CHAPTER VII.

WELLS.

Different kinds of Wells.—*Shallow Wells:* their Liability to be Contaminated when in Certain Localities; Yield of Shallow Wells; 'Drip-water.'—*Deep Wells* sunk under Various Conditions; Faults.—*Artesian Wells:* London and Paris Basins; other Conditions giving rise to Artesian Wells; 'Blow' Wells.—*Chances of Failure:* Faults; Deep Well at St. Louis, U. S.; Ridge of old Rocks under the London Basin.—*Yield of Wells:* Quantity of Water Passing into the Stratum; Infiltration of Tidal and other Waters; Line of Saturation; Cone Theory; United Effect of Pumping from Neighbouring Wells; Means Available for Increasing the Yield of a Well; Headings *versus* Additional Boring; How the Yield of Wells should be Recorded; Temperature of Well Water.—*Well Sinking:* Excavating; Form of Well and Headings; Materials Used for Steining Wells; Method of Proceeding with the Work; Cast and Wrought Iron Cylinders; Diameter of a Well; Carbonic Acid in Wells.—*Well Boring:* Chinese System and its Defects; Rod Systems; Rods, their Jointing, Dimensions, and Resistance to Torsion; Boring Tools; the 'Miser;' Advantages of Sinking a Well previous to Boring; Shell-pumps; Modifications in Boring Apparatus by M. Kind and M. Dru; Mather's Boring Apparatus; Fauvelle's System; Recovery of Broken Rods and Tools from Bore-holes; Wrought and Cast Iron Bore-pipes; Cost of Sinking and Boring.

IN a previous chapter notice has been taken of some of the conditions under which water from the clouds penetrates into the earth, and accumulates there in subterranean depressions, until it overflows in the form of a spring, or escapes or is recovered through an outlet formed artificially and called a well. Wells are either shallow or deep, these terms being understood with more than their usual significance; they may also be divided into ordinary and artesian.

Shallow wells are those which are sunk comparatively but a short distance into a superficial water-bearing stratum, and are supplied by the infiltration of rain and other water which falls on the adjacent surface of the ground, or which is drained from ponds, cesspools, sewers, rivers, or other reservoirs and channels. The numerous wells sunk for domestic purposes in many villages and towns are as a rule of this kind, while in the great city of London itself hundreds of such wells, both public and private, are to be found; and until the ravages of disease and death were traced to the drinking of the water which these wells were known to yield, they were classed amongst the greatest boons the inhabitants enjoyed. The supply was within easy reach, and could be readily pumped up; moreover, the water itself was clear, cool, sweet, and sparkling. Chemistry, however, has found in these very tempting qualities elements of the greatest mischief and danger, some examples of which are afforded by the analyses given in a previous chapter (p. 25).

These serious objections, it must be understood, are urged only against those shallow wells which are situated in the immediate neighbourhood of towns, cemeteries, highly-cultivated lands, and other sources of organic matters with which the water is liable to become contaminated. Localities may frequently be discovered where the conditions are favourable for sinking shallow wells, and where at the same time the water will be wholesome and comparatively pure. The quantity derivable by these means will depend upon the depth of the well, the nature and position of the water-bearing stratum in which the well is sunk, and the disposition of the impermeable stratum below.

If the well be sunk in a bed of gravel or sand, or other permeable stratum, where the conditions are similar to those represented by fig. 8 (p. 48), the water derived from it will be simply that which, in percolating downwards through the pores and fissures, flows in through the sides of the well, because of the diminished resistance to its passage, quicker (and from a larger surface) than it can filter away through that part of the bottom of the well in which the water is standing. This '*drip-water*' is an element in the yield of all shallow wells, and of certain deep ones; but, except in the case just referred to, it is never more than an insignificant portion of the whole. Suppose now that a well is sunk in the permeable stratum shown in fig. 9 (p. 48); its condition will remain similar to that of the last-mentioned well, until the 'spring is tapped'—that is to say, until the well is carried down below the line of saturation, A B S; the supply will then no longer be limited to the drip-water, but will be drawn from the subterranean reservoir formed by the depression in the underlying impervious stratum. The depth to which such wells must be sunk will depend simply upon the vertical distance from the ground surface to the line of saturation, a distance which will sometimes vary considerably, even in closely adjacent sites ; irregularities or undulations of the retentive substratum may divide the geological basin into different reservoirs with different lines of saturation, and thus render the selection of the most favourable site a somewhat doubtful task. Shallow wells are frequently sunk in the vicinity of rivers and lakes, and are supplied by the water filtering through the sands, gravels, or rocky detritus which forms their margin.

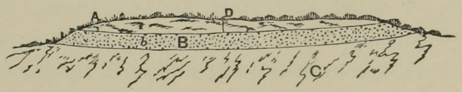
Deep wells are those supplied by water which has had to percolate and filter through large masses of the earth's crust, and has therefore been considerably modified in character by the substitution of soluble mineral matters for the organic and other impurities it held when previously in the state of river or other drainage water. The difference between shallow and deep wells, then, as properly understood, consists rather in the greater or less distance of the source of the water which flows into it than in the actual depth of the well ; for, as will be presently seen, a deep well, or more properly a deep-seated well, may be formed by sinking through a moderately thin bed of clay or rock into a water-bearing stratum, whose nearest drainage area or outcrop is at a considerable distance. Perhaps the most simple conditions under which a deep well may be sunk are to be found where the lower and saturated portion of a massive water-bearing formation is penetrated by the well ; as, for instance, by sinking through the exposed surface of the chalk between *s* and *s''* (fig. 16, p. 55), or of the greensand between *s* and *s* (fig. 18, p. 59). In both these cases the most favourable sites would undoubtedly be in the immediate neighbourhood of the springs *s* and *s'*, where the line of saturation could be reached, and a large supply obtained from wells of inconsiderable depth. The sinking of such wells at Watford was at one time strongly advocated as presenting great advantages for a metropolitan supply.*

Such wells, although shallow if their actual depth alone be regarded, are properly classed as deep-seated wells, because the water which supplies them has traversed through a considerable thickness of the water-bearing formation. Indeed wells sunk on the hills between *s'* and *s''* (fig. 18) would, although deeper, be in a far less favourable condition ; for, after having pierced a much greater depth of the stratum, they would then only be drawing from the same store of water as in the other case.

In the chalk and the New Red Sandstone districts of England are to be found most of the important deep wells sunk wholly through a water-bearing stratum ; and the great thickness to which these formations attain (see Chapter IV.) admits of such wells being carried to a very considerable depth.

Fig. 48 represents a water-bearing stratum, B, lying in a shallow basin upon an impermeable bed, C, and capped with a layer, A, also impermeable. The stratum, B, may be of such a free and porous character, that the rain, falling upon and draining towards its outcrop, may pass readily into the lower portion of the basin. A well sunk, say at D, would probably yield a considerable volume of water ; and although the thickness of the strata, A and B, and the depth of the well, may not be very great, yet the water supplying the well would be compelled to pass through a considerable thickness of filtering medium, and the well itself would be properly classed as deep-seated.

FIG. 48.



The conditions which affect the success of a well, as far as the yield of water and its level are concerned, are so varied, that any attempt to illustrate them with an approach to completeness would necessarily prove futile ; the cases which are given in this chapter, therefore, must be regarded only as a few types of the conditions that are frequently met with in practice.

One of the most frequent and influential causes of either success or failure, as the case may be, is the existence of faults in the strata in which a well is sunk. Referring to fig. 12 (p. 49), let it be supposed that the fault there shown has been filled with an impervious material, forming a dyke which serves to retain the water in the permeable stratum lying above it. A well sunk, say at A, in the latter, would yield a supply more or less abundant according to the extent of the exposed surface of that part of the water-bearing stratum, while one sunk on the other or lower side of the fault would evidently be a failure, as far as the yield is concerned. If, however, the fault were filled with the detritus of the adjacent strata, in such a manner as to freely admit the passage of the water, it is obvious that the most favourable site would be one below the fault, carefully selected with regard to the position of the fault on plan, and also in such a manner that the fault would be intersected by the well ; for the water from a comparatively large extent of the stratum would be drained into the fault, and thence into the well. Should the fault not be struck in the vertical line of the well, a tunnel or heading driven from the well into the fault would have a similar result.

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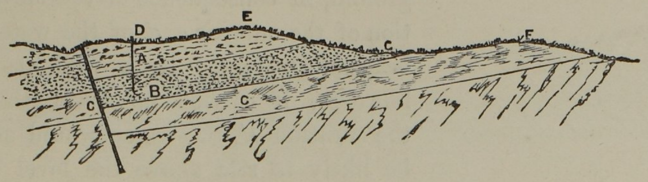
* See Reports, by R. Stevenson, to the London and Westminster Water Company (1840), and to the London (Watford) Springwater Company, by S. C. Homersham, C.E. (1850).

Fig. 49 represents a case in which the impermeable stratum C has been faulted against the permeable stratum B, in such a manner as to retain the water in the lower part of the latter, as shown by the dotted line. A well sunk at D, through the impermeable stratum A, into the water-bearing stratum below, would probably yield a large supply; for the rainfall on the whole extent of country between E and F would be drained by the valley G, and would probably find its way towards B.

Fig. 49.



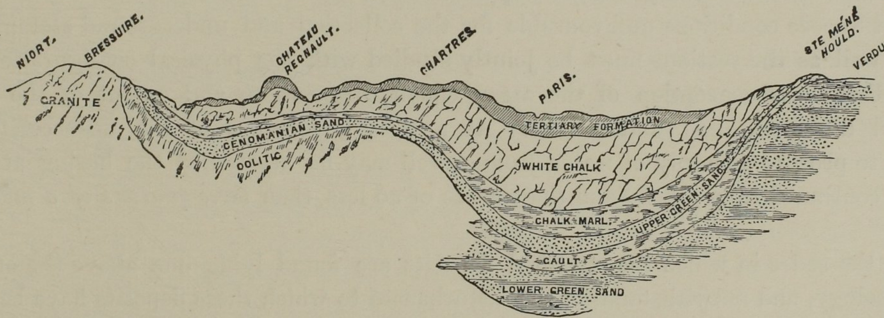
The foregoing cases of deep-seated wells may all be classed as *ordinary*, in distinction from *artesian* wells. The term artesian well has been variously understood; by some, as a well that is partly or entirely bored, instead of sunk in the usual manner for its whole depth; by others, as a well which has had to penetrate an impermeable stratum before reaching the permeable one from which the supply is derived. Here, however, it will be understood to signify a well supplied from a stratum where the water is held down under pressure by a superimposed impermeable stratum, so that when the latter is pierced through (an operation generally conducted by boring), the water will be forced upwards in the well or bore-hole to a height depending upon that pressure. According to this definition, none of the deep-seated wells already referred to are properly artesian; for, although they may have penetrated an impervious bed before reaching the water-bearing stratum, it may be seen that the water when found was hydrostatically in the same condition as that in a deep well sunk in a water-bearing formation entirely.

