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New York State Museum

JOHN M. CLARKE, Director

Museum Bulletin 159

THE MINERAL SPRINGS OF SARATOGA

BY

JAMES F. KEMP

ALBANY
UNIVERSITY OF THE STATE OF NEW YORK
1912

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New York State Education Department
Science Division, January 20, 1912

Honorable Andrew S. Draper LL.D.
Commissioner of Education

SIR: I have the honor to transmit to you herewith a manuscript report on the *Mineral Springs of Saratoga* which has been prepared at my request by Professor James F. Kemp, expert member of this staff, and I recommend the publication of this report as a bulletin of the State Museum.

Very respectfully
JOHN M. CLARKE
Director

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Approved for publication this 20th day of January 1912

A. S. Draper
Commissioner of Education

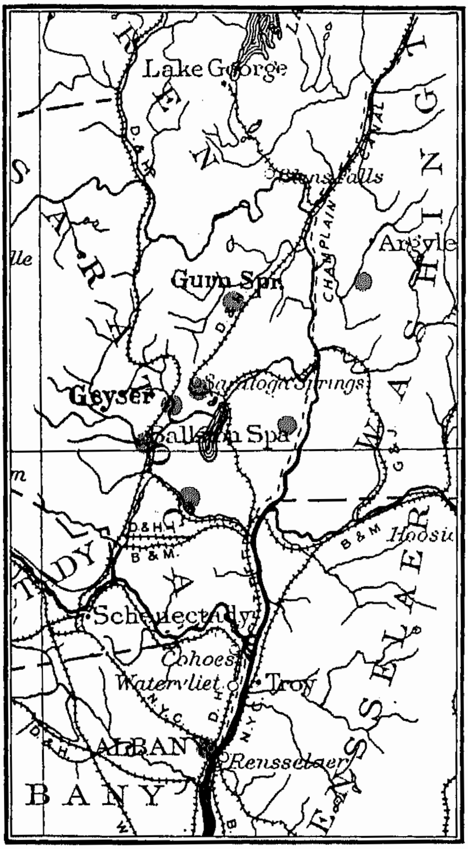

Figure 1 Outline Map of Mineral Springs Albany to Glens Falls

FOLLOWING FIRST PAGE

Education Department Bulletin

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New York State Museum

John M. Clarke, Director

Museum Bulletin 159

THE MINERAL SPRINGS OF SARATOGA

BY

JAMES F. KEMP

INTRODUCTION

This paper was originally written as a chapter for the bulletin upon the geology of the Saratoga Springs quadrangle which is being prepared by H. P. Cushing and R. Ruedemann. To both these geologists the writer is greatly indebted. The local geology will be set forth by them in due season. To Professor Cushing special acknowledgments should be made for the invitation, extended with the approval of the State Geologist, Doctor Clarke, to join him in the Saratoga work.

Assistance from the Hon. Edgar T. Brackett and Mr J. C. Minor, jr, in connection with books, early records, analyses and the like, has been received to a degree that has aided greatly in bringing together the necessary but widely scattered data. The writer's thanks are due to both these gentlemen.

With regard to the source of the mineral matter and gases in the springs, the writer has consulted many papers not specifically cited. Acknowledgments may be made at this point to those of A. Gautier, "Annales des Mines," 9:316, 1906; F. C. Lincoln, "Magmatic Emanations," Economic Geology, 2:258, 1907; R. T. Chamberlin "The Gases in Rocks," Carnegie Institution, 1908, and to the recent volume of A. Brun, "Recherches sur l'exhalaison volcanique," Geneva, 1911.

HISTORICAL SKETCH

The mineral springs of Saratoga first attracted the attention of the white settlers soon after the middle of the eighteenth century. In early colonial days they were westward of the first line of settlements and off the main line of such travel as there was between the valley of the Hudson and the valleys of Lake Champlain and the St Lawrence. The colonists, naturally, established themselves first in the valley of the Hudson and their earliest settlements in this region were some ten miles to the east of Saratoga Springs. The line of communication between the French villages in the valley of the St Lawrence and the Dutch and English colonists in and around Albany, whether used for peaceful or hostile purposes, also followed this main waterway. The springs were in the heart of the Mohawk hunting grounds and their salty waters undoubtedly attracted the wild animals before they caught the eye of the Indian. So far as we know, the High Rock spring was first discovered. Its mound of calcareous tufa would naturally be more conspicuous than the mere uprising of water and gas from a crevice in the rock. The High Rock was in the midst of a depressed area, at the foot of a rock escarpment and along the west side of a brook. While the smaller features are disguised by the village improvements of today, the rock bench is conspicuous, and the larger features can easily be restored in one's imagination. About a century after its discovery by the whites, a pit was sunk below the High Rock mound with the hope of cleaning the conduit and increasing the flow. It is recorded that the excavators found the mound itself resting upon two pairs of crossed logs. The logs were supported by muck and tufa, the whole forming a section of seven feet. Still lower were two feet of tufa, then one foot of muck with another log, then three feet of tufa, beneath which were charred sticks, the remains of a fire.[1] Evidence of this sort would suggest the presence of primitive man some thousands of years before the advent of the whites.

Of the identity of the first white man who viewed the High Rock spring we may not be assured. There is some reason to think that a wounded French soldier was the pioneer. But the first one whose visit attracted special attention was Sir William Johnson, the picturesque character, whose life is intimately associated with the early history of the Mohawk valley. Sir William afflicted with a bodily ailment went to the High Rock spring in 1767. His stay benefited him and he aided much in directing attention to the waters. Four years later the first cabin was built near the spring itself and then the long procession of distinguished visitors was well under way. In 1783, Generals Washington, Schuyler and Hamilton with Gov-

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[1] A sketch and cross section appears in a paper by Dr Charles F. Chandler, in the American Chemist for December 1871, page 204.

ernor Clinton honored the primitive watering place with their presence. Four years later came Dr Samuel L. Mitchill, who was for many years the leading scientific man in New York. Accommodations improved, but in the earlier years Ballston Spa was more sought than Saratoga Springs.[1] In the early part of the nineteenth century the tide of travel again turned to Saratoga Springs and has held this course ever since.

As early as 1770 the medicinal properties of the waters were commented upon by Doctor Constable of Schenectady, and in 1793, in volume 2, page 1, of the Memoirs of the American Academy of Arts and Sciences, was published a letter from Dr Samuel Tenney, a regimental surgeon, at Saratoga. In the same year appeared a "Dissertation upon the Mineral Waters of Saratoga," by Dr Valentine Seaman of New York. In the course of the next century a rather extended series of papers and separate books was devoted to this subject, and it is to be hoped that with the development of the springs as a health resort of increasing prominence the curative properties of the waters and the attractions of the beautiful village and surrounding country will be more and more widely known.

The following chronological list[2] gives the dates when the older and better known springs were discovered as natural flowing vents, or were developed with the drill:

High Rock	1767	Pavilion	1839	Eureka	1868
Red Spring	1784	United States	1839	Geyser	1870
Congress	1792	Empire	1846	Crystal	1870
Columbian	1805	Excelsior	1859	Champion	1871
Hamilton	1806	Saratoga A	1865	Vichy	1872
Washington	1806	Seltzer	1865	Kissingen	1872
Putnam	1835	Union	1868	Hathorn No. 2	1890
Star	1835	Hathorn	1868	No. 3	1905

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[1] It is important to discriminate properly between Saratoga and Saratoga Springs. Saratoga is a town on the banks of the Hudson. Along its western boundary lies Saratoga Springs which is a separate town and village. Saratoga on the river was settled over fifty years before the springs attracted the attention of the whites. The battle of Saratoga was named from the eastern township, not from the springs. The fame of the springs has so far overshadowed the older settlement as to cause some confusion of mind among persons at a distance.

[2] This list is taken chiefly from a work compiled by the local newspaper, the Saratogan, and entitled, Our County and its People, page 390, 1899.

This is not a complete list of the springs. There are, for example, northeast of the village and about a mile from the High Rock, the Ten springs, or Excelsior, and the Eureka White Sulphur group. Opposite Congress Park, across Broadway, is the Ainsworth. To the south are the Chief, Adams and Arondack (formerly the Kissingen) besides many drilled wells. The accompanying map gives all these locations and several others not specifically referred to.

In Ballston Spa, mineral springs were known toward the close of the eighteenth century. The modern ones, however, come up through drill holes which are put down through slate to the limestone at depths varying from 604 to 715 feet. There are four now active, namely, the Iron springs, not possessing much if any gas at present, the Artesian Lithia, Hide's Franklin and a new one recently opened called the Washington.

In the 1835 edition of the work of Dr J. H. Steel entitled "Analysis of the Mineral Waters of Saratoga and Ballston," it is stated that the Quaker springs are situated ten miles southeast of Saratoga Springs and that they contain lime, magnesia, iron, and a certain percentage of common salt and soda. The gaseous contents are small in comparison with those already described; their mineral impregnation is not sufficient to entitle them to much attention.

These springs still exist and are feeble in their manifestations of activity. A few bubbles of carbonic acid gas and of sulfuretted hydrogen come through the waters.

In Mather's Report on the First District, New York State Geological Survey, 1843, page 103, there is the following record of Reed's mineral spring:

> This spring is in South Argyle, Washington county, near the Moses kill. It is an acidulous carbonated water, something like the Saratoga waters, but the gas does not escape very abundantly from the fountain. Bubbles of carbonic acid gas rise from the bottom of the fountain at short intervals, and the water has a pleasant acidulous taste, but it does not sparkle. It is resorted to by the people around and many ride there from Saratoga to drink the water for a change. It is a pleasant acidulous water. It is used by the people of the vicinity for raising their dough preparatory to baking it, no yeast being required. . . . The spring rises from a fissure in limestone near its junction with slate rocks, which are metamorphic, or belong to the Taconic division of rocks.

This spring must have been on the east side of the Hudson river and at least fifteen miles northeast of Saratoga Springs.

The most northerly of all the springs now important is the Gurn, eight miles from the village of Saratoga Springs. It is very actively

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flowing, well carbonated and of the same general composition as the Saratoga waters. An analysis is given later.

Still farther north in the village of Whitehall, thirty-nine miles from Saratoga Springs, is a spring called the "Adirondack," feebly carbonated and of greatly contrasted composition to the Saratoga waters in that it contains less of sodium chlorid than of either calcium or magnesium carbonate, and almost as much calcium sulphate. The total dissolved solids is only about one-eighth or one-tenth that of the Saratoga waters. (Bulletin 32, U. S. Geol. Survey, pages 27 and 32, 1886.)

To the south the mineral waters have been discovered even beyond Ballston. Thus, at Round Lake, in 1875, a drill hole was put down which reached a total depth of 1403 feet. At a point below 1300 there was struck a flow of water of composition not unlike the Saratoga waters. Its analysis is given later. The hole was torpedoed, however, and after the explosion the flow was lost.

In 1827, a well was even drilled in Albany 500 feet deep, on Ferry street, and yielded carbonated waters of the general composition of those at Saratoga Springs (L. C. Beck, Mineralogy of New York, 1841, page 138). An analysis is cited later. Albany is forty miles from Saratoga, and respectively thirty-two and twenty-six from Ballston and Round Lake. No other drilled wells have been recorded in the interval from Round Lake to Albany.

Thus waters, carbonated and of a somewhat similar composition are known over a stretch of approximately forty miles in a general north and south direction from Albany to Gurn springs, or if we include the Adirondack springs, at Whitehall, of about sixty-five miles. Between Albany and Round Lake, a distance of twenty miles, none are known. And again from the Gurn spring to Whitehall, a distance of thirty miles, none have been reported. These statements are in a measure useful in connection with general geographical conceptions, but they are not expressed in a way to be of geological significance. The springs should be grouped in northeast and southwest lines, along the known faults or fault systems. Apparently then, the Ballston-Saratoga Springs-Gurn series are to be taken on one line, with perhaps the Whitehall spring at the extreme north. The Round Lake well is five miles to the east of this line; the Quaker springs eight miles; Reed's spring in South Argyle, eight or more; and the Albany well nearly fifteen miles east of its southern prolongation.

BRIEF STATEMENT OF THE LOCAL GEOLOGY

The careful work of Professor Cushing and Doctor Ruedemann has established the following section of the strata at Saratoga Springs, from above down:

The Canajoharie shales (formerly called the Hudson River or sometimes the Utica slates). Of unknown but great thickness.	
The Amsterdam limestone (formerly called the Trenton limestone)	50′
A very important erosion interval represented in the Champlain valley by the Chazy limestone 300 feet thick, and the upper part of the Beekmantown (formerly called the Calciferous sandrock) 1200 feet. Land conditions seem to have prevailed in the Saratoga region.	
Little Falls dolomite (the lower member of the Beekmantown or Calciferous)	300′+
Hoyt limestone (formerly called the Saratoga limestone)	100′
Theresa passage beds, alternate limey and sandy layers	50′–75′
Potsdam sandstone or quartzite	200′ or less
Grenville series of ancient gneisses and metamorphic rocks with intrusive igneous masses	Indefinitely thick

Exclusive of the shales or slates at the top, which are above the productive horizon of the mineral waters, we have thus about 500 feet of limestones and dolomites, resting upon 200 feet or less of hard sandstones, and these upon the ancient metamorphosed gneisses, granites etc., which were formerly collectively described as Laurentian or Archean.

When tapped by the drill the mineral waters are chiefly obtained from the Little Falls dolomite. When the drill has penetrated the slates it strikes the waters, if such are found at all, in limestones, not far below the underside of the slates. It is possible that in some instances this may be in the Amsterdam (or old Trenton), but where the drill cores or the drillings have been identified, it is easy to recognize them as belonging to the Little Falls dolomite. The drilled wells in Saratoga Springs itself start either in the slates or in the Amsterdam (Trenton) limestone, but quickly pass through one or both of these and enter the Little Falls dolomite. In the Congress diamond drill core, which has been preserved and is available for study, the following section was disclosed:

Gravel	18′ 2″
Amsterdam limestone	16′
Little Falls dolomite	283′
Total	317′ 2″

The Hathorn drilled well penetrated to a depth of 1006 feet, of which the last few feet are reported as Potsdam. This rock is so easy to identify that there can be little question that the drill stopped in it, but the determination of the other members needs revision, and the cores are unfortunately no longer available. The depth of the well shows so much in excess of the general section as given above that there may be repetition from faulting.

The farther east wells are drilled at Saratoga Springs from the line of Spring street, the thicker the slate will be found. At Doctor Strong's sanatorium after 86 feet of gravel, nearly 300 feet of slate are reported before the limestone was met.

The drilled wells of the gas companies and the holes for mineral water at the Geysers, two miles south of Saratoga Springs, begin in the Canajoharie (Hudson River) slates. They find the waters, however, in the underlying limestones. The holes run between 300 and 400 feet deep at the General Carbonic Company's wells. The farther south one goes, the greater is the thickness of slate. Thus, at Ballston, it is 600 or 700 feet and at Round Lake between 1300 and 1400 feet.

To the north of Saratoga the Gurn spring apparently emerges from the Little Falls dolomite. The vent is some feet below the capping of gravel and is no longer visible, but the nearest outcrops are all of the dolomite.

Of the geological history of the district from the close of the time marked by the formation of the slates — that is, from the later Ordovicic period — we have but scant records, as will be set forth in the report of Professor Cushing and Doctor Ruedemann. Whether other sediments once covered the slates and were then removed by erosion is doubtful. The lack of sediments suggests land conditions at least for the greater part of the time. The strata shared in the mountainous uplifts to some extent, but near the springs the dips are still very flat and notable folds are not immediately concerned with them. Important faulting has taken place and one fault in particular, as will next be described, has an intimate relationship to the springs. The dips next the faults show a drag down to the southeast on the western side of the break, and an upward drag on the eastern, or dropped side. As the fault escarpments are the more prominent outcrops one could easily gain the impression that the inclination was all to the southeast, but Cushing and Ruedemann find the predominant dips in between the faults to be flat to the west or northwest. The sinking of the surface and of the strata themselves, toward the low points of the region, Saratoga lake and the Hudson river, seems therefore largely due to faulting and to the greater erosion of the soft slates by the continental ice sheet. The geological age of the faults is obscure. They may at least have been the scene of renewed movement in fairly recent geological time.

At some time in this long interval the volcanic plug at Northumberland was developed, but the quarrying operations of the years 1910–11 have revealed some obscure and puzzling relations which will be fully discussed by Professor Cushing in a forthcoming bulletin.

The advent of the Continental glaciers from the north and in very recent geological time has served to spread over the region a heavy mantle of gravel and sand, such that the rocky strata are often buried beneath as much as 150 feet of loose deposits. From the bedrock the natural springs usually emerge into this gravel and sand and then find their way to the surface. Doubtless there are others which have never been discovered and which become lost in the general ground waters. Where they have been observed it has been usual to sink through the gravel to the bedrock, find the orifice and conduct the water to the surface in some sort of a tube which has been cemented tightly to the rock around the crevice.

Various estimates have been made of the time which has elapsed since the recession of the ice sheet. They vary from 10,000 to 50,000 years. If the section revealed in excavating beneath the High Rock mound is correctly interpreted there must have accumulated some 13 feet of tufa and muck since the aborigines built a fire; apparently also since the great ice sheet had scraped the bedrock clear.

THE FAULT AT SARATOGA SPRINGS

A structural feature of the local geology which early claimed attention is the fault which runs along just west of the main line of the springs in Saratoga village. It is revealed by a cliff of Little Falls dolomite some 30 or 40 feet high and with precipitous front except where partially or wholly covered by earth. The fault has been traced by Cushing and Ruedemann to the north across the sheet as their map will show. To the south its exact course is obscured by the glacial drift and sands, but it seems to make a westward swerve at Congress street and Broadway and turn along Oak street after which it may turn south again, but its exact course is hidden by the drift.

The fault as it appears west of the springs along Spring avenue is not one of great displacement. The Little Falls (Beekmantown) dolomite forms the cliff to the westward and possesses the characters of the upper portion of this particular stratum. As it is followed northward beyond the Maple avenue quarries the Amsterdam (Trenton) limestone still remains on top of it, proving that the top of the escarpment is near the upper limit of the dolomite.

At the foot of the escarpment and in the rear of the Star spring bottling works, Cushing and Ruedeman discovered a block of Amsterdam (Trenton) at the surface on the downthrown side. This fixes within fairly close limits the amount of the displacement at this point. If the cliff is about 30 feet and the thickness of the Amsterdam is 50 feet and some of the Amsterdam still remains beneath the surface on the east side, and if its bottom can not have been far above the top of the escarpment on the uplift side, we have 80 feet as an extreme possibility and 50 feet as a not improbable amount.

The displacement may be greater at other places along the fault line, but for so continuous a break it is impressive to find the throw so small. The Amsterdam limestone is soon succeeded by the slates to the eastward.

The most striking feature of the fault lies in the fact that no mineral spring has been discovered to the west of it, and where it can be sharply located no spring is known very far to the east of it. The Strong well is approximately 1100 feet from it; the Excelsior or Ten springs about 3000 feet. The wells of the Natural Carbonic Gas Co. and of the Lincoln Company are some similar distance if we give, as seems necessary, credit to the westward swerve along Oak street. The course of the fault being obscured by the drift, we do not know what its relations to the springs farther south may be. To the north the fault splits into two; the main one following the escarpment of the ancient crystalline rocks and a branch striking northeast toward the Gurn spring. This spring emerges a short distance from the branch fault.

As the springs are not found west of the known fault, it is important to remark that in the region of Saratoga village the slates also fail on this side. The Amsterdam limestone is indeed known, but the slates cease on its east side. Slates are, however, at the surface between the main fault and the Gurn spring branch, but only in limited exposure. Generally speaking, therefore, we may say that both springs and slate lie east of the fault and that the waters of carbonated and saline character apparently belonging to this series of springs have not been discovered more than three-quarters of a mile from its assured outcrop, whereas most of them are where the fault is known and within a few hundred feet of it. In this connection, however, attention should again be drawn to the weak Quaker springs, to Reeds spring in South Argyle, and to the Round Lake well, all of which are some miles east of this particular fault.

The line of springs along Spring avenue, in the village of Saratoga Springs, north and south of the High Rock, are not far from the 280 foot contour. The Hathorn and Congress to the south are a few feet higher but are under 300 feet. The springs west of the steam railway at the Geysers are both above and below the 300 foot contour but do not reach the 320. The Gurn spring is between the 280 and 300 foot contour.

At Ballston Spa, Hides Franklin comes out with a strong pressure at 276, but the other three are below the 260 foot contour.

West of Saratoga Springs and Ballston, the 300 foot contour speedily crosses even the lowest stream valleys and the general level for from two to five miles is between 300 and 400 feet. At Rock City Falls, seven miles due west of Saratoga Springs, the 500 foot contour crosses the main line of drainage, Kayaderosseras creek. Still farther in this direction and within the limits of the quadrangle the altitude attains 1000 feet and to the north, still within the quadrangle, the culmination is about 2000.

