STRATIGRAPHY, STRUCTURE, AND THE MINERAL WATERS OF SARATOGA SPRINGS - IMPLICATIONS FOR NEOGENE RIFTING

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INTRODUCTION

The carbonated mineral springs of Saratoga have been the object of considerable interest ever since their discovery by colonists in the late eighteenth century. The three major previous studies (Kemp, 1912; Cushing and Ruedemann, 1913; and Colony, 1930) express the crux of the problem as we see it today. Foremost, among these, is the abundant CO_2 gas and the difficulty of explaining its presence in such large amounts by known shallow, oxidizing mechanisms of generation, or by hydrolysis reactions involving carbonates, the reasons for which will be partially addressed below and further during the field trip. The only known applicable methods remaining are thermal: 1) either direct degassing of an igneous melt or decarbonization of carbonate rocks adjacent to an intrusion, or 2) decarbonization in water-rock equilibria during metamorphism. Recourse to the former mechanism in terms of cooling Paleozoic plutonism has been taken by all three of these earlier workers because of chemical inconsistencies that are also incompatible with low-temperature methods of CO_2 formation; i.e., negligible sulfates, nitrates, and phosphates. This interpretation presents an apparent paradox for all known igneous activity in the Northeastern United States ceased with dike swarms in the middle Mesozoic--about 100 million years ago. Since it is now known that anomalous convective and conductive heat flow from this time should have long since ceased allusions to dying metamorphic or igneous fires from the past are not a really very satisfying explanation; indeed, they have only served to deepen the mystery.

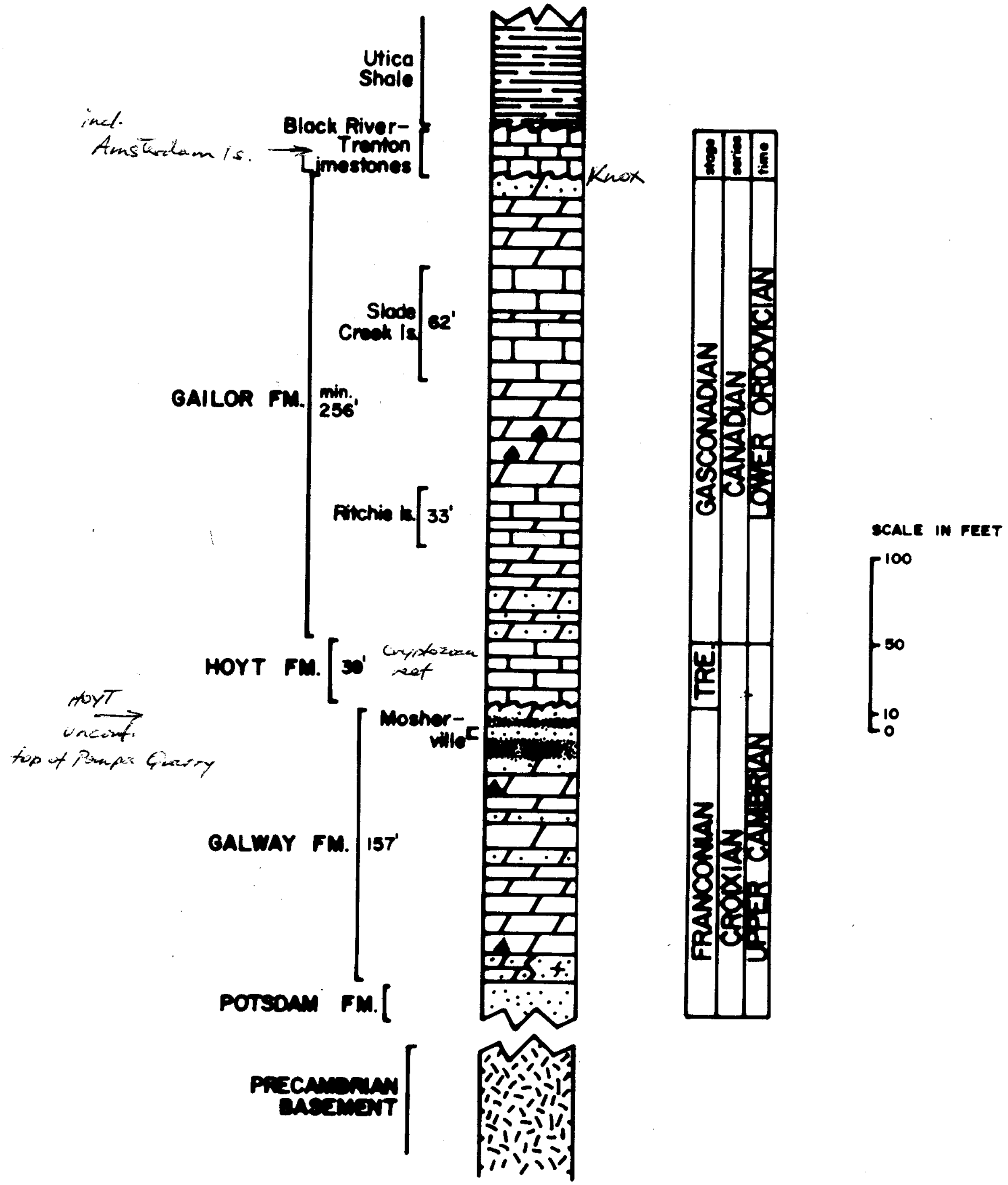
We must ask then, are the waters and gas at Saratoga really thermally generated; and, if so, how can we understand the source of the thermal processes in more definite terms?

