The following paper was read:—

Borehole Water Supplies in the Union of South Africa.

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Introduction.

Part I: General.—(1) Mechanism of Infiltration; (2) Water-Table; (3) Fluctuation of the Water-Table; (4) Geological Dependence of Storage; (5) Selection of Sites; (6) Yields; (7) Overpumping; (8) Dynamiting of Boreholes; (9) Difficulties in Drilling; (10) Deep Boring; (11) Flowing Supplies; (12) Coastal Supplies; (13) Difficult Areas; (14) Future of Boring in the Union.

Part II: Formations and Their Water-bearing Qualities.—

(15) Introduction; (16) Old Granite; (17) Witwatersrand and similar Ancient Systems; (18) Ventersdorp System; (19) Dolomite and Black Reef Series; (20) Pretoria Series; (21) Malmesbury Beds; (22) Bushveld Igneous Complex; (23) Waterberg and Matsap Series; (24) Table Mountain Sandstone; (25) Bokkeveld and Witteberg Series; (26) Karroo System; (27) Karroo Dolerite; (28) Cretaceous and Tertiary Systems.

Part III: Table of Yields, etc.

Although such does not appear to have received adequate recognition, the occupancy of the vast spaces of South Africa and their closer settlement have been made possible principally through the agency of the boring machine. I firmly believe that more has been achieved towards the general development of the country from the comparatively few thousands of pounds spent annually upon State boring, than from all the millions expended upon large diversion and storage schemes. Neither can the valuable boring work done by various private contractors and individuals be overlooked in this connection. It is significant and satisfactory, too, that the demand for boreholes shows no signs of abatement.

Fifteen years ago I had the privileges of summarising before this Society our somewhat scattered knowledge concerning Underground Water in the Union,[1] but manifestly a great deal more is known about it to-day. During nine years of association with the Union Irrigation Department this subject has received the closest attention and, in the hope of elucidating some governing principles that could be useful in practice, the records of the boreholes that had been sunk by the Department since Union, over 10,000 in number, were progressively tabulated and analysed according to locality, formation, depth and yield. It was also planned to publish a couple of memoirs upon the several branches of water supply in this great and, as yet, little-known land after sufficient information had been collected thereon, but such work has unfortunately had to be suspended and is, I fear, not likely to be renewed.

Rather than allow this wealth of information to be lost, I have proceeded to condense a portion of it into the following remarks, though for lack of space it becomes impossible to deal specifically and comprehensively with each of the districts of the Union as schemed originally. Furthermore, it is only possible to handle one aspect at the moment, the highly important subject of springs and particularly of dolomite supplies being left to be dealt with on some future occasion.

Most of these boring records were prepared, and the data from all of them laboriously analysed, by Mr. H. F. Frommurze, *B.Sc.*, now of the Geological Survey, who also helped to bring together much other information which has been drawn upon freely after revision, and for which due acknowledgment must be made. For permission to utilise such material I am furthermore indebted to Mr. A. D. Lewis, *M.A.*, *M.Inst.C.E.*, Director of Irrigation.

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1 *Proc. S.A. Soc. C.E.*, xi., p. 8, 1913

PART I.—GENERAL.

1. *Mechanism of Infiltration.*

Often have persons expressed their surprise that, on digging into the ground shortly after a rain, the soil is found apparently as dry as before, suggesting that little, if any, of the precipitation could ever succeed in reaching the zone of saturation. This is largely because it is not realised that soil, perfectly dry to all outward appearance, especially when fine-grained, can yet retain surprisingly large amounts of moisture—the powdery black "turf" of the Bushveld can, for example, carry up to 8%. Once the precipitated moisture has sunk down some 8 or 10 feet, it will not be brought back to the surface by capillarity, though it will still be available to roots. The entering moisture, spreading out as a film over each particle of soil, is slowly passed on from grain to grain under the action of gravity, though the process would usually not be obvious to the eye; only through systematic determinations of the moisture-content of the soil could the passage of the moisture be traced downwards to the capillary fringe above the water-table.

This receives an illustration from the Punjaub region of India, where to unknown depths the soil is a uniform, fine-grained sand. Mr. F. E. Kanthack informs me that over a certain area the ground-water level prior to irrigation used to stand at about 200 feet, but that ten years of irrigation from canals and wells raised the table to within 20 feet from the surface. Nevertheless, the sand thrown out from the wells during that time gave no ocular indication of the downward travel of the moisture, which was rendered obvious only by the progressive rise of the ground-water level.

Infiltration is dependent primarily upon (*a*) the rainfall and (*b*) the nature of the soil and sub-soil, and secondarily upon (*c*) the climatic conditions and (*d*) the geographical situation. Evidence in respect to (*b*) is presented below, while the other factors have been discussed by many writers and rather well by Meinzer,[2] and were also briefly dealt with by the Author in 1913.

[2] O. C. Meinzer. The Occurrence of Ground Water in the United States. *U.S. Geol. Survey Water Supply Paper*, No. 489, 1923.

In South Africa the soil-covering is generally scanty, the rocks—in varying stages of weathering—cropping out rather abundantly, so that much of the rain falls upon and enters the fissured rock-formation nearly directly, to percolate at first downwards and then laterally to progressively lower levels.

2. *The Water-Table.*

Should the descending moisture encounter a more clayey soil layer or a zone of deeply-weathered rock, there may be brought about a local accumulation some distance above the main field of saturation. Such "perched water-tables" are commonly pierced at shallow depths in boring and their limited and generally impermanent contributions can mostly be ignored, and indeed are usually cased off in practice.

Truly porous formations are much restricted in this country, the underground water consisting mainly of liquid stored up in irregularly distributed crevices in the bed-rock, so that, where the latter is less jointed, it may be waterless. The term "water-table" would more correctly denote the general surface attained by such waters distributed within the network of cracks; one which may indeed show considerable variation in level within short distances and may even be interrupted in places. On the contrary, in the midst of waterless ground restricted reservoirs or "pockets" may sometimes occur, which it would be the prime object of the driller to locate and tap.

This commonly rather approximate water-table of course fluctuates seasonally, but to what extent as regards the Union is unknown, though indirectly differences of level of up to 30 feet are suggested (Section 3). Almost invariable in boring is the rise of the water in the perforation, when a supply is struck. In pervious or highly jointed strata this figure is small, but in the harder and more solid formations the water may rise a matter of 20, 50 or more feet, and in a few cases even flow out at the surface (Section 11). In the amygdaloidal diabase of the South-Western Transvaal such rise is generally between 15 and 30 feet in amount. When a borehole is sunk alongside an existing dug well, it will usually not strike water until much below the rest-level in the shaft.

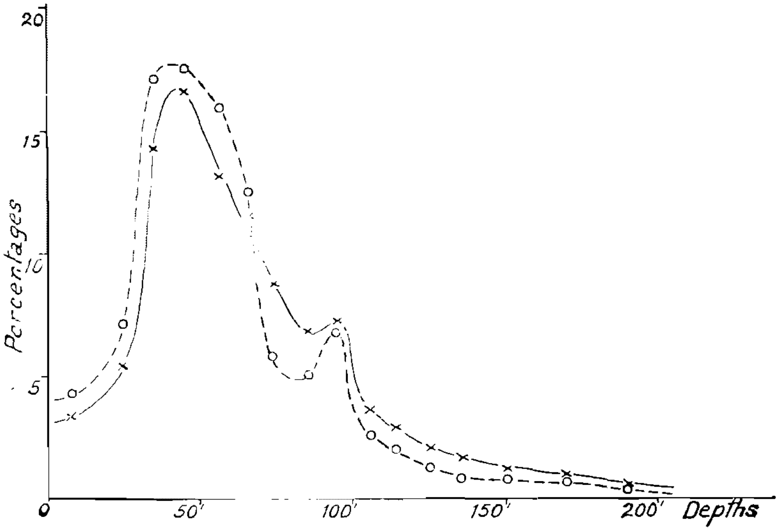

FIG. 1.—Probability curves for boreholes in Ventersdorp Diabase, Lichtenburg District, solid line—probable depths to water; broken line—probable relative yields—at varying depths.

Beneath the main zone of saturation the formation may be dry, yet with water-bearing strata deeper down. Of this advantage can sometimes be taken, as for instance beneath certain of the dolerite sheets of the Karroo, in the Witwatersrand Beds underlying the Dolomite on the East Rand or in the Table Mountain Sandstone below the Dwyka conglomerate in Natal and Zululand.

Some interesting results become apparent upon plotting the frequencies with which water is struck at any particular depth, as in Fig. 1, which is constructed from the logs of 542 boreholes drilled in the Ventersdorp diabase within the Lichtenburg district. The ordinates of the first curve represent the percentage number of holes, while in the second one, which is very similar, they denote yields expressed as percentages of the total output. Both are typical, asymmetrical curves of the form

$$\frac{dy}{dx} = \frac{y(x+a)}{f(x)}$$

such as one obtains with such irregularly varying quantities as rainfalls, run-offs, etc.[3] The curious deviation in

[3] H. A. Foster. *Proc. Amer. Soc. C.E.*, xlix., p. 825, 1923.

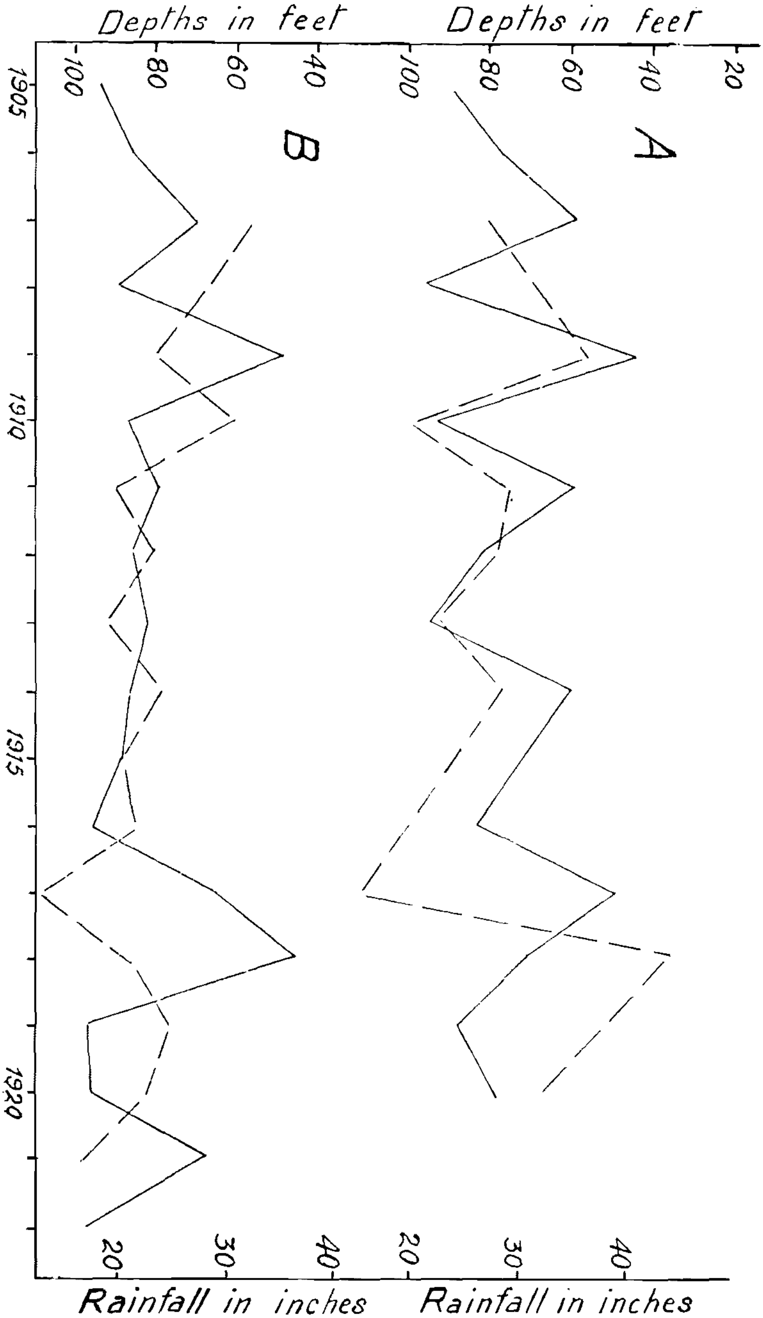

FIG. 2.—Diagrams showing the relationships between the rainfall (solid lines) and the mean depth at which the water was struck during that year (broken lines)—A, in the coal measures of Middelburg, Transvaal: B, in the old granite of Lichtenburg.

each between 75 feet and 100 feet, amounting to a minor repetition of the curve, is probably to be connected with physical changes in the rocks at about the limit of the zone of weathering. It will be observed that the most frequent depth of the water-table (the mode) is only 43 feet, whereas the arithmetical mean gives the much higher figure of about 63 feet.

3. *Fluctuation of the Water-Table.*

It is frequently stated that South Africa is " drying up," and as evidence therefor instances are cited of areas in which the water-table has fallen to the extent of many feet, of boreholes that have weakened or failed, and of springs that have ceased to flow. Reference can, for instance, be made to the Final Report of the Drought Commission of 1924. Such statements must, however, be interpreted with caution.

Systematic measurements of the seasonally fluctuating levels in individual wells and boreholes have unfortunately not been made, and evidence thereon is obtainable only by indirect methods. Groups have been studied, each representing the new boreholes drilled in a particular formation in one district during successive years and the *average depth* at which water was struck then plotted against the mean rainfall for those years, as shown in Fig. 2. Admittedly those particular boreholes must have varied considerably in their environments and, furthermore, have pierced rock of varying stages of decomposition and porosity, yet it is remarkable to find so close correspondences throughout the wide territory so studied. It will be observed that just after a good rainy season, or during the succeeding year, the new boreholes struck their waters on the whole at shallower depths and *vice versâ*. It would not do to press this interpretation too closely, yet it is suggestive that in the Eastern Transvaal, where the strata consist of horizontal, alternating Karroo shales and sandstones, such response shows a smaller lag as compared with the South-Western, where igneous formations prevail.

This computed variation in the table is quite considerable—from 10 to 30 feet, which incidentally forms a strong argument for the carrying down of every borehole to a depth sufficient to make it independent of such periodical oscillation.

A second conclusion from these diagrams is that over the southern half of the Transvaal at least there has been no marked general drop of the table with time. Indeed, in the Potchefstroom district there has been a slight rise apparently, in Wolmaranstad no change, and in Klerksdorp a distinct fall. While these deductions are from their method of derivation put forward with reserve, they cause one to doubt whether the underground resources of the country are so definitely on the down-grade. I feel inclined to regard as a more important factor towards that end the well-observed radical changes in the nature of the veld, since the run-off is nowadays nearly everywhere higher and more concentrated, and that would make the co-efficient of absorption distinctly less. It cannot be denied, however, that in certain, though fortunately restricted, areas the local concentration of windmills is making progressively heavier demands upon the underground resources, and that the water-table is tending to vary in more direct proportion to the annual rainfall and to a greater amount and may be dropping.

4. *Geological Dependence of Storage.*

The close connection of underground supply with the underlying formation is of course unquestionable, though influenced—often very considerably—by the climatic factor. Rock such as granite, that shows nearly fresh and solid outcrops in a dry part of the country, can be deeply weathered and distinctly absorptive in a wet area. Formations again are generally harder and less weathered within rugged country than over plains, other things being equal. Certain formations are troublesome, being expensive to drill or providing many failures, for example, the Red Granite and the Norite of the Bushveld, the Dolomite universally and in places the Old Granite of the Transvaal. In others failures are rare, for instance, the Contemporaneous Diabase of the Pretoria Series and, less so, the Ventersdorp Diabase that covers such wide areas in the South-Western Transvaal. The Coal Measure, too, are generally easy to drill and yield relatively few blanks.

Nevertheless, with any particular formation a restricted area may sometimes be found wherein failure is repeated, though the same strata are water-bearing round about; the reasons therefor are sometimes inexplicable. At other times it is a narrow belt of country usually underlain by a particular group of strata that has proved troublesome, for example, the relatively thin Upper Ecca Shales or the Bushveld Marls around the margin of the Springbok Flats, or the Red Beds within the Orange Free State.

