THE ORIGIN AND USE OF THE NATURAL GAS

AT

MANITOU, COLORADO

By

WILLIAM STRIEBY

FURNISHED BY THE MANITOU MINERAL WATER CO.

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The waters of the mineral springs at Manitou owe their sparkle and piquancy to the carbonic acid with which they are naturally surcharged. The beautifully clear water as it issues from its subterranean channels is accompanied in several of the springs by a considerable flow of exceedingly pure carbon dioxide. When dipped from the springs it continues to effervesce for some little time, and the agreeable flavor of the gas makes the drink very palatable in spite of the large quantity of alkaline mineral matter which it holds in solution.

For many years these springs have been locally esteemed as furnishing both a refreshing beverage and a valuable medicinal agent, but it is only with the last six or seven years that the bottled waters have been put upon the market to supply a wider circle of admirers. In order to give to the bottled waters the charm of the original effervescence, it was necessary to recharge them with carbon dioxide; and this was done at first in the manner usually employed in bottling seltzer, and some other gassed beverages. This process, briefly consisted in the preparation of carbon dioxide from sulphuric acid and marble-dust, and the absorption of it by the mineral water by agitation under pressure in strong iron cylinders. Then it was bottled in the common way, or sometimes was enriched by the addition of ginger syrup and flavorings, and put up as ginger-ale, or as the Manitou Mineral Water Company felicitously called it, "ginger champagne." About the year 1889 the desirability and feasibility of using the natural gas from the springs to re-charge the mineral water and champagne was suggested to the Company, and this plan, proposed by the writer and carried out under his supervision, was soon put into practical operation.

It may be of interest to discuss the origin of this natural gas, and then to describe the means by which it is made to again impregnate the mineral water taken from the springs.

In seeking to trace the sources of this abundant supply of natural gas, it will be helpful to consider certain of the prominent geological and topographical features of the district in which the springs occur. Manitou lies in a mountain gulch or valley at the base of Pike's Peak, and just at the entrance to Ute Pass. In fact the valley is but the roded and widened outlet of the Pass--itself a narrow-water-carved channel through which the drainage of an area some seventy-five to one hundred square miles in extent finds its way to the eastern base of the mountains. The stream which drains this tract obtained the name "Fontaine qui Bouille" from the bubbling or boiling springs on its banks at Manitou. On the south and west of the picturesque little city rise the granite slopes of Pikes Peak, while to the north are piled up the huge masses of stratified rock which flank the other side of the valley. Thus Manitou lies at the junction of the old archaean rocks, with more recent sedimentary formations. Just west of Manitou, however, the limestone beds are found for a short distance on both sides of the Ute Pass. The archaean rocks at Manitou consist almost exclusively of highly feldspathic red granite which disintergrates very readily under atmospheric agencies. Further up the Pass are found patches of syenitic gray granites containing soda feldspars. There are no igneus rocks in this neighborhood save a few narrow dikes, and on the south slope of Pikes Peak, about two miles from the summit, one exposure of phonolite, but not many miles distance at Cripple Creek, large areas of eruptive rocks are exposed to view. A number of rock slips or faults in the granite are to be seen in the neighborhood of the Peak.

At Manitou and to the northwest, only the paleozoic series of sedimentary beds are exposed, e. g. silurian, carboniferous and juratriasic, and these are mainly represented by limestones and sandstones. The granite slopes of the Front Range, which extend in a generally north and south line, are depressed in a sort of recess or bay at Manitou and to the northward, and these older sedimentary beds rest upon them, and outcrop in their regular order, showing themselves for several miles up the Ute Pass. To the northwest of the Ute Pass and continuing in the same direction, extends a long, narrow strip of the same series of sedimentary formations. Probably these two areas were once continuous and have since been separated by erosion. At the lower end of the latter, or Manitou Park, area,a prominent fault having a slip of three or four hundred feet follows the junction of the granite with the southern side of the sedimentary beds, (note), and at Manitou, near the Rainbow Falls, there is also a fault with a slip of twenty feet or more, which takes about the same direction. It is probable that these faults form a continuous fissure over the short interval between the two areas, and quite possible that the influence of this fissure or slip determined the course of the stream which cut the Ute Pass so deeply in the rocks. From the prevailingly slight dip of the strata it is probable that the sedimentary beds at Manitou do not extend to very great depths beneath the surface, and the same observation applies also to those at Manitou Park. At Manitou the general inclination of the beds is to the southeast, though there are several folds which steeply incline some portions of them just west of the city. There are, however, in the vicinity of the springs at Manitou, a couple of small flexures of strata, indicated mainly by rock exposures on the north side of the valley which should be noticed.

"See the Pike's Peak Folio, edition of 1892, U. S. Geological Survey."

