ON THE PRESENT STATE OF OUR KNOWLEDGE OF UNDERGROUND TEMPERATURE, WITH SPECIAL REFERENCE TO THE NATURE OF THE EXPERIMENTS STILL REQUIRED IN ORDER TO IMPROVE THAT KNOWLEDGE.

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THE principal object of the writer in presenting this paper to the Institute is to enlist the co-operation of mining engineers in carrying out some of the experimental researches which appear to be still wanted in order to place on a firmer basis our knowledge of the rate at which the temperature of the earth increases in going downwards. Without such co-operation the present state of knowledge on the subject could never have been attained, confessedly imperfect though it be, and without more aid of the same kind it is not likely to be much increased.

The writer will first give a brief and condensed account of the experimental results already arrived at; he will then enumerate the chief sources of error which must be taken into account in estimating the relative value of such results; and he will conclude by suggesting a few lines of inquiry and observation, in which the help of practical engineers would be of the utmost value.

In the following tabular statement will be found a list of some sixty sets of observations of underground temperature arranged according to the average rate of increase of temperature in depth :—

TABLE I.

PLACE.	Depth from Surface (in feet) of Deepest Observation.	Increase of 1° F. per Foot.
1. Anzin, in the north of France, Shaft 3 ...	473	28·1
2. Do. do. do. Shaft 4 ..	443	28·4
3. Weardale, Slitt Hill Shaft	660	33·5
4. Cornish Mines, mean	552	34·8
5. Anzin, Shaft 2	607	37·7
6. Allenheads, High Underground Engine Shaft	807	40
7. Cornwall and Devon, mean of 415 observations	672	40·8
8. South Balgray, west of Glasgow... ...	525	41
9. St. Petersburg	656	44·1
10. Oolitic Coal Mines of Virginia, U.S. ...	600	45
11. Anzin, Shaft 1	656	47·2
12. Boldon Colliery, Durham	1,514	49
13. Blythswood, near Glasgow, Bore 1 ...	347	50
14. Mouillelonge Mine (Saône-et-Loire) ...	2,676	51
15. Sperenberg, near Berlin	3,390	51·5
16. Sich's Brewery, Chiswick, near London ...	395	52 (?)
17. Yakutsk, Siberia	540	52
18. Kentish Town, London	1,100	52·4
19. Do. do.	1,100	52·9
20. Blythswood, Bore 2	354	53·5
21. Kentish Town, London	1,100	54
22. Rosebridge Colliery, near Wigan ...	2,445	54·3
23. Oolitic Coal Mines of Virginia, U.S. ...	780	54·6
24. Neue Salzwerk, Westphalia	2,281	54·68
25. Near Geneva	(?)	55
26. Torcy Mine (Saône-et-Loire)	1,951	55·2
27. Military School, Paris	568	56·25
28. St. André's Well, 50 miles west of Paris	830	56·4
29. Grenelle, Paris	1,794·6	56·9
30. Mendorff, Luxemburg	2,394	57
31. South Hetton Colliery, Durham	1,936	57·5
32. Monkwearmouth Colliery, Durham ...	1,499	60
33. Channel Islands (Sark and Herm) ...	222	60
34. Swinderby, west of Lincoln	1,500	62·5
35. Fowler's Colliery, Pontypridd, S. Wales	846	62·7
36. Allenheads, Gin Hill Shaft	440	66·6
37. Kingswood Colliery, near Bristol... ...	1,769	68
38. Manegaon, India	310	68
39. Saint Louis, North America	3,837	68·5
40. Swinderby, west of Lincoln	2,000	69
41. La Chapelle, St. Denis, near Paris ...	2,065	72·8
42. Crawriggs, Kirkintilloch, near Glasgow...	350	75
43 to 47. Schemnitz, in Hungary, 5 places ...	1,358	75·5
48. Astley Pit, Dukinfield	2,055	80
49. Irish Mines (Wicklow, Waterford, Cork, and Kerry), mean	342	84·6
50. Seraing, near Liége, Belgium	1,657	90
51. Mont Cenis Tunnel	5,280	93
52. La Chapelle, St. Denis, near Paris ...	2,065	94·3
53. Přzibram Mines, Bohemia	1,100	107
54. Chanarcillo Mines, Chile, mean	930	129·6
55. Booth Waterworks, Liverpool	560	131
56. Přzibram Mines, Bohemia	1,832	135
57. Minas Geraës Mines, Brazil, mean ...	318	157·2

