CHAPTER IV.

SPRINGS AND WELLS.

All porous materials that are wetted by a liquid are capable of retaining it in their interstices by "capillary attraction," just as a sponge does, and in the same way, when they are saturated, will allow the excess to drip out, and when they are compressed will give up a further quantity according to the pressure. The same is the case with rocks: sandstone, sand, and gravel* will absorb, as a rule, about one quarter of their weight of water without allowing any to flow out by gravity before they become *saturated*. If, afterwards, any further quantity of water flows in at one end a corresponding amount flows out at the other. But there are certain soils, such as clay, which do not allow water to penetrate them readily, and are known as "impervious strata." If rocks were laid horizontally, the one-third of the rainfall that permeates into the ground would be stopped by a layer of clay, and would form an underground reservoir of what has been called "ground water." But the internal forces acting in the body of the earth

* The ordinary idea of "rock" is something compact and hard, but geologically it is more convenient to speak of all formations of the earth's crust as rocks, and such is the universal custom in geological works.

have twisted and bent the strata into curves, which are called *anticlinal* when the sides descend away from one another, like the letter A, and *synclinal* when they slope towards each other, like a V, the highest and lowest points being called respectively an anticlinal or synclinal *axis*. The angle made with the horizon is called the *dip*, which is expressed in degrees, and also described as east, west, &c., according to its bearing. The subsequent action of water in denuding or wearing away the upper portions of the rock leaves the synclinal curves as basins, with the edges of the strata exposed at the surface. The line of emergence of a stratum at the surface is called its *outcrop*, and its direction the *strike*. The strike on a flat surface would be at right angles to the dip, but this relation is much disturbed by inequalities on the surface, so that the outcrop becomes a sinuous or wavy line. Rain falling on the upturned edges of a porous bed, such as sandstone or gravel, descends till it meets with a saturated layer. If there be no outlet the entire stratum becomes in time saturated, and is then said to be *waterlogged*. But in cases where a valley has been cut by a river or by prehistoric glaciers through a lower portion of the beds, the rain that has entered above escapes at the lowest level as SPRINGS (Fig. 20).

Along the Kentish coast in places near the sea level at the base of the chalk, considerable volumes of water escape into the sea, derived from the rainfall on the Weald, and it has been suggested that such water might be rendered available not only, as at present, for the watering-places on the south coast, but even as a supplement to the metropolitan supply.

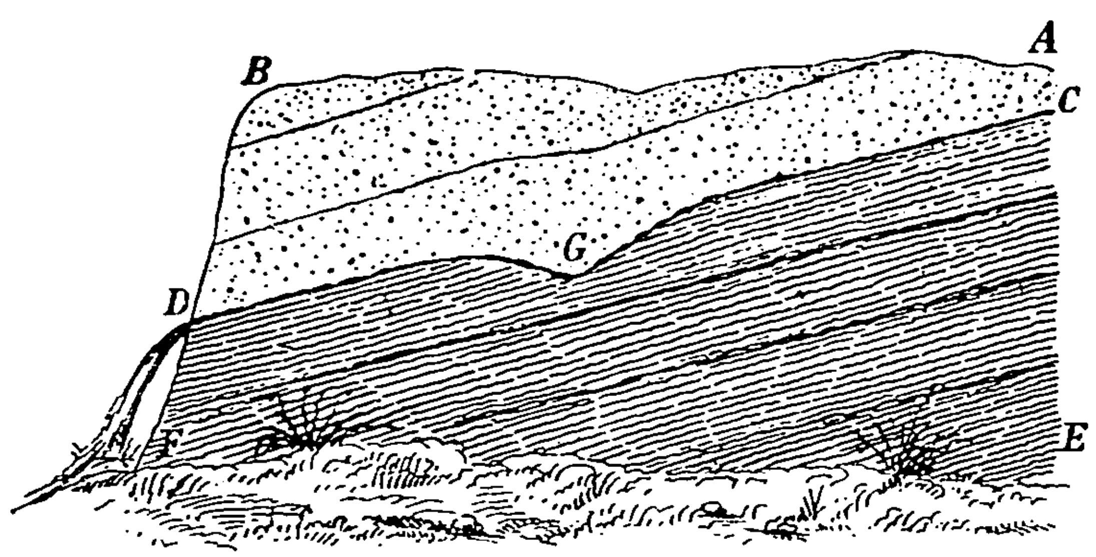

FIG. 20. Diagram of spring.

In other cases where the side of a synclinal curve has been worn away unequally, the body of water on

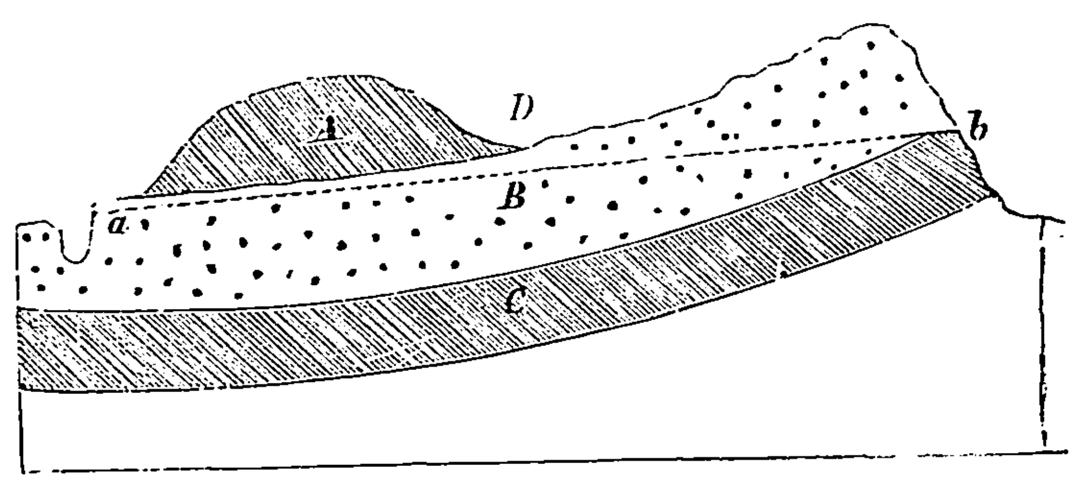

FIG. 21. Springs in synclinal.

the longer slope will overbalance that on the shorter, and the springs will appear on the lower outcrop (Fig. 21). During the passage of the water through the rocks it dissolves a number of their mineral constituents, assisted greatly by the carbonic acid which

it has absorbed from the atmosphere, and by that which has been formed by the oxidation of organic matter derived from the surface. In this way it may become saline or hard, aerated or chalybeate, according to the composition of the strata it has traversed. This solvent action on chalk and limestone frequently excavates underground channels and large caverns, which in many cases constitute natural subterranean reservoirs of very considerable capacity. Occasionally rivers in cretaceous districts disappear in a "swallow hole" of this kind and reappear at a point some distance further, as is the case with the Mole near Dorking and other rivers. Such an appearance may sometimes be mistaken for a spring, but its composition will generally reveal that it is really a surface water.

