On underground temperatures : with observations on the conductivity of rocks, on the thermal effects of saturation and imbibition, and on a special source of heat in mountain ranges / by Joseph Prestwich.

Contributors

Prestwich, Joseph, 1812-1896.
Royal College of Surgeons of England

Publication/Creation

London : Harrison and Sons, printers, 1886.

Persistent URL

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UNDERGROUND TEMPERATURES;

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OBSERVATIONS ON THE CONDUCTIVITY OF ROCKS; ON THE THERMAL EFFECTS OF SATURATION AND IMBIBITION; AND ON A SPECIAL SOURCE OF HEAT IN MOUNTAIN RANGES.

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JOSEPH PRESTWICH, M.A., F.R.S., F.G.S., &c.

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[*From the* PROCEEDINGS OF THE ROYAL SOCIETY, No. 246, 1886.]

"On Underground Temperatures; with Observations on the Conductivity of Rocks; on the Thermal Effects of Saturation and Imbibition; and on a Special Source of Heat in Mountain Ranges."

By JOSEPH PRESTWICH, M.A., F.R.S., F.G.S., &c.

Received January 24. Read February 12, 1885.

1. *Introduction.*

The opinions of physicists and geologists as to what may be the probable thickness of the crust of the Earth differ very materially. On the strength of its great rigidity and the absence of tides, physicists contend for a maximum thickness and the comparative solidity of the whole mass of the globe. On the evidence of volcanic action, the crumpling and folding of the strata in mountain ranges, its general flexibility down to the most recent geological times, and the rate of increase of temperature in descending beneath the surface, geologists contend for a crust of minimum thickness (although respecting the measure of this there is great difference of opinion) and a yielding substratum, as alone compatible with these phenomena.

My intention here is not to enter upon the general question, but to lay before the Society the results of an inquiry on one section of it—namely, the rate of increase of temperature beneath the surface,—a subject equally affecting the argument on both sides. My attention was more specially directed to this subject in connexion with an inquiry on the cause of volcanic action, during which I found that the recorded observations gave so wide a choice in the selection of a mean rate for the increase of temperature, or as termed by Professor Everett, the "thermometric gradient," that very different values might be and were attached to it by different writers. I was thereby led to collect the scattered evidence bearing on the subject, with a view to see whether it were not possible to fix upon some more definite and less elastic rate.

If the inquiry does not lead to any material alteration of the averages now usually accepted, it may, at all events, serve to eliminate some sources of error, and to restrict the limits within which the true rate may lie. It may also serve to show how far the differences in the observations in different geological areas are due to causes common to all, and how far they are special to each or due primarily to geological structure and local causes.

At present, owing to the wide differences in the recorded observations, it is very usual to take a general mean rate of 1° F. for every 50 to 60* feet of depth, or of 1° C. for every 30 mètres. Others take even a lesser rate of increase, and everyone must have felt the want of the greater certainty which can only be given by a restriction of the limits of variation to more definite bounds. I had already in connexion with work on artesian wells, and as a member of the Royal Coal Commission of 1866, in connexion with the "Possible Depth of Working," got together a considerable number of observations, and to those I have added a considerable number of others, many of them not before recorded. Although some of the earlier observations may seem to be of little value, I have thought it best to keep the record of all in the general list (Table I) for reference in case of need, as with corrected data respecting the surface temperature and height, some of them may possibly hereafter prove available. A list of all local observations may be useful also at any time for further research which is still much needed, particularly in connexion with artesian wells, which under all circumstances, appear to afford the best and surest index of underground temperatures.

I need scarcely say that I treat the subject solely from the geological point of view. For its physical and mathematical aspects, the papers of Sir William Thomson,† Professor Everett,‡ Professor Lebour,§ and the Rev. O. Fisher,|| should be consulted.

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* The more rapid gradient of 1° in 50 feet has been the one adopted by some physicists and geologists, but generally one of 60 feet to the degree, or even more, is adopted.

† "On the Reduction of Observations of Underground Temperature," "Trans. Roy. Soc. Edin.," (1860) vol. xxii, p. 405; "On the Secular Cooling of the Earth," *ibid.* (1862), vol. xxiii, p. 157.

‡ "On a Method of Reducing Observations of Underground Temperature," "Trans. Roy. Soc. Edin." (1860), vol. xxii, p. 429; "On Underground Temperature," "Proc. Belfast Nat. Hist. Soc. for 1873–4"; Reports of Committee of Brit. Assoc. for 1868–1884.

§ "On the Present State of our Knowledge of Underground Temperature," "Trans. North of England Inst. Min. and Mechan. Eng.," vol. xxxi (1882), pp. 59, 204.

|| "Physics of the Earth's Crust," Chapter I.

The subject of underground temperature is far from being new. It attracted attention a century and a-half ago, some observations having been made by Gensanne in 1740 in the mines of Alsace, which if we take the mean annual temperature at the mines of 47° F., give, curiously enough, an increase of 50 feet per degree Fahr.

Towards the end of the century, a few experiments were made by Saussure in Switzerland, and by Humboldt in America, but the more important ones were those made by Daubuisson in 1803, in the mines of Saxony and France, which gave a rate of increase varying from 54 to 72 feet per degree F. De Trebra carried on similar observations in one of the Saxony mines for two years, which, taking the surface temperature at 44°, show an increase of 57 feet per 1° Fahr.

Passing over some minor observations, we come to the series of careful and systematic observations commenced in Cornwall by Dr. Forbes and by Mr. R. Were Fox, about 1820, and which were carried on by the latter continuously until 1857. Other Cornish geologists followed, Mr. W. J. Henwood especially, who between 1837 and 1858, made a large number of experiments, not only in Cornwall, but also in the mines of South America. Notwithstanding that the instruments had not the perfection of those of later date, the observations are of great value, as they were conducted under very varied conditions, and with a full understanding of the various causes of interference to be guarded against. They show very considerable variations in the rate of increase with depth. Mr. Fox records a range for 1° F. of from 32 to 70 feet, from which De la Beche deduced a mean from 46 to 51 feet; and Henwood, while finding the results to range as widely as did Mr. Fox, nevertheless estimated from a large number of averages the gradient for 1° F. to be from 37 to 41 feet only.

In 1822, Cordier published his celebrated "Essai sur la Température de l'Intérieur de la Terre," and in this he recorded the observations previously made by Gensanne, Daubuisson and Fox, together with some observations made by himself in the coal-pits of France. The several results showed variations extending from 13 to 57 mètres per 1° C., but he concluded the mean to be about 1° C. per 25 mètres of depth.

Amongst the most careful of the early observations are those made by De la Rive and Marcet in an artesian well at Pregny near Geneva. In this case, the thermometer was protected against pressure, and the result gave a rate of increase of 48½ feet per 1° F.

This was shortly followed by Professor Phillip's well-known observations in the deep coal-pit of Monkwearmouth, Sunderland; great precautions were taken against error, and in the result an increase of 1° for every 62 feet of depth was obtained.

At this time a number of deep artesian wells were being made in France by Messrs. Degousée and Laurent and other engineers, and M. Walferdin invented an overflow maximum thermometer, which carefully guarded against pressure, gave excellent results, and which he employed to check many of the earlier observations made without this necessary precaution. The numerous artesian wells also made about this time in Algeria, Venice, and other parts of the Continent by Degousée and Laurent, gave important results. Those in Algeria seem to show that the rate of increase is there more rapid than in Europe.

Admirable discussions of the question were made from time to time by Arago: the last being that published in his "Œuvres Complets" in 1856. In this he reviews the whole subject, gives elaborate particulars of most of the recorded observations, with the advantage of more accurate surface temperatures, and concludes that the rate of increase is very variable, and may be taken at from 20 to 30 mètres for each degree centigrade.

In 1861 Sir W. Fairbairn gave an account of the observations, so frequently referred to, in the Dukinfield Colliery, where the rate of increase was estimated at 1° F. for every 79 feet.

Professor Hull also brought together in his "Coal Fields of Great Britain" (Edit. 1873), a number of observations made in the coal-pits of this country, and drew especial notice to the Rosebridge Colliery temperatures. The general conclusion at which he arrived was that the underground temperature varies, being much influenced by the dip of the strata, but may, as a mean, be taken at 60 feet per 1°.

The Royal Coal Commission of 1866–70 was the means of obtaining through its Committee "On the Possible Depth of Working," a mass of most valuable evidence from practical coal-owners, inspectors, and managers, relating to the temperatures at depths in the coal mines of Great Britain. The general opinion of these gentlemen was that the temperature increased at the rate of about 60 to 63 feet for each degree F., and the Committee concluded that the rate of increase of the temperature of the strata in the coal districts of England is in general about 1° F. for every 60 feet of depth.

In 1867 a Committee of the British Association was appointed (at the suggestion, I believe, of Sir W. Thomson) "for the purpose of investigating the Increase of Underground Temperatures downwards in various Localities of Dry Land and under Water," with Professor Everett as secretary. To this Committee we are indebted for a series of sixteen very valuable annual reports, in which are recorded a large number of observations carried on with corrected instruments supplied by the Committee, and under the able superintendence of its secretary. Each set of observations is discussed at length; the causes of interference are considered; and detailed particulars are given of all the conditions of depth, strata, isolation, &c., under which they were made.

In the summary of results given in the Report for 1882, Professor Everett, after describing the instruments used, the methods of observation, and the many questions affecting the value of the observations, such as the heat generated by the boring tools, or by chemical action, the effects of ventilation, the convection of heat by air and water currents, &c., proceeds to a comparison of results. Taking the list of 36 localities of which Professor Everett gives the recorded results, and classifying them as—1. Metallic Mines; 2. Coal Mines; 3. Wells and Wet Borings; 4 Tunnels; he found that in the—

Metallic Mines, the increase of temperature with depth varied from 1° F. in 47 feet to 1° in 126 feet;

Coal mines, the range was 1° F. in 45 feet to 1° in 79 feet;

Wells and borings gave from 1° F. in 41 feet to 1° in 130 feet, or excluding the wells of La Chapelle and Bootle, which are open to suspicion of convection currents, the least rate of increase was 1° in 69 feet;

Tunnels. In the only two great tunnels in which observations have been made, that of Mont Cenis gave an increase of 1° for 79 feet, and that of St. Gothard of 1° for 84 feet, but in a subsequent report Dr. Stapff has shown that an important modification is necessary for a portion of the tunnel.

In deducing a mean from these various results, Professor Everett has considered it best to operate not upon the number of feet per degree, but upon its reciprocal—the increase of temperature per foot; and assigning to the results of the observations at the thirty-six localities of which he gives the list, weights proportional to the depths, he finds the mean increase of temperature per foot to be 0·1563, or about $\frac{1}{64}$ of a degree per foot—that is, 1° F. in 64 feet.* In the subsequent report of 1883, however, taking the corrected readings of Stapff for the St. Gothard and Mont Cenis tunnels, this mean is reduced to 1° F. in 60 feet.

Scattered observations have also been made within the last few years in different parts of the world, some in particular of much interest on the deep hot artesian well of Buda-Pesth, by Professor Szabo, and by others in America and elsewhere; while temperatures of a number of ordinary wells have been taken by the Rivers Pollution Commission. Amongst those to whom I am indebted for furnishing me with observations in wells and mines in their respective districts,

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* Professor Everett observes, however, in a previous paper (1874) that some of the best observations give a rate of about 1° F. for 56 feet of descent, and that this seems a fair average.

not hitherto recorded, are Professor G. Dewalque of Liège, Professor Gosselet of Lille, M. F. L. Cornet of Mons, and others.

Professor Lebour has further discussed the subject, with reference especially to the nature of the experiments still required to improve our knowledge of it, in an interesting paper read before the North of England Institute of Mining and Mechanical Engineers, in 1882. In this he gives a list of observations made at fifty-seven localities, and deduces from them an average rate of increase of 1° F. per 64·28 feet of descent; but he remarks that all the observations recorded are by no means of equal value, and points out that the mean rates of increase in the best observations cluster about the numbers 1° F. per 50 or 60 feet.

General List. (*Table I, p.* 56.)

I have given in a general list all the observations on underground temperatures of which I have been able to find a record.* The number of different localities, mines, &c., where such observations have been recorded, amounts to 248, and the number of stations† to 530. I have only omitted a few which were obviously wrong, together with some of the observations repeated frequently in the same mine, or repeated more frequently than necessary for our object in mines in the same district, and which would only add needlessly to the length of the list.‡ Neither have I considered it necessary to give in all cases the full details of the observations, as these will be found in the original papers referred to. I have confined myself to giving the principal and essential facts and results.

The observations are given in the order of date, an order which, as a general rule, agrees with that of their reliability, although there are several remarkable exceptions. The superiority of the later observations consists chiefly in the perfection of the instruments and methods of experimentation. Most of the more general disturbing causes interfering with accuracy of the results were well understood and guarded against by the early observers.

The particulars of depth, temperature, and modes of proceeding, are given in the terms of the original observers. On two points only, on which their information was often unavoidably imperfect, have I made any alteration—points which even now are in many cases not accurately determined—viz., the mean annual temperature of the surface, and the height of the surface above the sea-level. These

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* I should feel greatly obliged by information respecting any other observations.

† By "station" I mean all the separate points in a mine, or at the several depths in a well, at which the observations have been made.

‡ Mr. Henwood's long and valuable series of observations in the Cornish and foreign mines will be found in vols. v and viii, "Trans. Roy. Geol. Soc., Cornwall." I have given all his principal instances.

alterations will account for occasional differences in the thermometric gradients, between the observations as originally recorded and as given in these lists, which in most cases will be found referable to my taking a different mean annual temperature to that used by the original observer.

HEIGHT OF THE SURFACE.—As this influences both the surface and underground temperatures, it is important that it should be determined with precision. This is not always possible, although the later publications of the Ordnance Survey have in many cases furnished us with levels, which, if not at the precise spot, are sufficiently near to form, with a knowledge of the country, a near estimate; but not unfrequently mines are in out-of-the-way places, where only roughly approximate estimates can be made. Several of the surface heights given in this table necessarily come into this category, and are therefore subject to future correction; while there are many cases in which I am unable to give even an approximate height.

MEAN ANNUAL TEMPERATURE.—This is a point on which it is indispensable to have exact information, for it is one in which the difference even of one or two degrees materially affects the calculations. There are yet, however, many of the places in the lists, where satisfactory information is wanting, and the accepted temperature may therefore require revision. For places on the Continent, the works of Arago,* which embody all that was then known of the mean temperature of places, both in France and other parts of the world, are of great value. The publications of the Meteorological Society of Scotland have done much to give us exact data respecting the mean temperature of places in Great Britain,† and I am further indebted to Mr. Robert H. Scott, of the London Meteorological Office, for valuable information respecting the latest recorded mean temperature of places both in this country and on the Continent. There are, besides these, the older and more general tables of Dove.

Where the temperature of the locality cannot be had, that of some place near and on or near the same level has been taken. Where there is an important difference of height between the place at which the surface temperature has been taken and the site of the underground experiment, an approximate allowance of one degree F. (+ or −) is made for every 300 feet of difference of level. When, however, as is sometimes the case, a mean annual surface temperature is not obtainable, a near approximation may often be made by means of ordinary surface wells of about 40 to 50 feet deep, and springs. This plan has been, especially in the earlier observations, frequently adopted.

What is really desirable is that the datum line whence to commence

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* "Notices Scientifiques," vol. v, p. 518. Edit. 1857.

† Especially the number of Journal for November, 1883.

the measure of the increase of temperature with depth, should be placed at that point below the surface, at which the changes of annual temperature cease to have effect. Any such determination* might also with advantage be applied to the correction of the past observations.

In the absence of this information, we have for the present to be satisfied with the mean surface temperature, where known, and take that as the datum line from which to calculate the descending rate. Sometimes this has been the mode adopted, and the gradient calculated from the surface; at other times it has been calculated by supposing the mean invariable surface-temperature to lie at a depth of 50 feet, and taking that as the datum level from which to start. Thus, some of the original estimates have been founded on calculations commencing from the surface, and others at 50 feet beneath it.

Either, therefore, some of these estimates are too high in consequence of the deduction of 50 feet from the depth, or others are too low in consequence of not making an allowance for the zone of variable temperature. But as the mean annual temperature of the ground at the surface generally in these latitudes exceeds that of the air by about 1°, it follows that if we take the mean temperature of the air at the place of observation, and calculate the rate of increase from the surface, instead of allowing 1° for the higher temperature of the ground and with a datum line 50 feet lower, we shall come to nearly the same result. At the same time it must be admitted that in so doing, we may sometimes be liable, especially with stations of moderate depth, to make the rate of increase with depth less than it should be. It is therefore the more important in future observations to determine if possible the temperature at a depth of 50 to 60 feet—or where the first bar of uniform temperature may happen to be—and to calculate from that point the rate of increase of temperature with depth. Failing this, starting from the surface with the mean annual temperature of the place will no doubt give an approximate result. Thus the mean temperature of Paris is 51° F., and the temperature of the cellars of the Observatory at a depth of 95 feet is 53° F., or 2° higher, so that if in this instance, whether we start with a surface temperature of 51° or a temperature of 52° at a depth of 50 feet, the result would be almost exactly the same.

In looking over Table I, the essential differences in the results obtained in Mines, Coal-pits, and Artesian wells will be at once apparent. This arises both from the circumstance that not only in each of these

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* This was done in the case of the experiments at Grenelle, where a datum line based on the temperature and depth of the cellars of the Paris Observatory was employed. These are 29 mètres (95 feet) deep, and the thermometer stands invariably at 11·7° C. (53° F.), the mean annual temperature of Paris being 10·6° C. (51° F.). This is, however, a greater depth than necessary.

are the geological conditions very dissimilar, but also that the disturbing causes are of a different order. In Mines, the latter are attributable to—

1st. Air currents established for ventilation, and by convection;
2nd. The circulation of underground waters;
3rd. Chemical reactions;
4th. The working operations.

And in Artesian Wells, to—

1st. The pressure of the column of water on the thermometer;
2nd. Convection currents in the column of water.

While a general cause affecting each group is conductivity, which variably influences all the rocks, and which is itself liable to be influenced by a number of causes to which we shall refer separately.

We shall be able therefore to deal more readily with the subject, if, as Professor Everett has done, we divide the observations in Table I into groups in accordance with these considerations, and take each separately in the following order:—

I. Coal Mines.
II. Mines other than coal.
III. Artesian Wells and Bore-holes.
IV. Tunnels.

I. Coal Mines. (*Table II, p.* 88.)

Considering the general uniformity of geological structure of the Coal-measures, the temperature observations in coal mines are more discordant than might be expected. This depends upon various causes, of which ventilation is seemingly the principal, while in some cases differences of conductivity may possibly have influenced the results. It is true that in most cases the sources of error have been carefully guarded against, but it is doubtful whether in others sufficient allowance has been made for them, and whether in some they have not altogether been overlooked. The main disturbing causes are as follows:—

Loss of Heat through Exposed Surfaces.—To guard against the cooling of the coal or rock produced by ventilation, it has been customary to place the thermometer in holes 2 to 3 feet deep, but it is a question whether this is sufficient, for we are rarely informed, as is essential, of the precise time that the face of the coal or rock has been exposed. Even in the best observations we are only told that they have been made in "freshly exposed faces," which may or may not be sufficiently soon. For on these working faces the ventilation is necessarily well maintained, and consequently the difference between the temperature of the air and of the strata is there often most considerable, and the cooling of the rock very rapid.

On the surface of the ground the diurnal variation of temperature extends to the depth of about 3 feet, and it has been shown by means of thermometers sunk in the grounds that at a depth of[*]—

1 foot the monthly fluctuation is from 33° to 54·0° or = 21·0°
2 feet „ „ „ 36 to 52·5 or = 16·5
4 „ „ „ 39 to 51·8 or = 12·8
8 „ „ „ 42 to 50·0 or = 8·0

At the depth of 29 feet at Greenwich, the annual fluctuation is still 2° to 3° F., and to reach the limits of range, or where it is at last reduced to $\frac{1}{16}$th of a degree F., we must go in this climate to a depth of from 50 to 80 feet.

Now it is evident that, owing to ventilation, there is a permanent difference between the temperature of the air in a mine and the temperature of the rock, analogous to the diurnal variation on the surface of the ground, and that its effects will extend with equal, if not greater, rapidity in the one case as in the other.

Any surface of rock exposed to air of a lower temperature will lose heat with a rapidity proportionate to the difference in temperature between the two bodies and to the conductivity of the rock. Therefore as convection currents and ventilation are constantly introducing into the shaft and mine air of a lower temperature than the underground rocks, these latter must suffer a loss of heat from the moment they are so exposed. To avoid this, the best observers have, as just mentioned, operated in freshly exposed surfaces, where the loss is at a minimum: on the other hand, numerous observations have been made on surfaces exposed for a length of time and often under conditions of which we are not informed.

Thus in the well-known case of the Dukinfield Colliery, near Staleybridge, it is stated that the bore-holes were driven to such a depth as to be unaffected by the temperature of the air in the shaft, and the thermometers were left in the holes from $\frac{1}{2}$ to 2 hours; but we are not informed of the depth of the holes, nor of the temperature of the air in the shaft, nor of how long the rock had been exposed. We know only that the shaft, which was a very large one and carried to a depth of 2151 feet, took 10 years to sink. At this depth the temperature of the rock was 75° F., and the estimated rate of increase was calculated to be 99 feet for 1° F. The observations were carried on during the whole of the time that the work proceeded. Although we do not know the temperature of the air, the action of convection currents or of ventilation is clearly shown in the irregularities of the rock temperatures in summer and winter, even at great depths. Thus, on the 12th June, 1849, the shaft had reached a depth of 704 feet, and the rock temperature was 58°. The same temperature was noted with slight fluctuations until the 22nd December, at which time the

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[*] Prof. James D. Forbes, "Trans. Roy. Soc. Edin.," vol. xvi, p. 189.

depth had been reached of 810 feet. In February, 1857, at a depth of 1450 feet, the temperature was 67¼°, which rose with abnormal rapidity to 72¾° in August, at a depth of 1689 feet. It then slightly decreased, partly recovering and ending in October at 72¼°, when the depth was 1840 feet. In March, 1858, it had fallen to 71½° at 1881 feet, and then rose by July, at 2055 feet, to 75½°. After the winter, in March, 1859, at 2151 feet the thermometer stood at 75°, or half a degree less than it did in July at a depth of nearly 100 feet less. I can only attribute these fluctuations to the influence of the seasons and convection currents, or to some unmentioned form of ventilation. A new shaft sunk in 1858, not far from the other, gave, in the same way, analogous results, viz., an increase of 1° F. for every 90 feet.

When, however, at a subsequent period, and when the works of this colliery had been carried to the great depth of 2700 feet, observations were made in galleries at a distance from the shaft, with instruments furnished by the British Association Committee, and in holes 4 feet deep, an amended reading of 1° for every 72 feet was obtained. Still that rate of increase is slow, and Professor Everett has drawn attention to the fact that there are other collieries such as those of Ashton Moss, Denton, and Bredbury, within a few miles of Dukinfield, in which the results are in close agreement with those obtained in the latter. It has been suggested in explanation of this, that the rapid dip of the strata at Dukinfield facilitates the transmission and escape of heat. It is quite possible that this cause may have an influence, as the experiments of Herschel and Lebour have shown experimentally that the conduction of heat is more rapid along the planes of cleavage, or bedding, than across them. Nevertheless no such difference exists in other mines where the stratigraphical conditions are alike; the strata in the Liège, Mons, and Valenciennes coalfields (Nos. 140, 214-16, 145) are more disturbed, and dip at more rapid angles than at Dukinfield, and yet the deep temperatures there give no such slow rate of increase.

Again, Mr. Garside draws attention to the circumstance that the Red Sandstone, overlying the Coal-measures in the area, is highly charged with water, which is largely drawn upon for water supply. This may reduce the temperature of that mass of rock, but the effects would hardly reach to the great depths and extent observed.

Some of the anomalous results may also be attributable partly to the excellent ventilation of these deep pits. At the Dukinfield Colliery, about 58,000 cubic feet of air circulate through the pit per minute. The mean annual temperature of the air at the surface is 48° F., while the return air from the pit has a temperature of 73°. But then again the ventilation at Rosebridge and other large pits—where the rate of the increase of temperature is more rapid and nearer the probable normal—is not less carefully attended to. Still, that ventilation has a preponderating influence is shown by an experiment of Mr. Wynne, who found that in a rise of the Dukinfield Colliery, where owing to defective ventilation the temperature of the air and rock were both 76°, the rate of increase from the surface gave only 55 feet per degree.

Other causes have also been suggested for the lower temperature of the Dukinfield pit. Mr. Dickinson states that before the shaft was sunk, two of the principal seams of coal in the upper part had been worked away from other pits, and that the lower seams had been worked a long way from the outcrop down towards the Astley pit.*

The Dukinfield observations, therefore, while they confirm the general law of increase of temperature with the depth, are scarcely admissible in estimates concerning the exact rate of increase of temperature with the depth, and it would be safer to omit them in such calculations.

I do not mean to imply that good observers have or would select long exposed and cooled surfaces, but others have done so, and my object here is to show that cooling must at once commence, and that it is difficult to escape in any part of the pit, or however early the experiments are made, from the effects of ventilation. It is not a question of weeks or months, but of days, if not hours.

Effects of Ventilation.—The evidence given before the Committee of the Royal Coal Commission of 1867, "On the Possible Depths of Working," is particularly valuable for the information it affords respecting the effects of ventilation.

At the Pendleton Colliery (Nos. 104 and 122), near Manchester, the coal in a level 500 yards from the down brow, had a temperature of 70°, and at 1000 yards distant, in the same level, and when just opened, it had a temperature of 83° F.

At the Rosebridge Colliery, Wigan, the temperature of the Raven coal in the shaft was 78°, whilst at 630 yards distant it had a temperature of 88°. The air at the bottom of the down-shaft at a depth of 1800 feet was 60·5°, and, after circulating 1500 yards, 73°. At another time it was 51·5°; after circulating 2400 yards, 67·5°; and after 3140 yards, 71°. In July, 1858, the strata at the same depth had a temperature of 80°; in March, 1861, it was reduced to 72°.

At the Annesley Colliery (No. 106), Nottinghamshire, a fresh cut coal at a depth of 1425 feet had a temperature of 73°, and six months later it had fallen to 64°. In another case, the coal cooled 11° in three months.

The volume and velocity of the air currents vary greatly. In one place a circulation of 5000 cubic feet per minute is recorded. In another pit the circulation was 100,000 cubic feet per minute, while

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* Coal Commission Report, vol. ii, "Depth of Working."

in the upcast shaft, 7½ feet in diameter, of another pit, 150,000 cubic feet of air passed per minute.

At the Hetton Colliery (No. 116), Durham, the dependence of the temperature of the strata upon distance from the shaft, in connexion with ventilation, is well shown in a table by Mr. Wood, of which the following is an abstract.

Surface temperature at date = 36°. Holes in coal 3 feet deep.

Depth from surface.	Distance from shaft.	Cubic feet of air per minute.	Temp. of coal.	Temp. in current of air.	Rate of increase in depth for 1° F.
1100 feet	312 yards	104,000	60°	50°	100 feet
1270 „	915 „	50,000	63	58½	91 „
1360 „	1640 „	18,600	66	62	80 „
1354 „	3664 „	3,200	68	68½	67 „
1400 „	3550 „	4,972	70½	72	64 „
1395 „	4332 „	5,000	71	73	63½ „

In this case we have four observations made nearly at the same depth, and yet showing a rate of increase with depth varying from 80 feet to 63½ feet for 1° Fahr.

In the Seaham (Durham) Colliery the circulation of air is very large,—193,346 cubic feet per minute. At a depth of 1524 feet and 1642 yards distant from shaft, the temperature of the air was found to be 61°: at 2726 yards distant and at the same depth it was 67°; and at the face of the coal 82°. The temperature of the return air=76½°.

At the Eppleton Colliery, Durham, in October (?) the temperature of the air at the intake at a depth of 850 feet and 110 yards distant from shaft was 44°, and after circulating 1960 yards, 59½°, or an increase of 15½°.

Some joint observations by Mr. Wood and Mr. Dickinson in the Monkwearmouth Colliery (No. 30), Sunderland, gave the following results. 29th March, 1870. Temperature of surface = 42°.

Depth.	Distance from shaft.	Temp. of the air.
1676 feet	Bottom of down shaft	50° F.
1676 „	.... 2134 yards	66 „
1638 „	.... 2850 „	74 „
1646 „	.... 3112 „	81 „
1640 „	.... 4030 „	82 „

This pit is so dry that it requires water to lay the dust.

Mr. Dickinson found that at a depth of 2088 feet in one of the Pendleton pits the temperature at 500 yards from the engine brow was 78°, and at 1000 yards distant 82°. In the same pit at a depth of 2214 feet and distant 200 yards from the engine brow, the coal in a hole 3 feet deep was 76°, and at a distance of 930 yards 82°, while in a hole 7½ feet deep the temperature was 84°. The general opinion amongst the witnesses seemed to be that the effect of ventilation was to reduce the temperature of the pits some 9° to 10° F., though some estimated it at as much as 15° to 20°.

The effect of exposure is well shown in the following records from one of the pits at Ruabon.

		Temperature		
			in holes 3 feet deep	
Temp. of air at date on surface.	Depth.	of air in gallery.	of coal.	of bed below coal.
60°	1002 feet	58·0°	60·0°	67°
62	1503 ,,	58·5	70·5	68
57	1605 ,,	71·0	73·0	77
65	1770 ,,	71·0	78·0	74

No other particulars are given. The rate of increase here for the first 1000 feet is 1° for every 95 feet, whilst for the whole 1770 feet the rate of increase is 1° for every 61 feet. This is clearly due to the circumstance that the shaft had long been sunk to 1004 feet and the mine cooled, and only recently opened to 1770 feet.

