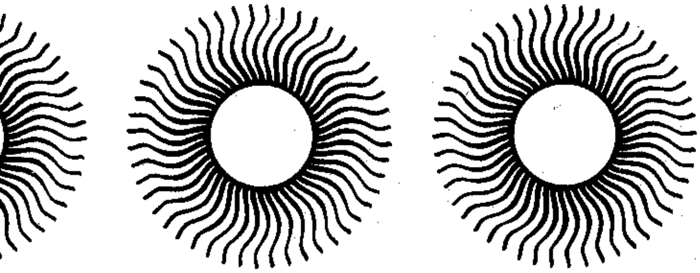


Geothermal Resource Evaluation: Eastern New York State

NYSERDA 79-6

New York State Energy
Research and Development
Authority

The **New York State Energy Research and Development Authority** is a public benefit corporation chartered by the New York State Legislature. It is governed by a 12-member Board of Directors appointed by the Governor with the consent of the Senate. State Energy Commissioner James L. Larocca is Chairman of the Board and the Chief Executive Officer. An Executive Director manages the Authority's RD&D programs, staff, and facilities.

The mission of the Authority is best summarized in Governor Carey's 1978 Energy Message to the Legislature.

> *Today, our State energy research, development and demonstration program reflects the understanding that no single supply technology or conservation strategy will reduce New York's almost total dependence upon energy imports. Rather, New York State's program is based on the conviction that identifying and developing a broad range of new energy technologies and matching each technology with its appropriate application is the best approach for attacking our energy problems.*

The Authority's RD&D policy and program stresses well-designed research, development and demonstration projects, based on technologies with potential for commercialization within five years. It seeks to accelerate the introduction of alternative energy sources and energy-efficient technologies and to improve environmental acceptability of existing fuels and energy processes. Finally, the Authority seeks to ensure that Federal research programs reflect the needs of the State.

The use of New York contractors and an awareness of energy-related growth opportunities are part of the Authority's effort to support industry in New York. Concentrating on these objectives ensures that NYSERDA's RD&D programs will produce maximum benefits to the citizens and businesses of New York, while attracting the participation of both the private sector and the Federal Government.

NYSERDA derives its research and development revenues from assessments upon the intrastate sales of the State's gas and electric utilities. The Authority also derives income from the investment of retained earnings and leased property, as well as from bond financings of pollution control facilities.

Further information about NYSERDA's RD&D programs may be obtained by writing or calling Dr. A. Bruce Bishop, Executive Director, NYSERDA, Rockefeller Plaza, Albany, N.Y. 12223; (518) 465-6251.

Hugh L. Carey
Governor

James L. Larocca
NYSERDA Chairman

GEOTHERMAL RESOURCE EVALUATION
EASTERN NEW YORK STATE

NYSERDA 79-6

August 1979

Prepared for

NEW YORK STATE
ENERGY RESEARCH AND DEVELOPMENT AUTHORITY

Project Manager
Dr. Burton Krakow

Prepared by

DUNN GEOSCIENCE CORPORATION
Latham, New York

Project Geologist
James R. Young

Project Advisor
James R. Dunn

Project No. 18/ET-RER/78

NOTICE

This report was prepared by the Dunn Geoscience Corporation in the course of performing work contracted for and sponsored by the New York State Energy Research and Development Authority (hereafter the "Authority"). The opinions expressed in this report do not necessarily reflect those of the Authority or the State of New York and reference to any specific product, service, process or method does not necessarily constitute an implied or expressed recommendation or endorsement of same. Further, the Authority and the State of New York make no warranties or representations, expressed or implied, as to the fitness for particular purpose, merchantability of any product, apparatus or service or the usefulness, completeness or accuracy of any processes, methods or other information described, disclosed or referred to in this report. The Authority and the State of New York make no representation that the use of any product, apparatus, process, method or other information will not infringe privately owned rights and will assume no liability for damages resulting from use of or other reliance upon any information contained in this report.

TABLE OF CONTENTS

1.0 CONCLUSIONS

1.1 Several sets of information gathered in the course of this study demonstrate a high probability of a thermal derivation for portions of Saratoga Springs water with good indications that a concealed geothermal system exists at depth. Briefly summarized, these are:

(1) Analogy; all known global occurrences of carbonated waters which are similar to Saratoga (e.g., free gas content and low pH) are either directly related to obvious thermal sources (volcanicity, anomalous heat flow, metamorphism at depth) or show some other evidence of thermal derivation.

(2) The only known thermal springs in the Northeast occur on the eastern edge of the Hudson Valley some 50 km from the City of Saratoga Springs.

(3) The difficulty in explaining the presence of so much CO_2 by any normal, cold geologic process.

(4) The lack of significant sulfates, nitrates and nitrites in most of the carbonated waters which is incompatible with known low temperature methods of CO_2 formation.

(5) A net flux of CO_2 through the system indicating the addition of the gas is a dynamic, not a fossil process.

(6) A distinct negative $\delta^{18}O$ "shift" in the water indicating the CO_2 gas originated at elevated temperatures.

(7) Carbon isotope values ($C^{13}/12$) of a few per mil negative that are compatible with a derivation from "deep" (mantle) CO_2 and/or decarbonation of carbonate at elevated temperatures (skarn formation).

(8) Anomalous quantities of dissolved SiO_2 up to 70 mg/l (after dilution with cold, shallow waters) indicating that a fluid zone of heat exchange is associated with the Saratoga system.

1.2 The near normal temperatures of the waters from the Saratoga Springs wells are explained as follows:

A minimum of nine to ten grams/liter of CO_2 appear to be required to explain the observed oxygen isotope shift. Since approximately one-half of this amount is seen in the gassiest Saratoga waters, this implies that the system is effectively "degassing." The considerable cooling process from gas expansion, the obvious mixing with the large quantities of shallow, cooler water, and heat conduction all apparently combine to produce the near normal water temperatures observed at the surface.

1.3 A high probability of the presence of a heated basement fluid analogous at least in part to a metamorphic brine with an attendant convective geothermal system has also been demonstrated.

1.4 The subsurface temperature of this system cannot be determined at this time due to dilution by a basinal brine component of unknown total salinity and by cold meteoric water.

1.5 Direct silica geothermometry suggests the last subsurface reservoir temperature of the thermal fluid to be in the range of 90° - 120° C (assuming no dilution whatever; however, the evidence is overwhelming that considerable dilution of the thermal fluids does occur). Much higher temperatures for the undiluted thermal fluids appear possible (1) based on laboratory work which indicates that temperatures of at least 300° C are needed to cause metamorphic reactions which release CO_2, and (2) based on the normal temperatures which exist during the devolatilization of igneous rocks. Our current best judgment is that a small amount (relative to the total water in the Hudson Valley basin) of high temperature thermal fluid is being continuously introduced into the basin. Temperatures of up to 300°C for this fluid are possible.

1.6 Evidence suggests that the primary thermal system(s) lies somewhere east or southeast of the Saratoga fault joining the Towns of Ballston Spa and Saratoga Springs. The eastward-thickening wedge of Ordovician shales topped with lacustrine clays provide a very effective cap for the carbonated waters and can mask any associated thermal anomalies in this area. The primary zones where superheating may occur are most likely along fault or fracture zones.

1.7 The proportion of CO_2 which is derived from deep crustal sources versus that derived from chemical reactions between thermal fluid and carbonate rocks of the Paleozoic is not known at this time.

2.0 RECOMMENDATIONS

Our findings indicate a reasonably good possibility that one or more convective geothermal systems are associated with the Saratoga-type carbonated waters. Accordingly, we recommend that the proposed Phase II evaluation and exploration program be implemented. This program has two goals: (1) the refinement of subsurface temperature estimates; and, (2) locating the heated zone(s). Successful completion of this program should improve the chances for a successful deep test well.

3.0 INTRODUCTION

3.1 Initiation

Discussions with Mr. Richard F. Napoli of NYSERDA during the fall of 1977 led to the submission of a proposal for this project on December 28, 1977. This project was conceived as being Phase I of a three phase study of geothermal resources in east-central New York, each phase being separately funded and authorized. The Phase I proposal was subsequently accepted and approved by NYSERDA leading to a contract dated March 8, 1978.

3.2 Personnel

The Project Geologist for this study was James R. Young who was responsible for the organization and operation of the program as well as developing the basic scientific concepts and preparing this report. Dr. James R. Dunn as Senior Project Advisor worked closely with Mr. Young in operating the program and in reviewing concepts. Project and contract administration was performed by George M. Banino. Several other members of the Dunn Geoscience Corporation staff aided in this program. In particular, John A. Middleton provided assistance in sample collection and data compilation.

Dr. George Putman of State University of New York at Albany served as a consultant to the project in the field of geochemistry. He assisted in evaluating the large volume of data, and was responsible for the writing of the isotopic section of this report.

4.0 PURPOSE

This study was designed as the first phase of an evaluation of possible geothermal resources in east-central New York. Its primary purpose was to evaluate the long-standing hypothesis that some components of the Saratoga waters (notably CO_2) were derived from a thermal reaction (Kemp, 1912). Related purposes included estimating the potential for an associated geothermal system(s), its subsurface temperature (if possible), and the desirability of proceeding with a larger scale program.

Assuming that the results appeared positive on all these counts, Phase I was also slated to include the design of a program of regional exploration to select a specific site for a test well. This too has been accomplished in the form of a proposal (Phase II) submitted on November 28, 1978. The third phase was to be the actual drilling of a test well.

5.0 SCOPE

Phase I was designed around two preliminary, inexpensive techniques of geothermal exploration: (1) geologic literature review, and (2) a regional sampling of the waters. In the case of Saratoga the literature review has not only included gathering information pertinent to the area, but has expanded into a study of CO_2-HCO_3 waters over the world. The modeling of this type of system CO_2 - HCO_3 - Cl - Na - Ca - Mg waters has proven extremely difficult due to complicated carbonate chemistry and the paucity of comparative data.

While many fairly reliable sets of analyses exist for some of the famous wells in the City of Saratoga Springs virtually no data later than 1930 exists for the less publicized occurrences. The sampling program was designed, therefore, not only to include some of the famous wells of Saratoga, but to place more emphasis on other carbonated water localities as well as uncarbonated ones. Furthermore, the program was expanded to include both spring and fall rounds of sampling to determine (1) if seasonal chemical fluctuations were present, (2) the reliability of the spring analyses and, (3) the extent of surface water dilution.

6.0 ACKNOWLEDGEMENTS AND PREVIOUS WORK

6.1 Acknowledgements

Foremost among the scientific contributors to this study is Dr. Ivan Barnes of the United States Geological Survey of Menlo Park, California. His published work on CO_2-HCO_3^- systems has been an invaluable guide in evaluating the Saratoga system, as has his method of determining the derivation of the CO_2 and HCO_3^- of this type system which he has shared with good effect. In addition, his isotopic analyses of samples from six carbonated wells have served as a reliable check for mass spectrometric measurements of gases and for isotopic $C^{13}/12$, $O^{18}/16$, and $^{D}/H$ analyses.

Particular thanks are also due to Mr. Carl Edwards, chemist with the New York State Parks Commission at the Saratoga Springs Park; who has systematically analyzed the wells and the Saratoga Springs Reservation over a number of years. His generosity in supplying this data and other basic information about the wells is gratefully acknowledged.

Too numerous to mention although instrumental to the success of this study has been the information supplied by various well drillers, chemists, and, particularly, water conditioner dealers on the locations of privately-owned CO_2 and saline water wells.

Lastly, heartfelt appreciation is expressed to the many patient people who permitted us to trek through their homes with assorted paraphenalia in an effort to sample their waters.

6.2 Previous Work

The naturally carbonated mineral springs of Saratoga have been the object of considerable interest ever since their discovery by colonists in the late eighteenth century. It was quite common to ascribe all sorts of beneficient medicinal properties to unusual waters in those times and Saratoga first received medical citations as early as 1770. During the ensuing 19th century testimonials proliferated and a major resort spa grew to flourish around the increasing number of mineral wells drilled in and around the town of Saratoga. This activity naturally fostered many studies which were largely "pseudo scientific" in nature and mostly designed to tout the curative properties of the waters. Several early sets of analyses were also performed by reputable chemists of the time, notably Dr. John Steele (1840) and Professor Charles F. Chandler (1875). Their analytical work can be considered relatively accurate for some of the major constituents in the waters. The first interpretation of the system was attempted by Professor James F. Kemp (1912) who combined this and other data with new sets of analyses by the U. S. Department of Agriculture to produce an exhaustive study of the waters.

Kemp's work still remains as an outstanding example of scientific analysis, even though it was performed over 65 years ago. Not only does he compile a complete historical/analytical sketch of the Saratoga area springs and wells, he cites other occurrences from Albany to Whitehall and links them into a unified interpretation. Among some of his noteworthy conclusions are these: (1) that "faults furnish an upward passage for the gas and dissolved mineral matter ....but the tight cap of slates above the limestones acts as a roof to prevent their escape, except in the springs and bore holes"; (2) the gas (CO_2) is one of the most important features of the water and is generally present in amounts between one to five volumes gas/volume solution; (3) the temperature of the waters averages between 50°F and

53°F, 2°F to 5°F above the mean annual temperature for Saratoga Springs; and (4) that the source of the gas was probably due to the action of silicic acid on limestone or expiring volcanic activity (citing the volcanic plug of Northumberland, Stark's Knob, as evidence) somewhere deep-seated in the basin to the east.

Cushing and Reudemann (1913) touched next upon the springs in their study of the geology of the Saratoga area. While they did not attempt an in-depth look, noting that such an effort would be redundant after Professor Kemp's work, their mapping supported the conclusion that the points of issuance of the water were fault-controlled. They also found that Stark's knob was allochthonously related to the Taconic thrust sequence* (i.e., faulted in and could not have generated the CO_2); however, they still concurred with Kemp's major interpretation that a deep-seated igneous source for the gas and waters occurred in the easterly basin.

The last significant study of the waters was conducted by R. J. Colony for the specifically appointed Saratoga Springs Commission under the aegis of the State of New York in 1930. While the commission's primary concern was the well-being of the large health resort, considerable data was collected about the waters themselves. Among these were new sets of chemical analyses arranged in a table corresponding to a north-south well progression. These showed a somewhat inconsistent but general increase in total salinity and various separate salts from north to south. Bicarbonates were also plotted from well to well, the result showing that the rate of increase of the chlorides was greater than the rate of increase of the bicarbonates from north to south.

Additional analytical information was determined by Lester W. Strock in 1940. By virtue of two early emission spectrographic analyses he

---

*Thrust-faulted from the east.

determined that the Orenda and Geyser wells contained anomalous zirconium and beryllium. While the present study has not verified the beryllium, our work confirms the presence of unusual amounts of zirconium.

The last published contribution to the Saratoga problem was by Lang (1959) who, on the basis of a single isotope analysis, concluded that the $C^{13}/12$ ratio for the CO_2 gas at Saratoga was compatible with a derivation from marine limestones.

While Kemp initially proferred a thermal derivation, most subsequent workers have either skirted or ignored the problem for primarily two reasons: the cool surface temperature of the waters, and, the lack of known igneous activity in eastern North America since the Mesozic (100,000,000 years ago). These facts have led to at least three other unpublished hypotheses of origin for the CO_2 being advanced from time to time:

(1) the direct oxidation of carbonaceous beds (i.e., coal or peat) or by organic decomposition with the accompanying production of CO_2 or methane;

(2) the reaction of the $CaCO_3$ of the Beekmantown limestones with H_2SO_4 produced from the near-surface oxidation of sulfide minerals and/or the decomposition of organic detritus producing humic acids; and,

(3) the release of structurally entrapped, thermally provoked CO_2 of Mesozic age deep in the basin to the east being released due to renewed tectonic activity and the accompanying easing of lithostatic pressure through erosion.

7.0 METHODS

Water from 39 springs and wells from around the Saratoga basin has been sampled and analyzed by Health Research Inc., a Division of New York State Laboratories. Of these, about 1/2 are from previously unsampled locations. The waters from the spring sampling (36 locations) have been analyzed for F (free), N (ammonia), N (nitrate, nitrate), Cl, SO_4, Be, B, Fe, K, Na, Zn, Ca, Li, Mg, SiO_2, Zr, Br, I, PO_4, Cd, Pb, Al, Ba, Sr, Sn, Cr, Mn, Y, pH (laboratory and field), alkalinity (to methyl orange) and total dissolved solids. Be, Zn, Cd, Pb, Cr and Mn were omitted in the fall sample analyses, and N (total), TOC (total organic carbon), and alkalinity (laboratory: pH 4.5) were added. These trace metals were deleted from the fall format due to their insignificance in the spring sampling while TOC was added to aid in carbon isotope interpretations. Three characteristic uncarbonated saline water wells were also added to the fall round to aid in determining the components added by wall-rock reaction.

Due to an anticipated lower water table, less meteoric dilution and, therefore, greater brine-gas concentrations, systematic isotope sampling was conducted during the fall program. Analyses were performed for $C^{13}/12$ (water and gas) and $O^{18}/16$ (water and gas) on all wells and four surface bodies of water by Krueger Enterprises, Inc. $C^{13}/12$ measurements were also made on some typical samples of Paleozoic carbonate, Precambrian marbles, and graphite within the marbles. All of these analyses have been received but proposed $^{D}/H$ measurements could not be made due to equipment problems. Because of a possible interlaboratory bias, precision problems with the oxygen isotope determinations, and lack of $^{D}/H$ data, the interpretation of much of this isotope data is uncertain at best and is not considered in this report.

During the summer, six critical wells were selected for preliminary gas isotope and carbonate precipitate sampling. These were performed at no expense by Dr. Ivan Barnes of the U.S. Geological Survey, Menlo Park, California, for Dr. Putman of the State University of New York at Albany and serve as a check for the commercial analyses.

Samples for Ra^{226}, another known component of the Saratoga waters, were also collected during the fall from all wells. Results from these are listed under a separate heading.*

The geologic structure of the area has been synthesized for this project and is summarized in Plate I. In addition, published magnetic, gravitational and seismic information has been gathered. Prominent linears from U-2 photography have been integrated with other unpublished fault data and are also summarized on Plate I.

A thorough research of carbonated water systems has been conducted and the results filed and indexed.

---

*For further discussion concerning collection methods and data reliability, please refer to the appendix.

8.0 GEOLOGIC SETTING

The lower and central Hudson Valley is a prominent north-south linear structure which extends from New York City northward to join with the Lake George graben and Champlain Basin which extends to Montreal. This zone of weakness may be over 650,000,000 years old (Precambrian) and the Hudson Valley may have been the site of a long, narrow sea 650 million to 430 million years ago (Cambrian and Ordovician ages).

8.1 Stratigraphy

8.1.1 Precambrian. Precambrian basement rocks underlie the sedimentary basin. These rocks are from 1 - 2 billion years old and consist of mixed metasediments including calcitic and dolomitic marbles, quartzites, and various metaclastics (paragneisses), and mixed igneous rocks with iron- and titanium-rich anorthosites and gabbros forming an Adirondack core. Granitic and syenitic gneisses (charnockites and mangerites) are very common, with the former frequently enriched in radioactive minerals with or without magnetite.

8.1.2 Potsdam and Theresa Formations. The lowest sedimentary unit is the Potsdam sandstone which unconformably rests on Precambrian Basement. This sandstone is Cambrian in age and surrounds and laps onto the Adirondack terrain which was part of an emergent continental shield during Potsdam time. The Potsdam sandstone may be up to several hundred feet thick, but because it was deposited on a highly irregular surface and probably did not cover all the emergent Adirondack area, its thickness and detailed nature is not predictable. It is overlain by the Theresa Formation, an intermixed sandstone and dolomite sequence.

8.1.3 Carbonate Rock Series. Several Cambro/Ordovician and Ordovician carbonate rock units overly the Theresa Formation in the northern Hudson Valley region. The bulk of them comprise the Beekmantown Formation, which is essentially a series of dolomites with minor limestone and interfingering sands apparently developed as reefs, tidal flats and channel deposits. The Beekmantown is of irregular thickness (~500 feet) due to the regional Knox Unconformity. Above the Knox are limestones, the Trenton-Black River and the Amsterdam, which outcrop less than 100 feet in thickness in the Saratoga region.

8.1.4 Shales. Above the carbonate sequence is a thick series of shales, siltstones, and minor sandstones of the Utica and Snake Hill Formations (= Schenectady + Normanskill + Austin Glen). The sequence is poorly understood because of glacial cover, its spatial position at the transition of depositional units, and the complicating factor of the Taconic allocthon. As can be seen in Figure 1, the shales' thickness increases rapidly to a possible maximum of 10,000 to 12,000 feet.

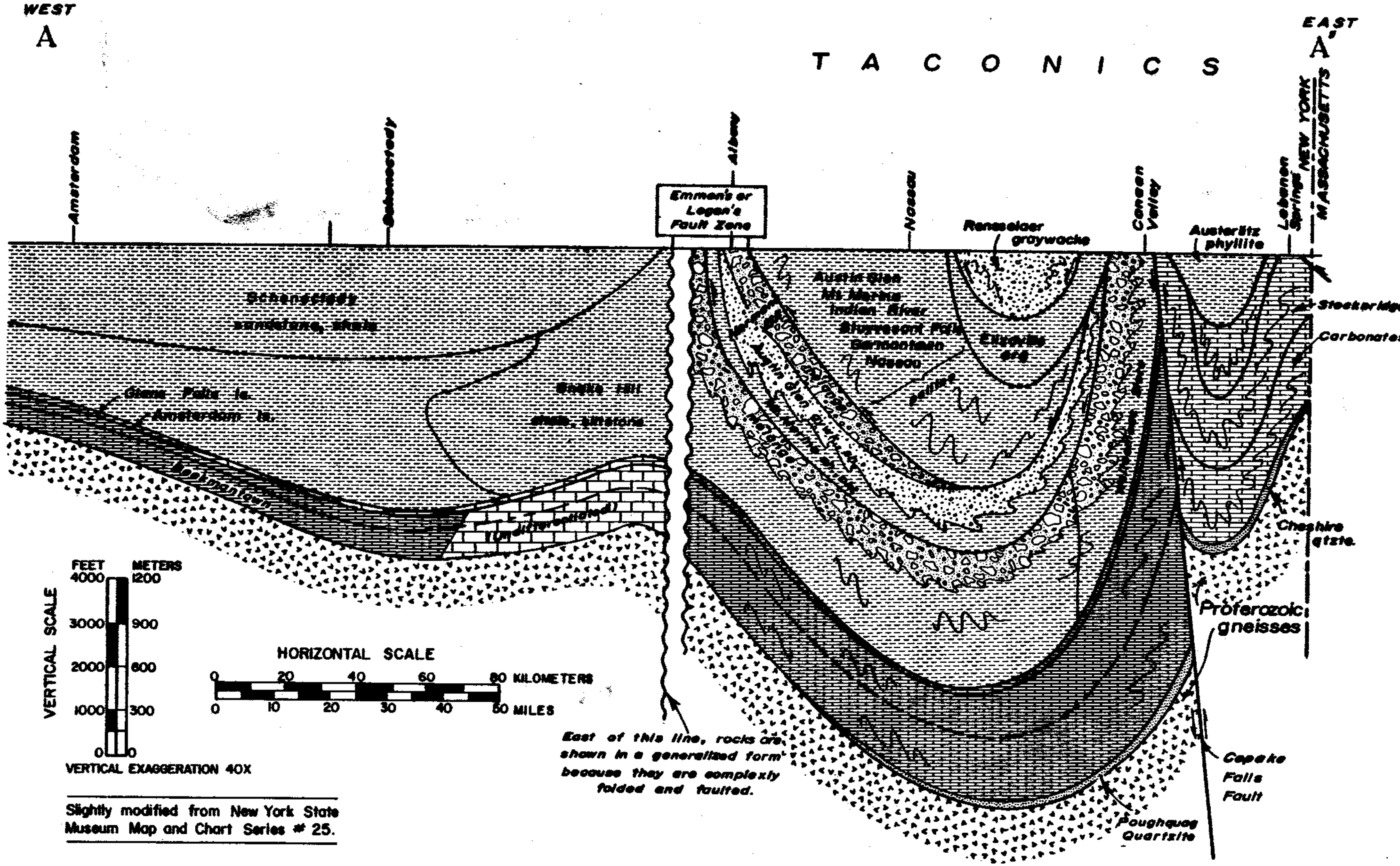
8.2 Structure

8.2.1 The Albany-Saratoga area is at the confluence of contrasting geologic provinces. Northwest are the structurally complex medium to high grade metamorphic rocks of the Precambrian Adirondacks. To the east are the lower Paleozoic low grade metamorphosed rocks of the Taconic Mountains. The structure of the Taconic rocks is generally complex with deformed allocthonous and autocthonous rocks. To the southwest and west of Albany the rocks are lower-to mid-Paleozoic and are relatively simple structurally. Block faulting occurs below the Silurian rocks with movement occurring during sedimentation. The Silurian and Devonian formations dip gently to the south or southwest a few tens of feet per mile.

