SECRETARY FOR MINES,
PRETORIA.

I have the honour to transmit for publication a memoir on "A Chemical Survey of the Underground Water Supplies of the Union of South Africa" by Dr. G. W. Bond, Chief Chemist to the Electricity Supply Commission. The report embodies the results of Dr. Bond's investigation of underground waters over a period of six years.

Through the courtesy of the Electricity Supply Commission the Geological Survey is able to publish the report as a companion volume to Memoir 34, "The Water-Bearing Properties of the more important Geological Formations in the Union of South Africa" by Dr. H. F. Frommurze.

Memoir 34 represents the first large-scale attempt to deal with the underground water resources of the Union as a whole while the present memoir is the first general survey of the chemical quality of waters occurring from the various geological formations in South Africa.

The need of water for many industrial purposes, as well as for mining, agricultural and domestic uses, is obvious to all. Of prime importance is the quality of water. The nature of dissolved matter and the amount in solution materially affect the efficiency and economy of steam raising and of some industrial processes in which large quantities of water are used. Corrective chemical treatment of the various types of water in order to render them suitable for industrial use is an important aspect of this problem and is discussed in some detail in this memoir. The composition of underground water is also important in relation to problems of nutrition and health, and in this connection one might instance the surveys of fluorosis and dental caries conducted by the Department of Public Health, or the investigations of the Veterinary Research Laboratory at Onderstepoort on the effect on livestock of highly saline or hard waters.

An aspect of particular interest to geologists is that the chemical character of a water might afford a clue to the probable origin of the rock formation in which it occurs.

The memoir should be of the greatest use to all who are interested in the chemical character of underground water from the industrial or the scientific standpoint.

I have the honour to be,
Sir,
Your obedient servant,

LOUIS T. NEL,
Acting Director, Geological Survey.

Pretoria,
16th February, 1945.

This memoir has been submitted in fulfilment of the requ
ments for the degree of Doctor of Science in the Faculty of Sc
University of South Africa.

CONTENTS.

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Faculty of

A GEOCHEMICAL SURVEY
of the
UNDERGROUND WATER SUPPLIES
of the
UNION OF SOUTH AFRICA.

With particular reference to their utilisation in power production and industry

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I.—INTRODUCTION.

Previous Work.

The water bearing properties of the more important geological formations in the Union of South Africa have deservedly received a good deal of attention, particularly in the publications of A. L. du Toit (1 and 2)[*] and H. F. Frommurze (3).

On the other hand the nature and chemical composition of the underground water supplies of the Union, their adaptability for technical purposes and the possibility of their chemical improvement, have not received adequate study.

Little has been published on the extremely interesting problem of the relation between geogloical formations and the composition of the underground water, and the modifying influence of climate.

The investigations of Rindl (4), Hahn and others are confined to the thermal medicinal springs of the Union, and the numerous economically important, salt "pans" have also received a fair but not sufficient amount of study.

The first and only serious attempt towards a systematic classification of the underground water supplies of the Union was made by Juritz (5) in 1908. He, however, confined his investigations entirely to the Cape Province and only to underground water from the younger geological formations occurring in that province. In addition there are other important limitations. For example, little was known at that time regarding the importance of hydrogen ion concentration and consequently Juritz gave no pH. figures for the borehole and spring waters examined—an unfortunate omission in view of the fact that a knowledge of the pH. condition of the water is essential when considering the adaptability of a water for technological purposes, and devising methods of chemical improvement.

As regards adaptability for technological purposes, Juritz very roughly classified the waters examined into very bad, bad, fair, good and very good, but it is considered that he had in mind suitability only as regards locomotive boilers, for judging by modern standards, some of the waters classified as good, would certainly be of very doubtful use for boiler feed "make-up", even after having been subjected to expensive and complicated chemical treatment.

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[*] The numbers in brackets refer to the Bibliography at the end.

Furthermore, our standard regarding the purity of water supplies for boilerfeed "make-up" have been radically altered since 1908, this being due to changes in boiler design and performances.

Through lack of detailed geological data, in many of the areas studied, Juritz did not attempt a comprehensive geo-chemical classification, but nevertheless drew attention to some outstanding characteristics of the waters from certain younger geological formations of the Cape Province.

In 1908, Tudhope (39) also published a very short note on the chemical characteristics of a few borehole waters in the Cape Province. There are, unfortunately, some very obvious errors in the hardness figures given (39, p. 139) and it is difficult to judge whether Na_2CO_3 is present or not.

Since 1908, a large amount of detailed geological survey work has been carried out by the Union Geological Survey and there is thus far more geological data available than in 1908, which renders the task of attempting a geologic classification somewhat easier.

In 1913, in a paper dealing with the geology of underground water in South Africa, Du Toit (1, pp. 18–19) drew attention to the fact that, from published analyses, it was clear that there is a definite and fairly close connection between the chemical composition of the underground water and the geological formation from which it is derived. In this paper he compiled a table showing the average composition of water derived from the younger geological formations found in the Cape Province, and drew certain conclusions from them. However, average analyses of water (the analyses of the waters averaged as they stand) can be most misleading, owing to great variations in concentration. The only way to average a group of water analyses is first to express the constituents as percentages of total solids, thereby eliminating the concentration variable, and then to average the percentage compositions.

In 1916 Wallis (38) published a very short paper on railway borehole supplies (mainly in the Ventersdorp beds) in the Vryburg–Mafeking–Bulawayo section. However, this paper cannot be regarded as a serious attempt at a survey, for apart from the very restricted area covered, there are several errors in the analyses shown (38, pp. 24–29).

In 1928, in another very comprehensive paper dealing with the geology of underground water supplies in the Union of South Africa, Du Toit (2, p. 103) drew attention to the fact that inadequate study had hitherto been made of the salinity of borehole and spring waters, particularly regarding their dependence upon geological and climatic factors and also their adaptability for technological use.

Since this latter date, nothing further has been published on this very important aspect of underground water supplies of the Union, although the chemical branch of the South African Railways and Harbours Administration have collected a considerable amount of borehole data in connection with chemical treatment of water supplies for locomotives, but this is as yet unpublished. Moreover, numerous analyses have also been made by the Government Laboratories and by private analysts, but these analyses are concerned mainly with the potability of waters and are very incomplete.

In 1935 Sibson (6, p. 5) drew attention to the importance and necessity—from the point of view of power station operation—of a more detailed chemical survey of the natural water supplies of the Union.

In 1942 Gevers (31), in a paper on the carbon dioxide exhalations from springs in Pondoland arising in the Dwyka Tillite, discussed the composition of the waters of Dwyka Series in Pondoland in relation to the Dwyka waters elsewhere. However, this paper was concerned mainly with the problem of the carbon dioxide exhalations.

OBJECTS AND SCOPE OF STUDY.

The author's primary object is to attempt a general chemical classification of the underground water supplies of the Union of South Africa with reference to their utilisation for the purposes of power production and industry generally.

The enormous increase in electric power production during the past 30 years and the encouragement now being given by the Government of the Union for the establishment of rural industries (e.g. the formation of the Industrial Development Corporation) would appear to indicate the great necessity for this kind of investigation. Furthermore the Government has recently given notice of its intention to establish a "Water Supply Commission" in the near future.

An endeavour will also be made to trace the relation between the various types of waters and the geological formations in which they originate, and also the modifying influence of climate on the composition of the water. All the important geological formations of the Union will be considered. Comparisons will also be made with waters in similar formations in Australia and other countries.

It will be shown that the chemical character of a water often throws light on the probable origin of the rock formation in which it occurs, i.e. whether the formation was of marine or fresh water origin. The author sincerely trusts therefore, that this study may be of some value to this branch of geology.

The author has also investigated in some detail the relation between the calcareous tufa deposits and underground water in the vicinity.

A detailed study of the salt pans is outside the scope of the investigation, but the author has discussed the relation between the brine in these pans and the "ground water".

A detailed study of the thermal and medicinal springs of South Africa, is also outside the scope of the present investigation. Reference will however, be made to these occurrences and it may be mentioned here that many of the so-called "mineral springs" are no more saline than the average borehole or spring waters in the same formations and differ only in the fact that they are sometimes hot or warm. In fact the term "mineral" spring is often a misnomer, for frequently the concentration of dissolved salts is extremely low.

Then there is the nutritional aspect. The investigation at Onderstepoort Veterinary Research Laboratory of Steyn and Reinach (79) have drawn attention to the fact that the continual use over years of highly saline or highly alkaline water as drinking water, may lead to certain chronic diseases in animals and human beings. The author trusts therefore that his survey of the ground waters of the Union may prove of some value in connection with research of this nature.

It is also hoped that this survey will prove of value in connection with the researches of Dr. Ockerse and others into the incidence of dental fluorosis and caries in the Union.

Another possible avenue of usefulness is in regard to pollution of natural underground water supplies by mine waters or sewage. If the general characteristic of waters arising in a certain geological horizon are known, then it should be quite easy to detect whether pollution has occurred.

Several cases of this nature have come up before our Courts in recent years, but nothing was known at the time regarding the general characteristics of *unpolluted* borehole waters in different geological horizons.

The author's investigation is principally confined to sub-surface waters, that is spring or borehole water, for surface waters are subject to considerable variation in concentration and composition, and one is not always certain as to their source. Hence river, lake and dam waters are not considered in this study, nor for that matter are mine waters for they are generally very acid and often polluted.

The author is fully aware that there are definite limitations regarding assignment of waters to certain geological horizons. For the purpose of this investigation waters have been assigned to certain geological horizons for the reason that the rocks of those formations outcrop at or near the surface in localities where the water emerges as a spring or is tapped by means of boreholes.

Fortunately for the purpose of this investigation the majority of boreholes in the Union are well under 200′ so that there is generally little doubt as to the geological horizon in which these waters arise, but hidden or unsuspected igneous intrusions, i.e. dykes and sills, often considerably modify the water, and may often be the cause of anomalies in the general run of waters in a formation.

Wherever available the author has given borehole depths. Furthermore, a very large number of the samples were collected personally by the author during motoring tours of the Union, and in such cases steps were generally taken to confirm that the boreholes were actually located in the geological horizon under study. It can therefore be reasonably certain, within the limits of present geological knowledge, that the waters tabulated in the following pages are derived from a particular geological horizon.

In Juritz's paper (5), there is a tendency to concentrate too much on one particular town or locality, so that a true cross section of the formation is not obtained.

It will be observed that in his survey the author has made every endeavour to collect samples from as wide an area as possible so that the whole of a given geological formation may be more or less covered. This of course, was not always possible owing to paucity of boreholes in certain areas or to inaccessibility.

In the following pages the adaptability of the underground water supplies of the Union will be considered under the following headings :—

Domestic Supply (General and Potable).
Agriculture (Irrigation and Watering Stock).
Industrial :—
(*a*) Power Production (Steam Raising and Cooling Water).
(*b*) General Industrial use.

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The author expresses his great indebtedness and thanks to the following :—

The Electricity Supply Commission for permission to publish analyses, made by the author during the course of his work, of cooling waters (E.S.C. sub-stations) town waters and other data, and for various facilities.

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Mr. Britten, Officer in Charge, Government Laboratory, Johannesburg, for certain analytical data.

Dr. T. Ockerse of the Department of Public Health, for analytical data collected by him during the course of investigations into the prevalence of dental fluorosis in the Union. These analyses were particularly useful as many were from remote and inaccessible parts of the Union from which the author experienced difficulty in obtaining samples.

Mr. Black, of Messrs. Fraser and Chalmers, for certain analytical data mainly from the South East Cape Province.

Considerable use was made of Dr. A. L. Hall's (70) valuable compilation of rock analyses, etc., from various sources.

(Acknowledgements are made in the text regarding other analytical data used. The majority of tabulated analyses were, however, carried out by the author himself).

Acknowledgements are made in the text to the geological work of Drs. A. L. du Toit, Frommurze, Gevers and other Union Geologists.

The author is particularly grateful to Dr. A. L. du Toit for the interest he has displayed in this investigation.

II.—ANALYTICAL DATA.

ANALYTICAL METHODS.

Since the primary object of this investigation is a survey of the chemical nature of the underground water supplies of the Union, with particular reference to adaptability to power production and industry generally, the analyses were naturally carried on in such a manner as to throw light upon this aspect and differ in this respect from many of those previously published, which were generally carried out with a view to potability, and are therefore incomplete in many respects.

These analytical data have been collected over a period of some eight years. Unless otherwise acknowledged, all the analyses given in the following pages were carried out by the author or under his direct supervision.

Attention is drawn to the following :—

(i) *Hydrogen ion concentrations.*—As regard pH. determinations, the author has shown in a previous publication (7, pp. 61–62) that the colorimetric determination of pH.

can (under certain conditions) be somewhat unreliable. Unfortunately the pH. figures given in most of the published analyses applying to this country have hitherto been based on colorimetric methods and are, therefore, not always reliable.

The pH. figures given in the author's analytical tables were determined by means of a Beckmann Electrical pH meter, manufactured by the National Technical Laboratories, Pasadena, U.S.A. (glass electrode). This instrument was regularly checked with standard pH. buffer solutions and found to be most reliable.

(ii) *Hardness Figures.*—The total hardness figures were determined by means of the potassium palmitate method or else calculated from the results of gravimetric analyses. In a previous paper the author (8) has shown that the usual routine methods of determining hardness by means of the soap solution method can be totally misleading in the case of waters of high hardness or containing appreciable amounts of magnesium and chlorides, while even the Hehner method has its drawbacks.

It is unfortunate that in many of the analyses carried out prior to, say, 1922, not only was the total hardness determined by soap solution, a method liable to err with some classes of water, but even the temporary and permanent hardness were thus determined. The practice was to determine total hardness by soap solution; another portion of the sample was then boiled and filtered and the residual hardness determined by soap solution. This was supposed to give the permanent hardness. The temporary hardness was obtained by difference. These methods sometimes gave an approximate result but more often than not gave rise to some extraordinary hardness figures. In this connection attention is drawn to some of the analyses published in the Union Geological Survey Memoir (70, pp. 478–479). These were taken from Tudhope's paper (39) to which reference has already been made in the previous section. Several similar errors also are to be found in Wallis' paper (38, pp. 214, 219). Some of the hardness figures bear little relation to the CaO and MgO figures given.

The author has come across numerous other examples when examining old analytical records dealing with the Union. In fact he has found it necessary to discard the hardness figures in all these old analyses and calculate them instead from the gravimetric figures for CaO and MgO (if given). Unfortunately in many of these old analyses no alkalinity figures were given and many other essential figures are missing, so it was not always possible to calculate the temporary and permanent hardness figures or to say whether Na_2CO_3 or $NaHCO_3$ was present or not. The author (83) has dealt with this matter in a previous publication.

For the foregoing reasons much of the old analytical data could not be used for this study.

(iii) *Sodium Carbonate and Bicarbonate.*—When the total hardness was less than the methyl orange alkalinity, the difference was taken to be sodium carbonate or bicarbonate.

In most cases it was found that only sodium bicarbonate was present, though occasionally especially in Red granite and Beaufort series waters, the water showed a phenolphthalein alkalinity, and had a pH. of over 8·3, indicating the presence of sodium carbonate as well.

(iv) *Nitrates and Nitrites.*—The presence of nitrates and nitrites in a water may be regarded as accidental, inasmuch as those compounds are not generally derived from the rock formation in which the water arises, and their presence is due to a number of extraneous causes. These causes will be discussed subsequently (Page 164).

Nitrates and nitrites were however, always determined by the author, as they serve to a certain extent, as an indication as to whether or not the sample has been polluted. As will be shown hereafter, high nitrates alone are not necessarily an indication of pollution (Page 165).

Nitrates were determined *quantitatively* by the phenolsulphuric acid method and reported as NO_3.

Nitrites were tested *qualitatively* by the metaphenylenediamine method.

(v) *Silica.*—Silica, that is soluble colloidal silica as distinct from the suspended matter which was always filtered off, was determined by *gravimetric* methods. Large amounts of the sample were taken to dryness with HCl and baked for an appropriate time and taken up with acid. It was found that the colorimetric methods for silica determination were not accurate enough for the purpose.

The results have all been expressed as SiO_2.

(vi) *Fluorides.*—Although with one exception, fluorides have never been found in ground waters in the Union of South Africa in amount likely to affect adaptability for industrial uses, nevertheless, the occurrence of even small amounts of fluorides is a matter of great importance in view of endemic dental fluorosis. As is well known the presence of fluorides in drinking water, even in amounts as low as 1·0 parts per million may give rise to the dental disease known as "mottled enamel".

The author therefore deemed it advisable to test for fluorides in all water samples, and some very interesting facts have emerged. (These facts will be discussed on pages 169-180).

As regards the determination of fluorides, it was found that the usual distillation method for the determinaton of fluorides in water, as evolved by Willard and Winter (11) and modified by Armstrong (12) was far too long and tedious for the routine examination of large numbers of water samples.

The method finally adopted was a slight modification of a microchemical colorimatric method also evolved by Willard and Winter (11). This modification was worked out in the Electricity Supply Commission's laboratory, and Ford (13) has shown that this method, on account of its rapidity, is entirely suitable for the direct routine determination of fluorides in water samples and gives a close approximation to the distillation method, even in the case of highly saline waters.

Through the courtesy of Dr. T. Ockerse, the author's fluoride tests have, several times, been checked by the Division of Chemical Services (who used distillation methods referred to previously and no appreciable difference was observed.

(vii) *Sulphates.*—Sulphates were determined gravimetrically in the usual manner (as $BaSO_4$).

(viii) *Potassium.*—Except in the case of brines from certain salt pans, potassium is never present in any quantity in the Union waters, very rarely exceeding 0·5 parts K. per 10^5.

Data from other analysts cited by the author, often give figures for K. but the quantity is always extremely small.

The author therefore, did not determine potassium quantitatively, but used a spectroscopic test as an indication of the approximate order of magnetude.

(ix) *Rock Analyses.*—Rock Analyses were carried out by the methods of Washington and Hildebrand.

(x) *Sodium.*—There is no *reliable* method for the determination of sodium in all types of water. Even the "uranyl zinc sodium acetate method broke down with certain types of water. Therefore sodium was not determined. As indicated under (iii) Na_2CO_3 or $NaHCO_3$ was assumed to be present when the total hardness was found to be less than the alkalinity. In those cases calcium and magnesium are present as $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$ (i.e. temporary hardness); hence chlorides, sulphates, fluorides must be present as the sodium salts.

INTERPRETATION AND REPORTING OF ANALYTICAL DATA,

It is hardly necessary to point out that in solution the various metallic and acidic radicles exist in the form of ions and many combinations are possible.

The author has, generally speaking, studiously refrained from making any "hypothetical" combinations of ions.

There are cases however, in which it is safe to work out hypothetical combinations, for example, a water showing an appreciable soda alkalinity. In this case it is legitimate, as previously mentioned, to express all magnesium and calcium as bicarbonates, and the sulphates, chlorides, nitrates, fluorides, etc., as the sodium salts (or a small part potassium).

With most waters, however, this practice of combining ions is dangerous. The chief difficulty, of course, lies in the fact that there is, as already stated, no accurate method for the determination of sodium. It is to be regretted, therefore, that so many of the older analysts have given way to the temptation and have attempted to express their analytical data in combined form, following a stereotyped formula for combination. This has often led to glaring errors, for example, in many of the older analyses, the analyst reports that calcium sulphate and chloride and magnesium sulphate and chloride are present, in spite of the fact that the water shows an appreciable soda alkalinity and no permanent hardness at all (Wallis 18, p. 214, and Tudhope, 39).

As already mentioned, the author has analysed the waters primarily from the technological viewpoint, so that in the following tables, figures are reported for such items as total, temporary, permanent, calcium and magnesium hardness, as well as methyl orange alkalinity. In addition, however, the silica, fluoride, nitrite, nitrate, chloride, sulphate, etc., content is given, but data as regards free and saline ammonia, oxygen absorption, etc., are excluded, as these figures are only of interest with regard to potability and do not affect the chemical characteristics of the water in any way.

In his analytical tables, the author has given the ordinary analysis of the water, but in addition has expressed all the important constituents *as percentages of the total salts,* thereby eliminating the factor of concentration.

The statement is often made that no two borehole waters, even in the same formation, are ever alike. That this is not the case is well brought out in the author's tables. In most cases the apparent difference between borehole waters located in the same formation is merely one of concentration. It is therefore contended that by expressing the results as percentages of the total solids a much truer comparison can be made between different waters. Essential similarities are brought to light and the data become intelligible, instead of being a mere jumble of figures.

It will be observed that in the Tables, a few of the percentage figures are placed in brackets. These bracketed figures are regarded as being abnormal and not in line with the general run of waters in that formation. The bracketed figures are not included in the average. The CaO : MgO ratio is given in the case of each water sample, so that a comparison may be made with the CaO : MgO ratio in the rock formation in which the water arises.

III.—HYDROLOGY.

THE GEOLOGY OF THE UNDERGROUND WATER SUPPLY OF THE UNION OF SOUTH AFRICA.

Before proceeding to a detailed study of the chemical characteristics of the underground water supplies of the principal geological formation in the Union of South Africa, it will be necessary for the purpose of this study to summarise what is known of the geology of the underground water of this country.

Underground water is classified according to origin into meteoric or vadose waters and magmatic or juvenile waters.

Magmatic or juvenile waters are waters which existed in the original molten magma and issue from great depths in the earth.

Meteoric or vadose waters are waters which have infiltrated into the earth from the surface Included in this group are "connate" waters, that is sea water of ancient oceans, which have been trapped in the sediments laid down in those seas.

Infiltration of rain water from the surface of the ground is dependent primarily upon—

(*a*) The rainfall: infiltration is generally regarded as being proportional to annual precipitation;
(*b*) The amount and nature of the soil and subsoil, and porosity of the underlying rock mass;
(*c*) Geological factors such as jointing, dip of strata, presence of faults, dykes, etc.;
(*d*) Climatological factors;
(*e*) Geographical situation.

As regards (*a*), Du Toit (14, p. 120), is inclined to regard the magnitude of the annual precipitation as a much overrated factor and points out that though the supply is maintained by infiltration from the annual rainfall, yields are almost independent of the magnitude of the season's rainfall. For example, there is less difficulty in obtaining water in the semi arid Karroo than over much of the Transvaal with treble the rainfall. Du Toit ascribes this to the fact that the more clayey characteristics of the soil developed in the wetter regions tends to prevent the ingress of the surface water as freely as in the drier areas.

With regard to (*b*), the soil covering in the Union is, generally speaking exceedingly scanty and rock outcrops relatively abundant. This fact plays an important part regarding infiltration of rainfall into the ground.

The underlying rock masses can be divided into *water-yielding* and *non-water yielding*. The former class can be subdivided into

(1) Porous or permeable rocks which hold water throughout their mass;

(2) Rocks practically impervious in mass but holding water in joints, cleavage places, fissures and other openings such as faults and "shatter belts".

To this class crystalline rocks, such as granite, belong, though granite is frequently porous in the "weathered" or decomposed zone very near the surface.

Du Toit (15, p. 169) has shown that the rock strata of the Union taken as a whole, unfortunately possesses a very low degree of porosity and that this is especially true of the rocks of the Karroo system which cover quite half of the Union of South Africa.

For example, Du Toit gives the average porosity of the Dwyka tillite as not exceeding 2 per cent. The Beaufort series averages about 4 per cent., while the Stormberg series averages about 11 per cent. The Ecca series, including the coal measures, averages about 12 per cent. but shows a fairly wide variation.

Quite apart from the porosity there is the fact that, as pointed out by Du Toit, over a very large area the Karroo strata are lying nearly horizontal, which means that the bedding planes are not suitably inclined to receive the rainfall. Now, infiltration of rain water in inclined strata largely proceeds by way of bedding planes, whereas in horizontal strata the infiltration, unless the rock is of a porous nature, proceeds by less well developed vertical joints in the rock mass.

Sandstones are generally regarded as being among the most porous of rocks, but this apparently does not apply to the Union sandstones. According to Wybergh (16, p. 67) the results of a very large number of tests on sandstones from different geological formations in the Union, gave the low average figure of 12·4 porosity. Further 70 per cent. of these samples gave a figure of under 15 per cent.

Enormous areas in the Union are covered by the ancient crystalline granitic and gneissoid rocks which, except for limited porous zones due to surface weathering, may be regarded as non-porous.

Permeable strata are apparently confined to the partly consolidated sandstones and the marls of the Cretaceous system which happen to be very poorly represented in the Union, being limited to the South of the Cape Province and to the Zululand coast. Owing to this lack of permeable strata in the Union, the rainfall infiltrates into the rock mass and there circulates by means of bedding planes, joints and fissures in the rocks just below the " zone of weathering " and consequently at no great depth. There is thus, generally speaking, no real " water table ", the underground water tending to accumulate in pockets.

Geological structure therefore plays a major part regarding infiltration and accumulation of underground water in this country.

Apart from the question of the dip of strata, faulting and folding of strata, and the presence or absence of well defined joints and fissures, it is a well established fact that intrusions of igneous rock can play a large part in affecting the circulation of underground water in the intruded rocks. Springs often occur in the vicinity of dykes. For example, the dolerite instrusions in the Karroo sediments, the intrusive diabase sills in the Pretoria series and the dykes and quartz veins in the Dolomite series and in the Old grey granite.

Pressure Water.—On account of the above facts, there are consequently no large " artesian " basins in the Union such as occur in Australia. Merensky (17) has described a local artesian basin in the banded gneiss at Koperberg, Namaqualand. A much larger artesian basin occurs in the Uitenhage district, Cape Province, and has been described by Frommurze (3, pp. 16–18) and also by Du Toit (18).

Very small localised artesian areas have been reported in the Dolomite series of the Springs district, Transvaal.

Apart from small artesian basins, a few flowing boreholes, due to relatively local structure are known and are mainly connected with the Karroo basin, though a few are reported from the Dolomite and other formations.

A. Young (19) has described tidal phenomena in the " flowing " and interconnected boreholes at Tarka Bridge, near Cradock, some 160 miles from the coast and at an altitude of 2,700 ft., and has attributed the phenomena to extra-terrestial causes.

Du Toit (2, pp. 91–93) states that, generally speaking, ground water is struck at comparatively shallow depths, that is, well under 200 ft. and that it is seldom worth going below 400 ft. though occasionally holes over 1,000 ft. have been drilled with good yields (e.g. at Pretoria, in Pretoria Series).

IV.—THE RELATION BETWEEN THE UNDERGROUND WATERS AND SURFACE LIMESTONES.

A geological phenomenon which is of interest in connection with the chemical nature of underground water is the formation, in the more arid regions of the Union of South Africa, of secondary limestone deposits variously known as " Calcareous tufa ", " Surface Limestone " and " Calcrete ".

It is necessary to distinguish between these true secondary limestone deposits and lime-encased pebbles and boulders of dolerite which are often found on the weathered outcrops of the Karroo dolerites or Ventersdorp lavas, and which are the result of " weathering ".

The true secondary limestone deposits or calcareous tufa occur as nodules or as continuous sheets on, or a few feet below, the surface of the soil.

These sheets may vary from one or two feet to well over a hundred feet, though usually they are never of any appreciable thickness. The calcareous tufa deposits have been described by R. B. Young (44) and others.

The tufa is apt to develop upon those formations containing limestone, dolomite, or calcium silicates, providing of course, that the climate is sufficiently arid, for example, the regions underlain by the Dolomite series, the Ventersdorp lavas, the Dwyka tillite, the Ecca shales, the Lower Beaufort shales, and the Amygdaloidal basalt of the Springbok Flats. The tufa is found more particularly on flattish ground.

The calcareous tufa varies considerably in chemical composition as shown by Wybergh (20) and others, but essentially it consists of calcium carbonate with an exceedingly small amount of magnesium carbonate, the variations in chemical composition being due to the presence or absence of material derived from the soil. Sometimes the tufa is almost pure calcium carbonate, but more commonly it has a high silica content, and less commonly, appreciable iron oxide and alumina.

Du Toit (14, p. 407) states that in the formation of tufa the bulk of the clayey matter in the soil appears to be pushed aside by the accumulating carbonate of lime leaving the large sand grains and pebbles to be enveloped. That this is generally the case would appear to be proved by the high silica and low $Al_2O_3.Fe_2O_3$ content of the calcareous tufa. However, as will be shown later, this is not always the case and occasionally the tufa contains a large amount of $Al_2O_3.Fe_2O_3$ as well as SiO_2 which is indicative of admixture with the clayey material in the soil.

The explanation usually given to account for these secondary surface limestones is that they originated through the evaporation of calcareous underground water at the surface of the ground, the ground water having been drawn to the surface by capillary attraction (Du Toit 14, p. 407; Wybergh 20, p. 14).

Du Toit draws attention to the partial elimination of magnesium compounds compared as with the parent rock. Wybergh (20) gives a large number of analyses of calcareous tufa from different parts of the Union, but no reference appears in the local literature regarding the nature of the ground waters from which these deposits were primarily derived.

In view of the complete absence of the sulphates and chlorides of sodium, calcium and magnesium and sodium carbonate, as well as the very appreciable reduction of magnesium carbonate in these deposits, it appears to the author that the term *evaporation* conveys a wrong idea as to the origin of these deposits.

RELATION BETWEEN GROUND WATER AND CALCAREOUS TUFA

In view of the abovementioned fact that there is nothing in local literature regarding the relation between these tufa deposits and the ground water, and in order to throw more light on the origin of these deposits, the author carried out the following investigation:—

> Analyses were made of certain calcareous tufa deposits and compared with the analyses of underground water in the immediate vicinity of those deposits. Table A gives the results of these comparative analyses.

TABLE A.—RELATION BETWEEN THE GROUND WATER AND CALCAREOUS TUFA.

COMPARATIVE ANALYSES OF CALCAREOUS TUFA AND UNDERGROUND WATER FROM SAME VICINITY.

	1		2		3		4		5		6		7		8	
	Victoria West.		Bloemhof.		3 Miles West of Britten.		Christiana Townlands.		Beaufort West Townlands.		Hofmeyr.		Kalkheuvel 389 Pretoria District.		Farm Tweefontein Kaap Plateau West of Campbell.	
	Tufa Percentage.	Water Percentage on Total Solids.	Tufa Percentage.	Water Percentage on Total Solids.	Tufa Percentage.	Water Percentage on Total Solids.	Tufa Percentage.	Water Percentage on Total Solids.	Tufa Percentage.	Water Percentage on Total Solids.	Tufa Percentage.	Water Percentage on Total Solids.	Tufa Percentage.	Water Percentage on Total Solids.	Tufa Percentage.	Water Percentage on Total Solids.
Moisture	1·5	—	0·2	—	0·8	—	0·7	—	—	—	—	—	—	—	0·3	—
SiO_2	24·3	2·4	6·5	4·4	19·08	0·65	10·18	3·2	16·0	4·6	28·0	2·85	15·37	7·6	0·8	3·7
$Al_2O_3Fe_2O_3$	8·3	0·6	0·6	0·9	1·1	—	0·9	—	9·10	1·6	2·0	—	1·2	—	0·3	0·2
CaO ($CaCO_3$)	24·4 (43·5)	14·8 —	53·0 (95·0)	27·3 —	44·5 (80·0)	7·2 —	49·5 (86·0)	15·0 —	37·30 (61·0)	15·8 —	28·0 (50·0)	10·0 —	45·1 (80·0)	14·3 —	53·5 (95·0)	18·0 —
MgO	5·7	7·4	0·98	17·0	0·63	4·0	1·05	13·2	2·05	7·4	8·0	15·4	1·3	19·8	1·8	20·0
($MgCO_3$)	(12·0)	—	(2·05)	—	(1·3)	—	(2·2)	—	(4·65)	—	(16·5)	—	(2·73)	—	(3·8)	—
Cl	Nil	26·3	Nil	9·1	Nil	57·0	Trace	26·0	Nil	7·9	Nil	23·0	Nil	4·4	Nil	8·7
SO_3	0·12	9·4	0·05	1·74	0·07	1·24	0·14	3·0	Nil	14·8	Nil	12·6	Nil	1·6	0·16	2·15
CO_2	35·0	12·6	39·66	38·5	33·87	1·1	37·37	24·7	35·3	22·5	34·0 (by diff.)	14·0	—	38·5	42·2	36·0
Na_2CO_3	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	4·15	Nil	Nil	—	14·6	Nil	Nil
TOTAL	99·4	—	100·05	—	100·05	—	100·44	—	99·75	—	100·00	—	—	—	98·6	—
Ratio CaO : MgO	1 : 0·2	1 : 0·5	1 : 0·2	1 : 0·6	1 : 0·014	1 : 0·02	1 : 0·8	1 : 0·8	1 : 0·06	1 : 0·3	1 : 0·3	1 : 1·54	1 : 0·03	1 : 1·4	1 : 0·03	1 : 1·1
Analyst	G. W. Bond.	G. W. Bond.	G. W. Bond.	G. W. Bond.	G. W. Bond.	G. W. Bond.	G. W. Bond.	G. W. Bond.	Dr. J. Moir.	C. F. Juritz.	Govt. Lab.	G. W. Bond.	Govt. Lab.	G. W. Bond.	G. W. Bond.	G. W. Bond.
Geological Horizon	Lower Beaufort Shales.		Ventersdorp Diabase.		Dwyka Series.		Dwyka Series.		Lower Beaufort Shales.		Upper Beaufort Series.		Bushveld Sandstone or Amygdaloid.		Dolomite Series.	

The analysis of the water is expressed as a percentage of the total solids. In each case the CaO : MgO ratio of the tufa and waters is given.

Sample 1.—Victoria West, C.P. (Calcareous deposits on rocks of the Lower Beaufort series).

If a comparison be made of the deposit and the water from which presumably it was derived, it is found that there has been a total elimination of chlorides and sulphates, and about 50 per cent. elimination of magnesium.

The ground water in this case was of the highly saline chloride-sulphate type.

The analyses of the tufa indicates that in this case at least, there has not been a total exclusion of clayey matter from the soil in the manner suggested by Du Toit, for the $Al_2O_3.Fe_2O_3$ and SiO_2 content is appreciable. Moreover the tufa is much harder than the usual type.

Sample 2.—Bloemhof, Transvaal (on lavas of the Ventersdorp system).

A composite sample of the calcareous deposit was taken on the east side of the town, as well as a sample of borehole water from the immediate vacinity of the deposit.

The water was of the temporary hard (carbonate) type. The tufa was fairly soft, and the analysis showed it to be very pure, though there has been a slight admixture with sandy material, as shown by the SiO_2 content. In contrast to the previous case, there has been little or no admixture with clayey material from the soil, a fact indicated by the low Al_2O_3–Fe_2O_3 content.

The comparative analyses show that there has been a complete elimination of chlorides and sulphates (sulphates were however, low in the ground water). There has been 70 per cent. elimination of magnesium.

Sample 3.—Near Britten, Transvaal (on rocks of the Dwyka series).

The tufa was sampled from a deposit 3 miles west of Britten, on the main road to Kimberley.

The analysis of tufa shows it to be fairly pure, though the high silica content indicates contamination with grains of sand. The low $Al_2O_3.Fe_2O_3$ points to the exclusion of clayey material in the manner suggested by Du Toit.

The water is of a highly saline type. The comparative analyses shows an elimination of chlorides and sulphate and almost complete elimination of magnesium.

Sample 4.—Christiana Townlands, Transvaal (Dwyka series?).

The deposit was taken from the townlands north of the town. The water in the vicinity was a fairly saline type. Almost complete elimination of chlorides, sulphates and magnesium is shown.

Sample 5.—Beaufort West, C.P. (On rocks of Lower Beaufort series).

The analysis of the deposit from the Beaufort West townlands indicates a certain amount of admixture with both the sandy and clayey matter in the soil.

The ground water was a temporary hard, high sulphate water, containing a little sodium bicarbonate. (The analysis of the water was an old one, made by Juritz, of a Beaufort West water, not necessarily in the immediate vicinity of the deposit).

There has been a complete elimination of sulphate, chloride and sodium carbonate, while a considerable reduction in magnesium has taken place.

Sample 6.—Hofmeyr, C.P. (On rocks of the Upper Beaufort series).

The ground water is of a highly saline type (chloride-sulphate water).

The analysis of the tufa indicates a considerable admixture with sand. There has been a partial elimination of magnesium and total elimination of the sulphates and the chlorides of calcium, magnesium and sodium, which were very high in the ground water.

Sample 7.—Kalkheuwel 389, Pretoria District (On Bushveld sandstones, overlain by Bushveld amygdaloidal basalt).

The ground water in the immediate vicinity of the deposit is shown to be a very hard water but with an appreciable sodium bicarbonate content. The CaO : MgO ratio is 1 : 1·4. The analysis of the limestone (quoted by Wybergh) shows it to consist almost entirely of calcium carbonate, the $MgCO_3$ and Na_2CO_3 having been almost completely eliminated.

Sample 8.—From farm Tweefontein, Kaap Plateau, West of Campbell (Dolomite series).

The analysis of the deposit indicates that it is very pure indeed. As a matter of fact it is not a true tufa inasmuch as the sample was not taken from the surface of the ground, but from the bottom and sides of a very long open trough, used for conveying water from a hillside spring down a very long slope to a farm house, so there has been no admixture with sand. This deposit had been accumulating for years.

The analyses of the deposit and the spring water were included among the others in Table 1, as the formation of the deposit appears to throw light on the formation of the true surface limestones, which abound on the surface of the ground in the vicinity of the spring.

The spring water is extremely hard and 82 per cent. of the total dissolved salts consists of the bicarbonates of calcium and magnesium (or 63 parts $CaCO_3$ per 10^5). The CaO : MgO ratio is 1 : 1·1. (For the complete analysis of this water see Sample 110, Table in Section XI).

The analysis of the deposit shows an almost complete elimination of magnesium, the deposit consisting of 95 per cent. $CaCO_3$ with only 3·8 per cent. $MgCO_3$, whilst the other compounds present in the spring water have been practically eliminated.

The calcareous tufa found on the surface of the ground in the vicinity of the spring is almost identical in composition except for a small admixture with sandy material.

The flow of water down the trough is too rapid for any appreciable concentration to take place, yet there is an almost continuous deposition of $CaCO_3$.

In this spring water the concentration of the bicarbonates of calcium and magnesium is extremely high, namely, 63 parts (as $CaCO_3$ per 10^5.) The pH. of the water was 7·9, whilst the "free CO_2" was only 0·02 parts per 10^5.

Now the work of Tillmans and Heublein (41) has shown that the amount of CO_2 required to hold $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$ in solution over and above the amount of CO_2 to convert insoluble $CaCO_3$ and $MgCO_2$ in the soluble bicarbonates increases rapidly at high concentration of the two bicarbonates (any excess of CO_2 over this is termed "free CO_2" or "agressive CO_2"). It follows that in a water like that of this spring, which is heavily charged with the bicarbonates, the slightest loss of CO_2 would immediately result in a breaking down of equilibrium and deposition of the normal carbonates. $Ca(HCO_3)_2$ is even less stable than $Mg(HCO_3)_2$; moreover $CaCO_3$ is much less soluble than $MgCO_3$, so that the resulting deposit tends to consist of nearly pure $CaCO_3$.

The stability of the bicarbonates can be destroyed by evaporation, rise in temperature or mechanical agitation.

In this particular case evaporation and concentration, as shown, play a very small part, so that the heat of the sun is sufficient to disturb the equilibrium and break down the bicarbonates with the resultant deposition of $CaCO_3$, mixed with a very small amount of $MgCO_3$, the other compounds present in the spring water remaining in solution.

As already stated the calcareous tufa lying on the surface of the dolomite in the vicinity of the spring is also almost pure $CaCO_3$.

The data shown in Table A indicate that *whatever the nature of the ground water*, the rufa consists almost entirely of $CaCO_3$ with or without admixture with a little sand or clay. It would appear therefore that loss of CO_2, through rise in remperature, rather than evaporation of the ground water is the cause of the formation of the calcareous tufa deposits in the Union. Had the formation of the tufa been the result of evaporation of ground water at the surface, one would expect to find a little calcium sulphate, etc., in the tufa, while magnesium would be considerably higher than it is in these limestones.

It might be argued that the more soluble salts had been leached out over a considerable period of time. This might be true of the more soluble compounds like sodium and magnesium chlorides, sodium carbonate and sodium sulphate, but one would not expect all the calcium sulphate to be leached out and certainly not practically all the magnesium carbonate.

The formation of these surface limestones is therefore in no way different from the formation of stalactitic and stalagmitic limestones in caves in the Dolomite or to the formation of travertine spring deposits in Pondoland and elsewhere; that is, it is due to loss of CO_2.

Another close analogy is the formation of nearly pure $CaCO_3$ scale in the cooling systems of turbo-alternator plant or in the cooling water jackets of oil engines. This problem is discussed in Section XXV. It will be shown that, *whatever the nature of the raw (untreated) water used for cooling, the resultant scale always consists almost entirely of $CaCO_3$*. $MgCO_3$ is negligible in amount, whilst all other compounds are absent. This is in direct contrast to boiler scales, the composition of which depends on the raw water used and degree of concentration. In steam boilers two factors are involved, namely, thermal decomposition of the bicarbonates and excessive concentration of all dissolved solids. In cooling waters, on the other hand, though the temperature rises, it is always well below boiling point, while concentration of dissolved solids is always very small compared with that of boiler waters. Hence the chief factor involved is loss of some CO_2 due to the slight rise in temperature of the cooling water.

CONCLUSIONS.

In this section the relation between underground waters and surface limestone deposits has been discussed. It has been shown that whatever the nature of the ground water, the tufa consists mainly of calcium carbonate, with a very small amount of magnesium carbonate, there being generally some admixture with sandy material and, less commonly, with clayey material from the soil.

It is here suggested that the formation of these surface limestones is not due so much to the evaporation, concentration and consequent deposition of salts from the ground water but to loss of some CO_2 resulting in the breakdown firstly of the bicarbonate of calcium and subsequently that of magnesium. An analogy is drawn with the formation of calcium carbonate scale found in cooling water systems of steam power plant and oil engines.

V.—THE WATERS IN THE "OLD GREY GRANITE" AND GNEISSOID COMPLEX.

From the point of view of this study this formation is of very great importance, for enormous areas of the Union are occupied by the ancient granitic and gneissoid complex. Du Toit (2, p. 10[illegible]) states that fully one-tenth of the boreholes, sunk by Government since Union, penetrate the ancient granites and gneisses. In fact this formation comes a close second in area to the Beaufort series of the Karroo system.

Since, however, the regions occupied by the "Old" granite complex are mainly agricultural, there are but few towns of importance located on the formation compared with, for example, the Beaufort or the Ecca formations of the Karroo system.

DISTRIBUTION AND RAINFALL.

The principal areas are practically the whole of the Northern Transvaal, the Eastern Transvaal, Eastern and Coastal Natal and the North Western Cape Province, including Namaqualand. Inliers of the Old granite are found in the South Western Transvaal and in the North Western Rustenburg District; and there is also the very large granitic boss between Johannesburg and Pretoria, as well as the Vredefort boss on the Transvaal and Orange Free State border.

Average Rainfall—	*Per Annum.*
Zoutpansberg District	10″ to 15″
Pietersburg District	15″ to 25″
Letaba District	15″ to 30″
North-Western Transvaal	15″ to 20″
Pilgrims Rest District (Kruger Park)	15″ to 20″
Nelspruit/Barberton Districts	25″ to 35″
Swaziland	30″ to 45″
Zululand and Natal Coast	35″ to 40″
South-Western Transvaal	25″ to 30″
Rustenburg	22″
Rand/Pretoria	25″ to 30″
Namaqualand and North-Western Cape	5″ to 10″

UNDERGROUND WATER SUPPLY.

As would be expected in the case of such a hard compact plutonic rock, the quantity of water obtained by drilling varies a good deal, being dependent upon the depth of weathering and the presence or absence of crevices and joints. Du Toit (2, p. 104) draws attention to the surprising fact that these hard rocks commonly yield excellent supplies, though sometimes at great depths.

According to Frommurze (3, p. 43) in the van Rhynsdorp. Kenhardt, Namaqualand and Bushmanland districts of the N.W, Cape Province, the average yields are under 12,500 gallons *per diem* at depths of about 100 ft. and with a 45 per cent. of failures.

In the Mafeking, Vryburg and Northern Rustenburg districts, the yields vary from 16,000 to 18,000 gallons *per diem* at similar depths but with a much lower percentage of failures.

The small inliers of granite in the Western Transvaal and the Pretoria-hand boss give yields of from 18,000 to 25,000 gallons *per diem* at average depths of under 60′ and with a fairly low percentage of failures.

In the Northern Transvaal districts the yields, according to the same authority are very much less, varying from 10,000 to 20,000 gallons at depths of about 100′ and with a slightly higher per cent. of failures.

The yields in the Swaziland, Barberton and Northern Natal are very high, as would be expected from the higher annual rainfall varying from 25,000 to 42,000 gallons *per diem.*

GEOLOGY AND LITHOLOGY.

In this and the succeeding sections it is proposed to give a very brief resumé of the geology and lithology of each formation under study but only as far as it has a bearing on the chemical characteristics of the underground water.

The granitic rocks range through coarse granite porphyry, medium grained granites, aplites, granulites, quartz diorites and to well foliated gneisses in which amphibolites and other dark rocks may occur. The granite is frequently seamed with quartz felspar pegmatites, particularly in Namaqualand and in the Northern Transvaal.

The essential minerals are quartz, orthoclase felspar, microline felspar, plagioclase (albite to andesine) feldspar, with a ferromagnesium mineral, which is generally biotite (rarely muscovite mica) or sometimes hornblende. In many places plagioclase felspar and hornblende become so abundant that the rock approximates to diorite.

The "Old Granite", as a whole, is a soda rather than a potash granite as the following typical analyses show.

These particular analyses were selected on account of the fact that water samples had been collected by the author from the vicinity.

It is to be regretted that none of the published analyses of the old granite give the fluorine content.

From the point of view of this investigation the chief facts brought out by these analyses are as follows :—

(1) The consistency in chemical composition of the granite proper, in spite of mineralogical differences.

(2) The fairly high alkali content of the granitic rocks and the fact that Na_2O generally exceeds or is at least equal in amount to K_2O.

(3) The preponderance of CaO over MgO (average ratio about 1 : 0·4).

ANALYSES OF OLD GRANITES.

	1.	2.	3.	4.	5.	6.
	%	%	%	%	%	%
SiO_2	72·06	73·92	71·00	70·01	72·99	[illegible]
Al_2O_3	14·78	14·07	15·50	14·20	14·47	[illegible]
Fe_2O_3	0·52	0·52	1·50	0·42	0·15	[illegible]
FeO	1·46	0·89	1·50	3·24	1·31	[illegible]
MgO	0·72	0·38	0·70	0·55	0·34	[illegible]
CaO	1·40	1·22	1·60	2·06	1·25	[illegible]
Na_2O	5·00	3·83	3·80	3·14	3·37	[illegible]
K_2O	2·42	4·35	3·30	4·45	5·22	[illegible]
H_2O +	0·71	0·44	—	0·63	0·63	[illegible]
H_2O −	0·02	0·01	—	0·02	0·02	[illegible]
CO_2	0·43	—	Nil	0·15	0·53	[illegible]
TiO_2	0·28	0·21	0·35	0·48	0·30	[illegible]
ZrO_2	Nil	Nil	—	Nil	—	Nil
P_2O_5	0·10	0·09	0·20	0·20	0·10	[illegible]
S	0·01	0·01	—	0·02	—	[illegible]
MnO	0·04	0·04	Nil	0·06	0·02	[illegible]
BaO	0·04	0·02	—	0·10	—	[illegible]
Loss at 110° C.	—	—	0·40	—	—	
Loss on ignition	—	—	0·60	—	—	
TOTAL	99·99	100·00	100·65	99·74	99·70	[illegible]
Ratio CaO : MgO	1 : 0·5	1 : 0·3	1 : 0·44	1 : 0·26	1 : 0·27	[illegible]

(1) Old granite at Pietersburg	Analysis T. Kameda
(2) Old granite at Halfway House, Pretoria District	Analysis T. Kameda
(3) Old granite near Vaal River Bridge, Parys	Analysis H. Weall
(4) Old granite West of Hillcrest, Camperdown, Natal	Analysis R. B. [illegible]
(5) Old granite near Port Shepstone, Natal	Analysis A. Williams
(6) Old granite 2 miles South of Pietersburg	Analysis T. Kameda

QUALITY OF THE WATER.

The quality of the water is to a certain extent dependent on geographical and climatological factors and for that reason the author has tabulated the analyses of samples collected from the formation in three groups :—

(i) Southern, Eastern and Northern Transvaal, Tables 1 and 1 (*a*).
(ii) Eastern Natal and Natal Coast, Table 2.
(iii) North Western Cape, Table 3.

(i) *Southern, Eastern and Northern Transvaal.*

In Table 1 are tabulated analyses of 20 samples of Old granite waters from the Southern and Eastern Transvaal and the Northern Orange Free State, the majority of which were analysed by the author.

In Table 1 (*a*) are tabulated analyses of 22 samples of granite waters in the Northern Transvaal.

It will be observed that the granites in the Eastern and Southern Transvaal and Orange Free State give rise to comparatively pure waters, for the average concentration of salts is only about 15 parts per 10^5 For this reason the granitic waters from this region would fall into the author's " Pure Water Group E "..

For a discussion on the utilisation of the pure watergroup see the requisite chemical treatment (Section XXV). It may be stated here however, that these waters are suitable for all domestic purposes (except of course when polluted), for irrigation and for watering stock, and, after very little chemical treatment, for nearly all technological purposes.

TABLE No. 1.—OLD GRANITE IN THE SOUTHERN AND SOUTH-EASTERN TRANSVAAL AND ORANGE FREE STATE.

Sample Number	46	101	179	129	188*	55	180	466	404	378	144	143	201	549	557	405	568	583	587	595	Average
Parts $CaCO_3$ per 10^6 Water:																					
Methyl Orange Alkalinity	9·5	4·0	14·5	3·0	5·0	4·2	5·5	5·5	3·0	11·5	11·0	3·5	18·5	7·0	5·5	5·3	4·5	6·25	8·0	55·4	—
Total Hardness	7·3	3·0	10·5	3·4	5·5	4·0	4·5	5·4	2·5	8·8	10·9	3·2	13·6	3·5	5·6	4·2	4·5	1·75	5·3	55·4	—
Permanent Hardness	Nil	Nil	Nil	0·4	0·5	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	0·1	Nil	Nil	Nil	Nil	Nil	—
Temporary Hardness	7·3	3·0	10·5	3·0	5·0	4·0	4·5	5·4	2·5	8·8	10·9	3·2	13·6	3·5	5·5	4·2	4·5	1·75	5·3	55·4	—
Hardness due to Ca Salts	3·9	2·8	2·7	0·7	1·0	1·0	1·4	2·2	1·9	2·9	5·4	1·0	7·8	2·3	1·8	1·5	—	1·75	2·1	8·3	—
Hardness due to Mg Salts	3·4	0·2	7·8	2·3	4·5	3·0	3·0	3·2	0·6	5·8	5·5	2·2	5·8	1·2	3·8	2·7	—	Trace	3·2	46·9	—
Soda Alkalinity	2·2	1·0	4·0	Nil	Nil	0·2	1·0	0·1	0·5	2·7	0·1	0·3	4·9	3·5	Nil	1·1	Nil	4·5	2·7	6·8	—
Parts per 10^5 of Water:																					
Total Solids (at 105°C.)	16·0	11·2	20·8	10·5	15·0	8·9	13·6	13·2	10·0	19·0	18·4	7·1	24·0	12·3	12·0	26·0	12·1	8·63	13·3	(84·4)	14·3
Silica (as SiO_2)	—	3·2	4·3	3·0	3·2	2·0	4·6	3·4	1·0	3·4	2·1	1·0	4·3	—	3·0	3·7	—	—	1·4	—	—
Fluorides (as F)	—	Nil	Trace	Nil	Nil	—	Trace	0·04	Trace	Nil	Nil	Nil	—	—	Nil	0·9	—	—	Nil	0·025	—
Nitrites	—	Nil	Nil	Nil	Present	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	0·002	—
Nitrates (as NO_3)	—	0·1	0·4	0·8	1·4	0·01	0·4	1·6	Nil	0·8	Nil	0·05	0·1	0·07	Nil	0·6	0·1	Nil	Trace	0·07	—
Chlorides (as Cl)	1·76	1·1	1·4	1·3	3·0	1·6	0·7	0·4	0·5	1·3	1·4	0·6	0·4	Nil	1·06	6·0	0·80	0·99	1·06	9·23	—
Sulphates (as SO_4)	Trace	Trace	Trace	Trace	Trace	1·5	Trace	Trace	0·1	Trace	1·5	1·2	—	Nil	0·12	2·25	0·36	0·36	0·05	0·8	—
Potassium Salts (as K)	—	Under 0·5	Under 0·5	Under 0·5	—	Trace	Under 0·5	—	Trace	Under 0·5	Under 0·5	Under 0·5	—	—	Trace	—	—	—	Trace	—	—
pH. Values	8·0	7·7	7·2	7·0	7·1	7·4	7·0	6·9	7·7	6·9	7·8	7·1	—	7·5	6·45	8·1	—	—	7·4	7·5	7·4
Percentage on Total Solids:																					
SiO_2	—	28·5	20·6	28·5	21·5	22·0	33·5	26·0	10·0	18·0	10·4	14·0	18·0	—	25·0	14·2	—	—	10·6	—	20·5
CaO	13·8	13·9	7·2	3·7	3·7	6·2	5·7	9·1	3·4	8·5	16·2	7·8	18·4	10·5	8·3	3·25	—	11·4	8·0	5·5	8·6
MgO	8·4	(0·7)	15·0	10·6	12·6	13·2	8·8	9·8	7·6	12·1	12·0	12·4	9·8	4·1	12·5	4·20	—	Trace	9·6	(21·2)	9·6
Cl	11·0	9·9	6·7	12·4	(20·0)	17·8	5·2	3·0	5·0	6·9	7·6	8·4	1·7	(Nil)	8·8	(23·0)	6·7	11·5	8·0	10·6	8·3
SO_4	Trace	Trace	Trace	Trace	Trace	(16·6)	Trace	Trace	1·0	Trace	8·7	(16·8)	—	Nil	1·0	8·6	3·0	4·1	0·3	0·94	1·6
Soda Alkalinity (as Na_2CO_3)	14·0	9·9	19·2	Nil	Nil	2·2	8·0	0·75	5·0	15·2	0·54	4·2	20·2	27·2	Nil	4·6	Nil	(52·2)	12·0	8·4	8·5
Total Hardness (as $CaCO_3$)	46·0	27·6	50·0	32·5	37·0	44·0	33·0	41·0	25·0	46·2	59·0	44·0	57·0	26·5	46·6	16·2	37·2	20·3	40·0	65·0	38·8
Perm. Hardness (as $CaCO_3$)	Nil	Nil	Nil	3·8	3·3	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	0·6	Nil	Nil	Nil	Nil	Nil	—
Temp. Hardness (as $CaCO_2$)	46·0	27·6	50·0	28·5	33·5	44·0	33·0	41·0	25·0	46·2	59·0	44·0	57·0	26·5	46·6	16·2	37·2	20·3	40·0	65·0	36·5
Ratio CaO : MgO	1 : 0·6	(1 : 0·06)	1 : 2·0	1 : 3·0	1 : 3·0	1 : 2·0	1 : 1·5	1 : 0·9	1 : 2·0	1 : 1·4	1 : 0·7	1 : 1·6	1 : 0·5	1 : 0·4	1 : 1·5	1 : 1·3	—	—	1 : 1·2	—	1 : 1·1

* Polluted.

DESCRIPTION OF SAMPLES IN TABLE No. 1.

Sample No.	District and Province.	Borehole Depth. Feet.	Locality, Description and Remarks.	Date.
46	Boksburg, Transvaal	—	Borehole in Birchleigh, Main Line Pretoria/Johannesburg	14/ 4/38
101	Pretoria, Transvaal	150	Borehole 8 miles South of Irene on Pretoria/Johannesburg Main Road	25/10/39
179	Pretoria, Transvaal	100	Borehole on Zevenfontein 40, 20 miles South-West of Pretoria	7/ 6/40
129	Johannesburg, Transvaal	—	Borehole on farm Zandfontein 1. 10 miles North of Johannesburg	10/12/39
188	Johannesburg, Transvaal	100	Borehole Lombardy East, Johannesburg	8/ 7/40
55	Johannesburg, Transvaal	116	Borehole in Illovo, Johannesburg North	19/ 9/39
466	Johannesburg, Transvaal	50	Borehole in Craighall, Johannesburg North	29/11/41
549	Johannesburg, Transvaal	—	Borehole, Stand 448, Linden Extension, Johannesburg North (Anal. Cydna Lab.)	—
180	Krugersdorp, Transvaal	—	Borehole at Nooitgedacht 99, 11 miles North East of Krugersdorp	6/ 6/40
404	Nelspruit, Eastern Transvaal	—	Spring on road from Kaapsche Hoop, 6 miles South-West of Nelspruit	July, 1941
378	Ventersdorp, Transvaal	—	Shallow well at Klipplaatdrift 6	June 1941
144	Piet Retief, Southern Transvaal	—	Borehole in Piet Retief	6/ 2/40
143	Barberton, Eastern Transvaal	—	Spring at Barberton	22/12/39
201	Mafeking, Western Transvaal	80	Borehole, 50 miles South-South-West of Mafeking. (Anal. Govt. Lab.)	1907
587	Potchefstroom, Transvaal	—	Borehole on farm Kopieskraal 89, 4 miles West of Parys	20/10/42
557	Nelspruit, Eastern Transvaal	100	Borehole on farm Blinkpoort 166, 3 miles North of White River	14/ 8/42
405	Nelspruit, Eastern Transvaal	—	Spring at Sabie Bungalows, North-East of White River	8/ 7/41
568	Nelspruit, Eastern Transvaal	180	Borehole, portion of farm Manchester, Karino. (Anal. Govt. Lab., Johannesburg)	20/10/37
595	Barberton, Eastern Transvaal	—	Borehole Park Gate Estates, Malelane. (Anal. McLachlan & Lazar)	1942
583	Swaziland	—	Spring Enzulweni near Mbabane. (Anal. James Gray)	1932

The only towns or villages of any importance in these regions are Barberton, Nelspruit, Mbabane, White River and Parys.

In percentage composition these waters do not differ greatly from the strongly alkaline granitic waters of the Northern Transvaal, though the percentage of soda is generally lower. The chief difference is mainly one of concentration, due to difference in rainfall.

The waters of the Old granite in this region generally contain an appreciable amount of sodium bicarbonate. It is therefore not surprising to find that the SiO_2 content of the waters expressed as a percentage of the total salts, is very high, with an average of 20·5 per cent. SiO_2.

Palmer (66) states that " Waters issuing from areas of crystalline felspathic rocks (i.e. granites) are characterised by high primary alkalinity, low concentration and a notable proportion of silica ", while Clarke, in his " Data of Geochemistry " (43, pp. 195–197) states that water issuing from felspathic rocks are likely to contain silica as the chief inorganic constituent though the absolute amount is likely to be small.

These facts are, of course, in accordance with what is known to take place during the weathering of felspathic rocks by carbonated rain waters. In a simplified form the reaction can be represented thus :—

$$\underset{\text{(Orthoclase felspar)}}{K_2O.Al_2O_3.6SiO_2} + 2H_2O + CO_2 =$$

$$K_2CO_3 + 4SiO_2 + \underset{\text{(Kaolin)}}{Al_2O_3.2SiO_2.2H_2O}.$$

From the albite type of plagioclase felspar ($Na_2O.Al_2O_3.6SiO_2$), Na_2CO_3 or $NaHCO_3$ is formed, while from the anorthite type of plagioclase felspar ($CaO.Al_2O_3.2SiO_2$), $Ca(HCO_3)_2$ is formed. From the ferro-magnesium minerals (mica, hornblende, etc.), $Mg(HCO_3)_2$ is formed in addition, but it must be remembered that the ferromagnesium content of the Old granite is small, as indicated by the low MgO content of the rocks.

The chief products removed in solution from the Old granite would therefore be Na_2CO_3 and K_2CO_3 (or $NaHCO_3$ and $KHCO_3$), SiO_2 or $NaSiO_3$ $Ca(HCO_3)_2$ with a much smaller amount of $Mg(HCO_3)_2$. As there is an excess of alkali, silica is no doubt present as Na_2SiO_3, but this point is discussed (Page 168).

In view of the preponderance of CaO over MgO shown in typical analyses of the Old granite, it is very surprising to note that the ratio of CaO to MgO for the granitic waters in this region averages 1 : 1·1. Possibly this is due to the fact that the ferromagnesium minerals, though in less proportion are more prone to decomposition than the calcium bearing silicates. It will be shown subsequently that, the waters in the Bushveld granite formation, like the Bushveld granite rock itself, show a great preponderance of CaO over MgO, and the same applies to the Old granite waters in the North-Western Cape.

Chlorides are never present in any quantity. The average, expressed as a percentage of Cl. on total salts, is only 8·2 per cent.

Sulphates are rarely present in any quantity. (Average 1·7 per cent. SO_4 in terms of total salts.)

Soda alkalinity is generally present in fair amount. Expressed as a percentage the soda content is 8·5 per cent. expressed as Na_2CO_3) which is not nearly as high as the alkaline soda waters in the Northern Transvaal.

The pH. varies somewhat but is generally fairly low, as appears to be the case with most granitic waters. The soda alkalinity is therefore nearly always due to sodium bicabonate and not the carbonate.

The total hardness is only moderately high. Expressed in terms of total salts the scale-forming salts average about 38 per cent. (as $CaCO_3$). Permanent hardness salts are rarely present since there is generally an appreciable soda alkalinity, so that the hardness is nearly always due to the bicarbonates of calcium and magnesium.

Fluorides are seldom present and then only in traces. The chief exception is the spring water at Sabie Bungalows, Eastern Transvaal which shows the extremely high fluoride content of 9·0 parts per million. (The author's figure was checked by the Division of Chemical Services.)

Turning now to the waters in the Northern, North-Western and North-Eastern Transvaal, the analyses of which are shown in Table I (A), we find two distinct types of waters in the Old Granite Complex.

There is the highly saline type found in Northern Zoutpansberg (in the Beit Bridge, Messina, Mopani districts) and also in the Satara area of the Kruger National Park.

Then there are the soda-rich alkaline waters found in the rest of the Northern Transvaal (particularly in the Pietersburg district) and extending into Southern Rhodesia. Incidentally it may be mentioned that the majority of the granitic waters in the latter country appear to be of the alkaline soda carbonate type (Wallis 58, Buchan 59, Maufe 60).

We will take the latter type first. In Table I (A) are tabulated the analyses of 14 waters of this type from the Pietersburg, Louis Trichardt, Pilgrims Rest and Letaba districts. The only centres of any importance are Louis Trichardt, Pietersburg and Tzaneen. As aforementioned they differ very little, except in concentration and percentage of soda alkalinity, from the granitic waters of the Southern and South-Eastern Transvaal. The average concentration of salts is high, about 7·2 parts per 10^5.

Soda alkalinity is frequently high in absolute amount, while expressed as a percentage the average is 15 per cent. (as Na^2CO^3).

Silica is also consistently high, with an average of 12·4 per cent.

Chlorides average 12·8 per cent. Cl, which is higher than in the previous group.

Fluorides are more commonly present but not in appreciable amount. One sample (No. 412) however, shows as much as 4·8 parts F. per million.

Sulphates are low, the average being only 1·5 per cent. SO_4.

The technological utilisation of these waters will be discussed under the Alkaline Soda Carbonate Group. (Section XXV).

It may be stated here that these waters can be used for all domestic purposes, and for watering stock, while the absolute amount of Na_2CO_3 is generally not high enough to prevent these waters from being used for irrigation purposes.

TABLE 1 (*A*).—OLD GRANITE WATERS IN THE NORTHERN TRANSVAAL.

	Soda Carbonate Waters.															Highly Saline Chloride Sulphate Wat					
Sample Numbers	558	559	428	410	68	332	408	411	412	560	392	222	406	590	Average.	322	512	561	574	575	582
Parts $CaCO_3$ per 10^5 Water:																					
Methyl Orange Alkalinity	51·0	32·5	40·0	11·0	47·5	38·5	58·2	29·0	13·5	51·1	117·5	7·0	47·7	* 18·5	—	73·5	18·5	81·0	96·0	67·0	72·0
Total Hardness	40·0	34·4	34·0	7·9	28·1	36·0	31·7	25·5	11·7	26·2	74·0	6·0	54·1	15·3	—	137·0	51·3	132·0	138·0	63·2	141·0
Permanent Hardness	Nil	1·90	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	6·4	Nil	—	64·5	32·8	51·0	42·0	Nil	69·0
Temporary Hardness	40·0	32·5	34·0	7·9	28·1	36·0	31·7	25·5	11·7	26·2	74·0	6·0	47·7	15·3	—	73·5	18·5	81·0	96·0	63·2	72·0
Hardness due to Ca Salts	15·7	12·6	14·2	2·1	9·2	10·5	24·1	5·9	3·5	9·6	33·0	2·7	18·2	8·6	—	30·0	17·1	—	—	27·2	26·0
Hardness due to Mg Salts	24·3	21·8	19·8	5·8	18·9	25·5	7·6	19·6	8·2	16·6	41·0	3·3	35·9	6·7	—	107·0	34·2	—	—	36·0	115·0
Soda Alkalinity	11·0	Nil	6·0	3·1	19·4	2·5	26·5	3·5	1·8	25·5	43·5	1·0	Nil	3·2	—	Nil	Nil	Nil	Nil	3·8	Nil
Parts per 10^6 of Water:																					
Total Solids (at 105°C.)	76·2	46·8	63·4	22·1	63·0	78·0	97·6	44·0	29·2	72·0	210·0	(14·0)	74·0	24·3	70·2	280·0	72·0	666·0	366·0	119·8	263·0
Silica (as SiO_2)	—	—	—	4·0	7·4	10·0	7·6	6·0	4·4	7·2	1·2	2·0	7·4	2·8	—	—	8·0	—	—	—	7·2
Fluorides (as F)	0·06	0·06	0·04	Nil	—	Nil	Trace	0·02	0·26	—	0·14	Nil	0·07	Nil	—	—	—	—	—	—	—
Nitrites	—	—	Nil	Nil	Nil	Nil	Nil	Nil	Nil	—	—	Nil	Nil	Nil	—	0·09	Nil	Nil	Nil	Nil	Nil
Nitrates (as NO_3)	3·1	5·0	Nil	1·2	0·02	Trace	Nil	0·6	3·6	Trace	1·3	0·7	0·08	Trace	—	0·10	6·4	Nil	Trace	0·05	0·10
Chlorides (as Cl)	12·4	3·9	12·0	2·7	4·6	10·6	19·3	4·1	3·2	5·3	47·6	1·1	15·3	1·06	—	87·0	17·0	262·0	148·0	29·6	90·0
Sulphates (as SO_4)	2·2	0·48	4·0	0·2	Trace	0·05	2·0	1·0	0·07	1·2	7·5	Trace	0·3	0·04	—	24·0	4·1	84·4	9·9	2·5	24·0
Potassium Salts (as K)	0·53	0·05	0·5	Under 0·5	Under 0·5	Under 0·5	—	Under 0·5	Under 0·5	—	2·6	—	Under 0·5	—	—	—	Small Amount	—	—	—	—
pH. Value	7·0	7·15	7·9	7·0	8·3	8·5	7·7	8·2	7·4	—	—	7·2	7·5	7·15	7·6	—	7·6	—	—	—	(9·0?)
Percentage on Total Solids:																					
SiO_2	—	—	—	18·0	11·7	12·8	7·8	13·6	15·0	9·9	(0·6)	13·2	10·0	11·5	12·4	—	11·0	—	—	—	2·7
CaO	11·7	14·9	12·6	5·0	8·1	7·2	4·4	7·5	6·6	7·5	8·8	10·7	13·8	20·0	9·9	6·0	13·2	—	—	12·7	5·5
MgO	12·8	18·2	12·4	10·4	11·8	13·2	9·8	17·7	11·1	9·2	7·8	9·4	18·2	10·2	11·9	15·2	19·0	—	—	12·0	17·4
Cl	16·3	8·4	18·8	12·2	7·3	13·6	19·8	9·3	10·9	7·4	22·7	7·9	20·6	4·3	12·8	31·0	23·5	38·8	40·0	25·0	34·0
SO_4	2·9	1·02	6·3	0·9	Trace	0·06	2·1	2·3	0·24	1·60	3·6	Trace	0·4	0·2	1·5	8·6	5·7	12·5	2·7	2·06	9·1
Soda Alkalinity (as Na_2CO_3)	15·5	(Nil)	10·0	14·5	39·5	3·3	28·6	8·2	6·5	37·5	22·5	7·8	(Nil)	14·6	14·9	Nil	Nil	Nil	Nil	(3·2)	Nil
Total Hardness (as $CaCO_3$)	53·0	(73·0)	53·5	35·5	44·5	46·0	32·5	58·0	40·0	36·3	35·5	43·0	(73·0)	63·0	45·4	49·0	70·0	19·4	38·0	52·0	53·5
Permanent Hardness (as $CaCO_3$)	Nil	(4·0)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	(8·7)	Nil	Nil	23·0	45·0	7·6	11·5	(Nil)	26·0
Temporary Hardness (as $CaCO_3$)	53·0	(69·0)	53·5	35·5	44·5	46·0	32·5	58·0	40·0	36·3	35·5	43·0	65·0	63·0	46·4	26·2	25·0	11·8	26·5	52·0	27·5
Ratio CaO : MgO	1 : 1·1	1 : 1·2	1 : 1·0	1 : 2·6	1 : 1·1	1 : 1·8	1 : 2·2	1 : 2·4	1 : 1·7	1 : 1·3	1 : 0·9	1 : 1·0	1 : 1·3	1 : 0·5	1 : 1·2	1 : 2·5	1 : 1·5	—	—	1 : 0·9	1 : 3·2

* Deposits iron oxide on standing.

† Hardness re-calculated.

[redacted]

TABLE 1 (A).—OLD GRANITE WATERS IN THE NORTHERN TRANSVAAL.