They run transversely across the valley, and may be described as being only more abrupt or sudden inclinations of the southeastwardly dipping strata. It is at the crests of these low folds that the springs appear. The oldest limestones are very silicious, and in places just west of Manitou where they are shattered and bent, often contain cavities filled with argilaceous red oxide of iron. The "Caverns" so much visited at Manitou occur in the limestone, and show the results of a former great chemical activity at that point. When first discovered, very considerable beds of the same ferruginous matter covered the floors and filled some of the passageways of the caves. The springs are found at three points in the valley, and these places are at the apices of a triangle roughly equilateral. The group including the Navajo, Manitou, Cheyenne and Shoshone, which lies in the center of the town, and forms the eastern end of the triangle, has the largest flow of water and gas. The eastern of the two transverse rock flexures occurs at this point. West of this group the valley widens and divides, and the Ute iron spring is found in Engleman's Canon, a short distance above its mouth, and almost in the granite. The third position, that of the Hiawathe group, is in the general line of the vàlley, near the limestone rocks, and not far below the entrance to the Ute Pass. It is said by old residents that the largest springs was not many years ago found at this place, but that it was deeply covered and quite obliterated by deposits of gravel brought down the Pass during a severe freshet. In the neighborhood of each group of springs the gravel and wash has been cemented by a tufaceous substance deposited from the waters and called locally "soda-rock." The Navajo group and the Ute Iron spring are near to the line of contact of the granite with the sedimentary beds; the Hiawatha group is near the line of the Ute Pass fault. In all cases the springs lie close to the streams, and in the creek bed near some of them, numerous small vents are shown by rising bubbles of gas.

The rain and snow descending upon the earth bring with them matters washed from the air, and after reaching the ground the waters dissolve portions of all the soil and rocks over which and through which they make their way. It is therefore natural to seek in the waters of these springs for evidence concerning the rocks they have traversed, and thus, if possible, trace nearer to its origin the accompanying gas. The following analysis of water from several of the more important springs were made by Prof. Elwyn Waller, Ph. D., of New York, from samples taken from the springs by the writer in the summer of 1891. These results have been confirmed by analysis made in the laboratories of Colorado College on several different occasions, when the samples were also taken in the summer season.

Constituents Found	In parts per 100,000 of Water		
	Navajo Spring	Manitou Spring	Ute Iron Spring
Sodium	53.959	52.176	41.370
Potassium	7.650	8.219	6.018
Lithium	0.201	0.230	0.035
Calcium	27.560	47.382	21.747
Magnesium	7.859	8.173	3.939
Iron	0.032	0.028	0.326
Aluminium	0.092	0.069	0.140
Chlorine	24.625	24.781	17.520
Sulphuric anhydride	18.410	18.232	20.703
Carbon dioxide	195.366	193.545	104.159
Silica	4.230	4.280	6.200
Oxygen in bases	39.296	38.910	23.203
Water in bicarbonates	29.962	39.588	21.305
Totals	439.243	435.613	266.665
Totals in grains per gallon	256.157	254.041	155.514

The elements found in the Hiawatha group of springs are the same as those shown to be in the other groups.

Below are tabulated the salts contained in the waters, calculated according to the conventional methods, from the preceding figures.

Salts Probably Present	In Parts per 100,000 of Water		
	Navajo Springs	Manitou	Ute Iron
Sodium chloride	40.803	41.061	29.030
Potassium sulphate	17.067	18.335	13.425
Sodium sulphate	18.749	17.397	25.792
Sodium bicarbonate	115.804	110.518	78.540
Lithium bicarbonate	1.946	2.235	0.336
Calcium bicarbonate	192.613	191.900	88.076
Magnesium bicarbonate	47.812	49.719	23.965
Iron Oxide (ferric)	0.046	0.040	1.037"
Alumina	0.174	0.130	0.264
Silica	4.230	4.280	6.200
Totals	439.244	435.615	266.665

Ferrous bicarbonate.

The temperature of the Navajo and Manitou springs was tested on two or three occasions and found to be about 15 C. In July, 1894, it was also the same. On December 31, 1894, after five days of quite cold weather(the thermometer registering nightly-- 18 C or lower), and again on January 10, 1895, after a continuous period of cold weather, the temperature of several of the springs was tested, and samples of water from some of them also taken. The temperatures observed, and the residues obtained by evaporation of the samples of water, are given in the subjoined table. The residues are given in grains per gallon.

Date of Test		Navajo	Manitou	Ute Iron	Ute Chief	Hiawatha	Hiawatha No. 2
Dec. 31	(Temperatures C.	14 .5	14 .5	12.0	11.0	#11 .5	11 .5
	(Residues	178.40	.....	"109.52	....	119.16	51 .10
Jan. 10	(Temperatures C.	14 .5	14 .5	7 .0	....	#12 .0	11 .0
	(Residues	177.57	176.12	113.66	....	117.86	50 .85

"A small precipitate of an iron compound had formed and settled before the analysis was begun--the result is therefore a little low.