STRATIGRAPHY

A large geologic literature exists on the Paleozoic stratigraphy of eastern New York, especially the Cambrian and Ordovician carbonate rocks of the Mohawk Valley and adjacent areas and only a brief description is included here. We will note or briefly stop at all the major lithologies present at Saratoga, however, appreciable time will only be spent with the carbonate section; the principal portion of the aquifer containing the carbonated waters.

A generalized stratigraphic column for the area is depicted in Figure 1. It is based partly on new data from several drill core logs obtained in two quarries near the City of Saratoga Springs (one of which will be visited during this trip) and partially on the published literature. A brief, weighted description of the units is offered below.

GENERALIZED STRATIGRAPHY OF THE SARATOGA AREA



▲ Black Chert

▨ White Chert

(Modified after Mazzullo etal. 1978)

FIGURE 1

PRECAMBRIAN BASEMENT ROCKS

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.

PALEOZOIC AQUIFER SEQUENCE

Potsdam Sandstone - Upper Cambrian

Unconformably overlying the Precambrian basement, the Potsdam sandstone displays moderate lateral variations in thickness and may even have onlapped onto islands which were portions of the ancestral Adirondacks. It is nearly always characterized by a basal conglomeratic layer that grades upward into a well-sorted beach sand with common ripple marks that usually weathers white or buff in outcrop along the southern and eastern Adirondack periphery. It is primarily composed of well-rounded quartz grains with siliceous interstitial cement often making the rock over 95% SiO_2. The basal beds reflect poorer sorting with detrital feldspar, in particular, locally comprising up to 15% or more of a given outcrop. Individual strata form thin layers separated by well-defined bedding planes that may aid in forming effective fracture permeability. While the thickness of the Potsdam is variable, it is believed to total about 100 feet in the Saratoga area and to increase fairly rapidly eastward.

CARBONATE SERIES LOWER TO MIDDLE ORDOVICIAN

Galway Formation

The Potsdam sandstones are gradually replaced upwards by quartzose dolostones and dolostones of the Galway formation without a distinct separating stratigraphic horizon. The name Theresa was commonly used in the past for this alternating transitional sequence, however, the type Theresa occurs north of Watertown and is not continuous through the subsurface. The type Theresa is Ordovician in age whereas that in the eastern Mohawk Valley is Cambrian, hence, the preferred name Galway (Fisher and Hanson, 1951; and Rickard, 1973).

In its upper portions, the Galway is a rather monotonous series of thinly bedded, (two to four feet) fine grained dolostones broken primarily by thin (usually two feet or less) layers of sands and sandy dolostones. Apparently deposited as lime muds in a low energy, shallow marine environment, the formation has been extensively dolomitized, wiping out many of the primary structures. The top 16 feet of this formation consist of interbedded light gray, medium grained, dolomitic sandstone and chert, including a distinctive marker bed of novaculite with characteristic banding and mottling. Its greater resistance to weathering has made it the site of a local unconformity upon which the Hoyt limestone was deposited in the Saratoga Area (George Banino, personal communication).

The remainder of the formation is composed of beds of medium to light gray, massive crystalline, fine to medium grained dolomite. Dolomite and calcite inclusions (usually white and occasionally rose colored) are found throughout the formation but are more abundant in several zones containing vugs with quartz crystals. Quartz grain content in general increases toward the bottom of the formation, reflecting the gradational contact with the Potsdam sandstone.

Hoyt Limestone

A medium gray, cryptocrystalline to coarse crystalline limestone with variable sand content, the Hoyt has received a great deal of attention due to the presence of abundant authigenic K-feldspar and its large, well preserved specimens of cryptozoa. Approximately 40 feet thick in the Saratoga area, the Hoyt reef has been interpreted to represent a high-energy area of carbonate buildup immediately landward of the point of wave-base impingement on the upper Cambrian shelf (Owen, 1973).

Gailor Formation

A series of massive bedded, medium crystalline dolomites varying from light to dark gray, the beds of the Gailor have been extensively dolomitized and are noticeably free of primary structures. Interbedded within the dolomites are occasional thin beds of finely crystalline to cryptocrystalline light gray limestone as well as two major (though local) limestone members. The Ritchie limestone (Fisher and Hanson, 1951; Fisher and Mazzullo, 1976; Mazzullo, et al, 1978) is described as approximately 43 of dark gray, fine to medium crystalline, slightly dolomitized calcilutite. The Slade Creek limestone (Mazzullo, et al., 1978) consists of about 62 feet of dark gray, fine to coarsely crystalline calcilutite.

Trenton and Black River Carbonates

Following deposition of these lower Ordovician carbonates, most of the eastern North American continental shelf was uplifted and eroded forming the regional Knox Unconformity. Deposited on top of this surface are the Middle Ordovician Amsterdam and Trenton Black River limestones; coarsely crystalline, dark gray, fossiliferous limestones separated by a marked disconformity (Fisher and Hanson, 1951). Their thickness is quite variable in the Saratoga area, but the range seems to be from zero to a possible maximum of 250 feet (Colony, 1930).

CAP ROCK - LATE ORDOVICIAN

Shales

Efficiently confining the carbonated mineral waters to the aquifer are an eastward-thickening wedge of poorly understood shales that are truncated at Saratoga by the McGregor and Saratoga faults. Respectively termed the Canajoharie and Schenectady formations (equivalent to the Utica shale) in parts of the Saratoga area; these rocks unconformably overlie the thin Trenton Black River carbonates. Further east and south, the assumed lateral equivalent, the Snake Hill shale, is overlain by the allochthonous rocks of the Taconic thrust sequence.