The dependence of supply upon the angle of dip of the strata, upon cleavage or jointing, upon intrusive dykes and sheets, upon unconformities between two systems, and upon other vital factors have been discussed in my 1913 paper, to which there is but little to add. It might be remarked that in inclined strata infiltration largely proceeds by way of the planes of bedding, whereas in horizontal strata the same rôle has to be played by the vertical and less well-developed jointing that may often be interrupted by layers of almost unjointed and compact shales. Inclined stratified formations are therefore as a rule more productive than flat-lying ones. Attention might be directed to the higher yield from the tough Dwyka conglomerate of the Southern Cape as compared with that of the Northern Cape, Natal or South-West Africa, which is due to the strongly folded and highly cleaved condition of the rock within the former region.

5. *Selection of Sites.*

This is the crux in boring and compels for its proper discussion the entry into a field marked by acute controversy.

Many persons are under the belief that, by only sinking to the level of the nearest river or by going deeply enough, water is to be obtained practically anywhere, the marked falling off in the water-bearing capacity of rocks with depth being insufficiently realised. From the old-established custom of having the homestead in a hollow or on the bank of a spruit, there has in late years been a departure in the opposite extreme, and it is not uncommon nowadays to find almost the impossible required in the shape of a supply right on a narrow rocky ridge, the edge of a plateau, or at the base of a bare granite knob.

In locating a site one has largely to be guided by first principles, by experience of local conditions and by a knowledge of the results acquired during previous work upon adjoining ground, or, in default thereof, in a similar formation elsewhere having a comparable environment. That the surface configuration alone may have relatively little influence upon the character of the sub-surface supply has been demonstrated in practice, boring in pans or in laagtes having not infrequently failed, whereas water has readily been obtained on higher ground close by. Tabulation of the many boreholes sunk in the granite-gneiss country around Bandolier Kop in the Northern Transvaal brought out the rather unexpected conclusion that those located on higher ground (where the conditions were otherwise not adverse to drilling), including some on the divides of this rolling country, gave almost the same proportion of successes, though with a lower average yield, as those situated in hollows. A similar peculiarity was discovered 15 years ago, when drilling the Genesa block in the Vryburg disrict. How far this is general or is peculiar to the particular formation—granite and gneiss in both instances—has not been determined, but it might apply quite well in the case of other formations.

Reference must now be made to two supposed and much-discussed aids to location, namely, the Divining Rod and the Mechanical or Electrical Water-finding Instrument.

An enormous amount has been written upon the subject of "dowsing," the latest being an imposing volume by Sir William Barrett and Mr. T. Besterman, 1926, in which is brought together evidence to show that certain persons possess a mysterious, though undoubted, faculty for divining water by means of the twig, and it must frankly be admitted that the data as set out by them are of such a kind as to bear out their contentions in the case of certain particular individuals. On the other hand, I have in similar fashion collected and published[4] some of the abundant data on this subject in the possession of the Irrigation Department, and have been driven to the very different conclusion that, as a strictly practical proposition, water divining generally has been and is a failure in South Africa. Isolated instances there are of unquestioned successes by its means, but against these must be set a much higher proportion of failures;

4 *Irrigation Department Magazine*, vol. ii., pp. 35-41, 1923.

the predicted depths and quantities in such cases have but rarely been fulfilled, while there are many farms on which no diviner has as yet been successful. To sum up, it can be stated that the rod, as exercised by the average diviner or " water-wijster " in this country, is distinctly unreliable. Twenty years ago I found that a number of farmers in the Britstown district had ben sinking wells in the conical hills (spits kopjes) not far below their apices, following the advice of the " Wonder Kind," a lad credited with almost supernatural powers. Needless to state, all such attempts failed and common sense was thereby rehabilitated. Implicit faith in the " stick " has in numerous instances been responsible for the sinking of wells and boreholes in spots where closer inspection would have shown the rock to be quite solid and only very doubtfully water-bearing; for example, in certain borings made by the Municipalities of De Aar and Theunissen.

In the case of the various Water-finding Instruments the swinging of a magnetic needle within a closed case containing an insulated coil have to be construed as a sign of underground water, and the intensity of the oscillations as an indication of the shallowness and strength of the supply underfoot. Tests were made upon the farm Klipfontein at Pretoria under my direction by Mr. H. F. Frommurze, of a Mansfield and a Schmidt Finder on various dates and hours over a series of points marked by pegs in soil-covered ground underlain by norite, and the behaviour of the needles carefully recorded. The two instruments were at any one instant more or less concordant, but over any peg they behaved differently from hour to hour and from day to day, the peg showing maximum disturbance on one date not continuing to do so on some other occasions, and the deflection in some cases being actually reversed.

Of great weight is evidence of a positive character, namely, the finding of water by boring on spots where the needle gives no appreciable deflection or oscillation. Out of nine established cases in various parts of the Transvaal tested in this fashion and bored upon with success by the Irrigation Boring Branch may be mentioned the Municipal borehole at the Bon Accord Quarry, Pretoria, sunk 18 years ago in hard norite upon a site where no responses could be obtained from the Mansfield

Finder and where several water diviners had also failed to get any reaction, and nevertheless furnished 75,000 gallons on test, and is still in use with some 14,000 gallons per diem. Other boreholes near by have proved unsuccessful. It might be remarked, concerning a certain individual advertising one of these finders extensively, that my travels have brought to notice dozens of glaring failures, together with a number of affidavits to that effect from both private persons and Municipal bodies, among which can particularly be mentioned those of Theunissen, Utrecht, Jansenville and Paul Roux.

Without wishing to deny that the needle could perhaps be influenced by water underground, I am inclined to believe that these instruments mainly reveal either changes in the electrostatic potential of the atmosphere just above the ground-level, which is somewhat under 100 volts per metre of rise above the earth's surface, or else fluctuations in the strength of earth currents. Nevertheless it can hardly be doubted that in the near future an instrument will be designed on truly scientific lines to enable us to locate subterranean reservoirs with precision and also speed.

6. *Yields.*

That a decomposed, friable formation should produce by means of a borehole from 5,000 to 25,000 gallons, *i.e.*, from 800 to 4,000 cubic feet, per diem, seems not unreasonable, but that an apparently solid plutonic rock, so compact that the cores thereof may have to be broken off for their extraction, should furnish, and that continuously, equally large volumes is indeed astonishing. In difficult formations and situations, a few hundreds of gallons in the 24 hours may be all that can be obtained—merely enough for domestic purposes, but in good country from 40,000 to 70,000 is not uncommon. Tested yields of over 100,000 gallons per diem are rare and usually imply special geological conditions, such as a dolomitic or quasi-artesian source. As examples, all of which have exceeded 200,000 gallons on test, can be instanced the Municipal boreholes at Vryburg (piercing Dolomite beneath Dwyka conglomerate) and certain ones around Ceres (in Bokkeveld shales), and around Willowmore (in folded Bokkeveld and Witteberg Beds). The passages in these rocks must obviously have to be large in order that flows of such magnitude into a perforation of 6, or at most, 8 inches diameter could be produced and maintained.

Infiltration is currently regarded as being roughly proportional to the annual precipitation, but I am inclined to view the magnitude of the rainfall as a much overrated factor, except in areas possessing a thick sand cover. Curiously, for example, there has been less trouble in obtaining good yields from the hard, close-grained, tilted Karroo beds around Laingsburg, Grootfontein and Prince Albert in the Cape—a region with a rainfall of somewhere about 5 inches—than from the same formation in the Umfolozi settlement in Zululand—one of over 30 inches. We can also compare certain surprising successes in the arid region of the Namib or Namaqualand with distinctly puzzling failures in the well-watered territories of Natal and the Transvaal.

This paradox arises presumably from the fact that within the semi-arid region the rocks are widely exposed at the surface or possess a veneer of a relatively porous nature, display cracks that are open and unfilled with clayey matter, are but slightly decomposed, and contain in their pores hardly any colloidal substances. The occasional rains are therefore able to penetrate them easily. In the area of high rainfall the rocks on the contrary are often concealed beneath deep loamy or clayey soils, are usually decomposed in depth and have their crevices and pores filled with amorphous or colloidal matter derived from extreme weathering of the constituent minerals. Infiltration will thus be hindered, as is also suggested by the high co-efficient of run-off. Confirmation of this explanation is to be found in the observation brought out from the analysis of the records for the intrusive diabases of the Central Transvaal, that, where those rocks have become thoroughly decomposed to abnormal depths, the borehole yields instead of being large, are well below the average. Many similar cases involving other formations could also be quoted in support of this view, which, while to my mind of fundamental importance, does not appear to have been recognised hitherto, for it seems to have tacitly been assumed that larger supplies should generally characterise regions of higher rainfall.

Maintenance of yield is of vital importance, though to be sure the average farm borehole is rarely drawn upon to anything like its full capacity, and, unless very shallow or badly situated, should not fail during seasons of drought, if run at not more than the advocated maximum of 50 or 60% of its orginally tested output. It is with instances where the large amounts of, say, 40,000 or more gallons per diem are regularly being withdrawn, as in the case of a village, factory or railway depôt, that there is danger from overpumping, especially during dry years. Insufficiently is it realised that of the rainfall only a small fraction is able to get stored up. There is little information available on this point, but over the sand-covered Dolomite of the Krugersdorp district the mean annual infiltration has been computed to be 11.5% of the normal rainfall (26.3 inches), or 3 inches in all.[5]

For most igneous and sedimentary formations and under varying environments the effective contribution from meteoric sources would probably range between 1 and 4 inches per annum, which would be equivalent to an addition of from 40,000 to 160,000 gallons per square mile per diem. There would have to be a decidedly rapid and free underflow towards the borehole, if an equivalent supply were to be withdrawn at a single point in that area; if not, the water-table would be forced to drop progressively in the vicinity of the borehole, producing a cone of depletion, and much less than the above amounts obtained. Further, since the actual storage capacity of the average rock formation is relatively small, the removal of, say, an inch of contributed rainfall would involve a fall of the table over the area of depletion to the extent of several feet probably.

The specific yields of the more important formations in different parts of the Union will be dealt with in Part II.

7. *Overpumping.*

That great and sometimes lasting injury can be done through excessive pumping is obvious, but there are also cases in which the supply fails, although the reservoir has not yet become exhausted, as duplication of the borehole will prove. Such a condition would seem to be favoured by brief, heavy pumpings alternating with

[5] *Irrigation Department Magazine*, vol. iii., p. 2, 1924.

longer rest periods, under which action the fine particles of clay first become sucked out of the enclosing strata and then pack together, thus clogging the pores and crevices in the walls of the hole, which action is aggravated by slime, rust from the casing, etc. A good example was afforded by the two Municipal boreholes in Port Shepstone, Natal, drilled in soft Ecca shales and drawn upon heavily at the rate of several thousands of gallons per hour for a few hours a day. The cause of the failure having been diagnosed, one of the holes was dynamited with small charges at progressively lessening depths, through which about three-fourths of the original yield were ultimately recovered. It might be remarked that at Galveston, Texas, the artesian wells gradually fell off in their yield, though new holes indicated no decrease in the hydrostatic pressures. This diminution was ultimately cured by a system of periodic back-flushings under pressure. Though difficult to put into practice in the case of an ordinary borehole for obvious reasons, this method should not be overlooked as a possible means for restoring the yield of an over-pumped borehole.

When a borehole has to be strongly drawn upon by engine and large cylinder, it is suggested that such pumping be spread over a longer period, with shortened stroke, if necessary, rather than heavily, briefly and intermittently. If a borehole furnishes only a few thousands of gallons per diem and is equipped with an engine, the supply may have to be obtained through several spells of pumping and recovery every day. It may then be found more convenient to sink a well alongside, tunnel through to the borehole and pump in one spell, the shaft providing an effective storage that could be heavily drawn on for an hour or so a day, but with less danger to the borehole. Such, for instance, has been done on certain farms situated on the Norite in the Rustenburg district.

8. *Dynamiting of Boreholes.*

Under certain circumstances such a policy can be resorted to when the completion test shows an insufficient supply, though hardly ever except in the case of shot-drilled holes. With the latter the walls of the perforation become puddled and the pores and crevices blocked under the grinding action of the crown. Not uncommonly, therefore, the completion-form of a shot-drilled hole shows a lower figure than that found after the borehole has been in operation for some time.

When in such a case the water is observed to enter from one or more joints in the walls, the detonation of a few sticks of high-grade explosive, or even of larger charges, opposite each fissured section may produce an appreciable increase in the yield. It is difficult to generalise, but improvement may be quite marked in the case of dolomite and hard rocks, such as quartzite, or in crystallines, though only rarely considerable in the case of the softer sedimentary strata. Where the cores are of sound rock and the tested supply is trivial, dynamiting will generally prove useless. Blasting should be done while the machine is still on the spot, as the hole commonly needs to be cleared after the operation and the casing, which for safety has had to be raised or removed, replaced.

9. *Difficulties in Drilling.*

(*a*) *Open Fissures.* In boring cavernous formations, such as the Dolomite, the temporary loss of feed water may be a serious matter, sometimes impracticable to stop by means of clay, chopped straw, etc.; particularly troublesome is this in core-drilling, when the shot are also carried away. Cementation is then the only remedy, though, pending the setting of the material, drilling cannot be resumed for several days, and, as this course may have to be repeated at various depths, the delay may be considerable. Various experiments have been carried out by the Irrigation Boring Branch towards speeding up this work, and it was found that the addition of calcium chloride to the cement in the proportion of about 1 part to 20 enabled drilling to be resumed in about 24 hours', though preferably in 36 hours' time. Quick-setting alumina cement is still more efficient, though more expensive, but is only rarely obtainable in this country; with it the time becomes reduced to six hours.

(*b*) *Running Sand and Mud.* Coarse sand can usually be kept out with perforated casing and finer material with special screens of brass gauze, but in the case of fine mud the smallness of the mesh required restricts the flow considerably, while the filter tends to clog. To provide a greater area, while still holding back minute particles, a special screen was designed and manufactured by the Boring Branch of the Irrigation Department, and has been described by Mr. L. D. O'Grady.[6] The water is drawn through the continuous gap between successive turns of a spiral of wire wound in a groove cut around a slotted or perforated tube, the pitch of the thread being just a shade more than the gauge of the wire. This type of screen, which has been applied with success in the Kalahari, can be made to stop all sediment having a particle-diameter greater than 1/100th of an inch with the minimum of resistance, and is not only stout and durable, but, being screwed on beneath the pump cylinder, can easily be drawn out and replaced.

There are, however, certain formations, such as the Kalahari Marls, the yellow-weathered Malmesbury Slates of the Cape Peninsula or the Bushveld Diabase of the Transvaal, that furnish impalpable muds capable of passing right through an ordinary filter-paper. Particularly troublesome has been a belt running along the foot of the ridge of the "Daspoort Quartzite" at Silverton, Pretoria, where, beneath a mantle of sand the completely rotted diabase yields an abundance of muddy water rather like yellow colour-wash, while pumping frequently results in the collapse of the borehole. To cope with this unwelcome situation the following ingenious method was devised: The depth of the turbid water standing in the borehole having been determined by measurement as, say, 12 feet, numerous small perforations are drilled in the casing at about 10 feet from the bottom, which is closed, the string of casing put down and the pump inserted. The supply can only enter through the ring of perforations and, being derived from the top of the column of water standing in the hole, is after the lapse of a few days found to be clear or only slightly discoloured. Pumping at a moderate rate is usually found not to disturb the yellow pulp surrounding the lower part of the closed-ended casing, but the success of this scheme is mainly dependent upon constancy in the height of the water-table.

Experience with this formation and elsewhere has, however, shown that it is much better to continue the

[6] *Irrigation Department Magazine*, vol. iii., p. 31, 1924.

drilling through the clayey water-saturated zone (with the casing following down the tools closely, so as to avoid caving) until more solid ground is reached, and then casing off the upper section with its impalpable mud. Care has to be taken to make an efficient seal, otherwise clay will be washed into the borehole and the latter will soon become filled with mud. A good example is Borehole No. 9481, near Mulder's Vlei, Stellenbosch, wherein 134 feet of water-bearing clays were passed through overlying decomposed granite. As the supply failed to clear, the casing was ultimately taken down to 328 feet, at which depth the granite hardened up, and the hole finished off at 346 feet. The yield of 5,000 gallons per diem was much less than that got in the upper half of the boring, but in a case of this kind one has perforce to be content with a smaller supply of clear water from the greater depth.