The term artesian has been confined by some to those wells from which the water ascends with a force sufficient to rise above the surface of the ground. These, however, are more properly overflowing artesian wells.

The conditions which give rise to the phenomena of artesian wells are as varied in detail as those of ordinary deep wells, although, like the latter, they depend upon one simple principle for their action. Artesian wells are most generally situated in geological basins such as that, for instance, represented by fig. 14 (p. 50), in which a water-bearing stratum B is found in the hollow of an impermeable bed C, and underlies an impermeable stratum A, which extends below a line joining the outcrops of the water-bearing stratum. The London basin, sections of which, from their frequent illustration, are so very familiar, affords a very complete and interesting example of the alternation of permeable and impermeable strata, yielding a supply to numerous artesian wells. (*See* also p. 50.)

The city of Paris is like that of London, situated in an extensive geological basin; and on the accompanying section, taken in a north-easterly direction from Niort to Verdun, are shown the positions of some of the more important borings which have been carried through it. Those of Passy and Grenelle, situated in Paris itself, are 1,923 feet and 1,795 feet in depth respectively; while from the latter boring the water rises through a $3\frac{3}{4}$-inch stand-pipe to a height of 128 feet above the ground surface.

Fig. 50.

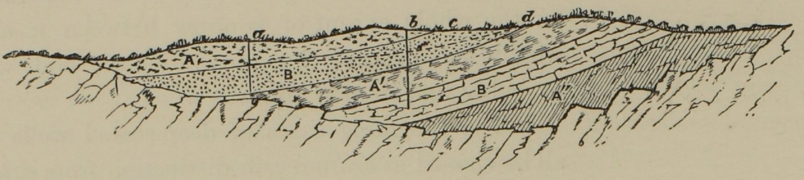


Horizontal scale, 80 miles to an inch. Vertical scale, 2,000 feet to an inch.

The section shown in fig. 48, although taken across a geological basin, does not represent a district in which artesian wells properly so called would be met with; for the water supplying the wells sunk into the water-bearing stratum, as at D, would, except for the fluctuation in the line of saturation, rise no higher than the level at which it was first found.

In fig. 51 is presented a section of a series of stratified deposits resting upon the older rocks. The impermeable beds, A, A′, A″, alternate with the permeable ones, B, B′, and serve to retain under pressure the water which finds its way to their lower portions. If a well were bored at *a*, the water pent up in the stratum B would probably rise very nearly to the surface of the ground, in consequence of the elevation of the outcrop *c*, *d* of the water-bearing stratum. In a well at *b*, however, if carried no lower than the stratum A′, the water would not be likely to rise above the level at which it was first found, and the well could not, therefore, be classed as artesian, the term being understood as above defined. Moreover the yield of the well would vary to a certain extent with the rise and fall of the line of saturation (shown as dotted in the figure), due to the balance between the inflow of rainfall at *b*, *d*, and the draught upon the stratum by wells as at *a*.

Fig. 51.



Suppose now the boring to be continued below the impervious bed A′; the water-bearing stratum B′ would then be tapped, and in all probability a large and permanent supply be obtained, the water standing at a level as high perhaps as before. Effects similar to those just described may frequently be traced to faults in the strata.

An interesting type of artesian well is found in those numerous 'blow wells' of Lincolnshire which have already been mentioned (p. 50), and which are simply perforations through the boulder clay down to the chalk, from which the water rises above the surface of the ground, frequently with a pressure sufficient to supply the upper storeys of the houses.

Of the *chances of failure* to procure a satisfactory yield from a well, some have been referred to already. From a well sunk into the impermeable stratum A (fig. 10, p. 49), only an insignificant supply could be expected; although a considerable portion of the rain falling on the surface from E to D would find its way into the stratum A; for there is no basin in which this water could be stored, and from which it could be drawn, and scarcely any would be intercepted by the well in its rapid passage to the spring at S. In the district of which fig. 11 is a section, an opportunity is afforded for boring an artesian well at D; the yield, however, could only be small, because of the confined drainage area at E F. An ordinary deep well sunk at A would remain quite dry, excepting at such times as the intermittent syphon spring, S, would be acting, an occurrence which the existence of the artesian well at D would be likely to prevent entirely.

But, perhaps, as before remarked, the most prevailing cause of unexpected failure or success is the existence of faults, and it is only by the most careful study of the circumstances and evidences of the case that proceedings may be taken with any confidence.* It is not enough, moreover, to regard one section of the strata merely, and the illustrations which have been given are supposed to be in districts where other sections taken through the wells would not expose conditions unfavourable for the collection and underground storage of water. The geological plan as well as the sections must be jointly studied with the physical configuration of the district, in order to obtain that clear conception of the arrangement, disposition, and extent of the strata, which is necessary to avoid disappointment and failure. As a notable instance of the unsuccessful issue of most persevering efforts to procure a supply of water from a well may be mentioned the boring at St. Louis, U. S., which, after being continued to a depth from the surface of no less than *three-quarters of a mile*, was hopelessly abandoned.

Uniformity in the order in which the stratified deposits are found lying one above the other is one of the great features of geology, and notwithstanding the disturbances to which these deposits have been subjected, and the varying conditions under which they were formed, there is a regularity which gives to the geologist a justifiable confidence in his speculations. Curious instances, however, are sometimes met with of the most reasonable expectations in these matters being overthrown, and a very remarkable one is in connection with the lower greensand of the London basin, to which reference has already been made (p. 58). Fig. 52 is a section across the London basin from north to south, showing the probable ridge of old rocks which interferes with the formerly supposed continuity of the Lower Greensand under this city; the representation of the ridge is of course ideal, and is given merely to show the general nature of the phenomenon.†

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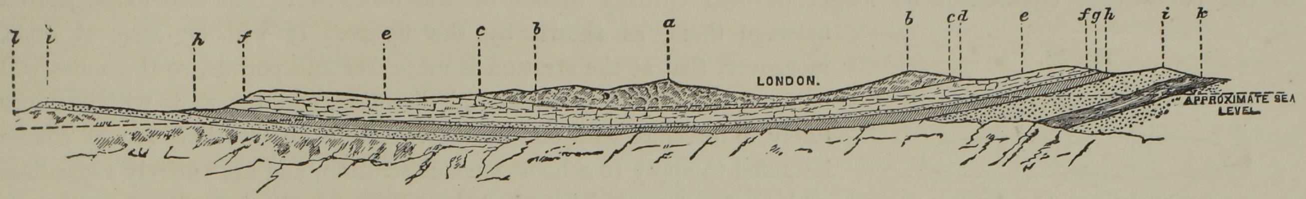
* One of the wells of the Kent Waterworks Company, at Deptford, yields more than 5,000,000 gallons per day—a quantity accounted for principally by the existence of a great fault in the London basin which traverses this district, and of which mention has been made already in Chapter IV.

† Geology of Parts of Middlesex, etc., by W. Whittaker, B.A. F.G.S.; Memoirs of the Geological Survey of Great Britain.

Fig. 52.



The quantity of water which a well will be likely to yield is a matter which, from the number and variety of modifying circumstances, cannot be with certainty estimated ; and all that can be done is to regard the varying conditions of the case, and to form a comparison with the yield of wells similarly situated. Regard must first be had to the drainage area of the water-bearing stratum, from which the supply will probably be derived, the rainfall upon that area, and the proportion of the rainfall that is likely to infiltrate into the stratum. The drainage area is not necessarily confined to the outcrop of the water-bearing stratum itself, for this may be so situated as to receive the drainage from a considerable catchment area of impermeable surface. The subjects of rainfall and its infiltration have been treated in Chapters III. and IV., but there will be in some cases infiltration from rivers and lakes of sufficient importance to take into account. The dip and nature of the water-bearing stratum itself, as affecting its capability for transmitting and storing water, its lithological character, and the prevalence of fissures, must receive due attention ; and here, again, Chapter IV. of this work may be of assistance. Having approximately ascertained the amount of water received by the stratum, it is necessary to enquire how much is given out again as springs, now on the surface, now subterranean flowing away by some fissure or fault to a lower stratum, and now in the bed of a river, helping to augment its flow. Whenever a water-bearing stratum comes in contact with a volume of water, whether it be a river, a lake, or even the sea, unless the hydrostatic forces be exactly balanced against each other—namely, that of the water saturated in the stratum, and that of the free water in the reservoir or stream—there must necessarily be a current inward to or outward from the water-bearing stratum. Sometimes the rise and fall of the tides brings about an oscillation of the current, and as evidence of this may be noticed the infiltration of salt water into wells sunk near the coast, after a succession of high tides. Sometimes the direction of the current is determined by the variations in the level of the line of saturation in the water-bearing stratum. Streams passing in their course over an exposed portion of water-bearing stratum are liable to an augmentation or diminution of their flow, according as the line of saturation rises above the stream level or falls below the river-bed. The depression of the line of saturation by pumping has in numerous instances resulted in the infiltration of tidal and other water into wells, most notably in Liverpool, in the London basin, and on the south and south-east coasts of England.*

Having thus traced the course of the water until it is found stored in a subterranean reservoir, it now remains to be seen how a shaft sunk or hole bored into the water-bearing stratum enables the water in this reservoir to be withdrawn.

