CHURCH

Trans-A I M E., Vol. VII, pp 45-76



THE

# HEAT OF THE COMSTOCK MINES.

BY

JOHN A. CHURCH, E. M.,

PROFESSOR OF MINING IN THE OHIO STATE UNIVERSITY, COLUMBUS, OHIO.

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PRESENTED TO THE AMERICAN INSTITUTE OF MINING ENGINEERS AT THE CHATTANOOGA MEETING, MAY, 1878, BY PERMISSION OF LIEUT. GEORGE M. WHEELER, CORPS OF ENGINEERS, U. S. A., IN CHARGE OF U. S. GEOGRAPHICAL AND GEOLOGICAL SURVEYS WEST OF THE ONE HUNDREDTH MERIDIAN.

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[TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

# *THE HEAT OF THE COMSTOCK MINES.*

BY PROF. JOHN A. CHURCH, E.M., COLUMBUS, OHIO.

(Read at the Chattanooga Meeting, May, 1878, by permission of Lieut. Geo. M. Wheeler, Corps of Engineers, U. S. A., in charge of U. S. Geographical and Geological Surveys, west of the 100th meridian.)

ONE of the most striking phenomena connected with the mines on the Comstock lode is the extreme heat encountered in the lower levels. This heat is not due to the burning of candles, heat of the men, and decomposition of timbers, all intensified by bad ventilation, as was the case nearer the surface. It proceeds from the rock, which maintains constantly a temperature very much higher than the average of the atmosphere in Nevada.

The heat of these mines is a matter of more than usual interest, for they are the only hot ones now worked in the United States, and both in the present temperature encountered and in the increase which is to be expected as greater depths are reached, they appear to surpass any foreign mines of which we have a record.

Hot mines are known also in other countries, as in the tin and copper lodes of Wales, where one of the veins worked by the United Mines is known as *the* hot lode. It has springs which discharge water at a temperature of 116° Fahrenheit, the depth being 220 fathoms, or 1320 feet. The heat of the air in these workings is given at 100° to 113° Fahrenheit. The air is bad, and the heat in the drifts seems to be traceable to defective ventilation rather than to the real necessities of the case. Air is supplied through a small pipe, and is drawn from a place where the temperature is 95° Fahrenheit. Under such circumstances it is not surprising to read that in this hot mine the air is hotter than the rock, a state of things which I have never observed in the Comstock. Other mines have been reported to the British Coal Committee as having temperatures of 106° Fahrenheit and thereabouts, but the only positive comparisons that are available at this writing are the following, all from Cornish mines:

| Mine. | Depth in feet. | Temperature. Air. | Rock. |
|---|---|---|---|
| Tresaveau, | 1584 | 86° | 83° to 85° |
| Consolidated Mines, | 1500 | 87° | 86° |
| " " | 1722 | 94° | 93° |
| " " | 1764 | 94° to 96° | 92½° to 93½° |

These high temperatures appear to be partly due to the usual sources of heat in mines, and partly to chemical action in the rock, for the average depth in which the heat rises one degree Fahrenheit from the surface downward varies with the ground. It is given by Mr. W. S. Henwood as follows:

| | |
|---|---|
| In granite, | 51 feet. |
| In slate, | 37.2 " |
| In cross veins, | 40.8 " |
| In lodes, | 40.2 " |
| In tin lodes, | 40.8 " |
| In tin and copper lodes, | 39.6 " |
| In copper lodes, | 38.4 " |

The copper-bearing lodes are therefore the hottest, and in Cornwall heated ground is thought to be a good indication of copper, just as hot ground is looked upon in the Comstock mines as a favorable sign of ore.

## TEMPERATURE IN THE COMSTOCK MINES.

The rock in the lower levels of the Comstock mines appears to have a pretty uniform temperature of 130° Fahrenheit. This was the reading obtained for me on several occasions by Mr. Comstock, foreman of the Ophir mine, and about the same temperature was found by Mr. Perrin, foreman of the Chollar Potosi, Mr. Cosgrove, foreman of the Yellow Jacket ($139\frac{1}{2}$° F. and 136° F.), and by myself in the Crown Point and other mines.

These readings were obtained by placing a thermometer in a drill-hole immediately after the hole was finished, and leaving it there for periods varying from ten minutes to half an hour. Very little or no difference was discovered between holes which were drilled wet or dry, or if wet, between holes which were naturally wet, and those which were made so artificially. No doubt there must be some difference due to these varying conditions, but they are so slight as to be completely masked by the steady flow of heat from the rock during the exposure of the thermometer.

The holes in which the thermometers were placed were not sunk especially for this work of testing, but were the ordinary drill-holes made for the purpose of blasting the rock. They varied therefore from about ten inches to three feet in depth.

No variations in the height of the thermometer were found to be caused by this difference of depth, and this also is quite reasonable.

Mining on the Comstock proceeds with extraordinary rapidity. The drifts are advanced steadily at the rate of three, five, and sometimes even eight and ten feet a day, and therefore the ground in which the miners are working is always fresh ground. The low conductivity of minerals to heat forbids the supposition that a rock of 130° Fahrenheit temperature can lose heat sensibly to any depth in the course of twenty-four hours. The shallow holes which were made use of always lay in new ground, and exhibited results which may be accepted with as much confidence as if they were twenty feet or more deep. Very often they were in ground which had been exposed only one or two hours, having been sunk immediately after a blast which threw off four or five feet of the rock. The surface which was thus thrown down had not been exposed more than twenty-four hours. The high temperature and small flow of air in the heading forbid the supposition that any sensible diminution of heat could have taken place at the bottom of the drill-hole under such circumstances. The surface of the rock exposed to the air of the drift was found to be about 123° Fahrenheit, the experiment being made near the "header" or end of the drift. The air itself was found to show considerable uniformity when its temperature was taken under circumstances that were at all similar. In freshly opened ground it varied from 108° to 116° Fahrenheit, and higher temperatures are reported at various points, reaching in fact as high as 123° Fahrenheit in the 1900 level of the Gould & Curry.

The temperature of the air is subject to more fluctuations than that of the rock, for the simple reason that it is artificially supplied to the mine, and varies according to the distance to which it is carried, the quantity, velocity in the pipe, and its initial temperature. All of these elements of the problem vary within wide limits. The initial temperature of the air which supplies a particular drift will, for instance, depend upon whether it is drawn from the surface, the bottom of a shaft, where it is often cooler than above ground, or from some old air-way, where it has had time and opportunity to take up heat.

Nevertheless, even under such variable circumstances as these, the temperature of the air in a new drift does not ordinarily vary much more than eight degrees, and in this variation the length of the drift appears to be the most important factor.

This uniformity of temperature, under such changing conditions is due to the well-known fact that the amount of heat absorbed from the walls of a drift or shaft in a mine depends upon the difference in the initial temperature of the air and rock. The greater this difference, the greater is the absorption, but as soon as the temperature of the air-current approaches that of the rock, the heat absorption proceeds much more slowly.

In the Comstock mines it is the custom, without exception, to blow the air through galvanized iron pipes, the diameter of which is usually from eight to twenty inches. The size most used is eleven inches in diameter, and the usual amount of air blown is about seven hundred cubic feet per minute, this being the supply for two to six or more men, working in one or two "headers."

In most cases the air is not sent down from the surface, but taken from some point in the incline or at the bottom of the shaft. Its temperature may be assumed at about 85° or 90° F. in summer, though it is sometimes higher than this. Its velocity in the air-pipe is not very far from one thousand feet per minute. From these data it will be seen that we have about fifteen or twenty degrees of heat added to the air, in a period of time varying from one-half minute to two minutes. The iron of the pipe is so thin and its conductivity so great that we practically have a slender current of air moving through a body of hotter air. Even this statement of the case does not exhibit all the opportunities for absorbing heat which are forced upon the air.

The iron receives heat both by immersion in the hot air, and by direct radiation from the still hotter walls. The currents confined in it must be thrown against its sides by eddies, and the air is thus made to absorb heat by contact as well as by the transmission of heat rays through it. It is probably to this cause that the uniformity of the air temperatures obtained at the headers may be attributed. They depend almost entirely on the heat of the ground there and very little upon the temperature of the air at the point of supply.

