On the Cause of the Heat of the Bath Waters.

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ALL thermal springs issue, without an exception, in positions which may be arranged under three heads :—

1. Volcanoes, either actually existing or which have exhibited eruptions within the memory of man—The hot springs of Iceland, those in the neighbourhood of Vesuvius, Ætna, and Ischia; those in the Eifel Mountains near the Rhine, and in Auvergne in Central France ; and the springs which are universally found to accompany volcanoes in South America, California, Kamschatka, and the Canary Islands, are all proofs of the intimate connexion between thermal springs and volcanoes.

2. Igneous rocks, or those of igneous origin, among which is granite. The European thermal springs for the most part are in this position ; those in the Pyrenees and the Alps, where granite has uplifted the stratified rocks of a very recent date ; the thermals of the Erzgebirge Mountains, in the north-east of Bohemia, where whole hills are composed of clinkstone, and other trappean materials, and their shapes assume quite a volcanic character ; those of the Bohemian Riesengebirge, a continuation of this range ; those by the Black Forest, for example Wildbad, where the hot springs rise at the junction of the granite and the clay slate, and in the Taunus Mountains, near the Rhine, are instances. There appear, from the observations of Dr. Bouè, to be many hot springs connected with the mountains of European and Asiatic Turkey, and no country abounds with them more than that of the Caucasus.

3. Points where the strata, although not actually pene-

trated by any volcanic or igneous rock, exhibit great marks of violence and dislocation—There always exist *faults* in the neighbourhood of such hot springs; there is also, sometimes, a peculiar conformation of the strata, which exhibit an elevation by some force at a single point, and where a circle is formed of inclined strata, all pointing to this point as the centre. This exhibition of dislocation from an upheaving force appears to be connected with those thermal or quasi-thermal springs which exist in the recent portions of the secondary formations in England.

Now, this last position is that of Bath. There are here, as Dean Conybeare remarks,[1] "cases of subsidence which are accompanied by vertical fissures, or faults, traversing the strata to a great depth, and in which the whole series of strata affected by them (soft as well as hard) is let down together. . . . They must be referred to causes seated at a great depth, and acting in the same manner as the force producing earthquakes." He mentions instances which have since been frequently supplemented, and are familiar to all Bath geologists.

The heat of the waters of Bath must have startled the Roman conquerors. They had, indeed, known well the high temperature of the Baths of Nero, in the Bay of Naples; but this was in the immediate neighbourhood of a burning mountain. Bath had no volcano in its vicinity. Nor is the phenomenon less surprizing now. Sir Charles Lyell calls attention to the fact that there is not even an extinct volcano nearer Bath than those of the Rhine and the Eifel, four hundred miles off.

What, then, is the cause of the heat of the Bath waters?

The theories which were formerly framed to acccount for the origin of the heat of thermal springs have greatly lost credit. A thermal spring is a spring whose mean temperature exceeds the mean temperature of the place where it comes to the surface; and some theories, such as the burning of coal, the decomposition of iron pyrites (by which the late Professor Quekett explained some of the Bath heat), and many others, are obviously inap-

(1). Conybeare and Phillips, p. 23.

plicable to many of the numerous thermal springs that are now known to exist.

One favourite theory was, and is, that the heat of thermal waters depends upon certain chemical combinations, indicated by the mineral contents of the springs; it being contended that the heat increased with the quantity of these mineral contents. But the heat of a thermal spring by no means depends on the quantity of its fixed mineral constituents. Most of the thermal springs are considerably impregnated with foreign ingredients, but there are instances of hot wells, such as Pfeffers in the Alps, and Gastein in the Salzkammergut, which are almost as pure as distilled water, and have a temperature of 120 Fahr.; and it is quite certain that facts do not warrant any law of the increase of temperature corresponding with the increase of the quantity of fixed ingredients. In the case of salt springs it has no doubt been generally observed that the more salt they contain the hotter they are, but the salt can have no effect upon the temperature. Professor Bischof gives the following temperatures and fixed ingredients of four springs near the Laacher See; and his figures shew that in that volcanic tract the rule does not hold:—

	Fixed constituents.	Temperature.
Heilbronn ..	0.0053	52.9
Tönnistein ..	0.0025	54.9
Fehlenbor ..	0.0019	57.6
Burgbrohl ..	0.0013	58.1

The non-correspondence between the heat and the fixed ingredients will appear further on a comparison of the ingredients and temperature of several thermal springs which are considerably elevated above the mean of the climate. On examining the list given by Dr. Daubeny, on Volcanoes, 2d. Ed. 1848, p. 57, who gives not the absolute temperature, but merely the elevation above the mean of the climate, and the solid ingredients, I find that the connexion between these two quantities is by no means constant:—

Quantity of fixed constituents.	Temperature above the mean climate.
0.9	71.
2.	85.
15.	71.
33.	57.
57.	107.
62.	57.
87.	36.
119.	20.

