EXPLORATION FOR GEOTHERMAL RESOURCES
IN THE CAPITAL DISTRICT OF NEW YORK

Final Report

Prepared for

NEW YORK STATE
ENERGY RESEARCH AND DEVELOPMENT AUTHORITY

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and

United States Department of Energy
Grant Number DE-FG05-79 ER10082

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221/ET-RER/80

ERDA Report 81-11

November 1981

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First Printing: November 1981

ABSTRACT

Water chemistry, gas analyses, and geophysical methods including gravity and magnetic surveys, microseismic monitoring, and temperature gradient measurements were used in the Capital District area to evaluate the potential for a hydrothermal geothermal system. Water and gas chemistries provided indirect indicators, and temperature gradients provided direct indications of a geothermal system. Gravity results were supportive of gradient and chemistry data, but seismic and magnetic work have thus far provided little information on the potential system. Gradients throughout the area ranged from an average background value of about 10° C/km to a high of roughly 44° C/km. The highest gradient values, the most unusual water chemistries and largest carbon dioxide exhalations occur along the Saratoga and McGregor faults between Saratoga Springs and Schenectady, and indicate a good potential for a usable hydrothermal geothermal system at depth.

CONTENTS

<u>Section</u>	<u>Page</u>
1 INTRODUCTION	1-1
Introductory Statement	1-1
Personnel	1-1
Purpose	1-2
Scope	1-2
Acknowledgements	1-2
2 GEOLOGIC SETTING	2-1
Introductory Statement	2-1
Stratigraphy	2-1
Structure	2-3
3 METHODS USED AND RESULTS OBTAINED	3-1
Introductory Statement	3-1
Standard Water Chemistry	3-1
Silica and Silica Decay Analyses	3-20
Gas Analyses	3-27
Down Hole pH Measurements and Isotopes	3-36
Magnetometer Survey	3-38
Gravity Survey	3-43
Seismic Work	3-58
Temperature Gradient Measurements	3-60
4 DISCUSSION	4-1
5 CONCLUSIONS	5-1
6 RECOMMENDATIONS	6-1
7 REFERENCES	7-1
APPENDIX A CHEMICAL METHODS	A-1
APPENDIX B SEISMIC REPORT	B-1
APPENDIX C GRADIENT DATA	C-1
APPENDIX D GLOSSARY	D-1

ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
2-1	Geologic Map	2-2
2-2	Geologic Section A-A'	2-4
2-3	Geologic Section B-B'	2-6
3-1	Location Map for Standard Geochemical Samples	3-2
3-2	Location Map Showing High Boron Concentrations	3-16
3-3	Location Map Showing High Fluorine Concentrations	3-17
3-4	Location Map Showing High Lithium Concentrations	3-18
3-5	Location Map Showing High Strontium Concentrations	3-19
3-6	Location Map for Silica Samples	3-21
3-7	Rough Contouring of Silica Data Showing Areas of Slightly Anomalous Silica Content	3-28
3-8	Silica Decay Analysis Results	3-29
3-9	Silica Decay Analysis Results	3-30
3-10	Wells With High Helium Concentrations	3-37
3-11	Magnetometer Traverse Southwest of Saratoga Springs Map View	3-41
3-12	Magnetometer Traverse Through Ballston Center - Map View	3-42
3-13	Plot of Data From Magnetometer Traverse Southwest of Saratoga Springs	3-44
3-14	Plot of Data From Magnetometer Traverse Through Ballston Center	3-46
3-15	Revised Simple Bouguer Gravity Anomaly Map of the Capital District	3-48
3-16	Detailed Simple Bouguer Gravity Anomaly Map of the Berlin- Poestenkill Area	3-50
3-17	Detailed Simple Bouguer Gravity Anomaly Map of the Schenectady Saratoga Springs Area	3-52
3-18	Location of Saline and Carbonated Waters Relative to Simple Bouguer Gravity Anomalies	3-54
3-19	Locations of Temperature Gradients Over 20° C/km Relative to Simple Bouguer Gravity Anomalies	3-56
3-20	Seismic Monitoring Network - Station Locations	3-59
3-21	Temperature Gradient Measurement Locations	3-62
3-22	Contour Map of Temperature Gradients	3-66

TABLES

<u>Table</u>	<u>Page</u>
3-1 Site Specifics for Standard Geochemical Sampling.	3-3
3-2 Geochemical Data from Standard Sampling	3-6
3-3 Site Specifics for Silica Sampling.	3-22
3-4 Silica Decay Data	3-31
3-5 Free Gas Sample Composition	3-34
3-6 Composition of Dissolved Gas in Water Samples	3-35
3-7 Down Hole pH Measurements	3-39
3-8 Geomagnetic Data Reduction - Traverse Southwest of Saratoga Springs.	3-45
3-9 Geomagnetic Data Reduction - Traverse Through Ballston Center	3-47
3-10 Site Specifics for Temperature Gradient Measurements.	3-64

SUMMARY

Several geochemical and geophysical methods were applied to the Capital District area of New York in order to evaluate the potential for a low temperature hydrothermal geothermal system. Detailed water chemistry, a broad silica survey, and gas analyses indirectly suggest the potential presence of a geothermal system. A temperature gradient measurement program was undertaken in which gradients were determined in 76 different abandoned water wells. These wells generally exceeded 100 meters in depth, with the actual range being 80 to 605 meters. The gradients measured indicated a background value of about 10° C/km, and the highest reproducible gradient measured was roughly 44° C/km. The area of highest gradients, most unusual water chemistry, and greatest carbon-dioxide gas exhalation straddles the Saratoga and McGregor faults between Saratoga Springs and Schenectady. Supportive evidence for potential hydrothermal circulation along these faults was obtained from the gravity survey, in which gravity anomalies can be roughly related to the chemical and thermal anomalies. A magnetic survey was run in the area, but proved to be of little value as a result of a high degree of cultural overprint interfering with the measurements, and the general north-south orientation of the faults, causing a minimization of reading variation at these latitudes. A microseismic monitoring network operated for approximately four months, during which no significant geothermally related activity was seen. This program did, however, detect eight small earthquakes in the area of interest, although none could be directly related to the potential system.

The results of the exploration program provide both direct and indirect evidence of a potentially usable hydrothermal geothermal system at depth in the area, and a drilling program is recommended to further evaluate the thermal data in the area of highest apparent interest.

Section 1 INTRODUCTION

INTRODUCTORY STATEMENT

This report is written to complete the requirements for the second phase of exploration for geothermal resources in east-central New York. It follows the first phase report submitted by Dunn Geoscience Corporation (DGC) to New York State Energy Research and Development Authority (ERDA) and the United States Department of Energy (DOE) dated August 15, 1979, in which a basic literature search and geochemical analyses of waters in the area were conducted. The Phase I report concluded that a geothermal system in the area was probable. The second phase evaluation and exploration was implemented through a research contract called "Exploration for Geothermal Resources in the Capital District of New York," and dated August 20, 1979, between DGC and ERDA, which entered a contract with DOE. Funding was through ERDA and DOE. A closely related research contract similarly funded was negotiated with the New York State Geological Survey to conduct seismic studies.

PERSONNEL

The project geologist for this Phase was James R. Young until December 1, 1979, when he left and was replaced by Margaret R. Sneeringer. The project geologist has been responsible for organization, coordination and operation of the field program, data reduction, and report preparation. Dr. James R. Dunn was Senior Project Advisor and helped in data interpretation and modeling. George M. Banino was responsible for contract administration. A number of Dunn Geoscience staff geologists were involved in the field program; but, in particular, Joel A. Hubscher, Daniel P. Fenno, and Steven A. Chisick should be noted for their participation in the program.

Dr. George Putman of the State University of New York at Albany assisted in geochemical evaluation of water and gas analyses. Mr. Charles O. Porter of Hudson Valley Community College conducted magnetic and gravity surveys in the area and assisted in the interpretation of existing and new data. Dr. Walter Mitronovas of the New York State Geological Survey was responsible for the organization and operation of the seismic network. He is also responsible for the seismic section of this report.

Geochemical analyses were performed under the direction of Robert Weinbloom by Health Research, Inc., a branch of the New York State Department of Health. Gas analyses were performed by Chemical Projects, Limited, of Toronto.

PURPOSE

This work has been the second phase of an exploration program to evaluate the possibility of geothermal resources in the Capital District of east-central New York. Direct evidence of geothermal systems has been sought and an effort made to locate zone(s) of deep crustal fluid discharge or other possible heat sources. The ultimate goal of this phase has been to try to define the system as precisely as possible in order to establish target areas for further study leading to drilling.

SCOPE

Phase II has involved an expanded water chemistry program and several geophysical methods. In the water chemistry program, some of the same springs and wells studied in Phase I were retested; but, more importantly, a large number of previously unidentified wells producing the unusual Saratoga-type water were located and sampled, and the effective area of interest was thus expanded. Aside from standard chemical analysis for major and trace elements, a broad scale silica sampling program was undertaken, as well as a free and dissolved gas analysis program. Geophysical methods included a seismic monitoring program concentrating on seismic noise and microearthquakes possibly resulting from activity associated with geothermal sources at depth, a small scale magnetic survey, and a gravity survey along with reevaluation of previous gravity data. The most successful aspect of this phase has been the measurement of temperature gradients in abandoned water wells throughout the area. Because of the success of the temperature gradient program and the fact that such measurements are the most direct indication of heat, the major thrust of data collection has been in that direction.

ACKNOWLEDGEMENTS

Particular thanks are extended to the water conditioner dealers and well drillers who opened their files and provided information on saline and carbonated wells throughout the area, and/or abandoned deep wells for gradient measurements. Thanks for their patience and cooperation are also extended to the homeowners who allowed us to sample their water and make gradient measurements in their wells.

Dr. James Simpson of the Lamont Doherty Geological Observatory is also acknowledged for his efforts to provide additional isotope data for this system.

SECTION 2

GEOLOGIC SETTING

INTRODUCTORY STATEMENT

The basic geologic setting has been fairly well defined in previous reports, and it would be redundant to describe it again here. The brief review of stratigraphy and structure, as written in the interim report, and a geologic map (Figure 2-1) have been included for quick reference. Two cross-sections drawn through the area of interest have been added. It should be noted that these cross-sections (Figures 2-2 and 2-3) have been prepared on the basis of known surface geology, and are, therefore, interpretations of the subsurface. There is almost no reliable deep drilling data in this area and, therefore, the accuracy of cross-sections is limited by interpretation of surface geology.

STRATIGRAPHY

Precambrian - A Precambrian basement consisting of mixed metamorphic rocks from one to two billion years old underlies the sedimentary basin of the lower and central Hudson Valley. Where exposed in the Adirondacks to the northwest, the Precambrian consists of calcitic and dolomitic marbles, quartzites, and various metaclastics, as well as granitic and syenitic gneisses, with anorthosites and gabbros forming the Adirondack core. The nearest Precambrian rocks are silicic (non-carbonate).

Cambrian - The lowest sedimentary unit is the Cambrian Potsdam sandstone, which lies unconformably on the Precambrian rocks. The Potsdam sandstone may be up to one hundred feet thick, but the irregular nature of its lower contact makes it difficult to predict its true thickness at any given site. The Potsdam sandstone is overlain by another Cambrian unit; an intermixed sandstone and dolomite sequence known as the Theresa Formation.

Cambro-Ordovician to Ordovician - Overlying the Theresa Formation is an irregular thickness of dolomites, interfingering with limestones and sandstones, known as the Beekmantown Group. The irregular nature of the Beekmantown Group is caused by the regional Knox Unconformity which forms its upper contact.

Middle to Late Ordovician - Above this unconformity are the Black River-Trenton limestones, outcropping with more than 100 feet of thickness in the Glens Falls

area. Overlying the carbonate rocks is a thick series of shales, siltstones, and minor sandstones of the Utica and Snake Hill Formation, the latter of which is composed of the Schenectady, Normanskill and Austin Glen members. This sequence is poorly understood because of glacial cover, the positionally transitional nature of the units, and the complicating factor of the Taconic allocthon. These shales have a possible maximum thickness of up to 3,500 feet.

Early Devonian - Devonian rocks represented in this area include the Helderberg Group, a series of limestones and cherty units. The Helderberg limestone is seen basically as a prominent cliff face known as the Helderberg Escarpment. The rocks of the Catskills to the south and southwest of the Albany area are sandstones and shales of the Devonian Catskill Delta complex.

STRUCTURE

The major structural features of the area include the structurally complex Adirondack Mountains to the northwest, predominantly made up of medium to high grade metamorphic rocks of Precambrian age. To the east are lower Paleozoic low grade metamorphic rocks of the Taconic Mountains nested within the Middlebury Synclinorium, also a structurally complex mass. West and southwest of Albany lie the lower to mid-Paleozoic rocks, with pre-Silurian units exhibiting penecontemporaneous block faulting, but otherwise basically simple structure.

In the Hudson Valley itself, detailed structure and stratigraphy are uncertain, but it is suggested that the valley was the site of complex shelf sedimentation in Cambro-Ordovician times. Those sediments were later thrust to the west over the present basin with the allocthonous front (also called Emmon's or Logan's Line) passing approximately north-south just east of the Hudson River.

The geologic map and cross-sections (Figures 2-1, 2-2, and 2-3) summarize our interpretation of the geologic structure of the area of interest.

Section A-A'

FIGURE 2-2

Horizontal Scale 1:62,500

Legend

- Osc — Schenectady Formation: shale, thin limestone
- Oc — Canajoharie Formation: shale
- Otm — Taconic Melange: chaotic mixture of Early Cambrian through Middle Ordovician lithologies
- Oag — Austin Glen Formation: graywacke, grit
- On/Osh — Normanskill shale / Snake Hill Formation: alternating shale, siltstone, minor sandstone (flysch)
- Owl — Walloomsac Formation: slate, phyllite, schist, metagraywacke
- Otbr — Trenton & Black River Group: limestone, chert
- Osf — Stuyvesant Falls Formation: shale, siltstone, minor limestone
- Obk — Beekmantown Group: limestone, dolostone, local chert
- Ocbk — Beekmantown Group: sandy dolostone
- Op — Poultney Formation: thin limy shales
- Ep — Potsdam Formation: quartzite, sandstone
- Ecw — West Castleton Group: alternating thin shales & siltstones
- En — Nassau Formation: slate, shale, thin quartzite
- Er — Rensselaer Formation: grits, graywacke, minor shale
- Erb — Bomoseen Member: subgraywacke, minor shale, minor grits
- pC — preCambrian: undifferentiated

B

Section B-B'

FIGURE 2-3

Horizontal Scale 1 : 62,500

Legend

	Shelf (west)	Basin (east)
Upper Ordovician	Osc	Osh, Owl
Middle Ordovician	Oc	Oag, Otm
	Otbr	On, Owl
Knox Unconformity		
Lower Ordovician	Obk, Oebk	Op
Upper Cambrian	Ep	Ecw
Middle Cambrian		En
Lower Cambrian	Hiatus	
PreCambrian	pE	Er, Erb

Osc	—	Schenectady Formation: shale, thin limestone
Oc	—	Canajoharie Formation: shale
Otm	—	Taconic Melange: chaotic mixture of Early Cambrian through Middle Ordovician lithologies
Oag	—	Austin Glen Formation: graywacke, grit
On/Osh	—	Normanskill shale/ Snake Hill Formation: alternating shale, siltstone, minor sandstone (flysch)
Owl	—	Walloomsac Formation: slate, phyllite, schist, metagraywacke
Otbr	—	Trenton & Black River Group: limestone, chert
Osf	—	Stuyvesant Falls Formation: shale, siltstone, minor limestone
Obk	—	Beekmantown Group: limestone, dolostone, local chert
Oebk	—	Beekmantown Group: sandy dolostone
Op	—	Poultney Formation: thin limy shales
Ep	—	Potsdam Formation: quartzite, sandstone
Ecw	—	West Castleton Group: alternating thin shales & siltstones
En	—	Nassau Formation: slate, shale, thin quartzite
Er	—	Rensselaer Formation: grits, graywacke, minor shale
Erb	—	Bamoseen Member: subgraywacke, minor shale, minor grits
pE	—	preCambrian: undifferentiated

SECTION 3

RESEARCH METHODS USED AND RESULTS OBTAINED

INTRODUCTORY STATEMENT

In this section the rationale for using each research method and a description of the method will be made. Where appropriate, comments will be made about the accuracy or efficiency of the technique. Results are summarized and discussed.

STANDARD WATER CHEMISTRY

Rationale

Much work has been done in the world on the geochemistry of waters of high temperature geothermal systems, but relatively little has actually been done to characterize the chemistries of the lower temperature waters. For the most part, it has been determined that the water involved in such systems is largely meteoric, with possibly some deep magmatic contribution. Water chemistry is a sensitive indicator of the nature of potentially economic geothermal systems and its use in Phase I produced significant clues regarding the possible presence of a geothermal system. Water chemistry work was continued in Phase II because new wells were located and comparative analysis was important. Also a check of some of the earlier analytical work was considered appropriate.

Method

In Phase I of this study, water samples were collected from 38 locations and classified according to their major chemistry. In Phase II of the program, seven locations from Phase I were resampled, and 28 new locations sampled (Figure 3-1, Table 3-1).