Drifts that do not exceed two or three hundred feet in length are *usually* not above 110° or 112° F. in temperature and more often they are below this. But when the length increases to 1200 and 1500 feet the temperature may rise to 116° F. without any other change in the circumstances.

So far as my personal experience goes, the latter temperature has not been exceeded in any drift into which a good current of air is blown. By a "good current," I mean one of not less than seven hundred or one thousand cubic feet a minute. Still there is no hesitation in asserting my confidence in the higher temperatures which others have sometimes obtained. The view which I take of the phenomenon and its cause admits of such exceptional heat at particular points as a rational consequence of the forces at work. But I regard them as exceptional, and believe the average temperature of those drifts which are considered to be distinctively "hot," is usually not above 108° to 112° F., though rising to 116° F., when they are very long.

These limits are, however, not in the least degree true of the water which enters the drifts from the country rock, and also from the lode rocks. That approaches more nearly 150° Fahrenheit. The vast body of water which has filled the Savage and Hale & Norcross mines for more than a year, and from which it is safe to say a million tons of water have been pumped within twelve months, gave me a temperature of 154° Fahrenheit. Even after being pumped to the surface through an iron pipe exposed, in the shaft of the Hale & Norcross, to a descending current of fresh air for more than a thousand feet, and then flowing for one or two hundred feet through an open sluice in a drain-tunnel which discharges into a measuring-box, the water in this box was found to have a temperature of no less than 145° Fahrenheit.

But the water varies in temperature in different parts of the lode, like the rock and the air. In the East crosscut 2000 foot level, of the Crown Point Mine, which is noted for its extreme heat, the water, after flowing for nearly one hundred and fifty feet over the bottom of the drift, was found to have a temperature of 157° Fahrenheit. On the contrary, in other places the water is much less hot, but I believe it is as a rule always hotter than the air, and in many cases it appears to be hotter than the rock is found to be, except in especially hot spots.

## HOT AND COLD BELTS.

In giving this short description of this remarkable phenomenon, the fact has frequently been referred to that there are points in the mines which are much hotter than the average. The East crosscut of the Crown Point 2000 foot level, which was temporarily abandoned and boarded up on account of the heat, gave me an *air* temperature of 150° Fahrenheit, the thermometer being thrust through a crack in the boarding. I felt convinced that at the head of this crosscut the heat must be higher than this, and Mr. Balch, foreman of the mine, informed me that it had been proved so.

Another hot spot is in the Imperial Consolidated Mine. The incline there has always been very hot, and near the bottom, above the sump, but under the shoot, a position which allows of no ventilation, except that which is induced by local air-currents, the air must stand at 130° Fahrenheit or higher, though I did not test it. In this mine the Black Dyke splits, sending a shoot off to the northeast, and a drift has been run on the two thousand foot level, along the eastern side of this branch dyke.

This proved to be a very hot spot indeed. Rock, air, and water were all so much above the usual limits of temperature even in these hot mines that the work of cutting the drift must have been extremely severe. It might not have been accomplished if the expedient had not been adopted of boarding or "lagging" up the sides of the drift with a double thickness of plank, breaking joints. This confined the water, which poured down the walls, to a tight chamber, and left the main part of the drift for the men to work in with comparative comfort. The lagging remains, and has been carried around into the main drift, which is still in active use. Its joints are calked with tow, and, one of these being stripped for me, the steam from the water immediately poured out and proved to be scalding-hot when tested by the finger. I did not, however, succeed in getting a fair reading of the thermometer, because the crack was too small to admit more than the end of the bulb. The thermometer must have been cooled by the evaporation of condensed moisture from its bulb; but, even under these adverse circumstances, the temperature of the stream was taken at 123°.

The Belcher south incline has a hot belt of rock, quite narrow, a short distance above the nineteen hundred station, and similar hot places are found in most of the mines.

I am inclined to the opinion that, as a general rule, these hot areas lie in belts, and are not irregular or promiscuously placed in the mass of East country rock. Where this seems to be disproved by the distance run in the superheated rock, it will probably be found that the drift, or incline, and the hot belt have the same direction.

It is noticeable that the neighborhood of a dyke is apt to be hotter than any other portion of the rock. An example of this has already been given in the Imperial Consolidated Mine, where a drift run immediately east of a branch dyke is still wet and intensely hot, although opened for about two years. The incline of this mine, which is very hot, is also quite near the Black Dyke.

But nearness to the Black Dyke is also a characteristic of most inclined shafts on the lode. Some are west of it; some in it for long distances; others east of it. These inclines do not all exhibit greater heat than the average of the mines, and there must be some special reason for the heat of the Imperial Consolidated incline, which was referred to above.

Hot belts are also found at the contact of the diorite and propylite in the Virginia mines. The diorite is itself in active decomposition, and mines which have carried drifts in or near it are very hot. The Julia has explored a quartz seam, which appears to lie entirely in the diorite, and this has proved to be one of the hot belts.

This apparent concentration of the heat in the line of contact of two rocks is not supposed to be due to any thermal or electro-thermal action, but to depend merely upon the fact that in this neighborhood the ground is more broken and the surfaces of the rock increased. These conditions are obviously favorable to the action of atmospheric waters.

Belts of excessively hot ground are not the only noticeable phenomena in these mines. More remarkable still are the belts of unusually *cold* rock. These are fewer in number than the hot belts, but they are strongly marked. They are always wet, and the water that drips through the crevices of the shattered rock that composes them is noticeably cold to the touch, and cools down the air of the drift. Such a wet, cold belt of rock exists on the eight hundred foot level of the Justice Mine, and there is a very decided change of temperature in passing from one to the other side of it. Lest the low temperature of this spot should be attributed to the water which drains through it from the surface, it is well to add that water drips from the rock in numerous places in these as in most mines, and that usually it is hot, or at least warm.

Other cold belts are found in the mines which are not so cool as that in the Justice, but are perceptibly cooler than the rock at a short distance from them. They complete a well-linked chain of heat phenomena, extending from rocks that are sensibly cold to the touch, and may not have a temperature above 50° or 60° Fahrenheit, through rocks that have the average atmospheric temperature, and those which are as hot as surface rocks ever become in Nevada, to those which have a temperature of 157° Fahrenheit. There is no reason to doubt that the gradation is quite regular, and the transition from the lower to the higher temperature is made through a much larger series of intermediate steps than the accidental thermometer readings taken show.

Finally, in the chain of testimony relating to this phenomenon is to be noted the condition of the rock. Wet places have been spoken of, but the rock cannot be considered as generally wet. There are water-ways, and many of them appear to reach the surface, but they are of limited breadth, like the belts of hot rock. This water is usually hot, but sometimes cool or tepid.

Very often, usually in fact, the rock is perfectly dry, though very hot. That is the case in all the mines. Wet rock is the exception, and dry rock the rule, through the whole lode. In the drifts cut through this hot, dry rock, the walls of the freshly exposed surfaces are painful to the hand, and the air is often filled with dust. The rock is both hard and tough, but, in spite of its strength, it gives an impression of fine porosity to the touch, due probably to its trachytic character. It often has the odor of clay, but not always. It may be slightly adherent, or the impression of dryness upon the tongue may be due to its heat, or to the fine dust which covers every fragment.

## SOURCE OF THE HEAT.

Wherever eruptive or plutonic rocks are found it is quite common to witness evidence, in the breaking out of hot springs, that heat agencies are still active within them, and this phenomenon is so frequently observed that hot springs are often referred to as the last phase of eruptive activity. The heat in the Comstock and other mines similarly situated is quite generally spoken of, for instance, as the feeble remnant of a temperature that once reached the point of rock fusion, but the facts encountered have compelled me to seek another explanation. It is impossible to assemble in an annual report all the data upon which this conclusion is based, but many of them will be given. They have led me to refer the high temperatures encountered in the mines not to the internal heat of the earth, nor to the residual heat of the rocks, which were once melted, but to chemical action now maintained in the erupted rocks.