Mr. Lupton mentions that in a pit 1425 feet deep, the fresh cut coal had a temperature of 73°, whereas at the end of six months it had fallen to 64°. In another case a period of three months had sufficed to reduce the temperature 11°.

After the air in the pits has circulated a certain distance (estimated by one of the witnesses at one mile), it may become in the face of the workings hotter than the rock; while the difference, which arises from the heat of the lights and the men in an instance given, does not exceed +2°.

The extent to which the temperature of the air affects that of the coal is also shown in the table of experiments, given on next page, made by Mr. Wood in another Durham Colliery (No. Report, p. 140). Here the difference between the coal and the air in the part of the pit through which the intake air circulates, is from 4° to 6½°, or an average of 5°; whereas in the return air at the same distances from the shaft, the differences are reduced to an average of 1¼°.

In the Crumbouke mine the face of the coal which had been worked two years had, according to Mr. Dickinson, lowered 4°. A similar loss was shown at the Rosebridge Colliery, but after a longer interval. In an adjoining pit, the difference between the temperature of the air in the galleries and of the coal varied from 10° to 12½° F.

At the Rosebridge Colliery other observations made three, four, and nine years after opening the colliery showed, that at 1410 feet deep, and 200 yards from shaft, the temperature of the coal was = 66° F., and at 360 yards = 70° F., while at 1800 feet deep and 215 yards

Jane Pit, Hetton Colliery. Depth below surface.	Circulation of air per minute.	Distance from shaft.	Temperature of				Temperature (the mean annual surface being 47°) calculating	
			Intake air.	Coal.	Return air.	Coal.	1° for 60 feet of depth.	1° for 50 feet of depth.
feet.	cub. ft.	yds.						
1080	41,800	410	58½°	65°	70½°	68°	65°	68½°
1270	41,580	955	59½	65	71	73½	68	72½
1320	30,030	1247	62	66½	69½	72	69	73½
1360	28,000	1640	63	67	70	72½	70	74¼
Average 1357½	35,352	1063	60¾	65¾	70¼	71½	67½	72¼

from shaft the temperature of coal was = 65° F. Mr. Bryham states that the reduction of temperature effected in this pit by ventilation amounts to from 15° to 20° F., or even more in a strong current.

Other returns give the column of air circulating through the pits at from 50 to 150 million cubic feet in the twenty-four hours, with a gain of temperature of from 10° to 20° F., which shows how great the abstraction of heat from large and well-ventilated coal-pits must be. These effects are rendered very apparent by some tables put in by Mr. Lindsay Wood, of which the following is an abstract:—

	Depth below surface.	Distance from downcast shaft.	Intake air, cubic feet per minute.	Temperature of	
				Intake air.	Return air.
	feet.	yards.		Fahr.	
Eppleton Colliery, Durham, 13th Oct., 1869. Mean surface temp. = 53° F.	1100	312	78,720	61·0°	70°
	1450	2925	11,550	69·0	
	1395	4130	4,500	72·0	
Working face	”	4440	”	74·0	
The same pit *off work*, 23rd Oct., 1869. Surface temp. = 52° F.	1100	312	52,200	57·5	69
	1395	4130	3,240	71·5	
Monkwearmouth Colliery, 25th Oct., 1869. Surface temp. = 45° F.	1676	80	38,250	56·5	77
	1646	1430	71,500	63·0	
	1638	2850	5,000	75·7	
Working face.......	1646	3256	”	81·2	
Murton Colliery—*off work*.	1339	410	76,160	54·0	68
Working face.......	1374	4400	1,600	70·0	
Surface temp. = 50°.					

Even in the two pits off work, we have in the one instance 44,550 cubic feet of air passing out per minute, with a gain in temperature above that of the outer air of 17° F., and in the other case 25,500 cubic feet pass out with a gain of 18° F.

In these instances the temperature of the outer air was only in one observation under 50° F. At other seasons of the year, with the outer thermometer lower, and with the difference of temperature between the circulating air and the strata greater, the loss of heat would proceed still more rapidly. Mr. Forster mentions that he has known ice form at the bottom of a coal shaft, and Mr. Bald, speaking of the Whitehaven Collieries, states that the circulation of air sometimes causes the water to freeze on the sides of the shaft, and "even form icicles upon the roof of the coal within the mine," whilst the air from the rise-pit issues in a dense misty cloud.

In consequence of the allowance necessary to be made for these effects of ventilation, some of the witnesses, while taking the actual rate of increase at about from 50 to 60 feet for each degree F., considered that the normal rate might not be more than 50 feet per degree.

As a rule, the deeper the mine the greater must be the ventilation, and therefore, the more rapid must be the cooling of the underground strata. But the amount of ventilation depends also not only on depth, but on the quantity of gas present in the coal. Mr. Warington Smyth says,* that "in round numbers 100 cubic feet of air per minute may be required for the health and comfort of each person underground, or for 100 men, 10,000 cubic feet; but if fire-damp be given off—say at the rate of 200 cubic feet per minute—we should need at the very least thirty times that amount of fresh air to dilute it, or 6,000 cubic feet in addition. Increase the number of men and liability to gas, and 40,000 to 60,000 cubic feet of air may be indispensable for safety."

It is evident, therefore, that the rate of cooling from ventilation in different coal mines and at different depths is likely to be very variable. The greater the heat and the more gas in the coal, the more rapid will be the cooling, and this may possibly account for the great discrepancies between the thermometric gradients at different collieries. Until, however, we are in possession of all the collateral conditions, it will not be possible to assign in each instance, the precise weight to be attached to this disturbing cause.†

Other Causes which may affect the Temperature of the Coal Strata in Underground Workings.—Apart from the chemical decomposition of

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* "Coal and Coal Mining," p. 205.

† Mr. W. Warington Smyth gives, in his Anniversary Address to the Geological Society in 1868 (pp. 79—87), some interesting particulars respecting ventilation and other causes affecting underground temperatures.

minerals, which is of rare occurrence in coal mines, and the heat arising from the men, horses, and lights, which can only be of importance in shallow mines, for in deep mines it is rarely that that source of heat brings up the temperature of the air to the normal temperature of the rock, there are few causes likely to produce an abnormal rise of temperature. There is one, however, which though of exceptional occurrence, should be noticed in connexion with this subject, and that is the heat produced by the crushing of the rocks which sometimes takes place in coal mines.

The Crushing of Rock.—It is certain that in coal mines where pillars are crushed and the strata pressed up in *creeps*, more or less heat is liberated. No experiments, however, have been made to determine what, in these cases, are the exact effects produced, but some of the evidence given before the Coal Commission fully establishes the general fact. Mr. Elliot,* in speaking of one of the pits in South Wales, mentioned that when "a creep takes place, he has known the temperature very much increased," and in one case where "the pressure began to crush the pillars, the heat produced was so great that he feared it would set fire to the coal." In some cases the pressure has been such as "to grind the rock to powder, like the effect of a dozen mill-hoppers, and this was accompanied by considerable heat." He had often found the air very hot when a sort of temporary creep occurred.

Escape of Gas.—On the other hand, a cause productive of a loss of heat is a more constant disturbing cause. There are few coals which do not give off gas when first exposed. In some seams it may be observed exuding from the freshly broken surfaces with a hissing sound; and, if in large quantity, as in the case of the so-called "blowers," or sometimes near faults, it issues with a rushing noise like the steam from a high-pressure boiler. Some of these blowers will be exhausted in a few minutes, others will last for years—like that at Wallsend, which gave off 120 feet of gas per minute.† The common gas on these occasions is light carburetted hydrogen. It must exist in the coal under the enormous pressure either highly condensed, if not in a liquid state, otherwise it is hardly conceivable how the discharge could be maintained so long. The pressure of this gas is said to equal sometimes 300 to 400 lbs. to the square inch.‡

In any case the escape of this gas from the coal, in which it apparently exists in an infinite number of small cavities, must be to

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* Coal Commission Report "On Possible Depths of Working," p. 112.

† "Coal and Coal Mining," p. 204.

‡ [Sir Frederick Abel states that, if cavities are bored into the coal and plugged, the gas speedily accumulates so as to exercise a pressure of several hundred pounds upon the square inch, as indicated by pressure-gauges fixed into the cavities. "Nature," December 3rd, 1885. Under this enormous pressure we do not know what the critical point may be.—January, 1886.]

reduce the temperature of the body from which it escapes, though here again no special experiments have been made to ascertain the exact loss of heat from this cause. I find, however, one of the witnesses* on the Coal Commission remarking that in a pit the depth of which had been increased from 830 to 1588 feet, the temperature of the coal was lower at the greater than at the lesser depth, and he attributed this to a strong blower of gas issuing from the coal, which at that point was sensibly cooler to the touch.

On a Table also put in by Mr. Elliot, and referring apparently to the same case, it is stated that,—

In the Lower Duffryn Mine at a depth of......	1588 feet,
—and distant from shaft......	1850 yards,

the temperature of coal in a wet hole with a blower of gas was 62° F., whereas it was found that—

At a depth of..............	1269 feet,
Distance from shaft........	1020 yards,

the temperature in a dry hole with little gas was 74° F.

At the Cym Neol Colliery, at depths of 990 and 1150 feet, and 1350 and 1070 yards distant from shaft, the temperature was respectively 62° and 65°, which is abnormally low, but it is stated that the observations were made in wet holes *with blowers.*

This escape of gas from the body of the coal may account for the observation of another witness to the effect that "the coal gives out heat quicker than the rock," and that the temperature of the coal is, on the whole, less than that of the associated rocks. In several cases observations have been made in the same pit, both on the coal and on the underlying shale, and generally the temperature of the rock has been found to be higher than that of the coal. In the Rams Mine, Pendleton, for example, the temperature of the coal in a hole 3 feet deep was 82° F., and in the floor 83° F.; in the Crumbouke Mine the coal was 80° F., and the floor 82° F.; and in other levels it was 80° and 80°, and 78° against 82° F. In one of the Ruabon collieries the relative temperatures varied as follows:—

Depth	1002 feet;	temperature	= 60° F. in coal,	and	67° F.	in floor.
,,	1503	,,	,,	70½	,,	68	,,
,,	1605	,,	,,	73	,,	77	,,
,,	1770	,,	,,	78	,,	74	,,

As the conductivity of the coal (0·00068) is less than that of sandstone (0·00672) or shale (0·00235), the coal should retain its heat longer than the rocks. If the coal is cooler than the rock, it must

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* Mr. Wilmer: "Coal Commission," p. 118.

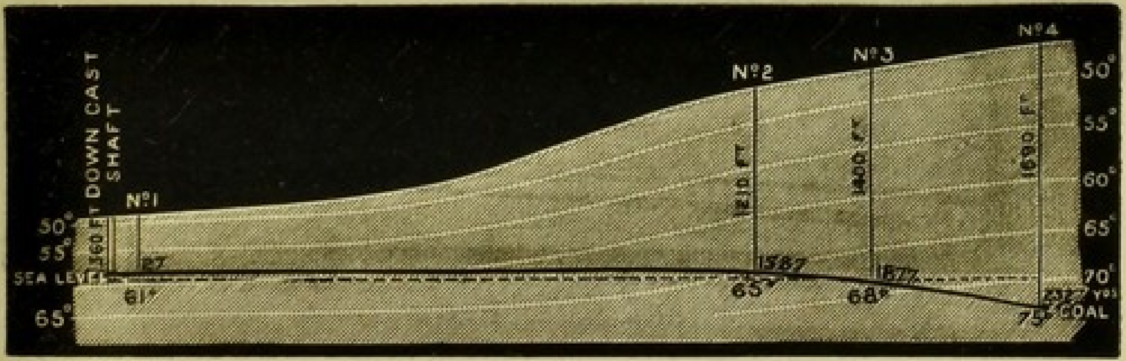
arise from an independent source of cooling in the coal, such as that just mentioned which would be caused by the escape of gas condensed under great pressure. It is an effect important to notice, inasmuch as not only is the discharge of gas from coal of frequent, and often constant occurrence, but also from the circumstance that it affects especially the fresh opened surfaces of coal in which the temperature observations have so commonly been made.

The Effects of Irregularities of the Surface.—Although it was known that the underground isothermals under mountain masses are not prolonged in horizontal planes, but follow in a certain ratio the curves of the ground above, little was known to what extent mines were affected by the smaller irregularities of the surface until Mr. George Elliot, M.P.'s experiments in coal pits in Glamorganshire, showed that there is a sensible increase of heat with an increase in the mass of the superincumbent strata. This important point has been rarely, or never sufficiently, taken into consideration in any of the underground temperature observations.

The following observations and sections of Mr. Elliot* laid before the Coal Commission were mostly made in abandoned parts of the pits, so as to avoid as far as possible both the effects of ventilation and of working, and the holes, in which the thermometers were placed, were 4 feet deep. Only the depths and temperature of the coal are given in the original sections. I am responsible for the isothermal lines which I have plotted on these data, for the purpose of showing the more precise manner in which the temperature at depths is influenced by the surface heights.

At Upper Duffryn Colliery, in South Wales, the top of the shaft is 400 feet above the sea level, and the shaft 360 feet deep. The seam of coal has been followed southward for a distance of 2327 yards, at which point it is 190 feet lower in respect to the sea level than at the entrance. This difference might account for a lowering of 3° to 4° in the temperature, but not for the difference of 14°, which is due to

FIG. 1.—Section at Upper Duffryn, Aberdare District.



Rise

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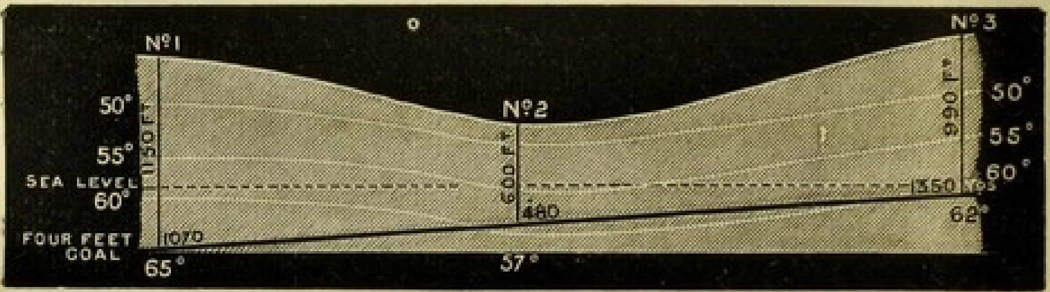
* "Coal Commission Reports," vol. ii, p. 105—111.

the circumstance that at this point the surface of the ground has risen so much that the seam of coal lies 1690 feet below the surface, or 1330 feet lower than at the bottom of the shaft. The distance from the shaft might partly account for this difference, but only partly for that between stations 2, 3, and 4.

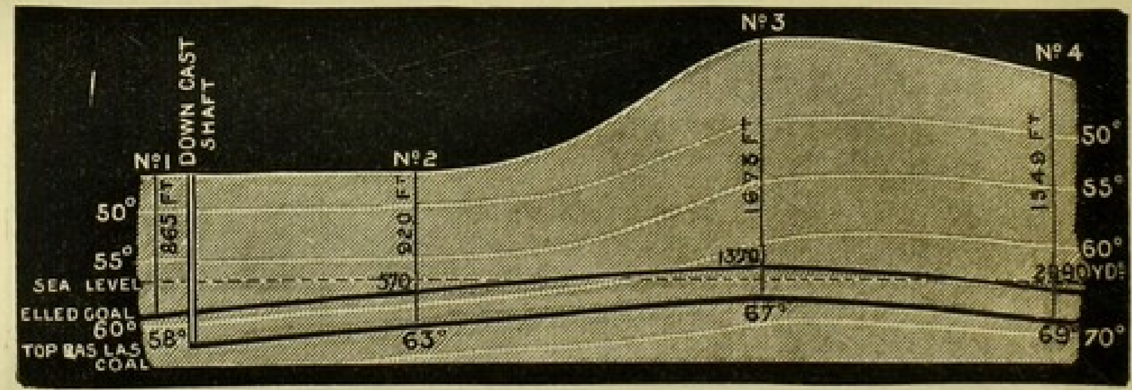
At the Cym Neol Colliery one station is under a valley, and two under the adjacent hills, rising about 500 feet above the valley. No. 2 station is only 480 yards distant from shaft (not in section), against 1070 from Station No. 1, and 1350 yards from Station No. 3. At that time the temperature of the outer air was 69° F.

FIG. 2.—Section at Cym Neol, Aberdare District.



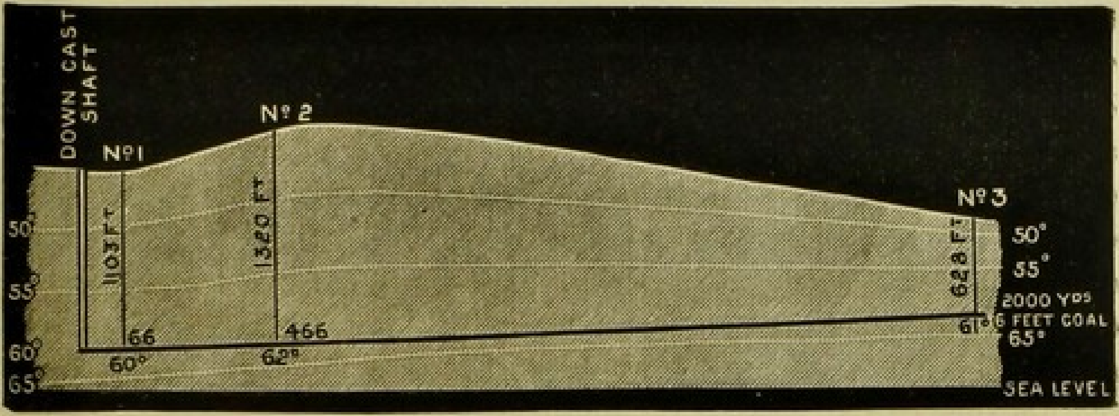
In a similar way the New Tredegar Colliery is situated in a valley 670 feet above the sea level, and the works pass under a hill which rises 617 feet above the valley, with the effect of raising the temperature of the same coal 11° F., though 2° to 3° of this may be owing to distance from shaft. At the time the thermometer outside stood at 60° to 70° F.

FIG. 3.—Section at New Tredegar, Aberdare District.



At the Vochriw Dowlais Colliery, on the other hand, the top of the shaft is on a hill 1330 feet above the sea level, and the seam of coal, which there lies 1103 feet below the surface, is followed first under a hill which rises 217 feet above the pit mouth, and then under a valley only 818 feet above sea level, or 512 feet lower than the pit mouth. Notwithstanding the distance of Station No. 3 from the shaft, the fall of temperature due to the fall of the surface is apparent, though the temperature at Station No. 2 is too low, which the witness attributed to a strong current of air passing at the time. Outside the thermometer marked 59° F.

Fig. 4.—Section at Vochriw Dowlais, Aberdare District.



It will be noticed that the observations in all these pits were made when the thermometer outside stood high, so that the cooling effects of the outer air would be less at the stations near the shaft than at other seasons.

There is no other coal-field in Britain so hilly as that of South Wales; still it frequently occurs that a shaft is sunk in a valley, and the works pass under adjacent hills (or the reverse), which though not so high as those of Wales, are of sufficient height to influence the temperature more or less.

Many of these are points which have commonly not been noticed in the discussion of this question, yet they must not unfrequently have influenced the observations. In all coals there is an escape of gas when first opened out, and in some it is very large, as in several of the South Wales pits; others are merely called "gassy," and there fewer precautions are required. Amongst the pits in England, where recorded temperature observations have been made, and which are situated in districts sufficiently hilly to be affected by irregularity of surface, are the Dukinfield and some of the pits in the Manchester district.

Selection of Observations.—It will be apparent from the existence of these many disturbing causes, that not only should we know that the instruments employed are properly constructed and properly used, but we should also in all cases know,—1st. Height of the ground above the sea level. 2nd. The exact mean annual temperature of the surface. 3rd. Depth beneath the surface of the ground of each station where the observations are made. 4th. Distance of those stations from the shaft. 5th. Temperature of the air and volume in circulation at the stations. 6th. Exact length of time that the face of the coal or rock has been exposed. 7th. Whether or not there is much gas given off from the coal. Besides these more essential points, it is well to know the temperature of the air outside, the dip of the strata, their hydrogeological conditions, together with any local causes tending to increase or lower the temperature.

It is only when all these essential conditions are known and can be taken into account, that we can hope to arrive at a more exact estimate of the real rate of increase of temperature with depth in Coal Mines. It is to be feared that very few of the observations recorded in Table II satisfy this standard. While they present many points of interest, and confirm the general fact of an increase of temperature with depth, they fail, I think, to give the more precise information required. For these reasons I feel that only a very small selection can be made, and I doubt whether those even give sufficiently true readings, though they may give the best approximation that can at present be obtained.

In making the selection, the points I have looked to are (1) accurate mean surface temperature, (2) height of ground, (3) temperature of air in gallery—or, when that is not given, such a distance from shaft as will ensure the minimum of difference between the temperature of the air and the rock*—(4) distance of the working face from the shaft, and (5) depth of trial hole. Permanence of temperature at a station is not, as it has been often considered, a sign of its correctness, or of its being the true normal temperature. On the contrary, when it is stated that the thermometer in the same hole continues to give the same reading for a long period, it is evident that, instead of having a more definite value, it cannot represent the normal temperature of the rock, but that of the rock or coal after cooling to a point at which an equilibrium has been established between the temperature of the strata and that of the circulating air. Such readings therefore are too low.

Amongst the best recorded observations are those at Boldon in the Newcastle coal-field (No. 150). The holes in the rock were there 10 feet deep, the temperature of the air in the gallery was nearly the same as that of the rock, and the mean annual temperature well known.

At the North Seaton Mine (No. 217), the station being half a mile from the shore, and more than that distance from the shaft, a certain uniformity of temperature between the rock and the air was necessarily ensured, although that is not mentioned.

The experiments at Hetton Colliery (No. 116) seem to fulfil the required conditions, but I do not place implicit reliance on them, because the holes were first filled with water and then left for forty-eight

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* It is said that at about the distance of a mile from the shaft the temperature of the air approximates to that of the coal, but this of course is a very variable result.

hours, after which the thermometers were left in them for twenty-four hours, so that the coal was exposed for at least for three days, if not more, to a current of 5000 cubic feet of cooler air per minute. Further, it is stated that there was no difference in the temperature after the lapse of a fortnight. I infer from this that the coal here again had reached a cooling point at which the equilibrium between the air and coal had been temporarily established.

The experiments at South Hetton (No. 136) have especial value, as they were made in a bore-hole drilled into the strata at the bottom of a shaft, 1066 feet deep, to a further depth of 878 feet. The first reading made on the completion of the hole, and while yet dry, gave a temperature of 96° F. Three years later the experiments were repeated, but in the meantime the hole had become filled with water, and silted up to the depth of 234 feet. The thermometer was, however, pushed down in the silt to the depth of 26 feet, and a temperature of 77° recorded. Whilst no doubt the first readings were rather too high, as the heat caused by the tools could not have been all lost,* it is equally probable that convection currents may have cooled the mud in the bore-hole. Taking, however, the temperature in the bore-hole between the depths in it of 100 and 670 feet (1166 and 1736 feet below surface), we have a difference of 11°, which gives a rate of increase of 52 feet per degree.

The strong ventilation, and the uncertainty about the length of exposure, are objections to the otherwise careful records of the Pendleton Colliery (No. 104), and the same doubts attach to the other deep works of this district. It is true that many of the observations are said to have been made in newly-opened ground, but we do not know whether this means an hour, a day, or a week, and as in all newly-opened mines the ventilation must be well kept up for the sake of the workmen, the rate of cooling must be rapid.

The Wakefield pit (No. 120) had been newly opened. Ventilation was stopped as much as possible at the stations, and the temperature of the air was very near the normal; the hole in the coal was 6 feet deep, and distant 600 yards from the shaft. In the Barnsley pit (No. 119) the station was too near the shaft, and the air was much below the normal.

The observations, both in the Radstock and Kingswood Collieries (Nos. 163 and 155), were made in holes only 2 feet deep, and the thermometers allowed to remain respectively two, five, and seven days—long enough for the rock to cool, as shown by the fact that after another week the thermometer at Kingswood gave the same reading. The temperature of the air is not given.

I pass over the Upper Duffryn, Tredegar, Cwyn Neol, and other

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* The boring was only stopped about twenty minutes before the experiments were made.

collieries, in consequence of the deflections of the isothermal lines by irregularities of the surface.

The particulars of the Norley Colliery, Wigan, (No. 111) are insufficient, though the result there obtained seems to confirm the observations at the Rosebridge Colliery.

The observations in the Mons Collieries (Nos. 215, 216) were made at a distance from the shaft, and in dry galleries without ventilation.

At Liège (No. 141) the unusual precaution was taken of making the holes 5 mètres deep, while the temperature of the air in the galleries was only 1° lower than that of the coal.

I have not taken any of the earlier observations, owing to the uncertainty attaching to the instruments, and, after eliminating others for the reasons named, we are reduced to the following small number of available observations:—

Original number in Table I.	Place.	Depth of pit.	Temperature of rock or coal.	Rate of increase for 1° Fahr.
		feet.		feet.
150	Boldon, Newcastle	1514	79°	47
136	South Hetton, Durham—the last 670 feet.......................	1736	77	52
126	Rosebridge, Wigan...............	2445	94	53
217	North Seaton....................	620	61	45
120	Wakefield.......................	1455	78	50
141	Liège, Belgium	1656	87	46
216	Mons, Cuesmes Colliery..........	1680	82	54
215	„ La Louvière Colliery	1456	81	49
		Mean rate of increase....		49·5

This seems a very small selection to make, but I believe that the disturbing causes I have mentioned operate so constantly, that an element of uncertainty is introduced at the very opening of a pit, and that, without further precautions than hitherto taken, the observations are not reliable for the purpose of those exact values necessary to determine the true thermometric gradient.

Instead of making the observations in a newly-opened and well-ventilated part, with fresh faces of the coal emitting pent-up gases, it might be desirable to try an isolated abandoned unventilated gallery, and there place thermometers in the coal and the rocks above and below the coal. The holes should be 5 or 6 or more feet deep, and the gallery then closed at distances of 200 to 300 feet by a series of diaphragms to stop ventilation and convection currents, and the place not opened for several months, by which time the end station would possibly have acquired the temperature of the circumjacent body of strata; or the place might be bricked up.*

It is only in a few instances that temperature observations have been made in carboniferous strata in other than coal-pits; in these others there is no indication of the excessive range which the observations in shafts and galleries have shown. The following table gives the results obtained in bore-holes sunk in search of coal. At Creuzot there is a thick capping of Triassic strata, and the coal strata dip rapidly.

Original number.	Place.	Depth.	Rate of increase for 1° F.
		feet.	feet.
123	Blythswood	347	52
124	South Balgray	525	42
68	Creuzot, Torcy Colliery	1817	57
69	„ Mouillonge Colliery	2677	52
		Mean	50·8

If we were to unite these two series of observations, we should get for the Coal-measures a rate of increase of temperature as nearly as possible of 50 feet per degree Fahr., although there seems to be local variations dependent upon structure, the percolation of water, and other causes.

II. Mines other than Coal. (*Table III, p.* 96.)

The causes affecting the thermal conditions of Metalliferous Mines are very different to those which obtain in Coal Mines. In them we have to deal almost exclusively with crystalline and schistose rocks. Not only does the conductivity of such rocks differ materially from that of the Coal-measures, but the disturbing causes common to the two have in general very different values.

Ventilation is a cause affecting both, but it affects them unequally; and while in Coal Mines the influence of water is generally very small, it plays an important part in Metallic Mines. On the other hand, chemical decomposition and hot springs, which are common disturbing causes in the latter, are of rare occurrence in the former.

Ventilation.—I have so fully described the effects of ventilation in the section on Coal Mines, that I only need mention here in what respects its effects differ in other mines. Besides, we are not in possession, in respect to metallic mines, of such detailed particulars as those which the Report of the Coal Commission gives of the Coal

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* Or, deeper holes and well distant from the shaft might answer.

Mines. The effects are modified in the two cases by differences in the structure of the shafts and galleries, and while in the one the presence of the coal-gases necessitates excessive ventilation, in the other, hot springs and chemical decomposition, though they raise the temperature, do not render so active a ventilation imperative.

In some of the Cornish mines the current of air is hardly felt, and it is stated generally by Mr. Robert Were Fox,* that in deep mines the temperature of the rock and that of the air do not materially differ, except when the currents are strong. At the same time it is evident that strong currents of air do sometimes prevail. An instance is mentioned by Mr. Robert Hunt,† where at the bottom of a mine 1950 feet deep, the current of air was so strong that it was difficult to keep a candle alight. In another, in all the levels (which were of great extent) of one hot lode at the depth of 1410 feet, the ventilation was so effective that the temperature of the air was never higher than 70° F.

