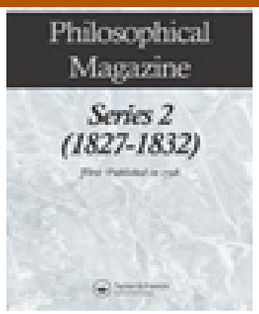

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XXXI. Facts bearing on the theory of the formation of springs, and their intensity at various periods of the year

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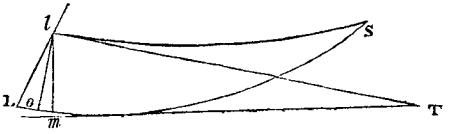
Describe from s as pole the circle $l\,o$, then is $o\,m$ the third cor-



rection. Draw at m a tangent and make $\mathrm{T}\,l = \mathrm{tang\ D}$, then is

$$\sin \mathrm{T} = \sin l\,m \,.\, \mathrm{cotang\ D}.$$

but $m\,o \,.\, \sin 1'' = \mathrm{tang\ D}\,(1 - \cos \mathrm{T}) = \mathrm{tang\ D} \,.\, 2 \sin^2 \frac{1}{2}\,\mathrm{T}$
$\frac{1}{2}\,\mathrm{tang\ D}\,4 \sin^2 \frac{1}{2}\,\mathrm{T} = \frac{1}{2}\,\mathrm{tang\ D}\,(2 \sin \frac{1}{2}\,\mathrm{T})^2 = \frac{1}{2}\,\mathrm{tang\ D} \sin^2 \mathrm{T}$

$$= \tfrac{1}{2}\,\mathrm{tang\ D}\,\mathrm{cotang}^2\,\mathrm{D} \sin^2 l\,m = \frac{\sin^2 \mathrm{L}\,l - \sin^2 \mathrm{L}\,m}{2\,\mathrm{tang\ D}}.$$

Hamburgh, Jan. 16, 1831. C. RUMKER.

XXXI. *Facts bearing on the Theory of the Formation of Springs, and their Intensity at various Periods of the Year.* *By* W. J. HENWOOD.

THAT those springs which exist during the winter and disappear as summer approaches, owe their origin to rain, has not I believe been disputed. But whether we may ascribe to the same cause those on which changes of the seasons appear to exert but little influence, has been frequently discussed. In the mining districts of Cornwall, registers of the performance of the steam-engines employed for pumping water, is periodically published by Messrs. John and Thomas Lean, of Camborne. These documents supply information from which it is not difficult to calculate the quantity of water drawn by each engine in a month, and consequently the intensity of springs at the spot. The particulars contained in the following columns are of some consequence in this investigation.

In some of the extensive mines several steam-engines are required; and as they are usually erected at a considerable distance from one another, each drains the whole of a certain district. Hence I think we may safely assume the water drawn by one engine as representing the intensity of the springs at that spot. The numbers in Table I. denote cubic feet of water drawn by one engine; in Table II. the averages of the respective mines are for one engine on each; but in Table III. the numbers are intended for cubic feet of water drawn by all the engines on each of the respective mines.