This action is not a combustion, for the oxidizable minerals in the lode and its accompanying rocks, the metallic sulphides, are little altered. In fact, the total quantity of pyrite and other sulphides is not large for the neighborhood of a mineral lode, but on the contrary, strikingly small, and not sufficient to maintain the heat of the rocks and water, except under circumstances of unusually rapid oxidation. That no metallic oxidation of any moment goes on in these rocks is susceptible of proof. The metallic sulphurets in the rock show little sign of decomposition, and this is true even in layers of the propylite, that are fissured and seamy and drenched with water, whether hot or cold. In fact, the preservation of the sulphur compounds, in presence of so much heat and moisture, is a noticeable fact, which I have frequently remarked in all the mines.

An examination of such analyses of the mine waters as I am able to find confirms this statement. In the geological view of the Comstock lode which Mr. King has prefixed to the third volume of the report on the Fortieth Parallel survey, an analysis of water taken from the Savage 600 level is given. This is compared in the following table with other analyses recently published in the Virginia newspapers:

*Analyses of Water from the Comstock Vein, taken at Different Levels.*

| | Savage. 600 ft. Grains per gallon. | Gould & Curry. 1700 ft. Grains per gallon. | Gould & Curry. 1800 ft. Grains per gallon. | Hale & Norcross. Grains per gallon. |
|---|---|---|---|---|
| Silica | 1.77 | 2.21 | 4.025 | 3.500 |
| Sodic chloride | 0.13 | 0.04 | 1.162 | 1.327 |
| Calcic sulphate | 29.40 | 14.35 | 16.683 | 22.532 |
| Magnesic sulphate | 1.77 | ........ | ........ | ........ |
| Sodic carbonate | 0.91 | ........ | ........ | 18.518 |
| Potassic carbonate | 7.56 | 6.42 | 26.199 | 8.342 |
| Magnesic carbonate | 2.98 | ........ | ........ | ........ |
| Alumina and Ferric oxide | 0.05 | trace. | trace. | trace. |

This table shows that the source of the heat cannot be the decomposition of a metallic sulphide like pyrite, for the resulting sulphate would be highly soluble, and the water would be much stronger in sulphuric acid. It is true that sulphuric acid enters more largely into the analysis than any other acid, but even if this is derived entirely from the decomposition of pyrite, the quantity is entirely insufficient to account for the effects. The Hale & Norcross water, for instance, contains only 54,219 grains of solid matter to the gallon of water weighing 58,373 grains, or less than a tenth of one per cent. Of this solid matter only five and a third grains are sulphur, and this quantity corresponds to a little less than eleven grains of pyrite, containing, say 5.3 grains sulphur to 5.2 grains iron.

If these substances were not in combination, the iron and sulphur in oxidizing would give out heat enough to raise 42,462 grains of water one degree Fahrenheit in temperature, or the heat given out

2

would be sufficient to raise 408 grains of water from 50° F. (the assumed temperature of surface water) to 154° F., the temperature of this great body of water. This calculation omits the loss of heat which would be suffered by the breaking up of the combination of iron and sulphur, as they exist in pyrite. It is only an approximation, but it shows clearly that the oxidation of the iron and sulphur accounts for less than $\frac{1}{143}$d of the heat present in this water.

It is true that the analyses given do not account for the portion of calcic sulphate which has been deposited as an insoluble precipitate in the crevices of the rock. Gypsum is present everywhere, in fact, in and out of the vein, but its quantity is quite limited in the lower levels, and considered as the cumulative result of many centuries of activity, it affords additional proof that the oxidation of the pyrite has been very small in amount.

### AMOUNT OF HEAT WITHDRAWN FROM THE ROCKS.

The quantity of water pumped from the mines the past year must have been as much as 350,000 or 400,000 tons a month. If its temperature is assumed to be only 135° Fahrenheit, and the average temperature of the air for the year 50° Fahrenheit, we have in the year, say $350,000 \times 12 = 4,200,000$ tons of water raised eighty-five degrees in temperature; or as the usual expression is, $4,200,000 \times 85 = 357,000,000$ ton-heat units have been absorbed by the water. If the heating power of anthracite coal is estimated at 7500 heat units to the ton, the heat in this water is as much as would be obtained from the combustion of 47,700 tons of coal. A cord of pine wood weighing 2700 pounds, will probably give about 4300 heat units in practice, so that 84,000 cords would be necessary to keep up the heat withdrawn from the rocks in the mine waters alone.

If ten tons of air pass through the mines collectively each minute, or 14,400 tons daily, and the air when discharged from the mines has an average temperature of 92° Fahrenheit, the total quantity of air for the year will be 5,256,000 tons, and the average rise in temperature 42 degrees. The specific heat of air being 0.267, we have $5,256,000 \times 0.267 \times 42 = 58,940,784$ ton-heat units for the amount of heat absorbed by the air. This corresponds to an expenditure of 7859 tons of anthracite coal, or 13,707 cords of wood. The total quantity of heat carried out of the mines yearly by the water and air is therefore 416,000,000 ton-heat units, to produce which, in ordinary industrial operations, would require 55,560 tons of anthracite, or 97,700 cords of wood.

The number of men employed under ground in the mines of the upper Comstock is less than three thousand, and the heat from their bodies, together with that produced by the burning of the large numbers of candles, could not account for any considerable proportion of this heat. Indeed, it may be assumed, in the absence of calculations, that all the heat from these and other ordinary sources of heat in mines is no more than sufficient to compensate for the large amount of refrigeration produced by the liberation of the compressed air which is employed in every mine to work numerous underground machines. This heat absorption has not been taken into account in the above calculations.

In another respect, also, these calculations are defective and give results very much too low. Usually the air enters the mine dry and leaves it saturated with moisture, the evaporation of which indicates an amount of heat absorption, which would probably increase the above figures surprisingly.

These calculations, imperfect as they are, show that the source of the heat is one that acts on a magnificent scale, and also that it cannot reside in the small quantity of pyrite which is oxidized. That source is probably the chemical alteration of the feldspathic minerals of the propylite and other rocks. This change consists apparently in the process of transforming feldspar to clay, technically known as kaolinization, from the fact that china clay, or *kaolin*, is produced in this way. Numerous zones in which this process of alteration has gone so far as to produce complete disintegration of the rock are passed in drifts cut into the country rock on both sides of the lode. No analyses of this decomposed material are at hand; those which have been published always being made upon the clays of the lode itself, where the introduction of silica in large quantities has necessarily exerted a dominating influence upon all alterative processes. In the absence of such analyses, it is impossible to say whether the decomposition that has taken place to such a marked extent at a distance from the quartzes, owes any of its force to the special solfataric action to which the filling of the lode may be ascribed, or whether more general agencies have been sufficient to produce the observed effects. Nor can it be declared without such a critical analytic examination, that this great mass of heated rock, extending for miles in length and breadth, and for thousands of feet in depth, has passed through ages of drainage from the surface without undergoing some general change in its chemical structure.

On the contrary I assume that alterative action has gone on throughout portions of these rocks, and is still in progress. The usual explanation for the heat which is found to exist in eruptive rocks in so many districts, namely, that it is the last manifestation of the heat which formerly fused the rocks, is rejected because of the persistence with which the supply of heat is maintained under circumstances that make extraordinary drafts upon it. From data previously given, it will have been noticed that the mines receive about ten tons of air per minute, and raise its temperature from 50° Fahrenheit, which I suppose to be about the yearly average of the atmosphere at Virginia and Gold Hill, to about 92°. This represents a constant abstraction of heat from the rock, amounting to no less than 161,482 ton-heat units daily, corresponding to the combustion of thirty-seven cords of wood. The real quantity is probably at least ten per cent. greater than this, the difference being represented by the vaporization of moisture in the downward course of the air.