The Hiawatha spring is covered with an iron cap, cemented to the curbing and water tested on December 31 was obtained from the overflow and caught in a gallon measure, and as the vessel was cold the temperature obtained was probably too low. On January 10 the thermometer was held in the water escaping from the overflow pipe. This overflow pipe is buried under four or five feet of gravel and is some twenty or thirty feet in length.

The gas emitted from all of these springs is pure carbondioxide. The quantity given off from the different springs is quite unlike, varying from a few hundred cubic centimetres per hour to three or four hundred litres or more in the Navajo and Cheyenne. The flow from each spring is, generally, during the greater part of the year, very uniform in quantity, though it is said that after heavy rains or when snow is melting the quantity given off is increased. This increase may arise from greater hydrostatic pressure of the swollen stream upon small vents in the creek bed and unseen vents along the banks near the springs, thus forcing more gas through the main channel. The foreman of the bottling department of the Manitou Mineral Water Company's plant report that a diminution of the flow of both water and gas occurs in the Navajo group of springs during the coldest weather of winter. It is to be observed that the spring waters never become turbid or roily after storms and freshets, although the surface streams are especially affected in this way. One of the springs of the Hiawatha group (the covered one) is slightly turbid from insoluble salts which probably result from re-actions occuring in close proximity to the spring. Some of the spring waters on standing, quickly deposit a precipitate, while others, even from the same group of springs, remain clear for a much longer period. Considerable pressure is developed by the escaping gas when the waters are immediately bottled and hermetically sealed as soon as drawn from the springs. Large glass vessels are apt to be burst by the pressure of gas if filled quite full before sealing.

The surface waters in the district under examination contain relatively very small quantities of mineral matters in solution; nor are there springs or pools in the area which drains through the Ute Pass that are known to be high mineralized. In the upper part of the Pass between Cascade and Green Mountain Falls there are springs and small marshy spots where a notable quantity of hydrated sesquioxide of iron is liberated from feruginous waters, and these waters come apparently from the granites on the south side of the Pass. No thermal springs are found in this vicinity other than those at Manitou.

Taking the three analyses given above as a basis of discussion, and using also the later results as data, certain points among the many possible inferences will here be noted.

1. All the springs hold the same salts in solution, a fact which seems to point to a common origin.

2. The waters of the Navajo and Manitou springs are almost identical in mineral contents, while the Ute Iron Spring contains a much smaller quantity of dissolved salts. There is also a difference in the weight of the residues from the Hiawatha springs. It is very probable that percolating waters from the streams or from local seepage channels, make their way into the springs--such influx being greater in some springs and smaller in others. In the Ute Iron spring calcium and magnesium are low, and silica, chlorine, iron, sulphuric-anhydride, soda and potash relatively high. The proximity of the spring to the silicate rocks on the south, and to the very broken silicious silurian limestone and cambrian quartzites on the north and west, suggest reasons for a possible change in this spring water, on the supposition that its main source is the same as that yielding the waters of the other groups.

3. The presence of so large quantities of the bicarbonates of calcium and magnesium points to a prolonged contact of the waters with the limestones.

4. The almost total absence of iron salts indicates either a source quite free from ferruginous minerals, or more probably the oxidation of dissolved iron and its previous precipitation as hydrated sesquioxide by the carbonated alkaline matters with which it comes in contact as the waters move toward the springs.

5. The high percentage of chlorides may be derived from the silurian rocks or with less probability from the more distant joratriasic beds, since no saline deposits in them are known in this vicinity.

6. The large percentage of sodium bicarbonate probably indicates an origin among silicate rocks, whence the soda (and potash) may come as carbonates formed by the decomposition of the rocks by atmospheric waters containing carbonic acid, or as alkaline silicates, which react upon the limestones (calcium carbonate) before reaching the surface.

7. The sulphates may come from unseen gypsum beds such as are found two or three miles away, and lower down the Fountain creek, but it is more probable that they come in greater part at least from the oxidation of sulphides in granites, igneus rocks or even sedimentary beds. The oxidation of ferrous sulphate, such as was described as occurring in the Ute Pass, gives rise to sulphuric acid, and by subsequent reaction with carbonates to sulphates of the alkalies. The ferruginous deposits in the broken silurian limestone indicate such reaction.

8. The concentration of the solutions--that is, the large quantity of mineral matters contained in the spring waters, comes evidently from prolonged contract with rocks, such as would arise from percolation, and probably also from an increased solvent power of the water, due to heat or pressure, or both combined.

