CHAPTER IV.

SPRINGS; AND THE WATER-BEARING FORMATIONS OF VARIOUS DISTRICTS.

Infiltration of Rainfall—Experiments by Dickenson, Dalton, and Charnock—Barlow's Suggestions concerning the Dalton Gauge—Estimate of Absorption into the Tertiary Sands and Greensands—Absorbent Capacities of various Rocks—Experiments as to Absorbent Capacity of Sand, by Prestwich; and of Chalk, by Dr. Smith—Caverns and Fissures in Limestone Springs—Water-bearing Strata—General Conditions under which Springs are found—Springs caused by Faults—Artesian Springs—Range, Lithological Character, and Hydrographical Conditions of the several Geological Formations: Alluvium; Newer Pliocene; Later Tertiary Deposits; Drift, Red Crag, Coralline Crag, Norwich Crag, Miocene, Eocene; Bagshot Sands; the London Clay; Lower Tertiary Strata; the Chalk, Chalk Marl, Upper Greensand, Gault, Lower Greensand; the Wealden; Upper Oolitic; Portland Stone, Portland Sand, Kimmeridge Clay; the Middle Oolitic; Coral Rag, Calcareous Grit, Oxford Clay; Lower Oolitic; Cornbrash, Forest Marble, Great or Bath Oolite, Fuller's Earth; Inferior Oolite and Sand; Lias Beds; the New Red Sandstone, or Trias; the Magnesian Limestone, or Permian Group; Carboniferous Series; Coal Measures, Millstone Grit, Carboniferous Limestone; Devonian or Old Red Sandstone; Silurian, Cambrian, and Igneous Rocks—Conclusion.

THE distribution of subterranean water and the phenomena of springs are amongst the most important and interesting subjects with which the engineer is called upon to deal. Of the rain which falls upon the surface of the land, a portion flows off as streams and rivers to the sea; another portion is evaporated again into the atmosphere, part is absorbed by vegetation, and part sinks into the pores and fissures of the soil. It has been supposed, as stated in the previous chapter, that, generally speaking, one-third is lost by evaporation and absorption, one-third is carried away by streams, and the remaining third percolates through into the bowels of the earth, to find a vent by natural or artificial means. Upon this subject, however, Mr. Jos. Prestwich, in his admirable 'Inquiry respecting Water-bearing Strata around London,' remarks: 'From calculations over large areas, it would appear that about one-half of the rain which falls is lost by evaporation and taken up by vegetation, and that the other half drains on the surface or passes into the ground.'* It would be vain, however, to pronounce a dogma on such a point as this, the varied circumstances of surface covering, amount of vegetation, porosity of substratum, slope of ground, intensity or concentration of rainfall, and humidity, temperature, and prevalence of wind, rendering hopeless the attempt at anything but a statement of extreme cases and approximate averages. In a bare, precipitous, rocky, and impervious district, it is but natural to find the rain drained off with hardly a perceptible loss; on the other hand, a flat, bare, sandy tract will secure a very large proportion of the rain that falls, allowing it to pass downward to a level beyond the reach of evaporating influences. Between these limits there is an endless variety of cases, and it is only by long experience and careful observation that there can be formed a reliable estimate of either how much rainfall may be secured from a given catchment area, or what quantity of water may be expected from sinking or boring into a water-bearing formation.

With a view to determine the proportion of the amount infiltrating to that of the total fall of rain, Mr. Dickenson recorded a series of observations which are tabulated below, and are the most complete, and perhaps the most reliable, of any that have been made on this subject. The observations were conducted at Abbots Hill, near Hemel Hempstead. The contrivance for ascertaining the amount of percolation was constructed on the principle suggested by Dr. Dalton, and consisted of a vessel of wood, formed of staves, hooped and jointed like a barrel, and sunk into the ground so that the upper edge was near the surface level. The bottom was saucer-shaped and of lead, a pipe of the same metal serving to conduct away the filtered water to a graduated gauge; there was also an overflow-pipe leading from near the top of the vessel, which, however, was eventually found to be useless. The materials with which the vessel was filled were, at the top, a layer of about ten inches of the ordinary surface soil of the district—a sandy, gravelly loam—then a thickness of about fifteen inches of sandy gravel, gradually becoming coarser as it approached towards the main mass, which was composed of clean coarse gravel, perfectly free from sand and clay. It was supposed, however, that the amount of percolation registered was somewhat greater than that which is obtained in practice, the soil in the gauge being of a more loose and absorbent nature than that of the surrounding country.

* A Geological Inquiry respecting the Water-bearing Strata of the Country around London, p. 112. By Jos. Prestwich, F.G.S.

Rainfall and Infiltration at Apsley Mill, Hertfordshire.

MONTHS	1836		1837		1838		1839		1840		1841		1842		1843		1844		1845		1846		1847		1848	
	Common gauge	Dalton's gauge	Common gauge	Dalton's gauge	Common gauge	Dalton's gauge	Common gauge	Dalton's gauge	Common gauge	Dalton's gauge	Common gauge	Dalton's gauge	Common gauge	Dalton's gauge	Common gauge	Dalton's gauge	Common gauge	Dalton's gauge	Common gauge	Dalton's gauge	Common gauge	Dalton's gauge	Common gauge	Dalton's gauge	Common gauge	Dalton's gauge
January...	2·40	2·32	2·40	2·10	·31	·04	1·40	1·04	3·95	3·05	1·50	—	1·36	·60	1·46	1·25	1·90	·80	3·35	2·40	3·97	5·05	1·80	—	1·33	·81
February	2·04	2·04	2·85	2·92	2·65	·86	1·45	1·51	1·32	1·00	1·02	—	2·02	2·10	2·42	1·95	3·62	1·50	·70	—	1·28	·84	1·42	1·76	3·25	3·00
March ...	3·65	2·51	·75	·01	1·55	2·73	1·92	1·22	·34	—	1·65	·53	2·20	1·62	·88	—	2·22	2·65	1·30	—	1·07	·02	·98	—	3·57	2·75
April......	2·57	1·74	1·32	—	1·35	—	1·65	·71	·34	—	1·85	—	·47	—	2·10	—	·33	—	1·45	—	2·52	·28	1·68	—	2·68	·70
May	·70	·03	·94	—	·84	—	1·22	·10	2·62	—	1·68	—	1·85	—	5·00	·74	·47	—	2·25	—	1·59	—	2·15	—	·21	—
June	1·80	·01	1·86	—	2·85	—	3·31	·05	1·33	—	3·00	—	2·00	—	1·56	·25	1·18	—	1·60	—	·51	—	2·30	—	3·19	—
July	2·29	·10	1·30	—	2·35	·09	4·36	·15	1·18	—	2·80	—	1·93	—	2·09	—	1·95	—	2·30	—	1·90	—	1·91	—	2·42	—
August ...	2·24	·15	3·00	·05	·95	—	3·65	·09	1·90	—	3·62	—	1·40	—	2·66	—	2·72	—	1·97	—	3·28	—	1·21	—	2·38	—
September	2·60	·07	1·38	·05	2·47	·03	3·22	1·50	2·31	—	4·00	—	4·50	1·30	·63	—	1·42	—	2·00	—	1·70	—	2·06	—	2·12	—
October ...	4·55	3·82	1·55	·02	2·68	·07	1·68	·09	1·50	—	4·40	5·99	1·41	·30	4·82	·91	4·38	1·13	1·65	—	6·36	3·98	2·59	—	4·50	2·58
November	3·95	3·14	2·05	·18	3·55	2·91	4·40	4·70	4·25	2·57	4·28	4·87	5·77	5·00	2·45	2·70	3·07	3·57	2·94	·30	1·47	·10	1·70	—	1·12	·47
December	2·21	1·72	1·70	1·62	1·58	1·84	3·02	3·75	·40	1·57	2·30	2·80	1·52	·84	·40	·30	·31	—	3·02	2·80	·90	—	3·40	2·38	2·92	2·68
	31·00	17·65	21·10	6·95	23·13	8·57	31·28	14·91	21·44	8·19	32·10	14·19	26·43	11·76	26·47	8·10	23·57	9·65	24·53	5·50	26·55	10·27	23·20	4·14	29·69	12·99

MONTHS	1849		1850		1851		1852		1853		1854		1855		1856		1857		1858		1859		1860		1861	
	Common gauge	Dalton's gauge	Common gauge	Dalton's gauge	Common gauge	Dalton's gauge	Common gauge	Dalton's gauge	Common gauge	Dalton's gauge	Common gauge	Dalton's gauge	Common gauge	Dalton's gauge	Common gauge	Dalton's gauge	Common gauge	Dalton's gauge	Common gauge	Dalton's gauge	Common gauge	Dalton's gauge	Common gauge	Dalton's gauge	Common gauge	Dalton's gauge
January...	1·80	—	1·24	—	3·76	3·07	5·15	2·64	2·55	1·27	2·48	·95	·79	—	2·97	2·28	3·60	2·80	·70	1·82	1·21	—	3·53	2·95	·50	·98
February	2·18	·40	1·33	·41	·76	·85	1·15	1·02	1·44	—	·93	·45	1·18	1·25	1·46	1·30	·21	·32	1·60	·59	1·91	·09	1·22	·90	2·00	1·70
March ...	·97	·09	·22	—	4·30	3·18	·34	—	1·75	—	·32	—	2·28	1·20	1·07	·45	1·88	—	1·18	·80	1·77	—	2·32	·92	2·31	·75
April......	2·00	—	3·00	—	1·55	·04	1·13	—	2·60	—	·86	—	·40	·19	3·10	·90	2·35	1·11	2·46	—	2·62	—	1·32	·35	·80	—
May	2·98	—	1·67	—	75	—	1·70	—	1·91	—	3·48	—	2·35	—	3·95	1·70	·83	—	2·33	—	2·04	—	3·67	·24	·91	—
June	·40	—	1·20	—	1·75	—	4·49	—	3·70	—	·97	—	1·76	—	1·25	·19	2·20	—	·65	—	3·70	—	6·10	2·44	2·45	—
July	2·79	—	2·90	—	2·56	—	4·70	1·50	3·88	—	1·90	—	5·00	—	1·68	—	1·70	—	2·63	—	3·80	—	2·22	—	3·92	·70
August ...	1·88	—	1·14	—	2·00	—	4·08	—	3·00	—	1·75	—	1·43	—	2·75	—	3·38	—	2·40	—	2·40	—	4·44	—	·55	—
September	3·80	—	1·91	—	·64	—	3·87	—	1·70	·24	·51	—	1·72	—	2·13	—	3·65	—	1·80	—	3·75	—	2·65	·13	1·75	·43
October ...	1·82	—	1·56	—	2·42	—	4·80	·80	3·60	1·65	2·23	—	5·47	—	2·92	—	5·80	1·70	1·94	—	3·03	—	1·65	·62	1·25	—
November	1·47	—	2·67	—	1·03	—	6·95	6·56	1·68	·57	1·31	—	2·05	1·87	1·30	—	2·06	1·35	·78	—	3·09	1·70	2·70	2·30	3·36	2·25
December	2·50	1·03	1·66	1·39	·66	—	2·78	2·11	·65	·60	1·53	—	1·46	·92	2·05	·60	·47	·18	2·03	—	3·30	2·80	2·40	1·26	1·40	·35
	24·65	1·52	20·50	1·80	22·18	7·14	41·14	14·63	28·46	4·33	18·27	1·40	25·89	5·43	26·63	7·42	28 13	7·46	20·50	3·21	32·62	4·59	34·22	12·11	21·20	7·16

MONTHS	1862		1863		1864		1865		1866		1867		1868		1869		RAINFALL		INFILTRATION		Percentage of Infiltration to Rainfall
	Common gauge	Dalton's gauge	Common gauge	Dalton's gauge	Common gauge	Dalton's gauge	Common gauge	Dalton's gauge	Common gauge	Dalton's gauge	Common gauge	Dalton's gauge	Common gauge	Dalton's gauge	Common gauge	Dalton's gauge	Total for each Month	Mean	Total for each Month	Mean	
January...	2·18	1·50	3·34	2·33	1·09	·52	3·68	—	4·02	3·68	3·30	1·80	3·78	1·28	3·41	2·75	82·21	2·417	52·08	1·531	63·3
February	·40	·45	·47	·35	1·01	·42	2·03	2·82	3·34	2·27	1·57	1·07	1·70	·35	2·23	1·70	56·16	1·65	38·19	1·12	68·0
March ...	4·04	2·87	·75	—	2·34	1·59	1·12	·60	1·82	·80	2·29	·80	1·57	·40	1·71	·51	58·43	1·72	29·00	·85	49·5
April......	2·52	1·52	·77	—	1·00	·35	·26	—	1·79	·03	2·27	—	1·88	—	1·93	·02	56·92	1·67	7·94	·23	13·6
May	3·18	·87	1·07	—	2·25	—	2·21	—	1·75	—	3·16	·18	·85	—	3·53	—	68·09	2·00	3·86	·115	5·75
June	2·20	—	4·32	—	1·20	—	2·50	—	3·50	—	1·07	—	·55	—	1·00	—	73·51	2·16	2·94	·086	4·00
July	1·63	—	·85	—	·46	—	2·15	—	1·63	—	4·12	—	·39	—	1·03	—	80·72	2·37	2·54	·074	3·1
August ...	2·33	—	2·99	—	·59	—	4·89	—	2·62	—	1·90	—	3·89	·04	1·67	—	83·06	2·44	·33	·009	·37
September	2·51	—	3·40	—	2·92	—	·59	—	4·30	—	1·85	—	2·49	—	3·64	—	81·99	2·41	3·75	·110	4·57
October ...	3·68	—	1·87	—	1·12	—	6·57	·60	1·06	—	2·02	—	2·90	—	1·33	—	101·11	2·97	24·26	·71	24·0
November	1·15	—	1·80	—	2·60	—	2·53	2·15	2·03	—	·68	—	1·66	—	2·23	—	86·13	2·53	49·26	1·44	57·2
December	1·62	·88	1·13	·65	·38	—	1·72	·97	2·35	·97	1·61	—	5·67	2·68	3·96	·85	65·01	1·91	40·54	1·19	62·3
	27·44	8·09	22·76	3·33	16·96	2·88	30·25	7·14	30·21	7·75	25·84	3·85	27·33	4·75	27·67	5·83	893·34	26·247	254·69	7·465	28·5

Previously to the observations of Mr. Dickenson, Dr. Dalton himself had conducted experiments for three successive years on the infiltration through the surface soil of the new red sandstone districts around Manchester.* The vessel contained a few inches of sand and gravel, and was then filled up with 'good fresh soil.' Observations were made also for five years on the soil of the magnesian limestone, at Ferrybridge in Yorkshire, by Mr. Charnock.† In this case the vessel was filled with two feet of 'gravel and sand, capped by soil.' Averaging the results of the several gaugings, we have the following:—

Observers	Mean annual fall of rain on the surface during the period the experiments were continued.	Mean annual quantity of rain filtered through 3 feet of ground	Proportion per cent.
	Inches	Inches	
Dr. Dalton	33·5	8·39	25·0
Mr. Dickenson . . .	26·19	10·23	39·0
Mr. Charnock . . .	24·60	4·82	19·6

Commenting upon these results, Mr. Prestwich says:‡ 'It must be observed, in explanation of the apparent discrepancies between these results, that Dr. Dalton used the common surface soil of the district (new red sandstone), which contains a good deal of clay, and would probably be very absorbent and retentive; Mr. Dickenson took the lighter gravelly loam overlying the chalk, and common in the tertiary and secondary districts around London; whilst Mr. Charnock employed the heavier magnesian limestone soil of Yorkshire; and further, his experiments having reference to a special agricultural question, the soil was occasionally stirred. In this latter instance, therefore, the evaporation from the surface would be increased, which, joined with the fact of this soil being much more argillaceous, would account for the infiltration of water being so much less than in the other experiments.'