Fortunately for the purposes of this survey, Captain T. G. Taylor, superintendent of the Yellow Jacket mine, has caused observations to be taken for several months on the temperature of the air current in different parts of that mine. By noting the increase of heat and the amount of air flowing through the drifts, I have been able to obtain an approximate estimate of the amount of heat drawn from the rock surfaces. It is approximate only, because the records of surface temperatures for several months were accidentally destroyed, and I was compelled to replace them from the careful records taken by Mr. B. Gilman, of the Chollar Potosi mine, which is in Virginia, and has a higher position and a different exposure from the Yellow Jacket. The present calculations are presented merely to show that these observations contain trustworthy evidence that the heat taken up by the air cannot be derived from deep sources, by transmission through the rocks, nor from a magazine of heat lying dormant in the strata.

The Yellow Jacket is a downcast mine, and the air current passes down the vertical shaft to the 1119-foot level, thence down the incline to the 1732 level, through a drift to the south winze, and thence down this winze to the 2200 level, the bottom of the mine. On its way from the 1732 it sends a current through the 1935 and 2040 levels, these currents being reunited in the north winze, which is the upcast. The north winze does not reach to the surface, and no air rises to day in the mine, the entire current flowing into the Imperial and Bullion mines, both north of the Yellow Jacket, and both of them exclusively upcast.

Captain Taylor has placed Fahrenheit thermometers of the common kind, with japanned tin cases, at the surface, foot of the vertical shaft (1119 level), 1732 south and north winzes, 1935 north winze, and 2040 south and north winzes. The observations obtained are extremely suggestive, the plan of the mine being such as to eliminate complications from the single problem of heat absorption by moving currents of air from rock surfaces. From the 1531 level two parallel winzes are sunk on the lode, inclining with it. They are four hundred and thirteen feet apart, and connected on every lower level by the main north and south drift. The south winze is downcast, and the thermometers placed here on the different levels measure the increase of heat in the winze itself, while those which are hung at the north winze measure the increase of heat which each "split" of air gains in moving through 413 feet of drift, that being the distance between the winzes. This fortunate arrangement of the ventilative currents presents the most favorable opportunity I have ever observed for studying the problems involved. The thermometers should be replaced with standard instruments, and the air current measured twice a week for a year, in each drift. The result would be the best series of observations obtainable, probably in any American mine, for the comparative shortness of the paths followed by the air when contrasted with the long drifts of some coal mines, is compensated for by the high temperature of the rocks, and the marked increase of heat in the air.

Before giving the table of results obtained during the first half of 1877, it is necessary to say that they are merely tentative. The destruction of the surface readings and the absence of good standard instruments forbid the acceptance of the results as perfectly accurate indications of the heat absorption. Only two of the monthly records which were taken—those for May and June—refer entirely to this mine, the surface readings of these having been preserved. The irregularity due to the introduction of surface temperatures does not, however, affect the underground readings, but merely makes it impossible to correctly gauge the absorption of heat in the vertical shaft. The gain of heat, after the foot of the vertical shaft is passed, is fully given for the whole six months, the records in the lower levels being continuous from that point.

The air-current entering the mine July 2d, 1877, was measured and found to be 18,140 cubic feet. On the 1732 level the "split" or secondary air-current was found to contain 7200 cubic feet, and for the purpose of illustrating the steady flow of heat from the rock, we may reasonably assume that 18,000 cubic feet of air enter the mine every minute, and that this current is divided into three splits of 6000 cubic feet each, which pass from the south winze 413 feet to the north winze, on each of the three levels, 1732, 1935, and 2040. The second of these is out of consideration, from the fact that there is only one thermometer on it, so that no comparison of the initial and final temperatures can be made. From the average temperatures given above we find that the gain on the two other levels was:

| | |
|---|---|
| 1732 foot level, . . . . . . . . . | 10.56° F. |
| 2040 " " . . . . . . . . . | 7.87° F. |

Six thousand cubic feet of air weigh nearly 400 pounds avoirdupois, and the amount of heat absorbed in travelling 413 feet through the drift is:

| | |
|---|---|
| In the 1732 level, . . . | 1128 pounds Fahrenheit heat units. |
| " 2040 " . . . | 840 " " " " |

As one pound of anthracite has been assumed to produce 7500 heat units, and one pound of wood 3185 heat units, the heating power of these two drifts is per minute,

| | |
|---|---|
| For the 1732 foot level, . . | 0.150 lbs. coal, or 0.353 lbs. wood. |
| " 2040 " " . . | 0.112 " " 0.264 " " |

The reason for the different absorption in the two levels is that the initial temperature of the air in the drifts increases from 78.20° at the 1732 level, to 85.96° on the 2040, by its journey of about 520 feet in the winze connecting the two levels. The absorption of heat by a moving current of air is known to vary with the difference in temperature of the air and the rock surface. The nearer these approach each other in temperature, the less is the heat absorption.

The most conclusive evidence that the incessant drain of heat cannot be maintained by a constant store accumulated in the rock is supplied by the 1732 level. The exact date at which the drift connecting the two winzes on this level was finished, is not in my possession, but as the station in the main incline was completed in July, 1874, it is fair to conclude that the drift was cut through by the end of 1875. This would give one year's exposure of the rock surfaces by January, 1877, the date when the thermometer readings were begun. The quantity of air flowing through is assumed to be 6000 cubic feet, as in the previous calculations. The gain of heat under these circumstances was as follows, in degrees Fahrenheit and monthly averages:

YELLOW JACKET MINE, 1732 FOOT LEVEL, 1877.

| | South Winze. | North Winze. | Gain. |
|---|---|---|---|
| January, | 75.62 | 86.50 | 10.88 |
| February, | 76.85 | 83.87 | 7.02 |
| March, | 76.10 | 88.89 | 12.79 |
| April, | 77.48 | 88.23 | 10.75 |
| May, | 81.42 | 91.11 | 9.69 |
| June, | 79.39 | 91.62 | 12 23 |
| Average for six months, | | | 10.56 |

As before shown, the heat absorption amounts to 1128 pound heat units per minute, which corresponds to the heat from 0.15 pound of coal per minute, or 216 pounds in twenty-four hours.

In this drift then, with an average age of at least a year and a quarter, the rock surface gives out as much heat as would be obtained from coal fires, placed at distances of 100 feet, the whole length of the drift, and each burning 52.3 pounds of coal daily. Only one candle burns constantly in the drift, and the travel does not amount to more than two hundred trips of one man in one direction in twenty-four hours. The effect of this travel is limited to the change of shifts and the transport of rock and timber, both of which are concentrated in short spaces of time. A hoisting-engine in the winze uses about 9000 cubic feet of compressed air daily, at fifty pounds pressure, which is quite sufficient to neutralize all the heat that can be obtained from the transitory presence of men in the drift. To further show how completely this source of heat may be neglected, it is enough to say that only the morning observation, at 6 A.M., is made at or near the time of this travel.

In other respects I have not observed any circumstances which throw serious doubt upon the thermometer readings. The instruments are not standards, it is true, but they are properly hung on timbers, and usually with ten or twelve inches of wood or air between them and the rock surface. Whenever compared with one of the Survey thermometers, hung in the centre of the moving air-current, they have not shown a variation of more than one degree. The daily readings are quite uniform, the fluctuations of more than one degree not exceeding 23 in a series of about 360 observations. The highest fluctuation noticed is three degrees.

There can be no doubt that the discharge of heat is real, that this heat is constantly removed by the air, and that it comes from the rock. When we regard the two main hypotheses which have been trusted to explain the high temperature so often noticed in volcanic rocks, namely, internal heat of the earth, and residual heat stored up in the rock mass, it is difficult to understand how either of these sources can maintain this enormous discharge of heat for years. The circumference of the drift is about twenty-eight feet, outside of timbers, the dimensions being six feet six inches at bottom, five feet six inches at top, and eight feet high, when the timbers are twelve inches thick. The area of the walls is therefore $413 \times 28$, or 11,464 square feet, and the heat radiation amounts to 142 pound units per square foot in twenty-four hours.