The average rate deducible from all the results given in the above table is 1 deg. Fahr. per 64·28 feet of descent; but all the observations recorded are by no means of equal value, as will be readily understood when the various modes adopted by the different observers, and the specially favourable or unfavourable conditions of time, place, or surroundings, come to be considered. Moreover, the rates shown in the Table are taken from the reading at the deepest point to which no accidental error seems to attach, and from the assumed mean annual temperature at the surface in each locality. In almost every case many intermediate readings could be given which would materially alter the average. Of these intermediate readings some are very abnormal, and evidently due to accidents of various kinds, some of which can be explained away and some not. The full readings can, most of them, be found in the Reports of the British Association Committee on Underground Temperature, where they are discussed by Professor J. D. Everett, F.R.S., the able Secretary to the Committee.*

In estimating the relative value to be attached to the rates of increase given in the Table, perhaps the most important point to be considered is the method pursued in obtaining the thermometric readings from which they are deduced.

All the observations were taken either in water or in air.

Those taken in water may be divided under two heads, viz., where the water was in wells or shafts and other workings in mines, and where the water filled boreholes.

Where the water was in shafts and other workings of mines, some of the observations were taken where the water was stagnant, others where the water was running, *i.e.* of the nature of a feeder.

* See British Association Reports from 1867 to the present time. When it first entered upon its labours the Committee consisted of the following members:—Sir William Thomson, F.R.S.; E. W. Binney, F.R.S.; Principal Forbes, F.R.S.; A. Geikie, F.R.S.; James Glaisher, F.R.S.; Rev. Dr. Graham; Professor Fleeming Jenkin, F.R.S.; Sir Charles Lyell, Bart., F.R.S.; Professor J. Clerk Maxwell, F.R.S.; G. Maw; Professor J. Phillips, F.R.S.; W. Pengelly, F.R.S.; Professor Ramsay, F.R.S.; Professor Balfour Stewart, F.R.S.; G. J. Symons; Professor James Thomson; Professor J. Young; and Professor J. D. Everett, Secretary. In 1881 the Committee consists of:—Sir William Thomson, F.R.S.; G. J. Symons, F.R.S.; Sir A. C. Ramsay, F.R.S.; Professor A. Geikie, F.R.S.; James Glaisher, F.R.S.; W. Pengelly, F.R.S.; Professor E. Hull, F.R.S.; Professor Prestwich, F.R.S; Dr. C. Le Neve Forster; Professor A. S. Herschel; Professor G. A. Lebour; A. B. Wynne; W. Galloway; Joseph Dickinson; E. Wethered; and Professor J. D. Everett, F.R.S., Secretary.

The object of the investigation in all cases being to find the temperature of the rock at certain depths, it becomes important to know how far that of water stagnant within walls of rock, wide apart as in mines, or narrow as in boreholes, or issuing from the rock in form of springs, can be regarded as corresponding with it. As to this the most diverse opinions have been held by high authorities. Sir William Thomson says:—"All sound naturalists agree that we cannot derive accurate knowledge of underground temperature from mines; but every bore that is made for the purpose of testing minerals gives an opportunity of observation."* The late Professor Phillips said:—"It is in the solid rock that the best observations, and those most suited to the purpose of philosophical reasoning, are to be obtained."† On the other hand, Fox and Henwood, to whom is owed more actual work on the subject than to any other *savants*, thought differently, the former saying, "I am disposed to attach most importance to observations on springs of water not coming from the roofs of galleries, or evidently proceeding from higher parts of the mines;"‡ whilst Mr. Jory Henwood, who may be said to have tried all methods, concludes:—"After most careful consideration of the subject, and consultation with others who have also been engaged in this inquiry, it has been thought best to confine the observations as much as possible to the temperature of the streams of water immediately issuing from the unbroken portions of the rocks and veins."§ As Mr. Henwood proceeds to show, the temperature of the air of mines is affected by a number of factors which tend to render it very different from that of the rock, and that water flowing through or standing in pools in the levels is exposed to the same modifying causes.