STRUCTURE

One of the few points which all previous workers have agreed upon is that faults play a major role in controlling the pathways and points of issuance of the waters. This is indeed the case at Saratoga where the large McGregor Fault "breaks up" into several smaller faults, one of which, the Saratoga Fault, has helped contain a vast reservoir of the carbonated waters. Striking about N15E, this system is subparallel to the dominant fault set spanning the Adirondack uplift (Isachsen, 1975). The vast majority of these faults are of the high angle, normal type although a few high angle reverse faults also exist. As the Adirondacks are approached from the Mohawk River, the relief of these scarps tends to increase suggesting that they may have been recently reactivated.

A secondary set of faults with generally less apparent vertical displacement but more sharply defined scarps also exists in this area. These are clearly displayed in the brittle carbonates which are quite literally diced by these breaks. Perpendiculars drawn to the dominant members of this set point toward the center of the Adirondacks, suggesting that they are tensional features formed in response to the uplift. In a few places, small grabens have even been formed, one excellent example of which will be visited during the field trip.

Although mapping has not disclosed evidence for Quaternary movement of these structures, their youthful aspect appears clear. The steep scarps that occasionally exhibit faults directly at their feet decry a prolonged exposure to weathering or glacial unroofing. Should their sharp, blocky character persist under the masking shale cap, the heterogeneity of mixing in the mineral waters can be better understood.

THE WATERS

While the name of Saratoga Springs tend to conjure up visions of bubbling natural orifices, most of carbonated mineral waters actually issue from driven wells that have punctured a thin shale cap to tap the water-bearing Gailor Formation. Only at Gurn Spring, Reid's Mineral Spring, the original Old Iron Spring in Ballston Spa, and the original High Rock Spring in Saratoga Springs has the water had sufficient "force" to drive its way to the surface. Shearing and crushing along the fault from which these springs rise has apparently created sufficiently permeable zones for the waters to flow for a time.

CO_2-charged waters are found not only in the immediate vicinity of Saratoga Springs, but over much of the Cambro-Ordovician basin from Albany north to Whitehall and west along the Mohawk Valley at least as far as Rotterdam Junction (Figure 2). The northern and western boundaries coincide roughly with the first carbonate outcrops while the eastern limit is not known. The areal extent of these waters approaches 1,000 square miles with all observed occurrences confined to the western limb of the central Hudson Valley "geosyncline".

A final physical observation concerns the temperature of the waters. In earlier measurements (Kemp, 1912) as well as recent ones, the waters of Saratoga Springs and Ballston Spa have been found to span a narrow range of $48^{o}F$ to $56^{o}F$. Seasonal variations are noted, yet the range of temperature fluctuation is more