Experiments have been made to ascertain the radiation of heat from a blast furnace smelting iron ores. Its walls were probably less than five feet thick, and within the furnace a furious fire, producing an average temperature, in the upper part of the furnace, of probably 1200° Fahrenheit, was constantly maintained, and under these circumstances the radiation in twenty-four hours was ascertained to be about 145 Fahrenheit pound-units of heat per square foot per hour, or 3450 per twenty-four hours. The heat, as constantly given out by the walls of this drift, is therefore nearly four per cent. of that which the furnace walls radiated. Considering the long exposure of the rock—for one year—and the unremitted removal of heat, it seems incredible that a definite store of heat placed in the volcanic mass, once for all, could furnish the necessary supply. The amount of heat transmitted is inversely as the distance between the source and the point at which it is discharged, so that with a definite store of heat the rock near the drift would cool rapidly, and a layer of cooled rock would be established in a few years which could not give passage to the amount of heat that experiment shows to be constantly given off even in levels that have been open and well ventilated for five years and more. It is on such considerations and facts that I base the suggestion advanced in this report, that the supply of heat is constantly maintained by chemical action of some kind. There is only one kind of chemical action that is known to have gone on to any considerable extent in the Comstock rocks, and that is the alteration of feldspar to kaolin.

The facts here given are held to indicate that this extensive alteration is still in progress.

Even if this conclusion is granted, it still remains to show how the heat produced by this alteration can be poured into the drifts in such quantities. There is good evidence that the chemical action is not confined to the surfaces of the mine openings, for in that case the rock would necessarily flake off and swell in consequence of its superficial alteration. This takes place to a considerable extent, but not enough to account for more than a small portion of the heat, and there are extensive areas where the drifts remain for years without any visible sign of decomposition in the rocks. The principal part of the chemical action must take place in the body of the rock mass, and it is evidently necessary to find some means for the constant conveyance of the heat produced to the artificial openings.

The vehicle for the conveyance of this heat I conceive to be gaseous currents, heated by the chemical action spoken of, penetrating the rocks in every direction, and tending to discharge themselves into any free channel, like a drift, opened in the ground. The source of this gas is primarily the atmosphere. Water is capable of absorbing 0.025 of its own volume of nitrogen, 0.046 of oxygen, and its own volume of carbonic anhydride at the ordinary atmospheric pressure. At a higher pressure the absorption is greater, and as the water in the rocks two thousand feet below the surface is under a considerable hydrostatic head, it probably contains a maximum quantity of gas.

The fixation of this water in the solid form, by combination with the silicate of alumina, necessarily liberates the gas it has dissolved, and this gas must then seek to discharge itself at the only point that is free under natural conditions,—the surface. On its way upward it continually meets fresh supplies of water, and is reabsorbed until the water becomes saturated. As the water would always carry down carbonic anhydride and air derived from meteoric sources, there would be additions at every rainfall to the store of gas in the strata, and the cumulative results of years of this action must be the saturation of the rocks with gas, so that whatever is liberated by the solidification of the water will find no place to rest without pushing out some of the gas already held so abundantly in the interstices of the rocks. From the point where this chemical alteration of the feldspar takes place there must be a discharge of gas at least equal in quantity to the rainfall which reaches that depth, and this stream of hot gas will take its way to the surface and maintain the heat lost by radiation from the rocks through which it passes.

Though rocks readily yield passage to vapors and gases when dry, the contrary is true when they are wet; then the pores filled with water are closed to the gases. On the Comstock we find areas of wet and dry rock disposed in highly inclined sheets, of which the dry greatly preponderate in thickness, forming, indeed, the main mass of propylite, in which the wet portions stand as isolated layers. Both are heated, and to an equal degree, or at all events the experiments hitherto made have not been careful enough to ascertain any variation, but in the higher heat of the mine waters we may possibly have evidence of some wet bands that maintain a temperature excessively high even for the Comstock.

It is quite possible that the wet layers serve as channels to carry down a reagent, water, which produces heat by chemical combination in the lower depths, and the dry rocks serve to transmit to the surface the gases liberated from the combining water, and bringing the resultant heat with them. Thus the wet rocks are heated by decomposition in place, and the dry rock by the passage of hot gases from that decomposition.

It is, therefore, conceivable that the rapid flow of heat into the drifts is caused by streams of hot gas filtering readily through the porous rock, under the pressure to which it must be subjected, as a consequence of its deep subterranean position. These gaseous currents do not make themselves evident to the senses over the ordinary surfaces of drifts, but they frequently pour out of drill-holes with strength sufficient to flare a candle-flame. "Blowers" of gas are met with, but not with more than usual frequency in mining operations. Accumulations of choke-damp in old drifts are common, though perhaps not more so than in all mines. The mine waters evidently contain gas, which bubbles through them, and sometimes in quantity sufficient to produce a moderate boiling.

None of the analyses quoted above give the amount of carbonic anhydride present in the mine waters, but there are evidences that it must be dissolved in considerable quantities. All water-channels in the mines fill up with a reddish powder, caking but slightly, and sometimes nearly filling conduits that are placed at a considerable distance from the source of the water. In the absence of analysis, this may be assumed to be composed mainly of alumina, lime, iron, and silica, precipitated by the evaporation of the gaseous carbonic anhydride, which is recognized as a powerful agent for the solution of these substances in water. Similar depositions occur in other mines from this cause, and they indicate decomposition of the neighboring rocks.

The presence of such gas currents affords another explanation of the hot spots observed in the mines. In discussing this phenomenon it was observed that these places lay in belts of rock that are peculiarly susceptible to decomposition, but if the rocks are permeated by currents of hot gas, it is evident that those portions which are most fissured will give the most ready means of exit to the gas, and therefore be kept at the highest temperature. Such may be the true cause of the high heat observed in the Imperial incline, lying along the Black Dyke, which is not everywhere exceptionally hot; and also in the Northeast drift, on the 2001 level of the same mine, which is run along a branch dyke. The Black Dyke appears to be, on the whole, less susceptible to decomposition than the rocks which inclose it, but it is frequently accompanied by highly fissured rocks some feet in thickness, a phenomenon common to eruptive dykes. A thin and unimportant seam of quartz is also found at many points in its course, which indicates the presence of a previous crevice, or broken ground. These conditions evidently are favorable to the free passage of currents either of gas or water.

Such currents of gas do not account for the cold belts of rock, which are not dense, but, in every case noticed, fissured and wet, and it is probable that both the causes here advanced—local decomposition of different intensities and gaseous currents—are in action.

It is to be regretted that the casual and frequently intermitted observations upon heat, which were all that the pressure of other duties permitted me, were not so calculated as to take advantage of the accurate results obtained by Sir William Thomson, from Professor Forbes's observations in the trap rock of Calton Hill, Edinburgh. He found that if a plate of this material, one foot thick, had one side kept at a temperature constantly one degree hotter than the other side, the heat which would pass through it, in one year, would be sufficient to raise 144.1 cubic foot of water one degree in temperature; or, 0.3863 cubic feet in twenty-four hours. But the amount of heat transmitted varies as the thickness of the plate, and it would be necessary to ascertain accurately the heat at different depths, in the same locality, before the true rate of transmission in the Comstock drifts could be settled. Only one observation of the surface temperature in a drift was made. With a temperature of 136° F., in a drill-hole bored in the freshly exposed rock of the heading, and an air temperature of $110\frac{1}{2}°$ F., in the drift, a thermometer laid on a projecting point of the wall, fifteen or twenty feet from the heading, showed 123° F. This surface must have been about four days old. The reading gives a certain amount of precision to the expression of a fact well known to the miners,—that the rock cools rapidly in the first few days of exposure.

But while the observations made in these mines are neither exact enough nor complete enough to permit general deductions on the basis of Sir William Thomson's formulæ, it is possible to make sufficient use of them to demonstrate the fact that transmission alone cannot produce the results observed. Between the 2200 and the 1732 levels of the Yellow Jacket mine there lies a stratum of rock 468 feet thick. Its lower surface is constantly maintained at a temperature which is, taking the mean of two readings, 138° F., and from the walls of a drift opened at its upper surface there is a constant absorption of heat by an air-current, amounting to 142 pound heat units per square foot and twenty-four hours, this being the mean of a six months' period of observation.