The modifying causes alluded to—the presence of workmen, combustion of candles or lamps, ventilation currents, etc.—do not affect boreholes where convection of the water filling them, and the possible ingress of abnormally warm or cold springs, are the chief vitiating agents. Accordingly, among the observations taken in water, it would appear that those in bore-holes may *a priori* be presumed to yield the most trustworthy results.

But although it is probably right to view observations of temperature in the ordinary air of open mines with considerable suspicion, the case is much altered when they are taken in holes, even of shallow depth, driven

* Transactions of the Geological Society of Glasgow, Vol. III., Part 1, sec. 29.

† Reports of the British Association, Vol. V., page 292 (1836).

‡ Transactions of the Royal Geological Society of Cornwall, Vol. III., page 320.

§ Transactions of the Royal Geological Society of Cornwall, Vol. V., page 387.

from the walls or roofs of mines, and carefully plugged off from the workings. Indeed, such observations are amongst the best that have been recorded.

It does not come within the limited scope of this paper to detail all the observations mentioned in the preceding list, but in three cases this will be done, each being selected as typical of a method of procedure, and for having been carried on at a considerable depth with exceptional care by excellent observers.

The first case is typical of the wet-boring process pure and simple.

The second is typical of the wet-boring process with special appliances for reducing or doing away with the effects of convection.

The third is the best example of observations in dry short borings from mine workings.

The details given will, moreover, illustrate very clearly some of the difficulties met with in investigations of this kind.

The first case is that numbered 31 in the Table. The observations were made in 1872, at the writer's request, by Mr. J. B. Atkinson, for the British Association Committee, in a bore two and a half inches in diameter sunk from the bottom of South Hetton Colliery, Durham. A protected Negretti thermometer was used. The following figures are quoted from the Fifth Report of the Committee, British Association Report for 1872, page 133:—

TABLE II.

Depth from Bottom of Shaft.	Depth from Surface of Ground.	Temperatures observed during Boring in April, 1869.	Temperatures observed in April, 1872.
Feet.	Feet.	Deg. Fahr.	Deg. Fahr.
100	1,166	...	66
200	1,266	...	68¾
288	1,354	72	...
300	1,366	...	70
400	1,466	...	72
500	1,566	...	74½
582	1,648	82	...
600	1,666	...	76⅛
644*	1,710	...	75 †
670	1,736	...	77⅛
858	1,924	96	...

* The hole below this point was full of sludge, but the next recorded depth was reached by the thermometer by attaching a spike to its metal case.

† When repeated, at a later period, this reading was found to have been accidental, being probably caused by insufficient time having been allowed to the thermometer. A normal reading between 77 and 76 deg. should be substituted. See Sixth Report, 1873, page 254.

Still quoting Professor Everett's Report (page 133):—" The following are the rates of increase deduced from Mr. Atkinson's observations, omitting the temperature 75 deg. at the depth of 644 feet:—

Depth in Feet.		Increase in Degrees.		Feet per Degree.
100 to 200	...	2¾	...	36
200 to 300	...	1¼	...	80
300 to 400	...	2	...	50
400 to 500	...	2½	...	40
500 to 670	...	1⅝	...	62
600 to 670	...	1	...	70
100 to 670	...	11⅛	...	51·2

" The average increase between the depths of 100 feet and 670 feet is 1 deg. in 51·2 feet. These depths are reckoned from the top of the bore-hole, which is 1,066 feet below the surface of the ground. Mr. Lebour assumes that the temperature at the depth of 60 feet from the surface of the ground is 48 deg. Accepting this estimate, we have a difference of 29⅛ deg. in 1,676 feet (1,066 + 670 − 60 = 1,676), which is at the rate of 1 deg. in 57·5 feet."