Before proceeding, it is perhaps worth while to note a fact, very simple in itself, yet one by neglect of which the unwary may be caught. It is, that the level at which the water stands in a well is not necessarily the line of saturation in the stratum ; for there may be, in certain cases, several feet of water standing in a well whose bottom may be a hundred feet or more above the line of saturation. Such water is only the 'drip water,' already referred to, and would soon vanish before the efforts of a pump of reasonable capacity. Indeed the drip water would be mistaken for an index of the line of saturation only where such was not exactly known, and where the well had been left for some time without record and without interference ; for, in the progress of the sinking, there will be ample evidence of the line of saturation being reached, and, on the other hand, when the well is complete, and the permanent pumps are at work, the level may be easily known by the height to which the water rises after the pumping has been stopped. Suppose for a moment that the water in the well stands at the level of the line of saturation. If now the water be pumped at a certain constant rate until the water-line in the well remains depressed by a given amount, the line, or rather surface of saturation in the stratum, will be depressed into, approximately, an inverted cone whose apex is at the water-line in the well, and whose base is on the level of the line of saturation, the inclination of the water surface being determined by the equilibrium which must exist between the force of gravity tending to accelerate the flow of the water, and the frictional and capillary resistances which tend to retard it. Of necessity the inclination will be steeper in a close stratum through which the water filters with comparative difficulty than it will be in a stratum of an open, free, or

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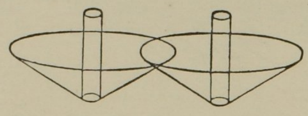
* See a Paper by Mr. Braithwaite, Trans. Inst. C. E., vol. xiv. p. 507.

more porous character, such as sand, gravel, or rocky detritus. The result of this is that, to secure a given yield from a well, the water-line must be lowered to a greater depth below the line of saturation in the former case than in the latter. The question of the mutual effect of the pumping from ordinary deep wells is here involved ; for where two such wells are so near as that their cones of drainage intersect, as it were, the portion of the cones thus isolated is no longer devoted entirely to one or the other well, but has to be shared between them, as shown by the figure. It will be seen at once, moreover, that as the stratum is more free and porous, so the cones will be more extended in a horizontal direction, and the wells will be more likely to interfere with one another. These observations are of course intended to apply to a homogeneous stratum, and are entirely regardless of long fissures, which may bring distant wells into direct communication with each other, and of faults and dykes which may isolate adjacent ones by dividing the stratum into areas more or less independent of each other. In the Red Sandstone district remarkable instances are found both of the mutual effect of the pumping from wells separated by a long distance, and of the apparent disconnection of wells very near together. It is evident that in such particular cases the supply is principally obtained from fissures or definite subterranean channels, rather than by a uniform percolation through the mass.

Fig. 53.



The above effects are of course local, being independent of that which results from the general depression of the line of saturation by pumping; the latter may be conceived as a representation, on a larger scale, and for a group of wells, of that depression into a cone which takes place in the case of each individual well.

In order to increase the yield from a well already executed, the following means are available. The water level in the well may be lowered ; this is really giving a greater hydraulic head to induce the extra flow. Or the surface of the well below the water-line may be increased, either by further sinking or boring, or by driving headings. The question of lowering the water level in the well is simply one of the continual expense of increased pumping power—due to the greater lift—as compared with the first cost of extending the well. Apart from the relative feasibility or expediency of driving headings or continuing the well downwards, as far as their execution is concerned, and supposing the same extra surface to be exposed by either operation, there are the following considerations :—further sinking or boring would open up a part of the stratum, which, from the superincumbent weight, would in all probability be more dense, and through which, therefore, the percolation would be less free; and this will explain the circumstance, frequently occurring, of the additional yield from, say, a bore-hole continued at the same diameter being less per foot as the boring is carried down. Headings would perhaps be more likely to intersect extra faults and fissures from which an increased supply would be obtained ; while, on the other hand, if there be in the stratum layers of a more retentive character, tending to hold up the water in sheets, the continuation of the well downwards would perhaps be more advantageous than its extension horizontally. Where headings can be conveniently driven, they will as a rule expose a larger surface of the stratum ; and they will moreover present the advantage, where the pumping is intermittent, of acting as a reservoir or lodgment to store the water, from which it may afterwards be pumped at a rate greatly in excess of the average yield. For such headings to be most efficient, they should be only just above the lowest level to which the water is ordinarily pumped ; for, if they be below that level, they will be useless as reservoirs, because the water will never be drawn off from them; and whenever they are above that level, the surface they expose will be more or less unavailable for draining a supply into the well. In determining upon the relative advantages of driving headings or of deepening the well, and also in determining the level at which headings should be driven, it must not be forgotten that, as the water-bearing formation is more and more taxed by additional pumping, the line of saturation will become gradually depressed, and may thus leave the executed headings far above the level at which they could be of any material service.

In his report upon the supply of water to Liverpool, Mr. Stevenson expresses the opinion that in the attempt to procure a permanent supply from the New Red Sandstone, the sinking of additional wells would probably be more successful than expensive tunnelling. In the view advanced in the report, however, no regard is had to the vastly increased surface from which the water may escape in the case of the headings, compared with that of the additional well placed at a distance. It is nevertheless pointed out and admitted in the report that, with the system of headings or tunnels, the number of pumping stations will be less.

It was stated just now that the only grounds upon which to base even a rough estimate of the probable yield of a well are comparisons of the circumstances and conditions of the case with those of other wells already executed, and whose yield is known. But the records of the yields of wells, numerous though they be, are only very rarely accompanied by the data requisite to make them as valuable as they ought to be. The level of the line of saturation at the time of the pumping operations should be determined and noted as frequently as convenient. It is best ascertained by observing the height to which the water rises *rapidly* after the pumping has been stopped. The subsequent *gradual* rise of the water-line, after the cessation of pumping, will be due to a rise in the *general* level of the line of saturation in the neighbourhood of the well, caused by the draught upon the stratum having diminished. In the next place should be recorded the level at which the water stands in the well at the time when the quantity named is being pumped ; for, by taking the difference between this level and the level of the line of saturation, the hydraulic head causing the flow may be known. Then should be given such particulars of the well itself that the area of the exposed surface of the water-yielding stratum, from which surface the supply is being drained, may be ascertained, that part only being regarded which is below the level of the water in the well, and which is not shut off by impervious steining. There would then be data upon which to found an estimate of the probable yield of a well sunk or bored in a similar stratum

The temperature of well-water increases with the depth below the surface of the ground from which it is taken ; but both the absolute temperature and the rate of increase vary considerably in different localities and strata. Careful observations on the water from the Artesian well at Grenelle show an increase of 1° Fahrenheit for each 59 feet of depth, with a maximum temperature of about 82° for the total depth of 1,800 feet. M. de Giradin found at Rouen an increase of 1° Fahrenheit for every 37½ feet in one instance, and in another 1° Fahrenheit for every 55½ feet. A mean of these and other observations may be taken in round numbers at 1° Fahrenheit for every 50 feet of depth. It is necessary, in making observations of this kind, to ascertain carefully the depth at which the water is issuing from the stratum. Mr. Clarke found that water taken from the bottom of a well at St. Albans, 540 feet deep, was 4° warmer than that pumped from the well in the usual manner. Springs will occasionally be found rising at excessive temperatures, as, for instance, those at Bath, in Somersetshire, of 117° Fahrenheit, and those of Orense, in Gallicia, which have a temperature of at least 180° Fahrenheit.

WELL-SINKING.

The process of well-sinking consists generally of the two operations of first excavating, and then protecting the sides of the excavation by steining. The former is usually conducted in the ordinary manner, as far as the loosening of the material is concerned. Thus, hard rock which cannot be conveniently removed by other means is blasted. The plumb-bob and a rod of the well's diameter in length are sufficient guide for the workmen. The loosened material is mostly raised to the surface of the ground in buckets attached to a rope working from a windlass or 'jack-roller' above. When steam machinery is afterwards to be used for boring, and sometimes indeed where this is not the case, it is employed to facilitate the sinking, by saving time and labour in raising the excavated material. In passing down through a stratum of sand charged with water, the sinking is sometimes carried on by a process which belongs rather to boring than to sinking, as commonly understood. The sand is loosened by tools attached to rods worked from above, and is then withdrawn with the assistance of 'misers,' to be hereafter described. Indeed, the 'miser' alone is frequently capable of both excavating and collecting, without the previous assistance of any other tool. Messrs. Docwra & Son occasionally use a miser eight feet in diameter, and capable of removing nearly two cubic yards of material at each lift (*See* p. 107). It is probable that, under certain circumstances, Milroy's excavator, or an apparatus similar to it in principle, might be used with very great advantage and economy. Very successful results have been obtained with it in sinking cylinders for bridge piers through strata of sand lying in the beds of rivers and elsewhere.

The form of wells is generally circular on plan, the circle being a figure whose perimeter is the least possible in proportion to the contained area, and in consequence the lining or steining of the well is reduced to the minimum. The circular form is also the one in which, when the pressure from without is uniform, as it mostly is approximately, the steining will offer the greatest resistance to that pressure. It moreover presents many advantages for the execution of the work which cannot be obtained with any other form ; for instance, the application of boring tools—the miser especially—for carrying on operations under water. In hard rock, where no steining will be required, the form is not of so much consequence, and the ellipse and other figures are sometimes adopted ; indeed, after the line of saturation has been reached, and when, therefore, it is desirable to have a large exposed surface from which the water may flow into the well, better results, as far as this latter view is concerned, will follow a departure from the circular form, whether for a continuation of the well downwards or for the headings or galleries which may be driven out in other directions ; for the less the section of the shaft or heading resembles the circle. the larger will be the surface exposed with a given amount of excavation. Concerning the directions and extent of headings, no particular rules can be laid down, as the dip of the strata, and the probability of faults or fissures being intersected, will influence the case. Speaking generally, perhaps the best results will be obtained by confining the direction of the headings on plan to a straight line passing through the well, where this is practicable, instead of allowing them to return one upon another, and thus extend from the well within only a small radius. If the object be simply to provide underground storage-room, this consideration is unimportant; but if, on the other hand, the object be to increase the average yield of the well, the disposition of the headings on plan should be carefully studied with this view. At the waterworks at Chatham, carried out by Mr. Pilbrow for the supply of Chatham and Rochester, are some very extensive headings in the chalk, their general section being a curvilinear triangle forming a pointed arch with a height, in some parts, of 25 feet. The limits prescribed by legal right will of course affect the determination of the plan of the headings; for they must not, without proper and legal arrangements, be carried beyond the boundaries of the property which is under the authority of the owner of the well. As long as the excavations or other works do not intrude within the boundary of the adjacent property, the water derived from the well is legally considered as due to that well, even if adjacent wells, or other sources or channels of water be affected by its abstraction; in other words, the owner of the adjacent property cannot, as the law now stands, show a vested right to any of the water so abstracted.*

