by Middle Ordovician Mohawkian carbonates (Lowville, Amsterdam, Orwell and Glens Falls Formations), graywackes (Austin Glen Formation) and shales (Snake Hill and Walloomsac Formations). The Cambrian-Ordovician carbonates and sandstones are considered to have been deposited on a shallow shelf (miogeocline) on the western side of the Great Appalachian geosyncline.

From Rutland County, Vermont, southward into eastern Washington and Rensselaer Counties, New York, and central-Columbia County, New York, lies the Taconic Sequence nested within the Middlebury Synclinorium. These rocks consist of green and maroon to gray-black slates, siltstones, graywackes, ultramafics, cherts, quartzites and grits with minor associated sandstones and limestones deposited in a deeper water (eugeocline) slope, basin, and rise sitting on the eastern side of the Great Appalachian geosyncline. The rocks within the sequence range from Precambrian(?) and Early Cambrian to early Middle Ordovician age. The eastern part of the sequence was subjected to low-grade metamorphism and the whole sequence is intensely folded and faulted. The Taconic sequence and the shelf-sequence are the same age.

The Taconic consists of Early Cambrian slates, shales and minor quartzites (Nassau Formation, Bull Slate, Mettawee Slate) which are underlain by a number of graded grits and graywackes (Rensselaer Graywacke and Bomoseen Member) that have ultramafic pillow lava and metadiabases. The age of the Rensselaer, Bomoseen and their associated volcanics is either early Early Cambrian or Late Precambrian. Locally

overlying the Nassau, are Middle Cambrian dark gray slates, siltstones and minor limestones (West Castleton Group).

Over most of New York and Vermont, the Middle Cambrian has not been recognized.

Sedimentation resumed in Late Cambrian time and continued into the late Early Ordovician as a thick sequence of dark shales, calcitic shales and sandstones (Germanantown, Hatch Hill, and Poultney Formations) were deposited in the eugeocline.

On the shallow water carbonate shelf, deposition was discontinuous throughout the Late Cambrian and Early Ordovician in New York and Vermont in the Beekmantown Group. At the close of the Beekmantown deposition, the shelf was uplifted, eroded and slightly deformed. This uplift produced a recognized faunal break and a massive karst surface. This is a world-wide unconformity or period of erosion which is known in the United States as the Knox Unconformity. At this time normal faulting produced a series of north to northeast trending fault blocks. In the early Middle Ordovician, the seas transgressed onto their ancient shelf, inundating the northern Champlain Valley prior to entering southwestern Vermont and eastern New York. This interpretation is supported by the types and thicknesses of Mohawkian limestones found in and around the Capital District.

Complete foundering of the shelf in the later Middle Ordovician produced the thick black shales (Snake Hill and Walloomsac Formations) and the graywackes (Austin Glen Formation) to the east, which were apparently derived from rising uplifts to the east and the north. Subsequently, the Taconic Sequence was emplaced in its present position at this late Middle Ordovician time.

The present Adirondack Mountains are dome mountains which came into existence during one or more periods of arching in the early Paleozoic. This interpretation is clear from the numerous grabens formed in the Cambrian and Ordovician that ring the Adirondack perimeter and, thereby, date most of the block faulting within the Capital District Region.

The fault front which marks the westward edge of the Taconic Sequence is known as Emmon's or Logan's Line. This fault is poorly exposed in outcrops and is delineated by a variety of fault melange, tectonic slivers and geomorphic relief.

West and southwest of Albany lie the lower to mid-Paleozoic rocks, with pre-Devonian units exhibiting penecontemporaneous block faulting. The Devonian units (Helderberg Group and the Catskill Delta Complex) on top of above mentioned pre-Devonian units form the escarpment and highlands familiar to all who visit the Capital District.

STRUCTURE

The geologic structure of the area is complex as a result of various periods of faulting and folding. Plates 9, 10, and 11 in Appendix A depict geologic cross-sections which show our interpretation of the nature of the subsurface. The interpretation is somewhat different than that which might be drawn from the N.Y.S. Geological Survey's State Geologic Map.

The geology of the Capital District Region with the Taconic Sequence of slates, siltstones, graywackes, and grits and the carbonate-orthoquartzite suite surrounding the Taconics' have been studied since the early eighteen-hundreds. However, despite all the geologic work that has been done, the Capital District Region is still the subject of many vigorous controversies. Most specifically, the nature and origin of the Taconic Sequence and its relationship to the surrounding carbonate-orthoquartzite suite of the same age is controversial.

Because the geology is so controversial, the cross-sections of Plates 9, 10 and 11 are also controversial.

SEARCH FOR SPRINGS

Through interviews and as part of field mapping an attempt was made to locate other warm springs. No warm springs were found in New York but two were located at the west side of the Hoosic River Valley northwest of Williamstown, Massachusetts (for location see Plate 5). The northernmost was 67° F and the southern one was 68° F. The springs are near the base of the hill and issue from the Stockbridge carbonate rocks.

SECTION 3

SILICA AND TEMPERATURE MEASUREMENTS IN WELLS

Starting in mid-October and through December samples of water were taken from active domestic wells in the general vicinity of Lebanon Springs. The temperatures of the waters were also measured. The purpose of this work was to determine if any wells were abnormally warm or if any wells had a component of thermal water as indicated by the silica content. Because neither the temperature nor the silica content would give unequivocal results, unless exceptionally high temperatures or silica contents occurred, both methods appeared to be necessary. All wells which were accessible to the field people were measured regardless of the geologic environment of the wells.