9. The difference in temperature of the several springs is remarkable as showing that either the waters come from different sources, or if coming from the same source have been cooled in an unequal degree by passing through diverse strata, or through the influx of cooler foreign waters. It was assumed under (2) above that the most probable view was that the same water is made to vary its content of dissolved mineral matters by the admixture of other waters; and the variation in temperature between the springs will be found on inspection of the table above to be in striking harmony with this supposition. The temperature in general is lower when the mineral content is lower, but it should be remembered that the inflowing foreign waters may also pass through strata so deeply buried as to be much warmer than mere surface waters.

10. The variation of the springs between summer and winter, in their contents of mineral matters dissolved, in the quantity of water flowing from them, and in the volume of gas yielded, together with remarkable uniformity of temperature throughout the year in some of them, are evidently significant phenomena. The causes producing them will be discussed in subsequent paragraphs.

Before proceeding to deduce from the foregoing statement a theory of the derivation of the carbon dioxide of the Manitou springs, it may be helpful to recall to mind some of the explanations most frequently given for the production of natural gas in large quantities beneath the surface of the ground. First, then, may be mentioned the slow, natural distillation of the buried or fossil organic matters that are found in many strata, notably in the shales. The volatile products evolved in this manner contain large quantities of marsh-gas and similar combinations of carbon and hydrogen, with but little carbon dioxide. The wide distribution of gas wells over the country attests a very general chemical action of this sort yielding combustible gases. At Colorado City, three miles distant from the Manitou springs, a small flow of combustible gas has been obtained from the two wells already bored. A second cause, obviously a true one where the proper conditions exist, is found in the heat of lavas of igneus rocks where they come directly in contact with limestones. It may be doubted whether much gas is ever produced by actual rise of temperature in this way without the aid of moisture, but unquestionably superheater waters carrying dissolved mineral matters and accompanied by vapors and gases produced by such igneus rocks, would effect the liberation of this gas. Thirdly, limestones deeply buried under the later deposits of rock will suffer an increase of temperature due to the rise of isogeothems, and heated mineralized waters will then bring about chemical reactions with the limestones. Simple rise of temperature alone will not suffice in such enclosed zones to liberate the carbon dioxide, though with the aid of moisture it may metamorphose the limestones to marble. A last cause to be noticed here is the chemical decomposition of limestones effected, with or without high heat, by acid waters or by salts which react with the carbonates of lime and magnesia, forming a new series of salts and setting free carbonic acid gas. This last cause has been in part anticipated in the two preceding theories of the derivation of the gas.

As the development of a theory of the formation of carbon dioxide probably turns in no small degree upon the action of substances in solution derived from the rocks, it is appropriate here to consider some of the results of investigation along this line. The disintegration of surface rocks by atmospheric agencies is very apparent to the eye, and the products of this resolution of the rocks have been the subject of careful study. Carbonic acid from the atmosphere, or that derived from the oxidation of decaying organic matters in the soil plays a very important part in the disintegration of silicate as well as of carbonate rocks. It produces in the former class carbonates of the alkalies and alkaline earths, and these salts are carried away along with some silican and metallic carbonates, etc., in the percolating waters. It is believed that all rocks, at least to very great depths, are permeated with water which has made its way from the surface downward, and which exerts an action like that shown on rocks near the surface of the ground. As these meteoric waters descend they gradually lose the more active elements, dissolved oxygen and carbonic acid, with which they began their journey-being exhausted in short distances when they percolate slowly through the rocks, and carrying them to great depths when they pass through porous or shattered rocks, especially when they find channels or fissures in which to flow; but as the waters reach more deeply buried zones a new resolvent power and chemical activity is developed in greater and greater degree by the increasing heat and pressure to which they are subjected. Under the influence of these stimuli the metamorphism of rocks proceeds at a vastly increased rate, kaolinization, solution, chemical combination and crystallization working a silent, ceaseless change in many kinds of deeply buried formations. Evidence of this heightened action of heated waters is afforded to us in the hot springs of all countries, as a rule, waters which issue from the earth at high temperatures bring with them excessive quantities of dissolved mineral matters. The modern theories of the filling of fissure veins is largely based upon the greater solubility of silicious and calcareous compounds, metallic sulphides and other vein matter, in the heated waters at the deeper parts of the earth's crust to which such crevices extend, or to waters heated by bodies of igneus rocks in process of cooling; although of course at any depth, small or great, the solvent action of water takes place, and solution may proceed more rapidly in one kind of rock than another. The application to be made of the foregoing observations depends upon the fact that waters thus highly charged with mineral matters in rock fissures would be well adapted to produce reactions upon limestones if they should chance to come in contact with them. It should not escape notice that the flow of gas at Manitou takes place within a very limited area, and that no other similar springs are found in this immediate region. It is very local phenomenon. Whatever the causes which give rise to the gas, they can have no general application to the similar series of rocks extending for many miles along the mountain slopes, else the evidence of their action would be more widely distributed. Hence some local cause is to be sought at Manitou as the producer of the gas.