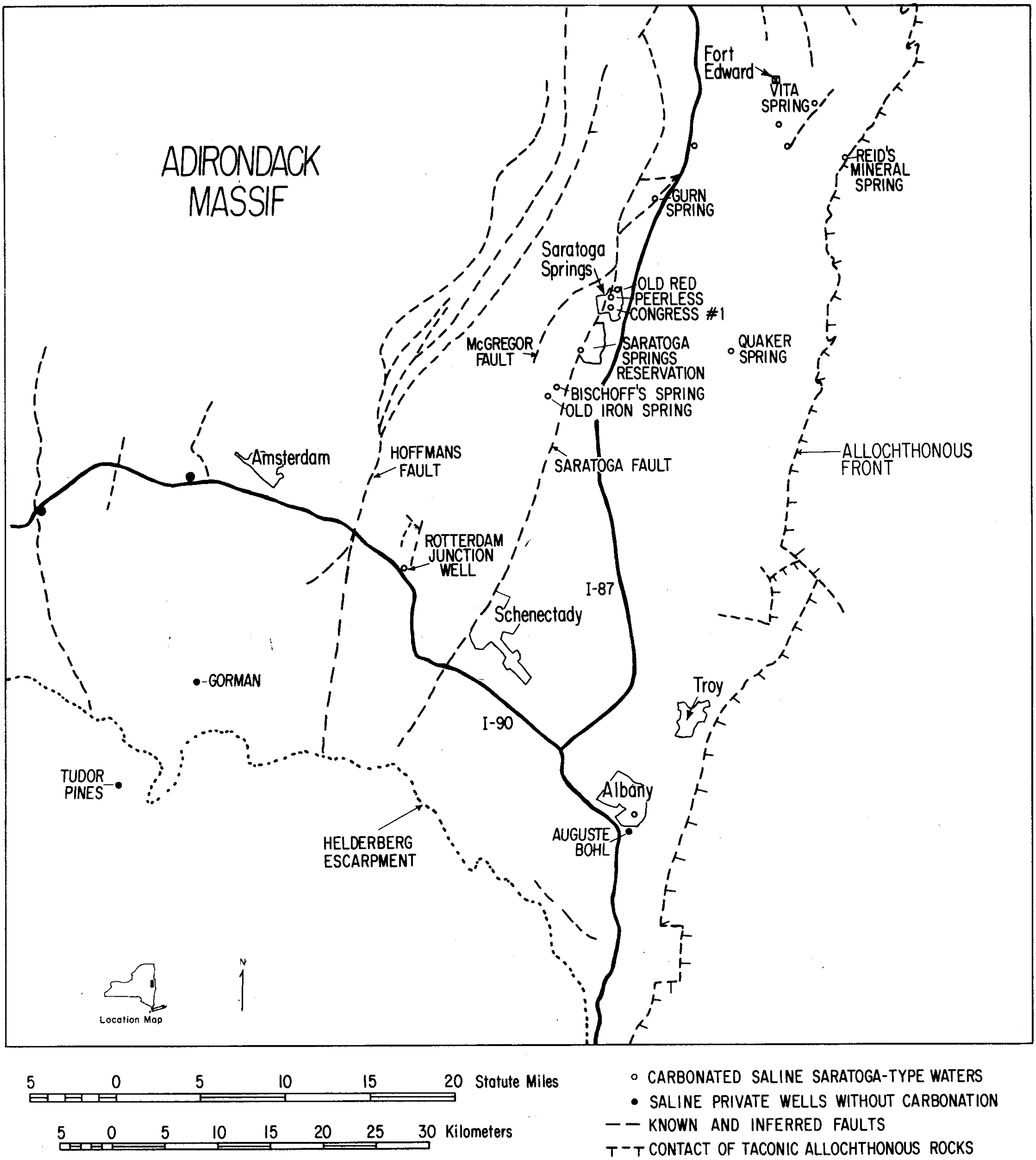


FIGURE 2 LOCATIONS OF WELLS WITH SARATOGA TYPE WATERS OR SALINE WATERS IN THE SARATOGA BASIN

Geology from Geologic Map of New York, 1970, New York State Museum and Science Service Map and Chart No. 15

subdued than in gravel aquifer wells of the same area. Since the mean annual air temperature of Saratoga Springs is 48°F, the wells average about 4°F above normal for this area. This range can be explained quite adequately in terms of the normal geothermal gradient and the average depth of the wells, since surface control wells of similar depths exhibit the same temperature span. In conjunction with the known lack of igneous activity in eastern North America, the cool surface temperature of the water has been one of the major stumbling blocks to any interpretation of thermal processes in an origin of the waters.

CHEMISTRY

The third major complicating factor that appears to have inhibited our understanding of the carbonated waters is complex mixing of water components, including a significant connate water component. Although this was suggested quite early (Cushing and Ruedemann, 1913), no attempt was ever made to test this hypothesis, possibly because uncarbonated wells were not known at the time. In the course of new work several pristine "brine" wells have been located south of the City of Albany and westward along the Mohawk Valley, apparently outside the zone of carbonation. These results are presented in Table 1 and discussed first below because their chemical nature is critical to the task of gauging the proportions of mixing at Saratoga.

SALINE BASINAL OR FORMATION WATERS

By definition, the word brine means to possess at least as much salt as seawater. It is accordingly used loosely herein for the sake of convenience since inspection of Table 1 will show that the total dissolved solids (TDS) content of these waters varies only from 1900 ppm to 6000 ppm and they are properly termed as saline waters. In other respects, the 3 sample waters cited show the following distinct chemical patterns:

1) High Cl^-, Na^+, Br^-, I^-, Sr^{++}

2) Low HCO_3^-, K^+, SiO_2, Ca^{++} and Mg^{++}

3) A ph of 7-8

4) Distinctive groupings of the following molar ratios:

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

In their proportions of major ($Cl^- > Na^+ >> HCO_3^-$) and minor constituents these waters are very similar to connate basinal brines of the NaCl type (White, 1965), except for their much lower salinity. While it is possible that these waters may not have been of higher salinity in the geologic past, proximity to surficial ground water, isotopic data and the similarly diluted basinal brines of Illinois all suggest a continuing and considerable dilution with meteoric water. The ultimate age of at least some of the saline components could therefore be as old as the Paleozoic.

TABLE 1

	SOUTHERN BRINE WATERS			METEORIC SURFACE WATERS		SARATOGA SPRINGS CARBONATED WATERS									
	TUDOR PINES	YEZZI	GORMAN	BLOODGOOD	SARATOGA VETERINARY HOSPITAL	HATHORN no. 3	ORENDA	GEYSER	LINCOLN no. 12	ROSEMARY	HATHORN no. 1	BIG RED	PEERLESS	RED
Date & Time of Sampling	5/25/10	5/02/11	10/20/10	10/06/23	10/06/11	4/19/14	4/09/11	4/09/11	5/04/12	4/18/14	4/18/13	4/09/13	4/18/13	4/18/11
Water Temperature °C	11.1	15.5	10.6	15.5	11.5	10.0	10.0	5.0	12.0	12.0	11.9	11.0	11.0	12.0
Ph(field)	8.2	7.2 SU	7.2	9.2	8.5	6.0	6.2	6.0	6.4	6.0	6.2	6.0	6.0	6.3
Chloride	800	1700	3,000	3 LT	3	6300	(3) 4500	1200	1400	280	1800	2300	1000	550
Sulfate (SO_4)	20	2 LT	2	2	3	4.0	23.0	11.0	12.0	20.0	11.0	28.0	11.0	6.0
Alkalinity (Methyl Orange)	283.0	276.0	194	116	216	4010	3020	2140	2020	1650	1990	2460	1825	1150
Sodium	590	1100	1800	36	70	2600	1900	800	720	280	930	1400	730	310
Potassium	7	11	20	.8	2.8	320	240	98	100	72	94	91	93	36
Calcium	7.2	18	75	2.1	10	680	510	330	410	240	410	340	420	260
Magnesium	2.0	4.5	19	.44	4.7	420	270	200	90	160	100	260	100	76
Iron	3.4	.30	.50	.05	.12	3.8	2.7	9.3	8.7	7.0	2.1	11.0	1.9	6.7
Nitrate and Nitrite	0.2 LT	0.2 LT	.2 LT	.2 LT	.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
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
Ammonia	4.5	3.8	13	.30	1.7	18.0	12.0	6.0	NA	3.6	7.0	11.0	4.6	4.0
Phosphate	0.008	0.008	.007	.059	.009	0.015	0.018	0.041	0.047	0.039	0.015	0.050	0.036	0.030
Bromide	13.0	35.0	130	.56	1.5	90.0	61.0	22.0	24.0	11.0	2,7	3,5	2,0	11.0
Iodide	1.0	5.3	3.5	.006	.098	3.6	2.5	0.56	0.79	0.12	0.80	1.0	0.38	0.28
Boron	0.93	0.9	1.0	.2 LT	.50	2.3	3.0	1.4	1.3	1.1	1.6	2.0	1.1	0.79
Lithium	2.0	4.4	8.7	.02	.19	10.0	7.8	2.6	2.7	0.63	3.8	4.9	2.4	0.83
Silica	5.4	11.0	10	11	11	7.1	7.3	27.0	33.0	38.0	7.9	46.0	9.6	37.0
Strontium	1.4	6.7	34	.1	1.3	21.0	16.0	6.9	6.7	4.2	6.7	18.0	4.2	5.2
Barium	0.5 LT	0.9	12	.5	.5	8.6	8.6	1.8	3.4	1.1	3.2	5.0	1.1	1.1
Zirconium	0.01 LT	0.01 LT	.003 LT	.003	.010	0.32	0.23	0.04	0.04	0.01	0.10	0.04	0.08	0.01 LT
Total Dissolved Solids	1870	3310	6550	140	230	15190	10580	4280	4210	3220	5250	7710	3820	2170