By contrast when we turn eastward, Saratoga lake, one important low point, stands at 204 and the Hudson river at 100. With such flat dipping strata even though the commoner dip is to the northwest rather than the southeast, the general course of the ground waters would be to the southeast, and such head as would exist in the normal ground water would be exerted in this direction. William R. Hill C. E., by a careful series of levelings upon the waters standing in the wells of the Natural Carbonic Gas and Lincoln Spring Companies at a time when no pumping was being done and the waters had resumed their normal positions, and by determining the resultant of his observations, reached the conclusion that the natural flow was in a direction s. 65 e. or 25 degrees south of east. While these expressions must be taken as general they undoubtedly express the truth.

GENERALITIES REGARDING THE NORMAL GROUND WATERS

The waters which are found beneath the surface of the earth are now regarded by students of the subject as of three kinds which are technically called:

1 Meteoric, derived from the rainfall.
2 Magmatic or Juvenile, derived from igneous rocks.
3 Connate, which as sea waters and lake waters saturate sediments and are buried with them.

1 **Meteoric waters.** This group embraces the waters of ordinary character and of general occurrence. The rain falls upon the earth and divides into three parts:

a A portion evaporates at once and passes back into the atmosphere.
b A portion runs off on the surface and helps directly to maintain the general drainage.
c A portion sinks into the ground through porous soils, cracks, or other cavities in the rocks and contributes to the "ground water."

The name "ground water" is applied to the subsurface waters which stand at a fairly constant level, wherever the rainfall is sufficient to maintain them, certainly in all but excessively arid regions. The ground water supplies wells, in which it is found in our climate at comparatively shallow depths. It supplies the ordinary springs, and in this way contributes to the drainage, acting as a reservoir and being tapped away at those low points, behind which there is sufficient head to force it to the surface. The movement of this reservoir of water as a whole is very slow, but at individual vents the emerging portion may flow rapidly. Experience in recent years with deep mines and bore holes has led to the belief that as a rule the ground water only attains a depth of 1000 or 2000 feet, since in sinking deep shafts the miners find that by impounding the waters in the upper levels and pumping from them, they pass through the wet zone, and at greater depths have no water at all to pump. Even the small amounts of water required in drilling have to be sent down from the surface or the upper levels. Estimates of the amount of water contained in the outer crust have therefore greatly diminished in later years. Thus, in 1861 Delesse, a French geologist, by assuming a certain porosity for the strata and calculating the amount of water required to fill the cavities, reached the conclusion that, were all this water to be spread over the surface, it would make a layer 7500 feet deep.[1] Estimates by others will be found in the citations. They vary through the following values: C. S. Schlichter 1902, 3000–3500 feet; C. R. Van Hise 1904, 226 feet; Chamberlin and Salisbury 1903, 800 to 1600 feet.

The writer in 1901 endeavored to draw upon mining experience and upon deep boreholes in discussing the ground water and concluded that it extended as a rule to a depth of only 1000 to 2000 feet. If we allow 5 per cent for the voids in rock, this would mean a layer 50–100 feet; or if 10 per cent, 100–200 feet. Ten per cent is the extreme of voids in the most porous and 5 per cent is nearer a fair estimate, but these two values are usually employed.

M. L. Fuller of the United States Geological Survey in 1906, after a very extended experience with holes drilled for water, in his work upon the division of the Survey dealing with water supply, concluded that the ground water would amount to a layer 96 feet deep if it were spread out on the surface. At 5 per cent of cavities in the rocky strata, this would go down about 2000 feet, or at 10 per cent about 1000 feet. T. Sterry Hunt determined the cavities in the hard, white Postdam such as we have at Saratoga Springs to lie between 1.39 and 2.47 per cent of the volume. Less metamorphosed varieties yielded from 6.94 to 9.35. (Chemical and Geological Essays, p. 166, 1878.) These figures will help to make more definite in our minds the amount of water of this kind with which we have to deal.

The meteoric ground waters in their migrations through the rocky strata dissolve some mineral matter. The rain takes up a little carbonic acid gas from the atmosphere and has to this extent its solvent powers increased. It has also oxygen, nitrogen and other gases in far less amount. The dissolved air is higher in oxygen and carbonic acid and lower in nitrogen than is the ordinary atmosphere. Potash, soda, lime, magnesia, and iron dissolve most readily from the rocks. Silica is also taken in very small quantity, as are several other rock-making components. On the whole, lime is the most abundant and widespread of the dissolved bases, and in ordinary spring waters the dissolved matter varies from a minimum

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[1] M. L. Fuller. Total amount of water in the earth's crust. Water Supply and Irrigation Paper. U. S. Geol. Surv. 160. p. 59, 1906.

of 5 grains to a maximum of about 50 grains per U. S. gallon of 231 cubic inches. These values are practically equivalent to from 85 to 850 parts in a million. If we keep some such general figures as these in mind we can carry along an idea as to the way the mineral springs under discussion compare with ordinary waters. Saratoga waters range from a minimum of 300 to a maximum of about 1200 grains of dissolved solids per gallon.

Regarding the movement of waters through the crevices of the rocks, the friction greatly increases with the decrease of the diameter of the conduit. Thus if we deal with ordinary pipes, under a constant head, the friction increases inversely as the diameters. A pipe which has a diameter one-eighth that of another, develops eight times as much friction, and the friction operates to lessen the flow greatly.

2 **The magmatic waters.** Observers of volcanic eruptions have long been impressed with the vast amount of steam emitted under great pressure at times of outbreak. The explosive violence of the outbreaks has been chiefly attributed to it. In some instances only such gaseous emissions, together with shattered rock, issue from the crater, as was the case at Mont Pelee, Martinique, except for the solid spine which was forced out in the closing stages. Molten lava failed. Emissions of steam are also yielded, sometimes for months by consolidating lava streams which have already poured out on the surface. The amounts have at times been calculated and they are very impressive.

It was formerly a widespread belief that this water was derived from the ocean or from seas near whose shores volcanos are usually, but not invariably, situated. Geologists imagined that the sea water percolating downward and inward, was drawn by capillary attraction to the molten rock and became involved in its substance. This conception has seemed impossible to many later students of the subject who can not believe that water would or could be drawn through rock gradually becoming hotter and hotter, until the water successively passed its boiling point, its point of dissociation into oxygen and hydrogen and necessarily reached a temperature still higher by 1500 to 3000 degrees Fahrenheit before it could be absorbed by the molten rock. It seems to many at least that as soon as the water encountered temperatures much above its boiling point it would be driven outward. The writer therefore rejects the oceanic source of the water manifested in volcanic eruptions as too improbable to deserve confidence. Water locked up in hydrated silicates which are melted into a rising flood of fused rock might become involved. Possibly confined reservoirs of artesian water which had no escape might also be absorbed, but it seems still more reasonable to think of the water gas, the carbonic acid and the other gases as original component parts of the magma, belonging to it as much as the silica and the common run of bases.

The presence of this water is still further shown by the effects exerted upon limestones where penetrated by masses of molten rock which have never reached the surface. So many new minerals have been produced partly from the limestone and partly by contributions from the igneous mass, that the agency of magmatic waters has been invoked by almost all students of the subject in order to explain the results.

In regions of dying volcanic activity, hot springs and emissions both of carbonic acid gas and of carbonated waters are the rule. Where the composition of the waters is markedly different from the composition of the rocks through which they rise, some observers have seen reason to attribute to them a deep-seated magmatic source. Carlsbad, Bohemia, with its springs rich in lime, arising from granite, a rock extremely poor in lime, is a famous case in point. Deep-seated magmatic waters have seemed to some observers the simplest explanation.

The waters are presumably evicted from the molten mass in its process of crystallization into the anhydrous silicates which make up the ordinary igneous rock. Obviously existing first as gases in the deep-seated mass, they pass with loss of heat into the liquid form and furnish hot springs and in their later stages possibly cold ones. The waters were called "juvenile" by E. Suess, the venerable Austrian geologist, because they reach the surface for the first time and therefore are young, or newly born. In America the name magmatic is somewhat more current.

In the most recent of the more important contributions to this subject,[1] P. Brun gives a number of analyses of gases which he has collected from regions of dying volcanic activity. He fails to find water gas in notable quantity, but does detect much hydrochloric acid. He concludes that the vapors which have been hitherto observed arising from volcanic vents are ammonium chlorid and

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[1] P. Brun. Recherches sur l'exhalaison volcaniques, Geneva, 1911. The work is summarized in English by Alex. Winchell in Economic Geology.

other gases, together with finely divided dust, but not steam. Mr Brun's results have made a deep impression and so far as they go, are opposed to magmatic waters. They are however so different from the hundreds of analyses made before him by competent chemists, that many, including the writer, still adhere to the views set forth above.

We have as yet no sharp chemical criteria with which to distinguish magmatic waters from meteoric, except perhaps that carbonic acid is, as a matter of observation, when present in copious supply, usually in a region of dying volcanic activity. F. C. Lincoln has made a careful review of the records and has arranged the results in fifty representative analyses. He then finds that the gases when averaged from the fifty cases are, in the order of abundance, and expressed in parts per hundred:

Nitrogen (N_2)	44.360
Carbon dioxid (CO_2)	36.303
Oxygen (O_2)	9.026
Sulfuretted hydrogen (H_2S)	4.991
Hydrochloric acid (HCl)	2.057
Hydrogen (H_2)	1.601
Sulfur dioxid (SO_2)	.966
Marsh gas (CH_4)	.638
Carbon monoxid (CO)	.032
Ethane (C_2H_4)	.001

Of the nongaseous matters, water is much the commonest, constituting up to 95 per cent of the total condensed. In the above figures some, probably a rather important portion, of the nitrogen and oxygen is due to the admixture of atmospheric air in the sample. Since carbon dioxid only forms .03 per cent of atmospheric air, very little of it can have been derived from this source.

These statements regarding the magmatic waters are made, not with the idea of presenting a brief in their advocacy, but because they are significant and must be considered in any discussion of mineral springs.

3 **Connate waters.** Connate is a name recently applied by A. C. Lane to those waters which are, so to speak, born with the rocks which contain them, and which, absorbed by sediments during deposition, are carried down with the sediments when the latter are buried beneath other accumulations. If the sediments are marine, oceanic

waters will remain in them. If they are lacustrine, fresh water will be absorbed. The common brines found by the drill in old marine deposits are undoubtedly connate, but their preservation is largely due to being inclosed between impervious beds above and below. When we deal with fresh-water sediments the connate waters do not have great difference in composition from the ordinary meteoric ground waters. In judging of marine connate waters it is important to bear in mind that some geologists think the sea to have been a less concentrated solution in its early history, and in the very remote times represented, for instance by the Grenville series of the Saratoga section, that it was comparatively fresh. Rivers have indeed been pouring into it their burden of dissolved materials and as these are not removed by evaporation, except to the extent in which they are driven over the land in spray caught up from breaking waves by the wind, the conclusion has followed that the sea is like a great evaporating pan, constantly becoming more concentrated. One line of attack upon the problem of estimating the age of the earth has been to assume fresh-water oceans and calculate from the known composition and volume of rivers the time required to bring the oceanic waters up to their present concentration.

On the other hand, there are geologists, notably Edouard Suess in Vienna, and R. T. Hill in New York, who urge that the oceans themselves were fed by magmatic waters from volcanos or their equivalents, in the early history of our planet, and that, as is well known regarding some volcanic waters, the salt was also furnished in this way. These views are at least worthy of respect; they seriously affect calculations of the age of the earth, although they do not conflict with the belief in weaker oceanic waters in the remote past. Connate waters underground almost inevitably are subject to admixtures of meteoric ground waters.

THE COMPOSITION AND CHARACTER OF THE SARATOGA WATERS

Having established the general conceptions regarding underground waters, we may next take up the composition of the local mineral springs and their place among mineral waters as found in nature. Many analyses have been prepared in the last seventy-five years or more and a considerable number within the last ten. A few introductory remarks may be made upon analyses in general and the methods of reporting the results, before the actual waters are discussed.

The analysis of a water is conducted by taking a suitable and carefully measured sample from the spring and evaporating it to dryness so as to secure the dissolved matter. The composition of the evaporated residue is then determined by the chemist. It must be remembered that the residue from a water such as is afforded by the Saratoga springs is a complex mixture containing a number of bases and acids, each of which is determined by itself. Thus in the Saratoga waters there have been customarily reported ten elements which are present in acids, namely, chlorin, bromin, iodin, fluorin, carbon, sulfur, phosphorus, boron, nitrogen and silicon. Each of these makes an acid of its own. Some ten elements furnish the bases, namely, sodium, potassium, lithium, magnesium, calcium, barium, strontium, iron, aluminum and manganese. With these must be placed the rarer ammonium and still rarer rubidium. When the chemists have determined these acids and bases they endeavor to combine the results as they believe them to exist in the original water. They do so on assumptions of the relative chemical affinities of the elements for one another and divide the acids among the bases so as to use up the supply of each. Probably the results represent with a fair degree of accuracy the combinations as found in the springs, but as subsequent discussion will show, there inevitably arise minor differences among chemists.

In later years the theory of ions has gained great support. According to this conception, the dissolved compounds exist in dilute solutions in the form of incomplete molecules, the same being held in this condition by electromotive force. The incomplete molecules are called ions. Thus, whereas in an older analysis, we would find reported $NaCl$, Na_2CO_3, (or $NaHCO_3$), $NaBr$, NaI, Na_3PO_4, KCl, K_2SO_4, $MgCO_3$ (or $Mg(HCO_3)_2$), $CaCO_3$ (or $Ca(HCO_3)_2$), CaF_2, $FeCO_3$ (or $Fe(HCO_3)_2$), $BaCO_3$ (or $Ba(HCO_3)_2$), Li_2CO_3 (or $Li(HCO_3)$), $SrCO_3$ (or $Sr(HCO_3)_2$), Al_2O_3, and SiO_2; in one in the last ten years we find, Cl, HCO_3, Br, I, PO_4, SO_4, Na, K, Mg, Ca, Fe, Ba, Li, Sr, Al and SiO_2. As a separate statement the latter authority might then combine them into salts but whereas as the earlier chemists sometimes calculated carbonates, such as Na_2CO_3, $MgCO_3$, $CaCO_3$, etc., the later analysis gives them all as bicarbonates, respectively $NaHCO_3$, $Mg(HCO_3)_2$, $Ca(HCO_3)_2$, etc. Each chemist determined boron — the former combined it with sodium as a biborate; the latter as a metaborate.

There is no very serious objection to either of these courses as above outlined. Fashions change among chemists as among other people, but the method of reporting by ions probably involves fewer possibilities of mistaken assumptions. People at large, however, are not yet accustomed to these terms and an analysis in the newest form possesses for most readers less significance than one in the old style.

There are other differences in the methods of reporting analyses. The older method and the one most widely intelligible among those not skilled in chemistry, is to give the dissolved matter in grains per U. S. gallon of 231 cubic inches. More rarely, older analyses are expressed in grains per Imperial gallon of 277.272 cubic inches. The U. S. gallon contains 58,373[1] grains; the Imperial, 70,048.4 grains. Both involve the old system of apothecary's weights. In later years it is a growing custom to express the analysis in parts per million, a method which falls in best with the metric system, in which the analyses are universally made. We can roughly pass from the grains per U. S. gallon to parts per million by multiplying the former by 17,[2] or from parts per million to grains per gallon by dividing by 17. The writer much prefers parts per million, which is of course in the metric system milligrams per liter. Enough parallel values will, however, be given to make the statements significant to one accustomed to grains per gallon.

It may further be remarked that the total of solids actually weighed after evaporation of the sample is necessarily always less than the summation of the dissolved salts, where the latter are given as bicarbonates. The extra carbonic acid molecule or partial molecule of the bicarbonate passes off in evaporation.

Among the analyses made of the Saratoga waters in the last hundred years three groups may be established:

The oldest were principally performed by Dr John H. Steel, a physician resident of Saratoga Springs in the early years of the past century, and the first one to give the waters thorough scientific study. Doctor Steel published a book on the springs[3] in which

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[1] A. C. Peale, in his paper on the Mineral Springs of the United States in 14th Ann. Rept. U. S. Geol. Survey, p. 71, gives a U. S. gallon as 58,372 grains and the Imperial as 70,000 or 277 cubic inches.

[2] More accurately by 17.13. The reciprocal is .058.

[3] John H. Steel M. D. An Analysis of the Mineral Waters of Saratoga and Ballston, with Practical Remarks on their Medical Properties, etc. Saratoga Springs, 2d ed. 1838. Earlier imprints appeared in 1817 and 1825. The 1825 edition has a geological map. The strata are classified as: I Primitive class — granite, gneiss, syenite, mica slate and soapstone; II Transition class — argillaceous slate and gray-wacke; III Secondary class — compact limestone. A copy with the map is in the New York Public Library.

he brought together a series of analyses made in the 30's or earlier. With these in the chart, figure 2, have been combined a few others of this early time or of the next decade. All these analyses are compiled in the tables at the close of this bulletin.

The second group was made about thirty years later. Just before and just after 1870, Dr Charles F. Chandler prepared a very valuable list, representing nearly all the better known springs both in Saratoga and Ballston. They were chiefly published in the "American Chemist" for December 1871, page 203. As used here they are amplified by one or two made in 1871–73 which appear in Cairn's Quantitative Analysis. In 1905 or thereabouts the United States Department of Agriculture through its Bureau of Chemistry prepared an interesting series in connection with the investigation of mineral waters placed on sale throughout the country. Some of the samples were bought in the open market and a still larger series was obtained at the springs by a representative of the bureau.

Besides the analyses used in the charts, a number have been prepared at the request of owners of springs by chemists of standing and have been used in circulars or other advertising matter. They, so far as available, and all the ones used in the charts, have been compiled in the tables of analyses on pages 65–74. They are less significant than groups made by the same chemist, whose sampling and methods would be naturally more uniform, but they have value. One must also hold judgment somewhat in abeyance as regards the significance of analyses because of the artificial strengthening of natural waters both with salts and with carbonic acid. To some extent this has been done.

In all the general statements which follow, the total of dissolved solids is based on bicarbonates. These results, therefore, as earlier stated, will be somewhat higher than the weight of the residue obtained by evaporation. The extra molecule of carbonic acid is driven off on evaporation. The bicarbonate, however, probably represents the salt as it exists in solution. In the first set of curves only the most abundant of the dissolved salts are used, namely, $NaCl$, $Ca(HCO_3)_2$, $Mg(HCO_3)_2$ and $NaHCO_3$. The others will be commented upon but are too small to make much of a showing when plotted as curves.

In total dissolved solids the maximum found in the Saratoga waters by the earlier analysts is 11,215 parts in a million, reported for the Congress spring in 1843, by J. R. Chilton. The minimum is 3787, reported by J. H. Steel for the New Washington.

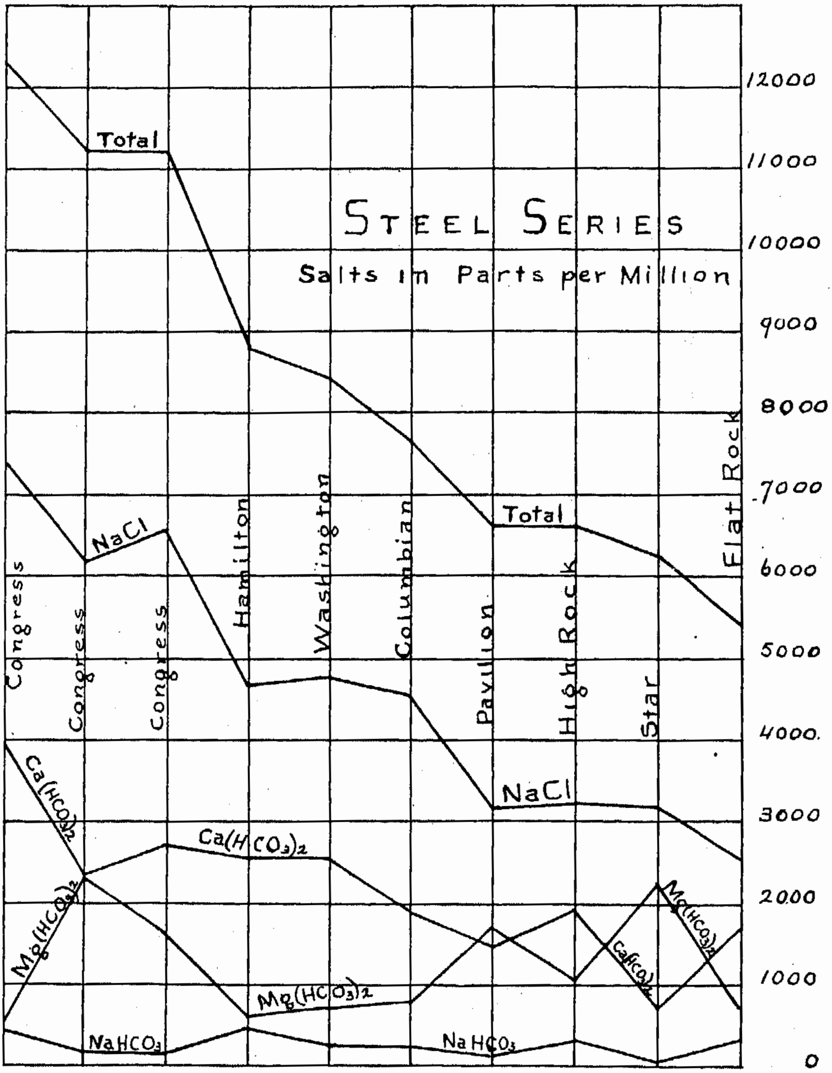

Figure 2 Diagram of dissolved salts based on the analyses of Dr John H. Steel, 1838. The horizontal lines indicate parts per million. Each vertical line represents one analysis.