The use of a Kemmerer down-hole sampler allowed us to sample previously inaccessible waters in abandoned wells throughout the area. These samples were collected either from very near the bottom of the well or from near the middle part of the well. The delivery line was marked in meters, and the entire sample was collected from the same depth.

When a domestic water well was active, samples were collected from the tap, or if water conditioning apparatus was involved, directly from the holding tank before being treated. When possible, water was allowed to run long enough to clear the holding tank and start pumping directly from the well. This was not possible in

Location Map for Standard Geochemical Samples.

Phase II sample numbers refer to table 3-1 (prefix 150-).

FIGURE 3-1

Table 3-1

SITE SPECIFICS FOR STANDARD GEOCHEMICAL SAMPLING

<u>Well Number</u>	<u>Name</u>	<u>Well Depth(ft.)</u>	<u>Sampling Date</u>
15001	Beerle	140	10/31/79
15002	French	280	11/1/79
15003	Rosemary	425	11/8/79
15004	Orenda	344	11/9/79
15005	Excelsior	Spring	11/12/79
15006	Old Iron	640	11/12/79
15007	Lamb	365	11/12/79
15008	Burns	400	11/13/79
15009	Hendrickson	176	11/14/79
15010	Roberts	263	11/14/79
15011	Martin	293	11/15/79
15012	Doster	200	11/15/79
15013	Wall	300	11/20/79
15014	Stefanovich	Spring	11/21/79
15015	Muller	600	11/21/79
15016	Guilderland Animal Hospital	310	11/26/79
15017	Henault	520	11/27/79
15018	Carpinello	180	11/27/79
15019	Ferrante (10m)	400	11/28/79
15020	Harrington	400	11/30/79
15021	Franklin	285	11/30/79
15022	Gaylord	246	12/1/79
15023	Conte	244	12/3/79
15024	Big Red	300(?)	12/4/79
15025	Mancuso	600	12/19/79
15026	Carr	400	12/6/79
15027	Horstman	180	12/6/79
15028	Urda	600	12/7/79
15029	Locke	277	12/10/79
15030	Smith	160	12/20/79
15031	Welch	306	1/2/80
15032	Saratoga Veterinary Hospital	300	1/29/80
15033	Ferrante (50m)	400	1/29/80
15034	Ferrante (100m)	400	1/29/80
15035	Watson	150(?)	1/30/80
15036	Duncan	130	1/31/80
15037	Banino	220	1/31/80

all cases because of low flow wells or other problems causing significant inconvenience to the owners.

New wells were located with the aid of local well drillers and water conditioning dealers who opened their files for our use. Several advertisements were placed in local papers in a fairly successful campaign asking owners of saline or carbonated waters to contact us in order to make sampling arrangements.

Each sample was collected in five plastic bottles, some treated with acids in order to fix in solution or precipitate out certain elements for analysis. Field titrations for alkalinity, field pH, and temperature measurements were made at the time of sampling. Samples were analyzed for a wide range of major and trace elements. Analyses for standard constituents of dissolved solids, including Na, K, Ca, Mg, Cl, SO_4 , Br, nitrogen species, total Fe, silica, aluminum, and total solids (TS), and for minor constituents such as F, I, phosphate, total organic carbon (TOC), Ba, Sr, Li, Hg and Zn were performed. The analyses were made at the Health Research Inc. Laboratories of the State Health Department.

Evaluation of Methods

Analytical methodology and precision estimates are listed in Appendix A. The estimates of analytical precision refer to procedural replication, and have been tested by the submission of duplicate samples at different times. Analytical precision is generally within $\pm 10\%$ of the reported analysis. Obvious errors in the analyses have been resubmitted and corrected, but there is some degree of analytical error in most of the results. These minor discrepancies should not present any serious problems in terms of interpretation of the results however.

Summary of Results

Several water "types" have been recognized in the Saratoga Springs area, and have been interpreted as mixtures of surface, connate, and possibly magmatic fluids. The waters are basically saline, with variable amounts of carbon dioxide, methane, and other gases. The classification scheme devised in Phase I follows below.

Surface waters - uncarbonated, less than 360 mg/l HCO_3^- , total solids less than 500 mg/l. Major element chemistry, variable; minor element chemistry, "normal"; K, 0-3 mg/l; SiO_2 , 5-15 mg/l.

Saratoga-type waters - carbonated (free CO_2), up to 5000 mg/l HCO_3^- , total

solids range from 2000 mg/l to 20,000 mg/l. Major element chemistry, $\text{HCO}_3 > \text{Cl} > \text{Na}$ (molar relationship); minor element chemistry, excess K, 30-340 mg/l, SiO_2 up to 70 mg/l.

Saline waters - uncarbonated, less than 400 mg/l HCO_3 ; total solids up to 6500 mg/l. Major element chemistry, $\text{Cl} > \text{Na} > \text{HCO}_3$ (molar relationship), minor element chemistry, normal K, 7-11 mg/l, normal SiO_2 , 10-17 mg/l.

Neutralized sodium bicarbonate waters - carbonated (free CO_2) up to 2750 mg/l HCO_3 , total solids range from 100 - 4000 mg/l. Major element chemistry, $\text{HCO}_3 > \text{Na} > \text{Cl}$ (molar relationship); minor element chemistry, excess K, 20-70 mg/l, slightly high SiO_2 , 13-22 mg/l.

Sulfate waters - carbonated and uncarbonated, from 2000 - 1250 mg/l HCO_3 ; total solids up to 5500 mg/l. Major element chemistry, $\text{SO}_4 > \text{HCO}_3 > \text{Cl} > \text{Na}$ (molar relationship); minor element chemistry, excess K, up to 50 mg/l in carbonated wells, normal K, 1-8 mg/l in uncarbonated wells, slightly anomalous SiO_2 , 15-22 mg/l.

The waters analyzed during Phase II of the project, as presented in Table 3-2, can be similarly classified into the above water types. A good correlation can be made between the analyses for duplicated locations from last year.

Discussion

Further analysis of these water types is here undertaken, in an effort to determine through chemical indicators, the possible thermal processes associated with these components.

(1) Saline water chemistry - Saline formational or connate waters of relatively low salinity and without free CO_2 occur in the lowermost Paleozoic carbonates of the Mohawk Valley and to an undertermined extent to the south in the Hudson Valley. Such waters are also present in the greater Saratoga area but they are commonly mixed with other components. On the basis of sampling to date, these waters have maximum salinities of about 10,000 mg/liter (ppm) commonly with chloride stoichiometrically slightly in excess of Na, and with low Ca and Mg contents. Br, I, K, Sr, Ba, and B in amounts proportional to those in sea water are invariably present. Maximum alkalinity values are a few hundred mg/l. Alkalinity = Total anions - $\sum (\text{Cl} + 2\text{SO}_4 + \text{Br} + \text{F})$ and thus in samples with low borate (the

Table 3-2

CHEMICAL DATA FROM STANDARD SAMPLING

<u>Sample No.</u>	<u>15001</u>	<u>15002</u>	<u>15003</u>	<u>15004</u>	<u>15005</u>	<u>15006</u>
T ^o C	13.3	11.4	12.6	9.9	10.6	10.4
pH	7.9	8.0	6.1	5.8	6.6	5.8
Alkalinity (field)	194.0	1690.0	2940.0	3360.0	3560.0	1410.0
SO ₄	4.0	8.0	29.0	15.0	20.0	4.0
Cl	450.0	330.0	350.0	3100.0	2700.0	1700.0
Na	180.0	450.0	350.0	2300.0	2300.0	550.0
K	3.4	8.4	72.0	220.0	36.0	35.0
Ca	55.0	5.4	260.0	720.0	120.0	290.0
Mg	26.0	2.3	190.0	310.0	120.0	80.0
Fe	0.77	0.13	6.6	2.8	7.8	13.0
NO ₂	5.0	5.0	5.0	7.0	7.0	5.0
NH ₃	0.49	2.3	2.8	5.2	11.0	3.4
N _{TOT}	0.7	3.3	3.7	9.0	13.0	4.4
TOC	5.0LT	11.0	5.0LT	34.0	5.0LT	5.0
PO ₄	0.008	0.04	0.07	0.053	0.049	0.074
F	0.26	2.0	0.37	0.46	0.44	0.42
Br	6.7	18.0	18.0	82.0	67.0	26.0
I	0.62	2.5	0.10	2.0	1.8	0.35
B	0.29	1.2	1.0	3.4	2.5	0.98
Al	0.05LT	0.05LT	0.05LT	0.59	0.063	0.05LT
Li	0.5	3.2	1.2	7.3	10.0	2.0
SiO ₂	8.8	7.6	44.0	10.0	15.0	46.0
Sr	3.1	2.8	4.3	13.0	37.0	8.4
Ba	2.2	0.9	2.4	14.0	20.0	7.2
Hg	0.0004LT	0.0004	0.0004	0.0004LT	0.0004LT	0.0004LT
Zn	0.07	0.36	0.05LT	0.05LT	0.05LT	0.05LT
TS	1180.0	2250.0	2429.0	10370.0	7825.0	2567.0

LA = Lab Accident

LT = Less Than

NA = Not Analyzed

INTF = Interference
Results in mg/l.

Table 3-2 continued

Sample No.	15007	15008	15009	15010	15011	15012
T ^o C	12.2	12.1	10.8	10.2	11.0	12.2
pH	8.1	9.3	8.9	6.5	6.3	6.6
Alkalinity (field)	720.0	410.0	690.0	2470.0	2270.0	2260.0
SO ₄	5.0	3.0	4.0	7.0	28.0	34.0
Cl	270.0	390.0	350.0	1500.0	120.0	700.0
Na	400.0	350.0	460.0	1500.0	490.0	950.0
K	4.2	NA	3.5	100.0	15.0	17.0
Ca	2.3	0.9	0.9	170.0	73.0	65.0
Mg	0.4	0.6	1.7	83.0	54.0	28.0
Fe	0.29	NA	0.05	8.8	1.7	0.39
NO ₂	5.0	5.0	6.0	13.0	5.0LT	5.0
NH ₃	0.95	NA	1.6	5.8	5.2	8.5
N _{TOT}	1.2	NA	1.8	7.7	6.3	9.5
TOC	16.0	NA	5.0LT	6.0	32.0	12.0
PO ₄	0.047	NA	0.057	0.036	0.013	0.028
F	4.2	NA	3.6	0.18	0.2	0.5
Br	16.0	NA	14.0	42.0	15.0	44.0
I	0.92	NA	1.8	1.4	0.020	0.16
B	1.1	NA	0.88	3.4	2.0	3.7
Al	0.05	NA	0.05LT	0.36	0.05LT	0.05LT
Li	2.0	NA	1.9	3.5	0.9	6.4
SiO ₂	8.3	7.2	7.6	12.0	13.0	10.0
Sr	1.0	NA	1.0	18.0	7.6	11.0
Ba	0.5LT	NA	0.5LT	20.0	5.6	11.0
Hg	0.0004LT	NA	0.0004LT	0.0004LT	0.0004LT	0.0004LT
Zn	0.16	NA	0.05	0.05LT	0.05LT	0.05
TS	1136.0	1073.0	1263.0	5458.0	2177.0	3179.0

LA = Lab Accident

LT = Less Than

NA = Not Analyzed

INTF = Interference

Results in mg/l.

Table 3-2 continued

<u>Sample No.</u>	<u>15013</u>	<u>15014</u>	<u>15015</u>	<u>15016</u>	<u>15017</u>	<u>15018</u>
T ^o C	9.9	9.6	10.8	11.5	12.2	10.9
pH	7.7	7.7	7.7	7.8	9.7	7.3
Alkalinity (field)	280.0	110.0	670.0	640.0	490.0	450.0
SO ₄	6.0	22.0	5.0	2.0	11.0	310.0
Cl	4100.0	2.0LT	240.0	4900.0	7.0	66.0
Na	2600.0	2.6	290.0	2700.0	250.0	45.0
K	34.0	0.5	1.8	21.0	2.1	NA
Ca	89.9	35.0	7.1	35.0	0.5LT	39.0
Mg	33.0	3.8	5.7	18.0	0.4	84.0
Fe	3.4	0.96	0.1	0.52	1.5	NA
NO ₂	5.0	5.0LT	5.0LT	5.0	10.0	NA
NH ₃	19.0	0.053	0.45	6.4	0.91	NA
N _{TOT}	19.0	NA	1.3	8.5	1.4	NA
TOC	5.0LT	NA	8.0	17.0	5.0LT	NA
PO ₄	0.024	NA	0.032	0.010	0.067	NA
F	3.0	0.1LT	2.5	1.8	3.9	NA
Br	82.0	NA	6.5	56.0	5.2	NA
I	14.0	NA	0.035	35.0	0.17	NA
B	0.79	0.2LT	0.28	1.1	1.2	NA
Al	0.052	0.37	0.05LT	0.05	0.35	NA
Li	12.0	0.01LT	0.31	11.0	0.6	NA
SiO ₂	6.7	8.7	7.7	5.5	11.0	17.0
Sr	58.0	NA	1.0	19.0	1.0	NA
Ba	16.0	NA	0.5LT	6.9	0.5LT	NA
Hg	0.0006	NA	0.0004LT	0.0004LT	0.0004LT	NA
Zn	0.05LT	NA	0.36	0.84	0.05	NA
TS	9816.0	160.0	1079.0	8810.0	554.0	1010.0

LA = Lab Accident

LT = Less Than

NA = Not Analyzed

INTF = Interference

Results in mg/l.

Table 3-2 continued

Sample No.	15019	15020	15021	15022	15023	15024
T ^o C	10.5	10.8	8.7	11.0	8.1	8.9
pH	6.3	7.6	6.4	6.3	6.7	6.1
Alkalinity (field)	4630.0	2410.0	250.0	2740.0	70.0	4660.0
SO ₄	INTF	180.0	16.4	9.0	8.0	5.0
Cl	5700.0	800.0	6000.0	2800.0	14000.0	1200.0
Na	3800.0	1400.0	3500.0	1200.0	2700.0	1300.0
K	78.0	13.0	39.0	110.0	18.0	110.0
Ca	580.0	12.0	140.0	270.0	5000.0	380.0
Mg	320.0	5.0	43.0	120.0	650.0	230.0
Fe	39.0	0.05LT	5.9	6.3	15.0	240.0
NO ₂	10.0	5.0	8.0	7.0	90.0	16.0
NH ₃	22.0	3.5	13.5	10.0	0.81	5.4
N _{TOT}	31.0	3.5	13.0	11.0	1.2	LA
TOC	5.0LT	5.0LT	5.0LT	5.0LT	7.0	18.0
PO ₄	0.056	0.003	0.012	0.007	0.14	0.084
F	0.12	2.6	2.4	0.2	0.2	0.2
Br	160.0	25.0	130.0	46.0	100.0	40.0
I	12.0	3.0	18.0	0.27	0.27	0.76
B	4.0	1.3	0.37	0.97	0.94	0.55
Al	0.11	0.05LT	0.082	0.066	0.097	0.13
Li	25.0	5.0	14.0	5.0	0.51	4.0
SiO ₂	14.0	8.2	2.4	13.0	6.8	55.0
Sr	100.0	3.3	91.0	36.0	2300.0	12.0
Ba	50.0	0.5LT	17.0	36.0	9.1	6.3
Hg	0.0004LT	0.0004	0.0004LT	0.0004LT	0.0004LT	0.0004LT
Zn	0.05	0.05	0.05LT	0.05LT	0.06	0.05
TS	19500.0	4070.0	10600.0	7550.0	29700.0	6070.0

LA = Lab Accident
 LT = Less Than
 NA = Not Analyzed
 INTF = Interference

Results in mg/l

Table 3-2 continued

<u>Sample No.</u>	<u>15025</u>	<u>15026</u>	<u>15027</u>	<u>15028</u>	<u>15029</u>	<u>15030</u>
T ^o C	11.2	10.9	11.7	10.5	8.3	10.6
pH	8.7	6.9	9.5	7.2	8.2	9.7
Alkalinity (field)	1680.0	1430.0	320.0	1020.0	310.0	10.0
SO ₄	7.0	5.0	2.0	3.0	14.0	6.0
Cl	380.0	120.0	2.0	680.0	32.0	6.0
Na	760.0	310.0	100.0	850.0	10.0	190.0
K	2.1	50.0	0.8	6.0	0.1	1.4
Ca	5.7	99.0	0.5LT	13.0	72.0	0.7
Mg	2.0	32.0	0.1	8.6	16.0	0.2
Fe	0.86	0.39	0.05	3.7	0.05	0.29
NO ₂	5.0	5.0	5.0	7.0	5.0	5.0
NH ₃	0.37	3.8	1.5	2.6	0.044	1.8
N _{TOT}	0.42	4.2	1.6	2.6	0.040	1.8
TOC	13.0	5.0	27.0	11.0	0.5	5.0
PO ₄	0.024	0.011	0.02	0.033	0.003	0.040
F	4.4	0.5	0.9	1.4	0.1LT	2.1
Br	14.0	INTF	INTF	18.0	INTF	15.0
I	0.070	0.044	0.005	0.78	0.005LT	0.15
B	0.46	0.50	0.29	0.41	0.26	1.2
Al	0.05	0.044	0.005	0.42	0.05	0.25
Li	0.3	1.7	0.41	3.4	0.01LT	0.9
SiO ₂	4.3	8.8	12.0	5.9	6.6	12.0
Sr	1.0LT	2.8	1.0LT	4.6	1.0LT	1.0LT
Ba	0.5LT	3.4	0.5LT	3.7	0.5LT	0.5LT
Hg	0.0004LT	0.0004LT	0.0004LT	0.0004LT	0.0004LT	0.0004LT
Zn	0.05LT	0.05LT	0.05LT	4.3	0.05LT	0.05LT
TS	2050.0	1640.0	328.0	2110.0	304.0	500.0

LA = Lab Accident
 LT = Less Than
 NA = Not Analyzed
 INTF = Interference

Results in mg/l.