Since the transmission of heat through a one-foot stratum of rock, having a difference of one degree between the temperature of its upper and lower surfaces, is sufficient in twenty-four hours to heat 0.3863 cubic foot of water, one degree Fahrenheit, for each square foot of surface; we have, $0.3863 \times 62.447 = 24.123$ pound heat-units, transmitted through eruptive rock in twenty-four hours, per square foot of surface, under these conditions. For a stratum 468 feet thick, the transmission, being inversely as the thickness, would amount to 0.0515 pound heat units, per square foot for each degree of difference in temperature between the upper and lower surfaces.

To maintain the radiation of 142 pound heat units, per square foot of surface on the upper level, at this rate of transmission, would require a temperature of $142 \div 0.0515 = 2757$ degrees Fahrenheit on the 2200 level.

Mr. Charles T. Hoffmann found the following temperatures in the 1531 level of the Yellow Jacket mine in 1873:

| | |
|---|---|
| Dry-hole in upper part of the header, . . . . | 123° F. |
| Wet-hole in lower part of the header, . . . . | 120° F. |
| Air in the drift, . . . . . . . . . | 102° F. |

Taking the difference between the heat of the dry-hole on this level and that found on the 2200 level, or 138°—123° = 15°, we have an increase of fifteen degrees in 670 feet of depth. This gives an average rate of increase amounting to one degree for 45.67 feet, and this is so near that determined by me for the whole ground (one degree to 45.45 feet), that for the purpose of this calculation we may safely take one degree to 45.5 feet of descent to be the rate of increase for this mine. By this there should be an increase of 4.4 degrees between the 1531 and the 1732 levels, and the temperature of the latter would be that of the 1531 *plus* the increase; or 123° + 4.4° = 127.4°. Therefore, the difference between the temperature of the 1732 and the 2200 levels is nominally 138°—127.4° = 10.6°. Our rock stratum of 468 feet thickness accordingly has its lower surface constantly maintained at a temperature 10.6° higher than its upper surface. Its rate of transmission being 0.0515 pound Fahrenheit heat units, per square foot and twenty-four hours, the radiation on the 1732 level should be 0.0515 × 10.6° = .05459 heat units. This is only 3.84 per cent. of the radiation which is found to be actually taking place.

The case may also be stated in another way. If the transmission through a one-foot stratum is 24.123 pound units per square foot, in twenty-four hours, for each degree of difference in temperature, and the radiation on the 1732 level is 142 pound units for the same surface and time, it is evident that a rock stratum having its lower surface kept 10.6 degrees hotter than its upper surface, could at this rate not exceed a thickness of 1.8 feet. For a stratum of this thickness would transmit 13.4 pound heat units per square foot in twenty-four hours, and 13.4 × 10.6° = 142 units for the radiation. Instead of the height of 468 feet between the 2200 and 1732 levels, the law of transmission would not admit of a stratum more than twenty inches thick between the surface where a radiation of 142 foot-pound heat units is in progress and the surface where an excess of 10.6° F. is maintained.

It is true that the accuracy of these results is vitiated by the fact, that the walls of the drift represent a little more than four times the real upper surface of the stratum, but even if allowance is made for this only sixteen per cent. of the total radiation in the drift can be accounted for by mere transmission. Rude as the calculations are, they establish the assertion that some other cause for the passage of heat through these rocks must be sought.

It would be interesting to learn the rate at which heat passes through these rocks under the combined operation of gaseous currents and ordinary transmission. Ample opportunities exist for trustworthy experiments upon the subject, for there are scores of diamond-drill bore-holes, each some hundreds of feet in length, on different levels in all parts of the lode. But no data have been collected even for such rough calculations as I have ventured upon in this paper.

On this account it is equally impossible to apply, at present, Joule's discovery that gases do not lose heat, or not so much heat, in expanding when they pass through a porous plug as when they are delivered freely. The rock evidently acts as such a plug to any gases contained in them. Nevertheless, the fact is, it does cool rapidly; its rate of transmission, excessive as it is by Sir William Thomson's formula, not being sufficient to maintain its temperature with an air-current passing. To what depth this refrigeration extends is not known.

It is easy to see that the presence of gaseous currents in the strata of the earth is not confined to the region of the Comstock lode, but must take place wherever meteoric waters are carried into low-lying strata, and there enter into chemical combination with mineral substances. The regenerative action by which each dose of rain-water intercepts the escaping currents of gas, as they rise through the rocks, and adds to the store it has brought from the surface, until the point of saturation is reached, must also go on wherever hydration takes place in underlying rocks. The extreme discrepancies in the records of subterranean rock temperatures, so far as they have been observed, have never been explained, but it seems probable that wherever kaolination is taking place, the temperature, both of the strata affected and of those overlying them, will be raised.

It has been pointed out above that the susceptibility of the Comstock rocks to feldspathic decomposition cannot be considered a peculiarity, since volcanic areas in other places, exhibit similar heat phenomena. All the rocks, propylite, diorite, and andesite, show this tendency to break up under the action of water. On the surface there are areas where the alteration has been deep, and others of just as ancient exposure, where hardly anything more than discoloration has taken place, the material remaining firm. A similar state of things is found below the surface, and at all depths reached by the works. Soft seams, hard rocks, which remain hard through years of exposure, and hard rocks which flake down and soften under the action of the air, are all met with, and apparently are not distinguished by mineralogical differences.

Upon examining these varying layers, the conclusion seems irresistible that the very soft rocks have been the channels of the meteoric waters, and perhaps also of rising mineral waters, while the solid and unaltered ones have not been the seat of water movements to any great extent. This observation makes the heat of the hard rocks all the more noticeable. They are hot, and sometimes rock which is perfectly solid, both before and after exposure to the air, is as hot as any of the layers met with, though, as a rule, the more decomposed seams are either colder or hotter than the unchanged layers.

In the decomposed layers which I have supposed to be the channels of the rising solfataric waters, the clay exists in a state of incomplete hydration. It absorbs water with great avidity, and under such circumstances develops unusual heat. When drifts are opened in such material, the clay absorbs moisture from the air currents, swells, and throws off flakes of rock which would come down indefinitely if they were not kept back by timbers. Sometimes, the breaking of a pump allows water to rise upon such a stratum, and then the swelling is so great and forcible that timbers twelve and fourteen inches thick are broken and split into small pieces.

These decomposed layers may be looked upon as the furnaces of the district. They are found on both sides of the vein, and in all the rocks of the region. Sometimes widely separated, they also frequently lie within one or two hundred feet of each other. Considering the low specific heat and conductivity of rocks, it is not surprising that a temperature of 130° Fahrenheit should have been reached and maintained at depths of fifteen hundred feet and more, where radiation is necessarily slow.

Whatever the exact mode of decomposition is, it is certain that the result is the same as if the Comstock mines were excavated in a mass of burning material. At present the source of the decomposition is probably atmospheric action. For a certain distance from the surface, which may be approximately put at 1000 feet, the process was complete or nearly so, before the advent of man. The fire had burned out, and the rock had cooled down.

When this zone of burnt-out rock had been passed in the mines a lower zone was entered, and here the fire was found to be still in progress. It is not unfrequently said that the heat of the mines has not increased as they have deepened, and in proof of the assertion it is reported that the first bodies of hot water struck were nearly as hot as those that have been tapped at lower levels.

I am inclined to doubt the strict accuracy of this statement, though it is quite possible that isolated bodies of water, tapped on the upper levels, may have had high temperatures, and been derived from portions of the country rock that were in a more vigorous state of chemical action on that level than the general mass. But the average heat of the water has increased in going lower. Mr. King, as before quoted, gives 70° to 75° Fahrenheit as the average from the surface down to the 700 foot level, and 108° Fahrenheit as the maximum in the lowest workings of the Empire, Crown Point, and Hale & Norcross, which at that time (1869) were about 1000 feet below the surface. This conclusion was formed after a careful comparison of numerous observations. It is probable that after passing through a certain thickness of rock, in which alteration had nearly ceased, the average temperature has increased with some uniformity to its present stand-point.

## FUTURE INCREASE OF THE HEAT.

This brings me to the important question, Will the heat continue to increase? If it does increase, will it rise to the point of boiling water?