10. *Deep Boring.*

As compared with practice 20 years ago, boreholes are certainly being carried down to greater depths on occasions, and there are a number of cases on record where the water was only struck well below 400 feet, which is not surprising when we recall the occasional inrushes met with in mining operations. Nevertheless, as the Table in Part III. bears out, supplies are generally obtained at under 200 feet, and in certain formations or areas at under 100 feet. In 1913 the question of deep boring was discussed by the Author and a list given of deep boreholes in the Cape Province with their depths and yields, from which it was manifest that but few of them could be regarded as eminently successful, even ignoring their excessive cost in drilling, equipping and operating. All work subsequently done has supported the conclusion that it is rarely worth going below 400 feet unless a second site is definitely barred out, and it is imperative that a moderate or small supply shall be provided at the spot in question.

Of additional holes in the Union exceeding 500 feet the following may be noted:—

No.	District	Depth.	Water struck at.	Yield.	Formation.
778	Pretoria	503′	417′	1,500	Felsites
1,187	Springbok Flats	508′	—	Nil	Stormberg beds
1,776	Bloemfontein	518′	145′	2,400	Beaufort beds
3,077	Hoopstad	581′	515′	48	Ecca beds
—	Danielsrust Station, O.F.S...	584′	—	Nil	Beaufort beds
2,926	Springbok Flats	591′	229′	40	Ecca beds
2,749	Springbok Flats	630′	—	Nil	Stormberg beds
922	Springbok Flats	690′	472′	4,800	Ecca beds
2,921	Marico	700′	204′	4,000	Pretoria beds
—	Bloemfontein	705′	(various)	3,000	Beaufort beds
1,482	Lichtenburg	712′	30′	3,600	Dolomite
165	Bethal	831′	785′	2,000	Coal measures
1,621	Springbok Flats	835′	300′	4,800	Stormberg beds
245	Standerton	886′	415′–691′	1,200	Coal measures
3,920	Springbok Flats	890′	—	Nil	Stormberg beds
121	Standerton	890′	880′	60,000	Coal measures
—	Kroonstad	1,000′	84′	Little	Beaufort and Ecca
770	Pretoria	1,432′	1,430′	28,000	Pretoria beds
—	Hofmeyer	1,507′	(various)	?	Beaufort beds
11	Springbok Flats	1,564′	—	Nil	Stormberg beds
10	Springbok Flats	1,787′	—	Nil	Stormberg beds
—	Bloemfontein	3,002′	60′	Little	Beaufort beds

The above remarks do not apply where the geological conditions are such as to favour truly artesian supplies, as set forth in Section 11. Excluding such cases, it is found that percolation and storage are dependent mainly upon the presence and abundance of the small joints and fissures in the fresh or slightly weathered rock. The Author has drawn attention to this feature in the case of the sandstones of the Great Karroo by measurements of their actual pore spaces, which were found to be relatively low, from 2 to 5%,[7] while judging from the yields obtained in the Transvaal, the porosity *in depth* of both the Coal Measures and Bushveld Sandstone cannot be very great, though outcrop specimens are quite absorbent, having pore spaces of from 7 to 18%.

11. *Flowing Supplies.*

A generation ago flowing water was quite frequently struck at shallow depths in the Central Cape Karroo; indeed, in boring convenience of situation was often sacrificed towards that end. With time the ratio of flowing holes declined and the depth of the water-table increased, so that nowadays it is rare to have the water overflowing. In the Queenstown district, one of several that could be instanced, there were drilled in the years 1894-1908, 5 10, 9, 22, 14, 24, 15, 31, 51, 22, 25, 16 and 18 holes, the corresponding flowing cases being respectively 5, 10, 7, 7, 3, 6, 0, 2, 1, 1, 0, 0 and 0, while the average depth at which the waters were struck increased from 55 feet to 67 feet. The records for the districts of Tarka, Cradock, Hanover, Graaff Reinet and Victoria West show the same kind of thing.

By some persons this has been interpreted to indicate the progresive depletion of the long-accumulated stocks of ground-water through decrease in the rainfall and through overpumping, but it should be noted that in the past the boreholes were often drilled in stream-beds, near springs and behind dykes; with the elimination of all such favourable sites the less satisfactory ground has had to be tackled.

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[7] *Trans. Royal Soc., S.A.*, iv., part 3, p. 169, 1915.

The most productive hole in the Karroo is probably the shallow one on the farm Tafelberg, near Rosmead, drilled about 100 yards behind a fine dolerite dyke that crosses a wide shallow depression and has behind it a large catchment of shales and sandstones with a faint and favouring dip towards the intrusion. Up to 1914 it gave a steady flow estimated at about a million gallons per diem and had in 1918 a static pressure still of 15½ lbs. per square inch, but fell off enormously in its yield in 1920, and since then has been more directly dependent upon the incidence of the rainfall. Attention might also be directed to the flowing and interconnected boreholes at Tarka Bridge, Cradock, described by Professor A. Young,[8] which must obtain their tepid and slightly saline supplies from some considerable depth. The town of Keetmanshoop is dependent for its supply upon a flowing borehole sunk through an igneous sheet that cuts across and then comes to overlie soft Ecca shales, the water being held in the latter under pressure beneath the massive dolerite covering.

Flowing water is not confined to the Karroo strata with their favouring intrusions, having occasionally been obtained (where the conditions have been suitable) not only in other stratified formations, such as in the Pretoria beds (Rustenburg and Potchefstroom), but in the Ventersdorp amygdaloidal diabase (South-Western Transvaal) and even in the red granite (Bushveld) and ancient gneisses (Namaqualand). A couple of instances are known in Natal of productive boreholes penetrating the slightly tilted Table Mountain Sandstone below the tough Dwyka conglomerate; more advantage ought to be taken of such a favouring structure, which is common in the coastal belt of that Province. Now and again water travelling along the plane of a fault can be intercepted, as for example in the celebrated case of the Newlands Spring, Cape Peninsula, the flow of which was finally tapped some distance further along the responsible fracture-line that traverses the close-grained Malmesbury slates in a group of borings put down within quite a small circle.

In contrast to the above cases, in which small or localised reservoirs have been pierced, are those in which

[8] *Trans. Roy. Soc., S.A.*, vol. iii., p. 61, 1913.

true artesian basins have been tapped, such as that of the Uitenhage district or of South-West Africa. The first of these is of considerable geological complexity, wherefore it will suffice to state that the water can be struck in one of three distinct formations: (*a*) in jointed Table Mountain quartzites beneath a covering of Cretaceous clays, *e.g.*, Imanzi (Balmoral) and Sandfontein (Uitenhage Commonage); (*b*) in the gritty and conglomeratic basal zone of the Cretaceous beds of the Zwartkops Valley, the water being charged with sulphate or carbonate of iron, the gusher at Zwartkops Junction, 3,620 feet deep, indicating a high potential, with strong mineralisation;[9] and (*c*)—though not yet demonstrated by actual practice—in the sandstones of the Cretaceous "Wood Beds" of the Lower Sundays River Valley within a belt running eastwards from Kirkwood towards Coerney and southwards to Addo, though the borings therein would generally have to be deep.

The splendid flows, amounting in individual cases to over half a million gallons per diem, obtained in the Kalahari region to the south of Gobabis and east of Mariental have only briefly been referred to in print, being derived from a zone of porous Karroo sandstones sandwiched between tight shales. It is worthy of notice that the Administration of South-West Africa has prudently taken steps towards reserving all artesian water to the Government, prohibiting all boring within the artesian area except under permit, insisting that the casing be efficiently sealed against leakage and compelling the discharges to be properly controlled by stop-valves. This essential legislation, which was passed none too soon, has terminated the squandering of a valuable asset. I believe that there is just the possibility of the southern edge of this basin falling within Union territory in the pointed tongue of waterless and uninhabited ground adjoining the dry Nossob channel, and have accordingly suggested that trial borings be made in that quarter.

In 1920 artesian water was struck by the Cape Copper Company in banded gneiss at a depth of nearly 1,000 feet at Koperberg, Namaqualand, and since then

9 *S.A. Journ. Sci.*, vol. ix. p. 119, 1913; details regarding the Uitenhage district will appear in the forthcoming "Explanation of the Geological Map" of that area.

a number of other other diamond-drill holes, all put down for copper, have intersected water under pressure at Carolusberg and at Garracoup Junction, which was also cut in the workings of the O'okiep and Homeeb Mines. In three instances at least these supplies were obtained just within a zone of supposed "quartzites"—more probably a flat-bedded, foliated, quartz-vein—but in the other instances well above that horizon; in all cases, however, close up to copper-bearing dykes or bodies that traverse the laminated gneiss. The latter together with the "quartzite" has been thrown into several anticlines and synclines in which the dips are moderate, and it is maintained by Merensky[10] that boring at suitable spots in the troughs should tap water under pressure in or above the "quartzite." From my limited acquaintance with these occurrences such is not unlikely, though it would seem that a mere synclinal or monoclinal structure in the laminated gneiss alone might at times be sufficient. There are many places where the borings would otherwise have to be deep. The waters found so far as of good quality and only slightly saline, but the supplies generally might not be very large and would, of course, have to be husbanded. As regards the several synclines, Springbok, Koperberg and Carolusberg lie on the northern side of one; the next one to the north, 12 miles wide, has Nababeep, O'Okiep and Concordia in its southern part, the "quartzite" sinking in its axis to a depth of about 4,500 feet before reappearing in the north at Ratel Poort. Similar structures can be studied to the west of Steinkopf and to the south-west of Anenous and are reported also to the east in Bushmanland.

12. *Coastal Supplies.*

Important stretches of our coast-line consist of scrub-covered sands or dunes devoid of springs or streams, while such waters as are obtained from vleis or wells are not uncommonly brackish; we may cite, for example, the shores of much of Namaqualand and Bredasdorp, and St. Helena, False, Mossel and Algoa bays.

Where erosion has cut through the covering of blown sand or recent limestone, the latter is often found to be resting upon a rock-shelf that is standing at some

10 *S.A. Min. and Eng. Journal*, xxxviii., No. 1898, p. 627, 1928.

distance above sea-level and is sloping gently seawards. The rainfall, on being absorbed by the porous covering, sinks down and then percolates along slight depressions or irregular channels eroded in the buried rock-surface, to issue in the form of springs on the shore itself, an excellent instance being Schoonmakers, near Port Elizabeth. Sometimes the water bursts out on the beach below high-tide level, as at Strandfontein (Olifants River mouth, Van Rhynsdorp) or the Coega River mouth (Algoa Bay), and not improbably much water is issuing beneath the ocean itself at these and other places along the shore, Fig. 3. Success in boring would largely be dependent upon the striking of one of such saturated zones of under-drainage within the base of the sand or limestone resting upon the rock platform, rather than in the latter, though flowing water actually issues at 10 feet above sea-level from a borehole on the shore near Mount Edgecombe, apparently from the dipping Coal Measures that here underlie the thick, red coastal sands of Natal.

The problem is attaining some importance because of the opening up of new spots as settlements, holiday resorts or townships, each of which has its own peculiar local conditions. As examples from a long list can be cited Saldanha Bay, Little Brak River, Plettenbergs Bay and Gonubie River.

13. *Difficult Areas.*

Apart from numerous patches of ground dotted all over the country that have already given failures and that will have to be taken in hand anew some day, there are a few quite large areas in which drilling has been or will prove troublesome.

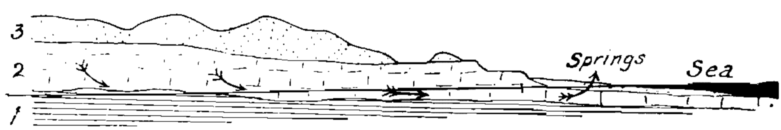

FIG. 3.—Geological section to illustrate the springs near the Coega River Mouth. 1, blue clays; 2, porous limestones; 3, white dune sands.

(*a*) *The Lebombo Flats.* This forms a strip running just inside the Lebombo Range, from Northern Zululand to the Letaba River at least, with a breadth of from 10 to perhaps 20 miles—largely a bush-clad plain with low rises and occasional kopjes. Stormberg basalts dipping eastwards compose the prevailing formation, but they are intersected by a system of nearly parallel, vertical dolerite dykes striking nearly north and south, often not more than 50 feet apart. Measured in an east-west direction, they may possibly average so many as 50 per linear mile. The basalts and the dykes weather rather similarly, but the latter tend to make faint narrow ridges or give rise to lines of boulders; over the red soil-covered ground they may not be traceable. They are of importance in that they cut the stratified lavas into narrow strips, so that a borehole comes to obtain its supply from an elongated compartment of basalt that rarely exceeds 100 yards in breadth, bounded on east and west by relatively impervious walls made by two dykes.

Yields are accordingly low, added to which the water is sometimes brackish—regrettable in view of the recent considerable agricultural developments in this belt, for, apart from the few large rivers, the Flats are nearly waterless and the rainfall distinctly low. When about to drill, efforts should be made to avoid these defining dykes and, whenever lack of exposures renders such a course necessary, shallow east-west trenches should be dug in advance to disclose their positions.

(*b*) *Kalahari Region.* The fringe of this immense sandy region has been under the attack of the drill for some years now, and that portion within the Union is slowly being retrieved, though the costs of operating in such hinterland and of casing are high. The information thus disclosed is so vast that it can hardly even be summarised and by rights ought to be made the subject of a separate paper.

The covering of superficial deposits is often very deep—over 200 feet being common, with a recorded maximum of 463 feet—and embraces such contrasted types of material as red dune-sand, calcareous tufa, surface quartzite, red marl, potclay, sandstone and conglomerate, several of which may be encountered in any one boring.[11] Such alternating hard and soft bands are troublesome to pierce, while the marls that have been cut in depth in fully one-fifth of the boreholes in Vryburg and Kuruman, make treacherous drilling and are on occasions waterless. While the general order of succession seems to be fairly uniform over wide areas, rapid variations in the degree of calcification or silicification of the materials give rise to very different results, both as regards the nature of the stuff passed through and its water-bearing character in boreholes only a mile or so apart. At first advantage was taken of the various dry river beds, such as those of the Molopo and its tributaries, Kuruman, Nossob and Auob, water usually being struck in fairly soft formations at between 100 and 200 feet, but operations have since been extended to the sand and bush-covered plain remote from any such channels. In the absence of any outcrop trial is usually made at any suitable spot and, if unsuccessful, a second attempt is made half a mile or more away in the hope that the material pierced at that point may prove more favourable. The bulk of the boreholes obtain their water at depths of over 200 feet and sometimes over 300 feet, as in the north-west corner of Mafeking, where the Old Granite is buried beneath a deep mass of sand, potclay and gritty or pebbly material.

The thick mantle of Kalahari Beds conceals in Kuruman and Vryburg an uneven surface of ancient rocks, and boring has shown that the deepest parts of these old valleys may contain water-bearing rubble, gravels and sands beneath several hundreds of feet of marl, clay or other dry material; especially is this the case on the eastern side of the Koranna Berg. With little or no surface indications as a guide, it may need more than one trial before such a hollow is struck, though not infrequently water is got in the underlying hard rock, but not in such abundance. Of 142 boreholes around the Koranna Berg (of which one-sixth exceed 300 feet) the average depth is 230 feet, yield 10,800 gallons and failures 32%, while in Mafeking and Vryburg the corresponding values for 64 cases are 213 feet, 9,200 gallons and 30%. In both areas the mean quantity is brought up by a few good supplies.

[11] See Du Toit, *Geology of South Africa*, pp. 367-370, 1926.

14. *The Future of Boring in the Union.*

(*a*) It might be thought that, under the combined attack through these many years, both by the Boring Department and by the numerous private drillers, the scope for boring would by now have become immensely restricted, but, so far as can be judged, that is far from being the case. There still remain wide unoccupied areas of Crown Lands, the limits of which are only slowly being reduced under the onslaughts of the drill, for example, Bushmanland, much of Gordonia, the northern parts of Waterberg and Zoutpansberg, and the lengthy strip that constitutes the Lowveld of the Eastern Transvaal and Swaziland, the Bechuanaland Protectorate and Southern Rhodesia.