Having thus examined the situation at Manitou and briefly reviewed some theories of the evolution of carbonic acid gas from the earth, it is now possible to more definitely assign a reasonable cause and source of the flow of gas in question. It seems to be generally agreed that the carbonates formed through the decomposition of silicate rocks by atmospheric waters will not by any known reactions in those rocks alone account for a large flow of gas. Also the evolution of carbon dioxide by the slow, natural distillation of carbonaceous matters, deeply buried in strata, is an explanation not applicable to the present case, because of the great purity of the Manitou gas. The disengagement of the gas from limestones subjected to heat from rising isogeotherms appears improbable becanse the strata at Manitou seems not to be very deeply buried, and because the salts found in the water of the springs point to another class of rocks as a source, and also because the springs are confined to so limited an area.

The presence of masses of igneus rocks near the limestones may be considered a possible explanation of the phenomenon, since though no such eruptions outcrop near Manitou, there may yet be intrusive masses of them buried more or less deeply beneath the gravely or sedimentary beds. The waters of the springs would probably have a much higher temperature than they now possess if masses of igneus rock retaining still sufficient heat to cause the water to dissolve its large percentage of mineral matter, occurred in this immediate neighborhood. Altogether, in the absence of some positive evidence of the presence of such heated rocks this explanation must be quite doubtful.

It remains then to discuss the probability of the formation of this gas by chemical reaction of dissolved substances in a flow of water which reaches the limestones of Manitou, and to examine whether there are at hand sources whence this saline solution might reasonably be expected to come. This explanatién differs from the preceding one mainly in that source of the reacting salts is more remote. Is there such a source of active chemical solutions present at Manitou, and if that be asserted, what evidence can be adduced in support of a theory of this sort? It must be admitted that positive proof is not now attainable, but there are some considerations which may be urged in favor of such a theory.

Reference has already been made to the faults and rock-slips at Manitou, and to the probability of the presence of an extensive and profound rock-fissure extending from Manitou continuously along the general line of the Ute Pass up into Manitou Park. In view of the presence of an extensive outflow of igneus rocks not many miles distant at Cripple Creek, and of an outcrop of phonolite nearer still on the south side of Pike's Peak, it is altogether likely that a deep fissure such as that at Manitou, if not in some way connected with those disturbances and the loss of interior liquid matter under this region, yet penetrates to depths strongly affected by these heated zones. If a fissure occurs at Manitou which penetrates the earth's crust sufficiently to reach highly heated rocks, the natural action observed in fissure-vein filling will be very actively induced, and highly mineralized solutions will result as before explained. And if further the fissure at Manitou extends to Manitou Park or communicates with fissures of the Cripple Creek district or with those in some other elevated region, the waters which everywhere find exit in such rock crevices, would, in seeking their level, according to physical laws, naturally emerage at the lower point where the springs are found. Heated waters, or waters even slightly heated, on coming into contact with the superincumbent limestones of Manitou would promptly set up chemical reactions caused by the presence of soluble matters such as the silicates of the alkalies and other metals, silicic acid, sulphides, sulphates, etc., derived from the heated rocks. The reactions which would take place need only be generally indicated here since they are not peculiar to this theory. Alkaline silicates would change to carbonates; alkaline bicarbonates, in so far as these reactions were possible, to sulplates, or, --if chlorine combinations of lime and magnesia exist in the silurian limestone--to chlorides, in both cases--at even a very moderately elevated temperature--with the evolution of carbon dioxide; iron salts would first become carbonates and then peroxidise, setting carbon dioxide free and forming a ferruginous precipitate. If the waters were only slightly hot, silicic acid would form insoluble calcium silicate with liberation of carbon dioxide. In the case of hot waters the basic carbonates of magnesia and probably also of calcium would be formed instead of normal or acid salts by reactions of the salts of alkalies, etc. These, with other known and possible reactions, account for the generation of the gas. The salts contained in the spring waters may also be fairly explained in part by these reactions, and in part by reactions produced, and other salts introduced, through the accession of seepage waters in the passage to the springs. The concentration of solutions, or the high percentage of salts in the water, is well explained by this derivation. A large fissure like the one assumed to exist at Manitou must receive meteoric waters by seepage along its whole course, and such additions bring with them each their small quantity of dissolved salts. The waters which emerge from the fissure at or above Manitou must also be considerably changed in mineral contents by the accession of seepage waters from the local rocks, and these changes are probably greater at some points than at others. The difference in temperature between the various springs, and also their difference in mineral matters dissolved in the water, may thus be credibly explained. The surface waters do not readily make their way through the "soda-rock" into the springs and hence the springs do not become roily and the temperature of the water remains quite constant, retaining still enough heat to be designated as "Thermal" in the U. S. Government reports.