The last three are salt springs.

In these figures the influence of height is not taken into account, but I have not thought it worth while to make the reduction for height, as it seems very clear that the temperature does not increase with the quantity of fixed substances. One more witness against this opinion may perhaps be thought quite sufficient. Prof. Forbes, in his paper on "The Thermal Waters of the Pyrenees," in the Philosophical Transactions, 1836, says, "A common opinion prevails that the quantity of the hydrosulphurets contained in these springs is in proportion to their temperature, and I have even heard the existence of cold sulphureous springs in the Pyrenees denied altogether. Yet, not only are such to be found, but even within not many yards of others having a high temperature, and almost an identical mineral composition." After citing instances, he adds, "When to these facts we add others scarcely less curious, of springs of totally different mineral composition issuing from nearly the same spot, and with temperatures from 160 to 180 Fahr., as we see at Ax and Thuez, we are forced to conclude that the source of mineralization must be independent to a great extent on that of high temperature, and that the arguments as to the origin of thermal springs, founded upon their chemical composition, must be to a certain degree fallacious."

Dr. Daubeny suggested that all the heat of thermal springs was produced by the mixture of foreign ingredients, particularly nitrogen; but Professor Bischof put this theory to the test of experiment. In order to ascertain whether this was the cause of heat in a mineral spring richly impregnated with carbonate of soda, he took anhydrous carbonate of soda, mixed with concentrated sulphuric acid, smoking muriatic acid and water, in the quantity indicated by the analysis of the spring, and found the temperature increased only 1° 35. Again, he took the most favourable instance, and mixed sodium with sulphuric and muriatic acid, and then found that the temperature was raised in one case, only 2°, and the other 4°. These experiments prove that chemical compositions of this nature cannot produce the high temperature of hot wells.

From the wide spread existence of thermal springs, and the failure of the other explanations of the source from which their heat arises, we are compelled to conclude that they owe this heat to their origin being deep in the earth; if so, the deeper we descend, the hotter we should find the water; and when there is a deep seated source of disturbance, which has produced cracks and fissures in the lower strata, any water found at the bottom of these fissures must be hot, and will, if raised to the surface by the action of some elevating force, exhibit the phenomenon of a hot spring. Except where there has been this disturbance at a considerable depth, no such fissures could exist, and accordingly no hot springs are found except in such localities. The force with which hot springs come to the surface is governed by the same law which determines the rise of the water in the case of Artesian wells; and, except where volcanic forces supply the expansive power of vapour and gas from below, we generally find in the neighbourhood of hot springs a sufficient elevation to reduce this force to the influence of hydrostatic pressure alone.

The changes produced by earthquakes on springs of this character are to be looked upon as principally affecting the fissures by which the meteoric waters descend, and the thermal waters ascend.

Let us enquire, then, whether the Bath waters owe their heat to the depth from which they rise.

Now, what are the conditions of depth, if this is the source of heat of the Bath waters, which must exist to produce their temperature? Assuming the mean temperature of Bath to be 50°, they exceed it by 66°.

Let us enquire at what depth below the surface of the earth at Bath we may expect a temperature of 116°? In 1836, Dr. Daubeny, in his report to the British Association on mineral and thermal springs, says, "the temperature augments as we descend, on the average, about 1° Fahr. for every 100 feet;" this would make their depth 6,600 feet."

Sir Charles Lyell, in his *Principles of Geology*, ed. 1868, states Professor Phillips's observations in two coal shafts, one near Durham, and another near Manchester, as giving the augmentation at 1° Fahr. for every 65 to 70 feet. In Saxony he states the observed rate in a mine to be a degree for every 65 feet; and at the Dolcoath Mine, in Cornwall, a degree for every 75 feet; but, he says, that the experimental well at Grenelle, near Paris, gives an increase of one degree for every 60 feet to the depth of 1,800 feet, and ultimately he adopts the mean increase of 1° Fahr. for every 65 feet of depth.

The great extent to which Artesian wells have been bored, since the well of La Grenelle was made, and the more exact methods of observation which have been lately employed enable us to lay down a more accurate rule. An important collection of facts will be found in the reports of the Committee appointed by the British Association some years ago to ascertain the state of increase of underground temperature in descent. These reports are continued to 1872.