Mr. Prestwich estimates that the proportion of rainfall infiltrating into the arenaceous beds of the London basin is as follows:—

	Total Mean Annual Rainfall	Amount of Infiltration	
	Inches	Inches	Per cent.
Lower Tertiary Sand	25	12	48
Upper Greensand	28	10	36
Lower Greensand	$26\frac{1}{2}$	16	60

Mr. P. W. Barlow, in his paper 'On the Water-bearing Strata of the London Basin,' read before the Institution of Civil Engineers in 1854, after questioning to a certain extent the accuracy of Mr. Dickenson's experiments, suggested that 'the only really satisfactory manner of arriving at a correct result as to the amount of water which infiltrates the soil would be by sinking cylinders of much larger dimensions, and in several positions, so as to obtain an average result. The ground should be under-pinned, and a bottom added to the cylinder without disturbing the surface soil.'§

The experiments which have been referred to are, unfortunately, all on this most interesting and important subject to which any value can be attached. Indeed, it is remarkable, and much to be regretted, that careful experiments on the amount of infiltration into the soils and surfaces of every water-bearing formation throughout England have not been systematically conducted. But it is to be hoped that this gap in the scientific records of the engineering profession will not long remain unfilled.

'Rocks,' says Professor Anstead,‖ 'vary greatly in the quantity of water they retain, in the way which they retain it, in the relative facility with which they absorb or part with it, and in the degree of accidental interruption that can interfere with the free course of the water beneath the surface. Thus sands, if loose, allow water to percolate freely through them; if hardened, they conduct water very badly, or not at all; if broken, they offer natural channels, permitting a very perfect, but partial, transmission. So limestones, under

* Mem. Lit. & Phil. Soc. of Manchester, vol. v. part ii. p. 346.
† Journ. Agric. Soc. vol. x. p. 516.
‡ Prestwich, On the Water-bearing Strata around London, p. 111.
§ Min. Proceedings Inst. Civil Engineers, vol. xiv. p. 52.
‖ An Elementary Course of Geology. By Prof. T. D. Anstead, M.A.

certain circumstances, are good conductors, and, under other circumstances, very bad conductors of water; and this is governed by the nature of the rock, its condition, its position, and generally by those facts observed and described by the geologist. Even clays, although generally tough and quite impermeable, retaining water to any extent, are sometimes broken by permeable joints, and sometimes are mixed with so much sand and lime as not to be absolutely close.

'Of the different kinds of rocks met with in nature, sand and gravel may be considered the most open, but both require careful examination, if we would discover their true condition. Thus, many sand rocks, although themselves loose and containing much water with which they would readily part, have undergone a partial consolidation, or are traversed by a multitude of crevices, and sometimes by systems of faults parallel to each other, filled up with clay, quartz, or oxide of iron, and crossed by others at right angles to them. The whole mass of rock is thus divided into compartments, or cells, which have little communication with each other, and one such compartment being drained by pumping, others at a distance are not necessarily affected. When part of a rock of this kind is covered with gravel, little difference might be anticipated; but if the surface gravel covers up and conceals boulder clay of a stiff and tenacious character—and this is by no means uncommon in various parts of England—the compartments above alluded to will be very differently filled with water in various parts of the same district.

'Loose sand rock alternating with bands of marl, and not intersected by impermeable bands, such as forms the great mass of the new red sandstone series, in the middle and south of England, usually allows water to percolate freely to its base, the marl beds only forming local interruptions, and retaining the water at the surface only so long as it is running towards some natural vent. Harder sands and sandstones, such as the millstone grit, form an almost impassable barrier for water, and conduct it to some other more permeable rock.'

In the following table will be found the results of a series of experiments conducted by Mr. Prestwich with a view to ascertain the permeability of the tertiary sands, and the upper and lower greensand formations.

TABLE SHOWING THE ABSORBENT POWER AND RELATIVE PERMEABILITY OF SOME OF THE PRINCIPAL WATER-BEARING STRATA.*

Formation	Division	Place of Specimen	Lithological Character	Quantity of Water absorbed by 1 cubic foot		Quantity permeating through equal portions of the sands in 1 hour.
				Cub. Ins.	Gallons	Cubic Inches
Lower Tertiary Strata	Upper	Hertford	Fine sand, light coloured, slightly argillaceous	669	2·41	1·8
	„	„	Fine sand, light coloured, rather more argillaceous	712	2·56	
	„	Croydon	Coarse mixed bright green and yellow sand	626	2·25	5·7
	Middle	Charlton	Fine sand, light ash yellow	723	2·60	5·1
	Lower	Croydon	Very fine light-coloured sand, rather argillaceous	774	2·79	1·5
Upper Greensand	Upper	Devizes	Very fine and argillaceous sands, light green	853	3·07	3·6
	„	„	Very fine and rather less argillaceous, and greener	821	2·96	
	„	Gatton	Very fine and argillaceous light green sand	842	3·03	1·2
	„	Godstone	Very fine and more argillaceous light green sand	883	3·18	
Lower Greensand	Upper	Limpsfield	Very fine, white and pure siliceous sand	518	1·87	9·6
	„	Chilworth	Fine bright ochreous siliceous sand	615	2·21	18·0
	„	Leighton	Bright ferruginous sand, siliceous, rather coarse	712	2·56	14·4
	Lower	Reigate	Fine yellow sand, slightly argillaceous	734	2·64	4·8
	„	Chilworth	Rather coarse light greenish sand	605	2·18	7·5
	„	Betchworth	Very coarse sand, with small pebbles of quartz	605	2·18	8·4

* The experiments on the absorption of water were made with portions of sand measuring 40 cubic inches; the specimens were well dried, and a measured quantity of water then added until they were fully saturated without alteration of bulk. The permeability, which is only shown relatively, was determined by measuring the quantity of water that passed through 15 inches of the different sands in a glass tube 1¼ inches in diameter, and bent at right angles, under a pressure of 6 inches of water in the longer branch of the tube.

It will be seen that a cubic foot of the materials experimented upon will hold from about two gallons to rather more than three gallons of water, or about two-sevenths to one-half of their bulk. Commenting further on the results, Mr. Prestwich says: 'It is also evident that it is not the purest sands which hold the most water. The presence of clay increases the capacity for water, at the same time that it rapidly diminishes the permeability of the strata, a very small quantity appearing to have great influence in this respect. The strata which, in these experiments, unite the greatest absorbent power and permeability are those consisting of clear siliceous sand, with grains about the size of clover seed. When the grains are very fine, they hold less water. The coarsest sands being mixed with a small quantity of clay, their real permeability is not known.'* Common garden mould, overlying ochreous flint gravel at Clapham Common, was found by Mr. Prestwich to absorb about 2·6 gallons of water per cubic foot.

The capacity of chalk for holding water is illustrated in the following table, in which are recorded results of a series of experiments conducted by Dr. John Smith, formerly Assistant in the Chemical Laboratory and Fordyce Lecturer in Marischeal College, Aberdeen.

TABLE SHOWING THE CAPACITY OF DIFFERENT SPECIMENS OF CHALK FOR HOLDING WATER.

Locality and Depth from the Surface of the Ground at which the Specimens of Chalk were obtained	Weight of the Chalk per cubic foot when thoroughly dry		Weight of Water in a cubic foot of Saturated Chalk		Measure of Water in a cubic foot of Saturated Chalk
	lbs.	oz.	lbs.	oz.	Gallons
Boxmoor, Herts, 5 feet deep, from a cutting	88	9	26	4¾	2·63
Boxmoor, Herts, 12 feet deep, from a cutting	85	6	26	8	2·649
Boxmoor, Herts, 30 feet deep, from a cutting	90	5	26	8½	2·655
Abbot's Langley, Herts, 5 feet deep, from a cutting	110	8	19	14	1·988
Abbot's Langley, Herts, 40 feet deep, from a cutting	105	11	21	11	2·169
St. Albans, Herts, 29 feet deep, well that supplies the town	89	7	28	3	2·823
St. Albans, Herts, 146 feet deep, well that supplies the town	94	1¾	26	8	2·649
Bushey, Herts, 4 feet deep, from lime-kilns	106	15	21	3	2·119
Bushey, Herts, 51 feet deep, from lime-kilns	104	6	22	6½	2·244
Bushey, Herts, 35 feet deep, well near lime-kiln	118	13½	16	15¼	1·695
Loudwater Mill, Herts, Chalk Rock, frequently met with in boring . . .	137	5¾	9	10½	0·966
Gravesend, Kent, 3 feet deep, well	88	1	28	0¾	2·804
Gravesend, Kent, 60 feet deep, well	93	10¾	25	7¾	2·542
SPECIMENS OF CHALK PROCURED FROM BELOW LONDON CLAY.					
Hartsbourne, Bushey Heath, Middlesex, well 400 feet deep; clay 230 feet deep above the chalk	142	14½	9	0	0·897
Kentish Town, Middlesex, 500 feet deep; clay, gravel, and sand, 270 feet deep above the chalk.	106	2	19	8½	1·951
Kentish Town, Middlesex, 538 feet deep; clay, gravel, and sand, 270 feet deep above the chalk	111	6	18	4	1·826
Kentish Town, Middlesex, 500 feet deep; clay, gravel, and sand, 270 feet deep above the chalk	111	5	15	15	1·595

Mr. Prestwich found † that the quantity of water percolating through a mass of chalk was only $\frac{1}{6400}$ of the quantity which passed through an equal bulk of sand in the same time.

The following table shows the weight and volume of water contained in several well-known rocks when saturated. The saturation is not under an exhausted receiver. ‡

ABSORBENT POWER OF VARIOUS ROCKS.

Name of Stone	Locality	Quality of Stone	Weight per cubic foot.		Grains of Water absorbed in each cubic inch	Bulk of Water absorbed (2 inches, cubes = 1)
			lbs.	oz.		
Craigleith . .	Edinburgh . .	Sandstone . .	145	14	20·4	0·080
Darley Dale . .	Derbyshire . .	Ditto . . .	148	3	18·5	0·072
Mansfield, red . .	Nottinghamshire .	Ditto . . .	148	10	26·3	0·104
Ditto, white .	Ditto . .	Ditto . . .	149	9	23·5	0·092
Ancaster . . .	Lincolnshire . .	Oolitic Limestone .	139	4	42·0	0·166
Barnack . . .	Northamptonshire .	Ditto . .	136	12	36·0	0·141
Bath (Box) . .	Wiltshire . .	Ditto . .	123	0	42·8	0·169
Ketton . . .	Rutlandshire . .	Ditto . .	128	5	38·2	0·151
Portland . . .	Dorsetshire . .	Ditto . .	135	8	34·4	0·135
Bolsover . . .	Derbyshire . .	Magnesian Limestone	151	11	20·1	0·079
Brodsworth . .	Yorkshire . .	Ditto	133	10	54·6	0·215
Park Nook . .	Ditto . .	Ditto	137	3	56·0	0·221
Chilmark . . .	Wiltshire . . .	Siliceous Limestone .	153	7	7·2	0·068

* Prestwich, On the Water-bearing Strata around London.

† Trans. Inst. Civil Engineers, vol. xiv. p. 77.

‡ Report of Commissioners on Building-stones for the Houses of Parliament.

'With regard to the fact that in limestones and such-like rocks there do exist great natural caverns, and that even in clayey beds there are alternating bands of sand and gravel, capable of receiving a considerable quantity of water, communicating with the surface, and sometimes passing down to immense depths, there can be no doubt whatever; and it is equally certain that in some of them, at any rate, the sheets of water are of very considerable extent. This is known not only by the examination of such rocks of the kind as are exposed at the surface, and by the appearances they there present, but also from the occasional cavities discovered in boring for artesian wells, and also in sinking deep shafts in mining districts.