The coincidence between the diminution of the salts and that of the water and gas during the coldest winter months, probably arises in this manner. The feeders of this fissure-flow are in large part the seams and cleavage cracks in the rocks adjacent to the main fault or its branches, and they in turn derive their supply from the surface waters which percolate downward. In the very cold weather the seepage waters--as is well known in mining regions at high elevations--are greatly diminished, being held in check by frost, so that the supply is lessened in the main fault. In like manner the slopes of the Ute Pass and the neighborhood hills, which may be supposed to furnish the seepage waters of the sedimentary beds at Manitou are restraining (by frost) their quota of the supply for the springs. Especially would this be true if, as appears probable, the more elevated and comparatively shaded south side of the Pass furnishes the bulk of the seepage waters which make their way to the springs; Under these conditions the temperature of the springs would not generally greatly vary in summer or winter, since the coldest surface waters of the latter season which mingle with the decreased fissure-waters would also be much diminished in volume. With the decrease in water would come a decrease in salts, and so also of the gas produced by the reactions previously outlined.

The salts coming from the assumed fissure beneath the limestones naturally tend to follow the seams and bedding planes of the stratified rocks and thus to make their way down the easterly slopes without coming to the surface. The resistance to this flow resulting from friction and perhaps from sharp folds and faults east of Manitou, causes the waters to force an exit through the broken and folded strata at the western side of the city. The two small flexes of surface rock before mentioned appear to give in their crevices the opportunity for a final escape to the surface of the water and gas. All the circumstances, therefore, connected with the position and flow of the springs, and the mineral contents of the water, etc., seem to be consistent with, if they do not favor this explanation.

Briefly, then, the theory advanced of the origin of the natural gas at Manitou may thus be summarized. Water percolating through silicate rocks and becoming highly mineralized under favorable conditions of temperature and pressure, makes its way through cracks and profound rock-fissures by the action of gravity and the ascensional power imparted by heat to the limestones west and north of Manitou. It is here increased in volume and in dissolved salts by the numerous additions of seepage waters from the local rocks, and also lowered in temperature at the points where these influxes occur. By chemical reactions some of the dissolved salts are changed, and the carbon dioxide originally held (almost entirely) by the limestones is liberated from the combination but dissolved in the water on account of the great hydrostatic pressure. As the waters rise through the irregular channels enlarged from cracks and seams, the pressure decreases, and more and more of the dissolved gas escapes from the water, until at last when the surface is reached at the various springs the gas emerges with the rythmic flow due to the irregularities in the channels of exit.

Of the many temptations to comparisons and generalisations growing out of his study upon the origin of the natural gases at Manitou, the writer yields to the two following: (1) The caverns at Manitou mark the scene of a former considerable chemical activity, possibly induced by the same causes now at work in the lower strata in the manner mentioned above. If the theory advanced in this paper is true, caverns of like kind may now be in process of excavation which will in time rival or eclipse those so much admired in the now drained and fragmentary parts of strata on the west side of Williams' canon. (2) The data in the hands of the writer, concerning the carbonated mineral springs of other localities are too meagre to permit of any very general comparisons or deductions, but it would appear from published descriptions that in some notable instance, at least, the flow of carbon dioxide, just as at Manitou, occurs where there are no igneous rocks, but at points where the older rocks have been faulted or fissured below overlying limestones. A case in illustration occurs at the Saratoga springs in New York. The silurian limestone is there faulted by a fissure which extends down into the archaean rocks below, and no other visible cause appears for the generation of the gas. Also the conditions of the Canon City, Colo., carbonated springs seem, from an examination of the geological maps to be very similar to those at Manitou--but the writer has no positive knowledge as to whether or not the rock fissures in that region extend to the vicinity of the springs as is the case at Mantou. The published analyses of the water from the springs at Canon City show that in respect of both the kinds of salts and the quantity of them present, they very closely resemble the springs at Manitou.

The second part of this paper concerns the use made by the Manitou Mineral Water Co., of the natural gas which comes from the springs. A description of the steps taken and the apparatus devised to accomplish this end may be of interest. In the early days the Navajo group of springs bubled and fizzled in a peaty morass, and could be approached with difficulty. The Navajo spring which gave the most gas and water was then curbed with cement and stone and the swamp filled up with earth. From this spring was drawn the water put up by the Company in 1889, at the time the proposition was made to use the escaping gas to recharge the bottled water. In the accomplishment of this plan three problems required solution, namely: (1) to ascertain the quantity of gas available for use; (2) to devise means for catching and storing the gas; (3) to obtain a gas-pump which would continuously and practically compress the gas to the degree obtained in the old gas-generators, i. e. some 60 to 80 lbs. per square inch.