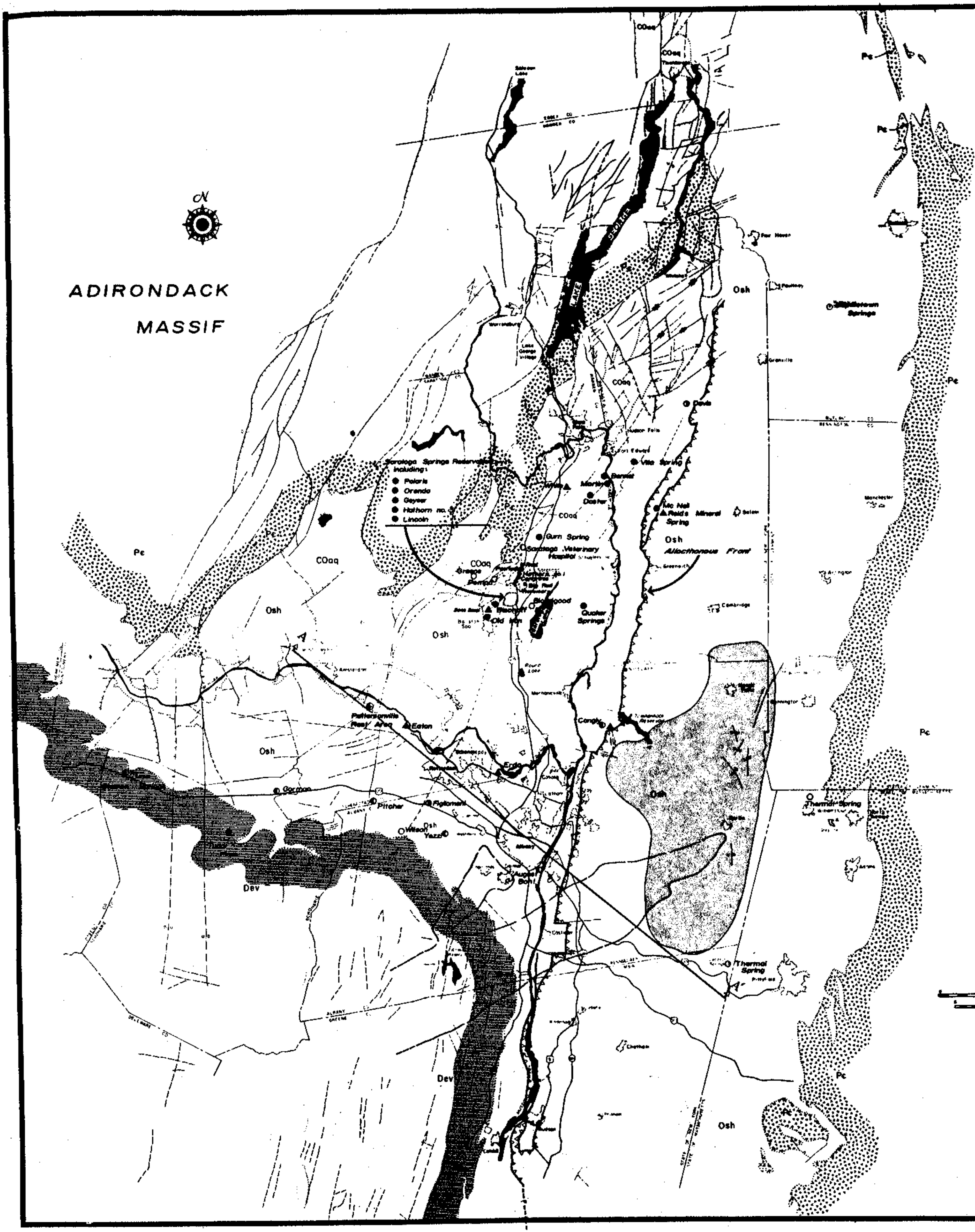
8.2.2 The Hudson Valley is an exceedingly complex geologic structure. It was near the north-south Cambrian-Ordovician Taconic subduction zone during which it was at or adjacent to complex eugeosynclinal graywacke-melange sedimentation. Those sediments were later thrust westerly over the top of the present basin area as major crustal plates collided together in the region. The famous north-south Emmons' or Logan's line which passes approximately through Albany separates the structurally simple rocks to the west and southwest from the complex structural zone believed to begin approximately beneath the center of the basin.

8.2.3 The detailed structure and stratigraphy of the Hudson Valley is not known. To our knowledge no holes have ever been drilled through the shales in the Albany area. Projecting structures or stratigraphy into an area as complicated as the Hudson Valley where strong deformation occurred during the emplacement of allocthonous sediments can only be misleading.

The generalized structure and stratigraphy shown in Figure I is slightly modified from the N.Y.S. Geological Survey generalized cross-section for New York State. The line of the cross-section is shown on the accompanying map. As is portrayed by the cross-section, the nature of the carbonate rocks and sandstones underlying the shaley facies of the valley is not known; however, the foremost stratigraphers of the area, Friedman, Fisher, et.al., believe that all available evidence indicates that the formations most likely extend throughout the northern Hudson River Valley basin.



Slightly modified from New York State Museum Map and Chart Series # 25.


N
ADIRONDACK
MASSIF
Pc
COoq
Osh
Dev
Saratoga Springs Reservation
including:
● Polaris
● Orenda
● Geyser
● Hathorn no. 3
● Lincoln
Gurn Spring
Saratoga Veterinary Hospital
Quaker Springs
Old Iron
Bischoff
Blodgood
Pompa
Greene
Dester
Morris
Bennet
Vita Spring
Davis
Mc Neil
Reid's Mineral Spring
Allocthonous Front
Hudson Falls
Fort Edward
Salem
Cambridge
Greenwich
Granville
Middletown Springs
Manchester
Arlington
Bennington
Thermal Spring
Round Lake
Mechanicville
Congdon
Pattersonville Rest Area
Eaton
Amsterdam
Schenectady
Erdo
Gorman
Pitcher
Figliomeni
Wilson
Yazzo
Albany
Augustine Bohl
Chatham
A
A'
LAKE GEORGE
Warrensburg
Lake George Village
Fair Haven
Poultney
Schroon Lake

DUNN GEOSCIENCE CORPORATION
5 Northway Lane North
Latham, N.Y. 12110

Thermal Springs and CO_2 Wells of the Mid-Hudson Valley

GEOLOGY BY
Jonas Young
DRAWN BY Robert H. Grady
[illegible]
CHECKED BY
Jonas Young
DATE
[illegible]
PROJECT NO. [illegible]
MAP NO. [illegible]
SHEET 1 OF 1

LEGEND

GEOLOGY

- ▨ Dev- Devonian Limestones and Sandstones
- ☐ Osh- Overlying Ordovician Shales including: Normanskill Shale and Taconic Allochton.
- ☐ COaq- Cambro-Ordivician Aquifer including: Trenton-Black River Limestone, Beekmantown Dolomites Theresa Formation, and Potsdam Sandstone.
- ☐ Pc- Pre-Cambrian Basement
- —— Boundary of Lithologic Units
- ------ Generalized Boundary of Lithologic Units

FAULTS*

- Normal Faults with Hatching on Downthrown Block.
- Normal Fault- Inferred
- Normal Fault- Inferred from Subsurface Information. D = DOWNTHROWN, U = UPTHROWN
- Thrust Fault with Sawteeth on Overthrust Plate.

*Note: Most Thrust Faults associated with the Taconic Allocthon have been deleted for clarity.

SPRINGS and WELLS SAMPLED DURING THIS PROGRAM.

- ● Free-CO_2 Wells and Springs
- ◑ Brine Wells with greater than 500 PPM Alkalinity.
- ◐ Wells with less than 500 PPM Alkalinity.
- ○ Thermal Springs and Control Wells

SPRINGS and WELLS SAMPLED PREVIOUSLY with PARTIAL CHEMICAL DATA AVAILABLE.

- ▲ Free-CO_2 Springs and Wells.
- △ Brine Wells

- ▨ Generalized Negative Gravity Anomaly - 70 mgal contour REGIONAL BACKGROUND ~ -40 mgal
- ☐ Generalized Positive Aeromagnetic Anomaly

SCALE 1:250,000
5 0 5 10 15 20 MILES
5 0 5 10 15 20 25 30 KILOMETERS

BASE MAP INFORMATION:
New York State Museum and Science Service
Map and Chart Series no. 15, 1970
Map and Chart Series nos. 31 B,E, 1977

9.0 DATA PRESENTATION AND DISCUSSION

Each of the waters sampled has been given an index number and a grouping which is used systematically throughout this report. Two criteria of group selection have been used with some subjective intermixing:

(1) similar chemical properties, and

(2) spatial relationships.

For the sake of clarity and conciseness the salient characteristics of the various water groupings have been summarized in Table 2 followed by discussions on a group basis. Individual well parameters will be found by referring to Plates 2 and 3 of the appendix.

9.1 Physical Observations

9.1.1 Distribution of Saratoga-Type Waters

CO_2-charged waters have been found from the Albany-Schenectady area northward about 45 miles to Fort Edward and Argyle. (Several new sites have been described in the present research.) The total area which is underlain by such waters may be over 1,000 square miles. The western and northern boundary roughly coincides with the outcrops of the first dolomites to the west of the basin, while the eastern limit seems to be bounded by the allocthonous front. The CO_2-rich waters, therefore, seem to be confined to the western limb of the Hudson Valley geosyncline.

9.1.2 Surface Issuance Controls

As mentioned above, it was Kemp's early conclusion that the surface manifestations of the carbonated waters were essentially fault controlled. Certainly this appears to be the case at Saratoga where the westward-thinning wedge of shales is truncated by the Saratoga fault;

the conduit along which the early free-flowing carbonated springs issued. Our work has confirmed this conclusion since all new water sources (saline and/or carbonated) have been found to lie along apparent linears probably representing major subsurface faults or fracture systems. This is hardly surprising, however, since the thick, fissile Ordovician shales should form a very effective caprock having only limited fracture permeability.

9.1.3 Temperature of the Waters

Temperature measurements were performed on each of the waters during sample collection (Plates 2 and 3) and are summarized in Table 2. In general these have not borne out the earlier conclusion that the wells of the Saratoga group are 2 to 4° C warmer than the normal ground water temperature of that area. In fact, the waters may be 1 to 2° C cooler than deep ground water.

Earlier measurements upon which this comparison is based were made in shallow gravel aquifer wells (Kemp, 1912; Heath, 1963) of the same area. During the course of the spring and fall sampling, we also made comparative temperature measurements at three sites within the Saratoga Springs Reservation. The results are as follows;

	Spring	Fall
Ferndell Spring (Free-flowing hillside spring)	6°C	14.1°C
Geyser Brook	7°C	13.5°C
State Seal (~100 foot well into shale)	5°C	15.5°C

While these measurements indicate that the carbonated wells are from 2 to 8° C warmer than shallow ground water in the spring, the measurements made of the waters from the control wells <u>of similar depths</u> indicate the carbonated waters to be about the same temperature, perhaps 1 to 2° C cooler. This latter deep ground water group must be considered a more representative check than shallow wells of surface water.

During the fall the carbonated waters are in fact cooler than the shallow ground-water. They are also cooler by several degrees than the check wells and show only a 1-2° C pattern of warming from spring to fall. This implies that gas evolution in these wells is a more effective temperature controlling mechanism than warm meteoric water dilution.

Close inspection of Plates 2 and 3 shows, in fact, that there is another 1 to 2° C negative temperature shift with increasing HCO_3^- content in the waters of different wells. This further suggests that the evolution of gaseous CO_2 from the waters as they rise up the well pipe has a cooling effect. While downhole temperature measurements are needed to quantify this effect at Saratoga, data collected from the Kizildere geothermal field in southwestern Turkey show that the exsolution of a 1.5 to 2.0% content of dissolved CO_2 gas as it travels up a 500 m borehole cools the fluids about 10° C (James, 1975).

When the far larger amounts of CO_2 at Saratoga are considered in conjunction with the dilution effects from saline basinal water and meteoric waters, the cool surface temperature of the waters at Saratoga is quite plausible; indeed, it should perhaps be expected.

9.2 Water Chemistry

9.2.1 Thermal Waters

Thermal waters from the two presently known locations were sampled and designated as such in Plates 2 and 3. The Lebanon Springs site consists of a single high-flow spring (~500 gpm) reportedly issuing from a bedrock fracture within a developed spring house excavated through thin glacial cover just west of a major thrust fault separating the Stockbridge Limestone and the Walloomsac Slate. However, at Williamstown, Massachusetts, about 15 miles north northeast, several thermal water wells are known, including Sand Springs which issues along the same fault system from Pleistocene cover at a discharge rate of about 400 gpm at a fairly constant 74° F. A private residence nearby with similar thermal water (residence of Fred George) was selected for sampling for logistical reasons.

The analyses indicate that these waters are very similar to each other and normal surface ground water in this area (Hobba, 1976). The slight relative enrichment of Ca, Mg, and Sr in Lebanon Springs probably reflects leaching from the Stockbridge Limestone while the minor sulfate may be a product of oxidation in the slates.

The low TDS values of these waters and their low contents of silica (9.1 + 10 mg/l, spring and 15 + 16 mg/l fall) indicate that these waters have not been heated much above their present temperature; perhaps a maximum of 30° to 40° C. Moreover, their locations at the base of mountains along the same major thrust fault system suggest that an unusually deep circulation mechanism may be responsible for their anomalous surface temperatures.

Conversely, we must also note that these are the only two thermal springs north of Virginia in the eastern United States. Their presence in the eastern portion of the Hudson Valley basin some 40 to 50 km from

WATER GROUP SUMMARY

	Saratoga Springs	North Central	Southern Brine	Thermal Waters	Control Wells	Sulfate Waters (Mixed Types)
Temperature						
Spring	9-12° C	8-14° C	9-16° C	22-23° C	11-13° C	9-13° C
Fall	10-14° C	11-16° C	11-14° C	22-23° C	11-16° C	9-13° C
Carbonation	Free CO_2: 1200-5000 mg/l HCO_3	Free CO_2: 900-2750 mg/l HCO_3	Uncarbonated: 250-400 mg/l HCO_3	Uncarbonated: 100-160 mg/l HCO_3	Uncarbonated: 2-360 mg/l HCO_3	Carbonated and uncarbonated
Total Dissolved Solids	2000-15,000 mg/l decreasing northward	4000-1200 mg/l	4500-1900 mg/l	200-100 mg/l	500-100 mg/l	5500-2500 mg/l
Major Chemistry	$HCO_3 \geqslant Cl > Na$	$HCO_3 > Na > Cl$	$Cl > Na > HCO_3$	Variable	Variable	$SO_4 > HCO_3 > Cl > Na$
<u>Minor Chemistry</u>						
Potassium	Large Excess 40-340 mg/l	Intermediate Excess 20-70 mg/l	Normal 7-11 mg/l	Normal 1 mg/l	Normal 0-3 mg/l	8-50 mg/l Excess in carbonated wells
Silica						
Spring	7-46 mg/l	8-15 mg/l	5-11 mg/l	9-10 mg/l	6-7 mg/l	9-14 mg/l
Fall	12-70 mg/l	13-22 mg/l	10-17 mg/l	15-16 mg/l	11-12 mg/l	15-22 mg/l
Zirconium	Anomalous	Anomalous	Not Detected	Not Detected	Not Detected	Anomalous in carbonated well
<u>Molar Ratios (Spring)</u>						
Na/Cl	.65-1.13	1.0-3.5	.73-1.14	.98-1.20	20-40	Variable
Na/K	11-26	22-92	140-170	9-40	63-83	Variable
Cl/K	11-28	12-45	80-180	8-40	1.5-3.0	Variable
$\frac{Br \times 1000}{Cl}$	6-16	10-60	5-9	18	12-70	Variable
Ca/Mg	.6-2.8 Variable	1.0-3.1	2.2-2.7	1.1-1.5	Variable	Variable

free CO_2 discharges of apparent thermal origin is a very strong coincidence. While deep circulation of normal ground water along the faults would seem to be indicated, we must wonder whether or not an abnormally high geothermal gradient is also partially responsible for their anomalous discharge temperatures.

9.2.2 Surface Water Control Wells

A group of four wells tapping normal surficial groundwater was selected as a control group in the immediate vicinity of Saratoga Springs. Two of these are driven into the Beekmantown Formation west of the city (Pompa and Y. K. Greene) while the other two (Bloodgood and the Saratoga Veterinary Hospital) are located in the overlying shales east and north of Saratoga Springs.

Plate 2 shows these waters to subgroup according to lithology with wells in carbonate rocks having higher HCO_3, Cl, Ca, and Mg concentrations than non-carbonate rock wells. The molar ratios of Table 4 also show a distinct separation of these waters from the other groups which can be used as a basis for interpretation. The only anomaly in the group appears to be the Pompa well which has a relatively high concentration of NaCl. Since this well is situated within 50 feet of a major east-west fault it seems likely that it contains a small component of saline water which may have been transmitted several miles along this conduit.

9.2.3 Southern "Brine" Group

The southern brine group includes 6-7 wells (spring and fall), 4 of which may be examples of diluted, yet chemically characteristic basinal brines. As such, they are very important since they provide some means of gauging the proportions of elements added to the Saratoga-type waters by carbonic acid leaching and thermal effects. The exceptions in this group are: the Figliomeni well, a neutralized high-bicarbonate water; the Pattersonville well, a complex mixed type with some Saratoga components, and the Congly occurrence which is situated in an area of known (unavailable for sampling) carbonated waters and which may also have mixed components--notably K+.

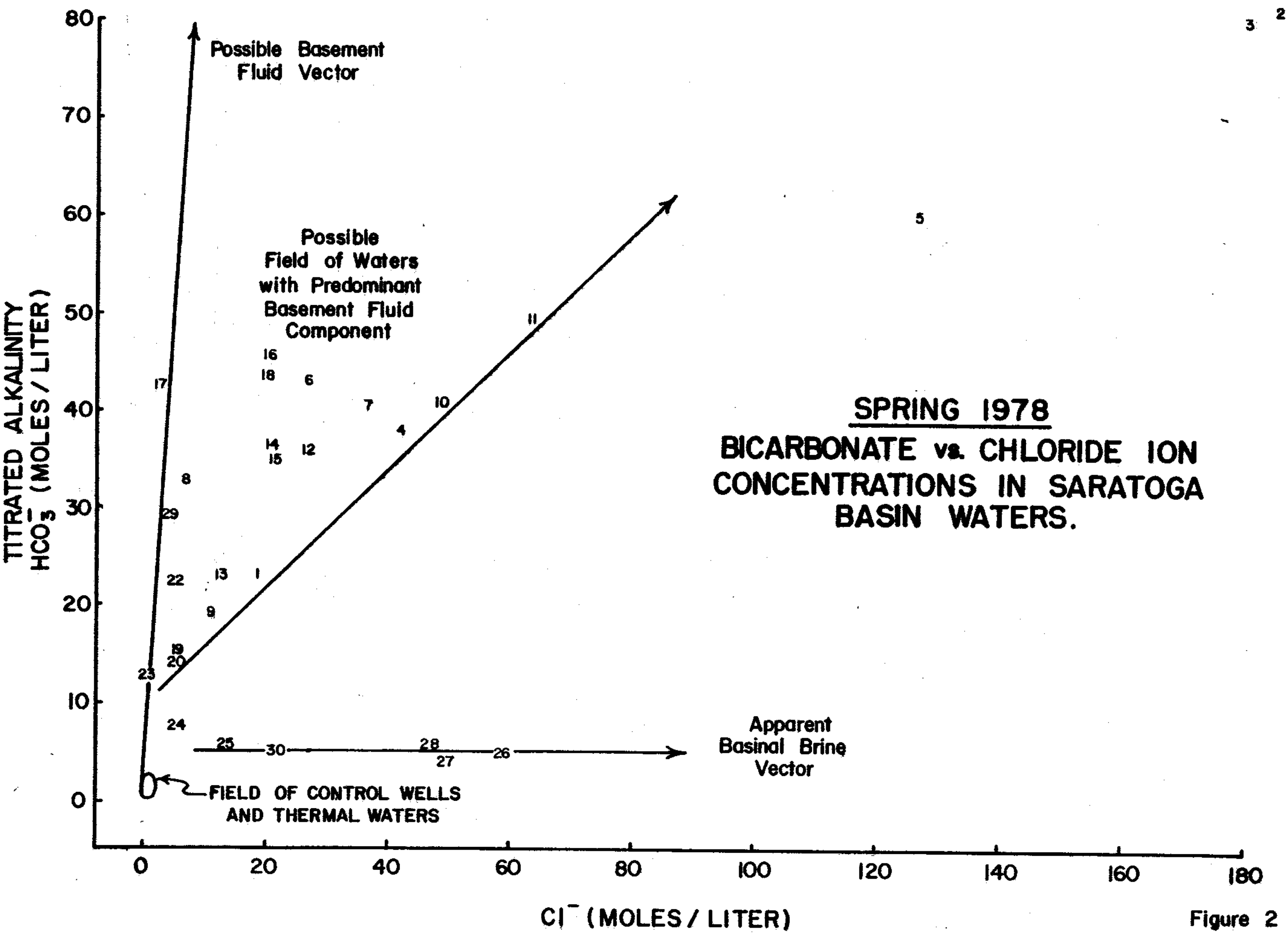
The chemical parameters of the remaining four wells show some significant patterns as follows:

(1) High Cl-, Na+, Br-, I-, Sr++
(2) Low HCO_3-, K+, and SiO_2
(3) undetectable Zr
(4) distinctive groupings of the following molar ratios:

$$Na/Cl, \frac{Br \times 1,000}{Cl}, \; Na/K \text{ and } Cl/K$$

When compared with the chemistry of other basinal waters and brines in marine sedimentary basins (White, 1965), the waters of this group would appear to have very similar chemical patterns and may have a similar origin as well. The only essential difference between these waters and the true basinal brines is their very dilute nature, consequently they are referred to herein as saline waters.

Figure 2 best illustrates this distinction among water types. While the salinity of these wells peaks at about 5000 mg/l, a vector was drawn to indicate the expected composition trend without assuming this value of salinity to be an endpoint. In fact, evidence of higher salinities exists in the three most saline Saratoga wells (Hathorn #3, Orenda, and Bischoff) which appear to have a larger saline water component. Past analyses, too, indicate TDS values on the order of 20,000 ppm to be fairly common in the now defunct Ballston Spa wells suggesting that a "pristine" or original brine (corrected for HCO_3, etc.) may have been of 1% or more total salinity. For now, however,



SPRING 1978

BICARBONATE vs. CHLORIDE ION CONCENTRATIONS IN SARATOGA BASIN WATERS.

Figure 2

the question of maximum salinities of a basinal brine component must remain an open question, and the length of the vector in Fig. 2 carries no implication for this.