Another condition almost necessary for the formation of underground reservoirs of water and of springs is the inclusion of the porous water-bearing strata between upper and lower layers of an impervious material like clay, heavy marl, or shales. The weight of the superincumbent strata often causes the spring to emerge with considerable force, as at the fountain of Vaucluse and other places.

In its transit through the porous rock the water will undergo a natural filtration, which will be proportionately complete according to the distance traversed and the rate of progress, which will in its turn depend on the fineness of the filtering strata.

At the same time, by contact with dissolved oxygen and by the action of the bacteria which it gathered at its first entrance into the soil, the organic matters will be decomposed into harmless mineral substances, like ammonia and carbonic acid, which are often present in considerable quantities in moderately deep or subsoil waters. Later, the ammonia is oxidised into nitrates, the bacteria and all suspended particles are removed, and the water emerges as springs or remains as deep water to be reached by boring, in either case being clear and bright, and almost absolutely free from germs and organic matter. For this reason spring water has always been considered to be an ideal supply. But, inasmuch as mere mechanical filtration cannot remove the dissolved mineral constituents, many springs, especially in Gault, Greensand, and New Red Sandstone, are so charged with salts of soda, magnesia and lime, or so impregnated with iron, as to be quite unfitted for drinking.

Springs are of two classes, LAND SPRINGS and DEEP SPRINGS; the former are mostly found on the face of slopes, and are caused by the outcrop of the impervious floor, of clay, for instance, which hinders the water from descending further. Deep springs arise from fissures in the impermeable strata, which allow the water in the layers beneath to rise to the surface. The former class frequently become dry in periods without rain, and consist of surface water more or less filtered and oxidised. Deep springs are nearly

always permanent, and yield water free from organic impurities if surface drainage has been excluded.

Besides upheaval and depression, the rocks have frequently experienced dislocation by cracks or faults which often interrupt the strata and throw them for great distances out of their level. A continuous line of springs often reveals the presence of a *fault* (Fig. 22). The course of the underground water may also be cut off or diverted by this cause, so that the

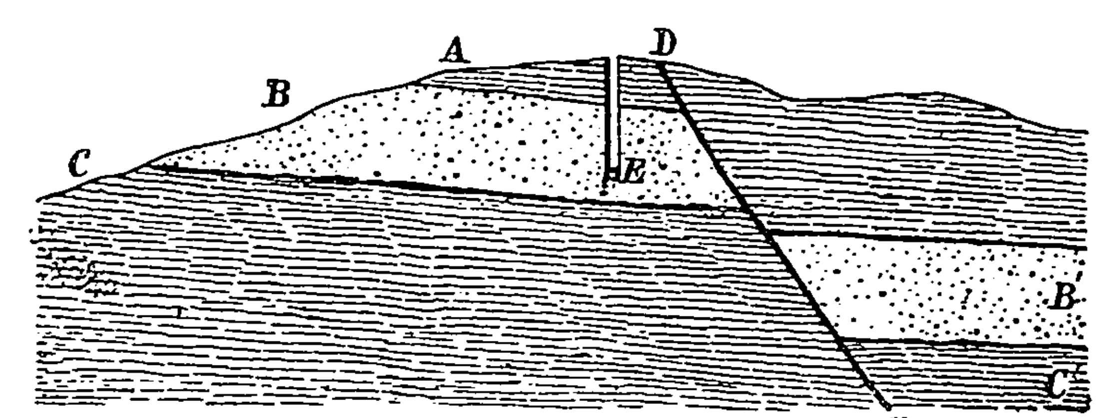

FIG. 22. Fault cutting off springs from water-bearing strata.

final lowest outcrop of the original water-bearing strata may be totally devoid of springs. Moreover, the underground current may pass to great depths, and even to points horizontally far remote from where it penetrated. For these reasons in seeking for water it is necessary to acquire a good knowledge from geological maps of the structure of a country, and particularly of the occurrence of faults. In regions imperfectly explored the surface must be carefully inspected for outcrops, and all natural sections which may be revealed at the sides of valleys and precipices must be examined to ascertain the nature and dip of the strata. A line of springs at the side of a valley may often be traced by a strip of marshy land or by the extra greenness of the herbage, marking either a natural outcrop or a fault. Such a junction of the strata should be followed across the country, and sinkings or borings made in portions of the line that showed no springs might be expected to tap hidden sources of supply which had not risen to the surface owing to less pressure or less permeability of the strata. Faults are more difficult to trace, and would require the assistance of a geological map or of an experienced geologist, but they frequently include subterranean spaces or pockets in which large quantities of water have accumulated. They are marked in geological maps by straight or curved lines on the opposite sides of which the strata are interrupted or broken. The dips are denoted by arrows showing the direction in which the beds slope downward, and a figure to show the angle to the horizon.

The proportion of water held by a rock or soil is often much larger than would be supposed. It has been stated that a square mile of sandstone 130 feet deep contains water sufficient to maintain a flow of a cubic foot a minute for more than thirteen years, as the average content of porous soils when saturated is from 25 to 33 per cent.; this estimate is a low one. The quantity cannot be well judged by the feel or appearance, as it depends almost entirely on the state of aggregation.