	Soda Carbonate Waters.															Highly Saline Chloride Sulphate Waters.								
	558	559	428	410	68	332	408	411	412	560	392	222	406	590	Average.	322	512	561	574	575	582	588	604	Average
per 10^5 Water :																								
aity.	51·0	32·5	40·0	11·0	47·5	38·5	58·2	29·0	13·5	51·1	117·5	7·0	47·7	* 18·5	—	73·5	18·5	81·0	96·0	67·0	72·0	1·4	† 43·5	—
	40·0	34·4	34·0	7·9	28·1	36·0	31·7	25·5	11·7	26·2	74·0	6·0	54·1	15·3	—	137·0	51·3	132·0	138·0	63·2	141·0	8·1	54·5	—
	Nil	1·90	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	6·4	Nil	—	64·5	32·8	51·0	42·0	Nil	69·0	6·7	11·0	—
	40·0	32·5	34·0	7·9	28·1	36·0	31·7	25·5	11·7	26·2	74·0	6·0	47·7	15·3	—	73·5	18·5	81·0	96·0	63·2	72·0	1·4	43·5	—
Salts.	15·7	12·6	14·2	2·1	9·2	10·5	24·1	5·9	3·5	9·6	33·0	2·7	18·2	8·6	—	30·0	17·1	—	—	27·2	26·0	7·5	33·5	—
Salts.	24·3	21·8	19·8	5·8	18·0	25·5	7·6	19·6	8·2	16·6	41·0	3·3	35·9	6·7	—	107·0	34·2	—	—	36·0	115·0	0·6	21·0	—
	11·0	Nil	6·0	3·1	10·4	2·5	26·5	3·5	1·8	25·5	43·5	1·0	Nil	3·2	—	Nil	Nil	Nil	Nil	3·8	Nil	Nil	Nil	—
o^5 of Water :																								
.)	76·2	46·8	63·4	22·1	63·0	78·0	97·6	44·0	29·2	72·0	210·0	(14·0)	74·0	24·3	70·2	280·0	72·0	666·0	366·0	119·8	263·0	96·6	98·0	245·0
	—	—	—	4·0	7·4	10·0	7·6	6·0	4·4	7·2	1·2	2·0	7·4	2·8	—	—	8·0	—	—	—	7·2	8·5	—	—
	0·06	0·06	0·04	Nil	—	Nil	Trace	0·02	0·26	—	0·14	Nil	0·07	Nil	—	—	—	—	—	—	—	—	0·05	—
	—	—	Nil	Nil	Nil	Nil	Nil	Nil	Nil	—	—	Nil	Nil	Nil	—	0·09	Nil	Nil	Nil	Nil	Nil	Nil	Nil	—
	3·1	5·0	Nil	1·2	0·02	Trace	Nil	0·6	3·6	Trace	1·3	0·7	0·08	Trace	—	0·10	6·4	Nil	Trace	0·05	0·10	Trace	Nil	—
	12·4	3·9	12·0	2·7	4·6	10·6	19·3	4·1	3·2	5·3	47·6	1·1	15·3	1·06	—	87·0	17·0	262·0	148·0	29·6	90·0	44·5	29·1	—
	2·2	0·48	4·0	0·2	Trace	0·05	2·0	1·0	0·07	1·2	7·5	Trace	0·3	0·04	—	24·0	4·1	84·4	9·9	2·5	24·0	6·4	2·4	—
)	0·53	0·05	0·5	Under 0·5	Under 0·5	Under 0·5	—	Under 0·5	Under 0·5	—	2·6	—	Under 0·5	—	—	—	Small Amount	—	—	—	—	1·2	0·33	—
	7·0	7·15	7·9	7·0	8·3	8·5	7·7	8·2	7·4	—	—	7·2	7·5	7·15	7·6	—	7·6	—	—	—	(9·0?)	7·9	7·6	—
n Total Solids :																								
	—	—	—	18·0	11·7	12·8	7·8	13·6	15·0	9·9	(0·6)	13·2	10·0	11·5	12·4	—	11·0	—	—	—	2·7	3·8	—	—
	11·7	14·9	12·6	5·0	8·1	7·2	4·4	7·5	6·6	7·5	8·8	10·7	13·8	20·0	9·9	6·0	13·2	—	—	12·7	5·5	4·3	19·0	10·1
	12·8	18·2	12·4	10·4	11·8	13·2	9·8	17·7	11·1	9·2	7·8	9·4	18·2	10·2	11·9	15·2	19·0	—	—	12·0	17·4	(0·25)	8·5	14·4
	16·3	8·4	18·8	12·2	7·3	13·6	19·8	9·3	10·9	7·4	22·7	7·9	20·6	4·3	12·8	31·0	23·5	38·8	40·0	25·0	34·0	46·0	29·5	33·5
	2·9	1·02	6·3	0·9	Trace	0·06	2·1	2·3	0·24	1·60	3·6	Trace	0·4	0·2	1·5	8·6	5·7	12·5	2·7	2·06	9·1	6·6	2·5	6·2
a$_2$CO$_3$).	15·5	(Nil)	10·0	14·5	39·5	3·3	28·6	8·2	6·5	37·5	22·5	7·8	(Nil)	14·6	14·9	Nil	Nil	Nil	Nil	(3·2)	Nil	Nil	Nil	Nil
aCO$_3$).	53·0	(73·0)	53·5	35·5	44·5	46·0	32·5	58·0	40·0	36·3	35·5	43·0	(73·0)	63·0	45·4	49·0	70·0	19·4	38·0	52·0	53·5	8·4	55·5	43·2
(as CaCO$_3$).	Nil	(4·0)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	(8·7)	Nil	Nil	23·0	45·0	7·6	11·5	(Nil)	26·0	7·0	11·2	18·8
(as CaCO$_3$).	53·0	(69·0)	53·5	35·5	44·5	46·0	32·5	58·0	40·0	36·3	35·5	43·0	65·0	63·0	46·4	26·2	25·0	11·8	26·5	52·0	27·5	1·4	4·43	26·8
	1 : 1·1	1 : 1·2	1 : 1·0	1 : 2·6	1 : 1·1	1 : 1·8	1 : 2·2	1 : 2·4	1 : 1·7	1 : 1·3	1 : 0·9	1 : 1·0	1 : 1·3	1 : 0·5	1 : 1·2	1 : 2·5	1 : 1·5	—	—	1 : 0·9	1 : 3·2	(1 : 0·0)	1 : 0·4	1 : 1·4

* Deposits iron oxide on standing.

† Hardness re-calculated.

DESCRIPTION OF SAMPLES IN TABLE 1 (A).

Sample No.	District and Province.	Borehole Depth. Feet.	Locality, Description and Remarks.	Date.
558	Zoutpansberg, Northern Transvaal	—	Borehole on Lubeslust 685. (Anal. Div. C.S. per Dr. Ockerse).	August 1942
559	Zoutpansberg, Northern Transvaal	—	Borehole on Kortgedacht 96. (Anal. Div. C.S. per Dr. Ockerse)	August 1942
428	Pietersburg, Northern Transvaal	—	Borehole in Dendron, 30 miles North of Pietersburg. (Anal. Div. C.S. per Dr. Ockerse)	1941
410	Pietersburg, Northern Transvaal	90	Borehole on Townlands, 1 mile South of Pietersburg	July, 1941
68	Pietersburg, Northern Transvaal	60	Municipal Well in Pietersburg	14/ 1/39
532	Pietersburg, Northern Transvaal	—	Borehole 6 miles South of Bandolier Kop on Main Road to Pietersburg	18/ 3/41
408	Letaba, North-Eastern Transvaal	—	Borehole in Malopena Camp, Kruger National Park	July, 1941
411	Pietersburg, Northern Transvaal	120	Borehole in Marabastad	July, 1941
412	Pietersburg, Northern Transvaal	100	Borehole of farm Rietkolk 68, North of Chunies Poort	July, 1941
560	Pietersburg, Northern Transvaal	60	Municipal Well in Pietersburg. (Anal. Govt. Lab., Johannesburg)	23/ 8/37
592	Zoutpansberg, Northern Transvaal	180	Borehole at Alldays, 80 miles North-West of Louis Trichardt. (Anal. Div. C.S. per Dr. Ockerse)	1940
222	Pietersburg, Northern Transvaal	108	Borehole on Pusela 9, Tzaneen	30/ 9/40
406	Pilgrims Rest, Northern Transvaal	—	Borehole on Satara Camp, Kruger National Park	July, 1941
590	Zoutpansberg, Northern Transvaal	—	Borehole in Louis Trichardt *	11/11/42
522	Zoutpansberg, Northern Transvaal	—	Borehole in Mopani School. (Anal. Govt. Lab., Johannesburg)	13/12/40
512	Zoutpansberg, Northern Transvaal	—	Well in Messina	27/ 2/42
561	Zoutpansberg, Northern Transvaal	200	Borehole, Beit Bridge. (Anal. Govt. Lab., Johannesburg)	18/11/36
574	Pilgrims Rest, North-Eastern Transvaal	301	Borehole in Kruger National Park, 5 miles West of Sabie River, 15 miles West of Portuguese East African Border. (Anal. Gov. Lab., Johannesburg)	7/ 7/43
575	Pilgrims Rest, North-Eastern Transvaal	160	Borehole on Capri 381, Kruger National Park, South of Satara Camp. (Anal. Govt. Lab., Johannesburg)	20/12/37
582	Zoutpansberg, Northern Transvaal	—	Borehole Mopani Koshuisgronde. (Anal. Govt. Lab., Johannesburg)	22/11/42
588	Letaba, Northern Transvaal	—	Thermal Spring on Eiland 134. (Anal. C. F. van der Walt)	March, 1941
604	Potgietersrust, Northern Transvaal	—	Borehole on Gilead 664. (Anal. Div. C.S. per Dr. Ockerse)	1942

* Not the town supply which arises in the Waterberg formation.

The Old granite in the Zoutpansberg area of the Northern Transvaal, gives rise, as the name would suggest, to a highly mineralised and somewhat saline type of water. Small areas in the central portion of the Kruger National Park (South of Satara), and in the Eastern Letaba district, also yield similar water. The author was unable to obtain many samples from these areas, therefore a few analyses by other analysts are included in Table 1 (*a*), but unfortunately these analyses are not all complete.

The total salines in these waters are extremely high, averaging about 248 parts per 10^5. Of these salts chlorides average 33·5 per cent. (as Cl.). Sulphates are fairly high compared with the other granitic waters in the Transvaal (6·2 per cent. SO_4 in terms of total salts).

There is insufficient data concerning pH. values, fluorides and silica, though the latter appears to be low compared with other granitic waters.

Total scale-forming salts are moderately high, giving an average of 44 per cent. (as $CaCO_3$).

There is nearly always much more magnesium than calcium. These waters differ from the other granitic waters in the Transvaal in showing no soda alkalinity. Instead permanent hardness salts are present averaging 19 per cent. (as $CaCO_3$) in terms of total salts.

This permanent hardness is due mainly to magnesium chloride, so that these waters are potentially corrosive as well as scale forming.

Some of these highly saline waters arise in the schists and gneissic belts associated with the Old granite, and their highly minerlised nature can (with the exception of chlorides) be readily explained, for the rocks are rich in calcium and magnesium particularly the latter element.

The high chloride content of these waters is not readily explained. It may be partly climatological for the rainfall in the Zoutpansberg is only about 10″–15″ pr annum. However, in the Letaba district, where saline waters also occur, it varies from 15″–20″.

In a subsequent section it will be shown that some of the Red granite waters have a relatively high chloride content (though the absolute amounts are not high) and it is suggested that these waters, i.e. Warmbaths, are probably magmatic waters.

There is the possibility in the case of the saline Old granite waters of the North-Eastern Transvaal, that the very high Cl (and SO_4) may be derived from cyclic salts borne inland by the prevailing S.E. winds from the Indian Ocean which is only about 180 miles distant.

Kent (61, p. 40) uses this argument to account for the high salinity of the Letaba thermal springs. The low silica and relatively high SO_4, also suggest a cyclic origin. (Compare these analyses with sea water salts similarly expressed as a percentage, as shown in Table 27, Page 157).

It may be mentioned here that the Letaba thermal springs do not differ appreciably from the usual run of saline granitic waters in this area. It is significant that these saline waters in the Old granite are restricted to the North-Eastern portion of the Transvaal not far from the Coast, which is also a region of low rainfall, while elsewhere in the Northern Transvaal the granitic waters approximately to the soda carbonate group of waters.

Highly mineralised as are these waters, they are hardly comparable with the Old granite waters of the North-West Cape Province. As will be shown later, the concentration of salts in these latter waters average over 600 parts per 10^5, while waters with concentrations of over 1,000 parts are occasionally found.

The sulphate content of the latter water is also nearly thrice as great as in the Old granite waters of the North-Eastern Transvaal.

Though the chloride content of the saline granitic waters of the Northern Transvaal is lower than that of the typical chloride-sulphate waters of marine origin like those arising in the Cretaceous and Bokkeveld formation to be described hereafter, nevertheless they approximate to that type and the utilisation of these saline granitic waters will be discussed under Group A (Section XXV).

It may be stated here that these waters are generally far too saline for domestic use, sometimes for watering stock and in a few cases even for irrigation purposes unless the soil is particularly well drained.

(ii) *Natal and Natal Coast.*

In Table 2 are shown analyses of 13 samples of granitic waters collected and analysed by the author. In Natal the Old granite is exposed either along the coastal belt or at no great distance from it. The only villages of importance are Empangeni, Margate, Umzinto and Paulpietersburg.

Though the total salts in these granitic waters average only [illegible] parts per 10^5, chlorides form a large part of them (31 per cent expressed as Cl). This relatively high Cl content is due to the fact that salt laden mists are carried a short distance inland by the prevailing winds, and the salts (more particularly magnesium chloride) are deposited in the soil.

Silica is only moderately high, averaging 10 per cent. SiO_2

Fluorides, if present at all, are only in traces. (The highest figures obtained were 0·4 parts F. per million, which is well below the limit of safety).

The CaO : MgO ratio is 1 : 1·25 which is not unexpected in view of the proximity to the coast.

Sulphates are fairly low, averaging 3·2 per cent. SO_4 in terms of total salts. Scale-forming salts are comparatively low (29·0 per cent. as $CaCO_3$). Soda alkalinity is very rare instead, permanent hardness is generally present (12·7 per cent. $CaCO_3$). Consequently these waters are more corrosive than scaleforming.

Though the iron content is very low (well under 0·5 parts Fe per 10^5 some of these granitic waters but more especially those with a low pH., show a tendency to deposit iron oxide on standing.

These waters have been classified by the author as belonging to a slightly Saline Group B, and their utilisation is dealt with under that group (Section XXV).

It may be stated here that these waters can be used for all domestic purposes, for watering stock and for irrigation.

(iii) *North-West Cape.*

The author could not obtain samples from this remote arid and sparesely populated region, but through the courtesy of Dr. Ockerse, of the Public Health Department, and Dr. Steyn of Onderstepoort Laboratory, has been able to furnish, in Table 3, the results of 13 analyses of these waters which are unfortunately not complete. The data in Table 3 shows that these granitic waters from the Kenhardt, Namaqualand and Upington districts of the North-Western Cape Province are the most mineralised in the Union with an average total solids content of 690 parts per 10^5. Occasionally the total salts exceed 1,000 parts per 10^5.

The total scale forming salts average 33·6 per cent. (as $CaCO_3$) but $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$ only average 7·8 per cent., the rest of the hardness (26 per cent.) being due to the sulphates and chlorides of calcium and magnesium.

The high sulphate content of 19 per cent. SO_4 is at first puzzling for the granite itself contains no appreciable quantity of sulphide minerals. Even had the high salinity of these waters been due to a recent marine transgression in these regions, or to salt-laden mists from the sea, i.e. cyclic salts, that would not explain the very high SO_4 content. (Compare the percentage composition of these waters with sea water (7 per cent. SO_4) as shown in Table 27, Page 157).

The author therefore puts forward the following explanation :—

(*a*) The Dwyka Tillite, which as will be shown hereafter, gives rise to high chloride and high sulphate waters (15 per cent. SO_4), has only recently been stripped from these areas and there are still a large number of thin veneers of that formation covering the Old granite in this region.

(*b*) The higher ground consists of Dwyka tillite and consequently there is a certain amount of drainage from these rocks into the granite.

(*c*) Though winds might carry sea spray (i.e. cyclic salts) for some distance inland, it is highly improbable for geographical reasons that this would affect districts so far inland as Kenhardt and Upington. In any case such would not account for the exceedingly high proportion of SO_4 in those waters. (Compare with saline granitic waters in the North-Eastern Transvaal).

The author suggests therefore that for the above mentioned reasons the Dwyka tillite appreciably modifies the chemical characteristics of the granitic waters of these regions. (Compare with the percentage composition of Dwyka waters as shown in Table 18, Page 115).

The high concentration of salts in these granitic waters of the N-Western Cape is mainly due, as in the case of the Northern Transvaal granitic waters, to the strong aridity of the climate.

These waters have been allocated to the author's Highly mineralised Chloride-sulphate Group A. of waters, the technological utilisation of which is discussed under that group (Section XXV). It may be mentioned here that the majority, on account of the enormous concentration of salts are totally unfit for domestic use.

The presence of appreciable fluorides makes them even more unsuitable. In fact, according to the investigations of Steyn and Reinach (79) at Onderstepoort Laboratory, these waters are actually poisonous to stock and human beings, on account of their salinity. Except in the case of very well drained soils these waters are also far far too saline for irrigation.

Turning to the general characteristics of granitic waters, the significance of the fluoride content of all these granitic waters is discussed (Page 169).

Another interesting feature of all these granitic waters (including as will be shown later, the Red granite waters) is the very low potassium content. From the analyses of Old granite rocks, it will be seen that though there is generally slightly more Na_2O than K_2O, nevertheless the K_2O content is appreciable. Potassium, even in the highly mineralised Old granite waters of the N-W. Cape, is generally under 2 parts K per 10^5. Expressed as a percentage of total solids the potassium on an average works out an only 0·2 per cent. K. The reason for this low potassium content of all underground waters in the Union is discussed in Section XXIV, (Page 171).

Saline as are the granitic waters of the North-Western Cape and the Zoutpansberg districts of the Northern Transvaal, they are hardly comparable with the waters of the Granitic Complex of Western Australia, where the average concentration is about 800–1,000 parts salt per 10^5, while figures of 1,200 parts are quite common. (Simpson 57).

It is indeed fortunate that the majority of granitic waters in the Union of South Africa contain only moderate amounts of dissolved salts.

VI.—THE WATERS ARISING IN THE CAPE GRANITES.

The Cape granite is of but little interest to this study, since its occurrances are very limited, being restricted to the South-West and West of the Cape Province. Further, most of the areas where in the Cape granite outcrops, obtain water supplied from perennial springs issuing from the Table Mountain series. Consequently the author has not studied this formation in detail.

The Cape granite is much younger than the Old grey granite and is intrusive into the Malmesbury series. It is a porphyritic biotite granite, not differing greatly from the Old granite mineralogically, except that Orthoclase is the predominating felspar.

The author was able to collect only 5 samples of borehole water from the Cape granite formation. The chief difficulty is that many areas shown ont he geological maps asb eing occupied by the Cape granite, are in reality covered by fairly thick sandy deposits of recent age, and though the boreholes may in some cases have been sunk into granite, the waters are partly derived from the overlying deposits and are exceedingly brackish. These waters properly belong to the Recent coastal deposits to be described (Page 148).

However, the analyses shewn in Table 4 were from boreholes actually located in Cape granite.

TABLE No. 2.—"OLD GRANITE" IN NATAL.

Sample Numbers	341	342	343	345	351	331	393	506	508	509	510	530	537	Average
Parts $CaCO_3$ per 10^5 Water.														
Methyl Orange Alkalinity	4·2	5·0	20·0	2·5	1·5	6·0	7·2	8·5	12·0	8·5	11·0	2·2	30·5	—
Total Hardness	10·4	7·2	24·8	4·4	8·0	13·6	7·7	12·1	16·8	12·0	12·1	2·4	29·0	—
Permanent Hardness	6·2	2·2	4·8	1·9	6·5	7·6	0·5	3·6	4·8	3·5	1·1	0·2	Nil	—
Temporary Hardness	4·2	5·0	20·0	2·5	1·5	6·0	7·2	8·5	12·0	8·5	11·0	2·2	29·0	—
Hardness due to Ca Salts	1·6	1·6	12·0	2·1	1·2	6·6	2·3	2·5	5·6	0·8	5·7	0·3	9·3	—
Hardness due to Mg Salts	8·8	5·6	12·0	2·3	6·8	7·0	5·4	9·6	11·2	11·2	6·4	2·1	19·7	—
Soda Alkalinity	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	1·6	—
Parts per 10^6 of Water.														
Total Solids (at 105°)	36·0	42·0	38·2	(16·0)	38·2	31·0	31·2	35·0	35·0	31·0	33·0	(13·4)	50·4	36·4
Silica (as SiO_2)	3·2	3·2	4·8	2·0	2·0	4·4	—	2·0	5·0	3·6	5·3	2·0	4·0	—
Fluorides (as F)	Nil	Trace	0·04	Nil	Nil	Nil	0·008	0·04	0·04	0·02	Nil	Nil	Nil	...
Nitrites	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	...
Nitrates (as NO_3)	Nil	Nil	Nil	Nil	0·04	2·8	Nil	0·04	1·6	0·24	0·64	Nil	1·6	...
Chlorides (as Cl)	12·0	19·5	8·6	5·8	21·3	10·6	8·9	13·4	8·5	10·0	8·3	3·2	7·1	—
Sulphates (as SO_4)	4·6	0·06	0·04	0·04	0·03	0·09	0·86	0·8	0·8	* 0·8	0·7	0·12	2·3	...
Potassium Salts	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	0·2	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	...
pH. Values	6·5	6·3	7·5	6·5	6·3	7·2	7·7	6·5	7·5	6·9	7·4	6.9	7·3	7·3
Percentage on Total Solids.														
SiO_2	8·9	7·6	12·7	12·6	5·2	14·2	—	5·6	14·2	10·7	16·0	15·0	7·9	10·2
CaO	2·5	2·1	16·6	8·2	1·74	12·0	4·1	4·0	8·8	1·5	9·7	(1·5)	10·3	7·3
MgO	9·7	5·2	12·6	5·5	7·05	9·0	6·9	10·9	12·6	(4·2)	7·9	6·3	15·4	9·1
Cl	33·0	46·0	22·8	36·5	55·0	34·5	28·5	38·0	23·0	32·5	25·2	23·6	14·0	31·8
SO_4	(12·7)	0·14	0·1	0·25	0·89	2·9	2·76	2·3	2·3	2·6	2·1	8·8	4·6	3·2
Soda Alkalinity (as Na_2CO_3)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	(3·4)	Nil
Total Hardness (as $CaCO_3$)	28·7	17·0	(66·0)	27·8	21·0	44·0	24·6	34·6	48·0	38·8	36·5	17·8	(57·2)	29·9
Perm. Hardness (as $CaCO_3$)	17·2	5·2	12·7	12·0	17·0	24·5	(1·6)	10·2	13·7	11·4	3·4	(1·5)	(Nil)	12·7
Temp. Hardness (as $CaCO_3$)	11·7	11·8	(53·0)	15·7	3·9	19·4	23·0	24·0	34·0	27·5	33·4	16·3	(57·2)	19·2
Ratio CaO : MgO	1 : 3·9	1 : 2·5	1 : 0·8	1 : 0·7	1 : 4·0	1 : 0·75	1 : 1·7	1 : 2·7	1 : 1·3	(1 : 9·7)	1 : 0·8	1 : 4·0	1 : 1·5	1 : 1·25

* Deposits iron oxide on standing.

Sample No.	District and Province.	Borehole Depth.	Locality, Description and Remarks.	Date.
		Feet.		
341	Port Shepstone, South Coast, Natal........	—	Spring on Grasmere No. 2, 11 miles North of Port Edward....	28/ 3/41
342	Port Shepstone, South Coast, Natal........	140	Borehole at Ramsgate, South of Margate....................	31/ 3/41
343	Port Shepstone, South Coast, Natal........	—	Spring, Watershed 1016, near Cherrywood Park..............	1/ 4/41
345	Umzinto, South Coast, Natal..............	—	Well at Kenterton..	1/ 4/41
351	Umzinto, South Coast, Natal..............	—	Borehole at Renishaw Hospital near Scottburgh..............	16/ 5/41
331	Camperdown, Natal.......................	—	Borehole at Drummond....................................	10/ 3/41
530	Mapumulu, Natal.........................	—	Spring on Tongaat–Noodsberg Road, about 13 miles from Tongaat	1/ 4/42
393	Lower Umfolozi, Zululand..................	—	Borehole at Empangeni. (Dr. Ockerse, Anal. Div. C.S.)......	1941
506	Lower Umfolozi, Zululand..................	150	Borehole (No. 9526), on Lot K 24, 3 miles West of M'Posa Railway Station...	30/ 1/41
508	Lower Umfolozi, Zululand..................	100	Borehole on Lot 210 near Lagoza Halt near Empangeni.......	29/ 1/42
509	Lower Umfolozi, Zululand..................	—	Borehole on farm 171a about ¼-mile from Empangeni.........	29/ 1/42
510	Lower Umfolozi, Zululand..................	—	Borehole on Addison's farm, 4 miles North-East of Empangeni	19/ 2/42
537	Lower Umfolozi, Zululand..................	—	Borehole on Lot 230, Empangeni...........................	25/ 3/42

E.

611	612	613	614	615
*	*	*	*	*
34·8	29·3	56·2	29·8	8·0
197·0	167·0	395·0	95·7	873·0
162·2	137·7	338·8	68·9	865·0
34·8	29·3	56·2	29·8	8·0
140·0	90·0	145·0	42·7	575·0
57·0	77·0	250·0	53·0	298·0
Nil	Nil	Nil	Nil	Nil
911·0	446·0	1592·0	295·0	5342·0
—	—	—	—	—
0·53	0·72	0·72	0·83	Nil
—	—	—	—	—
44·0	0·4	153·0	26·2	221·0
271·0	129·0	348·5	75·3	847·0
210·0	112·5	409·0	54·0	161·0
8·5	3·9	4·8	3·7	2·1
7·9	7·6	7·8	7·9	7·5
—	—	—	—	—
8·6	11·6	5·1	8·1	9·6
2·5	6·9	6·3	7·1	3·6
30·5	29·7	22·3	25·4	25·5
23·5	25·0	26·0	18·2	4·8
Nil	Nil	Nil	Nil	Nil
22·0	37·0	25·2	32·5	26·3
17·8	31·0	21·4	23·4	26·0
4·2	6·0	3·8	9·1	0·3
1 : 0·3	1 : 0·6	1 : 1·2	1 : 0·87	1 : 0·

TABLE No. 3.—"OLD GRANITE" AND GNEISS IN NORTH-WESTERN CAPE PROVINCE.

Sample Numbers	389	388	387	[illegible]	[illegible]	391	486	487	608	609	610	611	612	613	614	615	Average
Parts $CaCO_3$ per 10^6 Water:																	
Methyl Orange Alkalinity	19·0	7·0	8·0	[illegible]	19·2	32·5	30·2	30·6	* 26·9	* 50·7	* 18·9	* 34·8	* 29·3	* 56·2	* 29·8	* 8·0	—
Total Hardness	159·0	117·0	17·0	[illegible]	[illegible]	92·5	101·0	80·0	460·0	164·5	155·5	197·0	167·0	395·0	95·7	873·0	—
Permanent Hardness	140·0	110·0	9·0	77·0	[illegible]	60·0	71·0	49·4	443·1	113·8	136·6	162·2	137·7	338·8	68·9	865·0	—
Temporary Hardness	19·0	7·0	8·0	[illegible]	[illegible]	32·5	30·0	30·6	26·9	50·7	18·9	34·8	29·3	56·2	29·8	8·0	—
Hardness due to Ca Salts	46·0	97·5	6·0	[illegible]	[illegible]	61·6	56·0	51·2	250·0	87·0	134·0	140·0	90·0	145·0	42·7	575·0	—
Hardness due to Mg Salts	113·0	19·5	11·0	27·0	[illegible]	30·9	45·0	28·5	210·0	77·5	21·5	57·0	77·0	250·0	53·0	298·0	—
Soda Alkalinity	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	—
Parts per 10^6 of Water:																	
Total Solids (at 105°C.)	518·0	386·0	34·2	[illegible]	[illegible]	216·0	280·0	221·0	1259·0	701·0	545·0	911·0	446·0	1592·0	295·0	3342·0	690·0
Silica (as at SiO_2)	—	—	—	—		—	2·0	1·1	—	—	—	—	—	—	—	—	—
Fluorides (as F)	0·01	0·2	0·02	0·3	[illegible]	0·3	—	—	0·21	0·42	0·46	0·53	0·72	0·72	0·83	Nil	—
Nitrites	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Nitrates (as NO_3)	—	—	—	—	[illegible]	22·6	8·9	16·0	20·2	12·2	Trace	44·0	0·4	153·0	26·2	221·0	—
Chlorides (as Cl)	245·0	199·0	10·6	45·3	[illegible]	58·2	83·5	36·0	480·0	158·0	98·0	271·0	129·0	348·5	75·3	847·0	—
Sulphates (as SO_4)	36·5	23·7	3·2	55·0	[illegible]	28·7	63·2	62·5	128·0	232·0	221·0	210·0	112·5	409·0	54·0	161·0	—
Potassium Salts (as K)	1·2	1·8	—	0·3	[illegible]	0·4	—	—	2·8	2·4	2·6	8·5	3·9	4·8	3·7	2·1	—
pH Values	7·0	7·6	6·8	7·0	[illegible]	7·9	—	—	7·6	7·5	7·6	7·9	7·6	7·8	7·9	7·5	7·6
Percentage on Total Solids:																	
SiO_2	—	—	—	—	—	—	0·7	0·45	—	—	—	—	—	—	—	—	—
CaO	5·0	14·0	9·8	20·[illegible]	[illegible]	16·0	11·2	13·0	11·0	6·4	14·5	8·6	11·6	5·1	8·1	9·6	11·0
MgO	8·7	2·0	12·9	5·8	[illegible]	5·7	6·4	5·15	6·7	4·0	(1·6)	2·5	6·9	6·3	7·1	3·6	5·8
Cl	47·0	50·6	31·0	26·[illegible]	[illegible]	27·0	30·0	(16·4)	38·0	20·5	18·8	30·5	29·7	22·3	25·4	25·5	30·2
SO_3	7·1	6·1	9·3	29·[illegible]	[illegible]	13·2	22·5	28·3	10·1	30·2	42·0	23·5	25·0	26·0	18·2	4·8	19·3
Soda Alkalinity (as Na_2CO_3)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Total Hardness (as $CaCO_3$)	30·6	30·2	49·5	51·[illegible]	[illegible]	43·0	36·0	36·2	36·5	21·3	30·0	22·0	37·0	25·2	32·5	26·3	33·6
Perm. Hardness (as $CaCO_3$)	27·0	28·5	26·3	41·[illegible]	[illegible]	28·0	25·5	22·5	35·0	14·8	26·2	17·8	31·0	21·4	23·4	26·0	25·8
Temp. Hardness (as $CaCO_3$)	3·7	1·8	23·5	9·[illegible]	[illegible]	15·0	10·7	14·5	1·5	6·5	3·8	4·2	6·0	3·8	9·1	0·3	7·8
Ratio CaO : MgO	1 : 1·7	1 : 0·14	1 : 1·3	1 : 0·[illegible]	[illegible]	1 : 0·4	1 : 0·6	1 : 0·4	1 : 0·6	1 : 0·6	(1 : 0·1)	1 : 0·3	1 : 0·6	1 : 1·2	1 : 0·87	1 : 0·4	1 : 0·52

* Total Hardness calculated from gravimetric figures for CaO and MgO.

DESCRIPTION OF SAMPLES IN TABLE No. 3.

Sample No.	District and Province.	Borehole Depth.	Locality, Description and Remarks.	Date
		Feet.		
389	Namaqualand, Cape Province..............	—	Borehole at Garies. (Dr. Ockerse Anal. Div. C.S.)...........	1940
388	Namaqualand, Cape Province..............	—	Borehole at Sobatsfontein. (Dr. Ockerse Anal. Div. C.S.)....	1940
387	Namaqualand, Cape Province..............	—	Borehole at Springbok. (Dr. Ockerse Anal. Div. C.S.).........	1940
382	North-Western Cape......................	—	Borehole at Pella. (Dr. Ockerse, Anal. Onderstepoort Lab.)....	1940
486	Gordonia, Cape Province..................	—	Well at Lutzputs, West of Upington. (Anal. Govt. Lab., Johannesburg)..	17/ 5/21
615	Gordonia, Cape Province..................	—	Borehole on farm Steenkampdal. (Anal. Onderstepoort Lab., per Dr. Steyn)..	1938
487	Gordonia, Cape Province..................	—	Well at Langklip, West of Upington. (Anal. Govt. Lab., Johannesburg)..	17/ 5/21
608	Gordonia, Cape Province..................	123	Borehole on farm Kalkdam. (Anal. Onderstepoort Lab., per Dr. Steyn)..	1938
609	Gordonia, Cape Province..................	—	Borehole on farm Netherlea..............................	1938
610	Gordonia, Cape Province..................	—	Borehole on farm Bloemdal...............................	1938
611	Gordonia, Cape Province..................	—	Borehole on farm Vrowenspan.............................	1938
612	Kenhardt, Cape Province..................	—	Borehole on farm De Rust................................	1938
613	Kenhardt, Cape Province..................	—	Borehole on farm Narougas Noord.........................	1938
614	Kenhardt, Cape Province..................	—	Borehole on farm Klipbaken..............................	1938
391	Kenhardt, Cape Province..................	—	Borehole at Pofadder. (Dr. Ockerse Anal. Div. C.S.)........	1940
386	Namaqualand, Cape Province..............	—	Borehole at Namies. (Dr. Ockerse Anal. Div. C.S.)...........	1940

Sample No.
157
158
159
149
161

TABLE No. 4.—CAPE GRANITE.

Sample Numbers	157	158	159	149	161	Average
Parts $CaCO_3$ per 10^5 Water.	*	*	*	*		
Methyl Orange Alkalinity	2·7	2·7	3·5	2·5	6·0	—
Total Hardness	6·0	3·9	6·0	2·5	17·4	—
Permanent Hardness	3·2	1·2	2·5	Nil	11·4	—
Temporary Hardness	2·7	2·70	3·5	2·5	6·0	—
Hardness due to Ca Salts	1·8	0·8	1·5	1·1	5·4	—
Hardness due to Mg Salts	4·2	3·1	4·5	1·4	12·0	—
Soda Alkalinity	Nil	Nil	Nil	Nil	Nil	—
Parts per 10^6 of Water:						
Total Solids (at 105°)	20·8	12·6	28·0	18·0	(79·0)	20·0
Silica (as SiO_2)	0·7	0·8	1·0	2·0	2·3	—
Fluorides (as F)	Nil	Nil	Nil	Nil	Nil	—
Nitrites	Nil	Nil	Nil	Nil	Nil	—
Nitrates (as NO_3)	Trace	0·6	Trace	Nil	Trace	—
Chlorides (as Cl)	0·9	4·3	13·8	6·0	40·1	—
Sulphates (as SO_4)	0·3	0·2	0·15	0·5	0·34	—
Potassium Salts	Trace Only	Very Small Amount	Very Small Amount	Trace	Small Amount	—
pH. Values	5·9	7·2	6·8	7·1	7·6	6·9
Percentage on Total Solids:						
SiO_2	3·35	6·3	3·5	10·1	2·9	4·9
CaO	4·8	3·5	3·0	3·35	3·85	3·7
MgO	8·1	8·2	5·3	3·25	6·1	6·2
Cl	47·5	34·0	49·2	33·5	50·5	42·9
SO_4	1·4	1·6	0·54	2·8	0·4	1·3
Soda Alkalinity (as Na_2CO_3)	Nil	Nil	Nil	Nil	Nil	Nil
Total Hardness (as $CaCO_3$)	28·8	30·7	21·5	14·0	22·0	23·4
Permanent Hardness (as $CaCO_3$)	15·8	8·8	8·9	(Nil)	14·4	12·0
Temporary Hardness (as $CaCO_3$)	12·8	21·3	12·5	14·0	7·6	13·6
Ratio CaO : MgO	1 : 1·7	1 : 2·3	1 : 1·7	1 : 1·0	1 : 1·5	1 : 1·7

* Deposits iron oxide on standing.

DESCRIPTION OF SAMPLES IN TABLE No. 4.

Sample No.	District and Province.	Borehole Depth.	Locality, Description and Remarks.	Date.
		Feet.		
157	Cape	140	Borehole, farm Vredenhof, Groot Constantia, Cape Town. Crystal clear but deposits iron oxide on standing	17/ 3/40
158	Somerset West, Cape Province	—	Borehole, farm 2 miles North-East of Firgrove near Somerset West. Crystal clear, but deposits iron oxide on standing	13/ 3/40
159	Stellenbosch, Cape Province	—	Borehole, Edenvale, 4·5 miles South-West of Stellenbosch. Crystal clear but deposits iron oxide on standing	19/ 3/40
149	Stellenbosch, Cape Province	—	Borehole at Helderberg	2/ 2/40
161	Stellenbosch, Cape Province	—	Borehole, 1·5 miles West of Vlottenberg Station. Sand covering granite	19/ 3/40

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waters is, however,
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The pH. of these waters
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The iron content of wat
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arising in the Table Mou
mesbury series exhibit th

The concentration is qu
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Chlorides, though seldom
high. Expressed as a
per cent. Cl. Sulphates,

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waters, the slight salinity is
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The Cape granite water
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VII.—THE WATERS IN
THE BUSHVELD
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The alkali rocks form
North of Rustenburg.
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district.

The average annual rai
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A peculiarity of most of these waters is that though they were crystal clear when freshly sampled, they invariably deposited a little ferric oxide on standing even for a short time. The iron content of these waters is, however, low, generally well under 0·5 parts Fe per 10^6.

The pH. of these waters is on the low side, averaging 6·9, and, as will be shown in a subsequent section, such tendency to deposit iron oxides on standing is confined to waters with a low or very low pH. The iron content of waters is discussed on page 174. It may be mentioned here that most of the waters in the Cape Peninsula, including those arising in the Table Mountain series and many of them from the Malmesbury series exhibit this tendency.

The concentration is quite low, averaging only bout 20 parts per 10^6. This applies, of course, only to areas where the Cape granite is not overlain by superficial deposits.

Chlorides, though seldom high in absolute amount, are relatively very high. Expressed as a percentage of total salts the average is 41 per cent. Cl. Sulphates, however, are very low.

These Cape granite waters resemble the granitic waters of the Natal cost in nearly every respect and as in the case of the latter waters, the slight salinity is due to the salt-impregnated mists from the sea being carried a short distance inland and deposited on the soil.

The Cape granite waters have therefore been allocated by the author to the slightly saline Group B. and the same remarks apply as regards utilisation and corrective chemical treatment, as in the case of the Old granite waters in Natal.

VII.—THE WATERS IN THE GRANITES AND FELSITES OF THE BUSHVELD IGNEOUS COMPLEX AND IN THE ALKALI ROCKS OF THE PILANSBERG.

A large area in the Central Transvaal is occupied by these rocks, but there are no towns or villages of any size except Warmbaths, and a part of the area is Native Reserve, but the Leeuwpoort, Mutue Fides, Zaaiplaats and Rooiberg tin mines, as well as the South African Alkali Ltd., Factory on Zoutpan 467, Pretoria District, are located on granites.

Distribution and Rainfall.

The Red or Bushveld granite froms part of a basin in the Central Transvaal stretching from the Pilandsberg in the West to Pokwani in the East, but is considerably interrupted in the centre by coverings of younger rocks. It includes granites which are not red in colour and recent work by the Geological Survey show that there are several varieties and ages of granite in this group.

The alkali rocks form the hilly broken country, Pilansberg, 40 miles North of Rustenburg. Very much smaller occurrences of these Alkali rocks are found in Sekukuniland and near Hatherley, Pretoria district.

The average annual rainfall in these areas varies from 15″ to 25″ in the West to 25″–30″ in the East.

The Red granite forms part of the "acid" phase of that huge intrusive igneous assemblage known as the "Bushveld Igneous Complex", occurring as a lopolith in the heart of the Transvaal Bushveld country. The Red granite and associated felsites have been described in great detail by Hall, Lombaard and others. The waters arising in the basic zones of the complex are described later.

The Red granite is younger than the norite and other basic rocks.

The essential minerals in the Red granite are:—

Microperthite (an intimate intergrowth of Orthoclase, Albite and Oligoclase felspars) and quartz, with hornblende rather than biotite as the ferromagnesium mineral.

The reddish fine grained felsites and granophyres are very similar.

Typical analyses of the Red granite and felsites will be given later. The Alkali rocks of the Pilansberg and Sekukuniland have been studied in great detail by Shand (62, 63, 64). These rocks, though younger than the Red granite, are genetically connected with them and since they give rise to very similar waters they are discussed under the same heading. These Alkali rocks exhibit both plutonic and volcanic phases, while volcanic breccias and tuffs are present.

The chief rock type are:—

(1) Red Felsites and Trachytes.
(2) Red Syenites.
(3) Nepheline Syenites (Foyaites) and Phonolites (Tinguaite and Microfoyaite)
(4) Volcanic breccias and tuffs.

It is not necessary for the purpose of this study to give a detailed mineralogical description of all these highly complex rocks, but it may be stated that all (even the tuffs and breccias) are characterised by a very large proportion of soda-rich minerals like soda-hornblende, aegerine-augite, aegerine, soda felspars, nepheline, sodalite and cancrinite. There is comparatively little quartz. It is not surprising therefore to find that the Na_2O content is higher in these rocks than in any other rock types met with in South Africa.

Another very important characteristic of these rocks is that fluorite (CaF_2) is a common accessory mineral (Shand 62, pp. 127, 128, 140, 143). Even the vesicles of the lavas are sometimes filled with fluorite while it even forms part of the cementing material of the volcanic breccias (Du Toit 14, p. 191). Fluorapatite [$Ca_3(PO_4)_2.CaF_2$] is also sometimes present.

Unfortunately only two of the large number of published analyses of the Pilansberg Alkali rocks give the fluorine content. In both these analyses the fluorine is appreciable. None of the published analyses of the Red granite and associated felsites give the fluorine content. Two recent analyses of the Red granite made by the author are included in the following table of typical rock analyses, and in these the fluorine has been determined.

As far as this study is concerned, the chief interest in these typical rock analyses is the high Na_2O and K_2O content of the Red granite and associated felsites, and the exceedingly high Na_2O content of the Alkali rocks of the Pilansberg and Sekukuniland.

ANALYSES OF ALKALI ROCKS, RED GRANITE AND FELSITES.

Sample Numbers	1	2	3	4	5	6	7	8	9	10
SiO_2	57·77	49·88	48·35	39·78	51·35	74·00	73·00	74·10	72·40	72·80
Al_2O_3	19·08	21·70	23·10	20·46	11·45	11·85	13·78	13·25	14·04	11·97
Fe_2O_3	0·78	1·30	2·48	2·49	9·40	Nil	—	1·75	—	2·79
FeO	4·69	0·53	1·89	3·29	2·41	3·00	3·52	0·75	2·4	2·63
MgO	1·00	0·07	0·89	2·36	0·54	0·35	0·40	0·15	0·72	0·06
CaO	2·27	3·92	3·92	10·90	3·27	1·50	0·96	1·10	2·00	0·06
Na_2O	5·53	11·80	13·20	10·98	10·80	3·20	3·91	3·40	3·30	3·34
K_2O	5·26	4·66	4·58	3·30	2·52	5·25	3·09	5·00	4·00	5·31
H_2O+	1·51	—	—	—	—	0·70	—	0·45	0·38	0·64
H_2O-	0·29	2·35	2·91	0·83	3·20	0·20	0·15	1·15	Trace	0·09
TiO_2	1·20	—	0·45	0·33	2·75	0·10	0·10	0·20	0·16	0·68
MnO	0·22	—	—	0·10	1·25	0·05	Trace	—	Trace	0·17
P_2O_5	0·21	—	—	3·33	—	0·20	—	Trace	—	0·15
Cl	—	0·44	1·49	Nil	—	—	—	—	0·01	—
F	Present	1·25	—	0·30	—	—	0·09	—	0·05	—
CO_2	9·42	2·30	—	1·25	—	—	0·52	—	—	—
TOTAL	99·23	100·20	100·85	100·08	99·48	100·28	99·43	100·20	—	100·64
Ratio CaO : MgO	1 : 0·44	1 : 0·18	1 : 0·35	1 : 0·2	1 : 0·16	1 : 0·23	1 : 0·42	1 : 0·14	1 : 0·3	—
Analyst	W. de Kock	F. Pisani	F. Pisani	S.J. Shand	F. Pisani	W. Weall	G.W. Bond	J. Moir	G.W. Bond	B Lombaard

DESCRIPTION.

(1) Red Syenite, Eleventh Poort, Olievenfontein, Pilansberg.
(2) Foyaite, Olievenfontein, Pilansberg.
(3) Aegirine Foyaite, rich in sodalite, Leeuwfontein, Pretoria District.
(4) Ijolite, Spitzkop, Sekukuniland.
(5) Lujaurite, Tussenkomst, Pilansberg.
(6) Coarse Red Granite, Petronella Siding, North of Pretoria.
(7) Red Granite (granophoric), near Sybrandskraal.
(8) Red Granite, Salt Pan, near Pretoria.
(9) Red Granite from quarry, near Aapies Rivier Station, Pretoria District.
(10) Felsite, Klipplaatdrift 84, Bronkhorstspruit District.

In the former rocks K_2O appears to predominate slightly, while in the latter rocks Na_2O is generally greatly in excess over K_2O.

Comparison with typical analyses of "Old Granite" shown in Section 5 does not reveal any appreciable difference in chemical composition between the Red granite and the "Old Granite", though there are mineralogical differences. The alkali content in the former is however, slightly greater than in the latter.

In both the Red granite and the Alkali rocks the CaO content is verly low, but greatly exceeds MgO.

UNDERGROUND WATER SUPPLIES.

Du Toit (2, p. 118) points out that since the Red granite is generally less coarse and more homogenous than the Old granite, the Red granite is unfavourable to deep boring and very few holes have been put down to more than 250′, and that only moderate or small supplies can be expected. The tough and fine grained Red felsites and granophyres are generally avoided on account of drilling difficulties, but in weathered zones give fair supplies at shallow depths.

Frommurze (3, pp. 133–134) gives the following figures :—

	Pretoria.	Brits.	Rustenburg.	Marico.	Middelburg (Tvl.).	[illegible]
Average depth....................	130 ft.	94 ft.	99 ft.	135 ft.	135 ft.	[illegible]
Average yield *per diem* in gallons...	14,000	11,700	20,500	13,500	20,000	[illegible]
Percentage of failures.............	38	37	—	55	37	[illegible]

No data are available for boring results in the Pilansberg Alkali rocks.

QUALITY OF THE WATER.

In Table 5 are shown the results of analyses of 20 samples of water from the Red granite covering the Pretoria, Waterberg, Potgietersrust and Middelburg districts of the Transvaal. The majority were carried out by the author, but a few by other analysts are included, which latter unfortunately do not give the SiO_2 content.

The author could not obtain samples from the Pilansberg Alkali rocks, but through the courtesy of Dr. Ockerse of the Department of Public Health, 7 analyses of waters from these rocks were made available and are shown in Table 5. Unfortunately these latter do not give the SiO_2 content.

The waters arising both in the Red granite and Felsites and in the Alkali rocks are very interesting and characteristic.

(i) *The Waters in the Pilansberg Alkali Rocks.*

The chief characteristics is the appreciable soda alkalinity and the consistently high fluoride content.

The concentration of salts is generally fairly low, round about 28 parts per 10^5. Soda alkalinity is always present. Expressed in

---

ample Numbers.

Parts $CaCO_3$

Methyl Orange Al

Total Hardness...

Permanent Hardn

Temporary Hardn

Hardness due to

Hardness due to

Soda Alkalinity..

Parts per 1

Total Solids (at 1

Silica (as at SiO_2)

Fluorides (as F)..

Nitrites.........

Nitrates (as NO_3)

Chlorides (as Cl)..

Sulphates (as SO_4

Potassium Salts (

pH. Values......

Percentage o

SiO_2.........

CaO.........

MgO.........

Cl.........

SO_4.........

Soda Alkalinity (a

Total Hardness (a

Perm. Hardness (a

Temp. Hardness (

Ratio CaO : MgO.

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'Old Granite", though
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-	Marico.	Middelburg (Tvl.)
	135 ft.	135 ft.
	13,500	20,000
	55	37

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TABLE No. 5.—RED GRANITE AND FELSITES OF THE BUSHVELD IGNEOUS COMPLEX.

Sample Numbers	602	86	87	93	106	131	325	327	324	298	328	191	318	317	316	429	430	431	432	433	56
Parts $CaCO_3$ per 10^5 Water:																					
Methyl Orange Alkalinity	15·2	15·0	17·0	26·0	21·0	10·8	6·5	6·5	26·0	5·5	7·5	31·5	8·0	8·0	7·0	9·0	20·0	5·5	3·2	1·5	7·
Total Hardness	2·45	3·5	4·1	9·3	9·2	6·1	3·4	3·0	20·0	2·8	2·2	33·6	6·4	6·8	5·2	6·5	14·0	5·0	2·2	1·0	2·
Permanent Hardness	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	2·1	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Temporary Hardness	2·45	3·5	4·1	9·3	9·2	6·1	3·4	3·0	20·0	2·8	2·2	31·5	6·4	6·8	5·2	6·5	14·0	5·0	2·2	1·0	2·
Hardness due to Ca Salts	2·24	2·9	3·4	7·1	7·8	4·8	1·8	1·8	11·2	1·8	1·6	17·4	4·0	5·4	3·6	5·4	8·9	4·0	2·2	1·0	1·
Hardness due to Mg Salts	0·21	0·6	0·7	2·1	1·2	1·3	0·6	1·2	8·8	1·0	0·6	16·2	2·4	1·4	1·6	1·1	5·1	1·0	Nil	Nil	0·
Soda Alkalinity	12·8	11·5	12·9	16·7	11·8	4·6	3·1	3·5	6·0	2·7	5·3	Nil	1·6	1·3	1·8	2·5	6·0	0·5	1·0	0·5	5·
Parts per 10^5 of Water:																					
Total Solids (at 105°C.)	42·0	38·3	35·0	37·0	32·0	18·3	17·0	16·0	36·0	15·0	15·0	(59·0)	10·4	16·8	13·0	19·6	20·6	11·5	(4·0)	(6·6)	32·
Silica (as at SiO_2)	6·8	5·3	4·5	3·6	5·6	4·8	3·8	4·0	3·8	3·0	4·0	6·4	3·3	3·0	2·5	—	—	—	—	—	5·
Fluorides (as F)	—	0·1	0·6	0·5	0·16	0·11	0·2	0·06	0·4	0·04	0·22	0·07	Nil	0·44	0·35	0·5	0·07	0·26	0·12	0·02	—
Nitrites	—	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Nitrates (as NO_3)	—	Nil	Nil	Nil	Nil	Trace	0·4	0·32	Nil	Trace	0·24	1·0	0·8	0·1	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Chlorides (as Cl)	8·5	7·8	7·1	3·6	2·1	1·4	3·6	4·7	4·3	3·6	4·3	12·1	5·0	5·0	2·2	2·1	1·1	0·71	1·0	0·3	0·8
Sulphates (as SO_4)	0·85	0·2	0·1	0·2	Trace	Trace	Trace	0·03	Trace	Trace	Trace	0·3	Trace	Trace	Trace	0·8	1·4	0·58	0·5	0·4	1·7
Potassium Salts (as K)	0·7	Under 1·0	Under 0·5	Under 0·5	—	Trace	Under 0·5	Under 0·5	Under 1·0	Under 0·5	Under 0·5	Small Amount	Trace	Under 0·5	Trace	0·02	0·1	0·16	0·24	0·20	—
pH. Values	—	8·2	8·1	8·1	7·8	7·3	7·4	7·0	8·3	7·7	7·0	7·3	7·0	7·3	8·0	8·3	7·7	6·4	(6·0)	6·3	—
Percentage on Total Solids:																					
SiO_2	16·0	13·8	13·9	9·7	17·4	26·5	22·0	25·0	10·5	20·0	26·5	10·9	20·0	18·0	19·2	—	—	—	—	—	15·6
CaO	2·9	4·2	5·4	11·5	13·8	14·8	5·9	11·2	17·0	6·7	10·6	16·5	13·4	18·0	15·4	13·2	16·8	19·5	(31·0)	8·5	3·4
MgO	0·2	0·6	0·8	2·3	1·5	2·75	3·5	7·5	9·7	2·6	4·0	11·0	5·8	3·3	7·0	5·6	6·8	3·5	(Nil)	Nil	0·6
Cl	20·0	20·5	20·3	9·8	6·5	7·7	21·0	29·4	12·0	24·0	29·0	20·5	30·5	30·0	17·0	10·7	3·7	6·2	25·0	(4·9)	21·0
SO_4	2·0	0·5	0·3	0·5	Trace	Trace	Trace	0·18	Trace	Trace	Trace	0·5	Trace	Trace	Trace	4·0	4·6	5·0	(12·4)	6·5	5·3
Soda Alkalinity (as Na_2CO_3)	32·0	32·0	39·0	48·0	39·7	27·0	19·4	21·8	17·7	18·0	37·0	Nil	(9·8)	(8·4)	15·2	13·5	21·5	(4·6)	26·5	(8·1)	17·0
Total Hardness (as $CaCO_3$)	5·8	9·2	11·7	25·0	28·5	33·5	20·0	18·7	(55·0)	18·7	14·6	(57·5)	39·0	40·5	40·0	33·0	47·0	43·5	(56·0)	15·2	7·8
Perm. Hardness (as $CaCO_3$)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	(3·5)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Temp. Hardness (as $CaCO_3$)	5·8	9·2	11·7	25·0	28·5	33·5	20·0	18·7	(55·0)	18·7	14·6	(53·0)	39·0	40·5	40·0	33·0	47·0	43·5	(56·0)	15·2	7·8
Ratio CaO : MgO	1 : 0·1	1 : 0·1	1 : 0·14	1 : 0·2	1 : 0·1	1 : 0·2	1 : 0·6	1 : 0·0	1 : 0·5	1 : 0·4	1 : 0·3	1 : 0·7	1 : 0·4	1 : 0·2	1 : 0·4	1 : 0·4	1 : 0·4	1 : 1·17	(1 : 0·0)	(1 : 0·0)	1 : 0·

TABLE No. 5.—RED GRANITE AND FELSITES OF THE BUSHVELD IGNEOUS COMPLEX.

PILANDSBERG ALKALI ROCKS.

106	131	325	327	324	298	328	191	318	317	316	429	430	431	432	433	563	Average	395	396	397	398	552	600	601	Average
21·0	10·8	6·5	6·5	26·0	5·5	7·5	31·5	8·0	8·0	7·0	9·0	20·0	5·5	3·2	1·5	7·7	—	24·5	19·0	28·5	18·8	36·5	12·6	10·0	—
9·2	6·1	3·4	3·0	20·0	2·8	2·2	33·6	6·4	6·8	5·2	6·5	14·0	5·0	2·2	1·0	2·5	—	19·9	13·0	16·9	7·4	1·5	6·6	6·0	—
Nil	Nil	Nil	Nil	Nil	Nil	Nil	2·1	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	—	Nil	Nil	Nil	Nil	Nil	Nil	Nil	—
9·2	6·1	3·4	3·0	20·0	2·8	2·2	31·5	6·4	6·8	5·2	6·5	14·0	5·0	2·2	1·0	2·5	—	19·9	13·0	16·9	7·4	1·5	6·6	6·0	—
7·8	4·8	1·8	1·8	11·2	1·8	1·6	17·4	4·0	5·4	3·6	5·4	8·9	4·0	2·2	1·0	1·9	—	14·8	7·7	12·0	6·7	0·5	3·5	3·5	—
1·2	1·3	0·6	1·2	8·8	1·0	0·6	16·2	2·4	1·4	1·6	1·1	5·1	1·0	Nil	Nil	0·5	—	5·1	5·3	4·9	0·7	1·0	3·1	2·5	—
11·8	4·6	3·1	3·5	6·0	2·7	5·3	Nil	1·6	1·3	1·8	2·5	6·0	0·5	1·0	0·5	5·2	—	4·6	6·0	11·6	11·4	35·0	6·0	4·0	—
32·0	18·3	17·0	16·0	36·0	15·0	15·0	(59·0)	10·4	16·8	13·0	19·6	20·0	11·5	(4·0)	(6·6)	32·8	24·5	29·8	30·0	39·0	30·2	(98·0)	16·4	19·8	28·4
5·6	4·8	3·8	4·0	3·8	3·0	4·0	6·4	3·3	3·0	2·5	—	—	—	—	—	5·0	—	—	—	—	—	—	—	—	—
0·16	0·11	0·2	0·06	0·4	0·04	0·22	0·07	Nil	0·44	0·35	0·5	0·07	0·26	0·12	0·02	—	—	0·32	0·07	0·5	1·05	3·51	0·43	0·21	—
Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	—	Nil	Nil	Nil	Nil	Nil	—	—	—
Nil	Trace	0·4	0·32	Nil	Trace	0·24	1·0	0·8	0·1	Nil	Nil	Nil	Nil	Nil	Nil	Nil	—	Nil	Nil	Nil	Nil	Nil	—	—	—
2·1	1·4	3·6	4·7	4·3	3·6	4·3	12·1	5·0	5·0	2·2	2·1	1·1	0·71	1·0	0·3	6·8	—	—	1·4	3·6	3·6	7·1	0·71	1·42	—
Trace	Trace	Trace	0·03	Trace	Trace	Trace	0·3	Trace	Trace	Trace	0·8	1·4	0·58	0·5	0·4	1·7	—	0·61	0·05	5·3	0·48	7·3	—	0·25	—
—	Trace	Under 0·5	Under 0·5	Under 1·0	Under 0·5	Under 0·5	Small Amount	Trace	Under 0·5	Trace	0·02	0·1	0·16	0·24	0·20	—	—	0·11	0·15	0·35	0·15	0·3	0·33	0·3	—
7·8	7·3	7·4	7·0	8·3	7·7	7·0	7·3	7·0	7·3	8·0	8·3	7·7	6·4	(6·0)	6·3	—	7·4	7·7	7·3	7·8	7·9	(9·8)	7·9	7·2	7·6
17·4	26·5	22·0	25·0	10·5	20·0	26·5	10·9	20·0	18·0	19·2	—	—	—	—	—	15·6	18·0	—	—	—	—	—	—	—	—
13·8	14·8	5·9	11·2	17·0	6·7	10·6	16·5	13·4	18·0	15·4	15·2	16·8	19·5	(31·0)	8·5	3·4	11·5	28·0	14·3	17·0	10·6	(0·30)	21·3	17·7	18·2
1·5	2·75	3·5	7·5	9·7	2·6	4·0	11·0	5·8	3·3	7·0	5·6	6·8	3·5	(Nil)	Nil	0·6	3·4	6·9	7·3	5·0	(0·8)	(0·4)	18·9	12·6	10·3
6·5	7·7	21·0	29·4	12·0	24·0	29·0	20·5	30·5	30·0	17·0	10·7	3·7	6·2	25·0	(4·9)	21·0	18·6	—	4·7	9·2	10·2	1·2	4·3	7·1	7·1
Trace	Trace	Trace	0·18	Trace	Trace	Trace	0·5	Trace	Trace	Trace	4·0	4·6	5·0	(12·4)	6·5	5·3	2·0	2·1	0·17	(13·4)	1·36	7·4	—	1·2	2·6
39·7	27·0	19·4	21·8	17·7	18·6	37·0	- Nil	(9·8)	(8·4)	15·2	13·5	21·5	(4·6)	26·5	(8·1)	17·0	28·2	16·2	21·3	31·0	34·8	37·7	39·0	21·2	28·7
28·5	33·5	20·0	18·7	(55·0)	18·7	14·6	(57·5)	39·0	40·5	40·0	33·0	47·0	43·5	(56·0)	15·2	7·8	25·3	66·6	43·0	43·2	21·0	(15·3)	40·2	30·3	40·7
Nil	Nil	Nil	Nil	Nil	Nil	Nil	(3·5)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
28·5	33·5	20·0	18·7	(55·0)	18·7	14·6	(53·0)	39·0	40·5	40·0	33·0	47·0	43·5	(56·0)	15·2	7·8	25·3	66·6	43·0	43·2	21·0	(15·3)	40·2	30·3	40·7
: 0·1	1 : 0·2	1 : 0·6	1 : 0·6	1 : 0·5	1 : 0·4	1 : 0·3	1 : 0·7	1 : 0·4	1 : 0·2	1 : 0·4	1 : 0·4	1 : 0·4	1 : 1·17	(1 : 0·0)	(1 : 0·0)	1 : 0·2	1 : 0·3	1 : 0·25	1 : 0·5	1 : 0·3	(1 : 0·08)	(1 : 1·4)	1 : 0·8	1 : 0·7	1 : 0·6

DESCRIPTION OF SAMPLES IN TABLE No. 5.

Sample No.	District and Province.	Borehole Depth.	Locality, Description and Remarks.	Date.
		Feet.		
431	Rustenburg, Transvaal	—	Borehole on farm Doornfontein 827, 8 miles West of Rooiberg Tin Mine. (Anal. Div. C.S. per Dr. Ockerse)	1941
432	Waterberg, Transvaal	—	Borehole on Kwaggafontein 996, near Leeuwpoort Tin Mines. (Anal. Div. C.S. per Dr. Ockerse)	1941
602	Waterberg, Transvaal	—	Spring in Sanatorium, Warmbaths. (Anal. H. Weall)	1932
86	Waterberg, Transvaal	69	Borehole on Camping Ground, Warmbaths	29/ 8/39
87	Waterberg, Transvaal	—	Borehole (Becketts) in Warmbaths	29/ 8/39
106	Waterberg, Transvaal	—	Borehole Rietspruit 611, 11 miles East of Rooiberg Tin Mines	29/ 8/39
93	Pretoria, Transvaal	80	Borehole on Main Road near Aapies River	29/ 9/39
131	Pretoria, Transvaal	85	Borehole at Kekana, 6 miles North of Hamanskraal	29/12/39
325	Pretoria, Transvaal	—	Borehole at N.A.D. Post, Langkraal, 2 miles West of Hamanskraal	4/ 3/41
327	Pretoria, Transvaal	64	Borehole on farm Klipdrift 123, 2 miles East of Hamanskraal	4/ 3/41
324	Pretoria, Transvaal	—	Borehole on farm De Quarry, 3 miles from Salt Pan	4/ 3/41
298	Pretoria, Transvaal	—	Spring on road to Salt Pan, 3 miles South	4/ 3/41
328	Pretoria, Transvaal	—	Borehole near Petronella Siding on Main Road	4/ 3/41
318	Bronkhorstspruit, Transvaal	90	Borehole on farm Klipspruit 99, near Sybrandskraal	24/11/41
317	Bronkhorstspruit, Transvaal	—	Borehole on farm Zusterhoek 105, on road from Enkeldoorn Police Post to Sybrandskraal	24/11/41
316	Bronkhorstspruit, Transvaal	—	Spring near road, 1 mile South of Enkeldoorn Police Post	24/11/41
433	Bronkhorstspruit, Transvaal	—	Borehole on Kameelpoorts Nek 69, 11 miles North-East of Sybrandskraal. (Anal. Div. C.S. per Dr. Ockerse)	24/11/41
420	Potgietersrust, Transvaal	—	Borehole on Rietfontein 1042, 8 miles West-North-West of Naboomspruit. (Anal. Div. C.S. per Dr. Ockerse)	1940
191	Potgietersrust, Transvaal	—	Borehole Moorddrift Station	7/ 7/40
430	Rustenburg, Transvaal	—	Borehole on Kaffirskraal 352, 11 miles South-West of Beestekraal 29. (Anal. Div. C.S. per Dr. Ockerse)	1941
563	Middelburg, Transvaal	—	Spring near Loskop Irrigation Works. (Anal. Govt. Lab., Johannesburg)	3/ 8/38
395	Rustenburg, Transvaal	—	Well at Kaffirskraal 890. (Anal. H. Meyer)	1941
396	Rustenburg, Transvaal	40	Borehole on Saulspoort 269. (Anal. H. Meyer)	1941
397	Rustenburg, Transvaal	—	Spring, Wydhoek 701. (Anal. H. Meyer)	1941
398	Rustenburg, Transvaal	300	Borehole on Buffelspan 588. (Anal. H. Meyer)	1941
552	Rustenburg, Transvaal	—	Borehole on Ledig 744. (Anal. Div. C.S. per Dr. Ockerse)	1941
600	Rustenburg, Transvaal	—	Borehole on Boekenhoutfontein, 889. (Anal. Div. C.S. per Dr. Ockerse)	1941
601	Rustenburg, Transvaal	—	Borehole on Buffelskloof 219. (Anal. Div. C.S. per Dr. Ockerse)	1941

terms of total salts the average is 28·7 per cent. (as Na_2CO_3). As aforementioned, the alkali content of the rocks (particularly Na_2O) is extremely high, so it is not surprising to find that the waters show appreciable soda alkalinity.

The potassium content of these waters is very low, the highest amount being only 0·35 parts K per 10^5 (or 9·0 per cent. K in terms of total salts). The reasons for the very low potash content of these and other waters in the Union will be discussed later (Page 171), but in any case, as previously mentioned, Na_2O greatly exceeds K_2O in the Pilansberg Alkali rocks.

In spite of the appreciable soda alkalinity the pH. of these waters does not appear to be exceptionally high, averaging only 7·6 in the samples tested, so that the soda alkalinity is generally in the form of sodium bicarbonate rather than the carbonate. The chief exception is that of the Ledig borehole (sample 552). The pH. of this water (9·8) is the highest so far recorded in South Africa, excluding that of the concentrated liquor in the soda pan near Pretoria. In the Ledig sample appreciable sodium carbonate as well as sodium bicarbonate is therefore present.

As mentioned, no data is given for silica.

In the typical rock analyses previously given, calcium was seen greatly to exceed magnesium, the average ratio being 1 : 0·3. Therefore it is not surprising to find that in the waters CaO exceeds MgO, the ratio being about 1 : 0·6. Chlorides are low, averaging only 7·1 per cent. Cl. in terms of total salts.

Sulphates are also low, averaging 2·5 per cent. SO_4 interms of total salts, and this sulphate is undoubtedly present as sodium sulphate since there is never any permanent hardness—instead there is an excess of soda.

Scale-forming salts are consequently restricted to calcium and magnesium bicarbonate, which average about 40 per cent. (as $CaCO_3$) in terms of total salts.

The most striking feature of these waters is the consistent fluoride content. Fluorides always appear to be present, generally in amount greatly exceeding the safety limit of 1 part F per million laid down by Public Health Authorities. One sample, namely, that in the highly alkaline Ledig water has the extraordinary high fluoride content of 35·1 *parts F per million* (3·8 per cent. F. in terms of total salts), the highest so far recorded in the Union, excluding the highly concentrated soda-salt liquor in the Soda Caldera at Salt Pan.*

An interesting fact, arising out of the appreciable soda alkalinity always present in these waters, is that the fluorine is *always present* in the *form of sodium fluoride (NaF)*, and not calcium fluoride (CaF_2). For example, had the CaF_2 been present in the Ledig sample (7·1 parts CaF_2 per 10^5), this would have given rise to a permanent hardness of 9·2 parts (as $CaCO_3$) per 10^5, which is easily determinable. No permanent hardness was found, but instead a soda alkalinity of 35·0 parts Na_2CO_3 per 10^5 is present, and so in the other waters.

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* Since the above was written a spring water on Doornhoek 134, Rustenburg District, was found to contain 67.2 parts F per 10^6 (6.4 per cent in terms of total salts).

As aforementioned only two of the published analyses of the Pilansberg Alkali rocks show the fluorine content ; in both the fluorine is appreciable, but all the Pilansberg rocks contain fluorite and some have fluorapatite as an accessory mineral, so that it is highly probable that all these rocks contain appreciable fluorine. It is not surprising therefore to find that fluorides are always present in appreciable amount in waters arising in these rocks.

The significance of the fluoride content of these waters will be discussed further.

These waters are allocated to the Alkaline Soda Carbonate Group D. of Waters. The percentage Na_2CO_3 or $NaHCO_3$ content is not as high on average (28 per cent. as Na_2CO_3) as in the case of the waters arising in the Upper Beaufort series (37 per cent. Na CO_3).

The utilisation and chemical correction of these alkaline waters from the Pilansberg rocks is dealt with under Group D., but it may be stated here that these waters can be used for all domestic purposes and for watering stock since the *absolute* amount of Na_2CO_3 of $NaHCO_3$ is not high, whilst for the same reason these soda alkaline waters can be used for irrigation. The soda content however offers difficulties with regard to their utilisation as boiler feed water.

(ii) *Waters in the Red Granites and Felsites.*

The concentration of salts in these waters varies a good deal, on account of differences in rainfall. On the Eastern margin of the Red granite the concentration of salts is very low and in this respect these waters therefore approximate to the author's pure water Group E, but their percentage composition is much the same as in the case of the other Red granite waters.

On the average, however, both in concentration and composition these waters are very similar to the alkaline waters of the Pilansberg. Scale-forming salts are lower than in the Pilansberg waters. This could be anticipated for the analyses of the Red granites show a slightly lower CaO and MgO content than the Pilansberg Alkali rocks. The CaO : MgO ratio is even lower at 1 : 0·3 compared with the 1 : 0·6 of the Pilansberg waters.

The chief difference however, is in the chloride content. This varies a good deal in Red granite waters but on the average is fairly high at 18 per cent. Cl. Such applies particularly to the borehole waters from Warmbaths, which some observers assume to be magmatic or juvenile waters.

Incidentally, it is interesting to observe from the author's analyses in Table 5 that the water from the well known thermal spring in the Warmbaths Sanatorium differs hardly at all, except in temperature, from the other borehole waters in Warmbaths. The chief difference between the Warmbaths waters and the other waters in the Red granite is in the absolute amounts of sodium bicarbonate and chloride. Certainly the Warmbaths waters appear to fit in with the definition of a magmatic water as given in Clarke (43, p. 24) : "Virgin [illegible] juvenile waters on the contrary, are fairly constant in all [illegible] particulars, and carry *sodium bicarbonate, alkaline silicate,* heavy [illegible] etc., as chief constituents, with chlorides and sulphates [illegible] accessories and *practically no carbonates of the alkaline earths* [illegible]

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Boron appears in co
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Red granite waters

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Red granite water.
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The alkaline earths are certainly low (CaO less than 5 per cent.) while the $NaHCO_3$ is very high and Na_2SiO_3 high.