The measurement of the gas was effected as follows: A large tin funnel, stiffened at the wide opening with heavy wire, and made very short from large to small end, was sunk mouth downward under the water of the spring as deeply as possible. The mouth of the funnel was bent after several trials to conform to the irregularities of the spring, and the funnel when thus fitted was held in place by wooden supports, because pressed upward with much force by the rising gas. A large bell-glass of a capacity of 7 or 8 litres was used to make the measurement. This bell-glass when filled with water by immersion in the springs was held mouth downward over the small opening of the funnel whence the gas now escaped, and as the gas entered it the water was displaced. The bell-glass was gradually raised out of the water as the gas accumulated, until when it was full of gas the mouth just dipped beneath the surface of the water. In this ~~my~~ way the gas was measured at the then prevailing atmospheric pressure. Owing to the very rapid flow of the gas, the time required to fill the bell-glass could not be very accurately determined, though by repeating the experiment many times and taking an average of the time records, the number of seconds required to fill it was ascertained with sufficient accuracy for practical purposes. The quantity of gas evolved daily was now easily computed, provided the flow was constant as observation had seemed to indicate. With these figures it was possible to calculate the number of bottles of water that could be recharged with this natural gas per diem. Roughly speaking, water will absorb its own volume of carbon dioxide whatever be the pressure to which the water and gas are subjected. Assuming a pressure to at which the company would bottle waters, the reduction in volume of the gas was obtained by the use of the formula $v = \frac{vp}{p'}$.

The rise of temperature, due to compression, could practically be neglected since the water sufficiently cooled the gas. The number of bottles which could be filled from this supply of gassed water was $\frac{v'}{A}$

if A represented the capacity of each bottle. Thus the Company was assured that the supply would be much more than sufficient for the then daily output of the works.

The second problem involving the construction of apparatus for catching and storing the gas was somewhat more troublesome. The conditions were (1) that the waters of the spring, which were used for bottling, must be preserved from contamination by metallic salts; (2) that the gas must be forced by its own pressure to an appropriate gasholder; (3) that the spring must be accessible for cleaning and adjustment of the overflow pipes which carry the water to the bottling works. Another point which had some influence in determining the character of the apparatus to be used, was the wish of the Company to have all parts of it open to inspection by visitors to the works--a policy the wisdom of which has been amply justified by subsequent experience. To meet these requirements it was decided to immerse a bell-shaped vessel in the spring to catch the gas. From this bell the gas could be carried in pipes to the works, two or three hundred feet distant. In order to give the gas sufficient pressure to force it through the conducting pipe, and sent it into a receiver or gas-holder, it would be necessary to depress the bell in the spring water sufficiently to allow for the difference in level between the surface of the water on the outside and that of the water within. At the gasholder this conducting pipe would have to dip into water several inches in order to make a water-seal connection, to prevent loss of gas in case of accident to the pipe or bell, and in the gas-holder itself, a slight pressure would be needed to send the gas to the pumps. In preparation for the reception of this bell the spring was cleared out and somewhat deepened, and upon the rocky bottom, a short distance above the vents whence issue the gas and water, a shelf of cement, circular in plan, and about six inches wide, was built within the inclosing walls of the spring, which were also made cylindrical. On this shelf the bottom of the bell was to rest. An incident in the work of deepening the spring and constructing the shelf and walls is worthy of passing note. The volume of gas was so great that workmen could not remain a moment in the excavation without apparatus to supply fresh air. This was provided by the use of a dentist's gas-inhaler connected with a piece of common garden hose reaching above the curb of the spring. Even with this inhaler it was necessary to stop the nostrils of the men with plugs to keep out the gas. When, as often happened, one of these nasal stoppers become displaced, the workman would precipitately bolt for the surface with a shout of pain from the sharp sting of the gas in the nose and air-passages. Tears would flow from the eyes of those engaged in working at the bottom of the spring.

The material of which to make the bell was important from the fact that the water of the spring must be used for bottling. Iron rust would destroy the clearness of the water; lead, copper, and zinc would add poisonous salts, which, although present in very minute quantities, would yet cause distrust in the minds of users of the water; silver was the ideal metal, but its then high value barred its use. Block-tin was accepted, though the difficulties in the way of its use were quite serious. The form of the bell adopted is shown in sectional elevation and plan in the annexed plate. It was built by the Hartt-Manufacturing Co. of Chicago, after plans of the writer. The sheets of block-tin (No. 12 American wire guage thickness) were held in place and stiffened by a skeleton form made of heavy iron wire encased in tin pipes. The frame as thus made has been found in subsequent use to be too light, and the bell requires the most careful handling to prevent distrotion and cracking; otherwise it has well fulfilled its purpose, and now (Jan. 1895) is almost as good as when first set in 1890. In order to show to the many visitors the flow of gas in the spring, the top of the bell was made of plate-glass, and just below the glass hung an electric incandescent light. The bell is held firmly in place, by iron stays fastened to the curbing.#

The temperature of the springs (about 60 Fahr) is so high that the gas is loaded with moisture, and condensation in the conducting pipe results, especially in cold weather. In order to prevent a stoppage of the pipe a drip-trap (see plate) made of gas pipe was inserted at the lowest point in the line, and an escape for the accumulating water provided.