All the above represent virgin ground mostly, but the continued sub-division of farms is producing a universal and undiminishing demand for the drill. The tardy recognition, that much of South Africa suffers from endemic drought, is leading to the boring of new holes within the occupied areas or to the deeping of old ones, a policy that is becoming extended even to those parts of the country possessing a supposedly adequate annual rainfall, *e.g.*, Central and Eastern Natal. Supplies are being demanded for new schools, railway sidings and cottages, police camps, factories and native reserves, while there are also a number of growing villages, which, being as yet unable to embark upon any schemes of storage, are for the present compelled to remain dependent upon boreholes. For some time to come no falling off in such operations is to be anticipated.

(*b*) Speaking generally, the difficulties inherent in drilling are unlikely to diminish with time. Less favourable sites in both a geographical and geological sense will have to be accepted; renewed attempts will be made upon farms hitherto attended by failure; the more mountainous or rocky portions are being occupied, so that certain tough and compact formations will ultimately have to be tackled, such as the Ventersdorp quartz-porphyries and the Rooiberg Felsites; in the hotter or malarial districts the homesteads are now being built on eminences and sometimes upon bare granite knobs, and supplies are being demanded right alongside those dwellings.

(*c*) These several factors will conspire to raise the proportion of failures, while certain boreholes will incidentally be carried down to greater depths than is the rule at present, so that the average cost of a successful hole is bound to increase, unless an equivalent saving can be effected in operating costs. The percussion drill of to-day is a highly efficient tool and little further economy appears possible, except the more general use of petrol or oil instead of steam in certain of the outside districts. With the shot-drill, however, the elaborate experiments carried by Mr. L. D. O'Grady, of the Irrigation Department, have proved that increased speeds of rotation, the proper shaping of the bit, the hardness of the latter and the rate of feed of the shot can collectively lead to an appreciably greater rate of cutting. Utilising combination-machines, Major C. A. Anderson, Boring Engineer to the Southern Rhodesian Government, has obtained marked increases in efficiency and economy, as against the ordinary separate rotary and percussion types in general use.

(*d*) There is an aspect to which attention might specially be directed, and that is the strong tendency towards large-diameter boreholes. Not many years ago 5 inches, or at most 6 inches, was accepted as adequate; to-day the farmer insists on at least 8 inches, while some persons demand 10 inch holes or larger, mainly through the misapprehension that a proportionately greater yield will thereby be obtainable. For all ordinary purposes a diameter of 5 inches is ample, being sufficient to take the largest size of cylinder required.

It is clear that this insistence upon larger holes is leading not only to slower rates of drilling and to higher costs for casing, but to the employment of much heavier and expensive machinery than is necessary, such resulting in increased operating and transporting charges and incidentally in greater liability to breakages of stems, jars, etc. The modern drill is certainly called upon to pierce some remarkably hard and often objectionably fissured rocks, and the tools must therefore be of heavier pattern, but on economic grounds a superior limit would appear to be set to the diameter, which to my mind is being greatly exceeded.

(*e*) Turning to the other side of the picture, one may look forward to the time—perhaps not far distant—

when the satisfactory location of sites will have become possible through some properly designed mechanical instrument. Until then the only plan is to make a study of the ground in the light of the experience gained in the Union during these years, and it is precisely towards that end that this admittedly imperfect contribution has been prepared.

To conclude, it can be affirmed that for many years to come South Africa will continue to make important demands upon the skill of the boring engineer and his agent, the slow, but transforming drill.

PART II.—FORMATIONS AND THEIR WATER-BEARING QUALITIES

15. *Introductory.*

Only the more important and widespread formations can be discussed, yet it will be observed that the Transvaal receives rather full treatment. This happens because, although boring was extensively carried out in the Cape prior to Union, the demand has since been greatest in the Northern Province; in Natal and Zululand again there has been no pressing need because of the higher rainfall.

The following accounts must clearly be recognised as attempts at generalisation, to which there must be continual exceptions; indeed a casual study of any one of the detailed tabulations will bring out the variability in depth, yield, etc., in individual cases. Nevertheless the averages set down are often of considerable aid when boring is being planned or is in progress in any particular formation within a certain district, read in conjunction of course with the principles that have been enunciated in Part I.

It might be remarked that, of the cases recorded as "failures," quite a fair proportion appear to have been abandoned too soon, judging from the computed mean depth at which the water has been struck in the particular formation and locality. Sometimes this has been due to mechanical difficulties, sometimes to the presence of unexpectedly hard rock at a shallow depth, but there are still a goodly proportion of cases in which the applicants have insisted either in boring on an unsuitable spot or upon prematurely stopping the drilling in order to bore on another site. For a good deal of this last the water diviner is responsible.

The various formations are treated below according to their stratigraphical relationships, beginning with the oldest. It is, however, impracticable to detail their geographical distribution within the Union or their essential lithological characters and modes of weathering, for which reference should be made to current geological works and to the geological maps and sheet explanations of the Union Geological Survey.

The question of the salinity of borehole waters is only incidentally referred to, as its geological and climatic dependence were to some extent considered in 1913. Much, however, could be written upon this extensive subject and upon the still more important and allied one of industrial supplies and their chemical improvement, a problem that has not received adequate attention in this country.

16. *The Old Granite.*

Fully one-tenth of the boreholes sunk by the Government since Union penetrate the ancient granites and gneisses. While few in number in the belt traversing Natal, Swaziland and the Eastern Transvaal, they are abundant in the highveld of Pietersburg, Zoutpansberg and Rustenburg, and in the sand-covered districts of Mafeking and Vryburg, but scattered in the wide, sparsely populated areas between Prieska and the Atlantic. The granite inliers of the South-western Transvaal have all been extensively drilled.

The rocks range from homogeneous, medium or coarse-granites to massive, platy or well-foliated gneisses, granulites and amphibolites, in which veins of pegmatite, aplite and occasionally quartz are common. For convenience we can also include the various strips of basic and other schists, quartzites, crystalline limestone, banded ironstones, etc., into which these granitic rocks are mostly intrusive. These still older formations have not been much drilled, it is true, but present few difficulties, apart from their usually tilted and sheared character, for the fact that the softer beds are often deeply weathered enables water to be obtained in them usually without trouble. A marked exception is presented in the greenstones and greenstone-schists of Rhodesia, which constitute a distinctly tough and difficult formation.

The character of the underground supplies in the crystalline rocks is dependent upon the behaviour of the latter under weathering, which in turn hinges upon rainfall and environment very largely (Sections 4 and 6). They make, for example, several fairly distinct types of country, namely: (*a*) barren ranges and rock-floored valleys with curved surfaces scaling off under insolation (the arid central belt of Namaqualand); (*b*) bare exfoliating hills rising from a plain of deep red sand that is mostly underlain by more gneissic and friable types (Bushmanland); (*c*) bush-clad undulations and flats with reddish soil and bare knobs or tors (Pietersburg); (*d*) rolling country with coarse pale soil concealing the decomposed rock and showing few outcrops (Lichtenburg); (*e*) red, sandy, bush-covered plains with the fresh rock surprisingly close to the surface (Northern Rustenburg and the Eastern Lowveld); and (*f*) bushy plains with great thicknesses of sands, clays, etc., concealing the solid rock (Kalahari border in Mafeking and Vryburg).

Almost universally there is a greater tendency for the gneissose and banded types to weather along the planes of foliation and to acquire a most valuable fissile character, but occasionally even the homogeneous granite is friable to considerable depths, largely as the result of partial kaolinisation of the felspar crystals. In most cases the water nevertheless appears to be stored up in the crevices and joints rather than in such porous portions of the rock, it being indeed remarkable to find the sound formation traversed by such joints at distances in some cases of over 300 feet beneath the surface. Three peculiarities occasion some surprise: (1) the depths to which it may be necessary to go, (2) the excellent supplies so commonly obtained in these compact plutonic rocks, and (3) the good yields to be got upon the rising ground in certain areas (Section 5).

As regards Namaqualand—*type a*—boring in the central belt is, if we except the areas referred to in Section 11, somewhat problematical. In Van Rhynsdorp, with a mean rainfall of about 5 inches also, the average yield has only been 4,200 gallons per diem and the failures 3%. Two of these holes, 420 feet and 481 feet deep, struck supplies of 2,800 and 3,000 gallons at 374 feet and 365 feet beneath 200 feet and 300 feet of sandy covering, the water rising to 360 feet only. This introduces us to *type b*, in which the saturated sands occupy only the thalweg or axis of the buried valley and therefore may not be struck at the first attempt. Thus at Knie Brand, west of Steinkopf, one hole struck the floor too soon, one obtained water right on the contact at 272 feet, while the third got its supply at 302 feet, the rock not yet being reached at 310 feet. In Bushmanland the conditions would probably be rather similar.

At the other extreme stands *type d*, the South-western Transvaal—Klerksdorp, Lichtenburg, Wolmaranstad, Ventersdorp and Bloemhof—extensively drilled, with only one-tenth blanks, water struck at mean depth of 85 feet, rising to 46 feet, mean yield 25,600 gallons—the highest for any area; 90,000 has occasionally been obtained. In the Pretoria-Johannesburg area the high mean figure of 20,000 is due to the inclusion of boreholes in the schistose rocks lying in the direction of Krugersdorp, all productive and giving the remarkably high average among themselves of 47,500 gallons. Without them the granite proper furnishes the mean of only 9,100, while the failures constitute one-fifth. A strip along the Yokeskei River has proved most unsatisfactory owing to the remarkably solid character of the granite there.

The extensive operations in Pietersburg and Zoutpansberg, *type c*, show the water to be much deeper, a bit more so in the latter district, the averages for both taken together being, depth to water 112 feet, rising to 73 feet, and yield 21,500 gallons, while the failures constitute 25%. The rocks reported as "schists" are generally amphibolites and have proved rather tough, giving the smaller return of 13,500. On the other hand, in certain belts of crystalline limestones veined by the granite the water is struck at appreciably shallower depths, at the mean of only 86 feet, yet with a mean volume of 27,700 gallons. More advantage should be taken of such rocks, though their waters are hard, faintly sweetish or sometimes a little bitter.

In the northern part of Rustenburg, *type e*, the water is deeper and scantier than in any other area in the Transvaal. The average depth of the successful holes is 194 feet—which is not due to the inclusion of any exceptional ones—the mean depth down to water as great as 161 feet, but the average yield is 19,500, which is good. The overburden may in the west be surprisingly thick, but the rock beneath is often so hard, that from 2 feet to 3 feet can only be done in it in a day. In this area the absence of water cannot be presumed at a less depth than 200 feet, and the unduly high percentage of failures, 40, is explicable by the fact that many of them have been stopped above that distance. On the contrary, a number of holes were sunk to 350 feet, but no water or only small amounts found in them.

Similar conditions prevail in Mafeking and Vryburg, *type f*, the granite becoming progressively covered towards the north-west by superficial deposits, that ultimately exceed 400 feet in thickness, but the results have generally been better than in Rustenburg. In North-western Mafeking the water has sometimes not been struck until between 300 feet and 400 feet, but in the north-west of Vryburg only 3 out of 8 holes to over 300 feet were successful. In Prieska and Kenhardt the conditions again are rather like those in the Northern Transvaal and the results have been satisfactory.

Throughout the Union one can sometimes take advantage of the upper side of a quartz reef, pegmatite or aplite body, or a basic dyke, in the old granite, particularly one of Karroo dolerite. The improvement is due to fissuring developed in the granite bordering the dyke, but sometimes the latter is appreciably jointed or is decomposed, and then itself carries water. In the southern part of Southern Rhodesia Major C. A. Anderson has found it advisable prior to boring to have the contacts and courses of all dykes around the spot, suspected as well as partially exposed, determined, because of the liability of the underflow to interception by a possible second intrusion on the higher side.

17. *Witwatersrand and similar Ancient Systems.*

The lower portion of the "Rand" system consists of a series of quartzites, forming characteristic ridges, alternating with thick bodies of reddish slates, and including in the Heidelberg, Parys and Klerksdorp districts important sills of intrusive diabase. The quartzites can nearly always be avoided and the drilling done in the soft slates or the diabase; the water indeed is mostly shallow, so that wells may be found more economical, as for example about Germiston and Benoni. The results are closely comparable with those obtained in the Pretoria Series with its similar sills (Section 20a).

The upper portion consists of a great mass of bedded quartzites and grits, which, while hard in depth, have through weathering acquired a condition near the surface rather like that of a sandstone, and are then not difficult to penetrate. In the Klerksdorp district the entire system, inclusive of diabasic intrusions, gave only 11% of failures and an average yield of 28,200 gallons, one-eighth of the holes exceeding 70,000 on test, while the mean rate of drilling was so high as 8.6 feet per diem.

The above remarks can be applied to the areas made by very similar formations (Pongola and Insuzi Beds) in Piet Retief, Paulpietersburg and Northern Zululand. In the case of the Kheis System of Prieska and Kenhardt the dominant quartzites are very hard, so that some of the intercalated bands of quartz-schists, phyllites or granulites may have to be selected. In the Kraaipan Series of Mafeking and Vryburg it is usually possible to avoid the massive banded ironstones and cherts and to utilise the interbedded chloritic schists and phyllites; nevertheless nearly 40% of the holes were failures and supplies averaged only 18,500 gallons, both less in amount and greater in depth than in the adjacent granite.

18. *Ventersdorp System.*

(*a*) In the case of the older division, known as the Zoetlief Series, the highly massive and tough rhyolitic lavas have largely been avoided, and the drilling done in the more fissile varieties and in the associated sediments. Poor supplies hence characterise this formation, the failures in the Vryburg district amounting to 31% and the average yield being just under 11,000 gallons.

(*b*) The younger, or Pniel Series, occupies great stretches, chiefly between Johannesburg and Greylingstad and in the area lying between Mafeking, Ventersdorp, Bothaville, Kimberley and Vryburg, comprising for the most part flattish ground that has been extensively drilled and that furnishes water at shallow depths in most consistent fashion. The prevailing formation is of igneous origin, a blue-green, fine-grained, basic lava breaking up under weathering into crumbling brown and yellow material and producing a red loamy soil from which project unweathered, hard lumps having a red crust; depressions of the surface may be occupied by grey or black clayey soil or by calcareous tufa. The formation is not an undivided unit, but consists of a succession of lava-flows. The uneven contact between one and the next flow is particularly liable to weathering, while the calcite patches in the pores of the rocks and in the original gas-cavities of the vesicular parts of the sheets tend to get dissolved out, so that the formation has had developed within it various horizontal or inclined zones having a relatively high porosity.

Close upon 2,000 holes have been drilled in these volcanic rocks, the failures amounting to nearly 15%, of which a goodly proportion were abandoned prematurely, mostly at the request of the applicant, while some of the others were stopped because of deflection due to residual cores of fresh rock, reported in the logs as "boulders." The averages for the formation are: Total depth, 97 feet; depth to water, 70 feet; water rises to 41 feet; yield, 21,160 gallons; and footage, 7.2 feet per diem. Among the above are 11 with a capacity of over 100,000 and 34 of 75,000 and more, but only three flowing holes. Tabulation shows that the shallow outliers of Karroo Beds in the South-western Transvaal do not influence the water-table to any extent, but, where the Dwyka conglomerate has only recently been stripped off by erosion, the diabase is much less weathered than usual, so that failures are more common.