'As being, perhaps, one of the most interesting of these, and proving that springs obtained from great depths are sometimes dependent on atmospheric supplies, and obtained by means of the peculiar geological structure of the country, we may mention the case of a fountain at Nismes, in the south of France, the supply from which, even in times of great drought, amounts to 145 gallons of water per minute; but it is found that, when it rains heavily at a distance of about six or seven miles from the fountain, in a north-westerly direction, an increase takes place suddenly in the supply, so that it then pours forth as much as 1,000 gallons per miuute, the temperature of the water supplied undergoing no change. It is clear, in this case, that the spring must be fed from a distance, and by means of long channels, which allow the water to flow rapidly through them. The rapidity of communication also is so great that these channels must in all probability be open.' *

'Limestone formations are very apt to be hollowed into caverns by the solvent power of carbonic, and perhaps also of other acids, derived from vegetable decomposition held in solution in the percolating water. Such caverns often run to great distances under ground, and frequently contain running streams, and even considerable rivers, as is the case in the cavern of the Peak and Castleton, in Derbyshire, and in that of the Nicojack Cave, in Georgia, U.S., on the Tennessee River, where a waterfall occurs at a distance of three miles under ground (Edin. Phil. Jour. 1,426). When such streams emerge to daylight, we have the phenomenon in question, as in the cavern of the Gaucheros, in the valley of Caripe, in Cumana, described by Humboldt; in the celebrated fountain of Vaucluse, which issues as a considerable stream from the cave at the foot of a perpendicular limestone cliff; and in a number of caves in Carniola and Illyria, where "almost every lake or river has a subterraneous source, and often a subterraneous exit. The Laibach River rises twice from the limestone rock, and is twice again swallowed up by the earth before it makes its final appearance (Davy). The rivers Sarapa and Blanco, which flow from the lake of Yojoa, in Honduras, both enter subterranean channels, through which, having passed—in the one case a mile, in the other a mile and a half—under ground, they reappear." ' †

When water falls from the clouds in the form of rain and snow, sinks into the ground and percolates until it reaches an impermeable stratum, appearing again at the surface at some lower level, the outgush is called a spring. The general conditions under which springs are met with in nature are necessarily most varied, dependent as they are on the geological structure of the locality, the alternation and inclination of pervious and impervious strata, and their endless contortions, dislocations, and faults. Water-bearing strata are such as are of an open, porous, or absorbent nature, and overlie other strata of an impermeable quality, the latter serving to retain the water in the former. The simplest case in which a spring is developed is where a pervious stratum overlies an inclined impervious one, as in fig. 8, the rain falling upon the surface of the former being delivered at S as a land or shallow-seated spring. If the impervious substratum be depressed into a hollow or basin, the water will necessarily accumulate in the same, and the lower part of the porous stratum will become permanently saturated. Fig. 9 illustrates such a case, A B S being the *line of saturation*; and inasmuch as the water is sustained partly by capillary attraction, it will be seen that this line need not necessarily be horizontal.

Fig. 8.

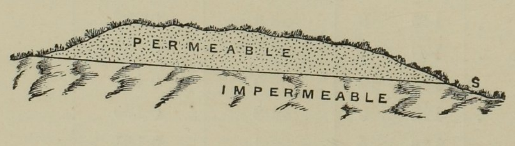
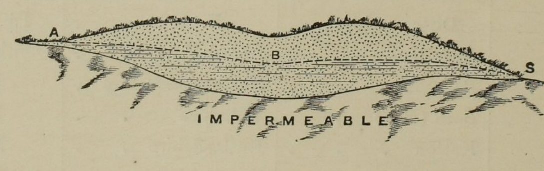


Fig. 9.



Where the overlying pervious stratum is comparatively shallow and of small extent, the springs issuing from it will generally be of an intermittent character, being limited by the variations of the rainfall; but, on the other hand, where it is of considerable extent and depth, it acts as a natural storage reservoir, and the rain falling at intervals on the upper surface is delivered with a uniform flow. Friction and capillary attraction, acting in opposition to gravity, are the chief agents in bringing this about.

* Anstead's Elementary Course of Geology.

† Encyclo. Brit. vol. xvii. p. 601.

It would at first sight appear strange that the water does not rather ooze out as a sandsoak along the junction of the impervious with the pervious bed, than make its appearance at certain places only on this line, and then in the form of continuous gushing streams. This, however, is explained by the fact that on the surface of the impermeable bed numerous irregularities exist similar to those on the exposed surface of the land, and these conduct the water in definite channels and courses. Rents and fissures, acting as subterranean drains, assist in the concentration of the flow of water at certain points. Springs are sometimes found at the lower outcrop, C, fig. 10, of a permeable bed, A, lying between two others, B, B, which are impermeable; the supply, however, is limited to the rainfall on the basset, or exposed surface of the higher outcrop, D, and as much of the drainage from the upper impermeable stratum B as flows down the sides of the hill and is intercepted by the stratum A.

There is a class of intermittent springs the phenomenon of which is attributed to an action similar to that of the syphon. In fig. 11, B is a permeable stratum lying on an impermeable one C, and having a layer of an

Fig. 10.

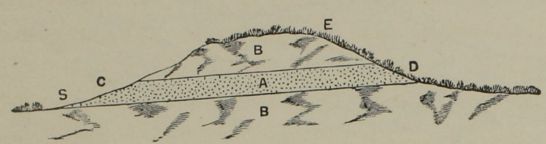
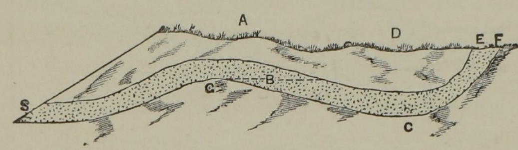


Fig. 11.



impermeable material above it. The layer B may for a moment be conceived as a tube. Rain falling on the basset E F will penetrate and descend into the pervious stratum B, and will accumulate in the subterranean reservoir C until it attains to a level sufficient to overflow at G, appearing in the form of a spring at S. If the part S G C of the impervious stratum be regarded as a syphon tube, it will be understood that the water which has accumulated in the basin will be drawn over the ridge in the impermeable bed until the water level has been lowered to a point at which the syphon will cease to act, and water will not again issue from the spring until the reservoir has received a supply sufficient to bring the syphon again into action. A well-known example of such a case may be seen beside the road leading from Buxton to Castleton.

In the next class of springs are those having their origin in faults or dislocations in the stratified rocks, whereby the disjointed portions are forced to different levels. Fig. 12 is a section* across a valley, B, looking up the same, in the neighbourhood of a fault. The hills A, C, are supposed to be formed of a permeable stratum $a\ a'\ a''$, resting on an impermeable bed of clay $b\ b'\ b''$. Between these two hills is a valley of denudation, B, towards the head of which the junction of the permeable stratum $a\ a'$ with the clay bed $b\ b'$ produces a spring at the point S; here the intersection of these strata by the denudation of the valley affords a perennial issue to the rain water which falls upon the adjacent upland plain, and, percolating downwards to the porous stratum $a\ a'$, accumulates therein until it is discharged by numerous springs in position similar to S, near the head and along the sides of the valley.

Fig. 12.

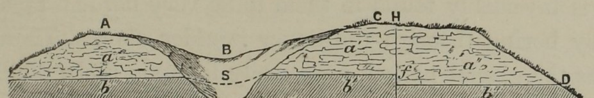
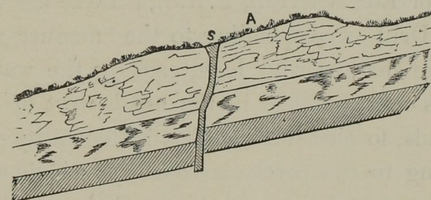


Fig. 13.



'The hill C represents the case of a spring produced by a fault H. The rain that falls upon this hill between H and D descends through the porous stratum a'' to the subjacent beds of clay b''. The inclination of this bed directs its course towards the fault H, where its progress is intercepted by the dislocated edge of the clay bed b', and a spring is formed at the point f. Springs originating in causes of this kind are of very frequent occurrence, and are easily recognised in cliffs upon the seashore.

'Three such cases may be seen on the banks of the Severn, near Bristol, in small faults that traverse the low cliff of red marl and lias on the north-east of the Aust passage. In inland districts, the fractures which cause these springs are usually less apparent, and the issues of water often give to the geologist notice of faults of which the form of the surface affords no visible indication.'

Springs are occasionally thrown out by dykes or thin layers of impermeable material intersecting a water-bearing stratum, as in fig. 13. The water will accumulate between the impermeable substratum and the dyke,

* Taken from Dr. Buckland's Bridgewater Treatise.

until it makes its appearance on the surface at S. In limestone districts, springs are admitted to be amongst the best indications of the existence of faults. These are generally detected by a series of springs issuing at various levels, not confined to valleys, but appearing even on table-lands and elevated plains.

The next condition in which water is found is where it is held down in a porous bed by a superimposed layer of an impervious nature, as shown in fig. 14. A and C are beds of clay, or other impervious material, and B is a water-bearing stratum. Water will accumulate in the hollow of the lower impervious stratum until it is pressed upwards against the under side of the upper one by hydrostatic force. If, therefore, a well be sunk, or a hole bored, say at K, the water will rise to a level determined by this hydrostatic pressure. Such wells are called *artesian*, from the French province of Artois, where they are very common, and were executed with the greatest success as far back as the twelfth century. If the upper surface of the impervious stratum be below the

Fig. 14.

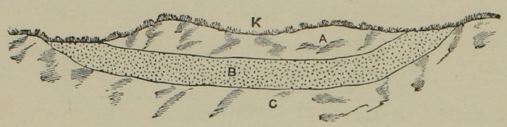
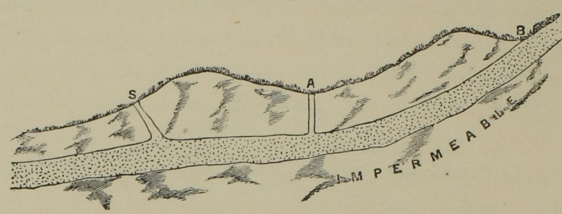


Fig. 15.



level determined by the hydrostatic force just mentioned, a borehole through the impervious stratum at that point will give rise to an overflowing artesian well. A natural fissure in the impermeable stratum will, under similar circumstances, give rise to an artesian spring. In Fig. 15 these conditions are illustrated. The rise of the water from the borehole at A, or the spring at S, will be seen to depend on the elevation of the outcrop of the pervious stratum at B.

Having briefly illustrated some of the various general conditions under which water is to be found in and issuing from the bowels of the earth, we will now proceed to notice, somewhat in detail, the waterbearing strata of particular geological formations, beginning with the later deposits.

Alluvium.—Lying in the bottoms of all the valleys in the south are beds of river gravels, occupying considerable areas, and often of considerable thickness, forming terraces one above the other. Vast sheets of 'post-glacial' gravel occur also in the valley of the Humber, and in the valley of the Mersey at Manchester: the lower part of the latter river, however, in the neighbourhood of Liverpool, is devoid of alluvium. From these deposits, water is very commonly obtained by means of shallow wells.

The *Pleistocene*, or *Newer Pleiocene*, deposits are of post-tertiary age, and consist chiefly of unstratified till, or boulder clay, intermingled with beds of sand and gravel and occasionally stratified clays. They cover the greater part of the centre of Scotland, and the northern, midland, and eastern counties of England, with the exception of the Penine Chain and the Derbyshire Hills, these hills rising like islands from the vast sheets of drift of Yorkshire and Lincolnshire on the one hand, and Lancashire, Cheshire, and Warwickshire on the other. Both in East Anglia, as described by Mr. Searles V. Wood, jun., F.G.S.,* and in Lancashire, as described by Professor Edward Hull, F.R.S.,† there are two boulder clays, divided by a middle sand and gravel, known as Middle Drift, corresponding to the 'manure gravels' of Ireland, and, like them, more or less full of shells, and therefore charged with lime, causing the water which is invariably found in them to be very hard. This sheet water is often reached in the north-west of England by boring through the upper boulder clay. These clays and sands, formed during what is known by geologists as the glacial period, necessarily lie upon rocks of all ages, according to the particular locality, which may be observed on the silurian of Cumberland and Wales, equally with the trias of Warwickshire and the chalk of East Anglia. The 'blow wells' of Lincolnshire are borings through the impervious beds down to the chalk, from which the water rises above the surface of the ground.

The uppermost or newest of the three great divisions into which geologists divide the stratified rocks of the world is known as the *Tertiary*; this is again subdivided into three divisions known as the Pliocene, Miocene, and Eocene. The pliocene consists principally of certain beds developed chiefly in Norfolk and Suffolk, locally known as 'crags,' and divided by the geologist into the 'Norwich,' or 'Mammaliferous Crag,' the 'Red Crag,' and the 'Coralline Crag'—the oldest of the three.

The *Norwich Crag* consists of beds of gravel, sand, and loam, containing the bones of various mammals, the ear-bones of whales, and numerous freshwater and land shells. From the immense quantities of bones containing phosphates of lime, the deposit is largely used for the manufacture of artificial manure. In Suffolk it is well seen at Southwold, and in Norfolk on the banks of the Yare, where it is covered with stratified flint gravel.

* Various Papers in Quarterly Journal of Geological Society and in the Geological Magazine.

† Trans. Man. Lit. Phil. Soc. vol. ii. series iii. Memoirs of Geological Survey, Country around Oldham.

The *Red Crag* is generally about 40 feet thick, consisting of quartzose, sand, and gravel, stained a very deep ferruginous red, much current-bedded, and containing many fragments of shells. It generally rests upon the London clay, but is occasionally found on the coralline crag, in which case the latter has always experienced denudation and erosion before the deposition of the former.

The *Coralline Crag* is never more than 20 feet thick, occupying an area of only 65 or 70 square miles, between the rivers Alder and Stour, in Suffolk. It consists of soft building-stones, and marly and calcareous sands, full of polyzoa, formerly considered to be corals, giving the name 'Coralline.'

Miocene.—This division of the tertiary only occurs in Britain in the Isle of Mull, in Scotland, where certain shales, with basalt and volcanic ash, contain miocene plants, and at Bovey Tracey, in Devonshire, where miocene clays, more than 200 feet thick, occur associated with lignite—known as 'Bovey coal,'—and miocene plants.

The *Eocene* strata are divided into three divisions, known as Upper, Middle, and Lower Eocene. The first of these comprises the Bunbridge and Hempstead beds; the latter are the highest eocene beds in England, and consist chiefly of freshwater marls, reaching a thickness of 170 feet at Hempstead and Parkhurst Forest, in the Isle of Wight. The former beds consist of tufaceous freshwater limestone below, and marls above; the limestone is well seen at Scorrell, Headon Hill, and Binstead; it is quarried in several places, furnishing the best building-stone of the Isle of Wight.