The technique used was to let water flow through a tap for a period of about five minutes until the well pump went on and then let the pump run for about five minutes before making the temperature measurement and collecting the water sample. Although the people of the area were very helpful and cooperative, the field people did not feel that they could inconvenience home owners for more than this period of time. In all, 78 measurements were made. The information obtained is summarized in Table 3-1 and the locations of the wells are shown on Plate 12, the SiO_2 contents and water temperatures are shown on Plate 13.

The silica contents ranged from 2.1 ppm to 17 ppm and the water temperatures varied from 2.4° to 15.5° C. The temperatures of some wells were not measured because of a coordination problem.

The silica contents were plotted against corresponding temperatures for the area in question. This produced a shot-gun type diagram, with an obvious, though general positive correlation of silica content and temperature. A rough statistical evaluation of the highest and lowest silica contents and their corresponding temperatures, and highest and lowest temperatures and their corresponding silica contents confirmed that high silica contents and high temperatures are related, and similarly low silica contents and low temperatures are related. The value of this exercise is apparent when examining the geographical relationships of the data. In areas where there are consistently higher silica values, there is a corresponding higher average water temperature, and although individual measurements may appear not to fit, the general delineation of slightly warmer areas can

TABLE 3-1
SILICA CONTENTS AND WATER TEMPERATURES

Sample No.	Name	Date	Silica ppm	T(°C)	Location
101	Mueller	10/18	6.9	7.2	Rt. 20, West Lebanon
102	Lebanon Springs High	10/16	5.4	8.3	Rt. 22, Lebanon Springs
103	Darrow School	10/16	7.5	7.8	Off Rt. 20
104	One Better Hair Dresser	10/16	9.2	11.8	Rt. 33 near cemetery
105	Spring	10/16	4.8	10.0	Richmond-Canaan Rd.
106	Seagroats Florist	10/18	15.0	8.3	Satterlee Hollow Rd., Berlin
107	Shyffer	10/16	5.9	7.2	Deerhill Rd., Richmond, Mass.
108	Hingher	10/18	12.0	7.2	Coonbrook Rd., Petersburg
109	Bagpipe School	10/18	2.4	7.8	Pucatou Rd., Lindsay, Petersburg
110	Kuster	10/16	6.2		Beebe Pond Rd., Canaan
115	Adams	10/18	15.0	12.7	Rt. 43, Stephentown
116	Roberts	10/17	9.7		Cannon Rd., New Lebanon
117	Hanson	10/17	5.9		Churchill Rd., New Lebanon
118	Leab	10/18	5.6	11.9	Rt. 43, Hancock, Mass.
119	Wilson	10/17	5.2		Valley Rd., Canaan
120	Burns	10/17	13.0		Rt. 5, Canaan
122	Saviano	10/17	13.0		Canaan Rd., Canaan
123	Saviano	10/17	5.0		Canaan Rd., Canaan
124	Nevers	10/17	14.0		Canaan Rd., Canaan
125	Overly	10/17	15.0		Cannon Rd., New Lebanon
126	Walter	10/17	13.0		Cannon Rd., New Lebanon
127	Benson	10/17	12.0		Rt. 5, Lebanon Springs
128	Oherly	10/17	7.5		Rt. 5, Lebanon Springs
129	Town Petersburg	10/17	8.3	7.8	Rt. 2, Fly Creek
130	Defreest	10/17	14.0		Rt. 5, New Lebanon
131	Fooby	10/17	14.0		Knap Rd., Stephentown
132	Monette	10/18	5.7	11.8	Rt. 43, Hancock, Mass.
133	Swersey	10/17	6.9		Goodrich Hollow Rd., Stephentown

Table 3-1 (continued)

Sample No.	Name	Date	Silica ppm	T(°C)	Location
134	Jacobs	10/17	4.7		Goodrich Hollow Rd., Stephentown
135	Stephentown Elementary	10/15	16.0	14.0	Stephentown
136	KOA	10/18	16.0		Rt. 43, Stephentown
137	Franze	10/18	12.0	14.7	Rt. 43, Stephentown
138	Pease	10/17	8.9		Rt. 22, Stephentown
139	Potter	10/17	11.0		445 West St., Stephentown
140	Hicks	10/17	10.0		West Rd., Stephentown
143	Fedorowicz	12/18	7.3	11.8	Rt. 66, Nassau
144	Herbert	12/18	8.1	11.9	Rt. 20, Nassau
145	Frederickson	12/18	13.0	11.6	Chestnut St., Nassau
146	Marra	12/28	12.0	12.5	Hoags Corners, Nassau
147	Jahn	12/28	14.0	11.5	Rt. 16, Nassau
148	Gelotte	12/28	16.0	10.5	Uphams Corners Rd., E. Nassau
149	Wells	12/28	7.0	9.9	Rt. 18, N. Nassau
150	No Name	12/28	8.4	13.0	North Schodack Rd., E. Greenbush
151	Kline	10/16	8.7	6.1	Rt. 22, Lebanon Springs
152	Soldato	10/16	5.0	6.1	Rt. 22, Lebanon Springs
153	Lasher	10/16	10.0	9.4	Rt. 20, Near Mt. Lebanon School
154	Brophy	10/16	6.9	9.4	Beauty Salon, New Lebanon
155	Wick	10/16	5.7	8.3	Shaker Rd., New Lebanon
156	Sime	10/18	6.0	16.5	S. Stephentown Rd., Stephentown
157	Skarzynski	12/28	15.0	10.4	Burden Lake Rd., E. Schodack
158	Tremper	10/16	4.2	7.2	Queechy Lake, Rt. 22
159	Berkshire Farm	10/16	2.1	6.7	Queechy Lake, Rt. 22
160	Johnson	10/16	3.4	5.6	Old Queechy Lake Rd., Canaan
161	Hector	10/16	5.7	3.3	Dermody Rd., Canaan
162	Luhrmann	10/16	5.0		Cherry Lane, New Lebanon
163	Town Spring	10/17	7.9	10.0	Hinton's Rest Stop, Stephentown