↑ analysis ok

LT = less than

GROUND WATERS OF METEORIC ORIGIN

Two analyses of representative natural surface waters from ground waters in wells near Saratoga Springs without a saline or connate component are also offered in Table 1. These waters are low in total dissolved solids with bicarbonate contents typical of waters in equilibrium with air or soil gas (Deines, et al., 1974) and a pH commonly near 8 or greater.

SARATOGA WATERS

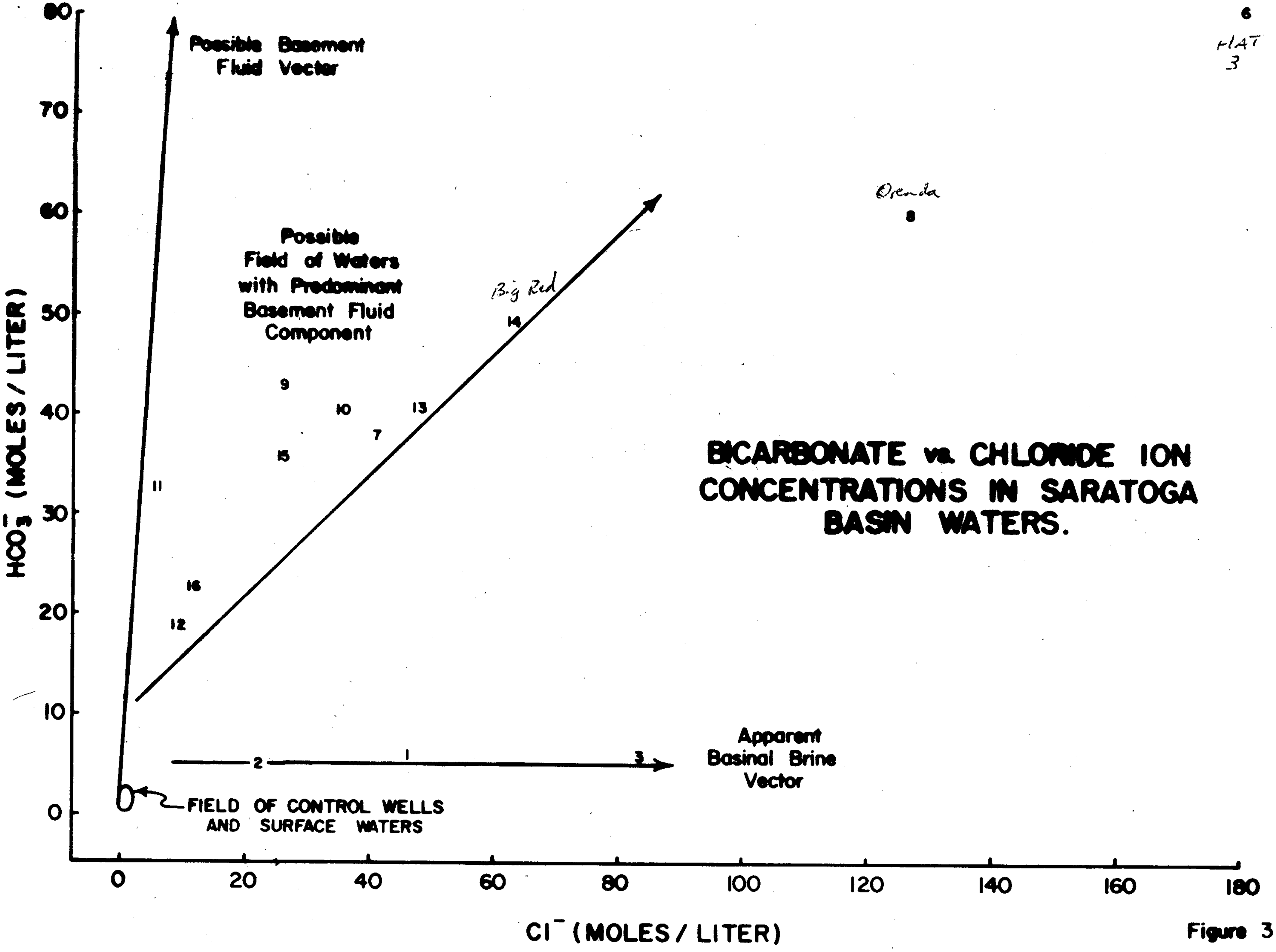
The wells tapping the waters of this group constitute what is usually thought of as the famous carbonated "springs" of Saratoga, new analyses of which are listed from south to north in Table 1. The primary and striking feature of these waters is, of course, the presence of large amounts of HCO_3^- and, particularly, free CO_2 in amounts up to 6 gms/ℓ or more. Equilibrium between dissolved CO_2 (CO_2 aqueous) and water produces carbonic acid, which in turn tends to be neutralized by reaction with the aquifer or host rocks. A simplified version of this reaction would be:

$$\underset{\text{From Carbonic Acid}}{2H^+ + 2HCO_3^-} \quad + \quad \underset{\substack{\text{From Carbonate}\\ \text{Wall Rocks}}}{CaMg(CO_3)_2} \quad = \quad \underset{\text{Ions in Solution}}{Ca^{++} + Mg^{++} + 4HCO_3^-}$$

It is considered very significant that all of the carbonated waters have large bicarbonate contents (commonly from 2,000 to 4,000 PPM) but are commonly not neutralized to a pH of 7. Indeed, measurements made at the wellhead show pH values as low as 5.5, although readings between 5.8 and 6.5 are more usual. With such pH values, approximately a tenfold or greater increase in the existing bicarbonate content would be needed to reach neutrality under conditions of constant CO_2 content. Used alone, however, the bicarbonate content is not a direct measure of the content of dissolved CO_2. Used in conjunction with the pH, an apparent P_{CO_2} at equilibrium can be calculated that commonly yields values between 2-4 atmospheres. With lower pH values probable in the resevoir, an entry of the gas into the carbonate aquifer at a point(s) not too far distant from the wells is implied.

An illustration of the variations among bicarbonate and chloride in these waters is shown in Figure 3. On this plot, saline basinal waters (low HCO_3^-/Cl form a vector along the abscissa which is quite distinct from the field of carbonated waters. Also of note are the presence of several wells where HCO_3^- exceeds Cl^- towards a possible steep (ordinate) composition vector. All carbonated waters contain greater amounts of Ca^{++} and Mg^{++} (derived by reaction with the wall rocks) than saline basinal waters of comparable salinity, but more significant is the trend in general stoichiometry: $HCO_3^- > Na^+ > Cl^-$. This shift in relative Na/Cl indicates that for the most part, the carbonated waters are not derived by simply adding carbon dioxide to the saline basinal waters, although a component of the latter is required by the contents of Cl^-, Br^- and other minor ions common to both waters.

If due allowance is made for Ca^{++} and Mg^{++} gained by carbonate wall rock dissolution, then a distinct sodium (with minor potassium) bicarbonate water component emerges for many of the carbonated waters. The presence of this component is reflected in a number of older analyses of Saratoga mineral waters



BICARBONATE vs. CHLORIDE ION CONCENTRATIONS IN SARATOGA BASIN WATERS.

Figure 3

where sodium (± potassium) bicarbonate is reported as one of the presumed "salts" in solution where stoichiometric Na exceeds Cl. This water component is represented on Figure 3 as a "basement" fluid vector in that the source or site of initial carbonation is considered to be along faults and fracture zones in the underlying Late Proterozoic rocks.

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

Where δ = isotope fractionation in sample; expressed in parts per thousand

(per mil) difference relative to the standard, SMOW for D and ^{18}O, PDB for ^{13}C

D = deuterium isotope of hydrogen

^{18}O = oxygen isotope mass 18

^{13}C = carbon isotope mass 13 *precipitate

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

While the characteristics of the Saratoga waters strongly imply mixing with a connate or formational water source, meteoric "flushing" of this component appears to be required to understand the isotope data. Most formational waters of high salinity (>100,000 TDS) are characterized by relatively high δD and higher $\delta^{18}O$ values from isotopic exchange with the host rocks, therefore plotting to the right of the meteoric water line (Craig, 1961). Low salinity wells comparable to Saratoga have been measured in the shallow parts of the Illinois basin, however, and clearly exhibit flushing. These plot closer to the meteoric line than the deep wells into the same basin as shown in Figure 4 (Clayton and others, 1966). Small volumes of a very highly saline brine (~30-40% in magmatic high temperature or metamorphic water) added to meteoric water might account for the observed isotope data, but is problematical in terms of the chemistry of the uncarbonated saline wells until systemwide analyses are performed.