Mr. Wethered (British Association Reports, 1883, p. 149) gives the following table, showing the comparative porosities of various rocks:—

Old Red Sandstone ..	Bristol	·642
Old Red Flags	Caithness	·086
Old Red Conglomerate ..	Gloucestershire ..	1·172
Carboniferous Limestone	Clifton	·010 to ·049
Millstone Grit	Bristol	·058
Ditto	S. Wales (very coarse)	·355
Ditto	Forest of Dean ..	1·119
Pennant Grit	Bristol	·112
Bunter Sandstone ..	Heidelberg	·838
Magnesian Conglomerate	Clifton	·133
Magnesian Limestone ..	Clifton	1·044
Great Oolite (hard) ..	Bath	1·473
Ditto (soft)	Bath	2·157
Inferior Oolite Stone ..	Cheltenham	1·496
Ditto Pisolitic	Cheltenham	·146

The estimation is usually made by steeping a weighed average sample in water for forty-eight hours, rapidly wiping with a damp cloth, and again weighing, the results being recorded in parts by weight of water absorbed by 100 parts of rock. Other observers have found loose sandstones to absorb from 4 to 29 per cent., and chalk 10 to 25.

Permeable rock below the permanent water level of a district may be regarded as a reservoir of which the cubic content is limited by the size of the spaces between the grains and the width of the fissures and cracks by which the rock may be traversed. When water passes directly through such fissures and cracks and does not percolate, as in the Carboniferous

Limestone, it is often mere unpurified surface drainage. It was given in evidence by Professor Boyd Dawkins, at a Local Government Board inquiry at Coventry, in 1896, that fissures in the Permian rock might account for contamination of the corporation well by the polluted waters of the river Sherbourne, distant half a mile away, and analyses by the author seemed to confirm such view. Shingle and gravel always contain water, which, however, is often brackish from old marine strata, even at distances from the sea, and in inhabited districts is generally contaminated by surface drainage, except at great depths. In some places on the sea-shore fresh water can be gathered from the shingle directly the ebb tide has removed the layer of salt water. A great number of Continental cities, such as Paris, Vienna, &c., are supplied by springs, also a number of cities in the United States, especially in the west. Such supplies generally require to be brought from a great distance, but if the conduits are well made and properly protected, the expense of filtration is obviated.

The best spring water is that which rises from granitic, jurassic (oolite), and cretaceous strata. That from gypseous, saline, pyritous, anthracite, bituminous, or clayey beds, or from deep alluvial deposits like the "dirt bed" of the South of England, is almost invariably of bad quality. If a spring augments in volume during winter or after rains, or if its temperature shares the fluctuation of the seasons, it is to be looked upon with suspicion as being partially fed from the surface.

Spring and deep water require to be guarded with special care on its way to the consumer, as they furnish a medium in which adventitious germs very rapidly propagate.

Where a water supply is taken from springs, it is necessary, in order to avoid the risk of pollution from manured land, that each spring should be opened up to the source, and proper intake works constructed with a watertight conduit from each intake, and that sufficient land should be acquired round each spring to secure the water against pollution by surface or subsoil drainage.

The divining rod, *virgula divina*, *baculus divinatorius*, or in French *baguette*, allied to the *caduceus* of Hermes and to the rod of Aaron, is still used in exploring for underground water. In the Middle Ages it was relied on for the detection of criminals as well as for finding buried treasure and running water. It had various forms, as seen in the annexed illustrations (Fig. 23). It is believed to have been transmitted from the Mongols, through Scythia and the Tartars, to the Persians and Jews. It is said to be still in vogue in Pennsylvania for petroleum, and in Cornwall for metallic lodes. But in these practical times, when still employed, as it is extensively for the discovery of springs, it appeals only as a kind of scientific instrument, depending on some yet unexplained force