An analysis shows that in the continuous block of the South-western Transvaal the districts of Klerksdorp, Lichtenburg, Ventersdorp, Bloemhof and Wolmaranstad stand arranged in the order of their productivity, which is almost the same as that of their respective mean rainfalls. Another interesting point is that the earlier-drilled holes have consistently given better averages than the later ones, much of which can be accounted for, as set forth in Section 3, by the gradual extension of drilling to higher and less favourable ground, thus:—

	1904–19.			1920–25.		
	No. of holes.	Total depth.	Yield.	No. of holes.	Total depth.	Yield.
Klerksdorp	155	94′	26,070	67	96′	20,450
Lichtenburg	478	94′	22,400	120	103′	20,350
Ventersdorp	20	83′	21,170	20	98′	17,840
Bloemhof	232	103′	20,480	22	107′	15,320
Wolmaranstad ..	180	86′	18,920	69	87′	14,300

The Heidelberg district conforms closely with the above areas, it being curious that no failures were recorded, although the formation was generally so hard, that the average daily footage was but 4 feet. The Johannesburg district gives comparable averages, though from a much greater mean depth, 148 feet. It is not surprising that the supplies struck in North-western Rustenburg should be deep and somewhat erratic, the area being characterised by a high proportion of failures, but the results in North-eastern Marico are more consistent, though the water is only obtained at the mean depth of 130 feet. In the Mafeking district comparable yields are got, and at lesser depths, while the rock is easier to drill, but in Vryburg, with a lower rainfall and a harder formation, the average yield is only 15,500 gallons, yet from a lesser depth, though it is curious to note that the holes drilled since Union are on the whole shallower, yet better. In more than half of these Vryburg cases the diabase was concealed by calcareous tufa to the depth of from 2 feet up to as much as 120 feet in thickness. While excellent yields are normally to be anticipated under such conditions—the town supply of Mafeking is a fine example—it is instructive to note that on the farms Weltevreden and Graspan, where the tufa was respectively 106 feet and 120 feet thick, the waters were weak.

The waters in this formation are generally hard from the presence of carbonates of lime and magnesia and sometimes slightly saline in the western districts; attention can be directed to the descriptions given by Wallis of such waters from Devondale Siding and Mafeking, which have to be softened for boiler purposes.[12]

[12] *Proc. S.A. Soc. C.E.*, xiv., pp. 214-6, 1916.

19. *The Dolomite and the Black Reef Series.*

This lower section of the Transvaal System is widely spread within the Central Transvaal and Griqualand West, but unfortunately constitutes the most troublesome formation that we possess, on account not only of its erratic yields, but of the mechanical difficulties experienced in its actual drilling. There is manifestly reluctance to bore where the solid, brown, channelled dolomite peeps out from beneath the prevailing red sandy soil or white tufa, or where masses of intensely hard chert make frequent outcrops. Elsewhere, on the other hand, the dolomite is concealed by soil and loose chert rubble, which may, in most erratic fashion and with no indication at the surface, descend to depths of 50, 100 or more feet. Within this jumble of soil and flinty angular blocks progress with the percussion drill can be exasperatingly slow and the casing sometimes only driven with difficulty. The dolomitic rock itself is relatively soft and easy to bore, but the frequent thin layers and seams of chert, and particularly the thicker bars of that material, may refuse to be cut at rates of more than a few inches per diem, even under the onslaught of a heavy rotary machine. Furthermore, the all-too-common presence of open or of mud-filled fissures and sometimes of great cavities, developed through subterranean solution along the joints and bedding planes of the rock, are responsible for high losses in feed-water and not infrequently necessitate cementation, with serious loss of time (Section 9*a*).

The bulk of the Dolomite country is without surface supplies, the ground being highly absorbent and the infiltration making its way through the network of fissures into larger underground channels, to emerge at length under favourable circumstances in the form of large springs. Quite a number of farms situated upon this formation and within well-occupied districts are still without any natural supply, well or borehole. The dolomite rock itself is practically non-porous and, unless the borehole strikes a part of the subterranean network in which the water is stored up or is travelling it will be dry. This explains why deep boreholes within sight of dolomite springs and sunk well below the latter may prove fruitless, *e.g.*, at Kloofzicht, near the Pretoria "Fountains," or at Oberholtzer, on the Wonderfontein

Loop. These solution-fissures furthermore become of less importance with increasing depth and are rare below about 400 feet; this is why deep boring is sometimes unsuccessful.

Along vleis and depressions the water-table is more continuous and success is almost assured, *e.g.*, the Klip River Valley, near Johannesburg, while hollows floored with calcareous tufa are usually favourable, since such white limestone is frequently indicative of shallow ground-water; dykes or quartz reefs, of which advantage could be taken, are not numerous. Of late years boring has been extended to the higher and more rocky ground in which dry sink-holes are not uncommon, *e.g.*, between Krugersdorp and Ventersdorp, so that the many failures experienced to-day are not surprising.

The Dolomite is floored by the quartzite group of the Black Reef Series, which tends to hold up the percolation and therefore to form a water-plane. It can commonly be drilled with greater success although hard, for example in the anticline running westwards from Randfontein to the Mooi River, or in the curving belt at Vryburg, wherein two holes, passing down to the diabase below and fed from the Dolomite above, each gave over 200,000 gallons per diem, constituting the town supply. The Black Reef boreholes in this district average 15,800 gallons per diem, 22% being failures.

Yields are good in the Dolomite of the East Rand, Klip River Valley and Heidelberg, blanks and holes with trivial supplies being surprisingly few, but the proportion of failures rises to the west and south of Krugersdorp, through Lichtenburg 20%, Pretoria 31%, Marico 33%, North-Western Rustenburg 38·% and Potchefstroom 50%. Most curiously, while the Kaap plateau gave no blanks in Vryburg (although two holes had only small quantities), its extension into Kuruman, a region of somewhat lower rainfall furnished 43% of failures.

It will be observed that the averages are high throughout, and it is true that, if adequate fissures are cut, splendid supplies can then be tapped. We may cite the huge volumes obtained by the Rand Water Board both in the Upper Klip River Valley and at Zuurbekom, mainly from shafts and large-diameter boreholes, sunk mostly to depths of between 250 and 300 feet. Up to over half a million gallons per diem have continuously been extracted at certain of these stations, while the wells at Zuurbekom have for years been furnishing from 5 to 6 million gallons daily, though under conditions that are certainly unique.[13]

As regards the quality of the Dolomite waters, carbonates of lime and of magnesia to the amount of from 10 to 39 parts per 100,000 constitute the bulk of the dissolved solids, chlorides and sulphates being only rarely present, and then only in small quantities, but such temporary hardness can readily be removed by the addition of lime, as is, for instance, practised in the case of the railway supply at Pretoria.

20. *The Pretoria Series.*

This consists of three thick groups of blue shales or slates parted by three groups of whitish quartzites, which because of their superior hardness produce the striking longitudinal ranges enclosing the Bushveld region and forming the Gatsrand, south of Johannesburg. There is also an important zone of volcanic rocks, while the strata have furthermore been split up by numerous thick sills of intrusive diabase (Section 22*a*). The beds are nearly everywhere dipping at angles of from 10 to 40°.

(*a*) Boring has mainly been done in the shaly groups and in the accompanying igneous rocks, since they generally occupy the valleys. As the result of thermal metamorphism these shales have in certain areas been extensively converted into compact, tough and sometimes semi-crystalline rocks (hornfelses), and have become difficult to drill, the rate of boring being often reduced to less than a foot a day with either type of machine. From the Wilge River, through Pretoria to Schier Poort, the shales are soft; thence to Groot Marico they get progressively tougher, and past Zeerust and round to Vliege Poort they may be strongly hornfelsed, such metamorphism having been most intense in the highest zones of the series. From Carolina northwards to the Olifants River a similar change is found, but near Potgietersrust the shales are hardly altered.

[13] For details, see *Union Geological Survey;* Explanation of Sheet 52, Johannesburg.

This variation in their texture and compactness is reflected in the boring returns, for, while the percentage of failures in the Pretoria stretch is only 3, that in the Rustenburg area is 21, to improve to 11 in the region beyond, while the average yield has diminished from about 30,000 to 20,000 gallons, although the mean depth has increased. In the western districts the indurated shales have wherever possible been avoided and the diabases and quartzites exploited instead, with the rather surprising result that, although the average depth of boring has had to be increased from 109 feet to 124 feet and the distance down to water from 71 feet to 90 feet, the percentage of failures has diminished from 39 to half that, while the mean yield has risen from 23,400 to 33,850 gallons. This improvement is to be correlated with the more jointed character of the quartzites and to their recrystallisation, which has made them "sugary" in texture and more prone to crumble into fragments beneath the soil. In Rustenburg these quartzites have at times been reported by drillers to be still "broken" at depths of 75 feet or even 80 feet. In the Lydenburg district, although the yields are smaller, owing to the high grade of metamorphism in the shales, the failures have been few, due not improbably to the high fainfall, which exceeds 30 inches.

(*b*) The above applies to the sedimentary strata alone, but the wealth of basic sills has compelled the drilling of many holes partially or wholly in such igneous rocks (Section 22*a*). Where both diabase and sediments —usually shales or hornfelses—have been pierced in the same hole, a yield above the average has usually been reported, due in part to the importance of the contact-plane thus provided, wherefore we find averages of 32,200 in Pretoria, 27,400 in Rustenburg, but only 19,000 in Marico, which last is probably due to the intense hardening of the strata along their junctions with the diabase sheets. There being nearly everywhere a marked dip, it so happens that certain holes, starting in shales, have ended up in underlying diabase or *vice versâ.* Tabulation has indicated an appreciable superiority in output—in the sense of more holes with large volumes—in the first-named of these two cases, except in Marico, where their difference is insignificant. Other things being equal, it would appear more advantageous, therefore, to select the site so that the diabase is reached and then penetrated after first piercing some 50 or 80 feet of shales, a course which the ground generally renders possible except in the case of small holdings.

(*c*) *The Ongeluk or Contemporaneous diabase*, a thick body of ancient lavas dipping at moderate angles, runs from Delmas through the town of Pretoria and through Koster to the western end of the Bushveld basin. Composed of bluish-green, fine-grained, compact rocks with occasional amygdales, it is very different from the crystalline intrusive diabases, and, when fresh, can be drilled at a greater rate than the latter. It furnishes a fertile red loam, beneath which the formation may be decomposed to the condition of red, yellow or white clays with cores of less-altered or of fresh rock down to depths of 40, 60 or exceptionally to 100 feet, as, for instance, on the Derby Settlement. Significantly, where the weathering has been very deep, as in Marico, the supplies have been small; good volumes have been most common when the soil and clay do not exceed about 20 feet in depth.

But few blanks have been reported from this formation, the yields, though not exceptional, being distinctly consistent. In Pretoria and Rustenburg a return of under 5,000 gallons is infrequent, and the average is 15,100 with mean depth of 95 feet. In Marico the failures are higher, offset, however, by the greater output from the successful instances, though obtained from a greater mean depth. Hardly any drilling has been done in Lydenburg in this belt, which is several miles wide, but good yields would probably be obtained, although the lavas have been much indurated in this district.

The equivalent formation in Griqualand West, in less weathered condition, occupies basins in Hay and Kuruman, but is much covered by superficial deposits in the latter district. The volumes obtained in Kuruman are, if we exclude a few boreholes with a big yield, low, and the proportion of failures high, 40% ; the rainfall is, however, only about 12 inches.

(*d*) That intensely hard facies of the Pretoria Beds known as the *Griquatown Series,* so extensively developed in Griqualand West and Bechuanaland, has studiously been avoided. Drilling has, however, proved that these yellow, brown, banded jaspers become quite soft and slaty at depths of a few hundred feet, so much so that the holes may actually need to be cased. The formation is unusually tight and the Kuruman district has provided a high proportion of blanks, while, excluding a couple of good successes, the yields have in general been small.

21. *The Malmesbury Beds.*

These tilted, phyllitic, slaty or flaggy rocks forming the low-lying portions of the South-Western Cape have been extensively drilled, though mainly by the private contractors. Under the rainfall of between 20 and 30 inches the beds have in places become deeply weathered to a yellow or red, clayey, laminated material passing down into pale blue clay-slate, and that in turn into the hard blue rock. Particularly is this the case beneath the talus of the mountain slopes or under the grey sands or the lateritic ironstones of the flats, such alteration extending sometimes to depths of 100 or even 150 feet, as, for example, between Durbanville and Mulders Vlei. The supply may thereupon be turbid, and it may be found almost impossible to keep the fine clay out of the borehole (see Section 9*b*).

In practice it is usual to continue a bit further after striking the hard blue rock, but in spite of the commonly weathered character of the strata, large individual supplies are rare, 20,000 gallons representing a good return. The average is low, only 9,250 gallons, while the mean depth is large, 144 feet, with the water struck at round about 87 feet.

A provoking feature is the brackish nature of the water in about one-third of the examples; indeed there are more cases of non-potable supplies than of dry holes. As pointed out in 1913, the salts consist principally of sodium chloride and magnesium chloride and sulphate, and this saline matter can be regarded perhaps as largely derived from sea-water trapped long ago in the tilted slates when the ocean overspread the coastal plains. This is even more marked in Van Rhynsdorp, where the rainfall is furthermore very restricted and gypsum may be abundant in the soil; the failures there are many.

In the decomposed granites intrusive in this formation somewhat larger quantities are struck at a mean depth of 105 feet, the quality being as a rule better than in the slates. It can be suggested in the light of Transvaal experience that the holes might be carried down a bit deeper in the granite than is customary.

22. *The Bushveld Igneous Complex.*

(*a*) *The Bushveld Diabase.* As remarked, the Pretoria Series, and to a less extent the Witwatersrand Beds, are extensively invaded by this greyish-green, crystalline rock, almost wholly in the form of sheets, up to hundreds of feet in thickness, introduced along the planes of stratification and hence dipping with the enclosing strata. Making boulder-dotted strips that extend regularly for great distances and that attain widths as much as a mile or more in places, they are of distinct importance areally.

Though the medium to coarse-grained rock is both hard and tough, and hence slow to drill, it is widely decomposed, forming near the surface a yellowish clay, but at greater depths a yellowish or reddish earthy mass enclosing cores of diabase, and below that again jointed and broken rock, that figures in most of the logs as "boulders." In much of the decomposed rock the original crystalline structure can still be made out, and the material is both porous and highly absorbent, but near the surface it has generally been broken down into a tenacious and somewhat impervious clay.[14] In two cases in the Pilandsberg area the depth of this zone of weathering was no less than 160 and 170 feet, while the yields therefrom were only 3,460 and 1,440 gallons respectively, which shows that the clayey nature of the completely weathered product effectually hampers infiltration.

On the whole excellent results have attended boring in this formation. Out of 48 holes in the Pretoria district there were only 6 failures and 6 furnishing less than 5,000 gallons per diem; yields of 20,000 and upwards were common, while no fewer than 15 gave 50,000 and over. The returns from Rustenburg are closely comparable, the mean rate of drilling being

[14] *Proc. S.A. Soc. C.E.*, xx., p. 41, 1922.

actually 12 feet per diem. In Pietersburg out of 20 boreholes into diabase intrusions 7 failed, the remainder averaging 28,900 gallons, struck at the mean depth of 98 feet, a result much better than in the adjacent granite. On the contrary the few examples drilled into diabase in the area between Pretoria and Johannesburg furnished on an average only 3,530, or about half that obtained in the granite.

The influence of these intrusions upon the water circulation in the invaded Pretoria beds has been discussed in Section 20.

(*b*) *The Bushveld Norite.* This formation occupies three areas: (1) that extending from Pretoria through Rustenburg to Vliege Poort with an irregular tongue stretching to the Bechuanaland border, (2) that running northwards through Potgietersrust, and (3) the long crescent stretching from near Belfast down the Steelpoort Valley to the Olifants River. They embrace some of the most attractive country in the Transvaal and have been widely settled, but lamentably it has often been found difficult to obtain adequate supplies in them.

The norite gives rise to the well-known black "turf" or "gumbo" soil, which, though friable in dry weather, forms a stiff puddle in the wet season; locally red loamy or clayey soils occur. The hard, grey, speckled crystalline rock commonly makes massive knobs and often displays fresh outcrops flush with the surface or just covered with grass or soil, so that one is frequently at a loss in picking a site where the rock underfoot would not prove solid, and many a borehole has had to be abandoned quite soon for that reason. Nevertheless in certain spots the formation may be weathered to depths of 25, 50 or even more feet, and there are usually narrow joints in the fresher rock occupied in the upper zones by decomposition products and open in the lower levels or partly filled with calcite, saponite, etc.