Table 3-2 continued

Sample No.	15031	15032	15033	15034	15035	15036	15037
T ^o C	10.2	9.7	9.7	NA	9.0	9.9	9.5
pH	6.8	8.7	6.4	6.2	8.0	7.15	9.5
Alkalinity (field)	3530.0	216.0	4600.0	NA	46.0	940.0	400.0
SO ₄	20.0	3.0	5.0	9.0	21.0	4.0	5.0
Cl	700.0	2.0	5100.0	8100.0	15.0	320.0	12.0
Na	1100.0	78.0	5200.0	5200.0	4.6	450.0	160.0
K	26.0	2.2	69.0	68.0	1.0	7.2	2.9
Ca	150.0	7.3	600.0	570.0	24.0	51.0	2.1
Mg	160.0	3.0	330.0	350.0	6.7	17.0	0.8
Fe	2.1	0.06	14.0	36.0	0.05LT	2.7	0.39
NO ₂	5.1	5.0	10.0	14.0	5.0	5.0	5.0
NH ₃	6.1	1.2	12.0	13.0	0.021	1.2	0.95
N _{TOT}	7.8	1.5	29.0	28.0	0.082	1.4	1.2
TOC	5.0	2.0	2.0	3.0	2.0	1.0	1.0LT
PO ₄	0.022	0.021	0.036	0.013	0.005	0.019	0.04
F	2.5	2.0	0.1LT	0.1LT	0.1LT	0.46	1.3
Br	25.0	6.8	170.0	170.0	INTF	12.0	INTF
I	.26	0.066	10.0	9.0	0.55	0.55	0.052
B	LA	0.65	2.6	2.6	0.2LT	1.3	0.62
Al	0.05LT	0.05LT	0.05LT	0.05	0.05	0.05	0.31
Li	2.1	0.23	25.0	27.0	0.01LT	1.0	0.51
SiO ₂	16.0	8.8	13.0	14.0	8.8	10.0	12.0
Sr	13.0	1.0	160.0	170.0	1.0LT	3.9	1.0LT
Ba	9.7	0.5	6.8	74.0	0.5LT	1.5	0.5LT
Hg	0.0004LT	0.0004LT	0.0004LT	0.0015	0.0004LT	0.0004LT	0.0004LT
Zn	0.05LT	0.05LT	0.05LT	NA	0.15	0.05LT	0.05LT
TS	4380.0	231.0	18900.0	19500.0	175.0	1490.0	435.0

LA = Lab Accident

LT = Less Than

NA = Not Analyzed

INTF = Interference

Results in mg/l.

major remaining anion) content is essentially equivalent to CO_3 or HCO_3 depending upon pH. Alkalinity is expressed as the equivalent weight of CaCO_3 , although it is actually present as bicarbonate ion in most samples. In older analyses note that this quantity may appear as HCO_3 , CO_3 , or CaCO_3 . Connate waters commonly also have minor or trace contents of F, Li, Fe, Al, N and variable SO_4 (low in these samples). All of these components are present in seawater from which most of the ions were probably derived. The bulk composition has been modified by exchange and reaction with the host rocks and by subsequent dilution by meteoric waters.

For example, in sea water the molar ratio $\text{BrX1000/Cl} = 1.5$ and $\text{IX1000/Cl} = .003$, while in the saline formation waters of this study $\text{BrX1000/Cl} = 5-10$, and $\text{IX1000/Cl} = 1-3$ with both of these ratios increasing markedly in the carbonated, mixed waters and also in groundwaters of this region. On the other hand, the ratio K/Na is about .021 in normal sea water and .006 - .008 in the saline waters of this area. However, in the carbonated waters of the Capital District the ratio increases to 0.08 or more.

Analyses of nitrogen species in water were initially instituted as a check for surface water contaminants (i.e., pollution). In general little or no such contamination has been found in any of the waters (this is not to be confused with dilution by meteoric waters). Small amounts of ammonia are common in connate waters and in most analyses this accounts for the bulk of the nitrogen. Analyses of organic carbon can provide similar information but in the waters of this study such analyses are also influenced by such dissolved gases as methane.

Typical saline waters have a pH of 7.2 - 7.7. In mixed water types the above characteristics and bulk chloride content can provide some indication of the proportion of saline water component present. Some examples of thermal waters are actually metamorphic waters produced by interaction between former formation waters and host rocks at elevated temperatures (ex. Salton Sea thermal brines and Steamboat Springs, Colorado). In these waters, chemical thermometers of the Na-K and dissolved silica types are useful predictors (K/Na and SiO_2 increase with temperature); however, only low ratios and low silica values occur in the saline waters sampled here.

(2) Carbonated-alkaline-saline waters - Introduction of carbon dioxide into the saline formation waters produces saline carbonic acid solutions which, in turn,

react with the reservoir or wall rocks to form bicarbonates. A schematic reaction is $2\text{H}_2\text{CO}_3 + \text{CaMg}(\text{CO}_3)_2 = \text{Ca}^{+2} + \text{Mg}^{+2} + 4\text{HCO}_3^-$ for carbonated waters in contact with dolomite. The resultant solutions increase in alkalinity as the reaction proceeds, and the pH tends to rise as the carbonic acid is neutralized. The alkalinity of the water is thus a measure of the extent of this reaction, but not of the degree of carbonation or CO_2 partial pressure. The latter can be calculated from the ionization constant for carbonic acid and the equilibrium constant between carbonic acid and pCO_2 .

Ultimately the wall rock reaction ceases when the reaction products (Ca^{+2} , Mg^{+2} , HCO_3^-) reach saturation under the pressure, temperature and chemical characteristics of the system. Calculated solubilities of carbonate species in the analyzed waters of this type, however, seldom indicate saturation, or even a close approach to it. It must be remembered, however, that the analysis data apply to well or tap discharges, and the conditions at the surface, to the extent that gas exsolution and dilution with meteoric waters is taking place, do not accurately reflect the subsurface environment. It is therefore difficult to represent the equilibrium conditions likely at depth for carbonate mineral reactions.

Comparisons of past analyses suggest that the overall salinity of these waters is declining with time, while the degree of carbonation (as judged by alkalinity) is the same or perhaps even slightly greater. This suggests that the aquifer capacity is limited and that a continued flushing or dilution by meteoric waters occurs with time. However, CO_2 appears to be continually replaced. Shorter term seasonal variations in CO_2 can also be noted in many wells.

The effect of dissolution reactions on the wall rocks is also evident for water constituents other than Ca and Mg. K/Na increases markedly, as noted above, possibly as a result of leaching of detrital and authigenic K-feldspar in the Potsdam and Beekmantown formations. Anomalous Y and Zr, as analyzed in last year's samples, are possible additions from the Potsdam formation as well. In wells with the highest total salinities among current samples (such as sample 15019 with total solids = 19,500 ppm, and Hathorn #3 with total solids = 15,190 ppm) the saline component alone totals 10-12,000 ppm which agrees with that observed in the uncarbonated saline waters outside. In past analyses of Saratoga waters of highest TS (cited because the Na/Cl ratio is more reliable) it is common for approximate Na-Cl stoichiometry to exist, and where Na is in excess (reported as NaHCO_3) the degree is slight to moderate (none exceed 9% excess). In contrast, many carbonated

waters of lower TS are markedly non-stoichiometric with excess Na; examples are the Rosemary and Martin wells, with 34% and 84% excess Na over Cl respectively.

In the past this trend was interpreted as indicating a "basement" fluid vector or water component being added to the saline basinal water to produce the carbonated-NaHCO₃ types. While this may still be true, there are several inherent problems, viz:

BrX1000/Cl ratios of these waters (12-13+) are appreciably higher than in the saline types (5-10), which is difficult to resolve with a simple mixing model without resorting to some unusual halogen fractionation process.

K/Na ratios of the carbonated waters as well as of neutralized "fringe" waters are more related to pH than any other property such as NaHCO₃ content, alkalinity or TDS. This relation, also, is incompatible with variable additions of a separate NaHCO₃-type water component.

Certain areal patterns of NaHCO₃-enriched waters are present (e.g., Fort Edward vicinity), but there is little evidence of any closer association with discharge from the basement, or faults therein, than other carbonated waters. Apart from NaHCO₃, these waters also show no anomalous contents of elements indicative of a different origin. In fact, spatially, NaHCO₃-enriched waters are prominent in many wells which lie within the shales east and south of Saratoga. In several cases in the past, NaHCO₃-type waters first encountered in a well were "pumped out" and replaced by more saline carbonated types, which suggest water stratification.

Neutralized NaHCO₃-type waters (pH 7-9) of relatively low salinity (TS < 5000 ppm) appear to be common in wells within shale and siltstone (Utica, Schenectady, Normanskill and equivalent formations) surrounding the principal area of carbonated waters from Saratoga to the Mohawk Valley. Aside from NaHCO₃ (Na > Cl, Alkalinity > 600), these waters may contain minor Ca and Mg up to about 200 ppm, which suggests they are weaker, now neutralized "fringe" versions of waters of similar character but with active carbonation and consequently lower pH. A typical example is #15028 (Urda in Niskayuna).

Another interpretation of all these features is that ionic filtration of carbonated-saline waters of waters of higher salinity takes place principally within the shales along with carbonic acid leaching. In this exchange-leaching process Cl is removed relative to Br and HCO_3 , and possibly some Ca+Mg are removed (or exchanged) relative to Na. These ions are removed in an adsorptive process as a result of charged layers in the clays, and by exchange within layers where charge and ionic size constraints allow.

Changes of this type via ionic filtration alone have been documented in ground waters crossing lithologic zones of river channel-floodplain-flank deposits. In this latter case, the source of HCO_3 is atmospheric CO_2 or soil gas, but alkalinities of 1000-2000 ppm are still developed in clay-silt lithologies at near neutral pH. In essence then, the ground water takes on a "formation water" character under these circumstances. Whether this analogy also holds here remains to be verified, but it is suggestive.

The possibilities of these types of reactions make the application of such geothermometers as K/Na and K-Na-Ca-Mg of questionable value. Figures 3-2, 3-3, 3-4, and 3-5 show the spatial distribution of four of the trace elements analyzed for both Phase I and Phase II samples. The elements boron, fluorine, lithium, and strontium are recognized as possible geothermal indicators because of their solution characteristics at high temperatures and their general association with geothermal fluids. It is significant to note that these trace elements are occurring in relatively high concentrations at coincident locations.

There are three areas of basic interest in terms of these elements: the immediate vicinity of Saratoga Springs and to the northeast, the area between Schenectady and Altamont, and a small area just north of Melrose. These areas also have the most saline waters and the largest concentrations of carbon dioxide, and could represent the currently most active conduits for these fluids from depth.

One well in particular should be mentioned because of its extremely unusual chemistry. Sample 15023 (Conte, in Johnsbury) does not appear to be related to the same system we are dealing with in the Capital District. Its chemistry is significantly different than that of the other waters, and the water is produced from Precambrian metamorphic rocks rather than the Paleozoic sedimentary sequence. It has the highest TS (29,700 ppm), a high Cl:Na ratio, and is very high in Sr (2300 ppm). The composition of the water cannot be readily explained as a result of contamination of some sort, but we have no other explanation at the present time.

Location Map Showing High Fluorine Concentrations

○ ≥ 4 ppm

■ ≥ 2 ppm

• < 1 ppm

▲ ≥ 3 ppm

● ≥ 1 ppm

FIGURE 3-3

● ≥ 1 ppm

FIGURE 3-4

Location Map Showing High Strontium Concentrations

○ ≥ 50 ppm

■ ≥ 10 ppm

● < 5 ppm

▲ ≥ 20 ppm

● ≥ 5 ppm

FIGURE 3-5

SILICA AND SILICA DECAY ANALYSES

Rationale

The dissolved silica (SiO_2) content of natural waters has been determined to be primarily a function of temperature and silica species (i.e., quartz, chert, cristobolite, amorphous silica). As such, it can be valuable as a geothermal exploration tool. When quartz is the silica phase with which the water is in equilibrium, dissolved SiO_2 concentrations in excess of 25-30 ppm for ambient waters discharged at the surface are considered anomalous and indicative of higher temperatures. Normal background silica values for this area appear to be in the range of 10-15 ppm, consistent with the normal water temperatures of 9-13°C. A relationship of SiO_2 content in normal groundwater to regional heat flow has also been noted, and can be applied over broad areas where distinct SiO_2 anomalies are not present. A survey of this type was applied to the area around Saratoga Springs, where there is a silica anomaly, in an effort to determine if a higher regional heat flow exists. Another survey was concentrated in the Lebanon Springs area, with good results.

Methods

After having let the water run for at least five minutes, samples were collected in plastic bottles (to avoid reaction with the container). Water temperature was measured at the time of sampling. An effort was made to sample water only from wells penetrating rock in order to be sure that the water was in equilibrium with wall rock. In areas of thick glacial cover, few wells penetrate rock because of the availability of water in the near surface sands and gravels. Sampling was also difficult around towns and cities, because of city water lines reducing the number of wells available for sampling. Silica concentration was also analysed on all samples collected for complete chemical analysis.

Samples for silica decay analyses were collected as for standard silica analysis, but twelve samples were collected from each location, and the caps were sealed with wax to prevent interaction with air. Samples were stored at 4°C and analyses performed every two weeks. Analytical errors are within $\pm 25\%$.

Summary of Results and Discussion of Silica Analyses

Figure 3-6 is an index map showing the locations of samples collected for SiO_2 analysis, exclusive of the sites for which complete chemical analyses were performed. Table 3-3 lists the SiO_2 values, water temperature, owner's name and

Location Map for Silica Samples
(Exclusive of Standard Chemical Sample Points)

Note : Density of sampling precludes numbering of sites,
 but site specific data are contained in table 3-3.

FIGURE 3-6

Table 3-3

SITE SPECIFICS FOR SILICA SAMPLING

<u>Sample Number</u>	<u>Name</u>	<u>Date</u>	<u>Silica ppm</u>	<u>T(°C)</u>	<u>Location</u>
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. 22 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., Lindsey Petersburg
110	Kuster	10/16	6.2		Beebe Pond Rd., Canaan
111	Viall	12/16	15.0	12.8	Rt. 67 Schaghticoke
112	Antolick	12/26	8.0	8.8	Rt. 67 Schaghticoke
113	Brookley	12/26	8.9	10.7	Rt. 67 Schaghticoke
114	Hemendinger	12/26	11.0	11.4	Rt. 40 Schaghticoke
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
121	Stefanovich	10/18	9.5	10.0	Rt. 22 Eagle Bridge
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		Canaan Rd., New Lebanon
126	Walter	10/17	13.0		Canaan Rd., New Lebanon
127	Benson	10/17	12.0		Rt. 5 Lebanon
128	Oherly	10/17	7.5		Rt. 5 Lebanon
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
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
141	Gifford	12/26	9.4	10.4	Rt. 114 Schaghticoke
142	Woelfersheim	12/26	14.0	14.0	Rt. 40 Schaghticoke
143	Fedorowicz	12/28	7.3	11.8	Rt. 66 Nassau
144	Herbert	12/18	8.1	11.9	Rt. 20 Nassau

Table 3-3 Continued

<u>Sample Number</u>	<u>Name</u>	<u>Date</u>	<u>Silica ppm</u>	<u>T(°C)</u>	<u>Location</u>
145	Frederickson	12/18	13.0	11.6	Chestnut St., Nassau
146	Marra	12/26	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., East Nassau
149	Wells	12/28	7.0	9.9	Rt. 18 North Nassau
150	No Name	12/28	8.4	13.0	North Schodack Rd., East 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
164	Atwater	10/17	16.0	6.1	West Rd.
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	Hyatt Cherryplain Rd.
168	Cherryplain Post Office	10/17	4.7	3.3	Old Rt. 22
169	Pearce	12/28	17.0	11.0	Palmer Rd., E. Greenbush
170	Guimarra	10/17	7.9	7.2	Miles Mountain Rd., Center Berlin
171	Miller	12/31	16.0	10.5	Rt. 9J Schodack Landing
172	Farrell	12/31	10.0	11.8	Rt. 9J Schodack Landing
173	Plath	12/31	16.0	12.0	758 Schodack Landing
174	Carl	12/27	15.0	13.4	904 Clove Rd., Schodack
175	Davids	12/31	15.0	12.0	Schodack Rd., Castleton
176	No Name	12/31	13.0	11.0	Schodack Rd., Castleton
177	Bottley	12/31	17.0	9.5	School Landing Rd., Castleton
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 (Rev.)	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
189	Gen. Cable	10/24	9.2		Rt. 396 N. Pownal