Table 3-1 (continued)

Sample No.	Name	Date	Silica ppm	T(°C)	Location
164	Atwater	10/17	16.0	6.1	West Rd., Stephentown
165	Meekins	10/18	9.2	15.5	S. Stephentown Rd.
166	Bummer	10/17	14.0	6.1	East Rock near Eagle Bridge
167	United Farm Agency	10/17	5.9	6.1	Ryatt Cherryplain Rd.
168	Cherryplain Post Office	10/17	4.7	3.3	Old Rt. 22
170	Guimarra	10/17	7.9	7.2	Miles Mtn. Rd., Center Berlin
178	Sawitzki	12/31	15.0	13.5	Lape Rd., Nassau
179	Lins	12/31	10.0	9.0	Waterbury Rd., Nassau
184	Fenander	10/18	5.3		Rt. 43, Hancock, Mass.
186	Miller	10/25	9.0		Rt. 95, N. Hoosick
187	Sheldon	10/25	6.5	10.3	Rt. 396, NY/VT border
188	Locke	10/25	6.1	8.3	Oblong Rd., Williamstown, Mass.
189	Gen. Cable	10/24	9.2		Rt. 396, N. Pownal, Vt.
190	Greylock H.S.	10/25	6.7		Williamstown, Mass.
191	Mt. Hope Farm	10/25	6.3		Williamstown, Mass.
192	Rhodes	10/22	5.5		Hancock Rd., Williams-town, Mass.
193	White	10/25	6.1		Oblong Rd., Williamstown, Mass.
194	Jericho Valley Motel	10/22	5.2		Rt. 43, Hancock, Mass.
195	Hamilton	10/21	4.2		Hancock, Mass.
196	Olds	10/21	4.9		Green Hollow Rd., Berlin
198	Zimmerman	10/18	6.1	12.0	Rt. 43, Stephentown
199	Carpenter	10/18	7.2		Rt. 43, Stephentown

be marked. In dealing with low silica concentrations, it must be remembered that the analytical uncertainty involved is exaggerated in its significance. Similarly the water temperature is affected by domestic use, and also has an error built in. It is therefore difficult to make anything but a general correlation as a result of the variability of conditions under which the samples are collected and analyzed.

We conclude that even though any one measurement may be erroneous and the temperatures in particular can be questioned, the trend is marked. Temperature measurements of active wells carefully and systematically done can be of value and silica measurements may be of particular value for determining if a well is abnormally warm.

In addition, for wells in the Lebanon Springs area, those wells with higher temperatures and higher silica contents tend to cluster and tend to be in areas of higher thermal gradients (see section 4). Thus, we conclude that measuring SiO_2 and temperatures of ordinary, active house wells is probably a good way to locate areas of higher temperature gradients. The technique has the virtue of being relatively inexpensive, certainly far cheaper than drilling to establish thermal areas. A logical sequence is to use the house well technique first and then drill to verify the thermal areas.

SECTION 4

THERMAL GRADIENTS

The temperature gradient is a good method for determining if there is any abnormal heat in an area. Usually such measurements are made by drilling wells from 100 to 200 meters deep, waiting for a month or so for the wells to equilibrate and then measuring the temperature of the wells either continuously or at regular intervals using a thermister probe. Rather than spend money to drill, the decision was made to determine if any abandoned wells were available in the area. To be usable, such wells should, ideally, be over about 100 meters deep and into rock. Wells were located through a combination of literature search, advertising and interviewing, and permission to make measurements in 25 such wells was obtained. There were many false leads because some abandoned wells were blocked, some could not be found, and permission to test some wells could not be obtained. In all, there were about three times more false leads than valid ones.

The equipment which was used was built by Keith Dayer as a subcontractor to DGC. The unit was used by hand lowering the thermister and reading temperatures at five meter intervals. The temperature data collected was graphed and run through a linear regression program to determine the thermal gradient of the well, and how well the data fit a line.

The results of the work are summarized in Table 4-1 and the locations shown on Plate 14. The wells varied in depth from 80 to 260 meters; gradients from 3.86°C to 30.59°C per km. The background geothermal gradient appears to be about $8 - 9^{\circ}\text{C/km}$. Gradients of over 17°C/km are over twice background and are considered to be significant and indicative of abnormal heat. Seven such wells were observed and are underlined on Table 4-1. Two additional 17^{0+}C wells are noted on Plate 14.