The middle eocene consists of two series, the Fluvis Marine and the Bagshot. The former is again subdivided into the Osborne and Hendon beds. The Osborne beds were so named by the late Professor Edward Forbes, from the fact of their being well seen near the royal demesne. They are composed of the St. Helen's sands above and the Nettlestone grits below. These sands are more or less charged with water, but it is of hard quality, from the vast number of fossil shells occurring in them, composed of carbonate of lime. The Hendon series are also found in the Isle of Wight. They consist of shelly sands, with earthy limestones, one bed of which attains a great thickness at Hendon Hill, where it is known as the Hendon Hill limestone.* The base of the Hendon series rests, in the Isle of Wight, on an unbroken succession of upper Bagshot sands, which are worked at Alum Bay for 'Glass House sand.' These, again, rest upon the Barton clay, the uppermost division of the middle Bagshot of the Isle of Wight, which is a dark tough clay, resting on sands known in the Hampshire basin as the Bracklesham beds; in the London basin, however, this clay is absent, and the upper Bagshot sands rest directly on the Bracklesham beds. Water is invariably found on the surface of the Barton clay.

The *Bagshot Sands*, as a continuous series of beds, extend from Esher, on the east, to near Strathfieldsaye, on the west, a distance of about 30 miles. They vary in width, reaching as far north as Virginia Water, and extend southward to the summit of the high ground north of Farnham. Their area has been estimated at 300 square miles,† but in a recent official document‡ they have been referred to as covering only 211 square miles. Their total thickness varies from 100 to 300 feet. They may be subdivided into: First, the Upper Bagshot Sands, a pure siliceous mass, slightly coloured by an oxide of iron. Second, the Middle Bagshot Sands, or Bracklesham beds, consisting partly of a green sandy bed, but principally of a stratum of a white and pale-yellow foliated marl. This division varies in thickness from 20 to 30 feet. Third, the Lower Bagshot Sands, which are similar in texture to the first or upper division, but darker in colour. The whole series is often obscured by a superficial covering of loose sand and gravel, varying in thickness from a few inches to 20 or 30 feet. These sands are, however, percolated by water, which descends until checked by the second division, known as the Bagshot marls; 'and when the disposition of the strata is favourable, it is thrown out to the surface at the junction of these marls with the upper sands, forming a series of springs round the retentive marly outcrop, and frequently collecting in pools of considerable area when partially intermingled with the surface drainage.' A few springs are thrown out from the lower Bagshot sands at their junction with the underlying London clay; it is but rarely, however, that the water is concentrated in any large quantity to a particular channel of escape.

The Bagshot sands were at one time the object of considerable attention, having been proposed by the General Board of Health as a gathering ground far the water-supply of the metropolis; but the idea has of late been abandoned, and apparently with good reason.

The *London Clay* is an extensive impermeable stratum, constituting a large part of Suffolk, nearly the whole of Essex, the whole of Middlesex, and portions of Berkshire and Surrey. It is found also in the north of Kent, bounding part of the estuary of the Thames; here it includes the Isle of Sheppey, and extends from Herne Bay southward nearly to Canterbury. It is bordered almost entirely by the tertiary sands, which it overlies (and which will be hereafter described), and the sea. It also occupies a large area in the Hampshire

* For further particulars of these and other beds in the Isle of Wight, see Min. Geolo. Soc. 'Geology of the Isle of Wight.' By H. W. Bristow, F.R.S.

† Report by Mr. Robert Godwin Austen, F.R.S., to the Commissioners of the General Board of Health, 1850.

‡ Report of Royal Commission on Water-Supply, 1869.

basin, and forms the coast from Christchurch to Worthing, whence it extends inland south of Chichester, and by Fareham, Southampton, and Ringwood. The depth of this formation is from 400 to 700 feet.

The London clay, which consists of a stiff clay, of a bluish or blackish colour, is interesting to us here principally from its being an impenetrable barrier against the influx of the drainage of the great metropolis into the subterranean reservoirs beneath. In both the London and the Hampshire basins it is covered by beds of drift gravel, through which water freely percolates. The numerous shallow wells, which as a rule are so largely contaminated with impure matter from surface drainage, receive their supply from this source.

The lower London tertiaries, consisting of the Reading and Woolwich beds, or plastic clay, and Thanet sands, are intermediate between the chalk and London clay, and are composed of an indefinite number of sand, clay, and pebble beds, irregularly alternating. The outcrop of the plastic-clay series extends in a narrow strip, of an average width of less than a mile, from Woodbridge, in Suffolk, in a south-westerly direction, through Sudbury, Bishop Stortford, Uxbridge, Windsor, and Reading, to about ten miles west of Newbury, in Berkshire; it then passes, generally in an easterly direction, by Guildford, Epsom, and Croydon, extending on both sides of the Thames beyond Stratford on the north, and appearing on the south side in detached portions as outliers on the chalk. It then continues eastward by Rochester, Faversham, and Canterbury, to the coast between Ramsgate and Deal, in which latter district the Thanet sands are so well developed. Eastward of London this formation is of considerable extent, having been brought to the surface by faults, but more especially by extensive denudation.

In viewing the lower tertiary strata as a great water-bearing formation, it is necessary to enquire into the disturbances which may have affected it, for the yield will be more or less diminished where the channels of communication have suffered break or fracture.

'Although the tertiary formations around London have probably suffered less from the action of disturbing forces than the strata of any other district of the same extent in England, yet they nevertheless now exhibit considerable alterations from their original position.' * It might have been expected that the trough-shaped form would have been so regular as to afford an uninterrupted communication throughout their whole extent, the entire length of outcrop contributing to the general supply of water at the centre; this is, however, far from being the case, and to follow the disturbances as they are found to occur, Mr. Prestwich proposes to divide this strata into four separate divisions by two lines, one running north and south through the valley of the Ravensbourne, another east and west through New Cross, extending in the direction of Windsor. The areas &c. of these divisions are as follows:—

Divisions	Total extent of Tertiary Area	Lower Tertiary Strata		
		Extent of Area	Length of Outcrop	Thickness of permeable portions
	Square miles	Square miles	Miles	Feet
North-Eastern	1524	64	95	36
South-Eastern	325	195	65	72
South-Western	741	45	130	22
North-Western	345	50	60	15
	2935	354	350	—

In the north-eastern division the 'northern outcrop of the lower tertiary strata is most unfavourable for a water-gathering surface, being placed along nearly its whole length on the sides and slopes of hills, and covered, to a very great extent, by beds of impervious drift. There is, however, another outcrop on the south of this division, ranging along the Thames from Stratford to East Tilbury,' and which is more favourably situated than the part just referred to. The supply of this division, which is by means of artesian wells, is on the whole small, although tolerably regular.

'In the south-eastern division the extent of exposed surface occupied by the lower tertiary strata forms a very large proportion of the whole,' and 'the water-bearing strata are of greater thickness than in any of the other divisions; but all these favourable conditions are rendered nugatory by its peculiar geological structure.' Referring to the western part of this division, Mr. Prestwich says that, 'as its sand and pebble beds are superimposed upon a base of chalk, and intersected by numerous valleys, the water absorbed on the surface of

* Prestwich.

the hills finds an outlet on the sides of these intersecting valleys, and is thence carried off in streams, which flow to the Thames.'

In the south-western division there are numerous artesian wells, from which in many cases the water rises above the surface of the ground.

In the north-western division the sands are 'covered generally, both on the hills and in the valleys, by thick beds of gravel and brick-earth ; and although these are to a certain extent permeable, yet, by retarding the passage of water from the surface, they must lessen the quantity which would otherwise be absorbed by the lower tertiary strata. The main sources, therefore, from which the supplies in this division are derived are the small transverse valleys and openings, which, running from the chalk district southward into the tertiary series, expose at their base and on lower levels a greater extent of the water-bearing strata.'*

Taking into consideration all the modifying conditions which affect the lower tertiary strata as a source of supply for the metropolis, Mr. Prestwich estimates that, of the total area of 354 square miles, only 24 are really available. But on this surface about 12 inches per annum, or 48 per cent. of the rainfall, may be relied on.

In England, the principal towns on the tertiary deposits are Hull, Grimsby, Boston, Spalding, Wisbeach, Norwich, Lowestoft, Ipswich, Harwich, Colchester, Chelmsford, London, Brentford, Uxbridge, Southampton, Christchurch, Portsmouth, and Chichester.

The tertiary beds occupy large areas in the Paris basin and the south-west of France. They are found also with post-tertiary beds, in extensive tracts in nearly every country in Europe. The great expanse of the Sahara is of the post-tertiary age, and, indeed, these deposits may be said to extend in the Old World from the Baltic to the south of the great African desert, and almost from the Atlantic to Central Asia. In the valleys of the Indus and the Ganges they predominate; and the whole of the central portion of Australia is supposed to be covered by them. In North America, they range from the Arctic Ocean to California parallel with the Rocky Mountains, skirt the Gulf of Mexico, and occupy the Atlantic coast of the United States. Right across South America, east and west in its widest part, this formation lies in the valley of the Amazon, and, turning south, ranges throughout the continent from Granada to Patagonia, inclusive. And through the recent researches of Professor Heer, it is evident that beds of miocene, tertiary age, occur within the Arctic circle, in the ice-bound coasts of Greenland and Spitzbergen, teeming with fossil plants, denoting a sub-tropical climate, like those found at Bovey Tracey, mentioned above.

Next in descending order to the plastic clay, and forming the highest and most recent deposit of the *secondary* series is the *Chalk*, one of the most important of the water-bearing strata with which the engineer will have to deal. In England, the chalk stretches in a north-easterly direction from Dorset to the coast of Norfolk, a length of over 200 miles ; it also extends into two ranges of hills running nearly east and west, the one, through Surrey and the north of Kent, to the sea at Dover, and the other, through Sussex, along the south coast to Beachy Head, forming respectively the North and South Downs.

A considerable portion of the chalk formation is laid bare in Lincolnshire, forming the Lincolnshire Wolds, and in Yorkshire it crops out again in a large strip, extending from the Humber as far north as Flamborough Head.

'In general,' says the Rev. W. D. Conybeare, 'an interval seems to have taken place between the completion of this formation and the deposition of those which rest upon it ; and the surface of the chalk at the line of junction usually bears marks of having undergone during that period a partial destruction subsequently to its consolidation, a bed of débris being spread over it, consisting chiefly of flints washed out of its mass, and the surface being irregularly worn into frequent cavities, many of them of considerable depth, filled with similar débris. On this débris rests the plastic clay, or the ash-coloured sand formerly described. Here, therefore, the transition from the chalk to the more recent formation appears to be abrupt, not gradual ; in a few instances, however, a bed of intermediate character, of cretaceous marl, is interposed at the junction, which may seem to countenance this idea—that where the series of deposits was permitted, from the circumstances under which they were formed, to proceed quietly, such a gradation may have taken place.'† In the upper chalk are layers of flint, of from four to seven or eight inches in thickness, and from two to many feet apart. Where these layers are absent, the stratification is often obscure. In the lower chalk, the flints are most usually wanting (which distinguishes it from the upper division), and the chalk itself is harder and not so white as in the upper.

The great chalk basin of London, as it is called, extends from the line of its junction with the greensand in Hertfordshire, Buckinghamshire, and Berkshire, on the north, to the escarpment or southern slope of the North Downs, on the south; while the Hampshire anticlinal axis is its south-west boundary. From the limits thus marked out, the chalk dips gently, south-east on the one side and north on the other, under the great bed of London clay already described, forming a vast receptacle for the water received on an area which Mr. Prestwich

* Prestwich, On the Water-bearing Strata around London.

† Conybeare's Geology of England and Wales.

has estimated at 3,794 square miles. The mean rainfall on this area is equal to nearly four thousand million gallons daily, or five times the summer stream at Teddington.* It has been assumed that one-half of this may be relied on as penetrating into the deep fissures of the chalk, there to be available for consumption. But that this is too high an estimate there is much reason for supposing, when we consider the large proportionate loss that must take place by evaporation, especially when the rain comes, as it does in our climate, in intermittent showers, frequently light and of comparatively short duration. It must be remembered, too, that it is not a perfectly smooth surface of bare absorbent chalk which is to receive the rainfall and conduct it downwards, but a rough and rugged surface of vegetation and vegetable soil, which, while it does not increase the quantity of the rain that falls, presents a vastly increased evaporative area upon which the sun and wind may act. On this very important and interesting point a large amount of conflicting evidence was adduced at a discussion at the Institute of Civil Engineers in 1854,† and even now the different views are entertained and advocated as strongly as ever. It will be sufficient for our present purpose, however, to assume that one-quarter of the mean annual fall will find its way to a depth beyond the reach of evaporating influences, and we shall have a supply equal to one thousand million gallons daily, or a quantity five times larger than that set down by the Royal Commission on Water-Supply as the reasonable future limit for the supply for the metropolis.‡

It now remains to be seen how much of this is practicably available for the wants of the community, and in considering this point we must refer for a moment to the two great lines of disturbance which traverse the London basin, and which have already been pointed out in connection with the lower tertiary sands. Here it will be found, however, that, from the great depth of the chalk formation in the London basin (500 to 1,000 feet), these faults do not succeed, as they would with a more shallow stratum, in interrupting the communication of the disjointed sections, unless some as yet undiscovered dykes of clay or other impermeable material are interposed, and act as impassable barriers. In such a case the water would to a certain extent be retained in the western division of the London basin, and this would, in one sense, make it the more favourable for the supply of London itself, the greater portion of which lies in the south-eastern corner of the north-western division. In connection with this subject, it is advisable to remark that the upper greensand, which immediately underlies the chalk,§ is regarded by some as a vast subterranean drain for the chalk waters of the London basin. As this arenaceous formation affords far greater facilities for the passage of water than does the chalk, and if, moreover, it be not dissevered into independent portions by the faults already referred to, it may play an important part in carrying off the water from the chalk into the sea, at its outcrop under the German Ocean.

The line of saturation in the chalk has in most parts an inclination corresponding roughly with the dip of the strata; thus, starting about mean tide level of the Thames, it has been shown by the Rev. J. C. Clutterbuck to have an inclination to the northward of about ten feet per mile, while to the west and north-west it stands at about thirteen or fourteen feet per mile.