Table 3-3 Continued

<u>Sample Number</u>	<u>Name</u>	<u>Date</u>	<u>Silica ppm</u>	<u>T(°C)</u>	<u>Location</u>
190	Greylock High School	10/25	6.7		Williamstown, Mass.
191	Mt. Hope Farm	10/12	6.3		
192	Rhodes	10/22	5.5		Hancock Rd., Williamstown
193	White	10/25	6.1		Oblong Rd., Williamstown
194	Jericho Valley Motel	10/22	5.2		Rt. 43 Hancock
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
200	Gorsky	1/3/80	12.0	12.0	Putnam Rd., Stillwater
201	Ferndell	1/3/80	12.0	3.5?	Saratoga Springs
202	Griffen	1/3/80	10.0	12.0	Spook Hollow Rd., Saratoga
203	Polaris	1/3/80	19.0	11.0	Saratoga Springs
204	Skellie	1/3/80	15.0	10.0	Mabb Rd., Saratoga
205	Hayes Well	1/3/80	9.5	11.0	
206	Brunson	1/3/80	8.2	11.0	Casey Rd., Saratoga
207	Geyser 2	1/3/80	40.0	6.5	Saratoga Springs
208	Walter Hayes	1/3/80	6.5	10.0	Hayes Rd., Saratoga
209	Barton	1/3/80	5.4	11.0	Rt. 9N Greenfield
210	Bellamy	1/3/80	8.0	9.0	Louden Rd., Wilton
211	No Name	1/3/80	6.0	10.8	Middlegrove Rd., S. Greenfield
212	Burger	1/3/80	11.0	11.0	Ruggles Rd., Saratoga
213	Demaria	1/3/80	9.5	13.0	Grand Ave., Saratoga
214	Hanehan	1/3/80	11.0	9.0	Caldwell Rd., Saratoga
215	Bourassa	1/3/80	13.0	10.5	Adams Rd., Saratoga
216	Robinson	1/3/80	14.0	10.0	Ketchums Corners, Stillwater
217	Braymer	1/7/80	10.0	12.2	Rt. 50 Wilton
218	Baldwin	1/7/80	9.6	9.0	S. Greenfield Rd., Greenfield
219	Hensley	1/7/80	12.0	11.5	King Rd., Northumberland
220	DeCoteau	1/7/80	14.0	10.0	Spiers Falls Rd., Greenfield
221	Reilly	1/7/80	8.9	8.0	Forest Ln., Northumberland
222	Tooker	1/7/80	8.8	11.0	Main St., Corinth
223	Gansevoort Market	1/7/80	8.1	10.5	Main St., Gansevoort
224	Ramsey	1/7/80	10.0	11.5	Hack Rd., Corinth
225	Johnson	1/7/80	15.0	13.0	Fortsville Rd. Fortsville
226	Torda	1/7/80	9.3	10.5	Spiers Falls Rd., Greenfield
227	Bacody	1/7/80	6.8	11.2	Selfridge Rd., Gansevoort
228	Orisek	1/7/80	9.0	12.0	Greene Rd., Greenfield
229	Hopkins	1/7/80	8.2	13.0	Selfridge Rd., Gansevoort
230	Crandall	1/7/80	9.4	9.5	Brigham Rd., Greenfield
231	McNeil	1/7/80	6.3	12.8	Gansevoort Rd. Fort Edward
232	Pratt	1/15/80	10.0	10.5	Parkhorst Rd., Wilton
233	Bouton	1/7/80	4.1	12.5	Clarke Rd., Gansevoort
234	Meyers	1/15/80	11.0	9.5	Rt. 9, Wilton
235	Killian	1/7/80	7.1	11.0	Bost Rd., Gansevoort

Table 3-3 Continued

Sample Number	Name	Date	Silica ppm	T(°C)	Location
236	Hartman	1/15/80	13.0	9.5	South Rd., Moreau
237	Shaw	1/15/80	9.6	11.0	Palmer Rd., Moreau
238	Craw	1/15/80	8.7	11.5	Traver Rd., Wilton
239	Jordan	1/15/80	14.0	4.5	Rt. 9, Wilton
240	Gates	1/15/80	10.0	12.5	Malta Ave., Malta
241	Charles Owen	1/16/80	11.0	6.0	MacElroy Rd., Clifton Park
242	George Owen	1/16/80	9.0	10.0	Eastline Rd., Malta
243	Kiehl	1/16/80	9.4	10.5	Randall Rd., Ballston
244	Seymour	1/16/80	13.0	11.0	Hop City Rd., Ballston
245	Geren	1/16/80	14.0	9.5	Sweetman Rd., Ballston
246	Deyoe	1/16/80	18.0	9.5	Maple Ave., Charlton
247	Mercer	1/16/80	11.0	9.5	Charlton Rd., Ballston
248	Greive	1/16/80	11.0	12.0	Outlet Rd., Ballston
249	Cook	1/17/80	12.0	10.5	Paisley Rd., Milton
250	Keicher	1/17/80	11.0	11.8	Ushers Rd., Halfmoon
251	Rastinehad	1/17/80	17.0	11.5	Middleline Rd., Milton
252	Kelch	1/19/80	13.0	14.0	Dunning St., Malta
253	Doherty	1/17/80	11.0	9.0	Sodeman Rd., Greenfield
254	Niland 1	1/18/80	11.0	21.0	Halfway House Rd., Mechanicville
255	Fedorick	1/17/80	12.0	9.5	Coy Rd., Greenfield
256	Holder	1/17/80	8.9	5.8	Ballston Lake
257	Arnold	1/17/80	7.9	9.5	Emigh Rd., Milton
258	Middletown	1/17/80	8.9	10.0	RD 2, Scotia
259	Harrington	1/17/80	13.0	10.0	Rock City Rd., Milton
260	Panoski	1/17/80	14.0	15.0	Swaggertown Rd., Scotia
261	Galarneau	1/17/80	8.8	11.0	Bliss Rd., Galway
262	Glendaal School	1/17/80	10.0	16.1	Bolt Rd., Scotia
263	France	1/17/80	11.0	10.0	Jockey St., Galway
264	Beers	1/17/80	13.0	12.5	Church Rd., Scotia
265	Roll	1/17/80	11.0	9.0	Jockey St., Galway
266	Minch	1/17/80	16.0	12.5	Sacandaga Rd., Scotia
267	Evans	1/17/80	11.0	11.0	Rt. 29, Galway
268	Niland 2	1/18/80	10.0	18.9	Halfway House Rd., Mechanicville
269	Ford	1/17/80	6.6	9.5	Jockey St., Galway
270	McMurr	1/18/80	13.0	N.A.	Vannes Rd., Mechanicville
271	Schworm	1/18/80	10.0	14.0	Depot Rd., Duanesburg
272	Illes	1/18/80	14.0	N.A.	Rd. 1, Mechanicville
273	Veglia	1/18/80	13.0	9.0	Skyline Dr., Duanesburg
274	Smith	1/18/80	14.0	8.5	Bemis Heights, Stillwater
275	Coons	1/18/80	13.0	11.0	Skyline Dr., Duanesburg
276	Millington	1/18/80	19.0	11.5	Lake Rd., Saratoga
277	Cieszynski	1/18/80	14.0	9.5	Duanesburg-Church Rd., Duanesburg
278	Doughty	1/18/80	11.0	9.0	Co. Rt. 75, Stillwater
279	Gasner	1/18/80	13.0	13.5	Alexander Rd., Duanesburg
280	Giepiela	1/18/80	8.9	13.4	RD #2, Mechanicville

Table 3-3 Continued

<u>Sample Number</u>	<u>Name</u>	<u>Date</u>	<u>Silica ppm</u>	<u>T(⁰C)</u>	<u>Location</u>
281	Woods 1	1/18/80	16.0	12.5	Herrick Rd., Duanesburg
282	Hopeck	1/18/80	13.0	9.5	RD #2, Box 68, Mechanicville
283	Woods 2	1/18/80	15.0	12.0	Herrick Rd., Duanesburg
285	Ferguson	1/21/80	11.0	N.A.	Sulphur Springs Rd., Florida
287	Langlois	1/21/80	16.0	8.5	Rt. 159, Duanesburg
289	Ostrander	1/21/80	13.0	10.5	Rt. 407, Duanesburg
291	Waddell	1/21/80	9.7	10.0	Ennis Rd., Princetown
293	Rodriquez	1/21/80	9.5	9.5	Coplon Rd., Rotterdam
295	Regnier	1/21/80	12.0	12.0	Currybush Rd., Rotterdam

address and sampling data by corresponding index number.

The highest silica concentrations, as determined in Phase I and confirmed here, occur in the Saratoga Springs area along the Saratoga Fault, and to the north-east. Figure 3-7 denotes the spatial distribution of the lower concentrations of silica throughout the area. As can be seen from the map, there is a definite elevation of the SiO_2 content of the ground water in the area around Saratoga Springs and south toward the area west of Schenectady. In the area around Lebanon Springs, New York, it has already been demonstrated that the higher silica contents of the ground water correspond to areas of higher temperature gradients and higher active domestic well water temperatures. This is apparent in the Saratoga-Schenectady area as well.

Summary of Results and Discussion of Silica Decay Analysis

An effort was made to check the metastable persistence of silica in solution over time. These silica decay analyses might have shed light on the usefulness of silica geothermometry for this area had they been successful. Figures 3-8 and 3-9 and corresponding Table 3-4, show the variation in silica content of samples from nine wells over the course of six months.

The results shown in Figures 3-8 and 3-9 can be entirely explained by analytical error, and so this study has not been successful. Nucleation of the silica may have been a problem and could be tested by repeating the analyses after adding a small amount of rock powder to each jar before sealing them, and periodically shaking the jars between analyses. If an indication of silica decay is not then realized, the usefulness of the anomalous silica values as temperature indicators should be questioned. At present, however, there is no other identified method of producing these anomalous silica values in natural waters of neutral to acid character where the coexisting silica species are known. This aspect of the waters must be considered unresolved.

GAS ANALYSES

Rationale

Free and dissolved gas samples collected at the same time as geochemical sampling define the area over which carbon dioxide is escaping. Knowledge of other gases contribute to understanding the origin of the fluids in the system.

Rough Contouring of Silica Data Showing Areas of Slightly Anomalous Silica Content.

Contour Interval $\approx 5\text{ppm SiO}_2$

FIGURE 3-8

FIGURE 3-9

Table 3-4

SILICA DECAY DATA (ppm SiO₂)

<u>Sample</u>	Decay Day											
	<u>0</u>	<u>14</u>	<u>28</u>	<u>42</u>	<u>56</u>	<u>70</u>	<u>84</u>	<u>98</u>	<u>112</u>	<u>126</u>	<u>140</u>	<u>154</u>
Ferrante	16.	18.	15.	15.	14.	14.	15.	16.	15.	15.	15.	14.
Lebanon Springs	13.	13.	12.	12.	12.	13.	13.	13.	12.	13.	13.	13.
Gurn Spring	58.	51.	5.5 LA	51.	55.	51.	54.	54.	54.	54.	51.	53.
Saratoga Veterinary Hospital	12.	8.4	9.7	7.8	8.7	8.5	8.5	8.2	8.2	8.5	8.6	8.7
Old Red	58.	45.	47.	45.	46.	45.	45.	42.	44.	45.	45.	45.
Rosemary	55.	49.	48.	50.	50.	49.	49.	48.	50.	40.	49.	50.
Old Iron	45.	43.	44.	44.	44.	43.	43.	41.	43.	44.	43.	45.
Carpinello	19.	14.	17.	14.	15.	13.	13.	17.	17.	18.	15.	12.
Big Red	12.	11.	10.	9.4	9.4	9.7	9.5	9.	8.8	9.8	9.4	9.0

LA = Lab Accident

Methods

Free and dissolved gas samples were collected at the same time samples for complete chemical analyses were taken. Free gas samples were taken where the gas was rapidly evolving from the water in fairly large quantities. Gas samples could not be taken at wells where the downhole sampler was used, because sufficient quantities of gas could not be collected directly from the sampler, and atmospheric contamination could not be prevented. Where possible, gas was collected in a funnel with a self-sealing rubber hose attached, and purged three times to be certain of no atmospheric contamination. A sample was then collected by syringe, also purged three times, and transferred into a Bistable gas sample packet and cold-welded shut (Plate 3-1). Two samples were collected at each site. Dissolved gas samples were carefully decanted into aluminum canisters coated inside with non-reactive material. The canisters were then capped under pressure and sealed with a sealing compound (Plate 3-2). The actual sample is taken from the pocket of gas exsolving from the water after sealing. Samples were analyzed for oxygen plus argon, nitrogen, carbon dioxide, helium, methane, ethane, ethene, and propane by Chemical Projects, Ltd., of Toronto. No ethene was observed in any sample, and so was not included in the results. Accuracy of the measurements was within 7%.

Summary of Results

The results of the free and dissolved gas samples are reported in Tables 3-5 and 3-6. Sample numbers correspond to those listed in Table 3-1.

Despite all the precautions taken to avoid atmospheric contamination, it is present in a number of the samples. Those samples in which the ratio of nitrogen to oxygen is roughly 3.7 are exhibiting atmospheric contamination, and those in which nitrogen comprises roughly 78% and oxygen and argon 21% of the samples, are simply air. Regardless of this, some interesting results are noted. Only one well is comparable to free gas samples collected during Phase I, which is sample 15011 (Martin), and the comparison is good. One other sample is common to both samplings, 15004 (Orenda) but the results for these cannot be compared because of virtually complete atmospheric contamination during Phase II sampling.

The major gases of interest exsolving from the waters are carbon dioxide (CO_2), methane (CH_4), and helium (He). The carbon dioxide is, of course, a well known constituent of the waters and its thermal origin has been demonstrated isotopically. The methane is slightly unusual in that it is accompanied by other hydrocarbons, and in some cases is produced in rather large volumes around the study

Plate I: Free Gas Sample Collection
into Bistable Gas Packet

Plate II: Water Sample Collection
for Dissolved Gas Analysis

Table 3-5

FREE GAS SAMPLE COMPOSITION

Sample Number	Oxygen + Argon	Nitrogen	Carbon Dioxide	Helium	Methane	Ethane	Propene	Total
15003*	21.6%	78.0%	0.11%	4.90 ppm	26 ppm	-	-	99.71%
15004*	21.4%	76.7%	0.08%	3.50 ppm	30 ppm	-	-	98.18%
15005*	21.7%	77.5%	0.08%	5.18 ppm	25 ppm	-	-	99.28%
15006	0.41%	9.69%	62.7%	5.20 ppm	21.0%	-	-	93.8%
15007	0.42%	8.37%	0.23%	5.20 ppm	88.0%	360 ppm	1 ppm	97.02%
15008	2.41%	28.3%	0.29%	392.0 ppm	61.0%	142 ppm	-	92.04%
15009	3.09%	13.9%	0.4%	5.80 ppm	72.2%	144 ppm	-	89.59%
15011	0.93%	46.2%	40.8%	1894. ppm	11.9%	268 ppm	1 ppm	100.00%
15015	5.02%	46.8%	0.42%	4303. ppm	40.9%	183 ppm	-	93.57%
15016	0.21%	8.17%	0.38%	34.77 ppm	84.3%	-	1 ppm	93.06%
15017*	21.7%	78.1%	0.08%	351.4 ppm	10 ppm	-	-	100.00%
15019	0.05%	1.59%	84.1%	3.86 ppm	7.37%	-	15 ppm	93.11%
15025*	22.2%	76.7%	0.13%	805.90 ppm	12 ppm	-	1 ppm	99.11%
15026*	21.3%	76.1%	2.25%	5.20 ppm	21 ppm	-	-	99.65%
15031	20.9%	75.9%	2.36%	1590.90 ppm	24 ppm	-	-	99.32%

*Contaminated samples where air apparently leaked into containers which failed to seal.