There is a boring at St. Louis, in America, where they have attained to a depth of 3,029 feet, and the temperature is said to be 107° Fahr., and careful observations of the Kentish Town well and the well of Grenelle show an increase of one degree Fahr. for every 54 feet in the one case, and every 56 feet in the other case. So a boring at the bottom of a shaft 1,066 feet deep shews an increase of one degree in 51 feet.

All observations in shafts exhibit irregularities, and I should be glad to have accurate observations of the temperature in the boring of 4,194 feet near Berlin, but the latest observations point to an increase of a degree for every 50 feet as the correct rule, at least when depths beyond 1,000 feet are reached.[2]

If we adopt this rule it will follow that the Bath waters should rise from a depth of between 3,300 and 4,000 feet below the surface of the earth, in order to acquire the heat which they now exhibit. They are forced to the surface through fissures or cracks produced by the violent dislocation which some upheaving agency has produced in Bath and its neighbourhood (and of which such evident traces are visible in the steep hills and valleys which add so much to its beauty), by the pressure, after the manner of Artesian wells, of a column of water standing to sufficient height in some neighbouring hills, and reaching down through fissures or permeable strata in those hills and below them to the level where the crust of the earth and the waters in contact with it are of a temperature of not less than 116°.

We may I think find, not in the Cotswold Hills, as hinted by Sir Charles Lyell, but in the Mendip Hills, quantities of water at heights sufficient to produce the phenomenon of the volume of hot water which springs forth at the surface in Bath. The carboniferous limestone of the Mendips affords such countless instances of great collections of water as to need no particular enumeration.

Of any actual tracing of the course of the hot springs there are only a few instances known to me. Mr. Townsend (Conybeare and Phillips 219) says, "By Hetlin Court, when the hot springs had failed to supply the usual quantity of water in a given time, the Corporation employed Mr. William Smith to remedy the evil. He laid open the ground, detected the cause of failure, and restored the springs. At that time I took notice of his

(2). See *Encyclopædia Britannia.* Artesian wells. 1875. "On an average, including the best data of all, those yielded by Artesian springs, the increase appears to be 1° Fahr. for every 50 or 60 English feet of descent." Principal Forbes, *Ency. Brit.*, Prel. Dissertation, 1856, s. 675.

operations, and at a great depth saw the springs through the blue marl." (T. 197). This was about 1803. Subsequently to this operation, says Mr. Townsend, "Mr. Palmer, then mayor, sunk in the sand of the King's Bath, as deep as he could venture to proceed, without endangering the pump room, yet he did not arrive at the blue marl. From the bottom of this sinking, he sent me a quantity of sand. This was alluvial, not calcareous, but silicious, and in this sand I ascertained the green quartz, with iron, such as we find beneath our chalks in Wiltshire, and from thence it came." (T. 197).

Lastly, we have Mr. Pinch's well, sunk in 1838 in Kingsmead Street, which after being sunk to a depth of 169 feet reached a dark red soil wherein the Bath hot water was found. This dark red soil was, Mr. Moore says, without doubt the upper portion of the Keuper, or New Red sandstone. The new red sandstone is here very thin apparently and the hot water was found rising through it. In the then state of the law it was thought that the Corporation of Bath had a right to prevent Mr. Pinch from digging so as to affect the flow of the hot water to the baths of the Corporation, and consequently he dug no deeper.

I apprehend no one imagined that the SOURCE of these hot springs was the red marl.

It is obvious that the position I have ventured to suggest, that the heat of the Bath waters is due to their rising from a depth of more than 3,000 feet below the surface, may be taken up with more success when the mineral contents of the Bath waters are compared with the character of the strata through which--if they rise from that depth—they would be expected to pass. *Tales sunt aquæ, qualis terra per quam fluunt* was the maxim of Pliny, and must be true now.

The Bath old well yields 126 gallons of water per minute, which is equal to 181,440 gallons per day. What must be the effect of such quantities of hot water as this passing through the strata. They do contain in each gallon 144 grains of salts—

carbonate of lime, sulphate of lime, sulphate of sodium, common salt, chloride of magnesium, besides iron. I shall be surprised if this exhibition does not indicate the passing of the Bath waters up out of the carboniferous limestone through the coal measures. However this may be, I believe every additional step in our knowledge of the geology of Bath will bring strong confirmatory evidence in favour of the opinion, that the heat of the Bath waters is due to the depth from which they ascend.