These mines must suffer, as in coal mines, a great and permanent reduction of temperature in the proximity of the down shafts. This is especially noticeable in severe winters, and when the ventilation is active the effects of this will extend to a considerable distance from the shaft. Daubuisson mentions that during a severe winter, and with the outer air at a temperature of $-15°$ R. ($-2°$ F.), the shaft of the Beschertgluck mine, in the Freiberg district, was lined with ice to a depth of 80 toises (480 feet), and that the temperature of the air at the bottom of the shaft was $\frac{1}{2}°$ R. (33° F.). Dr. Clark ("Travels in Scandinavia,") says that in descending the great iron mines of Persberg, in Sweden, which are 450 feet deep, he found large masses of ice covering the sides of the walls, and that it had accumulated in large quantities in the lower chambers. But the formation of ice is not confined to these more rigorous winter climates, for Mr. Moyle speaks of finding, on one occasion, ice in abundance in the Tin Croft Mine, Cornwall, at a depth of 318 feet below the surface, and says that the ladders became impassable, crevices were filled, and icicles formed all around! That this must produce a permanent effect is clear from the circumstance mentioned in connexion with coal mines, where the walls of deep mines near the shaft are so cooled in winter, that in summer the air circulating by them is of a higher temperature than the rock. On the other hand, the temperature of the air in a metallic mine is more apt than in a coal mine to become heated by the combustion of candles, the explosion of gunpowder, and the presence of the workmen.

Some of the observations of Mr. Fox show the effects of ventilation in the Cornish mines. Thus at Huel Damsel Mine (No. 21), the tem-

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* Coal Commission Report, vol. ii, p. 211.

† *Ibid.*, vol. ii, p. 87.

perature of the air at different levels varied very little, and was higher in the third level than in one lower.

Depth.	Temp. of air.	Depth.	Temp. of air.
480 to 540 feet	69°	780 to 840 feet	73°
600 „ 780 „	70	840 „ 900 „	70

That the temperature of the air does influence that of the rocks is shown by another series of experiments made by him in holes in the rock in Dolcoath Mine with the following results:—

	Depths.	Temperature of rock.	Rate of increase per 1° F.
I......	240 to 300 feet	58°	34 feet
II......	540 „ 600 „	58	71 „
III......	720 „ 780 „	63	57 „
IV......	1140 „ 1200 „	64	83 „
V......	1320 „ 1380 „	78	48 „

Mr. Fox does not give the temperature of the air, but states that the abnormally low temperatures of Stations II and IV arose from the passage of strong currents of air. The effect of these conditions, in estimating the rate of increase of temperature with depth, is clearly shown in the last column which I have added for this purpose.

But although there may be extreme cases, it is probable, as a general rule, that the ventilation does not produce the extent of difference between the temperature of the air and of the rock that it does in coal mines. Mr. Fox who, to avoid the effects of ventilation, always, if possible, made his observations near the ends of the levels, states that in those cases there is little difference between the temperature of the air and the rock. At the same time it is possible that, even then, the uniformity may be owing to the rock having permanently cooled down to the temperature of the air—though it may not be much. The following are cases in which the temperatures of both are given.

	Depth.	Temperature.		Rate of increase per 1° F.
		Air.	Rock.	
No. 71. Par Consols	1248 feet....	82°	84°	38 feet
No. 72. Botallock	1128 „	81	79	40 „
No. 77. Levant	1530 „	85	85	45 „
No. 79. Tresavean......	2112 „	91·5	90·5	52 „

Here it will be observed that there is only a difference of 1° to 2° between the temperature of the air and the rock, and that the rate of increase with depth is, with one exception, much more uniform.

May not circumstances such as these account for the marked discrepancies in the rate of temperature with depth observed in the Talargoch Mine (No. 158, 160); for although the temperature of the air is not there given, we know that it will vary with the distance from the shaft, of which particulars are given in the Brit. Assoc. Reports:—

Station.	Depth.	Distance from shaft.		Temp. of rock.	Rate of increase with depth.
III....	660 feet	120 yards	S.	54° F.	132 feet
V....	555 „	170 „	S.E.	52·9	140 „
IV....	465 „	190 „	S.W.	53·4	116 „
I....	1041 „	190 „	N.E.	60·8	88 „
VI....	636 „	840 „	S.W.	58·8	64 „
VII....	660 „	1240 „	S.S.W.	62	51 „

The two partial exceptions (IV, V) are in both cases at stations of lesser depths, and, being still near the shaft, are possibly more exposed to the influence of the outer air.

The effects of ventilation are also shown in another way. Some of the early experiments of Dr. Forbes were made in the water in *sumps* and pools, which necessarily would be much exposed to the cooling effects of the circulating air. His tables, which give the results of observations in six mines (No. 18), show a rate of increase of temperature relatively less with increased depth. The observations are so much at variance with those subsequently made by Mr. Fox and Mr. Henwood, that I can only attribute the discrepancy to the cause I have here named, viz., a relatively greater cooling of the water, due to increased ventilation at increased depths. It is not necessary to give the whole series: the following instances bring out the fact:—

Depth.	Temperature of the water.	Rate of increase per 1° F.
500 to 550 feet	65°	35 feet*
900 „ 950 „	71	44 „
1350 „ 1400 „	79	47½ „

The early observations of Mr. Fox, which were made in the same way in the water in fifty-three mines, gave also a diminished rate of temperature with increase of depth:—

Mean depth.	Rate of increase per 1° F.
354 feet	1° in 35·4 feet
448 „	1 „ 43·8 „
648 „	1 „ 64·2 „

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* The rapid rate constantly observed near the surface is probably in great part owing to chemical decomposition in the lodes which is most active near the surface, and also to a less active ventilation.

No further particulars and no greater depths were given, but Mr. Fox's later observations in rock give different results.

The Effects of the Percolation of Water.—But while the effects of ventilation are not so general and disturbing in Metallic Mines as in Coal Mines, the effects produced by the underground waters are of much greater importance. The alternation of impermeable with permeable strata, and the multiplicity of faults in the Coal-measures, so impede the descent of the surface-waters, that there are mines so dry as to necessitate the introduction of water to keep down the dust. The Metallic Mines being, on the contrary, commonly in crystalline, schistose, and slaty rocks, have more uniformity of structure; and, being also generally hard and compact, they are more or less impervious. When, however, they have been disturbed and fissured, they give freer passage to water; and when, further, they are traversed by veins and faults, these frequently serve as channels or conduits, more or less free, for the surface-waters, and considerable quantities of water pass through them. Consequently water is one of the great obstacles to deep mining with which the workmen have to contend. Water finds its way to all depths, and with more or less rapidity. Mr. Henwood states that in some mines a great increase follows soon on heavy autumnal rains, and that in others, months intervene before the effects are felt.

In districts formed of the usual alternations of sedimentary strata, it is estimated that on an average about one-third of the rainfall passes underground; while in Cornwall, where granites and slates exclusively prevail, Mr. Heuwood estimated in his survey of the Gwennap district—which consists chiefly of slates—that about a fourth of the rainfall is absorbed, the mean annual rainfall there being 46 inches, or equal to 166,834 cubic feet per acre. The local percolation is, however, extremely variable, as in some mines the quantity pumped up does not exceed 5 gallons, while in others it amounts to 186 gallons per minute.

The same observer found that water passes more freely through slate than through granite, the quantity yielded by mines in slate being about four times as much as that in granite. In a period of five years (1833–7) the water pumped per minute from forty mines, amounted on a mean to the following proportions :—

Granite.		Slate.		
Maximum.	Minimum.	Maximum.	Minimum.	
30	16	122	63	cubic feet per minute.

Mr. Henwood's account of the quantity of water that passes underground in the Gwennap district is of much interest. The mines in that district, over an area of 5500 acres, were combined for drainage purposes. A great adit carried away the water above the sea-level, while a deep-seated level collected the water at the depth of from 1100 to 1200 feet. At the time that Mr. Henwood wrote, the former was discharging 1475 cubic feet per minute, and from the latter 909 cubic feet were being pumped up, or together above 10 million gallons in the twenty-four hours. Taking the mean temperature of the surface at 50°, as the water issues at a temperature of from 60° to 68° F., or at an average of more than 12° above the mean of the climate, it is easy to conceive how large must be the amount of heat which the waters abstract from the mines, and how considerable the cooling of the enclosing rocks which must result therefrom.

Another observer, writing a few years earlier, states that the discharge at the Huel Vor Mine from a depth of 950 feet, was 1,692,660 gallons every twenty-four hours; at Dolcoath Mine, from about 1400 feet, 535,173 gallons; and at Huel Abraham Mine it reached the large quantity of 2,098,320 gallons.*

Mr. Henwood remarks that "the largest streams of water flow through cross-veins; small ones through the lodes, whilst but little issues from the rocks whether granitic or slaty."

Where the water dribbles slowly through the rocks to great depths, it will no doubt acquire the normal temperature of the depth, but where it passes more rapidly through the veins and lodes, the temperature will depend upon the time occupied in transit and on the volume of water. If the flow is rapid, as it evidently is in some mines, the surface-waters may carry the influence of the above-ground temperature to considerable depths. If on the other hand, the vein is one in which the ore is subject to decomposition by the surface-waters, those waters will have their temperature more or less raised. A copious stream of warm water is considered among the Cornish miners a favourable indication of the proximity of a lode. Nevertheless, Mr. Henwood, who, as we may feel assured, fully understood all the contingent conditions, considered that by a careful selection of the underground springs and by taking them when freshly opened, they gave safer temperature results than did the undisturbed rock.

Hot Springs.—These are not uncommon in metallic mines. They are due to two causes. 1stly, to chemical decomposition; 2ndly, to water coming from greater depths.

The first of these causes is a very general one—especially in copper and iron mines, in which the lode consists of iron and copper pyrites. The surface-waters decompose these sulphides, converting them into sulphates, which by further changes that need not be here described, pass into the oxides and carbonates of these metals. That the action

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* Dr. Forbes, "Trans. Roy. Geol. Soc. Cornwall," vol. ii, p. 167.

is general is shown by the circumstance that the upper part of all these lodes consists near the surface of a crust, several feet and sometimes several fathoms thick, composed of the oxidised products of copper and iron sulphides; this part of the vein is known in Cornwall under the distinctive term of *gossan.* In these cases, the water is commonly impregnated with some of the resulting soluble sulphates, and has its temperature raised by this decomposition.

Mr. R. Hunt mentions* two marked instances of the heating effects arising from this cause. In one case the temperature in the level of a copper mine stood at 100° F., but on the removal of a very large deposit of the copper pyrites "the level became cold enough to make the agent wish for a great-coat." The exact difference is not given. In another case, a large deposit of iron pyrites was opened at about half a mile distant from a hot lode, 1530 feet deep, in the Clifford Amalgamated Mine, and the mere fact of opening the mine there and removing the iron pyrites, considerably reduced the temperature in the mine. When it was closed the temperature rose to its former height. Springs of various degrees of heat (one was as high as 124°) are often met with.

The miners of Cornwall have long held that the lodes containing tin are, at equal depths, colder than those in which copper ores occur; a fact which is no doubt due to the facility with which the cupreous pyrites decomposes.

There must also be cases in which water from greater depths is brought up along lines of fissure (lodes and cross-veins); for as these are prolonged downwards, they may traverse at greater depths strata, veins, or faults, charged with water, which, when thus tapped, will outflow at any levels lower than the height at which the water stands in the supplying source.

It sometimes also happens that at the same depths, but in distant parts of the same level, the water is of different temperatures. In one instance there were springs at 102°, 110°, and 124°, and in another case (Wheal Wreath), the temperature of a small stream at the east end of a lode (tin) was 71°·5, while a spring at the west end of the lode had a temperature of 75° (both being at the depth of 1422 feet).

On the other hand, when the water is in considerable volume, and percolates rapidly, it must tend to have a lower temperature than the normal rock temperature, as in the instance where, in two adjacent mines, large streams both coming out of veins, had the same temperature of 67·5° at the respective depths of 588 and 722 feet. The observations of Henwood likewise tend to show that the range of temperature of water in the same level is subject to great variation.

In consequence of the uncertainty attaching on the one hand to

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* Coal Commission Report, A 4—10.

observations taken in rock, and on the other to those in water, Cornish geologists have been divided in opinion as to the best plan to adopt. The two great authorities on the subject, Mr. R. Were Fox and Mr. W. J. Henwood, respectively gave preference,—the one to rock and the other to water (or rather springs),—and we may feel sure that the subject was well weighed and considered by both. Either system is in fact open to some objections, and neither can be employed without recourse to those safeguards and precautions, which no one knew better how to use than these two experienced observers.

Mr. Henwood gives as his reason for preferring springs,—that the rocks forming the sides of the shaft and levels must, to a certain extent, partake of the temperature of the air circulating through them, and that this air could not escape the influence of heat-producing causes at one time, and at another of the cooling effects of the intake-air. For the same reason he objected to the use for temperature purposes of the water standing in the levels, or *sumps*. He found it difficult to select stations at which the influence of those conditions would be always alike, and he was led to confine his observations as much as possible to the temperature of the streams of water immediately as they issue from fresh opened unbroken rock,—before they could be affected by the temperature of the levels,—as the places which would give the most correct temperature readings.

The following observations appear to me amongst the most reliable of those obtained in springs. The deepest seated springs are probably the most free from interference by the surface temperature and other disturbing causes.

No. in Table.	Mine.	Depth.	Temp.	Therm. gradient.	Spring in rock or lode.
		feet.	Fahr.	feet.	
52.	St. Ives Consols	810	71°	41	*Rock.*
49*f*.	Wheal Trenwith	660	66	44	*Lode.*
49*g*.	South Roskear	834	71	40	*Lode.*
49*a*.	East Wheal Crofty	810	70·7	39	*Rock.*
79.	Tresavean	2112	93·5	48·5	*Rock.*
27.	Dolcoath	1440	82	45	*Lode.*
49*b*.	Consolidated	1764	92·5	41·5	*Lode.*
49*c*.	United Mines	1080	74	45	*Lode.*
49*l*.	East Wheal Virgin	1722	94·5	39	*Rock.*
51.	Devonshire Wheal Friendship	810	69·5	41·5	*Lode.*
			Mean..	42·4	

Instead of a few selected observations, Mr. Henwood took a larger number and a wider range, though to this there is the objection that he thereby includes a number of extreme and doubtful cases. Thus, he took the large number of 415 observations made in ten Cornish mines, and on reducing them to given mean depths, obtained the following rate of increase of temperature with depth:—

	Average depth.		Mean temp. at depth.		Rate of increase per 1° Fahr.
i.	180 feet	....	54·8°	....	36 feet
ii.	432 ,,	....	60·8	....	40 ,,
iii.	762 ,,	....	67·4	....	43·5*,,
iv.	1050 ,,	....	78·0	....	40 ,,

He elsewhere gives the mean temperature for other depths:—

Mean depth.		Mean temp.		Rate of increas
672 feet	....	66·9°	....	40 feet
1440 ,,	....	85·5	....	40·5 ,,

He noticed also that there was a difference between the temperature of the springs issuing from the granite and those from the slate rocks. The mean of 134 observations made to a depth of 1200 feet in Cornwall and Devon, gave the following thermometric gradients—

In granite	......	41·5 feet per 1° Fahr.
In slate	......	39·0 ,,

Further, taking separately the springs issuing from veins of different characters, he arrived at the following results:—

For cross-veins at a depth of	594 feet	....	40·0 feet per 1°	
For lodes generally ,,	660 ,,	....	41·6	,,
For copper lodes ,,	840 ,,	....	38·0	,,
For tin lodes ,,	552 ,,	....	51·5†	,,

The result of these and various other calculations, is that for the springs issuing from the rock, the mean thermometric gradient was 40·1 feet, and from the lodes 40·3 feet per degree.

The early observations of Mr. Fox were made in the mine waters, but his later experiments were made in the rocks, and he expressed afterwards some doubts as to the value of his earlier experiments.‡ He considered that the rock observations were free from the direct influence which the descent of the surface-waters exercises on the lodes

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* I am unable to explain this difference. The more rapid gradient in No. 1 is probably due to the heat resulting from the oxidation caused by the surface-waters

† There would appear to be some mistake in this figure, as in another page he states that the temperature in the tin and copper lodes conjointly at a mean depth of 444 feet is 61·4°, which gives a rate of increase of 39 feet per degree.

‡ Some were made in still water or *sumps;* others in the air of the levels.

and cross-veins—of which the effects may either be to raise the temperature of the underground springs when chemical decomposition is going on in the upper part of the lode, or to lower the temperature when the surface-waters are abundant and infiltrate rapidly.

The following observations made in the rock appear to be amongst the most reliable of the results obtained, the temperature having been taken in holes 2 to 3 feet deep, and the stations having been selected at places where no working had recently been going on, and as distant as possible from the shaft:—

No. in Table I.	Name of mine.	Rock.	Depth.	Temp. of rock.	Rate of increase for 1° F.	Observer.
			feet.		feet.	
19	Dolcoath	Granite	1350	78°	48	Fox.
76a—**77**	Levant	Granite and slate	1530	87	43·7	,,
			,,	85		
72	Botallock	Granite and greenstone	1128	79	40	,,
80	Fowey Consolidated	Slate	1728	93	41	,,
71	Par Consols...	,, ...	1248	84	38	,,
40	Consolidated ..	Slate	1740	85·3	49	Henwood.
122a	Tresavean	Granite	2130	99	43·5	Hunt.
78	Tresavean	,,	1572	82·5	48·5	Fox.
					Mean .. 44 feet	

This gives a mean thermometric gradient of just 44 feet per 1° F., or combining the results obtained by observations in springs with those in rocks, we get an average gradient of 43·2 feet per degree.

Mean of observations in springs	42·4 feet
,, ,, rock	44·0 ,,
Mean..	43·2 ,,

Foreign Mines.—We know too little of all the conditions which obtain in foreign mines to draw any definite conclusion as to the rate of increase of temperature. Possibly the observations may prove available when we have more certain information respecting the mean annual temperature at each place, the height of the mine above the sea, and the position, especially in mountainous districts, of each station with reference to its depth beneath the surface.

This latter element is one, which the coal-mines observations previously given, clearly show should be taken into account. In Cornwall it is not of much importance, as the elevations are small, and the mines are rarely more than 100 to 300 or 400 feet above the sea level; but the mines of Freiberg are on higher ground, whilst those of Prizbam and Chemnitz are situated amongst high hills, and the temperature at the end of a long gallery may be, in relation to depth beneath the surface, very different to that given by the depth of the shaft.

The mines of Freiberg are those in which the greatest number of observations have been made, though none of them are of very recent date. The deepest mine, and one in which the observations were made in holes in the rock (gneiss), gives, if we are right in our estimate of the surface temperature,* a rate of increase with depth of 54 feet per degree. But in this instance,—as in the case of Mr. Fox's observation (No. 73) in Dolcoath Mine, where the thermometer was left in position for one and a half year,—it was here left two years, and there must have been as before described, a cooling of the rock, such as would reduce the temperature so far below the normal, as to place it in equilibrium with the temperature of the cooler air in the galleries. The temperature of 66° at Freiberg, and of 76° at Dolcoath, with their thermometric gradients of 54 and 53 feet, I take to represent the normal temperature of the rock, minus the loss of heat due to ventilation; and if that can be estimated at anything like the loss shown to have taken place in a level in the Wheal Vor Mine, which, after it had been opened some time and the mine had been deepened, amounted to about 6°, or in a similar instance mentioned by Mr. Henwood, where the difference amounted to 7°, it would indicate a normal temperature of these mines more in accordance with the gradient which we have adopted on other grounds.

For the same reason the numerous observations made by Mr. Henwood in the mines of Brazil and Chili, are, for the present, not available, though it is possible that they may be rendered so at a future period, should the other factors necessary for determining the difference between the surface and the underground temperature be ascertained.

III. Artesian Wells and Borings. (*Table IV, p.* 106.)

This class of observations presents results much more uniform than those taken either in Coal or Mineral Mines, and whereas the observations in Mines were in Palæozoic or crystalline rocks, those in Wells are, with few exceptions, either in Cretaceous, Jurassic, or Triassic

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* This is based on the temperature of Dresden, the nearest place where we have recorded observations. The mean annual temperature of Dresden is 47°, and as the mine is situated at the height of about 1300 feet, or about 900 feet above Dresden, if we allow 1° for every 300 feet of elevation, we shall have about 44° for the surface temperature at the mine.

strata, where the rocks are, as a rule, softer, more permeable to water, and less disturbed.

Many of the interfering causes difficult to eliminate in the case of the Mines, do not exist with the Artesian Wells. The causes of interference in the latter are reduced mainly to two, namely, pressure on the instruments and convection currents. The early experiments, where no precautions were taken against pressure, are consequently unreliable. Walferdin introduced improved and protected instruments, although in some previous cases, as in Marcet and De la Rive's observations, protected thermometers had been used. The need of protection against convection currents had also not escaped attention, but it was not until the later observations, instituted by the Committee of the British Association, were made, that more efficient safeguards were introduced to protect more completely against the subtle influence of these currents.

It is clear that we must reject all the early experiments made with unprotected thermometers; and it is not certain whether also a large number of those made with protected thermometers, but without protection, and sufficient protection, against convection currents, should not also be rejected.

In large bore-holes the disturbance from this cause is so great that the consequences are at once sufficiently apparent to oblige the rejection of the observations. The ordinary deep artesian wells of Paris, such as Grenelle and others, all agree in showing a rate of increase of 55 to 58 feet per degree F.; but the great bore-hole (4¼ feet in diameter) through the same strata in another part of Paris (La Chapelle St. Denis), where the water does not overflow, gave a rate of increase of 39½ feet per degree for the first 100 mètres (328 feet), which is too rapid, whilst at the depth of 660 mètres (2165 feet) the rate of increase was only 1° in 84 feet. This is clearly due, as stated by Professor Everett, to the overheating of the upper part of the column of water and to the cooling of the lower part by the action of convection currents. In the report of a deep boring at Moscow it is stated, but without explanation, that from 350 feet to the bottom at 994 feet the temperature was nearly constant at 10·1° C. (50·2° F.). The diameter of the bore-hole is not given, but I judge from other circumstances that it is not less than 2 feet, and can only account for the uniformity of temperature by the action of convection currents. The mean annual temperature of Moscow is 39·4°.

Professor Everett* also directs attention to the manifest action of convection currents in a shaft at Allendale, about 350 feet deep, with nearly 150 feet of water, in which the temperature was practically the same at all depths.

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* Brit. Assoc. Reports for 1871 and 1869.

Depth.		Temp.
160 feet.	....	47·5°
200 ,,	....	47
250 ,,	....	47·7
300 ,,	....	47·7

One of the pits at Allenheads (No. 130) which was nearly full of water gave similar results.

Depth.		Temp.
50 feet.	....	47·2°
100 ,,	....	46·8
200 ,,	....	46·6
350 ,,	....	46·9

While in another shaft at Ashburton 620 feet deep, and with water standing to within 50 feet from the surface, the temperature at all depths was 53°, except at one point, where it rose to 53·4° and 53·2°.

Even in the deep and narrow bore-hole at Sperenberg, it was shown that the first experiments with thermometers protected against pressure, but not against convection currents, gave wrong results, for in the first instance at a depth of 100 feet, the temperature was found to be 11° R., and at 3390 feet, 34·1° R. Afterwards, when plugs were inserted to stop the currents, the temperatures at the same respective depths had altered to 9° R. and 36·16° R., showing therefore that the first readings were too high by 2° Reaumur near the top of the bore, and too low by 2·05° Reaumur at the bottom. Another experiment in the same well later showed that the difference at the bottom, between plugging and no plugging, was as much as $6\frac{3}{4}$° Fahr.*

Another narrow bore-hole, showing clearly the action of convection currents, was that sunk to a depth of 2000 feet, at Swinderby, Lincoln (No. 143).† The hole had remained undisturbed for nearly three weeks, and the water stood within a few feet of the top.

Depth.		Temp.
100 feet.	...	68° F.
300 ,,	....	68·75
500 ,,	....	68·75
600 ,,	....	69
900 ,,	....	69
1200 ,,	....	69·5
2000 ,,	....	79

Taking the mean annual temperature of Swinderby at 48°, this

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* Brit. Assoc. Report for 1876, p. 205, and 1882, p. 3. The differences were even considered to be under-estimated.

† Brit. Assoc. Reports for 1875 and 1876. Part only of these are in Table I.

gives a difference of 31° for the whole depth, or 64½ feet increase for each degree F. If it stood by itself this might appear nothing remarkable, yet it is evident, from the series of observations that were taken in this bore-hole, that the temperature or rate of increase at the depth of 100 feet, which was equal to 1° in 10 feet, and at 300 feet to 1° in 28 feet, is excessive, and that this excess can only have been acquired through loss of heat by convection currents at the bottom and a corresponding gain at the top, and thus making the readings too high at top and too low at bottom. If, however, we take an intermediate station at a depth of 1000 feet, where the temperature averages 69·2°, we get a mean, and more probably truer, rate of increase with depth of 47 feet per degree.

Owing to the large diameter of the bore, to the many water-levels in the rocks, and to the circumstance that when the observations were made there was no sufficiently free outflow of water on the surface, such as would check the convection currents, there can, I think, be no doubt that the temperature of the well at Bootle (No. 153), sunk in the New Red Sandstone at Liverpool, is influenced both by convection currents and by the influx of waters at different levels.

It is clear, therefore, that great uncertainty attaches to all observations made in bore-holes with standing water, the error being in proportion to the diameter of the bore-hole; and that where experiments have been made without plugging, all the deep temperature readings will be too low. Even with this precaution, it may be a question whether the bottom water and that of the adjacent rock may not have had their temperature permanently lowered before trial. This might be remedied to some extent by the use of more than one plug, and the stoppage of the circulation throughout the whole depth of the bore-hole for a certain time.

There are, however, some artesian bore-holes, where the sources of error have been reduced to a minimum. Amongst those are—

1. *Kentish Town* (No. 129).—These careful experiments were carried on for some years by Mr. Symons. From the circumstance that the mud at the bottom of the bore-hole into which the thermometer was sunk, was free from convection currents, the results obtained show, in all probability, a near approximation to the normal temperature. At the same time the long period that the well had stood neglected allowed the play of those currents in the water standing in the tube above the mud, and this may possibly have effected a slight reduction of temperature, but it cannot be very material.

2. *Richmond.*—The observations here were made by Professor Judd with standard instruments. The overflow was too small to give the correct temperature, though enough to check convection currents, and consequently the temperature was ascertained by letting down a thermometer to the bottom of the well.

3. The first experiments at *Grenelle* were made when the bore-hole had reached the depth of 400 mètres (1312 feet), and when no work had been going on for some weeks. The thermometers, of which three sets were used, were left down thirty-six hours. They were protected against pressure, and Arago remarks that the chalk through which they were boring made so thick a paste filling the bore-hole, that convection currents were hardly possible. All three sets of instruments gave results within a fraction of a degree to one another.*

4. In the bore-hole of the well at the *École Militaire* the experiments were made by Walferdin under very similar conditions.

5. *Pregny near Geneva.*—The thermometer was here protected against pressure, and to a certain extent against convection currents. The bore-hole was small, and the water stood at a small depth below the surface.

6. The observations at the well at *Ostend*, with the water also slightly overflowing, were made by Professor G. Dewalque, of Liège, with protected thermometers at the bottom of the bore-hole.

7. At *Sperenberg*, especial care was taken against convection currents, though how far these currents may have operated in reducing generally the temperature in the lower part of the bore-hole, before the experiments commenced, may be a little uncertain.

These seven wells give a mean rate of increase of rather more than 51 feet for each degree F. in depth (see p. 40). The reason why I have not included a larger number, is because in these cases I believe in the existence of some undetected errors, such, for example, as, amongst many others, those mentioned in the following instances.

Swinderby.—I have already explained my objections in this case. Of the first series of observations down to a depth of 1500 feet, Professor Everett remarks "it is obvious that nearly all the temperatures are largely affected by convection," he considered the bottom temperature at 2000 feet as less likely to be vitiated by convection in consequence of the small diameter of the bore-hole.

[But if we take, as I have suggested, a mean depth and a mean temperature, I believe we should have in the thermometric gradient of 47 feet per degree, a nearer approach to the true normal at Swinderby. Even in cases where the temperature is uniform from top to bottom, and there appears to be no clue to follow, as in the instance with the Moscow Well (No. 135), where Professor Lubinoff records a temperature of 10·1° C. (50·2° F.), if not for the whole depth of 994 feet, at least from 350 to 994 feet, it seems possible to obtain an approximate gradient. For the mean annual surface temperature being 39·5° F., and the half depth 494 feet, if we divide this by 10·7° (the difference

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* I have adopted this observation for Grenelle, in preference to that on the overflow water, for the reasons given further on.

between the surface and the well temperature), we get a quotient of 46·5, which agrees nearly with the thermometric gradient of the well at St. Petersburg (No. 44). March, 1886.]

Southampton.—The well was too long disused; during that time convection currents operated; apparently no protection against convection currents during the experiment.

Bootle.—The influx of water at different levels, and convection currents, render the results here valueless.

Rouen, St. Sever.—The thermometer was not protected against pressure, but the effect of the pressure was estimated and allowed for.

Troyes.—M. Walferdin thought it probable that the observations were affected by the heat caused by the boring tools, sufficient time not having been allowed to elapse after working before the thermometer was sent down.

Artesian Wells and Bore-holes in which the Water stood below the Surface, or rose very slowly so as to render it necessary to take the temperature at the bottom of the bore-hole.