The forms of wells are preserved and their sides protected, where necessary, by a lining called steining, commonly of brickwork, occasionally of timber or stone, and frequently of iron. The materials should be such as will not injuriously affect the quality of the water, nor be injuriously affected by the water. The water will be more subject to contamination by the steining in proportion to the length of time it remains in contact with it; indeed, there would be no apprehension of such effects except where the pumping is intermittent. Timber, as a rule, is objectionable from its liability to decay, and thereby not only become too weak to sustain the sides of the well, but also interfere with the purity of the supply. Although not coming strictly within the limits of this treatise, it may be mentioned that the timber used in the salt wells of Cheshire is found to be very durable, the saline matter appearing to act as a preservative against decay. Where masonry is used for steining a well, the carbonate of lime is liable to be dissolved out from the stone itself, or from the cementing material, especially when the water contains even a small amount of carbonic acid. It is necessary, therefore, to select a stone containing a large proportion of silica, as the ordinary carbonates and magnesian carbonates of lime are unsuitable under the circumstances. The cementing material, moreover, both for brickwork and masonry, should be decidedly 'hydraulic'—that is, containing a large proportion of silica and alumina; say, not less than 11 per cent. of the former and 6 per cent. of the latter. Iron is liable to decay by rusting—that is, by the formation on its surface of a hydrous oxide, which is slightly soluble in water; fortunately, however, the effect does not proceed so rapidly when the water contains earthy salts, as well-water invariably does to a greater or less extent; the oxidation, moreover, is not so active with cast-iron as with wrought.

Other considerations affecting the selection of a material for the steining of a well must have reference to its strength, the facility of its insertion, and its capability to resist the infiltration of water which it is desirable to exclude from the well. As far as the strength is concerned, this will depend upon the diameter of the well, the nature of the strata, its stability, and the superincumbent pressure upon it. The thrust upon the steining considered as an arch having to withstand the horizontal pressure of the strata will vary directly with the diameter of the well. In wells steined with brick the work is seldom less than 9 inch, except in private shallow wells and those of small diameter, say less than 5 feet. Stone can rarely compete with brickwork as a material for steining wells, on account of the labour required in its preparation; but where from local circumstances it is advisable to adopt it, selection should be made of that which can well resist compressive strains, and between which and the water of the well there will be no undesirable chemical action. The great advantages which iron presents for adoption are available most when the well has to be carried down through a stratum charged with water which it is necessary to exclude. Mr. Baldwin Latham mentions† a case in which four or five rings of brickwork, set in the best cement, having failed to keep out brackish water, an iron cylinder had afterwards to be introduced. Steining of brickwork is liable to fail from the draining away of a bed of live sand, or from other disturbances of the strata; and, again, the iron steining affords greatly increased facilities for the execution of the work where seams of water have to be intersected, as will be presently shown.

There are two methods of proceeding with the steining of a well in brickwork. In the older method, an iron curb, or a wooden curb shod with iron, and whose outer diameter is equal to the external diameter of the

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* Acton *v.* Blundell, *vide* 12 Mee & W. 324; Chasemare *v.* Richards, 29 L. J. (N. S.) Exch. 81; 5 Jur. (N. S.) 873; 33 L. T. 350, Exch. Ch.; 2 H. & N. 168; H. L. Ca. 346.

† Papers upon the Supply of Water to Towns. By Baldwin Latham, C.E.

cylinder of brickwork, is laid in the bottom of the excavation, after the latter has been carried down from the surface to the greatest depth at which the sides will safely stand. The brickwork is then carried up on the curb, and piled on above, in order that by its weight it may force itself down as the excavation proceeds below. Sometimes the curbs are suspended from cross timbers at the mouth of the well by iron rods with screwed ends, so that the lowering of the steining may be carefully regulated. When the pressure of the surrounding earth becomes so great that the cylinder of brickwork can no longer be induced to descend, a new cylinder of smaller diameter is sunk from the bottom of the well, and carried down in a similar manner, until *it* also becomes 'earthbound,' or 'earthfast,' when a new set-off is made and the operations proceeded with as before

The more modern system consists of a process of under-pinning—the weight of the steining already executed, when not entirely resisted by the friction against the sides of the excavation, being sustained on a curb by props from below, or by rods from above. Sometimes where the stratum is sufficiently firm, recesses are excavated, leaving between them piers upon which the steining is supported. In these recesses the brickwork is carried up to that already executed ; the piers of earth are then removed, and the steining can be completed.

The brickwork used for steining wells is either laid dry, or in cement or good hydraulic mortar, according to circumstances. In cemented work cast-iron curbs are sometimes built in at suitable intervals, to facilitate the execution of the well, and also to strengthen the work. Where the work is laid dry, one or two courses set in cement are introduced with a similar object, at intervals varying mostly from 5 to 12 feet.

In steining wells the bricks are laid flat, and are arranged to break-joint. In 9-inch work they are laid all as headers; and in 14-inch work there is generally an inner ring of the usual 9-inch work, all headers, and an outer ring of 4½-inch work, all stretchers. In wells up to 9 feet in diameter 9-inch work is generally sufficient; and 14-inch work may be adopted up to 14 feet diameter. If the ground is bad or loose a half-brick extra should be added.

To exclude moderate land springs, or other springs not met with under very great pressure, concrete or clay-puddle is introduced behind the steining; the latter, however, is preferable, as it is more certain to be water-tight than the concrete. When the bricks are laid dry, the swelling of the earth behind will gradually fill up the spaces between the bricks. It is very essential that the steining should be well backed up by working as close as possible to the sides of the excavation; and wherever, from any irregularity in the excavation, this is not convenient, the space should be well filled in either with puddle or brickwork; the latter is preferable, especially where a slip of earth has taken place, in which case the brickwork should be filled in in cement. The principal object of this is to prevent the collapse of the well by being forced in at one part by the pressure of the ground and spreading correspondingly at another part, which, had it been properly backed up, would have served as an efficient abutment for the former part, acting as an arch.

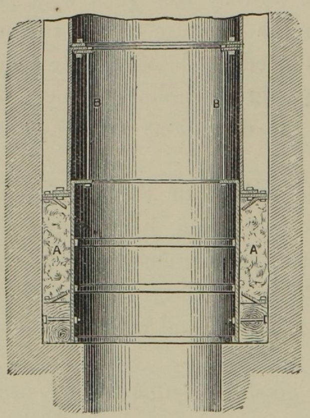
Iron cylinders are sunk in a manner similar to that first described for the cylinders of brickwork. They are most frequently inserted in order to continue the well when the ready progress of the brick steining has been interfered with by the irruption of water which it is desirable to exclude from the well. Until the water-yielding stratum has been passed through, the sinking of the cylinders is carried on with the assistance of the ordinary boring tools. The cylinders are generally of cast-iron made up of 5 or 6 feet lengths, bolted together by means of internal flanges, so that the exterior surface is perfectly smooth. The bottom length has, instead of a lower flange, a cutting or chisel-edge to facilitate the descent. The joints are made water-tight either with gasket soaked in tallow, or being caulked with iron cement. Wrought-iron cylinders used for steining are jointed with angle and T-iron by rivets counter-sunk on the outside so that a smooth surface may be presented. When the cylinders become earth-bound they are loaded, or else pressure is applied to them by jacks. They are sometimes also rammed down by wooden 'dollies.'

In the well of La Chapelle the wrought-iron cylinders (5′ 6″ in diameter) were composed of two thicknesses of ⅜-inch (1 centimetre) plates arranged so as to break-joint both horizontally and vertically. The cylinders were made up in lengths of 13 feet 1½ inches. At one end of each length the outer plates extended beyond the inner, and at the other end the inner extended beyond the outer; in each case the projection was for half the width of a tier, or ring of plates; and thus the several lengths of tubing were fitted into one another. The entire riveting was by counter-sunk rivets, so that a smooth surface was presented both inside and outside from the top to the bottom.

When the greatest pressure that can be conveniently applied, or that for the safety of the cylinder it is expedient to apply, fails to cause the cylinder to descend any further, a cylinder of smaller diameter is sunk within the former one, and carried down in the same manner.

Measures must be taken, where necessary, for rendering water-tight the junctions between the several lengths of brick and iron cylinders, especially where a change of diameter occurs. On Plate 1 will be found some good illustrations of the means generally adopted with this object. Fig. 54 shows a stuffing-box invented by M. Kind, in which the joint is rendered water-tight by a packing of moss, A A, pressed out against the sides of the well by means of the tightening screws B B. The moss is not liable to decay under the water.*

FIG. 54.



The diameter to be given to a well will depend, firstly, upon the space required for the pumps, mains, and machinery and fittings generally; also for the free access to them for repairs and adjustment, and for the removal, renewal, or enlargement of any or all of the parts. Secondly, in determining upon the diameter of the upper part of the well, due allowance must be made for the several reductions of diameter which may be necessary for the progress of the work, as already shown. The starting point should be the minimum diameter requisite at the level where the pumps have to be fixed; this level will be, of course, determined by the height to which the water will rise in the well, and the depth below this, to which the water must be lowered in order that a sufficient supply may be obtained. It is not safe practice to reckon anything for the suction lift of the pumps; what few feet will be available below the suction valves should always be included in the margin of safety: the less suction there is, the better. It is principally on these conditions that the dimensions of the well are determined; but, as will be seen presently, any boring operations which have to be conducted subsequently will be immensely facilitated by the previous sinking of the shaft. By a recent invention of Messrs. Mather and Platt, however, a most efficient double-acting pump is so arranged that it can be lowered into the bore-hole itself, and the necessity for sinking a large well down to the water-line is thus far avoided. (*See* Chapter X.)