Mine

Mine.	Strata and Form of Surface.	Surface above Sea-level.*	Bottom below Sea-level.	Distance from Sea.	Situation.
		Fathoms.	Fathoms.	Miles.	
a †Poldice	Slate, at the foot of a hill which rises about 16°	28	140	4	1 mile E. of St. Day.
... ...	... ... near the summit of the hill	40	114		
... ...	Granite at the bottom. Slate upward....	40	134		
b Huel Harmony	Slate, a plain at foot of a granite hill	62	46	3·5	1 mile N. of Redruth.
c HuelMontague	Slate	60	52		
d Huel Rose.....	Slate, between two small hills which rise about 8°	35 ?	95	2·75	6 miles N. of Truro.
e Poladras Downs	Slate, at foot of a granite hill which rises about 12°	46	59	5·	5 miles N.W. of Helston.
f Huel Hope ...	Slate, between two small hills which rise about 10°	50 ?	110	3·	4 miles W. of Camborne.
g United Mines	Slate, summit of a small hill	48	160 ‡	3·25	1·25 mile S.E. of St. Day.
h Huel Towan...	Slate, near summit of a hill which rises from the sea 10°	45	106	0·125	4 miles N.E. of Redruth.
i GreatSt.George	Slate	45	60	0·25	7 miles N. of Truro.
k Crinnis.... ...	Slate, an acclivity of about 8°	24	98	0·75?	2 miles E. of St. Austle.
l	... ...	14	58		
m Huel Falmouth	Slate, summit of a small hill	55	18	2·5	3 miles W. of Truro.
n Huel Maid....	Slate, an acclivity of about 15°	38	132 §	3·75	1 mile E. of St. Day.
o Ting Tang...	Slate, granite on the west at forty fathoms, a plain with a slight ascent; at foot of a granite hill	54 50	120 89	4·	1 mile S. of St. Day.
p Consols	Slate, summit and side of a hill rising about 14°	39	131	2·75	2 miles S.E. of St. Day.
... ...	... ...	23	171		1·5 mile.
... ...	... ...	29	151		
... ...	... ...	49	151	3·25	1·25 mile.
... ...	... ...	52	131	3·75	1 mile.
... ...	... ...	52	166		
q Huel Unity.....	Slate, between two small hills rising about 8°	37	53 ‖	4·5	0·5 mile N.E. of St. Day.
... ...	Slate, granite at 87 fathoms, acclivity about 8°	45	121 ¶	4·25	0·25 mile.
r Dolcoath.....	Slate, granite at 210 fathoms, plain at foot of a granite hill	62	188	4·	Camborne.
s Huel Damsel...	Granite, at foot of a hill rising about 17°	59	143	4·	1 mile S. of St. Day.
... ...	... ... plain	42	112		
t Huel Reeth	Granite, an acclivity of 12° at foot of a granite hill	66 ?	128	3·	3 miles W. of Hayle.
u Huel Gorland	Granite, summit of a hill	66	97	4·375	St. Day.
w Great Work ...	Granite, between two hills rising about 15°...	66 ?	60	4·	4 mile N.E. of Marazion.

* Many of the numbers in this column are from Thomas's Survey, p. 72–73. † The letters will be found at the head of the columns to which they respectively refer, in Tables II. and III. ‡ 120 fathoms of the bottom have for some years been filled with water.
§ 24 fathoms of the lower part full of water. ‖ 40 fathoms of the bottom full of water. ¶ 30 fathoms of the bottom are filled with water.

It appears to me desirable to determine the intensity of springs at various depths, beneath the same surface; and this will be seen in the following columns, which denote the quantities drawn out of Huel Hope Mine, on which there is but one engine.

TABLE I.

	Depth of Mine in Fathoms.	1825. Cubic Feet of Water drawn out.	Depth of Mine in Fathoms.	1826. Cubic Feet of Water drawn out.	Depth of Mine in Fathoms.	1827. Cubic Feet of Water drawn out.	Depth of Mine in Fathoms.	1828. Cubic Feet of Water drawn out.	Depth of Mine in Fathoms.	1829. Cubic Feet of Water drawn out.
Jan...	...	.....	74	2,428,149	77	2,699,121	88	*	112	2,889,535
Feb...	...	.....	71	2,123,209	...	2,536,137	108	3,292,749	...	2,748,953
Mar...	...	.....	...	2,562,010	...	3,362,051	...	3,125,796	...	2,788,771
April.	...	.....	...	2,309,617	...	3,073,158	...	2,872,231	...	2,659,448
May .	...	.....	77	2,092,514	...	2,873,097	...	2,874,119	...	2,788,974
June..	48	1,679,843	...	*	...	2,899,681	112	2,629,117	...	2,716,185
July...	53	1,482,723	...	1,766,160	...	2,833,634	...	2,662,792	128	2,285,164
Aug..	55	1,459,652	...	1,677,752	...	2,553,753	...	2,501,831	...	2,231,667
Sept..	56	1,335,605	...	1,584,818	...	2,273,581	...	2,264,919	...	2,242,170
Oct...	...	1,369,297	...	1,669,365	...	2,225,924	...	2,281,205	...	2,621,985
Nov...	...	1,346,398	...	*	...	2.309,194	...	2,146,405	...	2,489,828
Dec..	66	2,066,255	...	2,414,911	88	2,984,186	...	2,388,438	...	*

I by no means intend to imply that the increase observable in the preceding is entirely due to the augmented depth; for the horizontal excavations are continued at the same time, and I think a more extended series of observations requisite for determining what part of the increase should be assigned to each. The water is seldom drawn directly to the surface, but passes off through a gallery ("the adit"), which is excavated ("driven") from the nearest deep vale to the engine shaft, and is thence extended to the veins, which are usually much worked at this depth. The adit is in some mines forty-five fathoms from the surface; and by its great extension intercepts in its descent a large portion of the rain-water which has been absorbed by the earth. Of this quantity I have taken no notice. On the other hand there is a loss of water in the pumps, through imperfection of buckets and other apparatus; through the engine not making at all times its stroke of the full calculated length, and by its being sometimes worked more rapidly than the flow of water will supply ("going in fork"), and consequently drawing air.