Original number.	Place.	Strata.	Depth.	Temperature.		Thermometric gradient.
				At depth.	Mean surface.	
			feet.	Fahr.	Fahr.	feet.
129	Kentish Town	Tertiary, Chalk, and Old Red Sandstone	1100	69·9°	*49°*	52·3
231	Richmond....	Tertiary, Chalk, Jurassic, &c.........	1337	75·5	*49·6*	51·5
37	Grenelle, Paris	Tertiary, Chalk, and Greensand........	1312	74·7	*51*	55
36	École Militaire, Paris	Tertiary and Chalk..	568	61·5	*51*	54
29	Pregny	Tertiary (Molasse)..	713	62·7	*47*	48·5
207	Ostend	Tertiary and Chalk..	981	71·6	*50*	45
144	Sperenberg ...	Triassic rock salt and Gypsum	E. ft. 3490	115·5	*48·3*	52
					Mean	51·2

Overflowing Artesian Wells.—We now come to surer ground. Under certain conditions, these wells must give not only the nearest, but a very near, measure of the underground temperature, at the level from which the water rises. These conditions are—

1st. A sufficient depth and a sufficient distance of the out-crop of the water-bearing strata from the point of overflow. In a case like the Grenelle well, which is nearly 2000 feet deep, and where the stratum which serves as a channel for the water does not come to the surface for a distance of above 100 miles, these conditions are most favourable. It is very interesting to find, from information which M. Daubrée has just (Dec., 1884) obligingly obtained for me, that the temperature of the water at the Grenelle well is now precisely the same (27·8° C.), if not 0·1° C. higher, than it was at the commencement of the overflow forty-two years ago. In London, the distance of 10 miles at which the Lower Tertiaries and the Chalk out-crop is also no doubt sufficient, but it is a question whether the excessive pumping and constant passage of water may not have cooled the channels.

2nd. A sufficient volume and consequently rapid upward flow of the water in proportion to the depth, otherwise the water will part with some of its heat, as it rises through the tube. This may possibly be in some small degree the case at Grenelle, for in the carefully conducted observations of Arago and Walferdin, when the well had reached a depth of 400 mètres, the temperature (23·75° C.) gave a rate of increase of 55 feet per degree, instead of that of 58 feet when it overflowed. At the École Militaire, the rate was, as ascertained by Walferdin, 54 feet. It is possible, therefore, that the slower rate of increase at Grenelle indicated by the overflow water at a greater depth (548 mètres) may arise from a reduction of temperature due in part from the water overflowing with a velocity by no means great, but mainly from the diameter of the tube at the top being considerably greater than at the bottom.

The conditions of depth and volume are generally satisfactory in the case of the great saline wells in Germany, especially in the instance of the well at Neu Salzwerk. Humboldt states the supply of water was very abundant, the outflow being then at the rate of 422,000 gallons daily. Its ascensional force was remarkable, as was also the enormous discharge of carbonic acid. The deep artesian wells of Minden, which derive their water from the same source, give very similar results.

The discharge of water at the thermal springs of Mondorff in Luxembourg is very much less than at those of Neu Salzwerk. It is situated further south, and the height of the ground is considerably greater, being 673 feet above the sea-level; the mean annual surface temperature adopted by Walferdin was 48·4° F., but this was only an estimate. The mean temperature of Luxembourg, according to Arago, is only 8° C. (46·5° F.).

The depth of the artesian well at Tours is much less than that of the above, but the ascent of water was rapid and the discharge large. The observations there were made by Walferdin, as were also those at Rochefort.

The following list is confined to those wells where the overflow is abundant, and where the observations have been made by competent observers.

Artesian Wells in which there is an abundant overflow of Water at the Surface.

Original number.	Place.	Strata.	Depth.	Temperature.		Rate of increase per 1° Fahr.
				At depth.	Mean surface.	
			feet.	Fahr.	Fahr.	feet.
48*a*	Paris, St. Ouen	Tertiary	216	55·3°	*51°*	50
32	Lille	Cretaceous ; Carboniferous limestone	329	57·2	*50·5*	49
31	Tours	Cretaceous	460	63·5	*53*	44
101	Rochefort	Trias	2812	111	*54·5*	50
65	Mondorff	Lias and Trias	1647	78·3	*47·3*	53
182	Minden	Triassic (?)	2230	90·9	*48*	52
34	Neu Salzwerk	Liassic and Triassic	2038	88·3	*48*	50·5
144*a*	St. Petersburg	Silurian	656	54	*39·17*	44
						Mean.. 49·1

We thus have in these wells an average rate of increase of 49 feet for each degree F., or if we take the mean of the two lists, of almost exactly 50 feet per degree. Before, however, accepting this conclusion, two points should be reserved for correction hereafter, namely: 1st, the determination of the precise temperature at a depth where the annual surface changes cease to be felt. 2nd, whether there is any loss of heat, and what the amount, by the water in ascending through the tubes. This latter is, I believe, not an unimportant consideration.

The experiments at Grenelle indicate the probability of some such loss, and the form of construction of the tubes gives strength to the supposition. If the tubes of an artesian well were of the same diameter throughout, the passage of any given portion of the water from the depth to the surface would be direct, and the velocity the same throughout; but the tubes in almost all these wells decrease in diameter from the top to the bottom, consequently, instead of the whole body of water being in continuous and uniform motion throughout the length of the tube, the velocity of the water gradually decreases from the bottom to the top, currents are established at the points where the tubes enlarge, and a certain time beyond that required for its direct trajectory must elapse before the whole of the water issues at the surface.

For example, at Grenelle, where the difference between the size of the tubes at the top and bottom of the bore-hole is less than in some wells, there are four tubes of the respective diameters of 0·25 m., 0·22 m., 0·18 m., and 0·17 m. As the lesser the depth of the well the fewer the changes of tubes, the differences in this respect, together with the differences in length of the tube, may possibly help to explain the reason why the wells of 300 to 600 feet deep gave generally a more rapid rate of increase than the wells of 2000 feet, and may also account for the different rates of increase at the several wells, for which otherwise there is no apparent cause.

I have excluded a large number of overflowing wells because of the uncertainty which attaches to the instruments used, or to some essential point of which we are in ignorance, such, for example, as the influx of other springs, the precise depth, the size of the tubes, &c. These reasons apply to such wells as those of Newport (No. 210), Falkirk and Midlothian (45), Dunkirk and Bourbourg (209, 208), Alfort (49), Meaux (62), Arcachon (183), and others, where we do not know whether or not standard and protected instruments were used, or whether the experiments were in all such cases made by competent observers.

With respect to the extra-European observations, still greater uncertainty attaches from our ignorance of the general conditions, and especially of the exact mean annual temperature of the several places. At the same time there are some exceptions worthy of consideration. The experiments in the Sahara Desert (No. 88*a*) were made by an engineer of great experience in the construction of artesian wells, and accustomed to observations of this description, and are the mean of results obtained at a number of wells. The observations at Charleston and St. Louis appear reliable, only in these cases more particulars are desirable.

The African and Indian experiments seem to indicate a more rapid rate of increase of temperature with depth than occurs in Europe. Not so the American (U.S.) observations, which appear to indicate conditions very similar to those which obtain here. Not much weight can be attached to the solitary observation in South America. It requires confirmation.

IV. Tunnels.

The few observations of this class, limited as they are, show not only the modifications of the gradients caused by inequalities of surface, but bear also on some important geological questions connected with the structure of mountain chains and metamorphism. The first great tunnel was that of Mont Cenis, which is about 7 miles long, and passes under a ridge of the Alps rising 9532 feet above the sea level, and 5280 feet above the tunnel. After making a correction for the convexity of the surface, Professor Everett estimates the rate of increase of temperature with depth to be 1° F. in 79 feet. But the observations there were commenced late, and were not very complete.

In the St. Gothard tunnel, where very full and complete observations were carried out by Dr. Stapff, the results are of much interest. The tunnel is about 9 miles long; the summit level of the ridge above the tunnel is 10,040 feet above the sea level, and 5578 feet above the tunnel. This, after allowing for the convexity of the surface, gave a rate of increase of 1° F. in 82 feet. But Dr. Stapff* has since pointed out that in one part of the tunnel the rate is considerably more rapid. He found that the relative temperature of the ground above the northern end of the tunnel was much higher than in other parts—that in the plain of Andermatt the mean rock temperature was several degrees above the normal, while at the south end of the tunnel it was some degrees below it. The latter circumstance was easily explained by the presence of cold springs; and some higher temperatures in other parts of the tunnel were attributable to the decomposition of the rock; but there were no apparent reasons for this excess of temperature in the northern end of the tunnel, where it passes through gneiss and granite. The difference was such that instead of a rate of increase of 1° in 85 feet in the centre of the tunnel, or of an average rate of increase for the whole tunnel estimated by him at 57·8 feet, the rate was here 1° F. in 38 feet. Dr. Stapff says that there is no obvious explanation of the rapid increase in the granite rocks at this end of the tunnel, and that it is probably to be attributed to the influence of different thermal qualities of the rock. He mentions, further, that this granite belongs to the *massif* of the Finsteraarhorn, which is of a different (newer) geological age to that of the central axis of St. Gothard, and that it is therefore not to be wondered at. "if one of them be cooler than the other." He elsewhere remarks that there is also a well-known local focus of heat (decomposition of rock) below the valley of Andermatt, which may exercise a sufficient influence.

I myself am disposed to attribute the greater heat of these rocks to mechanical action rather than to the later protrusion of the Plutonic rocks, or to any subsequent decomposition of these rocks. If the pressure, force, and friction accompanying elevation of mountain chains be attended by the development of great heat—a heat sufficient to produce great chemical changes even in the Tertiary strata—then it may be possible for some of the newer mountain chains still to retain a portion of that heat. The facts brought forward by Dr. Stapff in the St. Gothard tunnel give material support to this view.

Although Mallet failed to show that the heat produced in the crushing of rocks by the lateral pressure, arising from the contraction of the crust of the earth as a consequence of its slow secular refrigeration,

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* "Trans. North of England Inst. Min. and Mechan. Engineers," vol. xxxiii (1883), p. 19.

was sufficient to fuse the rocks and account for volcanic phenomena, he nevertheless brought prominently forward the enormous heat-producing power of the disturbances caused by this contraction. He made a series of elaborate experiments to ascertain the force required to crush blocks of a given size (3 or 3½ cubic metres), and measured the work done by the *estimated* heat evolved by the crushing of 1 cubic foot of several classes of rock by the number of cubic feet of water at 32° F. converted into steam of one atmosphere, or 212° F. This method, although not perfectly satisfactory, is sufficient to prove the essential fact that a mechanical disturbance of the rocks may develop a large amount of heat. I must refer to his valuable paper* for full details of his results. The following is an abstract from his large table of experiments.

Class of rock.	Specific gravity. Water =1000.	Weight (pressure) per square inch at first yielding.	Mean pressure at which the cubes were completely crushed.	Temperature of 1 cubic foot of rock due to work of crushing.	Number of pounds of water at 32°, evaporated into steam at 212°.
		lbs.	lbs.	Fahr.†	lbs.
Caen Oolite	2·337	1,620	4,966	8°	0·288
Magnesian Limestone ..	2·571	3,699	16,333	26	0·9
Coal-measure Sandstone.	2·478	10,970	29,783	86	2·5
Devonshire Marble	2·717	11,708	34,938	114	3·44
Bangor Slate	2·859	15,510	41,590	144	4·51
Rowley Ragstone.......	2·827	24,039	63,737	213	6·86
Aberdeen grey Granite..	2·678	16,868	51,123	155	4·44
Inverary Porphyry	2·594	26,149	69,786	198	5·22

Thus with the ordinary sedimentary rocks the crushing weight (or that at which the blocks yield to pressure) is from 2¼ to 15½ tons per square inch of surface, while for the crystalline rocks it rises to 31 tons. The heat produced on the metal surroundings by the crushing was in most cases easily perceptible to the hand, and was so great in some of the granites and porphyries as to necessitate a delay for the apparatus to cool. Both Mallet and Rankin were of opinion that "in the crushing of a rigid material such as rock, almost the entire mechanical work (with the small residue of external work) reappears as heat." If, therefore, the disturbance affecting the massive strata of a great mountain range were sudden or of short duration, an intense degree of heat might be rapidly developed; but there is reason to suppose that such movements have been of extreme slowness during

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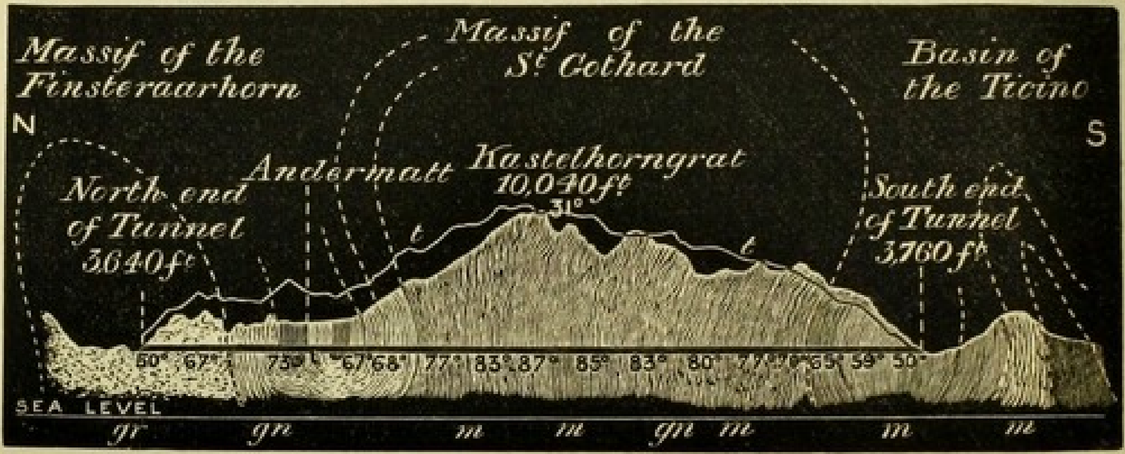
* "Phil. Trans.," vol. 163 (1873), p. 147.

† Omitting fractions of a degree.

long periods of time, and it was only when the tension had reached a certain point that fracture and disruption, accompanied by a more rapid motion of the parts, took place.

What the force of the pressure may have been in these cases is shown by the compression of the strata in the Alps, by the extraordinary folds and inversions of the rocks, and by the vertical cleavage (a resultant of pressure) which the whole mass of rocks has undergone. We may illustrate this point by the following generalised section across the central axis of the Alps along the line of tunnel.

Fig. 5.—Section across St. Gothard (reduced from the large section of Dr. Stapff).



gr. Granite. *gn*. Gneiss. *m*. Metamorphic schists. *t*. Temperature curves.

But although the compression may have been excessive, and the actual mechanical displacement great, the crushing was not so complete nor so sudden as to produce the extreme effects indicated by the experiments. Complete crushing is not, however, necessary for our object, since the experiments show that on the first yielding of the rocks, which takes place when the weight is rather more than one-third of the crushing weight, a large portion of heat is given off. Consequently not only would the heat be developed very gradually (and much of it might be dissipated during the long periods that the disturbances lasted), but also the major effects obtained artificially would never be realised in nature. Nevertheless, although fusion may not have taken place, there were molecular and chemical changes produced in the rocks which indicate the existence of very considerable heat; and there is reason to believe that this heat was often due to mechanical causes, and not to the protrusion of the molten granitic centres. In fact M. A. Favre and other Swiss geologists now consider the granite in those ranges to have been in existence in its present relative place when the elevation and crushing occurred.

Mallet further showed that the quantity of heat developed varied greatly in different rocks, and that, although compressed by the same force before their elastic limits were passed, yet, when released, it would render a quartz rock nearly three times as hot as a slate rock.

Consequently granite and gneiss, with their large proportion of free quartz, would be more affected than the other rocks.

When, therefore, we consider at how late a geological period some of the great mountain chains have been uplifted, it is not impossible, looking at the magnitude of the *massifs*, that some residual portion of the heat produced by compression, faulting, and crushing, may still exist in such modern chains as the Alps and the Himalayas, or in Continental areas of recent elevation when that elevation has been accompanied by compression and faulting. This is a consideration which, although exceptional, should not be overlooked in the general question of underground temperatures, especially in mining districts, where we have to deal with disturbed areas, with their faults, dykes, and mineral veins; at the same time, there can be little doubt that the disturbances in most of these areas are of such high antiquity that there is in most instances small probability of the rock showing remaining traces of thermal effects due to these causes. Nevertheless, when the area has been affected by late disturbances, it is possible for the thermic normal to be influenced by such a cause independently of the action of any volcanic or igneous rocks.*

CONDUCTIVITY OF THE ROCKS. EFFECTS OF SATURATION AND IMBIBITION.

Although it is evidently possible to account for many of the apparent discrepancies in the thermometric gradients by the causes discussed in the foregoing pages, yet it is equally evident that there are irregularities—not only between the rocks in the three groups of observations, but also common to individual instances in each separate group—which these causes do not adequately explain. As the rocks in each group are of very different lithological characters, and as there are also occasional lesser differences of characters in the members of each separate group, the common disturbing cause may in some measure depend upon those differences of structure and composition which variably affect the conductivity of the rocks.

The researches which bear most directly on this inquiry are those of Professors Herschel and Lebour† in this country, and M. Jannettaz‡ in France, the former relating more especially to the differences dependent upon the lithological structure of the rocks, and the latter to those dependent on the component minerals. Tabulating the results of Professor Herschel and Lebour's experiments in accordance with their geological relations, as grouped in Tables II, III, and IV, we obtain the following mean conductivities for the several groups of rocks:—

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* For a further discussion of this subject see a short paper by the author on "Regional Metamorphism," in "Proc. Roy. Soc.," vol. xl (1885), p. 425.

† The results of their investigation are recorded in the reports of the British Association for 1874–1882.

‡ "Bull. Soc. Géol. de France," 3rd Ser., vol. iii, *et seq.*

Table of Thermal Conductivities of Rocks, compiled from the Tables of Professors Herschel and Lebour.

Nature of rock.		Absolute thermal conductivity, *k*.	Absolute thermal resistance, *r*.	Average.	
				k.	*r*.
Crystalline and Volcanic rocks.	Granite (mean of five varieties).	0·00584	172	0·00562	178
	Porphyry (Germany) ..	0·00513	195		
	Porphyritic trachyte ..	0·00590	169		
	Basalt (Loch Katrine) ..	0·00560	179	0·00475	221
	Trap (Calton Hill)	0·00352	284		
	Serpentine	0·00515	199		
Schistose rocks and Slates.	Gneiss (Germany)	0·00514	195	0·00531	190
	Mica schist (Scotland)	0·00520	192		
	Slates (three varieties) ..	0·00561	184		
	„ (across cleavage).	0·00395	253		
	Clay-slate (two varieties)	0·00327	307		
	Quartzite	0·00954	105		
Sandstones.	Ganister sandstone	0·00630	159	0·00734	139
	Craigleith „	0·00947	105		
	Hard sandstones	0·00672	149		
	Micaceous flagstone (along cleavage).	0·00690	145		
	Micaceous flagstone (across cleavage).	0·00492	203	0·00323	252
	Soft red sandstone	0·00397	252		
	New red sandstone	0·00250	..		
	„ „ wet.	0·00600	166		
	Firestone (Upper Greensand).	0·00240	427	0·00172	689
	Quartzose sand........	0·00105	952		
	„ „ wet	0·00820	122		
Limestones, Oolites, &c.	Statuary marble	0·00530	189	0·00561	180
	Devonian „	0·00645	157		
	Carboniferous limestone	0·00550	182		
	Magnesian „	0·00522	192		
	Oolite (Ancaster)......	0·00370	270		
	Lias (building stone) ..	0·00360	278		
	Chalk	0·00220	455		
Argillaceous strata.	Coal-measure shale	0·00235	425	0·00242	411
	Clay (sun-dried)	0·00250	398		
	„ (the same wet and soft).	0·00350	270		
Mineral masses.	White quartz	0·00957	104		
	Alabaster	0·00360	278		
	Rock salt	0·01280	78		
	Coal (Newcastle)	0·00068	1470		
	Cannel coal	0·00120	787		

Or dividing this series into groups corresponding with the nature of the rocks in the several Tables of underground temperatures, the results are as under :—

	Mean conductivity. k.	Mean resistance. r.
1. Coal Mines (*carboniferous strata*).		
Sandstones. Shales; Clays	0·00433	267
2. Mineral Mines (*metamorphic and crystalline rocks*).		
Crystalline rocks Schistose rocks; Clay-slates.	0·00473	225
3. Artesian Wells (*mesozoic and tertiary strata*).		
Soft, and New Red, sandstones; Oolites Chalk; Greensands Clays; Marlstones (Lias)	0·00308	331

This shows a considerable difference between the conductivity of the metamorphic and palæozoic rocks of the Mineral and Coal Mines, and that of the newer strata in which the Artesian Wells are usually situated; but there are conditions, hydro-geological and structural, obtaining in the rock masses themselves, which introduce many modifications affecting the value of these differences.

For example, in each group there are subordinate beds, which may have more or less local influence. In the first there are seams of coal, of which the conductivity is extremely small, though these seams form but a fraction of the entire mass. Thus there are—

	No. of workable seams.	Total thickness of coal.	Total thickness of coal-measures.
In the coalfield of Newcastle	16	46 ft.	3,000 ft.
,, ,, N. Staffordshire	30	130 ,,	5,000 ,,
,, ,, South Wales	75	126 ,,	11,000 ,,

The coal therefore only enters as a very small fractional part into the constitution of the Coal-measures. Besides, the coal seams vary very much in thickness, and are of limited range, that is to say, they form thin plates never coextensive with the Coal-measures themselves; at the same time, when one thins out, it may be replaced by another on a different level.

In the crystalline and schistose rocks, veins and layers of quartz and of quartzite are of common occurrence, though very irregular in their mode of distribution. The quartz veins and seams are generally thin, but the quartzite often forms masses of large dimensions.

In the Artesian Wells gypsum and rock salt are of not unfrequent occurrence in the Triassic strata; in the remarkable instance of the

Sperenberg bore-hole, the latter forms a mass several thousand feet thick.*

The Influence of Water.—The above, however, are but local and minor conditions, subordinate to one of a much greater and wider influence. The conductivity experiments of Messrs. Herschel and Lebour were, with few exceptions, made with blocks of dried rock. In a few instances they repeated the experiment with *wet* blocks of the same material, and with a remarkable difference in the result. Thus—

	Conductivity.	
	Dry.	Wet.
New Red Sandstone	0·00250	0·00600
Quartzose sand	0·00105	0·00820
Clay	0·00250	0·00350
Mean	0·00202	0·00590

Here we have substances which when dry present great thermal resistance, becoming when wet amongst the best of the rock conductors of heat—equal, if not superior, to that of the crystalline and schistose rocks.

This condition becomes, in considering the question of conductivity in relation to underground temperatures, a matter of very great importance, for in nature dry rocks are the exception and wet rocks the rule. The level of permanent saturation of the strata is regulated by the sea level on the outside, and by the level of the river valleys and their tributaries inland. All the rocks below those levels are, as a rule, permanently saturated with water, while between the valleys the line of water level rises in proportion to the distance the water has to travel, and the friction offered by the rocks before it escapes as springs. In the chalk hills of Kent or Surrey, for example, which rise to the height of 500 to 600 feet, the water level stands 200 to 300 feet beneath the surface, while below that level, the rock, whatever its thickness, is in a state of saturation. In the valleys the chalk is saturated to the surface ; and Artesian Wells are always in relatively low levels. It is the same with the sandstones of the Trias or of the Coal-measures, only that in the latter the presence of faults often cuts off the supply, and segments exist with but little water except that of imbibition. This water of imbibition, or quarry water, is present in rocks above the line of permanent saturation, it being a property that depends on the capillarity of the rock, which is very strong in chalk and oolite, while it is slight in quartzose grits and sands. There are therefore few rocks in which the influence of water is not felt.

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* It may, however, be a question whether it is not intercalated with thin seams of gypsum.

The following is the proportion of water held in rocks by complete saturation :—*

	Complete saturation.	
Granite (hornblendic)	0·06	in 100 parts.
„ fine grained	0·12	„
Basalt, Auvergne	0·33	„
Silurian slates, Angers	0·19	„
Devonian limestone	0·08	„
Coal shale	2·85	„
Coal-measures sandstone	14·30	„
New Red Sandstone	13·43	„
Inferior Oolite	23·98	„
Calcareous freestone, Paris	16·25	„
Chalk	24·10	„

In the hard granites, sandstones, and limestones, the water of imbibition differs but little in proportion from that of saturation. The difference is considerable in the softer rocks. The following are some of the few experiments that have been made on this point.

	Quarry water.
Gneiss, slightly decomposed	3·00
Plastic clay	19·56
Chalk	19·30

It is clear then that the conductivity of the underground rocks must, except in some very hilly districts, be taken solely as that of wet rocks. In the harder and more compact rocks there will be little difference, but in the softer and more porous rocks the difference arising from this cause must be very considerable.

The conductivity even of coal will be increased, although the quantity of water that coal imbibes is very small. But unwrought coal also contains a large proportion of gas—and gas in a state of extreme condensation, or possibly in a state near liquidity, and this also may have an effect upon its conductivity.

Foliation and Cleavage.—The other condition, to which we have already alluded, is that produced by foliation and cleavage, and by the angle at which the strata lie. Messrs. Herschel and Lebour showed, for example, that the conductivity of slates varies accordingly as it is taken across or along the planes of cleavage—that while the conductivity along the planes of cleavage is equal to that of the crystalline rocks, it is no greater than that of soft sandstones across

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* These are on the authority of the late M. Delesse, "Bull. Soc. Géol. de France," 2nd Ser., vol. xix, p. 64.

those planes. The lamination in micaceous sandstones produces a similar result :—

	Conductivity.	Resistance.
Slates, along the planes of cleavage..	0·00561	184
,, across ,, ,, ..	0·00395	253
Micaceous flagstone, along the laminæ	0·00690	145
,, ,, across ,, ..	0·00492	203

M. Jannettaz* has extended the inquiry to a great number of other rocks, and he shows that the variation in conductivity in many rocks is largely dependent upon the presence of mica. He found that in a crystal of mica, heat was conducted about two and a-half times more rapidly along the planes of cleavage than perpendicular to it. In augite these axes of the thermic curve are in the proportion of about two to one.

FIG. 6.—Mica.

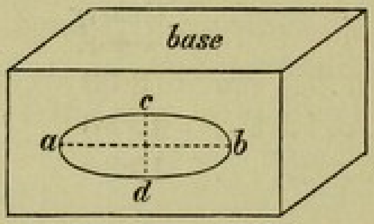
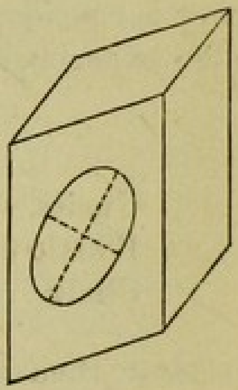


FIG. 7.—Augite (var. diopside).



a, *b*, *c*, *d*, the thermic curve ; *a*, *b*, the major axis ; *c*, *d*, the minor axis.

M. Jannettaz obtained results of a similar character, varying according to certain physical conditions, in a number of other minerals and in many rocks. The ratio of the minor to the major axis in the following rocks he found to be as follows :—

Gneiss of St. Gothard	1 : 1·50
,, from near Chamouni...............	1 : 1·23
,, passing into mica schist	1 : 1·63
Schists (triassic), St. Gervais..............	1 : 1·50
,, (carboniferous), Col Voza	1 : 1·80
Argillaceous schists	1 : 1·25
Cambrian Slate, Deville (Belgium)	1 : 1·86
Fissile micaceous limestone	1 : 1·31
Black and white limestone, Bonneville	1 : 1·06

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* "Bull. Soc. Géol. de France," 3rd Ser., vol. ii, p. 265 ; vol. iii, p. 499, *et seq.*

The thermic curves attain their maximum variation in talcose and micaceous schists and in slates. The greatest inequality, 1 : 3, was shown by a specimen of a talcose rock, of sp. gr. 2·7. The variation exists in all rocks showing schistosity or lamination, but in ordinary stratified rocks the thermic curve remains that of the circle. It was found that the variation exists also in rock crystal, gypsum, felspar, &c. All the specimens experimented upon were dry.

It is evident then that in gneissic rocks and slates, the dip, cleavage, and foliation may have a very important effect on the conduction of heat; lamination has a similar but lesser effect in argillaceous shales; in ordinary sandstones and limestones no such effects are produced. Whilst these effects therefore may be very manifest in the rocks generally associated with Mineral Veins, they can only be small in Coal Mines, although they may be in some places increased by a larger proportion of mica in the sandstones and shales. There is also the further consideration with strata, such as those of the Coal-measures, that although there may be separately little difference in the thermic axes of the different rocks, the differences of conductivity in the various component strata may, as with foliation, allow of a variable transmission of heat along the planes of the inclined strata at their outcrop. But, even if that be the case, the effect would be merely local, possibly affecting the mass of inclined strata to a given depth, but in no ways affecting the special problem in relation to the general body of strata unaffected by those local conditions.

CONCLUSIONS.

The list of selected cases on which these conclusions are based may appear small, but I feel satisfied that the sources of error in experiments of underground temperatures are so many and so obscure, that without the fuller information which we have in these few instances, the larger number are not available for our purpose, though they all bear on the general question, and with the corrected data before named it may be possible to utilise some of them hereafter. We now require, however, for this object those observations only which give the nearest possible approximation to the true thermometric gradient, and for this it is necessary to reject all the doubtful and more uncertain cases. For these reasons I have confined myself, in the case of the Coal Mines, to the limited number of the eight instances given in the list at p. 24; and in the Mineral Mines to eighteen of the seemingly most reliable rock and spring observations of Fox and Henwood. The Artesian Wells give more uniform results,—results which, under certain conditions, should be perfectly true. I have, however, only been able to select fifteen wells, of which eight are overflowing wells, and seven not-overflowing.