In the series made by Dr Charles F. Chandler just before and just after 1870 the maximum was afforded by the Glacier Spouting well, at 20,325 parts in a million, or about 2 per cent. Next to this is the Geyser Spouting well with 16,856. The minimum was afforded by the Seltzer spring with 5134 parts.

In the series from the Department of Agriculture, the maximum is the Carlsbad, with 12,950; the minimum, the High Rock, with 2347.

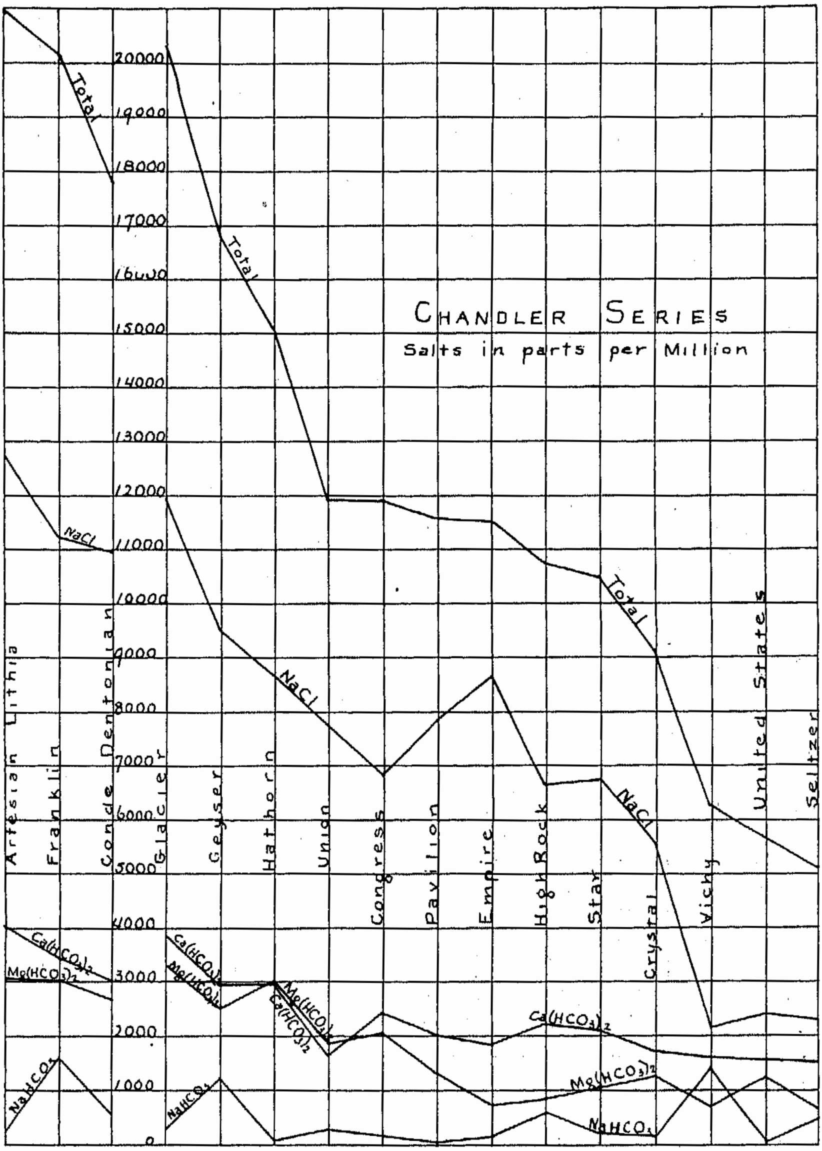

Figure 3 Diagram of dissolved salts based on the analyses of Dr Charles F. Chandler, 1873 The horizontal lines indicate parts per million. Each vertical line represents one analysis.

The State Department of Health has found in the new Hathorn No. 2, two miles or more south of the village, 16,350, and in the Champion spring only 1370.

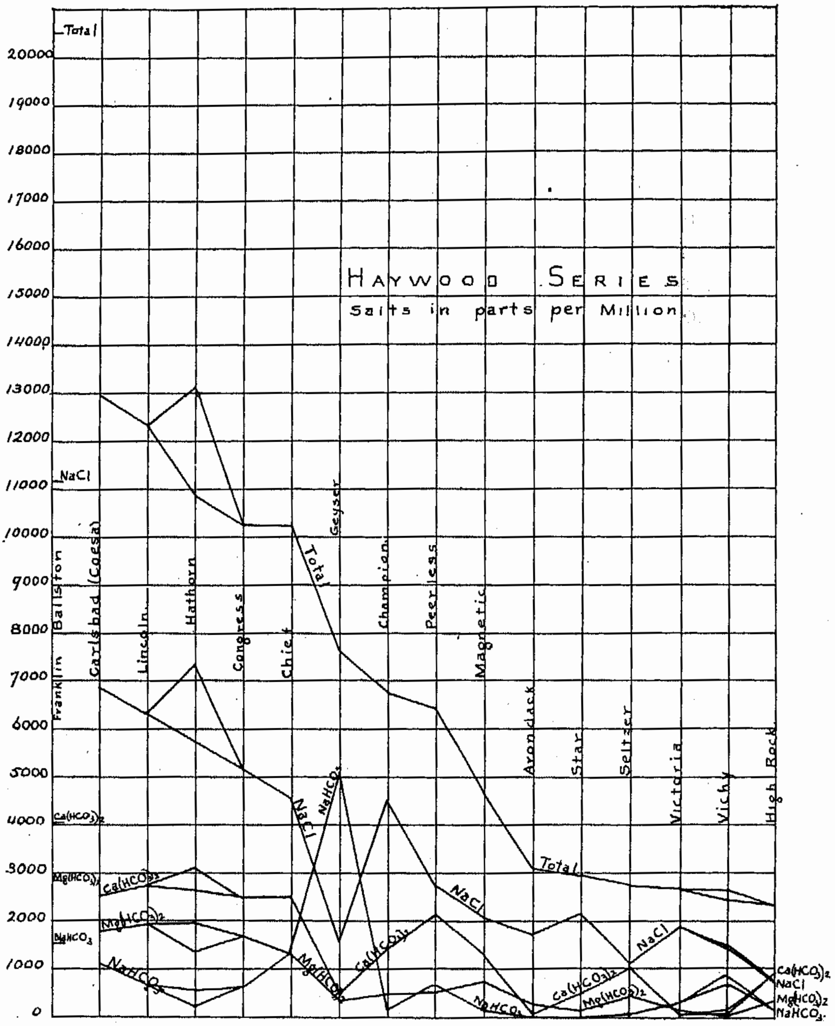

Figure 4 Diagram of dissolved salts based on the analyses of J. K. Haywood and B. H. Smith, of the United States Department of Agriculture, 1905. Each horizontal line indicates parts per million Each vertical line represents one analysis.

The Ballston waters give higher results than any above cited. Doctor Chandler found in the Artesian Lithia spring 20,965, and in the Franklin 20,134. An analysis recently made of the latter spring by the Department of Agriculture gave 20,542.

These values will establish some conceptions of the extremes. A study of the diagrams will give a better impression of the mean or general composition. While not capable of definite expression, one finds it nevertheless helpful to formulate a general idea of this sort. Where, upon the charts, the curves take an approximately horizontal course, they indicate a number of analyses of nearly the same character, and if this feature is specially marked, values fairly typical of Saratoga may be looked for. In the oldest set of eight different springs, the totals of six lie between 6000 and 9000 parts in a million (353 to 530 grains to the gallon). In Doctor Chandler's series of thirteen analyses, representing a range from 5000 to 20,000 parts per million, six lie between 10,500 and 12,000. In the thirteen from the Department of Agriculture, there is an almost even decline from the maximum, about 13,000 down to 3100. There are then six between 2300 and 3100.

In every analysis known to the writer, save one, NaCl or common salt is the most abundant of the dissolved ingredients. The solitary exception is an analysis of Geyser water, made by the Department of Agriculture, in which $NaHCO_3$, sodium bicarbonate, 5058 parts, is more than three times the NaCl, sodium chlorid, 1588 parts. The Geyser water, however, as analyzed by Doctor Chandler, was normal. The analysis with the high percentage of sodium bicarbonate possesses more human than scientific interest. Except for this exceptional case the NaCl curve is with small variations sympathetic with the curve of total dissolved matter. The NaCl is from two and one-half to three times as abundant as the next salt, calcium bicarbonate, $Ca(HCO_3)_2$. The maxima and minima of NaCl are: earliest set — 7385 and 2531; Doctor Chandler's set — 11,938 and 2187; Department of Agriculture — 6873 and 738.

Next to the NaCl, the calcium bicarbonate, $Ca(HCO_3)_2$ and the magnesian bicarbonate $Mg(HCO_3)_2$ are the salts chiefly in evidence. They may best be discussed together. They display marked sympathy with each other, the $Mg(HCO_3)_2$ being usually somewhat less than the $Ca(HCO_3)_2$. Among the older analyses, the maxima are for the calcium and magnesium salts, respectively, 3966 and 2325. The minima are 714 and 544. In the analysis of the Star water, however, E. Emmons reports 714 and 2218, respectively, a relation which is extraordinary, as the subsequent analyses of Star water are both normal. Probably the separation of calcium and magnesium in the analysis was faulty. In Doctor Chandler's series, the maxima are respectively 3860 and 3297; the minima 1528 and 685. In the Department of Agriculture series, 3098 and 1974; the minima 36 and 55.

In the oldest series of eight different waters the magnesium salt exceeds the calcium salt twice; in the Chandler series of thirteen waters, twice; in the Department of Agriculture series of fifteen waters, also twice, but each time in very small amounts, 104 to 236 and 36 to 130.

Since these heavily carbonated waters are immediately derived from a dolomitic limestone and are vigorous, natural solvents of both calcium and magnesium carbonate, the two salts are doubtless derived in very large part from the limestone. Their solubilities in carbonated waters are respectively at pressures of one atmosphere, 385 and 1310 per million for non-crystalline varieties.

Of the ratio of the calcium carbonate, $CaCO_3$, to the magnesium carbonate, $MgCO_3$, in the Little Falls dolomites we can not speak with accuracy, because different layers probably differ, but the rock undoubtedly has the calcium salt uniformly in excess of the magnesium. In pure dolomite the calcium carbonate bears a ratio to the magnesium carbonate of 1 to .768. In Doctor Chandler's series the ratios lie between 1 to .417 and 1 to 1.13; in the Department of Agriculture's between 1 to .255 and 1 to 3.61, but in the last case the quantities are very small, 36 and 130 parts per million respectively.

While in very small amounts and therefore not plotted in the charts the presence of barium and strontium bicarbonates with the closely related calcium salt should be mentioned. Strontium was detected by one of the early chemists and is mentioned as a trace; barium, however, escaped notice. In the Chandler series barium bicarbonate is mentioned in many analyses and varies from upper values of 35.4 parts in the Glacier Spouting well and 34.2 in the Geyser, respectively 2.08 and 2.01 grains per gallon, to a trace in the Seltzer. Strontium bicarbonate is rarer. While invariably reported its maximum was 7.2 parts in the Geyser (.425 grains per gallon) but it was only a trace in ten out of thirteen analyses. Obviously it is present in very small proportions. In the analyses from the Department of Agriculture the maximum barium bicarbonate was found in the Lincoln water, 22.1 parts in a million, but strangely with no strontium whatever. The values of the barium salt are then pretty well distributed in the other analyses down to none at all in two of the seventeen. Strontium bicarbonate was never found above a trace in seven analyses, and failed altogether in ten.

The last salt found abundant enough to plot on the charts was the bicarbonate of soda, $NaHCO_3$. In the oldest series of analyses it favors very small values, the maximum being 359 parts, the minimum, 54.4. In the Chandler series the maximum is 1409, the minimum 64.6. In the Department of Agriculture series we find the exceptional Geyser water with 5058, which may be rejected from serious consideration. Next to it is the Chief, 1367. In two none is reported whatever.

Following the salts mentioned, potassium chlorid, KCl, is the one which on the whole next merits attention. In the earliest analyses it was seldom calculated. Only one record has been made and that of the Red spring, 116.6 parts in a million (6.86 grains in a gallon) by Professor Appleton. Such little potassium as was reported by the early chemists was usually combined with bromin, but many times we find no mention of it at all. In the Chandler series potassium chlorid is uniformly reported and fails in no analysis. Its maximum is 686.5 parts per million (40.4 grains per gallon) in the Glacier Spouting well. Its minimum 22.1 (or 1.3 grains) in the Seltzer spring. Among the thirteen analyses one is between 600 and 700; one between 400 and 500; one between 200 and 300; eight between 100 and 200; and two less than 100. Obviously, the common experience is between 100 and 200, or between 6 and 12 grains per gallon. In the Department of Agriculture series of seventeen analyses potassium chlorid is uniformly reported; one, the maximum, exceeds 400 (Carlsbad water 415); five fall between 300 and 400; two between 200 and 300; two between 100 and 200; and seven below 100, the minimum being 7.2. A comparison of these two statistics leads to no very tangible conclusion.

In the earlier analyses the next salt in abundance after sodium bicarbonate is iron bicarbonate, more often reported as iron carbonate. It appears in thirteen out of sixteen analyses. If we express it uniformly as bicarbonate we find that in six analyses it exceeds 100 parts in a million (maximum 148.2); in seven analyses it is below 100, the minimum being a trace. In the Chandler series iron bicarbonate is uniformly reported. Its maximum value is 43.7 parts per million, its minimum is .9. In the Department of Agriculture series the iron is sometimes given as bicarbonate and sometimes as ferric oxid with alumina. The maximum of the bicarbonate is 132.9, the minimum, none at all, that is no iron whatever was found in one case. Where expressed as the oxid with alumina, the maximum is 80 in the same sample as the maximum bicarbonate.

It may be remarked that in the later development of the springs, deep-drilled holes are increasingly abundant and are cased with iron pipe. A small trace of iron might thus be contributed, as we are in any event dealing with quantities extremely small.

Iron in any form is not specially welcome to the purveyors of table waters, because, on standing, it separates as the hydrated ferric oxid and imparts a brown cloudiness to the water. This can be prevented by the slight addition of some harmless acid, such as citric, which keeps the iron in solution.

Manganese is an element so closely akin to iron that it may be mentioned here. It is not reported in any of the older analyses nor in the Chandler series, nor in the ones by other chemists recorded by A. C. Peale in Bulletin 32 of the United States Geological Survey. In the Department of Agriculture series it is but once mentioned as a trace.[1] Two analyses are quoted in "Our County and its People," page 401, of the Putnam spring. 8.23 parts per million (.484 grains per gallon), Lincoln spring 1.72 parts (.101 grains per gallon), but the analysts are not given.

Obviously the amount is very small and practically negligible as a factor in the general total.

The haloid elements bromin and iodin were very early discovered. Both are almost always mentioned in the older series of analyses. The bromin was usually assigned to potassium and expressed as potassium bromid. While ordinarily a mere trace, when combined with sodium iodid the sum for the Congress spring in one case was 100.6 parts in a million (5.92 grains in a gallon). Sodium iodid ranges from 30 to 60 parts per million with a maximum reported for the Empire spring by E. Emmons of 204 (12 grains per gallon).

In the Chandler analyses the bromin and iodin when recast were both assigned to sodium, all the potassium being given as chlorid or sulphate. The maximum elementary bromin is 112.9 parts per million (6.64 grains per gallon) equivalent to 145.5 parts of sodium bromid (8.56 grains per gallon) in the Congress spring. The minimum is 1.82 (.107 grains per gallon), corresponding to 4.52 (.266 grains) sodium bromid in the Empire. The maximum elementary

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[1] In the analysis of the Seltzer water, page 92, Bulletin Bureau of Chemistry, no. 91, it is calculated as Mn_3O_4. 7.3, although not mentioned in the elementary analysis which has the same total.

iodin is 8.67 parts (.51 grains) or expressed as sodium iodid, 10.30 parts (.606 grains) in the Empire. The minimum is a trace.

In the Department of Agriculture series the maximum elementary bromin is 76 parts in a million, corresponding to 113 parts of potassium bromid, in the Lincoln spring. The minimum was a trace in the Vichy spring. All these analyses are recast to the potassium salt. The iodin is much less. Its maximum elementary is 1.9, corresponding to potassium iodid 2.5 in the Lincoln. Its minimum is none at all.

The remaining haloid element, fluorine, was not reported in any of the earlier analyses, but it is almost always mentioned as a trace and assigned to calcium as calcium fluorid in the Chandler series. Fluorine is not mentioned in the analyses from the Department of Agriculture. Obviously when present its amount is extremely small, almost beyond the detection of ordinary analysis.

The presence of sulphates was noted by the early chemists who mention them in four out of sixteen analyses. In these, the sulfuric acid is assigned to sodium sulphate (Na_2SO_4) and ranges in amount from 28.56 parts in a million to 11.0 (1.68 grains in a gallon to .65). In one case it was calculated as magnesium sulphate, with .85 parts (or .05 grains). In the Chandler series it is always assigned to potassium sulphate and varies from 91.8 parts in the Star spring to a trace in several others (5.4 grains to a trace). In the Department of Agriculture series sodium sulphate is used. The maximum is 444.9 parts (26.2 grains) in the Arondack water, and the minimum 2.1 parts (.12 grains) in the Geyser.

Lithium is an element whose presence is greatly desired by the purveyors of mineral waters because of its supposed medicinal value. It does not fail in the Saratoga waters, but is in the customary small amounts. It was reported in only one case by the older chemists, in the Red spring, with 16.6 parts of lithium bicarbonate in the million (.94 grains in a gallon). As the bicarbonate it is mentioned in weighable amounts in all the Chandler analyses, varying from 194.6 parts in a million in the Hathorn (11.45 grains per gallon) to 15.3 as the lower limit (.9 grains per gallon) in the Seltzer. In the Department of Agriculture series the lithium is recast as lithium chlorid which is about six times the elementary lithium, whereas the lithium bicarbonate is nearly ten times. The maximum lithium chlorid reported is 44.9 parts in a million, but in a later analysis of the same water only 3 parts were found. In the seventeen analyses, two lie between 30 and 40 parts; one between 20 and 30; four between 10 and 20; and eight are less than 10, one being a trace. These figures mean from a maximum of 2.64 grains in a gallon, to a trace.

Phosphoric acid was detected in two cases by the early chemists and was assigned to calcium as $Ca_3(PO_4)_2$ each time by the same chemist. The amounts were 3.57 and 3.23 parts per million of calcium phosphate. In the Chandler series the phosphoric acid is assigned to the sodium, and when reckoned as sodium phosphate ranges from a maximum of .44 parts in a million (.026 grains in a gallon) to a trace in five out of thirteen cases. In the Department of Agriculture series the phosphoric acid radicle (PO_4) was only found once in seventeen cases; all the rest gave none. Calculated as calcium phosphate $Ca_3(PO_4)_2$ it was 3.8 parts in a million (.22 grains per gallon).

Boron in some form of boracic acid has been occasionally reported. None of the older chemists detected it. In the Chandler series it is calculated as biborate of soda, and is reported as a trace in every analysis, never exceeding this value. In the analyses from the Department of Agriculture none at all was found in three of the seventeen cases, but in the other fourteen it varies from a small amount to a trace. It was in no case actually weighed as its determination in small quantities is difficult.

Alumina was recognized by the early chemists and was reported in seven out of sixteen analyses. Its maximum was 26.69 parts in a million (1.57 grains in a gallon) in the Union spring and its minimum a trace in three cases. It is always mentioned in the Chandler series and varies from a superior value of 20.8 parts in a million (1.22 grains per gallon) in the High Rock, to a trace in three cases. The analyses of the Department of Agriculture are not expressed so as to be of much service. Elementary aluminum is combined with elementary iron. These are sometimes recast as the combined oxids, and sometimes a portion of the iron is apparently assumed and calculated as bicarbonate. The combined elements range from a maximum of 97.8 parts in a million (5.8 grains per gallon) in the Magnetic (partly recast as 80 parts Fe_2O_3, Al_2O_3, and 132.9 parts $Fe(HCO_3)_2$) to a minimum of .8 (.05 grains per gallon) in the Champion. The Magnetic spring is, however, very exceptional. The next value to it is 14.7, so that the general range is approximately from 15 to 1.