Much has been said and written concerning the depression of the water-line in the chalk under London by pumping from the numerous wells sunk through the clay. It has been stated that the depression is progressive, amounting to as much as two feet per annum. But it should be remembered that at the time the earlier observations were made the water pumped from the chalk was a comparatively insignificant quantity, while now it cannot be far short of twenty million gallons daily; and almost continually new wells are being sunk and fresh supplies obtained. For the water-level not to be affected by all this would be most unnatural; but it must not be inferred that the exhaustion of the reservoir is thereby threatened; or, to put it more properly, that of the thousand million gallons which we have seen to flow into this reservoir, not one tithe is available. It is the rule in all wells for the water-level to be lowered by an amount proportionate to the rate of pumping; but once that level is attained, the depression ceases, an equilibrium having been effected between the hydrostatic pressure of the infiltering water and the friction it has to overcome.

An important element in the consideration of the probable supply to be derived from the chalk of the London basin is suggested by the difference shown prominently in the table, p. 47, between the specific gravities and absorptive powers of the specimens of chalk from under the London clay and those from the outcrop of the chalk. Mr. Homersham, in his paper from which this table is extracted,|| says: 'The great weight of the London clay overlying the chalk situated below the metropolis appears to have condensed the chalk; at least, it is very much less permeable to water than where the chalk is not so thickly covered with clay; this explains the notorious difficulty of procuring large volumes of water from the chalk under London after sinking through the London clay.' The argument, indeed, seems to be borne out by the fact of the yield from the wells sunk on the

* P. W. Barlow, Min. Proceed. Inst. C.E. vol. xiv. p. 47.

† Min. Proceedings Inst. C.E. vol. xiv. p. 42.

‡ Report of Royal Commission on Water-Supply, 1869, p. cvii.

§ There is in many parts a stratum of chalk marl, between the chalk proper and the greensand, but it is considered probable by some that in a large portion of the London basin it does not offer much resistance to the passage of water from the one stratum to the other.

|| Journ. Soc. Arts, vol. iii. p. 175.

exposed surface of the chalk being so largely in excess of the yield from those sunk into the chalk under the London clay.

The chalk basin of Hampshire is bounded on the west by the outcrop in Dorset already referred to; on the north by a line drawn from Devizes to Alton (dividing the Hampshire basin from that of London); it is then limited on the east by the escarpment forming the northern slope of the South Downs. The chalk of this basin dips generally southward from five to fifteen degrees under the tertiary beds.

The chalk beds in Yorkshire and Lincolnshire have a dip of five yards in the mile towards the east. It is most probable that both here and in the Hampshire basin the great bulk of the water finds its way into the ocean, to regain its 'native home' unseen.

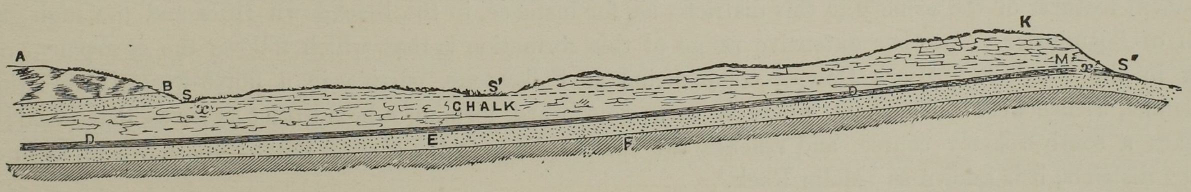
The manner in which the rainfall makes its way through the chalk has been the subject of much discussion, it being supposed, on the one hand, that it is mainly by a slow process of filtering through the pores of the chalk, weeks and months being occupied in descending to the lower levels; and on the other hand, that the amount of water passing in this manner is comparatively small, the great bulk being conveyed by fissures and crevices, and then stored in cavernous recesses. From the closeness of the texture of the chalk, and the powerful influence of capillary attraction, it is but right to suppose that an actual filtering through its mass would be a very tedious process indeed, and at the same time there is the fact that most chalk wells have the water in them at the highest level during the early part of the summer months, that is, some considerable time after the season of greatest rain. In support of the second theory, several curious facts may be adduced.

'At Tours, in 1830, a well was perforated quite through the chalk, when the water suddenly brought up from a depth of 364 feet a great quantity of fine sand, with much vegetable matter and shells. Branches of a thorn several inches long, much blackened by their stay in the water, were recognised, as also the stems of marsh plants and some of their roots, which were still white, together with the seeds of the same in a state of preservation, which showed that they had not remained more than three or four months in the water.' * It is recorded † that at Reimke, near Bochunn, in Westphalia, several small fish, three or four inches in length, were brought up by the water of an artesian well from a depth of 156 feet, there being no rivers or streams within several miles of the spot! 'In boring through the chalk in the valley of the Colne, various beds of hard chalk-like rock are encountered; these vary in thickness from 12 inches to 8 feet, and below them are found large fissures or cavities, from 12 inches to 12 feet in depth, strongly charged with water.' ‡

If these accounts are reliable, they show that the fissures in the chalk may be continuous from the surface to considerable depths; but on the other hand, if the passage of water through this formation were solely, or even chiefly, through these fissures, chalk well water would not have its uniform quality, and the character, exceptioned only in the above and similar rare cases, of being perfectly filtered. It is, perhaps, most correct to regard the chalk as a very fine close-textured filter, in which there are numerous and extensive, though in most cases discontinuous, under-drains; and that chiefly from these is water from chalk wells obtained.

From the absorbent nature of the chalk hills, they are characteristically dry, and there is no surface drainage to assist in the formation of streams in the higher valleys. Where, however, the valley-line intersects the line of saturation, small rivers are found to take their rise, the upper part of the valley frequently being dry. In such cases, as the rainfall influences the line of saturation, so will the head of the stream be found to vary in its position, higher up or lower down in the valley. Numerous springs are thrown out from the chalk along the line where it dips below

Fig. 16.



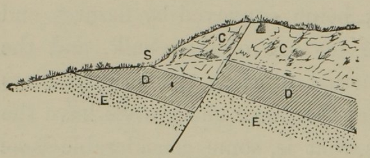
the tertiary formation; the chalk is here mostly saturated, and any addition to the supply of water to the highe levels will cause an overflow at these points, of which there are well-known instances at Watford and Amwell. Fig. 16 is a section from the border of the London clay (A) to the escarpment of the chalk (K), showing the tertiary sands (B), the chalk, the chalk marl (D), the upper greensand (E), and the gault (F); $x\,x'$ is the line of saturation. It will be seen that at S and S', where the line of saturation is intersected by the valleys, the water will overflow the surface, and from openings. In many places are springs developed under circumstances similar to these—as, for instance,

* Lyell's Geology, vol. i. p. 393.
† Bulletin de la Société Géo. de France.
‡ Report by Mr. Homersham to the Directors of the London (Watford) Spring Water Company, 1850.

at Chadwell, near Ware; Otter's Pool, near Watford; Frocksfield, near Hungerford; Beddington; Carshalton; Orpington; Gray's Thurrock; Springhead, near Gravesend; Ospringe, near Faversham; besides a number of smaller ones. Where the deeper and larger river valleys traverse the chalk area and intersect the line of water level, these valleys expose a series of springs, as does, for instance, the Thames in its course from Wallingford to Taplow, the Lea above Brocksbourne, the Ravensbourne, the Cray, and the Darenth, and, again, the Thames from Woolwich to Gravesend.

Along the escarpment or short slope of the chalk, numerous springs are thrown out by the chalk marl, occasioned probably by a peculiarity in the contour of the latter. If we suppose the stratum of chalk marl to be bent downwards, as at M, fig. 16, it will be seen that the rainfall on the escarpment of the chalk would appear as a spring at s″. A similar effect would be produced by a fault in the strata, as shown in fig. 17. Numerous towns and villages under the range of the chalk downs in Wiltshire and Oxfordshire, and further eastward, are supplied by springs from the foot of chalk hills, while many of them are thrown out under the escarpment of the North and South Downs. In regard to these latter, Mr. C. E. De Rance, F.G.S., has endeavoured to show* that they are due (in the Folkestone district) to the overflow of that portion of the sheet of water resting on the chloritic marl, at the base of the chalk, which, after flowing down the *dip* slope, away from the escarpment, is prevented from escaping into the sea by the hydrostatic pressure of the sea endeavouring to force its way inland through the porous chalk, the remainder only escaping during low tides, at which times such springs, in the neighbourhood of the sea, sensibly diminish. And he considers that the same action is exerted, although to a rather less extent, on most inland springs issuing from strata dipping inwards along lines of escarpment running with the *strike*.

FIG. 17.



Immediately below the chalk is the *Chalk Marl*, the latter graduating into the lower strata of the former in such a manner that it is difficult to trace the line of separation. It is mostly of an impermeable character, being more cretaceous or more siliceous as it merges into the chalk of the upper or greensand of the lower formation. The chalk marl occupies a band extending along the foot of the chalk escarpment, and varies in thickness from 300 to 400 feet. These beds are interesting as serving to retain the water in the chalk, and as being the means of throwing out numerous and frequently powerful springs, of which that at Lyddon Spout, between Folkestone and Dover, is a remarkable instance.

The principal towns on the chalk in England are Bridlington and Beverley, in Yorkshire; Louth, in Lincolnshire; Bury St. Edmund's, Saffron Waldon, Hertford, St. Albans, Windsor, Reading, Salisbury, Winchester, Dorchester, Lewes, Brighton, Guildford, Gravesend, Rochester, Canterbury, and Dover.

The *Upper Greensand*, or *Firestone*, is a formation of sand, sandstone, and loam, immediately underlying the chalk marl, and so closely resembling its lower beds as to render it difficult to ascertain with precision where it commences. Its dip is nearly everywhere conformable to the chalk.

This formation underlies the escarpment of the chalk in Yorkshire and Lincolnshire, extending from Filey, on the coast of the former, to near Wainfleet, in the latter county, where it is cut off by the Wash. It reappears on the north-west coast of Norfolk, near Burnham, and continues south in an almost unbroken tract as far as Cambridge, whence it ranges in a south-westerly direction through the counties of Cambridge, Bedford, Buckingham, Oxford, and Berks. It then extends in an irregular though continuous course through Wiltshire and Dorsetshire to the coast. In Somerset and Devonshire it is found in massive outliers, forming the most prominent features of the scenery in this district—as, for instance, in the Blackdown Hills and the high ground north of Beaminster. Another extensive range of this formation is that which follows the escarpment of the chalk in the North and South Downs, commencing at Folkestone, passing in a north-westerly direction to Maidstone, thence west to Farnham, where it turns southward, forming a broad tract as far as Petersfield; here it takes a south-easterly course, and reaches the coast a little to the east of Beachy Head, where, as in other Sussex districts, it is known as 'Malm Rock.'

The upper greensand is represented on the Continent by several deposits in France, by parts of the Quadersandstein of German geologists, the Upper Carpathian sandstone, and by several not unimportant deposits in Portugal, near Lisbon, and in Spain, at Ovedo. The rest of the upper greensand of England (the firestone of Mantel) is of the same date. In Spain the thickness of beds of this period is as much as fifteen hundred feet, according to the estimate of M. de Fernueuil.

Extensive beds of lignite have been found in some of the deposits of this period; there has evidently been a considerable quantity of wood and other vegetable matter floated down with mud, and more or less injured by exposure.

* Mackintosh's Scenery of England and Wales. (Longmans & Co.: London, 1869.)

The belt of greensand underlying the north-western escarpment of the chalk, and that bordering the south-eastern escarpment on the North Downs, belong to the London basin.

The faults which we have seen to pervade the London basin in connection with the lower tertiary sands are considered to extend to the upper greensand, and Mr. Prestwich estimates the area of the outcrop of this formation in the several divisions as follows:—

Divisions	Length of Outcrop	Area	Average thickness
	Miles	Square Miles	Feet
South-Eastern	67	7	25
South-Western	86	80	76
North-Western	102	82	75

In the north-eastern division, the greensand is so obscured by beds of drift, that 'it would be extremely difficult to ascertain correctly its area; and from its confusion with the chalk marl above, it is also difficult to estimate its thickness.' Referring to the south-eastern division, Mr. Prestwich says: 'The absence of drift on almost all this line of outcrop would favour the absorption of water on the surface; but, from the small development of the upper greensand and its argillaceous character throughout this district, and the existence of several transverse lines of faults, breaking the continuity of the strata, the difficulties presented to the subterranean flow and accumulation of water in this division of the upper greensand must be considerable. As this formation ranges into Surrey, however, its conditions of structure become more favourable.' In the south-western division, this formation 'is completely denuded, except where intersected by the transverse valleys of the Mole and the Wey, where it is covered by a drift of gravel.' The altitude of its outcrop, and its 'increased thickness, greater permeability, and clean denudation, render it probable that a very considerable quantity of water passes into the upper greensand in this division, which may, if no important faults intervene, be transmitted from these gathering surfaces to the portion of this deposit which lies beneath London.' Referring to the north-western division, Mr. Prestwich says: 'I am not aware of any disturbance that would interfere materially with a subterranean flow of water from the surface of the upper greensand in Berkshire, Oxfordshire, Buckinghamshire, and Bedfordshire to London.' Mr. Prestwich estimates that only 70 square miles of area, with an infiltration of 10 inches per annum, or 36 per cent. of the rainfall, are available for the supply of the metropolis from this source, after all necessary allowances are made.

The upper greensand of the Hampshire basin borders and dips under the chalk, as in the London basin.

On the whole, it can hardly be expected that large supplies can be obtained from this source, taking into consideration its limited available area and comparative shallowness, the latter rendering the passage of water in it liable to be interrupted by faults.

The *Gault* is a bed of tenacious clay, lying between the upper and lower greensands. It is of a dark bluish or greenish-grey colour throughout its entire range, and preserves a singularly uniform texture. It varies in thickness from 100 to 200 feet, and forms an impenetrable barrier between the water-bearing strata above and below it.

Numerous small springs are thrown out by the gault from the superjacent strata, and in Kent,* a sheet of water, of small extent, occurs at its base, supported by a phosphatic seam, cemented together by iron. The following towns in England are situated on the upper greensand and gault :—Ely, Cambridge, Devizes, Westbury, and Warminster; with the exception of these, there are but few towns or even large villages on these formations.

The senonian, turonian, and albian stages of D'Orbigny are equivalent to the chalk, upper greensand, and gault of English geologists ; while the greensand and gault are the *quader* and *planer* of the Germans.

The *Lower Greensand*, or Neocomian, is an important siliceous formation, having an available area of about 500 square miles. It immediately underlies the gault, which its outcrop skirts, following the tracts of country (in Yorkshire and Lincolnshire, and generally in the centre, south-east, and south of England) previously described as being occupied by the upper greensand.