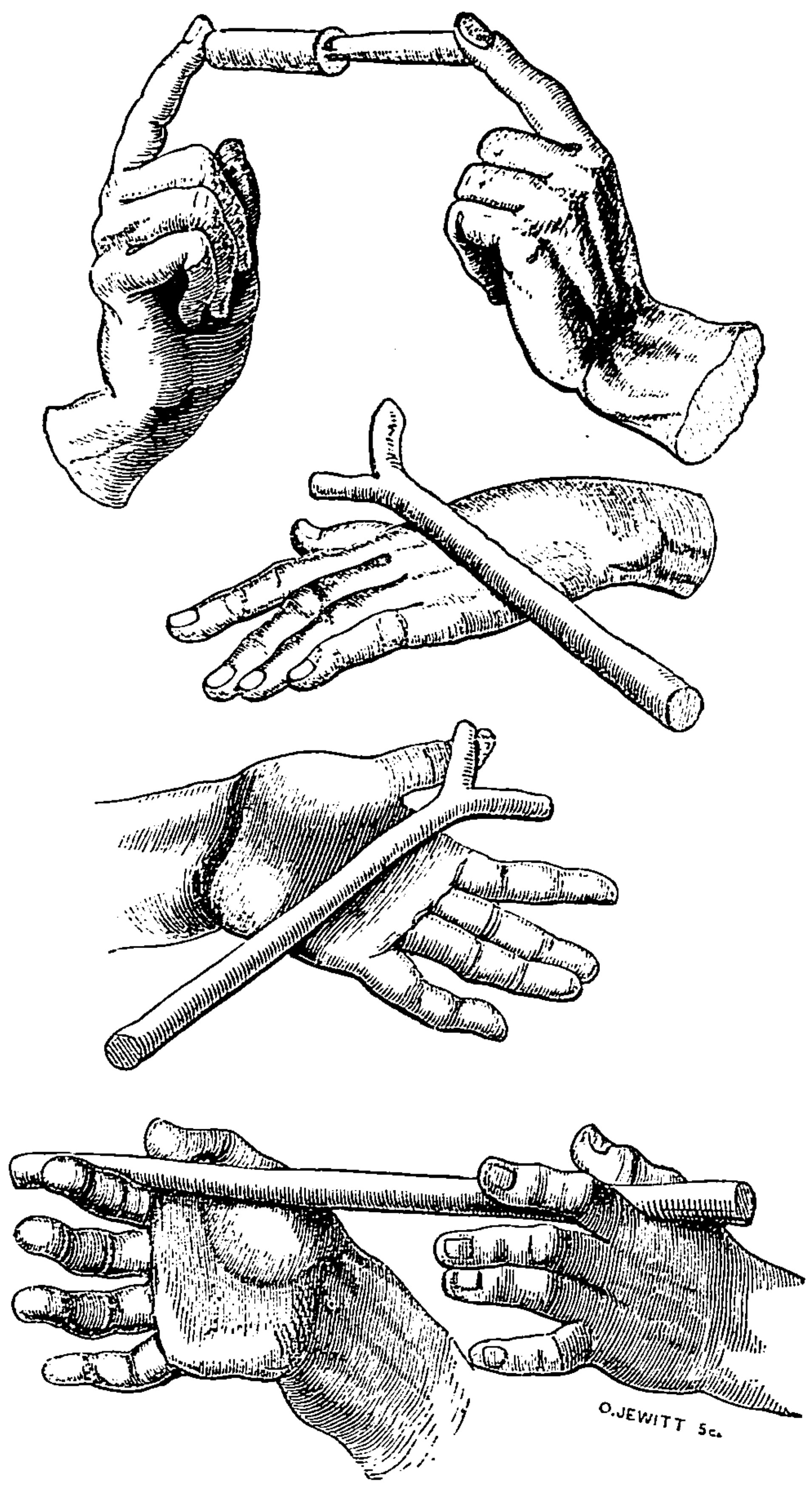

FIG. 23. Various forms of divining rod (Baring Gould).

of nature. Just as the magnetic needle moves towards

iron always, but towards copper only when carrying a galvanic current, a fact which we cannot really explain further than by calling it a "property" of iron, so it is perfectly possible that a rod in the hands of a specially sensitive individual may move under the "induction" of running water. That water in an immense number of cases has been found by means of the "divining rod" admits of no doubt. De Quincey affirmed that he had repeatedly seen it applied with success. Lord Winchilsea writes (February 9th, 1884) of J. Mullins, the well-known "dowser," or water-finder, of Coleherne, Box, Wilts: "First he cut a forked twig from a living tree and held it in his hands, one fork in each hand, the centre point downwards and the two ends protruding between his fingers. Stooping forward, he would walk over the ground to be tried. Suddenly he would stop, and the centre point would revolve in a half-circle until it pointed the reverse way. This he stated to be owing to the presence of a subterranean spring, and further, by the movement of the twig, he could gauge the approximate depth. My brother (Hon. H. Finch-Hatton) and I each took hold of one end of the twig protruding, as stated above, and held them fast while the phenomenon occurred, to make sure that it was not caused by the movement of the man's own hand or fingers. The tendency to twist itself on the twig's part was so great that on our holding firmly on to the ends it split and finally broke off. The same thing occurred on a bridge while standing over a running stream. Stagnant water seems to have no effect on the twig." Other crucial tests being applied, "all present considered the trial satisfactory in every way, and it certainly was conclusive of two things: first, the man's perfect good faith; secondly, the effect produced on the twig emanated from a power outside himself, and appeared due to the presence of running water." Similar testimony is given by Lord Heytesbury, the Earl of Jersey, Col. Wilson (who found the power less rare than is commonly supposed), and many others.

Another successful water-finder is L. Gataker, of Weston-super-Mare, who states that he is only affected by running water, and quite passive to stagnant. He says that "various kinds of wire or a watch-spring answer the same purpose as a twig or rod. A large number of people have the power to a certain extent. . . . I now use my hands alone, holding them out with palms towards the earth. I reckon the rod as an instrument only, and that the power itself is in the person."

The Rev. S. Baring Gould, in an interesting paper on the divining rod in his *Curious Myths of the Middle Ages* (from which the illustration on p. 74 is taken), says, "The forefingers are placed against the diverging arms of the rod, and elbows against the sides; it is thus held in front of the pit of the stomach, about eight inches off, delicately balanced. If the pressure of the balls of the fingers be in the least relaxed the stalk will naturally fall. It has been assumed by some that a restoration of the pressure will bring the stem up again towards the operator, and a little further will make it vertical. A relaxation then lowers it, and thus rotation. I cannot accomplish this. The lowering is easy enough, but no efforts of mine to produce revolution on its axis have succeeded."

Attempts have been made to identify the force with electricity or magnetism, but have hitherto failed. It is worth while for any one who has occasion to seek for underground water, before going to the expense of boring, to employ *first* a "water-finder" and at the same time to invite a scientific authority to test the process in detail without bias, as the practical success seems sufficient, if not to shadow a new law, like the discovery of the Röntgen rays, yet by explanation to put this peculiar power in a position where it could be more largely useful and less hesitatingly accepted.

Testing for the Source.—When a water is proved by analysis to be polluted, it is often difficult to discover the origin of the contamination, which may sometimes be situated at a considerable distance. Where the suspected source is accessible, a quantity of some substance which is easily recognisable is added either in solution or in suspension, and its appearance looked for in the incriminated water. The same process is of service in tracing the course of underground streams, leakages, &c. Of soluble substances, common salt is the cheapest, and is often sufficient; the amount of the white precipitate obtained on adding nitrate of silver will reveal any great increase of the chlorine.

Lithium chloride is sometimes used, the quantity required varying with the distance, rapidity of flow, permeability of the strata, &c. It is traced by the crimson lithium flame or by the spectroscope. Of course the original water must be tested for lithium first.

Soluble strontium salts have also been suggested, as they can be recognised in the same way, but they have the disadvantage that they may be rendered insoluble during the passage.

Fluorescin ($C_{20}H_{12}O_5$), an orange dye with a very strong green fluorescence, is one of the best agents for this purpose, as it is easily visible when diluted with many thousand times its weight of water, and an entire river may be coloured by a few kilogrammes. By its use underground communication was proved between the Danube and Auch, a small river which flows into Lake Constance. It only gives a coloration in alkaline liquids; therefore soda should be added with it. Magenta and other dyes have been employed. Prussian blue, bran, starch, or other finely divided solids, suspended in water, are used to ascertain whether the water has undergone proper filtration.

An example of the use of salt and starch for this purpose was reported from Switzerland in 1872. The village of Lausen was visited by a severe epidemic of typhoid. Some time previously four cases had

occurred at an isolated farmhouse in a neighbouring valley, separated from Lausen by a mountain of porous glacial moraine. It was suspected that the spring supplying Lausen was fed by the Fuhler brook, which ran past the farmhouse in the next valley. Eighteen hundredweight of common salt was put into a water-hole connected with this brook. In a short time the chlorides in the Lausen water showed a great increase, and the water actually became brackish. Afterwards two and a half tons of flour diffused in water were thrown into the hole, but no starch granules appeared at Lausen. Hence it was proved that the water had filtered through the mountain, and that the filtration had been sufficient to remove the starch granules, but not the typhoid germs. *Micrococcus prodigiosus* and other organisms have been used for testing the efficiency of filter beds, and it seems possible that non-pathogenic organisms of easy identification might be useful for ascertaining the origin of a pollution.