TABLE 4-1
TEMPERATURE GRADIENTS

Name	Date	Depth Meters	$^{\circ}\text{C}/\text{km}$ Gradient	Correlation Coefficient r^2	Location
Kennedy	10/12	145	8.70	.977	East Hill Rd., Austerlitz
Pownal	10/12	220	<u>23.63</u> ²	.969	Pownal, Vermont
Bayer	10/26	140	14.82 $^{\circ}\text{C}/\text{km}$	.986	Hancock, Mass.
Kitteridge	10/26	155	<u>17.03</u>	.958	Hancock, Mass.
Meskill	12/10	145	14.72	.992	Rt. 43 and Rt. 22, Stephentown
Garfield Road	12/10	185	<u>21.60</u>	.990	New House on Garfield Rd., Stephentown Center
Stalker	12/12	130	12.70 $^{\circ}\text{C}/\text{km}$	.974	Rigor Hill Road, Austerlitz
Jericho Valley	12/18	130	<u>18.36</u>	.988	Rt. 43, Hancock, Mass.
Barcia	12/18	185	7.95	.988	West Rd., West Rich- mond, Mass.
Nyewrighter	12/19	190	7.72	.986	Saltbox Farm Rd., Hancock, Mass.
Zweig	12/21	100	9.51 $^{\circ}\text{C}/\text{km}$	.913	Sweets Crossing Rd., Nassau
Zucker Isgood(1)	12/28	260	9.06	.980	Bailey Rd., Hancock, Mass.
Zucker Isgood(2)	12/28	125	6.73	.967	Bailey Rd., Hancock, Mass.
Liveright	12/31	160	<u>24.68</u>	.997	Wyomack Rd., South Stephentown
Hemingway	1/4	80	10.83	.896	West Rd., Lebanon Springs
Lindsay	2/5	95	9.49	.993	Rt. 2W, Petersburg
Toussaint	2/5	167	<u>30.59</u>	.999	Old Plank Rd., Poestenkill
Wigglesworth	2/11	160	7.01	.988	Churchill Rd., Pitts- field, Mass.
Rosenberg	2/15	80	12.40	.998	Off Rt. 22, Stephen- town

2. Underlined measurements are over two times estimated background gradient.

Table 4-1 (continued)

Name	Date	Depth Meters	$^{\circ}\text{C}/\text{km}$ Gradient	Correlation Coefficient r^2	Location
Synagogue	2/15	120	9.42	.983	Gentile Rd., East Nassau
	5/6	120	8.81	.995	(NEW EQUIPMENT/ ³)
Gazzola	3/4	220	8.66	.986	Fire Hill Road, Spencertown
Edgarston	3/4	192	<u>17.66</u> / ²	.997	Elm Street, Spencer- town
Eastman	3/4	160	<u>17.49</u>	.984	Angel Hill Road, Spencertown
	5/6	160	<u>18.47</u>	.991	(NEW EQUIPMENT/ ³)
Wicks	3/19	105	3.86	.956	Vt. Rt. 9, Bennington, Vermont
Kersten	4/21	80	5.00	1.000	Old Hillsdale Dairy, Hillsdale

2. Underlined measurements are over two times estimated background gradient.

3. Measurements made with new equipment as a check of data.

4-4

SECTION 5

GEOLOGIC CONTROL OF THERMAL SPRINGS

STRUCTURE

The Lebanon Springs water issues from dolomite of Ordovician age which occurs under what is called the Taconic Thrust fault. Phyllites or slightly metamorphosed shales and phyllonites/¹ are east of the dolomite and probably act as an impermeable barrier over the dolomite. The arrow on Plate 9 shows the position of Lebanon Springs. The most usual interpretation of such thermal springs in non-volcanic areas is that they are caused by normal groundwater circulating deeply enough into the Earth's crust to be warmed by normal geothermal heat and then rising to the surface under artesian pressure. This could be the situation at Lebanon Springs.

THERMAL GRADIENTS

The temperature gradients in the immediate vicinity of Lebanon Springs do not appear to be high. If a 10° C/km temperature gradient is assumed, the water would have to circulate to a little over one km (or 3000 to 3500 feet) in order to reach the temperature of Lebanon Springs.

PERMEABILITY

A very common cause of high permeability of rocks is a situation in which relatively plastic rocks such as shales, phyllites or phyllonites are faulted against brittle rocks like dolomite. The dolomite tends to fracture tensionally against the fault surface and, hence, tends to become more permeable under the fault. With the phyllite and phyllonite acting as barrier to water flow on top of the permeable dolomite, water could have penetrated the dolomite high in the hills to the north-northeast, moved deeply into the ground along this permeable zone in the dolomite, and then rise under artesian pressure to the Lebanon Springs area. According to this model, warm waters could occur for about two miles to the north of Lebanon Springs but would be much less likely to occur to the south.

1. Cataclastically metamorphosed schist-like rocks caused by shearing along faults.

WILLIAMSTOWN, MASSACHUSETTS

The thermal waters at Williamstown occur in a slightly different geologic environment and are found over a wider area. The Sand Spring waters (actually shallow wells) are found at the foot of hills of the quartzites of the Cheshire Formation (equivalent of Potsdam sandstone, but metamorphosed). The springs, again, may come from Ordovician dolomites, but the position of the contact between the Cheshire and the adjacent dolomite is not precisely known in the area of the springs. We have no good reason to suspect that deep circulation occurs in the area of Sand Springs, although a deep fracture system in the quartzite is not impossible.

Across the valley about one mile to the West of Sand Springs are two more thermal springs. Again they occur near the contact between dolomite and some other rock type, in this case the phyllites. The structural conditions appear to be different than those of Lebanon Springs because the dolomite does not appear to be overlain by phyllite. Very possibly the structural conditions are more similar to those at Sand Springs. The difficulty in finding a good structural explanation for the thermal waters in the Williamstown area makes the possibility of a crustal warm spot somewhat higher than at Lebanon Springs.