The elements of the problem are too vague for a definite opinion on this subject. We do not know how rapid the alteration of the feldspar is, how much heat it produces, nor how much surface-water reaches the hot ground yearly.

The temperature of the water in some of the springs at Steamboat, twelve miles distant from the lode, is sufficient local proof that the rocks of the region are capable of producing heat enough to raise a considerable quantity of water to the boiling-point, and at a certain depth this may be the temperature of the rock at the mines. It seems probable, however, that this depth is one that will not be reached by mining in this century, if ever.

In discussing this question it is necessary to keep clearly in mind the fact that there are two distinct classes of hot rocks encountered. One is the ordinary rock, which forms much the greater part of the ground worked in. The other contains a number of individual belts, or bands, of hot or cold rock, which are found inclosed in the former. The nature of these peculiar bands will be considered hereafter. It is upon the condition of the first class, or the rocks which compose most of the mining ground, that a discussion of the general temperature must be based. If we assume the rate of increase in these rocks to be uniform from 108° Fahrenheit at the 1000 foot level to 130° at the 2000 level, it represents 2.2 degrees Fahrenheit for 100 feet of depth, or 1 degree to 45.45 feet. The lower of these temperatures is that assigned by Mr. King to the "lowest workings of the Empire, Crown Point, and Hale & Norcross," and its depth at the time he wrote was between 1000 and 1100 feet. Mr. King gives this as the maximum temperature, and from the table of observations published by him it is probable that the average may have been in the nighborhood of 100° Fahrenheit. On the other hand the temperatures on the 2000 foot level and below that were sometimes 136° and 139° Fahrenheit. Assuming it at 140°, in order to obtain a maximum, we have a difference of 140°–100°, or an increase of 40° in 1200 feet of depth; an average of 4° to 100 feet, or 1° to 25 feet.

The great difference between this minimum and maximum calculation shows how untrustworthy such estimations are when based upon a limited number of observations. The uncertainty is greatly increased by the differences in temperature which exist within small distances. When such calculations are presented in this report they are to be accepted rather as illustrations than as positive estimations. It is also worth noticing that these rates of increasing temperature, taken in the hottest mines in the world, and where the heat is almost entirely due to natural causes, and not to the artificial conditions of bad ventilation, crowded mines and combustible material, do not much exceed those which have been reported in numerous other localities where no remarkable circumstances were noted. The higher rate, 25 feet to 1°, is perhaps excessive, but many determinations in ordinary rocks have given as much as 45½ feet.

The greatest depth to which engineers of the present day are looking forward as the maximum to which they may be called upon to sink is from 4000 to 6000 feet. The former depth will no doubt be reached by the present generation, but I believe preparations for sinking to the latter distance have not yet been made in any country.

If the heat of the general mass of rock increases at the rate of one degree for 45.5 feet, and the temperature at 2000 feet is 130° Fahrenheit, the increase for 2000 feet more would be 44° and the temperature, at the 4000 foot level, would then be 174° Fahrenheit. At the 6000 foot level it would be 218°.

By the maximum rate of increase calculated above, or one degree to 25 feet, the temperature at the depth of 4000 feet would be 210°, and at 6000 feet depth 290°.

It is, however, a matter for grave doubt whether under the existing circumstances of the Comstock region the rock will be found at any depth to have the temperature of 212° Fahrenheit. The access of atmospheric air and water must decrease proportionately to the depth, after a certain point is reached, and at that point the decomposition of the rock and the heat produced will be at a maximum.

The opinion that the heat will increase from its present standpoint, is a necessary deduction from the explanation which I give of the whole series of phenomena. I cannot agree with the conclusion of Mr. King, that the heat of the rocks is brought in by water that rises from great depths and in a heated condition. I consider that the reverse action is the one which is really going on. The rock heats the water.

The temperature of the rock was determined by a number of trials to be 130° Fahrenheit, as stated above, while water in large quantities comes into the workings, exhibiting a temperature of 154° Fahrenheit. According to the hypothesis here advanced there must be rock of this temperature somewhere in or near the lode. If the water is assumed to rise from great depths and the rate of increase is uniformly one degree for 45½ feet, the Savage and Hale & Norcross water of 154° temperature must come from the depth of about 3100 feet, if the temperatures taken in the Crown Point 2000 level are assumed as a basis for calculation. Unfortunately it was not possible to obtain data from the flooded mines, as their lower levels were covered by several hundred feet of water during the whole of the field season. The depth of 3100 feet is 900 feet below the level on which the water was struck.

Since the theory that the rocks are heated by water drawn from great depths has been rejected in this report, it is necessary to explain how it is that the water coming into the mines is almost uniformly hotter than the rocks, except when it is palpably surface water, filtering down through a shattered seam.

It seems to be pretty well settled that the waters of the lode occupy strata of rock which are generally parallel with it, these strata being separated by clays, dykes, or solid strata which are impervious to water, and accordingly retain the liquid between them. The numerous long drifts run to the eastward, cut these parallel strata in great numbers, and tap the water they contain, sometimes in formidable quantities. But in spite of the number of these drifts, it is probable that some bodies of water have never been drained, but remain in the country rock at levels much above the lowest workings of the mines.

I consider these water-bearing bands of rock lying parallel with the lode, to be identical with some of the hot bands previously described, and a little consideration will show that the seamy and shattered condition which fits a rock for storing up water in large quantities also increases its susceptibility to decomposition by increasing the surfaces acted on. The vast quantities of water which have again and again suddenly flooded one mine after another are evidence that the reservoirs which contain them are also made up of shattered seams, for the undecomposed rock of this region is finely porous, and not coarsely porous. It could hardly contain as much water as an ordinary sandstone, and certainly it could not give up its fluid contents with any great rapidity when in its natural condition. These facts have been recognized for a long time in the Comstock, where there is now a settled conviction among intelligent observers that the great inflows of water come from shattered and decomposed seams, parallel with the lode, and sometimes of great thickness. The old idea that the country rock contains cavernous openings holding large bodies of water has been abandoned, in consequence of the proof afforded by more than a hundred miles of exploratory workings, that the inclosing rocks are singularly free from vugs and open crevices. Very few have been found in proportion to the ground penetrated.

These facts force upon us the conclusion that the high temperature of the floods of water is not necessarily due to the depth of their origin. It is more probable that the hot waters come from seams which, on account of their shattered condition, are both more susceptible to chemical action and also more capable of storing up the fluid. They are the "hot belts" of the country rock. Not only is the deep origin of the hot waters not proved by the facts, but the contrary hypothesis is strongly borne out. When they are encountered, it is quite a common experience to strike them *below* the highest point of their source, and the mine is often flooded by such an occurrence to the depth of several hundred feet. The case of the Savage and Hale & Norcross mines is quite in point. The vast accumulation of water which has disabled them for nearly two years, was first struck in the 2200 level of the Savage and filled the two mines to the 1700 level, a height of 500 feet, besides filling the 2400 level of the Savage. The pressure which lifted this water through 500 feet of height cannot be attributed to the tension of any gas, for it has been shown in a former part of this report that the emanations of gas in the mines have never been very forcible.

The head of 500 feet under which this water entered the mine, and which was steadily maintained for several months, during which new pumps were put in, may be referred with the most probability to a simple hydrostatic pressure. Its origin was not deeper than the 2200 level, but, on the contrary, at least 500 feet above it, and this fact, taken with its temperature of 154° Fahrenheit, forms the most significant evidence in regard to the origin of all these bodies of heated water, for they present similar phenomena.

The uniform disposition of the rocks in the Comstock region, entirely unbroken as they are by faults, gives strong probability to the supposition that these collections of water extend to great depths. I suppose that there is a certain amount of convection in this water; currents from the upper portions of the strata setting downward and pressing up currents of hot water from lower depths. This action maintains the water in the upper parts of the strata at a higher temperature than it would otherwise have. The hot water drawn from the lower depths presupposes the existence there of rock of equal temperature. In fact, as there is a constant loss of heat near the surface, we must look upon the highest temperature observed in a large body of water, 154° Fahrenheit, as a mean obtained by mixing colder water from the upper rocks with hotter water from those below. The limited rainfall of Nevada would, however, make the yearly accession of water very small when compared with the quantities which we may suppose the rocks to hold as a permanent store, and this yearly addition would be heated, probably above 130° Fahrenheit, by the heat of the upper rocks, and the fresh chemical action set up by its presence.