ISOTOPIC TRENDS OF SARATOGA WATERS

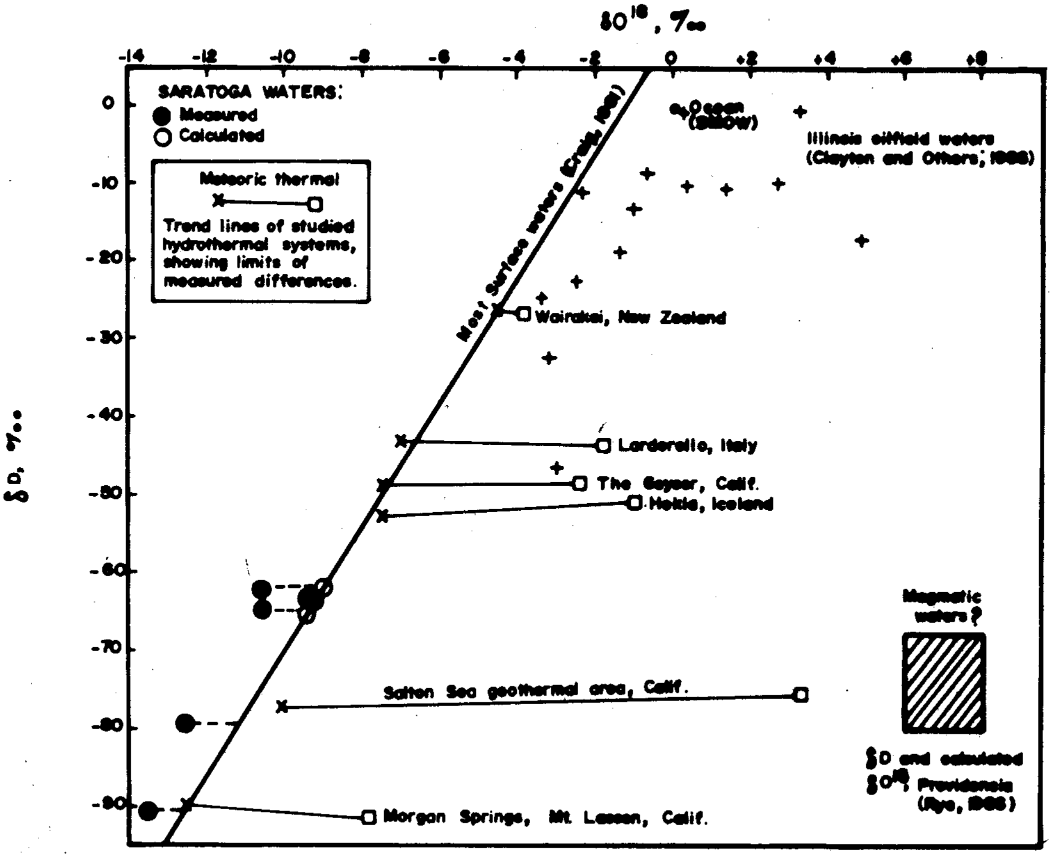


Figure 4. Isotopic composition of some thermal and mineral waters (modified after White, Barnes and O'Neil, 1973).

An oxygen isotope "shift" (-.8 up to -1 per mil) was found in two of the three samples above; i.e., $\delta^{18}O$ values relative to δD which are depleted from meteoric water and opposite to the effects of mixing with non-meteoric waters described above. 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. This type of oxygen isotope shift has been predicted for carbon dioxide-water systems, but has not actually been observed until now.

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 exist as aqueous CO_2, carbonic acid, and bicarbonate ions by ionization; and small amounts of 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.

These complications notwithstanding, total ^{13}C values of a few per mil negative are indicated for these Saratoga waters. A composite analysis made from drill core through the carbonate sections indicates ^{13}C values from 0 to -1 per mil negative for these aquifer rocks. 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).

The carbon isotope data are therefore consistent with a mixture of "deep" CO_2 and carbon from the known surficial rocks. Small amounts of methane present in a few of the wells may be derived from organic matter in the shales, but the reduced nature of the waters, in conjunction with the carbon isotope ratios, argue persuasively against oxidation of organic carbon as a source of CO_2 at Saratoga.

CO_2 SOURCES

Accepting the evidence for thermally generated CO_2, the implied heat requirement does not appear to be satisfactorily met by remnant heat from a cooling Mesozoic pluton. Heat flow measurements made in plutons throughout New England exhibit slightly higher values than the worldwide average (1.5×10^6 $ucal/cm^2$), or 1.5 HFO only in the most granitic members (Roy and Birch, 1968).

Worldwide CO_2 occurrences compiled in a recent map (I. Barnes, 1978) show a strong correlation with active plate boundaries where associated igneous activity, metamorphism and deep faulting are going on today. One of the very few exceptions is, not surprisingly, Saratoga which is all the more notable for its relative strength, i.e. free CO_2 not completely neutralized to HCO_3^-. Situated as it is in an ancient mountain belt, Saratoga derives its uniqueness not so much from its unusual waters, but from being in an area apparently lacking recent vulcanism. The cool surface temperature of the waters has served mostly to compound this problem with a peculiar irony.

In seeking an adequate 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 solution" (S. Holmes, c. 1910). 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 the releveling study done by Isachsen (1975) which has shown the Adirondacks to be rising at the rate of 6 cm/100 years in an oblate domal configuration. This in turn has prompted speculation that the uplift may be caused by thermal upwelling from a juvenile hot spot (K. Burke, personal communications) and the hypothesis, based on the tectonic record and recent structural evidence (the Neogene grabens of Lake Champlain and Lake George), that the Hudson Valley linear system may be a reactivated rift zone (K. Burke, 1977). The large Bouguer gravity low between Albany 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.

The data do not permit a clear definition of the particular thermal process operating at Saratoga; i.e., leakage of "mantle" CO_2, degassing of an upper or mid-crustal igneous intrusion, and/or decarbonation of basement marbles. They do clearly suggest, however, that one or more of these mechanisms is responsible for the principal characteristics of the waters. Considered in conjunction with the evidence for recent faulting, the Adirondack uplift and the notable gravity low east of Albany, the thermal data for Saratoga are added evidence for the hypothesis that the greater Hudson Valley linear represents the surface expression of an embryonic, reactivated rift zone.