When the source is inaccessible, as in cellars and other places, the water may come from a leaky hydrant, sewer, drain, or from a subterranean current. It will generally have passed through a considerable distance of soil, and in "made ground" districts will have almost certainly suffered pollution by organic refuse. It is necessary in such cases to first ascertain the general characteristics of the subsoil water of the district and of the public supply. As a rule, sewage passing through moderate thicknesses of soil does not materially alter in mineral constituents. So that if the polluted water contains more dissolved matters, and those of a character usual in sewage, than the general supplies of the district, it may reasonably be inferred that a drain or sewer has added the impurity. It is commonly sufficient to determine the total solids, chlorine, odour on heating, nitrates, and nitrites.

An example is given by C. F. Kennedy, of Philadelphia (parts per 100,000):—

	City supply.	Cellar No. 1.	Cellar No. 2.	Cellar No. 3.
Total solids.. ..	11·5	14·0	66·1	64·0
Odour on heating..	Faint	Faint	Strong	Urinous
Nitrogen as nitrates	0·07	0·10	0·35	None
" nitrites	None	Present	Present	None
Chlorine	0·4	0·64	7·7	12·8

In No. 1 cellar a small quantity of water had been almost constantly present for a long time, of which the source could not be ascertained. Analysis shows it to be similar to the general water supply, and points to its source being a leaky hydrant or pipe. Examination of a hydrant on the adjacent property showed a leak, and when it was repaired the water in the cellar ceased. It had passed through twenty-two feet of earth. No. 2 suggested a leaky drain, and this also proved to be correct. As to No. 3, the high chlorine, odour, absence of nitrates and nitrites, pointed to recent and profuse admixture with sewer water. This also was verified on examination.

Occasionally the indications are ambiguous, but when more samples are analysed to see the influence of rainfall, &c., unusual substances, like paraffin oil, soap, &c., sometimes appear, and afford a clue to the contamination.

Wells may be of three classes: *shallow wells*, fed by the surface water, and to be condemned in nearly all cases for the reasons already stated; *subsoil wells*, drawing the ground water from a greater depth; and *deep wells*, carried through the impervious strata on which the ground water rests into the water-bearing strata below. It will be seen that the depth of the well will depend on the distance of the impervious strata from the surface (Fig. 24).

Dip-wells are those in which the water rises to near the surface and can be ladled out, and are to be

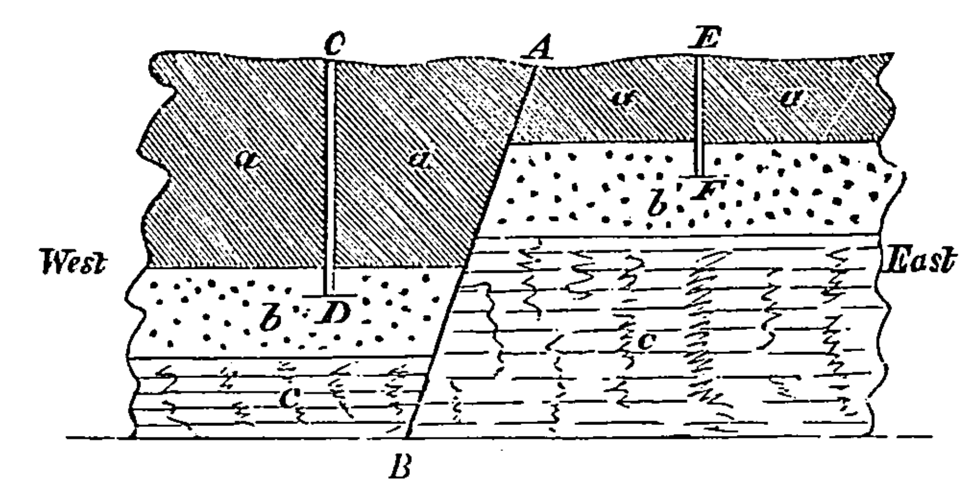

Fig. 24. Wells of different depths due to a fault.

distinguished from *draw-wells*, where the water must be raised by a pump or bucket.

A surface well drains an area which is greater the more the level of water is lowered by pumping, and the greater the porosity of the soil. The distance has been found by experiment to vary from fifteen to 160 times the amount of depression. Thus overflow or leakage from cesspools, drains, closets, or farmyards can enter a well from a distance that at first might appear safe. Pollution has in many cases been proved to have crossed a road. A roadside well in Argyllshire, supplied by a spring from a fissure in the granite, was found by the author to contain large quantities of nitrates, chlorides, and phosphates, substances which are characteristic of animal contamination. As there were no habitations near, it was difficult to explain the occurrence, until an inspection of the district revealed that on the hill above, about 500 yards away, were some fields which were liberally watered by liquid manure. Occasionally well water has been observed to smell of disinfectants which have been thrown into neighbouring drains.

Dr. S. W. Wheaton's report to the Local Government Board in 1895 on the causes of an outbreak of enteric fever in Quarry Bank Urban District traced it to polluted draw-wells close to houses and near leaking privies and defective drains, the walls of the wells being constructed of loose blocks only. Country wells of this character are daily being closed. In most large towns this has been done, but in outlying districts a great number are still tolerated on account of the difficulty of procuring a better supply. It was estimated in 1893 that there were still about twelve

millions of people in Great Britain supplied with domestic water from shallow wells.

Town pumps in the Middle Ages were the chief sources of the public water. It has already been mentioned how the increase of population caused the soil to become saturated with sewage, and how, therefore, the necessity arose that such sources, derived in nearly all cases from shallow wells, should, in the interests of health, be closed. Very few remain in remote villages, and these are being rapidly removed. On the Continent, particularly in Germany, the people still draw from the public fountains; these in the majority of cases, being fed by deep springs, are free from objection, except from the danger of the spread of infectious disease by the use of imperfectly cleaned vessels. In the East the public wells are centres of population, and their possession is of supreme importance. For example, in the Soudan campaign of 1896 the Murat and Ambigol wells were the first points seized and strongly held. The water of most of these Nubian wells, or rather pools, is brackish, and has a sulphuretted smell; but some rock cisterns give a small supply of pure water, which is supplemented at times by water sent up from the Nile on camels. The taste and odour imparted by the skins in which water is commonly transported in the East are highly unpleasant, but do not seem to be injurious.