The rocks were of the ordinary coal-measure kind; repeated alternations of sandstone, shales, coals, and fire-clays.

The second example chosen, number 15 in the list, is one which has created a large amount of interest on account of the great depth of the bore, the unusual pains which had been taken with the observations, and the apparently abnormal character of the results. This is the recent case of the celebrated boring at Sperenberg, near Berlin, which reached a depth of 4,172 feet. The writer had prepared a *résumé* of the temperature observations at Sperenberg based upon the British Association Report for 1876; but since the reading of the present paper a work of the highest interest has been published by the Rev. O. Fisher, F.G.S., in which the figures in question are given in what appears a still clearer form.*

* See " Physics of the Earth's Crust," by the Rev. Osmond Fisher, M.A., F.G.S., 8vo, London, 1881 (December), page 10.

The writer, therefore, has no hesitation in substituting this Table for his own:—

TABLE III.

Depth in Feet.	Temperature in R. Degrees.		Water shut off. Consequent Alteration in Temperature.	Surface temperature, 7·18 deg. Absolute Increase at each Depth in Col. 2.	Being at the rate of 1° R. per Number of Feet.	Absolute Increase at Depths.	Being at the rate of	
	Water shut off.	Water not shut off.					1° R. per Foot	1° F. per Foot.
15	9·40	10·35	− 0·95	...	...	...	...	...
30	9·56	10·20	− 0·64	...	...	...	...	...
50	9·86	10·40	− 0·54	...	...	...	...	...
100	10·16	12·30	− 2·14	2·98	33	...	...	...
300	14·60	13·52	+ 1·08	4·44	45	...	...	...
400	14·80	14·30	+ 0·50	0·20	500	...	...	...
500	15·16	14·68	+ 0·48	0·36	277	...	...	...
700	17·06	16·08	+ 0·98	1·90	105	...	...	...
900	18·50	17·18	+ 1·32	0·44	455	...	...	...
1,100	19·90	19·08	+ 0·82	1·40	143	11·72	94	42
1,300	21·10	20·38	+ 0·72	1·20	166	...	...	...
1,500	22·80	22·08	+ 0·72	1·70	118	...	...	...
1,700	24·10	22·90	+ 1·20	1·30	154	...	...	...
1,900	25·90	24·80	+ 1·10	1·80	111	...	...	...
2,100	27·70	26·80	+ 0·90	...	111	7·80	128	57
2,300	28·50	28·10	+ 0·40	1·80	250	...	...	...
2,500	29·70	29·50	+ 0·20	1·20	166	...	...	...
2,700	30·50	30·30	+ 0·20	0·80	250	2·80	214	95
2,900	...	31·60	...	...	...	...	...	...
3,100	...	32·70	...	...	...	...	...	...
3,300	...	33·60	...	...	...	...	...	...
3,390	36·15	34·10	+ 2·05	5·65	122	...	...	...
3,500	...	34·70	...	...	...	...	...	...
3,700	...	35·80	...	...	...	...	...	...
3,900	...	36·60	...	...	...	...	...	...
4,042	38·25	38·10	+ 0·15	2·10	310	7·75	212	95

In this Table the feet are Prussian feet, the difference between them and English being so small as to be immaterial.

The facts given in this Table are very remarkable, and a full discussion of them will be found in the British Association Report, already referred to, where Professor Everett, after making every correction for pressure, etc., arrives at 1 deg. Fahr. per 51·5 English feet as the mean rate of increase to 3,390 feet. In his book Mr. Fisher gives good reasons for regarding the actual rate of increase as rather higher.* For the purposes of this paper, however, the chief interest of the Sperenberg results lies in the fact that an apparatus was in this case successfully used to isolate the thermometer in the bore full of water, and (to a great extent) to stop or impede the action of convection. An inspection of columns 2, 3, and 4 will show how great and how varied, and consequently how difficult to allow for, is the influence of this action in experiments of this kind.