Respecting the sum of all these defects practical men are by no means agreed; the extremes may be taken at one-fifth and one-tenth of the whole. In an experiment at Huel Towan†, in which I had the honour to assist Mr. Rennie, the observed quantity was to the calculated as 83 : 92, or thereabout. I think we shall not be very far wrong if we consider the

† Phil. Mag. and Annals, N.S. vol. vii. p. 424. rain-

rain-water carried off by the adit, counterbalanced by the deficiency of the engine's actual performance, when compared with its calculated duty. In which case the preceding numbers would nearly represent the intensities at that spot, provided we could apply a correction for the increase due to the horizontal increase in the extent of the mine. But the whole of this water is not drawn from the bottom, for in most of the galleries ("levels") there is some which is conveyed to the engine without being permitted to descend; yet as the veins are usually very porous, the greater part (say four-fifths) comes to the bottom, and the larger portion of the remainder from but little above; this obtains, however the depth may be augmented. The columns in Table II. are independent of one another; the lowest number in each being unity, they exhibit the monthly intensity of the springs in the various mines, on a mean of seven years; the column "ratio" denotes the relation of the average number of strokes per minute made by all the engines in Cornwall, and "rain," the ratio of rain; both for the same period. I purposely select mines in various parts of the county, the most distant being about thirty-three miles apart.

Perhaps it may be expected that I should offer some explanation of the differences in the following columns; but were I to attempt it, it must after all be very hypothetical. I therefore decline affording any.

It may not be out of place to observe, that when the United Mines were worked to a depth of 208 fathoms, the mean monthly quantity of water drawn out was about 13,000,000 cubic feet; at present they are worked to 90 fathoms depth, and the mean may now be about 4,350,000 cubic feet.

The area of the portion of Gwenap parish, which would be included by a line drawn in an east-north-east direction from Pennance to Huel Friendship, thence west-north-west to Huel Derrick, and from there south to Pennance, is about 1969 acres. Within this line are all the mines mentioned in Table III., there being steam-engines worked on them; beside others on which there are no engines, they being drained by the adjacent mines. Within the bounding line there are not more than three or four wells, but along the south and west lines there are several at a little distance; whilst about a quarter of a mile north of the north line is the stopped mine of Huel Busy, in which the water is at the adit. This affords a tolerably favourable opportunity for comparing the quantity of rain, falling on a known area, with the evaporation, and the quantity of water afforded by springs in a given time, from the same spot. The following columns, Table III., contain such a comparison; the evaporation being estimated from the register of W. Snow Harris, Esq. of Plymouth, who kindly permits me to use his numbers; and the rain from the register, published by E. C. Giddy, Esq. of Penzance, in this Journal.

I believe I correctly follow Mr. Daniell* in estimating the evaporation "from water, vegetation, or ploughed land" as equal; although this does not coincide with Mr. Dalton's observations on the same subject†.

It has been already remarked, that the computed quantity exceeds that actually delivered; and if we consider the difference to be one-seventh of the whole, there will still be an excess of 104,407,394·15 cubic feet‡; nor will our conclusions be much falsified, by omitting the quantity afforded by wells, which probably does not much exceed 10,000 cubic feet per month. Whence then this excess?

Mr. Fox (whose kindness to me in innumerable instances has exceeded that of a parent) has in several cases detected muriate of soda in water from some of the mines situated several miles from the sea, and thence remarks: "It may be inferred from such facts as these, that the sea-water must in some places penetrate into the fissures of the earth, and consequently may in a greater or less degree assist in supplying the loss of moisture carried off by evaporation§," &c. The slate strata of Cornwall are usually considerably inclined, and the veins by which they are traversed being unconformable to the stratification, they must receive much of the water which percolates through the strata.

* Meteorolog. Essays, p. 122. † Manchester Memoirs, O.S. v. p. 361,670.