Silica was recognized by the early chemists and was mentioned in eleven out of sixteen cases. It ranged from 55.25 parts in a million (3.25 grains per gallon) to a trace. It is always reported by Doctor Chandler and has a maximum of 54.6 parts per million (3.2

grains per gallon) in the Crystal spring and a minimum of 11.3 parts (.66 grains per gallon) in the Geyser. In the Department of Agriculture series, silica is always reported. Its maximum of 42.7 parts (2.5 grains) is in the Magnetic. The minimum of 9.2 parts (.54 grains) is in the Arondack. The values are quite uniformly distributed between these values. Once in the Vichy spring, a portion of the silica is recast into 27.6 parts of calcium metasilicate, CaO,SiO_2.

In one of the older analyses, made by J. R. Chilton of the Washington spring, 3.4 parts in a million (.2 grains per gallon) of calcium chlorid, $CaCl_2$, are reported, and 11.56 parts of magnesium chlorid, $MgCl_2$ (.68 grains), but the later analysts do not estimate these salts. Aside from the ones already passed in review, no other determinations of solids were made by the early chemists.

In the Chandler series organic matter is mentioned as a trace in every analysis, but no other solids are recorded than the ones already discussed.

In the series from the Department of Agriculture organic matter as such does not appear, but several determinations not reported in the two earliest groups of analyses are mentioned. Ammonium was found in every case and when expressed as ammonium chlorid, NH_4Cl, it ranges from a maximum of 39.67 parts in a million in the Carlsbad water (2.33 grains per gallon) to a minimum of .15 parts in the Victoria. The radicles of both nitric (NO_3) and nitrous (NO_2) acids are uniformly given. When recast as sodium nitrate, $NaNO_3$, we find 60.7 parts for the Star, followed by 16.3 for the Arondack, 9 for the High Rock, 6 for the Seltzer and a trace or none at all for the other thirteen. Sodium nitrite, $NaNO_2$, appears as 44.3 parts per million likewise for the Star, 11.9 for the Arondack, 6.6 for the High Rock, 4.4 for the Seltzer, and a trace or none for all the rest. Occasionally in analyses of other chemists whose work is not used in the above review, potassium nitrate is mentioned but the amount is always small. The presence of these salts in notable amount is so exceptional in the waters as to raise a query in the minds of close students.

The above review will make clear in a general way the ranges of composition in dissolved salts as shown by the waters at different times and by different chemists. The current remarks will bring out also the variations of waters of this type and the changes in the course of some seventy-five years, except in so far as the obvious gradual weakening may have been compensated in later time by artificial additions. A brief summary and tabulation of the maxima and minima may now be given. All the values are in parts per million. Divide by 17 for grains per gallon.

Salt.	EARLY ANALYSES 1820–1850		C. F. CHANDLER 1860–1875		DEP'T OF AGRICULTURE 1902–1905	
	Max.	Min.	Max.	Min.	Max.	Min.
Total solids	11,215	3787.	20,325	5134.	12,950	2347.
NaCl	7385	2531.	11,938	2187.	6873	738.
KCl	116.6		686.8	22.1	415	7.2
KBr NaI	100.6	tr.				
NaI	204.		10.30	tr.		
NaBr			145.5	4.52		
KBr					113.	tr.
KI					2.5	None
LiCl					44.9	tr.
NH4Cl					39.67	.15
CaF_2			tr.			
$CaCl_2$	3.4					
$MgCl_2$	11.56					
$Ca(HCO_3)_2$	3966.	714.	3860.	1528.	3098.	36.
$Mg(HCO_3)_2$	2325.	544.	3297.	685.	1974.	55.
$Ba(HCO_3)_2$			35.4	tr.	22.1	None
$Sr(HCO_3)_2$	tr.	tr.	7.2	tr.	tr.	None
$Fe(HCO_3)_2$	145.2	tr.	43.7	.9	132.9	None
$Mn(HCO_3)_2$					tr.	None
$NaHCO_3$	459.	54.4	1409.	64.6	5058. 1367.	None
$LiHCO_3$	16.		194.6	15.3		
Na_2SO_4	28.56	11.			444.9	2.1
K_2SO_4			91.8	tr.		
$MgSO_4$	.85					
$NaNO_3$	28.56				60.7	None
$NaNO_2$					44.3	None
$Ca_3(PO_4)_2$	3.57				3.8	None
$Na_6(PO_4)_2$			.44	tr.		
$Na_2B_2O_4$			tr.	tr.		
$NaBO_2$					small amt.	None
Al_2O_3	26.69	tr.	20.8	tr.		
Al_2O_3, Fe_2O_3					80.	
SiO_2	55.25	tr.	54.6	11.3	42.7	9.2
$CaSiO_3$					27.6	None
Organic matter			tr.	tr.		

Besides the compounds quoted in the three series of analyses, one may find in the occasional commercial analysis the following additional ones: calcium sulphate, potassium nitrate, potassium silicate, sodium silicate, boracic acid and ortho-silicic acid. The only additional element is rubidium which, as the chlorid, is cited as a trace in an analysis of the Sans Souci spring of Ballston in " Our County and its People," page 408, no chemist being mentioned.

As stated in the general remarks on chemical analyses, there is much room for assumption in recasting analyses to compounds. It will be of interest therefore to summarize briefly the relative abundance of the elements or acid radicles. The values will be taken only from the Chandler series of analyses and those of the Department of Agriculture. In all cases the chlorine is the most abundant elementary substance, except in the extraordinary instance of the Geyser analysis in the latter series, whose sodium bicarbonate proportion is so high as to give it no scientific value. The sodium follows after the chlorine, and as a rule the calcium and magnesium come next, the calcium usually in excess. Potassium is next and is succeeded by bromine, barium and lithium. The other elements are very small. Ammonium although not an element, behaves like one, and in the Department of Agriculture series on the whole ranks barium. Silica, also not elementary, precedes barium. Iron and aluminum together come approximately between silica above and barium below. If we calculate the carbonic acid of the bicarbonates as HCO_3 it may, in waters with high lime and magnesia, exceed the chlorin and be the highest value of all. If we consider also the gas that escapes, it is the most abundant dissolved substance as the water exists two or three hundred feet beneath the surface.

Since it is difficult to follow variations of so many substances, a series of curves has been plotted and is shown in figures 5–8 inclusive. Analyses are sometimes prepared of the evaporated residues. They are then expressed in percentages of the total residue. They are very significant in being simpler than parts per million in the water itself. They also enable one to judge critically the amount of the commoner ingredients. As the concluding table of analyses at the close of this bulletin (p. 75, 76) a compilation of those which have appeared up to date is given. It was chiefly made by Mr J. C. Minor, jr. To Mr Minor's records one or two recent analyses have been added.

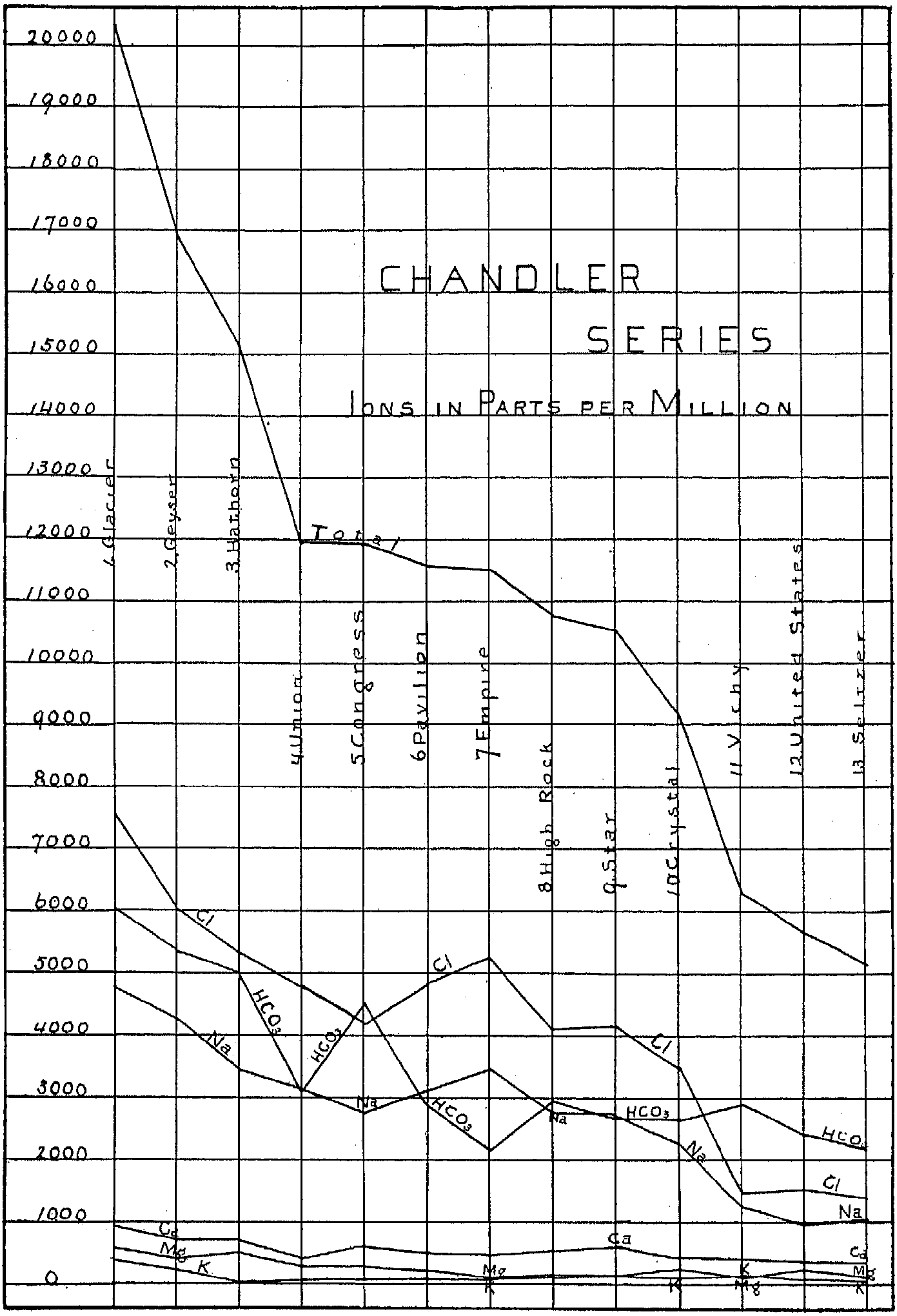

Figure 5 Diagrams of ions in parts per million

When statistics are prepared of these analyses, the following results become apparent. There are 66 analyses:

	MAXIMUM	MINIMUM	GENERAL RANGE
$NaCl$	87.	21.2	45–60
$Ca(HCO_3)_2$	40.6	1.4	15–30
$Mg(HCO_3)_2$	27.9	2.3	5–20
$NaHCO_3$	67.3	.6	1–15
KCl	11.2	.4	1–5

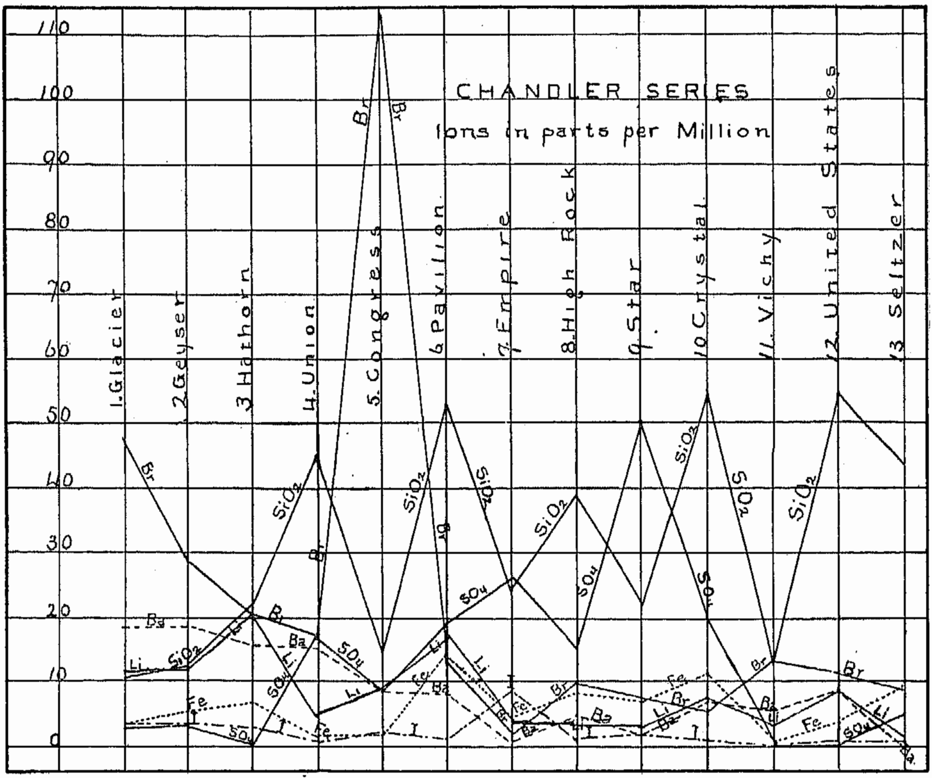

Figure 6 Diagrams of the rarer ions on an exaggerated scale as compared with figure 5

The extremely high values of NaCl are probably due to artificial strengthening. The minimum is due to the artificial addition of $NaHCO_3$, which relatively decreased the NaCl. NaCl above 60 per cent is an object of suspicion. The maximum, 40.6 of $Ca(HCO_3)_2$ is from a recent analysis of the High Rock. The next value is 40.4, of the Red spring. Then follow, 40.3 of the Magnetic and 38.6 of the Flat rock. All these have low total grains in the gallon, being respectively 129.4, 249.3, 214.7, and 253.8. All are from springs in

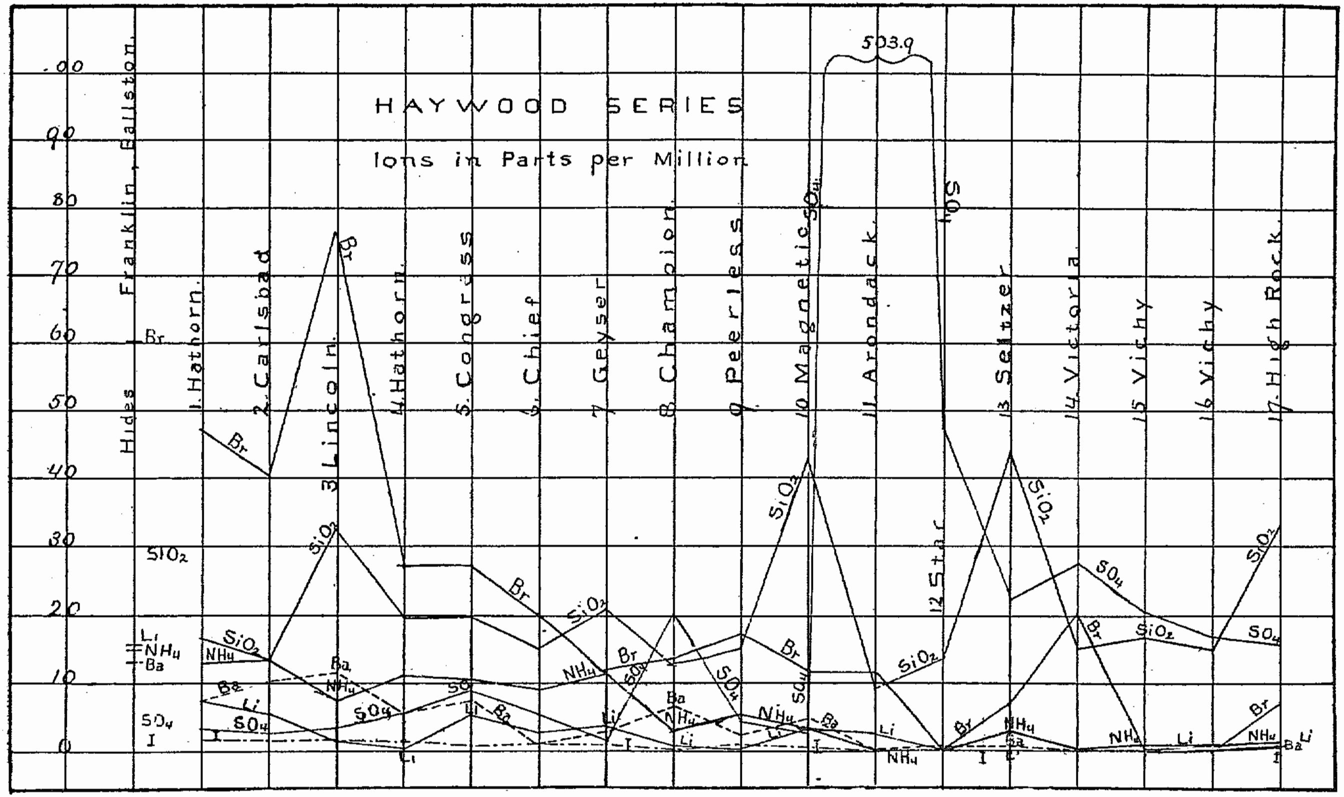

Figure 8 Diagrams of ions of the less abundant components, based on the analyses of J. K. Haywood and B. H. Smith 1905

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See Image 2
In Bulletin Folder

the northern part of the village. As the strength in salt and the total grains per gallon have diminished in later years, the relative amount of calcium bicarbonate has increased. This salt is always available for the carbonated waters to dissolve from the limestone. One would anticipate the same relation for the magnesium bicarbonate but in the high percentages of the table, it seems difficult to establish them. The magnesium salt is generally less than the lime, but in the six percentages of 20 and above, five exceed the lime salt, and one of the Congress' 1843, is almost equal.

In the values of $NaHCO_3$ above the superior limit of the general range, there are six, respectively: 22.4, 22.9, 25.2, 29.1, 33.0, and 67.3. All the other fifty-seven analyses (in three $NaHCO_3$ is not reported) run less than 15; forty-seven of them less than 10. The high values may be regarded in a questioning spirit.

In ten analyses no KCl is reported. Fifty-two others are less than 5. The three remaining are 6.8, 9.8 and 11.2.

These analyses are of interest when compared with those recorded for sea water on a subsequent page.

THE CARBON DIOXID

This gas is one of the most important features of the waters and is what gives them their palatable taste. Before undertaking its discussion a few fundamental properties of it may be recorded in order to make the subsequent statements intelligible. We have to distinguish between the uncombined (free) carbon dioxid and the portion combined with the bases as bicarbonates.

The combined portion remains in solution and is not apparent to general observation. The uncombined is also in solution in the depths of the earth, having formed with water, H_2O, carbonic acid, H_2CO_3, but as the water rises to the surface, this weak acid under the influence of diminishing pressures breaks up again into H_2O and CO_2. The gas escaping causes the effervescence or ebullition, as the case may be. Not all of it escapes because under the ordinary surface conditions the water retains in solution an amount of gas equivalent to its volume. That is, the water dissolves one volume of the gas. While the presence of the NaCl has some effect on the solubility of the CO_2, yet it is not enough seriously to influence the relations. The one volume of the gas which normally remains in solution can be driven off by boiling, or can be freed in a vacuum.

Ten cubic feet of CO_2, at ordinary temperatures and pressures, weigh practically one pound, so that one cubic foot is about .1 of a pound. If the specific gravity of air be taken as 1.0, CO_2 is 1.529. A liter of air weighs 1.293 grams, and a liter of CO_2 weighs 1.976. Gases are of course very sensitive to changes of temperature and pressure, and therefore in very accurate statements both have to be mentioned, but without going into too great refinements the above figures will answer for ordinary temperatures and pressures.

Since a gallon is 231 cubic inches, or .1337 of a cubic foot, a gallon of CO_2 weighs .01337 pounds or, as there are 7000 grains in a pound, about 93.6 grains. Where analyses are expressed in grains per gallon, and CO_2 is reported (as in the Chandler series) both as total CO_2, and as CO_2 in carbonates and bicarbonates, we can easily obtain the free gas by subtracting the latter from the former. If we then divide the free CO_2 expressed in grains by 93.6 we change it over to volumes. The necessary data are given in the Chandler series. In the analyses from the Department of Agriculture, the data are given in the thirteen analyses of samples taken directly at the springs. Since they are expressed in cubic centimeters per liter they read off directly in volumes, but it is obvious from the figures that they do not represent the total gas that reaches the surface with the waters.