9.2.4 Saratoga Springs Group

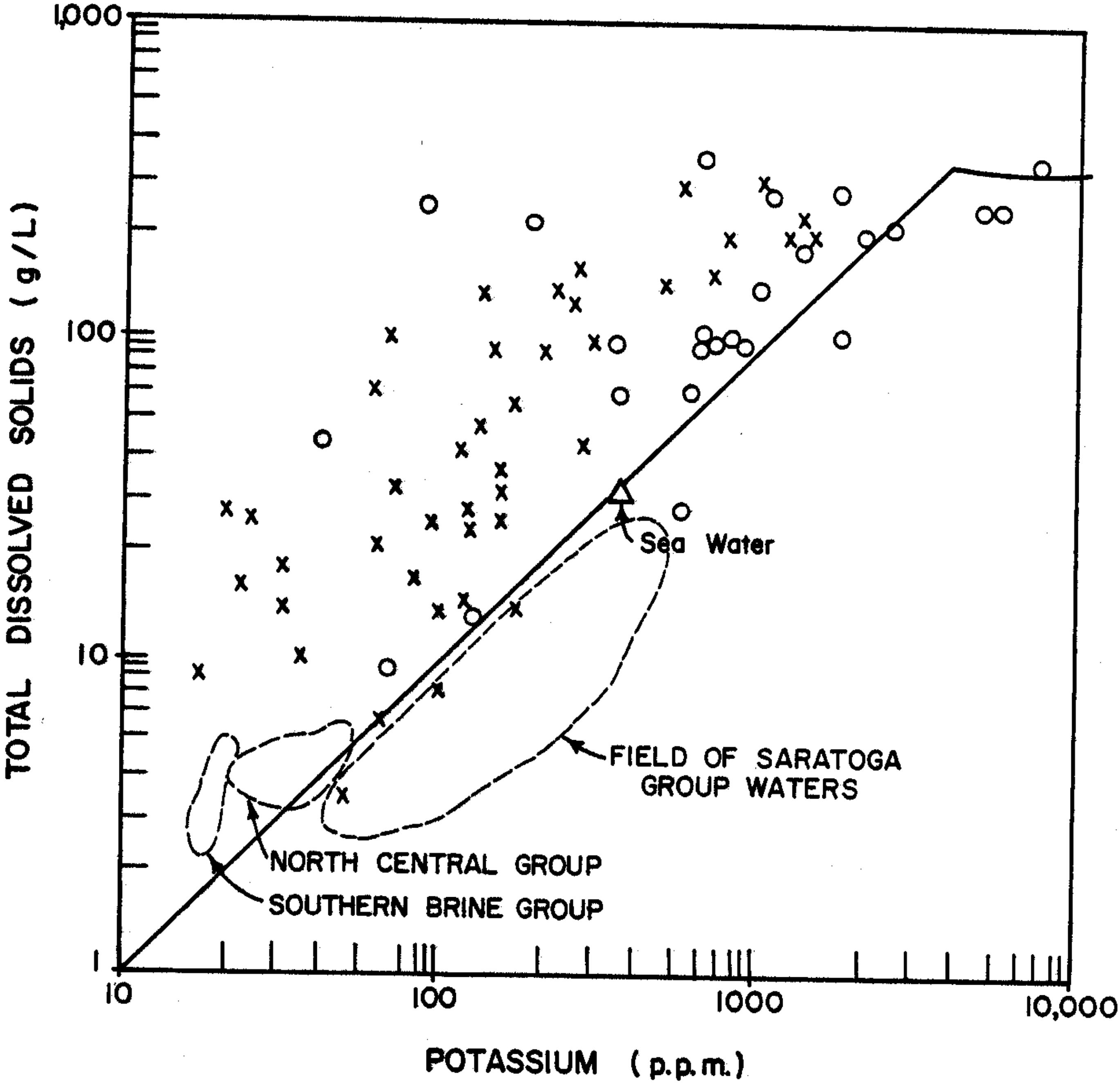
The wells of this group constitute representative examples of what is usually thought of as the famous carbonated "springs" of Saratoga. The vast majority of these are, however, driven wells that penetrate a thin shale cap into fracture zones in the water-bearing Gailor Dolostone of the Beekmantown Formation. Only in a few instances has the water had sufficient "force" to drive its way to the surface: at Gurn Spring, Reid's Mineral Spring, and the original (now inactive) High Rock Spring in Saratoga Springs. Most of the waters are tapped by drilling anywhere east of the Saratoga Fault, an extension of the major McGregor Fault which forms the Adirondack boundary to the northwest and north. This fault has trapped a vast reservoir of the carbonated waters from Ballston Spa to Saratoga Springs (Plate 1).

The sampled wells of this group were selected on the basis of availability, representative chemistry, and approximate equidistant spacing. Many wells were not sampled due to redundancy and the presence of earlier analyses, however, enough were selected to establish trends from previous results. These are arranged from south to north on Plate 2 (Old Iron through Gurn) and as numbers 1 - 14 on all tables in the appendix.

The primary and striking feature of these waters is, of course, the presence of large amounts of HCO_3^- and free CO_2. Field and laboratory alkalinity titrations were performed on these samples during the same day with close agreement. They show amounts of HCO_3^- up to nearly 5,000 ppm (Titrated Alkalinity of Table 3) present in two of the wells with a mode of approximately half this value. pH measurements vary from 5.5 to 6.5 at the wellhead, yet values less than this are probable in the reservoir since the pH rises rapidly with the exsolution of gaseous CO_2. Indeed, measurements were found to be several tenths of a pH point higher when made in a beaker at the wellhead less than a minute after collection than when the probe was held directly in the discharge. While all pH measurements were made in this second fashion, the variation makes values of $\leqslant 5.0$ in the reservoir seem reasonable.

Perhaps the second major feature of this group of waters is their obvious saline nature, NaCl or common salt being the primary constituent of most wells. If the uncarbonated saline waters can be considered representative of diluted basinal brines, their molar $^{Na}/Cl$ ratios fall in the range .70 to unity (Table 1 and Tables 2S and 2F, appendix). This tendency toward Cl-enrichment beyond stoichiometric NaCl is characteristic of most basinal brines and is seen here in the more saline wells of the Saratoga group. Tables 2S and 2F show, however, that there is general trend toward relative Na-enrichment from south to north within this group which correlates with a general decrease of total dissolved solids. This is particularly apparent in the anomalous Rosemary well which is truly a sodium bicarbonate water.

As can be seen in Figure 3 and Table 1 the relative amounts of potassium contained in the Saratoga group waters is distinctly higher than that of other North American basinal brines or ordinary sea water. While most brines of younger basins contain far higher total dissolved solids (from 200,000 to 300,000 ppm or more) some, such as the Illinois Basin, contain less (from 5,000 to 8,000 ppm). In all cases the relative abundance of potassium is less than that of seawater--except for Saratoga-type waters. In fact, the discrepancy for the Saratoga group waters is even larger than illustrated, since the total dissolved



POTASSIUM CONTENTS vs. TOTAL DISSOLVED SOLIDS IN OIL FIELD BRINES AND SARATOGA WATERS

OIL FIELD WATERS FROM SANDSTONE (o) & CARBONATE (x) RESERVOIRS

from Rittenhouse, G. et al. 1968

Figure 3

solids in Saratoga waters includes appreciable amounts of bicarbonates not found in other basinal brines.

The last two major elements, calcium and magnesium, may play a very important role in data interpretation. For the most part these elements can be considered to be derived by active carbonic acid leaching of the limestones and dolomites of the Paleozoic aquifer. As such, substantial differences among samples may reflect two sets of conditions:

(1) local variations in the chemical composition of the enclosing aquifer rocks, and

(2) transit time in the aquifer--providing that it be of short duration relative to the rate of rock dissolution.

Table 2 shows intriguing large scale variations in the Ca/Mg ratios from the spring sampling. While ratios from wells of the southern brine group show fairly uniform values from 2.2 to 2.7 (with the exception of Auguste Bohl - 1.09) the wells of the Saratoga group vary from .57 (Big Red) to 2.76 (Lincoln #12). Some variation may be expected due to analytical error and lithologic differences, yet the outcropping dolomites west of the Saratoga Fault are relatively homogeneous while these wells are concentrated in a relatively small area. Some apparent correlations with low Ca/Mg ratios are: (1) deep wells penetrating into the Theresa Formation (approximately 50% orthoquartzite) - Hathorn #3; (2) high yield wells along obvious linears--Orenda and Geyser; (3) $NaHCO_3$ waters with attendant high $\frac{Br \times 1000}{Cl}$ ratios indicating a dominant basement fluid component - Rosemary; (4) high SiO_2 values - Big Red, Rosemary, Geyser.

Table 2F of the fall results shows far less variation among the ratios with overall lower values normatively falling between 1.5 to 2.0. This general tendency may be related to the lower water table, however, this point is not clear at this time. The only distinctly anomalous

$^{Ca}/_{Mg}$ ratios (<1) in this set appear to be the Rosemary and Big Red wells which may be related to the sodium bicarbonate and high silica (metastable at these temperatures), respectively.

Considered as a group these correlations may indicate proximity to "feed" zones or sources for the CO_2 and basement fluids. Radionuclide data, as well as studies of possible isotope patterns and variations in pH are needed, however, in order to bear out this supposition.

Of the diverse suite of trace constituents present in this group of waters Br, I, Sr, Ba, and Li are considered important because they are usually characteristic of basinal brines: While some proportions of these components may be postulated to be derived by carbonic acid leaching of the Paleozoic carbonate aquifer and the underlying basement complex, the relatively high values of these elements varying in concert with the total dissolved solids must be considered good evidence of the presence of a saline basinal water component in this group of waters. Further testimonial to this is provided by the correspondence of element contents in relation to TDS value when compared to those found in the southern brine group.

Among the trace elements, zirconium contents appear to be very high. Analyses of over 2,800 samples of oil field brines provide a reliable data base which indicates normal Zr contents of about 10 ppb in basinal brines. Both sets of analytical results show zirconium to be sporadically distributed in distinctly anomalous amounts approaching 400 ppb. Normally, this could be considered a clear indication of reactions at elevated temperatures since the mineral zircon (the primary source of zirconium) is extremely stable at temperatures of less than 200°C. Unfortunately, this must be considered equivocal information in the case of Saratoga since information is lacking about the efficiency of carbonic acid leaching of zirconium and its transport in aqueous CO_2-bearing systems. Moreover, its presence in the north-central group where a cooler subsurface temperature is possible could indicate that leaching is the preferred mechanism. For now, this too will have to remain an open question.

Silica (as SiO_2) is present in distinctly anomalous amounts only in the Saratoga group of waters. Since we consider this to be perhaps the clearest indication of a subsurface thermal system it will be discussed separately under geothermometry.

9.2.5 North Central Carbonated Waters

This group includes five wells and springs located east and north of the City of Saratoga Springs as shown on Plate 1. In the principal aspect of carbonation these wells are similar to the Saratoga group, but in most other respects they are quite different.

The essential characteristics of this group are perhsps best shown by the molar ratios in Table 4 of the appendix and the water group summary. Na/Cl ratios indicate that most of these waters are sodium bicarbonate in nature like the Rosemary of the Saratoga group. Sodium is present in great excess in the Martin well just as Cl and Ca are depleted. This pattern is supported by the $\frac{\text{Br} \times 1,000}{\text{Cl}}$ ratios which indicate a relative depletion of Cl levels from the southern brine and Saratoga groups.

The major chemistry of this fluid would seem to be essentially $HCO_3 > Na > Cl > K$ in nature on the basis of the data for the wells of this group (Plates 2 and 3). This pattern may result from the addition of a Na-rich basement fluid component to the aquifer.

Although uneven but progressive dilution of the saline waters could also be used to explain the relative sodium enrichment, the correlation of low Ca/Mg and Cl/K ratios in the Martin and Rosemary wells suggest that this is not the case. Oxygen and carbon isotope information from the Martin well also reinforces this interpretation.

Another interesting aspect of this group is the relatively low SiO_2 content in conjunction with intermediate proportions of K. Both of these parameters would seem to indicate low subsurface temperatures ($< 50^{\circ}C$) for this group of wells. It is also possible to infer from these relationships that in these waters K^+ may partially be a product of carbonic acid leaching of K-feldspar in the basement or Paleozoic rocks. Therefore K^+ or $\ln(\frac{Na}{K})$ cannot be used alone as an indicator of subsurface temperatures.

9.2.6 Sulfate Waters and Middletown Springs

Four spatially unrelated locations (Vita Spring, Davis, Pitcher, and Sharon Springs) exhibit relatively high sulfate contents (> 1,000 mg/l) in the water and have, therefore, been grouped together. These represent mixed water types with variable "brine", carbonation (Vita Spring, Davis) and a large component of shale water. Apart from sulfate content these waters have little in common and their molar proportions and ratios should be used only tentatively in comparing analyses with other waters.

Middletown Springs also seems to be a misfit. It was placed between the two groups of carbonated waters in the spring analyses because of its northern location and anomalous HCO_3^- content. The presence of the latter was not borne out by the fall sampling and it has, therefore, been shifted to the surface water control group.

9.2.7 Vichy, France

Through a fortuitous set of circumstances, it was possible for our project geologist to visit Vichy, France, during a trip to Europe concerning other affairs. This was thought to be relevant because Vichy poseessed naturally carbonated springs that seemed at least as strong as Saratoga from the available literature. Its deliberate namesake, Saratoga Vichy, and the thermal nature of the springs in a large graben near the Massif Central, an area of Quaternary vulcanism, also contributed to this decision.

From the data in Plate 3 it can be seen that the two springs sampled at Vichy bear a striking chemical similarity to the postulated basement fluid component at Saratoga as represented by the north-central group (particularly the Martin well) and the Rosemary well. They are, in essence, sodium bicarbonate waters of higher surface discharge temperature than Saratoga without the reaction products added from the leaching of a carbonate rock (Ca^{++}, Mg^{++}, etc.).

One of these springs, Hôpital is clearly thermal (34°C) while the other appears to mix with a larger, cold component of surface water, discharging at a temperature of 19°C. Silica values are similar, however, and in both cases indicate subsurface temperatures less than those of the Saratoga system--apparently without dilution from a saline basinal water component.

9.2.8 Seasonal Fluctuations

While minor variations exist between some of the wells from spring to fall, three major patterns seem to be noteworthy and, to some extent, interrelated.

An inspection of Plates 2 and 3 will show that many of the pH values for the carbonated wells are substantially lower in the fall while many of the alkalinities are higher. Since these parameters are a function of the amount of CO_2 present, there is clearly an increase of gas indicated during the fall when the local water table is substantially lower. The increase, then, may be apparent and attributable to a smaller component of local meteoric water increasing the proportion of gas present.

The same mechanism is probably responsible for the large increase in silica noted in the fall in the deep wells. If the increased CO_2 can be interpreted to mean that a proportionally larger component of basement fluid is present, the rise in silica can most reasonably be attributed to the same source.

10.0 GEOTHERMOMETRY

Several chemical thermometers have been used as a means of predicting the prior existence of thermal effects in waters which are now ambient. These thermometers depend upon a difference in solubility of various minerals in contact with the water as a function of temperature. Although the solubility pattern developed at a higher temperature tends to be removed by re-equilibration at lower temperatures, the rate of change may be slow enough that an estimation of former temperatures is possible. The distribution of the relict pattern may also serve as an exploration guide in some cases. The Na-K-Ca chemical thermometer may not be applicable in systems with carbonic acid, but another based on dissolved silica (SiO_2) can be compared with the water analysis data of this report. A third method based on isotopes of oxygen can also be used with reliability to indicate the qualitatively temperatures at which CO_2 gas has been formed.

10.1 Alkali Geothermometer

The impetus for the present study was largely initiated by the CO_2 problem posed by the Saratoga waters and the high subsurface temperatures derived by applying the alkali geothermometer to existing data (Fournier and Truesdell, 1972). It is now apparent, however, that in the case of Saratoga type waters the values indicated by the alkali thermometer are likely to be misleading for three reasons:

(1) the presence of a saline basinal water component which tends to give high $^{Na}/K$ ratios (enriched in Na) and, therefore, lower temperatures;

(2) the high probability that most of the Ca^{++} and Mg^{++} component was added by low-temperature carbonic acid leaching in the carbonate aquifer;

(3) the possibility that low-temperature carbonic acid leaching of Proterozoic and/or Paleozoic rocks could contribute spuriously high amounts of K^+ and/or Na^+.

At this juncture, it is our opinion that <u>all three</u> of these mechanisms are involved to a varying extent in each water sample. Nevertheless, it may be possible to account for the first two effects among waters by the use of discriminate analysis. If so, a derivative of the geothermometer, ln $(\frac{Na}{K})$, may be of some use provided the effects of basement leaching can be assessed through some other means of estimating subsurface temperatures.

Perhaps the best way to perceive this problem is to consider the Rosemary and Martin wells as the best examples of essentially basement fluids mixed with a meteoric component. Certainly there is very little of an indigenous saline water component in these waters as is indicated by their similarity, low Ca/Mg ratios, high HCO_3/Cl ratios and isotope data for the Martin well. If this is the case, it is interesting to note that the Rosemary yields the lowest log K value or highest alkali thermometer result for all the wells — over 300°C. This seems consistent with a thermal interpretation, however, Table 3 shows anomalous alkali thermometer results for all of the high TDS wells, even the uncarbonated ones, as discussed above.

The best that can be said of the alkali thermometer at this time is that it reflects the pattern of subsurface heating inferred from the other data (i.e., SiO_2). In this respect it seems qualitatively accurate, however, it cannot be relied upon quantitatively.

10.2 Silica Geothermometer

The quantitative silica geothermometer is based on the solubility of quartz in water and has been widely used for over 10 years as the most generally reliable method of estimating subsurface temperatures in hot springs systems. Recent work by Swanberg and others has also shown a linear correlation of dissolved silica content in non-thermal waters with observed heat flow measurements throughout a large portion of the continental United States. In the first case, the mineral quartz dominates dissolved silica contents which may be used to quantitatively estimate subsurface reservoir temperatures. In the second case, several other silica species (chalcedony, cristobalite, or amorphous silica) may control dissolved silica (Fournier, 1975).

The equation relating the solubility, C, in mg SiO_2/liter water to temperature in the range of 0-250° C for the pure silica mineral quartz is as follows:

$$t^{o}C = \frac{1309}{5.19 - \log C} - 273.15$$

Insertion of the highest dissolved silica content into this equation (70 ppm from the Big Red Well) produces a value of 119° C as the last temperature of equilibration in the last subsurface reservoir. This value is most likely to be a minimum because: (1) dilution obviously occurs, and (2) dissolved silica of this quantity at ambient temperatures is distinctly metastable and may precipitate out of solution fairly rapidly.

A second question which should be posed, however, is whether or not quartz is the controlling phase of the contained silica species.

To this there can be no definite answer at this junction, however, several facts suggest that either quartz or chalcedony are controlling the dissolved silica contents. The best evidence of this is contained in the regional pattern of silica values in the meteoric waters, saline waters, and other carbonated waters. All of these exhibit low silica contents consistent with regional values, low subsurface temperatures, and controlling quartz phase. Should chalcedony by the dominant species, its equation of

$$t^{o}c = \frac{1032}{4.69 - \log C} - 273.15$$

yields a subsurface temperature of 89° C.

Accounting for this possibility and the fact that the quartz geothermometer does not appear to be as accurate below reservoir equilibration temperatures of 150° C (Fournier, 1975), it seems prudent to suggest that the subsurface temperature range indicated at this time is from approximately 90° C to 120° C.

Granting this temperature range to be accurate, two general reservoir models can be considered, viz:

(1) the waters are heated anomalously, but slightly, in the subsurface aquifer, possibly in the vicinity of the discharge;

(2) a small component of deep superheated water or deep superheated fluid ($CO_2 + H_2O$) imperfectly mixes with a larger, cold upper component of diluted basinal brines and/or meteoric water.

Should the first case be true and the heating be taking place in the aquifer, it is difficult to understand the sharp areal pattern(s) in the distribution of the higher silica values.

Relatively shallow heating of a single phase fluid to the degree directly indicated by the quantities of the SiO_2 (90° to 120° C) should produce more uniformity among the wells, not disparity. Most of the wells of the Saratoga group are located in a rather small area where distances < 300 m often separate chemically distinct wells (e.g., Rosemary and Lincoln) and/or wells with high and low silica values (e.g., Red and Peerless). Another fact to consider is that the saline water component has uniformly low silica values (10 - 15 mg/l SiO_2). This also argues strongly for the addition of SiO_2 by basement fluids and against a generalized low temperature heating in the aquifer toward the center of the basin.

We believe the second possibility to be the preferred choice in this instance. Considered in conjunction with the large amounts of free CO_2, and an association with excess Na^+ and K^+ relative to Cl^-, atypical of basinal brines; the SiO_2 values (to 70 mg/l) strongly argue for a zone of superheated fluid interaction in the basement. This is particularly true when the degree of mixing with dilute basinal brines and meteoric water (dilution of the original basinal brines with meteoric water may be a continuing process independent of carbonation) under Saratoga is taken into account. The data shows, for instance, that the Big Red well water with 70 mg/l SiO_2 also has a large saline water component. Taking only this factor into consideration, an amount of SiO_2 of at least 100 mg/l in the postulated basement fluid prior to dilution with basinal waters seems reasonable—possibly low.