‡ Mr. Dalton's experiments on the evaporation from mould and vegetative surfaces, to which I have already referred, are the only ones on these points which I have seen described in detail. If we follow the numbers there given by this illustrious philosopher, it will give a different value to the 8th and 10th columns of Table III. thus:

	Evaporation from a Surface of Water being for each Month unity, that from a Surface of Vegetation will be	The Evaporation on 1969 Acres, therefore	Differences between Water drawn and Evapor., and Rain.
		cubic feet.	*cubic feet.*
Dec.	..... ·9893	4848712·69	— 9045621·78
Jan.	..... ·672	3293576·19	+ 15012644·77
Feb.	..... ·264	1335643·8	+ 10146946·25
Mar.	..... ·178	1246293·71	+ 24972680·8
April	..... ·33	3018614·62	— 3861611·79
May	..... ·5412	8336444·65	+ 39824522·25
June	. ..... ·3366	4789535·2	+ 4823217·9
July	..... ·7276	7641600·89	— 1198998·76
Aug.	..... ·5589	7826444·45	— 1903063·6
Sept.	..... ·7577	9241229·49	— 10528726·26
Oct.	..... 1·1365	9946719·14	+ 19607897·3
Nov.	..... 1·0063	7500325·66	+ 26487825·57
		69,025,140·49	+114,337,712·65

cubic feet of water drawn, and evaporated more than the rain fallen; and when corrected for imperfection of apparatus, the excess still amounts to 59,881,580·54 cubic feet. The author has mentioned some of the objections to which his experiments are open. I shall therefore only remark that they seem to need repetition.

§ Cornwall Geol. Trans. iii. p. 324.

TABLE II.

	Poldice.	Huel Harmony.		Huel Montague.	Huel Rose.	Poladras Downs.	Huel Hope.	United Mines.		Huel Towan.	Great St. George.	Crinnis.		Huel Falmouth.	Dolcoath.	Huel Damsel.	Huel Reeth.	Ratio.	Rain.
	a	*b* 1st Ser.	2nd Ser.	*c*	*d*	*e*	*f*	*g* 1st Ser.	2nd Ser.	*h*	*i*	*k* 1st Ser.	*l* 2nd Ser.	*m*	*r*	*s*	*t*		
Jan.	1·32	1·02	1·62	1·16	1·48	1·36	1·37	1·	1·41	1·29	1·12	1·54	2·03	2·62	1·33	1·32	2·05	1·23	1·81
Feb.	1·31	1·35	1·47	1·	1·28	1·2	1·37	1·23	1·63	1·09	1·01	1·46	1·83	2·26	1·23	1·14	1·85	1·26	1·52
Mar.	1·43	1·36	1·77	1·02	1·5	1·16	1·53	1·33	1·75	1·17	1·09	1·76	1·95	1·6	1·27	1·34	1·99	1·32	1·41
April	1·24	1·2	1·68	1·01	1·39	1·29	1·4	1·34	1·46	1·17	1·11	1·5	1·61	1·38	1·23	1·23	1·38	1·23	1·19
May	1·28	1·42	1·29	1·03	1·47	1·29	1·36	1·48	1·64	1·24	1·07	1·31	1·89	1·72	1·24	1·28	1·29	1·17	1·19
June	1·17	1·09	1·22	1·05	1·2	1·37	1·27	1·12	1·31	1·16	1·12	1·2	1·57	1·86	1·17	1·28	1·12	1·11	1·
July	1·16	1·16	1·18	1·	1·12	1·16	1·13	1·04	1·32	1·09	1·2	1·2	1·59	1·44	1·04	1·11	1·04	1·07	1·14
Aug.	1·07	1·16	1·16	1·07	1·	1.18	1·07	1·38	1·16	1·04	1.19	1·12	1·56	1·	1·	1·09	1·	1·02	1·58
Sept.	1·	1·06	1·04	1·01	1·01	1·18	1·	1·16	1·03	1·	1·12	1·	1·53	1·03	1·	1·04	1·07	1·01	1·55
Oct.	1·08	1·04	1·2	1·1	1·03	1·24	1·04	1·25	1·03	1·06	1·13	1·1	1·78	1·79	1·02	1·02	1·23	1·	1·95
Nov.	1·04	1·17	1·	1·08	1·1	1·	1·06	1·34	1·05	1·01	1·04	1·2	1·	3·27	1·01	1·	1·42	1·03	1·66
Dec.	1·18	1·	1·52	1·24	1·49	1·	1·26	1·37	1·	1·13	1·	1·59	1·65		1·25	1·19	2·3	1·17	2·19

TABLE

Table III.