In the process of well-digging, the carbonic acid exhaled by the workmen, being specifically heavier than common atmospheric air, accumulates at the bottom of the well, to the great inconvenience of the men, and to the detriment of their activity. A continual supply of fresh air should be forced down through pipes, either by bellows, a fan-blast, or other appliance; or the foul air should be drawn up, through a tube, by an exhausting fan, or by being connected to a shaft leading up from a furnace. Lime water is occasionally used to remove the poisonous gas by absorption, but the mechanical arrangements for the purpose are preferable to the chemical. The necessity for an artificial supply of fresh air is first intimated to the workmen by the candles burning dimly.

When rock is being blasted, it is necessary, before the firing of the charges, for the workmen to ascend to a considerable height, say 100 feet at least, above the bottom of the well, in order to be safe from the effect of the explosion. Generally headings are driven, into which the men may retire for safety. The fumes from the powder may be partially cleared by dashing water down the shaft, or, better, by pouring water in a shower from a rose.

WELL-BORING.

The art of boring into the earth to considerable depths was known and successfully practised by the Chinese two thousand years ago; and it is somewhat curious that, after having undergone many modifications, the system which was then the prevailing one promises to be once more in the highest favour with engineers.

The characteristic feature of the Chinese system (the name by which it is still known) is the percussive action of a tool suspended by a flexible rope. The jumping motion is produced by a spring pole or lever to which the rope is attached; the twisting and untwisting of the rope causes the tool to act in a different position at each stroke. The tools used are of various kinds, depending on the nature of the strata to be pierced. Some of them are made to retain the detritus as it is produced, so that when the tool is raised, either a portion or the whole of the detritus is brought with it. Under certain circumstances, however, it is necessary to lower an instrument specially for the removal of the detritus, and that most commonly used is a cylinder or bucket with either a clack, spindle, or ball valve at the bottom. The lowering of this bucket is repeated until the hole is cleared, when the cutting instrument is again introduced, and the operation is carried on as before. The Chinese method, in its original simplicity, was superseded by the one next to be described, and principally because of the tendency of the bore-hole to get out of the straight line, a matter of little moment when penetrating a hard stratum, but one causing great inconvenience where, in softer strata, tubes have to be inserted for the preservation of the hole.

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* Proceedings of the Institution of Mechanical Engineers, 1867, Part VIII.

The system of boring most generally practised is that in which the tools are attached to rods, consisting of a number of short lengths jointed together: a combined vertical and definite rotary motion can thus be imparted to the tool. The process is as follows :—An ordinary well is first sunk to such a depth that the water from below will rise through the boring into it. The object of this is partly to facilitate the operation of boring; but chiefly to enable the pumps to be fixed without too great a length of suction, as already stated.

Where the boring is comparatively shallow, the rods may be connected by a chain or rope to a spring-pole or lever as in the Chinese system, which lever may be worked up and down by manual or other power according to circumstances. When, as is generally the case, the weight of the rods is too considerable to allow of this, a crab is used, and the rope by which the rods are suspended is passed a few times round the drum, so that when the free end is pulled tight there will be sufficient friction between the drum and the rope for the latter to bite, but when the free end is slackened, the rope on the drum will slip, and the boring rods fall through the required height, the crab winch being turned in the proper direction during the whole time.

In order to allow of the continuous rotary motion being given to the rods, the upper length is provided with a swivel joint, or sometimes the rods are suspended in dogs (fig. 55). Bars or levers (fig. 56) called tillers are then fixed on to the rods and worked as in a capstan.

Fig. 55.

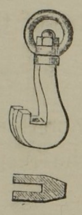


Fig. 56.

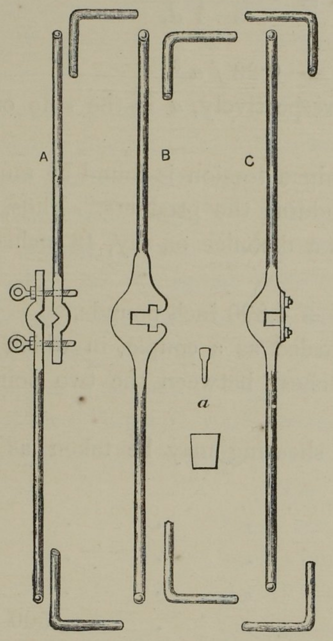
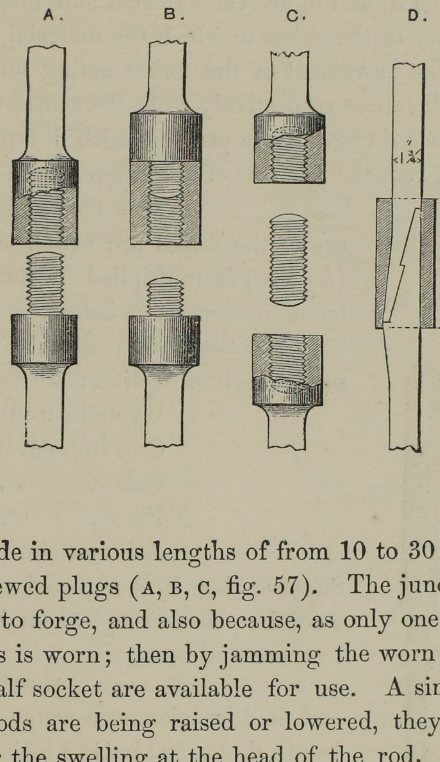


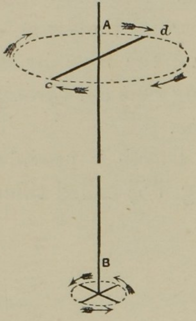
Fig 57



The rods used in boring are most commonly of wrought-iron made in various lengths of from 10 to 30 feet, and screwed together either by sockets or with separate collars or screwed plugs (A, B, C, fig. 57). The junction with separate collars (B) is preferred by some, because of being easier to forge, and also because, as only one-half of the collar is used in uncoupling, only one of the screws on the rods is worn; then by jamming the worn end of the socket on to the worn end of the rod, a new screw and a new half socket are available for use. A similar advantage is possessed by the separate screwed plug. When the rods are being raised or lowered, they are suspended in the dogs (fig. 55) already referred to, which catch under the swelling at the head of the rod. For working certain boring tools rods are used jointed with a scarf, over which a hoop is slid and wedged (fig. 57). Wrought-iron boring-rods are used in different sizes from one inch square and upwards, according to the nature of the strata, and the diameter of the hole being bored ; but the size most frequently used by well-borers for general purposes is 1¼ inches square. To work tools for an 8-feet boring, Mr. Docwra has successfully employed rods 4½ inches square.

When borings of considerable depth have to be executed, the weight of solid iron rods necessary for the purpose becomes very considerable, and there is moreover a jarring and vibration which not only interferes with the free working of the tool, but renders the rod very liable to crystallisation and ultimate fracture. To obviate these objections the rods have in many instances been made hollow, so as to have the same rigidity and resistance to torsion with less weight. To give the rods buoyancy in water those of hollow iron have been occasionally filled with cork or other light wood ; while boring rods almost entirely of timber have been very successfully employed, the lengths being jointed with iron screws and sockets in the ordinary way. M. Kind, who was the first to introduce the latter system, used the rods in about 50 feet lengths, and recommends for the purpose of making them, that straight-grown trees of the requisite diameter should be selected rather than that cut timber should be used, as there will be less danger of the wood warping, and the character of the wood will be more homogeneous. The use of timber affords very great facilities for balancing the rods by their buoyancy, whilst freedom from the jarring to which iron rods are liable is another strong inducement for the adoption of this material.

FIG. 58.



It is well to know the force which may be safely applied to the capstan levers or tillers attached to a boring rod. Let A B, fig. 58 represent a boring rod of any length, and let *c d* be the horizontal bar attached to it for the purpose of giving a rotary motion to the tool below. The arrows at *c* and *d* represent the forces applied at the ends of the bar, and those at B below represent the frictional or other resistances against the tool. The effect upon the rod itself is to cause each section to shear from or slide upon the contiguous sections until the bar is ruptured. The moment of the resistance of a rod or bar to this effect of torsion is as follows :—

For a solid circular section :—

$$M = \frac{f\,d_1^3}{5 \cdot 1}$$

For a hollow circular section :—

$$M = \frac{f\,(d_1^4 - d_2^4)}{5 \cdot 1\,d_1}$$

And for a solid square section :—

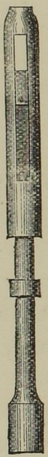
$$M = 0{\cdot}28\,f\,a^3$$

in which d_1 and d_2 are the external and internal diameters respectively, a is the side of the square, and f the intensity of the stress to which the material is subjected.

The movement of the forces acting on the bar to produce torsion is found by multiplying the forces into their distances respectively from the centre of the rod, and adding the products. Thus, if a man at each end of the bar *c d* (fig. 58) be pressing with a force of 50 lbs., at a distance of, say, 48 inches from the centre of the boring rod, the moment of these forces will be—

$$M = (50 \times 48) + (50 \quad 48) = 4{,}800 \text{ inch pounds,}$$

FIG. 59.



or, as the forces are equal, they may be regarded as a couple, in which case the common force (50 lbs.) is multiplied by the distance (96 inches) between the two points of action, the result being, of course, as before.

The ultimate resistance of materials to shearing may be taken as follows, in pounds per square inch of section :—

Wrought iron	50,000
Cast iron (average)	27,000
Oak	2,300
Fir	500 to 1,500
Ash and elm	1,400

Suppose then it is required to know what forces may be safely applied to the levers acting on a solid square wrought-iron bar whose side is 1·5 inch. The moment of resistance to ultimate fracture will be—

$$M = 0{\cdot}28 \times 50{,}000 \times 1{\cdot}5^3 = 47{,}250 \text{ inch pounds,}$$

and, if 4 be taken as a factor of safety, 47,250 ÷ 4 = 11, 812 inch pounds. If the length of the bar (*c d*, fig. 58) be 100 inches, then $\frac{11812}{100} = 118$ lbs. is the force which may be safely applied at the two extremities, with perfect safety as far as the resistance of the rods to torsion is concerned.

Reference has been made to the jarring vibration, and liability to fracture, of long boring rods, more especially those of iron, each time they are allowed to fall with the object of penetrating the rock or other stratum below. It is not necessary for the operation of boring, however, that the weight of the whole length of rods should be brought to bear upon the tool ; a sliding joint, known as the Œuyenhausen joint, is therefore frequently introduced, in order that only the portion of the boring rod below, and not that above, the joint shall be subject to the shock. The accompanying figure (fig 59) shows one of these joints.