Table 3-6

COMPOSITION OF DISSOLVED GAS IN WATER SAMPLES

Sample Number	Oxygen + Argon	Nitrogen	Carbon Dioxide	Helium	Methane	Ethane	Propene	Total
15003	5.90%	38.1%	52.4%	9.00 ppm	416 ppm	17 ppm	2 ppm	96.4%
15004	6.74%	29.4%	56.1%	2.76 ppm	533 ppm	19 ppm	1 ppm	92.24%
15005	6.96%	40.8%	42.2%	4.06 ppm	7.25%	118 ppm	3 ppm	97.21%
15006	6.62%	39.5%	38.8%	34.59 ppm	7.59%	214 ppm	4 ppm	92.51%
15007	6.62%	43.5%	6.80%	32.94 ppm	37.6%	358 ppm	-	94.52%
15008	11.5%	57.1%	5.10%	63.34 ppm	23.2%	99 ppm	-	96.9%
15009	6.74%	37.3%	1.48%	10.49 ppm	50.8%	190 ppm	-	96.32%
15010	10.4%	54.9%	15.1%	894.3 ppm	15.6%	135 ppm	-	96.09%
15011	9.93%	53.3%	29.9%	122.0 ppm	3.45%	62 ppm	2 ppm	96.59%
15012	9.93%	55.9%	25.6%	90.80 ppm	8.13%	30 ppm	1 ppm	99.57%
15013	10.7%	43.4%	0.36%	17.78 ppm	41.4%	826 ppm	-	95.86%
15014	16.3%	80.8%	0.57%	5.53 ppm	0.10%	-	-	97.77%
15015	9.70%	60.8%	0.68%	1114. ppm	26.9%	454 ppm	-	98.19%
15016	11.9%	49.6%	0.57%	28.32 ppm	34.8%	-	1 ppm	96.87%
15017	7.08%	54.6%	0.98%	61.84 ppm	36.7%	103 ppm	-	99.36%
15018	15.1%	82.2%	2.23%	7.01 ppm	0.19%	-	-	99.72%
15019	5.14%	27.2%	64.6%	2.55 ppm	2.02%	-	8 ppm	98.96%
15020	6.09%	39.2%	5.53%	7.20 ppm	47.2%	82 ppm	-	98.02%
15021	7.01%	34.8%	0.38%	16.71 ppm	52.4%	1280 ppm	-	94.59%
15022	5.78%	32.4%	48.2%	593. ppm	12.3%	430 ppm	-	98.74%
15023	5.59%	50.7%	0.29%	4354. ppm	38.3%	78033 ppm	599 ppm	95.32%
15024	6.14%	47.0%	44.4%	16.48 ppm	2.42%	80 ppm	5 ppm	99.96%
15025	6.55%	64.7%	0.29%	128.6 ppm	25.3%	441 ppm	1 ppm	96.85%
15026	7.47%	55.5%	25.2%	108.0 ppm	10.9%	359 ppm	2 ppm	99.08%
15027	12.1%	59.3%	0.21%	7.90 ppm	21.7%	166 ppm	1 ppm	93.31%
15028	8.04%	34.1%	2.33%	13.80 ppm	52.6%	678 ppm	8 ppm	97.07%
15029	14.6%	82.8%	1.42%	5.25 ppm	200 ppm	2 ppm	-	98.82%
15030	8.74%	65.6%	1.42%	6.27 ppm	23.5%	-	-	99.26%
15031	5.68%	32.7%	53.9%	427.3 ppm	7.53%	99 ppm	2 ppm	99.85%
15032	11.4%	63.2%	0.36%	136.4 ppm	21.9%	61 ppm	-	96.8%
15035	7.59%	52.0%	1.61%	13.62 ppm	36.9%	132 ppm	-	98.1%
15036	11.5%	54.9%	4.14%	40.77 ppm	26.2%	120 ppm	-	96.74%
15037	21.5%	77.8%	0.13%	6.72 ppm	35 ppm	-	-	99.43%

area. It may be significant in that methane is frequently associated with geothermal areas as a thermal decomposition product of organic material in associated sedimentary rocks. The exact nature and origin of the methane in this area, however, is poorly understood and at this time cannot be directly related to the occurrence of a geothermal system.

Lastly, the helium present here is extremely interesting. The normal concentration of helium in ground water is roughly 5 ppm, but here we are seeing concentrations that are three orders of magnitude greater than that normally occurring in ground water. The real significance of this is, unfortunately, not understood at this time. Helium has several associations which may be playing a part in the large concentrations observed here. The most obvious source of helium is radioactive minerals, since helium is a radiogenic decay product of uranium, thorium and all their decay products. It is possible that there is a deeply buried radioactive pluton, and the helium is being scavenged by the basinal water as it moves upward. Helium is also a common associate of methane in natural gas fields and petroleum reservoirs. Western New York is a known natural gas producing area, and the Capital District area is on the edge of the same basin from which the gas is produced. Helium here may be at least partially associated with the hydrocarbons. The helium may also be related to the carbon dioxide if a portion of it can be considered magmatic, as helium is also produced as a magmatic gas. The association is not clear in the analyses presented here because in some cases the helium occurs in high methane content wells, and in others with high CO₂ contents. Figure 3-10 shows the locations of the highest helium producing wells. It is interesting to note that there is little relationship between wells producing the highest concentrations of other chemical indicators and those producing the highest helium contents. Because of its limited coincidence with the other chemical indicators, the helium may not be genetically related to the geothermal system.

DOWNHOLE pH MEASUREMENTS

Rationale

As the mineralized waters issue at the surface, they exsolve large quantities of carbon dioxide and, in some cases precipitate mineral material that is no longer soluble with the subsequent change in conditions. Any attempt to calculate mineral equilibria, therefore, does not accurately reflect the dissolution and deposition characteristics of the subsurface environment, because the water composition and pH at the surface is not the same as at depth. Downhole pH measure-

Wells with High Helium Concentrations
(Dissolved Gas Analyses, Concentrations > 50 ppm)

ments may help in understanding the fluids and their interactions with the wall rocks at depth.

Methods

Downhole pH measurements were made with a Horizon pH meter, and silver-silver chloride electrode. Depth capability is 300 feet, with the cable marked every 25 feet. The probe is lowered and raised from the well by hand, and readings taken every 25 feet. The probe was calibrated with solutions of pH 4 and 8 before each run. Individual readings are accurate to within ± 0.1 pH point.

Summary of Results and Discussion

Downhole pH measurements have been made in four wells, and the data is presented in Table 3-7. A drop in pH was anticipated with increasing depth, however, the actual change shown in CO₂-rich wells is much greater than was expected. The data cannot be explained without further analysis. However, if the variations are valid, the pH variations may be a good way to obtain an idea of partial CO₂ pressures.

Isotope Analyses

Dr. James Simpson of the Lamont-Doherty Geological Observatory visited Saratoga Springs to collect samples from five wells to analyze for isotopes of carbon, oxygen, hydrogen, radon, and radium. These analyses were intended to provide information on the sources of the mineralized fluids, and may have been helpful in understanding the heating processes for the geothermal system. Dr. Simpson obtained partial results for radon and radium which were comparable with last year's data, but was unable to complete the other analyses within the time frame of this report. Therefore, no further evaluation of the isotopic nature of these waters can be offered here.

MAGNETOMETER SURVEY

Rationale

A small magnetic survey was run to identify and locate major faults more clearly. Differences in the magnetic properties of different rock types allows us to use these variations to locate geologic structures such as faults. In general, the magnetic properties of rocks vary with their content of magnetic minerals. The magnetic susceptibilities of different rock types are variable and overlap, but average values for various sedimentary, igneous and metamorphic rocks have been

Table 3-7

DOWNHOLE pH MEASUREMENTS

Well Number (Corresponds to Table 3-1)

<u>Depth (Ft.)</u>	<u>15005</u>	<u>15013</u>	<u>15018</u>	<u>15019</u>
Surface	6.8		8.7	6.4
25	7.0			
50	6.7			6.25
75	5.5	10.1 (70 ft.)		5.6
100	4.5	9.4		3.0
125	4.2	9.4		3.0
150	4.0	8.6	6.1	3.0
175	3.9	8.4		2.95
200	3.7	8.4		2.8
225		7.4		2.6
250		7.3		2.6
275		7.2		2.4
295		5.2 (290 ft.)		2.4

determined (Peters, 1976). Susceptibilities for igneous and metamorphic rocks are generally higher than for sedimentary rocks, and so faulting that might involve basement rocks should be detectable. There is also a range of values for different sedimentary rocks. If the susceptibilities of the rocks are significantly different, then faulting between them should also be distinguishable.

Method

Magnetometer traverses were run with a GeoMetrics G816 proton magnetometer borrowed from Dartmouth College in New Hampshire. Traverses were selected on the basis of the amount of information that could be derived from the traverse, and actual field accessibility.

Stations were selected on the basis of ease and accuracy of map location. Readings were made in gammas, with an accuracy within 10 gammas.

Summary of Results and Discussion

A small scale magnetic survey was run in the area between Saratoga Springs and Schenectady. In the Saratoga Springs area, two major faults are known. The McGregor Fault is a major high angle fault that is known to run from the Saratoga Springs vicinity northward into the Adirondack Mountains. In Saratoga Springs, it intersects the Saratoga Fault, which is inferred to run southward just west of Schenectady and into Altamont. These faults are of interest because of their apparent relationship to the issuance of carbonated and saline waters, particularly in the Saratoga Springs area. Temperature gradient data also appears to correlate with the assumed extensions of these faults. It is, therefore, desirable to locate more precisely the traces of these faults in order to best interpret the chemical and temperature data.

Three traverses were run in the area between Saratoga Springs and Schenectady in an attempt to locate these two important faults. The first traverse was through Saratoga Springs itself (Figure 3-11), where the fault locations are already fairly well known. In this way, it was hoped that the magnitude and characteristics of the magnetic variations over the faults could be determined and applied in traverses to the south. The second traverse was run through Ballston Center (Figure 3-12), and the last was in the Burnt Hills area. No map is shown for the latter area because virtually no usable data was obtained.

As a result of this survey, a small magnetic variation was noted over the Saratoga

Magnetometer Traverse
Southwest of Saratoga
Springs

Map View

FIGURE 3-II

Map View

Magnetometer Traverse
through Ballston Center

FIGURE 3-12

Fault, but no variation was seen over the McGregor Fault. Several factors influenced the results of the survey. Probably the most significant of these is that at the latitude of New York State, the magnetic susceptibility of the rocks on either side of the fault must be significantly different, or the magnetic variation on an east-west traverse over a north-south fault will be limited. Both the McGregor and Saratoga Faults are oriented about 20° east of north, so the traverses were oriented in a northwest-southeast direction in order to maximize the variations. Apparently in this area, fault displacement is not sufficient to allow us to measure differences in the magnetic susceptibility of the basement rocks or of the overlying sedimentary layers. Another problem encountered in the area was the effect of stray magnetic fields resulting from cultural features such as buried pipelines, telephone and electric lines, fences, and nearby railroad tracks. These features will induce magnetic fields that may interfere with the natural fields corresponding to subsurface structures and rock types, and thereby produce spurious results. Minor equipment malfunctioning was also experienced, particularly during the third traverse, decreasing the amount of data collected. As can be seen in the reduced data of Tables 3-8 and 3-9 and on Figures 3-13 and 3-14, small anomalies can be recognized over the Saratoga Fault, but a distinct anomaly representing the McGregor Fault cannot be identified. Since there is a problem with cultural overprint in the area (i.e., buried utilities, dense population, etc.), and considering that most of the known faults trend in a nearly north-south direction, it seems that this method has limited value in precisely identifying fault locations.

GRAVITY SURVEY

Rationale

Gravity, understood as an attractive force between masses, can be used to determine apparent excesses or absences of mass on a fairly local scale. Several gravity anomalies are apparent in the east-central area of New York as evidenced on the published Simple Bouguer Gravity Anomaly Map of East-Central New York (Diment, et al., 1972). On a revised version of the map (Figure 3-15, after Porter, 1980), it can be seen that there is a positive gravity anomaly underneath Albany, which may be an extension of a regional trend extending northward from Scranton, Pennsylvania. The anomaly is positive, suggesting an excess of mass, and may be a result of thick sediments of the miogeosynclinal area of the Appalachian system (Diment, et al., 1972).

Table 3-8

GEOMAGNETIC DATA REDUCTION
TRAVERSE SOUTHWEST OF SARATOGA SPRINGS
JULY 3, 1980

<u>Station</u>	<u>Reading Gammas</u>	<u>Time Minutes</u>	<u>Drift Rate Gammas/Minute</u>	<u>Correction(s) Gammas</u>	<u>Corrected Reading Gammas</u>
1	566478	-16	+0.674	-10.8	56636
2	568	-12		- 8.1	560
3	568	- 8		- 5.4	563
4	577	- 4		- 2.7	574
5	464				464
6	446	+11		7.4	451
7	436	15		10.1	446
8	516	18		12.1	528
9	525	24		16.2	541
10	396	27		18.2	414
11	424	30		20.2	444
12	437	35		23.6	461
13	583	33		22.2	605
14	433	38		25.6	459
15	317	7	+0.105	0.7 + 29	347
16	701	13		1.4	731
17	373	14		1.5	403
18	393	18		1.9	424
19	565	20		2.1	596
20	469	23		2.4	500
21	488	28		2.9	520
22	503	29		3.0	535
23	475	8	- .043	- 0.3 + 35	510
24	486	13		- 0.6	520
25	482	18		- 0.8	516
26	480	23		- 1.0	514
27	505	26		- 1.1	539
28	487	29		- 1.2	521
29	535	33		- 1.4	569
30	552	36		- 1.5	585
31	547	40		- 1.7	580
32	564	45		- 1.9	597
33	503	48		- 2.1	536
34	535	52		- 2.2	568
35	538	56		- 2.4	571
36	510	60		- 2.6	542
37	502	14	-0.17	- 2.4 + 32	532
38	490	18		- 3.1	519
39	529	21		- 3.7	557
40	510	24		- 4.2	531
41	503	28		- 4.9	530
42	514	34		- 5.9	540
43	495	37		- 6.4	521
44	556	41		- 7.1	581
45	577	44		- 7.7	601
46	504	47		- 8.2	528
47	501	53		- 9.2	524
48	510	55		- 9.6	532

Plot of Data From Magnetometer Traverse through Ballston Center

TOTAL
MAGNETIC
INTENSITY
56,XXX
GAMMAS

800 -

700 -

600 -

500 -

400 -

- Reliable reading
- △ Questionable reading

Station distances measured
perpendicular to Saratoga fault

FIGURE 3-14

Table 3-9

GEOMAGNETIC DATA REDUCTION
TRAVERSE THROUGH BALLSTON CENTER
JULY 7, 1980

<u>Station</u>	<u>Reading Gammas</u>	<u>Corrected Reading Gammas</u>	<u>Distance From Fault</u>
Base	56,525	56,525	0.83 miles west
1	464	464	0.59
2	515	515	0.38
3	520	520	0.28
4	529	529	0.17
5	526	526	0.02
6	524	524	0.08 miles east
7	595	595	0.13
8	582	582	0.18
9	604	604	0.31
10	581	580	0.37
11	595	594	0.46
12	624	623	0.50
13	684	683	0.62
14	741	740	0.77
15	771	770	0.91
16	763	762	1.02

Revised Simple Bouguer Gravity Anomaly Map
of the Capital District.

Values in Negative Milligals, 2 Milligal Interval
Data from Diment et al (1972), revised by C.O. Porter 1980.
SCALE 1: 250,000

There are also several negative gravity anomalies, representing apparent reductions in mass. A large anomaly parallels the New York border with Vermont and Massachusetts, and bulbs out toward the Albany-Schenectady area. This may be one of the largest negative anomalies east of the Mississippi River. A smaller negative anomaly exists in the Schenectady area; and the Saratoga Springs area exhibits complex gravity features. The published map, however, has been somewhat smoothed in order to make a more cohesive compilation of the data.

Methods

Gravity measurements were made with a Texas Instruments Worden Prospector Model gravimeter borrowed from the State University of New York at Albany. Measurement stations were selected on the basis of available existing elevation determinations in the vicinity of interesting temperature gradient measurements.

Charles O. Porter was responsible for the previous collection of much of the data in this area, and was able to go through and contour more accurately the original data as well as incorporate new data in some areas.

Summary of Results and Discussion

Some numerical modeling was performed, particularly on the large negative anomaly along Rt. 22 in the Petersburg to Lebanon Springs area (Figure 3-16). This modeling was intended to determine the plausibility of a large amount of the carbonate rock having been dissolved, leaving behind a solution cavity network capable of acting as a reservoir for thermal fluids.

The results of the calculations are consistent with the possibility of a "buried horizontal cylinder" occurring between Hoosick Falls and Berlin. Assuming a maximum density contrast, as that between non-porous marble and water, the hypothetical cylinder would have a diameter of roughly 2000 feet, and the depth to the center would be 5900 feet below average terrain. Since it is highly unlikely that a void of that size and shape could mechanically withstand collapse, a network of small scale solution cavities seems more reasonable, and a smaller density contrast required. If a density contrast of 0.2 is assumed, with the same depth to center, the diameter of the zone would be approximately 6000 feet. These calculations only serve to indicate that it is possible that there do exist deep reservoirs resulting from the solution of carbonate rock by acid or thermal waters from depth.

It was also decided to examine in more detail the configuration of the gravity

Detailed Simple Bouguer Gravity Anomaly Map
of the Berlin-Poestenkill Area
(from Porter, 1980)

Scale 1:250,000

FIGURE 3-16

anomaly in the Schenectady area, particularly in light of the high thermal gradients and issuance of carbonated saline waters in the area. In this area, it was necessary to supplement the existing data, and new data was collected where elevations were available. The survey was continued to the north toward Saratoga Springs, where a number of stations were remeasured as well. The expanded data set was then recalculated and contoured with the results depicted on Figure 3-17. The trace of the Saratoga Fault is apparent, and its east-dipping character confirmed by the slight offset of the anomaly to the east of the assumed trace of the fault.