Before closing the description of apparatus for catching the gas, it should be added that at one of the Hiawatha springs the owners have caught the gas by the use of an iron dome cemented upon the curbing of the spring. There is no way to get into the spring to repair pipes, etc., except by breaking the cement sealing. It would appear to be a wise measure to have provided a manhole with a movable cover in this dome to obviate that difficulty. A couple of iron bells placed in other springs are rusting rapidly and render the waters turbid.

The conducting pipe was buried under ground to prevent freezing.

The gas-holder is designed to hold twenty-four hours yield of gas from the springs. It contains no striking novel feature. The bell or holder is supported by three chains, which run over pulleys attached to heavy timbers set for this purpose in the Company's building, and bucket weights are loaded to give the required pressure to send the gas to the carbonating apparatus. The holder dips in water contained in a cemented cistern which can be conveniently drained and cleaned. A large manhole in the top of the holder provided access to the cistern and to the enclosed pipes. An electric incandescent lamp suspended just beneath the arched top of the holder permits inspection of the pipes for the ingress and exit of the gas; and for this purpose also a number of small glass plates are cemented in a perpendicular line on one side of the holder at intervals of about two feet. The pipe which brings the gas from the springs, and that which leads it to the carbonators, and that which provides for the escape of an excess of gas, rise from the cemented bottom of the cistern and are supported upon an iron tripod, as shown in the accompanying plate. The pipe for the entrance of the gas curves in the form of a gooseneck and dips under the water some five or six inches, to effect a water seal against back-flow. The overflow pipe is capped by a metal bell which dips into the water of the cistern so long as the holder is not yet full of gas, but when the holder is full the cap of the overflow pipe is raised from the water and gas is allowed to escape. This cap or gas-trap (see plate) is connected by a metal chain with the tops of the holder, and is therefore raised from the water when the holder rises above a certain height. This apparatus has sometimes caused trouble by the kinking of the chain connecting the holder with the metal cap. The chain should be made of small links so that it may readily coil in the little dish at the top of the metal cap, and uncoil again without kinks. A small rod suspended from the roof of the holder, which would lift the cap by an arm, would perhaps obviate any difficulty of this sort.

The problem of the compression of the gas in order to recharge the water with it, was one of vexation and difficulty. The plan at first attempted was to pump the gas into the old iron gas generator, whence it could be drawn and used in the same manner as was the artificially made gas. It was not successful, because the pump bought for the company would not continuously nor even for an hour, compress the gas without destroying the packing of the piston-head. The heat developed by the compression and the strain upon them, in a few moments reduced rubber washers to shreds, and leather ones, lasted but little longer. About this time the writer, while in New York City, heard of a new form of carbonating apparatus invented by the Wittemann Brothers. Three of these machines were then employed in practical work, and an inspection of the one operating in New York left no room for doubt as to their merit. The principal of the machine was one to tickle the fancy of a man of science. The gas was pumped into a small cylinder of glass or metal and the water to be carbonated was also pumped into the same chamber by the action of the same piston-rod. The water entered the cylinder of compressed gas through a smaller interior cylinder pierced by a great number of very small holes. The water was thus sprayed through the compressed gas, and was therefore most advantageously disposed for quickly absorbing the gas; in fact the absorption was instantaneous. The carbonated water now flowed to a balanced reservoir which operated to shut off the supply of gas or water or both, if necessary, to maintain a proper pressure and a constant supply for the bottling tables with which it was connected. Thus the machine was automatic and continuous working in its operation. The success attending the use of this pump induced the Company to put in several larger machines, of the same sort as their business increased. As a result of the experiences in the operation of the apparatus described in this part of the paper, several slight modifications might be made if new ones were to be constructed, but is fair to observe that in practical working the results have been on the whole very satisfactory.

The writer wishes to acknowledge the courtesy of the Manitou Mineral Water Company in assenting to the publication of many details pertaining to the successful operation of this business.

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Sodium Sulphate	1.367
Sodium Carbonate	5.326
Lithium "	.077
Calcium "	8.667
Magnesium "	2.005
Iron Oxide	.003
Alumina	.013
Silica	.308
Total	21.984