It is frequently necessary to hunt around for a soil-filled depression amid the norite outcrops for such restricted zones of weathering; it has been noticed that at the foot of a bare norite kopje the rock may be of a friable character and potentially water-bearing. I have even had drilling done with some success in the rudely stratified bands of iron-ore to be found enclosed in this formation, since the norite along the contacts of such bodies is banded and not unusually decomposed. For all that, failures in this formation have been many, particularly in the belt marginal to the Red Granite north-east of the Pilandsberg, where deep red soils prevail and outcrops are rare. On certain of these farms as many as half a dozen trials have been made and even the water-diviners have ignominiously failed.

The supplies are nevertheless generally found at shallow depths, usually at less than 100 feet and seldom at more than 150 feet; but few instances are known in which the water was struck at over 200 feet, so that it is generally less hazardous to make trial on another site, if nothing can be obtained before, say, 180 feet. Two boreholes were drilled in Rustenburg and two in Middelburg that furnished 100,000 gallons per diem, but generally the yields are from 40,000 downwards, the average for 103 cases being 26,000.

(*c*) *The Red Granite and the Rooiberg Felsite.* The first-named, also known as the Younger Granite, covers a wide proportion of the Central Transvaal and hems in the Springbok Flats. It gives rise to broken country with rocky knobs, or more commonly to rolling sandy ground with but few outcrops, though shallow gullies may expose the granite beneath the soil or a crust of lateritic ironstone or "ouklip." The rock is moderately coarse in grain and rather homogenous, normally more so than the Old Granite, and is rather durable, but may be decomposed in some of the valleys to a fair distance and may be irregularly fissured to much greater depths.

Only moderate or small supplies can therefore be expected, the uniform nature of the formation, unlike that of the Older Granite, being inimical to deep boring, so that few holes have been taken down to more than 250 feet. In Pretoria and Rustenburg the water was struck at some depth, 113 feet on an average, but in Middelburg, a district with higher rainfall, at only half that distance. The mean yields range from 7,000 to 15,000 gallons per diem. The celebrated spring at Warmbaths issues from this granite, though probably upon a line of thrust-faulting.

The closely associated *Felsites and Granophyres* are pinkish or purplish, tough, fine-grained rocks, giving rise to rugged and stony ground with a fair amount of timber, but only at certain points in the valleys is there any thickness of soil on them. This formation has deliberately been avoided because of its discouraging nature, the drilling being hard and tedious, but on the lower ground the compact felsites may be appreciably weathered and can carry water in the innumerable fine joints by which the rock is seamed. In the Middelburg district boring has mainly been done in such favourable situations and the majority of the holes have obtained their water at shallow depths.

23. *The Waterberg and Matsap Series.*

The red and brownish quartzites of the broken and fairly well-watered area north of Nylstroom have yielded only 14% of failures and an average of 12,400 gallons per diem, the holes having a mean depth of 175 feet, though drilled at an average rate of 10.3 feet per diem. The results in the sand-covered flats of the North-western Waterberg have proved erratic for, though wells indicate the water to be shallow in and about certain pans, the formation elsewhere has been disappointingly hard and dry.

The Middelburg district can show few boreholes in these beds, though the water is not deep, but the stronger supplies got are largely due to the influence of sheets of intrusive diabase.

The equivalent Matsap Beds of Kuruman and Hay form the bare folded chains of the Langeberg and Koranna Berg, and underlie the Kalahari sand within and round about those ranges. They have proved difficult to drill owing to the tilted attitude of the strata and to the presence of soft micaceous slates alternating with the extremely hard, jointed quartzites. Occasionally there is reported beneath the sand a peculiar material composed of angular lumps of quartzite set in a clayey matrix, such probably representing breccias reposing on the solid formation; sometimes indeed it is impossible to be certain at what point the Matsap Beds themselves have been entered.

Deep boring is essential, as seen from the fact that in Kuruman the water has been struck at a mean depth of 193 feet, rising to only 167 feet. The average depth of a successful borehole is 226 feet, while one-seventh of the total number exceed 300 feet, but the softness of the prevailing overburden raises the average rate to 8.5 feet per diem.

24. *The Table Mountain Sandstone.*

Though occupying wide areas in the south and south-west of the Cape, this series is of little importance from the boring aspect. That is because it usually builds mountain ranges or rough ground from which emerge perennial or intermittent streams, and along the base of which appear occasional springs, while the valleys themselves are excavated in other softer formations and are not infrequently fairly well watered. Many of the large springs in this region issue along or close to the junction of these sandstones with the overlying Bokkeveld slates, *e.g.*, Caledon Baths, Toverwater, etc.

The whitish, jointed and usually tilted quartzitic sandstones are slow and difficult to drill, and the supplies are never great, though of excellent a quality. A limited amount of boring in them has been done in the past in the Uitenhage district, but in the future they will probably be drilled rather extensively, mainly with the rotary machine.

In Pondoland, Natal and Zululand the same formation is well developed, lying horizontally for the most part, except in the coastal belt, where a seaward dip is prevalent and the strata are traversed by faults. The sandstones are redder and more felspathic, and hence softer, more porous and more deeply weathered commonly than in the Cape, and therefore relatively easy to drill, but, owing to the higher rainfall and the presence of small springs, there has been no clamour for boreholes on this formation. Moderate supplies are obtainable without difficulty, even on ridges and plateaux, while at times artesian or semi-artesian water can be tapped in it beneath a covering of Dwyka conglomerate, as has been done in the town of Melmoth and along the railway at Bonds Drift on the Tugela River.

25. *The Bokkeveld and Witteberg Series.*

For practical purposes these two can be considered together, inasmuch as the first-named passes up without break into the second; they are moreover closely associated, are often folded together and are difficult to differentiate in the field in certain areas. In the Bokkeveld shaly or slaty beds predominate, while sandstone and quartzite groups are subordinate; in the Witteberg the reverse obtains. These harder bands can mostly be avoided, wherefore the strata can easily be pierced, though the holes are liable to deflection because of the general tilted attitude of the rocks. It is, however, sometimes possible to take advantage of a hard bar, and by boring behind it to obtain a large and perhaps a flowing supply. Infiltration becomes facilitated by the tilted and often strongly cleaved character of the beds, the fissile nature of the softer strata, and the thinness of the soil, which facts serve to explain the unusually great depths at which water has sometimes been cut, for example in the Willowmore district at over 500 feet, though the quantities in such cases do not approach the average.

The yields are generally good, even in districts of low rainfall, such as Prince Albert, Oudtshoorn or Willowmore, but in Riversdale only moderate amounts have been got, while in Uitenhage the average is low, only 7,300 gallons per diem. From 20,000 to 50,000 is otherwise not uncommon and, as pointed out in Section 6, some exceptionally large yields, exceeding 100,000, have been recorded from Ceres and Willowmore.

The Bokkeveld quite commonly furnishes brackish and sometimes faintly sulphuretted waters, and indeed in Uitenhage district over 40% of the supplies could thus be classed. Magnesium sulphate occurs in addition to sodium chloride, but the waters from the more quartzitic Witteberg Beds are not so saline and do not have so high a proportion of magnesium compounds.

26. *The Karroo System.*

Occupying as it does just over one-half of the area of the Union, this assemblage of strata is naturally of extreme importance, yet, because of the slight variability displayed by the beds over immense distances, there is not as much diversity in the boring returns from different quarters as might be anticipated, and that too despite the great range in the annual rainfall—from 5 inches in the south-west to 35 inches in the north-east. This is largely due to the fact that upon excluding the very lowest and the very highest beds, which comprise only one-fourth of the total, the remaining three-fourths possess rather uniform lithological characters. It will, however, be useful to discuss separately that particular facies represented in the north-east, known as the "Coal Measures," in part, because of the abundant data upon that group within the several districts concerned.

(*a*) *The Dwyka Conglomerate or Tillite.* As seen in the south of the Karroo this queer, blue-green rock of glacial origin, with its numerous pebbles and boulders, would not appear a promising formation for subterranean water, the more so in that it is usually fresh right at the very surface and the rainfall is everywhere low. Although it is homogeneous, is mostly unbedded, and has an actual pore-space of only a few per cent.,[15] the rock is strongly cleaved and jointed as the result of folding and hence furnishes good supplies at many places, for example, at Matjesfontein Station. The average yield of 21 boreholes in the Prince Albert district works out at the surprising figure of 12,750 gallons per diem.

In Zululand, Natal and Pondoland, on the contrary the conglomerate is often very fine-grained and tough and, not having been folded, is uncleaved and only slightly jointed. Notwithstanding the high rainfall, under which it has often been converted into a buff earthy or clayey material, with even the inclusions therein weathered, the yields from it have been disappointingly low.

Throughout the west and north of the Karroo, Bushmanland, Gordonia and the southern half of South-West Africa, this formation lies horizontally, is softer than in the south, and is usually uncleaved, so that its yields are seldom large. The main trouble, however, with it, and with the succeeding group of the blue-green Upper Dwyka Shales, is the hard and often saline nature of the water, which not infrequently renders it undrinkable. In addition to common salt there are carbonates,

[15] *Trans. Roy. Soc., S.A.*, iv., part iii., p. 169, 1915.

chlorides and sulphates of lime and magnesia, not altogether surprising when it is realised that the majority of the saltpans in this quarter of the Union are situated upon the broad belt made by the Dwyka conglomerate and shales. The white-weathering outcrop of the carbonaceous, pyritic shales of the "White Band," with crystalline gypsum in the surface layers, gives water charged with sulphates of lime, iron and alumina, and therefore occasionally astringent, incrustations of alum forming upon the walls of wells and cuttings. When on the other hand this zone is struck beneath a protective covering of shales or of dolerite the unweathered material provides potable waters with perhaps only a slightly sulphuretted flavour.

(*b*) *The Ecca, Beaufort and Stormberg Series* that succeed cover an enormous area in the centre of the Union, enclosed within the ring made by the Dwyka Series, and hence embrace much of the Karroo proper, the Orange Free State and Natal; the northern facies of the Ecca will be dealt with in (*e*).

The strata consist of yellowish or greenish hard sandstones alternating with thicker bodies of flagstone, hard nodular "mudstone" and shales of differing textures and colours—green, blue, red and purple, while nodules of limestone and dolomite are not unusual. The sandstones are close-grained and their porosity is certainly not high—from 1 to 12%. Tilted up, folded and mostly bare along the southern margin of the Karroo, the strata have acquired a certain amount of jointing, and supplies are readily got at quite shallow depths, although the rainfall is very low.

To the north and also to the east the beds are nearly horizontal, but there is an abundance of intrusive dolerite in the form of curving sheets cutting through the strata at all angles, and also of narrow vertical dykes that may run for long distances. The sediments have thereby been divided into compartments of various sizes, bounded by the igneous rock, and it is nearly always possible to choose a site where the underflow has been intercepted by the dolerite and where the water would be shallow and strong. Sometimes the strata have been greatly hardened by the intrusive matter and drilling is slow; at other times the dolerite is in the form of a flat-lying sheet and is repeatedly struck at a relatively shallow depth. Pipes and fissures filled with Yellow-ground (Kimberlite) are by no means scarce in this area, and along their contacts with the Karroo Beds the latter have invariably experienced some uward tilting and shattering, so that excellent supplies are to be got in the soft igneous material by means of quite shallow wells. In the case of Kimberlite pipes large volumes can be obtained from depths often not exceeding 100 feet; indeed many of the abandoned diamond mines and prospects are of economic importance through yielding strong and permanent pumping supplies, *e.g.*, the Leicester (Klipdam) and Driekopjes Mine (Theunissen). The waters therefrom all possess high temporary hardness.

Certain individual peculiarities in the behaviour of the three Series might be pointed out. The Ecca Shales in the Hoopstad district—largely sand-covered—furnish only an average of a few thousand gallons per diem and show a high proportion of failures—40%. While the Lower Beaufort Beds in Prince Albert give—for drilling done prior to Union—over 23,000 gallons on an average under a rainfall of only 8 inches, the same group in King-williamstown and East London under a rainfall of 25 inches furnishes a mean of only 6,500 per diem. This is due to the broken nature of the country, coupled with the exceptionally hard and fine-grained character of the sandstones in the east, under which incidentally drilling is both deep and slow. On the contrary the Lower, Middle and Upper Beaufort Beds have been responsible in the Central Karroo for numerous shallow boreholes and for many flowing supplies. As mentioned in Section 11, there has been a great falling off in the number of the latter, so that it is rare nowadays to strike an artesian flow in those parts.

Owing to the limited scale of operations since 1910 in this region, only the pre-Union returns can in fairness be utilised for averaging. The proportion of failures has ranged from 5% in Queenstown to 10% in Graaff Reinet and Victoria West, 20% in Hanover and 23% in Cradock, the low figure in the first-named being no doubt due to the more porous nature of the yellow sandstones that alternate with the red, purple and blue shales. The yields of the non-flowing holes are surprisingly high, but tabulation brings out certain curious fluctuations in the means that most decidedly indicate a close dependence upon the seasonal rainfall. Prior to 1906 the averages for Aberdeen, Graaff Reinet, Victoria West, Hanover, Cradock and Tarka were respectively 19,000, 14,000, 17,000, 15,000, 16,000 and 25,000 gallons; during 1906 the new holes gave 31,000, 47,000, 53,000, 48,000, 42,000 and 62,000, with some reduction thereafter. Significantly 1902-5 were years of drought, while 1906, and next after it 1907, were marked by good rainfalls. There is no definite relation between the mean depths at which water was struck and the rainfall, the figures generally ranging between 30 to 45 feet for Hanover and Victoria West, 55 to 60 feet for Cradock, 50 to 80 feet for Tarka and 60 to 80 feet for Graaff Reinet.

The results in the Bloemfontein district have been satisfactory with relatively few failures and with an average output of 17,400, though the mean total depth is high, 183 feet, with the water struck at about 94 feet. The other districts in the Free State have been less satisfactory; Ladybrand with a failure list of one-third averages 12,500, with its boreholes drilled mainly in the Molteno Beds; Bethlehem and Vredefort are lower still, with Harrismith furnishing only a few thousands, while Kroonstad and Heilbron are somewhat variable.

Boring deeply has clearly been no remedy, for so long age as 1899 a hole was drilled by authority of the Volksraad at Aankom (Sydenham), near Bloemfontein, to the surprising depth of 3,002 feet, and only gave a trivial supply, while about 3,000 gallons were cut in the 705-foot borehole at the Bloemfontein Municipal Power Station. That sunk at Hofmeyer, Maraisburg district, to 1,507 feet in the Upper and Middle Beaufort Beds in search of brine yielded, so far as I can learn, no exceptional volume, some of which certainly came from the upper levels.

The composition of the waters from the several Series was discussed in 1913, so it will suffice to remark that a certain proportion of the supplies are brackish or slightly sulphuretted because of small amounts of iron sulphide in the beds, while those from the Coal Measures may carry sulphates.

(*c*) *The Ecca Coal Measures.* This northern facies with its important zones of horizontal pebbly grits and sandstones (freestones) alternating with flagstones, shales and coals has an extensive distribution in the Northern Orange Free State and Natal and in the Southern and Eastern Transvaal; outliers occur further to the north and north-west resting unconformably upon older formations and sometimes occupying shallow basins in the latter; intrusive dolerite is often present, but mainly in the south. The country is undulating or flat, carries numerous pans, possesses sandy and absorbent soils, and has a rainfall of 29 to 35 inches, wherefore boring is rapid and shallow, failures are few and yields fairly consistent.

That big section of it falling within the Transvaal can again be divided into three areas: (1) the main region of the south, south-east and east, (2) the outliers to the north of Pretoria, including the Springbok Flats, and (3) the North-western Waterberg and Northern Zoutpansberg. Over 1,100 holes have been drilled in these three blocks, the results averaging as follows:—

Area.	No. of holes.	Depth.	Depth to water.	Yield in gallons.	Failures.
1	952	147′	83′	15,400	9%
2	129	161′	88′	12,200	2%
3	86	218′	116′	16,750	17%

The results within the main Area 1 themselves vary according to the district, which in turn appear to be dependent not so much upon the rainfall thereof, as upon lateral changes in the lithological character of the sandstones, *i.e.*, from fine-grained to coarser and more porous types, upon the presence of dolerite, and (in the south-east) upon the passing of the Coal Measures beneath a group of rather tight shales—as in Wakkerstroom.