The thickness of this formation varies from about 20 feet, in Wiltshire, to above 600 feet, in Surrey. At

* 'On the Albian, or Gault, of Folkestone.' By C. E. de Rance, F.G.S. Geological Magazine, 1868.

Folkestone, it has been found by actual measurement to be 406 feet. The average thickness is estimated at 380 feet.

The term 'greensand,' as applied to the lower beds of that name, is a misnomer, the prevailing and almost universal colours of the sands and clays of this formation being 'yellow and ochreous, from the lightest tints to the darkest ferruginous shades.'* In Kent, the lower greensand has been divided by the Geological Survey into four groups or divisions:—1st, Folkestone beds ; 2nd, Sandgate beds ; 3rd, Hythe beds ; and 4th, Atherfield clay; named after towns or localities where they are well seen, the first three in Kent, the last in the Isle of Wight. The Folkestone beds are composed of soft yellowish sands, with ferruginous seams of siliceous ironstone, reaching a thickness at Folkestone of 150 feet. The Sandgate beds are much thinner, more clayey, and in Kent contain much water ; at Reigate they are worked for fullers' earth, of which they contain valuable beds. The Hythe beds are 200 feet thick, composed of soft sandstone, with occasional beds of great hardness, known as 'Kentish Rag.' The Atherfield clay is only seen at Hythe at extremely low tides, but at Atherfield Point, in the Isle of Wight, it reaches a thickness of 60 feet. In this island the lower greensand obtains an aggregate thickness of 950 feet, the Folkestone beds being locally known as 'Shanklin Sands.' The Atherfield clay belongs to that series of clays, occurring in Yorkshire, known as Speeton clay, proved by Mr. Judd to belong to the neocomian. In other parts many clay beds, as well as the coarse limestones, are replaced by sands, and occasionally, as in Wiltshire and Oxford and Bedfordshire, these divisions are not apparent. There is a considerable thickness of fullers' earth in the sands of Woburn.†

Regarding again the division of the London basins (already noticed), Mr. Prestwich estimates the area of the greensand as follows:—

		Square Miles.
South-Eastern Division		215
South-Western do.		135
North-Western do.		260
North-Eastern do. (uncertain)	(about)	40
		650

The outcrop of this formation is, like the upper greensand, bare and denuded; but in some parts of Bedfordshire (where the sand rests upon the impermeable Kimmeridge clay), Cambridgeshire, and Norfolk, there is a covering of impermeable drift. The whole range of outcrop is at a very considerable elevation above the level of London, rising sometimes in Kent and Surrey to as much as 600 feet above the level of the Thames in London. After allowing for the loss by disturbances, and the partial impermeable covering, Mr. Prestwich considers that only 230 out of the total area of 650 square miles are available for the supply of the metropolis. Assuming the mean annual rainfall to be 26·5, of which 60 per cent., or 16 inches per annum, may be supposed to infiltrate, a daily supply of 30 or 40 million gallons of water may be yielded; this, with 10 million gallons, the probable quantity to be derived from the upper greensand, will make a total of, say, 50 million gallons daily from these sources alone.

From the regularity with which the lower greensand crops out both to the north and south of London, and so continuously hugs the gault, it was long supposed that this water-bearing stratum continued, and might be met with under London in the same way as the lower greensands of the plains of Champagne are found under Paris at a depth of 1,800 feet. It has been ascertained, however, by boring at Kentish Town and Harwich, that although the tertiary and upper cretaceous formations occur in regular stratigraphical order as far down as the gault, there is beneath that argillaceous formation, in the case of Harwich, a black slaty rock, most likely of palæozoic age,‡ and in the case of the boring in London, a series of red and grey sandstone, which may have belonged to some member of the new, or possibly to the old, red sandstone. Similar evidence was obtained from a boring at Calais; and the only reasonable inference is, that a ridge of old secondary or palæozoic rocks, ranging from Belgium, passes under the chalk at Calais and Harwich, and extends under London, probably in the direction of Somersetshire. (*See* Chap. VII.)

'It is known that the lower greensands exist at Reigate, and are about 450 feet thick, and that they occur again in Bedfordshire with a thickness of about 200 feet. In both cases they dip towards London, disappearing beneath the gault. We know that they do not exist under London (Kentish Town). It follows, therefore, that in the one case they cease at some point between Reigate or Merstham and London, and in the other between Baldock and London. As at both ends they are of considerable thickness, and the gault is continuous, it is certain that the greensands must range from these outcrops some way towards London, probably thinning off gradually

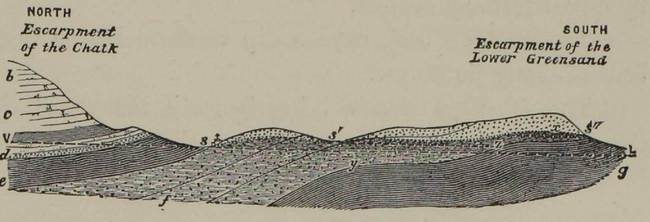
* Prestwich. † 2nd Series Geol. Trans. vol. iv. p. 103, to which the reader is referred for further particulars of this formation.

‡ It is said to contain lower carboniferous *posidoniæ*.

against the flanks of the underground ridge of old rocks. As far as they continue, so far will they form a valuable and copious water-bearing bed, the water from which would overflow at the levels lower than that of their outcrop. The extent of their underground range could only be determined by boring. It might be as far as Croydon, or even still nearer to London. The same would happen to the north of London, but the distance there is greater, the beds are not so thick, and the conditions generally are less favourable.' *

Mr. Prestwich, in his ' Inquiry respecting the Water-bearing Strata around London,' to which we have had so frequent occasion to refer, illustrates the phenomena of springs in this formation by a diagram, from which fig. 18 has been taken.

Fig. 18.



b is the lower tertiary strata, *c* the chalk, *d* the upper greensand, *e* the gault, *f* the lower greensand, *g* the upper part of the wealden formation, V L line of lowest valley-level of the district, $s\ s'\ x\ s''$ line of water-level, s, s', s'', springs.

Upon this Mr. Prestwich's very interesting remarks are as follow:—' The edges of this formation are bounded on the north by the Gault at s, and on the south by the wealden at s''; they are both impermeable strata, and present water-tight surfaces to the sand between them, so that any water which might find its way below the margins of these deposits could not escape again, but would follow the subterranean course of the intermediate strata. In the process of time, and by the constant operation of the rainfall, the large underground mass of the Lower Greensand has been filled to its edges with water, and any further addition causes it to run over. It is this overflowing which gives rise to the springs of the district. Their magnitude will depend upon the breadth and " massif " of the Lower Greensand, and upon the difference of level of the Gault and Wealden.

' We will now assume that the Lower Greensand consists throughout of sands of uniform texture. Supposing that no rain had fallen for such a time that the waters contained in it were in a state of equilibrium: they would then stand at the level V L, and all the springs would cease to flow. But when the mass of strata above V L is large, this can rarely happen, on account of the fall of rain taking place from time to time throughout the year, and the texture of the strata opposing a certain resistance to its passage, which impediment to its transit is sufficient to diffuse, uniformly over a long period, the delivery of the water that it receives irregularly at shorter intervals.

' The water first percolates downwards through the sands, until it reaches the line of water-level, and then flows horizontally towards, and tends to escape at, the point of lowest surface-level s. (We are now supposing that this is the only vent.) The successive rainfalls keep adding to its volume, until the resistance presented by the lithological structure of the mass is balanced by the weight of the head of water accumulated above the level s L; the flow at s then becomes constant, and the mean daily delivery will be an average of the total quantity of rain infiltered during a month, a year, or even a longer period, according to the size of the mass in which the water is stored.

' Where, however, there is more than one point of issue, if the marginal edges of the two series of impermeable strata at s and s'' are on the same level, the water flows both ways in nearly equal force; but when, as in fig. 18, the Wealden at s'' rise above the Gault at s, the water tends to accumulate at the Lower Greensand f, until it reaches a line connecting s and s''. This line will not be straight, but will present a curve varying constantly in its form according to the distance between s and s'', the resistance opposed to the passage of the water, and the variation of the rainfall. This would not so much affect the mainspring at s as the minor ones at s and s'', for when the curve s, s', x, s'' reaches, at x, a level higher than the point s'', the water above the line prolonged horizontally from s'' will tend to find its level and escape at s'', notwithstanding the rise of the strata in that direction. This spring would be the first to cease to flow in dry weather. A further fall of the water-level to the line $s'\ z$ would next affect the spring at s', whilst that at s might still maintain its perennial character so long as any water sufficient to overcome the resistance of the strata remained above the level of V, L.'

In consequence of the general uniform texture of the lower greensand, the water tends rather to ooze out along its line of junction with the gault, except where a particular depression of the latter concentrates the water at certain points, as in the valley of the Mole, at Dorking, and of the Wey, near Guildford.

The principal towns on the lower greensand formation in England are Biggleswade, Woburn, Maidstone, Ashford, and Folkestone.

The neocomian (neocomum) in the neighbourhood of Neufchâtel, Switzerland, the aptien of France, and the hilston and hilsglomerate of Germany, are equivalent to our lower greensand; in some places they have a thickness of 10,000 feet, extending along the shores of the Mediterranean and throughout Germany. It is probable that those also of Bogota, in South America, are of this class.

* Report of Royal Commission on Water-Supply, 1869.

The greensands have been so named from the green particles found therein, but the term is not one of sufficiently general application.

Chalk is found in Denmark, and in France the whole of the cretaceous series occurs. In Germany the development is not so considerable, but in Poland and Russia extensive tracts are occupied by the upper beds; they are met with also in North America.

The *Wealden Formation* of Kent and Sussex is entirely surrounded on the north and west by the lower greensand, and extends on the seacoast from Eastbourne on the south-west to Hythe on the east. The Hastings sands occupy the central portion of this tract, while, further, the coast around Dungeness is covered by a post-tertiary deposit.

The wealden beds have a dip conformable to the lower greensand, and consist of a stiff blue clay, with beds of shelly limestone.

The *Hastings Sands*, lying beneath the weald clay, have been divided by the Geological Survey, chiefly through the labours of Mr. Drew, into the following divisions :—

1. Upper Tunbridge Wells Sand.
2. Grinstead Clay.
3. Lower Tunbridge Wells Sand.
4. Wadhurst Clay.
5. Ashdown Sand.
6. Ashburnham Beds.

The first division (the Horsted sands of Dr. Mantell) is composed of soft yellow sandstones, with thin beds of clay; the third division is precisely like it, but is divided from it by a stratum of the stiffest clay, well seen at East Grinstead. The upper sand forms the well-known line of rocks at Penhurst, Rusthall, and Tunbridge Wells, while the third forms that of Uckfield.

The Wadhurst clay is a stiff brown, or blue, shaley clay, and is celebrated for containing the well-known 'wealden iron-ore.' Beneath this clay is the fifth division, the 'Filgate and Worth beds' of Dr. Mantell; they are set down by Mr. Drew as 250 feet thick at Ashdown Forest, and 160 feet at Hastings by Mr. Gould. The sand often contains alternating seams of sandstone and loam. The sixth division forms the lowest wealden beds of Sussex; it consists of shales, clays, and limestones; the latter are much worked at Heathfield and Petley Wood, in Sussex.

The wealden formation is slightly developed on the opposite coast of France, and extensively so in the north-west of Germany

Between the wealden and the oolites is interposed a set of beds, known as the *Purbeck Series*, named after the Isle of Purbeck, in Dorsetshire, where it is not only best seen, but is of its greatest vertical thickness. It consists of alternations of shales, marls, limestones, and clays, partly of freshwater and partly of marine origin. The limestones are much quarried for building purposes.

The Purbeck beds occur in a narrow band extending across the Isle of Purbeck, in a small patch in the Isle of Portland, and, again, in the Vale of Wardour, west of Salisbury; between these points, both the wealden and Purbeck are absent, and greensand rests on the Portland oolite.

In treating of the *Oolitic* formation, it will be most convenient to group the several strata into sections, each of which may be regarded as a water-bearing stratum.

The first section, or Upper Oolitic Series, includes the Portland stone, Portland sand, and Kimmeridge clay. The second, or Middle Oolitic, reaches from the coral rag to the Oxford clay, having the calcareous grit between. The third, or Lower Oolitic, embraces the cornbrash, forest marble, the great or Bath oolite, and the fullers' earth. The fourth includes the Inferior Oolite and sand, upper lias, lias marlstone, and lower lias.

It will be seen that these subdivisions are naturally defined by a successive alternation of permeable and impermeable strata, the latter forming the bases of the series of beds of the several subdivisions.

This great series, composed generally of calcareo-siliceous sands and sandstones, limestones, and argillaceous beds, extends in an irregular curved zone from the coast of Yorkshire, between Redcar and Filey Point, on the north-east, to the coast of Dorsetshire on the south-west. The breadth is extremely irregular, being in some parts more than sixty miles, while in others it is not more than about two miles.

In the north-east of Yorkshire it occupies a considerable breadth, but, suddenly contracting, extends southward, in a narrow strip scarcely two miles in breadth, through the East Riding to the Humber. It encircles the large tract of post-tertiary deposits which surrounds the Wash, then ranges in a broad belt in a south-westerly direction to Wilts, where it again somewhat contracts, thence continuing in a most irregular manner to the south coast, from Lyme Regis to the Isle of Purbeck, in Dorset. We will now consider somewhat in detail the sections mentioned above.

The *Upper Oolitic Series* underlies the cretaceous formations, but does not crop out to any great extent. The Portland oolite is a coarse earthy limestone, separated from the Purbeck beds by a vegetable soil of from

12 to 18 inches in thickness, known as the 'dirt' bed. Under it lies a bed of loose sand varying from 70 to 200 feet thick, the average being about 130 feet. Under the Portland sand is a thick bed of a blue and sometimes greyish-yellow colour, consisting in great part of bituminous shale, forming an impure coal, frequently approaching the character of peat. It varies in thickness from 100 to 600 feet. The upper oolitic series occupies an area of about 118 square miles in Yorkshire, where it dips under the greensand. It skirts continuously the same formation in Lincolnshire, where it is interrupted by the Wash, appearing again in a similar relative position, in a narrow strip, on the west coast of Norfolk, and extending southward to near St. Ives, Huntingdonshire. It crops up again in the north of Buckinghamshire, expanding into a width of about five miles; thence it extends in a south-westerly direction, by Abingdon, Swindon, Calne, and Trowbridge, to about midway between Castle Cary and Mere, whence it shoots to the eastward to near Tilsbury, and then southward, terminating abruptly, to the north of Dorset. In the district thus described springs are thrown out by the Kimmeridge clay, but from the small extent of available area the quantity is not very large, and as a rule the quality is inferior. In most cases it is deemed advisable to pierce the clay, and obtain a supply from the middle oolitic series.