SECTION 6

PRELIMINARY ANALYSIS, ECONOMIC FEASIBILITY OF DEVELOPING THE HEAT FROM LEBANON SPRINGS

INTRODUCTION

Although the geologic work demonstrated that there is probably an important thermal area running from about Lebanon Springs northwest 19 miles to Poestenkill, no wells or springs were found which were as warm as Lebanon Springs. Although we assume that the likelihood of finding comparable temperatures and, ultimately, of finding an economic water resource is excellent, such a resource could not be located within the financial constraints of this contract.⁴

Interested citizens of Lebanon Springs contacted ERDA and suggested that a town meeting might be held and that such a meeting might facilitate development of Lebanon Springs. With no other warm waters having been located, the Lebanon Springs themselves were analyzed for engineering feasibility.

The engineering study is preliminary in nature and is based on there being between 400 and 500 g/min available. The spring is labeled as having a flow of 500 g/min but without closing all leaks and shutting off all pipes which carry water to local homes, the actual flow cannot be verified. The flow should be determined before development proceeds.

The purpose of this section is to develop the economics of using the heat energy of the warm springs located in Lebanon Springs, New York. The report traces through the potential amounts of heat energy available from this warm spring, potential end-users of the heat energy, implementation costs of each end-user in order that they may effectively use the energy, and also briefly investigate the microhydroelectric potential of the warm spring.

This report provides estimates and initial calculations for the feasibility of warm water geothermal energy for district end-users and using the energy for primarily space heating needs.

4. Exploration for this contract was limited to trying to understand the cause of the existing warm springs and to determine if other usable warm springs or wells existed. Drilling for new warm water sources in a several square mile area was not in the program.

This report does not address the myriad of potential end-users for the geothermal energy at Lebanon Springs and should be used to provide some benchmarks for further investigations for the site.

POTENTIAL ENERGY FROM WARM SPRING AT LEBANON SPRINGS

Our initial task in the report was to estimate the potential energy available from the warm spring at Lebanon Springs.

From initial data provided, the current flow characteristics of the spring are as follows:

Flow Rate:	400 to 500 gallons per minute
Temperature:	72° to 69° F throughout year
Elevation potential of Spring:	120 feet differential

In order to evaluate the potential heat energy available to any end-user, certain limits were assumed. For the sake of developing the argument, the following are the calculations for energy availability.

Gpm:	400
Temperature Drop:	65° - 55°

Available Heat from Water:

$$Q = (400) (10) (500) = 2,000,000 \text{ BTUH}$$

Because the available energy is at low temperatures (a mean temperature of 70°), a heat pump would be required to raise the level of acceptability of this heat. In order to effectively use this "free" heat in conventional systems or modified conventional systems, water temperatures for these heating systems must be in the range of 110° to 115° F. This required temperature range is dictated primarily for maintaining comfort conditions of 68 - 70° F without having a draft sensation in the inhabited space.

The available heat energy equation then becomes:

Q _{Spring}	=	2,000,000 BTUH
Q _{Heat Pump}	=	4000,000 BTUH
Total Heat	=	2,400,000 BTUH
Output from Heat Pump		

Note: Q Heat pump is the heat energy (actually electric energy to drive the compressor) required to raise the level of the available heat. While it is a fact that this energy has to be input to the heat pump, the energy does become available in the form of heat energy to be used along with the energy captured from the spring.

If we were to express the total energy available from the heat pump in the form of electric energy or gallons of oil equivalent, it would look like this:

Heat Available	=	2,400,000 BTUH
Equivalent Kw	=	702.2 Kw
Equivalent Gallons No. 2 oil	=	16.9 gallons/hour

Once having determined the potential amounts of energy available from the spring, the next task was to determine what potential users might be found for this available heat energy, and what would be the up front costs to allow these users to implement warm water heat recovery.

Design Note: The initial temperature drop looked at in this preliminary analysis was from 65° F to 55° F. This particular temperature drop is conservative by nature. The most optimistic viewpoint would have been to use an initial temperature reading of 73° F which has been reported from the spring. A final temperature leaving the heat pump could be anywhere from 55° F and lower. It is important to note, however, that a lower leaving water temperature would require larger Kw inputs into the heat pump. In the final analysis, an optimization of actual design criteria versus Kw requirements would have to be made.

POTENTIAL PUBLIC USERS OF AVAILABLE HEAT ENERGY

The interested citizens of Lebanon Springs who contacted ERDA requested that the application of heating three public buildings with the spring waters be addressed. Those buildings are:

- Lebanon Springs Town Hall: Lebanon Springs Town Hall is down the hill from the actual location of the Spring. The linear distance from the Spring is about 1200 feet.

The existing heating system for the Town Hall is an oil fired hot water system with hot water convectors and fin tube radiators as the terminal heating devices. Presently the Town Hall consumes about 3200 gallons a year in No. 2 fuel oil.

- Lebanon Springs Town Garage: Adjacent to the Town Hall is the Town Garage which services and houses all the municipal vehicles. Separated by a distance of about one hundred (100) feet, the Town Garage has a heating system of oil fired warm air heaters to satisfy its space heating requirements. Present oil consumption of the Town Garage is approximately 2650 gallons No. 2 fuel oil per year.

- New Lebanon High School: Approximately 2200 linear feet west of the Town Hall/Town Garage complex is the New Lebanon High School Facility. The High School facility has a student population of about 600 students in grades 7 through 12. Besides normal activities and facilities in the high school, the facility also has an 80,000 gallon heated swimming pool.

The heating system for the high school complex is a No. 4 fuel oil low pressure steam boiler with individual steam heating units for all classrooms and support spaces. The pool heating is done from a steam to hot water converter from the central plant. Present oil consumption at the high school complex is approximately 48,600 gallons of fuel oil per year. From a total energy consumption basis, the high school is a far more attractive candidate than the Town Hall/Town Garage complex. The potential equalizer is the increased distance from the spring to the high school.