* *Op. jam cit.*, page 16.

The third selected example consists of observations taken for the Committee, at the writer's request, at Boldon Colliery, near Sunderland, in 1875, by Mr. Matthew Heckels, then manager of the colliery.

In this case special vertical bores some ten feet in length were made from the roof of a quiet part of the workings, and the thermometer was thrust up these holes attached to a stick, the holes being carefully plugged up, and the instruments left for several days, and only taken down to be read from time to time.

The observations were taken at 1,365 and 1,514 feet from the surface. The temperature at the former depth was 75 degs. Fahr., at the latter 79 degs. This would give 4 degs. increase for 149 feet; but reckoning from surface mean temperature, which here may be assumed as being 48 degs. Fahr., a much more normal rate is obtained, viz., 1 deg. Fahr. in 49 feet.

Indeed, nothing is more striking than the fact that, in by far the greater number of *good* sets of observations, the mean rates of increase cluster about the numbers 1 deg. Fahr. per 50 or 60 feet.

Professor Everett seems to give the preference to 1 deg. per 56 feet;* the Coal Commission of 1870, with considerably less data than are now available, accepted 1 deg. per 60 feet; and Mr. Fisher takes 1 deg. per 50 to 60 feet as the average.

That practically is the result arrived at by most of the observations which do not appear to be vitiated by untoward conditions. The chief amongst the latter will be now briefly considered.

First, as regards observations in water. In shafts, stagnant water is liable to variations of temperature according to the seasons even at a considerable depth, and after rainfall or drought. This is well shown in the observations taken by Mr. David Burns, F.G.S., in some of the Allenheads mines (Nos. 3, 6, 36 in Table I.) Discrepancies of this kind were also met with in the upper or "well" portion of the Kentish Town hole, as shown by Mr. Symons' results (Nos. 18, 19, 21 in the same Table). But the chief objection is the wholesale convection which is inseparable from such wide columns of water.

In boreholes of considerable depth the effects of changes in surface temperatures are practically *nil.* Convection is here, however, still a constant source of error. However narrow the bore, convection takes place, and, as a result, thermometric observations taken in them give, not the temperature of the rock at certain depths, but that of the moving water at those depths. Now, if the rock in which the hole is bored is of the same

* See Proceedings of the Belfast Natural History and Philosophical Society for 1873-74.

kind from top to bottom, it might be assumed that the convection currents set up by the heat below are uniform, and some correction of sufficiently general application might be used to convert the readings into true rock temperatures. But, as a rule, a bore passes through very numerous beds of rock of various kinds. Each kind has a special rate of heat-conduction of its own, and the changing conductivities become disturbing elements as regards the convection of the water. Knowing the absolute conductivity for heat of the various kinds of rock, it might be possible to discover the exact amount of effect produced at each horizon upon the convection currents, but the necessary calculations have not yet been made.

A more practical way of lessening the errors due to convection is that of plugging the hole both above and below the thermometer used. In the Sperenberg observations above recorded a very elaborate form of plug was used, which gave very satisfactory results; but its expense, and the amount of trouble required to work it, would preclude its use in most cases, more especially as bore-rods are necessary for its application. Besides, the Sperenberg bore, being for nearly 4,000 feet entirely in rock salt—*i.e.* enclosed in walls of homogeneous conductivity for heat—comes under the head of exceptional cases. Sand bags have been used as plugs, and so have India-rubber discs arranged along the wire supporting the thermometer in a considerable number of series. An umbrella-shaped plug, collapsing and expanding by means of a double wire, was devised by the writer for this purpose, and another, also by him, necessitating but a single wire, and acting on the same principle as a safety-cage, viz., falling freely so long as the wire remains taut, expanding and gripping the sides as soon as the wire is let go. To all these appliances there are objections in practice, and so far, the Sperenberg observations remain the only really successful ones with plugs for stopping or checking convection.