Taking these three classes of observations we obtain the following values for their several gradients:—

	Thermometric gradient per 1° Fahr.
Coal mines......................	49·5 feet
Mines other than coal............	43·2 ,,
Artesian wells	50·0 ,,

The mean of the three thus gives a general thermometric gradient of 47·5 feet per degree.

I do not, however, by any means consider this more than an approximation to the true normal gradient. In Coal Mines the effects of ventilation, and in other Mines the effects of chemical action and the circulation of water, have yet to be more accurately determined; while in the case of Artesian Wells, I believe the gradient of 49·5 feet may be too low in consequence of the unequal velocity of the water in deep overflowing wells, and of the uncertain measure of convection currents in those which do not overflow.

Admitting, however, these determinations to be approximately correct, they show that different geological areas have, in all probability, different gradients, and indicate possible inequalities in the underground isothermals, unless the altered conditions which come into play at greater depths tend to reduce and level them.

There is reason also to believe that the conductivity of the rocks at great depths may be affected by their hydrometric state and temperature. The descent of the surface water may ultimately be retarded or stayed by friction and heat. Faults, although they may stay its descent, leave untouched the water originally inclosed or imbibed. M. Delesse, who made some calculations on the probable depth to which water descends, concluded that water might circulate to the depth of about 8 miles before this limit was reached.

Further the experiments of Regnault determined the expansive force of the vapour of water up to a temperature of 239° C., the pressure then being equal to 27½ atmospheres. Beyond this, it has only been carried by empirical formulæ, but both experiment and calculation indicate that, with the increase of temperature, the increase of force is extremely rapid, and there is in all probability a point at which the vapour-tension of the heated water will equilibrate the hydrostatic pressure.

With respect to the possibility of change in the thermometric gradient at depths, it is known that the conductivity of wrought iron diminishes as the temperature increases, and at a rate agreeing very closely with the empirical law that the conducting power of iron for heat is inversely as the absolute temperature. What the variation in rocks may be has yet to be determined experimentally;[*] we may presume it to exist, although it may differ materially in degree.

Therefore, taking into consideration the probable limitation of the percolation of water, and the possible diminution of conductivity with increase of depth, if there should be any alteration in the thermometric gradient, at great depths, it will be more likely to be in the direction influenced by these more or less certain factors, or in favour of a decreased conductivity and a more rapid thermometric gradient, rather than otherwise.

I have made a few attempts to ascertain, with the data in our possession, whether there exists any indication of such variation within the limits of the depths reached, by comparing the gradients of the upper with the lower portions of the mines, but without arriving at any satisfactory result.[†] It is true that in the Coal Mines, taking a depth below 1000 feet, the gradient, in all cases except two, shows, with increased depth, an increased rapidity, but it is a question whether this is not due to ventilation and convection currents causing too low a reading of the gradients in the upper part of the mines, and so throwing an apparent gain into the gradients in the deeper parts of the mines.

In the Mines other than Coal, some show at great depths a more rapid, and others a slower gradient, but it has to be observed that generally there is greater steadiness in the gradients at depths beneath 500 or 600 feet, than in those which are shallower.

In Artesian Wells and bore-holes, on the contrary, the gradient is often more rapid in the upper than in the lower section of the wells, but this is clearly due to the action of convection currents; while the decrease in the diameter of the bore-hole with the increase of depth, by unequally checking the flow of water, differently affects the temperature of the water in the tubes as successive depths are reached.

Looking, however, only at the more certain and determined causes which have interfered with the value of even the best observations, I believe that the effect of them has been to make the readings for the Artesian Wells and bore-holes especially, as well as the Mines, too low; and it may be a question whether a general average gradient of 45 feet per degree would not be nearer the true normal than the one of 47½ feet obtained by the foregoing investigation.

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[*] The large proportion of iron present in the deeper seated igneous rocks is an element to be considered.

[†] See the figures between the brackets and in italics in Tables II, III, and IV.

I. GENERAL TABLE (

In this Table the observations are placed in order of date. T
is generally due to the use of improved methods and instruments,
All the observations are tabulated in the terms of the original pape
rected in accordance with later and better determinations. I
some of these corrected temperatures (marked *m*), and for others
"Notices Scientifiques" of Arago (marked *a*). In other cases th
and additions have also been made for the surface heights. Where t
place of observation is given, allowance being made for differen
the other columns having reference to the same observations.

By an Artesian Well is meant a drill-hole carried down to a dee
face. By bore-hole is meant a boring of the like description, ma

A few ordinary wells are introduced merely as guides to the me

I	II	III	IV
Locality.	Place of observation.	Height of surface above sea-level.	Mean annua temper ture of surface
		Feet.	Fahr.
1. Giromagny, near Belfort..	*Copper and lead mine..*	*1535*	*47° ?*
,, ,, ..	,, ,, ..	..	,,
,, ,, ..	,, ,, ..	..	,,
,, ,, ..	,, ,, ..	..	,,
2. Bex, Switzerland........	*Salt mine**	..	*45 ?*
3. Guanaxuato, Mexico.....	*Silver mine*...........	*6632*	*61 ?*
4. Cabrera ,, ...	,, ...	*8510*	*60 ?*
5. Tehuilotepec ,, ...	,, ...	*5776*	*63 ?*
6. Micuipampa, Peru.......	,, ...	*11614*	*46 ?*
7. Freiberg, Saxony........	*Beschertglück lead and silver mine*	*1378*	*43 ?*
,, ,, ...	,, ,,	,,	,,
,, ,, ...	,, ,,	,,	,,
8. ,, ,, ...	*Himmelfahrt* ,,	*577*	*46 ?*
,, ,, ...	,, ,,	,,	,,
,, ,, ...	,, ,,	,,	,,
9. ,, ,, ...	*Kuh-schacht* ,,	*656*	*45 ?*
10. ,, ,, ...	*Junghöhe-Birke* ,,	*1050*	*44 ?*
,, ,, ...	,, ,,	,,	,,
,, ,, ...	,, ,,	,,	,,
,, ,, ...	,, ,,	,,	,,

* The mine had been disused for three months.

UNDERGROUND TEMPERATURES.

discordance in those observations, which are repeated more than once,
to corrections of the mean temperatures of the place.
with the exception that the mean annual surface temperatures are cor-
indebted to Mr. R. H. Scott, F.R.S., of the Meteorological Office, for
the lists of the Scottish Meteorological Society (marked *s*), and to the
are those given by the original observers or by Dove. Corrections
temperature of the place has not been recorded, that of the nearest
in height, &c. (ante p. 7). (*a*) in Column VII refers to notes in

seated spring, which rises by that means *over* or *near* to the sur-
either in search of minerals or of water, and with or without water.
temperature at surface or at small depths.

	V Depths below surface.	VI Temperature at depths.	VII References and Remarks.
	Feet.	Fahr.	
1	332	53·6°	Gensanne, 1740; Arago, "Notices Scientifiques," vol. iii, p. 317 (1856). Temp. of Mulhouse, 51°.
	675	55·4	
	1010	66·2	
	1420	72	
2	721	63·5	Saussure, 1796; Arago, *op. cit.*
3	1712	98†	Humboldt, quoted by Arago, *op. cit.*, p. 338.
4	164	63	
5	358	75·5	
6	1500 ?	67	
7	722	54·5	Daubuisson. The original observations were published in the "Journal des Mines," vol. xiii, p. 113 (1803). The observations recorded here are given by him in his "Traité de Géognosie," 1819, p. 444, as the most reliable. Temp. of Dresden, 47° F.
	870	58	
	984	60	
8	328	50	
	590	54·5	
	870	58	
9	870	57	
10	656	57·2	
	804	59	
	936	61	
	1082	62·5	

† Temperature of spring issuing from lode. The air of the working galleries was 92° Fahr.

I Locality.	II Place of observation.	III Height of surface above sea-level.	IV Mean annual temperature of surface.
		Feet.	Fahr.
11. Brittany, Poullaouen	*Lead and silver mine*	*348*	*51° (a)*
,, ,, ...	,, ,,	,,	,,
,, ,, ...	,, ,,	,,	,,
12. ,, Huelgoet	*Lead and silver mine* ..	*568*	*50*
,, ,, ...	,, ,,	,,	,,
,, ,, ...	,, ,,	,,	,,
13. Freiberg, Saxony	*Alte Hoffnung Gottes* ..	*1300 ?*	*43 ?*
,, ,, ...	*Silver mine*	,,	,,
,, ,, ...	,, ,,	,,	,,
,, ,, ...	,, ,,	,,	,,
14. Whitehaven...........	*Coal pit*	*50—100*	*s 48·5*
15. Workington	,, ...	,,	,,
16. Percy Main............	,, ...	,,	,,
17. Killingworth...........	,, ...	,,	,,
18. Cornwall	*Various copper and tin mines*	*100—500*	*50**
,, ...	,, ,,	,,	,,
,, ...	,, ,,	,,	,,
,, ...	,, ,,	,,	,,
,, ...	,, ,,	,,	,,
,, ...	,, ,,	,,	,,
,, ...	,, ,,	,,	,,
,, ...	,, ,,	,,	,,
19. ,, Dolcoath	*Copper and tin mine* ..	*280*	*50*
,, ,, ...	,, ,,	,,	,,
,, ,, ...	,, ,,	,,	,,
,, ,, ...	,, ,,	,,	,,
,, ,, ...	,, ,,	,,	,,
,, ,, ...	,, ,,	,,	,,
20. ,, Huel Vor	*Tin mine*	..	*51*
,, ,, ...	,, ...	..	,,
,, ,, ...	,, ...	..	,,
,, ,, ...	,, ...	..	,,
,, ,, ...	,, ...	..	,,
,, ,, ...	,, ...	..	,,
,, ,, ...	,, ...	..	,,

* In Cornwall a mean surface temperature of 50°, 51°, 52°, or even 53° F. was adopted in the early underground observations, and thermometric gradients were calculated on those several different scales. The more recent observations of mean annual temperature, which I have received from the Meteorological Office, give for Penzance 51·8°, Truro 52°, Falmouth 51·4°, while Plymouth is 51·3°, and the high ground of Dartmoor 45·8°. Taking the height of the mining districts to vary from 100 to 800 feet, we may take the mean annual temperature of those districts "in block" at 51°. Mr. R. Were Fox placed thermometers 3 feet underground, at a height of 300 feet above the sea-level, near Dolcoath Mine, which gave a mean annual temperature of 49·94° F.; at 300 feet near Gooland Mine, which gave 48·99°; and at 120 feet at Falmouth, where it recorded 50·67°. His opinion was

	V Depths below surface.	VI Temperature at depths.	VII References and Remarks.
	Feet.	Fahr.	
11	246	53·5°	Daubuisson, "Journal des Mines," vol. xxi, p. 119 (1807). (*a*) Temperature of St. Brieuc.
	412	56	
	489	58	
12	230	54	
	459	62·5	
	781	66	
13	200	48·2	De Trebra, 1805–7, "Ann. des Mines," vol. i, p. 377 (1816), and vol. iii, p. 59. Obs. made in glazed niches in rock. The mean of 2 years' obs. No working going on.
	558	55	
	886	59	
	1246	66	
14	480	60	R. Bald, "Phil. Jour.," vol. i, p. 135 (1819). 48·5° is the temperature of Cockermouth.
15	504	60	
16	900	68	
17	1200	74	
18	500—550	65	Dr. Forbes, "Temperature of Mines," "Trans. Roy. Soc. Cornwall," vol. ii, p. 159 (1820). Average of observations made in six mines. Gives the temperature of the air and water. These are the water temperatures. (*a*) Here there was a strong current of air.
	600—650	63	
	700—750	65	
	800—850	66	
	900—950	71 (*a*)	
	1150—1260	71	
	1260—1350	74	
	1350—1400	79	
19	240—300	58	R. W. Fox, "Trans. Roy. Soc. Cornwall," vol. ii, p. 19 (1820). (*a*) Here there were strong currents of air. Obs. in rock, except the last, which was in water.
	540—600	59 (*a*)	
	720—780	63	
	1140—1200	64 (*a*)	
	1320—1380	78†	
	1380—1440	82	
20	6—60	52	*Ibid.* All these are water temperatures. (*a*) Here the temperature of the air in gallery was 72°.
	180—240	61	
	480—540	63	
	600—660	64	
	660—720	66	
	720—780	70	
	780—840	69 (*a*)	

---

that the mean surface temperature of Cornwall was under 51°, and possibly even less than 50°. This will account for the apparent discrepancy between the gradients of many of the original observers and those given in the Tables II, III, IV.

† A subsequent observation (No. 73) of Mr. Fox, made a year later, at the depth of 1380 feet, gave a rather lower reading. A thermometer 4 feet long was placed in a hole 3 feet deep, at a spot where no workmen were employed, and where the current of air was small. The hole was filled with clay round the stem of thermometer, which was left in that situation for eighteen months, and was found always to indicate a temperature of 76° or 76¼°. In the experiment of 1820 the thermometer was buried in the rock to the depth of 6 or 8 inches, and filled round with earth.

I Locality.	II Place of observation.	III Height of surface above sea-level.	IV Mean annual temperature of surface.
		Feet.	Fahr.
21. Cornwall, Huel Damsel	*Copper mine*	..	*51°*
,, ,,	,, ,,	..	,,
,, ,,	,, ,,	..	,,
,, ,,	,, ,,	..	,,
,, ,,	,, ,,	..	,,
,, ,,	,, ,,	..	,,
22. Neath, South Wales*	*Coal pit*	*150* ?	*s 50*
23. Carmeaux (Tarn)	,,	*820*	*55 ?*
,, ,,	,,	,,	,,
,, ,,	,,	,,	,,
,, ,,	,,	,,	,,
24. Littry, Calvados	,,	*197*	*51*†
25. Decise, Nièvre	,,	*492*	*55 ?*
,, ,,	,,	,,	,,
,, ,,	,,	,,	,,
26. Cornwall, Huel Alfred	*Copper mine*	..	*50*
27. ,, Dolcoath	*Copper and tin mine*	*280*	*50*
28. ,, Huel Trumpet	*Tin mine*	..	*50*
29. Pregny, near Geneva	*Artesian boring* (*not overflowing*)	*308* feet above Lake of Geneva	*48*‡
,, ,,	,, ,,	,,	,,
,, ,,	,, ,,	,,	,,
,, ,,	,, ,,	,,	,,
,, ,,	,, ,,	,,	,,
30. Sunderland	*Coal pit*	*87*	*47·5*
31. Tours	*Artesian well*	*180*	*53 ? (a)*
32. Lille (St. Venant)	,, ,,	*79*	*a 50·5*
33. Aire, Pas de Calais	,, ,,	*50 ?*	*49·7 ?*
34. Neu Salzwerk(*a*). Westphalia.	*Artesian salt-well*	*270*	*m 48 (b)*
Neu Salzwerk	,, ,,	,,	,,
,, ,,	,, ,,	,,	,,
,, ,,	,, ,,	,,	,,
35. Sheerness (*c*)	*Artesian well*	*10*	*m 49·2*
36. Paris, École Militaire	,, ,,	*213*	*a 51*
37. Paris, Grenelle Well	,, ,,	,,	*a 51*††
,, ,, ,,	,, ,,	,,	,,
,, ,, ,,	,, ,,	,,	,,

---

* The thermometer was here buried for some hours 1 to 2 feet under the ground.

† Temp. of Rouen is 50·7°.

‡ Temp. of Geneva, 48·4°; height above sea, 1335 feet.

§ French feet.

‖ Observation made in hole filled with water.

¶ The temperature of water at outflow in the first three observations did not

	V Depths below surface.	VI Temperature at depths.	VII References and Remarks.
	Feet.	Fahr.	
21	300—360	61°	
	480—540	69	
	600—660	70	
	720—780	70	*Ibid.* All these are air temperatures.
	780—840	73	
	840—900	70	
22	540 (*a*)	62	(*a*) Recorded by J. T. Price.
23	20	55	
	38	55·5	Cordier. "Essai sur la Température de l'Intérieur de la Terre," 1822. Temp. of the air in galleries at Carmeaux 23·5° C., and at Littry 21° C.
	597	63	
	630	67	
24	325 (*a*)	61	(*a*) The mean surface temp. was estimated from shallow wells adjoining the coal pits.
25	29	54·5	
	351	64	
	561	72	
26	930	70	R. W. Fox, "Trans Roy. Soc. Cornwall," vol. iii, p. 313, (1828).
27	1440	82 (*a*)	(*a*) Air 80.°
28	768	65	
29	100§	51·6	
	200	53·2	De la Rive and Marcet, "Mém. Soc. Phys. Geneva," vol. vi, p. 503 (1833). Thermometer protected against pressure. This depth is equal to 713 English feet.
	400	57·4	
	600	61·5	
	650	62·7	
30	1584	72·6‖	Phillips, "Phil. Mag.," vol. vi, p. 446 (1834).
31	460	63·5	Arago, "Notices Scientifiques," vol. iii, p. 347, *et seq.*
32	329	57·2	(*a*) Overflowing spring.
33	205	55·9	Arago, "Not. Scient.," vol. iii, p. 347 *et seq.*
34	787	70·7¶	(*a*) Recorded by Humboldt.
	1033	73	(*b*) Temp. of Boehum, which is one degree further south, is 48·6°. The boring was ultimately carried to a depth of 2113 feet.
	1073	81·5	
	2038	88·3	
35	361	60	(*c*) No reference given.
36	568	61·5	Walferdin, "Comptes rendus," 1836, p. 314.**
37	568	..	Walferdin, "Comptes rendus," 1837, p. 977; and Arago.
	1312	74·7	
	1656	79·6	

---

agree with the temperatures at depth (which are those given here) owing probably to the influx of water at intermediate depths.

** All Walferdiu's observations were made with overflow thermometers protected against pressure.

†† Temp. of Paris. Another datum line of invariable temperature (53° F.) at the depth of 28 mètres (92 feet) in the cellars of the Paris Observatory, is sometimes taken.

I Locality.	II Place of observation.	III Height of surface above sea-level.	IV Mean annual temperature of surface.
		Feet.	Fahr.
37. Paris, Grenelle Well	*Artesian well*	*213*	*a 51°*
38. Cornwall, Levant	*Copper and tin mine* ..	*80*	*50*
39. „ Tresavean	*Copper mine*	*362*	*50*
40. „ Consolidated ..	„ „	*318*	*50*
41. Rudersdorf, Berlin......	*Artesian well ?*........	*153*	*m 48·3*
42. St. Sever, Rouen.........	*Artesian boring*.....	*128*	*m 50·7*
43. St. André (Eure)	*Artesian well*	..	*51*
„ „	„ „	..	„
44. Yakoutsk, Siberia.......	*Well*................	*525*	*m 13*
„ „	„	„	„
„ „	„	„	„
„ „	„	„	„
45. Scotland, Carse of Falkirk.	*Artesian well*	..	*s 46·5*
„ „	„ „	..	„
„ „	„ „	..	„
„ Midlothian....	„ „	..	„
46. Cosseigne-les-Luxembourg	*Artesian boring*	..	*47*
47. Cornwall	*Various tin and copper mines*	..	*50*
„	„	„	„
„	„ „	„	„
48. Troyes, Aube	*Artesian well*	*359*	*a 52·3*
48*a*. St. Ouen, Paris.........	„ „	?	*51*
49. Alfort, Marne	„ „	..	*51·5*
49*a*. Cornwall, East Wheal Crofty.*	*Copper mine*	..	*50*
49*b*. Cornwall, Consolidated ..	„ „	*318*	„
„ „	„ „	..	„
49*c*. „ United Mines..	„ „	..	„
„ „	„ „	..	„
49*d*. „ Great Wheal Fortune.	„ „	..	*51*
49*e*. Cornwall, Marazion	*Copper and tin mine*...	..	„
„ „	„ „ ...	..	„
„ „	„ „ ...	..	„
49*f*. „ Wheal Trenwith	*Copper mine*	..	„
„ „	„ „	..	„
49*g*. „ South Roskear, Cambourne.	„ „	..	*50*
„ „	„ „	..	„

---

* Nos. 49*a* to 49*p* are from Mr. Henwood's paper, "Trans. Roy. Geol. Soc. Cornwall," vol. v, pp. 389—402.

Arago gives a depth of 377 feet with a temp. of 31° F.

	V Depths below surface.	VI Temperature at depths.	VII References and Remarks.
	Feet.	Fahr.	
37	1797	81·9°	Walferdin, "Comptes rendus," 1837, p. 977; and Arago.
38	1380	80	Henwood, "Report Brit. Assoc.," 1837. Thermometer buried in rock.
39	1572	82	
40	1740	85·3	
41	880	74·3	Bischof, "Edin. New Phil. Mag.," vol. xxiv, p. 132 (1838).
42	600	63·7†	Girardin, "Comptes rendus," 1838, p. 507.
43	246	54·5	Walferdin, "Comptes rendus," 1838, p. 503.
	830	64·4	
44	50	18·5	Erman, "Comptes rendus," 1838, p. 501.
	77	19·6	
	119	23	
	182**	31	
45	231	51·5	R. Paterson, "Edin. Phil. Mag.," vol. xxvii, p. 71 (1839).
	270	51·5	
	380?	53	
	..	..	Only the rate of increase given.
46	1105	78	Biver, "Comptes rendus," vol. x, p. 41 (1840).
47	354	..	Fox, "Brit. Assoc. Rep.," p. 310 (1840). Average of 53 mines. Only the rate of increase is given. In these cases see Table III.
	438	..	
	684	..	
48	410‡	60	Walferdin, "Bull. Soc. Géol. France," vol. xi, p. 29 (1840).
48*a*	216	55·3	Arago, "Notices Scientifiques."
49	177§	57·2	Lassaigne, "Comptes rendus," October, 1842.
49*a*	480	61	Small stream from lode.
	810	70·7	Small stream from rock.
49*b*	1704	89	Moderate stream from lode-end.
	1764	92·5	Large stream from lode-end.
49*c*	1080	74	Very large stream from *cross-course*.
	1260	89·5	Moderate stream from lode-end.
49*d*	804	70	Large stream from rock.
	864	73	
49*e*	222	56·5	Moderate stream from lode-end.
	480	63	Large ” ” ”
	600	66	Small ” ” ”
49*f*	180	55·5	Small stream from lode.
	660	66	Large ” ” ”
49*g*	702	62	Moderate ” ” ”
	774	68	Small ” ” ”
	834	71	

---

† Thermometer not protected, but pressure allowed for; remained down 16 hours.

‡ The last 107 feet were obstructed, so that the actual depth was 517 feet.

§ Water overflows.

I Locality.	II Place of observation.	III Height of surface above sea-level.	IV Mean annual temperature of surface.
		Feet.	Fahr.
49*h*. Cornwall, North Roskear.	*Copper mine*	..	*50°*
,, ,,	,, ,, ...	..	,,
,, ,,	,, ,, ...	..	,,
,, ,,	,, ,, ...	..	,,
49*i*. ,, East Pool	,, ,, ...	..	,,
,, ,, ...	,, ,, ...	..	,,
49*j*. ,, Wheal Uny, Redruth.	*Tin mine*	..	,,
,, ,,	,, ...	..	,,
49*k*. Cornwall, Chacewater, Redruth.	,, ...	..	,,
,, ,,	,, ...	..	,,
49*l*. Cornwall, East Wheal Virgin Consolidated Mines, Redruth.	*Copper mine*	..	,,
,, ,,	,, ,, ...	..	,,
49*m*. Cornwall, Wheal Towan, St. Agnes.	,, ,, ...	..	,,
,, ,,	,, ,, ...	..	,,
49*n*. ,, Wheal Prudence	,, ,, ...	..	,,
49*p*. ,, Wheal Vor ...	*Copper and tin mine* ...	..	*51*
,, ,,	,, ,, ..	..	,,
50. Cornwall, Binner Downs .	*Copper mine*	..	*50*
,, ...	,, ...	..	,,
,, ...	,, ...	..	,,
,, ...	,, ...	..	,,
,, ...	,, ...	..	,,
51. Devonshire, Wheal Friendship.	,, ...	..	,,
,, ...	,, ...	..	,,
,, ...	,, ...	..	,,
,, ...	,, ...	..	,,
52. Cornwall, St. Ives Consols	*Copper and tin mine* ...	..	*51*
,, ...	,, ...	..	,,
,, ...	,, ...	..	,,
,, ...	,, ...	..	,,
53. Cornwall, Wheal Wreath.	*Tin mine*	..	,,
,, ...	,, ...	..	,,
,, ...	,, ...	..	,,
,, ...	,, ...	..	,,
,, ...	,, ...	..	,,
54. Cornwall and Devon.....	*Various tin and copper mines*	..	*50*
,, ,, ...	,, ,, ..	..	,,
,, ,, ...	,, ,, ..	..	,,
,, ,, ...	,, ,, ..	..	,,
,, ,, ...	,, ,, ..	..	,,
55. Monte Massi, Tuscany*..	*Shaft* (?)	*174*	*56 ?*
,, ,, ,, ...	,, ...	,,	,,

* No water. Shaft well ventilated. An abnormal centre of heat in this district.

	V	VI	VII
	Depths below surface.	Temperature at depths.	References and Remarks.
	Feet.	Fahr.	
49*h*	402	61°	Small stream from lode.
	642	66	
	786	60·7	
	822	73	
49*i*	372	59	Large " " "
	"	58·5	Large stream from cross-course.
49*j*	390	58·3	Large stream from lode.
	432	60	Large stream from rock.
	486	61·5	Small stream from lode.
49*k*	768	75	Large " " "
	"	68	Small " " "
	"	72	Small stream from rock.
49*l*	1500	86·5	Large stream from lode-end.
	1722	94·5	Large stream from rock.
	"	92	Small stream from vein.
	"	91	Hole in rock.
49*m*	648	62	Moderate stream from lode.
	804	70	Small stream from rock.
	924	72	Small stream from lode.
49*n*	654	65·5	Large stream from lode.
49*p*	1420	80·5	Temperature of rock.
	1706	91	
50	300	56·5	Henwood, "Trans. Roy. Geol. Soc. Cornwall," vol. v, p. 389 and 402 (1843). The observations in all these mines were taken in springs issuing from the lode or rock.
	756	67	
	816	65	
	936	74·5	
	1056	82	
51	282	55	
	450	54	
	690	64	
	810	69·5	
52	108	57	*Ibid.*, p. 387.
	642	60·5	
	462	65	
	810	71	
53	162	53	
	1242	70	
	1422	71·5	
	"	75	
	1482	76	
54	180	54·8	*Ibid.*, p. 402. Average of various mines in ten districts.
	432	60·8	
	762	67·4	
	1050	78·6	
	1440	85·5	
55	1122	103	Matteucci, "Comptes rendus," 1843, p. 937; 1845, p. 816.
	1214	107	

I Locality.	II Place of observation.	III Height of surface above sea-level.	IV Mean annual tempera-ture of surface.
		Feet.	Fahr.
56. Neuffen, Wurtemberg*	*Shaft and bore-hole*	*1378*	*46° ?*
57. Mondorff,† Luxembourg	*Artesian well*	*672*	*47 ?*
"	" "	"	"
"	" "	..	"
58. Mons (Couchant de Flénu) §	*Coal pit*	..	..
59. Eastern Virginia, U.S., Mills's Pit.‖	*Coal pits*	..	*56·7*
60. Eastern Virginia, U.S., Wills's Pit.	" "	..	"
" "	" "	..	"
61. Eastern Virginia, U.S., Midlothian Pit.	" "	..	"
" "	" "	..	"
" "	" "	..	"
62. Meaux, Marne	*Artesian well*	..	*51*
63. Ostend, Belgium	" "	*20*	*m 50*
64. Vienna	" "	*637*	*m 50*
65. Mondorff, Luxembourg	" "	*584*	*47·3 ?*
" "	" "	"	"
66. Charleston, U.S.A.	" "	*20*	*m 66*
" "	" "	"	"
" "	" "	"	"
" "	" "	"	"
" "	" "	"	"
67. Conselica, Ferrara, Italy¶	" "	*27*	*m 53·9*
68. Creuzot (Torcy) Saône et Loire.**	*Bore-hole*	*1017*	*48·5*
69. Creuzot (Mouillonge)	" "	*1052*	"
70. 1837. Cornwall { Par Consols }	*Tin mine*	..	*51*
71. 1837 " "	*Copper mine*	..	"
72. 1837 " Botallock.	" "	*40*	*51*

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* The abnormal temperature in this boring is attributed by M. Daubrée to the proximity of masses of basalt of post-miocene age; and by which basalt the adjacent rocks have been altered. The surface temperature of Tubingen is 8·7° C. The temperature from 30 mètres downwards marked 38·7° C.

† The water overflowed from a spring met with at a depth of 450 mètres. Bore-hole continued to further depth of 730 mètres. Thermometer not protected.

‡ Temperature of the water which overflowed at this level.

§ Temp. not given: only the rate of increase of 1° C. in 33·25 mètres.

‖ At Mills's and Wills's pits the temperature given is that of the water collected at bottom of shafts.