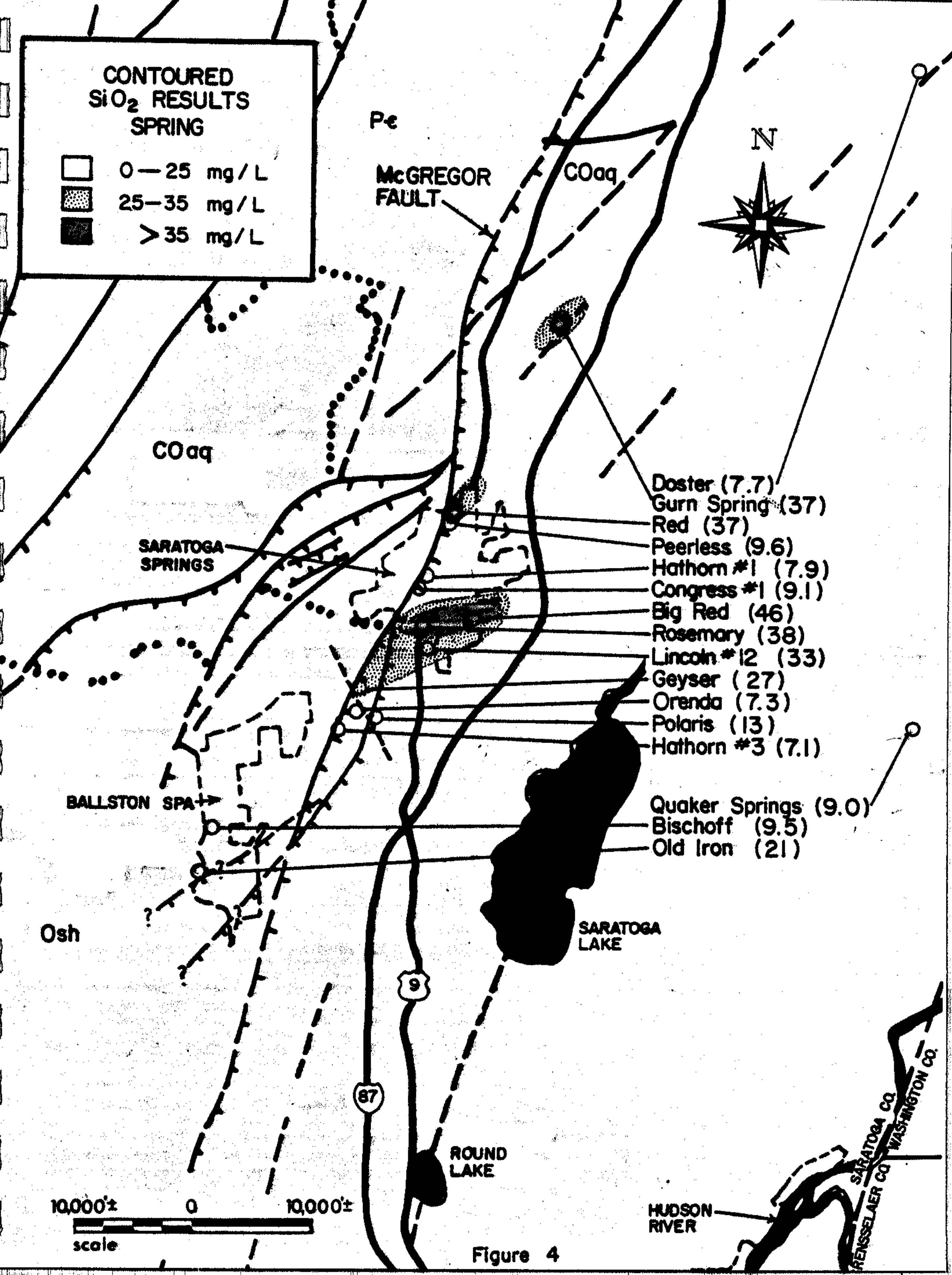

CONTOURED
SiO₂ RESULTS
SPRING
☐ 0—25 mg/L
▨ 25—35 mg/L
■ >35 mg/L
P€
McGREGOR FAULT
COaq
N
COaq
Doster (7.7)
Gurn Spring (37)
Red (37)
Peerless (9.6)
Hathorn #1 (7.9)
Congress #1 (9.1)
Big Red (46)
Rosemary (38)
Lincoln #12 (33)
Geyser (27)
Orenda (7.3)
Polaris (13)
Hathorn #3 (7.1)
SARATOGA SPRINGS
BALLSTON SPA
Quaker Springs (9.0)
Bischoff (9.5)
Old Iron (21)
Osh
SARATOGA LAKE
9
87
ROUND LAKE
SARATOGA CO.
WASHINGTON CO.
RENSSELAER CO.
HUDSON RIVER
10,000'± 0 10,000'±
scale

Figure 4

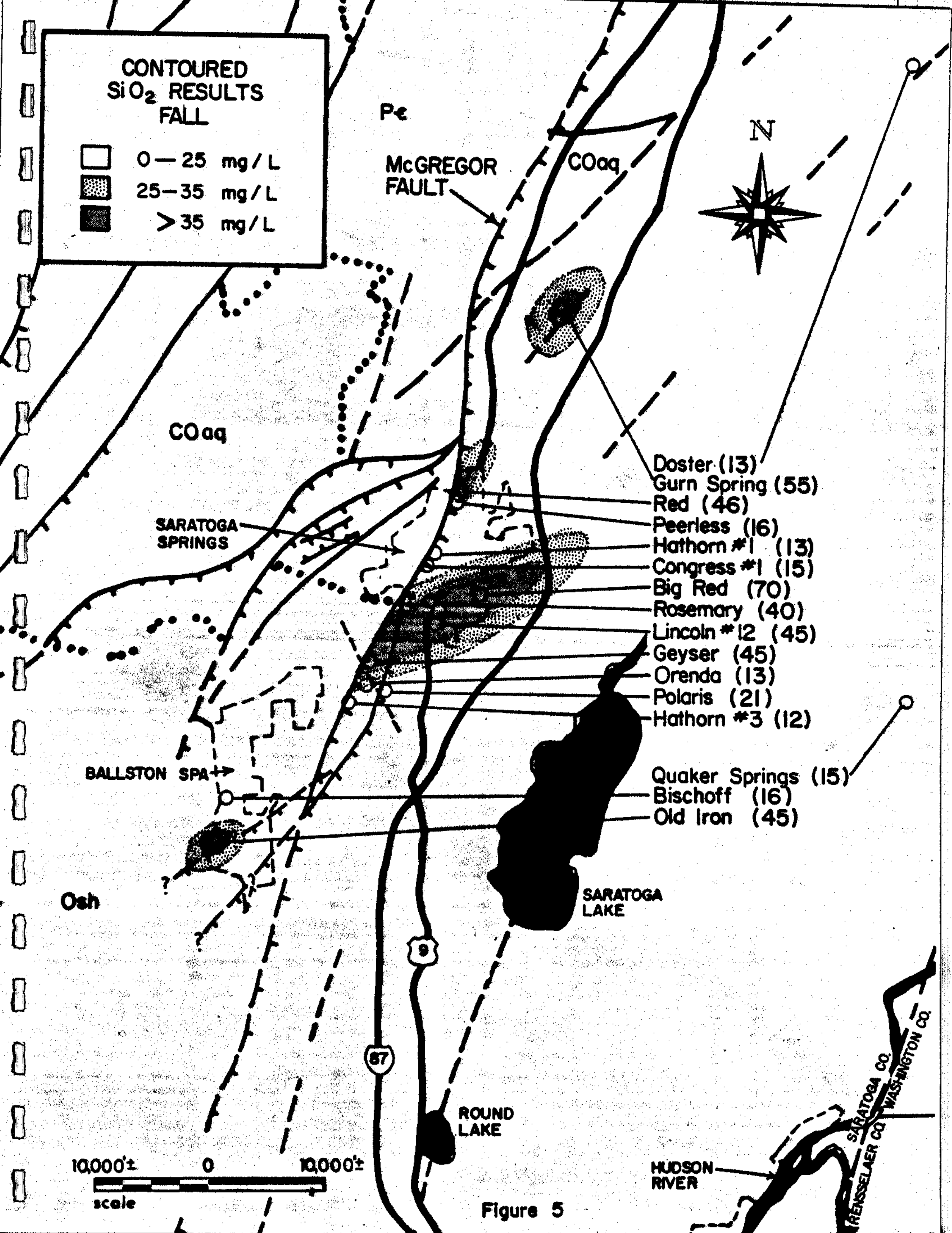

CONTOURED
SiO2 RESULTS
FALL
0 — 25 mg/L
25—35 mg/L
>35 mg/L
Pє
McGREGOR
FAULT
COaq
N
COaq
SARATOGA
SPRINGS
Doster (13)
Gurn Spring (55)
Red (46)
Peerless (16)
Hathorn #1 (13)
Congress #1 (15)
Big Red (70)
Rosemary (40)
Lincoln #12 (45)
Geyser (45)
Orenda (13)
Polaris (21)
Hathorn #3 (12)
Quaker Springs (15)
Bischoff (16)
Old Iron (45)
BALLSTON SPA
Osh
?
?
SARATOGA
LAKE
9
87
ROUND
LAKE
HUDSON
RIVER
SARATOGA CO.
WASHINGTON CO.
RENSSELAER CO.
10,000'±
0
10,000'±
scale

Figure 5

The SiO_2 results from the spring and fall sampling have been contoured in figures 4 and 5 along numerical guidelines suggested by recent work in New Mexico (Swanberg, 1979). They indicate several sets of anomalies extending approximately ten miles along the McGregor fault system. The central anomaly may be the most interesting of the group because of: (1) its larger size; and (2) the increasing silica values from west to east.

This last datum encourages the interpretation that the primary zone of fluid superheating may lie eastward under the thicker shale cover. The spatial position of the anomalies, however, should be considered only qualitatively indicative of the location of a zone of heating—not as direct pathfinders. This is due to the fault-controlled nature of the water pathways and the limited number of sampling points.

10.3 Stable Isotopes and Their Bearing on CO_2 Derivation

The results of standard isotope ratio analyses of hydrogen, oxygen, and carbon in several samples are listed below:

Sample	δD	$\delta^{18}O$	$\delta^{13}C$ in - Carbonate ppt.	$\delta^{13}C$ in - CO_2 gas
Hathorn #3	-64.2	- 9.22	+ .57	-5.03
Orenda	-63.6	-10.39	+ .60	-5.15
Big Red	-65.9	-10.36	-3.92	-6.84
Bennett Well	-79.0	-12.10	-4.35	-7.55
Martin Well	-90.4	-13.26	-4.91	ND

Where

δ = isotope fractionation ratio in <u>sample</u>; expressed in parts per thousand (per mil) difference relation to the standard

D = deuterium isotope of hydrogen

^{18}O = oxygen isotope mass 18

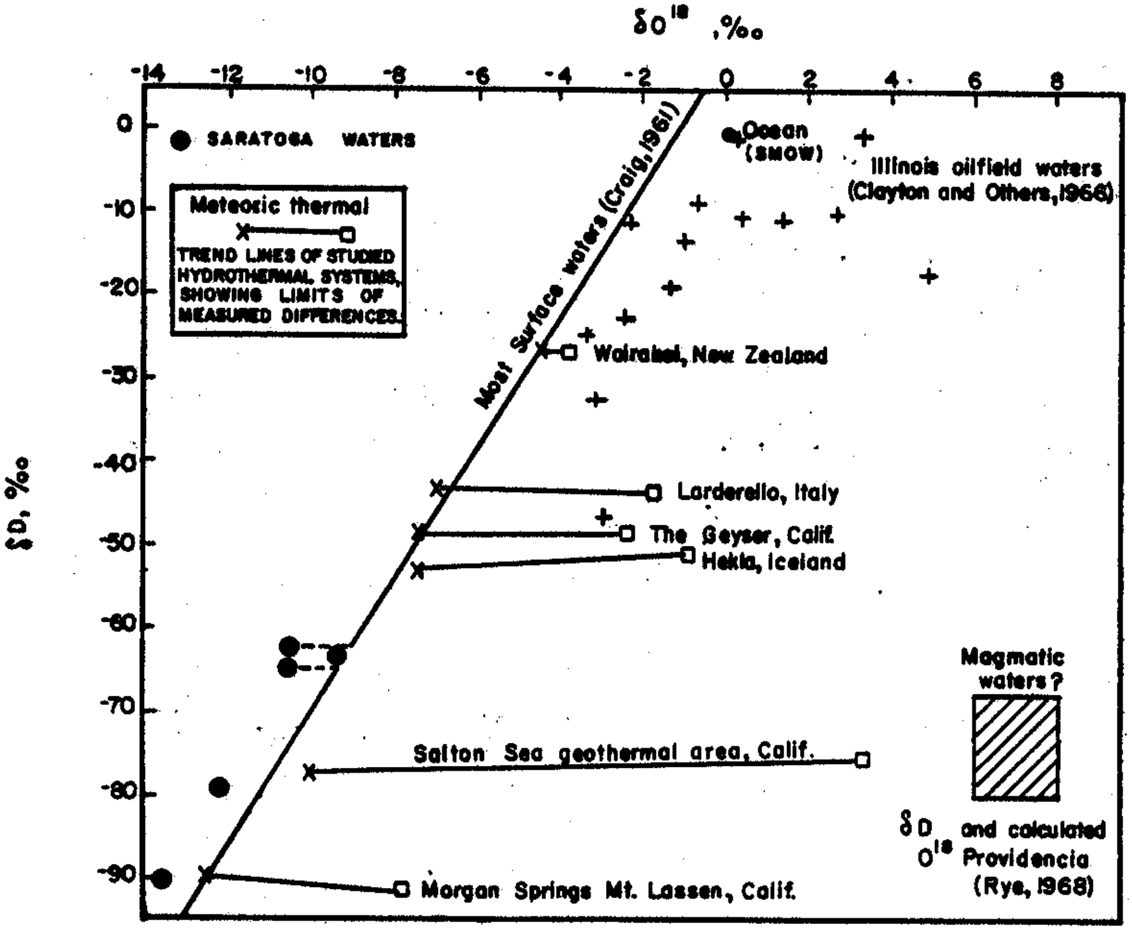
^{13}C = carbon isotope mass 13

These analyses were made in the isotope geochemistry laboratory of the U.S. Geological Survey, Menlo Park, California, under the supervision of V.R. O'Neil and I. Barnes.

Several significant implications emerge from this data; i.e.,

(1) water in the Saratoga system appears to be of meteoric origin (current water is $D = 8 \delta^{18}O + 10$) but some wells on the east side of the basin (represented by Bennett and Martin) have δD and $\delta^{18}O$ values too low for current precipitation. These latter values are consistent with subartic water and suggest a retention of ice age water in parts of the Paleozoic aquifer.

(2) The characteristics of the brine component of Saratoga waters imply a connate or formation water source, and not a derivation from unmodified sea water or solution of evaporites. Most connate brines and saline oil field waters, even at total salinities comparable to Saratoga ($<10,000$ TDS), however, are characterized



Isotropic trends of Saratoga and other thermal and mineral waters (modified after White, Barnes and O'Neal, 1973).

by relatively high δD and commonly appreciably higher $\delta^{18}O$ values as a result of isotopic exchange with the host rocks. Mixtures of these brines with meteoric water (new or old) could produce the δD values observed in Saratoga waters (although more variation relative to salinity would be expected), but larger (less negative) $\delta^{18}O$ values would result. Exactly this effect has been observed in other thermal and mineral waters (e.g. coast ranges of western North America), which are enriched in $\delta^{18}O$ relative to the standard meteoric water line. Small volumes of a very highly saline brine (~30-40% salinity) added to meteoric water might account for the observed isotope and chemical data, but is problematical as a fluid (with CO_2) derived from the Precambrian basement rocks.

(3) An oxygen isotope "shift" (- .8 up to -1 per mil) was found in the water of four of the five analyzed samples; i.e., $\delta^{18}O$ values relative to δD which are depleted (more negative) than meteoric water itself, and opposite to the effects of mixing with non-meteoric waters (connate brines) as noted above. This type of oxygen isotope shift has been predicted for carbon dioxide-water systems, but until now has not actually been observed. The significance of the shift lies in the implication of prior higher temperatures for the CO_2 (or CO_2+ water); upon cooling ^{18}O is strongly fractionated into the aqueous CO_2 phase thus depleting the water in this isotope.

If a maximum fractionation effect is assumed, isotopic mass balance relations would require a minimum of 9-10 gms. of CO_2 in equilibration per liter of water to produce the observed shift*. This is not unreasonable as roughly half this amount or more is present as dissolved gas (aqueous CO_2) in the more carbonated waters, but some net flux of CO_2 through the system (dynamic carbonation) seems indicated. This mechanism might account for the lack of higher $\delta^{18}O$ values typical of connate waters referred to in point (2), but at present this is uncertain and more reliable analyses are needed.

(4) Carbon isotope data are not conclusive as to the source of carbon dioxide, but do limit the possibilities. Interpretations are complicated by the fact that some dissolved carbon (as bicarbonate) is derived by solution of shallow crustal carbonate wall rocks; dissolved CO_2 gas exists as aqueous CO_2, carbonic acid, and bicarbonate ions by ionization; and small amounts of dissolved methane may also be present.

Isotope exchange occurs among all these carbon species, so that the actual analyses reflect the fractionation effects at ambient temperature (as between aqueous CO_2 and HCO_3^- ion) as well as a blend of carbon from different sources. The reported $\delta^{13}C$ values are for precipitated carbonate (representing bicarbonate in solution) and for CO_2 as free gas in the well or spring discharge.

The difference in $\delta^{13}C$ values for a given sample are due to CO_2 gas - HCO_3^- ion fractionation at the ambient temperature; a $\delta^{13}C$ value for total carbon can be estimated by combining the values in proportion to the respective masses present, but is approximate because of dependence upon CO_2 flux. Total carbon $\delta^{13}C$ values of a few per mil negative are indicated for Saratoga waters; a few

---

*The oxygen isotope composition of dissolved carbonate and possible exchange between the waters and shallow wall rocks introduce additional uncertainty in this estimate, but do not negate the basic principle.

available $\delta^{13}C$ values (other laboratories) indicate 0 to -1 per mil for Beekmantown carbonates, +1 to +2 for basement marbles and -2 for graphite in the marbles. CO_2 of igneous or deep crustal origin generally has values in the -4 to -8 per mil range, whereas that derived by decarboxylation or oxidation of organic matter is commonly much more depleted (large negative values -15 to -25 per mil).

The carbon isotope data of Saratoga is consistent with a mixture of "deep" CO_2 and carbon from the known surficial rocks, but not critical as to the latter. The data do suggest, however, that little carbon dioxide derived from organic carbon is involved. Small amounts of methane in analyses of the free gas phase from a few wells may be derived from organic matter in the shales, but the reduced nature of the waters, mass proportions of gases, and the carbon isotope ratios argue persuasively against oxidation of organic carbon as a source of CO_2 at Saratoga.

In summary, both the standard chemical analyses and the isotope data suggest a thermal process in the generation of carbon dioxide, a net flux of carbon dioxide through the system, and shallow level reaction (dissolution) with carbonate wall rocks.

10.4 Gas Analyses

Six gas analyses were performed concurrently with the isotope analyses by Dr. Barnes. The results are tabulated below:

	Hathorn #3	Orenda	Big Red	Bennet	Martin
He	<0.01	<0.01	<0.01	0.05	0.27
H_2	<0.01	<0.01	<0.01	<0.01	<0.01
Ar	<0.02	<0.02	0.04	0.09	0.57
O_2	0.02	0.37	0.18	0.02	0.06
N_2	0.14	1.37	1.80	4.06	45.25
CH_4	0.50	0.42	2.26	6.30	13.39
CO_2	99.08	97.52	95.77	89.64	40.73
C_2H_6	<0.01	<0.01	<0.01	0.01	0.01
	99.74	99.68	100.05	100.17	100.28

These analyses show several interesting trends, chief among them that the dominant gas is, not unexpectedly, CO_2. This is particularly true for the three Saratoga group wells, which top 95% CO_2 in all cases; the bulk of the remainder due primarily to methane and nitrogen.

The large relative increase of the methane, nitrogen, and argon components in the Martin and Bennet wells which are driven into shales can most easily be ascribed to these rocks; the methane, in particular. The large nitrogen component may be derived from atmospheric air trapped in meteoric shale water. The O_2 could have been used up by reaction with sulfides which are ubiquitous in shales, but the non-reactive argon simply varies with the nitrogen.

Thermal waters also commonly contain large excesses of radiogenic helium and argon which may be used as tracers in mixtures of deep heated thermal waters with near surface ground water (Mazor, 1977). Unfortunately, the detection of radiogenic argon is complicated by the relatively large amounts of atmospheric argon-40 often dissolved in the water. This appears to be the case in the Martin and Bennet wells which may contain excess argon; but not to an extent visible through the atmospheric veil.

The analyses indicate an enrichment of He over that in the atmosphere by a factor of approximately 10^4 in the Bennet well and 10^3 in the Martin well—values far beyond possible analytical error. The source of the helium is not known. Possibly it might be related to some deep heat source or it may be the result of radioactive decay of elements in the shales.

10.5 Radium ^{226}

The Saratoga waters have been known to contain anomalous amounts of radium since the early 1920's, only a few years after radioactivity was discovered. Unusual waters at resorts and spas were analyzed for their radium content at this time and until the 1960's, constituted the vast majority of data available on the radioactivity of natural waters. Not until then were systematic radioactive measurements of groundwaters done because of public concern over contamination emanating from atomic pile waste. Public health guidelines delineating preferred limits for Radium ^{226} in public water supplies were established then and are slowly being refined.

Three sets of analyses of Radium ^{226} in the waters of the classic Saratoga Springs-Ballston Spa wells were performed as an outgrowth of this concern during the 1960's and early 1970's. This data was kindly supplied by the Radiological Division of Health Research, Inc., consequently, most of the wells of this area were not measured for Ra ^{226} content during this program. The remainder of them were analyzed, however, and the results appear in Table 7 of the appendix.

Examination of this table shows that both the north central group of carbonated waters and the uncarbonated southern brine group have similar Ra ^{226} concentrations of from 5 to 15 pci/l. Only the Saratoga group contains higher amounts in levels that approach 400 pci/l (Hathorn #3) yet may drop as low as 6-10 pci/l (Congress). Inspection also shows that the majority of the Ra ^{226} contents of this group of waters vary sympathetically with the brine component with one possibly significant exception -- the Big Red well.

Since the natural radioactivity of water is considered to be derived primarily from the radioactive rocks and minerals with which it has been in contact, the underlying rocks of this area would appear to be more uraniferous than in the remainder of the sampling area. At present, we may consider at least two mechanisms of transmission to the carbonated water from two possible source areas:

(1) Through the brine component which has reached equilibrium with the more uraniferous Paleozoic sediments present only in this area.

(2) Through the carbonated component which may be leaching uranium-bearing minerals localized in faults in the Precambrian basement under the city of Saratoga Springs.

The first hypothesis is supported by the following observations: (a) the variation of Ra ^{226} levels fluctuating in concert with the brine component in most of the waters; (b) the presence of a minor uranium province (pegmatitic) in the adjacent northwest Adirondacks, a possible source area for the Paleozoic sediments. The second is favored by: (a) the low levels of radium for the Big Red well, its apparently major brine component; and, (b) the slightly favorable evidence (Ca/Mg ratios and isotopic values) at this time for local entry points of the carbonated basement fluid into the aquifer near the City of Saratoga Springs.

Resolution of this problem carries with it major information, since the first hypothesis implies the presence of a closed circulation environment; one probably induced by a fault with a major component of vertical offset east of Saratoga Springs. Further, sampling and/or more direct geophysical information concerning basement structure should permit a distinction between these two mechanisms.

11.0 GEOTHERMAL MODELS

11.1 While additional geochemical data should permit considerable refinement of a model for the Saratoga system, several major characteristics and implications of these waters appear to be clear at this point:

First, the Saratoga group of waters in general represent a complexly mixed system with at least five major components. They are:

(1) normal surface ground waters of meteoric origin;

(2) basinal brines of low salinity, probably through progressive dilution with meteoric water, but which may ultimately be as old as the Paleozoic in respect to saline components: major chemistry $Cl > Na > HCO_3$;

(3) a gaseous phase consisting primarily of CO_2;

(4) a fluid (containing the dissolved CO_2) possibly analogous to a metamorphic water whose major chemistry appears to be $HCO_3 > Na > Cl$;

(5) constituents added by reactions between the carbonated waters and wall rocks of two types: the Proterozoic basement and the Paleozoic aquifer.

Second, several water types representing one or several of these components can be recognized, in particular, the north-central group of waters, is chemically distinct from the Saratoga group; the major differences being in SiO_2, K^+, and Cl^- contents, a lower TDS, and a generally greater excess of HCO_3^-. This group may represent a water with a relatively larger basement fluid component mixed with meteoric water and a minor component of saline basinal water.

Third, a recognition of a particular water "type" in the Saratoga system is not, in itself, an indication of anomalous subsurface temperatures. For example, the north-central group is inferred to be of lower subsurface temperature than the Saratoga group because of lower SiO_2 and K^+, and yet it has a greater relative excess of HCO_3^-, possibly reflecting more basement rock water reaction.

However, there may be a more direct connection of anomalous temperature indicators and "feed" zones for CO_2 or CO_2-charged fluids (i.e., a dynamic CO_2 flux) if these can be established or located.

11.2 Given that the CO_2 is of thermal origin there are only three possible sources for the gas in two general areas.

The possible sources are:

(1) direct degassing of an igneous melt or degassing at the earth's mantle (deep CO_2);

(2) decarbonization of carbonate rocks adjacent to an igneous intrusion; probably Proterozoic marbles in the underlying basement;

(3) decarbonization of carbonate-bearing rocks in contact with thermal fluids;

The possible areas where heating may occur are:

(1) the lower crust or upper mantle, and

(2) the upper Precambrian crust.

Should the gas be of deep crustal or mantle origin unusually deep, active faulting or fracture zones are required to form an "escape valve" for the gas. Recent observations on other carbonated waters with HCO_3^- + N^+ and variable Cl^- suggest that they may be metamorphic waters associated with major fault or active tectonic zones such as the San Andreas Fault of California (Irwin and Barnes, 1975). Carbon isotope determinations in the latter even suggest that the CO_2 may be of mantle origin, and thus P_{CO_2} approximates the lithostatic pressure from the base of the crust to the surface. Surface temperatures of these waters are variable, however, and in some cases a near normal geothermal gradient may prevail. If this process is applicable to Saratoga, then a thermal zone where heat exchange of waters with heated CO_2 takes place would be sought.

The second possibility, intrusions in the upper crust, could also account for the characteristics of the waters in virtually all particulars. In this case, it is possible that the forerunners of an igneous intrusion in the lower crust have penetrated up zones of weakness to generate CO_2 by decarbonization of Proterozoic marbles. Additional CO_2 (SiO_2) would presumably be generated by devolatilizing of the intrusions. If aqueous fluids are present at this point then heat exchange to produce a carbonated "metamorphic fluid" of local aspect could occur.