The best guide to the amount of carbonic acid gas emerging with the mineral waters is furnished by the experience of the gas companies. The richest in gas was found to be the Adams well of the New York Company now the General Carbonic Company. It yielded five volumes of the gas leaving one volume in solution. The general average, however, was two or three.

THE WATER SEAL

Under the general topic of carbonic acid gas, note may be made of a very curious phenomenon connected with the natural flowing springs which have been drilled and cased. If even in the most gaseous one the top of the casing be covered tightly so as to prevent the escape of the water and gas, and if the tight cover be maintained in this condition long enough to permit all the free gas to rise and collect immediately beneath it so that the well becomes quiet, the well will not resume its flow on removing the obstruction. It must be artificially started with a pump. The phenomenon is called the *water seal,* since the spring is, as it were, sealed off by water.

The explanation lies in the following relationship of the solubility of carbonic acid gas to the pressure under which the water stands at time of solution. Thus, when the temperature is 55° F. under a pressure of one atmosphere water dissolves about one volume of carbonic acid gas. With a higher temperature it dissolves less, and with a falling temperature more. Under a pressure of five atmospheres it will dissolve at 55° F. about five volumes. Now an atmosphere is roughly 14 pounds pressure to the square inch, and is equivalent to a head of about 32 feet of water. In a standing column of water as soon as we pass a depth of 160 feet the overlying liquid will exert a pressure of 5 atmospheres and can keep 5 volumes of gas quietly in solution. As we go deeper more and more gas can be dissolved with the increasing pressure. The waters in the bored wells usually come from a depth of about twice 160, and are but half saturated with gas for that depth. All the gas is in solution just as it is in a siphon of carbonic water. If, however, we get an upward flow started, so that the dissolved gas under diminishing pressure can escape from solution, it replaces a part of the heavier water with the lighter gas, and greatly reduces the specific gravity of the water column, and therefore diminishes the pressure resting on its base. The solubility is reduced, more gas escapes and a flow of gas and water results. When a barrier is interposed the free gas escapes and collects at the top. Equilibrium of solution and pressure is established and the water stands quietly in the tube. Nevertheless it seems surprising, when one views the agitated spouting and gurgling of the springs, to think that they can be brought to rest by so simple a means.

It also follows that when carbonic acid gas is once in solution and at depths where the pressure prevents saturation and escape, the gas will remain in solution indefinitely. It is no more remarkable that this carbonated solution should be contained in the strata of the earth for one or several geological periods, than that a solution of common salt or of any other salt should do the same.

The Saratoga and Ballston springs are, on the whole, the richest in carbonic acid of those known in this country.

THE TEMPERATURE OF THE WATERS

The waters come to the surface with temperatures that are in almost all cases between 50° and 54° F. or 10°–12° C. Doctor Chandler records in a total of eight cases six between 50 and 52, and two at 48 and 46. For the Ballston waters he gives two at 52 and one at 54. Many readings at the wells of the General Carbonic Co. fall in with the first general statement of 50° to 54° F. The prevailing temperature is somewhat above the mean annual temperature for Saratoga Springs.

The temperatures are appreciably higher in the summer than in the colder season, undoubtedly from the effect of the admixture of surface waters which vary with the months of the year. Mr J. C. Minor, jr, has made the following observations upon the wells of the former New York Co., now the General Carbonic Company. All but the last two were pumped wells.

	April 24, 1909	June 7, 1909	August 15, 1909
Old Hurlbut Well	51.2 F.	52.3 F.	53.2 F.
No. 1 Well	50.3	51.8	56.8
[1] Hathorn No. 1	51.4	52.9	53.8
[1] Hathorn No. 2	51.0	52.5	53.6
Bridge	50.3	50.8	53.0
Hayes	51.2	52.1	53.2
Adams	48.2	49.8	50.5
[2] Carlsbad	.	50.7	51.4

THE SPECIFIC GRAVITY OF THE WATERS

Doctor Chandler records the specific gravity of nine of the Saratoga springs; they vary with the amount of dissolved solids ranging from a minimum of 1.0034 to a maximum of 1.012.[3] The Ballston waters which are specially rich in dissolved salts, range from 1.0125 to 1.0159.

CLASSIFICATION [4]

Mineral waters are necessarily classified upon the basis of their chemical composition. A grouping especially favored in America is the following. A thermal spring, as defined by A. C. Peale, is one whose temperature exceeds 70° F. The scheme below is Haywood's modification of Peale's original proposal:

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[1] These wells called Hathorn No. 1 and No. 2 are not to be confounded with the well-known spring in the village nor with the new flowing springs south of Geysers Station. The names are purely of local application.

[2] Now the Caesa.

[3] There is an obvious misprint in the tabulated analysis of 1.096 for 1.0096 under the Congress Water. Amer. Chemist, Dec. 1871, p. 203. It is repeated in Cairn's Quant. Analysis.

[4] This subject is well treated by A. C. Peale in "Mineral Waters of the United States," U. S. Geol. Survey, 14th Ann. Rep't.

With minor subdivisions much the same is also used by J. K. Haywood, in Bulletin 91, U. S. Dept. of Agriculture, from which the analyses have been taken and so often commented upon above. Peale's classification is based on recast salts, Haywood's on ions.

GROUP	CLASS	SUBCLASS	FURTHER DESCRIPTION	FURTHER DESCRIPTION
Thermal and Nonthermal	1 Alkaline	Carbonated or bicarbonated Borated Silicated	Iodic Lithic Potassic Calcic Magnesic Ferruginous	Nongaseous Carbon-dioxated Sulfuretted Azotized Carburetted Oxygenated
	2 Alkaline-saline	Sulphated Muriated Nitrated		
	3 Saline	Sulphated Muriated Nitrated	Aluminic Arsenic Bromic Iodic Silicious Boric	
	4 Acid	Sulphated Muriated		

1 Alkaline waters are those which give an alkaline reaction and contain carbonic, bicarbonic, boric or silicic acid ions in predominating quantity among the acids.

2 Alkaline-saline waters constitute an intermediate group between 1 and 3. They yield an alkaline reaction. Either with or without the acid ions mentioned under 1, they have in predominance, sulfuric, muriatic or nitric ions.

3 Saline waters are those which have an alkaline or neutral reaction and contain sulfuric, muriatic or nitric acid ions in predominating quantity.

4 Acid waters yield an acid reaction and contain either sulfuric or muriatic ions in predominance.

In descriptions Mr Haywood suggests that the terms in the table beginning with those headed "class" be used so that the columns with slight modifications come in the following order: 1, 4 through aluminic, 3, 2, 4 from arsenic to the close, 5. The Hathorn spring Mr Haywood describes as a nonthermal, sodic, muriatic, alkaline-saline (lithic, bromic, iodic) carbon-dioxated water. Other springs at Saratoga vary somewhat from this description. In those with high calcium, we might have to introduce calcic after sodic; perhaps also magnesic. Not every water has enough lithium, bromin or iodin to justify the terms lithic, bromic, or iodic. In a few sodium chlorid is in such marked predominance as to throw them into the saline class. The questionable analysis of the Geyser water with its extraordinary sodium bicarbonate, would come under the first class of alkaline waters. We are safe in saying, however, that the Saratoga waters belong under the alkaline-saline, rarely the saline classes. That they are all muriated and sodic. Some are calcic and magnesic, one or both. Some are lithic, bromic, iodic, one or several. Practically all of importance are carbondioxated.

VARIATIONS IN THE WATERS

In the course of the last seventy-five years there have been variations in the waters as shown by the analyses and by the experience of owners of springs. Even if we allow for differences in the accuracy of chemical methods, and of chemists themselves, throughout this long stretch, a solid substratum of sound inference remains. Several instances will be of interest, but it is not only important but necessary to understand the possible modifying factors.

In the early years of settlement and utilization all the springs issued from natural crevices in the rock, possibly, as in the case of the High Rock, coming to the actual surface through gravel, bog, calcareous tufa, etc. In order to protect and maintain the flow it soon became customary to sink a pit through the overlying loose materials to the bedrock, and cement tightly to the rock around the actual vent, a pyramidal or conical wooden tube, prolonged in a pipe, within which the mineral water reached the surface, undiluted by admixtures of surface waters, so far as these stood in the gravels etc.

As time went by wells were drilled into the rock, either to restore old and dying springs or else to develop new ones of which there might be no surface indications. If successful these bore holes would strike a productive crevice. If they were continued below it, without additional supplies, the hole might later be plugged below the productive point. Above the productive crevice, the hole would be cased by a larger pipe, fitted tightly into the bore hole with a gasket at its lower end. A smaller pipe having been introduced within the casing, it also had a gasket above the supply point. The waters thus rose in the inner pipe. The casing kept out the higher and of course weak ground waters, and maintained the strength of the deep-seated mineral spring. If, however, the casing should rust through as was the experience in seven years' service of one pipe in a well on the property of the New York Carbonic Gas Co., this protection would no longer be afforded and weakening of the waters might follow. There are also some unsuccessful holes in which casings may or may not be left, and down which surface waters are tapped by a relatively large inlet to the productive horizons. In one case, that of the Ainsworth well, a charge of explosive was set off several hundred feet beneath the surface and of course it shattered the surrounding rock, in a way which might give greater ingress to mineral waters, but might also give the weak surface waters a more favorable entrance.

Where active pumping is carried on, as has been the case on the properties of the gas companies, the ordinary level of the ground water is lowered near the pump or pumps and its surface forms an inverted cone, or approximation to a cone, called the cone of depression. The diameter of its base, or the radius of influence of the pump, can be determined by observation if there are wells all about. This matter was carefully studied on the property of the General Carbonic Co., and it was found that the remotest depression of the ground water observed was less than 400 feet from the pumps. The influence was irregular, some wells even quite near each other showed slight sympathy.

Where the wells have been drilled through slate in order to tap the productive limestone it is important to keep the casing tight because the slates furnish a water containing sulfur compounds, more particularly sulfuretted hydrogen, which even in small quantities gives an undesirable taste to the water. The inlet of surface waters from the slates is thus not only weakening to the spring but a detriment in other respects.

In the history of a water and in comparisons, it is unavoidable that samples should sometimes be taken from different vents on the same property. Thus, when older springs have given out, or perhaps have been obstructed with sediment, or have found other natural vents, new bore holes have been put down. But they are so near the old spring, as a rule, as to give presumptive evidence of tapping at least much the same underground source.

Parts per million

	J. H. Steel Before 1838	J. R. Chilton 1843	J. F. Dana ?	C. F. Chandler 1871	J. K. Haywood 1903–05
1 Congress spring					
Total	11197.9	11215.4	12324.3	11915.3	10232.7
NaCl	6545.0	6185.1	7384.8	6806.8	5141.6
$Ca(HCO_3)_2$	2701.3	2371.5	3966.1[a]	2437.8	2276.5
$Mg(HCO_3)_2$	1628.6	2325.6	544.0	2069.9	1674.9

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[a] Undoubtedly the separation of calcium and magnesium was incomplete, some magnesium being weighed as calcium.

	J. H. Steel Before 1838	J. R. Chilton 1840	E. Emmons 1839	C. F. Chandler 1871		J. K. Haywood 1903–05
2 High Rock spring						
Total	6604.5			10718.5		2347.2
NaCl	3214.7			6631.7		738.2
$Ca(HCO_3)_2$	1907.4			2239.6		906.8
$Mg(HCO_3)_2$	1047.2			933.6		364.9
4 Star spring						
Total			6244.1	10495.1		2958.0
MaCl			3179.0	6772.1		2150.5
$Ca(HCO_3)_2$			71.4	2115.8		481.9
$Mg(HCO_3)_2$			2218.5	1052.4		130.8
3 Pavilion						
Total		6613.7		11583.5		
NaCl		3190.9		7818.3		
$Ca(HCO_3)_2$		1455.2		2042.9		
$Mg(HCO_3)_2$		168.3		1304.4		
2 Geyser						
Total				16856.3		7656.0[a]
NaCl				9555.7		1588.8
$Ca(HCO_3)_2$				2896.8		471.4
$Mg(HCO_3)_2$				2538.8		364.9
3 Hathorn						
Total				15102.8	13170.0	10859.0
NaCl				8668.3	7343.7	5762.4
$Ca(HCO_3)_2$				2901.0	3098.3	2635.3
$Mg(HCO_3)_2$				2999.8	1974.7	1377.8

	C. F. Chandler 1869		J. K. Haywood 1903–05
5 Seltzer			
Total	5134.2		2737.0
NaCl	2283.1		1111.0
$Ca(HCO_3)_2$	1527.8		1000.0
$Mg(HCO_3)_2$	685.8		405.6
6 Vichy	1872		
Total	6244.5	2629.1[b]	2441.0[b]
NaCl	2187.9	1499.1	1459.5
$Ca(HCO_3)_2$	1623.8	158.8	167.3
$Mg(HCO_3)_2$	705.5	60.8	58.8

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[a] This is the analysis with 5058.3 $NaHCO_3$.

[b] These two analyses have respectively 837.1 and 693.1 $NaHCO_3$.

4 Kissingen, now the Arondack	Sharples 1872	J. K. Haywood 1903–05
Total	10958.7	3094.0
NaCl	5754.5	1725.1
$Ca(HCO_3)_2$	2384.4	104.1
$Mg(HCO_3)_2$	1198.0	236.2

1 Champion	C. F. Chandler[a] 1871	
Total	20324.9	6790.2
NaCl	11938.1	4521.6
$Ca(HCO_3)_2$	3860.2	1410.6
$Mg(HCO_3)_2$	3286.5	488.3

Ballston Spa

Franklin Artesian well (now Hide's Franklin spring)	C. F. Chandler 1869	Dep't of Agriculture Later than 1905
Total	20134.8	20542.6
NaCl	11208.8	11186.7
$Ca(HCO_3)_2$	3439.6	4007.2
$Mg(HCO_3)_2$	3023.7	2822.0

Study of these data brings out the following conclusions. The Congress spring shows no appreciable change from 1840 to 1870. From 1870 to 1903 it fell off about one-sixth or 12 to 13 per cent. The High Rock increased in strength from 1840 to 1870, presumably because of the prevention of inflowing surface water. It then fell off from 1870 to 1902 nearly 80 per cent in dissolved solids, most of all in NaCl. The Pavilion spring greatly increased in strength from 1840 to 1870, probably from improved protection against surface waters. The Star spring improved from 1839 to 1870, but then fell off from 1871 to 1903 over 70 per cent in strength. The Champion spring (discovered 1871) decreased from 1871 to 1903 about 70 per cent in strength. The Geyser spring from 1870 to 1903 fell off about 55 per cent. The Hathorn (discovered 1868) decreased from 1870 to 1903 about one-third in strength. The Kissingen or Arondack, as now called (discovered 1872), declined from 1872 to 1903 about 70 per cent. The Seltzer (discovered in 1865) from 1869 to 1903 fell off somewhat less than 50 per cent and finally the Vichy (discovered 1872) declined about 60 per cent.

The general conclusion from the concurrent testimony of these

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[a] Quoted by A. C. Peale, Bul. 32, U. S. Geol. Surv. p. 38.

comparisons is that the mineral waters, especially in Saratoga Springs village, have greatly declined in strength in the last thirty years.

By way of contrast two analyses are given of the Franklin Artesian water of Ballston Spa (discovered 1867), one made in 1869 and the other at least 35 years later in the Department of Agriculture, Washington. There is no appreciable change. The water comes from much greater depth than the Saratoga wells and far fewer wells have been drilled in Ballston.

THE ORIGIN OF THE MINERAL WATERS

The previous pages place before a reader the geological and chemical facts about the springs upon which, aided by experience gained elsewhere, the scientific explanations of their origin must be based. This interesting question did not fail to attract the attention of early observers. Dr J. H. Steel, to whom we owe so much of valuable record, was alive to the difficulties of the problem. On page 202 of the second edition (1838) of his book which was first published in 1817, he states in closing: "Much interest has been excited on the subject of the source of these singular and interesting waters, but no researches have as yet satisfactorily unfolded the mystery. The large proportion of common salt found among their constituent properties may be accounted for without much difficulty, all the salt springs of Europe as well as those of America being found in geological situations exactly corresponding to these,[1] but the production of the unexampled quantity of carbonic acid gas, and the medium through which the other articles are principally retained in solution, is yet and probably will remain a subject of mere speculation. The low and regular temperature of the water seems to forbid the idea that it is the effect of subterranean heat, as many have supposed, and the total absence of any *mineral acid* excepting the marine[2] which is combined with soda, does away with the possibility of its being the effect of any combination of that kind. Its production is therefore truly unaccountable."

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[1] Our more complete geological knowledge today would hardly justify us in admitting this sweeping statement.

[2] There are now known small amounts of sulfuric and nitric, but in the large way Doctor Steel's statement is true. It is reported that Doctor Steel was instrumental in organizing a company (in the decade of the twenties) to bore for salt deposits on the evidence of the springs, but that after drilling 110 feet the enterprise was abandoned.

Both W. W. Mather and L. C. Beck in their respective final State geological reports in 1842, discuss the springs but neither of them connects them with the fault which became later the object of much respect. In fact, while the cliff of limestone east of the springs is mentioned by Professor Mather in describing the valley in which the springs are found, he does not interpret it as a fault. On page 94 of the Report on the First District, Mather speaks as follows:

> The Saratoga Springs are supposed to derive their mineral qualities from the limestone and slate beds that underlie the town, or they may be more deeply seated; but the water is usually obtained from beneath the clay and "hardpan" beds that overlie the rock. Limestone rock that belongs to the calciferous group, crops out in the village and in many places in the vicinity, and the primary rocks are not far distant on the north and west.

Regarding Ballston, he expresses himself as follows, on page 98: "It is probable that the mineral qualities of the water originate at the contact of the fucoidal slate with the underlying Trenton limestone, which is probably not more than fifty feet below the level of the valley at the springs." He then cautiously advises boring at some low point until the limestone is struck and that the hole be continued even to the calciferous sandrock. "At Saratoga the course of the water is supposed to be in the limestone, and this limestone which is the lower portion of the Mohawk, or upper part of the calciferous sandstone, must lie at a depth of one hundred and fifty feet at Ballston. Borings, however, might entirely miss a seam productive of water." It is interesting to note that the wells which have been bored go down through about four times as much slate as was anticipated.

Doctor Beck in his valuable report on the mineralogy of the State, discusses the chemistry of the waters at some length and gives several of the analyses which have been used on an earlier page of this paper. On page 137, after speaking of the discharge of gas at Saratoga and at Ballston, sometimes explosively at the latter, he states: "From these facts, it is evident that here, as at Saratoga, there are certain agencies in operation which cause an abundant evolution of carbonic acid, a part of which has been originally held in solution by the water but another and perhaps much the largest part is an independent stream of gas, discharged in the form of a solfatara, or gaseous spring. That this gas originates at great depths and rises freely through the crevices in the rock, is rendered probable from its alternately breaking and disappearing at points somewhat distant from each other. And perhaps the opinion of

Berthier may here be applied, viz, that the water of the spring is forced up by the elasticity of the confined gas. . . . In general, the occurrence of carbonic acid in these waters is to be ascribed to the existence of large quantities of it held in solution by water at great depths, and therefore under enormous pressure; or by the gas itself being kept by the same agency in a liquid form, until, by the removal of the pressure, it assumes the gaseous state, and is thus disengaged." These phenomena have been discussed in the light of modern chemistry and physics under the topic Water Seal, on page 40. At some date between 1842 and 1871, when Professor Chandler published the paper, to be shortly reviewed, the fault was recognized and was regarded as of importance in connection with the springs.

In the years just before and after 1860, Dr T. Sterry Hunt, chemist of the Geological Survey of Canada, published a number of papers dealing with the chemical side of geology and among them one of much importance in connection with mineral waters.[1] The paper has had a decided influence upon some of the current views regarding the Saratoga Springs, although Doctor Hunt refers to the springs only in a general way. Doctor Hunt's attention had been drawn to many waters which issue from the lower Paleozoic strata of Quebec and Ontario. He viewed these waters as representing the ancient Paleozoic sea in which the sediments had been deposited; that is, he believed them to be "connate" as the term has been explained on page 19. In a still earlier contribution read before the Geological Society of London,[2] Doctor Hunt states "When we examine the waters charged with saline matters which impregnate the great mass of calcareous strata constituting in Canada the base of the Paleozoic series, we find that only about one-half of the chlorine is combined with sodium; the remainder exists as chlorids of calcium and magnesium, the former predominating, while sulphates are present only in small amount. If now we compare this composition, which may be regarded as representing that of the Paleozoic sea, with that of the modern ocean, we find that the chlorid of calcium has been in great part replaced by common salt, a process involving the intervention of carbonate of soda and the

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[1] The Chemistry of Natural Waters. Amer. Jour. Sci. March, July, and September 1865. Reprinted with some omissions in Chemical and Geological Essays, 2d ed. p. 93–167, 1878.