With reference to relatively high chlorine in waters arising in igneous rocks, Lindgren (35, pp. 47–48) states: "Waters rich in chlorine are sometimes found in ascending springs in igneous rocks, but always confined to regions of comparatively recent volcanic activity. Their conposition is somewhat different from the brines resulting from the dissolving of salts from sedimentary beds . . . Boron appears in considerable amounts". It may be mentioned that the author did not find boron in the Warmbaths waters or in other Red granite waters tested.

The Salt Pan, an extraordinary volcanic crater, or more correctly a sunken soda caldera is located in the Red granite formation. From this hollow considerable quantities of salt and sodium carbonate have been produced by the S.A. Alkali, Ltd. This soda caldera has been minutely studied by Wagner (36) who has ascribed the formation of the crater to a phreatic volcanic explosion. Red granite forms the rim and sides of the crater while the volcanic breccia is largely composed of the same rock. The material originally filling the "pipe" is speculative, though blocks of alkali syenite, related to the Pilansberg foyaites have been found.

It will be instructive to compare the composition of the brine from this caldera with the Warmbaths waters and with other waters from the Red granite analysed by the author.

Some recent analyses of the brine, including one made by the author, are compared in the following table with some analyses of Red granite water. The results are expressed as percentages of the total salts in order to eliminate the conentration variable.

PERCENTAGE ON TOTAL SALTS.

	1	2	3	4	5	6	7	8	9
CaO	—	0·02	Nil	—	—	2·9	5·4	6·0	5·9
MgO	—	Trace	Nil	—	0·2	0·2	0·8	1·3	3·5
NaCl	52·0	56·9	39·8	38·5	42·5	33·0	33·5	61·0	34·5
Na_2CO_3	31·0	37·4	36·4	60·0	53·0	32·0	39·0	37·0	19·4
SiO_2	0·11	0·07	—	—	2·3	16·0	13·9	26·5	22·0
SO_4	—	0·30	Nil	—	—	2·0	0·3	Trace	Trace
Total Solids as parts per 10^5	27,200	9,420	12·604	88·0	84·0	31·4	35·0	16·0	17·0
Ratio NaCl : Na_2CO_3	1 : 0·6	1 : 0·65	1 : 0·9	1 : 1·5	1 : 1·2	1 : 0·96	1 : 1·2	1 : 0·6	1 : 0·6

(1) Pretoria Soda Pan, Zoutpan 467, Pretoria District, Liquor from Borehole 12 on Gaylussite layer. (Anal. J. McCrae and H. Weall.)
(2) Pretoria Soda Pan, *Composite* sample from 27 boreholes samples on 26/11/42. (Anal. G. W. Bond.)
(3) Pretoria Soda Pan, Sample of brine. (Anal. by H. P. Meyer), cited by Ockerse and Meyer (78).
(4) Pretoria Soda Pan, Sample of " Fresh Water " borehole No. 3. (Anal. H. R. Blumenberg.)
(5) Pretoria Soda Pan, deep (" fresh water ") borehole No. 2, on South side of Caldera. (Anal. H. R. Blumenberg.)
(6) Thermal Spring in Red Granite, Warmbaths Sanatorium. (Anal. Govt. Lab., see sample 602, Table 5.)
(7) Borehole water in Red Granite, Warmbaths. (Anal. G. W. Bond, see sample 87, Table 5.)
(8) Borehole water in Red Granite, Petronella Siding, North of Pretoria. (Anal. G. W. Bond, see sample 328, Table 5.)
(9) Borehole in Red Granite, Langkraal, near Hamanskraal. (Anal. G. W. Bond, see sample 325, Table 5.)

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Wagner (36, pp. 1
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often gives rise to wate

From these comparative analyses it will be seen that the highly concentrated liquor from the centre of this soda caldera does not really differ greatly (except in concentration and in the percentages of CaO, MgO and SiO_2) from the usual run of Red granite waters. At the centre of the pan NaCl greatly exceeds Na_2CO_3, but as the edge of the pan is approached the proportion of Na_2CO_3 rises until it approximates (see analyses of " fresh water " borehole) to that of the ordinary Red granite water.

The absence of any appreciable quantity of calcium and magnesium in the soda liquor as well as the high proportion of NaCl to Na_2CO_3 can readily be explained on physico-chemical grounds. The liquor in the centre of the pan is highly concentrated and is therefore saturated in respect of certain ions [i.e. the solubility of $Ca(HCO_3)_2$, $Mg(HCO_3)_2$, SiO_2 and Na_2CO_3 in a 16–18 per cent. NaCl solution]. Hence the deposits of " trona " ($NaHCO_3.Na_2CO_3$, $2H_2O$) and gaylussite ($Na_2CO_3.CaCO_3.5H_2O$) in the bed of the pan. Magnesium is present in the ordinary Red granite water in little more than traces.

The presence of numerous siliceous concretions in the bed of the pan, the work of siliceous organisms (diatoms), no doubt also accounts for the silica which was present in fair amount in the original water, but is present in the brine only in traces.

Wagner (36, pp. 106–107) suggests as an *alternative* theory to account for the high chloride in the caldera liquor, that the chloride may be cyclic, that it is derived from sea spray blown inland during gales. The author however contends that not only is this improbable on account of the distance from the nearest sea coast, but it is quite unnecessary as a theory, for, as shown in the above Table, a *relatively* high percentage chloride is a characteristic of all Red granite waters compared with the Old granite waters.

Further, appreciable soda is another characteristic of all Red granite waters which can therefore be described as chloro-soda carbonate waters. The very nature of the crater or caldera at Salt Pan would lend itself to enormous concentration of the normal underground water draining from the surrounding Red granite. It is contended therefore that the soda liquor in the caldera has originated by concentration from Red granite ground waters.

To revert to the general characteristics of Red granite waters, it was mentioned that they were very similar to those arising in the Alkali rocks of the Pilansberg. As in the case of the latter waters fluorides are always present in appreciable amount and for the same reasons, it may be assumed that the fluoride is present as sodium fluoride, for soda alkalinity is always present.

Nineteen of the samples of Red granite waters shown in Table 5 were tested for fluorides, but only one sample gave a blank In many cases the fluoride content is above the Public Health safety margin of 1 part F. per million. This is one of the striking characteristics of Red Granite waters.

The waters in the Old granite in the Transvaal occassionally show an appreciable fluoride content, but many samples do not show even a trace. The Old granite in the North-West Cape Province often gives rise to waters with an appreciable fluoride content.

(5) Pretoria Soda Pan, deep (" fresh water ") borehole No. 2, on South side of Caldera. (Anal. H. R. Blumenberg.)
(6) Thermal Spring in Red Granite, Warmbaths Sanatorium. (Anal. Govt. Lab., see sample 602, Table 5.)
(7) Borehole water in Red Granite, Warmbaths. (Anal. G. W. Bond, see sample 87, Table 5.)
(8) Borehole water in Red Granite, Petronella Siding, North of Pretoria. (Anal. G. W. Bond, see sample 328, Table 5.)
(9) Borehole in Red Granite, Langkraal, near Hamanskraal. (Anal. G. W. Bond, see sample 325, Table 5.)

No other formation in the Union, excepting the Pilansberg Alkali rocks, gives rise to water which so consistently contains fluoride. It has been mentioned that the Pilansberg Alkali rocks nearly always contain fluorite (as CaF) as an accessory mineral, thus accounting for the consistent fluoride content of the waters arising therein. A search through the literature has not yielded any mention of fluorite as a normal accessory mineral in the Red granite, and the writer has not found any fluorite in thin sections of normal Red granite he has examined microscopically. Apatite is however sometimes present as an accessory mineral and this may contain a little fluorine. Unfortunately as aforementioned, the published chemical analyses of Red granite and syenites do not give the fluorine content. In the two analyses made by the author fluorine was determined but was not found to be exceptionally high.*

Small segregations of fluorite are however known to exist in the Red granites, for example, the occurrence at Walmansthal No. 116, Pretoria District (65 Lombaard) and it is probable that these segregations are more common than realised.

It may be mentioned that a composite sample of the brine in the soda caldera was tested by the author and found to contain 355 parts F. per million.

The significance of the fluorine content of these and other waters in the Union is further discussed (Pages 169–170).

Silica is consistently high, averaging about 18 per cent. SiO_2 in terms of total salts, though in absolute amounts seldom exceeding 5·8 parts SiO_2 per 10^5. In this respect the Red granite waters resemble the Old granite waters in the Transvaal. In both the silica content is relatively higher than in any other waters. The probable reason for this has been given previously.

Sulphates are seldom present in any amount, the average being 2·0 per cent. SO_4. In many cases traces only are present.

Soda alkalinity is nearly always present averaging, as in the case of the alkaline waters from the Pilansberg, about 28 per cent. as Na_2CO_3 in terms of total salts. The fact that the pH. of these waters is on the low side (averaging 7·4) indicates that sodium bicarbonate rather than sodium carbonate is generally present.

Scale-forming salts form only about 25 per cent. (as $CaCO_3$) of the total salts and are restricted entirely to calcium and magnesium bicarbonates.

These waters have been allocated to the author's Alkaline Soda Carbonate Group D. Actually on account of the relatively higher chloride they would be more strictly classified as a sub-group, namely chloro-soda carbonate waters.

The industrial utilisation of these waters and the necessary chemical corrective treatment is dealt with under Group D.

It may be mentioned here that these waters, provided they a not polluted, can be used for all domestic purposes, except when t fluorine content exceeds 1 part F. per million. They can be used f watering stock and also for irrigation, since the absolute amounts soda are never above 20 parts Na_2CO_3 per 10^5.

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* Since the above was written, Dr. Wasserstein of the Union Geological Survey h trographically determined for the author the fluorine content a few samples of Bus granite from various parts of the Bushveld complex, and found fluorine to vary about .02 to 0.2 per cent. F.

VIII.—THE WATE
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II.—THE WATER IN THE BASIC AND ULTRA-BASIC PLUTONIC ROCKS OF THE BUSHVELD IGNEOUS COMPLEX.

This formation is, of course, of very great economic importance on account of the platinum, chrome, iron ore, magnetite, and magnesite deposits found therein, but from the viewpoint of this study it is not perhaps of such great importance since the region underlain by these basic plutonic rocks is essentially agricultural and is either sparsely populated or else native territory. However, the formation yields water with very strking chemical characteristics and is well worthy of study.

DISTRIBUTION AND RAINFALL.

The basic rocks form the basal zone of the Bushveld Igneous Complex, and occupy the rim of a basin which stretches from Sekukuniland and Steelpoort in the East to the Bechuanaland border in the West and from Potgietersrust in the North-East to Rustenburg and Pretoria North in the South. The rim of basic rocks varies from 5 to 20 miles in breadth but is considerably interrupted by coverings of younger formations and in the Central area by the Red or Bushveld granite.

The only important centres situated on these rocks apart from the chrome and platinum mines, are Rustenburg and Potgietersrust, and, of course, part of Pretoria North. A great deal of this area is native territory (i.e. in Marico and Rustenburg districts, and Sekukuniland).

The rainfall varies from 15″ to 25″ but in the far West along the Bechuanaland border and North of Zeerust it drops considerably below this.

GEOLOGY AND LITHOLOGY.

The formation has been divided into a number of "zones" according to the type of basic rock, but all these types except the extreme ultra basic kinds such as dunite (of very limited occurrence) are, from the point of view of this investigation, similar.

They vary from diabase, gabbros and granodiorite, bronzitite, anorthosites to chromitite, peridotite and dunite.

The chief types, however, are the norite and pyroxenites. As regards the former (37 Lombaard, p. 22) has suggested that the name "norite" is a misnomer and that such rocks should be termed "gabbros".

It is sufficient to state that these gabbroid rocks consist mainly of a mixture of the more basic plagioclase felspars, i.e. labradorite and anorthite, with pyroxene minerals (either diallage or bronzite or more rarely hypersthene) accompanied by a little magnetite. By decrease in the felspathic constituent these norites or gabbros pass into pyroxenites which are generally rather coarse grained aggregates of pyroxene minerals (diallage, enstatite, bronzite or hypersthene) with very little of the more basic plagioclase felspars, and some iron ore.

Less common are the peridotites, which are olivine-pyroxene rocks rich in magnesia. (One of the water samples, namely that from the well at Mooihoek Chrome Mine was taken from that zone). Dunite is much rarer and consists almost entirely of the mineral hortonolite (olivine rich in iron).

Since the chemical composition of these various rock types throws light on the strking chemical characteristics of the waters arising therein, ten typical analyses of the main types of basic rock are given on the next page.

ANALYSIS OF BASIC ROCKS FROM THE BUSHVELD COMPLEX.

Sample Numbers	1	2	3	4	5	6	7	8	9	10
SiO_2	52·00	52·5	50·38	55·40	41·20	34·25	50·0	51·52	52·55	37·7
TiO_2		0·15	0·23	0·10	0·25	0·05	0·25	0·44	0·40	0·05
Al_2O_3		6·90	4·47	1·60	1·20	1·45	6·00	17·10	5·85	1·05
Fe_2O_3	15·80	4·50	14·48	Nil	4·00	2·90	4·15	2·46	1·45	10·90
FeO		6·80		9·35	8·20	35·55	9·40	5·74	8·65	1·30
Cr_2O_3		0·45	1·43	0·65	3·20	0·10	0·55	—	—	1·6
MnO or Mn_3O_4	Trace	Nil	0·34	0·15	0·10	0·40	0·15	0·02	0·15	Trace
MgO	28·40	23·25	20·73	32·45	34·40	22·00	21·90	10·72	26·20	35·9
CaO	3·30	4·30	5·28	0·45	1·35	2·35	4·40	10·00	3·30	Trace
K_2O	0·15	Trace	—	Trace	0·30	0·20	Trace	0·20	0·65	Trace
Na_2O	0·30	0·45	—	Trace	0·20	Nil	1·25	1·70	0·90	0·10
P_2O_5	—	Trace	0·04	0·20	—	0·05	0·10	0·02	0·05	0·1
S	—	—	0·14	—	0·05	—	1·35	—	—	—
H_2O+	0·18	0·6	0·05	Nil	5·20	0·55	0·65	0·13	0·30	11·15
H_2O-		0·5	—	0·15	0·25	—	0·15	0·01	0·25	0·80
CO_2	—	Nil	1·04	Trace	—	Trace	0·15	—	—	—
NiO	—	—	0·26	0·15	0·35	Trace	0·40	—	—	Trace
CuO	—	—	—	—	—	—	0·14	—	—	—
TOTAL	100·13	100·50	—	100·60	100·20	99·85	101·49	100·06	100·70	100·65
Ratio CaO : MgO	1 : 8·6	1 : 5·4	1 : 3·9	1 : 14·3	1 : 28·5	1 : 9·0	1 : 4·9	1 : 1·07	1 : 8·0	1 : 36·8
Analyst	G.W. Bond	H. Weall	Krupps, Ltd.	H. Weall	J. Moir	H. Weall	H. Weall	H. Lombaard	H. Weall	H. Weall

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(1) Pyroxenite,
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Uitvalgron
(3) Composite
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(4) Bronzitite
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TOTAL	100·13	100·50	—	100·60	100·20	99·85	101·49	100·06	100·70	100·65
Ratio CaO : MgO	1 : 8·6	1 : 5·4	1 : 3·9	1 : 14·3	1 : 28·5	1 : 9·0	1 : 4·9	1 : 1·07	1 : 8·0	1 : 36·8
Analyst	G.W. Bond	H. Weall	Krupps, Ltd.	H. Weall	J. Moir	H. Weall	H. Weall	H. Lombaard	H. Weall	H. Weall

(1) Pyroxenite, Chrome Mine, Groothoek 171, district Lydenburg (near well from which water sample No. 414, Table 6, was obtained).
(2) Oxidised pseudoporphyritic pyroxenetic diallage norite, Uitvalgrond No. 334, Rustenbrug district.
(3) Composite sample of oxidised norite, Schilpadnest No. 233, Rustenburg district.
(4) Bronzitite on Jaglust 333, South side of Olifants River, Lydenburg district (In vicinity of water sample 413, Table 6).
(5) Harzburgite, Vlakfontein 902, Rustenburg district.
(6) Hortonolite Dunite, Onverwacht 330, Lydenburg district.
(7) Sulphidic Platiniferous Norite, Dwarsrivier No. 86, Lydenburg district.
(8) Spotted "Norite", Schaapskraal No. 442, Lydenburg district.
(9) Pyroxene-Olivine Norite, Vlaklaagte 511, Rustenburg district.
(10) Chromite-bearing Bastite Serpentine, Vlakfontein No. 902, Rustenburg district.

The chief characteristics of nearly all these rock types from the basic zone is the great preponderance of magnesium over calcium, the latter rarely exceeding 5 per cent. This preponderance is not so marked in the diabasic and gabbroic phases as it is in the pyroxenitic and still more basic types, in which the calcium may be as low as a trace. In the anorthositic types of norite the position may even be reversed. Taking the rocks as a whole, however, they are *essentially high in magnesium and very low in calcium*, and this, as will be shown, has a marked effect on the waters arising therein.

Another important characteristic is the very low alkali content of all these rocks, which rarely exceed 1 per cent. of the rock. This is due to the fact that not only are the felspars very limited in amount but they consist of the more basic types of plagioclase felspar, from labradorite (5·5 per cent. Na_2O) to anorthite (Na_2O = 0·0 per cent. formula $CaO.Al_2O_3\ 2SiO_2$). The latter (anorthite) is the commonest felspar present Lombaard (37, p. 36) though only in the pure anorthosite rocks is anorthite plagioclase present alone. This low $K_2O.Na_2O$ content of the rocks has also an important bearing on the underground waters.

These basic rocks, more particularly the gabbroid and pyroxenitic types, give rise to the typical "black turf" soils with a similar composition to the fresh rock Lombaard (37, pp. 48–50).

UNDERGROUND WATER SUPPLY.

There are hardly any perennial springs. As regards borehole supplies Du Toit (2, pp. 117-118) mentions that the hard speckled crystalline "norite" commonly displays fresh outcrops flush with the surface or with just a foot or two of soil, so that it is often difficult to pick a site free from solid rock, consequently borehole failures in this formation are many (usually over 45 per cent.). Supplies when found, are usually at shallow depths (less than 100 ft.) The quantity is generally well under 30,000 gallons. Du Toit points out that in the diabasic sheets associated with the norite far better results are obtained in spite of the fact that the rock itself is tough and hard. This is due to the greater depths of "weathering" compared with the other types.

The boreholes in the diabasic sheets are also shallow with an average yield of 25,000 gallons *per diem* though several boreholes gave yields of 50,000 gallons or over. Excepting the Marico district the percentage of failures in the diabasic sheets is low (about 15 per cent. on average).

QUALITY OF WATER.

As mentioned, there are no perennial springs on the basic rocks of the Bushveld complex, and borehole supplies are scanty except in the diabasic zones.

The author was therefore able to collect only 15 samples of well and borehole waters from the Marico, Rustenburg, Pretoria and Lydenburg districts of the Transvaal. The analyses are shown in Table 6. Many of these samples are from the pyroxenitic zones of the complex.

The concentration of salts varies but tends to be moderately high, averaging 44 parts per 10^5.

The pH. of these waters is quite consistent and on the high side, averaging 7·7.

The chief characteristic is the very high silica content which averages 15·8 per cent. on the total solids. This is extremely high and serves to differentiate them from nearly every other water. The only other formations yielding waters with such a high silica content are the granites, but the granitic waters are generally rich in Na_2CO_3 or $NaHCO_3$.

At first sight the high silica in the basic rocks may appear surprising for soda alkalinity is never present. Instead there is always a small amount of permanent hardness. Arising out of this fact and from a consideration of the total solids figures, the author suggests that the silica in these waters is not present as sodium silicates but as colloidal silicic acid (H_2SiO_3).

The consistently high silica content of these waters can be explained as follows :—

> Waters charged with CO_2 attack rocks rich in olivine, enstatite, serpentine, and other magnesium silicate minerals with the formation of magnesium bicarbonate and silicic acid. The reactions may be represented thus :—
>
> (1) $MgSiO_4 + 4CO_2 + 3H_2O = 2Mg(HCO_3)_2 + H_2SiO_3$.
> (Olivine)
>
> (2) $MgSiO_3 + 2CO_2 + 2H_2O = Mg(HCO_3)_2 + H_2SiO_3$.
> (enstatite)
>
> (3) $H_4Mg\,3Si_2O_9 + 3H_2O + 6CO_2 = 3Mg(HCO_3)_2 + 2H_2SiO_3$.
> (serpentine)

Similarly with other magnesium silicate minerals.

The small amount of basic plagioclase felspar present in the rock gives rise to $Ca(HCO_3)_2$.

The ground water thus contains much $Mg(HCO_3)_2$, a fair amount of colloidal silica, no Na_2CO_3 and but little $Ca(HCO_3)_2$. On being drawn up to the surface by capillary action the water tends to deposit $MgCO_3$ in the form of magnesite, mixed with opaline silica. As a rule the magnesite rubble contains very little $CaCO_3$.

In this manner the loose surface magnesite deposits are formed.

Two comparative analyses are shown on page 55 to illustrate th relationship between these surface magnesite deposits and the gro

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TABLE No. 6.—NORITE, PYROXENITE AND OTHER BASIC ROCKS OF "BUSHVELD COMPLEX".

Sample Numbers	413	414	415	307	304	303	302	305	329	79	427	445	452	491	538	Average
Parts $CaCO_3$ per 10^5 Water:																
Total Solids (at 105°)	43·2	45·0	44·7	24·0	19·0	21·0	20·0	45·0	39·0	24·0	97·6	51·6	87·5	51·0	55·2	44·0
Methyl Orange Alkalinity	31·7	42·0	42·5	20·0	10·0	12·7	13·8	39·0	29·0	17·0	53·0	46·5	46·3	43·0	56·5	—
Total Hardness	36·7	43·0	43·4	23·2	12·0	14·7	16·8	41·0	34·4	17·6	65·7	49·8	47·5	44·0	58·0	—
Permanent Hardness	5·0	1·0	0·9	3·2	2·0	2·0	3·0	2·0	5·4	0·6	12·7	3·3	1·2	1·0	1·5	—
Temporary Hardness	31·7	42·0	42·5	20·0	10·0	12·7	13·8	39·0	29·0	17·0	53·0	46·5	46·3	43·0	56·5	—
Hardness due to Ca Salts	5·0	4·2	1·7	3·2	1·2	1·5	2·4	16·0	12·6	2·0	6·7	3·3	9·1	7·7	1·2	—
Hardness due to Mg Salts	31·7	38·8	41·7	20·0	10·8	13·2	14·4	25·0	21·8	15·6	59·0	46·5	38·4	36·3	56·8	—
Soda Alkalinity	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	—
Parts per 10^5 of Water:																
Silica (as at SiO_2)	7·0	6·6	5·6	4·5	5·0	4·0	5·0	4·8	5·0	6·0	—	6·8	6·2	7·2	3·5	—
Fluorides (as F)	Under 0·01	0·02	Trace	Trace	Nil	Nil	Trace	Trace	Nil	—	0·04	Nil	Nil	—	Nil	..
Nitrites	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	—	Nil	*Trace	—	Nil	—
Nitrates (as NO_3)	0·9	Nil	—	Nil	1·2	1·4	2·8	1·0	Nil	0·8	*11·6	0·4	*12·0	—	Nil	—
Chlorides (as Cl)	3·6	1·4	1·4	1·9	1·4	2·5	1·4	2·3	3·0	1·4	9·9	1·4	(11·4)	3·0	0·4	—
Sulphates (as SO_4)	Trace	Trace	Trace	Trace	Trace	0·04	0·05	0·1	Trace	Trace	4·0	Trace	4·3	0·84	0·05	—
Potassium Salts	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	0·4	Under 0·5	Under 0·5	—	Under 0·5	—
pH. Values	7·6	7·2	8·0	7·2	8·0	7·9	7·6	7·3	7·5	7·4	7·9	7·9	8·0	—	8·0	7·7
Percentage on Total Solids:																
SiO_2	16·2	14·4	12·5	19·0	26·3	19·0	25·0	10·6	12·8	25·0	—	13·2	7·1	14·0	(6·3)	15·8
CaO	6·5	5·1	2·1	7·5	3·6	3·8	7·7	17·2	18·0	5·0	3·9	3·6	5·8	7·4	1·2	6·5
MgO	29·5	34·5	37·0	31·0	23·0	25·5	29·0	22·0	22·5	26·0	21·7	36·0	17·5	28·0	40·7	28·6
Cl	8·3	3·1	3·1	7·9	7·4	11·9	7·0	5·1	7·6	5·8	10·0	2·7	(13·0)	5·9	(1·07)	6·6
SO_4	Trace	Trace	Trace	Trace	Trace	0·20	0·3	0·2	Trace	Trace	4·1	Trace	4·9	1·6	0·10	0·8
Soda Alkalinity (as Na_2CO_3)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Total Hardness (as $CaCO_3$)	85·0	96·0	99·0	88·0	65·5	70·0	84·0	91·0	88·0	74·0	67·0	96·0	(54·0)	86·0	104·0	85·4
Perm. Hardness (as $CaCO_3$)	10·5	2·2	2·0	5·0	10·6	9·5	15·0	4·4	13·8	2·5	13·0	6·4	1·4	1·9	3·0	6·7
Temp. Hardness (as $CaCO_3$)	74·0	94·0	92·5	83·0	52·5	61·0	69·0	86·0	74·0	71·0	54·0	90·0	52·5	84·0	101·0	78·7
Ratio CaO : MgO	1 : 4·5	1 : 6·7	1 : 18·0	1 : 4·1	1 : 6·4	1 : 6·7	1 : 3·8	1 ; 1·3	1 : 1·3	1 : 5·2	1 : 5·6	1 : 10·0	1 : 3·0	1 : 3·8	1 : 34·0	1 : 4·4

* Indicates Pollution.

DESCRIPTION OF SAMPLES IN TABLE No. 6.

Sample No.	District and Province.	Borehole Depth.	Locality, Description and Remarks.	Date.
		Feet.		
491	Lydenburg, Transvaal	—	Borehole in Steelpoort. (Anal. Govt. Lab.) (diabasic zone)	1922
427	Lydenburg, Transvaal	—	Borehole near Steelpoort. (Dr. Ockerse's report. Anal. D.C.S.)	1941
413	Lydenburg, Transvaal	—	Well at Chrome Mine Jagdlust 333, near Olifants River	July, 1941
414	Lydenburg, Transvaal	—	Well at Union Corporation Chrome Mine, Groothoek 171	July, 9141
415	Lydenburg, Transvaal	120	Borehole at Mooihoek 147, near Steelpoort	July, 1941
79	Rustenburg, Transvaal	180	Borehole in Rustenburg, used at Power Station	16/ 3/39
307	Rustenburg, Transvaal	110	Borehole on Main Road to Rustenburg, 3 miles North of Commissie Drift	28/12/40
305	Rustenburg, Transvaal	—	Borehole, Stuurmanskraal (Doornspruit 878), 13 miles North of Rustenburg	28/12/40
304	Rustenburg, Transvaal	—	Borehole on Main Road to Hartebeestpoort, 3 miles East of Kroondal	17/12/40
303	Rustenburg, Transvaal	160	Borehole, 7 miles South-East of Marikana on Main Road to Dam	17/12/40
302	Pretoria, Transvaal	120	Borehole, 5 miles West of Hartebeestpoort Dam on Main Road to Rustenburg. (Residence J. Pienaar)	17/12/40
329	Pretoria, Transvaal	120	Borehole, residence 1¼ miles North of Wonderboom	4/ 3/41
445	Krantzberg, Transvaal (N.W. Rustenburg)	—	Borehole at Swartkop Chrome Mines, 13 miles North of Northam	27/10/41
452	Potgietersrust, Transvaal	—	Borehole in Potgietersrust, West of Station	28/10/41
538	Marico, Western Transvaal	—	Spring on Brakfontein 307, North of Zeerust	9/ 5/42

Sample 1.—*Magnesite rubble* from Steelpoort Valley West of enburg.

The analysis was the average of 10 samples, while the sample of water was from the same vicinity. There is 92·0 per cent. $MgCO_3$ present in the rubble and a small amount of opaline silica.

Sample 2.—Surface magnesitic deposit from Brakfontein 307, North of Zeerust, Marico District (analysis on dry basis). This deposit was in the immediate vicinity of a spring, the analysis of which is given for comparison.

The water in both the above samples consisted mianly of magnesium bicarbonate and collidal silica.

	Sample No. 1.		Sample No. 2.	
	Deposit Percentage.	Water Percentage on Total Solids.	Deposit Percentage.	Water Percentage on Total Solids.
SiO_2	4·6	14·0	18·0	6·3
$Fe_2O_3.Al_2O_3$	0·9	—	6·20	—
CaO	1·9	7·4	0·36	1·2
($CaCO_3$)	(3·38)	(13·0)	(0·64)	(2·15)
MgO	43·8	28·0	41·50*	40·7
($MgCO_3$)	(92·0)	(59·0)	(63·5)	(84·0)
Cl	Nil	5·9	Nil	1·07
SO_3	Nil	1·3	Nil	0·10
CO_2	48·5	37·0	33·5	44·0
Na_2CO_3	Nil	Nil	Nil	Nil
TOTAL	99·7	—	99·56	—
Ratio CaO : MgO	1 : 23·0	1 : 3·5	1 : 115·0	1 : 34·1
Analyst	J. Gray.	Gov. Lab.	G. W. Bond.	G. W. Bond.

* Some of the magnesium in this deposit is combined as magnesium silicate.

Another striking feature of the waters from the basic zone of the complex is the high temporary hardness, averaging 78 per cent. of the total salts, while the total scale-forming compounds average 85 per cent. In this respect the waters resemble the dolomite waters to be described hereafter, and which are also of the temporary hard type. There is however, a distinct difference, for the dolomite waters are composed of an almost equal amount of calcium and magnesium bicarbonate, whereas the waters from the basic plutonic rocks of the Complex consist almost entirely of magnesium bicarbonate plus silica. (In the dolomite waters the ratio of CaO : MgO is 1 : 0·9, but in the latter the average ratio is 1 : 4·4. In one case the ratio is 1 : 18·0).

The great preponderance of MgO over CaO in the waters is to be expected for the reasons previously shown.

Chlorides are consistently low, averaging only 6·6 per cent. of the total solids. In only one sample (No. 452) was the Cl figure at all high and here pollution was obvious from the high nitrate and nitrite figures.

Sulphates are exceedingly low, averaging only 0·8 per cent. The small permanent hardness present must therefore be due to the chlorides of magnesium.

The fact that there is never any soda alkalinity is not surprising in view of the low alkali ($K_2O.Na_2O$) content of the basic and ultra-basic rocks, as brought out in the rock analyses cited.

Since 78 per cent. of these waters consist of temporary hardness salts, they have been allotted to the author's carbonate (temporary hard) Group " C " and their utilisation and chemical treatment will be dealt with under that group (Section XXV).

It must be emphasised, however, that, since these waters have such a comparatively high silica content and further consist mainly of magnesium carbonate they offer special difficulties in treatment for certain purposes. They can be used for all domestic and agricultural purposes and, after appropriate treatment, for steam raising, locomotive engine water and for general industrial purposes.

Like other temporary hard waters in Group C. the high bicarbonate hardness of these waters mitigates against their use as a cooling water unless treated.

The above investigation into the ground waters of the Basic Zone of the Bushveld Complex should prove of interest since there appears to be little or nothing in the overseas literature regarding the nature of ground waters arising in basic plutonic rocks.

Even Clarke in his classic " Data of Geochemistry " (43, p. 580) gives no analyses of such waters, but refers to the action of carbonated waters on peridotites and serpentines as producing *magnesium bicarbonate and opaline silica.*

Lindgren (35, p. 42) states that where magnesium rich rocks abound the underground waters are richer in magnesia than usual, and this substance *may even equal the calcium.* No reference is made to high silica content, and no analyses are given.

IX.—THE WATERS IN THE ROCKS OF THE WITWATERSRAND SYSTEM.

Although the Witwatersrand system is of such vast economic importance on account of the auriferous conglomerate beds in its upper horizons, it is of very little importance from the point of view of this study. This is on account of the fact that the system is restricted to the Witwatersrand, though there are small outcrops of these rocks in the Klerksdorp, Heidelberg, Greylingstad and Vredefort areas.

Further, the whole Witwatersrand area is supplied through the Rand Water Board systems with treated water from the Vaal River and therefore the underground water is of little interest to industry as a source of supply except to one or two breweries which utilise the borehole water from the lower Witwatersrand shales, that water being particularly suitable since it contains $CaSO_4$ and has a moderate hardness.

The comparatively few boreholes in existence are mainly located in the lower horizons of the Witwatersrand formation and are often polluted. Boreholes situated in the upper division of the Witwatersrand system are almost invariably contaminated with mine waters.

Furthermore, boreholes in the central part of the city of Johannesburg from Braamfontein to Doornfontein and Bezuidenhout Valley are not located in the Witwatersrand rocks, but in the Ventersdorp lavas. The numerous boreholes in the Northern suburbs are in the Old granite, and these yield very pure water.

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On account of these facts the author has not studied in detail waters arising from the Witwatersrand rocks. However as a matter interest, 13 analyses (mainly incomplete) from the lower horizons the system are shown in Table No. 8, and these indicate that the waters from the shale zones are comparatively pure, while those from the quartzite beds are exceptionally pure. (Average concentration salts for both zones is under 11 parts per 10^5).

As is the case with all pure waters, the pH. is always on the low side.

The total hardness is never high, and permanent-hardness generally exceeds the temporary hardness.

The waters fall into the author's pure waters Group E.

X.—THE WATERS IN THE VENTERSDORP VOLCANIC SYSTEM.

The waters arising in this formation are of some importance to this study, for the rocks of this system underlie very large farming districts, and there are also a fairly large number of small towns located on the formation.

DISTRIBUTION AND RAINFALL.

The formation can be divided into several regional groups:—

	Annual Rainfall.
(*a*) *Northern Cape Province*—	
The Barkly West, Kimberley, Herbert, Hopetown, Mafeking and Vryburg districts....	10″–15″
(*b*) *Western Transvaal*—	
The Schweizer Reneke, Christiana, Bloemhof, Wolmaransstad, Klerksdorp, Lichtenburg and Ventersdorp districts..............	15″–25″
(*c*) *The Johannesburg District*—	
This includes the Klipriversberg hills South of Johannesburg, and a narrow strip through the Central part of Johannesburg, from Braamfontein to Bezuidenhout Valley and also Kempton Park...............	30″–35″
(*d*) *Heidelberg District*—	
The area West of Heidelberg, known as the Suikerboschrand, and to the South-East including Balfour and Greylingstad......	30″–35″
(*e*) *A small patch in the North-Eastern Marico District.*	

GEOLOGY AND LITHOLOGY.

This volcanic system has been divided into a Lower or Zoetlief series and an Upper or Pniel (Ventersdorp) series.* In this study no differentiation has been made between the two series though the large majority of waters shown in Table 8 come from the Upper or Pniel series.

The Zoetlief series consists mainly of acid volcanic rocks such as quartz-porphyries, though there are some amygdaloidal trachytes and andesites, as well as volcanic tuffs, breccias, quartzites and shales.

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* Recent investigation by the Geological Survey indicate that the Zoetlief series is a much older formation and is unconformably overlain by the Ventersdorp system.

The rocks of the Ventersdorp system that overlie the Zoetlief series are predominantly of basic lavas, volcanic tuffs and breccias with tuffaceous quartzites, grits and so on. There are but a few acid lavas. From the point of view of this study the chief characteristic is the basic or intermediate nature of the igneous rocks and tuffs.

The lavas are generally blue or green diabasic types, in some places highly amygdaloidal, the vesicles mainly filled with quartz or chalcedony, the latter being red or vermilion coloured. The felspar is generally a plagioclase, usually very much altered and often porphyritic, while the ferro magnesian mineral is augite, also usually highly altered to uralite, chlorite, etc.

The lavas produce a red loamy soil, which in the more arid regions, is covered by calcareous tufa.

The tuffs and breccias consist of fragments of lavas and rock fragments from older rock formations with a matrix of much decomposed igneous material, of a basic nature.

Only two or three analyses of the Ventersdorp Amygdaloidal Lavas appear in the literature, while there are no analyses of the Ventersdorp breccias and tuffs.

These analyses are given below together with three recent analyses made by the author of breccias and tuffs.

ANALYSIS OF VENTERSDORP AMYGDALOIDAL LAVAS.

	1	2	3	4	5
SiO_2	53·00	54·85	63·64	55·38	63·84
TiO_2	—	0·95	—	—	—
Al_2O_3	19·70	15·15	22·98	—	—
Fe_2O_3	10·93	1·30	—	28·62	24·20
FeO	2·88	9·60	—	—	—
MnO	Trace	—	0·10	0·06	—
MgO	4·0	4·30	3·25	3·62	5·85
CaO	7·20	7·80	4·00	8·40	2·75
K_2O	0·79	1·50	1·30	0·98	1·63
Na_2O	0·82	3·05	1·87	1·65	(by diff.)
P_2O_5	Trace	—	—	—	—
Cl	—	—	—	0·03	0·07
FeS_2	0·25	—	—	—	—
H_2O+	—	1·40	1·98	0·10	0·02
H_2O-	—	—	—	0·58	1·64
CO_2	—	—	1·20	0·24	—
TOTAL	99·57	99·80	100·22	99·66	100·00
CaO : MgO	1 : 0·55	1 : 0·55	1 : 0·8	1 : 0·43	1 : 2·1
Analyst	B. Bay.	J. McCrae.	G.W. Bond	G.W. Bond	G.W. Bond

(1) Amygdaloidal Diabase, Klipriversberg Hills, 3 miles South of Johannesburg.

(2) Lava, Carsonville, Heidelberg District.

(3) Volcanic Breccia, on farm Elandskuil 110, 5 miles South of Ventersdorp, on road to Klerksdorp (in vicinity of borehole water sample No. 365, Table 8).

(4) Amygdaloidal Diabase, Olifantsvlei 16, 19·8 miles South of Johannesburg (outcrop not far from water sample 197).

(5) Tuff from a borehole, Rietfontein 18, 7 miles North-West of Benoni.

SHALE

Sample 1211		5
Part		
Methyl (	5·2	1
Total H	12·2	10
Permane	7·0	8
Tempora	5·2	1
Hardnes	5·2	3
Hardnes	7·0	6
Soda All	Nil	N
P		
Total so	18·0	16
Silica (a	2·5	0
Fluoride	—	—
Nitrites.	—	Tra
Nitrates	—	6·
Chloride	2·4	1·
Sulphate	Small mount	1·
Potassiu	—	—
pH. Val	—	5·
Per		
SiO_2....	13·8	5·
CaO....	16·0	11·
MgO....	16·0	17·
Cl.......	13·2	8·
SO_4....	Trace	10·
Soda All	Nil	Nil
Total H	67·5	63·
Perm. H	40·0	55·
Temp. F	27·5	8·
Ratio Ca	: 1·0	1 : 1

TABLE No. 8.—WITWATERSRAND SYSTEM.

	Quartzite Zones.							Shale Zones.						
Sample Numbers	128	218	227	554	577	578	579	580	127	211	551*	556*	562	Average
Parts $CaCO_3$ per 10^5 Water :														
Methyl Orange Alkalinity	5·0	0·3	0·5	5·0	0·5	4·0	3·0	3·0	7·5	5·2	1·5	1·3	1·0	—
Total Hardness	8·2	1·0	1·6	5·5	0·5	6·0	5·0	2·5	4·5	12·2	10·3	11·6	4·3	—
Permanent Hardness	3·2	0·7	1·1	0·5	Nil	2·0	2·0	Nil	Nil	7·0	8·8	10·3	3·3	—
Temporary Hardness	5·0	0·3	0·5	5·0	0·5	4·0	3·0	2·5	4·5	5·2	1·5	1·3	1·0	—
Hardness due to Ca Salts	3·6	0·2	0·5	—	—	—	—	—	2·2	5·2	3·4	—	1·2	—
Hardness due to Mg Salts	4·6	0·8	1·1	—	—	—	—	—	2·3	7·0	6·9	—	3·1	—
Soda Alkalinity	Nil	Nil	Nil	Nil	Nil	Nil	Nil	0·5	3·0	Nil	Nil	Nil	Nil	—
Parts per 10^5 of Water :														
Total solids at (105°C)	14·3	5·5	6·0	9·0	2·9	8·5	7·0	10·0	11·0	18·0	16·0	21·0	10·8	10·8
Silica (as at SiO_2)	1·5	0·6	0·5	1·0	—	—	—	—	1·2	2·5	0·8	—	0·3	—
Fluorides (as F)	Nil	Nil	Nil	—	—	—	—	—	Nil	—	—	—	—	—
Nitrites	Nil	Nil	Nil	Nil	Nil	Nil	0·004	Nil	Nil	—	Trace	0·007	Nil	—
Nitrates (as NO_3)	1·6	0·08	Trace	Trace	0·1	Nil	0·15	Trace	Trace	—	6·4	2·5	1·1	—
Chlorides (as Cl)	0·9	0·7	0·9	1·01	0·4	0·3	0·6	0·1	0·8	2·4	1·3	3·6	1·4	—
Sulphates (as SO_4)	1·2	Trace	Trace	0·2	Trace	Trace	0·2	0·05	Trace	Small Amount	1·7	0·2	1·2	—
Potassium Salts (as K)	Trace	Trace	Trace	—	—	—	—	—	Trace	—	—	—	—	—
pH. Values	7·0	6·9	7·0	6·9	—	—	—	—	7·3	—	5·6	—	—	6·9
Percentage on Total Solids :														
SiO_2	10·3	10·9	8·4	11·1	—	—	—	—	11·1	13·8	5·0	—	2·95	—
CaO	14·0	2·0	1·7	—	—	—	—	—	11·2	16·0	11·8	—	6·3	—
MgO	12·3	5·5	7·3	—	—	—	—	—	8·2	16·0	17·2	—	11·4	—
Cl	6·2	12·7	15·0	11·2	3·4	3·5	8·5	1·0	7·3	13·2	8·1	17·0	13·0	—
SO_4	Trace	Trace	Trace	2·2	Trace	Trace	2·85	0·5	Trace	Trace	10·6	0·94	11·1	—
Soda Alkalinity (as Na_2CO_3)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	5·0	29·3	Nil	Nil	Nil	Nil	—
Total Hardness (as $CaCO_3$)	56·0	18·0	26·5	61·0	17·2	70·0	71·0	25·0	41·0	67·5	63·0	54·5	40·0	—
Perm. Hardness (as $CaCO_3$)	22·0	12·8	18·2	5·6	Nil	23·2	28·5	Nil	Nil	40·0	55·0	49·5	21·3	—
Temp. Hardness (as $CaCO_3$)	34·0	5·2	8·3	55·4	17·2	46·8	42·5	25·0	41·0	27·5	8·0	5·0	9·3	—
Ratio CaO : MgO	1 : 0·9	1 : 2·7	1 : 4·3	—	—	—	—	—	1 : 0·7	1 : 1·0	1 : 1·45	—	1 : 1·8	—

* Polluted.

DESCRIPTION OF SAMPLES IN TABLE No. 8.

Sample No.	District and Province.	Borehole Depth.	Locality, Description and Remarks.	Date.
		Feet.		
218	Heidelberg, Transvaal.....................	—	Borehole, 2·5 miles West-South-West of Heidelberg on road to Vereeniging. (Lower Quartzites)..........................	15/ 9/40
227	Roodepoort, Transvaal....................	—	Borehole, ½-mile South of Roodepoort Station, on Main Reef Road. (Quartzites).....................................	10/11/40
128	Johannesburg, Transvaal..................	—	Borehole, residence of Mr. A. M. Jacobs, Westcliff, Johannesburg. (Orange Grove Quartzites)............................	18/12/39
554	Johannesburg, Transvaal..................	—	Borehole, Upper Linksfield, Johannesburg. (Orange Grove Quartzites)...	27/ 7/35
577	Johannesburg, Transvaal..................	—	Borehole, on Stand 848/9 Rosettenville. (Upper Quartzites.) (Anal. Govt. Lab., Johannesburg)........................	7/ 7/33
578	Johannesburg, Transvaal..................	—	Borehole, Lower Houghton Ridge. (Orange Grove Quartzites.) (Anal. Govt. Lab., Johannesburg)........................	30/ 8/33
579	Johannesburg, Transvaal..................	—	Borehole, Berea. (Hospital Hill Quartzites.) (Anal. Govt. Lab., Johannesburg)..	6/ 4/34
580	Johannesburg, Transvaal..................	—	Borehole, on Stand 2003. (Shales?) (Anal. Govt. Lab., Johannesburg)..	23/ 2/34
127	Johannesburg, Transvaal..................	—	Borehole, residence W. Tredre, Parktown. (Hospital Hill Slates)	11/12/39
211	Johannesburg, Transvaal..................	—	Borehole, Ohlsson's Breweries. (Hospital Hill Slates.) (Anal. McLachlan & Lazar)....................................	11/10/38
551	Johannesburg, Transvaal..................	—	Well in Saratoga Avenue, Doornfontein. (Govt. Reef Series)..	June, 1942
550	Johannesburg, Transvaal..................	—	Borehole, Walter Mansions, Eloff Street. (Jeppestown Shales.) (Anal. Govt. Lab., Johannesburg)........................	March, 1941
562	Johannesburg, Transvaal..................	—	" South " Borehole, General Hospital, Johannesburg. (Hospital Hill Slates.) (Anal. Govt. Lab., Johannesburg)............	3/ 3/34

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As far as this study is concerned the chief point of interest in the rock analyses, is the general predominance of CaO over MgO and the low K_2O and Na_2O content. The low alkali content of the volcanic tuffs and breccias is to be expected owing to the decomposed nature of the matrix of these rocks and their detrital origin. A higher alkali content in the basic lavas might be anticipated in view of the fact that labradorite plagioclase felspar is present, but, as aforementioned, the felspar in these rocks is not fresh and is usually much altered. As will be shown later, both the CaO : MgO ratio and the generally low alkali content of these rocks have a bearing on the composition of the waters derived from them.

UNDERGROUND WATER SUPPLIES.

In the Zoetlief series, which is limited in extent and mainly confined to the Vryburg district and consists, as already mentioned, of massive tough acid (rhyolitic) lavas, the supplies of ground water are very poor (about 11,000 gallons *per diem*) and the percentage of failures very high (about 31 per cent.) according to Du Toit (2, p. 107) and Frommurze (3, p. 53).

On the other hand, the Ventersdorp system proper is regarded as an extremely important water-bearing formation.

Except for a few hills like the Klipriversberg and Suikerboschrand, the Ventersdorp basic lavas and the pyroclastic rocks give rise to flat country, and "run off" is consequently very low. This flat country has been extensively drilled, consistently furnishes water at shallow depths, and drilling is fairly cheap. Dut Toit (2, p. 108) furnishes the following average figures :—

> Yield 21,000 gallons *per diem* at depths of about 70′–95′, with 15 per cent. failures.

Du Toit mentions that there are a few boreholes with capacities of over 75,000 gallons *per diem*.

QUALITY OF WATER.

As already stated, the majority of the samples are drawn from areas underlain by the basic lavas and volcanic breccias, and to a less extent by volcanic tuffs.

17 water samples have been taken from the following districts :—

Kimberley,
Barkly West,
Mafeking,
Bloemhof,
Wolmaransstad,
Lichtenburg,
Klerksdorp,
Ventersdorp,
Heidelberg,
Germiston,
Johannesburg.

The formation therefore has been well covered (Table 9).

The concentration of salts is moderately low, averaging about 37 parts per 10^5 and is fairly consistent, though, as would be expected the concentration of salts shows a tendency to rise in the more Westerly regions, which as already indicated, have a low rainfall. In no case however, was the concentration of salts very high. (The maximum was 69 parts per 10^5).

Silica is never high and expressed in terms of the total salts is very consistent, averaging 8·5 per cent. SiO_2.

Chlorides are very seldom high even in the more arid westerly districts of the Union. Expressed as a percentage the content is consistent averaging only 7·4 per cent. Cl.

This figure is interesting for in the Western Transvaal and Northern Cape Province "outliers" of Dwyka tillite give rise to "salt pans" which contain highly saline waters (brine) in which the chlorides are extremely high, and the sulphates high.

Boreholes sunk in the Ventersdorp lavas surrounding these pans, strike fresh water which is relatively free from chlorides and sulphates.

In fact, in one of the salt pans at Britten there is even the phenomenon of a number of boreholes sunk in the pan yielding strong brine solutions, while another, but deeper borehole, in the same pan yields fresh water. The explanation of course, is that the shallow boreholes are all in Dwyka tillite, while the deeper borehole obtains its water supply from the underlying Ventersdorp lavas.

In the author's opinion the above facts refute the theory that the salinity of the Dwyka waters is due to windborn salts from the ocean.

This matter is discussed however, when dealing with Dwyka waters.

Sulphates are nearly always low, and average only 2·6 per cent. SO_4 in terms of total solids.

Fluorides are occasionally found in very small amounts, but generally the Ventersdorp waters yield blanks or mere traces. The highest figure found was only 0·5 parts per million.

In nearly every case calcium exceeds magnesium, the average ratio being 1 : 0·78. This is not surprising, for as already shown, the Ventersdorp rocks show more calcium than magnesium. Sodium carbonate or bicarbonate is seldom present. Instead there is generally a small permanent hardness, which averages 4·9 per cent. of the total salts.

Now it will be shown in a subsequent section that the waters rising in the amygdaloidal basalts of the Stormberg System are characterised by their high sodium carbonate or bicarbonate content. These rocks also contain labradorite and other "soda" plagioclase felspars.

At first sight it is somewhat surprising to find that large numbers of waters from the somewhat similar Ventersdorp amygdaloidal lavas show no soda alkalinity. The writer offers the following explanation :—

> In the Stormberg amygdaloidal lavas, the felspars are generally fairly fresh so that there is more fresh and decomposable material from which the carbonated waters can leach out the alkalis. (This also applies to the Karroo Dolerites). On the other hand, in the Ventersdorp lavas, we are dealing with a very ancient rock system, infinitely older than the Stormberg basalts, and, as already mentioned, both the augite and the plagioclase felspars in the Ventersdorp lavas are generally highly altered, so that the present alkali content, as shown is low. (Compare the analyses of Ventersdorp rock, given previously with those of the Stormberg lavas shown later). Another fact is that the vesicles in the Ventersdorp lavas are generally filled with quartz or chalcedony while in Stormberg lavas the vesicles are quite often filled with soda-rich zeolite minerals. Furthermore some of the Stormberg basalts carry the soda-rich mineral nepheline.

The total scale-forming compounds in the Ventersdorp waters are very high averaging 74 per cent. $CaCO_3$ while the temporary hardness compounds, $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$ average 67·4 per cent. $CaCO_3$.

Sam	99	334
Met	33·0	10·0
Tot	34·9	10·2
Per	1·9	0·2
Tem	33·0	10·0
Har	14·0	2·6
Har	20·9	7·6
Sod	Nil	Nil
Tot	40·8	20·0
Silic	1·6	2·1
Flu	Nil	Nil
Nit	Nil	Nil
Nit	0·8	0·4
Chl	1·9	3·0
Sul	2·0	0·05
Pot	—	Under 0·5
pH.	8·2	7·6
SiO	3·9	10·5
CaC	19·0	(7·3)
Mg	20·0	15·0
Cl..	4·6	15·0
SO_4	5·1	0·3
Sod	Nil	Nil
Tot	85·0	52·0
Per	4·0	2·0
Ten	80·0	50·0
Rat	: 1·06	1 : 2·0

TABLE No. 9.—VENTERSDORP SYSTEM.

Sample Numbers	367	366	359	400	370	371	365	363	198	193	136	99	334	212	192	197	555	Average
Parts $CaCO_3$ per 10^6 Water:																		
Methyl Orange Alkalinity	24·0	9·5	28·7	38·0	24·0	22·0	11·5	31·5	32·3	34·5	24·0	33·0	10·0	6·5	22·7	18·5	6·7	—
Total Hardness	25·0	9·2	31·8	43·0	22·7	18·1	12·5	32·0	35·0	38·4	22·8	34·9	10·2	8·4	30·0	19·2	6·7	—
Permanent Hardness	1·0	Nil	3·1	5·0	Nil	Nil	1·0	0·5	2·7	3·9	Nil	1·9	0·2	1·9	7·3	0·7	Nil	—
Temporary Hardness	24·0	9·2	28·7	38·0	22·7	18·1	11·5	31·5	32·3	34·5	22·8	33·0	10·0	6·5	22·7	18·5	6·7	—
Hardness due to Ca Salts	13·4	5·0	16·2	26·5	11·4	9·1	5·0	13·2	13·5	17·7	11·4	14·0	2·6	3·9	13·2	9·6	3·3	—
Hardness due to Mg Salts	11·6	4·2	15·6	16·5	11·3	9·0	7·5	18·8	21·5	20·7	11·4	20·9	7·6	4·5	16·8	9·6	3·4	—
Soda Alkalinity	Nil	0·8	Nil	Nil	1·4	4·0	Nil	Nil	Nil	Nil	1·3	Nil	Nil	Nil	Nil	Nil	Nil	—
Parts per 10^6 of Water:																		
Total Solids (at 105°)	27·4	(12·2)	44·0	69·0	31·0	25·6	16·1	41·0	53·0	50·8	30·0	40·8	20·0	(13·0)	43·0	24·6	(10·0)	37·3
Silica (as SiO_2)	1·2	1·4	3·0	—	2·0	2·0	1·6	4·5	4·9	3·9	3·0	1·6	2·1	1·6	3·6	2·2	1·2	—
Fluorides (as F)	0·02	Trace	Trace	0·03	0·01	Trace	Nil	0·05	—	Trace	Nil	Nil	Nil	Nil	Nil	Nil	Nil	—
Nitrites	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	—	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	—
Nitrates (as NO_3)	0·4	Nil	3·2	Nil	0·8	Nil	0·6	0·8	4·1	0·3	1·2	0·8	0·4	0·14	1·4	1·6	0·64	—
Chlorides (as Cl)	2·5	1·8	3·2	9·9	1·4	0·9	2·5	2·1	5·1	7·0	1·8	1·9	3·0	1·0	4·2	1·8	0·2	—
Sulphates (as SO_4)	0·6	0·1	2·0	2·1	1·9	0·02	0·04	1·0	2·6	4·0	0·6	2·0	0·05	0·1	0·1	6·6	0·04	—
Potassium Salts (as K.)	Under 0·5	Under 0·5	Under 0·5	0·3	Under 0·5	Under 0·5	—	Under 0·5	—	Under 0·5	—	—	Under 0·5	Trace	Under 0·5	Under 0·5	Trace	—
pH. Values	8·0	7·3	8·0	7·4	8·4	7·9	7·5	7·7	—	7·3	7·4	8·2	7·6	7·0	8·0	7·7	(6·7)	7·7
Percentage on Total Solids:																		
SiO_2	4·4	11·2	6·8	—	6·4	7·8	10·0	11·0	9·2	6·9	10·0	3·9	10·5	12·3	8·3	9·0	12·0	8·4
CaO	27·3	22·8	21·0	21·5	20·5	20·0	17·5	18·0	14·1	17·5	21·5	19·0	(7·3)	16·5	17·0	21·8	18·5	19·7
MgO	17·0	13·8	14·0	9·6	14·5	14·0	18·8	18·2	13·3	14·2	15·3	20·0	15·0	13·8	21·0	15·6	13·6	15·4
Cl	9·1	(14·6)	7·3	(14·2)	4·5	3·5	(15·5)	5·1	9·6	12·3	6·0	4·6	15·0	7·7	9·7	7·3	2·0	7·4
SO_4	2·1	0·8	4·6	3·1	5·8	0·08	0·25	2·4	5·0	6·9	2·0	5·1	0·3	0·8	0·2	(27·0)	0·4	2·6
Soda Alkalinity (as Na_2CO_3)	Nil	6·5	Nil	Nil	4·5	15·5	Nil	Nil	Nil	Nil	4·3	Nil	Nil	Nil	Nil	Nil	Nil	—
Total Hardness (as $CaCO_3$)	91·0	75·0	72·0	63·0	73·5	70·0	78·0	78·0	66·0	68·0	76·0	85·0	52·0	65·0	70·0	77·2	67·0	74·0
Permanent Hardness (as $CaCO_3$)	3·6	Nil	7·0	7·2	Nil	Nil	6·2	1·2	5·1	6·9	Nil	4·0	2·0	(14·3)	(16·8)	2·8	Nil	3·1
Temporary Hardness (as $CaCO_3$)	87·0	75·0	65·0	55·0	73·5	70·0	71·0	76·0	61·0	61·0	76·0	80·0	50·0	50·0	53·0	74·0	67·0	67·3
Ratio CaO : MgO	1 : 0·6	1 : 0·6	1 : 0·7	1 : 0·45	1 : 0·7	1 : 0·7	1 : 1·0	1 : 1·0	1 : 0·9	1 : 0·8	1 : 0·7	1 : 1·06	1 : 2·0	1 : 0·8	1 : 1·2	1 : 0·7	1 : 0·7	1 : 0·78

DESCRIPTION OF SAMPLES IN TABLE No. 9.

Sample No.	District and Province.	Borehole Depth.	Locality, Description and Remarks.	Date.
		Feet.		
367	Bloemhof, Transvaal	140	Borehole at Bloemhof	June, 1941
359	Barkly West, Cape Province	58	Borehole at Warrenton	June, 1941
400	Lichtenburg, Transvaal	—	Borehole at Delareyville. (Anal. Onderstepoort)	—
370	Wolmaransstad, Transvaal	—	Borehole on farm Palmietfontein 91, 15 miles East of Wolmaransstad on Main Road to Klerksdorp	June, 1941
366	Wolmaransstad, Transvaal	90	Borehole on Wolmaransstad Townlands, 3 miles West of Town	June, 1941
136	Wolmaransstad, Transvaal	60	Borehole in Wolmaransstad	18/12/39
371	Klerksdorp, Transvaal	120	Borehole near Klerksdorp, 7 miles West, on farm Wolverand 55	June, 1940
365	Ventersdorp, Transvaal	190	Borehole, 5 miles South of Ventersdorp, on farm Elandskuil 110	June, 1941
363	Barkly West, Cape Province	160	Borehole on Main Road to Kimberley, 2·5 miles North of Koedoe Siding	June, 1941
198	Mafeking, Cape Province	200	Borehole in Mafeking, Wallace, Proceedings S.A. Society of Civ. Eng., Vol. 14. (Anal. ?)	1916
193	Kimberley, Cape Province	89	Borehole on farm de Kranz, 12 miles West-North-West of Modder River	29/ 7/40
99	Ventersdorp, Transvaal	110	Borehole in Ventersdorp	3/10/39
334	Heidelberg, Transvaal	100	Borehole on Main Durban Road, 8 miles South-East of Balfour	18/ 3/41
212	Germiston, Transvaal	95	Borehole on Main Road to Heidelberg, 1¼ miles South of Alberton	1940
192	Johannesburg, Transvaal	—	Borehole on farm Cosynook, Comptonville, 7 miles South-West of Johannesburg	30/ 7/40
197	Johannesburg, Transvaal	112	Borehole on farm Olifantsvlei 16, Klipriviersberg, 9 miles South of Johannesburg	30/ 7/40
555	Johannesburg, Transvaal	—	Borehole, Bezuidenhout's Farm, Bezuidenhout Valley, Johannesburg	28/ 7/42

These waters can be classified therefore as carbonate waters mporary hard waters) and the chemical treatment required to der them suitable for industrial and electrical power production poses is discussed under Group C.

It may be stated here that the majority of these waters can be used for all domestic purposes, watering live stock, and irrigation purposes.

XI.—THE WATERS IN THE DOLOMITE SERIES OF THE TRANSVAAL SYSTEM IN THE TRANSVAAL AND NORTHERN CAPE PROVINCE.

The Dolomite series is of great economical importance, as it is a great water carrier, and for this reason the author has devoted a considerable amount of study to the waters arising in this formation.

Distribution and Rainfall.

The Dolomite series covers large areas in the Western and Central Transvaal and to a smaller extent in the Eastern Transvaal. It forms the rim of a large basin encircling the Bushveld region, and stretches from near Mafeking in the West to Pilgrims Rest, Sabie and Carolina in the East. The North-Western and South-Eastern sections are obscured by coverings of younger rocks. A smaller belt stretches from Potchefstroom to Vereeniging. Large areas of the Northern Cape, namely the Kuruman, Taungs, Barkly West, Herbert and Hay districts are underlain by Dolomite (whilst the limestone beds of the Malmesbury series of the Cape have been correlated with the Dolomite). The only important towns or villages lying in the Dolomite are Kuruman, Postmasburg, Griquatown, Campbell, Taungs, Lichtenburg and Potgietersrust, but Mafeking and Pretoria derive their water supply from the Dolomite.

The annual rainfall varies from 10″–20″ in the Northern Cape, 20″–30″ in the Lichtenburg, Marico, Ventersdorp, Potchefstroom and Vereeniging Districts, to 30″–40″ in the Pilgrims Rest and Carolina Districts.

This variation in rainfall (as will be shown later) has a considerable effect upon the concentration of dissolved salts, but no effect at all on the composition.

Geology and Lithology.

The Dolomite series lies conformably on the Black Reef series which is too thin, or restricted to be of interest to this investigation. The Dolomite series is mainly composed of a series of magnesium limestones generally of a bluish colour, but weathering at the surface with a brownish crust, due to hydrated manganese and iron oxides. Chert layers are common, particularly in the upper beds. Thin sections under the microscope show the dolomite to consist of small crystalls of dolomite set in a mass of calcite. In places the Dolomite has undergone secondary silification.

The following are some typical analyses of *normal* dolomite taken over a wide area :—

ANALYSIS OF DOLOMITE.

	1	2	3	4	5	6	7	8
SiO_2	7·96	—	1·5	4·05	4·02	2·54	0·94	2·8
$Fe_2O_3Al_2O_3$	0·96	1·82	1·7	1·29	2·76	1·54	—	2·9
MnO	0·52	1·1	—	0·69	—	1·30	1·18	—
CaO	28·32	30·01	26·2	30·26	29·68	29·68	29·61	29·6
MgO	19·22	20·12	20·5	18·99	18·49	1931·	19·71	18·9
CO_2	—	45·3	—	—	43·66	44·56	46·69	45·2
Ratio CaO : MgO	1 : 0·68	1 : 0·67	1 : 0·77	1 : 0·62	1 : 0·62	1 : 0·65	1 : 0·66	1 : 0·64

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(1) 10 miles
C.P. (A
(2) Quarry
Transva
(3) Irene,
Stanley)
(4) 12 miles
by G.
(5) Lichten
(6) Pretoria
(7) Typical
Museum
(8) Outcrop
Transva

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Frommurze g

Heidelberg, Springs,
Germiston and Vere
Potchefstroom, Klerks
tenburg, Southern
Marico Districts....
Vryburg, Griquatown
Kuruman, Barkly W
Northern Rustenbu
Districts..........

(1) 10 miles West of Campbell, Kaap Plateau, district Herbert. C.P. (Analysis by G. H. Stanley).
(2) Quarry near Ottoshoop Station, district Lichtenburg, Transvaal (Analysis by Hayman's Laboratory).
(3) Irene, Pretoria District, Transvaal (Analysis by G. H. Stanley).
(4) 12 miles East of Griquatown, district Herbert, C.P. (Analysis by G. H. Stanley).
(5) Lichtenburg, Transvaal (Analysis by J. Gray).
(6) Pretoria, Transvaal (Analysis by J. Gray).
(7) Typical specimen of pure Transvaal dolomite in British Museum (Analysis by G. T. Prior).
(8) Outcrop South of Maloney's Eye, district Krugersdorp, Transvaal (Analysis by G. W. Bond).

(The manganese and iron are present generally as carbonate.)

The composition of the dolomite itself appears to be very consistent judging by the typical analyses (excluding, of course, cherty layers in the dolomite, " cave limestones " in caves in the Dolomite series, and calcareous tufa lying on the soil above the dolomite). The ratio of CaO to MgO is usually very consistent averaging 1 : 0·65.

In drier regions, i.e. Herbert district, the formation is covered by calcareous tufa.

Caves, filled with stalatitic and stalagmitic limestones are common everywhere in the dolomite.

WATER SUPPLIES.

The dolomite rock is compact and impervious, the porosity according to Wybergh (16) varies from 0·0 per cent. to 0·3 per cent., so that, from the water drilling point of view, the dolomite has a bad name. Frommurze (3, p. 83) however, has shown that in spite of this bad name, the *average* results obtained by boring are higher than in any other formation, though the percentage of failures is nevertheless high. This is due to the fact that although the porosity of the rock is low, the abundance of joint and solution channels in the dolomite enables great volumes of water to be held in the dolomite, and all the large perennial rivers of the Transvaal have their origin in the over flow of this water, while there are many large permanent springs.

As in other limestone terrains, the solvent action of rain water containing a little carbon dioxide gradually dissolves out huge caverns. The success or otherwise of a borehole is thus dependent on whether or not a solution channel, fissure or cave has been struck.

Frommurze gives the following figures :—

	Average yield in gallons *per diem.*	Average depth.	Percentage failures.
Heidelberg, Springs, Pretoria, Witwatersrand, Germiston and Vereeniging Districts.........	39,000	85	17·0
Potchefstroom, Klerksdorp, Ventersdorp, Lichtenburg, Southern Rustenburg and Southern Marico Districts..........................	33,000	77	30·5
Vryburg, Griquatown, Hay, Taungs, Herbert, Kuruman, Barkly West Districts............	25,000	112	23
Northern Rustenburg and Western Marico Districts..................................	21,000	99	50

As regards the numerous large springs issuing from dolomite everywhere, Frommurze states that they range from 6,000,000 to 13,000,000 gallons *per diem*.

QUALITY OF THE WATER.

In view of the importance of this formation as a water carrier, the author has collected and analysed 22 samples of the Dolomite waters from over a very wide area of the Transvaal and Northern Cape. A list of districts is given below. The results are shown in Table 10.

Except in the case of waters from the more arid regions of the Northern Cape (Herbert and Barkly West districts) the concentration of dissolved solids is very consistent, round about 20 to 30 parts per 10^5. In the more arid regions, as shown by samples 445, 109, 110, the concentration goes up to 75 parts. The average for all the samples is 34·8 parts.

Silica is always low and averages only 6·5 per cent. (as SiO_2) of the total solids and never exceeds 10·5 per cent.

The pH. is also very consistent and has the high average value of 7·8 per cent. In fact the Dolomite series is one of the few formations which yields water with a consistent pH. value.

Sulphates, mainly in the form of calcium sulphate, are generally present but in exceedingly small amounts averaging only 1·6 per cent. SO_4 in terms of the total solids.

Fluorides are almost entirely absent, only occasional traces being observed. This, of course, is not surprising for the Dolomite does not normally contain fluorite except in veins in the Dolomite near Ottoshoop, Western Transvaal, associated with lead and zinc deposits.

The chloride content is consistently low, averaging only 4·9 per cent. Cl. of total solids.

Sodium carbonate or bicarbonate is very rare, being found in only one of the samples examined. Instead there is nearly always a very small permanent hardness which, however, only averages 4 per cent. of the total solids. On an average 91 per cent. of the dissolved salts consist of scale-forming compounds of which 87 per cent. are bicarbonates of calcium and magnesium; thus these are essentially "temporary hard waters". No other formation has yielded waters found with such high percentages of calcium and magnesium bicarbonates.

Frommurze (3, p. 77) appears to infer that rain water, charged with carbon dixode gas, tends to dissolve the lime in preference to magnesium from the dolomite, but that such is not the case is shown from the following reasoning.

In the parent dolomite rock the average ratio CaO : MgO as shown by the 8 typical analyses given previously, is 1 : 0·63. Now in nearly all the water samples there is very slightly less MgO than CaO, and in a few cases there is actually more. The average ratio of CaO to MgO is 1 : 0·94. So that, although there is a good deal more CaO than MgO in the parent rock, the amounts present in the waters derived therefrom are nearly equivalent in amount. When, however, more than a certain amount of carbon dioxide is lost, then $CaCO_3$ tends to be deposited from the water in nearly pure condition, as shown by the analyses of calcareous tufa (page 13), the magnesium bicarbonate remaining in solution.

TABLE No. 10.—DOLOMITE SERIES—TRANSVAAL SYSTEM.