Springs or feeders of water at various horizons in a bore are a source of error, which must be of very usual occurrence, and which it is almost impossible to guard against. In some districts such springs may have, as Mr. Henwood held, practically the same temperature as the bed of rock from which they issue, and the error due to them may be correspondingly small, but often the feeders may be of much higher temperature, and must vitiate all readings taken in their vicinity. In the case of Mr. Henwood's Cornish observations, all of which were taken in springs issuing at various depths in mines, their great number, and the care and judgment with which they were selected and carried out, give great

weight to the means deduced from them. Thus No. 7 in Table I. is the mean of 415 observations of this kind. They were distributed as follows among the principal mining districts of Cornwall and Devon :*—

TABLE IV.

Districts.	Mean Depth in Feet.	Mean Temperature Fahr. in Degrees.
Saint Just	570	57·84
Saint Ives	774	63·56
Marazion	456	63·87
Gwinear, etc.	606	63·4
Helston	804	66·66
Camborne, etc.	588	62·13
Redruth, etc.	792	71·37
Saint Agnes	594	65·91
Saint Austell	816	70·62
Tavistock, etc.	432	59·07

It is, of course, very necessary to be able to know exactly at what depth the thermometer employed in taking borehole temperatures is standing. This would seem at first sight to be a very easy matter; but in practice much annoyance is caused by the lengthening—unequal lengthening the writer has more than once found it to be—of the wires used to suspend the instrument. A drum coupled with a mechanical counter is the most useful form of apparatus for lowering and raising thermometers in bores, the best wire for the purpose being pianoforte wire, which is much less liable to changes of length than the copper wire generally employed. (A drum of this kind, designed by Mr. Lindsay Galloway for the use of the British Association Committee, was exhibited to the meeting.)

Formerly, self-registering thermometers were commonly used, but the shaking, which it is all but impossible to avoid in raising them from any great depth in narrow bores, was so apt to displace the index that they are now given up. The instruments now recommended are of the type of Negretti and Zambra's so-called "mining thermometer," where the bulb is surrounded by a non-conducting substance, usually paraffin. Very slow action is thus ensured, and, after being left a sufficient time at any particular depth to mark the degree of temperature at that horizon, the mercury will remain practically stationary during the short time necessary to haul up the instrument.

Attention has already been called to the conductivity for heat of various rocks, as affecting the convection currents in the water filling

* See Cornwall Geological Transactions, Vol. V., page 402.

boreholes. The actual rate of increase of temperature in going downwards depends upon this same conductivity, such increase being more rapid as the index of conductivity is lower, slower as the rocks are better conductors. But it has been found that the index of conductivity of a rock when dry is very different from that exhibited by the same rock when wet; the latter offering far less resistance to the passage of heat than the former. This makes another source of error pertaining to observations in wet bores which should not be lost sight of.

The conductivity for heat of fissile or laminated rocks also varies according to the position of the laminæ with regard to that of the source of heat. Rocks of this kind, when vertical, conduct heat more rapidly than when horizontal, when dipping than when flat. Here there is another source of error due to conductivity. This one, like the last, can probably be fairly corrected, so far as shallow depths are concerned, now that the absolute conductivities of so many rocks are known, thanks to the arduous labours of Prof. A. S. Herschel,* only recently completed. But at great depths the rocks are no longer at ordinary temperature, and it is not to be assumed that at very high temperatures the index of conductivity for heat of any substance will be the same as at comparatively low ones. For errors possibly due to this cause there is as yet no correction, experiments on this portion of the subject being still a desideratum.