[2] On some points in chemical geology, Quar. Jour. Geol. Soc. Nov. 1859. Chemical and Geological Essays, 2d ed. p. 10, 1878.

formation of carbonate of lime. The amount of magnesia in the sea, although diminished by the formation of dolomite and magnesite, is now many times greater than that of the lime; for as long as chlorid of calcium remains in the water, the magnesium salts are not precipitated by carbonate of soda."

Doctor Hunt believed that the bicarbonate of soda which entered the sea in river waters and which resulted from the decomposition of the soda-feldspars was the agent which had brought about this change in the long stretch of geological time since the early Paleozoic. Obviously, if Doctor Hunt's views are correct about the presence of calcium and magnesium chlorids in large proportions in the early Paleozoic sea water the Saratoga Springs are not derived from this ancient connate water, since calcium and magnesium chlorids fail.

On January 20, 1871, Professor Charles F. Chandler delivered a lecture on "Water" before the American Institute, at the Academy of Music, New York City. The lecture was published in December of the same year in the American Chemist, a monthly journal of chemistry, then in its second volume. The paper is an extremely valuable contribution and made public nearly all the analyses used in the "Chandler Series" of the preceding pages. Speaking of the origin of the springs, on pages 202 and 204, Doctor Chandler expresses himself as follows:

> The Laurentian rocks consisting of highly crystalline gneiss, granite and syenite, are almost impervious, while the overlying Potsdam sandstone is very porous and capable of holding large quantities of water. In this rock the mineral springs of Saratoga probably have their origin. The surface waters of the Laurentian hills, flowing down over the exposed edges of the Potsdam beds, penetrate the porous sandstones, become saturated with mineral matter, partly derived, perhaps, from the limestones above, and are forced to the surface at a lower level by hydrostatic pressure. The valley in which the springs all occur indicates the line of a fault or fracture in the rocky crust, the strata on the west side of which are hundreds of feet above the corresponding strata on the east.
>
> The mineral waters probably underlie the southern half of the entire county, many hundred feet below the surface; the accident of the fault determining their appearance as springs in the valley of Saratoga Springs, where by virtue of the greater elevation of their distant source they reach the surface through crevices in the rocks produced by the fracture.
>
> Their common origin is also shown by analysis. All the springs contain the same constituents in essentially the same order of abundance, they differ in the degree of concentration merely. Those from the deepest strata are the most concentrated. . . .

Then follow mention of the common dissolved substances and instances of the deep artificial borings which are believed to penetrate the Potsdam sandstone and which bring up waters much stronger than the natural springs. Doctor Chandler concludes this topic by saying: "Down in the rocky reservoir the water is charged with gases under great pressure. As the water is forced to the surface the pressure diminishes, and a portion of gas escapes with effervescence. The wells deliver, therefore, enormous volumes of gas with the water, a perfect suds of water, carbonic acid and carburetted hydrogen."

The above is a very clear and interesting statement of the views prevailing at the time regarding the waters. The important point of the source of the carbonic acid gas is not taken up, as perhaps could hardly be expected in a popular lecture, but even granting the suggested origin of the dissolved mineral matter from ancient sea water, there remains the very important matter of the gas which finds no explanation. More detailed geological study has furthermore reduced the throw of the fault in Saratoga Springs to about 50 feet and the water so far as we know in the springs under discussion all enters the bored wells from the Little Falls dolomite, or as it was called at the time Doctor Chandler wrote, the Calciferous sandrock, and later on the Beekmantown. The great depth of some of the boreholes is due to the thickness of overlying slate. The deep Hathorn drilled well did indeed at a depth of 1006 feet end well within the Potsdam sandstone, but the water coming from this source is stated to have been much weaker than that derived higher up, presumably from the Little Falls dolomite. The lower waters were plugged off, and so far as the writer is aware, they present the only case known to us of waters actually coming from the Potsdam in the region of Saratoga.

In September 1880, the American Pharmaceutical Association met in Saratoga Springs. One of its members, Mr Charles F. Fish, prepared an interesting sketch of the springs which, after presentation, was printed in volume 28 of the Association's transactions. On page 488 we find the following:

> One explanation is that the water falls on the western height of land and percolates downward artesian fashion, dissolving and carrying with it the various substances of which the rocks are composed. These are decomposed by their reaction on each other, forming new compounds with the evolution of CO_2, which is dissolved by the water, highly impregnating it, and increasing its solvent power. Reaching the fault, the waters rise.

The mineral matter resembles sea water and is supposed to be derived from ancient oceans.

Others, supporters of a second view, derive the waters as before, but reject the derivation of the waters' dissolved burden from the rocks. They think it reaches the fault relatively pure and then is charged with mineral and gaseous constituents, which have come up through the fault from the internal fires of the earth. The substances are those customarily given off by volcanoes.

In a valuable "History of Saratoga County" by Nathaniel Bartlett Sylvester, Esq., of the local bar, published in 1893, will be found on page 32, the following outline which summarizes very well the views held by many at this date regarding the springs:

> The principal mineral springs of Saratoga county occur mostly in the villages of Saratoga Springs and Ballston Spa. The village of Saratoga Springs, where the greater number of the springs occur, is built directly over and extends for its whole length along on both sides of the dividing lines between the two great mountain systems above described, the Laurentian-Adirondack to the north and west, and the Appalachian to the east and south.
>
> This dividing line between the two mountain systems, over and along which the village is built, is there characterized by a deep fissure or rift in the underlying strata, known to science as a fault. The fault was doubtless caused by the deep subsidence of the Appalachian strata along the division line, consequent upon the mighty upheaval to the eastward, when the mountains arose from the Silurian sea. This profound subsidence of the Appalachian strata along the division line sank the bottom waters of the Silurian sea, which covered the land with all of its accumulated marine riches, into a vast abyss which now underlies the village to the eastward of the rock fissure. Out of this reservoir of old marine treasures, the gases there engendered still force the waters, which bring these marine riches with them, up through the deep fissures in the rifted rocks into the light of day, thus forming the natural mineral springs of Saratoga, which rise to the earth's surface in Saratoga county.

Again, on page 160, the same view is repeated in briefer statement. Judge Sylvester's description in its quaint and precise legal phraseology makes clear the widespread view of recent years that the Silurian sea water had saturated the rocks and that it had remained in them ever since so as to now furnish the mineral waters. We are forced to modify our unqualified acceptance by recalling Dr T. S. Hunt's conclusion that these ancient waters had a radically different composition from that of the springs (see above, pages 50, 51). One can not but raise the question also, whether, inasmuch as the area has apparently been land, it may be, ever since Paleozoic time, the ancient sea waters could well have been preserved throughout so long an interval. The fault, too, while a very long one, has only the slight disturbance of about 50 feet in Saratoga Springs.

If we are impressed with the possibilities of sea water in the rocks, and at first glance the generalities of composition suggest them, we may query if the ancient seas are the only source. The springs suggest rather the modern sea, with its high sodium chlorid, than the ancient ones with high magnesium chlorid, as described by Dr Sterry Hunt. Has the sea of fairly recent geological time ever covered the region of Saratoga?

We know from the rapidly growing number of buried river channels that the closing Tertiary period was a time of relative elevation in the northeast. The bedrock on which the water once flowed is now far below the present surface. The Glacial epoch apparently opened with elevated conditions but closed with a great depression of the land. Lake Champlain was certainly connected with the sea, as was shown by the skeleton of a whale, dug out of a sand bank in the town of Charlotte, Vt., when the Rutland and Burlington Railroad was under construction. The railroad runs through Charlotte at about 200 feet above tide, so that the sea water must have stood above this level. The present divide between Wood creek, the southern inlet of Lake Champlain, and the feeders of the Hudson near Dunham Basin, is a little over 160 feet. The postglacial sea might so far as we can see have crossed from Lake Champlain to the Hudson, but whether it stood as high as the 300 or 320 feet contours on which the springs emerge is not demonstrated, although not improbable. If the sea had stood above these strata, they being presumably filled with earlier fresh ground water, we may wonder if it could have found a way to fill their interstices, and drive out the fresh water. Sea water is heavier than fresh, and having access to the underground reservoirs of fresh water would probably have at least diffused itself through them. We may therefore admit that possibly an arm of the Atlantic stood in postglacial times above the present sites of the springs.

But the hypothesis of the sea water deserves very earnest attention. Our only safe ground is to run some careful comparisons between the mineral springs and the modern sea water, with perhaps some further reservations regarding possible differences between the oceans of today and those of the past.

Analyses of sea water have been prepared in the greatest abundance. Samples have been taken not alone from the ocean, but also from estuaries and arms which may be only brackish. Analyses are sometimes published of the water and its dissolved salts and sometimes of only the evaporated residue. Results in the latter case may be expressed either in the form of salts or in that of elements and ions. Taking a collective statement of results from F. W. Clarke's "Data of Geochemistry," Bulletin 330 of the United States Geological Survey, we find on page 23, that the general salinity of the ocean is about 3.5 per cent or 35,000 parts in a million, whereas our strongest Saratoga or Ballston waters fail to reach 2 per cent or 20,000 parts in a million, when we express the dissolved mineral matter as normal carbonates instead of bicarbonates. We may perhaps assume the admixture of surface waters as conceivably reducing the strength of the latter when compared with the former, or we may assume estuarine sea water, like that of the Baltic which is dilute. An average range for Saratoga Springs waters in former years was about 1 per cent or 10,000 parts in a million (see above, page 34) and from the most recent analyses we learn that a notable number lie between .2 and .3 per cent, or 2300 to 3100 parts per million. The latter values imply still greater admixtures of meteoric ground waters.

If the salts of the ocean are analyzed after evaporation to dryness, they yield a general composition as given by Dr F. W. Clarke (page 23) of

NaCl	77.76
$MgCl_2$	10.88
$MgSO_4$	4.74
$CaSO_4$	3.60
K_2SO_4	2.46
$MgBr_2$	.22
$CaCO_3$	.34
	100.00

Considered as elements no others would reach more than 0.001 per cent and are therefore negligible.

These results are obviously very different from the Saratoga and Ballston waters, in which, as has been shown on the previous pages, while we have NaCl as the chief ingredient, we yet have no $MgCl_2$, and almost no sulphates. The sea salts, on the contrary contain 10.80 per cent of the last named. In the oldest series of analyses of Saratoga waters (see above, page 24), the richest percentage in sulphates was .0028 and the poorest .0011. In the Chandler series the richest was 0.0091 and the poorest a trace. In the Department of Agriculture series the richest was 0.04449 per cent and the poorest 0.00021 per cent. Stated in this way, there is a very obvious and important difference between the mineral waters and the sea waters.

But we may run comparisons in another way: Dr F. W. Clarke summarizes upon page 95 of his invaluable work 264 analyses from eighteen different localities, whose salinity varies from a maximum of 5.854 per cent in the Red sea, to a minimum of 0.7215 per cent in the Baltic, where, as the writer has personally observed, both people and animals freely drink the water. When expressed as elements and ions there is extraordinary uniformity in the dissolved salts of the sea despite the widely varying salinity:

	MAXIMUM	MINIMUM	RANGE
Cl	55.96	54.62	1.34
Br	.19	.13	.06
SO_4	8.01	7.47	.54
CO_3	.46	.01	.45
Na	31.21	30.20	1.01
K	2.10	.64	1.46
Rb	.04	.03	.01
Ca	1.67	.89	.78
Mg	3.896	3.36	.536
Fe, SiO_2, PO_4, NH_4, NO_3, Al_2O_3, (Fe_2O_3)	.08	.02	.06

The last mentioned ingredients which are collectively grouped are only determined in a few instances. The same is true of rubidium (Rb). The greatest variability is shown by CO_3 and the next by potassium (K), but their amounts are relatively small. Calcium (Ca) also varies widely, but it also is small in amount. The most important ingredients, taken in order of abundance, chlorin (Cl), sodium (Na), the sulfuric acid ion (SO_4), and magnesium (Mg), change but slightly in this wide range of conditions.

When we come to compare the analyses of the Saratoga and Ballston waters with the above, certain allowances must be made. The mineral waters are heavily charged with carbonic acid which gives them greatly increased dissolving power upon limestone. We would expect the calcium and perhaps also the magnesium to be much in excess of the percentage in sea water. In making comparisons we would be justified in tentatively assigning the excess of calcium and of carbon dioxid over the figures of sea water to contributions provided in this way, and then recasting the remainder. We must also deal with analyses that are based upon *bona fide* natural waters. I therefore select a few chiefly from the series of

Dr Charles F. Chandler, adding to them several of later date, in which I have confidence. It has been necessary to reduce grains per gallon, or parts per million, to percentages of evaporated residue. Water must therefore be thrown out, and as compared with analyses previously discussed bicarbonates become normal carbonates.

Normal calcium carbonate in pure water (that is, containing no free carbonic acid) is stated by F. W. Clarke on the authority of T. Schloesing, to be soluble at 16° C. to the extent of 13 parts in a million (U. S. Geol. Surv. Bul. 330, p. 99, 1908). Calcium bicarbonate, that is, calcium carbonate in water with enough free carbonic acid to yield the bicarbonate, is soluble 385 parts in a million at 15° C. (Idem, page 99). Excess of carbonic acid increases the solubility as is shown by the values just cited for the Saratoga waters, which are about ten times that just given for $Ca\ (HCO_3)_2$ in pure water. On the other hand, sea water is not so good a solvent as pure water, and the Saratoga waters, in so far as they are brines, probably are also less favorable solvents than are pure waters.

Magnesium carbonate is stated by J. Roth (Allgem. and Chem. Geologie, I, 50. 1879), to be somewhat more soluble in carbonated waters than is calcium carbonate. The presence of calcium carbonate doubtless exercised some influence since in the Saratoga waters, just as Professor Roth states for waters in general, it is exceptional to find more magnesium carbonate than calcium carbonate.

	FRANKLIN, BALLSTON	HATHORN, SARATOGA	CONGRESS, SARATOGA	SELTZER, SARATOGA	HATHORN NO. 2, GEYSERS	GURN, WILTON
Cl	42.00	42.40	42.00	34.40	41.20	28.10
Br	.36	.16	1.10	.20	.10	.16
SO_4	.04	tr.	.09	.13	.04	....
CO_3	15.00	18.50	17.50	25.75	17.00	25.30
Na	28.8	27.30	27.60	25.50	30.80	26.00
K	2.0	.70	.80	.40	.48	2.33
Ca	5.0	5.70	6.00	9.30	6.22	11.20
Mg	5.0	4.00	3.40	2.80	3.07	3.40
Rest	1.80	1.24	1.51	1.60	1.09	3.51
	100.00	100.00	100.00	100.00	100.00	100.00

Of these analyses the first four are by Doctor Chandler. The fifth is of the recently bored well two miles south of Saratoga Springs and the analysis was made in the laboratory of the State Department of Health in 1911. The sixth is from the Lederle Laboratories, New York, and was made in 1910. It illustrates the most northerly of the present active springs, since the Gurn is eight miles from Saratoga Springs. The analysis brings out the tendency of the waters to the north to be richer in calcium, which in turn calls for more CO_3 and reduces the chlorin and sodium. The same effect is shown in the Seltzer water.

If in the above analyses we arbitrarily reduce the calcium to 1.67 as given in the sea water richest in this element, and the CO_3 to .46, as given in the sea water richest in this ion, thereby necessarily assuming the existence of calcium chlorid which no one has hitherto recalculated for the Saratoga waters, we can get a line on the ratio of sodium, chlorin, and magnesium. All this is done on the assumption that the high calcium is obtained from the limestone. Some magnesium is also undoubtedly obtained from the magnesium limestone, but the difference between the mineral waters and the sea water is not so great. In the recasting I have used the nearest round numbers. Thus, the analyses of the mineral waters have their several percentages respectively increased by dividing by approximately the following residual percentages: 82, 72, 79, 66⅔, 79 and 66⅔, left by abstracting the Ca and CO_3.

	SEA WATER	SEA WATER	FRANKLIN, BALLSTON	HATHORN, SARATOGA	CONGRESS, SARATOGA	SELTZER, SARATOGA	HATHORN NO. 2, GEYSERS	GURN, WILTON
Cl	55.12	55.01	51.20	54.36	53.17	52.60	52.00	43.23
Br	.18	.13	.44	.21	1.40	.30	.13	.24
SO_4	7.47	8.00	.05	tr.	.11	.20	.05	......
CO_3	.46	.14	.46	.46	.46	.46	.46	.46
Na	30.46	30.47	35.12	35.00	35.00	37.55	40.00	40.00
K	1.16	.96	2.42	.90	1.00	.60	.61	3.74
Ca	1.41	1.67	1.67	1.67	1.67	1.67	1.67	1.67
Mg	3.74	3.53	6.10	5.13	4.30	4.20	4.00	5.23
Rest	....	.09	2.20	1.60	1.91	2.40	1.40	5.40
	100.00	100.00	99.66	99.33	99.02	99.98	100.32	99.97

The first analysis of sea water is the one having the maximum CO_3, and is an average of six from the Black sea. The salinity varied from 22,230 parts in a million to 18,260. The second analysis of sea water has the maximum Ca and is from the Baltic sea. The salinity was 7215 parts per million. In these statements the carbonates are all calculated as normal carbonates, and the salinity is reckoned on the evaporated residue. In the mineral waters, expressed in the same way, the salinity varies from 16,870 parts per million for the Franklin well, and 16,283 for the Hathorn No. 2, to 4062 for the Seltzer.

Now when we critically compare these analyses we see that no mineral spring quite reaches the values in chlorin possessed by the sea water, but in four cases the approximation is very close. If we take away a little magnesium on the assumption that it was furnished by the limestones, the chlorin percentages for these four would be substantially like those of the sea water. So far as chlorin is concerned the parallel is close. On the other hand, the mineral waters are from 5 to 10 actual per cents richer in sodium and for this element no close parallel can be drawn. If we remove some magnesium for the reason just stated, the contrasts will be still further accentuated. In SO_4 the sea water is vastly richer, actually from 37 to hundreds of times as rich as the mineral waters. There is a fundamental difference here which can not be easily explained. The mineral waters are richer in bromine. They are uniformly richer in magnesium. They are both richer and poorer in potassium. On the whole, the lack of SO_4 in the mineral waters and its presence in the sea water as calcium and magnesium sulphate argues strongly against a marine source for the mineral waters. We can not imagine calcium and magnesium removed from connate sea water in any probable reaction in the earth, which would not yield other salts that also fail in the mineral waters. The notable excess of sodium can not easily be explained by a marine source, while the great richness in carbonic acid gas can only be referred to a source in the depths of the earth, probably from some expiring center of igneous activity. The writer is therefore led to the conclusion that both gas and dissolved mineral matter are derived from deep-seated sources.

There is an additional and apparently irrefutable argument. We have in a great many places in the Champlain and Hudson valleys practically the same geological section with the exception that it changes on the north because of the addition of the Chazy limestone. The section is frequently broken across by faults of vastly greater displacement than the one at Saratoga Springs; yet even uncarbonated brine springs are lacking.

If the Saratoga and Ballston springs derive their mineral matter from ancient sea water contained in the local strata, it is extraordinary that we have not abundant brine springs, even if not carbonated, in many localities to the north and south. So extraordinary is it that we are logically forced to abandon the explanation.

We may now direct special attention to the carbonic acid gas. There are four ways in which carbonic acid is produced in nature.[1] The simplest is by the direct oxidation of carbonaceous deposits, such as peat bogs, coal seams, and the like. It is one of the dangerous gases in coal mines, constituting the choke damp of the miner. We have no reason to believe, however, in the existence of carbonaceous beds of this sort beneath Saratoga and much reason to infer their absence. The second method is by the action of some free acid such as sulfuric upon limestone. Sulfuric acid is sometimes produced in nature by the oxidation of pyrites, in the presence of water. If it meets with limestone it destroys the carbonate of lime, evolving carbonic acid gas and forming calcium sulphate. Since hydrated calcium sulphate is the mineral gypsum, gypsum beds have been sometimes explained in this way. We have no reason to infer gypsum beds beneath Saratoga, nor do we find in the waters the calcium sulphate which would be demanded by this reaction. We may dismiss this explanation also.

The third method of formation is by the silicification of limestone. Silicic acid in solution, especially around the borders of still heated masses of igneous rock, displaces the carbonic acid of calcium carbonate and forms calcium silicates. The carbonic acid then migrates. It is possible that some such process as this deep down in the Grenville strata either has taken place or is taking place and that the gas thus liberated is still rising to the surface or has risen and now remains in solution in the waters.