PROPOSED SYSTEM

The investigated solution of using the available heat energy from Lebanon Springs

in the Town complex and High School consists of a piping system from the spring to each of these facilities and in turn retrofitting the existing heating system to use the heat energy.

In the case of the Town Hall complex, the distance from the spring to these facilities is about 1200 linear feet which includes the vertical drop of about 120 feet. The terrain for this initial distance is considerably rough and soil conditions were determined to be rocky.

The initial phase of design for Lebanon Springs would be well rehabilitation with new caisson and a 6" insulated buried pipe from the well to the Town Hall complex. In order to handle the Town Hall and the Town Garage, the pipe could be smaller but the initial size looked at was large enough to handle both the Town Hall Complex and the High School Complex.

In the Town Hall Complex, both building heating systems would have to be retrofitted in order to correctly use the new source of heat. The Town Hall itself would require a heat pump to serve its own needs plus some additions and modifications to the existing terminal heating system equipment of hot water convectors and fin tube radiation. The Town Hall system would be sized to handle the majority of its heating requirements with the ability to hold the building at 55° F when it is unoccupied.

The Town Garage would require the same type of retrofit procedure as in the Town Hall. A separate heat pump with a new terminal heating system would be required as the existing heating systems (oil fired unit heaters and furnaces) are practically unadaptable for use with hot water heating.

Design Note: After the heat is removed from the spring water, the cooler water would be discharged into an existing stream into which the spring now flows.

The High School Complex would require additional underground piping to get the warm water to the High School buildings. The Town Hall and High School are separated by a distance of 2200 linear feet of relatively good soil condition and no appreciable elevation difference. It must be noted, however, that this distance would have to be covered with a pump system in order to deliver the required flow to the High School. Again, the pipe size would be 6", insulated and underground.

Retrofit of the high school would consist of the addition of a major heat pump (2500 Mbh heat output - see Appendix C for computer selection), and replacement of all steam heating equipment with hot water heating equipment. Also included would be the replacement of all heat distribution piping. While this may seem a major retrofit of the High School building, the major energy would be achieved in this particular building.

ENERGY SAVINGS

In general, energy savings were calculated with the following parameters:

- Energy consumption levels of existing buildings were based on the 1978-1979 heating season and were actual gallons of oil per year. No additional reductions were taken into account because of further conservation efforts taking place at the school.
- Dollar savings from use of Lebanon Springs warm springs as a heating energy source were offset by the amounts of electricity and its associated cost (\$.05 per kwh) used to drive the heat pump. Dollar savings shown in the summary chart represent net potential dollar savings.

HYDROELECTRIC POTENTIAL

Because of the elevation difference from the spring site to the Town Hall Complex, the feasibility of microhydroelectric potential was investigated for the Lebanon Springs preliminary report.

With the initial flow characteristics and elevation difference, a potential of 8 kilowatts of electric energy could be achieved with the installation of a microhydroelectric plant. While this may initially seem rather small, the total yearly generation potential would be 70,804 kwh.

This electric energy could be directed to a number of different uses such as energy for pumping warm water from the Town Hall site to the High School site, energy for Town Hall use during the day and street lighting at night, or any other electric requirements in the Town Hall/Town Garage Complex.

It is important to note at this point that the hydroelectric potential does exist at the Lebanon Springs site and the simple payback would be approximately eight years.

SECTION 7

DISCUSSION

ALTERNATE RESEARCH PATHS

Although the framework of the project to study the Lebanon Springs area for the economic feasibility of using the spring or an alternate warm water source remained constant, the emphasis shifted somewhat as various alternatives appeared less feasible. The need for alternate approaches was considered likely in the initial research proposal and hence alternate paths were shown on the task diagram.

THERMAL DISCOVERIES

Several very important concepts evolved from the research and their value to future geothermal work is considerable. The concepts are unique and are of both local and national importance.

The value of domestic wells for silica and temperature analyses and thermal gradient measurements for geothermal investigation has been clearly demonstrated. Except for a small area south of Salt Lake City, the thermal gradient technique apparently has not been widely used. We have shown that: (1) temperature measurements broadly correlate with silica contents in domestic wells; and (2) either silica content or temperature may be used to indicate the probable presence of a thermal area. We stress that no one well measurement of temperature or silica is definitive, but an average of several wells is probably very significant. The technique of making temperature and silica measurements of domestic wells can be combined with measurements of radon content of the water using a new method which has been reported by geologists working in Maine. The new radon technique is very fast and easy to use.

We now believe that our new concept of making multiple measurements on domestic wells is by far the cheapest method of (1) narrowing the broad, hundred plus square mile geothermal target areas which we now have, and (2) showing us where the maximum concentrations of radon-bearing CO_2 -rich waters occur. The follow-up electromagnetic or resistivity geophysical measurements should direct us to specific drill targets in which warm, electrically conductive, and radon-rich waters can be located.

The temperature measurements of abandoned wells indicated that an irregularly-shaped thermal area extends from about Lebanon Springs northward and northwestward to Poestenkill about nineteen miles away. By including all wells with gradients over 17° C/km and domestic wells which have moderately high silicas and moderately high temperatures, the thermal area can be extended through Nassau almost to the Hudson River at Castleton to the west (see line enclosing thermal area on Plate 12). The westward extending arm is parallel to the extension of two east-west faults which bracket Castleton. As in the Schenectady-Saratoga area, fault lines may control at least some of the thermal anomalies.