The tools used in well-boring are of an almost endless variety, but the accompanying illustrations will give a fair general idea of their form and construction. In fig. 60, A to F are chisels for penetrating the harder strata; they are of various forms, as will be seen, and they are also of various dimensions. Mr. Docwra has used a flat chisel, forged solid, 3 feet 6 inches in width, and capable of being extended to a width of 5 feet 7 inches by wings bolted on at each side ; G is a tool consisting of an assemblage of four chisels enclosed in a cylinder, to which they are riveted ; H is a worm auger for loosening the material in the bore-hole : I and J are tools for working in clayey strata ; K is a shell with a clack, for bringing up loose and saturated materials from the bore-hole; L is a 'spring rhymer,' for enlarging and scraping the bore-hole. For bringing up 'slush' a 'pot-miser' (M) is frequently used, consisting of an inverted cone, which sinks into the stratum, and on becoming filled is drawn to the surface. In (fig. 61) is shown a 'miser' of the ordinary form: it consists of a wrought-iron cylinder, generally from one to two feet in height (those of larger diameter being the shallower), and of a diameter to suit the bore-hole. The bottom is arranged to act as an auger; indeed, the miser might be described as a very short auger for working holes of large diameter, sometimes alone, and sometimes to clear the hole after another tool has been used. For loose strata the opening in the bottom is sometimes provided with a valve which closes when the miser is lifted; but the arrangement now generally adopted consists of a plate *a*, cut in the form of a sector and fixed to a radial arm *b*, which is keyed on to the vertical rod of the machine. The plate slides on the bottom of the miser (inside), and the cylindrical part or body of the miser is worked by the radial arms *b b′* pressing against the frame *c*. When the miser is full, a half turn backwards is given to the rods, and the plate *a* is thus brought over the opening, closing it effectually. The arrangement originated with Mr. Docwra, who has successfully applied it in the misers of eight feet diameter before referred to. Boring rods, connected by a scarf, as shown at D, fig. 57, are generally used for misers of this description.

Fig. 60.

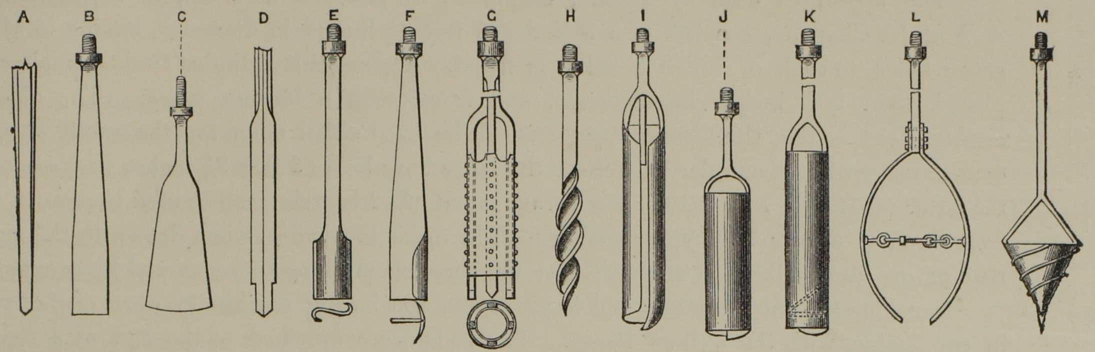


Fig. 61.

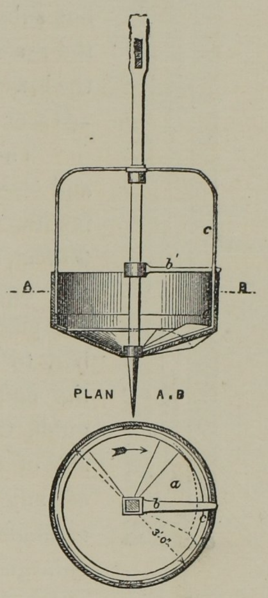
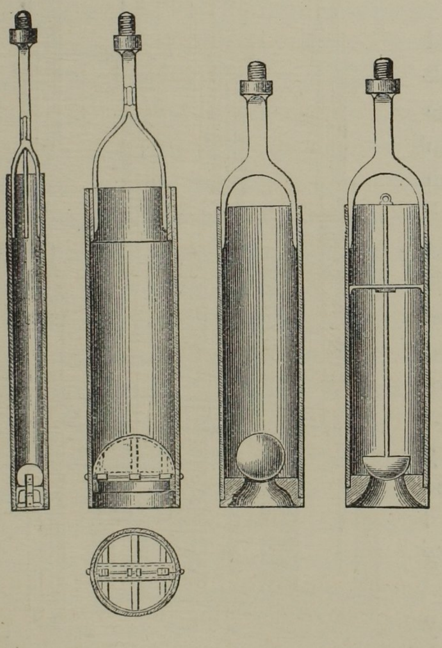


Fig. 62.

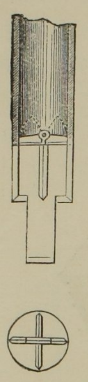


The tool having been worked in the holes by the means before described, for such a length of time that the detritus produced impedes its action and the progress of the boring, the rods are hauled up by means of dogs (fig. 55) to the surface of the ground or to the staging from which the operations are being conducted, wherever that may be. When the rod has reached the crab or windlass, it is secured against falling back into the bore-hole by the 'dogs' resting on cross planking. The lowest joint accessible to the workmen below is then unscrewed, and the rope or chain once more lowered to be attached to and to raise another length of the rods.

As the available height from the lower to the upper working levels is greater, so there is less time consumed in screwing and unscrewing the joints; and when it is considered that this raising and lowering of the tool is an operation very frequently repeated, occasionally several times in an hour, the advantages of a well being sunk previously to the bore-hole being started will be apparent at once. There is, moreover, a corresponding reduction in the weight of rods and the height through which they have be lifted.

The tool having been successfully brought up, an apparatus of one of the forms shown in fig. 62 is lowered into the hole, either by the rods or by a rope, for the purpose of removing the detritus left by the tool. The shell pump, as it is called, is worked up and down until it is filled with the detritus, when it is raised to the surface and emptied, and if necessary, again lowered, the process being repeated until the bore-hole is clear. In fig. 63 is shown a tool for working in hard strata and collecting the detritus at the same time; it is a combination of a double

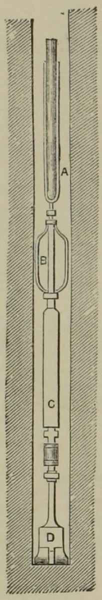
Fig. 63.



chisel and a shell pump, and by its use much of the time occupied by raising and lowering the rods is saved.

The apparatus used by Messrs. Degousée, C. Laurent, and Co., in boring the Artesian well at La Chapelle, consists of a cylinder 3 feet 3½ inches in diameter, having in the bottom seven holes, to each of which a valve is fitted. Around this cylinder twelve smaller ones are placed, each 10¼ inches in diameter, and fitted with a bottom valve. The object of the arrangement is that the former apparatus can be used either alone for the small boring, or in connection with the annular bucket for the large bore-hole (5 feet 9½ inches in diameter), while the latter (that is to say, the annular arrangement of 12 barrels), can be used to remove the débris from around a *core* left by the boring tool, in order to exhibit, when drawn to the surface, the true nature and inclination of the strata; the cores themselves are recovered by grapnels.

Fig. 64.



Considerable modifications and improvements in boring machinery were made by M. Kind in connection with the well at Passy. The rods were attached to the end of a timber beam worked by a steam engine, with hand valves as in the Nasmyth hammer, and a separate engine was used for raising and lowering the tools. The boring rods of oak have already been mentioned. The comminution of the rock was effected by a large *trepan*, into the framing of which the cutting teeth or chisels were inserted and wedged up. At first M. Kind employed the Œuyenhausen joint, but subsequently the tool was connected with a sliding joint which was thrown out of gear by the reaction of the column of water in the bore-hole, upon a disc unloosing the click that upheld the lower part of the trepan. M. Kind's tools have been used for sinking shafts of large diameter —13 or 14 feet—and with great success.*

The free-falling tool was considerably improved upon by M. Dru† in several borings and elsewhere. Fig. 64 is a section of the bottom of a bore-hole showing the general arrangements. A is part of the boring rod, in this case also of timber. The rods are in length about 30 feet, chosen from the thick part of the tree and not the toppings. In France, Lorraine or Vosges deals are preferred. The rod A is screwed to a square iron bar, to which are attached four other bars, curved in at the ends, and forming a 'lantern' B, which serves to guide the boring rod in the lower part of the hole. The size of the lantern may be readily varied to suit a boring of any diameter. Below the lantern is the releasing arrangement C, which, together with the tool D, is shown enlarged at A and B, fig. 65.

Fig. 66.

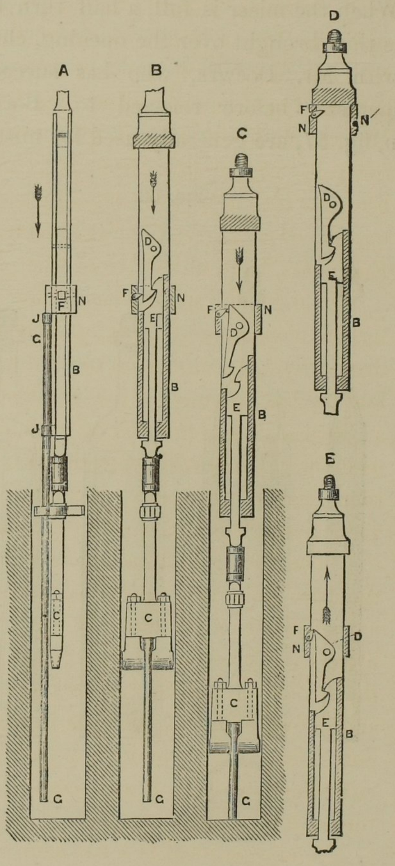
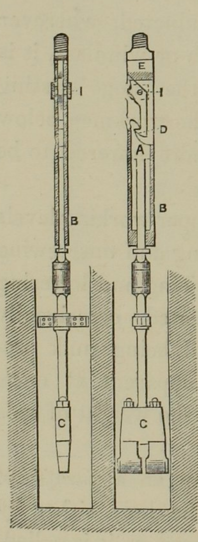


Fig. 65.