The last and most important explanation of free carbonic acid as it is met in foreign localities, is based on expiring volcanic or igneous action. It is a matter of observation that the copious emission of the gas is one of the characteristic features of volcanoes which are no longer active. As time passes the zone of gas emission appears to widen around them until it finally ceases. The amount furnished is in instances prodigious. One borehole at Sondra in Thuringia, Germany, 197 meters deep, yields daily at a pressure of about 230 pounds to the inch, over 500,000 kilos, or over 1,000,000 pounds of the gas. At another place, Oberlandstein, 6,000,000 litres in 24 hours are obtained, or 20,000 pounds of the gas.[2] The utilization of the gas is the basis of an important industry in Germany and supports a special journal.

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[1] An excellent general summary of the geology of carbonic acid gas is a paper by Rudolph Delkeskamp, Vadose and Juvenile Kohlensäure. Zeitschrift f. prakt. Geologie, Feb. 6, 1906, p. 33.

[2] N. Wender. Die Kohlensäure-industrie, Berlin, 1901, p. 72–73.

We are not definitely assured as to the reaction which produces the gas deep within the earth. Whether it is emitted directly from cooling masses of igneous rock, as is not unreasonable from some things that we know about them, or whether it results from the action of the igneous rock on limestone, perhaps through the intermediation of silicic acid, as was explained in an earlier paragraph, may be a matter of uncertainty.

If we endeavor to apply these views to the specific case of Saratoga, we are reminded of the volcanic plug discovered at Northumberland, on the west bank of the Hudson, about ten miles a little north of west from the springs in the village.[1] The plug is so isolated from all others of its kind and positive evidence of its age is so difficult to obtain, that its time of outbreak is very obscure. Since first studied ten years ago by Professors Woodworth and Cushing, it has been nearly half quarried away for macadam and concrete and its structure and features are much better exposed. If anything they have made it more difficult to understand. The complexity of the stratigraphical relations of the vicinity has been increased by Doctor Ruedemann's discovery of late Cambrian fossils in the slates. These matters will be fully discussed by Professor Cushing in the Bulletin on the Saratoga Quadrangle. The writer has had the privilege of visiting the plug with Professor Cushing and Doctor Ruedemann and of discussing the question at length. That the mass is volcanic seems to me the best explanation, and that it is an elliptical agglomerate representing an old vent and formed of bombs and masses of limestone torn off from the walls of the throat down below, I feel convinced. The excessive alteration argues for an outbreak which probably antedates the Tertiary period, but to what extent I can not say. The plug is so far as known the only purely volcanic rock within the confines of New York, Vermont, or of Massachusetts west of the Connecticut valley.

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[1] The plug was first recognized by J. B. Woodworth in the summer of 1901. It was carefully studied by him and described in the 21st Report of the N. Y. State Geologist, p. r 17–r 24. The petrography was contributed by H. P. Cushing, p. r 24–r 29. Professor Woodworth remarks the similarity with the Triassic traps of the Connecticut valley; and Professor Cushing very cautiously suggests the parallels between the plug and the same occurrences and those of the lower Hudson (i. e. the Palisades) and New Jersey. A Triassic age seemed the best suggestion for a confessedly obscure and uncertain occurrence.

No one could with much reason attribute the carbonic acid gas to the Northumberland plug itself, but the plug does serve to show the former existence of volcanic action and unless it has been thrust westward into its present position by some great reversed fault from an original situation farther east, as will be outlined by Professor Cushing, it may be considered significant to this extent. We may at least state that all the other geological features of Saratoga Springs and Ballston Spa are reproduced in many places northward throughout the Champlain valley. Practically the same geological section is seen. A great number of faults have been mapped and yet no such mineral springs have ever been discovered. The great quantities of carbonic acid gas in the water are distinctive of the two localities, Saratoga Springs and Ballston. The only other visible and distinctive feature of the Saratoga region as compared with the localities farther north is the volcanic plug. One may merely suggest the possibility of some more westerly and deep-seated manifestation of the same sort of activity through whose influence the carbonic acid gas rises through faults to the surface. The tight cover of slates east of the fault may have kept from emergence at the surface the waters in which the gas speedily became dissolved.

Even sodium chlorid itself has been attributed to volcanic sources. Thus Sir Archibald Geikie, in his Text-book of Geology, 4th ed. 1903, I, p. 269, when speaking of volcanic emissions, states: " Sodium chlorid sometimes appears so abundantly that wide spaces of a volcanic cone, as well as of the newly erupted lava, are crusted with salt which can be profitably removed by the inhabitants of the district. Considerable quantities of chlorids may be buried between successive sheets of lava, and in long subsequent times may give rise to mineral springs, as has been suggested with reference to the saline waters, which issue from volcanic rocks of old Red Sandstone and Triassic age in Scotland." Again, on page 469, we find: " Carbonic acid is here and there largely evolved within the earth's crust, especially in the regions of extinct or dormant volcanoes. Subterranean water coming in the way of this gas dissolves it and thereby obtains increased solvent power." Professor L. De Launay of Paris, in a very important work[1] upon the Investigation, Discovery and Management of Mineral Springs, under the caption

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[1] L. De Launay, Recherche, Captage et Aménagement des Sources Thermo-Minerales, Paris, Banday et Cie, 1899.

Carbonated Springs, Origin of the Free Carbonic Acid, page 130, speaks thus of carbonic acid gas, the original French being here rendered into English:

> When we examine the map of an entire country, whereon the mineral springs have been each indicated by a special sign, corresponding to their chemical composition, we soon see a general fact stand out, which could escape us in too detailed study or remain open to question, but which in a comprehensive survey is perfectly plain; it is the almost absolute restriction of springs with free carbonic acid to the regions of Tertiary or recent volcanic activity, such as the Auvergne, Bohemia, the Carpathians, the Apennines, etc.

In a discussion regarding the source of the waters of the Saratoga springs which was held in New York at a meeting of the National Academy of Sciences in November 1911, Mr Waldemar Lindgren raised the point that bromine was present in the waters but that so far as he was aware it had not been reported in volcanic emissions. It is, however, a well-known ingredient of the sea waters. On looking the matter up the writer realizes that bromine is far less abundant than chlorine, probably also less abundant than fluorine and iodine in the volcanic gases, and that it has not been so generally mentioned. Matteucci, however, in reporting upon the Vesuvian eruption of 1895, mentions hydrobromic acid as one of the fumarolic products.[1] It would be surprising if amid the very great quantity of chlorine, its other closely related haloids, bromine, fluorine and iodine were not all present in minor amounts. Both hydrofluoric and hydriodic acids were also observed by Mateucci. Fluorine and iodine have been more often reported than bromine which is, at best, a comparatively rare element.

In addition to the sodium chlorid just cited as a well-known volcanic exhalation, potassium and ammonium chlorid are also cited in the works which give analyses of these products. Sodium carbonate also forms by secondary reactions and in fact practically all the ingredients of the Saratoga mineral waters are reported, except those such as calcium, magnesium, barium, strontium, and iron carbonates, which would be easily dissolved from the limestones by circulating carbonated waters; alumina, iron oxids and silica which might come from these or other rocks through the medium of the same solvent.

The explanation which appeals most strongly to the writer is that the carbonic acid gas, the chlorids, bromids, iodids, fluorids, and

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[1] Comptes rendus, 129, 65, 1899.

sodium carbonate are deep-seated. The sodium carbonate might in part or in whole be dissolved from the feldspars in the old crystalline rocks. The carbonated waters take on calcium and magnesium carbonates from the limestones encountered in their upward journey, more especially from the Little Falls dolomite. They mingle with artesian waters from the west, which may furnish a good portion of the motive power toward the close of the ascent. Their greatest vents lie in or near the fault, which passes through Saratoga Springs, but not all are demonstrably on it. The Gurn spring is near a branch. The course of the fault is less clear at the Geysers, at Ballston and at Round Lake, but if not the same, then some other fault is probably present. For the old Albany well a similar explanation is suggested. The faults furnish the upward passages of the gas and dissolved mineral matter from the depths, but the tight cap of slates above the limestones acts as a roof to prevent their escape, except in the springs and bore holes. The source of the mineral matter and the gas is probably east of Saratoga Springs and Ballston.

TABLE I

Analyses by Dr John H. Steel, 1817 and earlier. Grains per gallon of 231 cubic inches

	CONGRESS	COLUMBIAN	WASHINGTON	HAMILTON	FLAT ROCK	HIGH ROCK	PRESIDENT	RED	TAYLOR'S WASHINGTON	TAYLOR'S JACKSON	TAYLOR'S ALEXANDER	ELLIS'S	SULFUR	BALLSTON VILLAGE	BALLSTON LOWS	BALLSTON SULFUR
Muriate of soda.......	471.5	201.5	231.5	269.5	194.8	210	135	117.58	313.54	240	238.4	188	23.6	159	142	64
Carbonate of lime.....	178.476	121	127.5	147.5	107.0	115	107.5	97	140	103.8	119.5	110.5	33.1	75.5	64.5	30
Carbonate of soda.....	16.5	22.5	16.5	24.5	11.2	18	19	24.48	26.46	18	19.6	10	1.4	9	10	6
Carbonate of magnesia.	3.356	1.5	2.5	7.9	1.5	.5	2.5	3	5.5	3	7	....	....	2.5	1.5	....
Carbonate of iron.....	6.168	7.5	6	3.0	7.5	4.5	6	6	4.1	5.2	5.5	7.5	1.9	7	6	4
Total............	676	354	384	452	322	348	270	248	489.6	370	390	316	60	253	224	104
Carbonic acid gas, cu. in	343	236	247	284	252.5	243	314	150.5	251	256.5	253	224.5	43.5	210	220	144
Temperature.........	50° F.	50° F.	48° F.	48° F.	48° F.	48° F.	51° F.	48° F.	48° F.	50° F.	48° F.	47° F.	50° F.	50° F.	52° F.	52° F.
Sulfuretted hydrogen, cubic inches........	....	....	....	....	....	....	....	....	....	....	....	....	11	....	....	7

NOTES. All the analyses are taken from "An Analysis of the Mineral Waters of Saratoga and Ballston, etc.," by Dr John H. Steel. Albany. E. & E Hosford, 1817. The Columbian spring was about 15 rods west of the Congress. The Washington was about 50 rods southwest of the Columbian. The Hamilton was about 50 rods northeast of the Congress and was in a marsh. The Flat Rock was about 100 rods down stream from the Hamilton. The High Rock was about 100 rods north of the Hamilton. The President was about 30 rods from the High Rock (presumably north), and in the same valley. The Red spring was northeast of the President, the distance not being given. Taylor's springs were about one mile east of the High Rock and were apparently the same as the Ten springs of today. Three of them were named Washington, Jackson and Alexander. Ellis's spring was about two miles south of the Congress, in a deep valley of the principal northern branch of Kayaderosseras creek. It was obviously near the Geysers and the valley of Coesa creek. The Sulphur spring was two or three miles up Coesa creek from Ellis's spring. The first Ballston analysis was of a spring near the center of the village. Low's spring was about 100 rods down stream. The Ballston Sulphur was twenty feet from the last named.

TABLE 2

Analyses by Dr John H. Steel, 1817–1825, and 1825–1837. Grains per gallon of 231 cubic inches

	WALTON	BALLSTON NEW SPRING	BALLSTON LOW TUBE
Muriate of soda......	274.8	145.0	158.5
Carbonate of soda....	5.2	12.0	13.0
Carbonate of lime....	140.0	61.5	61.54
Carbonate of magnesia	7.0	9.0	8.5
Carbonate of iron....	7.5	7.5	7.5
Silex...............	Small quan.	tr.	tr.
Alumina............	" "	tr.	tr.
Total..........	434.5	235.0	249.04
Carbonic acid gas....	Abundant	Abundant	Abundant
Temperature.........	47° F.	50° F.	50° F.

	CON-GRESS	COLUM-BIAN	WASH-ING-TON	HAMIL-TON	FLAT ROCK	HIGH ROCK	BALLSTON SANS SOUCI	BALLSTON NEW WASH-INGTON
Chlorid of sodium.......	385.0	267	281.5	297.3	148.816	189.10	143.733	89.83
Hydriodate of soda......	3.5	2.56	2.75	3.0	1.33	2.5	1.3	0.7
Bicarbonate of soda......	8.982	15.40	16.5	27.036	20.79	17.538	12.66	18.057
Bicarbonate of magnesia..	95.788	46.71	40.92	35.2	42.70	61.592	39.10	42.042
Carbonate of lime.......	98.098	68.00	92.60	92.4	60.573	69.29	43.407	41.51
Carbonate of iron.......	5.075	5.58	3.25	5.39	5.39	5.58	5.95	3.71
Silex..................	1.5	2.05	1.50	....	tr.	tr.	1.0	1.25
Hydrobromate of potash..	tr.	tr.?	....	tr.	tr.	tr.	....	....
Total............	597.943	407.30	439.02	460.326	279.649	345.68	247.15	197.099
Carbonic acid gas, cu. in..	311	272.06	262.5	316	287.5	304		
Atmospheric air, cu. in...	7	4.5	6.8	4	6.5	5		

NOTES. The analyses of the previous table together with the first three given on this table appear in the second edition of Doctor Steel's book, published in Saratoga Springs in 1825. The Walton spring was a few rods from the Flat Rock. The New spring of Ballston was uncovered by a freshet in 1817. It was some rods below the Village spring of the previous table. The Low Tube is apparently the Low spring of the earlier edition. The last eight analyses are from a later edition of Doctor Steel's book, published in 1838, just after his death. The determinations were all made anew. He also gives notes but no analyses of the President, Red, Ten springs, and Ellis'. He speaks of the Quaker springs, 10 miles southeast of Saratoga, as containing lime, magnesia, iron and a certain percentage of common salt and soda. The gaseous contents were small. At Ballston the Sans Souci was near Low's spring. The Park spring is credited with 5 grains of carbonate of iron. The New Washington had a spec. gr. of 1.0046. Temperature 51° F.

TABLE 3

Various early analyses. All stated in grains per gallon of 231 cubic inches

	1 CON-GRESS	2 CON-GRESS	3 CON-GRESS	4 UNITED STATES	5 EMPIRE	6 PAVILION	7 ALBANY	8 ALBANY	9 PUTNAM	10 RED	11 UNION	12 WALTON	13 WASH-INGTON	14 COLUM-BIAN
Chlorid of sodium.........	434.4	385.44	363.83	424.96	269.70	187.68	504.00	472.00	214.00	83.53	243.62	187.00	182.00	267.00
Carbonate of soda.........	16.0	.56	7.20	16.88	30.85	4.92	40 00	40.00	14.32[a]	15.33[a]	12.80	2.00	8.00[a]	15.4[a]
Carbonate of magnesia....	32.0	56.80	78.62	5.76	41.98[a]	56.92	16.00	12.00	51.60[a]	42.41[a]	84.27	75.00	66.00[a]	46.70[a]
Carbonate of lime.........	144.0	116.00	86.14	29.20	141.82[a]	52.84	32.00	32.00	68.80[a]	101.26[a]	41.60	26.00	84.00[a]	68.00[a]
Silica....................	tr.	......	.47	8.00	1.16	......	little	little	.84	3.25	......	......	......	......
Sulphate of soda..........	......	......	0.65	1.76	......	1.48	......	......	1.68	......	......	......	......	......
Carbonate of iron.........	......	......	0.84	......	tr.	3.51	8.00	8.00	7.00[a]	......	5.45	1.00	......	......
Total................	626.4	558.80	537.75	486.56	485.51	......	600.00	564.00	358.24	165.78	387.74	291.00	340.00	397.1
Carbonic acid gas, cu. in...	312.8	......	284.65	244.00	359.50	......	168.00	......	326.40	......	344.16	326	......	......
Azote.....................	7.2	......	......	......	......	......	......	......	......	......	......	......	......	......
Temperature ° F..........	......	......	......	50° F.	......	......	51°–52°F	......	......	......	......	......	......	......

NOTES. The first analysis is by J. F. Dana and was made before 1817. This analysis is by mistake attributed to J. D. Dana in Bulletin 32, page 38, United States Geological Survey. The second analysis is by Davy and Faraday, London, as cited in Bulletin 32, United States Geological Survey, page 38. The date is not given but it was obviously early. There was also potassium bromid, tr. sodium iodid, 4.02, iron oxid, 0.64. The third analysis is by J. R. Chilton (1834). There was also potassium and sodium bromid, 5.92; alumina, 0.32, atmospheric air, 5.41 cubic inches. The fourth analysis of the United States spring is by L. C. Beck. Mineralogy of New York, 137 (1842). No. 5 was by E. Emmons and is quoted in Bulletin 32, page 38. There was also 12.0 of sodium iodid or iodine. No. 6 is by J. R. Chilton (1840) and is taken from Bulletin 32, United States Geological Survey, page 40. It contained calcium phosphate, 0.19; potassium bromid and sodium iodid, 2.59; alumina, 0.42; atmospheric air, 5 30 cubic inches. The first analysis of the Albany spring is by William Meade M.D.; the second by L. C. Beck. Both are taken from Beck's Mineralogy of New York, 140 1842. The spring is in Albany, N. Y., not Saratoga. No. 9 by J. R. Chilton (1840) and is taken from Bulletin 32, United States Geological Survey, page 40. It contained also sodium phosphate, 0.21, potassium bromid, tr.; sodium iodid, 2, alumina, 56, atmospheric air, 6.40 cubic inches. No. 10 by Appleton, date not given in Bulletin 32, United States Geological Survey, page 40. Also potassium chlorid, 6.86 iron oxid and alumina, 2.10. No. 11 by J. R. Chilton (1841) taken from Bulletin 32, United States Geological Survey, page 41. Also sodium iodid, 3.60; alumina and silica, 1.57. Atmospheric air, 4.62 cubic inches. No. 12 by E. Emmons (1839). The spring is also called the Iodine or Star. Analysis taken from Bulletin 32, United States Geological Survey, page 41. Also sodium iodid, 3.50. Atmospheric air, 4 cubic inches. No. 13 by J. R. Chilton (1843). Analysis furnished by J. C. Minor, jr. No. 14 by E. Emmons. Analysis furnished by J. C. Minor, jr.

[a] Bicarbonates.

TABLE 4

Analyses in grains per U. S. gallon made by Dr Charles F. Chandler, 1860–1875, and taken from F. A. Cairn's Notes on Quantitative Analysis

	GLACIER SPOUTING WELL	GEYSER SPOUTING WELL	HATHORN	UNION	CONGRESS	PAVILION	EMPIRE	HIGH ROCK
Chlorid of sodium	702.239	562.080	509.968	458.299	400.444	459.903	506.630	390.127
Chlorid of potassium	40.446	24.634	9.597	8.733	8.049	7.660	4.292	8.974
Bromid of sodium	3.579	2.212	1.534	1.307	8.559	0.987	0.266	0.731
Iodid of sodium	0.234	0.248	0.198	0.039	0.138	0.071	0.606	0.086
Fluorid of calcium	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.
Bicarbonate of lithia	6.247	7.004	11.447	2.605	4.761	9.486	2.080	1.967
" " soda	17.624	71.232	4.288	17.010	10.775	3.764	9.022	34.888
" " magnesia	193.972	149.343	176.463	109.685	121.757	76.267	42.953	54.924
" " lime	227.070	170.392	170.646	96.703	143.399	120.169	109.656	131.739
" " strontia	0.082	0.425	tr.	tr.	tr.	tr.	tr.	tr.
" " baryta	2.083	2.014	1.737	1.703	0.928	0.875	0.070	0.494
" " iron	0.647	0.979	1.128	0.269	0.340	2.570	0.793	1.478
Sulphate of potassa	0.252	0.318	tr.	1.818	0.889	2.032	2.769	1.608
Phosphate of soda	0.010	tr.	0.006	0.026	0.016	0.007	0.023	tr.
Biborate of soda	tr.	tr.	tr	tr.	tr.	tr.	tr.	tr.
Alumina	0.458	tr.	0.131	0.324	tr.	0.329	0.418	1.223
Silica	0.699	0.665	1.260	2.653	0.840	3.155	1.458	2.260
Organic matter	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.
Total	1 195.582	991.546	888.403	701.174	700.895	687.275	680.436	630.500
Carbonic acid gas	465.458	454.082	375.747	384.969	392.289	332.458	344.669	409.458
Density	....	1.012	1.0115	....	1.096	1.0095	....	1.0092
Temperature	....	46° F.	....	48° F.	52° F.	....	....	52° F.