Subsoil or *ground water* is surface water which has percolated to a depth of about thirty feet through the alluvial gravel and sand which in many cases overlie the bed rock or floor of clay. It contains considerable amounts of nitrates and chlorides derived from previous sewage contamination (p. 245), but in itself is generally innocent, though, like river water, it requires to be carefully watched. Dr. Koch considers it entirely suitable for drinking, and the town supply of Frankfort is derived from the subsoil water of an extensive wood, which is carefully kept free from habitations and other sources of contamination. But in the neighbourhood of large cities such care could hardly be exercised on account of the value of the land. The extraction of subsoil water often effects a remarkable improvement in the health of a locality by removing the dampness.

The "line of saturation," or water-line, is the level at which the water stands, and to which it will rise in wells, in any water-bearing stratum. If the water were perfectly free to move this would be a horizontal line at the level of the lowest point of escape; but by the resistance of the rock or soil it is raised into a straight line or curve sloping upwards to the point of entry of the rainwater at the outcrop of the strata. In the London basin the highest point is the outcrop of the Gault clay below the chalk near Tring, in Hertfordshire. Thence it runs in a slightly curved line to the Thames near Lewisham, more or less disturbed by two intersecting faults and by some inequalities in the clay floor. Where, as at Watford the surface lies below this line, springs,

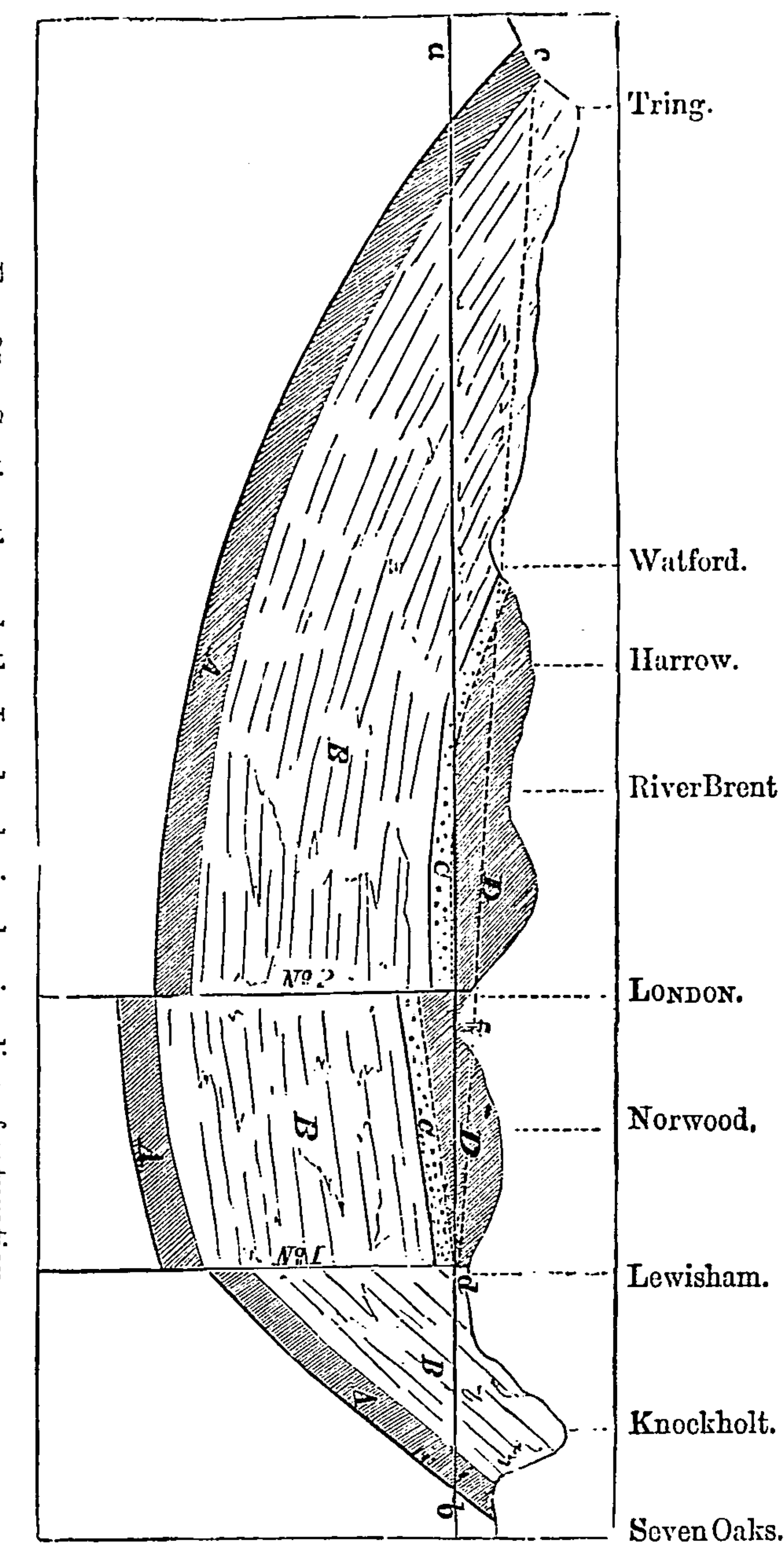

Fig. 25. Section through the London basin showing line of saturation.

are frequent (Fig. 25). Although the main run of the saturation line can be deduced from geological sections, the actual details can only be worked out by observations of existing springs. The smaller springs of a district where they run over beds of an impermeable nature may often be at a higher level than the general saturation line, but the lower end of this line is always found at the high-water mark of the main river or lake of the district, or at the level of the sea.