In either of these scenarios there exists the potential for a utilizable geothermal system, although, obviously, the potential is greater in the second case. Whichever model best fits Saratoga, the principle conduits of the resultant "metamorphic" waters or fluids are likely to be fault or major fracture zones in the basement rocks. These, therefore, seem to represent the most likely targets should an exploratory hole be drilled.

One more point should perhaps be mentioned again in this discussion. That is that the anomalous SiO_2 of the Saratoga group of waters gives us every reason to hope that a superheated fluid or heat exchange zone exists in the upper crust. While a shallow thermal zone could conceivably be retained from lower crustal "degassing" through unusually permeable fault zones, a larger mass flux in terms of heated water would seem more reasonable.

12.0 TECTONIC FRAMEWORK

Following the advent of the theory of sea-floor spreading by Vine and Matthews (1963) several insightful papers, particularly by J. Tuzo Wilson, rapidly established the concept of a dynamic ocean floor life cycle. Today the views that new oceans are created at sites of crustal rifting, grow outward from an upwelling mantle at accreting ridges and are consumed at subduction zones, are supported by many independent lines of evidence and accepted by the vast majority of geologists.

Present tectonic frontiers exist primarily in the areas of theory modification, unraveling past plate geometries, boundaries, and conditions as well as detailed studies of the contemporary framework. Most of the geometries and settings back to the Mesozoic Era are fairly well resolvable and documented at this point with room mostly for only minor embellishments at this time.

One of the early, obvious correlations to arise from the reconstruction of the present day plate mosaic, was the intimate association of volcanicity, seismicity, and geothermal resources with active plate boundaries. A closer breakdown shows at least as far as KGRA's (Known Geothermal Resource Area) are concerned, subduction zones and rifts account for most utilizable hyper-thermal systems. While being the loci for most connecting, high-temperature systems, accreting margins are ranked third primarily because of their largely inaccessible locations. Stable continental shield and platform areas are noticeably devoid of any recent igneous activity.

A more recent and equally striking tectonic correlation is provided by a compilation of global CO_2 discharges and zones of major seismicity (Barnes, Irwin, and White, 1978). Their map depicts a strong affinity of CO_2 discharges for active plate boundaries, ranking in number through subduction zones and rifts to transform faults. This naturally enhances the long-standing hypothesis that thermal processes are primarily responsible for CO_2 generation. Further, the coincidence of CO_2 discharges with major seismic areas suggest that CO_2 production is related to fundamental tectonic processes operating today.

In this context Saratoga is all the more anomalous. It is situated in an ancient mountain belt within a craton that has apparently been stable for at least 100 million years. Add to this the observation that the Saratoga system appears to be injecting into the Paleozoic aquifer at least five times the amount of thermally derived CO_2 usually associated with convective geothermal systems and a truly striking set of conditions is outlined. Unless a new or unusual process is operating here (i.e., calcining during carbonatite formation), circumstances would appear to dictate a closer examination of the regional tectonic framework. Or, in other words, it is not the CO_2 that is so unusual, it is its location that appears unusual.

In seeking an understandable mechanism, then, we turn to the growing body of knowledge on Northeast neotectonics and the axiom that, "once the impossible has been eliminated, whatever remains, no matter how improbable, must be the answer". With no other tangible expression of recent igneous activity, it seems necessary to conclude that the system is embryonic; that is, created by subsurface igneous and/or metamorphic activity that has had insufficient time to be more directly expressed at the surface.

Evidence for this view stems from a recent releveling study which has shown the Adirondacks to be presently rising at the meteoric rate of 9± 2 cm over the last 18 years in an oblate domal configuration (Isachsen, 1975). This in turn has prompted speculation that the Adirondack arch may be caused by thermal upwelling from a juvenile hot spot, and, further, the hypothesis, based on geomorphological evidence, that Lakes George and Champlain may represent reactivated Neogene grabens (K. Burke, 1976). The large Bouguer gravity low between Albany, New York, and Bennington, Vermont, seems consistent with this interpretation and may signal a thinning of the crust as do the negative anomalies associated with the African rift systems.

When we consider the excellent evidence for a thermal derivation of CO_2 in the Saratoga waters, it becomes very tempting to view the greater Hudson Valley linear (Lake George, Lake Champlain, and, at least, the mid-Hudson River Valley) as an embryonic rift system. The conjunctive upwelling Adirondacks, the large negative Bouguer gravity anomaly, and the discernible structural evidence are all consistent with this interpretation.

Seismic reflection profiling across the lowlands could reveal the basement structure and provide us with evidence for this theory which should, at least for the moment, be considered as a strong hypothesis.

APPENDIX

Appendix
Analytical Methodology

Parameter	Analytical Procedure	Reference	Precision
Fluoride, Free	Activity of fluoride ion measured using Orion ion-selective electrode	3	± 6.2% at 1.29 mg/l
Nitrogen, Ammonia	Indophenol blue-Ammonia reaction with alkaline phenol, hypochloride and nitroprusside	2	± 8.1% at 0.37 mg/l
Nitrogen, Nitrite	Automated diazotization with sulfanilimide and coupling with Azo dye	2	± 5.8% at 14.9 μg/l
Nitrogen, Nitrate plus Nitrite	Copper cadmium reduction of nitrate to nitrite determined by diazotization as above	2	± 4.7% at 2.6 mg/l
Chloride	Automated ferricthiocyanide	2	± 5.8% at 39.6 mg/l
Sulfate as SO_4	Automated reaction with $BaCl_2$ and methylthymol blue	3	± 5.0% at 29. mg/l
Carbon, Organic (TOC)	Purging of inorganic carbon, oxidation of organic carbon to CO_2. CO_2 detected by infrared spectroscopy	6	± 17.6% at 11.7 mg/l
Boron	Reaction of Boron with Curcumin to form red rosocyanine dye	3	± 6.6% at 1.0 mg/l
Barium	Direct aspiration atomic absorption spectrometry; nitrous oxide acetylene flame	2	± 5.9% at 1.4 mg/l
Iron	Direct aspiration atomic absorption spectrometry; air-acetylene flame	2	± 4.8% at 0.97 mg/l
Potassium	"	2	± 6.6% at 9.2 mg/l
Sodium	"	2	± 2.6% at 44.9 mg/l
Zinc	"	2	± 3.7% at 0.59 mg/l
Calcium	"	2	± 5.4% at 50.7 mg/l
Lithium	"	2	not available
Magnesium	"	2	± 7.7% at 16.6 mg/l
Strontium	"	2	not available

Parameter	Analytical Procedure	Reference	Precision
Bromide	Bromide oxidation followed by bromination of phenol Red D dye	3	± 5.1% at 0.74 mg/l
Iodide	Iodide proportionately catalyzes the reduction of ceric ions by arsenious acid	3	± 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	± 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	± 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 Electrometric	Titration to pH 4.5 with 0.02N H_2SO_4. Reported as "$CaCO_3$"	3	± 7.5% at 44.0 mg/l
Aluminum	Flameless atomic absorption spectrometry using graphite furnace	2,4	± 25.5% at 0.10 mg/l
Tin	"	2,4	not available
Yttrium	Plasma Emission	5	not available
Zirconium	"	5	not available

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. Jarrel-Ash Corp., Waltham Mass, (These parameters analyzed at Jarrel Ash by Jarrel Ash and NYSDH personnel.

6. Oceanographic International Corp., Instruction and Procedure Manual for the total carbon system Model 0524B.

	Thermal Waters		*Saratoga Springs Area*												
	LEBANON SPRINGS	FRED GEORGE	OLD IRON	BISCHOFF	HATHORN No.3	POLARIS	ORENDA	GEYSER	LINCOLN No.12	ROSEMARY	CONGRESS	HATHORN No.1	BIG RED	PEERLESS	RED
Date and Time of Sampling	8/26/11	4/28/10	4/16/10	5/04/10	4/19/14	4/19/10	4/08/11	4/08/11	5/04/12	4/18/14	5/04/14	4/18/13	4/09/13	4/18/13	4/18/11
Water Temperature °C	22.2	23.0	11.0	11.2	10.0	11.5	10.0	5.0	12.0	12.0	11.2	11.9	11.0	11.0	12.0
Ph (Field)	8.2	8.2	6.4	6.2	6.0	6.2	6.2	6.0	6.4	6.0	6.5	6.2	6.0	6.0	6.3
Chloride	8.	3.	700.	6500	6300	1500	4500	1200	1400	280	500	1800	2300	1000	550
Sulfate (SO_4)	2.5	9.0	5.0	22.0	4.0	7.0	23.0	11.0	12.0	20.0	40.0	11.0	28.0	11.0	6.0
Alkalinity (Methyl Orange)	127	92	1190	4080	4010	1900	3020	2140	2020	1650	984	1990	2460	1825	1150
Sodium	6.2	1.9	360	4300	2600	840	1900	800	720	280	340	930	1400	730	310
Potassium	1.LT	.1 LT	40	330	320	99	240	98	100	72	49	94	91	93	36
Calcium	34.	20	310	770	680	380	510	330	410	240	230	410	340	420	260
Magnesium	14	11	78	200	420	120	270	200	90	160	67	100	260	100	76
Iron	.05 LT	.05 LT	12.0	0.96	3.8	1.8	2.7	9.3	8.7	7.0	3.4	2.1	11.0	1.9	6.7
Nitrate and Nitrite	0.2	0.2 LT	0.2 LT	0.2 LT	0.2 LT	0.2 LT	0.2 LT	0.2 LT	0.2 LT	0.2 LT	0.2 LT	0.2 LT	0.2 LT	0.2 LT	0.2 L
Nitrogen, Nitrite	5 LT	5 LT	5 LT	5 LT	5 LT	5 LT	5 LT	5 LT	5 LT	5 LT	5 LT	5 LT	5 LT	5 LT	5 L
Ammonia	0.007	0.005 LT	3.7	21.0	18.0	5.5	12.0	6.0	NA	3.6	2.0	7.0	11.0	4.6	4.0
Phosphate	0.005 LT	0.005 LT	0.047	0.027	0.015	0.029	0.018	0.041	0.047	0.039	0.008	0.015	0.050	0.036	0.03
Flouride (Free)	0.024	0.1 LT	0.72	0.1 LT	0.58	0.82	0.78	0.78	0.22	0.56	0.16	0.70	0.19	0.68	0.76
Bromide	0.34	0.26	13.0	43.0	90.0	20.0	61.0	22.0	24.0	11.0	9.8	2.7	3.5	2.0	11.0
Iodide	0.004	0.004	0.42	4.0	3.6	0.62	2.5	0.56	0.79	0.12	0.27	0.80	1.0	0.36	0.28
Beryllium	0.02 LT	0.02 LT	0.02 LT	0.02 LT	0.02 LT	0.02 LT	0.02 LT	0.02 LT	0.02 LT	0.02 LT	0.02 LT	0.02 LT	0.02 LT	0.02 LT	0.02 L
Boron	0.20 LT	0.2 LT	0.75	4.8	2.3	1.7	3.0	1.4	1.3	+.1	0.47	16	2.0	1.1	0.79
Cadmium	0.002 LT	0.002 LT	0.002 LT	0.002 LT	0.002 LT	0.002 LT	0.002 LT	0.002 LT	0.002 LT	0.002 LT	0.002 LT	0.002 LT	0.002 LT	0.002 LT	0.002
Chromium	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 L
Aluminum	0.05 LT	0.05 LT	0.05 LT	0.05	0.06	0.05 LT	0.05	0.05 LT	0.05	0.05 LT	0.05 LT	0.05 LT	0.05 LT	0.05 LT	0.05
Lead	0.01 LT	0.01 LT	0.01 LT	0.01	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01	0.01 LT	0.01 LT	0.01 LT	0.01
Lithium	0.05 LT	0.05 LT	1.9	15.0	10.0	2.8	7.8	2.6	2.7	0.63	1.0	3.8	4.9	2.4	0.83
Manganese	0.03 LT	0.03 LT	0.30	0.03	0.14	0.15	0.14	0.17	0.19	0.14	0.13	0.12	0.14	0.25	0.20
Silica	9.1	0.10.0	21.0	9.5	7.1	13.0	7.3	27.0	33.0	38.0	9.1	7.9	46.0	9.6	37.
Strontium	0.34	0.05 LT	10.0	33.0	21.0	6.0	16.0	6.9	6.7	4.2	2.0	6.7	18.0	4.2	5.2
Barium	0.5 LT	0.5 LT	3.1	36.0	8.6	2.1	8.6	1.8	3.4	1.1	0.6	3.2	5.0	1.1	1.1
Tin	1.0 LT	1.0 LT	1.0 LT	1.0	1.0	1.0	1.0	1.0	1.0 LT	1.0 LT	1.0 LT	1.0	1.0	1.0 LT	1.0
Zinc	0.05 LT	0.05	0.05	0.05 LT	0.05	0.05	0.05	0.05	0.05 LT	0.05	0.05 LT	0.05	0.05 LT	0.05	0.05
Yttrium	0.01 LT	0.01	0.02	0.06	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01
Zirconium	0.01 LT	0.01 LT	0.01 LT	0.29	0.32	0.06	0.23	0.04	0.04	0.01	0.01 LT	0.10	0.04	0.08	0.01
Total Dissolved Solids	167	120	2560	14820	15190	4290	10580	4280	4210	3220	1820	5250	7710	3820	217

NOTE:
The units of all values are expressed in mg/l except Nitrogen, Nitrite which is µmg/l.

ANALYTICAL DATA

SPRING 1978 SAMPLING

			North Central Carbonated Waters							*Sulfate Waters*			*Southern Brine Waters*				
PEERLESS	RED	BURN SPRING	QUAKER	BENNET	MARTIN	DOSTER	MC NEIL	MC NEIL (duplicated)	MIDDLETOWN SPRINGS	VITA SPRING	SAMS	PITCHER	PATTERSON-VILLE	CONGLY	AUGUST BOHL	VEZZI	FIGLIO
4/18/13	4/18/11	5/04/14	4/27/12	4/25/12	4/20/15	4/25/11	4/27/15	4/27/16	4/25/18	4/20/11	4/25/15	5/02/13	5/02/15	4/27/15	4/28/11	5/02/11	5/02/
11.0	12.0	8.5	8.2	12.0	10.5	13.5	11.2	11.2	4.5	9.0	10.5	9.0	12.5	11.8	14.0	15.5	9.2
6.0	6.3	6.3	6.5	6.3	6.3	7.0	6.4	6.4	7.3	6.5	7.0	6.8	7.3	6.7	7.4	7.2 SU	7.3
1000	550	750	750	750	160	680	250	246	18	220	24	230	600	2100	1800	1700	170
11.0	6.0	9.0	10.0	36.0	21.0	25.0	6.0	7.0	12.0	1300	3000	2100	48.0	2.0	2 LT	2 LT	10.
1825	1150	1840	1810	2260	2130	2160	730.0	700.0	615.0 SU	1130.0	620.0	365.0	265.0	210.0	344.0	276.0	149
730	310	620	920	840	630	970	190	160	11	320	170	88	240	1000	1000	1100	750
93	36	70	18	65	18.	21	29	29	4.	52	8.0	1.2	4.	28	11	11	9.
420	260	320	82	250	100	97	180	160	24	390	280	340	150	140	27	18	74
100	76	100	21	73	58	26	35	36	4.2	130	530	390	35	34	15	4.5	1.7
1.9	6.7	16.0	2.1	7.7	1.8	.48	.88	.93	.05 LT	1.4	30.0	.10	.51	.17	.39	.30	.13
0.2 LT	0.2 LT	0.2 LT	0.2 LT	0.2 LT	0.2 LT	0.2 LT	0.2 LT	0.2 LT	3.3	0.2 LT	0.2 LT	0.2 LT	0.2 LT	0.2 LT	0.2 LT	0.2 LT	0.2
5 LT	5 LT	5 LT	5 LT	5 LT	5 LT	5 LT	5 LT	5 LT	5 LT	5 LT	5 LT	5 LT	5 LT	5 LT	5 LT	5 LT	5 L
4.6	4.0	5.0	2.3	11.0	7.0	12.0	0.6	0.6	.015	5.0	5.5	0.95	0.26	7.5	2.3	3.8	2.3
0.036	0.030	0.11	0.007	0.005	0.012	0.006	0.008	0.005	0.008	0.005 LT	0.005L	0.005LT	0.005	0.005LT	0.065	0.008	0.00
0.68	0.76	0.27	0.53	0.12	0.42	0.52	0.1 LT	0.14	0.1 LT	0.18	0.1 LT	0.1 LT	0.11	0.1 LT	.82	2.10	1.5
2.0	11.0	18.0	16.0	22.0	2.1	3.4	6.4	3.9	0.24	12.0	6.0	3.5	1.4	2.8	22.0	35.0	12.0
0.36	0.28	0.28	0.29	0.27	0.12	0.47	0.75	0.074	0.005LT	0.044	0.007	0.010	0.014	0.43	2.5	5.3	1.9
0.02 LT	0.02 LT	0.02 LT	0.02 LT	0.02 LT	0.02 LT	0.02 LT	0.02 LT	0.02 LT	0.02 LT	0.02 LT	0.02 LT	0.02 LT	0.02 LT	0.02 LT	0.02 LT	0.02 LT	0.02
1.1	0.79	1.0	1.6	2.7	2.0	3.5	0.67	0.74	0.20 LT	1.4	0.37	0.3	0.2	0.89	0.7	0.9	1.0
0.002 LT	0.002 LT	0.002 LT	0.002 LT	0.002 LT	0.002 LT	0.002 LT	0.002 LT	0.002 LT	0.002 LT	0.002 LT	0.002 LT	0.002 LT	0.002 LT	0.002 LT	0.002 LT	0.002 LT	0.002
0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 L
0.05 LT	0.05 LT	.33	0.05 LT	0.05 LT	0.05 LT	0.05 LT	0.05 LT	0.05 LT	0.05 LT	0.05 LT	0.05	0.05 LT	0.05 LT	0.05 LT	0.05 LT	0.05 LT	0.05
0.01 LT	0.01 LT	0.01 LT	0.01	0.01	0.01 LT	0. 01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01
2.4	0.83	2.0	3.7	2.6	1.1	5.3	0.44	0.47	0.05 LT	0.84	0.19	0.18	0.05	2.0	4.2	4.4	2.8
0.25	0.20	0.32	0.72	0.39	0.18	0.10	0.46	0.46	0.03 LT	1.8	0.35	0.17	0.15	0.59	0.03 LT	0.03	0.05
9.6	37.0	37.0	9.0	11.0	10.0	7.7	15.0	15.0	3.4	14.0	12.0	9.0	6.5	6.5	10.0	11.0	6.2
4.2	5.2	2.8	13.0	14.0	7.9	13.0	1.7	2.2	0.1	9.3	7.0	6.0	1.0	2.8	9.2	6.7	2.5
1.1	1.1	3.5	1.2	1.2	1.5	4.7	1.1	0.7	0.05	0.5	0.5	0.5	0.5	2.0	0.5	0.9	0.5
1.0 LT	1.0 LT	1.0 LT	1.0	1.0 LT	1.0 LT	1.0 LT	1.0	1.0 LT	1.0 LT	1.0 LT	1.0 LT	1.0 LT	1.0 LT	1.0	1.0 LT	1.0	1.0
0.05	0.05 LT	0.05 LT	0.30	0.09	0.05 LT	0.09	0.05	0.05	0.05 LT	0.05	3.0	0.05	0.05 LT	0.05	0.34	0.05 LT	0.05
0.01 LT	0.01 LT	0.01 LT	0.03	0.04	0.01 LT	0.01 LT	0.03	0.02	0.02	0.01 LT	0.01	0.01	0.05	0.02	0.01 LT	0.01 LT	0.03
0.08	0.01 LT	0.01 LT	0.05	0.23	0.12	0.10	0.01 LT	0.01 LT	0.01 LT	0.04	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01
3820	2170	3080	3330	3790	2590	3510	1160	1180	648	3900	5490	4120	1470	4430	3190	3310	1970

LT = Less Than
NA = Not Available
SU = Suspect

Southern Brine Waters						Surface Water Control Wells			
PATTERSONVILLE	CONGLY	AUGUST BOHL	VEZZI	FIGLIOMENI	TUDOR PINES	POMPA	V.K. GREENE	BLOODGOOD	SARATOGA VETERINARY HOSPITAL
5/02/15	4/27/15	4/28/11	5/02/11	5/02/13	5/25/10	5/23/10	5/23/10	5/23/10	5/25/10
12.5	11.8	14.0	15.5	9.2	11.1	11.8	12.8	11.2	12.3
7.3	6.7	7.4	7.2 SU	7.3	8.2	7.5	8.0	9.0	8.5
600	2100	1800	1700	170	800	6.	4.	3. LT	3. LT
48.0	2.0	2 LT	2 LT	10.0	20	80.0	8.0	3.0	3.0
265.0	210.0	344.0	276.0	149.3	283.0	300.0	255.0	109.0	219.0
240	1000	1000	1100	750	590	5.0	95	44	83
4.	28	11	11	9.	7.	3.	7.	1. LT	2.
150	140	27	18	7.4	7.2	180	7.6	2.1	6.3
35	34	15	4.5	1.7	2.0	29	5.3	.4	2.3
.51	.17	.39	.30	.13	3.4	.33	1.3	.05	.09
0.2 LT	0.2 LT	0.2 LT	0.2 LT	0.2 LT	0.2 LT	0.2 LT	0.2 LT	0.2 LT	0.2 LT
5 LT	5 LT	5 LT	5 LT	5 LT	5 LT	5 LT	5 LT	5 LT	5 LT
0.26	7.5	2.3	3.8	2.3	4.5	0.16	2.4	.28	1.5
0.005	0.005 LT	0.065	0.008	0.009	0.008	0.005 LT	0.018	0.063	0.015
0.11	0.1 LT	.82	2.10	1.5	0.84	0.26	1.60	0.76	1.8
1.4	2.8	22.0	35.0	12.0	13.0	0.88	0.46	0.27	0.10 LT
0.014	0.43	2.5	5.3	1.9	1.0	0.010	0.34	0.007	0.093
0.02 LT	0.02 LT	0.02 LT	0.02 LT	0.02 LT	0.02 LT	0.02 LT	0.02 LT	0.02 LT	0.02 LT
0.2	0.89	0.7	0.9	1.0	0.93	0.20	0.81	0.20	0.64
0.002 LT	0.002 LT	0.002 LT	0.002 LT	0.002 LT	0.002 LT	0.002 LT	0.002 LT	0.002 LT	0.002 LT
0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT
0.05 LT	0.05 LT	0.05 LT	0.05 LT	0.05 LT	0.05 LT	0.05 LT	0.94	0.05 LT	0.05 LT
0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT
0.05	2.0	4.2	4.4	2.8	2.0	0.05	0.18	0.05 LT	0.25
0.15	0.59	0.03 LT	0.03	0.05	0.03	0.04	0.03 LT	0.03 LT	0.03 LT
6.5	6.5	10.0	11.0	6.2	5.4	7.2	6.9	6.2	6.4
1.0	2.8	9.2	6.7	2.5	1.4	1.4	1.2	0.1	1.0
0.5	2.0	0.5	0.9	0.5	0.5 LT	0.5 LT	0.5 LT	0.5 LT	0.5
1.0 LT	1.0	1.0 LT	1.0	1.0 LT	1.0 LT	1.0 LT	1.0 LT	1.0 LT	1.0 LT
0.05 LT	0.05	0.34	0.05 LT	0.05 LT	0.05 LT	0.16	2.7	0.05 LT	0.05 LT
0.05	0.02	0.01 LT	0.01 LT	0.03	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT
0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT	0.01 LT
1470	4430	3190	3310	1970	1870	274	301	109	261