The *Middle Oolitic Series* occupies a tract in Yorkshire surrounding the outcrop of the upper oolite, extending inland from the coast between Scarborough and Filey Bay for about 40 miles, then proceeding south-east to Burdsall, beyond New Malton, whence it runs in a narrow, continuous strip about south-south-east. It continues through Lincolnshire, increasing in breadth, and extending to Spilsby, in the east, and southward to Stamford. A considerable portion of this tract is covered by the post-tertiary deposit in the valleys of the Witham and the Walland. In Huntingdon it occupies a large breadth of country, whence it ranges southward (in a tolerably regular belt to near Tetbury, in Gloucestershire, where it turns southward) by Trowbridge, following the tract of the Kimmeridge clay down to near Hilton, in Dorsetshire; here it turns abruptly west, and dies out between the greensand and the great oolite near Beaminster, in the same county. The coral rag does not accompany the remaining strata of this series throughout the whole district thus described. It appears first to the north-east of Oxford, near Piddington, whence it ranges in a curved line south-west by Farringdon, Wooton Basset, Calne, Trowbridge, and dies out a little to the west of Westbury, the Oxford clay here coming into contact with the gault. The coral rag has occasionally above it a bed of freestone of rather close texture, known as the upper calcareous grit. The coral rag, or coralline oolite, consists of a loose rubbly limestone, having both above and below it a bed of calcareous sand. The lower calcareous grit, which rests immediately on the subjacent Oxford clay, is a yellowish quartzose sand, containing about one-third of calcareous matter. The thickness of the coral rag and calcareous grit together may be taken at from 100 feet to about 230 feet, which latter it attains in Wiltshire. The Oxford clay, which is the lowest member of this division, occupies by far the larger portion of its range, extending in Huntingdonshire to a breadth of more than 30 miles. It is an argillaceous deposit, of a dark blue colour, which becomes brown on exposure to the air. It it frequently mixed with calcareous and bituminous matter. Its thickness varies from 300 feet to 500 feet, and probably attains to nearly 700 feet in the Midland counties. The dip of the beds generally in this division averages about 1 in 150, but, from a peculiar transverse lamination, or rather parallel lines of cleavage, occurring at different angles, the true lines of stratification are liable to be mistaken.

From the rifty and porous character of the upper strata of this division, water accumulates in large quantities, being retained by the impermeable subjacent bed of clay. It is in these districts that the peculiar phenomenon of rivers being engulphed or concealed is to be met with; the streams flowing over the superior Kimmeridge clay sink into the fissures and crevices of this formation, and appear again at a distance when thrown out by the Oxford clay below. Mineral springs are here frequently found. In the system of D'Orbigny, the étage corallien and étage Oxfordien of the calcaire jurassique, and the German Korallenkalk and Oxford Thon, are equivalent to our coral rag and Oxford clay. The latter is also known as the argile de Dives of Normandy. The middle oolites are present in France, and equivalent beds are found in Germany and the south of Russia.

The *Lower Oolitic* division occupies a broad tract extending east and west across the moorlands of Yorkshire, and inland from the coast for about 40 miles, having an average breadth of about 7 or 8 miles. There is also a considerable outlier of this formation in the lias of the North Riding of Yorkshire. Thence it extends south-east, in a narrow curved strip of not more than a mile or two in breadth, to Pocklington, where it dies out, the Oxford clay coming into contact with the lias group. South of the Humber it crops out again, and ranges all but continuously through the centre of the great oolitic formation to the coast of Dorset. In one part alone is the continuity interfered with, and that is where the carboniferous limestone, near Frome, in Somersetshire, intrudes on this formation. Throughout the whole range the great oolite invariably succeeds the Oxford clay of the superior series. In the central districts of England, it is generally broken into by the lias, there being numerous inliers of the latter formation in this formation, and outliers of the former in the lias; in consequence of this, it is very difficult to estimate anything like an average of its breadth.

The cornbrash is a coarse and impure rubbly limestone, having sometimes a crystalline appearance. It is of a grey or bluish colour, and 'may readily be discovered by the superincumbent red soil which constantly attends it.' It rarely exceeds 16 feet in thickness.

The forest marble (calcaire à polypiers of Normandy) is a fissile limestone of a bluish tint, approaching brown on the exterior. Its beds are mostly thin and slaty. In the south-west of England these beds are sometimes nearly 100 feet thick.

The great oolite (calcaire de Caen) is a stratified calcareous mass, with an oolitic freestone in the centre, from which the well-known Bath stone is obtained. The colour of the freestone is generally white, with sometimes a light cast of yellow. The average aggregate thickness of the beds, viz. from the cornbrash to the great oolite inclusive, may be taken at from 250 to 300 feet, while in some parts they probably attain a thickness of 400 feet. Under this formation is a bed of calcareous slate, known as Stonesfield slate; it is not more than two feet in thickness.

The fullers' earth gives its name to a series of calcareo-argillaceous beds, with occasional layers of soft rubblestone; with them are found clays of a greenish yellow, the fullers' earth proper. The fullers' earth beds vary considerably in thickness, from a few feet to as much as 130 feet. Springs are thrown out by them from the superjacent porous beds, and, from the large extent and thickness of the latter, are generally copious. In the Yorkshire district, the fullers' earth is replaced by beds of sandstone and shale, which develop springs in a similar way.

The *fourth division*, which is the last of the water-bearing formation of the oolitic or jurassic series, is chiefly composed of impervious strata, the only pervious portion being the inferior oolite and upper lias sand, which immediately underlies the retentive strata of the preceding division. The tract of country occupied by the inferior oolite and sands lies contiguous to the west and north-west of the lower oolitic beds already described. The impermeable beds, consisting of the upper lias shales, marlstone, lower lias shale, lias limestone, and lower lias marls, may be traced all but continuously, being only interrupted by the intrusion of the carboniferous limestone, which was seen also to interfere with the lower oolitic division. The lias group forms the coast of Yorkshire, from Redcar to a point beyond Whitby, occupying a triangular area reaching inland to a point near North Allerton (in the centre of this area is the outlying portion of the lower oolitic beds already mentioned); thence it sweeps in a curve to the south-east, by Easingwold, to Bugthorp, and again southward to the Humber, a little to the west of Hull. South of the Humber the lias beds occupy a tract at first not more than a mile in breadth, but gradually increasing until, in the Midland counties, it attains to a considerable width. Here it has within its limits Newark, Grantham, Oakham, Rugby, Northampton, Banbury, and Tewkesbury, contracting as it approaches Gloucester. Southward from Gloucester it ranges, in a comparatively narrow strip, by Bath, Glastonbury, and Yeovil; here it turns, first west, to near Taunton, then south, to the coast in a tract of about five miles in breadth, a considerable portion of which is concealed by the overlying strata of greensand, forming part of the high ranges of the Blackdown Hills. On the north coast of Somerset, from Dunster to Burnham, and on the south coast of Glamorganshire, from Dunraven to Cardiff, it again appears, but in these parts the superjacent pervious oolitic beds are wanting. The inferior oolite is generally distinguished from the great or Bath oolite by its brown tinge, occasioned by the oxide of iron it contains. The lower strata consist of thick beds of slightly calcareous sand, with layers of irregular calcareous concretions, and at the bottom a stratum of soft sandstone. In the middle and west of England, the inferior oolite and underlying sands are from 130 to 300 feet thick; in Lincolnshire it averages about 35 feet, in Yorkshire about 80 feet, in thickness. This division of the formation preserves its name on the Continent.

The lias consists of an alternation of thin beds of limestone and layers of argillaceous matter; the prevailing colour is blue, but some beds have a yellowish-white tint. The thickness of this formation varies from 400 to 1,000 feet. The water percolating through the inferior oolite, and filtering through the sands, is thrown out by the marl above the lias.

Grouping the several members of the oolitic formation, from the Portland stone down to the lower lias, they may be regarded as a vast series of pervious and impervious beds, involving a total thickness of at least 5,000 feet, having a gentle dip generally to the south-east. On the whole, they are very remarkably conformable. It has been shown, however,* that the inferior oolite and underlying sands thin off as they range eastward, probably dying out about the centre of Oxfordshire; the great oolite and its accompanying beds thin out to the east, and probably do not extend much farther than the inferior oolite. It would seem that the argillaceous formations, consisting of the Kimmeridge and Oxford clays and the lias, close in, as it were, and thus confine the water in the alternating pervious beds. The principal towns on the oolitic formation in England are Whitby, Scarborough, Lincoln, Stamford, Grantham, Newark, Oakham, Peterborough, Northampton, Bedford, Huntingdon, St. Ives,

* Report of Royal Commission on Water-Supply, 1869.

St. Neots, Rugby, Buckingham, Aylesbury, Oxford, Tewkesbury, Cheltenham, Gloucester, Malmesbury, Trowbridge, Chippenham, Bath, Frome, Glastonbury, Yeovil, Sherbourne, Bridport, Lyme Regis, and Weymouth.

The lias beds are found in France, Switzerland, Wurtemberg, Westphalia, North Germany, and Bavaria.

The *New Red Sandstone Series*, the lowest of the secondary formations, is one of the most extensive and important formations in England. On the continent of Europe it has been named the Triassic, from its threefold subdivision, the Keuper, the Muschelkalk, and the Bunter Sandstein. In England the middle division is, however, wanting. This formation occupies the coast of Durham and Yorkshire, from Hartlepool to Redcar, and extends inland up the valley of the Tees. It ranges in a continuous curved tract southward, through Yorkshire, along the valley of the Swale and the Ouse. In the neighbourhood of the Humber, a considerable tract of post-tertiary deposits covers the sandstone for a greater part of its width, threatening its continuity. It follows the western part of the valley of the Trent to Nottingham, and shortly expands into a considerable area, reaching south-east by Leicester, Rugby, and Stratford-on-Avon, and north-west to the estuaries of the Mersey and Dee. The Stafford-shire and Yarmouth coalfields and contiguous tracts of permian sandstone form two islands in this red sandstone plain while the same formations intrude upon it to the south-west of Stafford. From Liverpool it extends northward through Lancashire, in a very regular strip about five miles wide, by Preston, to Lancaster. South-ward from Worcester, the red sandstone formation ranges in an irregular tract to the estuary of the Severn, whence it may be traced, occupying detached and irregular tracts, through Somerset and Devon to Torbay. The keuper series is divided into the new red marl and the lower keuper sandstone, the former, which attains a thickness of 2,000 feet, consisting of red and grey shales and marls, sometimes micaceous, with beds of rock salt and gypsum, and the latter of thinly laminated micaceous sandstones and marls, passing downwards into white, brown, or reddish sandstone, with a base of calcareous conglomerate, or breccia. * These together average about 550 feet in thickness, and occupy the eastern half of the tract of the red sandstone formation, running from the Tees to Nottingham, and from Kidderminster to Devonshire; they form also the south-eastern border of the tract in the Midland counties, and cover a considerable area in Cheshire and Shropshire. The more or less porous sandstones of the lower part of the keuper series invariably contain considerable quantities of water, which, supported by the numerous seams of compact marl, issue as springs or are met with in boring, wherever these sandstones occur, to such a marked extent that they are generally known as the 'waterstones.' The bunter sandstone 'consists of an upper and lower bed of soft bright red variegated sandstone, and an intermediate one of harder reddish-brown sandstone, with quartzose pebbles, passing into conglomerate, with a base of calcareous breccia.' In respect to water-supply, however, it may be regarded as a nearly homogeneous mass, equally available throughout. The bunter sandstone dies out along a north-east line drawn through Leicestershire, while in the north-western parts of Lancashire and Cheshire it attains the enormous thickness of 2,000 feet. The dip of the beds of this formation is very slight, and, where underlying the lias, are conformable to it. A synclinal axis runs about north-west and south-east between the valleys of the Mersey and Dee, while the sandstone beds running through Lanca-shire dip to the west under the post-tertiary deposits which stretch along the coast. The new red sandstone is most extensively covered by beds of gravel and detritus; occasionally this is marly and impervious, but where it is otherwise, a supply of water is afforded to numerous shallow wells, the water being retained by the impervious substratum of red marl forming the upper bed of the red sandstone series.

'The bunter sandstone,' says Mr. Hull, † 'is by far the most important water-bearing formation in England, with the exception, perhaps, of the chalk and lower greensand, which, combined, occupy a much larger area, but, on the other hand, from their geographical position, receive a much smaller amount of rainfall, and yield harder water, owing to the presence in greater proportions of carbonate of lime. The water-bearing capabilities of each formation are due to similar lithological structures of the rocks themselves, and are independent of chemical constitution. They are due in each case to the permeability, the homogeneous texture, and composition of the strata, in the first instance, and to their occupying large unbroken areas, and attaining in many places a considerable amount of vertical thickness.'