SECTION 8

CONCLUSIONS

Additional thermal springs comparable to that at Lebanon Springs were not identified. In addition, no thermal wells were found in the southeastern Rensselaer County area in New York. Therefore, the existing thermal water at Lebanon Springs is the best potential site for demonstrating the value of thermal waters in the immediate area.

Based on an assumed available flow of 400 to 500 gallons per minute, preliminary engineering analyses indicate that the Lebanon Springs Town Hall, Town Garage and High School could be heated by the thermal water.

The potential oil savings which are possible using thermal groundwater heat pump systems to heat Lebanon Springs town buildings are summarized below:

<u>Building</u>	<u>Present Oil Consumption Gallons/Year</u>	<u>Cost at \$1/Gallon</u>	<u>First Cost of Energy Recovery System, Dollars</u>	<u>Savings/ Year, Dollars</u>
Town Hall	3,200	3,200	15,000	2,100
Town Garage	2,660	2,650	10,000	1,550
High School	48,600	48,600	208,000	27,836

Additional Initial Costs, Dollars

Town Hall and Garage, well development and piping	66,000
High School, piping from Town Hall	77,000

Based on a head differential of 120 feet from the spring to the first town building, additional energy can be derived from the water using a microhydroelectric plant capable of generating 70,804 Kw annually. The factors are summarized as follows:

400 g/m, 120 foot head	8 kilowatts energy
Annual potential available energy	70,804 Kw
Energy value at \$0.05/Kw	\$3,504 per year
Cost of microhydro plant	\$29,000

This study demonstrated that inactive domestic wells of approximately 300 feet or deeper and into rock are useful in rapidly and inexpensively measuring geothermal gradients for areas where deep domestic wells are common.

Tap water temperature measurements and determinations of silica content of samples from domestic wells have been demonstrated to be another useful tool in defining anomalous subsurface thermal conditions. While no one measurement is significant, the average values from several wells in an area are significant.

An area of over 200 square miles with Lebanon Springs in the southeast quadrant has been identified as having anomalously high geothermal gradients. The highest single gradient was measured at Poestenkill in the northwest quadrant and, thus, it is assumed that the anomalous thermal area extends beyond Poestenkill to the north and west.

The geology of the region is very complex and the explanation of the causes of the warm waters are equivocal. Deep circulation into rock with normal geothermal gradients appears to best explain the cause of the heat at Lebanon Springs. A warm spot in Massachusetts in an area about a mile north of Williamstown appears to be a good possibility to explain the springs on both sides of the Hoosick River Valley in that area.

The best reconnaissance method of locating thermal areas where Saratoga-type water occurs in largest volume now appears to be to measure silica, temperature and radon content of active domestic wells and plotting the data on maps.

Although the Lebanon Springs is supposed to flow at the rate of 500 g/min. the actual flow is not known.

SECTION 9

RECOMMENDATIONS

Any further work directed toward demonstrating the value of the warm water at Lebanon Springs should first solve the legal problem of the Springs' use. This includes both legal access to the waters and pre-existing water rights of those people already using the spring as a water supply.

Once legal access is obtained, the average sustained yield of the spring should be measured. The magnitude of existing use and possible alternate sources should be considered to determine the maximum volume of available thermal water for demonstration projects and other use.

The large thermal area which has Lebanon Springs at its southeast corner should be explored for both shallow warm water and for a deeper heat source.

The exploration techniques which should be used prior to any drilling in this area should involve measuring temperature and determining the radon and silica contents of domestic wells. This should be followed by geophysical measurements to locate conductive saline waters in areas of anomalous radon, silica, and/or temperature values.

Appendix A

Geologic Maps and Cross-Sections

Index to Plate Locations and Geologic Sections

Legend

- Plate 1 - Geologic Map: North Pownal Quadrangle
- Plate 2 - Geologic Map: Pownal Quadrangle
- Plate 3 - Geologic Map: Taborton Quadrangle
- Plate 4 - Geologic Map: Berlin Quadrangle
- Plate 5 - Geologic Map: Williamstown Quadrangle
- Plate 6 - Geologic Map: Stephentown Center Quadrangle
- Plate 7 - Geologic Map: Hancock Quadrangle
- Plate 8 - Geologic Map: Canaan Quadrangle
- Plate 9 - Section A-A' - Lebanon Springs, NY
- Plate 10 - Section B-B' - Stephentown, NY
- Plate 11 - Section C-C' - Williamstown, MA
- Plate 12 - Silica Sample Location Map - Sample Number
- Plate 13 - Silica Sample Location Map - Silica Content/Temperature
- Plate 14 - Temperature Gradients and Well Location Map

APPENDIX B

SUMMARY OF THE TACONIC GEOLOGIC CONTROVERSY

THE TACONIC CONFLICT

Eaton (1824)* produced the first geologic study of the area and immediately sparked the Taconic Controversy among his peers and students. Ebenezer Emmons in the 1840's published a series of geologic monographs and maps on the Taconics and proposed that all the formations, except the limestones, were Early Cambrian. James Hall, the New York State Geologist, took Emmons' views as a personal attack. The famous debate between James Hall and Ebenezer Emmons, both students of Eaton, involved a court decision and many well-known geologists of the last century. Hall was "victorious" and Emmons left New York for North Carolina.

In North Carolina, Emmons applied his "Taconic" ideas to the Smokies of Eastern Tennessee and Western North Carolina and Virginia. Today Emmons' imbricated over-thrusts idea, the Keystone of his "Taconic solution", is still the accepted interpretation in the Smokies.