Connected with the general low conductivity for heat of most rocks is the extraordinary time required before the heat due to boring operations is lost in bores of considerable depth, be they wet or dry. Many most carefully conducted observations have been rendered valueless from being made too soon after the boring tools have been removed. There are few exact data on this subject at present, but Mr. W. Galloway is now investigating it for the British Association Committee. It is, however, proved by many sets of readings (*e.g.* Nos. 31, 41, 52 in Table I.) that, under certain conditions, months may elapse before the water or air at the bottom of a deep bore regains a temperature at all representing that of the surrounding rock. This is a point on which persons practically acquainted with boring might give exceedingly valuable information. Even in the short hand-bores used in dry-air observations of the Boldon Colliery type a certain amount of time must be allowed to elapse before readings are taken.

The form of the surface should be considered in estimating the value of temperature observations taken even at great depths below it. A point in the ground vertically under a steep crest is more exposed to the

* See Reports of the British Association on Rock Conductivities, 1874 to 1882.

cooling influence of the air than a point at the same depth beneath a plain. The decrease of temperature upwards is about three and a half times more rapid in the air than in the rock, and the curves of the planes of equal temperature below ground will therefore necessarily be affected by the greater or less degree of convexity in the great surface features of the ground above. This is a point which must chiefly be kept in view in discussing observations taken in mountainous regions, such as those in short dry bores in the Mont Cenis, St. Gothard, and Hoosac Tunnels, in all of which very elaborate series of experiments on subterranean temperature have been and are being made (No. 51 in Table I.)

Many years ago Reich called attention to a belief held by the miners in Saxony that tin mines were colder than others.* In mines containing much pyrites the reverse is the case. In the mines on the Great Comstock lode, as every one knows, temperatures abnormally high are found —so abnormal indeed that they have been omitted from the Table in the present paper as being useless for comparisons with ordinary readings. Temperatures, not so unusually great as those of the Comstock lode, were found in the Schemnitz mines, in Hungary (43 to 47 in Table I.); others, also very irregular, in some bores in the immediate neighbourhood of lead veins in North Wales, taken recently with great care by Mr. Strahan of H.M. Geological Survey. Examples of this sort might be multiplied, showing that in connexion with mineral veins a normal or regular rate of increase of temperature is not to be counted on. What this may be due to it is not always easy to say, but with the facts before us it seems fair to conclude that chemical action is at the root of the matter. The decomposition of the metallic sulphides, which form the greater part of the mineral contents of most metalliferous veins, give rise to great heat. Some hot mineral springs are traceable to this cause. Other chemical decompositions may cause a lowering of the temperature at certain points within the interior of the earth's crust. To be on the safe side, therefore, it is necessary to exclude, or at any rate receive only with diffidence, all observations taken in the neighbourhood of mineral veins, when such observations are abnormal in character. When, as in the case of Mr. Henwood's remarkable series of experiments mentioned above, the results show no violent difference from those in regularly-bedded and unfaulted districts, it may be accepted then as a proof that chemical decomposition is working there but on a very small scale.

Again, there is no reason to assume that movements of the earth's crust

* Beobachtungen ueber die Temperatur des Gesteins in verschiedenen Tiefen in den Gruben des Sachsischen Erzgebirges, p. 87.

are now dead. Upheaval, sinking, and lateral squeezing of the rocks are still, no doubt, slowly going on now as formerly, and where such mechanical action exists there also will abnormal heat be evolved, and there will thermometric observations, as in the case of metalliferous districts, be vitiated by the fact that the heat registered may not be that of the great central hot kernel of the globe (to the existence of which every geological phenomenon points), but may be merely due to the fact that some of the many minor local foci of heat are being approached which chemistry and physics demonstrate must be found where certain chemical and mechanical actions are taking place.

As to what remains to be done in order to improve the present knowledge of the rate of increase of underground temperature, observations in coal mines under the sea have been pointed out by Professor Everett as likely to yield important results, and the assistance of members of the Institute is asked in this direction, as well as in any other which may be suggested to them by their practical knowledge of mines and mechanical appliances. The chief desiderata have been enumerated one by one as each chief source of error has come under notice.

In conclusion, the writer begs to disclaim any pretensions to originality in the present paper, nothing in which is new but its arrangement, and perhaps some of the views as to the worthlessness of certain observations.