	V	VI	VII
	Depths below surface.	Temperature at depths.	REFERENCES AND REMARKS.
	Feet.	Fahr.	
56	1263	101°	Daubrée, "Comptes rendus," 1845.
57	1476	‡74·7	Rivot, "Ann. des Mines," vol. viii, p. 79 (1845).
	2200	93·2	
	2297	? §	
58	..	..	"L'Institut," April, 1845.
59	420	63	Professor H. D. Rogers, 1846. Observations in Report on Coal Mines of Eastern Virginia.
60	386	62	
	570	65·5	
61	330	61·7	
	600	66·2	
	780	68·7	
62	230	57·2	D'Archiac, "Histoire des Progrès de la Géologie," vol. i, p. 77 (1847).
63	967	71·6	Dewalque, "Bull. Géol. Soc. de France," vol. xx, p. 235 (1849).
64	616	60·8	"Bull. Géol. Soc. de France."
65	1647	(*a*) 78·3	Walferdin, "Comptes rendus," 1853, p. 250. (*a*) Temp. of first overflowing spring. (*b*) " of the mud in bore-hole; this is unreliable on account of convection currents.
	2362	(*b*) 81·7	
66	50	68	Hume, "Edin. New. Phil. Journ.," vol. lvii, p. 178 (1854). Nothing said about protection against pressure or convection currents. Observations were taken at every 100 feet.
	100	68	
	400	72	
	1000	84	
	1106	88	
67	164	59	Scarabelli, "Bull. Soc. Géol. France," vol. xiv, p. 102 (1856).
68	1817	81	Walferdin, "Comptes rendus," 1857, p. 971.
69	2677	100	
70	768	74	R. Were Fox, "Brit. Assoc. Reports for 1857," p. 96.††
71	1248	84	
72	1128	(*a*) 79	(*a*) Under the sea—gallery quite dry.

¶ Water rose 2 mètres above surface.

** Eighteen protected thermometers used. The boring at Torcy had been suspended for six months. The observations at Mouillonge were made only after one to three days' rest. The two borings are 1500 mètres apart.

†† Most of these experiments were made at or near the ends of the deepest levels of the mines. Casella's thermometers were used in the later experiments. They were placed in holes 15 to 20 inches deep in the rock, which were carefully closed with clay, tow, or cotton. Thermometer left in for ½ to 1 hour.

I	II	III	IV
Locality.	Place of observation.	Height of surface above sea-level.	Mean annual temperature of surface.
		Feet.	Fahr.
73. 1822. Cornwall, Dolcoath	*Copper and tin mine..*	*280*	*50°*
74. 1857 ,, ,,	,, ,, ..	..	,,
75. 1853 ,, ,,	*Another lode..........*	..	,,
76. 1853 ,, Levant	*Copper and tin mine ..*	*80 ?*	*51*
76*a*. ,, ,, ,,	,, ,, ..	..	,,
77. 1857 ,, ,,	,, ,, ..	..	,,
78. 1837 ,, Tresavean	*Copper mine..........*	*362*	*50*
79. 1853 ,, ,,	,, ,, ...	,,	,,
80. 1853 ,, United or Fowey Consols.	,, ,, ...	..	*51*
81. 1857 ,, ,,	,, ,, ...	..	,,
82. ,, ,, ,,	,, ,, ...	..	,,
83. Chili	*Colorado mine........*	*3656*	..
,, ...	,, ,, ...	,,	..
,, ...	,, ,, ...	,,	..
,, ...	,, ,, ...	,,	..
,, ...	,, ,, ...	,,	..
84. Columbus, Ohio, U.S.A.*.	*Artesian well ....*	*834*	*m 53·3*
,, ,, ...	,, ,, ...	,,	,,
85. Dukinfield, 1848	*Coal shaft ....*	..	*48*†
,, ,, ...	,, ...	..	,,
,, ,, ...	,, ...	..	,,
,, ,, ...	,, ...	..	,,
,, ,, ...	,, ...	..	,,
,, ,, ...	,, ...	..	,,
,, ,, ...	,, ...	..	,,
86. Dukinfield, 1858........	,, *A new shaft*	..	,,
,, ,, ...	,, ...	..	..
,, ,, ...	,, ...	..	..
,, ,, ...	,, ...	..	..
87. Rehme, Westphalia	*Artesian well ....*	..	*48·6*‡
88. Louisville, Kentucky§ ..	,, ,, ...	*450*	*m 55·7*
88*a*. Sahara Desert..........	,, ,, ...	..	..
89. Naples, Largo Vittoria‖..	,, ,, ...	..	*m 59·9*
90. ,, Royal Palace....	,, ,, ...	..	,,
91. Ben Tallah, Algeria	,, ,, ...	..	*68 ?***
92. Baraki, ,, ...	,, ,, ...	..	,,
93. Oued-el-Halleg, ,, ...	,, ,, ...	..	,,

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* Walferdin's thermometers in strong iron case were used, but without protection against convection currents ; left down 28 hours.

† The surface temperature of Manchester is M 48·6°. Dukinfield stands higher.

‡ This is the temperature of Bochum.

	V Depths below surface.	VI Temperature at depths.	VII REFERENCES AND REMARKS.
	Feet.	Fahr.	
73	1380	76°	R. Were Fox, "Brit. Assoc. Reports for 1857," p. 96; also "Coal Commission Report," vol. ii, p. 211. (*a*) Near bottom of shaft. (*b*) Not far under the sea. (*c*) Far under the sea—no working going on. (*d*) A copious spring of water here gave 93·5°. (*e*) A hot spring in another lode.
74	1632	73	
75	"	79·5	
76	1530	(*a*) 74	
76*a*	"	(*b*) 87	
77	"	(*c*) 85	
78	1572	82·5	
79	2112	(*d*) 90·5	
80	1728	93	
81	1530	..	
82	"	(*e*) 116	Henwood, "Edin. Phil. Mag.," N.S., vol. vii, p. 147 (1858). The mine is 1500 feet deep; well ventilated. No water: rainless district. Obs. in holes in rock 2 feet deep.
83	288	64·8	
	762	67·5	
	900	67	
	1362	72	
	"	74·5	Wormley, "Amer. Journ. Science," 2nd Ser., vol. xxx, p. 106 (1860).
84	90	53	
	2575	88	Fairbairn: "Brit. Assoc. Reports," 1861, p. 53. Observations made in holes on side of shaft; thermometer left from half an hour to two hours. The holes all dry and mostly in shale or rock. No mention of temperature of air in the shaft, or of the depth of the holes.
85	17	51	
	711	58	
	900	60	
	1119	64	
	1338	67	
	1734	72	
	2151	75	
86	502	58	
	924	60	
	1000 ?	62 ?	
	1401	66·5	
87	2280	88 ?	Fairbairn, "Brit. Assoc. Reports," 1861.
88	2086	83·5	Delesse, "Revue de Géologie," vol. i, p. 9 (1862).
88*a*	..	..	Only the rate of increase given. See Table IV.
89	909	71·6	Mallet, "Neapolitan Earthquakes," vol. ii, p. 311 (1862).
90	1460	68¶	
91′	459	76	L. Ville, "Ann. des Mines," 6th Ser., vol. v, p. 369 (1864). Overflowing wells.
92	426	77	
93	371	73·4	

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§ Overflowing salt water; said to rise 52 mètres above surface.

‖ The water rose above the surface.

¶ Attributes this low temperature to the influx of water at different depths.

** The mean temperature of Algiers is 64·5°.

I Locality.	II Place of observation.	III Height of surface above sea-level.	IV Mean annual temperature of surface.
		Feet.	Fahr.
94. Reggio, Italy	*Artesian well*	..	*65·5°**
95. Ghadamés, Tripoli......	,, ,, ...	..	*73·4*
96. St. Petersburg	,, ,, ...	*15*	*m 38·6*
97. Messis, Algeria	,, ,, ...	..	*68 ?*
,, ,, ...	,, ,, ...	..	,,
98. Meiahadalon, Algeria....	,, ,, ...	..	,,
,, ,, ...	,, ,, ...	..	,,
,, ,, ...	,, ,, ...	..	,,
99. Chega, ,, ...	,, ,, ...	..	,,
100. Bothwell, Ontario, U.S..	,, ,, ...	..	*45 ?*
101. Rochefort, Charente Inf. .	,, ,, ...	..	*54·5*
102. Virac (Tarn)	,, ,, ...	*705*	*55 ?*
103. Montigny, Belgium	*Coal pit*	..	*51*
104.‖ Pendleton Colliery, Manchester.	,, ...	*126*	*m 48·6*
,, ,,	,, ...	,,	,,
,, ,,	,, ...	,,	,,
,, ,,	,, ...	,,	,,
105. Hucknall Torkard Colliery, Nottinghamshire.	,, ...	..	*s 48·9‡‡*
106. Annesley Colliery ,,	,, ...	..	,,
107. Kiveton Park Colliery ,,	,, ...	..	,,
108. Swanwick Colliery ,,	,, ...	*460*	*48*
109. Moira Colliery, Warwickshire.	,, ...	..	*48·5*
110. Ruabon, North Wales ..	,, ...	*420*	*48*
,, ,,	,, ...	,,	,,
,, ,,	,, ...	,,	,,
,, ,,	,, ...	,,	,,

---

* Temperature of Messina.

† The rate of increase is given at 1° C. in 30 to 31 mètres. No other particulars.

‡ Water rose above surface, at rate of 700 gallons per hour, from the Corniferous Limestone.

§ Temperature of air in gallery 68° F.

‖ Nos. 104 to 122 inclusive are from the Royal Coal Commission, 1866–70, vol. ii, "Report on the Possible Depth of Working."

¶ This was in the floor; temperature in coal 70° at a distance of 500 yards from the down-brow. In the same level 1000 yards from the down brow, the temperature was 83° in the coal, and 82° in the floor.

	V	VI	VII
	Depths below surface.	Temperature at depths.	References and Remarks.
	Feet.	Fahr.	
94	2297	†	"Revue de Géologie, vol. iii (1864).
95	394	84·2°	,, ,, ,, ,,
96	525	50·5	*Ibid.*, vol. iv (1865), the water overflows.
97	144	69·5	
98	277 67 193 263	71·6 75 76 77·2	Degoussée et Laurent, "Revue de Géol.," vol. iv, p. 25 (1865). Discharge of water per minute, respectively 150, 1200, 15, 50, and 270 litres.
99	138	73·4	*Ibid.*, p. 26 (1865).
100	475‡	54	Sterry Hunt, "Chem. and Geol. Essays," 1866, p. 159.
101	2812	111	Letter from Mauget and Lippmann, Paris, January, 1872. Overflowing mineral water.
102	971	84·2	"Revue de Géol.," vol. viii (1869). Overflowing well.
103	2180	73·4§	W. Warington Smyth, "Quar. Jour. Geol. Soc.," vol. xxiv, p. 81 (1868).
104	1650	74	"Coal Commission Report," vol. ii, pp. 90, 192, and 199.
	1944	77	
	2088	74¶	The work here had been open six years.
	2214	86**	Work here had been open six months.††
105	1250	70	"Coal Commission Report," vol. ii, p. 96. A new pit.
106	1425	73	,, ,, ,,
107	1200	71	,, ,, ,,
108	966	62·5	,, ,, Very wet shaft.
109	1030	..	,, ,, ,,
110	1002	60§§	*Ibid.*, p. 104. Temp. of air in gallery .. 58°
	1503	70·5	,, ,, ,, .. 58·5
	1605	73	,, ,, ,, .. 71
	1770	78	,, ,, ,, .. 71

** At 200 yards from the down-brow, the temperature was 80° in the coal and 84° in the floor. At 400 yards it was 82° in the coal and 86° in the floor. In a tunnel at the same level, the temperature of the shale was 76°; further on in fireclay it was 79°, and still further in hard rock 82°. Holes from 3 to 4 feet deep. Thermometers verified at Kew. Left 3 to 12 hours in holes perfectly dry.

†† When open one year the reading gave 84°.

‡‡ This is the mean annual temperature of Nottingham.

§§ This observation was not taken until long after the pit was sunk, and coal evidently cooled.

I Locality.	II Place of observation.	III Height of surface above sea-level.	IV Mean annual temperature of surface.
		Feet.	Fahr.
111. Norley Coal Co., Wigan ..	*Coal pit*	*157*	*48°*
" "	"	"	"
" "	"	"	"
" "	"	"	"
112. Aberdare, Upper Duffryn* Colliery, No. 1 Station.	"	*400*	*48·5*
" " 2 "	"	*1220*	..
" " 3 "	"	*1330*	..
" " 4 "	"	*1540*	..
113. " New Tredegar Colliery,† No. 1 Station.	"	*720*	*48?*
" " 2 "	"	*679*	..
" " 3 "	"	*1495*	..
" " 4 "	"	*1287*	..
114. " Dowlais Colliery, Ironstone Mine.	"	*1170*	*47*
" "	"	"	"
115. " Cwmbach	"	*480*	*48·5*
" "	"	*1300*	"
116. Hetton Colliery, Durham‡	"	*400*	*47*§
" " "	"	"	"
" " "	"	"	"
" " "	"	"	"
" " "	"	"	"
" " "	"	"	"
" " "	"	"	"
117. South Hetton Colliery, Durham.	"	*204*	"
" " "	"	..	"
" " "	"	..	"
118. Rosebridge Colliery, Wigan	"	*157*	*48*
" " "	"	"	"
" " "	"	"	"
" " "	"	"	"
" " "	"	"	"

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* Beyond No. 2 station the circulation of air was partially stopped, and beyond No. 3 station entirely stopped, that part of the colliery having been abandoned for 18 months. The other Aberdare experiments were in collieries that were working at the time, and the air not shut off. The temperatures taken 4 feet deep in the coal.

† Although the surface at No. 3 station is 124 feet lower than at No. 4, it is

	V Depths below surface.	VI Temperature at depths.	VII References and Remarks.		
	Feet.	Fahr.			
111	1049	75°	"Coal Commission Report," p. 104. Temp. in gallery....	.. 71°	
	1184	75	,, ,, ,, ..	.. 72	
	1282	78	,, ,, ,, ..	.. 73	
	1487	80	,, ,, ,, ..	.. 70	
112	360	61	*Ibid.*, p. 105, *et seq.* Temperature of air in gallery..	62° F.	Distance from shaft. 27 yards.
	1210	65	,, ,, ..	66	1587 ,,
	1400	68	,, ,, ..	66	1877 ,,
	1690	75	,, ,, ..	74	2327 ,,
113	865	58	,, ,, ..	60	110 ,,
	920	63	,, ,, ..	70	570 ,,
	1673	69	,, ,, ..	71	2090 ,,
	1549	67	,, ,, ..	72	1370 ,,
114	371	56	,, ,, ..	55	
	536	59	,, ,, ..	58	
115	250	55			
	988	61			
116	1100	60	*Ibid.*, p. 123. Temperature of air in gallery............	50° F.	Distance from shaft. 312 yards.
	1135	68	,, ,, ..	69	1935 ,,
	1270	63	,, ,, ..	58½	955 ,,
	1315	69·5	,, ,, ..	68	2980 ,,
	1360	66	,, ,, ..	62	1640 ,,
	1395	71	,, ,, ..	73	4332 ,,
	1400	70·5	,, ,, ..	72	3550 ,,
117	1368	72‖	*Ibid.*, p. 123.		
	1662	82			
	1938	96			
118	483	64·5	*Ibid.*, pp. 143 and 188. All the holes were 1 yard deep and made air-tight. Holes allowed to stand 8 hours before thermometers were put in. Thermometers left 30 minutes.		
	564	66			
	1674	78			
	1815	80			
	1890	83			

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further in the heart of the mountain, and the rise of surface at No. 4 is very abrupt.

Temperatures taken 4 feet deep in coal, in dry holes and no gas.

‡ Holes in coal 3 feet deep, filled with water, and left 48 hours. Thermometers then placed in them for 24 hours.

§ The mean annual temperature of Durham is 47·1°, and of Seaham is 47·7.°

‖ These temperatures were taken after boring operations had been suspended about a week; bore-holes full of water.

I Locality.	II Place of observation.	III Height of surface above sea-level.	IV Mean annual temperature of surface.
		Feet.	Fahr.
Rosebridge Colliery, Wigan	*Coal pit*	157	*48°*
" " "	" "	"	"
" " "	" "	"	"
" " "	" "	"	"
" " "	" "	"	"
" " "	" "	"	"
" " "	" "	"	"
" " "	" "	"	"
119. Sharlston Colliery, Barnsley[†]	" "	*240*	"
120. Victoria Colliery, Wakefield.	" "	*140*	*m 48·5*
121. Worthington Colliery, Lancashire.	" "	..	*48 ?*
122. Ram's Mine, Lancashire, Pendleton Colliery.[§]	" "	*175*	*48·6*
" " "	" "	"	"
" " "	" "	"	"
" " "	" "	"	"
122*a*. Cornwall, Tresavean[‖] ..	*Copper and tin mine*...	..	*50*
123[¶]. Blythswood, nr. Glasgow	*Bore-hole*.............	?	*m 47*[**]
" " .	"	..	"
" " .	"	..	"
124. South Balgray " .	"	?	"
" " " .	"	..	"
" " " .	"	..	"
" " " .	"	..	"
125. Carrickfergus, Belfast....	*Salt pit shaft*	..	*m 48·8*[††]
"	" "	..	"
126. Rosebridge, Wigan......	*Coal shaft*............	*157*	*s 48*
" "	"	"	"
" "	"	"	"
" "	"	"	"
" "	"	"	"
127. St. Louis, U.S. America..	*Shaft to 71 feet, then a bore-hole*	*481*	*m 55*
" "		"	"
128. Mont Cenis Tunnel......	......	*9529*	*27·3*[‡‡]

---

[*] The air at this depth was 18 to 22° lower than the rock temperature.

[†] The holes in this and the following pit were in coal and 2 yards deep, and perfectly dry. Thermometers left two days.

[‡] This was the temperature of a brackish spring issuing from a grit rock 2′ 9″ thick met with in sinking the shaft, and discharging about 1600 gallons per hour.

[§] These observations were taken two years after those of Mr. Knowles; the first three were made in holes 3 feet deep.

	V Depths below surface.	VI Temperature at depths.	VII References and Remarks.
	Feet.	Fahr.	
	1989 2037 2202 2235 2283 2322 2349 2400	85° 87 88·5 89 91·5 91·5 92 ? 93*	"Coal Commission Report," pp. 143 and 149. All the holes were 1 yard deep and made air-tight. Holes allowed to stand 8 hours before thermometers were put in. Thermometers left 30 minutes.
119 **120**	1005 1455	65 78	Distance from shaft. *Ibid.*, p. 157. Air in gallery.. 63° 270 yds. „ „ 65 600 „
121	1803	82‡	*Ibid.*, p. 194.
122	1944	72	*Ibid.*, p. 199. At 300 yds. from engine brow, 3 feet deep.
	2088	78	At 500 yds., hole 3 feet deep.
	„	82	At 1000 yds., hole 3 feet deep.
	2214	84	At 930 yds. from brow; hole 7 ft. 9 in. deep.
122*a*	2130	99	*Ibid.*, p. 85. Dry level hole, 4 ft. deep.
123	60 180 347	47·9 50·5 53·7	Brit. Assoc. Report of 1869. Water in bore-hole.
124	60 180 360 525	48·2 51·1 55·4 59·5	*Ibid.* Original depth 1040 ft.; bore-hole silted up to 525 ft., and full of water.
125	570 770	62·4 66	*Ibid.* A few feet of water in both shafts.
126	600 1674 1989 2235 2445	66 ? 78 85 89 94	The temperatures (except the first) were taken during the sinking of the shaft by drilling a hole to the depth of a yard, plugging with clay, and leaving the thermometer ½ an hour.
127	3029 3843	107 105	Brit. Assoc. Report of 1870. Better data wanted.
128	5282	85·1	Brit. Assoc. Report of 1871.

‖ Coal Commission Report, A 4, vol. ii.

¶ Nos. 123 to 165*a* are from the reports of Prof. Everett, Secretary of the Committee of Underground Temperatures, in "Trans. Brit. Assoc.," 1869–83, inclusive.

** Mean annual temperature of Glasgow.

†† Mean annual temperature of Belfast.

‡‡ This is the estimated mean temperature of the surface summit level.

I Locality.	II Place of observation.	III Height of surface above sea-level.	IV Mean annual temperature of surface.
		Feet.	Fahr.
129. Kentish Town	*Artesian well*	*187*	*49°*
,, ,,	,, ,,	,,	,,
,, ,,	,, ,,	,,	,,
,, ,,	,, ,,	,,	,,
,, ,,	,, ,,	,,	,,
,, ,,	,, ,,	,,	,,
130. Allanheads, Northumberland (Gin Hill Shaft)	*Lead mines*	*1360 ?*	*s 44·2*
,, ,,	,, ,,	..	,,
,, ,,	,, ,,	..	,,
131. Allanheads, Northumberland (High Engine Shaft)	,, ,,	..	,,
132. Allanheads, Weardale, Slit Mine	,, ,,	..	*45·3*
133. Allanheads, Breckonhill Shaft	,, ,,	*1174*	*44 ?*
,, ,,	,, ,,	,,	,,
134. Crawriggs, near Glasgow.	*Bore-hole*	*200*	*47*
,, ,,	,,	,,	,,
,, ,,	,,	,,	,,
135. Moscow	,,	*466*	*a 39·5*
,,	,,	,,	,,
136. Durham, South Hetton Colliery	*Shaft and bore-hole*	*100 ?*	*47·5*
,, ,, ,,	,, ,,	,,	,,
,, ,, ,,	,, ,,	,,	,,
137. Paris, La Chapelle St. Denis	*Artesian well*	..	*51·5*
,, ,, ,,	,, ,,	..	,,
,, ,, ,,	,, ,,	..	,,
138. Stowmarket	,, ,,	*185*	*s 49·4*
,,	,, ,,	,,	,,
139. Przibram, Bohemia‡	*Adalbert silver mine*	?	*44·7 ?*
,, ,,	,, ,,	..	..
,, ,,	,, ,,	..	..
,, ,,	,, ,,	..	..
140. Seraing, Liège, Marie Colliery	*Coal pit*	*177 ?*	*m 51·1*
,, ,, ,,	,,	,,	,,
141. ,, Henri Guillaume	,,	,,	,,

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* Subsequent observations made in 1879 established a temperature of 67·06° at 1008 feet.

† The thermometer could not be sunk below 857 feet, but the shaft extends to the depth of 957 ft.

	V	VI	VII
	Depths below surface.	Temperature at depths.	References and Remarks.
	Feet.	Fahr.	
129	305	56°	These are the results* of repeated observations commenced in 1869, by Mr. G. J. Symons. Rate of increase down to 910 ft. is 56 ft. for 1° F. Below that 49 ft. for each degree.
	500	60	
	700	62·8	
	850	65	
	1000	67·8	
	1100	69·9	
130	340	49·3	Water stands in shaft at 328 ft. No reliance is placed on this determination.
	390	51·2	
	440	51·3	
131	857†	65·7	Water stands at 797 ft.
132	660	65·1	Shaft full of water.
133	42	46·5	Water stands 24 ft. down shaft. Unreliable.
	342	46·6	
134	50	47	No weight attached to this determination.
	200	50	
	350	51	
135	350	50	Same temperature at all depths.
	994	50	
136	1166*a*	66	*a*. 100 feet deep in bore-hole. Brit. Assoc. Report of 1872. Shaft is 1066 feet deep, and bore-hole 863 feet. Total depth 1924 feet.
	1466	72	
	1736	77⅛	
137	328	59·5	Brit. Assoc. Report of 1873. The diameter of this bore-hole is 4 feet. Convection currents interfere with these results.
	1312	69	
	2165	76	
138	100	53	Original depth was 895 feet. Blocked. Uncertain results.
	283	54	
139	621	50·7	Brit. Assoc. Report of 1874. Observations made in holes 2 feet deep and far from the workings. Temperature of air not given.
	1209	58·3	
	1652	61·2	
	1900	61·4	
140	761	77	Temperature of air in gallery 77½° F. Observations made in holes 5 mètres deep. Thermometer left 24 hours.
	1017	78	
141	1656	87	

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‡ The section of this mine shows fifteen shafts. Herr Grimm attributes the slow increase of heat to the rocks, which are of Silurian age, being very quartzose.

I Locality.	II Place of observation.	III Height of surface above sea-level.	IV Mean annual temperature of surface.
		Feet.	Fahr.
142. Chiswick, Middlesex	*Artesian well*	*25*	*49·6°*
"	" "	"	..
"	" "	"	..
143. Swinderby, Lincoln	*Bore-hole*	*120 ?*	*48·5 ?*
" "	"	..	"
" "	"	..	"
" "	"	..	"
" "	"	..	"
" "	"	..	"
" "	"	..	"
144. Sperenberg, Berlin	"	?	*m 48·3**
" "	"	"	"
" "	"	"	"
" "	"	"	"
" "	"	"	"
" "	"	"	"
" "	"	"	..
" "	"	"	..
144*a*. St. Petersburgh	*Artesian well*	..	*39·17*
145. Anzin, Nord, France	*No.* 1 *Colliery shaft*	..	*50·5*
" "	" "	..	"
146. " "	*No.* 2‡ " "	..	"
" "	" "	..	"
147. " "	*No.* 3 " "	..	"
" "	" "	..	"
148. " "	*No.* 4 " "	..	"
" "	" "	..	..
149. Schemnitz, Hungary	*Elizabeth silver mine.*	from *1633* to *2504*	from *47* to *42* (mean *44·3*)
" "	*Maximilian* "		
" "	*Amelia* "		
" "	*Stefan* "		
" "	*Siglisberg* "		
150. Boldon, Newcastle	*Coal pit*	*97*	*47·1*§
" "	" "	"	"
151. Manegaon, India	*Bore-hole*	*1400*	*75 ?*
" "	"	"	"
" "	"	"	"
" "	"	"	"
152. Pontypridd, South Wales.	*Coal pit*‖	*554*	*49 ?*

---

* This is the mean temperature of Berlin.

† The depths here given are in Rhenish feet, 4052 Rhenish = 4172 English feet.

‡ In this shaft there was a seam of decomposing coal at a depth of 90 metres.

§ Temperature of South Shields.

	V	VI	VII
	Depths below surface.	Temperature at depths.	REFERENCES AND REMARKS.
	Feet.	Fahr.	
142	65	56·2°	Brit. Assoc. Report of 1875. Water stands 60 feet from surface. 5 feet shaft down to 200 feet, then a bore-hole.
	206	55	
	395	58	
143	100	68	Brit. Assoc. Reports of 1875-6. Springs at 790 and 950 feet. Strong convection currents affect results.
	500	68¾	
	1000	69⅛	
	1300	70⅛	
	1500	73	
	1950	78	
	2000	79	
144	100†	55	Brit. Assoc. Report of 1876. Diameter of bore at 3390 feet, 12 inches; then reduced to 6 inches. Bore-hole plugged to protect against convection currents, and observations corrected for pressure.
	700	70·8	
	1100	79·5	
	1500	84·5	
	1700	87·5	
	2100	96·3	
	3390	115·5	
	4052		
144*a*	656	54	Water overflows.
145	126	56½	Obs. made in holes 0·6 to 0·7 m. deep in sides of shaft during sinking. Little circulation of air; ¼ hour elapsed between boring hole and inserting thermometer. Temp. of air in the wet shafts, 1, 2, and 3 was from 52 to 54°: in the dry shaft, No. 4, 59°.
	658	67¾	
146	286	55	
	607	63½	
147	286	56	
	472	62½	
148	69	70¾	
	442	84	
149	1368	..	Brit. Assoc. Report of 1877. The actual temperatures are not given; only the rate of increase which averages for the 5 mines 75½ ft. for each 1° Fahr.
	830		
	935		
	715		
	1358		
150	1365	75	Still air in gallery 78½°. Trial holes 10 ft. deep; left four weeks to cool, temp. falling from 81 to 79°. Air travelled 3 miles and nearly stagnant.
	1514	79	
151	10	81	The bore-hole had been 20 months at rest. Water stands to near top of tube.
	60	81	
	150	82·7	
	310	84·7	
152	855	62·7	Report of 1878. Hole in coal 4 ft. deep.

|| The air current down the shaft amounted to between 20,000 to 30,000 cubic feet per minute. Neither the temperature of the air in gallery, nor the distance from the shaft are given. In the other parts of the mine, the air currents showed differences of 2 to 3°, according to the season of the year.

I Locality.	II Place of observation.	III Height of surface above sea-level.	IV Mean annual temperature of surface.
		Feet.	Fahr.
153. Bootle, Liverpool........	*Part shaft part bore-hole*	*40 ?*	*49·6°*
„ „	„ „	„	„
„ „	„ „	„	„
154. St. Gothard Tunnel	*Tunnel**..............	..	*31* temp. of crest.
„ „	„	..	
„ „	„	..	
„ „	„	..	..
„ „	„	..	..
155. Bristol, Kingswood......	*Deep pit colliery*......	*216*	*m 50*
„ „	„ „	„	„
„ „	„ „	„	„
156. „ „	*Speedwell colliery*.....	*216 ?*	„
„ „	„ „	„	„
„ „	„ „	„	„
158. Talargoch, Flintshire	*Lead mine, 1st pit*	*190*	*49·5*
„ „	„	„	„
„ „	„	„	*49*
„ „	„	„	„
„ „	„	„	„
159. Dukinfield†...........	*Coal pit*	..	*48*
„	„	..	„
„	„	..	„
„	„	..	„
160. Talargoch, Flintshire....	*Lead mine, 2nd pit*....	*190*	*49*
161. Manchester, Ashton Moss	*Coal pit*	..	*48 ?*
162. Cheshire, Bredbury......	„	..	*48·6*
„ Nook Pit	„	..	„
163. Radstock, Somerset, Wells May Pit	„	..	*50*
164. „ Ludlow Pit....	„	..	„
„ „	„	..	„
165. Southampton Common ..	*Artesian well*	*140*	„
165a. Ballarat, Australia......	*Copper mine*..........	..	..
166. Pitzbuhl, Magdeburg....	*Artesian well ?*........	..	*48·5 ?*
167. Artern, Thuringia	„ „	..	*47·5 ?*

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* The temperature of the springs in the tunnel was found to be higher than that of the rock.