Sample Numbers	215	214	196	217	213	190	182	110	102	73	56	38	36	226	231	364	372	109	416	425	446	454
Parts $CaCO_3$ per 10^5 Water :																						
Total Solids (at 106°)	28·0	30·0	25·8	28·0	16·0	45·0	33·6	76·0	36·0	17·0	28·0	14·0	41·0	15·0	21·0	8·0	29·6	76·0	29·0	40·0	74·2	33·2
Methyl Orange Alkalinity	25·5	25·5	19·0	25·0	14·5	41·0	31·0	61·5	32·0	14·0	24·4	12·0	39·2	12·7	19·2	6·0	28·5	62·5	28·0	39·5	58·8	29·0
Total Hardness	27·0	27·6	21·0	25·8	15·0	42·0	31·8	62·7	33·0	14·8	25·4	13·0	40·0	13·0	20·4	6·2	29·0	64·3	27·2	42·6	65·6	29·6
Permanent Hardness	1·5	2·1	2·0	0·8	0·5	1·0	0·8	1·2	1·0	0·8	1·0	1·0	0·8	0·3	1·2	0·2	0·5	1·8	Nil	3·1	6·8	0·6
Temporary Hardness	25·5	25·5	19·0	25·0	14·5	41·0	31·0	61·5	32·0	14·0	24·4	12·0	39·2	12·7	19·2	6·0	28·5	62·5	27·2	39·5	58·8	29·0
Hardness due to Mg Salts	12·4	12·6	10·2	12·0	7·1	20·4	15·8	23·7	16·2	6·1	10·9	5·8	18·4	6·0	9·2	2·5	9·0	24·3	10·1	21·0	26·3	12·5
Hardness due to Ca Salts	14·6	15·0	10·8	13·8	7·9	21·6	16·0	39·0	16·8	8·7	14·5	7·2	21·6	7·0	11·2	3·7	20·0	40·0	17·1	21·6	39·3	17·1
Soda Alkalinity	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	0·8	Nil	Nil	Nil
Parts per 10^5 of Water :																						
Silica (as SiO_2)	2·2	3·2	2·2	2·4	1·4	2·0	2·0	1·8	2·4	1·4	1·6	—	2·7	1·4	1·5	1·0	1·5	1·8	1·2	—	2·2	2·1
Fluorides (as F)	Nil	Nil	Nil	Nil	Nil	Trace	Nil	Trace	Nil	Nil	Nil	—	—	Nil	Nil	Nil	Trace	Nil	Nil	0·03	—	Nil
Nitrites	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	—	—	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Trace
Nitrates (as NO_3)	Nil	0·08	1·2	0·04	0·04	Nil	0·2	0·8	0·04	0·02	0·02	0·04	0·02	Nil	0·04	Nil	Nil	3·2	0·04	Nil	2·0	1·0
Chlorides (as Cl)	1·1	1·1	2·5	1·1	0·7	1·6	2·4	6·6	1·7	0·7	1·8	0·4	1·8	0·7	1·7	0·3	1·4	6·6	0·7	1·07	4·2	1·07
Sulphates (as SO_4)	1·4	0·1	1·4	0·1	0·1	0·1	0·1	2·01	0·1	0·05	1·2	0·2	1·8	0·04	0·1	0·03	0·12	1·9	Trace	0·3	2·5	0·7
Potassium Salts	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	0·05	—	Under 0·5
pH Values	8·1	7·9	7·6	7·8	7·9	7·4	8·1	7·8	7·9	7·4	8·1	7·8	7·7	7·9	7·5	7·6	8·2	7·8	8·0	8·0	8·2	7·0
Percentage on Total Solids :																						
SiO_2	8·0	10·3	8·5	8·5	8·7	4·4	6·0	3·7	6·7	8·2	5·7	—	6·7	9·3	7·2	12·4	5·0	2·3	4·1	—	2·9	6·3
CaO	24·6	23·3	22·0	24·0	23·0	25·5	26·5	18·0	25·0	20·8	21·6	23·0	26·0	22·5	24·3	18·0	18·0	18·0	19·6	29·3	19·8	21·0
MgO	22·0	20·0	18·0	19·9	21·2	19·0	18·8	20·2	18·0	18·0	20·3	21·0	22·5	18·7	21·5	18·0	27·0	21·0	23·5	22·0	21·0	20·5
Cl	3·9	3·7	9·7	3·9	4·4	3·7	7·1	8·7	5·1	4·1	6·4	2·9	4·5	4·6	8·0	3·75	4·7	8·7	2·4	2·7	5·65	3·2
SO_4	5·2	0·3	5·2	0·4	0·3	0·2	0·3	2·6	0·3	0·3	4·3	1·4	3·3	0·3	0·05	0·4	0·4	2·51	Trace	0·75	3·35	2·1
Soda Alkalinity (as Na_2CO_3)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	(2·4)	Nil	Nil	Nil
Total Hardness (as $CaCO_3$)	96·0	92·0	82·0	92·5	94·0	93·0	94·0	84·0	91·5	87·0	91·0	93·0	97·0	87·0	97·0	77·0	98·0	85·0	94·0	106·0	88·0	89·0
Permanent Hardness (as $CaCO_3$)	5·3	7·0	7·7	2·8	3·1	2·2	2·3	1·7	2·8	4·6	3·6	7·1	2·0	2·0	5·7	2·5	1·7	2·4	Nil	7·7	9·2	1·8
Temporary Hardness (as $CaCO_3$)	91·0	86·0	74·0	90·0	90·5	91·0	92·0	82·0	89·0	32·0	87·0	85·0	96·0	86·0	92·0	75·0	96·0	83·0	94·0	98·0	79·0	87·0
Ratio CaO : MgO	1 : 0·9	1 : 0·9	1 : 0·8	1 : 0·8	1 : 0·9	1 : 0·8	1 : 0·7	1 : 1·1	1 : 0·7	1 : 0·86	1 : 0·9	1 : 0·92	1 : 0·9	1 : 0·8	1 : 0·9	1 : 1·0	1 : 1·6	1 : 1·2	1 : 1·2	1 : 0·75	1 : 1·06	1 : 0·98

[redacted]

TABLE No. 10.—DOLOMITE SERIES—TRANSVAAL SYSTEM.

....	215	214	196	217	213	190	182	110	102	73	56	38	36	226	231	364	372	109	416	425	446	454	468	474	Average
Water :																									
....	28·0	30·0	25·8	28·0	16·0	45·0	33·6	76·0	36·0	17·0	28·0	14·0	41·0	15·0	21·0	8·0	29·6	76·0	29·0	40·0	74·2	33·2	49·2	42·0	34·8
....	25·5	25·5	19·0	25·0	14·5	41·0	31·0	61·5	32·0	14·0	24·4	12·0	39·2	12·7	19·2	6·0	28·5	62·5	28·0	39·5	58·8	29·0	42·5	36·0	—
....	27·0	27·6	21·0	25·8	15·0	42·0	31·8	62·7	33·0	14·8	25·4	13·0	40·0	13·0	20·4	6·2	29·0	64·3	27·2	42·6	65·6	29·6	43·5	37·6	—
....	1·5	2·1	2·0	0·8	0·5	1·0	0·8	1·2	1·0	0·8	1·0	1·0	0·8	0·3	1·2	0·2	0·5	1·8	Nil	3·1	6·8	0·6	1·0	1·6	—
....	25·5	25·5	19·0	25·0	14·5	41·0	31·0	61·5	32·0	14·0	24·4	12·0	39·2	12·7	19·2	6·0	28·5	62·5	27·2	39·5	58·8	29·0	42·5	36·0	—
....	12·4	12·6	10·2	12·0	7·1	20·4	15·8	23·7	16·2	6·1	10·9	5·8	18·4	6·0	9·2	2·5	9·0	24·3	10·1	21·0	26·3	12·5	16·52	11·4	—
....	14·6	15·0	10·8	13·8	7·9	21·6	16·0	39·0	16·8	8·7	14·5	7·2	21·6	7·0	11·2	3·7	20·0	40·0	17·1	21·6	39·3	17·1	27·0	26·2	—
....	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	0·8	Nil	Nil	Nil	Nil	Nil	—
ter :																									
....	2·2	3·2	2·2	2·4	1·4	2·0	2·0	1·8	2·4	1·4	1·6	—	2·7	1·4	1·5	1·0	1·5	1·8	1·2	—	2·2	2·1	2·3	1·4	—
....	Nil	Nil	Nil	Nil	Nil	Trace	Nil	Trace	Nil	Nil	Nil	—	—	Nil	Nil	Nil	Trace	Nil	Nil	0·03	—	Nil	Nil	Nil	—
....	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	—	—	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Trace	Nil	Nil	—
....	Nil	0·08	1·2	0·04	0·04	Nil	0·2	0·8	0·04	0·02	0·02	0·04	0·02	Nil	0·04	Nil	Nil	3·2	0·04	Nil	2·0	1·0	1·4	2·4	—
....	1·1	1·1	2·5	1·1	0·7	1·6	2·4	6·6	1·7	0·7	1·8	0·4	1·8	0·7	1·7	0·3	1·4	6·6	0·7	1·07	4·2	1·07	1·1	2·1	—
....	1·4	0·1	1·4	0·1	0·1	0·1	0·1	2·01	0·1	0·05	1·2	0·2	1·8	0·04	0·1	0·03	0·12	1·9	Trace	0·3	2·5	0·7	0·8	0·78	—
....	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	0·05	—	Under 0·5	Under 0·5	Under 0·5	—
....	8·1	7·9	7·6	7·8	7·9	7·4	8·1	7·8	7·9	7·4	8·1	7·8	7·7	7·9	7·5	7·6	8·2	7·8	8·0	8·0	8·2	7·0	7·1	8·3	7·8
Solids :																									
....	8·0	10·3	8·5	8·5	8·7	4·4	6·0	3·7	6·7	8·2	5·7	—	6·7	9·3	7·2	12·4	5·0	2·3	4·1	—	2·9	6·3	4·6	3·2	6·5
....	24·6	23·3	22·0	24·0	23·0	25·5	26·5	18·0	25·0	20·8	21·6	23·0	26·0	22·5	24·3	18·0	18·0	18·0	19·6	29·3	19·8	21·0	18·6	14·8	22·0
....	22·0	20·0	18·0	19·9	21·2	19·0	18·8	20·2	18·0	18·0	20·3	21·0	22·5	18·7	21·5	18·0	27·0	21·0	23·5	22·0	21·0	20·5	22·7	24·0	20·8
....	3·9	3·7	9·7	3·9	4·4	3·7	7·1	8·7	5·1	4·1	6·4	2·9	4·5	4·6	8·0	3·75	4·7	8·7	2·4	2·7	5·65	3·2	2·2	2·8	4·9
....	5·2	0·3	5·2	0·4	0·3	0·2	0·3	2·6	0·3	0·3	4·3	1·4	3·3	0·3	0·05	0·4	0·4	2·51	Trace	0·75	3·35	2·1	1·6	1·8	1·56
$_3$).........	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	(2·4)	Nil	Nil	Nil	Nil	Nil	Nil
....	96·0	92·0	82·0	92·5	94·0	93·0	94·0	84·0	91·5	87·0	91·0	93·0	97·0	87·0	97·0	77·0	98·0	85·0	94·0	106·0	88·0	89·0	88·8	87·0	91·0
CO$_3$)....	5·3	7·0	7·7	2·8	3·1	2·2	2·3	1·7	2·8	4·6	3·6	7·1	2·0	2·0	5·7	2·5	1·7	2·4	Nil	7·7	9·2	1·8	2·0	3·7	4·0
CO$_3$)....	91·0	86·0	74·0	90·0	90·5	91·0	92·0	82·0	89·0	32·0	87·0	85·0	96·0	86·0	92·0	75·0	96·0	83·0	94·0	98·0	79·0	87·0	86·6	80·0	87·2
....	1 : 0·9	1 : 0·9	1 : 0·8	1 : 0·8	1 : 0·9	1 : 0·8	1 : 0·7	1 : 1·1	1 : 0·7	1 : 0·86	1 : 0·9	1 : 0·92	1 : 0·9	1 : 0·8	1 : 0·9	1 : 1·0	1 : 1·6	1 : 1·2	1 : 1·2	1 : 0·75	1 : 1·06	1 : 0·98	1 : 1·2	1 : 1·6	1 : 0·94

Sample No.	District and Province.	Borehole Depth. Feet.	Locality, Description and Remarks.	Date.
217	Heidelberg, Transvaal	—	Borehole, 2 miles East of Glenroy on Main Road, Heidelberg–Johannesburg	15/ 9/40
215	Heidelberg Transvaal	60	Borehole on Johannesburg–Heidelberg Main Road, 15 miles South-East of Johannesburg	18/ 8/40
214	Heidelberg, Transvaal	78	Borehole on Vlakplaats, 313, 10 miles South-East of Germiston	18/ 8/40
213	Germiston, Transvaal	80	Borehole at "Barn Tea Room," 8 miles South-East of Johannesburg	15/ 9/40
196	Johannesburg, Transvaal	—	Borehole, Jackson's Drift, 11 miles South of Johannesburg	21/ 8/40
182	Mafeking, Cape Province	—	Spring water from Grootfontein, East of Mafeking	12/ 6/40
73	Kuruman, Bechuanaland	—	Borehole, Kuruman Power Station	19/ 4/39
56	Pretoria, Transvaal	—	Borehole at Pinedene, 8 miles South of Pretoria	26/ 9/38
102	Pretoria, Transvaal	100	Borehole, 1 mile South of Irene, on Main Road to Johannesburg	2/10/39
36	Lichtenburg, Transvaal	—	Spring, 1½ miles East of Lichtenburg	20/ 8/40
226	Krugersdorp, Transvaal	—	Spring at Maloney's Eye (contact with Pretoria Series)	10/ 4/40
38	Krugersdorp, Transvaal	—	Borehole at Zuurbekom. (Anal. Rand Water Board)	—
231	Pretoria, Transvaal	—	Spring at Fountains (contact with Pretoria Series)	24/ 1/40
364	Ventersdorp, Transvaal	90	Borehole on Zwartplaat, 5. 6 miles North of Ventersdorp,	June, 1940
372	Klerksdorp, Transvaal	—	Borehole near Kockemoer Station, 10 miles North-East of Klerksdorp	June, 1940
109	Herbert, Cape Province	—	Well on farm "Tweefontein," Kaap Plateau, near Campbell	4/10/39
110	Herbert, Cape Province	—	Spring on farm "Tweefontein," Kaap Plateau, near Campbell	23/10/39
416	Vereeniging, Transvaal	—	Borehole, 4 miles South-East of Daleside, near Vereeniging	19/ 8/41
425	Zeerust, Transvaal	—	Borehole at Ottoshoop. (Dr. Ockerse's Report Anal. D.C.S.), 1940	10/ 9/41
446	Barkly West, Cape Province	—	Well on farm "Hondfontein," near Gaap Siding. (Anal. Jas. Gray)	Sept., 1941
454	Potgietersrust, Transvaal	—	Spring, 4 miles North-West of Potgietersrust	28/10/41
190	Potgietersrust, Transvaal	160	Borehole on farm "Twin Valley Estate," North of Zebediela	7/ 7/40
468	Hay, Cape Province	—	Borehole at Kapstewel, M. 85, Postmasburg	3/12/41
474	Marico, Transvaal	—	Well at Vleischfontein Mission, North of Zeerust	5/ 1/42

The dolomitic waters, strangely enough, are very similar to those temporary hard waters" derived from the Ventersdorp lavas described previously, except that in the case of the latter, the total scale-forming salts average only $72 \cdot 5$ per cent. while chlorides and silica are slightly higher. It is also somewhat similar to the waters from the basic zone of the Bushveld igneous complex already described, but the latter waters are easily distinguished by the high silica content and preponderance of magnesium bicarbonate.

The dolomitic water is particularly amenable to chemical correction; the treatment and limitations of use are dealt with fully under the Carbonate Water Group C.

It may be stated here that these waters are satisfactory for all domestic purposes (though the untreated dolomite water may cause deposition of scale in pipe lines and hot water systems), watering live stock and irrigation.

The waters from the Dolomite series are perhaps the most consistent in composition of all examined. This is not altogether unexpected, for not only does the parent rock vary but little in composition, but there are no soluble or partly soluble salts to be leached out and solution of the calcium and magnesium salts is only achieved through the solvent action of carbonated water on the crystalline $CaCO_3$ and $MgCO_3$.

The Dolomite series is generally regarded as being of marine origin. The calcareous deposits were supposed to have been formed in the open sea, away from land, but at no great depths.

R. B. Young (42) has reported the occurrence of stromatolitic or algal limestones in the Dolomite, but he points out that algae flourish in both fresh and salt water, and in cold or warm climates. Thus the presence of algal limestone deposits do not constitute direct proof of any of such conditions.

In Table 10 it has been shown that both the chloride and sulphate content of all the dolomitic waters is extremely low (Cl. $4 \cdot 9$ per cent. on total solids $SO_4 = 1 \cdot 56$ per cent.).

When the percentage composition of these waters is compared with that of sea water, as illustrated in Table 27, (page 157), it would not appear at first sight that the constitution of the dolomitic waters supports the theory that the Dolomite is of marine origin.

It must be remembered, however, that the texture of limestones (before consolidation) is of such a nature that the limestone beds could hardly be expected to retain connate sea water, apart from the fact that a considerable period of time has elapsed since the formation of the Dolomite, which is believed to be of pre-Cambrian age.

Therefore no evidence can be deduced from the composition of the ground water arising in the Dolomite in support or otherwise of the marine theory of the origin of the Dolomite.

However, as will be discussed on page 77, there appears reason for doubting, from geo-chemical evidence, whether the Pretoria series which follows conformably on the Dolomite, is of marine origin.

XII.—WATERS IN THE PRETORIA SERIES OF THE TRANSVAAL SYSTEM.

The author has not been able to obtain samples from the equivalents of this series in the Kuruman, Barkly West and Prieska districts of the Northern Cape or the Namaqualand and Van Rhynsdorp districts of the Western Cape. Therefore the study has been confined to that portion of the Union where by far the major part of the Pretoria series outcrops, namely the Central, Western and Eastern Transvaal.

Distribution and Rainfall.

The main outcrop of the Pretoria beds in the Transvaal is round the rim of a great basin stretching almost uninterruptedly from the Marico district in the West to the Lydenburg–Carolina districts in the East. In the Potchefstroom district there is a smaller belt stretching from Potchefstroom to Vereeniging.

The annual rainfall in the regions underlain by rocks of the Pretoria series varies from 20″–25″ in the Marico district, to 25″–30″ in the Central districts and 25″–40″ in the Lydenburg and Carolina districts.

Geology and Lithology.

Geologically the series has been divided into three, namely the Timeball Hill, Daspoort and Magaliesberg, in order of succession, and a large sheet of contemporaneous andesitic lavas in the lower portion of the series. For the purpose of this study, however, the author has regarded the series as divided into a number of units made up of one or other of two contrasted lithological types namely :—

(*a*) Quartzite Zones.

(*b*) Shale Zones.

The shale, and to a far less extent, the quartzite zones, have been intruded by numerous sheets and dykes of basic igneous rocks, genetically related to the "Bushveld Igneous Complex".

The grayish-white quartzites of the Pretoria series have been described as consisting of grains of quartz cemented by secondary silica, and are generally of a looser texture than those of the Witwatersrand beds. Some outcrops contain much iron oxide in the form of magnetite and haematite. No reference is made in the literature to the presence of appreciable felspars, so that the normal (non-metamorphosed) quartzites may be regarded as non-felspathic; a point which as will be shown later has an important bearing upon the great purity of water derived from a quartzite zone.

The shales are very fine grained soft rocks, varying considerably in colour. In places they pass into slates or flagstones. Furthermore at their ontact with igneous intrusions these shales have been "baked" and metamorphosed into various types of hard schists (the quartzites being far less affected). The intrusive sills and dykes are all of basic type (diabases). As will be seen later, these intrusive rocks considerably modify the waters in the Pretoria shale beds near the point of contact

---

According to the
this series, as a whole,
perennial rivers such
rise in this formation
the quartzite ridges an
in these regions, thou
the shales and quartz

In the quartzite
per diem at depths of
31 per cent. In the s
gallons at depths of 51
the thermal metamorp
into the shales and, to
are changed into hard
but the chemical natu

Frommurze menti
base of the series yiel
72 feet, on average.

Frommurze also
sills are often in a sof
act as sponges, being
from 21,000–36,000 ga

As previously me
series are composed en
Hence it would be a
would be very pure in
author from borehole
this is the case. In fa
from the mountain st
With the exception of t
and in the Waterberg S
in the Union approxin
beds.

The concentration
spring water is consist
only 7·0 parts per 10

As would be anti
bases, the pH. is on t

Chlorides show a
13·7 per cent. in tern

Sulphates are pres

Sodium carbonate
Instead there is nearl
averages 13 per cent.

Total scale-formin
of which 40 per cent.
and magnesium bicarb

Magnesium salts a
the ratio of CaO to M

UNDERGROUND WATER SUPPLIES.

According to the investigations of Frommurze (3, pp. 95–105) this series, as a whole, may be regarded as a very good aquifer. Several perennial rivers such as the Marico, Crocodile and Pienaars Rivers lie in this formation. Numerous springs issue from dip slopes of the quartzite ridges and hills and from the principal source of supply in these regions, though there are also numerous boreholes in both the shales and quartzites.

In the quartzite zones the yield on an average is 16,000 gallons *per diem* at depths of 80–112 feet, the percentage of failures being 31 per cent. In the shale zones, the average yield is 12,000 to 40,000 gallons at depths of 51 to 116 feet, but the yield is much affected by the thermal metamorphism, caused in places by the igneous intrusions into the shales and, to a far less extent, the quartzites. The soft shales are changed into hard schists and this has modified not only the yield but the chemical nature of the water.

Frommurze mentions that the contemporaneous lava sheet at the base of the series yields 17,000 to 36,000 gallons *per diem* at 27 to 72 feet, on average.

Frommurze also refers to the fact that the intrusive diabase sills are often in a soft, friable, and decomposed condition and thus act as sponges, being full of underground water. These sills yield from 21,000–36,000 gallons daily at 83 to 93 feet on an average.

QUALITY OF THE WATER.

(i) *Quartzite Zones.*

As previously mentioned the normal quartzites of the Pretoria series are composed entirely of quartz grains with a quartzitic cement. Hence it would be anticipated that the waters derived therefrom would be very pure in quality. Analyses of 14 waters made by the author from borehole and springs, taken over a wide area, show that this is the case. In fact the purity of the waters, particularly those from the mountain streams, *often approaches that of distilled water.* With the exception of the waters rising in the Witwatersrand quartzites and in the Waterberg Sandstones, no other underground water supplies in the Union approximate in purity those in the Pretoria quartzite beds.

The concentration of dissolved salts both in borehole and mountain spring water is consistently low and averages, as shown in Table 11, only 7·0 parts per 10^5.

As would be anticipated in waters with such small amounts of bases, the pH. is on the low side averaging 6·9.

Chlorides show a good deal of variation but on average are about 13·7 per cent. in terms of total solids.

Sulphates are present only in traces or in very small amount.

Sodium carbonate or bicarbonate was found in only one sample. Instead there is nearly always a small permanent hardness, which averages 13 per cent. of the total dissolved solids.

Total scale-forming salts amount on an average to 54 per cent. of which 40 per cent. are the temporary hardness-forming calcium and magnesium bicarbonates.

Magnesium salts are nearly always present in excess over calcium, the ratio of CaO to MgO being 1 : 1·86.

The collodal silica content is very consistent, and, as would be expected from a water derived from such siliceous rocks, is relatively high, averaging 16·3 per cent. of the total solids.

Fluorides were not found in any sample tested.

The waters in the quartzite zones of the Pretoria series are allocated to the pure water Group E, and the utilisation of these waters is dealt with under that Group.

It may be stated here that these waters are iminently suitable for all domestic purposes, watering livestock and irrigation, while their great purity renders them suitable for almost every industrial purpose with little or no treatment.

(ii) *Shale Zones.*

These waters, unlike those of the quartzite zones, show a considerable variation in concentration, but on the average yield waters with the fairly low concentration of 24 parts per 10^5 (see Table 12). This is very low for shale waters. Both the concentration and composition of the dissolved salts are apparently largely influenced by the presence or absence of igneous sills and dykes. These igneous intrusions are not always observable from surface indications, but in cases where such bodies were discernable, they have been indicated in Table 12.

The pH. value varies considerably but is generally fairly high, averaging 7·8 per cent.

Soda alkalinity is sometimes present but generally in very small amounts (where high the presence of intrusive basic igneous rocks may be suspected). A small permanent hardness is sometimes present.

Sulphates are present as a rule, in little more than traces, though occasional boreholes show a high SO_4 figure.

Chlorides show some variation but the percentage is very low at 8·3 per cent.

The CaO is generally slightly less than the MgO, the ratio being 1 : 1·17. The percentage of CaO is double that of the waters in the quartzite zones.

Fluorides have not been detected in more than traces.

The silica content shows some variation, but as would be anticipated, is less than that of the quartzite waters, averaging 11·6 per cent. on total solids.

In most cases the Pretoria shales yield a fairly pure water which shows some variation both in composition and concentration, this being due, as previously stated, to the effect of igneous intrusions and to a less extent to climatological factors. Even in the worst cases the waters may be regarded as moderately hard and non-saline, very similar in most respects to the waters from the Ventersdorp system, though containing as a rule, a smaller concentration of mineral salts.

These waters have been classified under the carbonate waters Group C (temporary hard) though some of the waters may approximate to other Groups. The technological utilisation and corrective chemical treatment of these waters is dealt with under that group, but it may be stated here that these waters are suitable for all domestic purposes, watering livestock and irrigation.

In the previous section it was stated that for various reasons the Dolomite is generally regarded as being of marine origin but that the presence of algal limestones are not necessarily a proof of marine origin.

Sample N	240
Parts	
Total Soli	6·6
Methyl Or	3·4
Total Har	4·0
Permanen	0·6
Temporar	3·4
Hardness	0·5
Hardness	3·5
Soda Alka	Nil
Par	
Silica (as	1·1
Fluorides	Nil
Nitrites..	Nil
Nitrates (	0·04
Chlorides	0·6
Sulphates	0·3
Potassium	Trace
pH. Valu	6·8
Perce	
SiO_2.....	16·6
CaO.....	4·25
MgO.....	21·0
Cl.......	9·1
SO_4.....	4·5
Soda Alk	Nil
Total Ha	60·0
Permanen	9·1
Temporar	51·5
Ratio Ca	1 : 5·0

e collodal silica content is very consistent, and, as would
d from a water derived from such siliceous rocks, is relatively
veraging 16·3 per cent. of the total solids.
orides were not found in any sample tested.
e waters in the quartzite zones of the Pretoria series
d to the pure water Group E, and the utilisation of the
is dealt with under that Group.
may be stated here that these waters are iminently suitable
domestic purposes, watering livestock and irrigation, while
eat purity renders them suitable for almost every industrial
with little or no treatment.

(ii) *Shale Zones.*

ese waters, unlike those of the quartzite zones, show a
e variation in concentration, but on the average yield water
e fairly low concentration of 24 parts per 10^5 (see Table
very low for shale waters. Both the concentration and
ition of the dissolved salts are apparently largely influenced
presence or absence of igneous sills and dykes. These igneous
ns are not always observable from surface indications, but
here such bodies were discernable, they have been indicated
e 12.
e pH. value varies considerably but is generally fairly high,
ng 7·8 per cent.
la alkalinity is sometimes present but generally in very small
s (where high the presence of intrusive basic igneous rocks
suspected). A small permanent hardness is sometimes present.
phates are present as a rule, in little more than traces, though
al boreholes show a high SO_4 figure.
lorides show some variation but the percentage is very
per cent.
e CaO is generally slightly less than the MgO, the ratio
. The percentage of CaO is double that of the waters in the
te zones.
orides have not been detected in more than traces.
e silica content shows some variation, but as would be
is less than that of the quartzite waters, averaging 11·6
n total solids.
most cases the Pretoria shales yield a fairly pure water
some variation both in composition and concentration,
ue, as previously stated, to the effect of igneous intrusions
s extent to climatological factors. Even in the worst case
may be regarded as moderately hard and non-saline, very
respects to the waters from the Ventersdorp system,
ing as a rule, a smaller concentration of mineral salts.
ese waters have been classified under the carbonate
(temporary hard) though some of the waters may appro
Groups. The technological utilisation and corrective
nt of these waters is dealt with under that group, but
d here that these waters are suitable for all domestic
g livestock and irrigation.
the previous section it was stated that for various reasons
te is generally regarded as being of marine origin
sence of algal limestones are not necessarily a proof of

TABLE No. 11.—PRETORIA SERIES (QUARTZITE ZONE) TRANSVAAL SYSTEM.

Sample Numbers	108	403	66	219	228	232	230	239	373	356	240	320	314	472	Average
Parts $CaCO_3$ per 10^5 Water:															
Total Solids (at 106°)	4·6	7·0	8·5	9·4	6·0	5·0	4·8	5·6	7·6	12·1	6·6	6·4	12·5	5·6	7·3
Methyl Orange Alkalinity	1·1	4·2	4·5	1·8	2·0	1·7	1·5	2·8	4·0	8·2	3·4	3·0	6·5	1·0	—
Total Hardness	0·9	5·0	2·9	4·2	3·0	3·0	2·8	3·2	4·2	9·6	4·0	4·0	8·0	2·0	—
Permanent Hardness	Nil	0·8	Nil	2·4	1·0	1·3	1·3	0·4	0·2	1·4	0·6	1·0	1·5	1·0	—
Temporary Hardness	0·9	4·2	2·9	1·8	2·0	1·7	1·5	2·8	4·0	8·2	3·4	3·0	6·5	1·0	—
Hardness due to Ca Salts	0·6	1·9	1·4	1·0	0·7	0·6	0·4	1·3	0·8	3·6	0·5	3·5	2·4	0·2	—
Hardness due to Mg Salts	0·3	3·1	1·5	3·2	2·3	2·4	2·4	1·9	3·4	6·0	3·5	0·5	5·6	1·8	—
Soda Alkalinity	0·2	Nil	1·1	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	—
Parts per 10^5 of Water:															
Silica (as SiO_2)	0·9	1·3	1·5	1·0	1·0	0·6	0·8	1·0	1·6	2·0	1·1	0·9	1·7	1·0	—
Fluorides (as F)	Nil	Nil	—	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	—
Nitrites	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	—
Nitrates (as NO_3)	Nil	Nil	0·01	0·12	Nil	0·04	0·4	0·02	Nil	Nil	0·04	0·1	Nil	Nil	—
Chlorides (as Cl)	1·0	0·6	0·8	2·0	0·7	1·0	1·0	0·64	0·4	1·4	0·6	1·0	2·5	0·28	—
Sulphates (as SO_4)	Nil	0·1	Trace	Trace	Trace	0·2	0·2	0·09	0·06	0·03	0·3	Trace	Trace	0·1	—
Potassium Salts	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Under 0·2	Trace	Trace	Under 0·2	Trace	—
pH. Values	7·0	7·5	7·0	6·2	7·0	6·4	6·5	6·8	6·3	7·4	6·8	7·4	8·0	6·4	6·9
Percentage on Total Solids:															
SiO_2	19·6	18·5	17·5	10·5	16·5	12·0	16·6	17·8	21·0	16·6	16·6	14·0	13·6	17·8	16·3
CaO	7·3	17·0	9·2	6·4	6·5	8·0	4·8	13·0	16·0	17·4	4·25	4·6	10·4	1·8	8·3
MgO	2·4	17·0	6·6	13·8	15·2	17·0	20·0	14·5	18·4	20·0	21·0	21·6	17·8	12·4	15·5
Cl	21·7	8·6	9·4	21·0	11·6	20·0	20·7	11·4	5·3	11·6	9·1	16·4	20·0	5·0	13·7
SO_4	Nil	1·42	Trace	Trace	Trace	4·0	4·15	1·6	0·8	0·25	4·5	Trace	Trace	2·0	1·3
Soda Alkalinity (as Na_2CO_3)	4·3	Nil	12·8	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Total Hardness (as $CaCO_3$)	19·6	71·0	34·0	44·5	50·0	60·0	58·0	57·0	55·0	79·0	60·0	62·0	64·0	35·5	53·5
Permanent Hardness (as $CaCO_3$)	Nil	11·4	Nil	25·5	16·6	26·0	27·0	7·1	2·63	11·5	9·1	16·4	12·0	17·8	13·0
Temporary Hardness (as $CaCO_3$)	19·6	60·0	34·0	19·0	33·0	34·0	31·0	50·0	53·0	68·0	51·5	46·5	52·0	17·8	39·9
Ratio CaO : MgO	1 : 0·3	1 : 1·0	1 : 0·7	1 : 2·0	1 : 2·3	1 : 2·0	1 : 4·0	1 : 1·1	1 : 3·0	1 : 1·1	1 : 5·0	1 : 4·0	1 : 1·7	1 : 7·0	1 : 1·86

DESCRIPTION OF SAMPLES IN TABLE No. 11.

Sample No.	District and Province.	Borehole Depth.	Locality, Description and Remarks.	Date
		Feet.		
66	Carolina, Transvaal......................	—	Spring at Carolina......................................	13/ 1/39
219	Vereeniging, Transvaal....................	100	Borehole, 4 miles East of Evaton..........................	16/ 9/41
228	Krugersdorp Transvaal.....................	—	Spring at St. James Mission, Magaliesburg..................	11/10/40
232	Witbank, Transvaal........................	—	Borehole at Dryden, East of Delmas........................	25/11/40
230	Bronkhorstspruit, Transvaal................	50	Well on "Onbekend" 226, North-East of Benoni............	27/11/40
239	Lydenburg, Transvaal......................	—	Spring, 3 miles East of Helvetia Noord, 14 miles South-East of Dullstroom..	24/11/40
356	Lydenburg, Transvaal......................	—	Spring at Schoemanskloof..................................	7/ 6/41
403	Lydenburg, Transvaal......................	—	Mountain spring at Waterval Onder........................	15/ 7/41
240	Belfast, Transvaal........................	—	Borehole in Belfast......................................	24/11/40
320	Bronkhorstspruit, Transvaal................	100	Borehole in Doornkraal 134 near Premier Mine...............	5/ 1/41
314	Pretoria, Transvaal.......................	—	Borehole in Edendale, 3 miles West of Premier Mine.........	5/ 1/41
472	Rustenburg, Transvaal.....................	—	Well on Waterkloof 4, 8 miles South of Rustenburg.........	1/ 1/42
373	Krugersdorp, Transvaal....................	140	Borehole on farm Kaalfontein 105, 8 miles East of Cyferbult Siding	10/ 6/41
108	Rustenburg, Transvaal.....................	—	Mountain spring at St. Petrocks farm near Rustenburg........	1/10/39

we compare the percentage composition
he shaley and quartzitic zones of the Pr
water (Table 27, page 157), the most st
ely low chloride and sulphate content
ceous rocks, as is well known, tend
much more readily than do arenaceous r
tive capacity of the clayey material, an
d imperviousness of clays, any conta
not be readily leached out of the rocks.

For example argillaceous geological roc
eveld series, Cretaceous system, and the M
placeontological or other evidence are def
of marine origin, or else have suffered ma
idation yield, as will be shown subs
s, similar in percentage composition th
ntration to that of sea water.

Thus from the evidence collected in Tab
ar that the sediments of the Pretoria
m were not laid down in salt but in f
ght be argued that after such an ernorm
deposition of these sediments in the pre-Ca
e connate sea salts would have been lea
ever, does not agree with this argument
derable leaching in the shaley beds, o
h higher cloride and sulphate content.

The Pretoria beds follow conformably on
efore, if it be conceded that the former w
would be necessary to accept the theory t
esh water origin, for otherwise it would
a sudden change from salt to fresh wat

The very great thickness of the Dolo
strine origin, though, as aforementioned
stones to accumulate in fresh water. I
some diffidence, that either the whole
fresh water origin, or alternatively, tha
far less saline than the present oceans

Clarke (43, pp. 125–130) has shown tha
least, the chemical composition and co
has been practically constant, but fr
there is some support for the theor
were not nearly as saline as those o

If we compare the percentage composition of these waters both in the shaley and quartzitic zones of the Pretoria series with that of sea water (Table 27, page 157), the most striking difference is the extremely low chloride and sulphate content of the former. Now argillaceous rocks, as is well known, tend to retain connate sea water much more readily than do arenaceous rocks, owing to the high adsorptive capacity of the clayey material, and further, owing to the marked imperviousness of clays, any contained or adsorbed salts will not be readily leached out of the rocks.

For example argillaceous geological rock formations like the Bokkeveld series, Cretaceous system, and the Malmesbury series, which from plaeontological or other evidence are definitely proved to have been of marine origin, or else have suffered marine transgression after consolidation yield, as will be shown subsequently, highly saline waters, similar in percentage composition though not of course, in concentration to that of sea water.

Thus from the evidence collected in Tables 11 and 12, it would appear that the sediments of the Pretoria series of the Transvaal system were not laid down in salt but in fresh water. Of course, it might be argued that after such an ernormous period of time since the deposition of these sediments in the pre-Cambrian times that most of the connate sea salts would have been leached out. The author, however, does not agree with this argument for, even allowing for considerable leaching in the shaley beds, one would still expect a much higher cloride and sulphate content.

The Pretoria beds follow conformably on the Dolomite series and therefore, if it be conceded that the former were of fresh water origin, it would be necessary to accept the theory that the Dolomite is also of fresh water origin, for otherwise it would be difficult to account for a sudden change from salt to fresh water characteristics.

The very great thickness of the Dolomite is rather against a lacustrine origin, though, as aforementioned, it is possible for algal limestones to accumulate in fresh water. It is suggested therefore, with some diffidence, that either the whole of the Transvaal system is of fresh water origin, or alternatively, that the seas of that period were far less saline than the present oceans.

Clarke (43, pp. 125–130) has shown that for the past 100 years at least, the chemical composition and concentration of the open oceans has been practically constant, but from the work of Joly and others there is some support for the theory that the pre-Cambrian oceans were not nearly as saline as those of the present day.

XIII.—THE WATERS OF THE MALMESBURY SERIES, SOUTH-WESTERN CAPE.

Though of limited extent compared with other formations, this series is of no little importance from the point of view of water supply, since the area occupied by the Malmesbury series is comparatively well populated (by Union standards) and furthermore a portion of the wheat producing area of the Cape is located on this formation.

Distribution and Rainfall.

Appearing from beneath the Table Mountain sandstone it forms low-lying areas in the Van Rhynsdorp, Piquetberg, Malmesbury, Paarl, Stellenbosch and Somerset districts, while inliers brought up by faulting or folding are found in the Worcester, Bredasdorp and Swellendam districts. The main occurrence however, and the one from which the majority of the samples have been taken, stretches from Piquetberg to the Cape Peninsula and eastward to Paarl and Somerset West.

In the Cape Peninsula, Wynberg, Belville, Stellenbosch and Somerset West districts the annual rainfall is 20″–30″, and in addition has the benefit of the run off from the higher rainfall mountain areas in this neighbourhood.

In the Malmesbury and Paarl districts the annual rainfall averages 10″–20″; on the other hand the annual rainfall in the Van Rhynsdorp district is only 5″ to 15″.

Geology and Lithology.

This series has been tentatively correlated with the Dolomite series in the North. It consists mainly of highly tilted phyllitic slaty or flaggy rocks with some beds of limestone. In the main area referred to above, argillaceous beds predominate. The slates are close-grained, finely laminated rocks. Under the microscope they are seen to consist of minute grains of quartz, particles of clayey matter, with many micaceous scales. No fossils have been found.

The intrusion of the "Cape Granite" into the Malmesbury beds has resulted in intense contact metamorphism in places and has produced considerable mineralogical changes. In places the shales have been converted into phyllites or into mica, sericite, ottrelite, and andalusite schists.

The strata are generally well concealed by a clayey soil or by recent sand deposits. In places the rock mass itself has been weathered into white, yellow or brown sandy material to a depth as much as 150′. With reference to this very deep weathering Du Toit (2) mentions the fact that the water supply from boreholes therein is often very turbid, as it is often impossible to keep the fine clay out of the boreholes.

No analyses of Malmesbury shales or slates appear in the literature.

The following is an analysis made by the author, of typical Malmesbury slate, from near Somerset West :—

Sample Numb	377
Parts CaC	
Total Solids (	* 15·5
Methyl Orang	12·0
Total Hardnes	10·8
Permanent Ha	Nil
Temporary Ha	10·8
Hardness due	4·5
Hardness due	6·3
Soda Alkalinit	1·2
Parts p	
Silica (as SiO_2	1·4
Fluorides (as	Nil
Nitrites.......	Nil
Nitrates (as N	0·
Chlorides (as	1·
Sulphates (as	0·
Potassium Sal	Under 0·
pH. Values...	8·
Percentag	
SiO_2..........	9·
CaO..........	16·
MgO.........	16·
Cl............	8·
SO_4.........	0·
Soda Alkalinty	8·
Total Hardnes	69·
Permanent Ha	Ni
Temporary Ha	69·
Ratio CaO : M	1 : 1

THE MALMESBURY SERIES, STERN CAPE.

mpared with other formations,
m the point of view of water supply,
Malme.bury series is comparatively
ards) and furthermore a portion
Cape is located on this formation.

AND RAINFALL.

Table Mountain sandstone it forms
orp, Piquetberg, Malmesbury, Paarl,
icts, while inliers brought up by
the Worcester, Bredasdorp and
currence however, and the one from
s have been taken, stretches from
and eastward to Paarl and Somerset

nberg, Belville, Stellenbosch and
rainfall is 20″–30″, and in addition
the higher rainfall mountain areas

listricts the annual rainfall average
nual rainfall in the Van Rhynsdorp

D LITHOLOGY.

ely correlated with the Dolomite
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mestone. In the main area
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metamorphism in places and
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or into mica, sericite, ottrelite,

concealed by a clayey soil
rock mass itself has been
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ep weathering Du Toit (2)
m boreholes therein is
ep the fine clay out of the

les or slates appear in the

made by the author, of
erset West :—

TABLE No. 12.—PRETORIA SERIES (SHALE ZONE), TRANSVAAL SYSTEM.

Sample Number	124	220	139	313	358	374	375	376	301	300	377	390	451	507	Average
Parts $CaCO_3$ per 10^5 Water :															
Total Solids (at 106°)	53·2	16·8	20·8	14·6	36·1	12·4	9·5	*40·5	24·0	17·0	*15·5	15·4	23·2	38·2	24·0
Methyl Orange Alkalinity	40·5	10·0	4·5	10·0	30·0	9·0	5·5	36·5	18·5	13·0	12·0	12·7	28·5	42·5	—
Total Hardness	46·9	11·4	6·6	11·2	28·0	7·3	5·8	34·2	19·8	16·0	10·8	11·2	20·4	29·7	—
Permanent Hardness	6·4	1·4	2·1	1·2	Nil	Nil	0·3	Nil	1·3	3·0	Nil	Nil	Nil	Nil	—
Temporary Hardness	40·5	10·0	4·5	10·0	28·0	7·3	5·5	34·2	18·5	13·0	10·8	11·2	20·4	29·7	—
Hardness due to Ca Salts	20·9	4·8	2·1	3·4	8·0	2·3	1·6	8·2	9·0	9·1	4·5	4·8	10·0	13·3	—
Hardness due to Mg Salts	26·0	6·6	4·5	7·8	20·0	5·0	4·2	26·0	10·8	6·9	6·3	6·4	10·4	16·4	—
Soda Alkalinity	Nil	Nil	Nil	Nil	2·0	1·7	Nil	2·3	Nil	Nil	1·2	1·5	8·1	14·8	—
Parts per 10^5 of Water :															
Silica (as SiO_2)	2·0	2·0	0·8	—	4·0	1·0	0·8	3·8	3·1	2·3	1·4	—	1·6	3·2	—
Fluorides (as F)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	0·005	Nil	—	—
Nitrites	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	—	Nil	—	—
Nitrates (as NO_3)	0·1	0·3	3·2	0·2	Nil	0·3	0·6	0·3	Nil	0·6	0·1	—	Nil	—	—
Chlorides (as Cl)	1·4	1·4	3·0	2·0	2·8	1·1	0·7	2·1	2·8	2·5	1·3	0·7	0·7	1·8	—
Sulphates (as SO_4)	4·9	0·06	2·8	Trace	0·4	0·07	0·04	0·3	0·2	Trace	0·05	0·3	0·06	0·9	—
Potassium Salts	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	0·12	Under 0·5	—	—
pH. Values	7·1	7·4	7·3	8·1	7·8	(6·7)	7·6	8·0	7·7	7·8	8·5	7·4	7·3	—	7·8
Percentage on Total Solids :															
SiO_2	3·75	11·8	3·9	—	11·0	8·1	8·4	8·4	12·8	13·6	9·0	—	7·0	8·5	11·6
CaO	22·0	16·0	5·7	13·0	12·4	10·6	9·5	10·2	21·0	30·0	16·1	17·0	24·0	19·4	15·7
MgO	19·4	16·0	8·6	21·0	21·0	16·2	17·8	22·6	30·0	16·0	16·1	17·0	17·8	17·0	18·3
Cl	2·6	8·3	14·3	13·6	7·8	8·9	7·4	4·65	11·6	14·7	8·4	4·5	3·1	4·7	8·2
SO_4	(9·2)	0·36	(13·4)	Trace	1·1	0·6	0·4	0·67	0·8	Trace	0·32	1·9	0·3	2·4	0·8
Soda Alkalinty (as Na_2CO_3)	Nil	Nil	Nil	Nil	5·5	14·6	Nil	5·5	Nil	Nil	8·4	10·3	37·2	41·5	—
Total Hardness (as $CaCO_3$)	92·0	67·5	31·5	76·5	77·2	59·0	61·0	76·0	82·0	94·0	69·5	72·0	86·0	78·0	72·7
Permanent Hardness (as $CaCO_3$)	12·0	8·3	10·0	8·2	Nil	Nil	3·15	Nil	5·4	17·6	Nil	Nil	Nil	Nil	—
Temporary Hardness (as $CaCO_3$)	80·0	59·5	21·5	68·5	77·2	59·0	58·0	76·0	77·0	76·0	69·5	72·0	86·0	78·0	68·7
Ratio CaO : MgO	1 : 0·9	1 : 1·0	1 : 1·5	1 : 1·6	1 : 1·6	1 : 1·5	1 : 1·9	1 : 2·2	1 : 1·4	1 : 0·5	1 : 1·0	1 : 1·0	1 : 0·7	1 : 0·86	1 : 1·25

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* Contact igneous intrustion.

DESCRIPTION OF SAMPLES IN TABLE No. 12.

Sample No.	District and Province.	Borehole Depth.	Locality, Description and Remarks.	Date.
		Feet.		
124	Marico, Western Transvaal................	—	Borehole in Zeerust. (Shale Zone.)........................	81/11/39
451	Marico, Western Transvaal................	—	Borehole on Kleinfontein 76, West of Marico................	3/11/41
220	Vereeniging, Transvaal....................	90	Borehole on Doornkuil 201, 13 miles North of Vereeniging.......	16/ 9/40
313	Pretoria, Transvaal.......................	265	Borehole in Silverton, East of Pretoria......................	18/ 1/41
358	Pretoria, Transvaal.......................	—	Borehole at Donkerhoek 178, between Erasmus and Silverton....	8/ 5/41
374	Rustenburg, Transvaal....................	—	Borehole at Cyferbult Siding, East of Derby.................	10/ 6/41
390	Rustenburg, Western Transvaal............	—	Borehole in Koster. (Dr. Ockerse's report Anal. Div. C.S.)....	1940
375	Rustenburg, Western Transvaal............	150	Borehole, 3 miles South of Derby, on Townlands.............	10/ 6/41
376	Potchefstroom, Western Transvaal.........	—	Borehole, "Mimosa Inn," Kaalplaats 150, 17 miles North of Potchefstroom (near Dyke outcrop)......................	10/ 6/41
377	Potchefstroom, Western Transvaal.........	120	Borehole at Kraalkop 5, 35 miles North-East of Potchefstroom..	10/ 6/41
301	Krugersdorp, Western Transvaal...........	—	Borehole at Watershed Station, 5 mlies West of Magaliesburg..	9/12/40
300	Krugersdorp, Western Transvaal...........	—	Borehole at Vlakdrift Siding, 7 miles South-West of Magaliesburg	9/12/40
507	Lydenburg, Eastern Transvaal.............	—	Borehole in Ohrigstad. (Anal. Govt. Lab.)..................	1921
139	Lydenburg, Eastern Transvaal.............	—	Well in Lydenburg..	8/ 1/40

Moisture..........................
SiO_2..........................
$Al_2O_3 . Fe_2O_3 . TiO_2$..................
MnO..........................
CaO..........................
MgO..........................
$Na_2O . K_2O$ (by diff.)................
Cl..........................

Ratio CaO : MgO = 1 : 4·8.

The chlorine content is appreciable, in s
esting feature of this analysis is the pr
calcium.

UNDERGROUND WATER S

Frommurze (3) gives the following fig

	Yield Gallo per Di
Cape Town, Wynberg and Somerset West..........	22,0
Malmesbury and Paarl districts....................	11,6
Van Rhynsdorp...........	28,0

From the purely limestone beds Fro
which are more or less in line wi
in the North :—
37,200 gallons *per diem* at an av

QUALITY OF THE W.

In Table No. 13, the author has given
borehole water from the Malmesbury,
set West, Tulbagh and Cape Town

The chief characteristic of the waters
slates is their high salinity. The conc
ways very high averaging 172 parts pe
ptions are the Newlands, Albion and
issue from the Malmesbury beds
Town (Frommurze 58, p. 69), but m
ved from the overlying sandstones of
The pH. appears to vary somewhat
able.

The waters are extraordinarily consist
the main constituents are expre
lved salts.

As is the case in all saline waters
ging only 2·4 per cent.

There is not much data as regards flu
by the author a content of about
found.

	Per cent.
Moisture	0·57
S_1O_2	63·88
$Al_2O_3 . Fe_2O_3 . TiO_2$	34·40
MnO	trace
CaO	0·10
MgO	0·48
$Na_2O . K_2O$ (by diff.)	0·26
Cl	0·31
	100·00

Ratio CaO : MgO = 1 : 4·8.

The chlorine content is appreciable, in spite of leaching. Another interesting feature of this analysis is the predominance of magnesium over calcium.

UNDERGROUND WATER SUPPLIES.

Frommurze (3) gives the following figures :—

	Yield in Gallons per Diem.	*Depth in Feet.*	*Per cent. Failures.*
Cape Town, Wynberg and Somerset West	22,000	117	20
Malmesbury and Paarl districts	11,600	112	30
Van Rhynsdorp	28,000	152	7

From the purely limestone beds Frommurze gives the following figures which are more or less in line with those for the Dolomite series in the North :—

37,200 gallons *per diem* at an average depth of 124 ft.

QUALITY OF THE WATER.

In Table No. 13, the author has given the analyses of 12 samples of borehole water from the Malmesbury, Piquetberg, Stellenbosch, Somerset West, Tulbagh and Cape Town districts.

The chief characteristic of the waters in the Malmesbury shales and slates is their high salinity. The concentration of salt varies but is always very high averaging 172 parts per 10^5. Apparently the only exceptions are the Newlands, Albion and Kommetje springs, all of which issue from the Malmesbury beds near the Newlands suburb, Cape Town (Frommurze 58, p. 69), but most of this water is no doubt derived from the overlying sandstones of the Table Mountain series.

The pH. appears to vary somewhat, but insufficient data are available.

The waters are extraordinarily consistent in composition as shown when the main constituents are expressed as percentage of the dissolved salts.

As is the case in all saline waters, silica is consistently low, averaging only 2·4 per cent.

There is not much data as regards fluorides, but in 2 or 3 samples tested by the author a content of about 0·5 parts per million have been found.

The chief characteristic of these waters is the exceedingly high chloride content which in terms of the total salts averages 42 per cent. Cl. and the appreciable sulphate content which averages 5 per cent. SO_4. Both the chloride and sulphate are very consistent.

Na_2CO_3 or $NaHCO_3$ was found in only one sample. Instead there is nearly always an appreciable permanent hardness averaging 11·6 per cent. (as $CaCO_3$).

$Ca(HCO_3)_2$ and $Mg(HCO_3)_2$ are relatively very low averaging 12·3 (as $CaCO_3$).

The total scale-forming salts therefore only average 24 per cent. of the total solids, so that these waters may be regarded primarily as corrosive waters, on account of the high magnesium and sodium chloride content.

The percentage of calcium and magnesium is remarkably consistent, averaging 4·4 per cent. and 6·5 per cent., giving a ratio of CaO : MgO of 1 : 1·5. Samples taken from calcareous zones such as Piquetberg (though not actually from the limestones) will naturally show a higher proportion of lime and magnesium, as shown in sample No. 133, Table No. 13.

The waters in the Malmesbury series are allocated to the highly mineralised chloride-sulphate Group A. of waters, and the adaptability of these waters for technological use is dealt with under that group, but it may be mentioned here that the exceedingly high chloride content renders them very difficult to treat for industrial purposes; in fact some of them are unusable.

Some of these waters are too saline to drink, though most of them are used when no other water is available. They are not too saline for livestock watering and are suitable for irrigation provided the soils are well drained and situated in regions of good rainfall.

If we compare the percentage composition of the Malmesbury waters with those of sea water as set out in Table 27, the similarity is striking, particularly as regards the high chloride and sulphate content, the comparatively low hardness, the relatively high permanent hardness and the high proportion of magnesium salts and sodium salts.

Further, the relation between the constituents is nearly always the same as in oceanic water, namely, $Cl > SO_4 > CO_3$ and $Na > Mg > Ca$.

Since the Malmesbury beds are predominantly argillaceous and the districts concerned are areas of somewhat limited rainfall, it follows that these clayey rocks would tend to retain, to a certain extent, any sea water percolating through them, and prevent those salts being thoroughly leached out.

On certain geological evidence (Du Toit, 2, pp. 115–116) it is supposed that in a fairly recent geological period there was an inundation by the sea of the coastal plains of the South-Western Cape. The chemical evidence, as set out by the author in Table strongly supports this theory.

Sample Nun	267
Parts C	
Total Solids	84·
Methyl Ora	6·
Total Hard	17·
Permanent	11·
Temporary	6·
Hardness d	12·
Hardness d	4·
Soda Alkali	Nil
Parts	
Silica (as S	3·
Fluorides (	—
Nitrites....	—
Nitrates (as	—
Chlorides (	33·
Sulphates (	6·
Potassium	—
pH. Values	—
Percen	
SiO_2......	3·
CaO.......	3·
MgO......	5·
Cl.........	40·
SO_4......	7·
Soda Alkal	Nil
Total Hard	20·
Permanent	13·
Temporary	7·
Ratio CaO	1 : 1·

ters is the exceedingly
tal salts averages 42 per
which averages 5 per
very consistent.

only one sample.
rmanent hardness

ely very low averaging

only average 24 per
may be regarded
gh magnesium and

nesium is remarkably
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TABLE No. 13.—MALMESBURY SERIES (ARGILLACEOUS BEDS), CAPE PROVINCE.

Sample Numbers	321	133	135	162	156	263	264	265	266	267	150	470	Average
Parts $CaCO_3$ per 10^5 Water :													
Total Solids (at 106°)	96·0	106·0	74·0	380·0	(35·1)	440·0	221·0	154·0	46·0	84·0	94·0	197·0	172·5
Methyl Orange Alkalinity	0·0	28·35	17·0	7·5	8·0	21·0	25·5	17·0	5·7	6·3	11·5	19·0	—
Total Hardness	23·0	65·40	19·4	180·0	12·0	83·8	45·0	13·6	8·0	17·5	19·1	36·3	—
Permanent Hardness	14·0	37·05	2·4	172·5	4·0	62·8	19·5	Nil	2·3	11·2	7·6	17·3	—
Temporary Hardness	9·0	28·35	17·0	7·5	8·0	21·0	25·5	13·6	5·7	6·3	11·5	19·0	—
Hardness due to Mg Salts	15·0	32·8	13·7	97·2	10·2	66·0	27·0	10·0	5·0	12·5	13·2	12·2	—
Hardness due to Ca Salts	8·0	32·6	5·7	82·8	1·8	17·8	18·0	3·6	3·0	4·65	5·9	24·1	—
Soda Alkalinity	Nil	Nil	Nil	Nil	Nil	Nil	Nil	3·4	Nil	Nil	Nil	Nil	—
Parts per 10^6 of Water :													
Silica (as SiO_2)	2·6	2·2	1·2	4·0	2·0	1·8	1·9	4·2	2·5	3·0	2·2	2·0	—
Fluorides (as F)	—	—	0·06	Nil	Nil	—	—	—	—	—	Nil	0·06	—
Nitrites	—	—	Nil	Nil	Nil	—	—	—	—	—	Nil	Nil	—
Nitrates (as NO_3)	—	—	Nil	Nil	Nil	—	—	—	—	—	Nil	Nil	—
Chlorides (as Cl)	52·5	28·6	32·0	165·4	12·8	242·0	95·3	69·6	17·3	33·7	43·7	102·0	—
Sulphates (as SO_4)	0·24	15·0	6·0	14·3	1·7	9·0	4·5	8·5	2·0	6·3	7·2	9·0	—
Potassium Salts	—	—	Trace	Small Amount	Trace	—	—	—	—	—	Trace	Small Amount	—
pH. Values	(6·3)	—	7·1	7·5	7·4	—	—	—	—	—	7·3	7·0	7·1
Percentage on Total Solids :													
SiO_2	2·7	2·06	1·6	1·3	5·7	0·41	0·85	2·6	5·3	3·35	2·4	1·02	2·4
CaO	4·6	(17·2)	4·05	12·0	2·8	2·26	4·80	1·34	6·5	3·2	3·5	3·45	4·4
MgO	6·75	(12·4)	7·3	10·2	11·6	5·9	4·65	2·55	4·4	5·9	7·8	4·9	6·5
Cl	55·0	27·0	45·0	44·3	36·3	55·0	43·0	45·5	37·5	40·0	46·5	52·0	42·1
SO_4	(0·26)	(14·0)	8·0	3·95	4·8	2·0	2·0	5·5	4·4	7·5	7·7	4·6	5·0
Soda Alkalinity (as Na_2CO_3)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	(2·2)	Nil	Nil	Nil	Nil	Nil
Total Hardness (as $CaCO_3$)	25·0	(61·5)	26·0	46·5	34·0	19·0	22·2	(8·9)	17·4	20·5	20·3	18·4	23·9
Permanent Hardness (as $CaCO_3$)	14·6	(34·3)	3·3	(44·3)	11·4	14·3	8·5	(Nil)	5·0	13·3	8·1	8·7	11·6
Temporary Hardness (as $CaCO_3$)	9·4	(25·5)	23·0	(1·8)	23·0	4·7	11·8	8·9	12·4	7·5	12·5	9·6	12·3
Ratio CaO : MgO	1 : 1·5	1 : 0·7	1 : 1·8	1 : 0·8	1 : 4·0	1 : 2·5	1 : 0·9	1 : 1·9	1 : 0·7	1 : 1·8	1 : 2·2	1 : 1·2	1 : 1·5

DESCRIPTION OF SAMPLES IN TABLE No. 13.

Sample No.	District and Province.	Borehole Depth. Feet.	Locality, Description and Remarks.	Date.
470	Belville, Cape Province....................	—	Borehole at Kliphenvel..................................	8/12/41
156	Belville, Cape Province....................	—	Borehole at Kraaifontein. Deposits iron oxide on standing....	29/ 4/40
321	Belville, Cape Province....................	—	Borehole in Durbanville. Sample deposits iron oxide on standing	23/ 1/41
133	Piquetberg, Cape Province.................	384	Borehole at Cape Portland Cement Factory, Piquetberg. (Analysis by Cape Portland Cement Company)......................	3/11/39
135	Tulbagh, Cape Province....................	—	Borehole water—town of Tulbagh..........................	16/ 1/40
162	Stellenbosch, Cape Province................	80	Borehole from farm " Ridgemore," Geduld Siding, near Faure..	19/ 3/40
263	Cape....................................	—	Borehole, Uitvlugt, Cape Town. (Analysis Juritz, Ref. 103)..	1908
164	Malmesbury, Cape Province................	201	Borehole, Moorreesburg. (Analysis Juritz Ref. 131)........	1908
165	Malmesbury, Cape Province................	—	Borehole, Kalabaskraal. (Analysis Juritz, Ref. 129)...........	1908
266	Cape....................................	—	* Spring above Round House, Sea Point, Cape Town. (Analysis Juritz, Ref. 78)......................................	1908
267	Cape....................................	76	Borehole, Railway Steamshed, Cape Town. (Analysis Juritz, Ref. 78)...	1908
150	Somerset West, Cape Province.............	—	Borehole at Vergelegen, Somerset. West Deposits iron oxide on standing..	2/ 2/40

* Possibly in granite ?

V.—THE WATERS IN THE WA

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tpansberg, it is not of any econo
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Waterberg district, is still fairly wi

DISTRIBUTION AND RA

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exposures being in the Waterberg
importance in the latter district i
the Zoutpansberg occurrence, the on
however, is located on granite near
ones, from which it derives its wat
the central Transvaal, the occurre
ng only a small portion of the Midd
burg is the only centre of importa
very small occurrence of Waterbe
Cape, where it is known as the "
ccurrence is far too limited to be
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being 20″–25″ except in the No
In the Zoutpansberg the averag
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GEOLOGY AND LITH

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are rare. The colour of these r
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UNDERGROUND WAT

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em at a depth of 104 ft. Boreh
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XIV.—THE WATERS IN THE WATERBERG SYSTEM.

Although the Waterberg system occupies extensive tracts of rugged country in the North-Western and Central Transvaal and in the Zoutpansberg, it is not of any economic importance at present and a large part of the country occupied by Waterberg rocks, especially in the Waterberg district, is still fairly wild and sparsely populated.

DISTRIBUTION AND RAINFALL.

In the Northern Transvaal rocks of this system cover lagre areas in the Waterberg, Potgietersrust and Zoutpansberg districts, the greatest exposures being in the Waterberg district. The only centre of any importance in the latter district is Nylstroom.

In the Zoutpansberg occurrence, the only centre is Louis Trichardt, which, however, is located on granite near the margin of the Waterberg sandstones, from which it derives its water supplies.

In the central Transvaal, the occurrence is far smaller in extent, occupying only a small portion of the Middelburg and Pretoria districts. Middelburg is the only centre of importance.

A very small occurrence of Waterberg rock is also found in the Northern Cape, where it is known as the " Matsap " series. However, that occurrence is far too limited to be of interest in this study.

The Waterberg district is fairly well watered, the average annual rainfall being 20″–25″ except in the North-West where it is much lower In the Zoutpansberg the average annual rainfall falling on the Waterberg rocks is higher at about 30″–35″. In the Middelburg district it is about 25″–30″ per annum.

GEOLOGY AND LITHOLOGY.

The rocks of the Transvaal Waterberg are predominantly arenaceous. Red, purplish or chocolate-brown quartzites and quartzitic sandstones predominate with a few coarse conglomerate beds. Shales are rare. The colour of these rocks is very strking. In the Zoutpansberg district basic amygdaloidal basalts are found at the base of the sediments, in the vicinity of Louis Trichardt, but they are of small extent.

There is not much in the literature as regards the mineralogical composition of the Waterberg sandstones, but these are apparently regarded as quartzitic and ferruginous rather than felspathic, an important point when considering the waters arising in these sandstones.

The author has prepared and microscopically examined thin sections from several specimens of Waterberg sandstone from different localities but found in every case that the grains were almost entirely composed of quartz, with a ferruginous cement or matrix between the grains ; no felspar was observed.

The Waterberg system is not fossiliferous, but latterly many geologists, notably Du Toit, are inclined to regard these rocks as of pre-Cape and either of late pre-Cambrian or early Paloezoic age.

UNDERGROUND WATER SUPPLIES.

Du Toit (2, pp. 119, 133) states that the Waterberg sandstones in the rugged and fairly well watered area North of Nylstroom have yielded only 14 per cent. of failures and an average of 12,000 gallons *per diem*, at a mean depth of 175 ft. though drilling has proved erratic in the sand covered flats of the North Western Waterberg. For the Middelburg area Du Toit gives the following : " 26,800 gallons *per diem* at a depth of 104 ft. Boreholes are, however, few and far between ".

Quality of the Water.

Since the greater part of the country occupied by Waterberg sandstones consists of wild, rugged and sparsely populated country, it was found very difficult to obtain samples of either spring or borehole water. The author is therefore greatly indebted to Dr. Ockerse, of the Department of Public Health, for the use of four analyses collected by him in the course of his investigations into the prevalence of endemic dental fluorosis in the Northern Transvaal.

Tne analyses of six samples are given in Table 14 (*a*). With the exception of Sample 546, all these waters are remarkably pure, even when obtained from the more arid parts of the country.

The average as shown in Table 14 (*a*) is only 6·5 parts per 100,000. As would be anticipated in the case of waters arising in rocks consisting almost entirely of quartz grains, free from felspar, the pH. is low averaging 7·0.

The silica appears relatively high, but data is insufficient as the samples tested for Dr. Ockerse do not give the silica content.

Chlorides are low, averaging 11·2 per cent. of total salts.

Sulphates are variable but very low in amount.

As would be anticipated, soda alkalinity is nearly always absent and was found to be present in only one out of six.

Fluorides are sometimes present in very small amounts, but one sample gave 1·1 parts F. per million.

The hardness, due almost entirely to calcium and magnesium bicabonates, is always very low in amount, generally under 4 parts $CaCO_3$ per 10^5 and composing 52 per cent. in terms of the total solids.

Calcium is slightly in predominance over magnesium, the average ratio being 1 : 0·9.

The low concentration of salts may be explained by the fact that the sandstones are siliceous, and not generally speaking, felspathic. Further, most of the region is under moderately good rainfall.

The Waterberg waters are allocated to the pure water group E, and are entirely suitable for all domestic purposes, stock watering, irrigation and all technological purposes after the addition of a small amount of lime to elevate the pH.

The Rooiberg Series.

At one time the Rooiberg series in the Central Transvaal consisting of red felsitic lavas, shales, volcanic agglomerates and highly felspathic quartzites and sandstones, were regarded as forming the lower portion of the Waterberg system, but they have now been separated from that system.

As however, the Rooiberg series is of limited extent, and the areas occupied by it of no economic importance and samples difficult to obtain, it has not been studied by the author.

Since however, the volcanic tuffs and agglomerates and similar rocks are largely made up of fragments of the Red granite, and the sandstones are highly felspathic, it is considered likely that the waters derived therefrom would be very similar to those of the Red granites and alkali syenites, namely soda carbonate waters.

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TABLE No. 14 (*a*).—WATERBERG SANDSTONES, WATERBERG SYSTEM IN THE TRANSVAAL.

Sample Numbers	545	546	547	548	90	76	Average
Parts $CaCO_3$ per 10^5:							
Total Solids (at 105°C.)	11·6	(60·8)	2·8	4·4	4·0	10·0	6·5
Methyl Orange Alkalinity	6·0	40·3	2·0	1·5	1·0	3·7	—
Total Hardness	6·0	40·3	2·0	3·0	1·0	3·1	—
Permanent Hardness	Nil	Nil	Nil	1·5	Nil	Nil	—
Temporary Hardness	6·0	40·3	2·0	1·5	1·0	3·1	—
Hardness due to Ca Salts	2·8	18·8	0·8	1·2	0·5	2·0	—
Hardness due to Mg Salts	3·2	21·5	1·2	1·8	0·5	1·1	—
Soda Alkalinity	Nil	Nil	Nil	Nil	Nil	0·5	—
Parts per 10^5 Water:							
Silica (as SiO_2)	—	—	—	—	0·5	2·0	—
Fluorides (as F)	0·023	0·11	0·02	0·02	Nil	—	—
Nitrites	Nil	Nil	Nil	Nil	Nil	Nil	—
Nitrates (as NO_3)	Nil	Nil	Nil	Nil	Nil	0·04	—
Chlorides (as Cl)	1·42	7·1	0·7	0·14	0·7	1·2	-
Sulphates (as SO_4)	0·58	1·0	0·3	0·38	Trace	Trace	—
Potassium Salts (as K)	0·07	0·8	0·02	0·07	Trace	Under 0·5	—
pH. Values	6·75	(7·0)	7·1	6·6	7·2	7·5	7·04
Percentage on Total Solids:							
SiO_2	—	—	—	—	12·5	2·0	16·0
CaO	13·5	17·2	15·0	15·5	7·0	11·2	13·2
MgO	11·0	14·2	16·8	16·2	5·0	8·0	11·9
Cl	12·2	11·5	(25·0)	3·2	17·4	12·0	11·2
SO_4	5·0	1·64	(10·7)	(8·7)	Trace	Trace	1·6
Soda Alkalinity (as Na_2CO_3)	Nil	Nil	Nil	Nil	Nil	(6·0)	Rare
Total Hardness (as $CaCO_3$)	51·5	66·0	71·5	68·0	25·2	31·0	52·6
Permanent Hardness (as $CaCO_3$)	Nil	Nil	Nil	(34·0)	Nil	Nil	Rare
Temporary Hardness (as $CaCO_3$)	51·5	66·0	71·5	34·0	25·2	31·0	47·0
Ratio CaO : MgO	1 : 0·8	1 : 0·83	1 : 1·1	1 : 1·05	1 : 0·7	1 : 0·7	1 : 0·9

DESCRIPTION OF SAMPLES IN TABLE No. 14 (*a*).

Sample No.	District and Province.	Borehole Depth.	Locality, Description and Remarks.	Date.
		Feet.		
545	Waterberg, Transvaal......................	—	Borehole on Palmietfontein, 172, 50 miles North of Nylstroom. (Dr. Ockerse, Anal. Div. C.S.)................................	March, 1942
546	Potgietersrust, Transvaal..................	—	Borehole, Murchison 472, 70 miles North of Nylstroom. (Dr. Ockerse, Anal. Div. C.S.)................................	March, 1942
547	Waterberg, Transvaal......................	—	Borehole, Johannesburg 861, Post Office, Overysel, 106 miles West-North-West of P.P. Rust. (Dr. Ockerse, Anal. Div. C.S.)	March, 1942
548	Waterberg, Transvaal......................	—	Borehole at Melkrivier, 73 miles North of Nylstroom. (Dr. Ockerse, Anal. Div. C.S.)................................	March, 1942
90	Waterberg, Transvaal......................	—	Spring, 8 miles North of Warmbaths, on Main Road to Nylstroom	28/ 8/39
76	Zoutpansberg, Transvaal..................	—	Spring, North of Louis Trichardt. (Town supply)...........	11/ 3/39

THE WATERS IN THE TABLE MOUNTAIN SERI
THE CAPE SYSTEM.

Distribution and Rainfall.

he rocks in this series are found in the South-West and
Cape Province, in Pondoland and South-East Natal. Th
ds from Van Rhynsdorp through Clanwilliam to the Ca
ards in several parallel belts to Port Elizabeth, there is
derable break till Port St. Johns is reached. From I
the series forms a narrow belt at or parallel to the coast, ex
numerous breaks to Hlabisa in Zululand. Its age is p
-Devonian.

The rainfall falling on the rocks of this series averages
annum but may be as high as 40" in certain areas near th
As Frommurze (3, p. 115) points out, this series builds
d and mountain ranges, standing high above the surr
try and therefore forms platforms upon which the
pitations in the area takes place. The "run-off" fr
pitation gives rise to many perrennial streams.

Geology and Lithology.

This series, as much as 5,000 ft. in thickness in the Cape I
ilt up almost entirely of hard sandstones, generally i
pressure, and also frequently hardened by secondary silic
e are two shale bands of no great thickness.

The Table Mountain sandstones of the Cape Province are
sh in colour, fairly coarse grained and generally hard.

There appears to be no reference in the literature to the
lspar grains. A number of thin sections of the sandstones
examined microscopically by the author showed the gra
posed almost entirely of quartz, and no felspar was ob
sections examined.

The occurrence of felspar must therefore be rare. The
terial is either siliceous or ferruginous.

According to Du Toit the Table Mountain sandstone of I
milar, but further northwards in Natal the Table
stone tends to become felspathic in places. The Na
ntain sandstone is generally of a reddish-brown to pur
The Table Mountain sandstones in the Cape Province oft
ll quantities of iron oxide, and less commonly, of m
etimes in botryoidal masses; for example, the iron and r
osits at the eye of the Caledon Spring and the mangane
Constantia Nek.

The relation between these deposits and the groun
ussed later.

The absence of soluble compounds in the rocks gives r
ple and non-fertile sandy soils, and, as will be seen, ac
unmineralised nature of the waters arising therein.