Perhaps the most interesting feature to note is the fact that nearly every well or spring producing carbonated and/or saline water is associated with an anomaly. In the Saratoga Springs-Ballston Spa area, the waters are known to be associated with the faults. The Saratoga Fault produces a recognizable anomaly, and the intersection of the Saratoga and McGregor Faults is probably responsible for the irregular gravity features just northwest of the city. The well producing the most carbonated water yet observed in the area is near the Schenectady anomaly, and the saline carbonated waters in the Altamont area are at the southern portion of the same anomaly. There is a slight anomaly in the vicinity of Melrose pointing northward and then westward toward Mechanicville. Several carbonated saline wells have been sampled in that area (Melrose), and the water of the 2300 foot well at the Saratoga Board property in Mechanicville is reportedly a vichy water similar to that at Saratoga Springs.

Figure 3-18 shows the locations of saline and carbonated wells superimposed on the redrafted gravity data. It may also be noted that there is a similar correlation between the highest temperature gradients and the locations of the gravity anomalies. Figure 3-19 illustrates the relationship between the gravity data and the temperature gradient measurements. The gravity anomalies dealt with here are for the most part negative, suggesting a withdrawal of mass. This seems reasonable if one considers that caustic fluids entering the system could readily attack the carbonate rock walls of their conduits.

Positive anomalies might occur where entering solutions are saturated with the carbonate components or those of heavy metallic minerals, and a change of conditions, such as pH change or the exsolution of carbon dioxide, causes the precipitation of mineral material in pore spaces and fractures.

Detailed Simple Bouguer Gravity Anomaly Map
of the Schenectady-Saratoga Springs (from Porter, 1980)

Values in Negative Milligals
Scale: 1:250,000

FIGURE 3-17

Location of Saline and Carbonated Waters Relative to
Simple Bouguer Gravity Anomalies.
Values in Negative Milligals, 2 Milligal Interval
Data from Diment et al (1972), revised by C.O. Porter 1980.
SCALE 1:250,000

Locations of Temperature Gradients Over 20° C/km
Relative to Simple Bouguer Gravity Anomalies.

Values in Negative Milligals, 2 Milligal Interval
Data from Diment et al (1972), revised by C.O. Porter 1980.

SCALE: 1:250,000

FIGURE 3-19

Seismologist, included in Appendix B of this report.

TEMPERATURE GRADIENT MEASUREMENTS

Rationale

The most direct method for determining whether there is an indication of heat at depth is to make some sort of temperature measurement. This particular method, using abandoned water wells generally exceeding 300 feet in depth and filled with water has proven to be an excellent approach that is presently virtually unused elsewhere.

Method

Temperature gradient measurements were made using two different machines. The first is hand-constructed, and consists of a thermistor probe and multiple-scale chart recorder acting as a direct reading temperature meter. Well depth capability exceeds 640 meters (2100 feet), and the probe is manually lowered and raised from the hole. The cable is marked at five meter intervals.

The second instrument is a Yellow Springs Instruments multiple-scale thermistor thermometer, and thermistor probe with 610 meters (2000 feet) of cable. This instrument is battery operated and very portable. The cable is marked at five meter intervals, and manually raised and lowered in the well.

Temperature gradients were measured in abandoned existing water wells that exceeded 80 meters in depth. Temperature readings were made every five or ten meters, and the results graphed to determine the quality of the data, and the depth at which surface interference ceased. Data from depths exceeding those experiencing surface effects were treated by a least squares linear regression analysis to determine the temperature gradient. Determination coefficients, surface temperature, and temperature at 1000 meters, were also calculated. In most cases, surface effects ceased by 30 meters, but in some cases they were observed to nearly 100 meters. Measurements were made in a variety of outdoor conditions, from October through August, and a number of the measurements duplicated. Seventy-six wells were measured successfully for temperature gradients, with multiple measurements made in 15 of those wells.

Accuracy

These instruments have been operated side by side in several wells with no significant difference in the results obtained. Maximum differences in temperature between the two instruments during laboratory testing was 0.1°C . Both machines have

also been checked for adverse reactions to low temperatures, ranging from -1°C to -23°C , as they were operated in the field during the winter. Each appeared to operate satisfactorily in cold weather, and both instruments are readable to $\pm 0.05^{\circ}\text{C}$.

Summary of Results and Discussion

Table 3-10 lists the data obtained to date. Wells are listed by index numbers which correlate to the location map of Figure 3-21, and other information includes the date of gradient measurement, gradient measured, the determination coefficient for the calculated line, well depth, and the temperature at 1000 meters calculated from the average surface temperature and the individual gradients.

There are a number of problems inherent in this type of measurement. Although the shale that is present as the cap rock in this area is desirable as an insulator because of its low conductivity, it may for the same reason, give a gradient that is basically enhanced. Since the heat trapped below it will not readily flow through it, there will be a greater difference in temperature between the top and bottom of the well, and possibly a false representation of the amount of heat that is really available. For this reason, it is necessary to regard the measured gradients with caution, particularly where the shale is not very thick, and the wells do not penetrate the underlying rock. In this case, however, the significance of this type of exaggeration is small, because the major portion of the area under examination is covered by a thick shale sequence. We are, therefore, comparing high gradients in shale to low gradients in shale, and we can be fairly certain that the high gradients are truly representing an area of higher heat flow. This can be somewhat tested by measuring the gradient of a well that penetrates both the shale and the underlying carbonate rock. If there is greater heat flow, it should be constant over the change in rock type, and not reflect the change in conductivity or gradient. In only one instance are we fairly certain that we have this situation, and that is at the Saratoga Board Mill in Mechanicville. The well is reportedly 2300 feet deep, and carbonate rocks are said to be encountered at approximately 1000 feet. A gradient measurement was made to a depth of 605 meters (1985 feet) at five meter intervals, and there was no distinguishable change in the gradient over the reported rock type change. This may indicate that there is little difference in the rock conductivities, or that there is no actual change in rock type. The gradient was calculated to be 22.71°C/km , and the water temperature at 605 meters was 23.08°C (73.5°F). At one kilometer, (3128 feet) the water temperature should be about 31.6°C (88.9°F).

Temperature Gradient Measurement Locations
Index Numbers refer to Table 3-10.

FIGURE 3-21

The highest gradient measured to date was in a 120 meter well south of Ballston Spa, with a gradient of 64.45° C/km (well number 14). If this gradient is accurate, the water temperature at one kilometer should be 73.98° C (164° F). When replicate measurements were made on this well, however, the maximum gradient measured was 32.12° C/km. This change in gradient has also been noted in wells 3, 6, 15, 19 and 25 (see Figure 3-21). All are near the Saratoga Fault zone, and wells 6 and 19 are carbonated. The higher temperature gradients were measured during the winter, and occurred when CO_2 appeared to exsolve considerably deeper, suggesting a higher gas pressure. These differences in gradient and gas exsolution depth may be related (1) to gas influx, (2) to a CO_2 pressure increase because of a winter capping effect from frozen ground, (3) to circulation of ground water along the fault zone causing temperature variations, (4) equipment malfunction. It would appear to be unreasonable for the gas influx to be influenced by the time of the year, but if CO_2 is held in by frozen ground during the winter, P_{CO_2} could increase. To evaluate the potential role of equipment malfunction in gradient variations, gradients will be monitored over the entire year to determine natural variation for comparison to the values in question here.

The highest reproducible gradient was in a considerably shallower well (90 m) just west of the Schenectady area (well number 18). The calculated gradient for this well is 44.14° C/km, and if it is upheld at depth, the water temperature at one kilometer should be 53.07° C (127.53° F).

This method of collecting data has the problem that measurements can only be made where there are abandoned deep wells, not necessarily in all the places that are desirable. The sampling may, therefore, be significantly biased since a large number of the abandoned wells are abandoned because of poor water quality. These wells tend to be concentrated along the Saratoga and McGregor faults which apparently act as conduits for some of the thermal fluids. Also, shallow fresh water aquifers preclude the need for deep wells, and those areas tend to be data poor.

Figure 3-21 shows the locations of all the temperature gradients measured in the area thus far. The index numbers appearing on the map correspond with those on Table 3-10, listing various parameters for the wells. Figure 3-22 is a contour map of the gradient data using the most conservative values for those wells that have multiple gradients. As is readily visible, there is a distinct concentration of higher gradients on a line paralleling the Saratoga and McGregor Faults between Saratoga Springs and Altamont. The apparent background gradient for this area is

Table 3-10

SITE SPECIFICS FOR TEMPERATURE GRADIENT MEASUREMENTS

Well Number	Owner	Well Depth(m)	Date	(°C/km) Gradient	r ² *	(°C) T1000M**
1	Herbert	160	1/31/80	14.58	.985	23.51
2	Fort Ann School	265	1/2/80	24.84	.990	33.77
3	Dairy	170	1/31/80	39.97	.966	48.90
			4/25/80	11.66	.996	20.59
4	CIBA-GEIGY	270	1/25/80	6.86	.968	15.79
5	South Glens Falls Elementary School	100	2/6/80	10.00	.875	18.93
6	Big Red	92	1/8/80	33.35	.990	42.28
			4/25/80	12.42	.994	21.35
7	McKay	140	2/1/80	28.11	.980	37.04
8	Manell	160	1/9/80	22.51	.991	31.44
9	Macica	95	2/8/80	27.13	.998	36.06
10	USAF	160	1/23/80	19.21	.989	28.14
11	B.P. Station	165	1/25/80	27.69	.995	36.62
			5/5/80	25.02	.998	33.95
12	Rodriguez	90	2/6/80	17.00	.957	25.93
13	Lipskay	85	2/14/80	38.21	.994	47.14
14	Botta	120	2/1/80	64.45	.998	73.38
			4/28/80	31.33	.997	40.26
			5/1/80	32.12	.999	41.05
15	Reville	104	1/8/80	46.52	.998	55.45
			5/1/80	30.01	.998	38.94
16	Schaghticoke Fairground	105	1/8/80	14.85	.973	23.78
17	Kuczek	80	2/18/80	17.40	.997	26.33
18	Widmer	90	2/19/80	44.14	.989	53.07
			5/8/80	44.33	.995	53.26
19	Ferrante	125	1/7/80	42.05	.983	50.98
			1/9/80	51.96	.946	60.89
			4/25/80	24.63	.997	33.56
			4/28/80	25.41	.998	34.34
20	United Plating	300	1/7/80	26.56	.973	35.49
21	Wall	105	1/28/80	7.80	.976	16.73
22	Urda	178	1/9/80	29.64	.999	38.57
23	Jelly	220	10/12/79	22.60	.950	31.43
24	Camp Pinnacle	120	2/1/80	15.92	.982	24.85
			5/2/80	14.79	.996	23.72
25	Pollard	130	2/1/80	30.39	.995	39.32
			5/5/80	20.18	.997	29.11
26	Chan	90	2/7/80	32.14	.981	41.07
27	Bastion	135	1/11/80	26.62	.967	35.55
			5/5/80	16.67	.988	25.60
28	Dwiliski	95	1/24/80	12.33	.983	21.26
			5/6/80	13.07	.975	22.00
29	Miralles	160	1/4/80	19.15	.983	28.08
30	Rainville	155	12/21/79	13.18	.868	22.11
31	Toussaint	167	2/5/80	30.59	.999	39.52
32	Lindsay	95	2/5/80	9.49	.993	18.42

Table 3-10 Continued

Well Number	Owner	Well Depth(m)	Date	(°C/km) Gradient	r ² *	(°C) T1000M**
33	Rosenberg	80	2/15/80	12.40	.998	21.33
34	Meskill	145	12/10/79	14.72	.992	23.65
35	Garfield	185	12/10/79	21.60	.990	30.53
36	Liveright	160	12/31/79	24.68	.997	33.61
37	Jericho Valley Motel	130	12/18/79	18.36	.988	27.29
38	Bayer	140	10/26/79	14.82	.986	23.75
39	Nyewrighter	190	12/19/79	7.72	.982	16.65
40	Kitteridge	155	10/26/79	17.03	.958	25.96
41	Zucker Isgood 1	260	12/28/79	9.06	.980	17.99
	Zucker Isgood 2	125	1/3/80	6.73	.967	15.66
42	Wiggleworth	160	2/11/80	7.01	.988	15.94
43	Hemingway	80	1/4/80	10.83	.896	19.76
44	Synagogue	120	2/15/80	9.42	.983	18.35
			5/6/80	8.81	.995	17.74
45	Zweig	100	12/21/79	9.51	.913	18.44
46	Swartz	90	1/29/80	17.62	.985	26.55
47	Stalker	130	12/12/79	12.70	.974	21.63
48	Kennedy	145	10/12/79	8.70	.980	17.63
49	Barcia	185	12/18/79	8.45	.960	17.38
50	Lupe	110	2/26/80	17.88	.979	26.81
51	Edgarston	192	3/4/80	17.66	.997	26.59
52	Eastman	160	2/4/80	17.49	.984	26.42
			5/6/80	18.47	.991	27.40
53	Gazzola	220	3/4/80	8.66	.986	17.59
54	Wicks	105	3/19/80	3.86	.956	12.79
55	Calamaras	109	3/24/80	15.20	.983	24.13
56	Pangburn	145	3/31/80	22.54	.996	31.47
57	Franklin	90	3/31/80	15.00	1.000	23.93
58	Bowers	142	4/7/80	30.20	.991	39.13
59	Auriesville Shrine	150	4/17/80	8.86	.992	17.79
			4/30/80	8.90	.977	17.83
			4/30/80	9.94	.995	18.87
60	Kersten	80	4/21/80	5.00	1.000	13.93
61	Oravsky	100	4/28/80	12.97	.993	21.90
62	Hallsville Supply	95	4/29/80	7.71	.960	16.64
63	Zwack	125	4/30/80	11.73	.993	20.66
64	Quay	110	4/30/80	12.25	.997	21.18
			4/30/80	9.43	.971	18.36
65	Kuszek	125	5/2/80	4.76	.932	13.69
66	Sandy Hill Iron Works	100	5/29/80	4.55	.924	13.48
67	Hudson Falls Water Wks	105	5/29/80	3.63	.925	12.56
68	Saratoga Board	605	5/29/80	22.71	.999	31.64
69	Ballard Mobile Homes	220	6/9/80	17.24	.986	26.17
70	Mosher	220	6/13/80	21.07	.990	30.00
71	Walker	150	6/13/80	11.68	.989	20.61
72	Chisolm	150	7/9/80	20.37	.997	29.30
73	Levy	115	7/18/80	10.98	.978	19.91
74	Hancock Missile Base	195	7/18/80	12.21	.977	21.14
75	Olds	155	8/6/80	7.79	.993	16.72
76	Tudor Pines	270	8/6/80	21.35	.966	30.28

* determination coefficient.

** calculated temperature at 100m using mean surface temperature of 8.93° C.

Contour Map of Temperature Gradients

Contour Interval 10° C/Km.

Such precipitation of dissolved carbonate material occurs in the Saratoga Springs and Ballston Spa areas where tufa deposits are associated with several of the springs. Similar precipitation may be achieved in the subsurface environment, and new carbonate minerals be deposited. Such precipitations may have occurred at a farm near Cambridge in Washington County, where water issuing from a spring is now normal in mineral and carbon dioxide content. According to the owner, the water has been normal for approximately seven years, prior to which time it was analyzed and found to have extremely large quantities of dissolved CO₂, and was exceptionally caustic in nature. According to the owner, heavy duty copper pipes in his home were virtually destroyed in three years time. It is possible that the CO₂ has been sealed off since that time, perhaps by the deposition of mineral material in the conduit. The slight positive gravity anomaly in the vicinity may be reflecting mineral precipitation.

In any case, it would appear that a positive correlation may be made with the locations of the gravity anomalies and the known issuance of unusual waters, and with the temperature gradient data gathered thus far.

SEISMIC WORK

Rationale

This network is intended to determine microseismic activity in the area that may be associated with the geothermal system. Microearthquake activity has been associated with geothermal areas around the world, and is believed to result from stress adjustments to igneous intrusion, active faulting, or flow of thermal fluids from depth. Swarm type activity may pinpoint either the site of igneous activity, or conduits for the flow of thermal fluids into deep aquifers.

Method

A seismic network has been set up by the NYS Geological Survey and has been operating for approximately four months. Figure 3-20 shows the locations of the five stations currently operating in the Capital District area. Special short period instruments include G. Strekeisen Swiss manufactured amplifier - filter units and ink recorders, and W. Sprengnether Instruments seismometers and digital timing systems. The standard time receivers employed are manufactured by Caringella Electronics. Seismic records are changed every two days, and picked up and delivered to the State Geological Survey once a week. The results of the seismic program thus far are separately discussed in a report by Walter Mitronovas, State

roughly 10° C/km, so all those gradients exceeding 20° C/km, or twice background, are of interest. The shales act as an insulating cap rock, but there appear to be leaks in the system along the faults. Therefore, as expected, the gradients in the vicinity of the faults tend to be slightly higher.

Section 4

DISCUSSION

Direct evidence of anomalous geothermal heat has been demonstrated through the measurement of thermal gradients in abandoned water wells throughout the Capital District. The most promising area in which to conduct further exploration appears to be in the zone between Saratoga Springs and Schenectady, straddling the Saratoga and McGregor Faults. Both new and previous geochemical data support the assumption that these two faults are acting as primary conduits for mineralized waters and thermally derived carbon dioxide. The issuant points of these waters, and the higher thermal gradients coincide with gravity anomalies in the area, which are also suggestive of conduits from depth. Figures 3-18 and 3-19 demonstrate this correlation.