	Thermal Waters		*Saratoga Springs Area*									
	LEBANON SPRINGS	FRED GEORGE	OLD IRON	BISCHOFF	HATHORN no. 3	POLARIS	ORENDA	GEYSER	LINCOLN no. 12	ROSEMARY	CONGRESS	CONGRESS (duplicated)
Date and Time of Sampling	10/25/08	10/25/10	10/10/02	10/16/10	10/12/12	10/13/10	10/13/09	10/13/12	10/18/10	10/5/12	10/12/12	10/12/12
Water Temperature °C	22.5	22.1	10.5	9.9	10.2	13.5	10.2	14.5	10.8	11.9	12.1	12.1
pH (Field)	8.1	8.2	6.2	6.4	6.0	5.5	6.1	5.9	6.5	6.0	6.3	6.3
Chloride	7	3	750	6900	6900	1400	4100	1300	1200	560	450	390
Sulfate (SO_4)	28	9	INTERF.	INTERF.	INTERF.	INTERF.	INTERF.	INTERF.	INTERF.	19	INTERF.	54
Alkalinity Electron pH 4.5	126	92	1280	4340	4270	1050SU	3280	2100	2090	1960	960	970
Sodium	7.8	2.0	520	4400	3100	770	2300	640	740	590	340	350
Potassium	1.6	1.0	34	300	320	100	230	110	110	87	39	39
Calcium	34	20	320	950	950	400	750	320	340	270	200	140
Magnesium	15	12	79	470	410	160	300	150	190	190	64	63
Iron	.05	.05 LT	10	.07	.08	1.6	2.3	2.7	6.2	6.2	2.3	2.4
Nitrate and Nitrite	.2	.2 LT	.2 LT	.2	.2 LT	.2 LT	.2 LT	.2 LT	.2 LT	.2 LT	.2 LT	.2 LT
Nitrite	5 LT	5 LT	12	5	5	5	15	8	7	5 LT	5 LT	5 LT
Ammonia	.007	.007	3.2	3.2	16	4.3	12	4.3	4.5	4.1	.78	1.5
Nitrogen Total	3.8	.2 LT	3.6	26	21	6.1	LA	5.8	6.1	43	2.1	2.0
Carbon Organic (TOC)	3.8	1.8	1.0	1.0	1.8	9.0	.28	1.0	1.0 LT	34	10	1.0
Phosphate	.006	.010	.052	.018	.014	.019	.035	.014	.036	.10	.035	.014
Fluoride (Free)	.25	.1 LT	.45	.1 LT	.34	.74	.58	.52	.60	.32	.50	.50
Bromide	.95	.44	18	130	110	24	74	26	34	19	10	6.0
Iodide	.006	.004	.49	4.2	4.3	.54	2.6	.43	.87	.45	.19	.16
Boron	.20 LT	.20 LT	.86	3.2	3.5	1.1	1.6	.87	1.6	1.2	.79	.65
Aluminum	.05 LT	.05 LT	.05 LT	.06	.05	.05	.26	.05 LT	.05	.09	.05 LT	.05 LT
Lithium	.01 LT	.01 LT	2.0	14	12	2.8	10	2.8	2.7	1.9	.80	7.9
Silica	15	16	45	16	12	21	13	45	45	40	15	16
Strontium	.3	.05 LT	7.8	25	17	4.7	14	5.2	5.1	4.0	1.6	1.6
Barium	.5 LT	.5 LT	6.7	34	21	5.1	17	5.1	5.0	3.7	.7	.5
Tin	.05 LT	.05 LT	.05 LT	.05 LT	.05 LT	.05 LT	.05 LT	.05 LT	.05 LT	.05 LT	.05 LT	.05 LT
Yttrium	.003	.002 LT	.003	.002 LT	.002 LT	.002 LT	.010	.002 LT	.007	.002 LT	.002 LT	.004
Zirconium	.003 LT	.003 LT	.010	.123	.025	.100	.237	.053	.048	.045	.015	.009
Total Dissolved Solids	179	117	2610	17500	14610	4420	10780	4320	4240	3000	1710	1740

NOTE:

The units of all values are expressed in mg/l except Nitrogen, Nitrite which is µ mg/l.

ANALYTICAL DATA

FALL 1978 SAMPLING

rea						North Central Carbonated Waters					Sulfate Waters			
CONGRESS (duplicated)	HATHORN no. 1	BIG RED	PEERLESS	RED	GURN	QUAKER	BENNET	MARTIN	DOSTER	MC NEIL	VITA SPRING	DAVIS	PITCHER	SHARON SPRINGS
10/12/12	10/10/13	10/10/11	10/10/10	10/10/11	10/5/02	10/11/12	10/18/11	10/12/10	10/12/11	10/11/10	10/17/12	10/16/12	10/09/12	10/19/15
12.1	11.0	10.0	10.5	13.6	10.6	11.6	12.5	11.2	15.8	11.8	9.9	10.2	12.5	8.9
6.3	6.0	5.9	5.8	6.1	6.4	6.2	6.4	6.7	5.8 SU	6.8	6.7	7.4	7.2	7.8
390	1600	2500	980	650	750	700	450	190	600	260	230	16	230	51
54	INTERF.	9	4	4	5	INTERF.	40	INTERF.	INTERF.	INTERF.	INTERF.	INTERF.	2400	1800
970	2240	2660	1960	1340	1672	1550	1930	2340	2250	810	1220	640	380	290
350	950	1100	740	470	600	880	500	570	910	240	510	170	88	15
39	130	100	90	36	72	12	47	15	18	29	46	7.3	11	1.6
140	410	330	420	290	330	56	200	110	100	170	350	340	130	400
63	160	280	120	90	110	18	65	69	28	41	130	560	450	73
2.4	1.6	81	1.7	6.0	29	.47	1.9	1.5	.44	1.0	1.7	.05 LT	.21	.05
.2 LT	.2 LT	.2 LT	.2 LT	.2 LT	.2 LT	.2	.2 LT	.2 LT	.2 LT	.2 LT	.2 LT	.2 LT	.2	.2 LT
5 LT	5 LT	5 LT	7	5 LT	5 LT	5 LT	5 LT	5	5 LT	5 LT	5 LT	5	5 LT	5 LT
1.5	6.5	8.0	3.5	3.6	3.0	3.3	8.0	6.0	9.5	.59	5.5	3.4	1.1	.23
2.0	6.4	10	4.9	3.8	LA	3.5	10	7.2	LA	1.3	5.9	4	1.0	.5
1.0	6.0	88	8.0	1.0 LT	22	3.4	1.0 LT	20	1.4	1.0	2.4	6	1.0 LT	1.0 LT
.014	.027	.056	.032	.034	.15	.027	.031	.022	.014	.008	.008	.043	.002 LT	.005 LT
.50	.59	.23	.54	.58	.43	.34	.29	.20	.58	.20	.19	.11	.14	1.18
6.0	29	41	22	15	15	13	18	25	27	7.2	8.3	5.5	1.3	.71
.16	.78	.62	.45	.42	.15	.37	.16	.17	.60	.094	.040	.005 LT	.011	.009
.65	1.4	1.5	.96	.58	1.0	1.1	2.0	2.0	2.8	.68	1.2	.28	.37	.20
.05 LT	.22	.05 LT	.16	.08	.32	.06	.16	.05 LT	.05 LT	.05 LT	.22	.05 LT	.05 LT	.05 LT
7.9	3.8	4.8	2.6	1.2	2.0	3.0	1.9	1.1	6.9	.52	.83	.17	.18	.02
16	13	70	16	46	55	15	17	16	13	22	22	18	15	16
1.6	5.0	11	3.3	4.8	2.5	8.8	8.6	7.7	11	2.1	12	11	8.6	11
.5	5.3	8.7	3.8	3.4	7.4	2.6	2.8	7.9	16	3.0	.5 LT	.5 LT	.5 LT	.5
.05 LT	.05 LT	.05 LT	.05 LT	.05 LT	.05 LT	.05 LT	.05 LT	.05 LT	.05 LT	.05 LT	INTERF.	.05 LT	.05 LT	.05 LT
.004	.006	.002 LT	.008	.004	.007	.004	.005	.002 LT	.004	.007	.005	.002 LT	.012	.002 LT
.009	.120	.016	.090	.016	.003 LT	.066	.228	.210	.170	.009	.050	.003 LT	.003 LT	.003 LT
1740	5080	6460	3820	2430	3230	2650	2730	2600	3230	1270	3720	5460	4180	2400

SU = Suspect
LT = Less Than
LA = Lab Accident
NA = Not Available
INTERF. = Interference

Sulfate Waters				Southern Brine Waters								Surface Water Control Wells				
DAVIS	PITCHER	SHARON SPRINGS	SHARON SPRINGS (duplicated)	CONGLY	AUGUST BOHL	YEZZI	FIGLIOMENI	TUDOR PINES	GORMAN	PATTERSON-VILLE (duplicated)	PATTERSON-VILLE	POMPA	Y.K. GREENE	BLOODGOOD	SARATOGA VETERINARY HOSPITAL	WILSON
10/16/12	10/09/12	10/19/15	10/19/15	10/11/02	10/20/15	10/09/20	10/09/05	10/20/12	10/20/10	10/19/10	10/19/10	10/6/10	10/18/13	10/06/23	10/06/11	10/19/17
10.2	12.5	8.9	8.9	12.5	13.8	14.2	13.1	10.8	10.6	12.5	12.5	10.8	11.3	15.5	11.5	13.1
7.4	7.2	7.8	7.8	7.4	7.7	8.4	7.7	8.5	7.2	7.8	7.8	7.5	8.6	9.2	8.5	7.3
16	230	51	43	2100	1000	1700	170	750	2880	650	530	17	5	3 LT	3	20
INTERF.	2400	1800	1800	INTERF.	2 LT	2	9	2 LT	2	60	54	110	5	2	3	160
640	380	290	260	220	339	276	1516	284	194	330	330	296	370	116	216	270
170	88	15	12	950	530	670	640	500	1800	290	300	3.1	98	36	70	43
7.3	11	1.6	2.1	23	6.2	9.7	7.5	6.6	20	3.8	3.9	3.8	2.4	.8	2.8	5.1
340	130	400	400	140	20	16	6.9	6.9	75	140	200	130	4.7	2.1	10	57
560	450	73	90	55	10	5.5	1.7	2.2	19	45	47	41	4.1	.44	4.7	32
.05 LT	.21	.05	.05 LT	.8	.27	.22	.22	1.7	.50	.31	.37	.16	.12	.05	.12	.31
.2 LT	.2	.2 LT	.2	.2	.2 LT	.2 LT	.2	.2 LT	.2 LT	.2 LT	.2 LT	.2 LT	.2 LT	.2 LT	.2 LT	.2 LT
5	5 LT	5 LT	5 LT	84	5	5 LT	5 LT	5 LT	5 LT	5 LT	5 LT	5 LT	5 LT	5 LT	5LT	5 LT
3.4	1.1	.23	.25	7.5	.80	3.5	2.3	3.4	13	.29	.24	.20	2.4	.30	1.7	1.0
4	1.0	.5	LA	LA	64	5.3	3.0	5.3	17	LA	.5	.2 LT	2.6	.6	1.9	2.0
6	1.0 LT	1.0 LT	1.0 LT	1.0	1.0 LT	4.2	3.8	2.4	1.0 LT	1.0 LT	1.0 LT	1.2	1.0 LT	1.0	2.8	1.8
.043	.002 LT	.005 LT	.005 LT	.002	.041	.020	.017	.005	.007	.005	.007	.002	.014	.059	.009	.005 LT
.11	.14	1.18	1.15	.11	.1 LT	2.3	1.6	.1 LT	.19	.18	.20	.26	1.60	.78	1.7	.23
5.5	1.3	.71	1.3	29	14	35	10	20	130	3.3	3.3	1.3	6.3	.56	1.5	4.4
.005 LT	.011	.009	.008	.27	1.3	4.7	1.1	.89	3.5	.028	.027	.010	.45	.006	.098	.060
.28	.37	.20	.26	.40	.57	.69	1.0	.96	1.0	.29	.50	.20 LT	.84	.2 LT	.50	.39
.05 LT	.05 LT	.05 LT	.05 LT	.05	.05 LT	.05	.22	.05	.05 LT	.05 LT	.05 LT	.05 LT	.05	.05 LT	.05 LT	.05 LT
.17	.18	.02	.03	2.0	2.4	4.5	2.6	2.0	8.7	.06	.06	.01	.25	.02	.19	.10
18	15	16	17	10	17	11	12	10	10	11	11	12	11	11	11	15
11	8.6	11	9.3	21	3.6	5.4	2.0	1.6	34	.9	1.0	1.3	.9	.1	1.3	4.6
.5 LT	.5 LT	.5	.5 LT	9.1	2.8	2.4	.9	.5	12	.5 LT	.7	.5 LT	.5	.5	.5	.5 LT
.05 LT	.05 LT	.05 LT	.05 LT	.05 LT	.05 LT	.05 LT	.05 LT	.05 LT	.05 LT	.05 LT	.05 LT	.05 LT	.05 LT	.05 LT	.05 LT	.05 LT
.002 LT	.012	.002 LT	.003	.003	.002 LT	.004	.005	.006	.002 LT	.002 LT	.003	.002 LT	.002 LT	.005	.004	.002 LT
.003 LT	.003 LT	.003 LT	.003 LT	.003 LT	.003 LT	.003 LT	.025	.003 LT	.003 LT	.003 LT	.003 LT	.004	.017	.003	.010	.003 LT
5460	4180	2400	2520	4300	2030	3335	2070	1910	6550	1420	1480	436	290	140	230	454

Surface Water Control Wells						Vichy France	
POMPA	Y.K. GREENE	BLOODGOOD	SARATOGA VETERINARY HOSPITAL	WILSON	MIDDLETOWN SPRINGS	CELESTINS	HÔPITAL
10/6/10	10/18/13	10/06/23	10/06/11	10/19/17	10/26/09	07/14/10	07/14/09
10.8	11.3	15.5	11.5	13.1	10.7	19.3	34.4
7.5	8.6	9.2	8.5	7.3	7.6	6.7	6.8
17	5	3 LT	3	20	5	240	350
110	5	2	3	160	15	170	220
296	370	116	216	270	59	3385	3690
3.1	98	36	70	43	3.9	700	720
3.8	2.4	.8	2.8	5.1	2.3	84	35
130	4.7	2.1	10	57	24	LA	LA
41	4.1	.44	4.7	32	3.3	9.1	11
.16	.12	.05	.12	.31	.05	.05 LT	.14
.2 LT	.2 LT	.2 LT	.2 LT	.2 LT	1.5	.4	.2 LT
5 LT	5 LT	5 LT	5LT	5 LT	.5	5	12
.20	2.4	.30	1.7	1.0	.005	.005	.17
.2 LT	2.6	.6	1.9	2.0	.2	.1	.6
1.2	1.0 LT	1.0	2.8	1.8	1.0	10	10
.002	.014	.059	.009	.005 LT	.2	.095	.18
.26	1.60	.78	1.7	.23	.1	4.7	6.4
1.3	6.3	.56	1.5	4.4	.68	8.6	13
.010	.45	.006	.098	.060	.003	.007	.049
.20 LT	.84	.2 LT	.50	.39	.20	1.3	1.8
.05 LT	.05	.05 LT	.05 LT	.05 LT	.05	.5 LT	.05 LT
.01	.25	.02	.19	.10	.01	3.6	5.0
12	11	11	11	15	5	37	44
1.3	.9	.1	1.3	4.6	.05	.9	1.6
.5 LT	.5	.5	.5	.5 LT	.5	0.5 LT	0.5 LT
.05 LT	.05 LT	.05 LT	.05 LT	.05 LT	.05	1.0 LT	1.0 LT
.002 LT	.002 LT	.005	.004	.002 LT	.002	NA	NA
.004	.017	.003	.010	.003 LT	.003	NA	NA
436	290	140	230	454	102	3411	4566

SAMPLING SITES - SOURCE DATA

Sampling Site	Location	Owner	Description	Depth of Well, Bottom Hole Formation	Yield(GPM)
Lebanon Springs	Lebanon Springs	Town of Lebanon Springs	Overflow pipe	Natural spring; Stockbridge Limestone	∼500
Sand Spring	Williamstown, Massachusetts	Mr. Fred George	Overflow pipe	Natural spring; unknown	400
Old Iron	Ballston Spa, New York	Town of Ballston Spa	Free flowing well	640'; Beekmantown	<10
Bischoff	Ballston Spa, New York	Mr. Louis Pastore	Intermittent free flowing well	∼900'; Beekmantown	∼20
Hathorn #3	Saratoga Springs Reservation	State of New York	Free flowing well	806'; Hoyt Limestone or Beekmantown	3/4
Polaris	Saratoga Springs Reservation	State of New York	Free flowing well	209'; Amsterdam	2
Orenda	Saratoga Springs Reservation	State of New York	Free flowing well	344'; Trenton Limestone	45-50
Geyser	Saratoga Springs Reservation	State of New York	Free flowing well	150'; Amsterdam Limestone	3
Lincoln #12	Saratoga Springs Reservation	State of New York	Free flowing well	∼300'; Trenton Limestone	50-55
Rosemary	Grand Union Motel Saratoga Springs, NY	Mr. James Benton	Free flowing well	425'; Beekmantown	∼5
Congress #1	Congress Park Saratoga Springs, NY	City of Saratoga Springs	Free flowing well	Unknown, unknown	∼5
Hathorn #1	Saratoga Springs New York	Sity of Saratoga Springs	Free flowing well	1,006'; Potsdam	<10
Big Red	Saratoga Springs New York	Saratoga Race Track	Free flowing well	∼1,800'; Unknown But +1500' shale	∼8

Sampling Sites - Source Data (Continued)

Sampling Sites	Location	Owner	Description	Depth of Well, Bottom Hole Formation	Yield GPM
Peerless	Saratoga Springs, New York	City of Saratoga Springs	Free flowing well	200-300'; Unknown	<5
Red	Saratoga Springs, New York	City of Saratoga Springs	Free flowing well	200-300'; Unknown	<5
Gurn Spring	Gurn Springs, New York	Wilton Medical Center	Natural spring	Natural spring; 8' of Pleistocene cover on Beekmantown	<5
Quaker	Quaker Springs, New York	Quaker Springs Historical Society	Pump well	~400'; Unknown	Unknown
Bennet	Moreau, New York	Mr. Gerald Bennet	Inside basement tap	~200'; Unknown	Unknown
Martin	Moreau, New York	Mr. Jeffrey Martin	Outside tap	293'; Ordovician shale	<10
McNeil	Argyle, New York	Mr. Harold McNeil	Outside tap	80'; Pleistocene gravel (?)	Unknown
Sharon Spring	Sharon Springs, New York	Town of Sharon Springs	Overflow pipe	Natural spring; Silurian shale	Unknown
Vita Spring	Durkeetown, New York	Ms. Elizabeth Rozelle	Overflow	248'; Beekmantown(?)	<10
Davis	Smith's Basin, New York	Mr. James Davis	Basement tap	180'; Ordovician shale	Unknown
Pitcher	Dunnsville, New York	Mr. LeRoy Pitcher	Basement tap	180'; Ordovician shale	Unknown
Congly	Melrose, New York	Ms. Dolores Congly	Bathroom tap	330'; Ordovician shale	Unknown
Auguste Bohl	Bethlehem, New York	Auguste Bohl Equipment Corp.	Office tap	~150'; Ordovician shale	Unknown

Sampling Sites - Source Data (Continued)

Sampling Sites	Location	Owner	Description	Depth of Well, Bottom Hole Formation	Yield GPM
Yezzi	Guilderland, New York	Mr. Daniel Yezzi	Basement tap	Unknown; Ordovician shale	Unknown
Figliomeni	Parkers Corners, New York	Mr. Joseph Figliomeni	Basement tap	345'; Ordovician shale	Unknown
Tudor Pines	Central Bridge, New York	Tudor Pines Homes	Inside tap	~500'; Ordovician shale	Unknown
Gorman	Sloansville, New York	Mr. Gorman	Outside tap	Unknown;	Unknown
Pattersonville	Pattersonville, New York	N.Y.S. Thruway Authority	Inside tap	~100'; Ordovician shale	Unknown
Pompa	Milton, New York	Pompa Bros. Quarry	Outside tap	90'; Beekmantown	<10
Y.K.Greene	Wilton, New York	Mr. Y.Kittner Greene	Inside tap	500'; Beekmantown	Unknown
Bloodgood	Malta, New York	Judge Bloodgood	Outside tap	125'; Ordovician shale	Unknown
Saratoga Veterinary Hospital	Wilton, New York	Saratoga Vetrinary Hospital	Outside tap	300'; Ordovician shale	Unknown
Wilson	Altamont, New York	Mr. Arthur Wilson	Inside tap	180'; Ordovician shale(?)	Unknown
Middletown Springs	Middletown Springs, Vermont	Middletown Springs Historical Society	Natural spring	Reworked Pleistocene alluvium	<5
Celestins	Vichy, France	Unknown	Natural spring		Unknown
Hôpital	Vichy, France	Unknown	Natural spring		Unknown

TABLE 1S

Molar Concentrations x 10^3 of Major Elements
Spring Sampling

Index Number	Location	Na	Cl	K	Mg	Ca	Br
1.	Old Iron	15.66	19.74	1.02	3.21	7.73	.16
2.	Bischoff	187.04	183.32	8.44	8.22	19.21	.54
3.	Hathorn #3	113.09	177.68	8.18	17.27	16.97	1.13
4.	Polaris	36.54	42.30	2.53	4.94	9.48	.25
5.	Orenda	82.64	126.91	6.14	11.10	12.72	.76
6.	The Geyser	34.80	33.84	2.51	8.22	8.23	.28
7.	Lincoln #12	31.32	39.48	2.56	3.7	10.23	.30
8.	Rosemary	12.18	7.90	1.84	6.58	5.99	.14
9.	Congress #1	14.79	14.10	1.25	2.55	5.74	.12
10.	Hathorn #1	40.45	50.78	2.40	4.11	10.23	.34
11.	Big Red	60.89	64.87	2.33	14.80	8.48	.44
12.	Peerless	31.75	28.20	2.38	4.11	10.48	.25
13.	Red	13.48	15.51	.92	3.13	6.49	.14
14.	Gurn Spring	26.97	21.51	1.79	4.11	7.98	.23
15.	Quaker	42.63	21.15	.46	.86	2.05	.20
16.	Bennet	36.54	21.15	1.66	3.00	6.28	.28
17.	Martin	15.66	4.51	.46	2.38	2.50	.26
18.	Doster	42.19	19.18	.54	1.07	2.42	.43
19.	McNeil	8.26	7.05	.74	1.44	4.49	.08
20.	McNeil (duplicated)	6.96	6.77	.74	1.48	3.99	.05
21.	Middletown Springs	.48	.51	.10	.17	.60	.003

TABLE 1S (Continued)

Index Number	Location	Na	Cl	K	Mg	Ca	Br
22.	Vita Spring	13.92	6.20	1.33	5.35	9.73	.15
23.	Davis	7.39	.68	.20	21.79	6.99	.08
24.	Pitcher	3.83	6.49	.31	16.04	8.48	.04
25.	Pattersonville	10.44	16.92	.10	1.44	3.74	.02
26.	Congly	43.50	59.23	.72	1.40	1.40	.35
27.	Auguste Bohl	43.50	50.77	.28	.62	.67	.28
28.	Yezzi	47.84	47.95	.28	.19	.45	.44
29.	Figliomeni	32.62	4.79	.23	.07	.18	.15
30.	Tudor Pines	25.66	22.56	.18	.08	.18	.001
31.	Pompa	.22	.17	.08	1.19	4.49	.01
32.	YK Green	4.13	.11	.05	.22	.19	.005
33.	Bloodgood	1.91	.08	.03	.02	.16	.003
34.	Saratoga Veterinary Hospital	3.61	.08	.05	.09	.16	.001
35.	Lebanon Springs	.27	.23	.03	.58	.85	.004
36.	Fred George	.08	.08	.002	.45	.50	.003

TABLE 1S (Continued)