Underground Water Supplies.

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—THE WATERS IN THE TABLE MOUNTAIN SERIES OF THE CAPE SYSTEM.

Distribution and Rainfall.

The rocks in this series are found in the South-West and South of the Cape Province, in Pondoland and South-East Natal. The series extends from Van Rhynsdorp through Clanwilliam to the Cape and eastwards in several parallel belts to Port Elizabeth, there is then a considerable break till Port St. Johns is reached. From Port St. Johns the series forms a narrow belt at or parallel to the coast, extending with numerous breaks to Hlabisa in Zululand. Its age is probably Siluro-Devonian.

The rainfall falling on the rocks of this series averages 20″–25″ per annum but may be as high as 40″ in certain areas near the coast.

As Frommurze (3, p. 115) points out, this series builds up high ground and mountain ranges, standing high above the surrounding country and therefore forms platforms upon which the greatest precipitations in the area takes place. The "run-off" from this precipitation gives rise to many perennial streams.

Geology and Lithology.

This series, as much as 5,000 ft. in thickness in the Cape Province, is built up almost entirely of hard sandstones, generally indurated by pressure, and also frequently hardened by secondary silicification. There are two shale bands of no great thickness.

The Table Mountain sandstones of the Cape Province are generally whitish in colour, fairly coarse grained and generally hard.

There appears to be no reference in the literature to the presence of felspar grains. A number of thin sections of the sandstones prepared and examined microscopically by the author showed the grains to be composed almost entirely of quartz, and no felspar was observed in the sections examined.

The occurrence of felspar must therefore be rare. The cementing material is either siliceous or ferruginous.

According to Du Toit the Table Mountain sandstone of Pondoland is similar, but further northwards in Natal the Table Mountain sandstone tends to become felspathic in places. The Natal Table Mountain sandstone is generally of a reddish-brown to purple colour.

The Table Mountain sandstones in the Cape Province often contain small quantities of iron oxide, and less commonly, of manganese, sometimes in botryoidal masses; for example, the iron and manganese deposits at the eye of the Caledon Spring and the manganese deposit at Constantia Nek.

The relation between these deposits and the ground water is discussed later.

The absence of soluble compounds in the rocks gives rise to very simple and non-fertile sandy soils, and, as will be seen, accounts for the unmineralised nature of the waters arising therein.

Underground Water Supplies.

As shown by Du Toit (14, p. 216) and Frommurze (3, p. 115) boreholes rarely give good supplies on account of the low porosity of the Table Mountain sandstone, though in Natal the feslpathic grits yield better results. It is pointed out however, that the formation, though seldom weathered to any great depth, absorbs large quantities of water which issue as springs in conjunction with structures like faults, folds, joints and the contacts of the sandstone with the shale bands.

The main spring at Caledon, for example, yields 180,000 gallons *per diem*, while the Uitenhage springs yield as much as 1,000,000 gallons *per diem*.

Frommurze points out that this formation is of little importance from the boring aspect owing to the fact that the underground water in the Table Mountain sandstone tends to be stored in the above mentioned secondary structures and that it builds mountainous country, which is exceedingly well watered by streams and springs. Frommurze gives the following average figures from the few boreholes investigated :—

22,000 gallons *per diem* at a depth of 112 feet with 27 per cent. failures.

QUALITY OF THE WATER IN THE CAPE PROVINCE.

Although this formation is of little importance as regards borehole supplies it is nevertheless of vast importance as an aquifer, for the numerous perennial springs that rise in the Table Mountain sandstone mountains often form the sole source of supply for such coastal towns as Cape Town, Port Elizabeth, Knysna, Mossel Bay and so on, while numerous inland coastal towns like Bredasdorp, Oudtshoorn, Riversdale, Piquetberg and so on, which otherwise would be dependent on the highly saline borehole waters from the Malmesbury, Cretaceous and Bokkeveld formations, obtain all their water supplies from mountain springs in Table Mountain series.

In view of this and also on account of the fact that the Table Mountain sandstone waters have certain very interesting characteristics, the author has devoted a great deal of study to them.

In Table 14, the author has given the results of 19 analyses of Table Mountain sandstone waters in the Cape Province. (All spring waters, with one exception). These samples were collected over a wide area from the Cape Peninsula to Port Elizabeth and covering the districts of Caledon, Wynberg, Cape Town, Swellendam, George, Mossel Bay, Tulbagh, Willowmore, Bredasdorp, Worcester and Uitenhage.

One of their chief characteristics is the low concentration of mineral salts which average 12·9 parts per 10^5. (19 samples). Even the hot "mineral" spring at Caledon contains only about 20 parts dissolved salts per 10^5 parts, and therefore should hardly be termed a mineral spring.* This low mineral concentration of salts in the Table Mountain sandstone waters tempted Juritz (5) and many others to describe the waters as very pure and to rate them for boiler (locomotive?) purposes as exceptionally good ; in fact the ideal water with which to compare other waters.

Actually, though indeed of very low mineral content these Table Mountain sandstone waters are the most acid natural waters encountered in the Union excluding of course, mine waters such as those of the Rand, in which the high acidity is due to the oxidation of sulphidic ore materials in underground workings.

When Juritz published his paper (5), little or nothing was known regarding the hydrogen ion concentration of natural waters, and of course Juritz' analyses give no pH. figures.

Now pH. determinations immediately show up these waters very badly ; pH. figures as low as 4·5 are quite common.

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* Possibly not primarily derived from Table Mountain Sandstone.

Sample No.
167
168
169
171
170
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310
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98
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185
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269
269 a)
450
462

TABLE 14.—TABLE MOUNTAIN SERIES—CAPE SYSTEM IN THE CAPE.

Sample Number	167	168	169	166	170	310	176	98	138	185	417	57	58	312	269	269 (*a*)	450	171*	462	Average
Parts $CaCO_3$ per 10^5 Water :																				
Total Solids (as 106°)	12·4	11·6	16·0	21·0	9·0	8·0	10·4	8·6	5·0	9·1	8·0	8·2	6·4	30·2	12·4	30·6	9·7	20·3	8·25	12·9
Methyl Orange Alkalinity	0·8	0·75	1·8	0·5	0·5	1·6	—	1·8	1·4	0·5	0·2	0·9	—	2·5	0·5	0·5	2·1	3·7	0·35	—
Total Hardness	2·4	3·0	4·8	5·4	3·0	2·4	1·8	2·1	2·9	3·0	2·2	1·9	1·1	7·2	2·3	4·0	3·7	7·2	2·2	—
Permanent Hardness	1·6	2·2	3·0	4·9	2·5	0·8	1·8	0·3	1·5	2·5	2·0	1·0	—	4·7	1·8	3·5	1·6	3·5	1·8	—
Temporary Hardness	0·8	0·75	1·8	0·5	0·5	1·6	—	1·8	1·4	0·5	0·2	0·9	—	2·5	0·5	0·5	2·1	3·7	0·35	—
Hardness due to Ca Salts	1·0	0·7	0·9	1·2	0·5	1·0	—	0·5	0·4	1·0	0·4	0·4	0·40	0·4	1·0	1·84	3·3	6·2	0·8	—
Hardness due to Mg Salts	1·4	2·3	3·9	4·2	2·5	1·4	—	1·6	2·5	2·0	1·8	1·5	0·74	6·8	1·3	2·25	0·4	1·0	1·4	—
Soda Alkalinity	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	—
Parts per 10^5 of Water :																				
Silica (as SiO_2)	0·7	0·5	0·4	0·2	0·4	0·2	—	0·4	0·4	0·5	0·24	0·5	0·1	0·5	1·0	1·2	3·9	2·0	0·8	—
Fluorides (as F)	Nil	Nil	Nil	Nil	Nil	Nil	—	Nil	Nil	Nil	Nil	Nil	—	Nil	—	—	—	Nil	Nil	—
Nitrites	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	—	Present	—	Nil	Nil	—
Nitrates (as NO_3)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	0·1	Nil	0·02	Nil	0·10	—	Present	—	Nil	Trace	—
Chlorides (as Cl)	3·7	5·5	6·0	9·4	3·2	4·0	3·7	2·9	1·8	4·3	4·2	3·5	2·5	13·6	4·0	12·7	1·7	3·9	3·6	—
Sulphates (as SO_4)	0·2	0·1	0·05	0·2	0·1	0·05	0·2	0·3	0·03	0·3	0·04	0·9	0·13	1·5	0·42	2·0	1·18	0·1	0·36	—
Potassium Salts	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	0·1	Under 0·2	—	—	—	Under 0·5	Under 0·2	—
pH. Values	4·5	4·6	6·4	5·2	5·3	6·6	5·0	6·0	6·8	5·7	5·7	6·0	5·85	7·0	—	6·0	—	6·3	4·8	5·7
Percentage on Total Solids :																				
SiO_2	5·6	4·3	4·5	0·95	4·45	2·5	—	4·65	8·0	5·5	3·1	6·10	1·60	1·65	8·1	3·9	3·1	9·8	9·7	4·7
CaO	4·5	3·3	3·1	3·1	3·1	7·0	—	2·6	5·6	3·7	3·7	2·7	3·3	2·7	4·5	6·0	(19·2)	2·8	5·3	3·9
MgO	4·5	8·0	9·7	8·5	11·0	7·0	—	7·8	18·0	8·9	8·0	7·4	4·7	8·9	4·3	7·3	(1·75)	12·4	6·7	8·4
Cl	50·0	47·5	37·5	44·5	35·5	50·0	35·5	34·0	36·0	47·5	52·5	43·0	39·0	43·0	32·3	41·5	17·5	19·2	44·0	39·9
SO_4	1·6	0·9	0·3	0·95	1·1	0·6	1·9	3·5	0·6	3·3	0·5	11·0	2·03	4·9	3·4	6·5	12·2	0·5	4·4	3·2
Soda Alkalinty (as Na_2CO_3)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Total Hardness (as $CaCO_3$)	19·2	26·0	29·4	25·8	33·0	30·0	17·2	24·5	57·0	33·0	27·5	23·2	17·2	23·7	18·8	13·0	38·0	35·5	26·5	26·2
Permanent Hardness (as $CaCO_3$)	12·9	19·4	18·7	23·5	28·0	10·0	17·2	3·5	30·0	27·5	25·0	12·2	—	15·4	14·4	11·4	16·8	17·2	21·8	18·9
Temporary Hardness (as $CaCO_3$)	6·4	6·4	11·2	2·4	5·6	20·0	—	21·0	27·0	5·5	5·0	11·0	—	8·2	4·1	1·64	21·7	18·2	4·25	10·6
Ratio CaO : MgO	1 :1·0	1 : 2·3	1 : 3·0	1 : 2·7	1 : 3·5	1 : 1·0	—	1 : 3·0	1 : 3·2	1 : 2·4	1 : 3·0	1 : 2·7	1 : 1·4	1 : 3·0	1 : 0·95	1 : 1·2	(1 : 0·09)	1 : 4·4	1 : 1·3	1 : 2·2

* Possibly not primarily derived from Table Mountain Sandstone.

Sample No.	District and Province.	Borehole Depth.	Locality, Description and Remarks.	Date.
167	Caledon, Cape Province	Feet. —	Mountain Spring, 4·5 miles South-East of Hermanus. Dark brown colour, very slight deposit of Fe_2O_3 on standing	29/ 3/40
168	Caledon, Cape Province	—	Mountain Spring, near Cape Hangklip. Dark brown colour, very slight deposit of Fe_2O_3 on standing	3/ 4/40
169	Caledon, Cape Province	—	Mountain Spring 8 miles South-West of Caledon. Faint brown colour	7/ 4/40
171	Caledon, Cape Province *	—	Caledon Hot Mineral Spring, crystal clear	6/ 4/40
170	Caledon, Cape Province	—	Mountain Spring, 3 miles North-East of Elgin Station. Crystal clear but slight deposit of Fe_2O_3 on standing	10/ 4/40
166	Cape Peninsula, Cape Province	—	Mountain Spring, St. James, Cape Town. Very faint brown colour. Clear but slight deposit of Fe_2O_3 on standing	4/ 3/40
310	Swellendam, Cape Province	—	Water from Mountain Spring, North of Swellendam. Very slight brown colour ($Fe_2O_3 . Al_2O_3$ content 0·4)	7/12/40
176	George, Cape Province	—	Mountain spring from near George. Dark brown colour. (Analysis Govt. Lab., Cape Town)	28/ 1/36
98	Mossel Bay, Cape Province	—	Mountain spring, Mossel Bay. Dark brown colour	19/12/38
138	Tulbagh, Cape Province	—	Mountain spring, East side of Tulbagh (Witzenberg Mountains). Crystal clear	5/ 1/40
185	Riversdale, Cape Province	—	Spring, pale brown in colour from Langeberg Mountains, 5 miles North of Riversdale	—
417	Cape Town, Cape Province	—	Platteklip spring. Crystal clear. Table Mountain, Cape Town. Above upper shale band	6/ 9/41
57	Cape Town, Cape Province	—	Spring, pale brown colour. Gordons Bay (Steenbras)	30/ 9/48
58	Cape Town, Cape Province	—	Spring, pale brown colour. Constantia Nek, Cape Town. ((Anal. Municipal Chemist, Cape Town)	10/10/29
312	Cape Town, Cape Province	—	Borehole, St. James, Cape Town	28/ 1/41
269	Willowmore, Cape Province	—	Spring, Toverwater Poort (Juritz Anal. 63 Cape Govt. Lab.)	1908
269 *a*)	Bredasdorp, Cape Province	—	Spring, coffee coloured at Kloof, Bredasdorp. (Anal. Govt. Lab.?)	23/11/41
450	Worcester, Cape Province	—	Spring at Brand Vlei (Anal. Juritz Ref. 41)	1908
462	Uitenhage, Cape Province	—	Springs 7 miles North East of Uitenhage	24/10/41

* This spring issues from the Table Mountain Sandstone but possibly the supply of water is derived from pre-Cape rocks.

It would be interesting but almost impossible to assess the corrosive damage caused to pipe lines, hot water cylinders, iron or steel storage tanks, locomotive and steam boilers, etc., by the use, during the last, 90 years, of untreated or imperfectly corrected, Table Mountain sandstone waters in large centres such as Cape Town, Mossel Bay, George, Knysna and so on. Suffice it to say that the cost to the City of Cape Town formerly ran into thousands of pounds annually. Fortunately the acidity in these waters is easily corrected by the appropriate use of lime, so that for general purposes these waters can be rendered quite suitable. Unfortunately, however, the percentage concentration of chloride is high (40 per cent. Cl.) and as chloride cannot be removed by any ordinary treatment, it tends to accumulate in steam boiler plant (in cases where the percentage " make-up " is high) so that this water is far from ideal for higher pressure boiler work, even when corrected with lime. This fact is discussed subsequently.

The chief characteristic of the Table Mountain sandstone water in the Cape Province is therefore its consistently low pH. value, which averages 5·7.

The cause of this acidity is dealt with later in the section.

Another prominent characteristic is the faint brown to dark coffee colour of all spring waters in the Table Mountain series, sometimes even when the sample is taken at the very eye of the spring. Naturally the colour darkens as the water passes through dense beds of vegetation lining the courses of mountain springs. For example, the Platteklip Spring in Cape Town (No. 417, Table 14) which at a distance looks almost crystal clear, has a faint brown colour, when viewed through a colorimeter, and has a low pH. value.

The average layman, on account of this brown colouration and also on account of the fact that the Table Mountain sandstone waters often deposit a little brown oxide on standing, assumes that the water contains a great deal of iron and ascribes the dark colour to iron. Actually as will be shown later, the iron content of these waters is, on the average, of very low order. The colour is due entirely to the presence of organic colouring matter and, as will be shown later, high acidity is also partly due to organic matter in solution.

The actual content of organic matter is much lower than would be expected from their appearance. From a large number of analyses carried out by the author the organic material varies from 0·5 to 10 parts per 10^5. Even in the extremely dark coloured waters met with in the vicinity of Hermanus, George and Knysna, the organic matter does not exceed this figure.

Expressed however, as a percentage, the organic matter in the Table Mountain sandstone waters is very high, but does not exceed [illegible] per cent. (on total solids). This figure is interesting when compared with the figures for organic matter of some tropical and other rivers, quoted by Clarke (43, p. 110) :—

Uruguay River = 59·9 per cent. organic matter (on total solids).
Plata River... = 49·6 per cent. organic matter (on total solids).
Amazon River. = 15·0 per cent. organic matter (on total solids).
Nile River..... = 10·36 per cent. organic matter (on total solids).
Danube River. = 3·25 per cent. organic matter (on total solids).

The author found that the organic matter in the Table Mountain sandstone waters is water soluble, but not soluble to any extent in ether or alcohol. When however the original water is evaporated to dryness and the residue taken up again with water, it was observed that only part of the organic matter goes back into solution.

At one time these so-called " humic acids " were supposed to be mixtures of acids termed humic, crenic, apocrenic and ulmic acids, but there is much doubt about this. They are now believed to be a vague group of organic colloids possessing slightly acidic properties.

The organic colouring matter of the waters is derived from the abundant heath-like type of vegetation growing on the soils on the Table Mountain series. As pointed out by Adamson (22, p. 281) these soils tend to accumulate great quantities of humus and the surface is frequently black. In some cases a surface layer of sandy peat is formed. Since the Table Mountain sandstones consist almost entirely of quartz, there are practically no bases to neutralise the organic acids in the soils which are therefore distinctly sour (pH. from 4·5 to 5·0). Grasses, as remarked by Adamson, never form a conspicuous feature on the mountain tops. The plants are of small stature, and Monocotyledons, especially the Restinacea, are very abundant giving a marked character to the vegetation. On the slopes of the mountains Protea bushes grow in abundance. Along the water courses soil is formed more rapidly and tall reed-like plants such as Dovea muconata, Bezelia lanuginosae, Psaralea pinnata (water bush) are commonly found and it is from these plants in particular that both the colouring matter and the acidity of the waters are derived.

On the seaward slopes of the mountain dense forests are developed Phillips, (23).

The vegetation on the Table Mountain series in Natal is quite different and grasses are the most common form of vegetation. Wattle plantations are also a conspicuous feature on this series in Natal. The abundant heathlike type of vegetation of the Cape Province is absent, and consequently the waters from Natal lack both the colouration and acidity of the waters from the Table Mountain series in the Cape Province.

Reverting to the Table Mountain series in the Cape Province, it has already been pointed out that even at the eyes of springs, the water has generally a faint brown colour and is distinctly on the acid side.

It follows therefore that a certain amount of organic matter is picked up on the surface and from the soil, and this is only partly removed during the passage of rain water through the thick beds of sandstone. When however the ground water issues as a spring it will take up more colouring matter and tend to become darker and still more acid, as the stream progresses down the mountain slope.

Some of the darkest coloured waters are those from the Hermanus and George districts and these have a pH. of as low as 4·5.

Another characteristic of the water from the Table Mountain series in the Cape Province is the relatively high chloride content. Although the actual analysis shows as a rule only 3 to 6 parts, yet expressed as a percentage of the total solids the figure is very high and consistent, averaging 40 per cent. Cl.

Sulphates are always present in small amounts, averaging 3 per cent. SO_4 on the total solids.

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Silica shows some variation, but is never high, averaging only 4·7 per cent. SiO_2 of the total solids.

This is interesting in view of the fact that it is generally supposed that the so-called humic acids readily attack silica and that waters relatively high in organic matter are likely to be very high in silica as well (Lindgren 35, p. 28). Clarke (43, p. 111) however, casts doubts on this theory, and states that it appears that the alleged relation between humus and silica is purely coincidental and that there is no proof that humic acids can dissolve silica when alkalies are absent.

Since the Table Mountain series essentially a siliceous formation, the evidence collected by the author in Table 14, strongly supports Clarke's view, since 4·7 per cent. SiO_2 is very low compared with the 16 per cent. SiO_2 of the waters from the basic rocks of the Bushveld Complex, or 19 per cent. SiO_2 in the case of the waters from the Red granite.

Soda alkalinity is never present; instead there is a relatively high permanent hardness figure which is fairly consistent in amount, averaging 18·9 per cent. of the total solids and consisting mainly of magnesium chloride.

Temporary hardness due to calcium and magnesium bicarbonates is very low, generally less than half of the total hardness, and averaging only 10·5 per cent. of the total solids.

The total scale-forming salts only average 26·2 per cent. of the total solids, so that these waters may be described as very soft. (Compare for example the waters from the Dolomite series with 91·0 per cent. of scale-forming salts).

Lime salts only average 3·9 per cent. while magnesium salts average 8·4 per cent.—a ratio of CaO : MgO of 1 : 2·2.

As would be expected, fluorides were not detected in any of the samples.

There is a small amount of iron in the waters from the Table Mountain series.

The sandstones are characterised by red or brown ferric iron oxide stains along the bedding planes or joints in the zones of weathering, but that in depth the sandstones become grey or bluish-green due to ferrous iron compounds.

Harden (25, pp. 45–47) has shown that iron compounds in rocks and soils can be attacked and taken into solution by the action of CO_2 or by the action of organic matter in the percolating water (so called humic acids); both agents are present in waters from the Table Mountain Series.

With regard to the former action, Harden showed that all ferrous compounds are readily acted upon by carbonic acid and taken into solution as ferrous bicarbonate but are carried as such *only as long as the water contains a large excess of carbon dioxide in solution*. Precipitation is therefore effected by the escape of CO_2 to the atmosphere or through its absorption by plant cells (Bacterial action).

In the case of bacterial action, iron is supposed to be precipitated by bacteria. Both the above theories would appear to account for the fact that the waters tend to deposit a little iron oxide on standing for some days. This is either through the loss of CO_2 or from bacterial action. Iron oxide is also precipitated on boiling this, of course, being due to loss of CO_2.

Now this deposition of iron oxide from waters on standing is by no means confined to these waters. It has been shown in a previous section that the crystal clear borehole waters from the Cape granite often exhibit this tendency, as to the Old granite waters from the Natal coast (Table 3), and in fact several other types. The author has observed, however, that this characteristic appears to be confined to waters with either a very low or fairly low pH. value (7·0 or under) and is in no way connected with an exceptionally high iron content. In other words this phenomenon takes place in waters with a large excess of free CO_2 (consequently with a low pH.). Precipitation is therefore due to loss of some of this CO_2 or to bacterial action. (Bacteria, incidentally flourish in slightly acid solution).

From the author's determinations, iron, though always present in the water from the Table Mountain series, exists in very small amount. The iron content was found to vary between 0·05 to 0·6 parts Fe_2O_3, the average being generally about 0·2 parts per 10^5. A sample of the so-called "chalybeate spring" at Caledon in the Cape Province, (see sample No. 171, Table 14) tested recently by the author contained only 1·6 per cent. Fe_2O_3 (1·1 per cent. Fe).

Rindl (4) has given figures of 1·8–2·0 parts per 10^5 Fe_2O_3 for this Caledon spring sampled at different period, while Juritz's (5) analyses of several waters from the Table Mountain series average only 0·2 parts Fe_2O_3 per 10^5. The iron content of these waters, as *sampled at the surface*, is therefore very low and is no greater than in most waters.

It is possible, however, that owing to the marked instability of ferrous bicarbonate, much of the iron content of these waters is removed before the ground water reaches the actual surface, or immediately it reaches the surface in the case of the Caledon and other springs (the Caledon spring has given rise to great mounds of iron and manganese accumulated over long periods of time).

Numbers of small ferruginous pellets are also found in the surface layers of the soils of the Table Mountain series and sometimes sheets of "laterite" are also found on the surface. These iron oxide deposits in the soil originate no doubt in the same way as the calcareous tufa described in Section 4, that is by loss of CO_2 from the ground waters with consequent precipitation of ferric oxides.

Though magnanese was not systematically determined in all the Table Mountain sandstone waters tested, the author carried out a colorimetric determination of manganese on a few samples but found nothing more than traces. For 6 samples the Mn content varied from ·0005 parts Mn to ·0012 parts per 10^5, hence it appears that the manganese content of these waters is usually very small, though occasionally it must be higher, as evidenced by the spring deposits at Caledon and Constantia Nek.

The manganese is probably present as manganous bicarbonate, and its precipitation is due to the loss of CO_2 and subsequent oxidation (or probably to bacterial action).

(i) *Cause of Acidity.*

To turn now to the cause of the acidity of the waters from Table Mountain series in the Cape Province.

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the sample bottle h
as far as possible.
The graph (Fig
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The results of t
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Table Mountain seri
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This, at first si
(27) who carried out
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(1) The strea
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m waters on standing is
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l granite waters from the
other types. The author
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v pH. value (7·0 or under)
ionally high iron content.
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$)_2$ or to bacterial action.
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ries, exists in very small
ary between 0·05 to 0·6
about 0·2 parts per 10^5.
ring" at Caledon in the
(4) tested recently by the
(1·1 per cent. Fe).

parts per 10^5 Fe_2O_3 for
period, while Juritz's (5)
Mountain series average
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Mn content varied from
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d subsequent oxidation

of the waters from the

There appears to be little or no reference in the local literature regarding this problem. It is generally assumed, however, that the acidity is due to organic acids, colloquially referred to as "Palmiet" acids (humic acids), derived from the vegetation growing profusely on the ranges of Table Mountain sandstone.

In view of the somewhat low organic content of the waters some chemists have suggested that the high acidity is really due to free (uncombined) CO_2 dissolved in these waters, though with the exception of that of Hey (27) no work appears to have been done on the subject.

In order to clear up this point the author carried out the following investigations.

(ii) *Investigation into the Cause of Acidity.*

The pH. reaction of natural waters (free from organic and mineral acids like H_2SO_4) has been shown to be due to equilibrium between free carbon dioxide and bicarbonate ions kept in solution in conjunction with calcium and magnesium ions Greenfield and Baker, (26).

The author determined the relation between the free CO_2 content and the pH. in the case of a large number of different types of waters, and the results are shown in Figure 1.

The author first determined the pH. and free CO_2 content of a large number of crystal clear borehole and spring waters which were free from any appreciable amount of organic matter and from mineral acids. The samples were tested as soon as possible after sampling, the sample bottle having been filled to the stopper to exclude air, as far as possible.

The graph (Figure 1) shows that though there is not a direct relation between the free CO_2 and pH. there is nevertheless a strong tendency in that direction. A large number of the coffee coloured acid waters from the Table Mountain series were then tested in a similar manner. It was found that though free CO_2 was present in all the waters from this formation in the Cape Province, in no case was the content very high, and the points (free CO_2-pH) lie very much to the left of the curve for the other waters.

Incidentally it appears that natural waters with a free CO_2 content of over 4 parts per 10^5 are rare in the Union. There are, of course, a few springs like those in Pondoland with abnormal amounts of free CO_2.

The results of the tests carried out by the author would appear to indicate very clearly that the high acidity of the waters in the Table Mountain series in the Cape Province is not due entirely to an excessive amount of free CO_2 in solution but rather to organic acids (humic) derived from the vegetation through which the water percolates.

This, at first sight, may appear to contradict the work of Hey (27) who carried out some tests on one stream, namely the Bosboukloof stream which flows through the Trout Hatchery at Jonkershoek, and came to the conclusion that the acidity was due solely to dissolved CO_2. The following facts however, must be borne in mind:—

(1) The stream at Jonkershoek does not appear to be typical of stream water in the Table Mountain series. In a communication to the author received from Dr. Hey, it was pointed out that the stream issues from the junction of the Table Mountain series and Franschhoek Shales, and is

practically water white, there being not the slightest trace of any brown colour, in contrast with the pale brown to deep brown colour of the typical streams in the Table Mountain series. (Hey does not give a complete analysis of this water).

(2) The pH. of the water was 6·8 as compared with the 4·5 to 5·5 of the vast majority of the typical brown coloured waters from the Table Mountain series examined by the author.

Dr. Hey found that after boiling this pH. rose to 7·0 showing that in the case of the Jonkershoek stream the acidity was undoubtedly due to free CO_2.

Similar tests to those made by Dr. Hey were carried out by the author on some waters from the Table Mountain series in Natal which were cystal clear and relatively free from organic matter, and had pH. values from 6·5 to 7·0. The results were as follows :—

	pH. Value before Boiling.	*pH. Value after Boiling.*
Sample 422 (see Table 15)........	6·8	7·15
Sample 338 (see Table 15)........	6·5	7·0
Sample 339 (see Table 15)........	6·8	7·1
Sample 531 (see Table 15)........	6·5	7·1
Sample 521 (see Table 15)........	6·9	7·0

This proved that the very slight acidity of the water from this formation in Natal was due to free CO_2.

Similar tests were then carried out on the samples of coffee-coloured acid waters of the Table Mountain series from the Cape Province with the following results :—

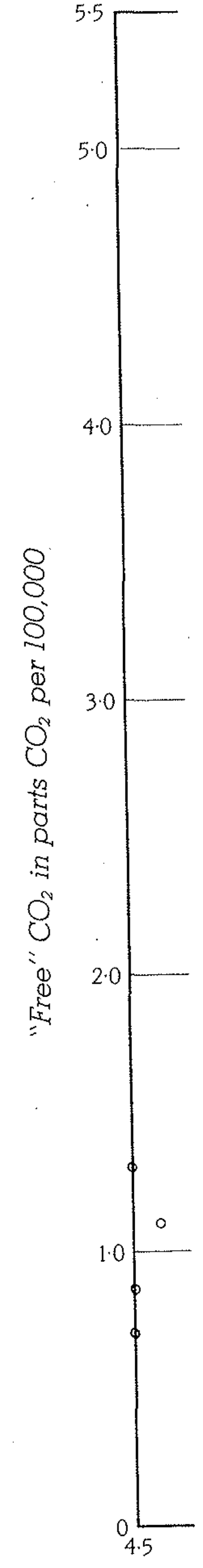
Sample No.	Table No.	Colour.	Free CO_2 Parts per 10^5.	Initial pH. Value.	pH. after Boiling.	Organic Matter Per cent.
168	14	Very Dark brown	0·88	4·50	4·60	25·5
167	14	Very dark brown	0·66	4·50	4·65	25·0
166	14	Light brown....	1·00	5·20	5·35	14·4
98	14	Brown..........	0·70	6·00	6·20	23·0
57	14	Pale brown.....	1·00	6·00	6·15	20·3
A.	Hermanus Reservoir *	Brown..........	0·20	6·20	7·10	25·0
184	14	Light brown....	1·00	5·70	5·90	22·0

* The water in this reservoir had been standing for a considerable period

All the above figures were the result of a number of repea tests.

The test on Sample A. shows an anomaly. Although the fre CO_2 (confirmed by two different methods) is exceedingly low an organic matter very high, the pH. is not as low as would be expecte and shows an appreciable rise after boiling, and attains the neutr 7·0 pH. point.

Otherwise all the foregoing tests indicate no appreciable rise pH. after boiling in any of the samples tested and this resultant p in no case approached the neutral point of 7·0



It is also shown that the acidity tends to vary with the depth of colour, and consequently with the organic matter content of the water (though the determination of organic matter by ignition of the total solids at low red heat affords only an approximate figure).

The low free CO_2 content of all the waters from the Table Mountain series is rather surprising, in view of the organic matter present, but this low free CO_2 content is confirmed by analyses made by many chemists. It must be explained that with the exception of the Hermanus water, all the samples tested by the author were freshly drawn. No doubt the CO_2 figure would be higher through oxidation of organic matter if the water were allowed to stand in reservoirs, etc., for a long period of time.

The normal dissolved oxygen content of the coffee coloured waters is high, usually 4·5 to 6 mls. per litre of O_2.

The results of the foregoing investigations prove clearly that the high acidity is mainly due to organic acids, and only in small part, due to free CO_2. This applies more particularly to the very dark brown waters.

(iii) *Utilisation.*

In view of the exceedingly low concentration of solids in all the waters in the Table Mountain series in the Cape Province, they would automatically fall into the pure water group E. but these waters differ from the others in that group, in having a very much higher acidity and a relatively higher chloride content. Their utilisation is discussed under Group E.

It may be stated here that these waters are potable, and entirely suitable for watering stock and for irrigation. If untreated they tend, as aforementioned, to corrode pipe lines and hot water installations. In view of the low lime content they would benefit by the addition of lime before being used for domestic consumption.

As regards the origin of the Table Mountain series, certain geologists Du Toit (14 p. 214), in view of the fact that no fish or definite marine invertebrate fossils have been found, are inclined to the view that the formation is of fluviatile origin rather than marine.

The results of the water analyses as set forth in Table 14 would, at first sight, appear to point to a sea water origin (i.e. the relatively high chloride) or to subsequent marine transgression after consolidation of these rocks. One important fact however, must be borne in mind—the mountain ranges which are built up of the Table Mountain series lie not only parallel to the sea, but at no great distance from the coast, and the prevailing South-Easterly winds heavily laden with salt impregnated moistures tend to pile up against these mountain ranges and deposit their moisture in the form of mists or rain. Hence springs on the seaward slopes of the mountain would tend to be contaminated with salts carried by these winds.

QUALITY OF WATER IN NATAL.

In Table 15, the author has set out the results of anlyses of waters from the Table Mountain series from the Port Shepstone, Upper Tongaat, Camperdown, New Hanover, Pinetown, Lower Tugela and Eshowe districts of Natal. With two exceptions these are all spring waters. As in the Cape Province, boreholes in this formation are few and far between, on account of the numerous springs arising in the mountainous areas built up of that formation.

The Natal waters contain very little mineral salts, the average concentration being only 11·4 parts per 100,000. They are very similar to those of the Cape Province, but unlike the latter are but slightly acidic, the pH. value, though low, averaging 6·9 as compared with the average of 5·7 of the latter. Furthermore, they are crystal clear in colour in contrast to the coffee coloured spring waters in the Cape Province and contain only a trace of organic matter. This is due to the absence of the "palmiet" vegetation so prolific in the mountain country of the Cape Province. Consequently the organic acids are absent. As shown in a previous page, the slight acidity found is due to dissolved CO_2.

The silica content is higher than in the case of the waters from the Table Mountain series in the Cape, averaging 10·4 per cent. of the total solids.

Fluorides were not found.

Chlorides, expressed as a percentage of the total solids average 32·1, a figure which, though high, is lower than that in the Cape (40 per cent.).

Sulphates at 2·1 per cent. SO_4 are a little lower than in the Cape. Sodium carbonate or bicarbonate, is never present; instead a small permanent hardness is always present, averaging 16·3 per cent. of the total solids. The temporary hardness salts, calcium and magnesium bicarbonates, are relatively higher than in the Cape, averaging 19·3 per cent. of the total dissolved solids, as against 10·6 per cent. in the case of the Cape.

The total scale-forming compounds, at 33·3 per cent. are a little higher than in the Cape waters (26·2 per cent.) but in spite of this these waters may be described as very soft.

Lime, at 6·8 per cent, is relatively higher than in the case of the Cape waters (3·9 per cent.) and this may be accounted for by the fact that the sandstones are not always composed entirely of quartz but are sometimes slightly felspathic.

The CaO : MgO ratio at 1 : 1·5 is less than that of waters occurring in the Table Mountain series in the Cape Province (1 : 2·2).

Owing to the low concentration of salts, these waters can be classified under the very pure water group E. The chemical correction and utilisation of these waters will be dealt with fully under Group E, but it may be stated that for domestic, stock watering, irrigation and most general industrial purposes these waters can be used *untreated.*

The low concentration of salts and in particular the low sulphate content and the CaO : MgO ratio would not appear to indicate contamination with entrapped sea water. The relatively high chloride content may be cyclic, that is caused by salt spray carried some little distance inland by wind and deposited by rain, for the Table Mountain sandstone formation runs parallel with and at no great distance from the coast in Natal.

No data is available regarding the quality of the Table Mountain sandstone water in Pondoland.

Sample Numbers......	2
Parts $CaCO_3$ per 1c	
Total Solids (at 106°)...	
Methyl Orange Alkalini	
Total Hardness........	
Permanent Hardness...	
Temporary Hardness...	
Hardness due to Ca Sa	
Hardness due to Mg Sa	
Soda Alkalinity.......	il
Parts per 10^5 of	
Silica (as SiO_2).........	
Fluorides (as F).......	il
Nitrites...............	il
Nitrates (as NO_3)......	il
Chlorides (as Cl).......	
Sulphates (as SO_4).....	
Potassium Salts.......	1c
pH. Values...........	
Percentage on Tota	
SiO_2.................	
CaO.................	
MgO.................	
Cl..................	
SO_4.................	
Soda Alkalinity (as Na_2	il
Total Hardness (as CaC	
Permanent Hardness (as	
Temporary Hardness (as	
Ratio CaO : MgO......	3

aters contain very little mineral salts, the avera
ng only 11·4 parts per 100,000. They are ver
f the Cape Province, but unlike the latter are b
pH. value, though low, averaging 6·9 as compare
of 5·7 of the latter. Furthermore, they are crysta
contrast to the coffee coloured spring waters in the
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wind and deposited by rain, for the Table Mountain
n runs parallel with and at no great distance from

ilable regarding the quality of the Table Mountain
Pondoland.

Numbers	42	41	422	347	338	339	529	531	532	518	521	Average
Parts $CaCO_3$ per 10^5 Water:												
Solids (at 106°)	10·0	8·5	11·2	(35·0)	*12·8	*17·8	14·0	5·5	6·0	11·2	17·2	11·4
hyl Orange Alkalinity	3·0	2·5	1·6	9·5	1·5	1·8	3·5	0·5	2·0	1·0	2·0	—
Hardness	3·8	3·1	2·6	18·0	2·4	3·6	2·8	3·4	4·3	4·3	4·3	—
anent Hardness	0·8	0·6	1·0	8·5	0·9	1·8	Nil	2·9	2·3	3·3	2·3	—
porary Hardness	3·0	2·5	1·6	9·5	1·5	1·8	2·8	0·5	2·0	1·0	2·0	—
dness due to Ca Salts	1·3	1·4	0·8	10·8	0·9	2·0	Trace	0·9	0·7	0·5	0·5	—
dness due to Mg Salts	2·5	1·7	1·8	7·2	1·5	1·6	2·8	2·5	3·6	3·8	3·8	—
Alkalinity	Nil	Nil	Nil	Nil	Nil	Nil	0·7	Nil	Nil	Nil	Nil	—
Parts per 10^5 of Water:												
(as SiO_2)	1·2	—	—	3·6	1·8	1·6	2·7	0·7	0·3	0·92	2·0	—
rides (as F)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Trace	—
ites	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	—
ates (as NO_3)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	—
rides (as Cl)	2·8	2·2	2·4	13·1	5·8	9·3	2·5	1·8	0·7	4·3	5·4	—
phates (as SO_4)	Trace	Trace	1·1	0·02	0·04	0·03	0·07	0·2	0·14	0·04	1·0	—
ssium Salts	Trace	Trace	0·05	Under 0·5	Trace	Trace	Trace	Trace	Trace	Trace	Trace	—
Values	7·0	7·2	6·8	7·2	6·5	6·8	7·3	6·5	6·85	6·5	6·9	6·9
Percentage on Total Solids:												
SO	12·0	—	—	10·4	14·0	9·0	(19·2)	12·6	5·0	8·3	12·2	10·4
O	7·2	9·3	4·0	17·0	3·9	6·2	(Trace)	9·0	6·6	3·5	1·6	6·8
O	10·0	8·0	6·45	8·3	4·7	3·6	7·8	18·2	23·2	13·4	8·7	10·2
[illegible]	28·0	25·7	21·5	37·5	45·0	53·0	18·0	32·5	(11·6)	28·5	31·5	32·1
[illegible]	Trace	Trace	9·8	0·6	0·3	0·2	0·5	3·3	2·35	0·35	5·8	2·1
Alkalinity (as Na_2CO_3)	Nil	Nil	Nil	Nil	Nil	Nil	(5·5)	Nil	Nil	Nil	Nil	Nil
Hardness (as $CaCO_3$)	38·0	36·2	23·2	51·5	18·8	20·5	20·0	61·5	(72·0)	38·5	25·0	33·3
anent Hardness (as $CaCO_3$)	8·0	7·0	9·0	24·5	7·0	10·2	(Nil)	(52·0)	38·0	29·5	13·3	16·3
porary Hardness (as $CaCO_3$)	30·0	29·2	24·2	27·0	11·8	10·3	20·0	9·5	(34·0)	9·0	11·7	19·3
CaO : MgO	1 : 1·4	1 : 0·9	1 : 1·6	1 : 0·5	1 : 1·2	1 : 0·6	1 : 7·2	1 : 2·0	1 : 3·5	1 : 5·2	1 : 5·4	1 : 1·5

* Deposits iron oxide on standing.

DESCRIPTION OF SAMPLES IN TABLE No. 15.

Sample No.	District and Province.	Borehole Depth. Feet.	Locality, Description and Remarks.	Date.
42	Pinetown, Natal..........................	—	Spring, Electric Substation, Marianhill..............................	23/ 4/37
41	Pinetown, Natal..........................	—	Spring near Electric Substation, Delville Wood...............	23/ 4/37
518	Pinetown, Natal..........................	—	Spring at Waterfall, Pinetown, near Durban.................	13/ 3/42
347	Pinetown, Natal..........................	160	Borehole in Pinetown, Mrs. Wright's house..................	4/ 4/41
422	Eshowe, Natal..........................	—	Spring at Eshowe (Dr. Ockerse Anal. D.C.S.)................	1941
338	Camperdown, Natal.......................	—	Spring, Umlazi Location, 15 miles West North-West of Isipingo	20/ 3/41
339	Port Shepstone, Natal....................	—	Spring, Oribi Gorge, 15 miles West South-West of Port Shepstone.	27/ 3/41
529	Lower Tugela, Natal.	129	Borehole on farm Errydale (W. Collins) about 9 miles North-West of Tongaat..	1/ 4/42
531	New Hanover, Natal......................	—	Spring just below Noodsberg...............................	1/ 4/42
532	New Hanover, Natal......................	—	Borehole at Wartburg, East of Pietermaritzburg..............	1/ 4/42
521	Lower Tugela, North Coast, Natal.........	—	Spring 2 miles North-East of Stanger......................	21/ 3/42

VI.—THE WATERS IN THE BOKKEVELD SERIES, CAPE SYSTEM.

The Bokkeveld series passes upwards with
itteberg series, and for the purposes of this stud
n be considered together.

Distribution and Rainfal

The Bokkeveld series, which lie conformably o
ries, forms low lying ground between the mou
ountain sandstones in the " Folded Mountain
estern and Southern Cape.

The Witteberg series, consisting mainly of
form comparatively low ranges of hills of an
sily distinguished from the higher ranges
ndstone in the vicinity.

The rainfall in the areas occupied by these
ole, very poor, averaging from about 15" per an
strict to 10" in the Willowmore district.

Geology and Lithology.

In the Bokkeveld series shaly or slaty be
t few sandstone and quartzite beds, while in the
ries the reverse obtains.

The Bokkeveld series consist of dark blue t
ales and mudstones with some micaceous flagst
ale beds are sometimes carbonaceous and rich i
ssils. Some feslpathic sandstones occur, but
ds are siliceous. The soils are rather clayey

The Witteberg series is predominantly arena
e very fine grained and white in colour. The
e commonly micaceous and occasionally carbon
aphite flakes.

Both the shale and quartzite beds of the
en bent into acute folds. Fossils are not
ainly of plant remains.

The age of the Bokkeveld series has been
wer to Middle Devonian and that of the
vonian to Lower Carboniferous.

From the point of view of this study, the i
e Lower Bokkeveld beds are definitely a mar
n laid down under salt water, while the
itteberg beds are generally regarded as having
ustrine or fluviatile conditions. Further ref
de later.

Underground Water Suppl

Du Toit (2, p. 121) states that the yields
n in districts of low rainfall such as Princ
Willowmore, yields of from 20,000 to 50,000
e common, but in Uitenhage the average yi
0 gallons *per diem*. Du Toit points out that

—THE WATERS IN THE BOKKEVELD AND WITTEBERG SERIES, CAPE SYSTEM.

The Bokkeveld series passes upwards without a break into the Witteberg series, and for the purposes of this study, the two formations can be considered together.

DISTRIBUTION AND RAINFALL.

The Bokkeveld series, which lie conformably on the Table Mountain series, forms low lying ground between the mountain ranges of Table Mountain sandstones in the "Folded Mountain Belt" of the South-western and Southern Cape.

The Witteberg series, consisting mainly of quartzitic beds, tend to form comparatively low ranges of hills of an almost white colour, easily distinguished from the higher ranges of Table Mountain sandstone in the vicinity.

The rainfall in the areas occupied by these formations is, on the whole, very poor, averaging from about 15″ per annum in the Uitenhage district to 10″ in the Willowmore district.

GEOLOGY AND LITHOLOGY.

In the Bokkeveld series shaly or slaty beds predominate, with but few sandstone and quartzite beds, while in the succeeding Witteberg series the reverse obtains.

The Bokkeveld series consist of dark blue to greyish or greenish shales and mudstones with some micaceous flagstones, while the lowest shale beds are sometimes carbonaceous and rich in marine invertebrate fossils. Some feslpathic sandstones occur, but the higher sandstone beds are siliceous. The soils are rather clayey and sweet.

The Witteberg series is predominantly arenaceous. The quartzites are very fine grained and white in colour. The shale and flagstones are commonly micaceous and occasionally carbonaceous with occasional graphite flakes.

Both the shale and quartzite beds of the Witteberg series have been bent into acute folds. Fossils are not common, and consist mainly of plant remains.

The age of the Bokkeveld series has been generally regarded as Lower to Middle Devonian and that of the Witteberg as Upper Devonian to Lower Carboniferous.

From the point of view of this study, the important fact is that the Lower Bokkeveld beds are definitely a marine formation, having been laid down under salt water, while the upper Bokkeveld and Witteberg beds are generally regarded as having been laid down under lacustrine or fluviatile conditions. Further reference to this will be made later.

UNDERGROUND WATER SUPPLIES.

Du Toit (2, p. 121) states that the yields are generally good; even in districts of low rainfall such as Prince Albert, Oudtshoorn or Willowmore, yields of from 20,000 to 50,000 gallons *per diem* being quite common, but in Uitenhage the average yield is low, being only 0 gallons *per diem*. Du Toit points out that the water is generally very brackish.

Frommurze (3, pp. 117–120) states that in the folded areas the permeability of the rocks is increased and infiltration becomes facilitated by the highly tilted and cleaved nature of the beds and supplies are good in quantity, but brackish and sometimes sulphurous.

The average depth at which water is struck is generally well under 100′ except in the Alexandria district. The percentage of failures is generally low, but the percentage of very brack supplies well over 40 per cent. In the Witteberg series the yield is generally much poorer owing to the quartzitic nature of the rocks and Frommurze gives an average of about 10,000 gallons *per diem* at depths of well over 200 ft. (except in the Prince Albert district).

QUALITY OF THE WATER.

Quite a number of fairly important centres are located on the Bokkeveld and Witteberg formations (e.g. Caledon, Uniondale, Willowmore, Bredasdorp, Steytlerville, Grahamstown, Bathurst and Port Alfred) but most of these towns draw their water supplies from the mountain streams of the Table Mountain sandstone formation. This is indeed fortunate for the waters from the Bokkeveld beds, and to a less extent, the Witteberg, are decidedly brackish. Some small towns however (e.g. Willowmore) are still dependent on brackish borehole supplies from the Bokkeveld beds.

In spite of the fact that borehole waters are not used to any great extent for domestic or industrial supplies, these waters are nevertheless of great interest to this study, on account of the fact that some of the Bokkeveld series at least, were without any doubt laid down under the sea.

The author had great difficulty in obtaining samples of water from the Bokkeveld or Witteberg beds, owing to the fact that a large number of boreholes in these formations have long ago been abandoned on account of salinity and a better quality water obtained from other sources, and has therefore included in the analyses of seventeen samples as shown in Tables 16 and 17 several of Juritz's analyses (5, pp. 478–479) made about the year 1908, which unfortunately are not complete.

Samples were drawn from the Willowmore, Caledon, Oudtshoorn, Uniondale, Prince Albert, Laingsburg, Albany and Worcester districts, and although few in number they are fairly representative of the Bokkeveld and Witteberg formations.

It must be emphasised that there is no clear line of demarcation between the upper Bokkeveld and lower Witteberg shales, and several water samples included in the Witteberg shales may originate in the Bokkeveld horizon.

The most striking feature of the waters from the Bokkeveld beds is the very high salinity, the average concentration being well over 200 parts per 100,000. There is a gradual decrease in salinity until the Witteberg quartzite zone is reached. These quartzites yield water of very low concentration, the average being about 10 parts per 100,000. The Witteberg shales, however, yield water of an average concentration of 90 parts, but as mentioned, some of these waters may come from the Bokkeveld horizon.

The chloride content is very high. In the case of waters the Bokkeveld beds, Cl. averages 41 per cent. in terms of total

in the folded areas the
ltration becomes facili-
f the beds and supplies
times sulphurous.

ruck is generally well
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n terms of total salts.

In the Witteberg series, the shale zones yield water with an average of 43 per cent. Cl. and the quartzite zones 31 per cent. *As appears to be the case in all saline waters the silica content is very low, averaging under 2 per cent.* The Witteberg quartzite waters, on the other hand, show an average of 10 per cent. SiO_2 in terms of total solids.

The sulphate content of Bokkeveld waters is high (13·5 per cent. SO_4). Those from the Witteberg beds, both in the shale and quartzite zones show an average of over 15 per cent. SO_4, though the absolute amount of SO_4 in the latter is low.

Except in the case of waters from the Witteberg quartzite zone, calcium predominates slightly over magnesium.

There is insufficient data regarding fluorides.

Na_2CO_3 or $NaHCO_3$ is very rare; instead there is nearly always an appreciable permanent hardness (over 17 per cent. as $CaCO_3$).

Although most of the Bokkeveld waters are exceedingly hard (hardness figure of over 100 parts $CaCO_3$ per 10^5 being quite common) yet in terms of total solids the scale-forming compounds only comprise per cent. of the total salts. The Witteberg shale waters show a slightly lower hardness while the waters from the quartzite zones have a hardness of only about 3 parts $CaCO_3$ per 10^5 (or 32 per cent. $CaCO_3$ expressed in terms of total solids).

Both the Bokkeveld and Witteberg shale waters fall naturally into the highly mineralised chloride-sulphate Group A of waters, the utilisation of these waters and the necessary corrective chemical treatment is discussed under Group A. It may be stated here however, that for nearly all industrial purposes and for use as boiler feed in steam plant, the waters from the Bokkeveld shale beds are far too saline.

The majority of these waters are non-potable on account of salinity though they could be used for watering livestock.

A few of the waters may be too saline for irrigation purposes, unless used in the case of loose porous soils, but the majority are suitable.

The remarks apply to a less extent to the waters from the Witteberg shale zones, but the Witteberg quartzite zones yield very pure water as far as concentration of salts are concerned.

The Witteberg quartzite waters would appear to fall into the pure water Group E, as the concentration of salts is low, but the chloride content, though low in actual amount, is relatively high in proportion to the other radicles 31 per cent.) and in very dry seasons even this water would tend to become slightly brackish. When used as feed water in steam boiler plant the chloride would tend to accumulate fairly rapidly in the boilers, but for all other purposes this water would be very suitable.

The very high salinity of water from the Bokkeveld beds can easily be explained.

On palaeontological grounds it has been established that the Bokkeveld beds were laid down in sea water, and, since these beds are predominantly argillaceous, any contained and adsorbed salts would not be readily leached out even though a considerable period of time had elapsed since the deposition of these beds. In other words these beds would be likely to retain connate sea water. Further, the areas concerned are those with limited rainfall, so that on account of restricted circulation in the rocks, the process of dilution would be a slow one.

As in the case of water from the Malmesbury saltes, a comparison of the average percentage composition of Bokkeveld waters with those of sea water is most striking. This comparison is given in Table 27.

The same relation between the constituents obtain as in the case of oceanic waters, i.e. $Cl > SO_4 > CO_3$ and $Na > Mg > Ca$.

It will be noted however, that, instead of the magnesium predominating the *average* CaO : MgO ratio is 1 : 0·96, though in a few waters the ratio is 1 : 2·6. It must be borne in mind that there the shales seem to be slightly calcareous, a fact which is reflected in the somewhat sweet nature of the Bokkeveld soils.

Palaeontological evidence as to the marine origin of the Bokkeveld beds is absolutely conclusive, but even if this were not the case, it is contended by the author that a comparison of the percentage composition of the Bokkeveld waters with that of sea water as set out in Table 27, would definitely point to the marine origin of these beds.

On palaeontological evidence it is assumed that there was a gradual change from the purely marine phases of sedmentation during the lower Bokkeveld to fluviatile or lacustrine conditions in the Witteberg period. Du Toit (14, p. 228). A study of Table 17 would however appear to indicate that salt water, or at least brackish water conditions prevailed even up to the deposition of the Witteberg quartzites. As regards the waters from the Witteberg quartzitic zone, it must be borne in mind that from the very nature of these sandstones they would be less likely to retain connate sea water than the underlying Witteberg shale beds, and being porous would tend in time to have most of the original salts leached out of them.

XVII.—THE WATERS IN THE DWYKA SERIES OF THE KARROO SYSTEM.

The Dwyka series, the lowest member of the Karroo system is, of course, of very great geological interest on account of its glacial origin, but from the point of view of this study it is not quite as important as some of the other members of this group, for example the Beaufort series, for the areas directly underlain by Dwyka tillite are somewhat sparsely populated and contain few centres of importance.

Distribution and Rainfall.

In the Transvaal the Dwyka series tends to be covered by the Ecca series. Small outliers of the Dwyka tillite occur in the Central Transvaal in the Witbank, Middelburg and Pretoria districts, but the formation is very thin and of small extent and of no importance to this study.

The Dwyka series forms the rim of the vast Karroo basin, and partly encircles the central portion of the Union, South of the Transvaal. In the South-East Cape the formation disappears beneath the ocean.

Except in the Bechuanaland, Calvinia, Prieska, Hopetown and Kimberley districts, the exposures of Dwyka tillite form narro belts. In the Transvaal and Cape Provinces the only centres of a

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e Transvaal and Cape Provinces the only centres

TABLE No. 16.—BOKKEVELD SERIES—CAPE SYSTEM.

Sample Numbers	352A	352B	352C	251	209	250	252	419	Average
Parts $CaCO_3$ per 10^5 Water :									
Total Solids (at 106°)	360·0	249·0	231·0	213·0	112·0	387·0	274·0	56·0	235·0
Methyl Orange Alkalinity	33·0	42·5	54·5	19·0	—	50·0	52·5	6·4	—
Total Hardness	168·0	88·0	120·0	49·0	48·0	70·0	112·3	19·8	—
Permanent Hardness	135·0	45·5	65·5	30·0	—	20·0	59·8	13·4	—
Temporary Hardness	33·0	42·5	54·4	19·0	—	50·0	52·5	6·4	—
Hardness due to Ca Salts	68·0	28·0	50·0	10·5	21·2	54·0	51·3	10·0	—
Hardness due to Mg Salts	100·0	60·0	70·0	38·5	26·8	16·0	61·0	9·8	—
Soda Alkalinity	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	—
Parts per 10^5 of Water :									
Silica (as SiO_2)	4·0	2·2	2·8	1·5	1·7	2·8	2·6	—	—
Fluorides (as F)	0·02	0·02	0·01	—	—	—	—	Nil	—
Nitrites	Nil	Nil	Nil	—	—	—	—	Nil	—
Nitrates (as NO_3)	Nil	0·32	0·3	—	—	—	—	0·01	—
Chlorides (as Cl)	152·0	86·0	130·0	110·6	36·3	153·0	95·1	21·0	—
Sulphates (as SO_4)	53·0	38·0	32·0	13·3	14·2	51·0	44·0	8·8	—
Potassium Salts	Small Amount	Small Amount	Small Amount	—	—	—	—	0·26	—
pH. Values	7·1	7·6	7·6	—	—	—	—	—	7·4
Percentage on Total Solids :									
SiO_2	1·1	0·9	1·2	0·7	1·5	0·72	0·95	—	1·1
CaO	10·6	6·3	12·1	(2·8)	10·6	7·8	10·4	10·0	9·7
MgO	11·1	9·7	12·1	7·3	9·7	(1·65)	9·0	7·0	9·40
Cl	42·0	34·5	56·0	52·0	32·0	39·5	34·5	38·5	41·25
SO_4	14·7	15·2	13·8	6·3	12·8	13·2	16·0	15·7	13·46
Soda Alkalinity (as Na_2CO_3)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Total Hardness (as $CaCO_3$)	46·5	35·0	52·0	23·0	43·0	18·0	41·0	35·5	36·75
Permanent Hardness (as $CaCO_3$)	37·5	14·2	28·3	14·0	—	5·1	21·8	24·0	20·7
Temporary Hardness (as $CaCO_3$)	9·1	17·0	23·6	8·9	—	12·8	19·0	11·4	14·54
Ratio CaO : MgO	1 : 1·05	1 : 1·5	1 : 1·0	(1 : 2·6)	1 : 0·9	(1 : 0·2)	1 : 0·9	1 : 0·7	1 : 0·96

Sample No.	District and Province.	Borehole Depth.	Locality, Description and Remarks.	Date.
		Feet.		
352A	Willowmore, Cape Province................	—	Municipal borehole, Wehmeyer Street, Willowmore...........	16/ 4/41
352B	Willowmore, Cape Province................	—	Municipal borehole, Knysna Street, Cape Province............	16/ 4/41
352C	Willowmore, Cape Province................	—	Well, Mrs. du Plessis, Willowmore.........................	16/ 4/41
209	Willowmore, Cape Province................	—	Well at Antonie Siding (Anal. Juritz).........................	1908
250	Willowmore, Cape Province................	19	Well at Klipgat (Anal. Juritz 143).........................	1908
252	Willowmore, Cape Province................	35	Well at Landdrost Plaats (Juritz Ref. 145)...................	1908
419	Oudtshoorn, Cape Province...............	—	Borehole at Armoed (Dr. Ockerse—Anal. D.C.S.).............	1940
251	Caledon, Cape Province....................	410	Borehole at Caledon (Anal. Juritz 140).......................	1908

Sample No.	District and Province.	Bo D
254	Laingsburg, Cape Province................	
253	Albany, Cape Province....................	
253 (*a*)	Albany, Cape Province....................	
448	Worcester, Cape Province..................	
484	Laingsburg, Cape Province................	
492	Albany, Cape Province....................	
210 (*a*)	Uniondale, Cape Province.................	
210	Uniondale, Cape Province.................	
216	Prince Albert, Cape Province..............	

TABLE No. 16.

Locality, Description and Remarks.	Date.
l borehole, Wehmeyer Street, Willowmore............	16/ 4/41
l borehole, Knysna Street, Cape Province............	16/ 4/41
s. du Plessis, Willowmore..........................	16/ 4/41
Antonie Siding (Anal. Juritz)......................	1908
Klipgat (Anal. Juritz 143).........................	1908
Landdrost Plaats (Juritz Ref. 145).................	1908
at Armoed (Dr. Ockerse—Anal. D.C.S.)...............	1940
at Caledon (Anal. Juritz 140)......................	1908

TABLE No. 17.—WITTEBERG SERIES—CAPE SYSTEM.

	SHALE BEDS.							QUARTZITE ZONE.			
Sample Numbers..........	254	253	448	253 (*a*)	484	492	Average	210 (*a*)	210	216	Average
Parts $CaCO_3$ per 10^5 Water:											
Total Solids (at 106°).......	43·0	107·5	153·0	84·5	65·0	99·0	92·0	9·2	10·0	10·8	10·0
Methyl Orange Alkalinity...	22·8	17·1	10·8	19·5	24·2	32·0	—	0·5	0·5	3·5	—
Total Hardness............	33·7	20·0	62·5	7·2	31·2	32·3	—	2·0	2·4	5·4	—
Permanent Hardness........	10·9	2·9	51·7	Nil	7·0	0·3	—	1·5	1·9	1·9	—
Temporary Hardness.......	22·8	17·1	10·8	7·2	24·2	32·0	—	0·5	0·5	3·5	—
Hardness due to Ca Salts...	21·8	9·5	15·3	4·3	21·8	18·5	—	0·7	0·7	1·8	—
Hardness due to Mg Salts...	11·9	10·5	47·2	2·9	9·4	13·8	—	1·3	1·7	3·6	—
Soda Alkalinity............	Nil	Nil	Nil	(12·3)	Nil	Nil	—	Nil	Nil	Nil	—
Parts per 10^5 of Water:											
Silica (as SiO_2)............	1·7	1·54	2·1	1·56	0·24	1·06	—	0·97	1·0	1·2	—
Fluorides (as F)...........	—	—	—	—	—	—	—	—	—	Nil	—
Nitrites..................	—	—	—	—	—	—	—	—	—	Nil	—
Nitrates (as NO_2)..........	—	—	—	—	—	—	—	—	—	Nil	—
Chlorides (as Cl)...........	21·0	42·1	81·2	27·2	19·0	56·0	—	3·5	3·5	2·1	—
Sulphates (as SO_4)..........	2·8	6·7	4·7	3·9	1·3	11·8	—	0·53	0·84	0·4	—
Potassium Salts............	—	—	—	—	—	—	—	—	—	Trace	—
pH. Values................	—	—	—	—	—	—	—	—	—	7·4	—
Percentage on Total Solids:											
SiO_2.....................	4·0	1·4	1·4	1·9	(0·24)	1·1	1·8	10·4	10·0	11·0	10·4
CaO.....................	28·0	4·9	5·6	2·9	18·8	10·5	11·8	3·95	3·9	9·3	5·7
MgO.....................	11·2	3·9	12·4	1·4	5·8	5·6	6·7	5·6	6·8	11·0	7·8
Cl.......................	48·5	39·0	53·0	32·5	29·0	57·0	43·0	38·0	35·0	19·4	30·8
SO_4......................	6·5	6·2	3·1	4·7	2·0	12·0	6·7	5·8	8·4	3·7	6·0
Soda Alkalinity (as Na_2CO_3)	Nil	Nil	Nil	(14·35)	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Total Hardness (as $CaCO_3$)	(78·0)	18·7	41·0	(8·4)	29·0	32·4	30·3	21·5	24·0	50·0	31·8
Per. Hardness (as Ca_2CO_3)	25·2	(2·7)	34·0	(Nil)	10·8	(0·4)	20·6	16·3	19·0	17·5	17·6
Temp. Hardness (as Ca_2CO_3)	53·0	16·9	7·0	(8·4)	37·0	33·0	29·7	5·4	5·0	33·0	14·1
Ratio CaO : MgO........	1 : 0·4	1 : 0·8	1 : 2·2	1 : 0·5	1 : 0·3	1 : 0·5	1 : 0·6	1 : 1·4	1 : 1·7	1 : 1·2	1 : 1·4

DESCRIPTION OF SAMPLES IN TABLE No. 17.

Sample No.	District and Province.	Borehole Depth.	Locality, Description and Remarks.	Date.
		Feet.		
254	Laingsburg, Cape Province................	400	Borehole at Tweedside (Juritz 162, Anal. Govt. Lab.)...........	1908
253	Albany, Cape Province....................	120	Borehole at Alicedale (Geol. Survey Memoir 32, No. 3451, Anal. Govt. Lab.)..	1908
253 (*a*)	Albany, Cape Province....................	112	Borehole at Alicedale (Anal. Juritz 157)......................	1908
448	Worcester, Cape Province..................	60	Borehole at Constable (Anal. Juritz 157)......................	1908
484	Laingsburg, Cape Province................	—	Borehole at Tweedside (Anal. J. Gray)........................	8/12/19
492	Albany, Cape Province....................	—	Borehole at Alicedale (Anal. J. Gray).........................	26/11/20
210 (*a*)	Uniondale, Cape Province.................	—	Spring water No. 3, Toverwater Poort (Geol. Survey Memoir 32, No. 3461)..	1908
210	Uniondale, Cape Province.................	—	Spring water No. 1, Toverwater Poort (Geol. Survey Memoir 32, No. 3461)..	1908
216	Prince Albert, Cape Province..............	26	Well, South side of Prince Albert..........................	29/ 6/40

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Britten, Christiana, Laingsburg and Prince Albert. In Nat
Tillite forms narrow belts of country more or less parallel to t
and the only centres of importance are Stanger, Camperdown an
of North-East Durban.

The rainfall on the Dwyka formation in the Cape Provi
on the whole, very poor but higher in the Western Transva
Pondoland :—

	A Ra
Laingsburg–Prince Albert area..................	5
Calvinia, Gordonia, Kenhardt, Bushmanland districts	5
Vryburg area...........................	15
Pondoland..............................	4
Natal Coastal areas......................	4
Bloemhof–Christiana......................	1

GEOLOGY AND LITHOLOGY.

There are several natural occurrences of some economic im
located on the Dwyka series, for example, the large number
pans, some of them large producers of common salt, are locate
Kimberley district in the Cape Province and between Christi
Britten in the Transvaal.

The carbon dioxide springs in Northern Pondoland and th
County, Natal, described by R. B. Young (30), and also by
(31) also arise in the Dwyka tillite, while the travertine marble
near Port St. Johns described by Kupferburger (32) are associa
these waters.

The Dwyka series is of limited thickness as compared
other members of the System.

The formation has been divided by geologists into th
Shales, Glacial Tillite, and Lower Shales, but in many pl
latter lower shale beds are absent, while in other places both t
and the Upper shale beds are missing.

The tillite is essentially an acient ground moraine, but
boulder-shales and fluvio-glacial beds are also present.

The tillite varies somewhat but is generally a very com
very hard, fine grained impervious blue and green material,
of particles of various rocks embedded in a fine grained ar
matrix, in which are also scattered irregular pebbles and b
variety of rocks, some of them being glacially "striated".

What is of particular interest to this study is the fact
out by Gevers (31, p. 250) that the Dwyka tillite (like all gla
contains more fresh and decomposable primary rock mat
any other series of the Karroo system, with the exception
of the Karroo dolerites and Stormberg lavas. The bearin
on the composition of its waters is discussed later.

The thin "Upper Shale" beds above the Dwyka tilli
to black in colour and carbonaceous. Occcasionally the sta
near its base, phosphatic nodules, as well as concretions of
and dolomite. There is generally a fair amount of sulphid
in the form of pyrites and marcasite, sometimes in nod
This iron sulphide content of the Upper Shales has, as will
later, an important bearing on the composition of the Dwy
in certain areas. Analyses of the Dwyka tillite rock are g

importance on the Dwyka formation are Kimberley, Hopetown, Britten, Christiana, Laingsburg and Prince Albert. In Natal the tillite forms narrow belts of country more or less parallel to the sea and the only centres of importance are Stanger, Camperdown and parts of North-East Durban.

The rainfall on the Dwyka formation in the Cape Province is, on the whole, very poor but higher in the Western Transvaal and Pondoland :—

	Annual Rainfall.
Laingsburg–Prince Albert area..................	5″–10″
Calvinia, Gordonia, Kenhardt, Bushmanland districts	5″–10″
Vryburg area..................................	15″–20″
Pondoland.....................................	40″–50″
Natal Coastal areas...........................	40″–50″
Bloemhof–Christiana...........................	15″–20″

GEOLOGY AND LITHOLOGY.

There are several natural occurrences of some economic importance located on the Dwyka series, for example, the large number of salt pans, some of them large producers of common salt, are located in the Kimberley district in the Cape Province and between Christiana and Britten in the Transvaal.

The carbon dioxide springs in Northern Pondoland and the Alfred County, Natal, described by R. B. Young (30), and also by Gevers (31) also arise in the Dwyka tillite, while the travertine marble deposits near Port St. Johns described by Kupferburger (32) are associated with these waters.

The Dwyka series is of limited thickness as compared with the other members of the System.

The formation has been divided by geologists into the Upper Shales, Glacial Tillite, and Lower Shales, but in many places the latter lower shale beds are absent, while in other places both the Lower and the Upper shale beds are missing.

The tillite is essentially an acient ground moraine, but in places boulder-shales and fluvio-glacial beds are also present.

The tillite varies somewhat but is generally a very compact and very hard, fine grained impervious blue and green material, made up of particles of various rocks embedded in a fine grained argillaceous matrix, in which are also scattered irregular pebbles and boulders of variety of rocks, some of them being glacially " striated ".

What is of particular interest to this study is the fact, pointed out by Gevers (31, p. 250) that the Dwyka tillite (like all glacial clays) contains more fresh and decomposable primary rock material than any other series of the Karroo system, with the exception perhaps, of the Karroo dolerites and Stormberg lavas. The bearing of this on the composition of its waters is discussed later.

The thin " Upper Shale " beds above the Dwyka tillite is blue to black in colour and carbonaceous. Occcasionally the stage carries, near its base, phosphatic nodules, as well as concretions of limestone and dolomite. There is generally a fair amount of sulphides of iron in the form of pyrites and marcasite, sometimes in nodular form. This iron sulphide content of the Upper Shales has, as will be shown later, an important bearing on the composition of the Dwyka waters in certain areas. Analyses of the Dwyka tillite rock are given later.

The Dwyka tillite is hard and very impervious; the pore space being only a few per cent. Du Toit (2, p. 122) points out however, that in spite of this and the low rainfall, good supplies can be obtained by boring in many places in the Southern Cape Province (e.g. Matjesfontein and Prince Albert), owing to the fact that the rock in these areas is strongly cleaved and jointed. In Natal, Zululand and Pondoland the Dwyka tillite is uncleaved and only slightly jointed. Therefore in spite of the high rainfall in these areas the yields are low and boreholes few and far between. Gevers (31, p. 248) also refers to the imperviousness of the tillite in Natal, and the resultant paucity of boreholes in that formation.

Frommurze (3, p. 156) furnishes the following data regarding the Cape Province, but gives no details about the tillite in Natal.

	Average Yield in Gallons. per Diem.	*Average Depths.*	*Per cent. Failures.*
Laingsburg–Prince Albert areas................	15,000-40,000	Under 100′	20
Calvinia, Kenhardt and Bushmandland districts	27,000	Under 100′	30
Vryburg..............	28,000	Under 100′	30
Gordonia..............	11,500	200′ or more	44

QUALITY OF THE WATER.

(i) *In the Cape Province and Western Transvaal.*

There are very few towns or villages situated on the Dwyka series, while in the North-Western Cape the country is very sparsely populated. Furthermore, many boreholes have been abandoned on account of the high salinity of their waters. The author therefore had difficulty in collecting samples and has been obliged to include among his anlyses, data from other sources, which unfortunately were not complete. He is indebted to Dr. T. Ockerse for analyses of several samples of Dwyka water from the North-West Cape and has also made use of some of Dr. Juritz's analyses made about 1908.