The results, grouped according to districts, are as follows:—

Piet Retief	30	112′	80′	26,400	7%
Ermelo	153	158′	63′	20,900	9%
Middelburg	127	120′	80′	18,200	6%
Standerton	388	145′	93′	10,700	19%
Bethal	242	142′	81′	8,860	7%
Wakkerstroom	12	206′	99′	7,300	8%
Northern O.F.S. ..	—	—	—	8,000	(approx.)

Analysis of the records show that in all the areas the water can be struck at various horizons within the group, from the junctions of or within the intrusive sheets, from the basal contact or even in the rocks below. In Area 1 more water is usually obtained from the sandstones below the coal horizon, but in Area 3 the coals and coaly shales constitute a much better reservoir than the enclosing sandstones. In Standerton more than half of the supplies were intersected either within dolerite cutting the sediments, or along such intrusive contacts, while the abundance of this rock in thick sheets has doubtless been responsible also for the unusually high proportion of blanks. Those cases in which the Coal Measures were penetrated and the water struck at their basal contact gave fair supplies.

It will be observed that in the majority of instances boring was continued after first striking water to about an equal distance further; the strata are, however, commonly easy to drill, and some excellent footages—10 to 30 feet—have been established in certain areas, *e.g.*, Standerton. The tendency to carry holes to greater depths and the policy of continuing in spite of dolerite has nevertheless during late years cut down the rate very considerably, so that to-day from 5 to 6 feet is a good average. The great depth of the water-table in the North-western Waterberg should be noted, though the results have on the whole been good. On the contrary, the Coal Measures around the Springbok Flats have proved disappointing.

(*d*) *The Stormberg Red Beds and the Bushveld Marls.* The first-named makes broken country along the margins of the Basutoland-Natal highlands and, possessing many small streams or springs, has not been drilled to any extent save in the districts of Wodehouse, Aliwal North, Ladybrand and Ficksburg. The red and purple mudstones and shales are, however, poor water-bearers and the supplies are usually contributed by the subordinate buff sandstones; advantage can nevertheless at times be taken of narrow dolerite dykes.

Their equivalent, the second group, is confined to the Transvaal and consists of from 200 to 300 feet of similarly coloured strata, which because of their softness are normally concealed beneath red loamy or sandy soils within belts several miles in width as a rule They are developed around the central part of the Springbok Flats and in the North-western Waterberg and Northern Zoutpansberg. Because of the dominant clayey nature of the material and the general absence of porous layers, or of dolerite, supplies are scanty and erratic, while caving during drilling is not uncommon. There is little advantage to be gained by deep drilling, since this argillaceous group is normally underlain by the tight Upper Ecca shales, wherefore it is not surprising to find that of those holes taken down to between 300 and 400 feet the majority have been failures. About 5,000 gallons per diem would be reckoned as a good supply.

(*e*) *The Bushveld Sandstone,* which follows, gives country with a heavy, pale, sandy soil, well-wooded, though waterless. The zone ranges from 200 to 600 feet in thickness and is made of white, cream, pink or red uniformly fine-grained soft sandstone, sometimes alternating near its base with red clays or clayey sandstones. Indurated streaks and veins are not unusual, otherwise the formation makes excellent drilling. When the site selected is such that the underlying marls are penetrated too soon, a dry hole may result, but in the sandstone itself good amounts are generally found and yields of 20,000 and over are sometimes obtained. Considering the undoubted porosity of the rock, it is rather surprising that these figures are not larger. The water moreover lies at some depth, the bulk of the boreholes having had to be taken down to between 200 and 300 feet.

(f) *The Stormberg Basalts.* Forming scantily wooded flats with a black clayey soil, or appearing in crumbly outcrops, these lavas have been extensively drilled in the Springbok Flats and to a less extent in a belt just north of the Zoutpansberg, where they are largely concealed by transported red sand. They consists of flow upon flow, and since these contain highly amygdaloidal and often oxidised zones, and since weathering has attacked the base and summit of each sheet particularly, the basalts constitute quite a good water-bearer. Indeed the proportion of failures is only 19%, the average yield being 26,500 gallons per diem, struck at a mean depth of 90 feet, while the general footage works out at as much as 14 feet per diem, not much less than that for the underlying Karroo sediments. Deep boring has not proved a success, for the nine holes that range from 400 to 1,000 feet are either dry or furnish small supplies that were actually obtained at shallow depths (Section 10).

The double basin-like structure of the Springbok Flats with the porous Bushveld sandstones dipping inwards beneath the basalts, has long suggested the possibility of artesian water, but the results to date have been disappointing. Of the 20 boreholes along its margins that have passed right through the edge of the basaltic covering into the sandstone beneath, the majority drawn their supply not from the latter, but from the basalts or else from their contact-plane. The deep hole on Ludlow at the time of its abandonment was still in the beds of the Bushveld Series at 1,787 feet, but that on Diepsloot had passed at about 1,254 feet through the latter into ancient quartzites, both of them without tapping any water under pressure. Furthermore, the Lower Karroo strata are not particularly porous hereabouts and are missing in certain parts of the basin owing to the unconformable overlap of the upper division, and hence cannot be viewed as a potential contributor.

The difficulties experienced with these same basalts along the eastern border of the Transvaal have been referred to in Section 13*a*.

27. *The Karroo Dolerite.*

The influence of intrusive sheets and dykes on underground supply is of course well known and need not be dwelt upon. It might nevertheless be remarked that, although many boring contractors insist on ceasing work upon striking dolerite, the experience of the Irrigation Boring Branch is that it is not unusual to obtain a good supply within such igneous rock; instances were cited in my 1913 paper. At many spots in the Orange Free State and Northern Karroo a known or unsuspected sill may underlie the shales and by many persons drilling would be stopped upon striking it. Experience has, however, shown that if the sedimentary covering ranges from 80 feet to 150 feet, it is generally worth while drilling into the igneous rock to a distance of at least 15 feet before giving up, as good supplies are not confined to the contact with the sediments, but may be found stored just within the hard, though jointed, dolerite.

28. *The Cretaceous and Tertiary Systems.*

Restricted in area, these formations, especially the first, are rather troublesome owing in part to the tendency to caving because of the softer bands present, in part to the frequent salinity of their waters; indeed in the Uitenhage district the water in just one-half the cases is reported as brackish or salt. Excluding certain flowing holes referred to in Section 11, the yields are usually moderate or low, averaging under 10,000 gallons, with the water struck at depths of between 120 feet and 130 feet. The Oudtshoorn basin differs only in the water therein being shallower. The Cretaceous clays generally are somewhat tight and a fair proportion give supplies of under 1,000 gallons only, but the sandstone bands in the red marls are better yielders, while even the Enon Conglomerate is a producer. In two cases in Oudtshoorn the supply was cut at the unconformable junction of this group with the Bokkeveld slates, and with the Table Mountain Sandstone in a number of instances in Uitenhage.

The Tertiary calcareous sandstones and limestones of Alexandria and Bredasdorp have not been too extensively drilled, but are not usually better yielders than the Cretaceous, though giving much fresher waters, *e.g.*, to the south of Addo.

The difficulties attending the boring of the Kalahari Beds, detailed in Section 13*b*, are increased by the occasional salinity of the supplies, though as yet such would seem to apply chiefly to the area traversed by the channels of the lowest sections of the Nossob, Molopo and Kuruman, wherein the waters are sometimes undrinkable, and to a tract just north of Upington.

Part III.—Table of Yields, Etc.

The following analysis does not include holes drilled during the past few years, while for certain areas sufficient post-Union records are not available, though it is not considered that the averages would be materially affected by the inclusion of later data. Cases with such nominal yields as 250 gallons per diem are included among the failures, the percentage proportion of which is calculated upon the total number of holes drilled. All the other averages, however, are based upon the number of productive examples, but, where artesian flows are involved, such instances have been omitted in computing the mean yield. In preparing these averages exceptionally deep, and in some ways experimental, boreholes have been ignored, while, in working out the mean footage, cases showing abnormally slow rates of progress have been omitted, as such have in most cases been due not to the excessive hardness of the formation, but to mechanical troubles.

In concluding, it should be made clear that the various figures here tabulated must be interpreted in precisely the same way as in the case of seasonal rainfalls and run-offs, that is to say, not as precise values, but merely as probable averages of quantities that must of necessity vary between distinctly wide limits. For these and other reasons no greater precision could be conferred upon them through the application of the method of least squares.

TABULAR LIST OF MEANS.

Area.	No. of holes.	Total depth.	Depth to water.	Water rises to.	Daily footage.	Annual rainfall.	Yield in gallons *per diem.*	Percentage of failures.
Old Granite.								
Pretoria-Jo'burg	62	130′	70′	37′	6.5′	28″	20,000	14
Northern Transvaal.. ..	479	156′	112′	73′	6.7′	21″	21,500	25
Rustenburg	130	201′	170′	133′	5.7′	22″	16,900	50
S.-Western Transvaal ..	404	122′	85′	46′	8.0′	21″	25,600	10
Mafeking	202	166′	120′	95′	9.0′	19″	19,900	35
Vryburg	136	158′	119′	101′	9.4′	17″	15,750	27
Van Rhynsdorp	16	184′	143′	116′	6.4′	5″	4,200	31
Schists in the Old Granite.								
Pretoria-Jo'burg	15	130′	85′	32′	8.5′	30″	47,500	0
Kraaipan System.								
Mafeking	35	178′	132′	109′	10.3′	18″	11,500	37
Witwatersrand System.								
Klerksdorp	98	109′	76′	37′	8.6′	24″	28,200	11
Ventersdorp System.								
Zoetlief Series.								
Vryburg..	29	116′	76′	63′	5.6′	17″	10,900	31

Pniel Series.								
Mafeking	40	136′	99′	79′	8.6′	22″	19,800	33
Vryburg..	113	103′	69′	50′	5.6′	17″	15,500	23
Klerksdorp..	262	93′	70′	29′	6.9′	24″	24,440	15
Lichtenburg	680	96′	68′	36′	7.6′	22″	22,000	14
Ventersdorp	45	91′	67′	34′	7.1′	23″	19,660	11
Bloemhof	322	103′	71′	44′	—	18″	20,250	21
Wolmaranstad..	307	87′	59′	37′	—	21″	17,560	16
Potchefstroom..	20	116′	79′	35′	—	24″	18,900	25
Heidelberg	15	104′	66′	27′	4.0′	27″	22,000	0
TRANSVAAL SYSTEM.								
Dolomite.								
Pretoria	32	129′	80′	41′	7.3′	29″	46,100	31
Rustenburg	56	148′	107′	68′	—	25″	19,900	38
Marico	30	117′	76′	57′	4.1′	21″	34,080	33
Lichtenburg	79	107′	68′	35′	—	22″	34,850	20
Ventersdorp	16	1337′	108′	70′	—	23″	22,000	25
Witwatersrand	29	129′	115′	61′	4.2′	29″	42,500	10
Heidelberg	9	100′	76′	36′	—	27″	30,570	0
Potchefstroom	22	139′	104′	77′	—	24″	26,370	50
Klerksdorp..	27	97′	76′	41′	—	24″	51,600	7
Vryburg	17	133′	75′	35′	—	16″	21,300	0
Kuruman	30	128′	112′	74′	7.0′	15″	32,300	43
Pretoria Beds.								
Potchefstroom..	127	89′	60′	22′	6.6′	24″	25,300	12
Lydenburg	19	107′	60′	30′	8.8′	35″	16,600	5
(a) Quartzites.								
Pretoria	33	119′	81′	38′	5.7′	29″	22,200	33
Rustenburg	115	121′	87′	52′	9.1′	27″	24,700	22
Marico	72	128′	93′	61′	6.8′	25″	32,400	28
(b) Slates.								
Pretoria	39	136′	88′	36′	9.0′	29″	29,700	3
Rustenburg	109	123′	87′	52′	11.3′	26″	22,000	30
Marico	15	110′	80′	50′	7.1′	25″	20,000	20
(c) Slates and Diabase.								
Pretoria	39	124′	86′	39′	6.8′	29″	32,200	13
Rustenburg	57	127′	93′	62′	8.0′	26″	21,500	14
Marico	30	122′	90′	60′	7.7′	25″	20,600	13
(d) Ongeluk Volcanics.								
Pretoria & Rustenburg	73	95′	73′	42′	7.0′	27″	15,100	10
Kuruman	28	157′	132′	95′	6.3′	12″	12,000	50
MALMESBURY BEDS.								
Malmesbury	62	144′	87′	44′	—	20″	9,250	7
BUSHVELD IGNEOUS COMPLEX.								
Diabase.								
Pretoria..	48	103′	74′	35′	6.3′	29″	25,400	12
Rustenburg..	122	116′	86′	52′	12.0′	27″	28,800	22
Marico	21	110′	70′	54′	7.3′	25″	21,600	40
Norite.								
Pretoria	49	113′	71′	34′	4.8′	27″	29,450	34
Rustenburg..	103	119′	94′	62′	6.1′	27″	23,000	39
Middelburg (Transvaal)	11	73′	51′	21′	—	30″	32,500	10

Red Granite.								
Pretoria	47	157′	113′	62′	7.2′	24″	6,900	28
Rustenburg	66	155′	113′	78′	—	24″	11,700	35
Middelburg (Transvaal)	11	77′	55′	20′	—	28″	11,400	17
Waterberg	30	140′	88′	50′	6.7′	25″	15,100	20
WATERBERG & MATSAP SERIES.								
Middelburg (Transvaal)	20	104′	74′	26′	—	29″	26,860	20
Waterberg	72	173′	92′	63′	10.3′	26″	12,400	14
Kuruman	136	226′	193′	167′	8.5′	11″	11,600	33
BOKKEVELD & WITTEBERG SERIES.								
Uitenhage	17	120′	90′	24′	—	15″	7,300	6
Willowmore	132	95′	60′	40′	—	9″	24,700	6
Willowmore (post-Union)	39	110′	66′	48′	10.8′	9″	19,000	33
KARROO SYSTEM.								
Dwyka Conglomerate.								
Prince Albert	13	160′	48′	32′	—	6″	12,700	—
Ecca Series.								
Prince Albert	18	81′	44′	26′	—	5″	29,300	—
Ecca Coal Measures.								
Transvaal, Area 1.. ..	952	147′	83′	30′	—	27″	15,400	9
Transvaal, Area 2.. ..	129	161′	88′	33′	—	24″	12,200	2
Transvaal, Area 3.. ..	86	218′	116′	72′	10.6′	18″	16,750	17
Heidelberg (Transvaal)	39	112′	70′	28′	16.3′	27″	15,500	8
Vredefort	57	112′	72′	45′	27.0′	25″	8,460	26
Beaufort Series.								
Bloemfontein	33	183′	94′	53′	12.0′	20″	17,400	33
Lindley	15	160′	98′	59′	21.4	24″	18,000	20
Winburg..	17	148′	90′	52′	13.6′	23″	11,200	35
Hanover	151	49′	31′	13′	—	10″	37,500	19
Hanover..	30	49′	23′	0	—	10″	24,600	*
Victoria West	152	68′	37′	16′	—	10″	43,500	10
Victoria West	26	53′	32′	0	—	10″	41,000	*
Cradock	450	78′	43′	22′	—	15″	24,700	20
Cradock	70	69′	26′	0	—	15″	30,000	*
Graaff Reinet	113	102′	72′	37′	—	15″	26,700	7
Graaff Reinet	10	52′	15′	0	—	15″	14,900	*
Aberdeen	75	90′	62′	24′	—	14″	26,100	—
Tarka	110	94′	60′	25′	—	18″	37,900	21
Queenstown..	123	87′	63′	29′	—	20″	22,300	5
Kingwilliamstown ..	21	170′	143′	53′	—	25″	7,300	20
Stormberg Series.								
Senekal	23	115′	61′	40′	15.0′	25″	10,700	40
Ladybrand	41	174′	42′	40′	17.0′	26″	12,500	34
Bushveld Sandstone.								
North-West Waterberg.	25	234′	139′	103′	13.8′	18″	10,450	6
Amygdaloidal Basalts.								
Springbok Flats	258	138′	90′	50′	15.0′	24″	26,500	19

* Flowing.