† These additional observations by Mr. Garside were made in the coal eams in

	V Depths below surface.	VI Temperature at depths.	VII References and Remarks.
	Feet.	Fahr.	
153	226	52°	Bore-hole at top 24 in. in diameter. No correction for convection currents. Springs met with at depths of 318, 800, and 1303 ft.
	1004	58·1	
	1302	59	
154	3100	79·9	Reports of 1878–9. Swiss end of tunnel.
	4101	83·8	
	4615	82·8	Italian end of tunnel.
	4965	83·7	
	4108	85·1	
155	441	54·7	"Brit. Assoc. Report," 1879.
	1367	68·5	
	1769	74·7	Ventilation slight, and care taken to avoid air-currents. Trial holes 2 ft. deep, plugged, and thermometer left twelve hours.
156	1232	66·7	
	1439	69·7	
	1769	74·7	
158	465	53·4	Report of 1880.—Obs., distant from shaft 570 ft. Holes 2 feet deep.
	555	52·9	,, ,, ,, 321 ,,
	636	58·8	,, ,, ,, 2522 ,,
	660	54	,, ,, ,, 360 ,,
	1041	60·8	,, ,, ,, 570 ,,
159	1987	74	Distance from air shaft, 1380 ft.; air 71½°.
	2407	80	,, ,, ,, 1890 ,, ; ,, 78¾.
	2416	81	,, ,, ,, 1800 ,, ; ,, 79.
	2700	86·5	,, ,, ,, 480 ,, ; ,, 75½.
160	660	62	Report of 1881. 1200 ft. from shaft. Air still.
161	2790	85·3‡	Hole 3½ ft. deep.
162	1020	62	The temperature of air in the galleries in these and preceding pit are not given.
	1050	62·3	
163	560	61·7	In holes 2 ft. deep. Distance from shaft and temp. of galleries not given. A moderate current of air was passing.
164	810	63	
	1000	63	
165	1210	69·7	"Brit. Assoc. Report," 1883.
165*a*	760	72·5	Holes 3 ft. deep filled with water.
166	495	..	De Lapparent's, "Géologie," 1881, p. 372.
167	1012	..	*Ibid.* The rate of increase only given.

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holes 4 feet deep, and thermometer left 48 hours. The pit was entirely free from water.

‡ The gallery was free from any strong air-current and the ground newly opened.

I Locality.	II Place of observation.	III Height of surface above sea-level.	IV Mean annual temperature of surface.
		Feet.	Fahr.
168. Buda-Pesth, Hungary ..	*Artesian well*	..	*a 50·5°*
,, ,, ..	,, ,, ...	..	,,
,, ,, ..	,, ,, ...	..	,,
,, ,, ..	,, ,, ...	..	,,
,, ,, ..	,, ,, ...	..	,,
,, ,, ..	,, ,, ...	..	,,
,, ,, ..	,, ,, ...	..	,,
,, ,, ..	,, ,, ...	..	,,
,, ,, ..	,, ,, ...	..	,,
,, ,, ..	,, ,, ...	..	,,
,, ,, ..	,, ,, ...	..	,,
169. Chicago	*Artesian well*	*600*	*m 45·9*
170. Chili, Chañarcillo	*Silver mine*	..	*64*
171. Brazil, Minas Giraës	*Iron mine*	..	*64·49*
172. Sark and Herm, Channel Islands	,, ...	..	*s 51·6*
172′. Sheboyan, Wisconsin† ...	*Artesian well*	*620*	..
173. Ireland, various mines ..	*Metalliferous mine*	..	*50 ?*
174. Cornwall, mean of ten mines.	,, ,, ...	*100—300*	..
175. Ireland, Wicklow	,, ,, ...	..	*s 49·5*
176. ,, Waterford......	,, ,, ...	..	*50 ?*
177. ,, County Cork	,, ,, ...	..	*m 51 ?*
178. Venice, Villa Francisco Grande.	*Artesian well*	..	*m 55·6*
179. Venice, Gasworks.......	,, ,, ...	..	,,
180. Brussels, Belgium	,, ,, ...	*193*	*m 50·3*
181. Aerschot, ,, ‡......	,, ,, ...	..	,,
182. Minden, Prussia	,, ,, ...	*238*	*m 48§*
183. Arcachon, Gironde	,, ,, ...	..	*55·4*
184. Pondicherry, East India .	,, ,, ...	..	*a 82·5*
185. Dundee................	,, ,, ...	*160 ?*	*m 46·6*
186. Bradford, Yorkshire.....	*Ordinary well*	*366*	*s 47·8*
187. Blackburn	*Abandoned coal shaft* ..	*347*	*48‖*
188. Birmingham private well.	*Ordinary well*	*340 ?*	*m 48·7*

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* An infiltration of water from a higher level was suspected.

† Flowing water was obtained at 1340 feet in the upper portion of a Silurian sandstone. Water rose 104 feet above the surface. Discharge of water = 225 gallons per minute.

	V	VI	VII
	Depths below surface.	Temperature at depths.	References and Remarks.
	Feet.	Fahr.	
168	190	59°	Communicated (1882) by Professor Judd, from letter of Professor Szabò. The observations were made in 1877 and 1878. There are hot springs and trachytic rocks in the neighbourhood. The high temperatures are dependent upon neighbouring old volcanic centres of activity.
	216	64·4	
	328	73·4	
	1279	116	
	1640	125	
	1968	142	
	2297	156	
	2487	163	
	2900	176	
	2966	178	
	3183	164	
169	751	55*	Schott in "Smithsonian Inst. Report," p. 249, 1874.
170	930	69·2	Henwood, "Trans. Roy. Soc. Cornwall," vol. viii, p. 751 (1871).
171	318	67·9	
172	222	55·5	
172′	1475	59·1	Chamberlin, "Geology of Wisconsin," vol. ii, p. 165 (1873–77).
173	342	53·4	The observations were made in sumps or springs.
174	672	68·8	
175	552	55·5	
176	672	57·5	
177	840	61·5	
178	118	58	Laurent, "Revue de Géologie," vol. xi, p. 258 (1875).
179	236	62·5	
180	215	54	Vincent and Rutot, "Ann. Soc. Géol. Belg.," vol. v, p. 77 and 99 (1878).
181	453	57·2	
182	2230	90·9	Raulin's "Géologie," 1879, p. 84.
183	413	61·9	
184	261	93·7	Medlicott, "Geol. Survey of India," 1881.
185	238	50	Sixth Report of Rivers' Pollution Commission, 1868. "Temperature of Wells."
186	360	54·5	
187	210	49·5	
188	300	50	

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‡ The water rose 5 mètres above surface.
§ See temperature of Boehum, p. 60.
|| The temperature of Stonyhurst is 47·9°.

I Locality.	II Place of observation.	III Height of surface above sea-level.	IV Mean annual temperature of surface.
		Feet.	Fahr.
188′. Birmingham Waterworks.	*Ordinary well*	*350*	*m 48·7°*
189. Kidderminster	,, ,, ...	*320*	*49 ?*
190. St. Helen's Waterworks .	,, ,, ...	*100 ?*	*49*
191. Tranmere, Cheshire	,, ,, ...	..	*49·4**
192. Wallasey, ,, ...	,, ,, ...	..	,,
193. Worksop	,, ,, ...	*127*	*m 48·7*
194. Scarborough	,, ,, ...	*176*	*m 47·8*
195. Eastbourne	*Artesian well*	*25*	*m 50·9*
196. Deal Waterworks	*Ordinary well*	*20*	*50*
197. Dover Castle...........	,, ,, ...	*380*	*m 50·3*
198. Dover Waterworks......	,, ,, ...	*40 ?*	,,
199. Grimsby Docks	,, ,, ...	*10*	*48*
200. Deptford Waterworks...	,, ,, ...	*31*	*s 50·3*
201. Sittingbourne	,, ,, ...	*50*	*49·5 ?*
202. Braintree..............	*Artesian well*	*220*	*49·5 ?*
203. Wimbledon............	,, ,, ...	*170*	*49·6*
204. Carisbrooke Castle, I. of W.	*Ordinary well*	..	*50 ?*
205. Colchester	*Artesian well*	*109*	*m 49·4*
206. Trowbridge Waterworks	*Ordinary well*	*140*	*49·5 ?*
207. Ostend†	*Artesian well*	*10 ?*	*m 50*
,, ...	,, ,, ...	..	,,
,, ...	,, ,, ...	..	,,
208. Bourbourg,‡ near Dunkirk	,, ,, ...	..	*50·2*
209. Dunkirk	,, ,, ...	..	*m 50·2*
210. Newport, Isle of Wight..	,, ,, ...	*60*	*50·9(a)*
211. Gosport................	,, ,, ...	*20*	*m 50·6*
212. Bothwell,§ Ontario	,, ,, ...	..	*45 ?*
213. Croix, Dept. du Nord....	,, ,, ‖........	..	*50 ?*
214. Mons, Grameries Colliery.	*Coal pit*	*344*	*50·5*
,, ,, ...	,, ...	,,	,,
,, ,, ...	,, ...	,,	,,
,, ,, ...	,, ...	,,	,,

---

* 49·4 is the temperature of Chester.

† The water issued at the surface with a temperature of 18° C., and rose 8 mètres above sea-level at the first depth, and 11 mètres at the last depth.

‡ The well was carried at a depth of 250 mètres into the chalk.

§ The water rose above surface at rate of 700 gallons per hour, from the Corniferous limestone.

	V	VI	VII
	Depths below surface.	Temperature at depths.	References and Remarks.
	Feet.	Fahr.	
188′	400	53·60°	Sixth Report of Rivers' Pollution Commission, 1868. "Temperature of Wells." (I am responsible for the description of wells.—J. P.
189	160	54	
190	270	50	
191	428	50	
192	246	51·8	
193	214	51·8	
194	214	54	
195	100	50	
196	115	52	
197	367	55·4	
198	220	52	
199	300	52·5	
200	250	54	
201	400	53	
202	430	54	
203	200	54·3	
204	240	52·5	
205	400	52·6	
206	200	52	
207	567	59	Letter from Prof. Dewalque; February, 1883.
	617		
	981	71·6	
208	544	59	Letters from Prof. Gosselet, February, 1883.
209	426	52	
210	467	62	Letter from Mr. H. Turner, September, 1883.
211	372	55	(*a*) The temperature of Osborne.
212	475	54	Sterry Hunt, "Chem. and Geol. Essays," p. 159.
213	271	57	Letter from M. Ortlieb, Feb., 1883. Average of 7 wells.
214	679	66¶	Letter from M. F. L. Cornet, April, 1883. A great quantity of water flowed from the rocks in this pit.
	1013	69	
	1141	60	
	1325	58·5	

‖ These wells pass through Tertiary strata and end in Carboniferous limestone. The water in all of them rises above the surface; one well delivers 12,000 litres per hour.

¶ Thermometer placed for not less than an hour in holes, 1 mètre deep, excavated in side of gallery.

I Locality.	II Place of observation.	III Height of surface above sea-level.	IV Mean annual temperature of surface.
		Feet.	Fahr.
215. Mons, La Louvière Colliery	*Coal pit*	*410*	*50·5°*
" "	"	"	"
" "	" *another pit*	*351*	"
" "	"	"	"
216. Mons, Cuesmes Colliery	"	*213*	"
" "	"	"	"
" "	"	"	"
" "	"	"	"
" "	"	"	..
" "	"	*197*	..
217. North Seaton, Newcastle[†]	"	*−40*	*47·5*
218. Ashton Moss Colliery, Manchester	"	..	*48*
220. Dolcoath, Cornwall	*Tin mine*	*280*	*50*
" "	"	..	..
" "	"	..	..
" "	"	..	..
" "	"	..	..
" "	"	..	..
" "	"	..	..
221. Passy,[‡] Paris	*Artesian well*	*158*	*51*
223. La Fayette, Indiana	" "	..	..
224. Buenos Ayres	" "	..	*62·7*
226. Croft, Whitehaven[§]	*Coal pit*	*72*	*48·5*
227. " "	"	..	"
228. Lye Cross, Dudley[‖]	"	*822*	*47·5*
229. Denton,[¶] Manchester	"	..	*48*
230. Richmond,[**] Surrey	*Artesian well*	..	*49·6*
231. " "	" "	..	"

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[*] In another trial made 300 mètres from the shaft, the temperature at the same depth was found to be 70·75° F.

[†] These observations were made by Professor Lebour at a point under the sea, half a mile beyond water-mark, and 660 feet below O.D.

[‡] Diameter of well at top, 4 feet.

The observations recorded in the preceding list (Table I) are grouped in the following Tables II, III, IV, according to class, geological structure, and geographical position :—

	V Depths below surface.	VI Temperature at depths.	VII References and Remarks.
	Feet.	Fahr.	
215	1194	76°	Letter from M. Cornet, April, 1883. Observations made 1200 mètres from the shaft in galleries; perfectly dry and not ventilated.
	1456	81	
	787	69*	*Ibid.* In dry gallery 100 mètres from shaft.
	1361	81	*Ibid.* In a new shaft without water.
216	1548	79·5	*Ibid.* At 2180 mètres from shaft. In galleries dry and not ventilated.
	,,	79·7	,, 2400 ,, ,,
	,,	78·5	,, 2600 ,, ,,
	1680	82	,, 700 ,, ,,
	,,	81·5	,, 900 ,, ,,
	1709	85	Ther. placed in a spring of salt water issuing from a bed of sandstone.
217	620	61	"Brit. Assoc. Report," 1883.
218	2880	84	Ther. left 48 hours in hole.
220	252	64	"Brit. Assoc. Report," 1883. (*a*) Observations considered defective.
	390	65	
	876	67·8	
	1118	65(*a*)	
	1884	70(*a*)	
	2124	83	
	2244	90	
221	1924	82·5	Letter from MM. Mauget and Lippmann, Jan. 1872.
223	213	55	"Rev. Géol.," vol. i, p. 9.
224	255	69·8	"Quart. Journ. Geol. Soc.," vol. xix, p. 69.
226	1140	73	"Brit. Assoc. Report for 1882."
227	1250		
228	700	57·5	
229	1370	66	
230	1176	70	Professor Judd in "Quart. Journ. Geol. Soc.," vol. xl, p. 724 (1884).
231	1337	75·5	

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§ Hole 4 feet deep, bored upwards in roof of coal. The stations in this pit were under the sea.

‖ Hole 4 feet deep in shaly floor, under the "10 yards" coal.

¶ Situated in the valley near Dukinfield.

** Slight overflow, 4 or 5 gallons per minute.

1st. Coal Mines.
2nd. Mines other than coal.
3rd. Artesian Wells and Bore-holes.

Column 1 of these tables gives the original number of the observation in the general list of Table I.

Instead of the columns for the height and temperature of the surface, given in Table I, another giving the thermometric gradient, are substituted in the following tables.

For subjects peculiar to the separate tables, special columns are introduced in each case.

The gradients for the total depths are given in stronger type than the others.

Column VIII in Tables II and III gives the temperature of the air in the gallery in which the rock or spring temperatures are taken.

TABLE II.—COAL

In this table there is no separate column for the strata, as they all

In the few instances where they are overlaid by newer strata, the par-

Column IV gives the distance in yards of the place of observation
the face of the coal. It is, however, not often recorded.

Columns V and VI give the depth of the hole drilled for the ther-

In Column VII, the numbers in brackets show the difference of
while the rate of increase *between these depths* is given also in *italics* in
depth.

I Number in the general list, Table I.	II Name of colliery and place.	III Depth of pit or shaft.	IV Distance of station of observation from shaft.
		Feet.	Yards.
	England.		
14	Whitehaven Colliery*..................	480	..
15	Workington Colliery	504	..
16	Northumberland, Percy Main	900	..
17	„ Killingworth	1200	..
150	Newcastle, Boldon....................	1365	..
	„ „	1514	..
	„ „	*1365—1514*	..
217	„ North Seaton	620	..
30	Sunderland, Monkwearmouth...........	1584	..
116	Durham, Hetton	1100	*312*
	„ „	1135	*1935*

Those observations in which there are readily-apparent errors, or which are repeated more correctly at later dates, are not brought forward from Table I. Nor has it been considered necessary to repeat the fuller particulars there recorded, nor other observations, except such as bear upon the rate of increase of temperature with depth. The numbers in the first column will readily enable the reader to refer back to these details in the first general list.

The thermometric gradient is in all cases calculated upon the mean surface temperatures, and allowing for height above the sea-level.

PITS AND SHAFTS.

consist of the usual shales, sandstones, and coals of the Coal-measures.
ticulars are given in Column II or in the notes.
from the shaft, showing the distance the air has to travel before reaching

mometer, and whether placed in the *coal*, *rock*, or *water*.
temperature between the two depths given in *italics* in Column III,
Column IX; the figures in thicker type refer to the gradient of the entire

V Position and depth of hole for thermometer.	VI	VII Temperature at depth	VIII	IX Rate of increase of depth in feet for each degree Fahr.	X Notes and remarks.
Coal (C). Rock (R). Water (W).	Depth.	of coal, rock or water.	of air in gallery.		
	Feet.	Fahr.	Fahr.	Feet.	
14 W	..	60°	..	**42**	* At Whitehaven and Workington the Coal-measures are unconformably overlaid by 200 to 300 feet of Red Sandstones and Marls.
15 ,,	..	60	..	**44**	
16 ,,	..	68	*70°*	46	
17 ,,	..	74	*77*	**47**	
150 R	10	75	*75·5*	49	
,,	,,	79	*78·5*	**47**	
,,	..	*(4·0)*	..	*37*	
217 ..	..	61	..	**45**	
30 R	..	72·6	..	**62**	
116 C	3	60	*50*	85	
,,	,,	68	*69*	55	

I	II	III	IV
Number in the general list, Table I.	Name of colliery and place.	Depth of pit or shaft.	Distance of station of observation from shaft.
		Feet.	Yards.
	England—continued.		
116	Durham, Hetton	1270	*955*
	,, ,,	1315	*2980*
	,, ,,	1360	*1640*
	,, ,,	1395	*4330*
	,, ,,	1400	*3550*
136	,, South Hetton*	1060	..
	,, ,,	,,	..
	,, ,,	,,	..
	,, ,,	*1166—1736*	..
	,, ,,	*1466—1736*	..
121	Lancashire, Worthington	1803	..
111	Wigan, Norley Coal Co.	1487	..
		600	..
126	,, Rosebridge†	1674	..
	,, ,,	2445	..
	,, ,,	*1674—2037*	..
	,, ,,	*2037—2445*	..
	,, ,,	*1674—2445*	..
104	Manchester, Pendleton‡ (340 feet of Triassic and Permian strata overlie the Coal-measures)	1944	..
	,, ,, ,,	2214	*400*
	,, ,, ,,	*1944—2214*	..
122	,, ,, ,,	2088	*500*
	,, ,, ,,	,,	*1000*
159	Dukinfield, Astley's‖ (708 feet of New Red Sandstone overlie the Coal-measures)	1987	*460*
	,, ,, ,,	2416	*600*

	V		VI	VII	VIII	IX	X
	Position and depth of hole for thermometer.			Temperature at depth		Rate of increase of depth in feet for each degree Fahr.	Notes and remarks.
	Coal (C). Rock (R). Water (W.)		Depth.	of coal, rock, or water.	of air in gallery.		
			Feet.	Fahr.	Fahr.	Feet.	
116	C		3	63°	*58·5°*	79	
	,,		,,	69·5	*68*	59	
	,,		,,	66	*62*	72	
	,,		,,	71	*73*	58	
	,,		,,	70·5	*72*	60	
136	R		100*a*	66	..	60	
	,,		400	72	..	59	
	,,		670	77	..	58	
	,,		..	*(11·1)*	..	*52*	
	,,		..	*(7·1)*	..	*52*	
121	W		..	82	*62?*	53	
111	R		..	80	*70*	46	
	..		..	66	..	..	
126	R		3	78	..	56	
	,,		,,	94	..	53	
	..		..	*(9·0)*	..	*40*	
	..		..	*(7·0)*	..	*58*	
	..		..	*(16·0)*	..	*58*	
104	R§		3 to 4	77	*64*	68	
	,,		,,	86	*67*	59	
	..		..	*(9·0)*	..	*30*	
122	R		3	78	*65*	70	
	,,		,,	82	*71?*	63	
159	,,		4	74	*71·5*	74	
	,,		,,	81	*79·0*	73	

* The temperature observations in this pit were made in a bore-hole (*a*) drilled at the bottom of the shaft, which is 1066 feet deep. The first series of observations were made by Mr. Atkinson in April, 1869 (Coal Commission Report, vol. ii, pp. 128 and 133), after the boring operations had only ceased twenty minutes. The temperature at the bottom of the bore-hole, then 858 feet deep, or 1924 below the surface, was 96°. The experiments were repeated after the boring operations had been suspended about a week, and the temperature found to be the same as before. But those made three years later (April, 1872), and recorded in the British Association Reports, show a considerable decrease of temperature. The abandoned bore-hole had then silted up to the depth of 644 feet. The encased thermometer was pushed down to 26 feet in this, or to a depth of 1736 feet from surface, where the temperature was found to be 77·1°.

† The observations were made in holes at bottom of shaft during sinking.

‡ The distances in Column IV are from the down-brow.

§ The temperature of the rocks in this pit was from 2° to 4° higher than that of the coals.

‖ The first series of observations at Dukinfield, although taken with great care, are wanting in details. We neither know the tempera-

I Number in the general list, Table I.	II Name of colliery and place.	III Depth of pit or shaft.	IV Distance of station of observation from shaft.
	England—continued.	Feet.	Yards.
159	Dukinfield, Astley's (708 feet of New Red Sandstone overlie the Coal-measures)	2700*	*160*
	,, ,, ,,	*1987—2700*	..
161	Manchester, Ashton Moss (1881)	2790	..
218	Ashton Moss (1883)	2880	..
162	Cheshire, Bredbury	1020	..
,,	,, Nook	1050	..
119	Barnsley, Sharlston Pit	1005	*270*
120	Wakefield, Victoria Pit	1455	*600*
105	Nottinghamshire, Hucknall Torkard†	1250	..
106	,, Annesley†	1425	..
107	,, Kiveton Park†	1200	*250*
108	,, Swanwick§	966	..
109	,, Moira‖	1030	..
155	Bristol, Kingswood Pit	441	..
	,, Deep Pit	1367	..
	,, ,,	1767	..
	,, ,,	*1367—1767*	..
229	Denton, Manchester	1317	..
156	Bristol, Speedwell¶	1232	..
	,, ,,	1439	..
	,, ,,	*1232—1439*	..
163	Bath, Radstock, Wells May Pit**	560	..
164	,, ,, Ludlow Pit	810	..
	,, ,, ,,	1000	..
110	North Wales, Ruabon	1002	..
	,, ,,	1503	..
	,, ,,	1605	..
	,, ,,	1770	..
	,, ,,	*1002—1770*	..
112	S. Wales, Aberdare, Upper Duffryn††	360‡‡	*27*
	,, ,, ,,	1210	*1587*
	,, ,, ,,	1400	*1877*
	,, ,, ,,	1690	*2327*
	,, ,, ,,	*1210—1690*	..
113	,, ,, New Tredegar††	865‡‡	*110*
	,, ,, ,,	920	*570*
	,, ,, ,,	1673	*1370*
	,, ,, ,,	1549	*2090*

V	VI	VII	VIII	IX	X
Position and depth of hole for thermometer.		Temperature at depth		Rate of increase of depth in feet for each degree Fahr.	Notes and remarks.
Coal (C). Rock (R). Water (W).	Depth.	of coal, rock, or water.	of air in gallery.		
	Feet.	Fahr.	Fahr.	Feet.	
159 R	4	86·5°	*75·5°*	**70**	ture of the air in the shaft nor the depth and position of the holes. Nevertheless, the later observations here given show also low temperatures. Mr. Dickinson, however, calls attention to the fact that before the shaft was sunk two of the principal seams of coal in the upper part had been worked away from the outcrop down towards the Astley shaft, and in one case a tunnel had been driven to where the shaft had come. * This pit has now (1884) been carried to the great depth of 3150 feet. † These were all new pits. ‡ Hole at bottom of shaft. § Very wet pit. ‖ An old pit. ¶ The strata dip about 1 in 6. ** Dip small. The Coal-measures in this district are covered unconformably by 100 to 200 feet of Jurassic and Triassic strata. †† The dip is small in these Aberdare pits. ‡‡ The depths in these pits are not the *depths of the shaft*, but are, in each pit, taken on one and the same level, and the depths given are those *beneath the surface*, the differences of depth being caused by the coal seam passing from the valley in which the shaft is situated under an adjacent hill.
..	..	(*12·5*)	..	*51*	
161 R	3½	85·3	..	74	
218 "	"	84	..	80	
162 "	"	62	..	78	
"	"	62·3	..	**78**	
119 "	6	65	*63*	**63**	
120 C	"	78	*75*	**50**	
105 "	2 ?	70	*68·5*	60	
106 "	"	73‡	*67*	59	
107 "	"	71	*72·5?*	55	
108 "	"	62·5‡	..	72	
109 "	"	66	..	**61**	
155 R	2	54·7	..	83	
"	"	68·5	..	77	
"	"	74·7	..	**71**	
..	..	(*6·2*)	..	*64*	
229 ..	4	66	..	77	
156 R, C	1	66·7	..	73	
"	2	69·7	..	74	
..	..	(*3·0*)	..	*69*	
163 R	2	61·7°	..	48	
164 C	"	63	..	62	
"	"	"	..	**67**	
110 "	3	60	*58°*	91	
"	"	70·5	*58·5*	70	
"	"	73	*71*	68	
"	"	78	"	**61**	
..	..	(*13*)	..	*59*	
112 C, R	4	61	*62*	30	
C	"	65	*65*	58	
C, R	"	68	*66*	60	
"	"	75	*74*	**54**	
..	..	(*8*)	..	*60*	
131 C	4	58	*60*	80	
"	"	63	*70*	61	
"	"	67	*72*	80	
"	"	69	*71*	74	

I Number in the general list, Table I.	II Name of colliery and place.	III Depth of pit or shaft.	IV Distance of station of observation from shaft.
	England—continued.	Feet.	Yards.
113′	South Wales, Aberdare, Vochriw Dowlais*.	1103	*66*
	" " " .	1320	*466*
	" " " .	628	*2000*
114	" " Dowlais (ironstone)	371	*160*
	" " " .	536	*485*
115	" " Cwmbach	230	*80*
	" " " .	988	*1600*
152	" Pontypridd	855	..
22	" Neath	540	..
226	Croft, Whitehaven	1140	*430‡*
227	" "	1250	*1340*
228	Lye Cross, Dudley......................	700	..
	Belgium.		
140	Liège,‡ Seraing Collieries	761	..
	"	1017	..
141	"	1656	..
	"	*761—1656*	..
	"	*1017—1656*	..
214	Mons,§ Grameries Colliery..............	679	..
	" "	1013	..
215	" La Louvière Colliery...........	1194	*1312*
	" "	1456	"
	" "	*1194—1456*	..
	" " a new shaft	1361	..
216	" Cuesmes Colliery.............	1548	*1531*
	" "	1680	*766*
	" "	*1548—1680*	..
	France.		
145	Anzin,‖ Valenciennes	126	..
	" Shaft No. 1	658	..
		126—658	..
24	Littry, Calvados¶	325	*197*
25	Decise,** Nievre	561	..
23	Carmeaux,†† Tarn	630	*69*

V Position and depth of hole for thermometer.	VI	VII Temperature at depth	VIII	IX	X
Coal (C). Rock (R). Water (W).	Depth.	of coal, rock, or water.	of air in gallery.	Rate of increase of depth in feet for each degree Fahr.	Notes and remarks.
	Feet.	Fahr.	Fahr.	Feet.	
113′ C	4	60°	*59°*	80	* In this pit the working proceeds from a hill towards a valley.
”	”	62	”	83	
”	”	61	*65*	42	
114 R	”	56	*55*	61	
”	”	59	*58*	45	† These are the distances of the stations under the sea. The sea there being about 12 fathoms deep. Taking the temperature of the sea at 48°, or deducting 72 feet, Professor Everett makes the thermometric gradients 45° and 47°, which is probably the more correct.
115 C	”	55	*48*	36	
”	”	61	*63*	78	
152 ”	”	62·7	..	62	
22 R	2	42	..	45	
226 ”	4	73	..	47	
227 ”	”	”	..	51	
228 ”	”	57·5	..	70	
140 R	16	77	*78*	30	‡ The dip of the coal in these pits is considerable. In the “Brit. Assoc. Reports,” the temperature of the ground at a depth of 5 mètres, is estimated at 54° F. The gradient here given is, however, calculated on a mean surface temp. of 51°.
”	”	78	*77*	40	
141 ”	”	87	*77·5*	46	
..	..	(*10*)	..	*90*	
..	..	(*9*)	..	*70*	
214 R	3¼	66	..	45	
”	”	69	..	56	
215 ”	”	76	..	48	§ The dip here is also considerable, and the Coal-measures are overlaid by a thick mass (300 to 400 feet) of water-bearing Lower Cretaceous strata.
”	”	81	..	49	
..	..	(*5*)	..	*52*	
R	3¼	81	..	45	
216 ”	”	79·7	..	53	
”	”	82	..	54	
..	..	(*2·2*)	..	*58*	
145 R	2	56·5	..	21	‖ Observations were made during sinking, in holes inserted horizontally in side of shaft.
”	”	67·7	*54*	39	
..	..	..	(*11·2*)	*47*	
24 C	2	61	*70*	36	¶ Strata nearly horizontal—pit dry.
25 ”	”	72	*73*	33	** The strata here dip 25° S.W., and overlie crystalline rocks.
23 ”	”	67	*74·3*	53	†† A new and dry pit; slow ventilation. The water of a well immediately above this pit, 38 feet deep, had a temp. of 55·5° F.