In Table 18 the analyses of fourteen samples of Dwyka water are given from widely separated localities covering the formation fairly well.

Analyses of "brine" from the numerous salt pans, situated on the Dwyka series in the Cape Province and Transvaal are not included in the Table as these are regarded as abnormal concentrations of the Dwyka water. Reference to these Dwyka "brines" is made later.

The concentration varies considerably and depends obviously on climatological factors, but is never low, averaging about 150 parts per 10^5.

The pH. varies but appears to be on the high side (average 7·6) though data are insufficient to allow of generalisation.

A characteristic is the low soluble silica content. This varies a little but is always low, averaging 3·0 per cent. of the total salts. As previously mentioned all saline waters have a low silica content.

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Fluorides are sometimes present but in very small amount, except at Brandvlei in the North-West Cape. The larger amounts present in this area may be accounted for by the fact that part of the inclusions in the tillite in the North-Western Cape at least, was derived from the granitic terrain of that very region. As shown in a previous section the Old granite of the North-West Cape gives rise to fluoride waters.

Chlorides naturally vary according to the concentration, but when expressed as a percentage of the total salts are found to be consistently high, averaging 30 per cent. Cl.

The chief characteristic of the Dwyka waters in these areas is the striking consistency of the sulphate content, which averages about 15 per cent. SO_4 of the total salts. On the contrary, the Dwyka waters of Natal are characterised by the very low sulphate content (less than 2 per cent.). The only other formations yielding waters with as high an SO_4 content are the Bokkeveld series, the Old granite waters of the North-West Cape, and, to a slightly less extent, the Ecca series in the Cape Province.

Na_2CO_3 or $HaHCO_3$ are never found in the Dwyka waters, but instead there is always an appreciable permanent hardness averaging 16 per cent. (as $CaCO_3$) of the total salts. About 48 per cent. of the salts are scale-forming; the bicarbonates of calcium and magnesium making up about 28 per cent.

The average CaO : MgO ratio is 1 : 0·92, but ratios of 1 : 2·0 are to be found.

The very high salinity of the waters and their relatively high SO_4 and Cl. contents automatically place them in the saline water Group A. The utilisation of and chemical treatment for industrial purposes is dealt with under Group A.

Some of the waters, namely those having concentrations of over 300 parts total solids, from the North-West Cape in particular, are not only totally unsuitable for industrial uses, but are really only suitable for human consumption in an emergency. A few are even too saline for watering livestock and, for irrigation, should only be used in the case of loose, well drained soils.

Most of the salt produced in the Union comes from salt pans, situated on the Dwyka tillite or Dwyka shales in the more arid Western areas of the Union, from Calvinia right up to Britten near Bloemhof in the Western Transvaal.

Although some work has been carried out regarding the origin of the pans Du Toit (14, pp. 424-425) the origin of the salts in the brines appear to be a matter of controversy and little or no work has been done on the subject.

In view of this fact the author has worked out the relationship between the composition of the brines and the ordinary Dwyka ground waters. Curiously enough very few complete analyses of the brines from inland pans appear in the local literature.* In the following table two analyses made by the author in 1922 of brines from the Britten pans, are given, together with two analyses cited by Rindl (33) and for comparison, the average analyses of Dwyka borehole water, taken from the author's Table 18.

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* Subsequently a chemical investigation has been carried out on the brines of the Union's salt pans in 1944 by the Salt Committee of the Directorate of Supplies.

It will be observed that there is a close resemblance in percentage composition between the brines and the ordinary Dwyka waters after taking into consideration certain factors.

The percentage of chloride is higher and that of sulphate is usually slightly lower in the brines. There has been an almost total elimination of calcium in the brine and a partial elimination of magnesium. Consequently the total hardness is reduced considerably. These facts are, however, readily explained on ordinary laws of solubility, i.e. the solubility of $CaCO_3$, $CaSO_4$ and $MgCO_3$ and Na_2SO_4 in a highly concentrated NaCL solution. That this is so is proved by the hard deposits found on the floor and rims of the pans. These deposits consist mainly of $CaSO_4$ and $CaCO_3$ with a smaller amount of Na_2SO_4.

	Sample No. 1.	Sample No. 2.	Sample No. 3.	Sample No. 4.	Sample No. 5.
	Brine from Britten Pan.	Brine from Britten Pan.	Brine? (Rindl).	Brine? (Rindl).	Average Dwyka Waters.
Specific gravity..........	1·213	1·200	—	—	—
Total solids per 10^5......	25,000	26,000	19,700	25,320	150
Per cent on Total Solids.					
CaO..................	0·28	0·20	0·90	0·09	12·60
MgO..................	4·00	3·25	0·70	1·60	11·60
Cl....................	48·50	48·80	55·00	50·00	30·20
SO_4..................	14·80	11·80	5·60	12·40	14·80
Soda Alkalinity.........	Nil	Nil	Nil	Nil	Nil
Total hardness (as $CaCO_3$)	10·50	6·80	3·40	4·10	48·00
Ratio CaO : MgO........	1 : 14·2	1 : 16·2	1 : 0·8	1 : 18·0	1 : 0·9
Complete analyses of the salts in the above brines :—					
NaCl..................	77·50	76·52	96·00	84·00	—
KCl...................	3·24	6·08	—	—	—
$MgSO_4$................	12·00	9·76	2·00	4·60	—
Na_2SO_4...............	7·10	5·58	3·10	12·20	—
$CaSO_4$................	0·50	0·48	2·20	0·20	—

Thus the concentrated brines do not differ basically from the ordinary run of Dwyka ground waters, and the problem of the origin of the salts in the concentrated brines is bound up with the problem of the salinity of the Dwyka waters, which is discussed later.

The origin of the high chloride and sulphate content of the Dwyka waters in the Cape Province and Western Transvaal is discussed later.

(ii) *Quality of the Dwyka Waters in Pondoland and Natal.*

The paucity of boreholes situated in the Dwyka of Natal has already been mentioned, but the author has managed to collect and analyse 6 samples of borehole and spring water, and has included one analysis of Dwyka water by another analyst. The results are also shown in Table 19. The districts covered are the Harding, Camperdown, High Flats, Umzinto and Lower Tugela districts of Natal.

In strong contrast to the highly saline Dwyka waters of the We of the Union, the total solids average only 44 parts per 10^5 in Na as compared with about 150 parts in the case of the former wate This fact can be accounted for partly by the high and regular rain

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Sample	368
Par	
Total S	402·0
Methyl	10·0
Total H	92·0
Perman	82·0
Tempor	10·0
Hardne	52·0
Hardne	40·0
Soda A	Nil
P	
Silica (	2·6
Fluorid	Trace
Nitrites	Nil
Nitrates	Nil
Chloride	230·0
Sulphat	6·0
Potassiu	Under 0·5
pH. Va	7·9
Pe	
SiO_2....	0·65
CaO....	7·2
MgO...	4·0
Cl......	57·0
SO_4....	(1·5)
Soda A	Nil
Total H	23·0
Perman	20·5
Tempor	(2·5)
Ratio C	1 : 0·6

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Sample No. 4.	Sample No. 5.
Brine? (Rindl).	Average Dwyka Waters.
—	—
25,320	150
0·09 1·60 50·00 12·40 Nil 4·10	12·60 11·60 30·20 14·80 Nil 48·00
: 18·0	1 : 0·9
34·00	—
— 4·60 2·20 0·20	— — — —

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TABLE No. 18.—DWYKA SERIES—KARROO SYSTEM IN CAPE PROVINCE AND WESTERN TRANSVAAL.

Sample Numbers	384	385	381	380	224	295	255	257	360	362	368	256	369	496	Average
Parts CaCO$_3$ per 10^5 Water:															
Total Solids (at 160°)	355·0	329·0	77·8	57·6	82·0	68·0	166·0	134·0	89·0	33·4	402·0	136·4	56·0	95·0	148·7
Methyl Orange Alkalinity	4·8	39·0	38·0	30·1	38·5	25·5	22·3	35·0	39·0	22·0	10·0	46·0	31·5	25·8	—
Total Hardness	210·8	89·0	43·0	36·1	46·8	34·4	41·0	47·8	74·0	28·8	92·0	70·7	35·0	46·8	—
Permanent Hardness	206·0	50·0	5·0	6·0	8·3	8·9	18·7	12·8	35·0	6·8	82·0	24·7	3·5	21·0	—
Temporary Hardness	4·8	39·0	38·0	30·1	38·5	25·5	22·3	35·0	39·0	22·0	10·0	46·0	31·5	25·8	—
Hardness due to Ca Salts	54·8	32·5	15·0	11·9	22·8	20·2	29·0	26·8	28·0	14·6	52·0	10·7	15·0	30·2	—
Hardness due to Mg Salts	156·0	56·5	28·0	24·2	24·0	14·2	12·0	21·0	46·0	14·2	40·0	60·0	20·0	16·6	—
Soda Alkalinity	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	—
Parts per 10^5 of Water:															
Silica (as SiO$_2$)	—	—	—	—	3·2	2·0	2·0	2·3	4·4	2·8	2·6	1·7	1·8	1·5	—
Fluorides (as F)	0·03	0·18	0·03	0·02	0·02	Under 0·01	—	—	Trace	Trace	Trace	—	0·11	—	—
Nitrites	Nil	Nil	Nil	—	Present	Nil	—	—	Nil	Nil	Nil	—	Nil	—	—
Nitrates (as NO$_3$)	Nil	Nil	Nil	—	1·2	Nil	—	—	Nil	2·8	Nil	—	2·4	—	—
Chlorides (as Cl)	147·0	95·1	12·8	7·1	17·7	18·8	73·0	48·5	20·6	2·4	230·0	20·3	14·5	24·0	—
Sulphates (as SO$_4$)	72·0	100·0	8·9	4·9	8·15	5·4	11·2	11·0	9·3	2·4	6·0	30·0	2·0	20·5	—
Potassium Salts	0·3	0·2	0·8	0·07	Under 0·5	Under 0·5	—	—	Under 0·5	Trace	Under 0·5	—	Under 0·5	—	—
pH. Values	7·6	7·1	7·4	7·5	6·9	7·6	—	—	7·8	7·8	7·9	—	8·0	—	7·6
Percentage on Total Solids:															
SiO$_2$	—	—	—	—	3·9	2·9	1·15	1·7	4·9	8·3	0·65	1·3	3·2	1·57	3·0
CaO	8·6	5·5	10·9	12·0	15·3	16·6	9·9	11·2	17·5	25·0	7·2	4·4	15·0	17·8	12·6
MgO	17·8	6·9	14·2	16·7	9·8	8·4	2·8	6·2	20·6	16·6	4·0	17·6	13·2	7·1	11·6
Cl	41·5	29·0	16·2	(12·3)	21·6	27·5	44·0	36·3	23·0	(7·1)	57·0	14·8	26·0	25·0	30·2
SO$_4$	20·3	30·0	11·2	8·6	10·0	8·0	6·8	8·2	10·2	7·2	(1·5)	22·0	(3·6)	21·5	14·8
Soda Alkalinity (as Na$_2$CO$_3$)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Total Hardness (as CaCO$_3$)	60·0	29·0	55·0	62·5	57·0	50·5	24·7	35·0	83·0	89·0	23·0	51·8	62·0	49·5	48·0
Permanent Hardness (as CaCO$_3$)	(58·0)	15·2	6·3	11·3	10·1	13·0	11·2	9·8	39·0	20·3	20·5	19·8	6·2	22·3	15·8
Temporary Hardness (as CaCO$_3$)	(1·4)	11·8	48·5	52·0	47·0	37·5	13·4	26·0	44·0	66·5	(2·5)	33·6	56·0	27·5	27·8
Ratio CaO : MgO	1 : 2·0	1 : 1·2	1 : 1·1	1 : 1·4	1 : 0·63	1 : 0·5	1 : 0·3	1 : 0·6	1 : 1·2	1 : 0·7	1 : 0·6	(1 : 4·0)	1 : 0·8	1 : 0·4	1 : 0·92

DESCRIPTION OF SAMPLES IN TABLE No. 18.

Sample No.	District and Province.	Borehole Depth.	Locality, Description and Remarks.	Date.
		Feet.		
384	Calvinia, North-West Cape..................	—	Borehole at Loriesfontein (Dr. Ockerse, Anal. Div. C.S.).........	1940
385	Calvinia, North-West Cape..................	—	Borehole in Brandvlei (Dr. Ockerse, Anal. Div. C.S.)............	1940
381	Prieska, North-West Cape....................	—	Spring at Prieska (Dr. Ockerse, Anal. Div. C.S.)...............	1940
380	Hopetown, North Cape......................	—	Borehole in Hopetown (Dr. Ockerse, Anal. Div. C.S.)............	1940
224	Prince Albert, Cape Province...............	—	Borhole North-East of Prince Albert.........................	8/10/40
295	Laingsburg, Cape Province.................	—	Borehole at Matjesfontein Railway Station....................	13/ 1/41
496	Laingsburg, Cape Province.................	—	Borehole at Matjesfontein (Anal. J. Gray)......................	22/12/19
255	Kimberley, Cape Province..................	360	Borehole in Beaconsfield (Anal. Juritz Ref. 177)................	1908
360	Kimberley, Cape Province..................	70	Borehole near Merton Siding.................................	16/ 6/41
257	Willowmore, Cape Province................	77	Borehole in Miller (Anal. Juritz Ref. 178)......................	1908
362	Jacobsdal, Cape Province..................	—	Borehole on farm Gouwskraal 100, about 1 mile North-West of Nelsdrift)..	16/ 6/41
368	Bloemhof, Transvaal.......................	80	Borehole 3 miles West of Britten on Main Road to Christiana	16/ 6/41
256	Vryburg, Cape Province....................	145	Borehole in Vryburg (Anal. Juritz Ref. 184)..................	1908
369	Bloemhof, Transvaal.......................	80	Borehole in Christiana......................................	Jun., 1941.

Sample Numbe

Parts CaC
Total Solids (a
Methyl Orange
Total Hardness
Permanent Ha
Temporary Ha
Hardness due
Hardness due
Soda Alkalinity

Parts pe
Silica (as SiO_2
Fluorides (as
Nitrites......
Nitrates (as N
Chlorides (as
Sulphates (as
Potassium Salt
pH. Values...

Percentag
SiO_2.........
CaO.........
MgO.........
Cl..........
SO_4.........
Soda Alkalinit
Total Hardnes
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TABLE No. 19.—DWYKA SERIES—KARROO SYSTEM IN NATAL AND PONDOLAND.

	NATAL.								PONDOLAND SPRINGS.				
Sample Numbers	296	174	337	344	379	525	517	Average	540	541	542	543	Average
Parts $CaCO_3$ per 10^6 Water:													
Total Solids (at 106°)	35·0	35·7	31·8	31·0	68·6	73·5	37·1	44·7	335·9	2515·0	417·2	416·0	921·0
Methyl Orange Alkalinity	12·5	20·0	18·5	9·0	34·8	12·5	19·0	—	638·0	535·0	197·0	213·5	—
Total Hardness	11·2	20·4	20·0	14·4	35·3	18·7	28·0	—	158·0	220·0	142·0	148·5	—
Permanent Hardness	Nil	0·4	1·5	5·4	0·5	6·2	9·0	—	Nil	Nil	Nil	Nil	—
Temporary Hardness	11·2	20·0	18·5	9·0	34·8	12·5	19·0	—	158·0	220·0	142·0	148·5	—
Hardness due to Ca Salts	4·6	10·5	11·2	4·8	15·0	5·0	19·7	—	108·0	110·0	88·0	92·0	—
Hardness due to Mg Salts	6·6	9·9	8·8	9·6	20·3	13·7	8·3	—	50·0	110·0	54·0	56·5	—
Soda Alkalinity	1·3	Nil	Nil	Nil	Nil	Nil	Nil	—	480·0	315·0	55·0	65·0	—
Parts per 10^6 of Water:													
Silica (as SiO_2)	2·0	2·0	1·8	2·0	—	4·0	2·0	—	3·0?	—	18·0	19·0	—
Fluorides (as F)	0·01	Under 0·01	Trace	0·05	0·01	Nil	Nil	—	—	—	—	—	—
Nitrites	Nil	Nil	Nil	Nil	—	Nil	Nil	—	—	—	—	—	—
Nitrates (as NO_3)	Nil	0·2	0·06	Nil	—	0·08	—	—	—	—	—	—	—
Chlorides (as Cl)	11·7	7·0	7·9	9·1	19·0	29·5	6·5	—	1070·0	678·0	110·0	102·91	—
Sulphates (as SO_4)	0·03	0·1	0·03	0·06	2·0	1·2	1·7	—	720·0	538·0	56·0	57·5	—
Potassium Salts	Under 0·1	Trace	Under 0·1	Trace	0·2	Under 0·5	Under 0·5	—	—	—	—	—	—
pH. Values	6·9	7·5	8·0	6·8	8·0	6·8	8·0	—	—	—	7·2	—	—
Percentage on Total Solids:													
SiO_2	5·7	5·6	5·7	0·4	—	5·5	5·4	5·9	(0·1?)	—	3·5	4·5	4·0
CaO	8·3	16·2	19·4	16·4	12·2	3·8	(29·0)	14·9	16·9	24·8	11·8	12·3	16·45
MgO	7·4	10·8	11·0	12·4	11·8	7·5	8·9	10·0	6·0	(17·5)	5·2	5·5	5·6
Cl	33·5	18·0	25·0	29·2	27·8	39·5	17·6	27·2	32·0	26·8	26·5	24·8	27·5
SO_4	0·9	0·3	0·09	0·2	2·9	1·6	4·6	1·5	21·5	21·5	13·4	13·7	17·5
Soda Alkalinity (as Na_2CO_3)	(3·7)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	15·2	13·2	13·6	16·4	14·9
Total Hardness (as $CaCO_3$)	32·0	57·0	63·5	46·5	51·3	25·5	(75·0)	44·3	46·5	57·0	34·0	35·5	40·8
Permanent Hardness (as $CaCO_3$)	Nil	1·1	4·7	(16·0)	0·7	8·4	(24·2)	3·0	Nil	Nil	Nil	Nil	Nil
Temporary Hardness (as $CaCO_3$)	32·0	56·0	58·5	29·0	50·8	17·1	50·8	42·0	46·5	57·0	34·0	35·5	40·8
Ratio CaO : MgO	1 : 0·9	1 : 0·7	1 : 0·6	1 : 1·5	1 : 0·97	(1 : 2·0)	1 : 0·3	1 : 0·7	1 : 0·4	1 : 0·7	1 : 0·5	1 : 0·4	1 : 0·34

TABLE No. 19.—DESCRIPTION OF SAMPLES FROM DWYKA SERIES, NATAL.

Sample No.	District and Province.	Borehole Depth.	Locality, Description and Remarks.	Date.
		Feet.		
296	Harding, Natal	—	Borehole at Enquabeni School	27/ 1/41
174	Camperdown, Natal	70	Borehole at Camperdown (Scheferman's residence)	21/ 5/40
337	Camperdown, Natal	80	Borehole at Eston	20/ 3/41
517	Camperdown, Natal	200	Borehole at Umlaas Road	13/ 3/42
344	Natal	—	Spring, Umhlabatzan No. 8215, 9 miles South of Highflats	1/ 4/41
379	Umzinto, Natal South Coast	—	Borehole at Umzinto, South Coast (1940), Analysis Govt. Laboratory	1940
525	Lower Tugela, North Coast, Natal	—	Borehole at Chaka's Kraal, Residence on Main Road	27/ 3/42
540	Port St. Johns, Pondoland	—	Spring, Isinuka, Port St. Johns (Anal. Juritz)	1908
541	Port St. John, Pondoland	—	Spring at Crater, Travertine deposit, Port St. Johns (Anal. C. E. v.d. Walt)	—
542	Bizana County, Pondoland	—	" Cone " Spring, Umtamvuna, near Bizana (Anal. B. Segal)	1941
543	Bizana County, Pondoland	—	" Mound " spring, Umtamvuna, near Bizana (Anal. B. Segal)	1941

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in Natal compared with the West.
and the West, the silica content
and is, moreover, most consisten
Only minute amounts of flu
the case of the Western Dwyka w
on the following grounds :—

> The detrital material i
> largely made up of pebble
> the " Old granite " of Na
> appears to be singularly f
> minerals, a fact reflected in
> of the Natal Old granite (

Though small in actual amou
high, averaging 27 per cent. Cl.

The sulphate content is ext
cent. SO_4 in terms of total salts,
the case of the Pondoland Dwyka
of the Western Dwyka waters.

Now the consistent and hig
waters in the West of the Unio
explained through the oxidation
in the upper beds of the Dwyka s
that the soil lying on top of the
is often impregnated with cryst
oxidation of the sulphide mineral
of the H_2SO_4 thus formed by lin
layers. In describing the lithologi
Dwyka, Du Toit (34, p. 25) also
of pyrites and marcasite in the zon
however, that in Natal the Uppe

Sodium carbonate or bicarbo
the Natal waters. Instead there i
hardness showing, averaging 3·0
cent in the Western Dwyka wat

The total scale-forming com
$CaCO_3$, while $Ca(HCO_3)_2$ and Mg
pounds) average 42·0 per cent.
magnesium, the CaO : MgO ratio
the waters are similar to those o

The cause of the relatively h
is cyclic salts carried inland by
rocks are exposed at no great dis

Du Toit (14, p. 488) states
not so productive as in the west
fresh water. Compared with the h
those of the deep seated Pondola
appear to be fresh, but this is on
are moderately hard and slightly
The author has accordingly place
" B," and the treatment and utili
ed under that

Natal compared with the West. Like the Dwyka waters of Pondoland and the West, the silica content is very low, averaging 5·4 per cent. and is, moreover, most consistent.

Only minute amounts of fluorides were found, even less than in the case of the Western Dwyka water. This can be readily explained on the following grounds :—

> The detrital material in the Dwyka tillite of Natal is also largely made up of pebbles and fragments of Old granite, but the "Old granite" of Natal unlike that of the N.-W. Cape, appears to be singularly free from fluorspar or other fluorine minerals, a fact reflected in the zero fluoride content of the waters of the Natal Old granite (Table 2).

Though small in actual amount, the chloride content is relatively high, averaging 27 per cent. Cl. of the total solids.

The sulphate content is extremely low, averaging only 1·5 per cent. SO_4 in terms of total salts, compared with the 15 per cent. in the case of the Pondoland Dwyka waters and 15 per cent. in the case of the Western Dwyka waters.

Now the consistent and high sulphate content of the Dwyka waters in the West of the Union and in Pondoland can be partly explained through the oxidation of the pyrites and marcasite present in the upper beds of the Dwyka series. Du Toit (14, p. 246) mentions that the soil lying on top of the Upper Shales in the Cape Province is often impregnated with crystals of gypsum resulting from the oxidation of the sulphide minerals and the subsequent neutralisation of the H_2SO_4 thus formed by lime from the calcareous nodules and layers. In describing the lithological characteristics of the Pondoland Dwyka, Du Toit (34, p. 25) also mentions the occurrence of nodules of pyrites and marcasite in the zone above the tillite. It would appear, however, that in Natal the Upper Pyritic Shales are missing.

Sodium carbonate or bicarbonate appears to be rarely present in the Natal waters. Instead there is generally a very small permanent hardness showing, averaging 3·0 per cent. as compared with 15 per cent in the Western Dwyka waters.

The total scale-forming compounds average 44·3 per cent. as $CaCO_3$, while $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$ (temporary hardness compounds) average 42·0 per cent. There is usually more calcium than magnesium, the CaO : MgO ratio being 1 : 0·7, and in this respect the waters are similar to those of the Western Dwyka waters.

The cause of the relatively high Cl. content in the Natal waters is cyclic salts carried inland by prevailing winds, since the Dwyka rocks are exposed at no great distance back from the coast.

Du Toit (14, p. 488) states that, though the tillite in Natal is not so productive as in the west of the Union, it invariably yields fresh water. Compared with the highly saline waters of the West and those of the deep seated Pondoland springs, the Natal waters may appear to be fresh, but this is only relative. Actually these waters are moderately hard and slightly saline, though not exactly brackish. The author has accordingly placed them in his slightly saline Group "B" and the treatment and utilisation of these waters will be considered under that group.

It may be stated here that these waters are potable and suitable for domestic use, irrigation, watering livestock, and, after appropriate chemical treatment, for most industrial purposes, but as far as boiler feed is concerned, the *relatively* high Cl. figure is a deterrent, as the chlorides would tend to accumulate.

The author was unable to obtain samples of waters from Pondoland and has therefore relied on the 4 analyses of spring waters cited by Gevers (31), shown in Table 19. All these samples come from springs which issue at the bottom of deep gorges more than 1,000 ft. below the surrounding plateau, and may not represent the general run of Dwyka waters in Pondoland.

The chief characteristic of these Pondoland springs is their extremely high salinity, the average of four analyses being 921 parts per 10^5 parts.

At first sight this is very surprising *in view of the high rainfall in the Pondoland coastal areas* (40–50″) compared with the rainfall on the Western Dwyka (5–10″).

The explanation given by Gevers (31, p. 247) is that the high concentration of salts is mainly due to the considerably greater depth of percolation than is the case of the ordinary Dwyka waters in Natal, for as mentioned previously, these springs issue at the bottom of gorges, so that the water had to percolate along fault planes and other lines of disturbance (the rock itself being impervious) till it could issue as springs 1,000 ft., or more, below the surface of the plateau.

Furthermore, as already mentioned, the Dwyka tillite, like all other rocks derived from morainic material, contains more fresh and decomposable primary rock material than most rocks in the Union.

Another characteristic, which sharply differentiates the Pondoland springs from Dwyka waters elsewhere, is the high sodium carbonate or bicarbonate content (15·0 per cent. of the total salts). Consequently no permanent hardness is present and the sulphates must be present in the form of Na_2SO_4 instead of the usual $CaSO_4$ and $MgSO_4$ in the case of other Dwyka waters.

There is not sufficient data with reference to the pH. value but one analysis gives the figure of 7·2. This indicates that $NaHCO_3$ and not Na_2CO_3 is present.

The origin of the high $NaHCO_3$ carbonate content of these waters, in contrast to those Dwyka waters of the West, may possibly be due, as suggested by Gevers, to base-exchange within the clayey groundmass of weathered Dwyka tillite along the fault planes, bearing in mind the great depth through which the spring waters have percolated in these areas, as compared with the average borehole in the Natal and Western Dwyka formations.

Lindgren (35, p. 53) has shown that waters rich in carbona
and bicarbonates of calcium and magnesium percolating throu
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of calcium and magnesium for sodium

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SiO_2........
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Fe_2O_3.......
FeO........
TiO_2.......
MnO........
CaO........
MgO........
K_2O........
Na_2O........
P_2O_5........
CO_2........
H_2O +......
H_2O −......
Ratio CaO : I
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Apart from this the Dwyka tillite rock from Pondoland appears to have an appreciable alkali content (K_2O, Na_2O) judging from the analyses cited by Gevers (31, p. 264). This analyses is given below together with one of weathered and leached Dwyka tillite from a fault fissure at the Bongwan Spring. This latter indicates the extent to which the Na_2O and K_2O have been leached out by the percolating waters :—

	Fresh Tillite, Bongwan. Per cent.	*Decomposed and leached Tillite from Bongwan. Per cent.*
SiO_2	65·49	75·21
Al_2O_3	14·83	16·03
Fe_2O_3	0·07	0·16
FeO	4·09	0·00
TiO_2	0·75	0·81
MnO	0·09	Trace
CaO	2·79	0·00
MgO	2·99	0·10
K_2O	2·68	0·27
Na_2O	3·12	0·44
P_2O_5	0·31	0·09
CO_2	0·27	0·07
H_2O +	2·62	5·97
H_2O −	0·12	0·12
Ratio CaO : MgO	1 : 1·07	—
Analyst	J. C. Dunne	J. C. Dunne

Another striking feature of the Pondoland spring water is the very consistent and high sulphate content (averaging 17·5 per cent. SO_4) which is very much the same as that of the Western Dwyka waters (15 per cent. SO_4). As already stated this can be partly explained by the occurrence of pyrites and marcasite in the Dwyka tillite, but the author is not satisfied that such is the sole cause of the high sulphate content.

The total scale-forming compounds are very much the same as in the Western Dwyka waters but there are of course, no permanent hardness-forming salts present ; as in the case of the Western waters CaO exceeds MgO, the average ratio being 1 : 0·34.

Gevers (31, p. 246) refers to the extremely high silica content of these Pondoland springs (18 parts per 10^5 SiO_2), but actually when expressed as a percentage of the total solids they amount to 4·0 per cent. an average which is in line with the 5·9 per cent. of the Natal waters and 3·0 per cent. of the Western waters, so that the silica content can in no way be described as high when compared with the silica content of some other types (e.g. granite waters with 16–18 per cent. SiO_2).

The chloride content is considerable and expressed as a percentage of the total salts averages 27·5 as compared with the 30·2 per cent. Cl. of the Western Dwyka waters.

These Pondoland waters are therefore very similar indeed to the Western Dwyka waters, except there is about 15 per cent. Na_2CO_3 or $NaHCO_3$ instead of the 15 per cent. permanent hardness salts.

Needless to state these Pondoland Dwyka spring waters are totally unsuited for any technical or domestic uses and would be classified under the saline Group "A", though they have an appreciable soda content.

In spite of great climatic differences, the similarity of all Dwyka waters (excluding those in Natal) is truly remarkable.

In Table 27, the percentage composition of Dwyka and other waters is compared with that of sea water. It will be observed that there is a marked resemblance to the latter though not so striking as in the case of the Malmesbury, Bokkeveld and Cretaceous waters which are undoubtedly contaminated by oceanic waters. The percentage of SO_4 is double that of sea water, but the extra SO_4 can no doubt, be accounted for by oxidation of iron sulphides from the tillite or Upper shales.

Du Toit (14, p. 247) in discussing the origin of the " Upper Dwyka Shales" (" White" pyritic and carbonaceous band) suggests that these sediments were in the nature of black organic, highly sulphuretted muds like those now forming in the Black Sea or Gulf of Bothnia, and were probably laid down in the deep water of an estuary, a view supported by the remains of fish, crustacea, etc. Also in picturing the formation of the tillite in the South, Du Toit (14, p. 497) suggests that the glacial muds and boulders were dropped into either *fresh or salt water.* However, he is of the opinion that elsewhere the ice front discharged into a body of *fresh water* except in South-West Africa where the tillite was laid down in the ocean (14, p. 242), as indicated by Marine invertebrates.

The absence of marine fossils not only from the Dwyka series elsewhere but from all the succeeding series of the Karroo system would appear to support the foregoing views.

However, the analyses of the Dwyka waters as a whole, with the exception of the waters in Natal, point rather to deposition in the sea or in brackish water, or else to a marine inundation, at some period after the formation of the Dwyka tillite. It would be difficult to account otherwise for the consistently high chloride and sulphate content.

Gevers (31, p. 252) suggests that the chlorides may be wind-borne. It is true that along the coast of Natal the Old granite, the Dwyka, and the Table Mountain sandstone waters show a slight salinity and this is obviously due to salt spray carried some distance inland during gales. It does not appear feasible however, to the author that the high chloride and sulphate and magnesium contents of the Dwyka waters in the Central part of the Union, and in the Karroo regions could be wind-borne. Apart from the vast distance from the coast there is the fact that the waters of the Ventersdorp and other older formations exposed in the same regions, show very little chloride (9·0 per cent. Cl.) and practically no sulphates.

It will be shown in the next two sections that not only the Dwyka but the Ecca and Lower Beaufort waters in the Cape Province are very saline (i.e. oceanic type) but with decreasing salinity, and it will also be shown that climatological factors are not always responsible. When, however, we come to the waters of the Upper Beaufort and Stormberg series, chlorides and sulphates are negligible.

The above facts would appear to support the theory that the Dwyka, Ecca and Lower Beaufort formations, have an estuarine and not a fresh water origin.

This matter is referred to again in subsequent sections.

XVIII.—THE

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XVIII.—THE WATERS IN THE ECCA SERIES OF THE KARROO SYSTEM.

From the point of view of this investigation the Ecca series is of great importance. There are far more towns and villages situated on this than on the preceding Dwyka series, particularly in Natal, though not nearly as many as on the succeeding Beaufort series. Furthermore, the vast coalfields of Natal and the Transvaal are located in this formation.

DISTRIBUTION AND RAINFALL.

In the Western Orange Free State, in the Cape Province and Pondoland, the outcrop, which varies from 10–80 miles, forms a belt inside that of the Dwyka series and is part of the vast Karroo basin.

In Southern Natal the formation is split by erosion into thin narrow belts which run roughly parallel to the coast, but in Northern Natal and the Transvaal the outcrop widens considerably.

Thin and very limited patches of the Ecca series outcrop in the Hamanskraal and Zoutpansberg areas of the Transvaal, and also along the Limpopo River, but they are of no importance to this study. In the Hamanskraal area, most of the boreholes are deep enough to tap the underlying Red granite waters, and hence they are typical Red granite waters.

	Average Annual Rainfall.
Transvaal	20″–30″
Northern Natal Coalfields areas	30″–50″
Natal	30″–40″
Pondoland	30″–50″
Southern Cape Province	5″–15″
North-Western Cape Province (Calvinia, etc.)	5″–10″
Orange Free State	15″–20″

GEOLOGY AND LITHOLOGY.

From the point of view of this investigation there is very little difference between the rocks of the Dwyka and those of the Ecca series, which follow conformably on the Upper Dwyka shales.

As far as the Orange Free State and Cape Province are concerned, the strata are *mainly argillaceous.* There are a few beds of fine grained greenish sandstones. The shales are almost indentical with those of the Dwyka shales, namely blueish or greenish shales, with abundant calcareous and pyritic concentrations and sometimes lenticular bands of limestones. No analyses are available.

Proceeding Northwards into Natal the rocks tend to alter and become more arenaceous, a fact, which it will be seen, is reflected by a change in the chemical characteristics of the waters. In Alfred County, Natal, and for some distance along the coast the argillaceous character is still retained, but the farther North we go we find the beds becoming more and more sandy, though with occasional softer layers Here according to Du Toit (14, p. 253), the sandstones are yellowish to whitish in colour and fairly coarse grained, passing into massive grits. They are frequently felspathic, the felspar often being quite fresh, mainly orthoclase and microline, indicating a granitic origin for the material. Sometimes the sandstones are micaceous and laminated. The same description applies to the Ecca in the Transvaal. The coal seams of the Transvaal and Natal have been allocated to the Middle Ecca beds.

Fossils are not common and consist of plant remains. The age of the series is Lower Permian.

UNDERGROUND WATER SUPPLIES.

There is apparently a great variation in water supplies in different localities underlain by the Ecca series. Frommurze (3, p. 139) gives the following figures :—

	Average Yield in Gallons per Diem.	*Average Depths.*	*Percentage of Failures.*
Hoopstad District..........	4,000	100′	40
Philipstown, Sutherland and Calvinia Districts.........	40,000	shallow	30
South-Eastern Karroo......	22,000-32,000	under 100′	30–40
Central Natal..............	12,500	110′	30
Eastern Transvaal..........	21,600	130′	6
Springs, Bethal, Witbank, Standerton and Frankfort	12,600	156′	5·7
Vredefort, Hoopstad and Kroonstad................	9,370	120′	9

Frommurze (3, p. 165) points out that in the North-West Cape the yield is often in an inverse ratio to the rainfall, and that everywhere the yields are much affected by the presence or absence of dolerite sheets and dykes which tend to dam up the water.

It will be seen that these intrusions also have an appreciable effect on the chemical characteristics of the water.

QUALITY OF THE WATER.

(i) *Quality of the Water in the Ecca Series in the Cape Province and Natal Coast.*

In Table 20 the author has tabulated 14 analyses of Ecca waters from a wide region.

The chief characteristics is the high concentration of dissolved salts averaging about 146 parts per 10^5 in the Cape Province and 181 parts on the Natal Coast.

There is insufficient data regarding the pH. of the waters, but it appears to be moderately low (about 7·5).

As is the case in all saline waters, silica is very low, usually under 2·5 per cent. SiO_2 in terms of total solids.

There is always more calcium than magnesium, the ratio of CaO : MgO being 1 : 0·72. This is in part due to the calcareous concretions in the shaley beds. On the other hand along the Natal Coast the ratio is 1 : 2·2. In that region the Ecca beds tend to become more arenaceous and therefore to contain less calcium. Excluding the Natal coastal areas, the average percentage of calcium is the same as in the Dwyka waters (12·4 per cent. CaO as against 12·6 per cent. CaO).

Chlorides are always very high, and the percentage, in terms of total salts, is 27 per cent. Cl. which is very similar to the 30 per cent. Cl. in the case of the Dwyka waters.

On the Natal Coast the percentage is as high as 51 per cent. Cl.

Sulphates are very high indeed (12 per cent. SO_4) and in this respect the waters are almost indentical with the Dwyka waters.

COAST.

346	527
44·0	* 263·0
11·5	22·0
24·4	82·0
12·9	60·0
11·5	22·0
7·2	20·0
17·2	62·0
Nil	Nil
4·0	1·7
Nil	Nil
Nil	Nil
Nil	Nil
23·0	147·0
0·05	2·9
Under 0·5	—
7·5	7·
(9·1)	0·
9·1	4·
15·7	9·
52·0	55·
0·14	1·
Nil	Ni
55·5	31·
29·3	22·
(26·2)	7·
1 : 1·7	1 :

TABLE No. 20.—ECCA SERIES—KARROO SYSTEM IN THE CAPE PROVINCE AND NATAL COAST.

	Cape Province.											Natal Coast.				
Sample Numbers	221	223	258	259	260	261	262	463	489	490	Average	346	527	528	526 (*a*)	526	Average
Parts $CaCO_3$ per 10^6 Water:																	
Total Solids (at 106°)	202·0	210·0	94·0	130·5	141·0	118·0	260·0	72·2	149·0	77·8	145·5	44·0	263·0*	338·0	—	80·6	181·4
Methyl Orange Alkalinity	45·0	35·5	31·5	47·0	38·0	67·0	48·5	29·7	28·6	27·6	—	11·5	22·0	42·5	—	3·0	—
Total Hardness	67·2	93·5	46·0	50·0	54·0	62·5	86·0	42·3	83·0	33·2	—	24·4	82·0	149·0	—	19·8	—
Permanent Hardness	22·2	58·1	14·5	3·0	16·0	Nil	37·5	12·6	55·4	5·6	—	12·9	60·0	106·5	—	16·8	—
Temporary Hardness	45·0	35·5	31·5	47·0	38·0	62·5	48·5	29·7	28·6	27·6	—	11·5	22·0	42·5	—	3·0	—
Hardness due to Ca Salts	25·2	58·8	23·2	27·5	33·0	35·5	43·0	15·7	44·0	10·7	—	7·2	20·0	37·0	—	2·6	—
Hardness due to Mg Salts	42·0	34·8	22·8	22·5	21·0	27·0	43·0	26·6	39·0	22·5	—	17·2	62·0	112·0	—	17·2	—
Soda Alkalinity	Nil	Nil	Nil	Nil	Nil	4·5	Nil	Nil	Nil	Nil	—	Nil	Nil	Nil	—	Nil	—
Parts per 10^5 of Water:																	
Silica (as SiO_2)	1·3	2·0	2·7	3·2	2·1	2·2	2·2	3·2	3·5	4·7	—	4·0	1·7	3·0	—	2·3	—
Fluorides (as F)	0·09	Nil	—	—	—	—	—	0·06	—	—	—	Nil	Nil	Nil	—	Trace	—
Nitrites	Present	Nil	—	—	—	—	—	Trace	—	—	—	Nil	Nil	Nil	—	Nil	—
Nitrates (as NO_3)	0·04	0·44	—	—	—	—	—	1·6	5·9	0·35	—	Nil	Nil	1·4	—	1·6	—
Chlorides (as Cl)	81·0	71·0	15·4	35·2	42·3	25·0	104·0	14·2	39·3	14·5	—	23·0	147·0	165·0	—	39·3	—
Sulphates (as SO_4)	15·0	36·0	14·7	12·7	15·3	5·3	20·4	10·7	23·5	13·6	—	0·05	2·9	18·0	—	2·9	—
Potassium Salts	Small Amount	Small Amount	—	—	—	—	—	—	—	—	—	Under 0·5	—	Under 0·5	—	—	—
pH. Values	7·7	7·5	—	—	—	—	—	7·6	—	—	7·6	7·5	7·0	7·8	—	7·5	7·45
Percentage on Total Solids:																	
SiO_2	0·04	0·95	2·87	2·36	1·5	1·86	0·85	4·4	2·35	(6·0)	2·0	(9·1)	0·65	0·9	—	2·9	1·15
CaO	7·0	15·6	13·8	12·2	13·0	17·0	9·2	12·0	16·4	7·7	12·4	9·1	4·25	6·0	—	1·8	5·3
MgO	8·2	6·7	9·8	6·7	6·0	9·2	6·7	14·6	10·3	11·2	8·9	15·7	9·3	13·2	—	8·4	11·7
Cl	40·0	34·0	16·4	26·0	30·0	21·2	40·0	19·4	26·5	17·8	27·1	52·0	55·0	49·0	—	49·0	51·2
SO_4	7·4	17·2	15·7	9·4	10·8	4·5	7·8	14·7	15·7	17·4	12·1	0·14	1·1	5·3	—	3·6	2·53
Soda Alkalinity (as Na_2CO_3)	Nil	Nil	Nil	Nil	Nil	(3·95)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	—	Nil	Nil
Total Hardness (as $CaCO_3$)	33·0	45·0	49·0	37·0	38·5	53·0	33·0	58·0	56·0	42·5	40·5	55·5	31·0	44·5	—	24·4	38·8
Permanent Hardness (as $CaCO_3$)	10·8	27·5	15·4	(2·23)	11·3	(Nil)	14·4	17·2	32·2	7·2	17·0	29·3	22·6	31·5	—	20·7	26·0
Temporary Hardness (as $CaCO_3$)	22·0	35·5	24·5	35·0	27·0	(53·0)	18·6	40·5	19·0	35·1	28·6	(26·2)	7·6	12·6	—	3·7	11·3
Ratio CaO : MgO	1 : 1·17	1 : 0·4	1 : 0·7	1 : 0·55	1 : 0·5	1 : 0·54	1 : 0·7	1 : 1·2	1 : 0·6	1 : 1·4	1 : 0·72	1 : 1·7	1 : 2·2	1 : 2·2	—	1 : 4·7	1 : 2·2

* Deposits iron oxide on standing.

DESCRIPTION OF SAMPLES IN TABLE No. 20.

Sample No.	District and Province.	Borehole Depth. Feet.	Locality, Description and Remarks.	Date.
221	Peddie, Cape Province	—	Borehole in Peddie	2/ 9/40
223	Laingsburg, Cape Province	55	Borehole 200 yards East of Buffels Rivier, Laingsburg	3/10/40
258	Phillipstown, Cape Province	133	Borehole in Paardevlei (Juritz, Ref. 188, Anal. Govt. Laboratory)	1908
490	Phillipstown, Cape Province	—	Borehole in Potfontein (Juritz, Ref. 188, Anal. Govt. Laboratory)	8/3/21
259	Aberdeen, Cape Province	—	Spring water, Oaklands (Juritz, Ref. 194, Anal. Govt. Laboratory)	1908
260	Jansenville, Cape Province	675	Borehole on Klipplaat (Juritz, Ref. 195, Anal. Govt. Laboratory)	1908
261	Somerset East, Cape Province	146	Borehole at Middleton (Juritz, Ref. 198, Anal. Govt. Laboratory)	1908
262	Somerset East, Cape Province	153	Borehole in Rippon (Juritz, Ref. 201, Anal. Govt. Laboartory)	1908
463	Britstown, Cape Province	—	Borehole in Britstown	7/11/41
489	Hopetown, Cape Province	—	Borehole in Kraankuil (Anal. Govt. Laboratory, Johannesburg)...	21/ 3/21
346	Durban, South Coast, Natal	100	Borehole at Winkelspruit Hotel, Winkelspruit	2/ 4/41
527	Lower Tugela, North Coast, Natal	—	Well at Umhlali Station	31/ 3/42
528	Inanda, North Coast, Natal	—	Borehole in Tongaat	1/ 4/42
526	Lower Tugela, North Coast, Natal	—	Spring on Cliff at Umhlali Beach	28/ 3/42

453	330	533	542	571	354	349 *(a)*	96	349	455	480	570	589	603	591	65	145	308	534	569	585
7·3	21·5	2·0	13·0	29·5	37·0	28·0	38·0	25·0	36·5	36·0	36·5	42·0	26·0	27·5	19·0	8·0	4·5	41·5	33·0	40·0
8·1	20·8	5·2	11·2	14·7	38·4	31·7	40·9	17·2	33·9	35·5	39·5	43·0	18·2	8·1	16·9	8·2	8·0	5·2	13·0	49·5
0·8	Nil	3·2	Nil	Nil	1·4	3·7	2·9	Nil	Nil	Nil	3·0	1·0	Nil	Nil	Nil	0·2	3·5	Nil	Nil	9·5
7·3	20·8	2·0	11·2	14·7	37·0	28·0	38·0	17·2	33·9	35·5	36·5	42·0	18·2	8·1	16·9	8·0	4·5	5·2	13·0	40·0
3·3	6·4	2·2	7·7	8·2	16·0	16·4	26·9	7·6	12·1	21·0	—	20·0	10·0	4·5	9·7	4·1	2·2	2·7	—	24·9
4·8	14·4	3·0	3·5	6·5	22·4	15·3	14·0	9·6	21·8	14·5	—	23·0	8·2	3·6	7·2	4·1	5·8	2·5	—	24·6
Nil	0·7	Nil	1·82	14·8	Nil	Nil	Nil	7·8	2·6	0·5	Nil	Nil	1·7	19·4	2·1	Nil	Nil	36·3	20·0	Nil
15·0	32·0	7·0	22·0	35·0	52·0	41·0	72·0	30·0	58·6	58·0	129·0	82·0	25·5	38·6	27·6	17·0	12·2	60·0	51·0	55·4
3·0	5·0	1·0	3·1	3·2	4·0	5·0	2·8	2·0	3·4	—	—	1·6	—	1·7	4·0	3·0	2·0	2·0	—	2·4
Nil	Nil	Nil	Nil	0·05	0·09	—	Nil	0·04	0·06	0·04	—	0·03	0·04	Nil	—	Nil	Nil	Nil	—	Nil
Nil	Nil	Nil	Nil	Nil	Present	Present	Nil	Nil	Trace	Nil	0·002	Trace	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Trace
0·3	0·8	Nil	0·64	Trace	1·6	Present	0·08	Nil	2·0	Nil	0·05	1·6	Nil	0·08	Nil	Nil	0·4	Nil	0·1	3·4
Trace	3·0	1·05	0·71	0·4	8·8	4·0	2·8	2·4	6·0	2·8	34·8	16·8	1·4	3·9	0·9	1·0	1·0	8·2	5·2	2·5
Trace	0·05	0·8	0·50	0·4	2·7	4·1	18·0	Trace	4·8	10·7	15·0	4·5	2·9	Trace	Nil	0·4	0·04	0·05	0·5	4·5
Under 0·5	Under 0·5	Trace	Trace	—	—	—	—	Under 0·5	Under 0·5	0·17	—	—	0·4	Under 0·5	—	Trace	Under 0·5	Under 0·5	—	—
7·0	7·2	6·8	7·65	8·0	8·0	7·5	7·7	8·0	7·4	7·4	—	7·2	7·5	8·3	7·3	6·8	7·3	8·2	—	7·6
20·0	15·6	14·2	14·1	9·2	7·7	12·0	3·9	6·7	5·8	—	—	2·0	—	4·4	14·6	17·6	16·5	3·3	—	4·3
12·4	11·2	17·4	8·6	13·2	17·3	22·0	20·3	14·2	11·5	20·0	—	13·6	22·0	6·5	19·7	13·6	12·0	2·5	—	25·2
12·7	17·8	17·0	14·0	7·5	17·3	4·9	7·8	12·7	14·9	9·9	—	11·2	13·0	3·6	10·5	9·4	19·0	1·7	—	17·7
Trace	9·4	14·8	3·2	1·14	17·0	9·8	3·9	8·0	10·3	4·8	26·7	20·5	5·5	10·0	3·3	5·9	8·2	13·6	10·2	6·2
Trace	0·2	1·1	2·3	1·14	5·2	10·0	25·0	Trace	8·2	18·4	13·6	5·5	11·4	Trace	Nil	2·4	0·3	0·08	1·0	8·1
Nil	2·5	Nil	8·6	45·0	Nil	Nil	Nil	26·6	4·6	0·9	Nil	Nil	7·1	53·2	8·0	Nil	Nil	64·0	41·0	Nil
55·0	65·0	74·0	51·0	42·0	74·0	77·0	56·0	57·6	58·0	61·0	30·3	53·0	71·0	21·0	61·5	48·0	66·0	8·7	25·0	89·0
5·4	Nil	46·5	Nil	Nil	2·7	9·0	3·9	Nil	Nil	Nil	2·3	1·2	Nil	Nil	Nil	1·0	24·0	Nil	Nil	17·1
48·5	65·0	27·5	51·0	42·0	71·8	68·0	52·5	57·6	58·0	61·0	28·0	51·8	71·0	21·0	61·5	47·0	37·0	8·7	25·0	71·9
1 : 1·03	1 : 1·5	1 : 1·0	1 : 1·6	1 : 0·6	1 : 1·0	1 : 0·7	1 : 0·3	1 : 0·8	1 : 1·3	1 : 0·5	—	1 : 0·8	1 : 0·6	1 : 0·6	1 : 0·8	1 : 0·7	1 : 1·6	1 : 0·7	—	1 : 0·8

TABLE No. 21.—ECCA SERIES IN NORTHERN NATAL, SOUTHERN TRANSVAAL AND NOR

Numbers	48	394	421	113	112	123	236	309	315	335	453	330	533	542	571	35
Parts $CaCO_3$ per 10^5 Water:																
Orange Alkalinity	17·0	40·7	2·0	26·0	13·5	27·7	14·5	49·5	1·3	42·5	7·3	21·5	2·0	13·0	29·5	37
Hardness	15·0	41·2	1·4	22·7	15·0	30·0	13·0	36·8	4·0	14·0	8·1	20·8	5·2	11·2	14·7	38
nent Hardness	Nil	0·5	Nil	Nil	1·5	2·3	Nil	Nil	2·7	Nil	0·8	Nil	3·2	Nil	Nil	1
orary Hardness	15·0	40·7	1·4	22·7	13·5	27·7	13·0	36·8	1·3	14·0	7·3	20·8	2·0	11·2	14·7	37
ness due to Ca Salts	8·0	24·5	0·57	12·3	6·0	16·0	8·7	16·0	0·4	6·0	3·3	6·4	2·2	7·7	8·2	16
ness due to Mg Salts	7·0	26·7	0·83	10·4	9·0	14·0	4·3	20·8	3·6	8·0	4·8	14·4	3·0	3·5	6·5	22
Alkalinity	2·0	Nil	0·5	3·2	Nil	Nil	1·5	12·7	Nil	(28·5)	Nil	0·7	Nil	1·82	14·8	N
Parts per 10^5 of Water:																
Solids (as 105°C)	23·0	68·6	5·1	33·0	30·0	45·6	22·0	60·6	8·0	55·3	15·0	32·0	7·0	22·0	35·0	52
(as SiO_2)	—	—	—	5·0	2·3	2·8	2·0	4·8	0·9	1·6	3·0	5·0	1·0	3·1	3·2	4
ides (as F)	—	0·02	Trace	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	0·05	0
tes	—	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Pre
tes (as NO_2)	—	Nil	Nil	Nil	3·2	0·3	Nil	0·2	0·3	0·04	0·3	0·8	Nil	0·64	Trace	1
ides (as Cl)	0·7	3·6	0·5	2·3	3·1	10·2	3·8	3·3	2·4	6·1	Trace	3·0	1·05	0·71	0·4	8
hates (as SO_4)	Trace	12·0	0·6	Trace	Trace	0·07	2·0	4·9	Trace	Trace	Trace	0·05	0·8	0·50	0·4	2
ium Salts (as K)	—	0·3	0·06	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Under 0·5	Trace	Trace	—	—
Values	7·4	8·0	7·3	8·0	7·7	7·5	7·4	7·5	6·5	7·7	7·0	7·2	6·8	7·65	8·0	8
Percentage on Total Solids:																
SiO_2	—	—	—	15·1	7·6	6·2	9·1	7·9	11·2	2·9	20·0	15·6	14·2	14·1	9·2	7
CaO	19·6	19·2	6·2	21·0	11·1	19·8	10·9	14·6	2·8	6·1	12·4	11·2	17·4	8·6	13·2	17
MgO	12·2	16·9	6·4	12·7	12·0	12·2	15·7	13·7	18·0	5·8	12·7	17·8	17·0	14·0	7·5	17
Cl	3·05	5·2	9·8	7·0	10·3	22·5	17·3	5·5	30·0	11·0	Trace	9·4	14·8	3·2	1·14	17
SO_4	Trace	17·3	11·7	Trace	Trace	0·15	9·1	8·1	Trace	Trace	Trace	0·2	1·1	2·3	1·14	5
Alkalinity (as Na_2CO_3)	8·7	Nil	11·7	10·2	Nil	Nil	7·3	22·3	Nil	55·0	Nil	2·5	Nil	8·6	45·0	N
Hardness (as $CaCO_3$)	65·0	60·0	27·3	69·2	50·0	65·0	59·0	60·5	50·0	25·3	55·0	65·0	74·0	51·0	42·0	74
nent Hardness (as $CaCO_3$)	Nil	0·7	Nil	Nil	5·0	5·0	Nil	Nil	36·6	Nil	5·4	Nil	46·5	Nil	Nil	2
orary Hardness (as $CaCO_3$)	65·0	59·0	27·3	69·0	44·6	61·0	59·0	60·5	16·2	25·3	48·5	65·0	27·5	51·0	42·0	71
CaO : MgO	1 : 0·6	1 : 0·9	1 : 1·0	1 : 0·6	1 : 1·1	1 : 0·6	1 : 1·4	1 : 0·9	1 : 6·2	1 : 0·9	1 : 1·03	1 : 1·5	1 : 1·0	1 : 1·6	1 : 0·6	1 :

Sample No.	District and Province.	Borehole Depth.	Locality, Description and Remarks.	Date.
		Feet.		
394	Weenen, Natal	—	Borehole in Weenen (Anal. D.C.S.)	1940
421	Vryheid, Natal	—	Well in Vryheid (Dr. Ockerse's Report Anal. D.C.S.)	1941
113	Klipriver, Natal	—	Borehole Near Pieters, 9 miles South of Ladysmith	10/11/39
112	Klipriver, Natal	103	Borehole on farm " Monte Christo ", 6 miles E.N.E. of Colenso	10/11/39
123	Klipriver, Natal	201	Borehole on farm Haig, 7 miles East of Ladysmith	13/11/39
48	Klipriver, Natal	—	Borehole in Colworth	4/ 5/36
571	Klipriver, Natal	—	Borehole at Elandslaagte School (Anal. Govt. Lab., Johannesburg)	19/ 9/41
309	Klipriver, Natal	350	Borehole on farm Graythorne on Tugela River near Pieters.	28/12/40
315	Richmond, Natal	60	Borehole in Richmond	6/ 1/41
236	Alfred, Natal	—	Borehole in Harding	2/12/40
335	Wakkerstroom, Transvaal	70	Borehole 1 mile East of Volksrust on Main Road	18/ 3/41
453	Newcastle, Natal	—	Spring water, Newcastle	25/10/41
330	Newcastle, Natal	—	Borehole, Clantarif Siding	13/ 3/41
533	Pietermaritzburg, Natal	—	Spring, 2 miles North of Pietermaritzburg	2/ 4/42
542	Utrecht, Natal	100	Borehole at Sandspruit, Utrecht	6/ 8/42
354	Bloemfontein, Orange Free State	—	Borehole on farm Damvlei No. 29, near Junction of Kaalspruit and Modder River	8/ 5/41
349 (a)	Boshof, Orange Free State	35	Borehole, Boshof Municipality	31/10/41
96	Heilbron, Orange Free State	—	Spring water, Heilbron	22/ 8/39
349	Frankfort, Orange Free State	100	Borehole on farm Paardefontein No. 906, 13 miles South of Villiers	5/ 4/41
455	Hoopstad, Orange Free State	137	Borehole in Hoopstad	20/10/41
480	Heilbron, Orange Free State	—	Borehole in Heilbron (Anal. Div. C.S. per Dr. Ockerse)	Jan., 1942.
570	Vredefort, Orange Free State	70	Boreholes in Kopjes (Anal. Govt. Lab., Johannesburg)	18/ 4/36
589	Hoopstad, Orange Free State	150	Borehole on farm Witbank, near Odendaalsrust	30/10/42
603	Vrede, Orange Free State	—	Borehole in Vrede (Anal. Div. C.S. per Dr. Ockerse)	1942
591	Heilbron, Orange Free State	—	Borehole in Wolvehoek	23/ 1/43
65	Ermelo, Transvaal	—	Borehole in Ermelo	14/ 1/39
145	Bethal, Transvaal	—	Borehole in Bethal	1/ 3/40
308	Witbank, Transvaal	—	Borehole in Minnaar	20/12/40
534	Standerton, Transvaal	—	Borehole in Standerton	1/ 4/42
569	Standerton, Transvaal	70	Borehole on Vlakfontein No. 15 (Anal. Govt. Lab., Johannesburg)	10/ 4/37
585	Bethal, Transvaal	—	Borehole near Maizefield	2/10/42

Pyritic disseminations in the Ecca shales partly explain this high sulphate content. On the Natal Coast the sulphate drops to 2·5 per cent. SO_4 and the explanation may be that, as in the case of the Dwyka beds, the Ecca beds become less pyritic as one proceeds north-eastwards into Natal.

As in the case of the Dwyka waters, the total scale-forming salts are only moderately high, averaging 40·5 per cent. (38·8 per cent. along the Natal coast) while the permanent hardness compounds are relatively high, averaging 17 per cent. (Dwyka waters in the Cape Province 15·8 per cent.). Along the Natal coast the permanent hardness is even greater (26 per cent.) and consists mainly of the chlorides of magnesium and calcium.

Data for fluorides is insufficient in the Western regions of Ecca, but the content appears to be low. On the Natal coast none at all was found.

The waters in the regions covered by Table 20 fall naturally in the highly mineralised chloride-sulphate group of waters "A" and their utilisation and treatment are dealt with later under that group. It will suffice at this stage to state that a few of these waters, particularly some of those along the Natal coast, are too saline for potable use, but they can be used for watering livestock. They are all suitable for irrigation, though a few of them are so saline that they are really only suitable for light well-drained soils. The high chloride content renders them unsuitable as feed water " make-up " for steam boiler work, though they could be used after appropriate treatment for locomotive feed water. The " oceanic " characteristics of these waters have been referred to in the previous section.

(ii) *The Quality of the Water from the Ecca Series in Northern Natal, the Transvaal and Northern Free State.*

Attention has already been drawn to the fact that in the above mentioned regions the Ecca series becomes arenaceous, being mainly composed of sandstones, with some softer sandy shales. It will be seen that the chemical characteristics of the water alter as well.

In Table 21, the author has collected and analysed 30 samples of water from Natal, Transvaal and Northern Orange Free State.

Unlike the Western and Southern Karroo and coastal Natal, the Ecca, in the above mentioned regions, does not yield a characteristic water. All types except the extremely saline are encountered, so it is not possible to allocate these waters to any one group.

The rainfall is much the same over all the areas concerned, so it is necessary to look for other reasons than climatic.

One probable cause is the variation of the rock from argillaceous to purely arenaceous. Another cause is the large number of dolerite dykes and sheets which traverse the Ecca beds in these regions, and affect considerably the chemical characteristics of the waters.

The concentration varies greatly but the waters, taken as a whole, do not carry excessive solids in solution (seldom over 50 parts per 10^5).

Silica varies greatly but is, on the average, considerably higher than in the Ecca waters elsewhere and this is to be expected since the waters are of non-saline types.

Fluorides are absent in the Natal and Transvaal areas, while only very small amounts are found in the Free State and all under the maximum permissible for potable purposes.

The pH. value shows a considerable variation.

There is nearly always slightly more calcium than magnesium present, but this is not so marked as in the waters of the Western and Southern part of the Union, where calcareous concretions and layers are apparently common.

Chlorides vary a lot but are very seldom above 11 per cent. Cl. in terms of total salts. This is very different from the Cl. content of the Dwyka and the Ecca waters in the West and South of the Union.

Sulphates are generally present in traces or small amounts, but occasionally very high values are obtained. This may be due to pyritic dolerite dykes or to pyritic seggregations in the sandstones.

Soda alkalinity is sometimes present, generally in small amount, but occasionally in appreciable amount. This may be due to a felspathic sandstone in the vicinity or to a dolerite dyke.

The total scale-forming salts vary a lot but are generally fairly high.

Permanent hardness compounds are sometimes present but generally in small amounts.

Owing to such variation the author has not been able to average these analyses as has been done in other tables.

In the Eastern Transvaal, in the Ermelo, Bethal and Witbank districts the Ecca waters tend to be very pure, with concentration under 20 parts per 10^5. This is probably due to high rainfall and the arenaceous nature of the Ecca in those regions.

From the results of the analyses shown in Table 21, it would appear that the Ecca sediments in these regions were laid down in fresh water and that the region did not suffer any subsequent transgression by the sea.

The waters are entirely suitable for domestic supply, irrigation and stock watering, but as regards utilisation for steam raising and other industrial purposes, the variation is too great to permit of a general statement, each water having to be treated on its merits.

XIX.—THE WATERS ARISING IN THE BEAUFORT SERIES OF THE KARROO SYSTEM.

This formation is by far the most important covered in this study for the following reasons :—

A vast and relatively well populated regions in the central part of the Union and forming more than a third of the Union, is occupied by rocks belonging to the Beaufort series. This region is at present devoted almost entirely to pasturage and, to a less extent, to agriculture, though it contains a large number of towns and villages.

Moreover, except in Natal, the northern and eastern Orange Free State, and part of East Griqualand, there are few perennial streams or permament surface waters, so that the area is mainly dependent on underground supplies. Hence the quality of the underground water becomes a matter of great importance.

DISTRI

This formation forms
the whole of the central p
border, excluding Basutola
There is a considerabl
and such influences to a ce
in the formation :—

Carnarvon, Beaufo
Fraserburg and
Colesberg, Middelbu
Bloemfontein, Beth
Cradock, Tarkastad
Queenstown and H
Transkei and Umta
Maclear, Cedarvill
Pietermaritzburg
Bergville and Harr
Vrede and Senekal

GEO

The Beaufort series f
The abundance of r
series to be palaeontolo
distinguishable from one
but the chief lithological s
beds, middel Beaufort be
beds. The age of the Beauf
For the convenience
formation into two grou
(1) Middle and U
(2) Lower Beaufor
The series is general
characterised by strong b
and " mudstones ", whic
of the Ecca. They comm
colouration is more mar
calcareous concretions.
The sandstones rang
layers to much thicker y
kinds. The alteration of
teraccing in the landsca
In addition the stra
Dolerite ", so numerous a

UNDER

The water bearing
depending on topograph
does not appear to be as i
as Frommurze (3, p. 16
South-Western corner, u
to that of the Central a
Du Toit (2, p. 133)
gallons *per diem* for the
Free State generally at
low percentage of failur

DISTRIBUTION AND RAINFALL.

This formation forms part of the vast Karroo basin and occupies the whole of the central part of the Union, South of the Transvaal border, excluding Basutoland and its immediate vicinity.

There is a considerable variation in the rainfall on these rocks, and such influences to a certain extent the quality of the water arising in the formation :—

	Average Rainfall per Annum.
Carnarvon, Beaufort West, Victoria West, Fraserburg and Sutherland................	5″–10″
Colesberg, Middelburg and Graaff Reinet.....	10″–15″
Bloemfontein, Bethulie and Burghersdorp....	15″–20″
Cradock, Tarkastad and Somerset West......	10″–15″
Queenstown and Hofmeyr...................	15″–20″
Transkei and Umtata.......................	30″–40″
Maclear, Cedarville, Bulwer, Kokstad and Pietermaritzburg..........................	40″–50″
Bergville and Harrismith..................	50″
Vrede and Senekal.........................	20″–25″

GEOLOGY AND LITHOLOGY.

The Beaufort series follows conformably on the Ecca series.

The abundance of reptilian vertebrate fossils has enabled the series to be palaeontologically divided into a number of zones, distinguishable from one another only by the variation in fossil type, but the chief lithological subdivisions recognised are the upper Beaufort beds, middel Beaufort beds (relatively very thin) and lower Beaufort beds. The age of the Beaufort series is Upper Permian to Lower Triassic.

For the convenience of this study the writer has divided the formation into two groups, i.e. :—

(1) Middle and Upper Beaufort.
(2) Lower Beaufort.

The series is generally more arenaceous than the Ecca, and is characterised by strong bands of sandstone parted by bodies of shales and " mudstones ", which are normally less argillaceous than those of the Ecca. They commonly show green, red and purple tints, which colouration is more marked in the upper division and may carry calcareous concretions.

The sandstones range from finegrained, hard, dark types on thin layers to much thicker yellowish or pale bluish softer highly felspathic kinds. The alteration of sandstone and shale gives rise to a marked teraccing in the landscape.

In addition the strata are cut by sheets and dykes of " Karroo Dolerite ", so numerous as to form a veritable network of igneous rock.

UNDERGROUND WATER SUPPLIES.

The water bearing properties of the Beaufort series are variable depending on topography and rainfall, though the effect of the latter does not appear to be as important as might be expected. For example, as Frommurze (3, p. 160) points out, the average yield in the arid South-Western corner, under a rainfall of only 5″ per annum, is equal to that of the Central areas under a rainfall of 15″–20″.

Du Toit (2, p. 133) gives figures ranging from 11,000 to 43,000 gallons *per diem* for the formation in the Cape Province and Orange Free State generally at very shallow depths, and with a relatively low percentage of failures.

In the Northern Orange Free State the borehole depths are deeper and the percentage of failures greater.

In Natal and the North-Eastern Free State the greatly dissected nature of the country has, as shown by Frommurze (3, p. 161), an adverse influence on the underground water storing capacity of the strata and yields are low.

Taken as a whole, the investigations of Du Toit and Frommurze have shown that the formation is an exceedingly good aquifer, nearly always yielding ample supplies at very shallow depths, and that such has been aided by the network of Karroo dolerite dykes and sills which act as water barriers.

In some districts the striking of flowing supplies was common, but there has been a great falling off in such cases during recent years, owing to the difficulty of discovering new sites where artesian conditions would be expected.

Quality of the Water.

(i) *The Lower Beds.*

The author has been somewhat handicapped by the fact that large tracts of country occupied by the Beaufort series, particularly in the Central and Eastern Cape Province and the Western part of Natal, have not been geologically mapped in detail, so that is has sometimes been difficult to ascertain whether a borehole is situated in the lower or upper horizons of the Beaufort series.

In Table 22 the author has collected analytical data for 39 samples, including a few of Juritz's analyses which however, do not give pH. values. As will be observed, the samples cover a very wide area, having been collected from some 28 districts in the Cape Province, Orange Free State and Natal.

There is no appreciable difference in quality between the waters arising in these lower beds of the Beaufort series and those of the Ecca waters in the Cape Province, for the former yield highly saline waters also of the chloride-sulphate type.

The concentration of salt is extremely high, though variable, the average of 39 samples being 106 parts dissolved solids per 10^6 parts. In the Northern Free State the salinity of the waters tends to become much lower.

The hydrogen ion concentration is fairly consistent, giving an average pH. of 7·6.

As is the case in the Ecca and all other saline waters, the silica content is consistently low, averaging only 3·8 per cent. SiO_2 in terms of total salts.

Fluorides are generally absent, though occasionally the water may contain a minute amount. Only one sample, namely that from Sutherland (No. 552) gave an appreciable fluoride figure (2·7 parts F per million, or 0·5 per cent. F.).

Chlorides show some variation, but are always high, averaging 22·5 per cent. Cl. in terms of total salts. This is a lower percentage than that for the waters in the Ecca series (27 per cent. Cl.).

Sulphates vary but are always present in appreciable quantity, averaging 10·8 per cent. SO_4 which, again, is slightly lower than that for the Ecca waters.

2992	105	1
:3 3·0	35·5	31
13 0·5	54·6	49
9 Nil	19·1	17
:3 0·5	35·5	31
:3 0·7	19·6	28
.09·8	35·0	20
N 2·5	Nil	N
;9 1·2	90·8	110·
23·0	3·4	2·
o Nil	Nil	Ni
N Nil	Nil	Ni
o1·6	0·3	Ni
:34·4	5·3	29·
:14·5	32·5	12·
nnder oo·5	Under 0·5	Sma Amou

In several sample total salts is well over as 65 per cent. The a (as Na_2CO_3).