Dana (1888) and Walcott(1888) continued work in the Taconics and established that the Taconics' were in part Ordovician. Dale's (1893, 1898, 1904, 1923) monumental work on the Taconics restarted the controversy. Dale postulated that the Taconics were a starved basin and the myriad lithologic units were alternating facies. Dale's field assistants Ruedemann (1909), Keith (1912, 1913) and Prindle and Knopp (1932) refuted in part Dale's facies idea and supported Ulrich (1903, 1911) that the Taconics had been thrust into place by the doming of the Green Mountains. Grabau (1909, 1938) supported Emmons and Dale and incurred the wrath of Ulrich. Grabau left the United States for "exile" in China.

During the last three decades, a number of geologists have worked in this area, and the debate, which has become known as the "Taconic Problem", has heated up. Briefly, the two main camps are:

The Allochthon's

Kay, 1942; Cady, 1945; Kaiser, 1945; Fowler, 1950; Zen, 1950, 1959,

* All references available at Dunn Geoscience Corporation

1960b, 1961, 1964a, 1967, 1972; Platt, 1960; Potter, 1972, 1979;
Radcliffe, 1966, 1969, 1978, 1979; Bird, 1963, 1969.

The Authochthon's

Bonham, 1950; Balk, 1953; Lockman, 1956; Bucher, 1957; Craddock,
1957; Weaver, 1957; Elam, 1960; Hewitt, 1961, 1963; Hertz, 1961,
1967; Cady, 1969; Keith, 1975, 1977.

From this discussion it should be clear that about any aspect of Taconic geology
will almost certainly be controversial.

Appendix C

TRANE "CENTRAVAC" HEAT PUMP SELECTIONS

Specifications for standard "centravac" equipment suitable for providing 167 tons in heat recovery for 3 evaporator water conditions:

1. Specified Evaporator Conditions

65°F water entering evaporator

50°F water leaving evaporator

Centravac Machine Specifications

No Centravac machine selection possible for these conditions

2. Specified Evaporator Conditions

65°F water entering evaporator

50°F water leaving evaporator

Centravac Machine Specifications

Power Requirement: 157 KW motor

Evaporator Water Design Flow Rate: 267 GPM

Evaporator Water Design Pressure Drop: 6.1 Ft. of water

Evaporator Circuiting: 2 pass

105°F water entering condenser

115°F water leaving condenser

Flow Rate through condenser loop: 501 GPM

Condenser Water Pressure Drop: 13.4 Ft. of water

3. Specified Evaporator Conditions

57.5°F water entering evaporator

47.5°F water leaving evaporator

Centravac Machine Specifications

Power Requirement: 165 KW motor

Evaporator Design Flow Rate: 401 GPM

Evaporator Design Pressure Drop: 12.8 Ft. of water

Evaporator Circuiting: 2 pass

105°F water entering condenser

115°F water leaving condenser

Flow Rate through condenser loop: 511 GPM

Condenser Water Pressure Drop: 13.9 Ft. of water

Note: The 165 KW motor needed for this selection is larger than standard and would represent an extra cost option.

Appendix A
Geologic Maps & Cross Sections

Map Key

**INDEX TO PLATE LOCATIONS
& GEOLOGIC SECTIONS**

Legend

● WELL LOCATION

GEOLOGIC MAP
June 1980

SCALE
0 2000 4000 6000
Plate 1

U.S.G.S. 7.5 MINUTE QUADRANGLE
NORTH POWNAL, N.Y.

GEOLOGIC MAP
June 1980

SCALE
0 2000 4000 6000

U.S.G.S. 7.5 MINUTE QUADRANGLE
POWNALE, N.Y.

Plate 2

GEOLOGIC MAP
June 1980

SCALE
0 2000 4000 6000

Plate 3

U.S.G.S. 7.5 MINUTE QUADRANGLE
TABORTON, N.Y.

GEOLOGIC MAP
June 1980

Plate 4

U.S.G.S. 7.5 MINUTE QUADRANGLE
BERLIN, N.Y.

GEOLOGIC MAP
June 1980

U.S.G.S. 7.5 MINUTE QUADRANGLE
WILLIAMSTOWN, MASS.

Plate 5

GEOLOGIC MAP
June 1980

SCALE
0 2000 4000 6000
Plate 6

U.S.G.S 7.5 MINUTE QUADRANGLE
STEPHENTOWN CENTER, N.Y.

GEOLOGIC MAP
June 1980

Plate 7

U.S.G.S. 7.5 MINUTE QUADRANGLE
HANCOCK, MASS.

TOPOLOGIC MAP
June 1980

SCALE
0 2000 4000 6000

Plate 8

U.S.G.S 7.5 MINUTE QUADRANGLE
CANAAN, N.Y.

- Owl-Walloomsac Formation
- OEs- Stockbridge Group
- Ec- Cheshire Formation
- pEmh- Mt. Holly Complex
- En- Nassau Formation
- Er- Rensselaer Formation
- Ea- Austerlitz Formation

Section A-A'
LEBANON SPRINGS, NY.

Plate 9

Horizontal Scale 1:24,000

- Owl - Walloomsac Formation
- OEs - Stockbridge Group
- Er - Rensselaer Formation
- Ea - Austerlitz Formation
- Crck - Canaan Knob Member

Section B-B'
STEPHENTOWN, N.Y.

Plate 10

Horizontal Scale 1:24,000

- Owl - Walloomsac Formation
- OEs - Stockbridge Group
- €c - Cheshire Formation
- €a - Austerlitz Formation

Section C-C'
WILLIAMSTOWN, MASS.

Plate II

Horizontal Scale 1:24,000

Silica Sample Location:
Sample Number
plate 12

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