The boring tool C is attached to an iron rod having a hook A at its upper extremity. The hook slides vertically in a box B, which is screwed to the bottom of the boring rod. At the end of the down stroke of the rods, the hook is engaged by the catch D, and the tool is then raised. The pin I of the catch works on either side in a hole made oval and with the longer axis vertical. The up stroke of the rods is terminated with a slight jerk, caused by the end of the wooden beam, from which the rods are worked at the surface, coming in contact with a stop provided for the purpose. The tail of the catch is thus thrown in contact with the inclined plane at E, by which the catch is released from the hook A, and the tool falls freely to the bottom. This reaction tool has been successfully employed for borings varying in diameter from 3¼ inches to 4 feet.

Another arrangement, designed and used by M. Dru for liberating the tool, is shown in the accompanying fig. 66. The tool C is screwed to a rod, upon which there is a hook E, working in a box B, as in the apparatus just described. The catch D works on a pin fitted in the vertical sides of the box. G G is the disengaging

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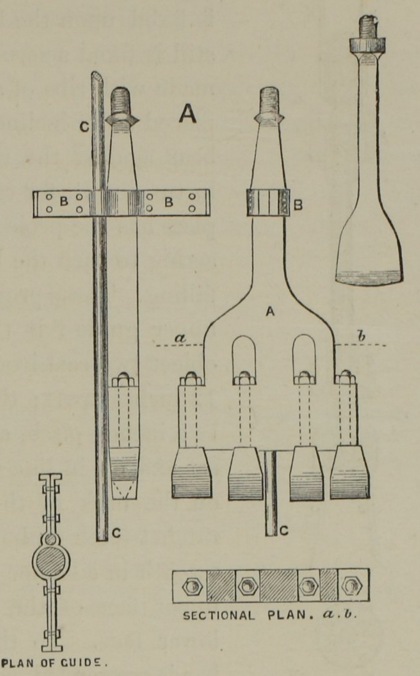
* Engineering, vol. vii. pp. 300, 303.

† Proceedings of the Institution of Mechanical Engineers, June 1867, Part III., from which this description is mostly taken.

rod, working in guides at J J, and connected with a hoop N which slides freely upon the box B. In the hoop N is a paul F, which acts upon the catch D in the manner to be described. When the apparatus is lowered, the rod G G reaches the bottom of the bore-hole first, and then with the hoop N remains stationary, whilst the box B and the tool C continue to descend. The catch D now begins to slide past the paul F and in doing so is forced by the paul away from the hook E, as shown in fig. 67, thus allowing the tool to fall freely and strike its blow. The boring rod and the box B still continue to be lowered, when the catch once more engages the hook, and the tool is raised. As the catch rises past the hoop it trips up the paul, as shown at F (fig. 66). This tool, like the one previously described, has proved completely successful in practical working.

Fig. 67.

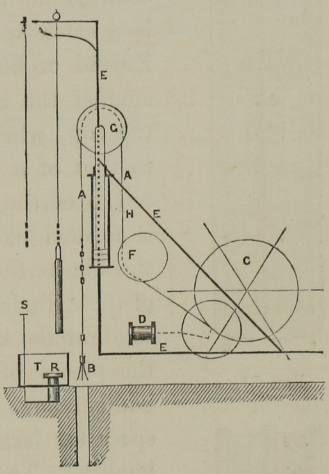


For borings of small diameter M. Dru uses a tool of the form shown at **B** (fig. 67), but for the larger borings the tool is arranged so as to admit two or more chisels, which can thus be made of a size convenient for forging and grinding, and moreover can be easily removed and replaced by others when they are broken, or when it is necessary to enlarge the hole. **A** (fig. 67) is a tool arranged with four chisels, the body A being of wrought iron. A cross-bar B is bolted on to the stock or body A, guiding the tool at right angles to the line in which the chisels act. C is the disengaging rod.

The system of boring just described, with the mechanism for releasing the free-falling tools—indeed the whole of M. Dru's arrangements so largely used in the Paris basin—are perhaps the most successful applications of the *rod* system. It has once more been the fortune of the *rope* system, however, to rise in the favour of engineers, by the achievement of successes far beyond those to which the rod system has attained. The defects of the original Chinese or rope system were the liability of the bore-hole to become crooked, and the indefinite and imperfect rotation which, at the best, could be given to the tool. Its great advantages were the rapidity with which a boring could be executed, in consequence of the time saved by not having to raise and lower, couple and uncouple, length after length of boring rod, whether iron or timber. In the machinery invented by Messrs. Mather and Platt, of the Salford Iron Works, Manchester, and next to be described, the advantages of the rope system have been increased by the successful application of steam power, and the imperfections have been corrected by very ingenious mechanical devices. A full and complete description of the whole of the machinery was given in an excellent paper by Mr. William Mather, read before the Institution of Mechanical Engineers,* and chiefly from this paper the following account has been taken.

The general arrangements for working the rope are shown in the accompanying diagram. 'The rope A A, fig. 68, from which the boring head B is suspended, is wound upon a large drum C, driven by a steam engine D, with a reversing motion, so that one man can regulate the operation with the greatest ease. All the working parts are fitted into a wood or iron framing E E, rendering the whole a compact and complete machine. On leaving the drum C the rope passes under a guide pulley F, and then over a large pulley G carried in a fork at the top of the piston rod of a vertical single-acting steam cylinder H.'

Fig. 68.



The boring tool having been lowered by the winding drum to the bottom of the bore hole, the rope is securely fixed to the framing by a clamp; steam is then admitted underneath the piston in the cylinder H, and the boring tool is lifted by the ascent of the piston rod and pulley G. On arriving at the top of the stroke the exhaust valve is opened, and the piston rod and pulley fall freely, and allow the boring tool to descend with its full weight to the bottom of the bore-hole. To prevent the piston striking the bottom of the cylinder an elastic cushion of steam is always retained, by placing the exhaust part a few inches from the bottom. The valves are worked by a self-acting motion, and as many as 24 blows per minute can be given.

The rope itself is a flat hempen one, about 4½ inches broad and half an inch thick, such as is commonly used at collieries. With proper usage the ropes will last for several years, if care be taken to tar them afresh before putting them away when out of use, and if they be not left damp upon the winding drum.

The 'boring-head' is shown in fig. 69, and 'consists of a wrought-iron bar about 4 inches diameter and 8 feet long, to the bottom of which a cast-iron cylindrical block C is secured. This block has numerous square

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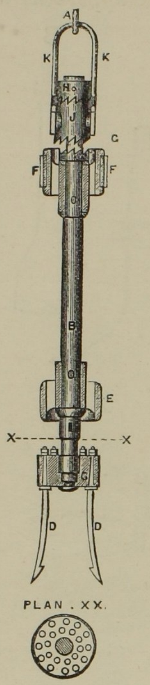
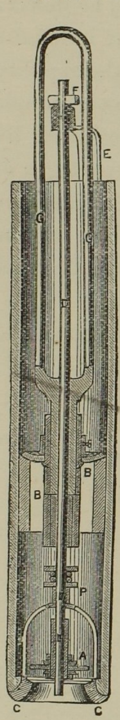
* Proceedings of the Institution of Mechanical Engineers.

Fig. 69.



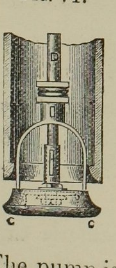
holes through it, into which the chisels or cutters D D are inserted, with taper shanks, as shown in fig. 69, so as to be very firm when working, but to be readily taken out for repairing and sharpening. . . . A little above the block C another cylindrical casting E is fixed upon the bar B, which acts simply as a guide to keep the bar perpendicular. Higher still is fixed a second guide F, but on the circumference of this are secured cast-iron plates made with ribs of a saw-tooth or ratchet shape, catching only in one direction; these ribs are placed at an inclination like segments of a screw-thread of very long pitch, so that as they bear against the rough sides of the bore-hole when the bar is raised or lowered, they assist in turning it, for causing the cutters to strike in a fresh place at each stroke. Each alternate plate has the projecting ribs inclined in the opposite direction, so that one half of the ribs are acting to turn the bar round in rising, and the other half to turn it in the same direction in falling. These projecting spiral ribs simply assist in turning the bar, and immediately above the upper guide F is the arrangement by which the definite rotation is secured. To effect this object two cast-iron collars G and H are cottered fast to the top of the bar B, and placed about 12 inches apart; the upper face of the lower collar G is formed with deep ratchet-teeth about two inches pitch, and the under face of the top collar H is formed with similar ratchet-teeth, set exactly in line with those on the lower collar. Between these collars, and sliding freely on the neck of the boring-bar B, is a deep bush J, which is also formed with corresponding ratchet-teeth on both its upper and lower faces; but the teeth on the upper face are set half a tooth in advance of those on the lower face, so the perpendicular side of each tooth on the upper face of the bush is directly above the centre of the inclined side of a tooth on the lower face. To this bush is attached the wrought-iron bow K, by which the whole boring-bar is suspended with a hook and shackle O, from the end of the flat rope A, fig. 69. The rotary motion of the bar is obtained as follows: when the boring-tool falls and strikes the blow, the lifting bush J, which, during the lifting has been engaged with the ratchet-teeth of the top-collar H, falls upon those of the bottom-collar G, and thereby receives a twist backwards through the space of half a tooth; and on commencing to lift again, the bush rising up against the ratchet-teeth of the top-collar H, receives a further twist backwards through half a tooth. The flat rope is thus twisted backwards to the extent of one tooth of the ratchet, and during the lifting of the tool it untwists itself again, thereby rotating the boring-tool forwards through the extent of twist between each successive blow of the tool. The amount of the rotation may be varied by making the ratchet-teeth of coarser or finer pitch. The motion is entirely self-acting, and the rotary movement of the boring-tool is ensured with mechanical accuracy.'

Fig. 70.