The PRESIDENT said, the members would join with him in passing a vote of thanks to Professor Lebour for the paper he had read. The heat of underground strata was a subject which affected deep mining very much indeed, and, of course, as years went on, and the upper beds of coal were worked off, this subject would affect them much more. He was sure that the members of the Institute would be glad to co-operate with Mr. Lebour in obtaining such information as he desired. So far as he was concerned, he could promise the Professor a series of observations under the sea.

Mr. BEWICK hoped that Mr. Lebour would, in the tabular statements embodied in his paper, give the geological formation in which the observations were taken. Allusion had been made to the temperature in some observations made at Allenheads, but the results would depend upon the period of the week at which they were taken. A large number of men and some horses were employed, and powder was exploded; all which would tend to cause some variation according to the time at which the

observations were made. Then, again, the proximity of veins would be an interesting matter to consider. There were a great many veins of different characters, containing lead, zinc, and copper ores, pyrites, and other matters; these and even the direction of the wind might affect the observations taken at Allenheads.

Professor LEBOUR said, he would give the geological formations in which the observations were taken when they were known; some of those who had taken the other observations had been careless. He believed the observations at Allenheads were taken in shafts under water. The shafts were the High Underground Engine Shaft and the Gin Hill Shaft; and he mentioned these observations to show the difference after a drought and after rain. The observations in the shafts at Allenheads were taken by Mr. D. Burns, F.G.S., in water in 1871. Otherwise he thought these observations in shafts were almost worthless.

Mr. BEWICK—Both the shafts mentioned are working shafts, and the observations must have been taken in the sump-hole.

Mr. BOYD said, one circumstance had struck him forcibly, namely, whether the increased temperature was entirely due to the superincumbent strata, or whether the sea level had any influence upon it. For instance, in piercing the Mont Cenis tunnel a temperature of 90 degs. was observed, which was considerably more than that obtained at depths very much nearer to the centre of the earth.

Mr. COOKE asked Professor Lebour whether the increased temperature might be due to heat being rendered sensible which had been latent on account of the compression in great depths, either in water, or air, or solid rock, that is, in fact, whether the pressure has anything to do with the increasing heat? He reminded them of the popular lecturer setting fire to tinder by the sudden compression of air in a cylinder, and of the necessity of cooling appliances, where air-compressing engines are used.

Professor LEBOUR said, pressure by itself could not develop heat. It was only where motion was destroyed as motion that it was converted into heat. Therefore, there was no reason for imagining that increase of temperature as descent was made below the earth's surface could be due to the pressure of the overlying rocks, or "cover."

Mr. BIRD asked Professor Lebour if there were not instances of variation in the same borehole. If there was a borehole 3,000 feet deep, was not the rate of increase different at the first thousand, and at the second thousand, and at the third thousand?

Professor LEBOUR said, Mr. Bird had touched upon a point which was the very pith of the whole matter. These differences in the increase

of temperature were among the difficulties of the observations. He did not know of any observations where they did not get differences of this kind. If they took two or three cases where there were observations every 50 or 100 feet, and took the difference between the temperature at 100 feet, and the temperature at the lowest depth (unless an abnormal one), they would find that the mean was something like 1 in 56 in most instances. Between those two they found great variations of all kinds in the rate: they sometimes found even decrease, and not increase. He cast aside all minor matters because they interfered with the general results which seemed to be generally established. If anyone would study the minor matters, and give the result of his observations, he would do great service to science. It was almost impossible for anyone not acquainted with localities to explain carefully the discrepancies in each case. If people connected with a locality would attend to the facts of that locality, they would do great service.

Mr. Bird understood Mr. Lebour to mean that if these matters were eliminated the rate of increase would be found to be uniform in one place, with a few exceptions.

Professor Lebour said that was so.

Mr. Boyd proposed, and Mr. Bird seconded, a vote of thanks to Mr. Lebour for his most interesting paper, which was unanimously carried, and the discussion was adjourned.