TABLE No. 22.—LOWER BEAUFORT BEDS IN T

Sample Numbers	350	205	207	119	120	237	272	225	277	278	279	294	194	289	186	464	276	94
Parts $CaCO_3$ per 10^5 Water:																		
Methyl Orange Alkalinity	23·0	13·3	34·0	40·5	33·5	31·0	32·0	32·0	32·0	44·0	13·4	23·7	9·0	16·0	35·5	22·5	31·0	48·
Total Hardness	176·0	92·0	45·9	71·9	42·3	174·0	66·3	22·2	103·1	53·0	45·5	33·2	13·7	17·5	58·2	24·0	46·3	53·
Permanent Hardness	153·0	78·7	11·9	31·4	8·8	143·0	34·3	Nil	71·1	9·0	32·1	9·5	4·7	1·5	22·7	1·5	15·3	5·
Temporary Hardness	23·0	13·3	34·0	40·5	33·5	31·0	32·0	22·2	32·0	44·0	13·4	23·7	9·0	16·0	35·5	22·5	31·0	48·
Hardness due to Ca Salts	88·0	61·0	28·5	36·4	24·1	79·9	34·3	12·2	63·5	22·5	15·0	23·2	4·7	9·0	31·2	12·8	33·3	24·
Hardness due to Mg Salts	88·0	31·0	17·4	35·5	18·2	94·1	32·0	10·0	39·6	30·5	30·5	10·0	9·0	8·5	27·0	11·2	13·0	29·
Soda Alkalinity	Nil	Nil	Nil	Nil	Nil	Nil	Nil	9·8	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Parts per 10^6 of Water:																		
Total Solids (at 106°C.)	220·0	160·0	95·0	151·0	88·2	390·0	97·0	46·0	320·0	96·5	190·0	59·0	53·0	44·5	97·8	41·4	100·0	125·
Silica (as SiO_2)	5·0	4·0	1·8	2·4	2·2	3·8	4·1	2·6	2·1	2·9	2·7	2·6	2·0	4·9	4·4	—	2·0	4·
Fluorides (as F)	0·09	—	—	Nil	Nil	Nil	—	0·04	—	—	—	0·01	Nil	—	Nil	0·04	—	Nil
Nitrites	Nil	—	—	Nil	Nil	Nil	—	Nil	—	—	—	Nil	Nil	—	Nil	Nil	—	Nil
Nitrates (as NO_3)	0·8	—	0·005	0·8	0·8	0·05	—	0·2	—	—	—	0·8	Nil	—	1·6	Nil	—	5·
Chlorides (as Cl)	110·0	55·0	22·3	43·3	18·8	190·0	19·8	5·7	79·7	17·8	83·0	13·8	23·1	11·4	18·4	5·0	27·4	35·
Sulphates (as SO_4)	10·7	26·0	9·8	17·7	7·2	8·5	15·0	3·3	80·0	9·1	11·8	11·6	3·2	0·4	10·9	3·7	9·2	8·
Potassium Salts	—	—	—	Small Amount	Small Amount	Small Amount	—	Under 0·5	—	—	—	Under 0·5	Under 0·5	—	Small Amount	0·2	—	Trac
pH. Values	7·3	—	—	7·4	7·4	7·6	—	8·0	—	—	—	7·5	7·0	—	7·9	7·6	—	7·
Percentage on Total Solids:																		
SiO_2	2·2	2·5	1·9	1·6	2·5	0·97	4·2	5·6	(0·7)	3·0	1·4	4·3	3·7	(11·0)	4·5	—	2·0	3·
CaO	22·1	21·3	17·0	13·6	15·0	11·5	18·8	14·3	11·1	13·0	(4·4)	21·6	(5·0)	11·2	17·4	18·6	18·8	10·
MgO	16·8	7·8	7·4	9·3	8·1	9·6	13·4	8·8	5·0	12·6	(6·4)	(6·7)	10·4	7·7	10·8	10·8	(5·2)	9·
Cl	49·5	34·5	23·5	29·0	21·2	48·5	20·5	(12·4)	25·0	18·4	44·6	23·0	43·2	25·5	18·6	(12·0)	27·4	28·
SO_4	4·9	16·3	10·3	10·8	8·1	2·2	15·4	7·2	25·0	9·4	6·2	19·4	6·0	(0·9)	11·1	8·9	9·2	6·
Soda Alkalinity (as Na_2CO_3)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	(22·5)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Total Hardness (as $CaCO_3$)	(80·0)	58·0	48·5	48·0	48·0	44·5	68·0	48·0	32·5	55·0	24·0	56·0	25·8	39·2	59·1	57·0	46·3	42·
Permanent Hardness (as $CaCO_3$)	(69·0)	48·5	12·8	21·0	10·0	36·6	35·0	(Nil)	22·2	9·3	17·0	16·0	8·9	(3·4)	23·0	3·6	15·3	4·
Temporary Hardness (as $CaCO_3$)	10·4	8·3	36·0	27·0	38·0	8·0	33·0	(48·0)	10·0	45·5	7·1	39·7	17·0	36·0	36·0	54·0	31·0	38·
Ratio CaO : MgO	1 : 0·7	1 : 0·4	1 : 0·4	1 : 0·7	1 : 0·5	1 : 0·8	1 : 0·7	1 : 0·6	1 : 0·5	1 : 0·9	1 : 1·5	1 : 0·32	1 : 2·0	1 : 0·7	1 : 0·6	1 : 0·5	1 : 0·3	1 : 0·

* Doleri

TABLE No. 22.—LOWER BEAUFORT BEDS IN THE CAPE PROVINCE, ORANGE FREE STATE AND NATAL.

19	120	237	272	225	277	278	279	294	194	289	186	464	276	94	283	286	173	195	456	235	285	
·5	33·5	31·0	32·0	32·0	32·0	44·0	13·4	23·7	9·0	16·0	35·5	22·5	31·0	48·0	24·0	25·5	38·5	33·5	29·0	33·0	26·0	2
·9	42·3	174·0	66·3	22·2	103·1	53·0	45·5	33·2	13·7	17·5	58·2	24·0	46·3	53·5	47·5	22·2	44·4	49·8	35·5	24·6	31·4	4
·4	8·8	143·0	34·3	Nil	71·1	9·0	32·1	9·5	4·7	1·5	22·7	1·5	15·3	5·5	23·5	Nil	5·9	16·3	6·5	Nil	5·4	1
·5	33·5	31·0	32·0	22·2	32·0	44·0	13·4	23·7	9·0	16·0	35·5	22·5	31·0	48·0	24·0	22·2	38·5	33·5	29·0	24·6	26·0	2
·4	24·1	79·9	34·3	12·2	63·5	22·5	15·0	23·2	4·7	9·0	31·2	12·8	33·3	24·2	28·0	11·0	17·8	19·8	15·3	8·4	20·1	2
·5	18·2	94·1	32·0	10·0	39·6	30·5	30·5	10·0	9·0	8·5	27·0	11·2	13·0	29·3	19·5	11·2	26·6	30·0	20·2	16·2	11·3	1
il	Nil	Nil	Nil	9·8	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	2·3	Nil	Nil	Nil	8·4	Nil	N
·0	88·2	390·0	97·0	46·0	320·0	96·5	190·0	59·0	53·0	44·5	97·8	41·4	100·0	125·0	93·0	61·0	90·6	87·5	50·1	(39·7)	54·0	8
·4	2·2	3·8	4·1	2·6	2·1	2·9	2·7	2·6	2·0	4·9	4·4	—	2·0	4·0	3·9	4·2	1·6	2·8	3·9	3·1	3·1	3
il	Nil	Nil	—	0·04	—	—	—	0·01	Nil	—	Nil	0·04	—	Nil	—	—	Nil	Nil	Trace	Nil	—	N
l	Nil	Nil	—	Nil	—	—	—	Nil	Nil	—	Nil	Nil	—	Nil	—	—	Nil	Nil	Nil	Nil	—	N
8	0·8	0·05	—	0·2	—	—	—	0·8	Nil	—	1·6	Nil	—	5·2	—	—	1·6	0·08	3·2	0·14	—	0
3	18·8	190·0	19·8	5·7	79·7	17·8	83·0	13·8	23·1	11·4	18·4	5·0	27·4	35·5	10·5	9·0	17·0	17·0	4·0	3·9	6·0	15
7	7·2	8·5	15·0	3·3	80·0	9·1	11·8	11·6	3·2	0·4	10·9	3·7	9·2	8·0	7·5	7·5	16·4	15·4	4·0	2·8	4·6	9
ll unt	Small Amount	Small Amount	—	Under 0·5	—	—	—	Under 0·5	Under 0·5	—	Small Amount	0·2	—	Trace	—	—	—	—	Trace	Under 0·5	—	—
4	7·4	7·6	—	8·0	—	—	—	7·5	7·0	—	7·9	7·6	—	7·4	—	—	7·5	7·7	7·0	7·9	—	7
6	2·5	0·97	4·2	5·6	(0·7)	3·0	1·4	4·3	3·7	(11·0)	4·5	—	2·0	3·2	4·2	6·9	1·7	3·2	7·7	7·7	5·7	3
6	15·0	11·5	18·8	14·3	11·1	13·0	(4·4)	21·6	(5·0)	11·2	17·4	18·6	18·8	10·7	16·8	10·2	11·0	0·1	16·8	11·8	20·6	17
3	8·1	9·6	13·4	8·8	5·0	12·6	(6·4)	(6·7)	10·4	7·7	10·8	10·8	(5·2)	9·3	8·0	7·3	17·4	13·7	15·8	16·2	8·3	8
o	21·2	48·5	20·5	(12·4)	25·0	18·4	44·0	23·0	43·2	25·5	18·6	(12·0)	27·4	28·3	(11·2)	14·7	18·6	19·4	(8·0)	(9·8)	(11·0)	18
8	8·1	2·2	15·4	7·2	25·0	9·4	6·2	19·4	6·0	(0·9)	11·1	8·9	9·2	6·4	8·0	12·2	18·0	17·4	8·0	7·0	8·5	12
	Nil	Nil	Nil	(22·5)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	(3·9)	Nil	Nil	Nil	(22·5)	Nil	N
)	48·0	44·5	68·0	48·0	32·5	55·0	24·0	56·0	25·8	39·2	59·1	57·0	46·3	42·5	51·0	36·5	49·6	57·0	70·0	61·8	58·0	52
)	10·0	36·6	35·0	(Nil)	22·2	9·3	17·0	16·0	8·9	(3·4)	23·0	3·6	15·3	4·4	25·0	(Nil)	6·4	18·4	12·9	(Nil)	10·0	21
)	38·0	8·0	33·0	(48·0)	10·0	45·5	7·1	39·7	17·0	36·0	36·0	54·0	31·0	38·0	25·5	36·5	42·0	48·0	57·0	61·9	48·0	31
·7	1 : 0·5	1 : 0·8	1 : 0·7	1 : 0·6	1 : 0·5	1 : 0·9	1: 1·5	1 : 0·32	1 : 2·0	1 : 0·7	1 : 0·6	1 : 0·5	1 : 0·3	1 : 0·87	1 : 0·5	1 : 0·7	1 : 1·6	1 : 1·1	1 : 0·9	1 : 1·3	1 : 0·4	1 :

283	286	173	195	456	235	285	34	92	105	125	481	132	482	483	485	493	494	552	567	*593	Average
24·0	25·5	38·5	33·5	29·0	33·0	26·0	25·5	23·0	35·5	31·5	29·5	37·0	24·6	28·3	37·0	28·5	45·0	22·7	31·8	10·0	—
47·5	22·2	44·4	49·8	35·5	24·6	31·4	42·5	20·5	54·6	49·0	53·5	27·3	36·6	49·7	43·0	32·3	62·4	25·0	73·8	7·2	—
23·5	Nil	5·9	16·3	6·5	Nil	5·4	17·0	Nil	19·1	17·5	24·0	Nil	11·7	21·4	6·0	3·8	17·4	2·3	42·0	Nil	—
24·0	22·2	38·5	33·5	29·0	24·6	26·0	25·5	20·5	35·5	31·5	29·5	27·3	24·6	28·3	37·0	28·5	45·0	22·7	31·8	7·2	—
28·0	11·0	17·8	19·8	15·3	8·4	20·1	25·3	10·7	19·6	28·7	27·0	11·4	20·0	31·2	26·2	13·5	26·4	22·5	41·8	5·2	—
19·5	11·2	26·6	30·0	20·2	16·2	11·3	17·2	9·8	35·0	20·3	26·5	15·9	16·6	18·5	16·8	18·8	36·0	2·5	32·0	2·0	—
Nil	2·3	Nil	Nil	Nil	8·4	Nil	Nil	2·5	Nil	Nil	Nil	9·7	Nil	Nil	Nil	Nil	Nil	Nil	Nil	2·8	—
93·0	91·0	90·6	87·5	50·1	(39·7)	54·0	81·0	41·2	90·8	110·0	117·2	70·2	57·0	92·0	77·9	70·5	122·0	47·2	190·4	(16·0)	106·0
3·9	4·2	1·6	2·8	3·9	3·1	3·1	3·0	3·0	3·4	2·7	—	4·0	3·0	2·9	2·8	2·5	0·62	—	2·4	2·8	—
—	—	Nil	Nil	Trace	Nil	—	Nil	Nil	Nil	Nil	0·03	Nil	—	—	—	—	—	0·27	—	—	—
—	—	Nil	Nil	Nil	Nil	—	Nil	Nil	Nil	Nil	—	Nil	—	—	—	—	—	Nil	—	Nil	—
—	—	1·6	0·08	3·2	0·14	—	0·4	1·6	0·3	Nil	9·9	3·2	—	—	1·3	—	—	Nil	4·7	Nil	—
10·5	9·0	17·0	17·0	4·0	3·9	6·0	15·4	4·4	5·3	29·1	21·3	10·3	8·5	19·5	17·7	14·0	27·6	17·0	70·4	0·4	—
7·5	7·5	16·4	15·4	4·0	2·8	4·6	9·7	4·5	32·5	12·3	22·4	3·0	10·4	13·0	3·2	12·9	9·4	0·8	9·7	0·3	—
—	—	—	—	Trace	Under 0·5	—	—	Under 0·5	Under 0·5	Small Amount	0·17	Under 0·5	—	—	—	—	—	0·1	—	Trace	—
—	—	7·5	7·7	7·0	7·9	—	7·9	7·3	7·8	7·1	7·8	7·2	—	—	—	—	—	7·5	—	7·6	7·6
4·2	6·9	1·7	3·2	7·7	7·7	5·7	3·7	7·3	3·7	2·4	—	5·7	5·2	3·15	3·6	3·55	(0·52)	—	1·26	(17·6)	3·8
16·8	10·2	11·0	0·1	16·8	11·8	20·6	17·2	14·7	12·0	14·8	12·8	9·2	19·1	19·0	18·5	10·8	12·2	(26·5)	12·1	(6·9)	14·8
8·0	7·3	17·4	13·7	15·8	16·2	8·3	8·5	9·5	15·4	7·4	9·1	9·2	11·6	8·1	8·5	10·6	11·8	(2·1)	6·9	13·0	10·4
(11·2)	14·7	18·6	19·4	(8·0)	(9·8)	(11·0)	18·8	(10·4)	(5·9)	26·5	18·1	14·7	15·0	20·5	22·5	19·9	22·5	35·8	37·3	(2·5)	26·1
8·0	12·2	18·0	17·4	8·0	7·0	8·5	12·0	11·0	(35·5)	11·0	19·0	4·3	18·2	14·2	4·1	18·2	7·7	1·7	5·1	(1·9)	10·6
Nil	(3·9)	Nil	Nil	Nil	(22·5)	Nil	Nil	(6·3)	Nil	Nil	Nil	(13·8)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	(19·0)	Rare
51·0	36·5	49·6	57·0	70·0	61·8	58·0	52·3	50·0	60·0	44·6	45·6	39·0	64·0	54·5	55·0	46·0	51·0	52·5	39·0	45·0	52·5
25·0	(Nil)	6·4	18·4	12·9	(Nil)	10·0	21·1	(Nil)	21·0	16·0	20·5	(Nil)	20·5	23·5	7·7	5·4	14·2	(4·9)	22·0	(Nil)	20·5
25·5	36·5	42·0	48·0	57·0	61·9	48·0	31·2	(50·0)	39·0	28·6	25·1	39·0	43·0	31·0	47·0	40·0	37·0	47·6	17·0	45·0	32·0
1 : 0·5	1 : 0·7	1 : 1·6	1 : 1·1	1 : 0·9	1 : 1·3	1 : 0·4	1 : 0·5	1 : 0·6	1 : 1·3	1 : 0·5	1 : 0·7	1 : 1·0	1 : 0·6	1 : 0·4	1 : 0·46	1 : 0·98	1 : 0·97	(1 : 0·08)	1 : 0·5	(1 : 1·9)	1 : 0·7

Sample No.	District and Province.	Borehole Depth. Feet.	Locality, Description and Remarks.	Date.
350	Graaff Reinet, Cape Province	60	Borehole, 2 miles East of Graaff Reinet on National Main Road	4/ 4/41
205	Graaff Reinet, Cape Province	—	Borehole in Graaff Reinet (Anal. Juritz 3453)	1908
207	Aberdeen Cape Province	317	Borehole in Aberdeen Road (Anal. Juritz, Ref. 233)	1908
119	Aberdeen, Cape Province	80	Well water at Aberdeen	1/11/39
120	Aberdeen, Cape Province	128	Borehole in Aberdeen	1/11/39
237	Umtata, Cape Province	—	Borehole near Umtata	23/11/40
272	Carnarvon, Cape Province	—	Borehole in Kaffirskraal, East South-East of Carnarvon. (Anal. Juritz, Ref. 205)	1908
225	Carnarvon, Cape Province	200	Borehole, Carnarvon Municipality	5/11/40
277	Richmond, Cape Province	406	Borehole at Richmond Road. (Anal. Juritz, Ref. 245)	1908
278	Cradock, Cape Province	—	Borehole at Witmos. (Anal. Juritz, Ref. 254)	1908
279	East London, Cape Province	65	Borehole in East London. (Anal. Juritz, Ref. 268)	1908
294	Prince Albert, Cape Province	—	Borehole, Railway Station, Prince Albert Road	12/ 1/41
194	Transkei, Cape Province	—	Borehole at Qoloro	5/ 7/41
289	Komgha, Cape Province	—	Spring at Komgha. (Anal. Juritz, Ref. 324)	1908
186	Tarka, Cape Province	—	Borehole on farm Klipfontein, near Tarkastad	3/ 7/40
464	Williston, Cape Province	—	Borehole in Williston. (Dr. Ockerse, Anal. Div. C. Services)	5/11/41
276	Graaff Reinet, Cape Province	—	Borehole in Graaff Reinet. (Anal. Juritz, Ref. 239)	1908
94	Adelaide, Cape Province	73	Borehole in Adelaide	28/ 8/39
283	Colesberg, Cape Province	400	Borehole in Colesberg. (Anal. Juritz, Ref. 283)	1908
286	Victoria West, Cape Province	—	Borehole in Pampoenpoort. (Anal. Juritz, Ref. 294)	1908
173	Victoria West, Cape Province	150	Borehole at Hutchinson Station	22/ 2/40
195	Beaufort West, Cape Province	—	Borehole at Kromrivier Station	10/ 8/41
285	Victoria West, Cape Province	61	Borehole in Biesjespoort. (Anal. Juritz, Ref. 293)	1908
34	Cradock, Cape Province	—	Borehole in Cradock	15/ 8/38
92	Fraserburg, Cape Province	190	Borehole in Fraserburg	13/ 9/39
105	Middelburg, Cape Province	200	Borehole in Middelburg	10/ 1/40
125	Victoria West, Cape Province	100	Borehole, 1¼ miles South-West of Victoria West	24/11/39
481	Murraysburg, Cape Province	—	Borehole in Murraysburg. (Dr. Ockerse's Report, Anal. Div. C.S.)	Jan., 1942.
132	Somerset East, Cape Province	—	Borehole, Victoria Park, Somerset East	3/ 1/40
482	Victoria West, Cape Province	—	Borehole at Nobelsfontein. (Anal. J. Gray)	22/12/19
483	Beaufort West, Cape Province	—	Borehole at Rhenoster Kop (Anal. J. Gray)	22/12/19
485	Queenstown, Cape Province	—	Borehole at Imvani. (Anal. Govt. Lab., Johannesburg)	8/ 8/21
493	Hanover, Cape Province	—	Borehole at Caroluspoort. (Anal. J. Gray)	8/12/19
494	Cradock, Cape Province	—	Borehole at Witmos. (Anal. J. Gray)	9/ 2/21
552	Sutherland, Cape Province	—	Borehole in Sutherland. (Anal. Div. C.S.)	1942
567	Kingwilliamstown, Cape Province	—	Borehole, Fort Montgomery Cheese Factory, Kingwilliamstown. (Anal. Govt. Lab., Johannesburg)	19/ 5/37
593	Mount Currie, Griqualand East, Cape Province	—	Spring on farm Lot 1, near Kokstad	26/ 1/43
456	Winburg, Orange Free State	—	Spring in Winburg	28/10/41
235	Brandfort, Orange Free State	100	Spring in Brandfort	20/10/41

As in the case of the Ecca waters, soda alkalinity is very rare. Instead there is nearly always a very high permanent hardness which in terms of total salts averages 17 per cent. (as $CaCO_3$), while the bicarbonates of calcium and magnesium average 32 per cent. (as $CaCO_3$), both figures being almost the same as those for the Ecca waters in the Cape Province.

There is almost invariably more calcium than magnesium, the CaO MgO ratio being 1 : 0·7, this figure being also indetical with that for the Ecca waters.

Climatic factors appear to play some part. For example the waters from the well–watered Northern districts of the Orange Free State are, as aforementioned, less saline than those from the arid Western Cape Province. On the other hand, the well-watered Umtata and East London districts with 30″–35″ of rain per annum yield highly saline waters with 190–300 parts of salts per 10^5. The essential composition of the waters remains however unaltered. The cause of such salinity is discussed in the following chapter.

Since the waters from the lower Beaufort series belong to the saline chloride-sulphate group of waters, their utilisation for technical purposes is dealt with under Group A.

It may be, stated here that since these waters are not quite as brackish as some other waters considered in previous sections, they can be used for watering livestock and for irrigation, but they are sometimes too brackish for drinking purposes.

In East Griqualand and Pondoland there are very few boreholes since the country is very well watered and there are numerous mountain streams. This water approximates to the pure water group " E ".

(ii) *The Waters in the Middle and Upper Beds.*

In Table 23 are shown the results of 33 analyses of water samples from 28 districts in the Cape Province, Orange Free State, East Griqualand and Natal, so that the formation has been well covered. The majority of these analyses were carried out by the author.

There is some doubt as to whether certain boreholes in Natal and the Cape Province are situated in the Middle or lower beds of the Beaufort series.

It will be observed from Table 23 that in spite of variations in rainfall, there is a remarkable consistency in concentration of salts in these waters, the total solids averaging 36 parts per 10^5.

One of the strking characteristics of these waters is the consistently high pH. value, which averages 8·2 ; the highest for any group of waters in the Union. Several waters show pH. values of 8·6 or over, one sample (No. 544) from Cedarville shows a pH. of 9·4. This is one of the highest recorded in the Union. The only borehole water to show a higher figure is that from Ledig, Pilansberg, located in the alkali rocks. (Page 42).

These high pH. figures are due to the very high Na_2CO_3 or $NaHCO_3$ content of the waters in the Upper horizons of the Beaufort series (averaging 37 per cent. expressed as Na_2CO_3).

In several samples the Na_2CO_3 or $NaHCO_3$ content in terms of total salts is well over 50 per cent. (as Na_2CO_3), some are even as high as 65 per cent. The average, as aforementioned, is about 37 per cent. as Na_2CO_3).

The highest absolute figure for soda alkalinity, is 32 parts (as Na_2CO_3) per 10^5. Quite often the pH. exceeds 8·2, with the result that the water shows a definite phenolphthalein alkalinity. In such case both soda carbonate and bicarbonate are present, *but generally speaking the soda alkalinity is due to sodium bicarbonate.* The probable cause of this high soda alkalinity will be discussed later.

Contrary to what is found in the alkaline soda waters from the Red granite and the Old granite, silica is consistently low, with an average of 6·4 per cent. SiO_2 in terms of total salts. There is very little variation.

Fluorides are sometimes found, but so far in only two cases in appreciable amount (No. 502, Dewetsdorp; with 4·8 parts F. per million or 2·1 per cent. F., and No. 498, Shannon,* with 4·5 parts F. per 105 or 1·4 per cent. F.). The significance of fluorides in *sodium carbonate* waters is discussed on page 170.

In striking contrast to the waters from the lower Beaufort beds which in percentage composition average about 22 per cent. Cl. the waters from the middle and upper Beaufort horizons average only 5·7 per cent. Cl. with very few exceptions. (The chief exceptions are the highly saline waters from Hofmeyr and Queenstown).

Also in striking contrast to the lower Beaufort and Ecca waters is the low sulphate content which averages only 5·3 per cent. SO_4 compared with 10·8 per cent. SO_4 in the lower Beaufort waters. The chief exception is the Hofmeyr water.

The total scale-forming salts average only 39·7 per cent. expressed as $CaCO_3$, so that, generally speaking, the hardness is moderately low. The hardness is all temporary, that is due to the bicarbonates of calcium and magnesium.

In a few cases the total scale-forming compounds amount to only about 10 per cent. or less, the waters consisting almost entirely of $NaHCO_3$ or Na_2CO_3 with a little silica and sodium sulphate.

There is nearly always far more calcium than magnesium, the average ratio being 1 : 0·62.

Consistently high soda alkalinity is apparently unusual in waters rising in sedimentary rocks for Lindgren (35, p. 53) writes :—

> "Waters containing Na_2CO_3 in large amounts are not common in sedimentary rocks but here and there springs or wells of this character are encountered. They are cold and usually contain some free CO_2 and H_2S".

With regard to the cause of this consistently high soda content of waters arising in the upper Beaufort beds, the author suggests two possible theories :—

(1) It has already been mentioned that the Beaufort sandstones are highly felspathic and further that the series is predominantly arenaceous. These felspars might possibly be the cause of the high soda content of the waters arising in these rocks. An essential for this theory is that the felspars should be soda felspars (e.g. albite to oligoclase plagiocl rather than lime felspars (andesine to anorthite plagiocl Further, the felspars should be comparatively *fresh.*

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*From later information Shannon (498) is Lower Beaufort and not Upp

Sample No.
290
488
291
100 (*a*) (*b*)
80
229
353
77
280
284
81
287
184
515
497
498
499
500
501
502
503
513
535
536
116
496
542
544
546
545
514

T BEDS IN CAPE PROVINCE, ORANGE FREE STATE, GRIQUALAND EAST AND NATAL.

84	116	117	496	497	*498	499	500	501	502	503	513	515	535	514	542	544	546	545	536	Average
·5	37·5	37·0	2·25	30·5	16·2	23·2	19·2	19·8	7·2	17·6	40·8	30·8	31·5	49·2	25·0	11·0	21·5	11·0	11·5	—
·4	10·0	26·4	0·75	21·0	6·2	23·1	17·1	14·7	1·1	2·2	72·5	19·8	17·2	87·0	23·9	2·5	12·9	2·2	5·7	—
il	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	31·7	Nil	Nil	37·8	Nil	Nil	Nil	Nil	Nil	—
·4	10·0	26·4	0·75	21·0	6·2	23·1	17·1	14·7	1·1	2·2	40·8	19·8	17·2	49·2	23·9	2·5	12·9	2·2	5·7	—
·4	5·9	15·9	0·70	14·4	5·7	14·5	6·8	10·2	0·7	2·2	37·0	10·5	10·3	27·4	11·4	1·3	9·5	1·2	3·1	—
·0	4·1	10·5	0·05	6·6	0·5	8·6	10·3	4·5	0·4	Nil	35·5	9·3	6·9	59·6	12·5	1·2	3·4	1·0	2·6	—
·1	27·5	10·6	1·5	9·3	10·0	0·10	2·1	5·1	6·1	15·4	Nil	13·0	14·3	Nil	1·1	8·2	8·6	8·8	5·8	—
·0	48·0	44·0	(4·8)	40·0	31·6	34·8	27·8	28·0	22·6	27·2	(128·0)	49·0	36·2	(154·0)	33·4	(15·0)	28·5	20·0	(16·8)	35·7
·0	1·5	2·6	—	—	—	—	—	—	—	—	2·6	1·8	1·4	4·4	3·0	2·2	2·6	4·0	1·6	—
il	0·10	Nil	—	0·03	0·45	0·02	0·01	0·05	0·48	0·04	0·09	Nil	0·01	0·10	Trace	Nil	Nil	Nil	Nil	—
il	Nil	Nil	—	—	—	—	—	—	—	—	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	—
ace	Trace	Nil	—	—	—	—	—	—	—	—	4·0	3·0	Nil	3·0	0·4	Nil	Nil	Nil	Trace	—
·3	1·8	1·8	—	1·4	3·6	0·7	2·1	1·0	5·7	1·0	34·8	2·1	0·36	35·2	0·9	0·36	0·3	0·35	0·36	—
·0	3·5	1·9	0·14	1·3	3·6	3·8	1·7	1·6	1·1	0·8	5·1	1·7	0·4	23·0	3·5	Trace	Trace	0·10	0·8	—
ler ·5	Under 0·5	—	0·02	0·16	0·05	0·14	0·14	0·2	0·06	0·14	—	Under 0·5	Under 0·5	—	Trace	Trace	Trace	Trace	Under 0·5	—
·6	8·4	7·9	7·4	8·7	8·7	7·6	8·9	8·6	8·0	7·7	7·3	7·5	7·6	7·5	7·6	9·4	8·2	8·8	8·1	8·15
7	3·	5·9	—	—	—	—	—	—	—	—	2·03	3·7	3·85	1·95	9·0	14·6	9·1	(20·0)	9·4	6·4
6	6·9	20·3	8·1	20·0	10·2	23·5	13·6	20·5	(1·75)	(4·5)	16·3	11·7	5·7	(9·9)	19·4	4·8	8·5	3·5	10·0	12·5
0	3·4	9·5	(0·4)	6·8	6·4	9·8	16·2	6·5	(0·7)	(0·0)	11·0	7·6	2·8	(15·6)	15·0	3·1	12·0	1·9	6·1	7·7
4	3·8	4·0	—	3·8	10·4	2·02	7·5	3·5	(25·0)	3·6	(27·0)	4·3	1·0	(22·6)	2·7	2·4	1·06	1·7	2·1	5·7
3	7·3	4·3	2·05	3·2	10·4	11·0	6·1	5·7	4·85	2·9	4·0	3·5	1·1	(15·0)	10·4	Trace	Trace	0·5	4·72	5·3
39	60·0	25·5	33·0	23·8	33·5	(0·3)	(7·5)	19·0	28·0	60·0	(Nil)	29·0	42·0	(Nil)	(3·6)	57·5	32·0	46·5	36·6	37·3
0	20·8	59·5	15·5	52·5	19·5	66·0	61·0	52·5	(4·85)	18·0	56·0	40·0	47·2	57·0	(71·0)	16·6	45·0	11·0	33·7	39·7
	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	(24·6)	Nil	Nil	(24·7)	Nil	Nil	Nil	Nil	Nil	Nil
0	20·8	59·5	15·5	52·5	19·5	66·0	61·0	52·5	(4·85)	18·0	(32·0)	40·0	47·2	(32·0)	(71·0)	16·6	45·0	11·0	33·7	39·7
·5	1 : 0·5	1 : 0·5	(1 : 0·05)	1 : 0·3	1 : 0·6	1 : 0·4	1 : 1·2	1 : 0·3	—	(1 : 0·0)	1 : 0·7	1 : 0·7	1 : 0·5	1 : 1·5	1 : 0·8	1 : 0·65	(1 : 1·4)	1 : 0·5	1 : 0·6	1 : 0·62

be Lower Beaufort and should therefore have been included in Table No. 22.G

TABLE No. 23.—MIDDLE AND UPPER BEAUFORT BEDS IN CAPE PROVINCE

Sample Numbers	290	291	100 (*a*)	100 (*b*)	80	229	353	77	280	81	488	284	287	184	116	117
Parts $CaCO_3$ per 10^5 :																
Methyl Orange Alkalinity	41·0	48·0	29·0	25·5	27·0	21·7	28·7	15·0	33·5	30·5	18·8	28·5	9·8	25·5	37·5	37·0
Total Hardness	9·0	35·5	12·6	1·4	23·4	11·5	17·6	12·9	20·4	13·7	1·8	26·9	7·5	14·4	10·0	26·4
Permanent Hardness	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Temporary Hardness	9·0	35·5	12·6	1·4	23·4	11·5	17·6	12·9	20·4	13·7	1·8	26·9	7·5	14·4	10·0	26·4
Hardness due to Ca Salts	6·0	13·7	6·3	0·9	11·7	7·0	6·8	7·8	13·1	6·7	1·6	16·4	4·5	8·4	5·9	15·9
Hardness due to Mg Salts	3·0	21·8	6·3	0·5	11·7	4·5	10·8	5·1	7·3	7·0	0·2	10·5	3·0	6·0	4·1	10·5
Soda Alkalinity	32·0	12·5	16·4	24·2	3·6	10·2	11·1	2·2	13·1	16·8	17·0	1·6	2·3	11·1	27·5	10·6
Parts per 10^5 Water :																
Total Solids (at 105°C.)	67·5	(105·0)	37·0	39·6	36·0	35·0	40·0	23·0	38·0	36·0	27·5	38·4	24·2	30·0	48·0	44·0
Silica (as SiO_2)	1·4	2·6	1·6	2·0	3·6	1·1	2·0	3·0	2·9	2·4	1·4	3·1	2·8	2·0	1·5	2·6
Fluorides (as F)	—	—	Nil	Nil	—	—	Nil	—	—	—	—	—	—	Nil	0·10	Nil
Nitrites	—	—	Nil	Nil	Nil	Nil	Nil	Nil	—	Nil	—	—	—	Nil	Nil	Nil
Nitrates (as NO_3)	—	—	0·04	0·04	Trace	Trace	0·02	Trace	—	0·04	Nil	—	—	Trace	Trace	Nil
Chlorides (as Cl)	10·8	(17·5)	1·2	1·9	0·6	4·4	3·6	1·0	2·9	1·0	2·7	2·0	3·5	4·3	1·8	1·8
Sulphates (as SO_4)	8·8	15·8	2·3	3·7	1·7	1·5	3·2	Trace	2·1	Trace	1·3	3·7	1·9	1·0	3·5	1·9
Potassium Salts (as K)	—	—	Under 0·5	Under 0·5	Trace	—	Trace	—	—	Trace	—	—	—	Under 0·5	Under 0·5	—
pH. Values	—	—	8·3	8·9	(7·1)	—	7·4	8·4	—	8·6	—	—	—	7·6	8·4	7·9
Percentage on Total Solids :																
SiO_2	2·0	2·5	4·3	5·0	9·9	3·2	5·0	13·0	7·6	6·7	5·1	8·0	11·5	6·7	3·	5·9
CaO	5·2	7·3	9·4	(1·4)	18·0	14·6	9·5	19·2	19·2	10·4	3·3	24·0	10·3	15·6	6·9	20·3
MgO	1·62	8·8	6·7	(0·5)	13·0	5·1	10·4	8·9	7·6	7·8	0·3	10·9	5·0	8·0	3·4	9·5
Cl	(16·0)	(16·6)	3·2	5·2	1·7	12·7	9·0	4·4	7·6	2·8	9·8	5·1	14·4	14·4	3·8	4·0
SO_4	13·8	15·0	8·2	9·3	4·7	4·3	8·0	Trace	7·1	2·8	4·7	9·6	7·8	3·3	7·3	4·3
Soda Alkalinity (as Na_2CO_3)	50·0	12·6	47·0	64·0	10·4	31·0	29·3	10·0	35·2	50·0	65·0	(4·4)	(9·8)	39·39	60·0	25·5
Total Hardness (as $CaCO_3$)	13·3	33·7	34·0	(3·5)	65·0	33·0	44·0	56·0	53·5	38·2	(6·6)	(70·0)	31·0	48·0	20·8	59·5
Permanent Hardness (as $CaCO_3$)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Temporary Hardness (as $CaCO_3$)	13·3	33·7	34·0	(3·5)	65·0	33·0	44·0	56·0	53·5	38·2	(6·6)	(70·0)	31·0	48·0	20·8	59·5
Ratio CaO : MgO	1 : 0·3	1 : 1·2	1 : 0·7	1 : 0·3	1 : 0·6	1 : 0·3	1 : 1·1	1 : 0·4	1 : 0·4	1 : 0·7	1 : 0·1	1 : 0·4	1 : 0·5	1 : 0·5	1 : 0·5	1 : 0·5

o From later infromation Shannon Valley may be Lower Beaufort and should

Sample No.	District and Province.	Borehole Depth. Feet.	Locality, Description and Remarks.	Date.
290	Albert, Cape Province	75	Borehole in Burghersdorp. (Anal. Juritz, Ref. 328)	1908
488	Albert, Cape Province	—	Borehole at Knapdaar. (Anal. Govt. Lab., Johannesburg)	1921
291	Sterkstroom, Cape Province	80	Borehole in Sterkstroom. (Anal. Juritz, Ref. 337)	1908
100 (a)	Rouxville, Orange Free State	145	Borehole in Rouxville	22/ 8/39
(b)	Rouxville, Orange Free State	300	Borehole in Rouxville	22/ 8/39
80	Smithfield, Orange Free State	98	Borehole in Smithfield	7/ 3/39
229	Senekal, Orange Free State	20	Well in Senekal. (Anal. Govt. Lab., Johannesburg)	5/11/40
353	Lindley, Orange Free State	80	Borehole in Lindley	30/ 4/41
77	Cathcart, Cape Province	—	Spring in Cathcart	6/ 3/39
280	Hanover, Cape Province	262	Borehole in Naauwpoort. (Anal. Juritz, Ref. 275)	1908
284	Hanover, Cape Province	60	Borehole at Mealiesfontein. (Anal. Juritz, Ref. 285)	1908
81	Thaba Nchu, Orange Free State	—	Borehole in Tweespruit	8/ 2/39
287	Cradock, Cape Province	115	Borehole in Driefontein. (Anal. Juritz, Ref. 309)	1908
184	Harrismith, Orange Free State	140	Borehole in Warden	10/ 6/40
515	Harrismith, Orange Free State	30	Borehole at Harrismith	19/ 2/42
497	Reitz, Orange Free State	—	Borehole at Reitz. (Dr. Ockerse, Anal. Div. C.S.)	1940
498	Bloemfontein, Orange Free State	—	Borehole at Shannon. (Dr. Ockerse, Anal. Div. C.S.)	1940
499	Bethulie, Orange Free State	—	Borehole at Bethulie. (Dr. Ockerse, Anal. Div. C.S.)	1940
500	Zastron, Orange Free State	—	Borehole at Zastron. (Dr. Ockerse, Anal. Div. C.S.)	1940
501	Trompsburg, Orange Free State	—	Borehole at Trompsburg. (Dr. Ockerse, Anal. Div. C.S.)	1940
502	Dewetsdorp, Orange Free State	—	Borehole at Dewetsdorp. (Dr. Ockerse, Anal. Div. C.S.)	1940
503	Wepener, Orange Free State	—	Borehole at Hobhouse. (Dr. Ockerse, Anal. Div. C.S.)	1940
513	Queenstown, Cape Province	—	Borehole at Queenstown	12/ 2/42
535	Bergville, Natal	125	Borehole in Bergville, 1½ miles from River, Forbes Residence	6/ 3/42
536	Bergville, Natal	95	Borehole on farm Tipperary, 6 miles from Bergville	7/ 3/42
116	Estcourt, Natal	75	Borehole at Frere, South of Colenso	20/10/39
496	Underberg, Natal	—	Spring at Underberg. (Dr. Ockerse, Anal. Div. C.S.)	1940
542	Bethulie, Orange Free State	—	Borehole in Bethulie	16/ 3/42
544	Cedarville, East Griqualand	—	Spring on farm of C. Southey, Cedarville Flats	20/ 6/42
546	Cedarville, East Griqualand	100	Borehole on farm of G. Murray, Cedarville Flats	20/ 6/42
545	Cedarville, East Griqualand	—	Spring on farm of J. M. Currey, Cedarville Flats	20/ 6/42
514	Maraisburg, Cape Province	—	Borehole in Hofmeyr	12/ 2/42

Du Toit (14, pp. 502–503) and other geologists have given evidence of an increasing aridity in climate from the lower Beaufort to Stormberg periods and have shown that the upper sediments of the Karroo system are probably of *desert* origin since they show definite aeolian characteristics.

If this be the case then the felspars in the sediments (derived from the granite rocks) would tend to remain comparatively fresh, since the process of "kaolinisation" of the felspars does not proceed to the same stage in an arid climate as it does in a humid climate.

(2) Another possible cause may be the basic igneous intrusions, the Karroo dolerites, which, as already stated, form a veritable network of igneous instrusions. It might follow that these basic intrusions with their fairly high content of decomposing plagioclase could be responsible for the appreciable soda content of the water. This would also apply to waters arising in the sediments of the succeeding Stormberg series, which as will be shown in he next section, are also characterised by a consistently high soda content.

Against this second theory is the fact that though the Stormberg sediments on the Basutoland borders are intersected with dolerite dykes and yield soda carbonate waters, the felspathic Bushvelds sandstones, of Stormberg age, which also give rise to waters with high soda content, are quite free from dolerite dykes.

Further, water at the contact with basic dykes or sheets of basic rocks invariably contain very much higher MgO than CaO. For example, samples Nos. 376 and 377, Table 12, and more especially sample No. 593, Table 22 and some of the samples in Table 6.

Therefore it would appear that the former theory is the more probable.

With regard to the decrease in chlorides and sulphates in the upper Beaufort waters and succeeding Stormberg waters as compared with those in the lower Beaufort beds and the Ecca shales, the explanation may lie in the higher rainfall in the areas occupied by the middle and upper Beaufort beds, but such is not altogether satisfactory, for some of the highly saline waters in the Ecca beds are found in areas of high annual precipitation.

The waters arising in the middel and upper parts of the Beaufort series are allocated to the Alkaline soda-carbonate group of waters ("D") and the utilisation of these waters and their corrective chemical treatment are dealt with under that group on. (Section XXV).

It may be stated here that these waters are suitable for all domestic purposes, watering liverstock, and irrigation. In perhaps one or two cases the absolute amount of Na_2CO_3 may be sufficient to prohibit its use for irrigation or for drinking.

Some of them, particularly those from the Cedarville district, have sufficient sodium carbonate and bicarbonate, to impart a strong taste to the water, and to attack aluminium domestic utensils.

XX.—THE WATERS IN THE SEDIMENTS OF THE STORMBERG SERIES, KARROO SYSTEM.

Under this heading the author has included sediments of the Transvaal Bushveld (the so called Bushveld sandstones and marls) and has made no attempt to differentiate between the three horizons into which the Stormberg series has been divided, namely the Molteno beds, Red beds and Cave sandstone.

The volcanic rocks of Stormberg age, including the Lebombo volcanics are treated separately in the next section.

As regards the Basutoland border area, there is actually no definite break between the upper Beaufort and Stormberg series, and the succession of rocks is perfectly conformable and, as far as this study is concerned, the distinction between the upper Beaufort beds and the Stormberg series is artificial. In the North the Molteno beds are apparently absent and the Cave sandstone lies on older beds. As will be shown later, the waters arising in the Stormberg beds are identical with those rising from the upper Beaufort beds.

DISTRIBUTION AND RAINFALL.

The sediments in the Orange Free State, Cape Province and Natal form high dissected mountainous country encircling the highlands of Basutoland.

On the Natal border of Basutoland, the beds are comparatively thin and of limited extent.

Along the western slopes of the Lebombo mountains in Zululand, Swaziland and the Eastern Transvaal, very thin beds of Stormberg sediments occur, far too thin to be of any consequence from the point of view of this study. In the Transvaal a very small portion of the important agricultural area of the Springbok Flats is underlain by sandstones and marls that are correlated with the "Cave Sandstone" of the Stormberg series. There are no towns of any importance in this Bushveld sandstone area. Small outliers of the Stormberg series are found at Blaauwberg, Rhodesdrift and Mopani in the northern Zoutpansberg district. No towns of any importance lie in these area.

The average annual rainfall in the Basutoland area is from 25–35 inches, in the Springbok Flats area is 25 inches, and in the northern Zoutpansberg districts the average rainfall over these sediments is 10–20 inches.

GEOLOGY AND LITHOLOGY.

The Lower or Molteno beds of the Stormberg series in the Basutoland area consist of gray and blue shales and coarse and fine grained yellow sandstones. Du Toit (14, p. 260) referreing to the sandstones, mentions that the quartz grains are *invariably accompanied by felspar* (mainly orthoclase and microline) in angular or sub-angular fragments. Dolerite dykes are very common.

The shales and mudstones are often arenaceous and include carbonaceous layers and seams of coal. The Red beds which follow the Molteno beds are characterised by red and purple shales, mudstones and red and yellow fine grained sandstones, *highly felspathic*. The Cave Sandstone beds which overlie the Red beds consist of white or cream coloured fine grained sandstones lithologically in no way different from the Red bed sandstones except that they are of a finer texture. Du Toit (14, p. 270) refers to their felspathic nature (mainly microcline felspar). Accessory minerals, in very small amounts, are zircon, maline and white mica.

· SAN

Sample Nu	77
Parts C	
Total Solids	·0
Methyl Ora	·5
Total Hard	·4
Permanent	Nil
Temporary	·4
Hardness d	·1
Hardness d	·3
Soda Alkali	·1
Parts	
Silica (as Si	5·6
Fluorides (a	·02
Nitrites....	Nil
Nitrates (as	·2
Chlorides (a	·2
Sulphates (a	·2
Potassium	·5
pH. Values	7·6
Percent	
SiO_2.......	7·6
CaO.......	4·3
MgO.......	9·8
Cl..........	4·4
SO_4.......	1·6
Soda Alkali	4·6
Total Hard	3·5
Permanent	Nil
Temporary	3·5
Ratio CaO :	1·4

NTS OF THE STORMBERG
SYSTEM.

s included sediments of the
veld sandstones and marls
e between the three horizons
divided, namely the Molteno

ge, including the Lebombo
ext section.
area, there is actually no
rt and Stormberg series, and
ormable and, as far as this
een the upper Beaufort beds
the North the Molteno beds
stone lies on older beds. As
in the Stormberg beds are
er Beaufort beds.

AINFALL.

te, Cape Province and Natal
encircling the highlands of

the beds are comparatively

nbo mountains in Zululand,
ery thin beds of Stormberg
consequence from the point
a very small portion of the
gbok Flats is underlain by
vith the "Cave Sandstone"
owns of any importance in
iers of the Stormberg series
d Mopani in the northern
nportance lie in these area.
sutoland area is from 25–35
nches, and in the northern
ll over these sediments is

LOGY.

mberg series in the Basuto-
nd coarse and fine grained
eferring to the sandstones,
ibly accompanied by felspar
r or sub-angular fragments.

arenaceous and include
he Red beds which follow
d purple shales, mudstones
es, *highly felspathic.* The
d beds consist of white or
ogically in no way different
hey are of a finer texture
nature (mainly microline
amounts, are zircon, tour

TABLE No. 24.—STORMBERG SERIES (SEDIMENTS) KARROO SYSTEM (INCLUDING "BUSHVELD SANDSTONES").

Sample Numbers	35	147	204	243	244	292	293	107	178	177	467	477	479	Avergae
Parts $CaCO_3$ per 10^5 Water:														
Total Solids (at 106°)	26·6	(5·8)	42·7	30·0	41·5	29·0	29·0	48·0	62·4	73·0	11·3	47·5	20·0	38·4
Methyl Orange Alkalinity	22·2	3·0	39·9	15·4	25·5	23·8	22·0	38·0	37·5	63·5	4·5	36·0	12·5	—
Total Hardness	8·5	1·1	24·5	14·9	25·1	14·0	16·0	32·5	5·4	53·4	5·8	32·0	5·6	—
Permanent Hardness	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	1·3	Nil	Nil	—
Temporary Hardness	8·5	1·1	24·5	14·9	25·1	14·0	16·0	32·5	5·4	53·4	4·5	32·0	5·6	—
Hardness due to Ca Salts	6·9	1·0	11·2	8·2	16·4	8·0	8·8	15·3	2·2	19·1	2·2	16·0	3·6	—
Hardness due to Mg Salts	1·6	0·1	13·3	6·7	8·7	6·0	7·2	17·2	3·3	34·3	3·6	16·0	2·0	—
Soda Alkalinity	12·5	1·9	15·4	0·5	0·4	9·8	6·0	5·4	32·1	10·1	Nil	4·0	6·8	—
Parts per 10^5 of Water:														
Silica (as SiO_2)	—	0·6	3·1	3·2	2·7	1·7	1·8	6·0	2·0	5·6	2·1	5·6	2·4	—
Fluorides (as F)	Trace	Nil	—	—	—	—	—	Trace	0·37	0·02	Nil	Nil	0·06	—
Nitrites	Nil	Nil	—	—	—	—	—	Nil	Nil	Nil	Nil	Small Amount	Nil	—
Nitrates (as NO_3)	Trace	Nil	—	—	—	—	—	0·6	Nil	3·2	0·3	1·6	0·4	—
Chlorides (as Cl)	1·8	0·6	2·4	0·84	2·5	1·5	2·4	3·5	10·0	3·2	0·36	3·2	1·8	—
Sulphates (as SO_4)	Trace	Trace	3·2	0·08	1·8	0·6	1·2	Trace	2·3	1·2	Trace	Trace	Trace	—
Potassium Salts	Under 0·5	Under 0·2	—	—	—	—	—	Under 0·5	Under 0·5	Under 0·5	Under 0·2	Under 0·5	Under 0·5	—
pH. Values	7·8	7·1	—	—	—	—	—	7·75	8·5	7·6	(6·5)	7·9	7·9	7·8
Percentage on Total Solids:														
SiO_2	—	10·3	7·2	10·6	6·5	5·9	6·2	12·4	3·2	7·6	(18·6)	11·8	10·0	8·3
CaO	14·4	9·6	14·6	15·3	22·2	16·6	17·0	18·0	19·5	14·3	11·0	18·8	10·0	15·4
MgO	2·4	0·7	12·3	9·0	8·5	8·3	10·0	14·2	20·7	19·8	12·5	13·5	4·0	10·5
Cl	6·7	10·3	5·6	2·8	6·0	5·15	8·3	7·3	(16·0)	4·4	3·2	6·7	9·0	6·3
SO_4	Trace	Trace	7·5	0·3	4·3	2·06	4·15	Trace	3·7	1·6	Trace	Trace	Trace	1·82
Soda Alkalinity (as Na_2CO_3	49·5	34·2	38·0	(2·0)	(1·2)	35·5	21·5	10·9	55·0	14·6	(Nil)	8·8	35·0	30·3
Total Hardness (as $CaCO_3$)	32·0	19·0	57·0	49·5	60·0	48·0	55·5	67·2	(8·8)	73·5	51·0	67·0	28·0	50·6
Permanent Hardness (as $CaCO_3$	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	(11·4)	Nil	Nil	Nil
Temporary Hardness (as $CaCO_3$)	32·0	19·0	57·0	49·5	60·0	48·0	55·5	67·2	(8·8)	73·5	(40·0)	67·0	28·0	50·6
Ratio CaO : MgO	1 : 0·2	1 : 0·07	1 : 0·8	1 : 0·6	1 : 0·4	1 : 0·5	1 : 0·6	1 : 0·8	1 : 1·06	1 : 1·4	1 : 1·14	1 : 0·8	1 : 0·4	1 : 0·7

DESCRIPTION OF SAMPLES IN TABLE No. 24.

Sample No.	District and Province.	Borehole Depth.	Locality, Description and Remarks.	Date.
		Feet.		
35	Ladybrand, Orange Free State.............	—	Borehole in Ladybrand Municipality.........................	2/ 9/37
147	Ficksburg, Orange Free State..............	—	Spring (perennial), Ficksburg..............................	11/ 4/40
204	Steynsburg, Cape Province.................	—	Borehole at Henning. (Geol. Survey Memoir 32, 3457. Anal. Govt. Lab.)..	—
243	Wodehouse, Cape Province.................	—	Large Spring at Halseton. (Anal. Juritz, Ref. 345)...........	1908
244	Aliwal North, Cape Province..............	—	Spring at Lady Grey. (Anal. Juritz, Ref. 355)...............	1908
292	Molteno, Cape Province...................	506	Borehole in Stormberg. (Anal. Juritz, Ref. 340).............	1908
293	Molteno, Cape Province...................	—	Borehole at Paardekraal. (Anal. Juritz, Ref. 341)...........	1908
467	Maclear, Cape Province...................	—	Spring in Maclear..	26/11/41
107	Waterberg, Transvaal.....................	—	Borehole in Bushveld Sandstone, Kalkfontein 784, 4 miles South of Radium..	30/ 8/39
178	Pretoria, Transvaal......................	400	Borehole on Graspan 358, 5 miles East-North-East of Pienaars River...	4/ 7/40
177	Pretoria, Transvaal......................	140	Borehole on Kalkheuvel 389, 3 miles East-North-East of Pienaars River...	3/ 7/40
477	Waterberg, Transvaal.....................	110	Borehole on farm Smaldeel 895, 6 miles North of Tuinplaats.....	12/ 1/42
479	Waterberg, Transvaal.....................		Borehole on farm Kromdraai 887, 16 miles East of Tuinplaats..	12/ 1/42

The Bushveld sandsto
also highly felspathic, l
the upper Karroo strat
Wybergh (16) gives a
dstones. From the poi
istic of all these Storn
ure and their porosity.
As mentioned in the p
an increasing aridity o
iod and the Stormberg
esert origin (Du Toit 14,
par grains in these san
important bearing on t
From palaeontological
s been put down as U

UNDERG

The borehole supplies
as follows :—

Northern Zoutpans
Springbok Flats are
Ficksburg, Ladybra
Wodehouse
(Molteno Beds
Stormberg Series)

Very little drilling ha
tricts, for the country i
ll watered by numerous

QUA

These districts underl
present time at any rat
portance. The formati
author has not devote
this series.

The areas in the north
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m that in the Bushvel

Thirteen samples were
ksburg, Steynsburg, Wo
clear districts, and the
chief characteristics o

There is considerable
arently depending on
erage about 38 parts per
nfall the concentration
t of the Basutoland b

The pH. is consistent

In view of the high sc
the silica content is
he total solids.

The Bushveld sandstones of the far North are very similar and also highly felspathic, but dolerite intrusions, so common a feature he upper Karroo strata in the South, are rare.

Wybergh (16) gives a porosity of 20 per cent. for these Bushveld stones. From the point of view of this study, the chief charac- stic of all these Stormberg sediments is their highly felspathic ure and their porosity.

As mentioned in the previous section, there is geological evidence an increasing aridity of climate in the later stages of the Karroo od and the Stormberg sandstones bear all the characteristics of *sert origin* (Du Toit 14, pp. 502–503) so that in depth the abundant par grains in these sandstones are probably fresh. This fact has important bearing on the composition of the underground waters.

From palaeontological evidence the age of the Stormberg sediments been put down as Upper Triassic.

UNDERGROUND WATER SUPPLIES.

The borehole supplies, according to Frommurze (3, pp. 152–153) as follows :—

	Average Yield in Gallons per Diem.	*Average Depth.*	*Percentage Failures.*
Northern Zoutpansberg...	Very little drilling.		
Springbok Flats area.....	17,400	180′–200′	20
Ficksburg, Ladybrand and Wodehouse districts (Molteno Beds of the Stormberg Series)......	13,550	90′	15

Very little drilling has taken place on the Basutoland border ricts, for the country is highly dissected and mountainous and is watered by numerous springs and vleis.

QUALITY OF THE WATER.

These districts underlain by the Stormberg sediments cannot, at present time at any rate, be regarded as of any potential industrial ortance. The formation is of limited extent, and consequently author has not devoted a great deal of study to the waters rising this series.

The areas in the northern Zoutpansberg occupied by this formation of very limited extent and sparsely inhabited. The author has been ble to obtain samples of the Bushveld sandstone water from these ote districts, but has no reason to doubt that the water will differ that in the Bushveld sandstones in the Springbok Flats.

Thirteen samples were taken over a wide area in the Ladybrand, ksburg, Steynsburg, Wodehouse, Aliwal North, Stormberg, Molteno, lear districts, and the Pienaars River and Springbok Flats areas. chief characteristics of the waters are shown in Table 24.

There is considerable variation in concentration of dissolved salts, arently depending on climatological factors, but the total solids rage about 38 parts per 10^5. In the Springbok Flats with its lesser fall the concentration of salts is always very high compared with of the Basutoland border areas.

The pH. is consistently high at an average of 7·8.

In view of the high soda alkalinity it is rather surprising to note the silica content is relatively low averaging only 8·3 per cent. he total solids.

The chloride content is lower than in the case of the middle and upper Beaufort waters, averaging only 6·3 per cent. Cl. in terms of total salts.

Sulphates are consistently low, averaging only 1·8 per cent. SO_4 on the dissolved salts.

$NaHCO_3$, rarely Na_2CO_3, is nearly always present in large amounts, averaging as much as 30 per cent. (as Na_2CO_3) in terms of total solids.

The author advances the same theory as was used in the previous section to account for the consistently high soda content of these waters, namely, the highly felspathic nature of these sandstones and their probable aeolian origin. Dolerite intrusions, though common in the South, are not found in the Springbok Flats and could not therefore be the cause of the soda alkalinity.

As in the case of the waters from the middle and upper Beaufort series, there is always more calcium than magnesium salts present, the ratio being 1 : 0·7.

Fluorides are rarely present and only one sample in Table 24 contains over 1·0 parts F. per million, namely sample 178. (Graspan 358), near Pienaars River) which has a fluoride content of 3·7 parts F.

Permanent hardness is, of course, very seldom present. Instead there is generally an appreciable soda alkalinity. The temporary hardness compounds $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$ are appreciable, averaging about 50 per cent. (as $CaCO_3$) in terms of the total solids.

These waters are very similar to those arising in the Stormberg volcanics (Table 25) except for the higher silica content and lower soda alkalinity of the latter. As aforementioned the waters are almost identical with those arising in the middle and upper Beaufort series. The chief difference is in the chloride content which is lower in the Stormberg series.

As mentioned in a previous section—taking the waters in the Karroo system as a whole—there is a gradual diminution in chloride and sulphate and in increase in soda alkalinity as we pass from the lowest member of the system, the Dwyka, through the Ecca to the Stormberg series.

These waters fall naturally into what the author has termed the alkaline soda carbonate group " D ".

Though the hardness is all temporary and is consequently easily eliminated, these waters on account of their high soda content present some rather difficult problems when considered for steam raising purposes. The correction or utilisation of these waters for industrial purposes is dealt with fully under the Group D waters.

Though appreciable " Black alkali " (soda) is nearly always present, it is not generally in sufficient concentration to affect the use of this water for irrigation, though one or two waters shown in Table 24 would only be suitable for irrigation with loose well-drained types of solids. They are suitable for domestic use and watering livestock.

The low chloride and sulphate content of these waters would, from arguments used in previous sections, point definitely to a fresh water and not a salt water origin.

XXI.—THE WATERS IN THE STORMBERG LAVAS.

Under this heading the author has included all volcanic rocks Stormberg age, including the Lebombo lavas, Bushveld amygda-idal basalts and the Drakensberg volcanic beds.

DISTRIBUTION AND RAINFALL.

The greatly dissected mountain land of Basutoland and the djoining high ground in Natal and the Barkly East districts of the ape Province are occupied by Stormberg lavas. There is also an tremely small occurrence of lavas and tuffs on the southern slopes f the Zuurberg in the southern Cape Province, far too limited to be f interest to this study.

The Lebombo range of hills, an exceedingly long but very narrow rip of lavas stretching from near Empangeni in Zululand, through waziland up to the Limpopo river along the Portguguese border, is f this age.

The Bushveld amygdaloidal basalts occupy a large part of the mportant agricultural district known as the Springbok Flats in the entral Transvaal, which includes small but important agricultural entres such as Naboomspruit, Settlers, Zebedela and Warmbaths.

A very small area underlain by the Bushveld amygdaloidal lavas es near Blaauwberg in the Zoutpansberg district.

The rainfall is as follows:—

Basutoland..................	25″–75″	per annum.
Lebombo Range, Zululand......	30″–35″	per annum.
Letaba and Zoutpansberg.......	15″–20″	per annum.
Springbok Flats area..........	20″–25″	per annum.

UNDERGROUND WATER SUPPLIES.

According to Du Toit (2, p. 128) and Frommurze (3, p. 155) the llowing are the yields:—

	Yield in Gallons per Diem.	*Average Depth.*	*Percentage Failures.*
(*a*) Springbok Flats area....	26,000	90′	19
(*b*) Zoutpansberg (very little boring)................	26,000	90′	over 19
(*c*) Lebombo Basalts.......	15,000	186′	20

In the Basutoland area, the formation, on account of abundant atural supplies in the form of springs and rivers, has not been rilled.

GEOLOGY AND LITHOLOGY.

In the Basutoland area these volcanic beds are composed of a ast succession of basic lavas, tuffs and agglomorates, with lavas rodominating.

Du Toit (14, pp. 274–275) has described the lavas as being mainly asalts, dark grey or black in colour, often amygdaloidal, with the as cavities filled with either agate, quartz or calcite, or with zeolites uch as heulandite, stilbite, etc. The rock itself is composed of augite ometimes with olivine) and plagioclase felspars (commonly labradorite r andesine).

Accessory minerals are magnetite and apatite. The nature of he rocks is essentially basic.

In the Lebombo range the lava is also generally basaltic, though towards the summit the basic lavas give place to the more acid and rhyolitic rocks. As far as this study is concerned, the majority of the rocks are highly basic varieties.

In the Springbok Flats the lavas are rarely exposed and are generally covered by a thick mantle of black or reddish soil. They are typical amygdaloidal basalts. Hatch and Corstophine (29, pp. 257–258) describe them as being of a sage-green colour, well spotted with amygdales, which are sometimes filled with calcium carbonate (in form of aragonite) and sometimes with pinkish-white zeolite (heulandite) or sometimes with agate and chalcedony. The matrix is similar to the Drakensberg lavas described by Du Toit.

The analysis of the Stormberg basalts throws light on the composition of water. Curiously enough there appears to be very few analyses recorded in the literature. A few are given below, including one made by the author :—

ANALYSES OF STORMBERG BASALTS.

	1.	2.	3.	4.
	%	%	%	%
SiO_2	46·00	50·75	42·20	45·75
TiO_2	2·57	1·15	1·90	2·00
Al_3O_2	22·25	13·80	8·45	15·80
Fe_3O_2	10·12	46·50	8·65	(Fe_2O_3) }
FeO	3·62	6·20	7·80	(11·20) }
MnO	—	0·10	0·15	Trace
MgO	2·90	7·10	8·90	3·62
CaO	5·60	8·90	9·80	8·25
K_2O	1·53 } 4·94	0·85 } 3·70	1·35 } 7·35	2·00 } 9·05
Na_2O	3·41	2·85	6·00	7·05
P_2O^5	—	0·20	0·90	—
H_2O +	0·85	2·35	2·80	— } 2·90
H_2O −	1·45	1·88	1·60	—
CO_2	—	—	—	2·39
TOTAL	100·40	100·75	100·50	100·89
Ratio CaO : MgO	1 : 0·5	1 : 0·7	1 : 0·9	1 : 0·43

1. Lebombo Basalt, Goba Portuguese Africa. (R. B. Young, Trans. G.S.S.A. 1921, XXIII, III).
2. Zuurberg Basalt, Cape Province. (Haughton and Rogers, Trans. R.S.S.A. 1924, XI, 245).
3. Nepheline Basalt, Limpopo River, Nothern Transvaal. (Rogers, Trans. G.S.S.A. 1925, XXVIII, 50).
4. Amygdaloidal Basalt (Nepheline) near Letaba Camp, Kruger National Park, Eastern Transvaal. (Analysis by G. W. Bond). Taken near where borehole water—Sample 418—was collected.

These analyses reflect the basic nature of these rocks.

A notable feature is the relatively high (Na_2O) soda content of these rocks, particularly the nepheline varieties, a fact which is reflected in the appreciable soda alkalinity of the basaltic waters.

The particularly high Na_2O and CO_2 content of the Letaba Camp basalt (No. 4) is due no doubt to the fact that the basalt in this area is a nepheline basalt, and in addition contains a particularly large number of zeolite and calcite amygdales.

The rocks as a whole always contain more CaO than MgO.

QUALITY OF THE WATER.

It was not possible to obtain samples of water from the Zuurberg or Zoutpansberg basalts, but in any case the formations in these regions are very limited in extent, but there is no reason to doubt that those waters will be similar to the basaltic waters elsewhere except that in the Zoutpansberg the water will be more concentrated than further south.

Except for Basutoland itself, the other areas have been well covered. From the economic point of view the areas underlain by Stormberg basalts are not of great importance. Eighteen samples have been taken from Barberton district, Letaba (Kruger National Park), Mount Aux Sources (Basutoland border), Warmbaths, Pienaars River, Springbok Flats and Umbombo district (Zululand), and the results are shown in Table 25.

The springs of the Basutoland area yield exceptionally pure water, that is as regards the concentration of salts, but elsewhere the Stormberg lavas yield waters of medium concentration, averaging about 40 parts total solids.

The silica content is fairly high, averaging 12·2 per cent. on the total solids, a fact which is not surprising in view of the high soda content of nearly all these waters.

Fluorides are not found except in minute amounts.

Chlorides are generally very low indeed, the average being 6·6 per cent. Cl. in terms of the total solids. In the Ubombo district in Zululand however, the chloride content tends to be higher, averaging 2·28 per cent. on total solids, while magnesium is relatively high, so that in dry seasons the water in this area may tend to become slightly brackish. Frommurze (3, p. 162) points out that further south, in the Hlabisa and Nongoma and Ngotsche districts the waters are often quite brack. The relative increase in chlorides in these areas can no doubt be accounted for by their close proximity to the sea so that prevailing winds and frequent mists deposit salt impregnated moisture on these areas.

Sulphates are extremely low, averaging only 0·8 per cent. SO_4 of the total salts.

The chief characteristic of these waters, like those from the Stormberg sedimentary rocks, is the soda alkalinity which is nearly always present in appreciable amount, averaging 14·7 per cent. (as Na_2CO_3), consequently permanent hardness is seldom found. The temporary hardness is moderately high, the scale-forming bicarbonate of calcium and magnesium averaging 52·7 per cent. of the total solids.

There is always more calcium than magnesium, the average CaO : MgO ratio being 1 : 0·6 except in the Zululand coastal district, where the water is slightly brackish, on account of cyclic sea salts and contains more MgO than CaO.

The pH. of these waters is high, averaging 7·7, but in the majority of cases below 8·3 indicating that $NaHCO_3$ and not Na_2CO_3 is present.

These waters are very similar indeed to those rising in the felspathic Stormberg sediments, except that the soda alkalinity is a good bit lower while the silica is higher than in the latter formations.

UTILISATION.

The springs arising in the exceedingly well watered Basutoland country give rise to waters which approximate more to the pure water Group " E ", on account of the low concentration of salts, but elsewhere the waters are typical alkaline soda carbonate waters (Group " D ") and the technical utilisation and treatment of these types is discussed under that group. (Section XXV).

It may be mentioned here that since the absolute quantities of Na_2CO_3 or $NaHCO_3$ present are never very great, these waters are quite suitable for all domestic purposes, watering livestock, and irrigation.

The basalts in the Zululand areas tend to yield slightly saline water and are classified therefore under Group " B ".

XXII.—THE WATERS IN THE CRETACEOUS, TERTIARY AND RECENT COASTAL FORMATIONS.

These formations are not of great importance in relation to this study since they are restricted in area, except along the Zululand coast, where, however, the country is wild and sparsely populated.

The enormous areas underlain by these formations in Portuguese East Africa do not fall within the scope of this study.

The chief interest in these waters lies in the fact that the strata are definitely of marine origin and have retained connate sea water.

DISTRIBUTION AND RAINFALL.

In the Cape Province the chief occurrances of Cretaceous strata are in the Worcester, Oudtshoorn, Mossel Bay, Humansdorp and Uitenhage districts, while in the Riversdale, Bredasdorp, Alexandria and the Cape Peninsula districts there are fairly extensive exposures of formations more recent than the Cretaceous.

Other occurrences of Cretaceous and the more recent formations in Pondoland and also in the Durban district are too limited to be of interest to this study.

Extensive exposures of these formations are found along the Zululand coast east of the Lebombo range.

The average annual rainfall varies as follows :—

Bredasdorp	10″–15″
Worcester, Oudtshoorn, Mossel Bay	15″–25″
Humansdorp, Alexandria	20″–30″
Zululand	40″–50″

GEOLOGY AND LITHOLOGY.

The lowest beds in the Cretaceous system consist mainly of pebble and boulder beds, while the upper beds consist mainly of clays, marls and sandstones. The lower beds are supposed to have been laid down under fresh water, but conditions changed to estuarine and finally marine (Du Toit 14, p. 338). Fossil marine mollusca are very abundant in the upper beds and there is no question as to their mar origin.

The Tertiary and Recent formations consist mainly of loose sa deposits. Some of the sands, as in the Cape Flats areas, are calcar

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....	40"–50"

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14, p. 338). Fossil marine mollusca are very
ds and there is no question as to their marine

cent formations consist mainly of loose sandy
nds, as in the Cape Flats areas, are calcareous.

TABLE No. 25.—STORMBERG LAVAS, KARROO SYSTEM (INCLUDING LEBOMBO VOLCANIC AND "BUSHVELD AM

Numbers	420	407	418	348	88	85	84	121	122	111	423	424	45
Parts $CaCO_3$ per 10^5 Water :													
Solids (at 106°)	73·3	19·0	66·0	8·0	40·2	35·0	59·0	48·0	54·0	38·6	42·2	28·0	22·
Orange Alkalinity	50·5	12·0	52·0	3·2	30·7	28·0	43·2	36·0	36·5	22·8	27·5	17·5	6·
Hardness	43·4	6·7	42·5	2·4	20·9	18·0	33·7	31·8	35·7	16·9	31·3	13·3	7·
manent Hardness	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	3·8	Nil	0·
porary Hardness	43·4	6·7	42·5	2·4	20·9	18·0	33·7	31·8	35·7	16·9	27·5	13·3	6·
ness due to Ca Salts	17·1	3·0	6·6	1·8	10·8	9·2	21·1	17·0	19·2	11·9	20·6	6·2	0·
ness due to Mg Salts	26·3	3·7	35·9	0·6	10·1	8·8	12·6	14·5	16·5	5·0	10·8	7·1	6·
Alkalinity	7·1	5·3	10·3	0·85	9·8	10·0	9·1	4·2	0·8	5·9	Nil	4·1	N
Parts per 10^5 of Water :													
(as SiO_2)	4·3	3·0	5·4	1·0	5·0	5·0	7·0	6·8	6·6	5·6	—	—	3
rides (as F)	Nil	0·02	Nil	Nil	0·05	Nil	—	Trace	Nil	0·02	Nil	0·01	Tr
ites	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	N
rates (as NO_3)	1·6	0·6	0·4	Nil	Trace	0·1	Nil	1·0	3·4	3·2	Nil	Nil	N
rides (as Cl)	7·5	1·2	6·0	1·1	2·0	1·1	2·7	2·8	5·3	2·8	1·4	0·05	6
hates (as SO_4)	1·5	0·15	Trace	0·02	Trace	Trace	0·6	0·25	0·6	Trace	1·4	0·05	0
ssium Salts	Under 0·5	Under 0·5	Under 0·5	Trace	Under 0·5	Under 0·5	—	Under 0·5	Under 0·5	Under 0·5	0·5	0·3	–
Values	7·1	7·5	7·3	7·8	7·8	7·9	7·7	7·3	7·6	8·1	7·5	7·6	(6
Percentage on Total Solids :													
	5·9	15·8	8·2	12·4	12·4	14·2	11·8	14·2	12·2	14·4	—	—	16
O	13·1	10·0	5·6	12·4	14·9	14·8	21·0	20·7	20·0	17·2	27·2	12·5	(1
O	14·3	8·0	21·7	3·0	10·0	9·8	8·2	12·2	12·4	5·2	10·2	10·4	(10
	10·2	6·3	9·1	13·7	6·3	3·2	4·6	5·8	9·8	7·3	3·3	3·05	(28
	2·05	0·80	Trace	0·15	Trace	Trace	1·0	0·51	1·0	Trace	3·3	0·18	1
Soda Alkalinity (as Na_2CO_3)	10·3	28·6	18·8	10·6	25·8	30·3	16·2	9·4	(1·7)	16·0	(Nil)	15·0	(N
Total Hardness (as $CaCO_3$)	59·5	35·5	64·0	30·0	52·0	51·5	57·0	66·0	66·0	44·0	73·0	47·5	33
manent Hardness (as $CaCO_3$)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	(9·0)	Nil	(
porary Hardness (as $CaCO_3$)	59·5	35·5	64·0	30·0	52·0	51·5	57·0	66·0	66·0	44·0	64·0	47·5	(2
CaO : MgO	1 : 1·1	1 : 0·8	1 : 3·8	1 : 0·24	1 : 0·7	1 : 0·7	1 : 0·4	1 : 0·6	1 : 0·6	1 : 0·3	1 : 0·4	1 : 0·8	(1 :

TABLE No. 25.—STORMBERG LAVAS, KARROO SYSTEM (INCLUDING LEBOMBO VOLCANIC AND "BUSHVELD AMYGDALOIDS").