When a well or boring reaches below the saturation line the water will stand at that level, only affected by pumping, which will lower the line for a considerable distance round. The effect will then be to exhaust the neighbouring wells, and if it continues at a rate faster than the incoming rain can percolate the whole stratum will be depleted. It is therefore necessary to leave periods of rest. It is a singular fact that in London, Saturdays, Sundays, and holidays are recorded by the higher level of the water in the great brewers' wells. When the limit is reached there is no advantage to be derived from deepening a well beyond the chance of opening into fissures or new strata; it is better to drive horizontal tunnels, or "adits," to extend the area of connection, and also to form an underground reservoir to make the supply more constant. These adits, or "headings," may be only borings from three to twelve inches in diameter; they immensely increase the yield and regularity of a well.

Two of the artesian wells at Trafalgar Square, which supply the Houses of Parliament, are connected by a horizontal tunnel 400 feet in length, which forms a reservoir with a capacity of 112,000 gallons. It must be remembered that an injunction and action for damages will usually lie against the sinkers of a well if the operations cause a loss or deviation of water from any well-defined channel, although there is no right to underground waters. (As to the methods of sinking and lining wells, Swindell on "Wells and Well-digging," in Weale's Series, may be consulted.)

In every case the greatest care must be taken by properly cementing the bricks inside and, if possible, by coating them with tar outside, to exclude the surface water. The lining must also be inspected at intervals, and any cracks filled up. The upper portion is often made of a succession of lengths of iron tubes screwed or jointed together with a watertight packing.

It is now possible to obtain large earthenware pipes of three and a half feet diameter with an internal flange to facilitate sinking. Where such pipes are carefully jointed together by cement and used for the upper twenty feet of a new or old brick well, security against surface water is assured.

Artesian wells are drilled through the rock by a boring machine, and are generally lined by lengths of iron tube screwed together. The water sometimes rises to a great height under the pressure of the superincumbent strata. (For detailed description of a number of deep wells round London see Hughes's "Waterworks," in Weale's Series, pp. 178—191.)

The accompanying illustration will give an idea of the construction of the different kinds of wells and of the line of saturation (Fig. 26). The famous artesian well at Grenelle is 1,798 feet deep, and gives 516 gallons of water per minute. One at St. Louis, U.S.A., is 3,843 feet deep. The water of deep wells is of great organic purity, but often of high hardness, as in the

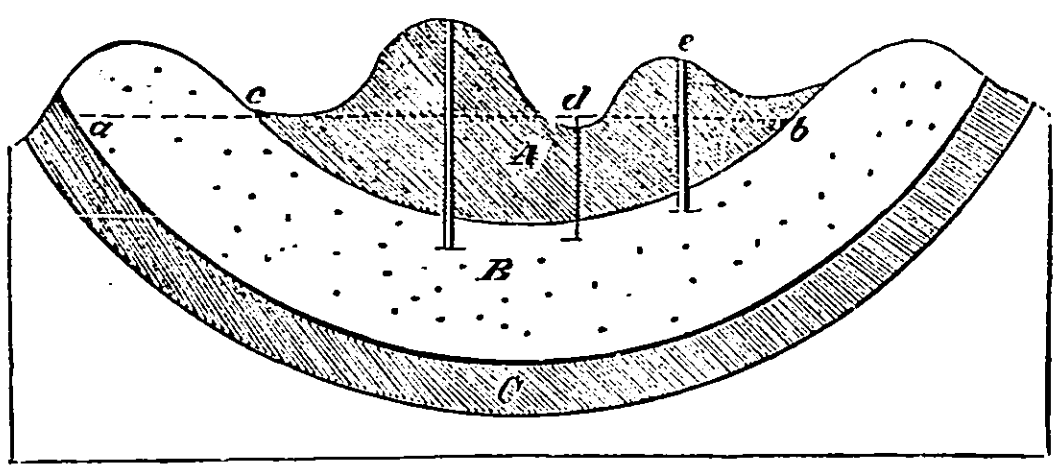

FIG. 26. Artesian wells.

Kent Water Company's supply from deep wells in the chalk. Mr. G. Webster has recently proposed to supplement the London water supply from borings in the chalk near Rickmansworth. He has already sunk five wells, which yield about 10,000,000 gallons of pure water daily.

The artesian wells of Dakota, U.S.A., are, perhaps, the most remarkable examples of their kind which have ever been opened, both as regards the pressure and the volume of the escaping water. More than 100 wells, from 500 feet to 1,600 feet deep, are at

present in successful operation in the district north of Yankton, and they yield a constant stream of water, which is apparently never affected by any of the surrounding influences. The pressure of the water is abnormally high in many instances, and up to 180 pounds per square inch has been registered by the gauges. The power is utilised in the more important towns for water supply, for protection from fire, and for driving machinery; and a very considerable saving is effected by the adoption of hydraulic apparatus in place of the steam engine. Artesian wells on up-country farms in Australia have been attended with considerable success, yielding at 1,500 to 2,000 feet constant supplies of 2,000,000 to 4,000,000 gallons daily, and thereby converting a waterless country into one supporting thousands of cattle and sheep.

At St. Denis, near Paris, there exists a well that is rather more than a curiosity. In sinking, three consecutive water-bearing strata were found actually representing the shallow, subsoil, and deep supplies. It was decided to sink three concentric tubes, the inner one to the lowest source, the middle one to the next, and the outer one to the layer next the surface. Thus three separate waters were obtained from different strata. The lowest was the only one safe for drinking purposes, but the others were suitable for technical use. The experiment opens out possibilities in sinking an artesian well of using by concentric pipes the water from upper layers for ordinary non-drinking purposes.