	United Mines. *g* cubic feet.	Consols. *p* cubic feet.	Ting Tang. *o* cubic feet.	Poldice. *a* cubic feet.	Huel Unity*. *qu* cubic feet.	Huel Damsel. *g* cubic feet.	Total Quantity of Water drawn out of the Mines. cubic feet.	Evaporation. cubic feet.	Total Quantity of Rain fallen. cubic feet.	Difference between Amount of Evaporation and Water drawn, and Rain fallen. cubic feet.†
1828.										
Dec.	4173845·58	12093580·69‡	2655401·21‡	5779876·36‡	4537336·89‡	1358625·53	30598666·28	4901155·05	44493000·75	− 8993179·42
1829.										
Jan.	4745878·97	13088543·09	2894792·25‡	6389641·04‡	5459162·6 ‡	1512631·72	34090649·68	4901155·05	22371581·1	+ 16620223·63
Feb.	4198094·75‡	11747636·98	2286188·89	5918852·9 ‡	4673173·76	1465502·51‡	30289449·8	5059256·83	21478147·35	+ 13870559·28
Mar.	5071161·97	13190497·02	2468925·09‡	6747528·66‡	5105922·77	1613395·1	34197430·64	7001650·08	10471043·55	+ 30728037·17
April	4579744·8	13108963·54	2585917·71	6088332·14‡	4641488·76	1426411·62	32430858·59	9147317·04	39311085·	+ 2267090·63
May	5328338·85	14537395·22‡	2530721·87	6479687·74‡	5056318·37‡	1558198·74	35490660·8	15403630·17	4002583·2	+ 46891707·77
June	4327238·2	13274758·99‡	2397175·23	5699157·68‡	4985978·89‡	1370039·29	32054348·3	14229159·84	32020665·6	+ 14262842·54
July	4067023·2	12694379·66‡	2522465·85	5912266·95‡	4910772·29	1185536·44	31292444·4	10502475·12	40133044·05	+ 1661875·47
Aug.	3732569·96	12448347·63	2470127·61	5394198·32‡	4442697·92	1200847·54	29688789·	14003300·16	39418297·05	+ 4273792·11
Sept.	3811897·04	11916143·56	2288730·67	5530541·7 ‡	4243524·71	1184951·96	28975789·65	12196422·72	48745745·4	− 7573533·03
Oct.	4295971·92	12338948·52	2606918·23	5981173·71‡	4858766·49	1256970·73	31338749·61	8752062·6	21677571·45	+ 18413240·76
Nov.	4344319·09	12171499·54	2706679·36	5739619·07‡	4548799·96	1234171·01	30745088·06	7453369·44	11757588·15	+ 26440869·35
							381192924·81	113550954·1	335880352·65	+158863526·26
							492,743,878·91			

* So much of this as a 4·5-inch pump draws, is from Huel Gorland.

† In the column of "Differences" when the sum of the "Water drawn," and "Evaporation," exceeds the "Rain," I prefix the sign +; and when the contrary the sign −.

‡ All the engines on the mines, for the months thus distinguished, (‡) are not reported: their performance I approximate from its duty in the preceding month, and from that of the others for the present.

But as the metalliferous veins, which have a direction of from east to west, or thereabouts, suffer frequent intersections and dislocations by the cross veins, they do not convey the liquid to a very great distance in their longitudinal extent. But the cross veins, which have a direction of about north and south, are in many cases supposed to traverse the Cornish peninsula from sea to sea, and although sometimes, are not frequently, dislocated, and consequently may be the medium through which sea-water may enter the mines. There are some mines in which the water stands at the adit, (North Downs and Huel Busy,) which intervene between those in which the muriate of soda was detected and the sea; but as the latter are by far the deeper, it may be readily admitted that the percolation may have taken place at or near the lowest levels. But it has not yet been shown that sea-salt does not exist in the water of North Downs and Huel Busy; and until a long continued series of observations shall show its absence, I think we may reasonably adopt Mr. Fox's suggestion.

The level at which the water stands in some stopped mines is not unworthy of notice. Poladras Downs is about a mile north of Huel Vor; before its working was resumed, the water during the winter stood at the adit, but in summer it sunk below that level, which is fourteen fathoms deep. Great Work and Huel Breage are about a mile west of Poladras; in winter the water runs out at the adit, but in summer it sinks three or four fathoms; the adit is about thirty fathoms deep. These facts have been communicated to me by G. S. Borlase, Esq. F.R.S. In Huel Falmouth, before the resumption of operations, the water rose to the adit, twenty-five fathoms deep, in winter; whilst in summer it sank about six or seven feet beneath it.

I believe it may be assumed as a general fact, to which there are not many exceptions, that, *cæteris paribus*, mines worked in the slate of Cornwall afford much more water than those in granite.

I believe my numbers do not coincide with Mr. Dalton's on the same subject*; but through the kindness of John Taylor, Esq. F.R.S., I am to be favoured with engine-reports and other information from his mines in Mexico; and if leisure permit, I hope to submit them to calculation, as they may assist in determining the question on which I feel compelled to differ from such high authority.

Perran Wharf, near Truro,
January 28th, 1831.

W. J. H.

* Manchester Memoirs, O. S. v. p. 346.