I Number in the general list, Table I.	II Name of colliery and place.	III Depth of pit or shaft.	IV Distance of station of observation from shaft.
		Feet.	Yards.
	North America.		
59	Eastern Virginia,* Mills's pit............	420	..
60	,, Will's pit..........	570	..
61	,, Midlothian pit......	780	..
	,, (Another account (*a*))	600	..
	,, ,, ...	780	..

TABLE III.—MINES

Those observations which were made in Springs issuing from the
in Wells or sumps, W, and those in holes drilled in the Rock, R.
an affix is made of R or L. The distance of the point of observation,
at the spot is known in very few instances. The nature of the strata

The Thermometric Gradient in Column IX refers to the entire
refer to the gradients for the intermediate depths (also in *italics* in
depths that is given (in brackets) in Column VII.

I Number in general list, Table I.	II Name of mine and place.	III Nature of rock.	IV Depth.
			Feet.
	England.		
27	Cornwall, Dolcoath Mine*	*Granite.*	1440
73	,, ,, (1822)..	,,	1380
75	,, ,, (1853)..	,,	1632
74	,, ,, (1857)..	,,	1632
220	,, ,, ...	*Slate* (*Killas*).	252

V	VI	VII	VIII.	IX	X
Position and depth of hole for thermometer.		Temperature at depth		Rate of increase of depth in feet for each degree Fahr.	Notes and remarks.
Coal (C). Rock (R). Water (W).	Depth.	of coal, rock, or water.	of air in gallery.		
	Feet.	Fahr.	Fahr.	Feet.	
59 W	..	63°	..	**74**	* Temperature of water collected at bottom of pit. Prof. Lebour's later statement relating to Virginian coal-pits (*a*) seems more reliable.
60 ,,	..	65·5	..	65	
61 ,,	..	68·7	..	65	
?	..	?	..	45	
?	..	?	..	**55**	

OTHER THAN COAL.

rock or lode, are marked S, in Column V; those in water collected
Accordingly as the springs (S) are known to issue from *rock* or *lode*
or station, from the shaft and the temperature of the air in the gallery
in the following tables is given in Column III.
depths given in Column IV; but where the figures are in *italics* they
Column IV). It is only the difference of temperature between those

Number in general list, Table I.	V	VI	VII	VIII	IX	X
	Position of thermometer.		Temperature at depth		Rate of increase of depth for each degree F.	Notes and remarks.
	Water (W). Spring (S). Rock (R).	Depth of hole in rock.	Of the rock or water.	Of air in gallery.		
		Feet.	Fahr.	Fahr.	Feet.	
27	S	..	82°	*80°*	**45**	* The Slate in this mine extends to depths of about 800 to 900 feet, the deeper levels are in Granite. This, the deepest of the Cornish mines, has now (1884) reached a depth of 2400 feet.
73	R	2	76	..	53	
75	,,	2	79·5	*78*	55	
74	,,	..	73	..	71	
220	,,	..	64	..	18	

I Number in general list, Table I.	II Name of mine and place.	III Nature of rock.	IV Depth.
			Feet.
	England—continued.		
220	Cornwall, Dolcoath Mine	*Granite.*	876
"	" "	"	2124
"	" "	"	2244
"	" "	..	*876—2124*
"	" "	..	*876—2244*
19	" "	*Slate.*	240—300
"	" "	*Granite.*	1320—1380*
"	" "	..	1380—1440
122*a*	" Tresavean	..	2130
20	" Huel Vor	*Slate.*	480—540
	" "	"	780—840
21	" Huel Damsel	*Granite.*	300—360
	" "	"	840—900
72	" Botallock*	*Granite and hornblendic rocks.*	1128
49*f*	" Wheal Trenwith	*Slate.*	180
	" "	"	660
49*g*	" South Roskear, Camborne.†	"	702
	" " " "	"	834
49*h*	" North Roskear "	"	822
49*i*	" East Pool "	"	373
49*j*	" Wheal Uny, Redruth‡ ..	"	486
49*k*	" Chacewater, "	"	768
49*l*	" East Wheal Virgin Consolidated Mines.	"	1500
	" " "	"	1722
49*m*	" Wheal Towan, St. Agnes.	"	924
49*n*	" Wheal Prudence "	"	654
49*a*	" East Wheal Crofty	"	480
	" "	"	810
49*b*	" Consolidated	"	1704
	" "	"	1764
49*c*	" United Mines	"	1080
	" "	"	1260
49*d*	" Great Wheal Fortune ..	"	840
	" "	"	864

Number in general list, Table I.	V	VI	VII	VIII	IX	X
	Position of thermometer.		Temperature depth		Rate of increase of depth for each degree F.	Notes and remarks.
	Water (W). Spring (S). Rock (R).	Depth of hole in rock.	Of the rock or water.	Of air in gallery.		
		Feet.	Fahr.	Fahr.	Feet.	
220	R	3 ?	67·8°	..	49	
,,	,,	..	83	..	**64**	
,,	,,	..	90	..	56	
,,	,,	..	(*15·2*)	..	*89*	
,,	..	..	(*22·2*)	..	*53*	
19	R	3	58	..	34	
,,	,,	3	78	..	48	
,,	W	..	82	..	**44**	
122*a*	R	..	99	..	43·5	* In the list given in page 34, the mean between these two depths (1350 ft.) is taken.
20	W	..	63	..	42	
	,,	..	69	*72°*	45	
21	air	..	..	*61*	33	
	,,	..	..	*70*	46	
72	R	1½	79	..	40	† One level extends about 2000 feet under the sea.
49*f*	S	..	55·5	..	40	
	,,	..	66	..	44	
49*g*	,,	..	62	..	59	
	,,	..	71	..	40	‡ Thermal springs have been met with in several of the mines in this district.
49*h*	,,	..	73	..	36	
49*i*	,,	..	59	..	41	
49*j*	,,	..	61·5	..	48	§ The great Gwennap adits used to drain many of the mines in this district.
49*k*	,,	..	72	..	35	
49*l*	,,	..	86·5	..	40	
	,,	..	92	..	39	
49*m*	,,	..	72	..	42	
49*n*	,,	..	65·5	..	42	
49*a*	,,	..	61	..	44	
	,,	..	70·7	..	39	
49*b*	,,	..	89	..	44·5	
	,,	..	92·5	..	41·5	
49*c*	,,	..	74	..	45	
	,,	..	89·5	..	32	
49*d*	,,	..	70	..	44	
	,,	..	73	..	39	

I Number in general list, Table I.	II Name of mine and place.	III Nature of rock.	IV Depth.
			Feet.
	England—continued.		
49*e*	Cornwall, Marazion	*Slate.*	222
	" "	"	480
	" "	"	600
70	" Par Consols	"	768
71	" "	"	1248
51	Devonshire Wheal Friendship	"	282
	" "	"	810
	" "	"	*282—810*
26	Cornwall, Huel Alfred	"	930
28	" " Trumpet	*Granite.*	768
38	" Levant	*Slate and granite.*	1380
76	" "	"	1530*
77	" "	"	1530
76*a*	" "	"	1530
40	" Consolidated	*Granite.*	1740
	" Tresavean	"	1572
78	" "	"	1572
79	" "	"	2112
	" "	"	2112
50	" Binner Downs	*Slate.*	300
	" "	"	756
	" "	"	1056
	" "	..	*300—1056*
80	" United or Fowey Consols	*Slate.*	1728
82	" " "	..	1530
52	" St. Ives Consols†	*Granite.*	108
	" " "	"	462
	" " "	"	810
	" " "	"	*462—810*
	" Wheal Wreath, St. Ives	"	162
53	" " "	"	1242
	" " "	"	1482
	" " "	..	*162—1242*
	" " "	..	*1242—1482*
	" " "	..	*162—1482*
18	" Average of six mines	*Granite and slate.*	500—550

Number in general list, Table I.	V	VI	VII	VIII	IX	X
	Position of thermometer.		Temperature at depth		Rate of increase of depth for each degree F.	Notes and remarks.
	Water(W). Spring (S.) Rock (R).	Depth of hole in rock.	Of the rock or water.	Of air in gallery.		
		Feet.	Fahr.	Fahr.	Feet.	
49*e*	S	..	56·3°	..	43	
	,,	..	63	..	40	
	,,	..	66	..	40	
70	R	..	74	..	**34**	
71	,,	..	84	..	**38**	
51	S	..	55	..	**56**	
	,,	..	69·5	..	**41·5**	
	..	..	*(14·5)*	..	*36*	
26	S	..	70	..	47	
28	,,	..	65	..	51	
38	R	..	80	..	46	
76	,,	..	74	..	67	* The station here was near the bottom of shaft.
77	,,	..	85	..	**45**	
76*a*	,,	..	87	..	**42·5**	
40	,,	..	85·3	..	49	
39	,,	..	82	..	**49**	
78	,,	..	82·5	..	**48·5**	
79	,,	..	90·5	..	52	
	S	..	93·5	..	48	
50	,,	..	56·5	..	**46**	
	,,	..	67	..	44	
	,,	..	82	..	33	
	..	..	*(25·5)*	..	*30*	
80	..	..	93	..	41	
82	..	..	116	..	28	† The levels of many of the mines in this district extend beneath the sea.
52	S	..	57	..	18	
	,,	..	60·5	..	49	
	,,	..	71	..	**41**	
	..	..	*(10·5)*	..	*33*	
	S	..	53	..	81	
53	SL	..	70	..	65	
	SR	..	76	..	59	
	..	..	*(17)*	..	*64*	
	..	..	*(6)*	..	*40*	
	..	..	*(23)*	..	*57*	
18	W	..	65	..	35	

I	II	III	IV
Number in general list, Table I.	Name of mine and place.	Nature of rock.	Depth.
			Feet.
	England—continued.		
18	Cornwall, average of six mines	*Granite and slate.*	700—750
	,, ,, ,, ...	,,	900—950
	,, ,, ,, ...	,,	1350—1400
54	,, and Devon.* Various mines in ten districts.	,,	180
	,, ,, ,,	,,	432
	,, ,, ,,	,,	762
	,, ,, ,,	,,	1038
	,, ,, ,,	,,	1440
47	,, average of 53 mines	,,	354
	,, ,, ,, ...	..	438
	,, ,, ,, ...	..	684
130	Allanheads, Northumberland......	*Carboniferous limestone.*	440
158	Talargoch, Flintshire	,,	660†
	,, ,, ...	,,	1041‡
	,, ,, ...	,,	636§
	,, ,, ...	..	*660—1041*
160	,, ,, ...	,,	660‖
172	Sark, Island of..................	*Syenite.*	324
			384
175	Ireland, Wicklow	*Silurian schists.*	552
176	,, Waterford	*Palæozoic schists.*	672
177	,, County Cork	*Carboniferous shales.*	840
	France.		
1	Giromagny, near Belfort, Vosges ..	*Porphyritic rocks.*	332
	,, ,, ,,	..	1420
	,, ,, ,,	..	*332—1420*
12	Huelgoet, Britanny..............	*Silurian slates.¶*	230
	,, ,, ...	,,	781
	,, ,, ...	,,	*230—781*
11	Poullaouen ,, ...	,,	459
	Switzerland.		
2	Bex, near Lausanne	*Metamorphic rocks.*	721

	V	VI	VII	VIII	IX	X
	Position of thermometer.		Temperature at depth		Rate of increase of depth for each degree F.	Notes and remarks.
Number in general list, Table I.	Water (W). Spring (S). Rock (R).	Depth of hole in rock.	Of the rock or water.	Of air in gallery.		
		Feet.	Fahr.	Fahr.	Feet.	
18	W	..	65°	..	43	
	,,	..	71	..	44	
	,,	..	79	..	47·5	
54	..	..	54·8	..	37	* The mines in this district are many of them very old.
	..	..	66·8	..	40	
	..	..	67·4	..	44	
	..	..	78·6	..	36	
	..	..	85·5	..	40	
47	..	..	..	..	35·4	
	..	..	..	..	43·8	
	..	..	..	..	64·2	
130	W	..	57·3	..	35	
158	R	2	54	..	132	† Station 120 yards distant from shaft.
	,,	,,	60·8	..	88	
	,,	..	58·8	..	64	‡ ,, 190 ,,
	..	..	*(6·8)*	..	*56*	§ ,, 840 ,,
160	R	2	62	..	51	‖ ,, 400 ,,
172	W	..	55·5	..	81	
	S	..	57·2	..	59	
	,,	..	58			
175	W	..	55·5	..	92	
176	,,	..	57·4	*57°*	90	
177	,,	..	61·5	..	80	
1	..	..	53·6	..	50	
	..	..	73	..	50	
	..	..	*(19·5)*	..	*56*	
12	W	..	54	..	75	¶ The slates are associated with quartzites and greenstone.
	,,	..	66	..	49	
	,,	..	*(12)*	..	*46*	
11	S	..	58·3	..	66	
2	..	..	63·5	..	30	

I	II	III	IV
Number in general list, Table I.	Name of mine and place.	Nature of rock.	Depth.
			Feet.
	Austria and Germany.		
8	Freiberg, Himmelfahrt mine	*Gneiss.**	870
10	,, Junghohe-Birke ,,	,,	656
	,, ,,	,,	1082
	,, ,,	,,	936
13	,, Alte Hoffnung Gottes ,,	*Gneiss.*	200
	,, ,, ,,	,,	886
	,, ,, ,,	,,	1246
	,,	,,	*886—1246*
7	,, Beschert Gluck ,,	*Gneiss.*	722
	,,	,,	984
			722—984
139	Przibram,† Bohemia	*Silurian schists.*	621
	,,	..	1209
	,,	..	1900
	,,	..	*621—1209*
	,,	..	*621—1900*
149	Schemnitz, Hungary	*Tertiary strata and syenite.*‡	1047
	America.		
3	Guanaxuato, Mexico	*Clay slate.*	1640
4	Cabrera ,,	?	164
83	Chili, Colorado Mine§	*Jurassic limestone.*	288
	,,	,,	900
	,,	,,	1362
	,,	,,	*900—1362*
170	,, Chanarcillo	,,	930
171	Brazil, Minas Giräes	..	318
	,, Morre Velho	*Clay slate.*	892
	Australia.		
65*a*	Ballarat, Victoria	*Palæozoic rocks.*	760

Number in general list, Table I.	V	VI	VII	VIII	IX	X
	Position of thermometer.		Temperature at depth		Rate of increase of depth for each degree F.	Notes and remarks.
	Water (W). Spring (S). Rock (R.)	Depth of hole in rock.	Of the rock or water.	Of air in gallery.		
		Feet.	Fahr.	Fahr.	Feet.	
8	W	..	58°	*59°*	72	* The gneiss of this district alternates with mica-schists, and is traversed in many places by masses and dykes of granite.
10	,,	..	57·2	..	50	
	,,	..	62·5	..	58	
	,,	..	61	..	55	
13	R	..	48·2	..	40	
	,,	..	59	..	55	
	,,	..	66	..	54	
	..	..	*(7)*	..	*51*	
7	R	..	54·5	..	63	
	,,	..	60	..	58	
	..	..	*(5·5)*	..	*48*	
139	R	2	50·7			† The workings communicate with a great drainage tunnel 1360 feet above the sea-level.
	,,	,,	58·3			
	,,	,,	61·4	..	126	
	..	..	*(7·6)*	..	*72*	
	..	..	*(10·7)*	..	*120*	
149	R	1½ to 2½	..	..	74	‡ These rocks are traversed by veins of rhyolite.
3	..	..	98	..	45	
4	..	..	63	..	55	
83	R	2	64·8	*66*		§ Total depth of mine 1500 feet.
	,,	,,	67	*65*	150	
	,,	,,	*(11·5)*	*76·5*	90	
	..	..	74·5	..	*40*	
170	W or S	..	69·2	..	110	
171	,,	..	67·9	..	105	
	..	..	81			
165*a*	R	3	72·5			

Table IV.—ARTESIAN

Column V.—The sign + indicates that the water overflows at the surface not rise to the surface, in which case the water usually stands in a shaft sunk to

Column VI.—These numbers give the difference between the temperature of differences between the special depths given in Column IV, for which the rate of

I Number in the general list, Table I.	II Name of place.	III Nature of the strata.	IV Depth of well or boring.
			Feet.
	England.		
35	Sheerness*	London Clay, Woolwich Sands and Thanet Sands	361
	„		450
129	Kentish Town, London	London Clay and Sands..... 325 feet	1100
		Chalk 646 feet	
	„ „	Upper Greensand and Gault. 143 feet	*0—550*
	„ „	Red Sandstones (Devonian?). 188 feet†	*550—1100*
230	Richmond, Surrey	Tertiary strata, 242, Cretaceous, 898, Oolite	1176
231	„ „	and Red Sandstones (Devonian ?), 257	1337
142	Chiswick	London Clay, Sands, and Chalk	396
165	Southampton	Tertiary strata, 400, and Chalk, 810†	1210
210	Newport, Isle of Wight	Tertiary Clays and Sands	467
143	Swinderby, Lincoln	Lias and Rhœtic 140 feet	2000
		New Red Sandstone 1259 feet	
	„ „	Permian Marls, &c. 372 feet	*0—1000*
	„ „	Carboniferous Shales and Limestones 129 feet	*1000—2000*
153	Bootle, Liverpool	Trias (Red Sandstones and Marls)	1302
	Scotland.		
45	Carse of Falkirk, Kennet House	Alluvial Beds and Coal-measures	270
45*a*	Midlothian, average of 11 wells	„ „ „	213—350
123	Blythswood, nr. Glasgow	Boulder Clay and Coal-measures	347
	„ „	„ „ „	*60—347*
124	South Balgray „	„ and Greenstone	525
	„ „	„ „	*120—525*
	France.		
209	Dunkirk	London Clay, Sands, and Chalk	426

WELLS AND BORINGS.

(the height of overflow is given where known) ; — indicates that the water does
a little below the water-level.
the surface and that of the depth, for which see Table I : those in brackets are
increase is given in *italics* in Column VII.

Number in the general list, Table I.	V Rise of water relatively to the surface.	VI Difference between the temperature at surface and at depth.	VII Rate of increase of depth for 1° Fahr.	VIII Notes and remarks.
		Fahr.	Feet.	
35	–	*10·8°*	34	* For the particulars of the strata of this and the other wells in the London Basin, see Whitaker's "Mem. Geol. Survey," vol. iv, Part I, pp. 423–571.
	–	*12·8*	35	
129	*−210*	*19·7*	52·3	
	”	*(10·6)*	*52*	
	”	*(9·0)*	*60*	
230	..	*20·4*	57	
231	+	*25·9*	51·5	
142	*−60*	*8*	49	
165	–	*18·7*	65	† The lower part of both these bore-holes was blocked by *débris*, the wells having been abandoned for several years before the temperature observations were made.
210	*+6*	*11·0*	43	
143	–	*30*	66	
	–	*(20)*	*50*	
	–	*(10)*	*100*	
153	–	*8·5*	153	
45				
	+	*5*	54	
45*a*				
	+	..	48	
123	–	*6·69*	52	
	..	*(5·3)*	*54*	
124	–	*12·52*	42	
	..	*(10·0)*	*40*	
209	+	*1·8*	235	

I Number in the general list, Table I.	II Name of place.	III Nature of the strata.	IV Depth of well or boring.
			Feet.
	France—continued.		
208	Bourbourg, near Dunkirk	London Clay, Sands, and Chalk*	544
213	Croix (Dept. du Nord) ...	Chalk and Carboniferous Limestone†...	271
32	Lille (St. Venant)........	Tertiary Sands and Chalk resting on Carboniferous Limestone†	329
33	Aire, near St. Omer‡	Tertiary Clays and Sands	205
36	Paris, École Militaire	Lower Tertiary Strata and Chalk	567
37	Paris, Grenelle	Lower Tertiary Strata, 148 feet........	1797
	,, ,, ...	Chalk .... 1394 feet........	*0—1312*
	,, ,, ...	Clays, Greensand ... 255 feet........	*1312—1797*
221	Paris, Passy	Same strata as at Grenelle	1924
48*a*	Paris, St. Ouen..........	Tertiary (middle) Strata	216
49	Alfort (Marne)‡	Lower Tertiary Strata.................	177
62	Meaux (Marne)‡	,, ,, ...	230
48	Troyes (Aube)	Chalk and Gault	410§
42	Rouen, St. Sever	Chalk and Jurassic Strata ?............	600
43	St. André (Eure)	Chalk and Greensand	830
31	Tours..................	,, ,, ...	460
68	Creuzot,‖ Torcy Colliery ..	Trias, 1312 ft.; Coal-measures, 505 ft.	1817
69	Creuzot, Mouillonge ,, ..	Trias, 1217 ft.; Coal-measures, 1460 ft.	2677
101	Rochefort	Triassic Beds	2812
102	Virac (Tarn)‡..........	,, ...	971
183	Arcachon (Gironde)‡.....	Upper Tertiary Strata................	413
	Belgium and Holland.		
180	Brussels................	Lower Tertiary Strata	215
181	Aerschot	,, ...	453
65	Mondorff, Luxembourg...	Lias, 177 feet; Red Marls, 675 feet.....	1647¶
	,, ,, ..	Muschelkalk, 465 feet; Red Sandstone, 1020 feet; Quartzose schists, 52 feet.	2362
46	Cosseigne - les - Luxembourg**	?	1105
207	Ostend.................	London Clay and Sands, 656 feet ...... Chalk, 210 feet	981
	,, ...	Red Chalk and Sand, ... 92 feet	*0—567*
	,, ...	Silurian schists 30 feet?	*567—981*

Number in the general list, Table I.	V Rise of water relatively to the surface.	VI Difference between the temperature at surface and at depth.	VII Rate of increase of depth for 1° Fahr.	VIII Notes and remarks.
		Fahr.	Feet.	
208	+	*9°*	62	* The water comes from the Landenian or Thanet Sands (at 544 feet), but the bore is continued to a further depth of 275 feet in the chalk. † The water rises from the Carboniferous Limestone. ‡ No information is given how these observations at these pits were made.
213	+	*7*	39	
32	+	*6·7*	49	
33	+	*5·9*	35	
36	–	*10*	54	
37	+	*30·9*	58	
	..	*(23·7)*	*55*	
	..	*(7·2)*	*61*	
221	+	*31·4*	60	
48*a*	+	*4·3*	50	
49	+?	*6*	30	
62	+?	*6*	38	
48	–	*7·8*	53	§ The lower part of the bore-hole, which was carried to a total depth of 517 feet, was obstructed. M. Walferdin supposes the heat caused by the boring instruments may have had scarcely time to be dissipated, but he assumed a higher surface temperature. ‖ At Torcy the works had been suspended six months. At Mouillonge three days.
42	–	*13*	46	
43	–	*17*	59	
31	+	*10·4*	44	
68	–	*32*	57	
69	–	*51*	52	
101	+	*56·5*	50	
102	+?	*28·25*	31	
183	+?	*5·4*	71	
180	–*5*	*3·7*	51	
181	+*16*	*6·9*	65	
65	+	*31*	53	
	..	*34·4*	68	¶ The overflowing spring rose from this depth. ** M. Biver gives the rate of increase, but not the surface temperature, nor particulars of how the observations were made. †† Although the water overflowed, it was in such small quantity that it was found necessary to take the temperatures at depths. There were small springs at 567 and 981 feet.
46	+?	..	45	
207	+††	*21·60*	45·4	
	..	*(9·0)*	*63*	
	..	*(12·6)*	*33*	

I Number in the general list, Table I.	II Name of place.	III Nature of the strata.	IV Depth of well or boring.
			Feet.
	Switzerland.		
29	Pregny, near Geneva	Molasse	713
	"	"	*0—200*
	" "	"	*200—650*
	Italy.		
67	Conselica, Ferrara	Alluvial Beds	164
94	Reggio*	Pliocene Marls	2297
178	Venice, Villa Francesco	Alluvial Beds	118
179	Venice, Gas-works	"	236
89	Naples, Largo Vittoria	Volcanic Tuffs and Tertiary Strata	909
90	„ Royal Palace	" "	1460
	Germany and Austria.		
34	Neu Salzwerk	Liassic and Triassic Strata	2038
64	Vienna	Tertiary Strata	617
168	Buda-Pesth	Tertiary and Triassic Strata†	2966
			0—328
	"	" "	*328—1640*
	"	" "	*1640—2966*
167	Artern, Thuringia*	.. .. ..	1012
	Rudersdorff, Prussia	Triassic Strata	880
87	Rehme, Westphalia	.. .. ..	2280
144	Sperenberg, Berlin	Gypsum and Anhydrite, 283 feet Rhen.	4052‡
	" "	Rock Salt 3769 feet Rhen.	Rh. *0—700*
	" "	"	*700—1500*
	" "	"	*1500—2100*
	" "	"	*2100—3390*
182	Minden, Westphalia	.. .. ..	2230
166	Pitzbuhl, Magdeburg*	.. .. ..	495
	Russia.		
144*a*	St. Petersburg§	Silurian Strata resting on Granite	656

Number in the general list, Table I.	V Rise of water relatively to the surface.	VI Difference between the temperature at surface and at depth.	VII Rate of increase of depth for 1° Fahr.	VIII Notes and remarks.
		Fahr.	Feet.	
29	*−20*	*14·7°*	48·5	
	..	*(5·2)*	*40*	
	..	*(9·5)*	*48*	
67	*+6½*	*5·1*	32	
94	..	..	56	* No particulars of these wells are given beyond depth and rate of increase.
178	+	*2·4*	57	
179	+	*6·9*	34	
89	+	*11·7*	78	
90	+	*8·1*	181	
34	+	*39·7*	50·5	
64	+	*10·8*	57	
168	..	*129·5*	24	† This is really a hot spring, due to the effects of old (Miocene?) volcanic action.
	..	*(26·4)*	*12*	
	..	*(51·6)*	*23*	
	..	*(53·0)*	*26*	
167	..	..	72	
	+	*26*	34	
87	+	*39·4*	58	
144	−	*67·2*	52	‡ 4052 Rhenish feet = 4172 English feet. The temp. obs. stopped at 3390 feet.
	..	*(13·0)*	*55*	
	..	*(13·2)*	*62*	
	..	*(12·1)*	*51*	
	..	*(27·7)*	*50*	
182	+	*42·3*	52	
166	..	..	48	
44*a*	+	*14·8°*	44	§ An earlier account ("Revue Géol." for 1865) gives a depth of 525 feet and a temperature of 50·5°.

I Number in the general list, Table I.	II Name of place.	III Nature of the strata.	IV Depth of well or boring.
			Feet.
	India.		
184	Pondicherry	Alluvial Beds	261
151	Manegaon	Coal-measures........................	310
			60—310
	Africa.†		
92	Algeria, Baraki	Marls and Gravels....................	426
97	,, Messis.........	Tertiary Strata ?......................	277
95	Ghadame, Tripoli........	?	394
88*a*	Sahara Desert (mean of several wells)..........	Tertiary Marls and Gravels.............	..
	North America.		
66	Charleston, S. Carolina...	Eocene Strata, 708 feet, overlying 398 feet of Cretaceous Strata............	1106 *100—400* *400—110*
84	Columbus, Ohio	Upper Devonian Sandstones and Shales.	2575
			90—257
88	Louisville, Kentucky	Upper Silurian Limestones and Sandstones...........................	2086
127	St. Louis	Lower Carboniferous Shales (429) feet..	3029‡
		Sandstone (360 ft.), Limestones (2725 ft.)	3843
169	Chicago§	Upper Silurian Limestone and Sandstone	751
212	Bothwell, Ontario	Corniferous Limestone (Devonian)	475
172	Sheboyan, Wisconsin.....	St. Peter's Sandstone (Lower Silurian)..	1475
223	La Fayette, Indiana......	?	213
	South America.		
224	Buenos Ayres	Pampean Beds	2[illegible]5

Number in he general st, Table I.	V Rise of water relatively to the surface.	VI Difference between the temperature at surface and at depth.	VII Rate of increase of depth for 1° Fahr.	Notes and remarks.
		Fahr.	Feet.	
184	..	*11·1°*	52	
151	—	9·5*	33	* This result is assuming the mean temperature to be 75·2°, which is that of Jabalpur, a neighbouring town nearly on the same level. In the Brit. Assoc. Rept. the rate of increase (68 ft.) is calculated from the temperature at the depth of 60 feet (81°) where the water may be affected by convection currents. † The surface temperature at the African wells is very uncertain.
	..	*(3·7)*	*68*	
92	+	*10?*	42	
97	+	*4·6?*	51	
95	+	*11*	36	
88*a*	+	..	36	
	..	*22*	50	
66	..	*(4)*	*75*	
	..	*(16)*	*44*	
84	..	*35*	73	
	..	*(35)*	*71*	
88	*+170?*	*27·8*	75	
127	—	*54*	56	‡ The observations at 3029 feet were taken with great care, and were considered reliable. The discrepancy at the greater depth is at present unaccountable, unless it were due to convection currents. § In this well an infiltration of water from a higher level was suspected.
	..	*(52)*	*74*	
169	+	*9·1*	88	
212	+	*8?*	60	
172	*+104*			
223	+			
224	+	*7·1*	36	

INDEX TO NAMES OF PLACES IN TABLE I.

HARRISON AND SONS, PRINTERS IN ORDINARY TO HER MAJESTY, ST. MARTIN'S LANE.