Driven wells are claimed to be an American invention. The idea is said to have originated from some successful attempts made by the soldiers during the

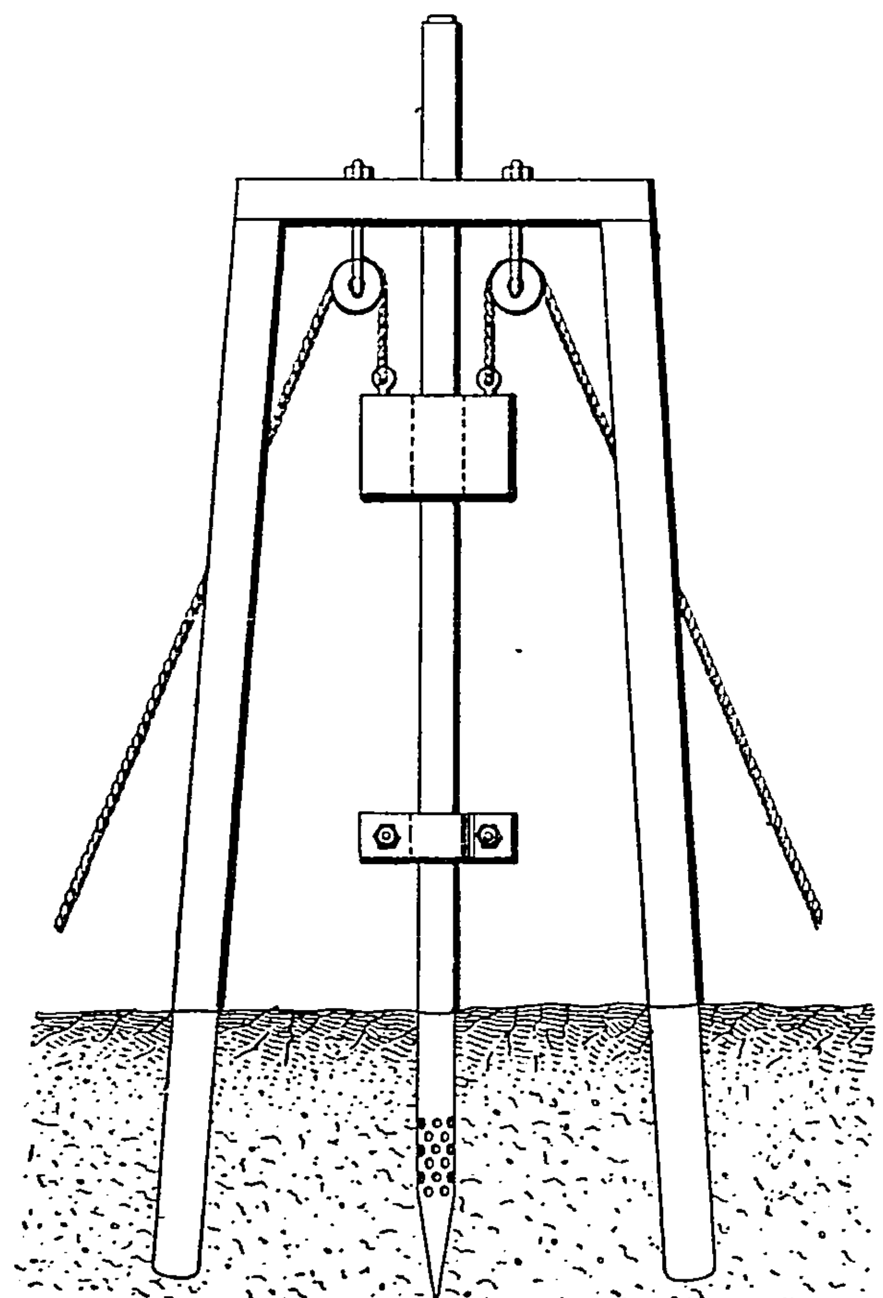

FIG. 27. Driving a tube-well.

Civil War to obtain water by driving gun-barrels into the earth. Norton's tube-well was first extensively used in the Abyssinian expedition, and in the Nile and other expeditions since. It is driven by

a ring weight, which is raised and allowed to fall (Fig. 27). When one length of tube is driven another length is screwed on, until the water is reached. More than 2,000 years ago the Chinese bored for water in much the same way, and erected water-towers when the pressure from the bore was not sufficient.

Dr. Koch (*Zeitschrift für Hygiene*, xiv., 1893) has recently condemned all brick wells as "irrational and dangerous, on account of unavoidable fissures in the walls, because they are always open or insufficiently covered, and, lastly, because laundry operations and the washing of utensils are often conducted at their margins, whence infective matter might easily find its way." But each of these faults could be easily obviated, except, perhaps, the permeability of the walls. The mouth should be raised, and the wall carried about a foot above the surface. He proposes that an iron pipe should be inserted and the well filled up with gravel and sand, while the pump should be placed at some distance off and connected by a properly protected pipe.

Tube-wells have two great advantages: they are cheaply driven, and the tube, in case of failure to find water, can be taken up and sunk in another place. Of course they will not penetrate hard rock, which can only be pierced by a percussion drill, as used for an artesian well. They are especially suited for loose gravels and sand, which are difficult to deal with in ordinary well-sinking operations; and if properly screwed together the tubes effectually exclude surface water. Besides frequent examinations of the borings brought up by the drill to ascertain the character of the strata, at intervals an analysis should be made of any promising supply of water reached in regard to its purity and constancy of composition. Rapid variations either in the volume or constituents indicate that the underground source is neither permanent nor copious. The author was recently consulted as to a tube-well driven through sea-sand and gravel at Netley. The high percentage of salt in the water at once indicated a serious leakage of sea water into the tube. Greenwell and Curry* state that a thirty-foot tube-well can be driven for a total cost of about £10.

P. Griffith (Society of Engineers, May, 1896) has given a detailed description of borehole and other pumps which have recently been employed, and of various modern provincial waterworks.

In the history of Eastern nations, the sinking and protection of wells constituted an all-important part of tribal existence. The oases of deserts were originated by natural springs, but towns and villages centred round wells, most of them dug in the rock, but many in looser strata were constructed with sometimes elaborate timber or brick casings. Contests often occurred as to the possession of these wells, such as the one between Abraham and

* *Rural Water Supply.* London: Crosby Lockwood & Son, 1896.

Abimelech (Gen. xxi. 25). An invading army generally destroyed or filled in the wells; the defenders sometimes poisoned them. This latter practice is now forbidden by universal consent in the articles of war. Large quantities of water were required to be raised for the use of man, of the numerous flocks and herds, and for the irrigation of the pastures. The simple rope and pitcher was at an unknown date improved upon by the windlass, which is said to figure in some Egyptian inscriptions. Afterwards a string of buckets on a chain was adopted, and later on other appliances, such as the lift, force, and centrifugal pumps.

The so-called Joseph's well at Cairo, which is probably over 1,000 years old, is a marvellous example of early well engineering. It is cut in the solid rock to a depth of 297 feet, and raises the water in two stages by means of an upper and lower system of buckets worked by oxen at the middle and at the top. A spiral way winds round the upper shaft to allow the oxen and labourers to gain access to the middle chamber.