Index Number	Location	Na	Cl	K	Mg	Ca	Br
22.	Vita Spring	13.92	6.20	1.33	5.35	9.73	.15
23.	Davis	7.39	.68	.20	21.79	6.99	.08
24.	Pitcher	3.83	6.49	.31	16.04	8.48	.04
25.	Pattersonville	10.44	16.92	.10	1.44	3.74	.02
26.	Congly	43.50	59.23	.72	1.40	1.40	.35
27.	Auguste Bohl	43.50	50.77	.28	.62	.67	.28
28.	Yezzi	47.84	47.95	.28	.19	.45	.44
29.	Figliomeni	32.62	4.79	.23	.07	.18	.15
30.	Tudor Pines	25.66	22.56	.18	.08	.18	.001
31.	Pompa	.22	.17	.08	1.19	4.49	.01
32.	YK Green	4.13	.11	.05	.22	.19	.005
33.	Bloodgood	1.91	.08	.03	.02	.16	.003
34.	Saratoga Veterinary Hospital	3.61	.08	.05	.09	.16	.001
35.	Lebanon Springs	.27	.23	.03	.58	.85	.004
36.	Fred George	.08	.08	.002	.45	.50	.003

TABLE 1F

Molar Concentrations x 10^3 of Major Elements
Fall Sampling

Index Number	Location	Na	Cl	K	Mg	Ca	Br
1.	Old Iron	22.62	21.15	.87	3.25	7.98	.23
2.	Bischoff	191.38	194.60	7.67	19.33	23.10	1.63
3.	Hathorn #3	134.84	194.60	8.18	16.86	23.70	1.25
4.	Polaris	33.49	39.48	2.56	6.58	9.98	.30
5.	Orenda	100.04	115.63	5.88	12.34	18.71	.93
6.	Geyser	27.84	36.66	2.81	6.17	7.98	.33
7.	Lincoln #12	32.19	33.84	2.81	7.81	8.48	.43
8.	Rosemary	25.66	15.79	2.23	7.81	6.74	.24
9.	Congress	14.79	12.69	.98	2.63	4.99	.13
9a.	Congress (Duplicated)	15.22	11.00	.98	2.59	8.73	.08
10.	Hathorn #1	41.32	45.13	3.32	6.58	10.23	.36
11.	Big Red	47.84	64.87	2.56	11.51	8.23	.51
12.	Peerless	32.19	27.64	2.30	4.93	10.48	.28
13.	Red	20.44	18.33	.92	3.70	7.24	.19
14.	Gum	26.10	21.15	1.84	4.52	8.23	.19
15.	Quaker	38.28	19.74	.31	.74	1.40	.16
16.	Bennet	21.75	12.69	1.20	2.67	4.99	.23
17.	Martin	24.79	5.63	.38	2.84	2.74	.31
18.	Doster	39.58	16.92	.46	1.15	2.50	.34
19.	McNeil	10.44	7.33	.74	1.69	4.24	.09

TABLE 1F (Continued)

Index Number	Location	Na	Cl	K	Mg	Ca	Br
20.	Sharon	.65	1.44	.04	3.00	9.98	.008
20a.	Sharon (Duplicated)	.52	1.21	.05	3.70	9.98	.016
21	Vita Spring	22.18	6.49	1.18	5.35	8.73	.10
22.	Davis	7.39	.45	.19	23.03	8.48	.07
23.	Pitcher	3.83	6.49	.28	18.60	3.24	.02
24.	Congly	41.32	59.23	.59	2.26	3.49	.36
25.	August Bohl	23.05	28.20	.16	.41	.50	.18
26.	Yezzi	29.14	47.95	.25	.23	.40	.44
27.	Gifliomeni	27.84	4.79	.19	.07	.17	.13
28.	Tudor Pines	21.75	21.15	.17	.09	.17	.25
29.	Gorman	78.29	81.23	.51	.78	1.87	1.63
30.	Pattersonville	13.05	14.95	.10	1.93	4.99	.04
30 a.	Pattersonville (Duplicated)	12.61	18.33	.10	1.85	3.49	.04
31.	Pompa	.13	.48	.10	1.69	3.24	.02
32.	Y.K. Greene	4.26	.14	.06	.17	.12	.08
33.	Bloodgood	1.57	.08	.02	.02	.05	.007
34.	Saratoga Veterinary Hospital	3.04	.08	.07	.19	.25	.02
35.	Wilson	1.87	.56	.13	1.32	1.42	.06
36.	Middletown	.17	.14	.06	.14	.60	.008
37.	Lebanon Springs	.34	.20	.04	.62	.85	.01

TABLE 1F (Continued)

Index Number	Location	Na	Cl	K	Mg	Ca	Br
38.	Fred George	.09	.08	.03	.49	.50	.005
39.	Celestins	30.45	6.77	2.15	.37	NA	.11
40.	L'Hôpital	31.32	9.87	.90	1.85	NA	.16

TABLE 2S

Selected Molar Ratios
Spring Sampling

Index Number	Location	Ca/Mg	Na/Cl	$\frac{Br \times 1000}{Cl}$	Na/K	Cl/K
1.	Old Iron	2.41	.79	8.11	15.35	19.35
2.	Bischoff	2.34	1.02	2.95	22.16	21.72
3.	Hathorn #3	.98	.64	6.30	13.83	21.72
4.	Polaris	1.92	.86	5.91	14.44	16.72
5.	Orenda	1.15	.65	5.99	13.46	20.67
6.	The Geyser	1.00	1.03	7.98	13.86	13.48
7.	Lincoln #12	2.76	.79	7.60	12.23	15.42
8.	Rosemary	.91	1.54	16.48	6.62	4.29
9.	Congress #1	2.25	1.05	8.51	11.83	11.28
10.	Hathorn #1	2.49	.80	6.70	16.85	21.16
11.	Big Red	.57	.94	6.63	26.13	27.84
12.	Peerless	2.55	1.13	8.87	13.34	11.85
13.	Red	2.08	1.13	8.38	14.65	16.86
14.	Gum Spring	1.94	1.27	10.40	15.07	12.02
15.	Quaker	2.37	2.02	9.45	92.67	45.98
16.	Bennet	2.08	1.73	12.77	22.01	12.74
17.	Martin	1.05	3.47	57.65	34.04	9.80
18.	Doster	2.26	2.20	21.91	78.13	35.52
19.	McNeil	3.12	1.17	11.35	11.16	9.53
20.	McNeil (duplicated)	2.70	1.03	5.92	9.41	9.15
21.	Middletown Springs	3.47	.94	6.00	4.8	5.1

TABLE 2S (Continued)

Index Number	Location	Ca/Mg	Na/Cl	$\frac{Br \times 1000}{Cl}$	Na/K	Cl/K
22.	Vita Spring	1.82	2.24	24.20	10.47	4.66
23.	Davis	.32	10.92	104.48	36.95	3.4
24.	Pitcher	.53	.59	6.17	12.35	20.94
25.	Pattersonville	2.60	.62	.59	104.4	169.2
26.	Congly	2.50	.73	5.91	60.42	82.26
27.	Auguste Bohl	1.09	.86	5.32	155.36	181.32
28.	Yezzi	2.43	1.00	8.97	170.86	171.25
29.	Figliomeni	2.64	6.80	31.30	141.83	20.83
30.	Tudor Pines	2.18	1.14	7.09	142.56	125.33
31.	Pompa	3.77	1.29	68.75	2.75	2.13
32.	YK Green	.87	36.63	45.50	82.6	2.2
33.	Bloodgood	3.19	22.62	37.50	63.67	2.67
34.	Saratoga Veterinary Hospital	1.66	42.67	12.50	72.2	1.6
35.	Lebanon Springs	1.47	1.20	18.20	9.0	7.67
36.	Fred George	1.10	.98		40.0	40

TABLE 2F

Selected Molar Ratios
Fall Sampling

Index Number	Location	Ca/Mg	Na/Cl	$\frac{Br \times 1000}{Cl}$	Na/K	Cl/K
1.	Old Iron	2.46	1.07	10.64	26.01	24.33
2.	Bischoff	1.23	.98	8.36	24.94	25.36
3.	Hathorn #3	1.41	.69	7.07	16.46	23.78
4.	Polaris	1.52	.85	7.60	13.10	15.44
5.	Orenda	1.52	.87	8.00	17.01	19.66
6.	Geyser	1.29	.76	8.86	9.89	13.03
7.	Lincoln #12	1.09	.95	12.69	11.44	12.03
8.	Rosemary	.86	1.62	15.01	11.53	7.10
9.	Congress	1.90	1.17	9.85	14.83	12.72
9a.	Congress (Duplicated)	3.37	1.38	6.82	15.26	11.03
10.	Hathorn #1	1.55	.92	8.02	12.43	13.57
11.	Big Red	.72	.74	7.91	18.71	25.36
12.	Peerless	2.12	1.16	9.95	13.98	12.01
13.	Red	1.90	1.12	10.20	22.20	19.91
14.	Gurn	1.82	1.24	8.84	14.17	11.49
15.	Quaker	1.89	1.94	8.21	124.72	64.33
16.	Bennet	1.87	1.71	17.73	18.09	10.56
17.	Martin	.97	4.63	58.23	64.63	13.97
18.	Doster	2.16	2.34	19.92	85.98	36.76
19.	McNeil	2.52	1.42	12.27	14.07	9.89
20.	Sharon	3.32	.45	5.56	15.94	35.15

TABLE 2F (Continued)

Index Number	Location	Ca/Mg	Na/Cl	$\frac{\text{Br x 1000}}{\text{Cl}}$	Na/K	Cl/K
20a.	Sharon (Duplicated)	2.70	.43	13.20	9.72	22.58
21.	Vita Spring	1.66	3.42	15.88	18.86	5.51
22.	Davis	.37	16.39	150.8	39.60	2.42
23.	Pitcher	.18	.59	2.47	13.61	23.06
24.	Congly	1.54	.70	6.11	70.24	100.69
25.	August Bohl	1.21	.82	6.21	145.38	177.86
26.	Yezzi	1.77	.61	9.11	117.47	193.26
27.	Figliomeni	2.46	5.86	26.07	145.12	25.00
28.	Tudor Pines	1.90	1.03	11.62	128.84	125.31
29.	Gorman	2.40	.96	38.44	153.06	159.27
30.	Pattersonville	1.89	.69	2.23	129.79	188.63
30a	Pattersonville (Duplicated)	2.58	.87	2.74	130.82	149.86
31.	Pompa	1.92	.28	3.34	1.39	4.93
32.	Y.K. Green	.70	30.23	5.53	69.44	2.30
33.	Bloodgood	2.90	18.63	83.3	76.53	4.16
34.	Saratoga Veterinary Hospital	1.29	36.23	2.14	42.52	1.18
35.	Wilson	1.08	3.32	97.5	14.34	4.32
36.	Middletown Springs	4.41	1.20	56.7	2.88	2.40
37.	Lebanon Springs	1.37	1.72	55.8	8.28	4.82
38.	Fred George	1.01	.98	35.7	32.31	3.31
39.	Celestins	NA	4.50	15.9	14.16	3.15
40.	L'Hôpital	NA	3.17	16.4	34.80	10.97

TABLE 3

CALCULATED RESULTS -

SPRING

Index Number	Location	Log K	Calculated Alkalinity	Excess Alkalinity	HCO_3	Excess HCO_3	Apparent Pco_2/Atm
1.	Old Iron	1.134	+18.784	-4.083	+23.778	+1.895	+1.280
2.	Bischoff	1.181	+10.232	-52.834	+81.526	+26.656	+4.389
3.	Hathorn #3	1.003	+11.333	-64.592	+80.127	+11.656	+4.314
4.	Polaris	1.061	+25.334	-5.768	+37.965	+9.135	+2.044
5.	Orenda	.994	+8.640	-44.273	+60.345	+12.692	+3.249
6.	The Geyser	1.039	+36.026	+0.952	+42.761	+9.847	+2.302
7.	Lincoln #12	1.008	+21.852	-8.167	+40.363	+12.503	+2.173
8.	Rosemary	.770	+30.798	+4.281	+32.970	+7.836	+1.775
9.	Congress #1	1.003	+17.605	+0.686	+19.662	+3.086	+1.058
10.	Hathorn #1	1.226	+20.356	-10.315	39.764	+11.081	
11.	Big Red	1.275	+44.314	-3.973	+49.155	+2.584	+2.646
12.	Peerless	1.046	+34.725	+3.548	+36.467	+7.285	+1.963
13.	Red	1.113	+19.040	-2.028	+22.979	+3.755	+1.237
14.	Gum Spring	1.090	+31.448	+5.814	+36.766	+12.575	+1.979
15.	Quaker	1.747	+27.640	+21.472	+36.167	+30.348	+1.947
16.	Bennet	1.214	+34.819	+15.383	+45.159	+26.681	+2.431
17.	Martin Well	1.399	+20.846	+11.145	+42.561	+32.801	+2.291
18.	Doster	1.693	+29.878	+23.012	+43.161	+36.182	+0.232
19.	McNeil	1.003	+13.649	+1.213	+14.586	+2.726	+0.785
20.	McNeil (duplicated)	.933	+11.732	+0.190	+13.987	+3.042	+0.753
21.	Middletown Springs	.687	+1.365	-0.029	+12.288	+10.745	+0.066

TABLE 3 (continued)

Index Location Number		Log K	Calculated Alkalinity	Excess Alkalinity	Titrated Alkalinity	Excess HCO_3	Apparent Pco_2/Atm.
22.	Vita Spring	.994	+12.192	+7.713	+22.579	-7.572	+1.215
23.	Davis	1.564	+2.107	+6.717	+12.388	-45.168	+0.066
24.	Pitcher	1.155	+3.059	-2.659	+7.293	-41.745	+0.561
25.	Pattersonville	1.936	+2.988	-6.483	+5.295	-5.068	+0.040
26.	Congly	1.60	-4.986	-15.731	+4.196	-5.585	+0.322
27.	Auguste Bohl	1.888	-4.515	-7.270	+6.873	+4.292	+0.052
28.	Yezzi	1.893	+1.122	-0.100	+5.515	+4.246	+0.042
29.	Figliomeni	1.778	+28.264	+27.826	+29.833	+29.324	+0.160
30.	Tudor Pines	1.797	+3.791	+3.099	+5.654	+5.131	+0.004
31.	Pompa	.675	+9.847	+0.048	+5.994	-5.372	+0.046
32.	YK Green	1.686	+4.740	+4.019	+5.095	+4.280	+0.003
33.	Bloodgood	1.623	+1.928	+1.829	+2.178	+2.040	+0.000
34.	Saratoga Veterinary Hospital	1.623	+4.039	+3.525	+0.043	-0.459	+0.000
35.	Lebanon Springs	1.115	+2.400	+0.044	+2.537	-0.310	+0.001
36.	Fred George	1.744	+1.713	-0.001	+1.838	-0.064	+0.001

All values expressed in moles/liter except:

Apparent Pco_2 = Atmospheres

Log K = Numerical

TABLE 4

Analyses of Saratoga waters by Dr. Charles F. Chandler (1860-1875), recast by Kemp as ions in parts per million

	Geyser Spouting	Hathorn #3	Congress	Empire	High Rock	Crystal	Vichy	United States
Cl	5 997.6	5 338.0	4 195.6	5 242.2	4 097.3	3 456.1	1 441.8	1 533.4
Br	28.9	20.4	112.9	1.9	9.7	5.5	13.0	11.2
I	3.6	2.7	2.0	8.7	1.2	0.9	tr.	0.6
HCO_3	5 374.0	4 993.2	4 519.9	2 189.4	2 977.6	2 618.0	2 896.0	2 398.1
SO_4	3.0	tr.	8.4	25.9	15.1	20.2	tr.	0.2
PO_4	tr.	0.1	0.2	0.3	tr.	0.1	tr.	0.2
SiO_2	11.9	21.4	14.3	24.8	38.4	54.6	12.8	54.1
Na	4 267.0	3 435.7	2 759.1	3 450.2	2 774.7	2 244.2	1 249.7	973.4
K	221.0	85.0	78.2	59.5	92.1	90.6	125.8	76.7
Li	11.9	20.4	8.5	3.6	3.4	7.6	3.1	8.5
Ca	710.8	712.3	598.4	457.3	549.6	425.0	397.8	388.6
Ba	18.4	15.8	8.4	0.6	4.5	6.6	5.4	8.2
Sr	2.7	tr.	tr.	tr.	tr.	tr.	tr.	0.1
Mg	417.1	492.7	340.3	120.1	153.5	210.0	115.9	203.7
Fe	5.4	6.8	1.9	4.4	8.1	22.1	0.2	3.9
Al	tr.	1.2	tr.	3.8	11.1	2.8	4.1	0.8
Total	16 856.0	15 102.8	11 915.0	11 567.2	10 718.5	9 132.4	6 244.5	5 641.0

Source: The Mineral Springs of Saratoga, James F. Kemp, N.Y.S. Museum Bulletin 159, 1912

TABLE 5

Analyses of Saratoga waters by J.K. Haywood and B.H. Smith, United States Department of Agriculture, 1905. Parts per million in ions.

	Hathorn #3	Lincoln	Hathorn #1	Congress	Geyser	Peerless	Vichy	High Rock	Hide S Franklin, Ballston
Cl	4 674.7	4 068.4	3 685.5	3 327.9	1 025.1	1 773.1	915.0	483.3	7 179.0
Br	47.1	76.0	26.9	26.8	11.8	16.8	tr.	6.7	60.0
I	1.7	1.9	1.5	0.8	1.0	1.0	tr.	.2	2.3
HCO_3	4 147.1	4 221.0	3 585.6	3 573.3	4 353.2	2 634.4	778.2	1 114.0	6 566.0
SO_4	3.4	3.5	5.6	8.7	1.4	4.0	20.2	15.7	3.0
PO_4	- -	- -	- -	- -	- -	- -	- -	- -	- -
SiO_2	16.2	32.7	19.6	19.8	20.8	14.8	16.2	33.4	27.6
Na	2 951.8	2 688.0	2 430.7	2 199.3	2 010.9	1 298.5	828.8	348.0	4 833.0
K	197.8	243.7	197.2	192.0	29.0	94.7	3.9	34.3	346.0
Li	7.4	1.8	0.5	5.4	3.6	0.4	0.1	0.9	15.5
Ca	765.0	675.8	650.7	562.1	116.4	530.4	48.7	223.9	991.0
Ba	7.5	11.7	5.5	7.1	2.6	2.1	- -	0.7	13.1
Sr	- -	- -	tr.	- -	tr.	- -	- -	- -	tr.
Mg	328.0	325.9	228.8	278.2	60.6	90.9	10.1	60.6	469.0
FeAl	6.7	13.9	9.8	14.7	8.4	5.6	2.2	12.3	21.4
NO_3	- -	tr.	- -	- -	tr.	- -	- -	6.6	- -
NO_2	tr.	- -	- -	tr.	- -	tr.	- -	- -	- -
MN	- -	- -	- -	- -	- -	- -	- -	- -	tr.
NH_4	12.8	7.3	10.7	10.3	11.4	5.9	0.9	1.5	14.5
Total	13 170.3	12 371.6	10 858.6	10 232.7	7 656.2	6 472.6	2 629.2	2 347.2	20 542.6

Source: The Mineral Springs of Saratoga, J. F. Kemp, N.Y.S. Museum Bulletin 159, 1912.

TABLE 6

SiO_2 Results in mg/l

Index Number	Location	Spring	Fall
1.	Old Iron	21	45
2.	Bischoff	9.5	16
3.	Hathorn #3	7.1	12
4.	Polaris	13	21
5.	Orenda	7.3	13
6.	The Geyser	27	45
7.	Lincoln #12	33	45
8.	Rosemary	38	40
9.	Congress #1	9.1	15
10.	Hathorn #1	7.9	13
11.	Big Red	46	70
12.	Peerless	9.6	16
13.	Red	37	46
14.	Gurn Spring	37	55
15.	Quaker	9.0	15
16.	Bennet	11.0	17
17.	Martin	10	16
18.	Doster	7.7	13
19.	McNeil	15	22
20.	McNeil (duplicated)	15	
21.	Middletown Springs	3.4	5.0

TABLE 6 (Continued)

Index Number	Location	Spring	Fall
22.	Vita Spring	14	22
23.	Davis	12	18
24.	Pitcher	9.0	15
25.	Pattersonville	6.5	11
26.	Congly	6.5	10
27.	Auguste Bohl	10	17
28.	Yezzi	11	11
29.	Figliomeni	6.2	12
30.	Tudor Pines	5.4	10
31.	Pompa	7.2	12
32.	YK Green	6.9	11
33.	Bloodgood	6.2	11
34.	Saratoga Veterinary Hospital	6.4	11
35.	Lebanon Springs	9.1	15
36.	Fred George	10	16

TABLE 7

Ra ^{226} pci/l*

Index Number	Location	Result	Sampling Date
1	Old Iron	10.1± .81	Fall, 1978
2	Bischoff	135± 5.4	Fall, 1978
3	Hathorn #3	430± 37	Spring, 1971
4	Polaris	102± 8	Spring, 1971
5	Orenda	232± 18	Spring, 1971
6	Geyser	25± 2	Spring, 1971
7	Lincoln #12	32± 2.2	Fall, 1978
8	Rosemary	12.2± .85	Fall, 1978
9a	Congress	32± 1.0	Spring, 1972
9b	Congress	6.0± .66	Fall, 1978
9c	Congress (Duplicated)	10.7± .86	Fall, 1978
10	Hathorn #1	220± 18	Spring, 1971
11	Big Red	23± 3.2	Fall, 1978
12	Peerless	82± 8	Spring, 1971
13	Red	81± 7	Spring, 1971
14	Gurn	42± 1.3	Fall, 1978
15	Quaker	6.1± .43	Fall, 1978
16	Bennet	1.6± .22	Fall, 1978
17	Martin	13.1± 1.2	Fall, 1978
18	Doster	8.6± .69	Fall, 1978
19	McNeil	19.4± 1.2	Fall, 1978
20	Sharon	3.9± .43	Fall, 1978
20a	Sharon Springs (Duplicated)	.25± .08	Fall, 1978
20b	Sharon Springs	.19± .17	Fall, 1978
21	Vita Spring	.5± .12	Fall, 1978
22	Davis	.15± .08	Fall, 1978

---

*pci/l = pico curies/liter

TABLE 7 (continued)

Index Number	Location	Result	Sampling Date
23	Pitcher	.12± .07	Fall, 1978
24	Congly	7.6± .46	Fall, 1978
25	August Bohl	3.1± .40	Fall, 1978
26	Yezzi	3.1± .29	Fall, 1978
27	Figliomeni	1.5± .26	Fall, 1978
28	Tudor Pines	1.1± .20	Fall, 1978
29	Gorman	13.2± .8	Fall, 1978
30	Pattersonville	1.3± .2	Fall, 1978
30a	Pattersonville (Duplicated)	2.8± .3	Fall, 1978
31	Pompa	2.3± .3	Fall, 1978
32	Y.K. Green	.14± .11	Fall, 1978
33	Bloodgood	.19	Fall, 1978
34	Saratoga Veterinarian Hospital	NA	
35	Wilson	NA	
36	Middletown Springs	.08	Fall, 1978
37	Lebanon Springs	.26± .08	Spring, 1971
37a	Lebanon Springs	.28± .13	Fall, 1978
38	Fred George	.4± .18	Fall, 1978
39	Celestins	25± 2	Summer, 1971
40	L'Hôpital	NA	

NOTE: NA = Not Available

BIBLIOGRAPHY

Armstead, H.C.H., Editor, 1973, Geothermal Energy: Review of Research and Development: Elnesco, 186 p.

Arnow, T., 1951, The Ground-Water Resources of Fulton County, New York: State of New York Water Power and Control Commission, Bulletin GW-24, 41 p.

Asselstine, E.S., and Grossman, I.G., 1956, Saline Waters in New York State-Upstate New York: State of New York Water Power and Control Commission, Bulletin GW-36, pp. 5-15.

Barbier, E., and Fanelli, M., 1976, Relationships as Shown in ERTS Satellite Images Between Main Fractures and Geothermal Manifestations in Italy: in Proceedings, 2nd U.N. Symposium on the Development and Use of Geothermal Resources, Vol. 2, pp. 883-888.