Since the system appears to be fault controlled, it is difficult to accurately predict its characteristics at depth. It is, therefore, necessary to undertake a drilling program to intersect the suspected shallow thermal reservoir underlying the Capital District area, and further explore an assumed deeper source of heat in order to properly determine the energy value available from the system. It is apparent, however, that a geothermal energy system does exist here, and steps to determine its actual utility are required.

Section 5

CONCLUSIONS

The presence of geothermal energy in the Capital District has been documented by thermal gradients measured in abandoned water wells.

Previous isotope analyses indicate a thermal origin for the carbon dioxide.

The gradients appear to be higher than in any other area described in the Northeast.

The most promising geothermal prospect area is in the Albany-Altamont-Schenectady-Ballston Spa vicinity. Another possible area of interest is the Lebanon Springs area.

Analysis of gravity variations suggests the presence of conduits or solution cavities which appear to coincide with the locations of the most highly carbonated and saline waters and the higher temperature gradients.

The gravity trough which runs along the east side of the exploration area along Route 22 is apparently one of the largest negative anomalies in the eastern United States.

The main geothermal area appears to be hydrothermal and fault controlled, with the Saratoga and McGregor Faults as the major conduits.

Section 6
RECOMMENDATIONS

A shallow drilling program with the intent of further defining the nature of the thermal areas should be initiated.

Once the system is better defined, drilling to intersect the deep source (or sources) of heat should commence.

Section 7

REFERENCES

- Diment, W. H., Revetta, F. A., Porter, C. O., Simmons, G., 1972, Simple Bouguer Gravity Anomaly Map of East-Central New York, New York State Museum and Science Service.
- Diment, W. H., Urban, T. C., Revetta, F. A., 1972, Some Geophysical Anomalies in the Eastern United States, in The Nature of the Solid Earth, E. C. Robertson, Ed., McGraw-Hill, pp. 544-574.
- Peters, J. W., 1976, Magnetic Susceptibilities Graph, in Introduction to Geophysical Prospecting, by M. B. Dobrin, McGraw-Hill, pp. 492-493.
- Porter, C. O., 1980, Contract Geophysical Work, Personal communication.
- Young, J. R., and Dunn, J. R., 1979, Geothermal Resource Evaluation, Eastern New York State, as submitted to New York State Energy Research and Development Authority.

Appendix A
ANALYTICAL METHODOLOGY

<u>Parameter</u>	<u>Analytical Procedure</u>	<u>Reference</u>	<u>Precision</u>
Fluoride, Free	Activity of fluoride ion measured using Orion ion- selective electrode	3	$\pm 6.2\%$ at 1.29 mg/l
Nitrogen, Ammonia	Indophenol blue-Ammonia reaction with alkaline phenol, hypochloride and nitroprusside	2	$\pm 8.1\%$ at 0.37 mg/l
Nitrogen, Nitrite	Automated diazotization with sulfanilimide and coupling with Azo dye	2	$\pm 5.8\%$ at 14.9 mg/l
Nitrogen, Nitrate plus Nitrite	Copper cadmium reduction of nitrate to nitrite de- termined by diazotization as above	2	$\pm 4.7\%$ at 2.6 mg/l
Chloride	Automated ferricthio- cyanide	2	$\pm 5.8\%$ at 39.6 mg/l
Sulfate as SO ₄	Automated reaction with BaCl ₂ and methylthymol blue	3	$\pm 5.0\%$ at 29. mg/l
Carbon, Organic (TOC)	Purging of inorganic car- bon, oxidation of organic carbon to CO ₂ . CO ₂ de- tected by infrared spec- troscopy	5	$\pm 17.6\%$ at 11.7 mg/l
Boron	Reaction of Boron with Curcumin to form red rosocyanine dye	3	$\pm 6.6\%$ at 1.0 mg/l
Barium	Direct aspiration atomic absorption spectrometry; nitrous oxide acetylene flame	2	$\pm 5.9\%$ at 1.4 mg/l
Iron	Direct aspiration atomic absorption spectrometry; air-acetylene flame	2	$\pm 4.8\%$ at 0.97 mg/l
Potassium	"	2	$\pm 6.6\%$ at 9.2 mg/l
Sodium	"	2	$\pm 2.6\%$ at 44.9 mg/l

Appendix A - Continued

<u>Parameter</u>	<u>Analytical Procedure</u>	<u>Reference</u>	<u>Precision</u>
Zinc	Direct aspiration atomic absorption spectrometry; air-acetylene flame	2	$\pm 3.7\%$ at 0.59 mg/l
Calcium	"	2	$\pm 5.4\%$ at 50.7 mg/l
Lithium	"	2	not available
Magnesium	"	2	$\pm 7.7\%$ at 16.6 mg/l
Strontium	"	2	not available
Bromide	Bromide oxidation followed by bromination of phenol Red D dye	3	$\pm 5.1\%$ at 0.74 mg/l
Iodide	Iodide proportionately catalyzes the reduction of ceric ions by arsenious acid	3	$\pm 9.6\%$ at 0.24 mg/l
Silica Reactive as SiO_2	Ammonium molybdate reaction with silica to form heteropoly acids. Reduction to heteropoly blue	3	not available
Nitrogen, Total Kjeldahl	Conversion to ammonia by H_2SO_4 - Na_2SO_4 digestion. Ammonia determined by manual indophenol blue	1	$\pm 8.9\%$ at 0.67 mg/l
Phosphate, Total as P	Conversion to ortho-P by acid persulfate digestion. Ortho-P determined by ascorbic acid reduction	2	$\pm 5.4\%$ at 0.24 mg/l
Solids, Dissolved	Filtration thru glass fiber filter. Evaporation, dried for 15 min. at 180°C	3	not available
Alkalinity Electro- metric	Titration to pH 4.5 with 0.02N H_2SO_4 . Reported as " CaCO_3 "	3	$\pm 7.5\%$ at 44.0 mg/l
Aluminum	Flameless atomic absorption spectrometry using graphite furnace	2, 4	$\pm 25.5\%$ at 0.10 mg/l

APPENDIX A
Chemical Methods

Appendix A - Continued

References

1. Adrat, D. and Canelli, E., New York State Department of Health Technical Memorandum, April, 1976.
2. EPA Manual of Methods for Chemical Analysis of Waters and Wastes.
3. Standard Methods for the Examination of Water and Wastewater. 14th Ed. APHA, AWWA, WPCF (1976).
4. Perkin-Elmer Corporation, Analytical Methods for Atomic Absorption Spectrometry using the HGA Graphite Furnace.
5. Oceanographic International Corp., Instruction and Procedure Manual for the total carbon system Model 0524B.

SEISMIC MONITORING IN THE ALBANY-SARATOGA SPRINGS AREA
AS PART OF THE EXPLORATION FOR GEOTHERMAL HEAT
IN NEW YORK AND NEW ENGLAND

First Phase
Final Report

Prepared for

NEW YORK STATE
ENERGY RESEARCH AND DEVELOPMENT AUTHORITY

Prepared by

NEW YORK STATE GEOLOGICAL SURVEY

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September 1980

Summary

The seismic activity within the study area that includes Hudson Valley north of Albany and area south of Lake George, is rather low compared to many active geothermal areas of the world. This is true both in terms of larger historical earthquakes and in terms of very small events (microearthquakes) as monitored by a special seismic network during the past year. No microearthquake swarms have been detected in the northern part of the study area between June 1979 and September 1980 and in the southern part between April and September 1980. Of the eight small events recorded by the geothermal seismic network all of them are well scattered within the study area in a similar pattern as the historical and older instrumental earthquakes. An exception, perhaps, may be two events near Lebanon Springs where no previous historical earthquakes are known. Unfortunately, from the very limited available data it is not clear whether the seismic activity, both historical and present, is in any way related to the geothermal activity or is it a result of some other tectonic forces. Finally, because of high population density and the associated cultural activity like traffic, large pumps, generators, and transformers within the study area, it will be difficult to determine if the geothermal activity in a form of escaping CO₂ gas, etc. causes higher than normal continuous earth vibrations (microseisms). If such areas exist they can be discovered using seismic methods only if the association will turn out to be extremely pronounced.

Introduction

The seismic monitoring network, geothermal project, was designed and implemented with the idea of determining, if possible, the following features about the seismic activity within the upper Hudson Valley and adjacent regions, north of Albany and south of Lake George: (1) the level of seismicity (2) the detailed nature of this activity--specifically, to see if it could be interpreted in terms of an insipient geothermal process which is believed to be responsible for the liberation of the CO₂ gas and associated phenomena within the area, and (3) the exact location and depth of this process.

Three initial seismograph stations, consisting of special portable smoked-paper recorders, were set up during June 1979 by the New York State Geological Survey (NYSGS) just south of Lake George to study the seismic and tectonic activity in this area. During fall and winter (1979-80) NYSGS acquired, modified, assembled and calibrated equipment for additional five stations, specially designed for the geothermal project. This equipment, consisting of ink recorders, was deployed starting April 1980 into a network of eight stations by incorporating the initial three stations to the north into one operation. Later (May-June 1980) two of the three initial stations were discontinued leaving a network of six stations that operated until the end of August 1980.

As soon as data started to come in it was being analysed in order to help answer the questions posed above. The smoked paper and ink records were analysed regularly to determine the arrival times of all seismic phases. This information was used to determine the origin time, location, and depth of all suspected local events. This was done using a special digital computer program developed for this

project. Most of the local events turned out to be nearby quarry blasts. They were identified as such by correlating their approximate origin times and locations with direct information from the logs of local quarry operators. In addition, the exact origin time and location for several of the local quarry blasts were determined specifically for this project using special instruments and procedures. This information was used to determine accurate velocities of seismic phases within the study area. The knowledge of seismic velocities is essential to locate accurately the rest of the events which were assumed to be natural earthquakes.

Instruments and Field Procedures

The instruments used at the initial three stations (LGE, COP, ACC - see Figure 1) south of Lake George consisted of special portable, smoked-paper recorders (Model MEQ-800), developed by W.F. Sprengnether Instrument Company of St. Louis, Missouri for quick field installation where AC power is not available. The record preparation and changing procedure for these instruments, however, is quite messy and time consuming and is not suitable, therefore, for long-term operations. These instruments, however, were already available at the NYSGS, acquired earlier for an unrelated project. The rest of the stations (five) consisted of seismic equipment especially designed and purchased for the geothermal project. They consist of ink recorders that are simple to operate and change records, can be installed relatively fast and operated over extended periods. The equipment was modified, assembled, and calibrated at the NYSGS from various components made by different manufacturers. Table 1 lists all major components, their serial numbers and other pertinent information on all equipment not owned by the NYSGS. For additional information on this equipment, as used in different

applications, see Wielandt and Mitronovas (1976).

Overall, the new equipment performed as well as could be expected under actual operating conditions. The few problems encountered and corrected during installation and operation were related to excessive humidity at some stations (during summer), strong radiation of electromagnetic waves from nearby microwave (?) towers at one station, and simple operator mistakes. For details on the above problems and their solution see Mitronovas (1980). Except for two short-wave time receivers damaged by lightning storms through the antenna, there were no major equipment failures so far.

During the search for possible station sites, it was discovered that most of the study area is very "noisy" in terms of background earth vibrations (microseisms). The noise is caused primarily by the cultural activity like traffic, pumps, generators, transformers, etc. associated with high population density especially within the Hudson-Mohawk Valleys. Microseisms are especially high at all locations where unconsolidated sediments are at the surface which includes, unfortunately, a large part of the study area. Only at sites away from intense traffic, pumps, and electric generators and transformers, where solid bedrock outcrops at the surface, is the noise level acceptable for a satisfactory seismograph station.

The high microseismic level over most of the study area is the main reason why the final station location (Figure 1) is somewhat different from those suggested in the initial proposal (Mitronovas and Bailey, 1979). For example, a strong effort was made to find one satisfactory site near Saratoga Springs without success because no acceptable bedrock outcrops were found in areas where a person was willing to operate the station. The station was finally located

farther north on solid rock at Mt. McGregor (MCG). Similar problems were encountered at other locations. The final network (Figure 1), as a result, extends over a wider area than was originally anticipated. However, in conjunction with the three special stations to the north (LGE, COP, ACC), this made it possible to survey a larger area than would have been possible with a network as initially proposed.

Each station was taken care of by a person who either worked or lived near that station. The duties consisted primarily of changing paper records daily (or in some cases every other day on weekends) and reporting any difficulties and problems to NYSGS at Albany. Blank records were prepared at NYSGS and delivered to each station once every two weeks at which time the registered records were picked up and returned to NYSGS for analysis. At the same time the station clocks were checked and resynchronized with the help of a master clock which was synchronized just before each trip using a special short-wave radio (time) receiver. Using a fast sweep oscilloscope (20 cm/sec) the master clock could be adjusted to within ± 0.001 sec of true (atomic clock) time from which each station clock, in turn, using fast drum speed (0.5 cm/sec) was adjusted to within ± 0.01 sec. Such a procedure, given the stability of the ST-400 clocks, made it possible to know the true time within ± 0.05 sec anywhere on the seismogram.

Figure 2 shows the amplification as a function of frequency (frequency response) for the station RPI. The frequency response is typical for other stations, only the absolute gain is different being limited only by the microseismic level at each location. The ground noise was caused primarily by the cultural activity and secondarily by meteorological factors like wind and rain. The frequency response

(filter parameters) was chosen to optimize the signal-to-noise ratio taking into account the frequency content of the expected noise and signal (earthquake and quarry blast phases). Table 2 presents a summary of important information about each station, including the absolute gain (or range in gain) and the period of station operation. Because the level of ground noise varied considerably with time at some locations, those stations were operated at more than one gain setting to take this into account. The two special stations by Lake George, LGE and COP, were discontinued during May and June, 1980, respectively, because the original station operators could not continue changing records and new people could not be found to replace them.

Data Analysis

Smoked paper and ink records (seismograms) were "read" manually using a fine ruler under magnifying glass to determine the arrival times of all visible seismic phases. The arrival times for phases with sharp onsets could be determined to within ± 0.05 sec from original records with drum speed of 120 mm/min. Any event that could be identified at three or more stations was assigned a number in a chronological order and included in a general list (these numbers are used to identify the events later). No further analysis was done on phases from distant events (earthquakes or quarry blasts). Most events can be identified at a glance whether they are local or distant from certain special characteristics of their phases. All local events were checked directly with the logs of all known quarry operators to determine which ones were man-made blasts. Except for special work on several such quarry blasts, to be described in the next paragraph, no further analysis was done on most of them. The phases from all remaining unknown local

events were then used in a digital computer program to determine the origin time, location and depth of these events. The computer program used for this purpose was selected, modified, and adapted especially for this study, taking into account the size of the network and the seismic velocities appropriate for this area. After the preliminary locations another attempt is made to check those events that occurred at suspicious times and locations to see if they may be quarry blasts. Sometimes additional quarries are discovered this way, and those local events that coincide with the additional information from such quarries are also eliminated. The rest of the local events are then assumed to be natural earthquakes.

To determine the seismic velocities within the study area an effort was made to use the potential information from the numerous local quarry blasts that were being detected routinely by the geothermal seismic network. For this purpose a smoked paper portable seismograph was specially modified to determine accurately (± 0.01 sec) the origin time of several quarry blasts. This was done by placing this instrument very close (~ 20 m) to a blast area to record the exact shot time using fast drum speed (1 cm/sec). Seven such blasts at four different locations were so recorded during this project. In each case the arrival times of the seismic phases at the network stations resulting from these blasts were measured accurately. From the known origin times, arrival times, and distance from the blasts to all the stations accurate seismic velocities are calculated. These velocities were then used in the computer program to determine more accurately the origin time, location, and depth of the unknown events within the study area.

Results

Table 3 presents all known historical and instrumental earthquakes which occurred in the study area and adjacent regions up to 1980, before the start of the geothermal seismic network. The information for the historical events comes from Milne and Smith (1966), Nottis and Mitronovas (1980 b), Smith (1966), and Stover (1980). For the instrumental earthquakes from 1970 to 1980 the information is exclusively from the Lamont-Doherty Geological Observatory (LDGO) quarterly and annual reports (1970-1980). Both the historical and instrumental events were large enough to be either felt directly or recorded by more distant seismograph stations. It represents 31 events within a time span of about 125, or about one event every 4 years on the average.

Table 4 presents all the events detected and located by the geothermal seismic network since June 1979 that are believed to be local natural earthquakes. Over one hundred other events recorded by this network, but not presented here, turned out to be local and distant quarry blasts or more distant earthquakes. In several cases (Tables 3 and 4) it is still not clear whether these events are natural or man made. Table 4 shows 8 events for a period of about 14 months, or about 7 events per year. Because all the instrumental events, including the LDGO events since 1970, are smaller than most of the historical earthquakes, it is normal to expect the number of events to increase rapidly with decreasing size without assuming a real increase in seismic activity with time.

With one exception, none of the instrumental earthquakes (Tables 3c and 4) have assigned magnitudes (M). This is because all of them were too small to be recorded at larger distances (greater than about 50 km), a condition that is necessary for the normal determination of magnitudes (Richter or Nuttli).