Mr. Farrant: I for one have felt very much the immense amount of work that Mr. Stewart and Professor Snape have always done for the Society, their anxiety to get papers, the trouble they have had to persuade people and the poor response they seem to get. In fact, I am ashamed of myself for not doing more. With regard to the younger men, I think they feel they are a little bit out of it. When they come here it is a very formal business and they do not feel at home as much as they might. Though I feel diffident, I would like to make a suggestion to the effect that we should have some system of getting the younger and the older men to meet in a more friendly and informal manner. If we had a meeting where no paper was read but where a general discussion takes place, or, perhaps, say, a visit to some engineering works of interest—there are a great number in Cape Town—we might do much better. I have noticed in my own department how much better the feeling is when men meet on work or at some conference. They meet one another and the young men are encouraged to put forward their views. If that was done here it is possible that they might come forward afterwards with papers. When they come here now they are diffident, they sit quietly and do not feel at home so much as if we met in an informal way. We should encourage them to say what they have on their minds about engineering.

Communications on paper, entitled:—

BOREHOLE WATER SUPPLIES IN THE UNION OF SOUTH AFRICA.

By ALEX. L. DU TOIT, *D.Sc., F.G.S.*

Mr. J. V. Metcalfe writes:—Dr. du Toit's papers are invariably interesting and represent much thought and painstaking effort on the part of the author and this paper is no exception. Much of the haphazard drilling and wild theorising should disappear in the light of the lucid explanations put forward.

The writer has had no personal experience of water locating instruments, but, frequently has heard of their misleading indications, both in regard to depth and quantity of water. In the case of the divining rod, as the author states, undeniable ability to locate underground water is possessed by certain individuals. Until witnessing some very convincing exhibitions of the use of the twig, the writer has been most sceptical, and later, received a greater shock to find that he himself, was possessed of certain powers that enabled him to locate water mains down to 3 inches diameter, sewers and, on one occasion, a small leak through fissured rock, round the flank of a masonry dam.

Some years ago, he carried out a few experiments on a diviner and found that by earthing the diviner's hands (a copper wire was attached to his wedding ring and earthed periodically) all action of the twig was arrested. Additional body capacity obtained by the writer's being electrically connected with the diviner, had no really definite result. Peculiarly, little difference was noticed when the operator wore crepe-rubber soles, leather soles or walked barefoot. All experiments were made over "strongwater" at a supposed depth of 80 feet. Opportunity has not since presented itself so as to enable experiments with an electricscope to be carried out.

Diviners assert that the action of the twig is confined only to water that is both covered and flowing, and this statement, in conjunction with the few experiments carried out, seems to indicate that the twig in some inexplicable way is affected by electrostatic charges developed by the moving body of water. This mysterious power however is of no small magnitude as the writer has had acacia-forks and other brittle twigs break off next to either of his hands and sometimes the hands themselves suffer no small damage. (In the writers experiments with twigs, all sizes were used from slender poplar forks to stout acacia—in an unsuccessful effort to try to prove the movements of the twig the results of auto suggestion).

In this particular district, Middleburg (Cape), drilling is frequently successful (as Dr. du Toit mentions with regard to the Beaufort series, here present) but one significant fact, corroborating the author's experiments at Klipfontein, is, that instruments for locating water proved ineffective or at least most misleading, with the result that such is the confidence of the farmers that they assert they "will drill to water or hear the cock crow the other side." In the majority of cases, water was obtained in the region of 100 feet depth.

As the author states, the present vogue of the large cylinder is undeniable. A very frequent practice is that of employing a large cylinder and to discharge straight into the lands for irrigating (such heavy discharge being necessary to combat porosity), whereas the use of a smaller pump in conjunction with the dam to act as a balancing reservoir would result in the husbanding of the supply, and the protection of neighbouring boreholes.

Over pumping is certainly more the rule than the exception.

With reference to large hole drilling, is this not advantageous in the case of deep drilling as with the fitting of smaller casing and cylinder—many alignment and jamming troubles would be obviated?

Dr. du Toit is not only to be congratulated on a most comprehensive and precise paper of great value and interest, but is to be sincerely thanked for the trouble and care he has taken in its preparation. It is deserving of the hearty appreciation of all.

Mr. A. H. Wallis writes:—Having been engaged, for the greater part of my career, in grappling with the problems of water supplies in parts of Africa where water is scarce and where—when underground water is obtained—it usually is so highly mineralised as to be almost useless for boiler purposes, I looked forward with avidity to the paper which is now before us. I must confess to a certain sense of disappointment on reading it, unreasonably perhaps, for one is inclined to expect far more than the results of the experimental scratchings in this vast country of ours would justify.

It is with feelings of gratitude that I remember the author's kindly and encouraging contribution to the discussion on an early attempt on my part to record some experiences of of my own on the Vryburg Bulawayo Railway, in a paper to the Society in 1916, and I trust the writer will not consider my remarks as unduly critical in commenting on his paper.

Since my paper referred to was written, it was my lot to have charge of the South-West Africa system of Railways, for two years, during which time the dreadful experience of bad water for locomotive purposes was a constant nightmare.

For some time past I have been threatening to inflict on the Society a paper giving the results of those experiences, together with a complete analysis of some sixty or seventy waters from boreholes and other sources. These analysis were made by no less an authority than Dr. McCrae, Government Analyist, Johannesburg, and I feel that for the analyses alone they will prove of value as records for the Society. Alas! however, the pressure of work will not permit of the preparation of such a paper at present.

Dr. du Toit's paper appears to deal with water as water only; but it is a sad experience of those who have to use it to have to divide the subject into two, *i.e.*, quality and water of bad quality. It is all very well to obtain water, but it is exceedingly disappointing after one has spent large sums in obtaining it by drilling, to find that it is useless for boiler purposes, which is more often than not the case.

One wonders how much of the above waters were fit for human consumption and what proportion was useful for commercial and industrial purposes.

In my experiences, water when obtained from boreholes in the Bechuanaland Protecorate in South-West Africa, at least 90 per cent. of borehole water was unfit for boilers and only a small proportion of such was capable of treatment other than by actual distillation.

Truly, boring is a gamble at all times and the chances of success are very small.

The figures given by Dr. du Toit are valuable, indeed, in the respect that they give the most likely series in which to find water as well as those in which success is not likely to be obtained.

It is gratifying to find that—in such series where boring was done, in which I was implicated (I say this seriously) my conclusions work out on very similar lines. Hence we conclude:—

Old Granite. Don't bore for water, chances very remote.
Schists in Old Granite. Certainty of obtaining water.
Kraaipan System. 63 % chance of getting water.
Witwatersrand System. 89 % chance of getting water.
Ventersdorp System. 68 % chance of getting water.
Pniel Series. 83 % chance of getting water.

Transvaal System.

Dolomite. 69 % chance of getting water.

Pretoria Beds.

Quartzites. 75 % chance of getting water.
Slates. 78 % chance of getting water.
Slates and Diabase. 87 % chance of getting water.
Ongeluk Volcanics. 79 % chance of getting water.

Malmesbury Beds. 93 % chance of getting water.

Bushveld Complex.

Diabase. 79 % chance of getting water.
Norite. 65 % chance of getting water.

Red Granite. 72 % chance of getting water.
Waterberg Matsap Series. 78 % chance of getting water.
Bokkeveld Witteberg Series. 88 % chance of getting water.

Karroo System.

Dwyka Conglomerate. Certainty of obtaining water
Ecca Series. Certainty of obtaining water.
Ecca Coal Measures. 90 % chance of obtaining water.
Beaufort Series. 86 % chance of obtaining water.
Stormberg Series. 64 % chance of obtaining water.
Bushveld Sandstone. 94 % chance of obtaining water.
Amydaloidal Basalt. 81 % chance of obtaining water.

Hitherto he has spoken of *water simply* irrespective of its commercial use. The information furnished by Dr. du Toit in his paper makes no discrimination between good and bad water obtained. When we come to discuss quality of water, that is to say water for boiler purposes, the probabilities of success have still to be further reduced. Schist in the Old Granite yields very good and pure water, in fact, all decomposed granite yield water is of good quality and at no great depth. Dolomite and limestone country usually gives highly carbonated and magnesia waters to about 25 parts per 100,000 of lime, but which is capable of being treated for boiler purposes.

Sandstone and Quartzites usually yield pure water.

Slates and Shales yield bad water, mostly oxides of ammonia and alumina which are corrosive and which frequently have chloride of sodium in quantity, which later can only be removed by distillation. *Diabase.* I have never been lucky enough to obtain water in diabase or basalts., although I have tried. *Karroo System.* The Karroo system I have usually regarded as clay slates and shales with horizontal intrusions of dolerite. Such borings that I have been associated with have been failures as regards yield and—when waters have been got —have been of highly mineralised nature associated with sulphuric acid re-actions, wholly unsuitable for boiler purposes.

It is noted that Dr. du Toit refers to Dwyka conglomerate. I have encountered glacial tillites in the Mafeking district of a very similar nature to Dwyka conglomerate, but have usually found this formation as a floating series of boulders resting on other formation of later periods. It has been my experience to bore through these with great difficulty but never to find water in the actual conglomerate.

Now that we have dealt with the author's table of yields, after fully agreeing with him in his remarks that they constitute a wealth of information worthy of being recorded in the annals of this Society, I would like to congratulate Dr. du Toit most warmly on his painstaking trouble taken to collate the data, together with the cognate points, for us.

We will now proceed to analyse his opening remarks. Passing by his text book description of methods of infiltration I do not think it wise or useful to lay down any general conclusion on the "Water Table," nor is it, in my opinion, sufficiently exact to proceed on lines in this matter such as is done in the Northern hemisphere where the text book formations seem to lie comformably. Out here there are signs of cataclysmic volcanic action which has contorted our geological formations to such an appalling extent as to make it impossible to say what lies beneath us; although to guarantee—however attractive it may seem—is only asking to be told later that our conclusions were incorrect. In places like Mafeking where the limestone spreads a long distance, it is more or less correct to say that the water lies at about 70 feet below the surface, but to lay down a hard and fast law on the subject is unsafe. Some analogy may be traced in the depth of water below the surface in certain areas, after deducting or making allowance for local conditions such as rainfall, but the country is generally so contorted and broken up by intrusions and volcanic disturbances that I have found it wise not to express opinions on the subject.

The ordinary Boer farmer is of opinion that water runs in veins or "aars" in the earth, in a manner similar to blood vessels in the human body. Many people have told me that if I had only bored three feet to the right or left I would have struck the "aar" or got plenty of water when—as a matter of fact I got none. However, of that anon.

That some boreholes rise and fall consequent on rainy and and dry seasons is frequently experienced more especially with boreholes up to about 500 feet deep. We do not know enough of the subject to be able to say much more. The South West African Government have legislated against the too free use of the Artesian holes in the Stampriet or Aub area.

With regard to selection of sites for boreholes I agree most strongly with Dr. Du Toit that only trained men should be allowed to select sites for bore holes. The geologist alone can spot intrusions which are lying across an otherwise sloping country and his trained eye can detect, from his knowledge of geology, where or where not water is likely to be found. As far as the dowser and his "stokkie," my experiences have been most painful and expensive with this gentleman. The most awkward point about them is that they do not wilfully mislead, but that they honestly believe that their methods are correct. I can only say that it is very nice to be assertive and dogmatic where one is spending other peoples money, but it is an entirely different thing to spend ones own money on such chance ventures as the "stokkie" expert desires. I cannot speak without exhibition of extreme intolerance on the subject, having learnt many a bitter lesson through giving credence to this misguided type of person, which is one of those which should be included in Gilbert's list of those who never would be missed.

I do not believe in dynamiting boreholes. Usually it is wasting money although the area of the infiltering surface may be enlarged. Usually their is great chances of blocking a bore-hole with serious consequences.

I fear that I have gone to too far a length in contributing to the discussion and so will conclude by expressing my heart-felt thanks to the writer for his able and instructive paper and trust that he will not take my remarks as evidence of destructive criticism for such is not intended.

Mr. J. D. Shannon said:—I have had experience of Dr. Du Toit's powers as a water-finder and can testify as to the value of his advice. He has here collected much useful information, but I only wish to refer to one point, viz., "maintenance of yield," p. 87, where he says that the ordinary farm borehole "should not fail during seasons of drought if run at not more than the advocated maximum of 50 or 60 per cent. of its original tested output." He does not explain how the original test is made, but the inference is that the real capacity is only about half the tested capacity. The tests and estimated yields of most boring contractors are very unreliable, and for many years I was dissatisfied and uncertain what was the right way to conduct these tests. Of late years, however, I have worked on a method which I have found very satisfactory in its results as far as I have been able to prove them.

The principle of this method is to test for the quantity of water that can be taken from the borehole without permanently lowering the watertable. In this way, before starting the continuous 24-hour test, the level of the water is taken in the hole. Pumping then proceeds and the quantity of water raised measured. On stopping pumping the level of the water is again taken, and if it is still at the same level or returns to it in a few minutes, it is considered the capacity of the hole has not been reached. If it takes some time to recover, however, the yield is considered to be the quantity pumped divided by the time from starting pumping till complete recovery. Thus, if 40,000 gallons were pumped in 24 hours continuous pumping, but it took a further 24 hours before the water came back to its original level, then the yield of the borehole would only be taken as 20,000 gallons per day. I have found this a very satisfactory rule to work to in providing the necessary machinery and fixing the pumping rate.

Reply by Author.

It is a matter of regret that more criticism has not been forthcoming on this paper inasmuch as it included several decidedly contentious matters.

The remarks made by Mr. A. H. Wallis were directed mainly towards the question of quality, more particularly as regards boiler supplies, and his experiences have to a large extent the author's sympathies. It was, however, pointed out that that question could hardly be touched upon and indeed would really mean many pages for even its general discussion. It is nevertheless felt that in this country there seems to have been no striking endeavours towards experiment with modern methods of water softening, as applied to small industrial supplies (through the use of such substances as permutite for example), and there is accordingly plenty of scope on the S.A. Railways in such direction.

On each of the irrigation boring returns a declaration is made as to the quality of the water obtained and it can be affirmed that only in few cases are the waters reported so brack, as to be unusable either for domestic or else for stock purposes.

The author cannot agree with Mr. Wallis's rather pessimistic opinion that the chances of success in boring are very small. Mr. Wallis naturally has in his mind inexhaustible supplies of from 20,000 to 50,000 gallons per diem along the railway systems and unfortunately only too frequently at spots not well favoured because of geographical, geological or climatic limitations. The problem of railway water supply is indeed one deserving of a paper all to itself. Otherwise it is maintained that the data presented demonstrate the practical success of boring within the Union, which has at a relatively small cost enabled vast areas to become occupied. The tabulated returns as a matter of fact show an average chance of 75 per cent. in obtaining water for general purposes, which, considering the low rainfall in general, the hardness of the formations quite commonly represented, etc., cannot be regarded as unsatisfactory.

It might be pointed out that the rock at Mafeking, referred by Mr. Wallis to the Dwyka conglomerate, is actually a hard conglomerate and agglomeratic zone within the Ventersdorp volcanics, which would explain the non-success of boring therein, for the overlying amygdaloidal diabase to the east constitutes a good reservoir.

As regards the dynamiting of boreholes it can only be repeated that quite a number of cases could be quoted, where considerable increases in yield resulted therefrom.

Mr. J. V. Metcalfe's experiments with the divining rod are of considerable interest and bear out those of the author that the movements thereof can not be ascribed to mere auto-suggestion. With the writer the turning of the "stick" consistently indicates the junction underfoot of two dissimilar formations, which has proved of no small value in the tracing out of such boundaries when concealed. Mr. Metcalfe's kindly remarks upon the paper generally are much appreciated.

Mr. J. D. Shannon's strictness regarding the methods of testing are well founded and his rule would appear a reasonable one. In the Irrigation Department the test is usually made over periods ranging from 24 to 48 hours, but in important cases, where a large permanent yield is a *sin qua non*, pumping has been done over much longer periods and the water level thereafter noted.

The figure of between 50 and 60 per cent. quoted has been fixed as the result of experience and has been adopted not so much because of a possible overestimate of the tested supply, but so as to provide a safe margin during the dry portion of the year as well as to allow for any silting in the borehole or clogging of the pores in the rock with time.