Barnes, I., and O'Neil, J.R., 1976, Metamorphic Reactions in Flysch Rocks: Proceedings of the International Symposium on Water-Rock Interaction, J.Cadek and T. Pacess, Editors, Prague, Czechoslovakia, pp. 309-316.

Bottinga, Y., 1968, Calculation of Fractionation Factors for Carbon and Oxygen Isotopic Exchange in the System Calcite-Carbon Dioxide-Water: Journal of Physical Chemistry, Vol. 72, No. 3, pp. 800-807.

Bottinga, Y., 1969, Calculated Fractionation Factors for Carbon and Hydrogen Isotope Exchange in the System Calcite-Carbon Dioxide-Graphite-Methane-Hydrogen-Water Vapor: Geochemica, et Cosmochimica Acta, Vol. 33, pp. 49-54.

Bowman, H.R., Herbert, J.J., Wollenberg, H.A., and Asaro, F., 1976, Trace, Minor and Major Elements in Geothermal Waters and Associated Rock Formations (North-Central Nevada): in Proceedings, 2nd U.N. Symposium on the Development and Use of Geothermal Resources, Vol. 1, pp. 699-702.

Broecher, W.S., and Oversby, V.M., 1971, Chemical Equilibria in the Earth: McGraw-Hill, publishers, 318 p.

Brondi, M., Dall'Aglio, M. and Vitrani, F., 1973, Lithium as a Pathfinder Element in the Large Scale Hydrogeochemical Exploration for Hydrothermal Systems: Geothermics, Vol. 2, pp. 142-153.

Brownlow, A.H., 1979, Geochemistry: Prentice Hall, 498 p.

Brunnschweiler, K.A., 1976, Geothermal Power Station on a Hot, Dry Rock Source: in Proceedings, 2nd U.N. Symposium on the Development and Use of Geothermal Resources, Vol. 3, pp. 1565-1570.

Clayton, R.N., Muffler, L.J.P. and White, D.E., 1968, Oxygen Isotope Studies of Calcite and Silicates of the River Ranch No. 1 Well, Saltan Sea Geothermal Gield, California: American Journal of Science, Vol. 266, pp. 968-979.

Clayton, R.N., and Steiner, I., 1975, Oxygen Isotope Studies of the Geothermal System at Wairakei, New Zealand: Geochimica et Cosmochimica Acta, Vol. 39, pp. 1179-1186.

Colony, R.J., 1930, Report on a Restudy of the Geology of the Saratoga Area and the Problem of the Mineral Waters: State of New York, Report of Saratoga Springs Commission, Legislative Document 70.

Combs, J., and Rotstein, Y., 1976, Microearthquake Studies at the Coso Geothermal Area, China Lake, California: in Proceedings, 2nd U.N. Symposium on the Development and Use of Geothermal Resources, Vol. 2, pp. 909-916.

Combs, J., and Wilt, M., 1976, Telluric mapping, Telluric Profiling, and Self-Potential Surveys of the Dunes Geothermal Anomaly, Imperial Valley, California: in Proceedings, 2nd U.N. Symposium on the Development and Use of Geothermal Resources, Vol. 2, pp. 917-928.

Cortecci, G., 1973, Oxygen 18 and Carbon 13 Contents of the Sulfates and Carbonates Associated in Some Oxidizing Geothermal Environments: Geothermics, Vol. 2, No. 2, pp. 51-56.

Cortecci, G., 1974, Oxygen Isotopic Ratios of Sulfate Ions-Water Pairs as a Possible Geothermometer: Geothermics, Vol. 3, No. 2, pp. 60-64.

Costain, J.K., Glover, L. III, and Ginha, A.K., 1977, Evaluation and Targeting of Geothermal Energy Resources in the Southeastern United States, Progress Report, April 1, 1977-June 30, 1977: UPI-SU-5103-4, 82 p.

Craig, H., 1954, Geochemical Implications of the Isotopic Composition of Carbon in Ancient Rocks: Geochimica et Cosmochimica Acta,Vol. 6, pp. 186-196.

Craig, H., 1961, Isotopic Variations in Meteoric Waters: Science, Vol. 133, pp. 1702-1703.

Craig, H., 1966, Isotopic Composition and Origin of the Red Sea and Salton Sea Geothermal Brines: Science, Vol. 154, pp. 1544-1548.

Cushing, H.P., and Ruedemann, R., 1914, Geology of Saratoga Springs and Vicinity: New York State Museum Bulletin 169, University of the State of New York.

Cusicangui, H., Mahon, W.A.J. and Ellis, A.J., 1976, The Geochemistry of the El. Jatio Geothermal Field, Northern Chile: in Proceedings, 2nd U.N. Symposium on the Development and Use of Geothermal Resources, Vol. 1, pp. 703-712.

D'Amore, F., 1975, Radon-222 Survey in Lardello Geothermal Field, Italy (Part I): Geothermics, Vol. 4, pp. 96-108.

D'Amore, F., and Nuti, S., 1977, Notes on the Chemistry of Geothermal Gases: Geothermics, Vol. 6, pp. 39-46.

D'Amore, F., and Gabroux, J.C., 1977, Signification de la Presence de Radon 222 Dans Les Fluides Geothermiques: Bulletin Voleanology, Vol. 40-2, pp. 106-115.

Deines, P., Langmuir, D., and Harmon, R.S., 1974, Stable Carbon Isotope Ratios and the Existence of a Gas Phase in the Evolution of Carbonate Ground Waters: Geochimica et Cosmochimia Acta, Vol. 38, pp. 1147-1164.

Deuser, W.G., and Degens, E.T., 1967, Carbon Isotope Fractionation in the System CO_2 (Gas) - CO_2 (aqueous) - HCO_3^- (aqueous): Nature, Vol. 215, pp. 1033-1035.

Dowgiallo, J., and Tongiorgi, E., 1972, Isotopic Composition of Oxygen and Hydrogen in Some Brines From the Mesozoic in Northwest Poland: Geothermics, Vol. 1, No. 2, pp. 67-69.

Eichmann, R., and Schidlowski, M., 1975, Isotopic Fractionation Between Coexisting Organic Carbon-Carbonate Pairs in Precambrian Sediments: Geochimica et Cosmochimica Acta, Vol. 39, pp. 585-595.

Ellis, A.J., and Mahon, W.A.J., 1964, Natural Hydrothermal Systems and Experimental Hot-Water/Rock Interactions: Geochimica et Cosmochimica Acta, Vol. 28, pp. 1323-1357.

Emrich, K., Ehhalt, D.H., and Vogel, J.C., 1970, Carbon Isotope Fractionation During the Precipitation of Calcium Carbonate: Earth and Planetary Science Letters 8, pp. 363-371.

Fancelli, R., and Nuti, S., 1974, Locating Interesting Geothermal Areas in the Tuscany Region (Italy) by Geochemical and Isotopic Methods: Geothermics, Vol. 3, No. 4, pp. 146-152.

Farmer, R.E., 1965, Genesis of Subsurface Carbon Dioxide: in Fluids in Subsurface Environments; American Association Petroleum Geologists No. 4, pp. 378-385.

Felmlee, J.K., and Cadigan, R.A., 1978, Radium and Uranium Data for Mineral Springs in Eight Western States: U.S. Geological Survey, Open-file Report 78-561, 45p.

Fouillac, C., Cailleaux, P., Michard, G., and Merlivat, L., 1976, Preliminary Geothermic Studies on Mineral Water in French Massif Central: in Proceedings 2nd U.N. Symposium on the Development and Use of Geothermal Resources, Vol. 1, pp. 726-730.

Fournier, R.O., and Truesdell, A.H., 1973, An Empirical Na-K-Ca Geothermometer for Natural Waters: Geochimica et Cosmochimica Acta, Vol. 37, pp. 1255-1275.

Fournier, R.O., and Truesdell, A.H., 1974, Geochemical Indicators of Subsurface Temperature-Part 2, Estimation of Temperature and Fraction of Hot Water Mixed with Cold Water: Journal of Research, U.S. Geological Survey, Vol. 2, No. 3, pp. 263-270.

Fournier, R.O., White, D.E., and Truesdell, A.H., 1974, Geochemical Indicators of Subsurface Temperature-Part 1, Basic Assumptions: Journal of Research, U.S. Geological Survey, Vol. 2, pp. 259-262.

Friedman, I., 1970, Some Investigations of the Deposition of Travertine From Hot Springs - The Isotopic Chemistry of a Travertine Depositing Spring: Geochimica et Cosmochimica Acta, Vol. 34, pp. 1303-1315.

Gasparini, P., and Mantovani, M.S.M., 1978, Radon Anomalies and Volcanic Eruptions: Journal Volcanal., Geothermal Resource, Vol. 3, pp. 325-341.

Grab, D.L., Meents, W.F., Friedman, I., and Shimp, N.F., 1966, The Origin of Saline Formation Waters, III, Calcium Chloride, Waters: Illinois State Geological Survey Circular 397, 60 pp.

Gunter, B.D., 1973, Aqueous Phase-Gaseous Phase Material Balance Studies of Argon and Nitrogen in Hydrothermal Features at Yellowstone National Park: Geochimica et Cosmochimica Acta, Vol. 37, pp. 495-513.

Heath, R.C., 1964, Ground Water in New York: State of New York Conservation Department Water Resources Commission, Bulletin GW-51.

Heath, R.C., Mack, F.K., and Tannenbaum, J.A., 1963, Ground-Water Studies in Saratoga County, New York: State of New York, Department of Conservation Water Resources Commission, Bulletin GW-49, 128 p.

Helz, G.R., and Sinex, S.A., 1974, Chemical Equilibria in the Thermal Spring Waters of Virginia: Geochimica et Cosmochima Acta, Vol. 38, pp. 1807-1820.

Hickey, J.L.S., and Campbell, S.D., 1968, High Radium-226 Concentrations in Public Water Supplies: Public Health Reports, Vol. 83, No. 7, pp. 551-557.

Hitchon, B., and Friedman, I., 1969, Geochemistry and Origin of Formation Waters in the Western Canada Sedimentary Basin-I. Stable Isotopes of Hydrogen and Oxygen: Geochimica et Cosmochimica Acta, Vol. 33, pp. 1321-1349.

Hobba, W.A., Chemerys, J.C., Fisher, D.W., and Peattson, F.J., 1976, Geochemical and Hydrologic Data for Wells and Springs in Thermal Spring Areas of the Appalacians: U.S. Geological Survey Open-File Report No. 76-550.

Hoefs, J., 1973, Stable Isotope Geochemistry: Springer-Verlag, publishers, 144 p.

Imahashi, M. Kamiya, H., and Watanuki, K., 1975, Participation of Sulfuric Acid in Thermal Water-Rock Interaction: Geochemical Journal, Vol. 9, pp. 177-180.

Irwin, W.P., and Barnes, I., 1975, Effect of Geologic Structure and Metamorphic Fluids on Seismic Behavior of the San Andreas Fault System in Central and Northern California: Geology, Vol. 3, No. 12, pp. 713-716.

Isachsen, Y.W., 1975, Possible Evidence of Contemporary Doming of the Adirondack Mountains, New York, and Suggested Implications for Regional Tectonics and Seismicity: Tectonophysics, Vol. 29, pp. 169-181.

Jacobson, R.L., and Langmuir, D., 1974, Dissociation Constanty of Calcite and $CaHCO_3^+$ from 0 to 50°C: Geochimica et Cosmochimica Acta, Vol. 38, pp. 301-318.

Kane, M.F., Simmons, G.Diment, W.H., Fitzpatrick, M.M., Joyner, W.B., and Bromery, R.W., 1972, Bouger Gravity and Generalized Geologic Map of New England and Adjoining States: U.S. Geological Survey, Geophysicsl Investigation Map, GP-839.

Kemp, J.F., 1912, The Mineral Springs of Saratoga: New York State Museum Bulletin 159, University of the State of New York.

Knauth, L.P., and Epstein, S., 1976, Hydrogen and Oxygen Isotope Ratios in Nodular and Bedded Cherts: Geochimica et Cosmochimica Acta, Vol. 40, pp. 1095-1108.

Kramer, J.R., 1969, The Subsurface Brines and Mineral Equlilbria: Chemical Geology, Vol. 4, pp. 37-50.

Krauskopb, K.B., 1967, Introduction to Geochemistry: 721 p.

Lang, W.B., 1959, The Origin of Some Natural Carbon Dioxide Gases: Journal of Geophysical Research, Vol. 64, No. 1, pp. 127-131.

Love, S.K., 1951, Natural Radioactivity of Water: Industrial and Engineering Chemistry, Vol 43, No. 7, pp. 1541-1544.

Lusczynski, N.J., and Geraghty, J.J., 1956, Saline Waters in New York State-Long Island, Staten Island and Manhatten: State of New York Water Power and Control Commission, Bulletin GW-36, pp. 1-4.

Matthews, A., and Katz, A., 1977, Oxygen Isotope Fractionation During The Dolomitization of Calcium Carbonate: Geochimica et Cosmochimica Acta, Vol. 41, pp. 1431-1438.

Mazor, E., 1972, Paleotemperatures and Other Hydrological Parameters Deduced from Mobile Gases Dissolved in Groundwaters; Jordan Rift Valley, Israel: Geochimica et Cosmochimica Acta, Vol. 36, pp. 1321-1336.

Major, E., 1977, Geothermal Tracing With Atmospheric and Radiogenic Noble Gases: Geothermics, Vol. 5, pp. 21-36.

Meidav, T., and Tonani, F., 1976, A Critique of Geothermal Exploration Techniques: in Proceedings, 2nd U.N. Symposium on the Development and Use of Geothermal Resources, Vol. 2, pp. 1143-1154.

Mitchell, R.H., and Krouse, H.R., 1975, Sulphur Isotope Geochemistry of Carbonatites: Geochimica et Cosmochimica Acta, Vol. 39, pp. 1505-1513.

Newland, D.H., 1906, The Mining and Quarrying Industry of New York State: New York State Museum Bulletin 102, 199 p.

Newland, D.H., 1909, The Mining and Quarrying Industry of New York State: New York State Museum Bulletin 132, pp. 40-45.

Newland, D.H., 1910a, The Mining and Quarrying Industry of New York State: New York State Museum Bulletin 142, pp. 53-57.

Newland D.H., 1910b, The Mining and Quarrying Industry of New York State: New York State Museum Bulletin 151, pp. 40-44.

Newland, D.H., 1912, The Mining and Quarrying Industry of New York State: New York State Museum Bulletin 166, pp. 40-44.

Newland, D.H., 1915, The Mining and Quarrying Industry of New York State: New York State Museum Bulletin 178, pp. 42-44.

Newland, D.H., and Hartnagel, C.A., 1928, The Mining and Quarrying Industries of New York for 1925 and 1926: New York State Museum Bulletin 277, pp. 66-68.

Newland, D.H., and Hartnagel, C.A., 1936, The Mining and Quarrying Industries of New York State for 1930 to 1933: New York State Museum Bulletin 305, pp. 56-58, 68-69.

Northrop, D.A., and Clayton, R.N., 1965, Oxygen-Isotope Fractionations in Systems Containing Dolomite: Journal of Geology, Vol. 74, pp. 174-196.

Norton, D., 1977, Exploration Criteria for Low Permeability Geothermal Resources, Progress Report, June 1975-March 1,1977: ERDA, C00-2763-1, 186 p.

Pačes, T., 1975, A Systematic Deviation From Na-K-Ca Geothermometer Below 75°C and above 10^{-4} atm P_{CO_2}: Geochimica et Cosmochimica Acta, Vol. 39, pp. 541-544.

Panicki, C., and Tongiorgi, E., 1976, Carbon Isotopic Composition of CO_2 From Springs Fumaroles, Mofettes and Travertines of Central and Southern Italy; A Preliminary Prospection Method of a Geothermal Area: in Proceedings, 2nd U.N. Symposium on the Development and Use of Geothermal Resources, Vol. 1, pp. 815-826.

Peale, A.C., 1886, Mineral Springs of the United States: U.S. Geological Survey Bulletin 32, pp. 18-41.

Potter, R.W., II, 1976, An Assessment of the Status of the Available Data on the PVT Properties for the Major Components in Geothermal Brines: in Proceedings, 2nd U.N. Symposium on the Development and Use of Geothermal Resources, Vol. 1, pp. 827-830.

Puckhaber, B.C., 1976, Saratoga: Journal Press, 91 p.

Risk, G.F., 1976, Detection of Buried Zones of Fissured Rock in Geothermal Fields Using Resistivity Anisotropy Measurements: in Proceedings 2nd U.N. Symposium on the Development and Use of Geothermal Resources, Vol. 2, pp. 1191-1198.

Rog, R.F., Decker, E.R., Blackwell, D.D., and Birch, F., 1968, Heat Flow in the United States: Journal of Geophysical Research, pp. 5207-5221.

Sharma, T., and Clayton, R.N., 1965, Measurement of O^{18}/O^{16} ratios of Total Oxygen of Carbonates: Geochimica et Cosmochimica Acta, Vol. 29, pp. 1347-1353.

Simpson, E.G., 1952, The Ground Water Resources of Schenectady County, New York: New York Water Power and Control Commission Bulletin GW-30, 110 p.

Smith, B.M., Grune, W.N., Higgins, F.B., Jr., and Terrill, J.G., Jr., 1961, Natural Radioactivity in Ground Water Supplies in Maine and New Hampshire: Journal of American Water Works Association, Vol. 53, No. 1, pp. 75-88.

Stoker, A.K., and Kruger, P., 1976, Radon in Geothermal Reservoirs: in Proceedings, 2nd U.N. Symposium on the Development and Use of Geothermal Resources, Vol. 3, pp. 1797-1804.

Strock, L.W., 1941, Geochemical Data on Saratoga Mineral Waters-Applied in Deducing a New Theory of Their Origin: American Journal of Science, Vol. 299, No. 12, pp. 857-899.

Swamberg, C.A., 1975, Detection of Geothermal Components in Groundwaters of Dona Ana County, Southern Rio Grande Rift, New Mexico: New Mexico Geological Society 26th Annual Field Conference Guidebook to the Las Cruces Country.

Taylor, H.P. Jr., Frechen, J., and Degens, E.T., 1967, Oxygen and Carbon Isotope Studies of Carbonites from the Roacher Sea District, West Germany and the Alno District, Sweden: Geochimica et Cosmochimica Acta, Vol. 31, pp. 407-430.

Thode, H.G., Shima, M., Rees, C.E., and Krishnamurtz, K.V., 1965, Carbon-13 Isotope Effects in Systems Containing Carbon Dioxide, Bicarbonate, Carbonate, and Metal Ions: Canadian Journal of Chemistry, Vol. 43, pp. 582-595.

Truesdell, A.H., and Singers, W., 1974, The Calculation of Aquifer Chemistry in Hot-Water Geothermal Systems: Journal of Research, U.S. Geological Survey, Vol. 2, No. 3, pp. 271-278.

Truesdell, A.H., 1976, Geoterm, A Geothermometric Computer Program for Hot-Spring Systems: in Proceedings, 2nd U.N. Symposium on the Development and Use of Geothermal Resources, Vol. 1, pp. 831-836.

Truesdell, A.H., 1976, Summary of Section III: Geochemical Techniques in Exploration: in Proceedings, 2nd U.N. Symposium on the Development and Use of Geothermal Resources, Vol. 1, pp. 53-86.

Truesdell, A.H., and Fournier, R.O., 1976, Calculations of Deep Temperatures in Geothermal Systems From the Chemistry of Boiling Spring Waters of Mixed Origins: in Proceedings, 2nd U.N. Symposium on the Development and Use of Geothermal Resources, Vol. 1, pp. 837-844

Veizer, J., and Hoefs, J., 1976, The Nature of O^{18}/O^{16} and C^{13}/C^{12} Secular Trends in Sedimentary Carbonate Rocks: Geochimica et Cosmochimica Acta, Vol. 40, pp. 1387-1395.

Vogel, J.C., Grootes, P.M. and Mook, W.G., 1970, Isotopic Fractionation Between Gaseous and Dissolved Carbon Dioxide: Z. Physik, Vol. 230, pp. 225-238.

White, D.E., 1957, Magmatic, Connate, and Metamorphic Waters: Geologic Society of America Bulletin, Vol. 68, pp. 1659-1682.

White, D.E., 1965, Saline Waters of Sedimentary Rocks: in Fluids in Subsurface Environment; American Association of Petroleum Geologists Memoir 4, pp. 342-366.

White, D.E., 1967, Mercury and Base Metal Deposits With Associated Thermal and Mineral Waters: in Geochemistry of Hydrothermal Ore Deposits, H.L. Barnes, editor, pp. 575-631.

White, D.E., 1970, Geochemistry Applied to the Discovery, Evaluation, and Exploitation of Geothermal Energy Resources: Geothermics, Special Issue 2, pp. 58-80.

White, D.E., Barnes, I., and O'Neil, J.R., 1973, Thermal and Mineral Waters of Non-Metoric Origin, California Coast Ranges: Geological Society of America Bulletin, Vol. 84, pp. 547-559.

Wold, R.J., and Isachsen, Y.W. 1977, Seismic Reflection Profiles of Lake George, Adirondack Mountains, New York as a Guide to the Meotectonic History of the Region: Geological Society of America, Abstracts with Programs, Vol. 9, p. 1233.

Wollenberg, H.A., 1976, Radioactivity of Geothermal Systems: in Proceedings 2nd U.N. Symposium on the Development and Use of Geothermal Resources, Vol. 2, pp. 1283-1292.

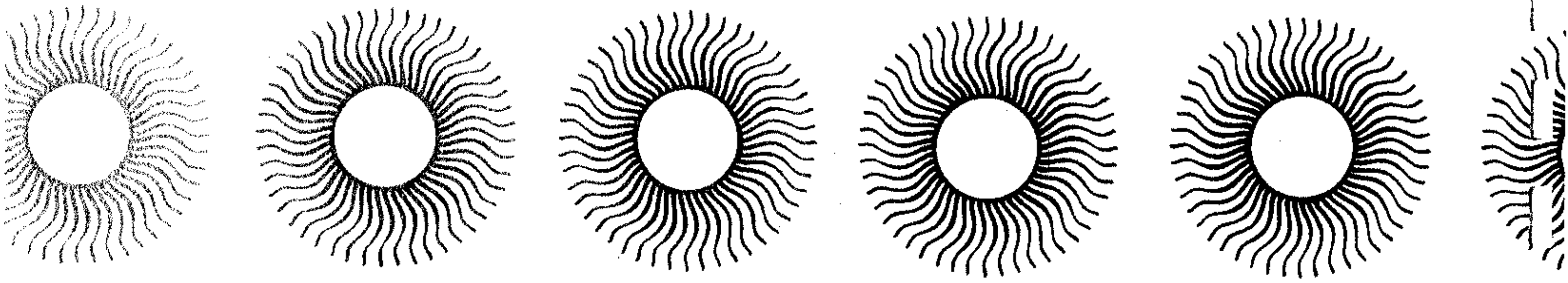
Wollenberg, H., Bowman, H., and Asaro, F., 1977, Geochemical Studies at Four Northern Nevada Hot Spring Areas: Lawrence Berkeley Laboratory, LBL-6808, 69 p.

Young, J.R., and Putman, G.W., 1978, The Puzzle of Saratoga—An Old Solution With a New Twist: Empire State Geogram Vol. 14, No. 2, pp. 17-31.

Zak, I., and Gat, J.R., 1975, Saline Waters and Residual Brines in the Shiraz-Sarvistan Basin, Iran: Chemical Geology, Vol. 16, pp. 179-188.

Zen, E., White, W.S., Hadley, J.B., and Thompson, J.R., Jr., editors, Studies of Appalacian Geology Northern and Maritime: Wiley, 473 p.

New York State Energy
Research and Development
Authority
Rockefeller Plaza
Albany, N.Y. 12223
(518) 465 6251



State of New York **Hugh L. Carey, Governor**

New York State Energy Research and Development Authority
James L. Larocca, Chairman **Dr. A. Bruce Bishop, Executive Director**