From all these considerations it is judged that until water temperatures above 154° Fahrenheit are observed, we may content ourselves with the belief that nothing in the present condition of things indicates the certainty that the heat will ever rise to the boiling-point of water, 212° Fahrenheit. As above stated, it is rational to suppose that the access of atmospheric air and water must diminish in proportion to the depth after a certain point is reached. At that point the temperature will be at a maximum. Below it there will be a state of equilibrium, probably for a very considerable depth. Below that the heat may diminish even to a point below that of the highest of the three zones. There must be some point where the absence of drainage allows the water to lie like a blanket over the rocks, protecting them from the action of air or gases from the surface. The known depth required for the production of a temperature amounting to 130° Fahrenheit, is so great, that we may fairly doubt whether air or water penetrate to lower depths in quantity sufficient to maintain mineral decomposition with the activity necessary to obtain the boiling temperature.

The boiling heat of the water at Steamboat Springs is evidence that the chemical action is going on there near the surface. The common impression that these springs are the last indications of the volcanic forces which poured out the torrents of melted rock that now cover this whole region, may be accepted in a modified form. The rocks of that neighborhood may be the last of a series that certainly occupied an enormous time for their ejection, and in that sense they are the last to undergo decomposition. Chemical action is nearer the surface in them, because it is newer. Its maximum line is higher than in the older rocks of the series, which are those that now inclose the lode. It is also quite possible that decomposition near the surface may be intensified by the action of organic acids drawn from the soil.

To recapitulate briefly the facts here given, this explanation of the heat phenomena connected with these remarkable mines therefore supposes the existence of a cold, and what may be called a burnt out, layer of rocks, extending for a thousand feet below the surface, a zone of hot rock still in active decomposition, which has been found to exist for a depth of about fifteen hundred feet more, and no doubt extends thousands of feet further, and, finally, a mass of cold rock at a great depth, which has not yet begun to decompose. This hypothesis will be found to satisfy all of the observed facts.

The peculiar bands of hot and cold rocks which have been described, are simply layers of rock in which decomposition has been delayed or hastened. When the texture of a rock is such that it resists decomposition longer than other layers in its neighborhood, it will be at its maximum temperature long after its fellows have passed theirs and cooled down, and this I conceive to be the situation of the hot bands. They are individual layers of rock undergoing delayed decomposition.

On the other hand, when a rock is peculiarly susceptible to the action of the air and water, its alteration will proceed more actively than that of the surrounding rock. It will, therefore, pass its maximum temperature sooner, and be cooled down by the time that its neighbors begin to be at their hottest. This is the state of the cold bands. These bands, in fact, offer us at several places in the mines, examples in miniature of the action that is going on upon a grand scale throughout the whole system of rocks.

All the known facts strengthen the supposition which is advanced in this report, that the heat in the mines is subject to a steady and moderate increase as their depth is increased, this comparatively regular progression being broken by the passage through belts of rock heated above the average of the "country."

In regard to the single mode of heat production suggested here, it is, of course, possible that other forms of mineral alteration than the transformation of feldspar to clay may have taken place, but they have not been observed. The minerals of the country rock and vein appear to be the same in depth as near the surface in the cold zone. The rocks are remarkably free from zeolites and other evidences of mineral interchange through the medium of water. Whatever has been done of this kind is almost confined to the deposition of quartz in the upper mines, and of quartz and calcite in the lower mines of Virginia and Gold Hill, and to the formation of clay. Calcite is found in the Black Dyke and in rocks of apparently similar composition east and west of the vein, and gypsum also occurs on the surfaces of fissured seams; but the quantity of both is so small, excepting in the Devil's Gate part of the district, that they might well be referred to the ordinary action of atmospheric waters in any series of strata.

## RELATION OF TEMPERATURE TO DEPTH.

The temperature of the rock has no relation to fixed levels. There do not appear to be horizontal zones in the earth, with a temperature peculiar to each one. But the relation of temperature to depth from the surface is apparent through all the variations due to differences in the rocks and other causes. The depths given are reckoned from the top of the present shaft or some old one in each mine, and there is no common datum assumed. The altitudes of the shafts vary to the extent of several hundred feet, but there has been a certain correspondence (though not a close one) in the depth at which hot water was tapped in the different mines. That is to say, the depth from the varying outline of the surface is the only one that can be called constant.

This is illustrated by the case of the Justice mine. The mouth of its shaft is nearly a thousand feet below the Gould & Curry croppings, and its lowest workings were about one thousand feet below the surface. These workings are, therefore, within a few feet of the same absolute level as the Gould & Curry 1900 foot station and drift, where the remarkably hot ground above referred to is reported to be. In the latter mine, an air temperature of 123° Fahrenheit is reported in the drift, but in the Justice the rock is still quite cool, and though the temperature of the mine is somewhat higher than on the surface, this increase is mainly due to the burning of candles, heat of the workmen, and other causes that raise the temperature of most mines.

What the future of the Justice in regard to temperature may be cannot be positively foretold, because the filling of its ore bodies is entirely different in character from that of the upper crevice. It is carbonate of lime, while the whole series of mines from the Utah to the Caledonia have quartz for their gangue. One is basic, the other acid. Still, as the heat is derived from the decomposition of the country rock, and depends upon the lode only so far as to be increased by the numerous surfaces exposed to atmospheric influences near the main channel, it is to be expected that the Justice and other mines in that neighborhood will, in sinking a few hundred feet more, take their places among the hot mines of America. The basic character of the gangue probably cannot of itself affect the result, and is to be regarded only as an indication of conditions in the formation of the lode which may have lessened the liability of the country rock to decomposition.

The depths referred to in this report are all vertical, and for that reason they do not represent the path which the atmospheric agencies have actually taken. That is to be measured along the dip of the rocks, which varies from 40 to 60 degrees. No other course is open to surface waters, which have been clearly proved to be limited in their lateral spread by the numerous clay seams which abound, both in the country rock and in the lode, and which generally dip with the other rocks. My own observations have convinced me that these waters may also be confined by sheets of massive and comparatively impermeable rock, of which there are countless exposures in the east crosscuts of the mines.

We must then consider that the path of these decomposing agencies has been followed, not only for a depth of 2400 feet in the Savage mine, but for a depth (on the dip of the rocks) that is approximately one-half greater than this, or nearly four thousand feet. For more than one-third of this distance the action has passed by; the chemical activity of the rock has ceased, though it is not exhausted. At the bottom of the lower portion, or four thousand feet from the surface, the decomposing action may perhaps be considered to be approaching its maximum.

These distances do not exceed, nor in fact equal, those which have been indicated by theory as the possible depths of atmospheric penetration. Observations upon volcanic action and deep artesian wells have familiarized us with the idea that chemical action, due to the presence of atmospheric air and water, is going on at the depth of thousands of feet; but no instance of this action at depths greater than those exhibited by the Comstock mines has been pointed out.

The Comstock mines, however, offer a greater promise of discovery in this matter of rock temperatures than any other that I am acquainted with. The extraordinary rapidity with which their operations are prosecuted, the extent of the works, and the fact that they open to inspection a great eruptive mineral lode thoroughly for two miles in length, and partially for many thousand feet more, give them unusual value as a field for investigation. They not only follow an eruptive dyke throughout its course, but they also explore a parallel system of eruptive rocks by crosscuts, which are often from 300 to 500 feet long, and sometimes stretch out to 1000 feet and more.

They are also certain to be opened to much greater depths than now, and with a rapidity that will no doubt make them foremost in deep mining within a few years. These conditions, combined with the peculiar susceptibility of the country rock to decomposition, give good reason for expecting that they will before long be the scene of thorough and perhaps conclusive studies in this interesting subject of earth temperatures. This was but a secondary part of my own work, which was chiefly confined to a geological study of the lode, and the many imperfections in this sketch are partly due to this fact.