Numerous important towns in England are supplied from wells sunk in this formation, the yield from which indicates the high permeability of this rock. Mr. Hull, in remarking upon the yield of the wells of Manchester and Salford, driven into the new red sandstone and lower Permian sandstone, states that six million gallons of clear water daily are 'drawn from an area which cannot be estimated at more than seven square miles, a great part of which is covered by buildings and paved streets, as well as being overspread by an almost im-pervious stratum of boulder clay.' He accounts for this larger supply from so restricted and unfavourable an area by supposing that the waters of the rivers Irwell, Irk, and Medlock, which in their course traverse the new red sandstone in the suburbs of Manchester and Salford, percolate into the sandstone rock, from which they are

* Hull 'On the Triassic and Permian Rocks of the Midland Counties of England.' Memoirs of the Geo. Survey, 1869. † Ibid.

afterwards drawn by pumping. 'If this be so,' says Mr. Hull, 'it shows what a wonderfully effective filter the sandstone is, for the waters of these rivers are so charged with impurities from various sources that the rivers themselves can be regarded as little better than filthy sewers.' The passage of water through the new red sandstone is, on the whole, probably more by percolation through the mass than by fissures and crevices, as in the chalk. Frequently, however, the increase in the supply of wells and boreholes by the comparatively small increase in their depth would seem to arise from a sudden influx of water by some fault or fissure, acting as a duct. Faults are unquestionably very numerous in the new red sandstone formation, but their favourableness or otherwise to the efficiency of the sandstone as a water-bearing formation depends, upon the one hand, whether they be open or filled with porous material, thus facilitating the passage of the water, or, on the other, filled with some impervious substance, whereby the formation is divided into independent 'boxes,' thus restricting the supply from any given well or boring to a limited area or gathering ground. Springs, often very copious, are thrown out from the red sandstone at its junction with the various members of the palæozoic series, of which the Wall-grange spring, near Leek, in Staffordshire, is a remarkable instance, the yield from it being estimated at three million gallons daily.

Brine springs and beds of rock salt are characteristic of this formation, and they are found in several parts of the country, as at Droitwich and Stoke, in Worcestershire, at Northwich, Winsford, Dunhan, Anderton, Moulton, Middlewich, Wherlock, Roughwood, Lawton, Baddiley, Durtwich, Audlem, and Nantwich, in Cheshire, and at Shirleywich, in Staffordshire. The following sections, which were furnished to Mr. Hull, will give a general idea of the thickness and position of these beds.

Sections of the Rock Salt and accompanying Strata at Northwich.

The Island Salt Works.

	Feet.
1. Quicksand	8
2. Red marl ('metal')	90
3. First salt rock	75
4. Indurated red clay, &c.	30
5. Second salt rock	75
6. Shale or marl ('metal'), with thin bands of salt rock, from a few inches to seven feet in thickness	180

Marston Mine.

	Feet.
1. Boulder clay, &c.	144
2. Red marl	
3. First salt rock	75–84
4. Indurated clay	30
5. Second or great salt rock bed	96

The principal towns on the new red sandstone series are Hartlepool, Middlesboro, Stockton, Darlington, North Allerton, Knaresborough, York, Doncaster, Gainsborough, Nottingham, Derby, Melton Mowbray, Leicester, Coventry, Warwick, Stratford, Stafford, Lichfield, Chester, Middlewich, Northwich, Stockport, Liverpool, Warrington, Preston, Lancaster, St. Asaph, Kidderminster, Worcester, Bristol, Wells, Bridgewater, Taunton, Exeter, and Teignmouth.

The Trias is extensively developed in Europe, and also in the New World. It is found in Belgium, Germany, Switzerland, Spain, and Russia, and is met with in the United States, Colombia, Mexico, and Bolivia.

Regarded generally, the rocks of the secondary epoch are very much scattered on the continent of the Old World. In the New they occupy a compact area, from the upper course of the Missouri to the north of Texas, and then extend in an arm eastward round the tertiary tract which skirts the Gulf of Mexico. In South America they are very inconsiderably developed.

Skirting the western boundary of the new red sandstone, and separating the latter from the carboniferous system, is the *Magnesian Limestone*, or *Permian Group*. It immediately underlies, although it is nowhere conformable to, the new red sandstone formation; the latter, indeed, forms the base of the great series of parallel beds which constitute the secondary and the greater part of the tertiary formations.

In a work of this kind, it is unnecessary to refer to the gigantic operations of Nature which brought about the disturbances in the palæozoic rocks before the deposition of the superior beds. These great geological changes and their results are of interest to us here only as far as they affect the conditions of the supply of water, otherwise a fitting opportunity would have been afforded for following out the sublime speculations of the geologist. The Permian formation appears in England in numerous detached portions. It forms, however, a range of hills, of inconsiderable elevations, extending from Sunderland, in a compound curve, to Nottingham. The tract of country occupied by the Permian rocks in this district is about five or six miles in width; on the coast of Durham, however, it extends from Shields to Hartlepool, while a little to the south of Darlington it is interrupted by the new red sandstone coming immediately on the millstone grit. In Lancashire, Cheshire, and Derby, and in Flintshire, Denbighshire, Shropshire, also, the formations are similarly situated, the Permian rocks bordering the red sandstone in narrow and detached strips, and separating them from the coal measures. The Staffordshire coalfield is skirted by the limestone on its eastern and western boundaries; and on the south of the Tamworth coalfield another large patch is found. A large triangular area, partly in Westmoreland, but principally in Cumberland, extends along the east of the Solway Firth, thence, in a south-easterly direction, for a distance of about fifty miles. On the western coast also, from St. Bee's Head, in Cumberland, to Wolney Island, inclusive, on the south, is a narrow strip of upper Permian sandstone.

The Permian series may be divided into the Upper Permian, consisting of red marls, with their bedded fossiliferous magnesian limestones (Zechstein of the Germans), and the Lower Permian, consisting of red and variegated sandstone and marls, with calcareous conglomerates (Kupferschiefer) and trappoid breccia.*

The thickness of this formation is very variable, being given as 330 feet in Lancashire, while they have been stated to attain in some parts to a depth of 700 or 800 feet.†

From the lower beds of the Permian series, large quantities of water may be obtained. In the county of Durham, two shafts were sunk within a few yards of one another, the yield from which amounted to fourteen million gallons per day, and was obtained from a stratum of sand which the shafts intersected.‡

When the Permian rocks are faulted against the coal measures, the supply will generally be affected by the faults, an instance of which is cited by Mr. Hughes, in the case of the Goldthorn well near Wolverhampton, sunk about 400 yards west of the great fault which throws down the Permian rocks to the level of the coal measures; the yield of this well is only 200,000 gallons per day. It is probable, however, that large supplies may be obtained from the lower Permian beds, when they immediately overlie members of the carboniferous series.

The principal towns on the Permian series are Tynemouth, Shields, Sunderland, Ripon, Carlisle, Wigton, Penrith, Appleby, Stockpool, Congleton, Shrewsbury, Wolverhampton, and Birmingham.

The Permian rocks are extensively developed in Perm, in Russia, where they were first worked out by Sir Roderick Murchison, who named them after the district.

Next in order is the *Carboniferous Series*, consisting of the upper or great coal measures, the millstone grit, and the carboniferous limestone. The *Coal Measures* are too well known to need any detailed description of their locality or lithological character. It may be remarked, however, that porous beds of grit, alternating with retentive ones of clay, are frequently met with in the coal measures. They mostly hold a considerable body of water, which is occasionally thrown out as springs. Water drains in very large quantities into coal mines, but it is so liable to contamination one way and another, that these sources cannot generally be regarded as available for domestic consumption in towns. The waters percolating among the coal measures are very often chalybeate, and saline and thermal springs are occasionally found.

On the coal measures are the following towns:—Morpeth, Newcastle, and Durham, in the Durham coalfield; Leeds, Bradford, Halifax, Huddersfield, Rotherham, Sheffield, Chesterfield, and Wakefield, in the Yorkshire coalfield; Blackburn, Bolton, Wigan, Warrington, Rochdale, Oldham, and Manchester, in the Lancashire coalfield; and Swansea, Aberdare, and Neath, in the South Wales coalfield.

Under the coal measures there is a series of coarse-grained hard quartzose sandstone grits and conglomerates, intercalated with some beds of shale, and occasionally with a few thin seams of coal. This series is known as the millstone grit. It often forms ranges of barren hills, covered merely with heather and here and there with a thin growth of peat. From the compact nature of these rocks and the bare surface they commonly present, these hills are largely used as gathering grounds for the supply of water to numerous large towns by gravitation.

In Leicestershire, the thickness of the millstone grit is estimated by Mr. Hull at only 50 feet, in North Staffordshire at 500 ; while in the north of England (in Yorkshire, Lancashire, and Derbyshire), the millstone grit series is divided into four, and even sometimes five, great masses of grit, separated from each other by thick beds of shales. The first and uppermost of these beds of grit is generally known by the name of the 'Rough Rock;' it is a massive grit, or conglomerate, with rounded pebbles of quartz. In some districts, however, it is extremely soft, and contains fewer pebbles, being dug for sand at Haslingden, where it is known as the 'Sand Rock.' The *Second Grit* is generally separated from the rough rock by 100 to 150 feet of shales. It consists of flags, sometimes divided into two portions by a bed of shale; these beds are particularly well developed in the neighbourhood of Haslingden, in Lancashire, after which place they have been named 'Haslingden flags' by Mr. Hull, F.R.S., who conducted the Government Geological Survey of that area. Below these flags is a bed of shale, sometimes 150 feet thick, resting on the *Third Grit*, which is generally very fine-grained, seldom conglomerate, and about 200 feet thick, but is sometimes split up into two beds, separated by shales. The fourth grit has been

* Hull, Mem. Geol. Society, 1869. † Ibid. ‡ Report by Robert Stephenson to the London and Westminster Water Company, 1840.

named the *Kinder Scout Grit* by Messrs. Hull and Green, from its forming the table-land of Kinder Scout, in the Derbyshire Peak country. Between Mottram and Staleybridge, it is stated by Mr. Hull to be 1,000 feet thick,* and he sets down the average thickness of the whole series at 5,500 feet of millstone grits. †

In the north the grit is partially permeable, its permeability varying with its density. Springs invariably issue from the base of each bed of grit, when it rests on shales, as at the foot of the escarpments of the Pennine range.

Yoredale Series.—These rocks consist of fine-grained grits, shales, and limestones, intervening in the north of England between the millstone grits and the carboniferous limestone. Like the former, it gradually thickens from south to north, being, according to Mr. Hull, F.R.S., 50 feet in Leicestershire, 2,300 in North Staffordshire, and 4,675 in Lancashire. ‡

The *Carboniferous* or *Mountain Limestone* (known on the continent of Europe as the calcaire de montagne, bergkalk, and kiesselschiefer) consists of an assemblage of imperfectly crystalline calcareous strata, sometimes divided by thin partings of clay, sometimes alternating with beds of grit and shale, and occasionally itself thinly laminated. Water finds a rapid passage through the numerous fissures of these rocks, and is thrown out as springs by the argillaceous partings just noticed, and also by the bed of shale which separates the limestone from the old red sandstone below. Springs are not frequently met with on the sides of the hills of this formation; but they are often found gushing out copiously round their bases. In limestone districts, springs frequently appear rising in elevated lands in a manner which may be readily accounted for by the existence of faults or fissures filled with impervious material, which serves to dam up the water until it overflows at the surface. (*See* p. 49.)

The phenomena of rivers and springs being engulphed in the caverns and fissures of the rocks, and reappearing after having followed a subterranean course, often of several miles, is common in the mountain-limestone districts. The occurrence of these swallow or swallet holes, as they are termed, is frequently of serious local importance, and the stopping of them, and thus averting the loss of water which they would otherwise occasion, is a branch of industry requiring no small skill on the part of those who make it a profession. After heavy falls of rain, the subterranean channels are frequently not of sufficient capacity to convey the whole of the waters; hence the presence in deep valleys of the limestone of small streams, which disappear during a drought, being then confined to their subterranean channels alone. The carboniferous formation is developed in Central France, Belgium, Westphalia, South Russia, Asia, North America, and Australia.

The *Devonian*, or Old Red Sandstone, formation occupies a considerable tract in Brecon, Hereford, and Monmouth, and again in the north and south of Devonshire and throughout Cornwall. In the Hereford district it consists of a red conglomerate cornstone and marl, and in the south-west of England it consists of a fine-grain micaceous sandstone-slate, alternating with argillaceous beds, occasionally soft, but more frequently indurated and slaty. The depth varies greatly, averaging about 3,000 feet. The strata of this formation, like those of the carboniferous series already described, are often highly inclined, being sometimes, especially in the south-western counties, perfectly vertical.

Water percolates, although slowly, through the sandstone, and is thrown out by the argillaceous beds which occur in the series. The principal towns on the Devonian series are Leominster, Hereford, Ross, Brecon, Abergavenny, Monmouth, Chepstow, Newport, Cardiff, Milford, and Ilfracombe. In South Devon and Cornwall, there are Plymouth, Devonport, Falmouth, and Penzance.

Equivalents to our Devonian are known on the Continent as vieux grès rouge, jüngere grauwackegebirge, and terrain paléo-psammerhytrique; they are extensively developed in the Hartz district and (old red sandstone) in Russia. They also occupy a large tract south of the great lakes in America.

The *Silurian Rocks* are divided into the Upper Silurian, consisting of argillaceous, micaceous, and concretionary limestones, and the Lower Silurian, consisting of sandstones and calcareous flagstones. The *Cambrian* consists of sandstones, limestones, and slates. The *Igneous Rocks* are of Cambrian, Silurian, Devonian, carboniferous, and Permian age, and occupy large areas in Devon and Cornwall, Wales, Cumberland, Westmoreland, Northumberland, and various parts of Scotland.

'Silurian strata extend over much of northernmost Europe, and corresponding latitudes in America. They have been found in Brittany, Westphalia, near Constantinople, and in Asia Minor. In South Africa, the southernmost parts of North America, Australia, and China, different contemporary rocks have been determined. In mineral character, they are generally distinct from the English beds, but offer no marked characters uniformly present.'§

These formations do not come within the province of this chapter, as their connection with water-supply is only in the capacity of catchment areas, of which notice will be taken hereafter.

* Mem. Geol. Survey. 'Geol. Country around Oldham.'

† Quart. Journ. Geol. Soc. for 1868, p. 320.

‡ Hull, 'On Thickness of Carboniferous Rocks of the Pendle Range.' Quart. Journ. Geol. Soc. 1868.

§ Anstead's Elementary Course of Geology

The geology of Great Britain has attracted most of our attention, as perhaps it should ; but it must be remembered, in the words of an eminent living geologist, that the field we have traversed mostly in detail 'is more varied, and has been the subject of more minute investigation, than that of any other equal area on the earth's surface. It presents in nearly continuous sequence almost all the rocks characteristic of the successive geological epochs ; consequently, it has become in a great measure a type of the geology of the whole world.' *

* Note by Edward Forbes, F.R.S., in Keith Johnstone's Physical Atlas.