The shell-pump used by Messrs. Mather and Platt for clearing the bore-hole from the detritus is shown in figs. 70 and 71, and 'consists of a cylindrical shell or barrel P, of cast-iron, about 8 feet long and a little smaller in diameter than the size of the bore-hole. At the bottom is a clack A, opening upwards, somewhat similar to that in ordinary pumps; but its seating, instead of being fastened to the cylinder P, is in an annular frame C, which is held up against the bottom of the cylinder by a rod D passing up to a wrought-iron bridge E at the top, where it is secured by a cotter F. Inside the cylinder works a bucket B, similar to that of a common lift-pump, having an india-rubber disc valve on the top side; and the rod D of the bottom clack passes freely through the bucket. The rod G of the bucket itself is formed like a long link in a chain; and by this link the pump is suspended from the shackle at the end of the flat rope, the bridge E preventing the bucket from being drawn out of the cylinder. The bottom clack A is made with an india-rubber disc, which opens sufficiently to allow the water and smaller particles of stone to enter the cylinder; and in order to enable the pieces of broken rock to be brought up as large as possible, the entire clack is free to rise bodily about 6 inches from the annular frame C, as shown in fig. 70, thereby affording ample space for large pieces of rock to enter the cylinder, when drawn in by the up-stroke of the bucket.' The pump is worked by means of the reversing motion of the winding engine at the surface, until it is filled by the material broken up by the boring-head. It is then raised to the surface and placed in a waste-tank T (fig. 68) upon a table R, worked up and down by a screw S. The cotter F, which holds up the clack-seating C at the bottom of the pump, is then knocked out. The table is lowered by means of the screw, and the whole clack-seating descending with it as shown in fig. 71, the detritus is washed out by the rush of water contained in the pump cylinder. The pump is then readjusted and lowered into the bore-hole, and the operation is repeated until the hole is cleared.

Fig. 71.



The boring-head itself can frequently be made to bring up with it a specimen or core of the strata which is being penetrated, by leaving out the inner row of cutters, shown in the plan, fig. 69. The outer cutters detach a slightly conical portion, which sometimes becomes jammed between them and can thus be safely raised. When this is not the case, the core is brought up by the employment of an ingeniously-devised grapnel.

Some idea of the rapidity with which these operations are conducted may be gathered from the following: The boring-head and shell-pump are lowered at the rate of 500 feet per minute, and raised at the rate of 300 feet per minute ; 24 blows are given by the machine per minute, and 10 minutes' working in red sandstone and similar strata will enable the cutters to penetrate about 6 inches in depth. The shell-pump remains down for about two minutes, and about two or three minutes are occupied in emptying it when it is drawn up. The following table will give some idea of the time occupied in boring through different strata at different depths.

Locality	Diameter of Bore-hole		Depth of Bore-hole	* Gross Time spent	Rate of Sinking per day		Description of the Strata, and Remarks
	Top	Bottom					
	Inches	Inches	Feet	Days	Ft.	Ins.	
Middlesboro' . .	18	18	1,312	540	2	5	New red sandstone, clay, white sandstone, red marl, gypsum, limestone, red sandstone, and pure salt rock. First 600 ft. bored in 100 days. Stoppages for pumping to test water 150 days.
Norwich . . .	24	18	1,184	616	1	11	Chalk and flints. First 900 ft. bored in 130 days.
Broughton . . . Manchester	18	15	575	192	3	0	Quicksand and gravel, red sandstone, with seams of red marl, very hard sandstone and clay. Bore-hole sunk from bottom of well 75 ft. deep.
Canterbury, No. 1	24	18	473	72	6	7	Chalk and flints
Ditto No. 2 .	24	18	446	67	6	8	Ditto.
Manchester . . .	24	15	466	95	4	11	Red sandstone 110 ft., red and variegated marls 220 ft., coarse gravel and pebbles 43 ft., compact red and white sandstone 20 ft., red and purple marls 73 ft. Bore-hole sunk from bottom of well 70 ft. deep.
Heathern . . . Loughboro'	9	9	455	142	3	2	Gravel, red marl, red and white sandstone, bands of gypsum and grey sandstone.
Salford . . . Manchester	18	18	442	—	—		Gravel, red sandstone, red marl, and white sandstone. Bore-hole sunk from bottom of well 20 ft. deep.
Stockport . . .	18	18	424	91	4	8	Red sandstone and red marl.
Weardale . . .	18	18	341	81	4	2	Coal measures; shales, blue and white stone, clay, and coal, alternately.
Halifax . . .	15	15	332	100	3	4	Chiefly hard flagstone.
Birkenkead . . .	18	18	322	61	5	3	First 100 ft. red and yellow sandstone; then white marl and sandstone alternately. Bore-hole sunk from bottom of well 186 ft. deep, making total depth from surface 508 ft.
Bradford . . . Yorkshire	24	18	295	160	1	10	Shales, sandstone, and coal bands alternately; millstone girt at bottom. Bore-hole sunk from bottom of well 55 ft. deep.
Wirral . . . Birkenhead	24	15	295	92	3	2	Red and white sandstone, hard and fine. Bore-hole sunk from bottom of well 23 ft. deep.
Tring	18	18	260	43	6	0	Chalk.
Pendleton . . . Manchester	15	15	252	26	9	8	New red sandstone.
Dundee, No. 1 . .	18	18	247	200	1	3	Whinstone
Ditto, No. 2 . .	18	18	234	155	1	6	Ditto.
Ditto, No. 3 . .	18	18	197	140	1	5	Ditto.
Ditto, No. 4 . .	18	18	60	19	3	2	Ditto.
Birmingham . .	18	18	172	49	3	6	Hard and dark red sandstone with pebbles; grey sandstone.
Caterham . . .	24	18	100	26	3	10	Green sandstone, blue clay, grey and white sandstone, marl, chalk, and flints.

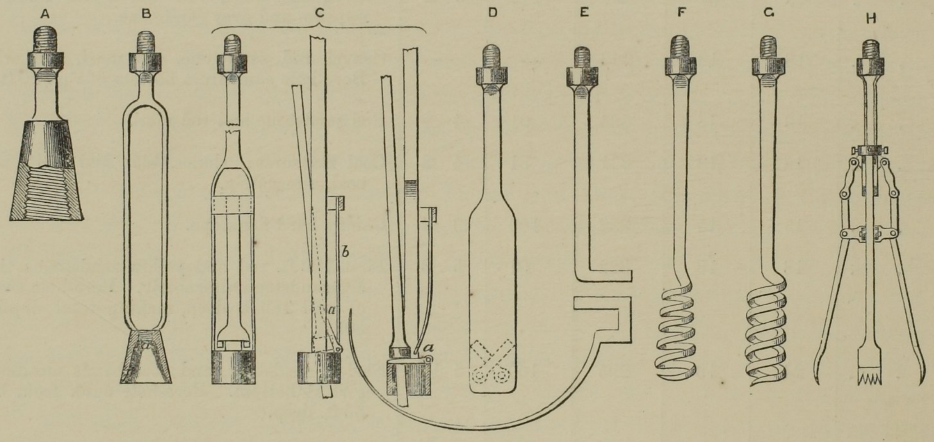
* The total time in weeks has been taken in every case without deducting Saturday afternoons and Sundays ; and the days mentioned are the ordinary working days of twelve hours.

The advantages which the patent boring apparatus just described holds over the most approved solid rod system are very great, and they increase rapidly with the depth of the boring. On the other hand, this rope system is not recommended, even by the inventors themselves, for borings of less than about 200 feet, on account of the expense of the machinery required.

In each and all of the systems of well-boring that have as yet been described, scoops or shell-pumps have to be lowered into the bore-hole to clear it from the detritus left by the boring tool. In *Fauvelle's system*, however, the time otherwise lost in this operation is saved. The boring rods are made hollow, and water is forced down them from the surface, which, rising again in the annular space between the rods and the sides of the boring, brings up with it the detritus from the bottom. In this manner a boring of 6 inches diameter was carried at Perfrignan in France to a depth of 560 feet in 140 hours of actual work, being at the rate of *four feet per hour.*[*] The system was introduced into this country by Beart, who secured a patent for the invention in the year 1844. Fauvelle claimed to having originated the idea as early as 1833; for while witnessing the progress of certain boring operations a short time previously, the spring was tapped, and Fauvelle observed that the rush of water brought up with it to the surface fragments of the strata of considerable size. Fauvelle subsequently modified his invention by forcing the water down the annular space between the sides of the well and the rods, allowing it to rise through the latter. The object was to give the rising current an increased velocity, and to afford a more smooth and uniform channel for the ascent of the fragments of rock. The improvement was soon manifest, and Fauvelle succeeded in bringing to the surface fragments of stone $2\frac{1}{2}$ inches by $1\frac{1}{4}$.[†] The principal drawback which attends the adoption of Fauvelle's system is the difficulty generally met with of finding water sufficient for the operation, inasmuch as water is mostly sought where as yet there is but little to be obtained. Nevertheless, the quantity required is not large, and there is no doubt that, under tolerably favourable conditions, M. Fauvelle's system might be adopted with great advantage.

In the operation of boring, numerous stoppages and accidents occur, from the liability of the tools to become jammed, or the rods fractured, and from many other causes; and instruments are required for recovering the pieces of rod, or any of the tools which may be left in the bore-hole. A (fig. 72) is a conical-screwed socket for recovering either timber or iron rods, the thread being made sharper, more like a wood screw in the tools that are used for the timber rods. B is a 'bell-top,' or 'bell-box,' consisting of a hollow cone of iron which serves to guide the rod into a screwed socket at *a*, arranged to act as a die. C is a latch-trap also, for the recovery of broken rods. In the first view the tool is shown being lowered over the rod, the joint in the latter pressing up the fork *a* against the spring *b*. When the joint is passed the fork slips down over the rod, and the tool is raised, with the rod in the position shown in the second view. D is a tool, the action of which is apparent. E is a crow's foot, and F and G are worms or screw grapnels for recovering rods and tools from the bore-hole.

Fig. 72.



In boring the well at La Chapelle, the rods were sometimes recovered by a tool consisting of a square box, in which were two parallel rollers or jaws sliding in two grooves inclined down towards each other. The top of the broken rod can freely pass up between the jaws or rollers as the tool is lowered; but on the latter being raised, the rod is seized and jammed between the rollers. H represents the four-armed screw pincers, also used

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[*] *See* the C. E. and Archts. Journal, Vol. 9, p. 305.

[†] Ibid