ACKNOWLEDGEMENTS

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ROAD LOG

CO-LEADERS: JAMES R. YOUNG
GEORGE W. PUTMAN

TOTAL MILES	MILES FROM LAST STOP	
0.0	0.0	Assembly Point - RPI Field House at 8:15 a.m. Departure Time 8:30 a.m. Leave Parking Lot and Proceed to Route 7
7.2	7.2	Turn right (north) on Adirondack Northway at Exit 6, Latham
21.7	14.5	Pass over pre-glacial Mohawk River Channel Between Exits 11 & 12
24.0	2.3	Pass excellent road cut exposure of Utica Shale cap rock. Stopping not permitted
32.4	7.4	Leave Adirondack Northway at Exit 15. Turn left on Route 50 toward City of Saratoga Springs
33.6	1.2	Turn right (north)on Route 9 McGregor Fault scarp on left
37.5	3.9	Turn left on Parkhurst Rd. Small exposure of Paleozoic carbonates in creek bed (Snook Kill) at Junction. Proceed up McGregor Fault Scarp
38.0	0.5	Turn left on Greenfield Road
38.4	0.4	Precambrian metasedimentary quartzite unit exposed in streambed
38.8	0.4	Stop 1 (15 minutes) Precambrian paragneiss exposed in roadcut. Note almandine garnet and sillimanite needles parallel to the foliation planes.
42.0	3.2	Turn left on Locust Grove Rd.
44.0	2.9	Cross Route 9N and proceed south on Brock Rd.
45.9	1.0	Turn right on Route 29

ROAD LOG (Cont'd)

TOTAL MILES	MILES FROM LAST STOP	
46.5	0.7	Turn right on Petrified Gardens Rd.
46.7	0.2	Stop 2 (one hour) Pompa crushed stone quarry excellent exposures of the Gailor and Galway Formations, a variety of sedimentary features, and several fault zones. Note upper-most Gailor novaculite zone, Hoyt unconformity, vuggy zone with quartz crystal fillings, karst breccia fillings, and fault gouge. Proceed east across road to the rim of a possible small Neogene graben
47.3	0.6	Proceed north on Petrified Gardens Rd. Passing over several small, sharp fault scarps and another possible Neogene graben
47.7	0.4	Stop 3 (15 minutes) Lester Park - well preserved specimens of cryptozoa of the Hoyt formation. Note its position at the lip of another fault scarp. Reverse direction and return to Route 29.
48.9	1.2	Turn left on Route 29 in the direction of Saratoga Springs
51.2	2.3	Turn right on West Avenue
52.6	1.4	Turn right on Route 50. Saratoga Springs State Park to the east and Saratoga Vichy bottling plant on the west
53.5	0.9	Turn left into Saratoga Springs State Park. Hathorn #3 mineral well on the left. Proceed on to Geysers Brook
54.0	0.5	Stop 4 (45 minutes) Disembark and walk up Geysers Brook passing the Polaris, Karista, Hayes, Island Spouter mineral wells. The Ferndell spring on the right is normal surface groundwater. Continue up the brook to the Orenda well and picnic area. Lunch stop. 12:00 p.m.

ROAD LOG (Cont'd)

TOTAL MILES	MILES FROM LAST STOP	
		Discussion of the chemistry of the waters. pH and temperature measurements of the Orenda well and several others. Note the large tufa mound from the Orenda discharge. Time: 1:30 p.m.
54.0	0.0	Leave Lunch area from parking area of Saratoga Performing Arts Center and turn right on Route 50
54.3	0.3	Turn right into park again
54.5	0.2	Pass old State Bottling Plant on right. Site of Geyser and State Seal wells. Proceed through park.
55.4	0.9	Turn left on Route 9. Lincoln and Washington baths on the left.
56.2	0.8	Stop 5 (10 minutes) Grand Union Motel on the right is the site of the anomalous Rosemary well. pH and temperature measurements of the water and a brief discussion of the significance of its different chemistry
56.2	0.0	Proceed north on Route 9 through City of Saratoga Springs. Pass Congress Park
57.4	1.2	Turn right at Library then left onto High Rock Avenue
57.4	0.0	Proceed up High Rock Avenue, passing Hathorn #1 mineral well
58.5	1.1	Stop 6 (15 minutes) High Rock and Peerless springs are across the road from one another. The natural High Rock is at the base of the Saratoga Fault scarp, a continuation of the McGregor Fault
58.5	0.0	Proceed north on High Rock Avenue to Route 50. Pass Red Spring
59.2	0.7	Turn right on Route 50
60.9	1.7	Turn right onto Adirondack Northway at Exit 15
93.3	32.4	Return to assembly point retracing outward trip

JOINT ANNUAL MEETING OF

NEW YORK STATE GEOLOGICAL ASSOCIATION

51st Annual Meeting

and

NEW ENGLAND INTERCOLLEGIATE GEOLOGICAL CONFERENCE

71st Annual Meeting

TROY, NEW YORK

October 5, 6, and 7, 1979

GUIDEBOOK

Gerald M. Friedman, *editor*

Hosts:

Department of Geology
Rensselaer Polytechnic Institute
Troy, New York 12181

and

New York State Geological Survey
Cultural Education Center
Empire State Plaza
Albany, New York 12230

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