With one exception, all of the LDGO events (Table 3c) are definitely less than magnitude 2.5 and probably less than 2.0. All of the events in Table 4 are smaller than 1. Figure 3 (curve A) shows the approximate relationship between magnitude (M) and maximum intensity (I_m) for the New York earthquakes. Before seismic instruments became available and used more widely, maximum intensity was the only way to indicate the approximate size of historical earthquakes. Note that I_m for historical events within the study area ranged from I up to VII (Table 3). Using Figure 3, this represents a range in magnitude from 1.5 up to 5.

In general, the accuracy in origin time, latitude and longitude (epicenter) and depth (hypocenter) determinations depends on the number of recording stations, their location relative to event, and accuracy in seismic velocities used in the computer program. The uncertainties in epicenter do not depend too critically on the accuracy in seismic velocities and are believed to be within ± 1 km for most events in Table 4. The uncertainties in origin time and depth, however, depend more critically on the accuracy in seismic velocities. The knowledge of exact origin times is not critical for this study but it is for depths. Based on accurate but limited quarry blast data, it was found that the seismic velocity structure at shallow depths within the study area is quite variable. At least three different velocity models were used in the computer program to determine hypocenter parameters, depending on where the location of an event happened to be. These velocity models and their areas of applicability are described in the July Project Progress Report (Mitronovas, 1980). The computer determination of depth for all events in Table 4 is zero which only means that the events are quite shallow. Because of the complexity in the seismic velocity structure within the

study area and because of relatively large distances between the limited number of stations over such a large area, true depths may be as much as a few kilometers, and in some cases up to 5 km. Only additional stations within the seismic network and better seismic velocities than known at present can determine the depth better.

Figure 4 shows the location of all earthquakes listed in Tables 3 and 4. The code letters and numbers are those given in Tables 3 and 4. From the available data it appears that the events detected by the geothermal project seismic monitoring network (Table 4) form the same general distribution pattern as the historical and earlier instrumental (LDGO) earthquakes (Table 3). It is clear that the present study did not uncover any special areas of unusually high seismic activity that could be related to high geothermal activity as known elsewhere (Liaw and McEvilly, 1979; Ward, 1972). The seismic activity that was detected here appears to fit well both in distribution and rate with the past historical and instrumental activity. Unfortunately, it is not clear whether the overall activity is related to a very low level geothermal activity or to other tectonic forces unrelated to geothermal process. Where the geothermal activity is very slow and at some depth the distinction between tectonicly and geothermally induced seismicity may be very subtle.

The location of the two events near Lebanon Springs (22, 54--Figure 4) may be an exception to the observation that all recent events fall within areas of past seismicity. No known historical and early instrumental earthquakes were ever reported from this area. It is difficult to make much of just two events. At the same time, the Saratoga Springs area (stippled region--Figure 4), where numerous felt tremors have been reported in the past (Dineen, 1980; Nottis and

Mitronovas, 1980a; The Saratogian, 1955) and where the rate of the CO_2 gas escape is known to be high, showed no instrumentally detected events during the course of the present seismic monitoring study. Perhaps the association of seismicity with geothermal activity near Saratoga Springs, and in the study area in general, is present but the rate of seismic activity is too low and/or intermittent to be substantiated in such a short monitoring span (about one year).

Finally, the possibility of an association of higher than normal continuous ground vibration (microseisms) with geothermal or related activity within the study area may also be difficult to substantiate or refute. No special intensive effort was made to study this problem so far. However, in the process of searching for potential quiet sites for seismograph stations it was discovered that microseisms were exceptionally high in many places. This noise is highest within the Hudson and Mohawk Valleys where population density is high and cultural activity is intense. It is believed that the main contribution to the high noise level may not be the geothermal or related activity like escaping gas, etc. but the cultural activity like traffic, large pumps, generators, transformers, etc. The meteorological factors like wind, lightning, thunder, etc. can also be significant at times but they are intermittent and can be independently monitored and accounted for. It is believed that because of the high cultural noise it will be very difficult, if not impossible, to demonstrate the relationship between geothermal and microseismic activity, even if it were there, unless this relationship is extremely pronounced.

Conclusions

1. The intense cultural activity consisting of traffic, large pumps, generator, etc. within the study area that includes the upper Hudson Valley north of Albany and area south of Lake George made it difficult to find quiet locations for seismic stations in some desired locations. As a result the final geometry of the seismic monitoring network turned out somewhat different from the originally suggested ideal distribution of stations.
2. The northern part of the study area, just south of Lake George, was monitored using three stations for about one year (May 1979 - May 1980). The rest of the study area to the south was monitored using five stations for less than five months (April - August, 1980).
3. Six quarry blasts in three different locations within the study area were analysed in detail to determine accurately the seismic velocities. The results are presented in the July Project Progress Report (1980). These results are used to locate the earthquakes more accurately.
4. The eight small earthquakes ($\text{mag} < 1$) detected and located by the geothermal seismic monitoring network form a pattern similar to the pattern outlined by the larger ($\text{mag} > 2.5$) historical and earlier instrumental earthquakes known from earlier studies. No swarm of small earthquakes were detected anywhere within the study area to pinpoint intense geothermal or related activity.
5. The high level of continuous earth vibration (microseisms) caused by the cultural activity may preclude a successful search to find areas of abnormally high microseisms that could be directly or indirectly related to the geothermal processes at depth like the movement of magma or the escape of gases.

6. Based on all available seismic evidence to date, historical and instrumental, it is still not clear whether the earthquakes are a result of tectonic forces or geothermal processes.

Recommendations

Because the seismic activity within the study area was found to be quite low it is suggested that the monitoring period be extended for another full year. The detection and location of additional events within the study area is essential for a better determination of the true cause of earthquakes here. For, although the general distribution and the low rate of seismic activity suggests a tectonic origin for the few already detected earthquakes, it is still possible that the seismicity may be related in more subtle way to the geothermal activity here.

References

- Dineen, R. (1980). Tremor reports in the Saratoga Springs area. Personal Communication.
- Lamont-Doherty Geological Observatory (1970-1980). Regional Seismicity Bulletins of the Lamont-Doherty Geological Observatory (LDGO) of Columbia University. Quarterly and Annual Reports (1970-1980).
- Liaw, A.L. and T.V. McEvilly (1979). Microseisms in geothermal exploration studies in Grass Valley, Nevada. Geophysics, Vol. 44, pp. 1097-1115.
- Milne, W.G. and Smith, W.E.T. (1966). Canadian earthquakes--1963. Seismological Series of the Dominion Observatory, Ottawa, pp. 3-5.
- Mitronovas, W. (1980). Seismic monitoring in the Albany-Saratoga Springs area as part of the exploration for geothermal heat in New York and New England. Initial and Monthly Progress Reports for September 1979-April 1980, May, June, and July, 1980.
- Mitronovas, W. and Bailey, H.H. (1979). Research Proposal from NYSGS to NYSERDA for the First Phase of the Seismic monitoring in the Albany-Saratoga Springs area as part of the exploration for geothermal heat in New York and New England (August 1979).
- Nottis, G. and Mitronovas, W. (1980 a). Unpublished responses to a newspaper ad placed in The Saratogian during the period of May 6 to May 23, 1980. The ad requested any reports from the Saratoga Springs-Ballston Spa area on felt tremors.
- Nottis, G. and Mitronovas, W. (1980 b). Unpublished records of newspaper articles and clippings concerning historical earthquakes in New York State at the N.Y.S. Geological Survey.

Saratogian, The (1955). Newspaper article on felt earthquakes in the Saratoga Springs area (January 21, 1955).

Smith, W.E.T. (1966). Earthquakes of eastern Canada and adjacent areas, 1928-1959. Publications of the Dominion Observatory, Ottawa, Vol. 32, No. 3, pp. 109-121.

Stover, C.W. (1980). Unpublished list of earthquakes and map of New York State. U.S. Department of Interior, Geological Survey.

Ward, P.L. (1972). Microearthquakes: Prospecting tool and possible hazard in the development of geothermal resources. Geothermics, Vol. 1, No. 1, pp. 3-12.

Wielandt, E. and Mitronovas, W. (1976). An electronic LP seismograph for surface-wave dispersion studies. Bul. Seism. Soc. of Am., Vol. 66, pp. 987-996.

Figure Captions

Figure 1. Seismic monitoring network of the geothermal project. For additional information on the instruments see Tables 1 and 2.

Figure 2. Ground amplification as a function of frequency for the RPI seismograph station. The shape of the response is similar for other stations, only the level of the curve is different at different stations. See Table 2 for the values of maximum gain.

Figure 3. Relationship between magnitude (M) and maximum intensity (Im).

Solid line (A) is the least-squares solution to available data from New York State (solid circles) and adjacent areas (open circles). The relationship of Aggarwal (B) for eastern North America and Richter (C) for western United States are shown for comparison.

Figure 4. Map of the study area and adjacent regions showing the location of all known historical and instrumental earthquakes.

FIGURE 1.

FIGURE 2.

FIGURE 3.

FIGURE 4.

Table 1. General Information and Serial Numbers of Major Seismic Equipment specially ordered for the Geothermal Project.

<u>Equipment</u>	<u>Manufacturer</u>	<u>Model No.</u>	<u>Serial Nos.</u>	<u>Cost</u>	
				<u>Each(\$)</u>	<u>Total (\$)</u>
Pen Motors (six)	MFE Corporation	T4-150B	82540 82541 82542 82543 82544 82545	116.00	696.00
Seisometers (five)	Mark Products	1-15B	S-0 5877-1 S-0 5877-2 S-0 5877-3 S-0 5877-4 S-0 5877-5	375.00	1870.00
Time Receivers (six)	Caringella Electronics	STR-1	None	99.95	599.00
Amplifiers (six)	Gunar Streckeisen & Co.	ST-LTV 763	7914-1 7914-2 7914-3 7914-4 7914-5 7914-6	2504.00	15024.00
Recorders (six)	Gunar Streckeisen & Co.	HAE LT1-30	914-1 914-2 914-3 914-4 914-5 914-6	1730.59	10383.51
Clocks (six)	Dyneer Sprengnether Instrument Company	ST-400	7413 7414 7415 7416 7417 7418	940.00	5640.00

Table 2. Seismic Monitoring Network of the Geothermal Project (1979-1980)

Station Code	Locality	Latitude (N)	Longitude (W)	Elevation (Meters)	Maximum Gain (at 12 HZ)	Dates of Operation	Station Operator
COM	Colfax Mountain Washington Co.	43.0910	73.3915	314	1,050,000	April 10-- Sept. 5, 1980	Dan Molloy
MBR	Malden Bridge, Columbia Co.	42.4661	73.5719	146	190,000- 360,000	April 13-- Sept. 5, 1980	Art Bernett
MCG	Mount McGregor, Saratoga Co.	43.2031	73.7489	323	663,000- 1,326,000	April 7-- Sept. 5, 1980	Dan Heffner
RPI	Rensselaer Polytechnic Institute, Troy	42.7314	73.6664	131	550,000	March 27-- Sept. 5, 1980	Bill May Pete Angerani
THP	Thatcher State Park, Albany Co.	42.6472	74.0064	354	1,170,000	March 18-- Sept. 5, 1980	Tom Schoffield John Jambback
ACC	Adirondack Community College Warren Co.	43.3542	73.6545	98	320,000- 640,000	June 1979-- Sept. 1980	Anson Piper
COP	Copeland Pond Washington Co.	43.4315	73.5574	140	220,000- 440,000	June 1979-- June 1980	Anson Piper
LGE	Lake George Warren Co.	43.4330	73.6885	146	220,000- 440,000	June 1979-- May 1980	Anson Piper

Table 3

A. Historical Earthquakes (1847-1969) Which Have Occurred in the Upper Hudson Valley and Adjacent Areas Within New York State.

Ident. Code	Date	Origin Time (EST)	Epicenter Location		Maximum Intensity (Im)
			Lat. (N)	Long. (W)	
H1	Jan. 11, 1847	22:20:00	42.70°	73.80°	III-IV
H2	Jul. 9, 1847	"AM"	43.40°	73.70°	III
H3	Dec. 17, 1855	14:00:00	43.50°	73.80°	IV
H4	May 11, 1877	15:02:00	42.63°	74.40°	IV
H5	Dec. 28, 1878	21:32:00	42.70°	74.30°	III-IV
H6	Mar. 18, 1881	21:30:00	42.80°	73.90°	IV
H7	May 2, 1882	06:00-07:00	42.90°	74.20°	III
H8	May 2, 1882	08:10:00	42.90°	74.20°	IV
H9	Aug. 10, 1889	08:40:00	43.40°	74.00°	V
H10	Dec. 17, 1894	03:00:00	42.48°	73.80°	IV-V
H11	Jan. 5, 1916	08:56:00	43.60°	73.70°	V
H12	Jan. 5, 1916	12:00-13:00	43.00°	74.00°	III-IV
H13	Feb. 2, 1916	23:25:00	42.80°	73.90°	V-VI
H14	Oct. 30, 1916	"PM"	43.30°	73.70°	III
H15	Nov. 1, 1916	21:30:00	43.40°	73.60°	V
H16	Oct. 1, 1917	21:30:00	43.30°	73.70°	III
H17	Apr. 20, 1931	15:54:00	43.40°	73.70°	VII
H18	Oct. 21, 1939	03:59:33	43.35°	73.65°	IV
H19	Oct. 2, 1942	17:29:51	42.6°+17°	73.8°+17°	I
H20	Aug. 24, 1952	19:07:00	43.00°	74.50°	V
H21*	Oct. 9, 1952	11:25:00	42.80°	73.70°	IV
H22	May 6, 1958	15:00:00	42.70°	73.80°	IV
H23	May 19, 1963	--	43.20°	73.30°	III
H24	Jul. 1, 1963	15:59:12	42.6°+17°	73.7°+25°	I

B. Historical Earthquakes (1847-1969) Which Have Occurred in Areas Adjacent to the Upper Hudson Valley Outside of New York State.

Ident. Code	Date	Origin Time (EST)	Epicenter Location		Maximum Intensity (Im)
			Lat. (N)	Long. (W)	
H25	Apr. 13, 1938	01:00:00	43.17°	73.12°	II
H26	Mar. 31, 1953	02:50:00	43.70°	73.00°	III

C. LDGO Instrumental Earthquakes (1970-1979) Which Have Occurred in the Upper Hudson Valley and Adjacent Areas

<u>Ident. Code</u>	<u>Date</u>	<u>Origin Time (EST)</u>	<u>Epicenter Lat. (N)</u>	<u>Location Long. (W)</u>	<u>Depth (KM)</u>	<u>Magnitude (Nuttli)</u>
L1	Jun. 16, 1972	05:01:58.6	42.80°	73.90°	--	--
L2	Sep. 18, 1974	02:23:09.2	43.38°	73.83°	5.0	2.5
L3*	Oct. 10, 1974	16:00:19.1	43.15°	73.85°	--	--
L4	Nov. 19, 1974	04:23:28.3	43.48°	73.98°	0.0	--
L5	May 25, 1975	20:48:49.45	42.85°	73.68°	0.0	--

*Uncertain whether man-made or natural
MM-Modified Mercalli intensity scale

Table 4. Geothermal Project--Seismic Monitoring Network Instrumental Earthquakes Which Have Occurred in the Upper Hudson Valley and Adjacent areas

<u>Recorded Event</u>	<u>Date</u>	<u>Origin Time (EST)</u>	<u>Epicenter Lat. (N)</u>	<u>Location Long. (W)</u>	<u>Depth (KM)</u>
2*	Jan. 4, 1980	15:27:35.14	43.590°	73.299°	0.0
9	Mar. 11, 1980	06:08:46.02	43.511°	73.795°	0.0
22	Apr. 24, 1980	13:31:04.03	42.499°	73.425°	0.0
28	May 5, 1980	16:11:13.27	43.437°	73.645°	0.0
35	May 13, 1980	13:35:37.86	43.345°	73.709°	0.0
50**	May 29, 1980	14:04:58.08	42.698°	73.709°	0.0
54	Jun. 6, 1980	12:40:07.67	42.466°	73.440°	0.0
67	Jun. 24, 1980	13:46:28.22	42.835°	73.714°	0.0

*Uncertain whether man-made or natural
**This event was felt in an office building in Troy, New York.
It was described as a slight tremor (Intensity II (MM)).
It is uncertain whether the event was man-made or natural.

APPENDIX B
Seismic Report

APPENDIX C
Gradient Data

KEY

APPENDIX D

Glossary

Appendix D

GLOSSARY

allocthonous front - the frontal edge of a mass of rock transported into an area by thrust faulting.

connate water - water entrapped in the pore spaces of sedimentary rocks at the time of deposition, and remaining out of contact with the atmosphere over geologic time.

fault - a fracture or zone of fractures in the earth's crust along which displacement of the sides relative to one another has occurred.

ground water - subsurface water - as distinct from surface water.

magmatic water - water derived directly from magma and thought to be reaching the earth's surface for the first time.

metaclastic rock - metamorphosed clastic rock.

meteoric water - water of recent atmospheric origin.

penecontemporaneous block faulting - block faulting occurring in soft rock - soon after deposition of the strata involved.

unconformity - a substantial break in the geologic record, as evidenced by discontinuous deposition, an erosional period, or a structural discordance.