TABLE 4 (*concluded*)

Analyses in grains per U. S. gallon made by Dr Charles F. Chandler, 1860–1875, and taken from F. A. Cairn's Notes on Quantitative Analysis

	STAR	CRYSTAL	VICHY	UNITED STATES	SELTZER	BALLSTON ARTESIAN LITHIA	FRANKLIN ARTESIAN	CONDE DENTONIAN
Chlorid of sodium	398.361	328.468	128.689	141.872	134.291	750.030	659.344	645.481
Chlorid of potassium	9.695	8.327	14.113	8.624	1.335	33.276	33.930	9.232
Bromid of sodium	0.571	0.414	0.990	0.844	0.630	3.643	4.665	2.368
Iodid of sodium	0.126	0.066	tr.	0.047	0.031	0.124	0.235	0.225
Fluorid of calcium	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.
Bicarbonate of lithia	1.586	4.326	1.760	4.847	0.899	7.750	6.777	10.514
" soda	12.662	10.064	82.873	4.666	29.428	11.928	94.604	34.400
" " magnesia	61.912	75.161	41.503	72.883	40.339	180.602	177.868	158.348
" " lime	124.459	101.881	95.522	93.119	89.869	238.156	202.332	178.484
" " strontia	tr.	tr.	tr.	0.018	tr.	0.867	0.002	0.189
" " baryta	0.096	0.726	0.593	0.909	tr.	3.881	1.231	4.739
" " iron	1.213	2.038	0.052	0.714	1.703	1.581	1.609	2.296
Sulphate of potassa	5.400	2.158	tr.	tr.	0.557	0.520	0.762	tr.
Phosphate of soda	tr.	0.009	tr.	0.016	tr.	0.050	0.011	0.003
Biborate of soda	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.
Alumina	tr.	0.305	0.473	0.094	0.374	0.077	0.263	0.395
Silica	1.283	3.213	0.758	3.184	2.561	0.761	0.735	1.026
Organic matter	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.
Total	617.367	537.155	367.326	331.837	302.017	1 233.246	1 184.368	1 047.700
Carbonic acid gas	407.650	317.452	383.071	245.734	324.080	423.114	460.066	358.345
Density	1.0091	1.006	....	1.0035	1.0034	1.0159	1.0135	1.0125
Temperature	52° F.	50° F.	50° F.	....	50° F.	52° F.	52° F.	49° F.

TABLE 5

Analyses of Saratoga waters by Dr Charles F. Chandler, recast as ions in parts per million

	GLACIER SPOUTING	GEYSER SPOUTING	HATHORN	UNION	CONGRESS	PAVILION	EMPIRE	HIGH ROCK	STAR	CRYSTAL	VICHY	UNITED STATES	SELTZER
Cl	7 571.8	5 997.6	5 338.0	4 797.4	4 195.6	4 806.2	5 242.2	4 097.3	4 188.2	3 456.1	1 441.8	1,533.4	1 396.2
Br	47.6	28.9	20.4	17.3	112.9	13.1	1.9	9.7	7.5	5.5	13.0	11.2	8.5
I	3.4	3.6	2.7	0.6	2.0	1.0	8.7	1.2	1.8	0.9	tr.	0.6	0.4
HCO_3	6 059.5	5 374.0	4 993.2	3 094.0	4 519.9	2 877.9	2 189.4	2 977.6	2 694.5	2 618.0	2 896.0	2,398.1	2 142.0
SO_4	2.4	3.0	tr.	17.0	8.4	19.0	25.9	15.1	50.7	20.2	tr.	0.2	5.2
PO_4	0.1	tr.	0.1	0.3	0.2	0.1	0.3	tr.	tr.	0.1	tr.	0.2	tr.
SiO_2	11.9	11.9	21.4	45.1	14.3	53.6	24.8	38.4	21.8	54.6	12.8	54.1	43.5
Na	4 790.6	4 267.0	3 435.7	3 148.4	2 759.1	3 095.3	3 450.2	2 774.7	2 724.1	2 244.2	1 249.7	973.4	1 037.0
K	392.1	221.0	85.0	93.5	78.2	83.8	59.5	92.1	127.5	90.6	125.8	76.7	16.1
Li	10.2	11.9	20.4	4.6	8.5	16.7	3.6	3.4	2.8	7.6	3.1	8.5	1.6
Ca	945.2	710.8	712.3	402.9	598.4	501.3	457.3	549.6	603.5	425.0	397.8	388.6	374.9
Ba	18.4	18.4	15.8	15.4	8.4	7.9	0.6	4.5	0.9	6.6	5.4	8.2	tr.
Sr	.6	2.7	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	0.1	tr.
Ng	592.6	417.1	492.7	306.5	340.3	213.2	120.1	153.5	173.4	210.0	115.9	203.7	112.7
Fe	3.5	5.4	6.8	1.4	1.9	14.1	4.4	8.1	6.7	11.2	0.2	3.9	9.5
Al	4.1	tr.	1.2	2.9	tr.	3.1	3.8	11.1	tr.	2.8	4.1	0.8	3.4
Total	20 325.0	16 856.0	15 102.8	11 920.0	11 915.0	11 583.5	11 567.2	10 718.5	10 495.0	9 132.4	6 244.5	5 641.0	5 134.0

TABLE 6

Various analyses of date later than 1850. Grains per gallon

	1	2	3	4	5	6	7	8	9	10
	EUREKA	EXCELSIOR	HAMILTON	KISSINGEN	KISSINGEN	SARATOGA A	CONGRESS	CONGRESS	HATHORN	STAR
Sodium chlorid	166.81	370.64	298.66	338.50	135.5	65.30	550.8	406.6	478.7	124.5
" iodid	4.67	4.24	3.59	0.04	....	....	....	....	....	....
" bicarbonate	8.75	15.00	34.25[a]	67.62	76.6	6.75	10.9	15.5	17.6	4.2
" sulphate	....	1.32	....	....	....	2.50	....	....	....	....
Potassium chlorid	....	....	....	16.98	16.9	0.36	26.1	40.0	32.8	0.0
" bromid	1.57	tr.	....	....	....	....	....	....	....	....
Calcium bicarbonate	41.32	77.00	97.99[a]	140.26	40.2	56.85	149.8	88.1	147.2	31.7
Magnesium bicarbonate	29.34	32.33	39.06[a]	70.47	70.4	20.48	138.1	42.1	130.5	9.4
" sulphate	2.15	....	....	....	....	0.29	....	....	....	....
Iron bicarbonate	3.00	3.22	4.62[a]	1.56	....	1.72	....	....	....	....
Alumina	0.23	....	....	tr.	....	0.38	....	....	....	....
Silica	0.53	....	1.00	1.28	....	1.46	....	....	....	....
Total	258.37	503.75	479.17	636.71	339.6	....	875.7	592.3	806.8	169.8
Carbonic acid gas, cubic inches	239.00	250	320	361.50	....	....	....	....	....	....
Atmospheric air, cubic inches	....	....	....	....	....	....	....	....	....	....

No. 1, Allen, analyst, United States Geological Survey, Bulletin 32, page 39. No. 2, Allen, analyst (1879), idem. Also strontium sulphate, tr., sodium silicate, 4; potassium silicate, 7.00. No. 3, Allen, analyst, as under No. 1. No. 4, Sharples, analyst (1872), as under No. 1. Also strontium bicarbonate, tr.; lithium bicarbonate, 5.13; barium bicarbonate, 0.99; potassium sulphate, tr.; sodium bromid, 1.80; calcium fluorid, tr. No. 5, Nichols (1896), from J. C. Minor, jr. No. 6, J. G. Pohle, analyst, as under No. 1. Also lithium bicarbonate, 1.72; calcium sulphate, 0.45; potassium sulphate, 0.37; calcium chlorid, tr.; magnesium chlorid, tr.; organic matter, tr. No. 7, L. W. Mears (1892), from J. C. Minor, jr. No. 8, Wheeler (1906), from J. C. Minor, jr. No. 9, C. F. Chandler (1884), from J. C. Minor, jr. No. 10, Smith (1904), from J. C. Minor, jr. No. 11, Ellery (no date), from J. C. Minor, jr.

[a] Normal carbonate, not bicarbonate.

TABLE 6 (*concluded*)

Various analyses of date later than 1850. Grains per gallon

	11 HIGH ROCK	12 VICTORIA	13 LINCOLN	14 MAGNETIC	15 CARLSBAD 3	16 CARLSBAD 1	17 CHIEF	18 PUTNAM	19 STRONG	20 AINSWORTH
Sodium chlorid	86.8	186.2	315.2	69.0	486.7	670.5	86.9	210.9	265.2	448.1
" iodid	....	....	....	....	....	....	....	....	....	....
" bicarbonate	19.7	32.8	32.8	16.0	52.5	12.0	74.1	19.8	68.9	5.7
" sulphate	....	....	....	....	....	....	....	....	....	....
Potassium chlorid	1.1	16.1	22.9	8.0	33.5	45.2	6.5	2.3	24.8	6.2
" bromid	....	....	....	....	....	....	....	....	....	....
Calcium bicarbonate	20.4	112.5	176.2	86.7	173.7	218.2	72.2	109.4	123.9	100.2
Magnesium bicarbonate	8.1	79.8	108.5	35.0	118.1	155.0	53.6	63.1	79.2	146.8
" sulphate	....	....	....	....	....	....	....	....	....	....
Iron bicarbonate	....	....	....	....	....	....	....	....	....	....
Alumina	....	....	....	....	....	....	....	....	....	....
Silica	....	....	....	....	....	....	....	....	....	....
Total	136.1	427.4	655.6	214.7	864.5	1,100.9	293.3	405.5	562.0	707.0
Carbonic acid gas, cubic inches	....	....	....	....	....	....	....	....	....	....
Atmospheric air, cubic inches	....	....	....	....	....	....	....	....	....	....

No. 12. Perkins (no date), from J. C. Minor, jr. No. 13. Perkins (1896), from J. C. Minor, jr. No. 14. Duffield (no date), from J. C. Minor, jr. No. 15. Smith (1901), from J. C. Minor, jr. No. 16. C. F. Chandler (1887), from J. C. Minor, jr. No. 17. Perkins (no date), from J. C. Minor, jr. No. 18. Perkins (1891), from J. C. Minor, jr. No. 19. Perkins (1902), from J. C. Minor, jr. No. 20. L. W. Mears (1889), from J. C. Minor, jr.

TABLE 7

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

	HATHORN	CARLSBAD	LINCOLN	HATHORN	CONGRESS	CHIEF	GEYSER	CHAMPION	PEERLESS
Cl	4 674.7	4 419.6	4 068.4	3 685.5	3 327.9	2 982.7	1 025.1	2 799.1	1 773.1
Br	47.1	40.3	76.0	26.9	26.8	20.2	11.8	13.5	16.8
I	1.7	1.6	1.9	1.5	0.8	1.2	1.0	0.2	1.0
HCO_3	4 147.1	4 244.5	4 221.0	3 585.6	3 573.3	3 966.7	4 353.2	1 604.3	2 634.4
SO_4	3.4	2.8	3.5	5.6	8.7	5.3	1.4	20.0	4.0
PO_4	....	....	....	....	....	....	....	....	....
SiO_2	16.2	13.5	32.7	19.6	19.8	15.0	20.8	12.3	14.8
Na	2 951.8	3 014.5	2 688.0	2 430.7	2 199.3	2 182.0	2 010.9	1 839.9	1 298.5
K	197.8	237.8	243.7	197.2	192.0	197.7	29.0	60.0	94.7
Li	7.4	5.3	1.8	0.5	5.4	2.8	3.6	0.9	0.4
Ca	765.0	628.6	675.8	650.7	562.1	601.4	116.4	348.3	530.4
Ba	7.5	10.1	11.7	5.5	7.1	1.1	2.6	6.3	2.1
Sr	....	tr.	....	tr.	....	....	tr.	....	....
Mg	328.0	298.8	325.9	228.8	278.2	217.1	60.6	81.1	90.9
Fe Al	6.7	13.1	13.9	9.8	14.7	3.7	8.4	.8	5.6
NO_3	....	....	tr.	....	....	....	tr.	tr.	....
NO_2	tr.	....	....	....	tr.	tr.	....	....	tr.
Mn	....	....	....	....	....	....	....	tr.	....
NH_4	12.8	13.4	7.3	10.7	10.3	8.9	11.4	3.1	5.9
Total	13 170.3	12 949.6	12 371 .6	10 858.6	10 232.7	10 207.0	7 656.2	6 790.2	6 472.6

TABLE 7 (*concluded*)

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

	MAGNETIC	ARONDACK	STAR	SELTZER	VICTORIA	VICHY	VICHY	HIGH ROCK	HIDE'S FRANKLIN, BALLSTON
Cl	1 313.4	1 185.9	1 325.8	720.1	1 238.8	915.0	893.3	483.3	7 179.0
Br	11.8	11.8	0.2	6.7	20.2	tr.	tr.	6.7	60.0
I	0.3	none	tr.	0.3	tr.	tr.	tr.	.2	2.3
HCO_3	1 816.8	275.5	472.4	1 114.3	365.2	778.2	684.3	1 114.0	6 566.0
SO_4	2.3	503.9	47.0	20.2	27.1	20.2	16.7	15.7	3.0
PO_4	....	....	2.3	....	....	....	....	....	....
SiO_2	42.7	9.2	13.7	40.4	14.8	16.2	14.7	33.4	27.6
Na	849.7	827.3	878.1	459.6	822.0	828.8	772.1	348.0	4 833.0
K	56.9	144.7	23.1	48.4	140.4	3.9	3.8	34.3	346.0
Li	3.2	2.5	tr.	0.1	0.2	0.1	0.6	0.9	15.5
Ca	326.4	25.7	120.5	247.0	8.9	48.7	41.3	223.9	991.0
Ba	4.4	0.1	0.4	0.7	....	....	0.1	0.7	13.1
Sr	tr.	....	....	....	....	....	....	....	tr.
Ng	122.8	90.6	25.4	67.5	21.6	10.1	9.1	60.6	469.0
Fe Al	97.8	3.5	3.2	5.1	4.2	2.2	4.2	12.3	21.4
NO^1	tr.	11.9	44.3	4.4	....	....	tr.	6.6	....
NO_2	tr.	0.02	tr.	tr.	....	....	tr.	....	....
Mn	....	....	....	....	....	....	....	....	tr.
NH_4	3.4	0.2	0.3	2.6	0.1	0.9	0.7	1.5	14.5
Total	4 675.9	3 094.2	2 958.0	2 736.8	2 663.5	2 629.2	2 440.9	2 347.2	20 542.6

Analyses of the salts dissolved in the spring waters of Saratoga and Ballston

SPRING		ANALYST	NA CL	CA (HCO$_3$)$_2$	MG (HCO$_3$)$_2$	NA HCO$_3$	KCL	TOTAL	GRAINS PER GALLON
Ainsworth	'89	Mears	63.3	14.2	20.8	.8	.9	100.	707.0
Arondack	'88	Sharples	53.5	22.1	11.0	10.6	2.7	99.9	633.6
"	'96	Nichols	39.9	11.8	20.6	22.4	5.0	99.7	339.6
"	'03	Hayward	74.3	4.4	10.0	....	11.2	99.9	134.7
Ballston Act.	'71	Chandler	62.0	19.6	14.9	1.0	2.7	100.2	1213.9
" Frankl.	'71	"	56.4	17.6	15.2	8.1	2.9	100.2	1167.9
Carlsbad 1	'87	Chandler	61.0	19.8	14.1	1.1	4.1	100.1	1100.9
Carlsbad 3	'01	Smith	56.0	20.0	13.7	6.1	3.9	99.7	864.5
"	'03	Hayward	54.0	20.0	14.2	8.7	3.2	100.1	742.3
Champion	'72	Chandler	59.2	19.2	16.4	1.5	3.4	99.7	1181.1
"	'03	Hayward	67.5	21.0	7.3	2.7	1.4	99.9	390.2
Chief	'98	Perkins	29.8	24.6	18.3	25.2	2.2	100.1	293.3
"	'03	Hayward	45.5	24.6	13.0	13.5	3.3	100.2	587.3
Coesa	'11	N. Y. Dept. of Health	49.4	24.5	9.8	12.2	4.0	99.9	707.5
Columbian	?	Emmons	67.4	17.2	11.8	3.9	....	100.3	397.1
Congress	'30	Steel	59.5	24.2	14.8	1.4	....	99.9	647.0
"	'43	Chilton	56.0	21.4	21.0	1.7	....	100.2	650.6
"	'71	Chandler	58.4	20.9	17.7	1.5	1.1	99.6	684.1
"	'92	Mears	63.5	17.2	15.8	1.2	3.0	100.7	875.7
"	1902	Hayward	51.3	22.4	16.6	6.3	3.4	100.0	585.5
"	1906	Wheeler	68.6	14.9	7.1	2.6	6.8	100.0	592.3
Empire	'52	Emmons	54.8	28.8	8.5	7.9	....	100.0	493.1
"	'71	Chandler	75.0	16.2	6.4	1.3	0.6	99.5	672.4
Eureka	?	Allen	68.0	16.7	11.9	3.5	....	100.1	246.1
Flat Rock	'30	Steel	48.0	31.2	13.8	6.8	....	99.8	310.0
" "	'71	Chandler	43.0	38.6	11.5	3.6	3.1	99.8	253.8
Geyser	'71	Chandler	57.5	17.4	15.3	7.3	2.5	100.0	977.4
"	1903	Hayward	21.2	6.3	4.8	67.3	0.5	100.1	437.6
Hamilton	'30	Steel	65.7	20.4	7.8	6.1	....	99.9	451.9
Hathorn	'71	Chandler	58.6	19.6	20.2	.5	1.1	100.0	870.6
"	'84	"	59.1	18.2	16.1	2.2	4.1	99.7	806.8
Hathorn	1902	Hayward	56.5	23.8	15.6	1.4	2.9	100.2	757.5
"	1903	"	53.5	24.5	12.9	5.5	3.4	99.8	625.7
Hathorn No. 2.	1911	N. Y. State Dept. of Health	52.4	19.8	14.5	12.7	.6	100.0	1216.1
High Rock	'30	Steel	56.1	20.5	18.4	5.0	....	100.0	337.0

Analyses of the salts dissolved in the spring waters of Saratoga and Ballston—(*continued*).

SPRING		ANALYST	NA CL	CA $(HCO_3)_2$	MG $(HCO_3)_2$	NA HCO_3	KCL	TOTAL	GRAINS PER GALLON
High Rock	'71	Chandler	63.0	21.0	8.9	5.7	1.5	100.1	620.4
" "	1903	Hayward	33.2	40.6	16.2	7.6	2.7	100.3	129.4
" "	1906?	Ellery	64.0	14.7	5.9	14.5	.8	99.9	136.1
Lincoln	'96	Perkins	48.0	27.0	16.5	5.5	3.5	100.5	655.6
"	1903	Hayward	52.6	22.7	15.8	5.4	3.2	99.7	704.6
Magnetic	?	Duffield	32.1	40.3	16.3	7.5	3.7	99.9	214.7
"	1903	Hayward	47.0	30.4	16.7	3.4	2.2	99.7	253.8
Paterson	'88	Chandler	52.0	24.8	17.1	3.5	2.2	99.6	519.0
Pavilion	'40	Chilton	49.3	22.5	26.0	....	2.1	99.9	379.7
"	'71	Chandler	69.0	18.0	11.4	.6	1.2	100.2	667.5
Peerless	'88	Chandler	46.4	31.6	13.3	6.1	2.5	99.9	412.1
"	1903	Hayward	43.4	33.8	8.6	11.8	2.5	100.1	371.5
Putnam	?	Chandler	43.0	25.2	27.9	1.3	2.4	99.8	621.9
"	'91	Perkins	52.0	27.0	15.5	4.9	.6	100.0	405.5
Red	?	Appleton	33.1	40.4	17.0	6.1	2.7	99.3	249.3
Royal	'88	Chandler	52.0	28.7	16.0	1.2	1.8	99.7	508.9
Saratoga A	'65	Pohle	87.0	8.8	3.1	1.0	.6	100.5	649.7
Seltzer	'71	Chandler	45.5	30.4	13.7	10.0	.4	100.0	295.0
Star	'71	Chandler	65.5	20.5	10.2	2.1	1.6	99.9	606.8
"	'95	"	41.7	36.2	14.5	5.6	2.1	100.1	328.8
"	1903	Hayward	76.8	17.2	4.6	....	1.2	99.8	162.7
"	1904	Smith	73.0	18.8	5.5	2.5	....	99.8	169.8
Strong	1902	Perkins	47.0	22.0	14.1	12.3	4.5	99.9	562.0
Union	'71	Chandler	66.3	14.1	16.0	2.5	1.3	100.2	685.4
Vichy	'71	Chandler	35.4	26.4	11.2	22.9	3.9	99.8	362.5
"	1902	Hayward	58.3	6.4	2.4	33.0	0.3	100.4	149.4
"	1903	"	61.6	6.7	2.3	29.1	0.3	100.0	138.0
Victoria	'90	Perkins	43.5	26.2	18.7	7.7	3.9	100.0	427.4
"	1903	Hayward	72.0	1.4	5.0	11.8	9.8	100.0	148.8
Washington	'30	Steel	58.0	30.4	8.5	3.3	....	100.2	485.0
"	'43	Chilton	53.5	24.7	19.5	2.3	....	100.0	340.0

NOTE. The above analyses were chiefly compiled by J. C. Minor, Jr. To Mr Minor's original series a few very recent ones have been added. Thanks are due Mr Minor for the use of his notes.

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