	420	407	418	348	88	85	84	121	122	111	423	424	458	461	474 (*a*)	475	476	478	Average
per 10^5 Water :																			
:06°)	73·3	19·0	66·0	8·0	40·2	35·0	59·0	48·0	54·0	38·6	42·2	28·0	22·3	18·0	53·1	61·0	54·0	31·0	41·7
lkalinity	50·5	12·0	52·0	3·2	30·7	28·0	43·2	36·0	36·5	22·8	27·5	17·5	6·5	5·5	36·5	32·5	42·0	12·5	—
	43·4	6·7	42·5	2·4	20·9	18·0	33·7	31·8	35·7	16·9	31·3	13·3	7·4	3·2	31·2	31·2	40·0	10·0	—
ness	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	3·8	Nil	0·9	Nil	Nil	Nil	Nil	Nil	—
ness	43·4	6·7	42·5	2·4	20·9	18·0	33·7	31·8	35·7	16·9	27·5	13·3	6·5	3·2	31·2	31·2	40·0	10·0	—
Ca Salts	17·1	3·0	6·6	1·8	10·8	9·2	21·1	17·0	19·2	11·9	20·6	6·2	0·8	0·2	15·6	13·2	16·0	6·8	—
Mg Salts	26·3	3·7	35·9	0·6	10·1	8·8	12·6	14·5	16·5	5·0	10·8	7·1	6·6	3·0	15·6	18·0	24·0	3·2	—
	7·1	5·3	10·3	0·85	9·8	10·0	9·1	4·2	0·8	5·9	Nil	4·1	Nil	2·3	5·3	1·4	2·0	2·5	—
10^5 of Water :																			
	4·3	3·0	5·4	1·0	5·0	5·0	7·0	6·8	6·6	5·6	—	—	3·6	3·0	5·0	4·6	4·0	5·0	—
	Nil	0·02	Nil	Nil	0·05	Nil	—	Trace	Nil	0·02	Nil	0·01	Trace	Trace	—	—	Trace	0·04	—
	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	—
)	1·6	0·6	0·4	Nil	Trace	0·1	Nil	1·0	3·4	3·2	Nil	Nil	Nil	Trace	1·8	3·3	3·2	0·28	—
	7·5	1·2	6·0	1·1	2·0	1·1	2·7	2·8	5·3	2·8	1·4	0·05	6·2	4·3	2·1	4·3	3·2	6·8	—
$_4$)	1·5	0·15	Trace	0·02	Trace	Trace	0·6	0·25	0·6	Trace	1·4	0·05	0·4	0·7	Trace	Trace	Trace	0·1	—
	Under 0·5	Under 0·5	Under 0·5	Trace	Under 0·5	Under 0·5	—	Under 0·5	Under 0·5	Under 0·5	0·5	0·3	—	—	Under 0·5	Under 0·5	Under 0·5	Under 0·5	—
	7·1	7·5	7·3	7·8	7·8	7·9	7·7	7·3	7·6	8·1	7·5	7·6	(6·4)	(6·3)	7·6	7·5	7·9	8·6	7·7
n Total Solids :																			
	5·9	15·8	8·2	12·4	12·4	14·2	11·8	14·2	12·2	14·4	—	—	16·2	16·8	9·4	7·5	7·4	16·0	12·2
	13·1	10·0	5·6	12·4	14·9	14·8	21·0	20·7	20·0	17·2	27·2	12·5	(1·4)	(0·7)	21·6	13·3	16·5	12·3	15·8
	14·3	8·0	21·7	3·0	10·0	9·8	8·2	12·2	12·4	5·2	10·2	10·4	(10·6)	(6·7)	11·9	11·8	17·5	4·2	10·7
	10·2	6·3	9·1	13·7	6·3	3·2	4·6	5·8	9·8	7·3	3·3	3·05	(28·0)	(24·0)	3·9	7·0	5·9	(22·0)	6·6
	2·05	0·80	Trace	0·15	Trace	Trace	1·0	0·51	1·0	Trace	3·3	0·18	1·8	3·9	Trace	Trace	Trace	0·3	0·8
(as Na_2CO_3)	10·3	28·6	18·8	10·6	25·8	30·3	16·2	9·4	(1·7)	16·0	(Nil)	15·0	(Nil)	13·4	10·5	2·3	4·1	8·7	14·7
as $CaCO_3$)	59·5	35·5	64·0	30·0	52·0	51·5	57·0	66·0	66·0	44·0	73·0	47·5	33·5	(18·0)	58·8	51·0	74·0	32·3	52·7
ness (as $CaCO_3$)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	(9·0)	Nil	(3·6)	Nil	Nil	Nil	Nil	Nil	Nil
ness (as $CaCO_3$)	59·5	35·5	64·0	30·0	52·0	51·5	57·0	66·0	66·0	44·0	64·0	47·5	(29·5)	(18·0)	58·8	51·0	74·0	32·3	52·7
)	1 : 1·1	1 : 0·8	1 : 3·8	1 : 0·24	1 : 0·7	1 : 0·7	1 : 0·4	1 : 0·6	1 : 0·6	1 : 0·3	1 : 0·4	1 : 0·8	(1 : 7·0)	(1 : 9·0)	1 : 0·6	1 : 0·8	1 : 1·06	1 : 0·3	1 : 0·

DESCRIPTION OF SAMPLES IN TABLE No. 25.

Sample No.	District and Province.	Borehole Depth. Feet.	Locality, Description and Remarks.	Date.
458	Ubombo, Zululand	—	Well, 2 miles North-West of Ubombo	5/11/41
461	Ubombo, Zululand	—	Well at Ubombo, 16 miles Sout-East of Ubombo	5/11/41
348	Bergville, Natal	—	Spring at National Park Hostel, Mt. Aux Sources	5/ 4/41
420	Barberton, Transvaal	—	Borehole at Komatipoort	20/ 9/41
407	Letaba, Transvaal	—	Borehole at Letaba Camp, Kruger National Park	July, 1941
418	Letaba, Transvaal	—	Borehole at Shingwedzi Camp, Kruger National Park	July, 1941
88	Waterberg, Transvaal	102	Borehole near Location, South of Warmbaths	29/ 8/39
85	Waterberg, Transvaal	100	Borehole at Abattoir, South-East of Warmbaths	3/ 8/39
89	Waterberg, Transvaal	111	Borehole on farm Bothavley 1187, near Codrington Siding	30/ 8/39
121	Pretoria, Transvaal	63	Borehole on farm Langkuil 836, near Codrington Siding	13/11/39
122	Waterberg, Transvaal	400	Borehole on farm Klippan 1019, 9 miles North-East of Pienaars River	13/11/39
111	Waterberg, Transvaal	180	Borehole on farm Merinovlakte 800, 8 miles South of Warmbaths	11/10/39
423	Waterberg, Transvaal	200	Borehole on farm Blaauwboschkuil 748, 11 miles North of Pienaars River. (Dr. Ockerse anal. Div. C.S.)	1940
424	Waterberg, Transvaal	—	Borehole in Naboomspruit. (Dr. Ockerse anal. Div. C.S.)	1940
474 (*a*)	Waterberg, Transvaal	160	Borehole on farm Leeuwkuil 1020, 2 miles West of Worthing Siding	12/ 1/42
475	Waterberg, Transvaal	—	Borehole in Settlers	12/ 1/42
478	Waterberg, Transvaal	180	Borehole on farm Klipplaats 944, 6 miles South of Crecy Siding	12/ 1/42
476	Waterberg, Transvaal	—	Borehole on Tuinplaats Siding	12/ 1/42

UNDERGROUND WATER SUPPLY.

Owing to the general high salinity of the water, there has been but little boring for water in these formations. Further, according to Frommurze (3, p. 122) and Du Toit (2, p. 130) these formations are somewhat difficult to drill owing to the tendency to caving, because of the soft and unconsolidated bands present.

Excluding the artesian area at Zwartkop, in the Uitenhage district, the yields are low, averaging under 10,000 gallons *per diem,* the water being struck at depths of between 120′ and 130′. A large percentage of the water is "brak".

The Tertiary beds at Alexandria give higher yields (31,000 gallons) but according to Frommurze the percentage of brak water is 77 per cent.

According to Frommurze the yields in Zululand are not high varying from 2,000 to 20,000 gallons *per diem* struck at about 100′, but the supplies are generally unpotable on account of salinity.

QUALITY OF THE WATER.

The author found great difficulty in obtaining samples of underground water from these formations, since, as aforementioned, relatively little boring has been carried out in these formation, and many boreholes have been abandoned, on account of high salinity.

Twenty-three analyses of waters from the Cretaceous, Tertiary and Recent coastal formations in the Cape Province and Zululand are shown in Table 26, including several of Juritz's analyses, made as long ago as 1908.

The chief characteristics of all these waters from the Cape Province is the exceedingly high salinity, concentrations of over 500 parts per 10^5 total solids being by no means uncommon, while the average is about 350 parts per 10^5, which is higher than in any other waters, except for the Old granite waters in the North-West Cape.

Unfortunately most of the samples from the formation in Zululand analysed by the author were taken near the railway line from Empangeni to Matubatuba, that is, on the landward margin of the Cretaceous formation, where the strata are relatively thin. It was found impossible to obtain samples of underground water from nearer the coast, where the beds are much thicker owing to the fact that the majority of boreholes and wells formerly in existence have been abandoned, on account of salinity.

Dr. Du Toit has assured the writer that the vast majority of boreholes put down along the coastal belt in Zululand many years ago by the Irrigation Department, yielded highly saline water, so that the true mean composite of waters in the Cretaceous and Tertiary beds in Zululand is likely to show far more salts than those shown in Table 26, which were taken near the margin. Therefore the waters on the Zululand coastal belt are shown as "highly saline" in the author's water map. The high salinity of all these waters, both in the Cape Province and Zululand, is interesting in view of the fact that the average annual rainfall is not low anywhere, while in Zululand it is very high indeed. *Climatic factors therefore seem not to influence salinity of ground water as much as is generally imagined.*

As is the case in all highly saline waters, silica is extremely low, in the case of the Cretaceous and the more recent waters in the Cape Province, the average SiO_2 content is under 1·5 per cent. in terms of the total solids.

Chlorides are always very high, averaging in the case of the Cretaceous water in the Cape Province, 42·1 per cent. Cl. in terms of the total salts. The chloride is present mainly as NaCl and partly as $MgCl_2$.

Sulphates are always high, averaging in the case of the Cretaceous waters in the Cape Province over 8 per cent. SO_4. The Tertiary and Recent waters have a slightly lower sulphate content.

In some of the Cretaceous waters there is more magnesium than calcium though the CaO : MgO ratio varies considerably and the average works out at 1 : 1·1. The percentage of CaO and MgO is never high, so that the total hardness is not very high, averaging 26 per cent. (as $CaCO_3$).

There is usually a good deal more calcium than magnesium in the waters rising in the Tertiary and Recent coastal deposits. This is on account of the fact that, as already mentioned, the sands are often calcareous, particularly in the Cape Flats area.

A characteristic feature is the very low $Mg(HCO_3)_2$ and $Ca(HCO_3)_2$ hardness (about a third of the total hardness) and the extremely high permanent hardness.

These waters therefore may be regarded as potentially corrosive as well as scale-forming.

Soda alkalinity is exceedingly rare. Instead there is a high permanent hardness.

Data regarding fluorides are insufficient but the indications are that these waters do not carry more than traces of fluorides.

These waters belong therefore to the highly mineralised chloride-sulphate group and their corrective chemical treatment and utilisation for technical purposes is discussed under Group A.

It may be stated here that the majority of waters from the upper beds of the Cretaceous system and the more recent formations in the Cape Province and Zululand are generally too saline for potable purposes, and sometimes even too saline for watering livestock.

In many cases they are even brak for irrigation purposes. Fortunately many of the towns situated on these formations are able to obtain fresh water supplies from other sources.

As in the case of water from the Malmesbury slates and Bokkeveld series, a comparison of the average percentage composition of the Cretaceous waters with sea water (Table 27), shows a striking resemblance except that there is not the same preponderance of magnesium over calcium. It must be remembered however, that the water would tend to pick up calcium from the clay and marl beds through which it percolated.

The essential characteristics of oceanic waters are however shown namely :—

$$Cl > SO_4 > CO_3 > \text{and } Na > Mg > Ca.$$

The waters arising in the Cretaceous and more recent formations can therefore be used as a basis of comparison when investigating the origin of other waters, for there is not the slightest doubt as to the marine origin of these beds or that they have retained a certain amount of the original (connate) sea water.

.CEOUS SYS'	
	565
)	46·5
)	176·0
)	129·5
)	46·5
3	—
7	—
.	Nil
8	615·0
0	—
:e	—
l	0·1
6	2·0
0	23·4
0	70·0
ıll ınt	—
0	—
06	—
5	—
3	—
0	38·5
0)	11·5
l	Nil
5	29·0
4	21·5
0	7·5
'·7	—

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TABLE No. 26.—WATERS IN CRETACEOUS SYSTEM AND RECENT COASTAL DE

	CRETACEOUS SYSTEM IN CAPE PROVINCE.													CR
Sample Numbers	141	140	206	246	245	248	249	247	448	449	472	565	Average	460	504
Parts CaCO$_3$ per 10^5 Water:															
Methyl Orange Alkalinity	40·0	* 4·5	25·5	73·0	15·2	27·0	28·5	94·0	1·0	17·3	43·0	46·5	—	10·0	4·0
Total Hardness	168·4	30·0	422·0	128·0	58·3	48·0	64·1	22·3	5·4	18·0	93·0	176·0	—	12·1	16·1
Permanent Hardness	128·4	25·5	396·5	55·0	43·1	21·0	35·6	Nil	4·4	0·7	50·0	129·5	—	2·1	12·1
Temporary Hardness	40·0	4·5	25·5	73·0	15·3	27·0	28·5	22·3	1·0	17·3	43·0	46·5	—	10·0	4·0
Hardness due to Ca Salts	54·6	10·0	192·0	41·0	41·0	32·5	25·6	6·3	1·6	10·8	48·3	—	—	3·5	4·9
Hardness due to Mg Salts	113·8	20·0	230·0	87·0	17·3	15·5	38·5	16·0	3·8	7·2	44·7	—	—	8·6	11·2
Soda Alkalinity	Nil	Nil	Nil	Nil	Nil	Nil	Nil	(72·0)	Nil	Nil	Nil	Nil	—	Nil	Nil
Parts per 10^5 of Water:															
Total Solids (at 106°)	575·0	64·0	(1550·0)	748·0	352·0	138·0	230·0	223·0	(16·8)	168·0	286·8	615·0	340·0	27·0	26·2
Silica (as SiO$_2$)	3·0	3·0	3·0	2·5	3·5	2·7	3·4	1·8	1·0	1·4	3·0	—	—	2·0	2·2
Fluorides (as F)	0·06	Nil	—	—	—	—	—	—	—	—	Trace	—	—	Trace	Trace
Nitrites	Nil	Nil	—	—	—	—	—	—	—	—	Nil	0·1	—	Nil	Nil
Nitrates (as NO$_3$)	0·05	Nil	—	—	—	—	—	—	—	—	1·6	2·0	—	0·02	0·04
Chlorides (as Cl)	257·0	26·6	662·5	316·0	167·0	59·4	105·0	76·4	7·6	76·0	100·0	23·4	—	6·1	9·7
Sulphates (as SO$_4$)	54·5	3·1	154·0	80·0	15·6	9·1	14·4	30·0	1·0	15·4	75·0	70·0	—	1·2	2·9
Potassium Salts	Small Amount	Trace	—	—	—	—	—	—	—	—	Small Amount	—	—	Under 0·5	Trace
pH. Values	7·5	7·3	—	—	—	—	—	—	—	—	7·0	—	—	5·6	6·1
Percentage on Total Solids:															
SiO$_2$	0·52	(4·6)	0·2	0·34	1·0	2·0	1·5	0·81	(6·0)	0·83	1·06	—	0·92	7·4	8·7
CaO	5·3	8·7	6·9	3·1	6·5	13·2	6·3	1·5	5·0	3·7	9·5	—	6·35	7·4	10·4
MgO	7·8	12·4	5·9	4·7	(2·0)	4·5	6·8	2·9	9·0	1·7	6·3	—	6·2	12·6	16·8
Cl	45·0	41·5	43·0	42·5	47·2	42·8	45·6	34·2	44·5	45·0	35·0	38·5	42·1	22·6	37·0
SO$_4$	9·5	4·9	10·0	10·6	4·4	6·7	6·3	12·7	6·0	9·3	(26·0)	11·5	8·4	4·45	11·0
Soda Alkalinity (as Na$_2$CO$_3$)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	(34·2)	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Total Hardness (as CaCO$_3$)	29·2	46·5	27·2	17·0	16·5	34·8	28·0	10·0	31·8	10·7	32·5	29·0	26·1	45·0	61·0
Permanent Hardness (as CaCO$_3$)	22·5	39·5	25·6	7·4	12·2	15·2	15·5	(Nil)	25·8	(0·4)	17·4	21·5	22·3	7·8	46·0
Temporary Hardness (as CaCO$_3$)	7·0	7·0	1·7	9·8	4·3	19·5	12·5	10·0	6·0	10·4	15·0	7·5	9·1	(37·0)	15·4
Ratio CaO : MgO	1 : 1·5	1 : 1·4	1 : 0·85	1 : 1·5	1 : 0·3	1 : 0·35	1 : 1·1	1 : 2·0	1 : 1·8	1 : 0·5	1 : 0·7	—	1 : 1·0	1 : 1·7	1 : 1·6

* Deposits iron oxide on standing.

† Org

TABLE No. 26.—WATERS IN CRETACEOUS SYSTEM AND RECENT COASTAL DEPOSITS.

System in Cape Province.								Cretaceous in Zululand.						Recent Coastal Deposits.						
8	249	247	448	449	472	565	Average	460	504	505	511	473	Average	151	165	469	564	572	573	Average
·0	28·5	94·0	1·0	17·3	43·0	46·5	—	10·0	4·0	16·0	21·0	†12·0	—	*17·5	0·8	73·0	24·0	21·5	36·0	—
·0	64·1	22·3	5·4	18·0	93·0	176·0	—	12·1	16·1	16·1	24·2	32·2	—	86·4	22·8	107·5	34·4	80·5	44·8	—
·0	35·6	Nil	4·4	0·7	50·0	129·5	—	2·1	12·1	0·1	3·2	20·2	—	68·9	22·0	34·5	10·4	59·0	8·8	—
·0	28·5	22·3	1·0	17·3	43·0	46·5	—	10·0	4·0	16·0	21·0	12·0	—	17·5	0·8	73·0	24·0	21·5	36·0	—
·5	25·6	6·3	1·6	10·8	48·3	—	—	3·5	4·9	6·4	8·1	13·8	—	31·2	7·4	67·2	23·8	46·0	19·0	—
·5	38·5	16·0	3·8	7·2	44·7	—	—	8·6	11·2	9·7	16·1	18·4	—	54·5	14·4	40·3	10·6	34·5	25·8	—
il	Nil	(72·0)	Nil	Nil	Nil	Nil	—	Nil	Nil	Nil	Nil	Nil	—	Nil	Nil	Nil	Nil	Nil	Nil	—
·0	230·0	223·0	(16·8)	168·0	286·8	615·0	340·0	27·0	26·2	75·6	103·0	78·2	—	331·0	91·2	235·0	(62·1)	206·8	161·0	205·0
·7	3·4	1·8	1·0	1·4	3·0	—	—	2·0	2·2	5·0	4·0	3·0	—	4·0	0·4	5·7	0·46	1·6	1·4	—
–	—	—	—	—	Trace	—	—	Trace	Trace	Nil	Nil	—	—	0·1	Nil	Nil	—	—	Nil	—
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–	—	—	—	—	1·6	2·0	—	0·02	0·04	Nil	Nil	Nil	—	Nil	3·2	Trace	0·16	Trace	Nil	—
·4	105·0	76·4	7·6	76·0	100·0	23·4	—	6·1	9·7	26·0	42·0	32·0	—	157·3	33·4	88·5	18·2	85·1	71·0	—
·1	14·4	30·0	1·0	15·4	75·0	70·0	—	1·2	2·9	7·3	5·7	7·3	—	10·5	6·2	6·8	4·4	12·8	6·1	—
–	—	—	—	—	Small Amount	—	—	Under 0·5	Trace	Under 0·5	Under 0·5	Under 0·5	—	Trace	—	Small Amount	—	—	Small Amount	—
–	—	—	—	—	7·0	—	—	5·6	6·1	8·0	7·7	6·3	—	6·9	5·2	7·4	7·28	—	6·8	6·7
·0	1·5	0·81	(6·0)	0·83	1·06	—	0·92	7·4	8·7	6·1	3·9	3·8	6·0	1·2	0·44	2·4	0·74	0·78	0·88	1·06
·2	6·3	1·5	5·0	3·7	9·5	—	6·35	7·4	10·4	4·6	4·4	9·8	7·3	5·5	4·65	16·2	21·3	12·6	6·65	11·1
·5	6·8	2·9	9·0	1·7	6·3	—	6·2	12·6	16·8	5·1	6·3	9·4	10·0	6·6	6·2	6·9	6·8	6·7	6·65	6·6
·8	45·6	34·2	44·5	45·0	35·0	38·5	42·1	22·6	37·0	34·5	41·0	41·0	35·2	47·3	36·5	38·0	29·5	41·0	44·5	32·9
·7	6·3	12·7	6·0	9·3	(26·0)	11·5	8·4	4·45	11·0	9·6	5·5	9·3	8·0	3·1	6·8	2·9	7·2	6·2	3·8	5·0
il	Nil	(34·2)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
·8	28·0	10·0	31·8	10·7	32·5	29·0	26·1	45·0	61·0	21·3	23·2	41·0	38·3	27·0	25·0	45·5	(56·0)	39·0	28·0	36·8
·2	15·5	(Nil)	25·8	(0·4)	17·4	21·5	22·3	7·8	46·0	(0·13)	3·1	25·7	18·2	20·8	24·0	14·8	17·0	28·6	5·5	18·5
·5	12·5	10·0	6·0	10·4	15·0	7·5	9·1	(37·0)	15·4	21·0	20·5	15·3	18·1	5·3	0·9	31·2	(39·0)	10·4	22·5	14·1
0·35	1 : 1·1	1 : 2·0	1 : 1·8	1 : 0·5	1 : 0·7	—	1 : 1·0	1 : 1·7	1 : 1·6	1 : 1·1	1 : 1·4	1 : 0·96	1 : 1·4	1 : 1·2	1 : 1·3	1 : 0·4	1 : 0·3	1 : 0·5	1 : 1·0	1 : 0·6

sits iron oxide on standing.

† Organic matter and H_2S present.

DESCRIPTION OF SAMPLES IN TABLE No. 26.

Sample No.	District and Province.	Borehole Depth. Feet.	Locality, Description and Remarks.	Date.
141	Worcester, Cape Province	260	Borehole in Worcester	20/12/39
140	Worcester, Cape Province	150	Borehole at Brandwacht. (Deposits iron oxide on standing)	20/12/39
206	Uitenhage, Cape Province	461	Borehole at Glenconnor. (Anal. Juritz, Ref. 365)	1908
246	Mossel Bay, Cape Province	—	Spring near Mossel Bay. (Anal. Juritz, Ref. 361)	1908
245	Oudtshoorn, Cape Province	—	Borehole at Welgedacht, 13 miles West of Oudtshoorn. (Anal. Juritz, Ref. 362)	1908
248	Alexandria, Cape Province	—	Spring at Nickerk's Hope. (Anal. Juritz, Ref. 371)	1908
249	Alexandria, Cape Province	—	Spring at Mimosa. (Anal. Juritz, Ref. 375)	1908
247	Uitenhage, Cape Province	—	Borehole at Stembokvlakte. (Anal. Juritz, Ref. 369)	1908
448	Uitenhage, Cape Province	—	Spring at Sandfontein. (Anal. Juritz, Ref. 368)	1908
449	Alexandria, Cape Province	—	Borehole at Sandflats. (Anal. Juritz, Ref. 374)	1908
472	Oudtshoorn, Cape Province	—	Spring at Oudtshoorn	29/12/41
565	Port Elizabeth, Cape Province	200	Borehole, Leslies, Walmer. (Anal. Govt. Lab., Johannesburg)	15/ 7/33
473	Hlabisa, Zululand	—	Spring at St. Lucia Bay	5/ 1/42
460	Ubombo, Zululand	—	Well in Monzi	5/11/41
504	Lower Umfolozi, Zululand	18	Well, Hunt, Leuchars & Hepburn's property, 200 yards East of Kwambonambi Station	30/ 1/42
505	Lower Umfolozi, Zululand	180	Borehole, Delville Estates, 600 yards West of Kwambonambi Station	30/ 1/42
511	Hlabisa, Zululand	—	Borehole at Matubatuba Station	20/ 2/42
151	Stellenbosch, Cape Province	60	Borehole East of Vlottenberg Station. (Superficial sandy deposits.) Deposits iron oxide on standing	16/12/40
165	Cape Peninsula, Cape Province	50	Borehole at Kommetje, Cape Town. (Sandy covering over T.M.S.)	16/12/40
469	Cape Peninsula, Cape Province	25	Well near Zeekoevlei. (Superficial sandy deposits)	9/12/41
564	Cape Peninsula, Cape Province	—	Borehole on farm Matroosfontein, Cape Flats	7/ 9/42
572	Namaqualand, Cape Province	—	Borehole, Alexander Bay State Alluvial Diamond Diggings. (Anal. Govt. Lab., Johannesburg)	2/10/36
573	Alexandria, Cape Province	—	Borehole in Alexandria	21/ 9/42

Incidentally Du Toit (14, p. 354) in a description of the small Cretaceous basin at Oudtshoorn states that there are no marine fossils in these beds to indicate that the sea ever extended into this region.

However, the analysis of Cretaceous water from a spring in Oudtshoorn (No. 472, Table 26) shows that it does not differ from the highly saline Cretaceous water found elsewhere, except that the sulphate content is higher than usual, so that it is possible that here the beds were laid down in an estuary.

It is interesting to note from Kenny (77, p. 140) that the Cretaceous shales of the West Darling district, Australia, also yield highly saline water, and that this water is probably of connate origin.

XXIII.—A COMPARISON OF WATERS FROM VARIOUS GEOLOGICAL HORIZONS.

Summary of Analtytical Data and Classification of Waters.

A summary is given in Table 27 of the analytical data (averaged) from each geological horizon, as tabulated in previous sections.

The underground waters of the Union have been classified by the author into 5 groups. There is naturally, a certain amount of mingling of types.

(i) *Group A.—Highly Mineralised Chloride-Sulphate Waters.*

The chief characteristics of this type are as follows :—

(1) These waters usually contain 100 to 400 parts of dissolved salts per 10^5.

(2) *Low Silica.*—Expressed as a percentage of the total salts SiO_2 is very low being under 4 per cent.

(3) *Chlorides.*—Very high in actual quantity and expressed as a percentage of the total generally exceed 27 per cent. Cl. but are as high as 51 per cent. Cl.

(4) Sulphates are relatively high, generally exceeding 6 per cent. So_4 and in the waters from some formations being as high as 17 per cent. SO_4.

(5) *Na_2CO_3 or $NaHCO_3$.*—Soda alkalinity is never present.

(6) *Hydrogen ion Concentration.*—The pH. varies but averages about 7·4.

(7) *Hardness.*—The total hardness is generally well under 48 per cent. (as $CaCO_3$) while the permanent hardness is generally well over 12 per cent.

As shown in previous sections, some of the waters in this group approximate more closely than the others to the oceanic type of water in which the relation between the constituents is as follows :—

$$Cl. > SO_4 > CO_2 > \text{and } Na > Mg > Ca.$$

Appreciable sodium and magnesium chlorides and sulphates are characteristic of this oceanic type.

Now, as stated in previous sections, it has been proved on palaeontological and other evidence that certain rock formations have either been laid down in the ocean, or else the strata have suffered a marine inundation at some period after formation. Further, since these formations are of an argillaceous character, they tend to retain some of this connate or entrapped sea water. Of these waters those arising in the Malmesbury and Cretaceous beds most closely approximate to sea water in composition.

In the case of the former it has been established that a marine transgression across the strata took place in comparatively recent times, while in the case of the latter it is known that the formation was laid down in the sea in a fairly recent geological epoch. Prolonged leaching could hardly have taken place in either case, it being remembered that the longer the period available for leaching, the less will the ground water resemble the original entrapped sea water.

For comparative purposes, an analysis of sea water is given in Table 27, which, also expressed as a percentage of dissolved salts, is the one cited by Clarke (43, pp. 126–127) and represents the mean of 77 analyses of oceanic waters, carried out by W. Dittmar. Incidentally, Dittmar's analyses indicate the extraordinary uniformity in percentage composition of the open oceans in spite of differences in concentration.

As previously stated there is some evidence from the work of Joly and others that the ancient oceans were not as saline as those of today.

The resemblance between sea water and some of the waters in the saline group, is most striking, but there is not the same preponderance of magnesium over calcium in the latter as exists in sea water This fact is readily explained on the grounds that these highly saline waters, representing entrapped or connate sea water, pick up a certain amount of calcium from the argillaceous beds through which the ground water percolates, since certain layers are calcareous.

It is interesting to note from Table 27 that there has been a gradual diminution in chloride and sulphate and a gradual divergence from the oceanic type of water, as one proceeds from the Dwyka series to the lower Beaufort series, while in the succeeding middle and upper Beaufort waters the percentage of chloride has dropped to a negligible amount.

As previously shown this diminution in saline characteristics cannot always be explained as due to climatological factors alone.

In conclusion it may be pointed out that although the waters in this group are very saline, their salinity is nothing like that of the majority of underground waters in West Darling District of Queensland, Australia (Kenny 77, pp. 146–151) and or in the granite of Western Australia (Simpson 57).

The salinity of many of these waters can only be described as terrific.

(ii) *Group B.—Slightly Saline Chloride Waters.*

Except for a lower sulphate content, there is very little difference in percentage composition between the waters in this group and the Group (A) waters.

In concentration there is, however, a vast difference for in this group the total salts are only about 30–35 parts per 10^5.

It has been suggested that the slight salinity of these waters can be explained on the grounds that the rock formations concerned are exposed very near the coast and that salt-laden mists from the sea, driven inland during gales, are responsible for the slight sa[illegible] The chloride in these waters is therefore cyclic.

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TABLE No. 27.—SUMMARY OF ANALYTICAL DATA.

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Type of	Table	Geological Formation.	Average Concentration in Parts per 10^5.	Average pH. Value.	Average Ratio CaO : MgO.	PERCENTAGE ON TOTAL DISSOLVED SALTS.								
						CaO.	MgO.	SiO_2.	Cl.	SO_4.	Na_2CO_3 or $NaHCO_3$.	Total Hardness as $CaCO_3$.	Permanent Hardness as $CaCO_3$.	Temporary Hardness as $CaCO_3$.
	—	Sea water for comparison. (Mean of 77 Analyses by Dittmar)	3,500	—	1 : 3·7	1·68	6·2	—	55·3	7·7	Nil	18·3	17·94	0·34
GROUP A. Highly Mineralised Chloride-Sulphate Waters.	26	Recent Coastal Deposits	205	6·7	1 : 0·6	11·1	6·6	1·06	32·9	5·0	Nil	36·8	18·5	14·1
	26	Cretaceous System	340	—	1 : 1·0	6·3	6·2	0·92	42·1	8·4	Nil	26·1	22·3	9·1
	3	" Old Granite " in North-West Cape Province	690	7·6	1 : 0·5	11·0	5·8	—	30·2	19·3	Nil	33·6	25·8	11·3
	1 (*a*)	" Old Granite " in North-West Transvaal	245	—	1 : 1·4	10·1	14·4	—	33·5	6·2	Nil	43·2	18·8	26·8
	16	Bokkeveld Series	235	7·4	1 : 0·96	9·7	9·4	1·1	41·3	13·5	Nil	36·8	20·7	14·5
	13	Malmesbury Series	172	7·1	1 : 1·5	4·4	6·5	2·4	42·1	5·0	Nil	23·9	11·6	12·3
	18	Dwyka Series in Cape Province and Transvaal	148	7·6	1 : 0·92	12·6	11·6	3·0	30·2	14·8	Nil	48·0	15·8	27·8
	17	Witteberg Series (Shales)	92	—	1 : 0·60	11·8	6·7	1·8	43·0	6·7	Nil	30·3	20·6	29·7
	20	Ecca Series in Cape Province	146	7·6	1 : 0·72	12·4	8·9	2·0	27·1	12·1	Nil	40·5	17·0	28·6
	20	Ecca Series on Natal Coast	181·4	7·5	1 : 2·2	5·3	11·7	1·15	51·2	2·53	Nil	38·8	26·0	11·3
	19	Dwyka Series in Pondoland	921	—	1 : 0·3	16·4	5·6	4·0	27·5	17·5	14·9	40·8	Nil	40·8
	22	Lower Beaufort Series	106	7·6	1 : 0·7	14·8	10·4	3·8	26·1	10·6	Rare	52·5	20·5	32·0
GROUP B. Slightly Saline Chloride Waters.	19	Dwyka Series in Natal	44·7	—	1 : 0·7	14·9	10·0	5·9	27·2	1·5	Nil	44·3	3·0	42·0
	4	Cape Granite	20·0	6·9	1 : 1·7	3·7	6·2	4·9	42·9	1·3	Nil	23·4	12·0	13·6
	2	" Old Granite " in Natal	36·4	7·3	1 : 2·5	7·3	9·1	10·2	31·8	3·2	Nil	29·9	12·7	19·2
GROUP C. Temporary Hard (Carbonate) Waters.	10	Dolomite Series	34·8	7·8	1 : 0·94	22·0	20·8	6·5	4·9	1·6	Nil	91·0	4·0	87·0
	9	Ventersdorp System	37·3	7·7	1 : 0·78	19·7	15·4	8·4	7·4	2·6	Occasional	74·0	3·1	67·3
	6	Basic Rocks of Igneous Complex	44·0	7·7	1 : 4·4	6·5	28·6	15·8	6·6	0·8	Nil	85·4	6·7	78·7
	12	Pretoria Series (Shale Zone)	24·0	7·8	1 : 1·25	15·7	18·3	11·6	8·2	0·8	Occasional	72·7	—	68·7
GROUP D. Soda Carbonate Waters.	23	Middle and Upper Beaufort Beds	35·7	8·2	1 : 0·62	12·5	7·7	6·4	5·7	5·3	37·3	39·7	Nil	39·7
	24	Stormberg Sediments	38·4	7·8	1 : 0·7	15·4	10·5	3·3	6·3	1·8	30·3	50·6	Nil	50·6
	25	Stormberg Lavas	41·7	7·7	1 : 0·6	15·8	10·7	12·2	6·6	0·8	14·7	52·7	Nil	52·7
	5	Red Granite	24·5	7·4	1 : 0·3	11·5	3·4	18·0	18·6	2·0	28·2	25·3	Nil	25·3
	5	Pilansberg Alkali Rocks	28·4	7·6	1 : 0·6	18·2	10·3	—	7·1	2·6	28·7	40·7	Nil	40·7
	1 (*a*)	" Old Granite " in Northern Transvaal	70·2	7·6	1 : 1·2	9·9	11·9	12·4	12·8	1·5	14·9	45·4	Nil	45·4
GROUP E. Pure Waters. (Slightly Acidic).	11	Pretoria Quartzites	7·3	6·9	1 : 1·9	8·3	15·5	16·3	13·7	1·3	Nil	53·5	13·0	40·5
	1	Old Granite in South and East Transvaal	14·3	7·4	1 : 1·1	8·6	9·6	20·5	8·3	1·6	8·5	38·8	—	36·5
	14 (*a*)	Waterberg Sandstones	6·5	7·0	1 : 0·9	13·2	11·9	16·0	11·2	1·6	Rare	52·6	—	47·0
	8	Witwatersrand System	10·8	6·8	—	—	—	—	—	—	—	—	—	—
	17	Witteberg Quartzites	10·0	—	1 : 1·4	5·7	7·8	10·4	30·8	6·0	Nil	31·8	17·6	14·1
	15	T.M.S. in Natal	11·4	6·9	1 : 1·5	6·8	10·2	10·4	32·1	2·1	Nil	33·3	16·3	19·3
	14	T.M.S. in Cape Province	12·9	5·7	1 : 2·2	3·9	8·4	4·7	39·9	3·2	Nil	26·2	18·9	10·6

Although the water in the Table Mountain series in Natal and in the Cape Province, and the waters arising in the Witteberg quartzites in the Cape Province have been placed in the pure water Group (E) on account of the exceedingly low concentration of salts, in percentage composition they approximate to the slightly saline Group (B) for the percentage of Cl. in these waters is over 31 per cent. Cl.

The relatively high chloride in these waters is also due, no doubt, to cyclic salt, since these formations also outcrop near the sea.

(iii) *Group C.—Temporary Hard (Carbonate) Waters.*

The chief characteristics of this group, as exemplified by the waters rising in the Dolomite, Ventersdorp system, Pretoria shales, and basic rocks of the Bushveld Igneous Complex, are as follows:—

(1) *Hydrogen Ion Concentration.*—The pH. of these waters is consistently high (about 7·8).

(2) *Concentration of Salts.*—Except in the very arid westerly regions, there is a medium concentration of salts ranging from 25–40 parts per 10^5.

(3) *Silica.*—Excluding the waters arising in the basic zones of the Igneous Complex, the SiO_2 content is moderately low, ranging from 6·5 to 11 per cent. SiO_2.

(4) *Chlorides.*—These waters have an extremely low Cl. content, ranging from 5 per cent. to 8 per cent. Cl.

(5) *Calcium and Magnesium Bicarbonates.*—A relatively very high temporary hardness is the chief characteristic of this group of waters. 68–90 per cent. of the dissolved solids in these waters consist of $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$. There is very little permanent hardness.

The waters arising in the basic and ultra basic rocks of the Bushveld Igneous Complex (more particularly in the pyroxenic and ultra basic rocks) should, by right, be allocated to a sub-group, for these waters, as shown on page 52, consist very largely of $Mg(HCO_3)_2$ and with an appreciable silica content. $Ca(HCO_3)_2$ is present in very small amount. The percentage of SiO_2 is extraordinarily high (16 per cent. SiO_2) and the absolute amounts present are higher than in any other waters, excluding the Pondoland Dwyka springs.

(iv) *Group D.—Soda Carbonate Waters.*

(Waters arising in the middle and upper Beaufort beds, the Stormberg sediments and lavas, Red granite, Pilansberg alkali rocks, and Old granite of the Northern Transvaal).

These waters may be regarded as a sub-group of Group (C), for they are also carbonate waters, the only difference being that, whereas in the case of Water Group (C), the alkalinity is mainly due to $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$, in the case of the soda carbonate group of waters there is, in addition, an appreciable amount of sodium bicarbonate and sometimes sodium carbonate. There is naturally a good deal of overlapping between Groups (C) and (D).

(1) *CaO : MgO Ratio.*—There is generally far more calcium than magnesium, except in the case of certain Old granite waters.

(2) *Silica.*—Except in the case of upper Beaufort and Stormberg waters, the SiO_2 content is generally very high, ranging from 12–18 per cent. SiO_2, in terms of total salts.

(3) *Sulphates.*—Except in the case of the upper Beaufort waters, the SO_4 content is very low indeed and even in the Beaufort waters it is not very high.

(4) *Na_2CO_3 or $NaHCO_3$.*—The chief characteristic of these waters is the very high soda alkalinity which ranges generally from 15–38 per cent. (as Na_2CO_3) and is due to $NaHCO_3$ rather than Na_2CO_3. Sometimes, however, Na_2CO_3 is present as well.

(5) *Hardness.*—Unlike the waters of the previous group $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$ seldom exceed 50 per cent. (as $CaCO_3$).

(6) *Chlorides.*—Except in the case of the Red granite waters, the chloride content is very low.

(v) *Group E.—Pure Water Group.*

(Witwatersrand system, Pretoria quartzites, Waterberg sandstones, Table Mountain series in the Cape Province and Natal, and the Old granite waters in the Southern Transvaal).

As would be anticipated, the pure waters are those arising in sandstones and quartzitic rocks.

The chief characteristics of this group are :—

(1) *Low Concentration of Salts.*—The concentration is generally well under 15 parts per 10^5.

Some of these waters, particularly some of those arising in the Pretoria quartzites, approximate to distilled water with total salinities of only 2 to 4 parts per 10^5.

(2) *Hydrogen Ion Concentration.*—There is generally a slight acidity, the pH. being just under 7·0. This is as would expected in waters arising in rocks composed mainly of silica and so devoid of bases. The slight acidity is due to free CO_2 in solution.

(As has been shown, the waters from the Table Mountain series in the Cape Province often show pH. values of as low as 4·5 which is due to acidic organic colloids and to a less extent to free CO_2.)

(3) *CaO : MgO Ratio.*—MgO generally exceeds CaO.

(4) *Silica.*—The SiO_2 content is generally quite high, particularly in the case of the Old granite waters in the Southern Transvaal. The exception is the water from the Table Mountain series in the Cape Province which, however, as aforementioned, approximates more to the slightly saline Group (B).

(5) *Chlorides.*—The Cl. content is generally moderately low, ranging from 8–14 per cent. Cl. with the exception of the waters arising in the Table Mountain series in the Cape Province and Natal, and in the Witteberg quartzites, all all of which show over 30 per cent. Cl. These waters, however, overlap as aforementioned into the slightly saline Group (B).

(6) *Hardness.*—These waters are all very soft.

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GENERAL OBSERVATIONS.

A study of Table 27 brings to light the following :—

The most saline waters (excluding the Pondoland Dwyka springs, which are few in number) are those rising in the Old granite of the North-West Cape, which show an *average concentration* of nearly 700 parts per 10^5.

The purest waters are those rising in the quartzite and sandstones of the Pretoria series, Witwatersrand system and Waterberg system.

The most alkaline waters are those arising in the upper Beaufort and Stormberg sediments, and in some of the Pilansberg alkali rocks.

The most acidic waters are the dark coloured Table Mountain series spring waters in the Cape Province.

The highest percentage of silica is found in the granitic waters and in the waters arising in the basic rocks of the Bushveld Igneous Complex. As already stated the latter waters also show the highest absolute amount of silica of all all waters (excluding the few Pondoland springs) in the Union.

The highest percentage of sulphate is found in the Old granite waters in the N. West Cape, and in the Dwyka waters in the Cape Province, Western Transvaal and Pondoland.

The most consistent of all waters are those arising in the Dolomite, which in *percentage composition* vary hardly at all, wherever found.

WATER MAP

A "Water Map" has been compiled by the author to illustrate the distribution in the Union of South Africa of the various types of water summarised above.

It must be strongly emphasised that this Water Map merely illustrates *the tendency for the ground waters in certain areas to conform to a certain type*, and there may be far more anomalies than shown in the map. In some cases this tendency is so definite as to become almost a law. For example, the waters arising anywhere in the upper Beaufort beds, with but only one or two exceptions, show a strong soda alkalinity, while waters arising in the Dolomite will, without exception, conform to Group (C).

On the other hand, the waters found in the lower Beaufort beds, though generally conforming to Group (A), will sometimes approximate to Group (D), and so on.

Needless to say, the boundaries of the different divisions on the map are, in most cases, purely arbitary (except on the boundaries of the pure water division in the C.P. which follow the outcrops of the Table Mountain series.)

In the compilation of this Water Map the chief difficulty arose in connection with the Ecca waters in the Northern Orange Free State, Transvaal and Northern Natal, which, unlike the Ecca waters in the Cape Province and Coastal Natal, do not conform to any particular type. Instead all types of water (except the highly mineralised chloride-sulphate type Group A) are found. Hence in these regions the compilation had to be based on actual analyses. For these areas the map may prove unreliable. Generally speaking, however, the Water Map should prove a very useful guide as to the type of water likely to occur in any particular area

A study of this Water Map brings to light the following interesting acts :—

(i) *Effects of Climate.*

It will be observed that in approximately two-fifths of the Union of South Africa, waters of the highly mineralised chloride-sulphate type prevail. Fortunately many of the waters of this type are found in the sparsely inhabited regions of the North-Western Cape and Namaqualand. Nevertheless, a large part of the important sheep farming districts of the Karroo have ground waters of this type.

It might be claimed that climatological factors are responsible for the high salinity of the waters in these regions since the rainfall is generally low, but, as has been pointed out previously, there are many exceptions. For example, in some of the districts in the Cape Province, in which the highly saline waters occur, there is a high rainfall, e.g. the springs in the Dwyka beds in Pondoland which show an average concentration of 920 parts per 10^5 in spite of very heavy rainfall, while highly saline waters are found in the upper Beaufort beds in Hofmeyr and Queenstown in spite of fairly high rainfall. Conversely, some of the regions in the Karroo in which soda carbonate waters are found are under more or less the same climatic conditions as those producing highly saline waters the difference in the waters being due to difference in the geological horizon.

Furthermore, along the eastern coast of the Union and Portuguese East Africa, where the rainfall is abnormally high, highly saline waters are encountered in the Cretaceous beds. Moreover, most of the saline waters approximate more to the *oceanic type* of water in which the relation between the constituents is $Cl. > SO_4 > CO_3$ and $Na > Mg > Ca$ rather than to the "*desert type*" in which the relation according to Lindgren (35, p. 28) is $SO_4 > CO_3 > Cl.$ and $Ca > Mg > Na$.

(ii) *Prevalence of Soda Carbonate Waters.*

It is interesting to note that the ground water of fully a third of the Union belongs to the soda carbonate ("black alkali") type.

(iii) *Purity of Natal Waters.*

Except along the coastal belts, the ground waters in Natal are comparatively pure.

IDENTIFICATION OF GEOLOGICAL HORIZON FROM NATURE OF GROUND WATER.

It will be observed from the analytical data summarised in Table 27, that, although waters from certain geological rock formations have very definite characteristics, these characteristics may be common to waters from certain other formations. Therefore the chemical nature of a borehole water should only be used with extrem caution as a guide to the identity of the horizon in which the wat arose. Perhaps the only water which has characteristics quite differen from any other is the water arising in the pyroxenic and other bas rocks of the Bushveld Igneous Complex. These waters contain almo entirely $Mg(HCO_3)_2$ and silica.

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It is known, however, that a borehole sunk to a certain horizon may yield, for example, highly saline water, but if continued to another horizon may yield fresher water or vice versa. For example du Toit (1, p. 23) cites the case of a borehole on a farm near Prieska, which struck strong highly saline supplies in Dwyka tillite at 205′, but when continued down into granite (by the aid of casing), yielded a supply of much less saline water. On page 62 the author has also given the example of the borehole in the Britten salt pan, which yielded non-saline water when continued down into the underlying Ventersdorp Lava, though boreholes located in the Dwyka tillite in the pan yielded highly saline water.

Therefore in a few instances it is possible to identify a geological horizon by the chemical nature of the ground water, but, as aforementioned, extreme caution must be exercised.

XXIV.—THE CONCENTRATION OF CERTAIN ELEMENTS IN THE UNDERGROUND WATERS OF THE UNION OF SOUTH AFRICA.

HYDROGEN ION CONCENTRATIONS.

Nothing has hitherto been published regarding the hydrogen ion concentration of the underground waters of the Union and therefore the pH. data tabulated previously should prove of interest.

The waters showing the highest ion concentrations are the dark coloured spring waters arising in the Table Mountain series in the Cape Province.

As shown in Table 14, pH. values as low as 4·5 are not uncommon in the waters from the Table Mountain series in the Cape Province, while the average for all the samples tested was 5·7. The cause of this acidity has been discussed fully, where it was shown that free CO_2 is only partly responsible, the main cause being the organic (humic) acids derived from the prolific heath-like type of vegetation growing in the soils on the Table Mountain series. As would be expected the waters showing the lowest hydrogen ion concentrations are certain soda carbonate waters.

The highest *average* pH. figure, namely 8·2, is shown by the waters in the middle and upper Beaufort beds. In these, values of between 8·5 and 8·8 are not uncommon, while a spring water in Cedarville, analysed by the author, had a pH. value of 9·4 (Table 23). In this particular water 57 per cent. of the dissolved salts consisted of $NaHCO_3$ and Na_2CO_3.

The highest pH. of any natural water yet recorded in the Union is that for the highly concentrated $NaCl—Na_2CO_3—NaHCO_3$ liquor in the soda caldera at Salt Pan, Pretoria district. A composite sample of the brine from 27 samples in the pan was tested by the author and found to have a pH. of 10·6. The next highest was that of a borehole in Ledig, Pilansberg (page 42). This water had a pH. of 9·8 and 37 per cent. of the salts consisted of $NaHCO_3$ and Na_2CO_3.

Atkins (45, p. 455) mentions that a sodium carbonate water in the Sudan had a pH. of 10·0.

Unfortunately the complete analyses of the soda carbonate waters of the Great Artesian Basin, West Darling district of Australia cited by Kenny (77, p. 150) do not include pH. figures.

It is unfortunate that no pH. figures are given in the analyses of sodium carbonate waters from different parts of the world cited by Clarke (43) and Lindgren (35).

A study of the data collected by the author shows that a high "Soda alkalinity" *does not necessarily mean a high pH. value* (by soda alkalinity is meant, of course, the difference between the total hardness and the alkalinity when the latter exceeds the former). For example, the analysis of Sample 503 in Table 23, shows that although 60 per cent of the salts in this water consists of soda alkalinity, the pH. is only 7·7. In this particular case $NaHCO_3$ and not Na_2CO_3 is present, whilst "free CO_2" is also present. Some of the Red granite waters also show an appreciable soda alkalinity but have very low pH. values (see Table 5). The determining factor is therefore the amount of "free CO_2". For practical purposes Na_2CO_3 is present when phenolphthalein indicator imparts a pinkish colour to the water (i.e. the pH. exceeds 8·2).

From the data already tabulated it will be observed that with the exception of the Dolomite waters, there is generally a variation in hydrogen ion concentration in the water from any particular geological horizon, even in those waters which are otherwise very consistent in chemical composition. The Dolomite waters show hardly any variation at all (pH. 7·8–8·0).

The work of Greenfield and Baker (26) has shown that the pH. reaction of water is largely due to equilibria between CO_2 and bicarbonate ions kept in solution in conjunction with calcium and magnesium ions.

The result of the author's investigation into the relation between "free CO_2" and the hydrogen ion concentration in natural waters in the Union is illustrated by figure 1.

NITRATES.

Nitrates in the ground water are not generally derived from the rock formation through which the water percolates, but from nitrates in the soil or from pollution.

The presence of nitrates in water is usually regarded as a sign of actual pollution, but, as pointed out by Clarke (43, p. 197) this is not necessarily the case.

Nitrates in the ground waters may be the result of one of the following causes:—

(1) Pollution of the water by human or animal agency.

(2) From nitrates in the soil, which in turn may be derived from—

  (*a*) The atmosphere, by the fixation of atmospheric nitrogen either through the agency of symbiotic bacteria in the soil or through electrical discharges during electrical storms, nitric acid being brought down subsequently by rain. The amount of nitrates derived from this latter source is generally regarded as small, but it must be pointed out that on the Transvaal Highveld, where electrical storms are so prevalent during summer months, the quota of nitrates produced in this manner may be quite appreciable.

  (*b*) By the oxidation of organic matter in the soil, through the agency of nitrifying bacteria or by reaction between organic nitrogenous matter and alkaline salts. Nitrates may thus occur in considerable amount in arid regions where nitrificati goes on rapidly. Skinner (46) states that some of the underground waters in Arizona contain as much as 16 parts nitrates (as N) per 10^5, and that this high nitrate content is derived from the soil and is not the result of pollution. Clarke (43, p. 198) cites an analysis of spring water from Cranac, Aveyron, France, in which NO_3 amounts to about 41 parts NO_3 per 10^5, or 36 per cent. NO_3 in terms of total salts. The Cl. content in this case is very low amounting to only 5·4 per cent. Cl. so that the high nitrate content in this water was definitely not the result of pollution, but of oxidation of nitrogenous matter in coal beds, through which the water percolated.

(3) Volcanic action.

Clarke (43, p. 259) suggests that nitrates in waters arising in volcanic rocks can be the result of recent volcanic activity, but in that case the nitrates always appear to be accompanied by boron compounds.

This could hardly be a source of nitrate in waters in the Union since no volcanic activity at all has taken place in recent times.

The highly mineralised Old granite waters in the North-West Cape (Table 3) often contain 20 or more parts NO_3 per 10^5. One sample (No. 615, Table 3) contains as much as 221 parts NO_3 per 10^5, but this works out on the percentage basis, at only 6·6 per cent. NO_3. Another sample (No. 613) contains 153 parts per 10^5 (9·6 per cent. NO_3).

Even the highly concentrated brine from the Matsap salt pan, Cape Province, described by Rogers (47) contains only 10 per cent. NO_3 in terms of total solids.

Most of the waters in the very arid Mandated Territory of South West Africa have an exceedingly high nitrate content. It is obvious that the exceedingly high nitrate content of the Old granite waters referred to above is not due to pollution but to the rapid nitrification which goes on in very arid regions, as in the case of the Arizona waters. The high nitrate may also be due in part to electrical storms.

The author has come across only one case of a spring water containing appreciable nitrates (526, Table 20), but the majority of shallow wells or borehole waters show small amounts of nitrates. Amounts of 1–2 parts NO_3 per 10^5 are quite common in town boreholes or well waters, this fact appears to point to pollution as being the main cause of the appreciable nitrate content, particularly as it is the experience of public analysts in the Union, that the nitrate content of well and borehole waters in the younger towns of the Union, show progressive increase with age.

However, it is not possible to be dogmatic, for apart from the evidence regarding the Old granite waters in the arid North-West Cape, the author has come across a few cases where boreholes in non-arid regions showed a fairly high nitrate content, but no nitrites and but little chloride was present, and furthermore, no contamination appeared possible.

When, however, the nitrate content is excessively high and the percentage of Cl. is abnormally high for the particular geological horizon under investigation, then it is reasonably certain that pollution has taken place. Thus a geo-chemical survey of the ground waters may prove of value of settling the problems of pollution.

Apart from the questions of pollution by sewage and the bacteriological condition of the water resulting therefrom, some authorities, on physiological grounds, consider that a water containing over about 1 part NO_3 is not potable even if bacteriologically pure. Furthermore, an appreciable nitrate content in boiler feed waters is undesirablesince there is the possibility of decomposition of the nitrates under certain conditions (i.e. in " dry areas " of boiler tubes).

SULPHATES.

Clarke (43, pp. 189–190) and Lindgren (35, pp. 49–52) classify as " sulphate waters " all waters in which SO_4 is the principal negative ion, and the analyses cited show sulphates in amount from 52 per cent. to 76 per cent. SO_4 in terms of total salts.

Excluding acid mine waters in which sulphuric acid or sulphates are generally present in considerable amounts as a result of the oxidation of pyritic ores, there are no waters in the Union corresponding to this class. *In the Union high sulphate waters are nearly always associated with very high chloride, but the SO_4 seldom exceeds* 10 *per cent. SO_4*. This association of Cl. and SO_4 suggests a relationship with oceanic waters or cyclic salts from the sea in which, as previously stated, the relation between the ions is Cl. $> SO_4 > CO_3$ and Na > Mg > Ca.

Lindgren (35, p. 28) states that in desert regions the relation between the constituents of the ground waters is $SO_4 > CO_3 >$ Cl.

In the very arid regions of the North-West Cape Province, where the rainfall is about 5″ per annum, the highly mineralised Old granite waters contain a large amount of sulphates. In a few of these SO_4 exceeds Cl. (Table 3). However, this relation is not general and on the average Cl. exceeds SO_4. The average SO_4 content in terms of total salts is 19 per cent. while the Cl. is 30 per cent. One sample (No. 613) namely a borehole water from the Upington district, contains 409 parts SO_4 (or 26 per cent. SO_4), while another contains 221 parts SO_4 or 42 per cent. SO_4, the highest percentage yet recorded in the Union.

The Dwyka waters of the Cape Province and Pondoland and the Bokkeveld waters also contain a fair amount of sulphate (over 13 per cent. SO_4) *but Cl. always exceeds SO_4*.

Both the Ecca series and lower Beaufort beds in the Cape Province yield waters with a SO_4 content of over 10 per cent., while the Malmesbury, Witteberg and Cretaceous waters and water from Recent coastal formations also contain appreciable sulphates, but in every case Cl. exceeds SO_4.

Apart from these, none of the waters from the other formations yields waters with consistently high sulphate values, that is, over 5 per cent. SO_4.

From the author's analytical tables and the Water Map, it will be noticed that high sulphate waters are exceedingly rare in the Northern Natal, Northern Free State and in the Transvaal (except for salt pans in the Dwyka Tillite in the Western Transvaal, and the highly saline granitic waters on the North-Eastern Transvaal border

Very occasionally waters in the Eccas series in these regions may yield high sulphate waters unaccompanied by high chloride. (For example samples 394, 380 and 96 in Table 21). In these waters the SO_4 ranges from 17 per cent. to 25 per cent., the Cl. from 4 per cent. to 5 per cent., and $Ca(HCO_3)_2$ and $MgHCO_3$ over 55 per cent. (as $CaCO_3$), so that those waters could be described as sulpho-carbonate waters.

The high sulphate content cannot be due to the aridity of the climate for the region is very well watered and the concentration of salts is only moderately high. It is suggested that the high sulphate in these isolated cases may be due to the proximity of a pyritiferous doleryte dyke, for dolerite dykes are very common in these areas, or it may be due to specks or films of pyrites in the Ecca beds.

Many high sulphate spring waters (including some of those listed as "Medicinal Springs") evolve a small quantity of H_2S gas due to the reduction of some of the sulphate by decaying organic matter.

SILICA.

As will be shown the quantity of silica in a boiler feed, water is a matter of great importance, and for that reason it is regrettable that so few of the published water analyses in this country show the silica content. Waters with high silica are, unfortunately, only too common in the Union.

Clarke (43, pp. 195–197) shows that in volcanic waters, and especially in geyser waters, SiO_2 may reach 50 parts per 10^5. He cites analyses of geyser water in which SiO_2 varies from 16–51 per cent. SiO_2 in terms of total salts. There are of course, no active volcanoes or geysers in the Union and hence waters of this type are unknown.

It has already been shown that the alkaline soda carbonate waters arising in the Old granite and the Red granite rocks (both rocks with a high alkali felspar content), show the highest average silica content, ranging on average from about 13 per cent. to 20 per cent. SiO_2 in terms of total solids, though in absolute amount the SiO_2 content very occasionally exceeds 5 parts SiO_2 per 10^5.

The arenaceous formations like the Pretoria quartzites and Waterberg sandstones yield pure waters with a relatively high percentage of SiO_2 (16 per cent. to 20 per cent. SiO_2) but in absolute amount the SiO_2 content is generally well under $2 \cdot 0$ parts SiO_2 per 10^5.

The waters with the most consistent silica content are those arising in the basic rocks of the Bushveld Igneous Complex. Not only is the average percentage of SiO_2 very high (16 per cent. SiO_2) but most of these waters have a silica content of 5–8 parts SiO_2 per 10^5, which is higher than any other waters, excluding the few Dwyka springs in Pondoland already discussed.

As already mentioned the waters of the highly mineralised chloride-sulphate group invariably contain very little silica (less than 3 per cent. SiO_2).

The temporary hard (carbonate) group of waters, of which the Dolomite waters are the best example, are extremely consistent in silica content which however, is moderately low (with the exception of the $Mg(HCO_3)_2$ waters from the basic zone or the Complex).

A fact which is brought to light by this survey, is that, although the waters with the highest percentage of SiO_2 are the soda carbonate group, it does not necessarily follow a high soda alkalinity is invariably accompanied by high silica content. For example the soda-rich waters from the upper Beaufort and Stormberg sediments do not contain much silica (from 6–8 per cent. SiO_2).

According to various authorities, waters rich in organic matter are supposed to carry much silica, but as shown on page 91, the dark coloured waters from the Table mountain series in the Cape Province carry very little silica (4–7 per cent. SiO_2).

The chemistry of silicic acid in aqueous solution is still a highly controversial subject, and there is considerable doubt as to whether the silicon is present as sodium silicate or as silicic acid.

Apparently the prevailing theory among analysts in the Union is that the silicon is present as sodium silicate, but from the author's experiences, this does not appear always to be the case.

Thresh and Beale (48) claim that 99 per cent. of the silicon in natural waters is molecularly dispersed, but Stumfer's (49) investigation on the problem as to whether the silica exists as a crystalloid or colloid contradicts this. He found that a comparison of silica concentration indicated by gravimetric methods (giving colloidal *plus* crystalloidal silica) and colorimetric tests (crystalloidal silica only) showed that, up to a silica concentration of 0·5 parts per 100,000, all the silica was present in the crystalloidal state, that is molecularly dispersed. Beyond 0·5 parts, the gravimetric test gave higher results, indicating an increasing amount of colloidal silica. Harman's (50) investigations also support this view.

Headden (51) regards silica as partly present in the form of alkaline silicates. Clarke (43, p. 195) however, states :—

> " In natural waters silica is actually present in the colloidal state and not in acid ions (SiO_2). On evaporation to dryness the silicate may form but only when there is a deficiency of other acid groups. Such a deficiency is indicated by a pronounced alkalinity in any highly siliceous water ".

In support of this view we may take the case of the $Mg(HCO_3)_2$ waters from the basic rocks of the Complex. As aforementioned the absolute amount of silicon is higher than in any other water, ranging from 5–7 parts SiO_2 per 10^5. *No soda alkalinity* is present. Furthermore, if all the silicon be calculated as Na_2SiO_3, the sum total of the constituents exceeds the total solids found by actual determination. (In these waters it is not difficult to work out a hypthetical combination of ions since only $Mg(HCO_3)_2$, $Ca(HCO_3)_2$, SiO_2 and a very small amount of chloride is present). Furthermore, as mentioned on page 52, the silica present in the surface magnesite deposits in these areas, is in the form of *opaline silica*, having been deposited from solutions as a *colloidal gel.*

However, in the case of the soda rich granitic waters, it would appear, from the total solids determinations, that part at least of the silicon is combined as alkaline silicates.

The chief difficulty in settling this problem is that as mentioned on page 8, there is no accurate method for the determination of sodium.

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FLUORIDES.

There is a certain amount of literature regarding endemic dental fluorosis ("mottled enamel") in the Union of South Africa, caused by the continual ingestion of toxic amounts of fluorine from the water used for cooking and drinking, during the period of maximum dental susceptibility (i.e. curing calcification). Nothing however, has hitherto been published regarding the distribution of fluorides in the underground waters of the Union from the geo-chemical aspect, though from the work of Ockerse (9, 10 and 78), Steyn (53), Staz (54) van der Merwe (69), and others, certain districts are known to be "mottled teeth" areas. The data collected by the author should therefore prove informative.

There appears to be very little in the overseas literature regarding the distribution of fluorides in ground water. Lindgren (35, p. 69) states :—

> "Fluorine is present in traces in many waters, both superficial and deep, but it appears in larger quantities in waters of the sodium carbonate type."

It would appear from the author's investigation that this also applies to the Union.

Unfortunately determinations of fluoride are rarely made, even in more complete water analyses. According to Gautier and Clausmann (55) the fluoride content of spring waters varies from 0·3 to 6 parts F. per million, being highest in waters issuing from areas of eruptive rocks. This also applies to the ground waters in the Union, for, as shown on page 43. all the waters issuing from the alkali volcanic rocks of the Pilansberg contain appreciable fluorides.

Lindgren (35, p. 54) and Clarke (43, pp. 193–194) cite only two analyses of waters containing fluorides, namely the Ojo Caliente spring, Taos, New Mexico, and the Sprudel, Carlsbad, Bohemia, *both sodium carbonate waters.* The fluoride in the former water amounts to 5 parts F. per million (or 0·19 per cent. F. in terms of total salts). In the latter spring water there are 1·6 parts F. per million (or 0·03 per cent. F.).

According to De Gouvenian (52) and Carles (56) the fluoride content of the famous Vichy water varies from 7–18 parts F. per million.

Sea water, according to Gautier and Clausmann (55) contains 0·3 parts F. per million. The author tested a sample of sea water from Durban Bay and obtained a figure of 0·8 parts F. per 10^5.

A potable water is usually condemned by Public Health Authorities if its fluoride content exceeds 1 part F. per million. In view of this fact it is interesting to note the high fluoride content of the celebrated Vichy and Carlsbad waters.

It should also be pointed out that recent investigations overseas have pointed to the necessity of having a small fluorine content in domestic water supplies, and in some water-works in the United States, NaF is added to the treated water in amount not exceeding 1 part part per million, as an insurance against dental caries.

The highest fluorine value for any natural water in the Union is that of highly concentrated soda liquor in the Pretoria salt pan. A composite sample taken from 27 boreholes in the pan was tested by the author and found to contain 358 parts F. per million (or 3 per cent. F. in terms of total salts). The pH. of this brine was, as already mentioned 10·6. Ockerse and Meyer (78) cite an analysis of a sample of the brine which shows 340 parts F. per million (0·27 per cent. F.). If we exclude this highly concentrated brine the largest amount of fluorine yet recorded in the Union is that in the borehole in Ledig, Pilansberg (sample 553, Table 5). As aforementioned, this water is highly alkaline with a pH. of 9·8 and a fluoride content of 35·0 parts F. per million (3·6 per cent. F. in terms of total salts) surely a record for a borehole water anywhere in the world.[*]

The author's investigations have brought to light the following facts concerning the distribution of fluoride waters in the Union :—

(1) It is only the Red granite water and waters issuing from the Pilansberg alkali rocks that consistently contain fluorides, over a part F. per million). With hardly an exception, these waters contain fluorides in appreciable amount.

Fluorides in appreciable amounts are sometimes found in the Old granite waters, particularly those in the North-West Cape, but generally speaking this is not a consistent feature of Old granite waters, while the amounts present are seldom of the same order as those in the Red granite and Pilansberg waters. The highest fluoride content in an Old granite water recorded by the author is that for the Sabie Bungalow spring (No. 405, Table 1), namely 9·0 parts F. per million (3·5 per cent. F.).

The probable source of the fluorine in these rocks has been discussed previously.

In connection with the association of fluoride waters with granitic rocks, it is intersting to note that the waters of the Colorado springs, where "mottled enamel" was first observed and described, come in contact with granite, McKay and Black, 67). In India the area affected by endemic fluorosis is underlain by granite or gneiss (68).

(2) Although waters with a consistent and appreciable fluoride content are, generally speaking, confined to alkaline waters issuing from granitic rocks and the Pilansberg alkali rocks, there are however isolated cases of waters which contain an appreciable quantity of fluoride, arising in formations other than granite or gneiss. The most important examples are the following :—

Kalkheuvel borehole water, Pretoria district, with 12 parts F. per million (2 per cent. F.), and a soda alkalinity of about 53 per cent. (as Na_2CO_3) (Ockerse 9, p. 6). The formation is probably the Ecca series.

Borehole waters in Shannon and Dewetsdorp, Orange Free State.

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[*] Since the above was written a strongly alkaline spring water (pH. 9·0 at Doornhoek 134, Pilansberg, District Rustenburg, was found to contain 67·2 parts F. per 106 (6·39 per cent. F. of total salts). 56 per cent. of the total salts consisted of Na_2CO_3 and $NaHCO_3$.

These waters rise in the Beaufort beds and have fluorine contents of 4·5 and 4·8 parts F. respectively (or 1·4 and 2·2 per cent. F.). Both waters have a high soda alkalinity over 27 per cent. as Na_2CO_3). See author's samples 498 and 502, Table 23.

Waters in certain localities in the Beaufort West district in the Cape Province, and a borehole on Vlakfontein 584, near Koster, Transvaal, also contain an appreciable quantity of fluorine.

(3) From data tabulated by the author in previous sections it will be observed that, except for the Old granite waters in the North-West Cape Province, *only those waters which contain Na_2CO_3 or $NaHCO_3$ contain an appreciable quantity of fluorine (that is excess of 1 part F. per million). The converse is however not necessarily true.* For example, the waters rising in the Beaufort beds and in the Stormberg rocks contain large amounts of soda alkali, yet only one or two (e.g. Shannon and Dewetsdorp) contain appreciable fluorine.

In section 7 it was shown that in these soda carbonate waters, the fluorine was present as NaF and not as CaF_2, since there is a large excess of Na_2CO_3 or $NaHCO_3$, and no permanent hardness.

This is a most important point. Various workers have observed that the attainment of gross symptoms of fluorine intoxication is definitely associated with the chemical nature of the fluorine compound, and it has been established that 20 times as much CaF_2 is needed to produce the same degree of severity of symptoms as is caused by NaF.

It is interesting to note that so far fluorides have not been found in more than mere traces in any of the waters in Natal and this applies even to the Old granite waters in Natal. One probable reason is that, as aforementioned, the Old granite in coastal Natal does not give rise to the soda carbonate type of water but to a slightly saline type; furthermore, owing to the high rainfall considerable leaching takes place, with the result that none of the Natal waters are highly mineralised. The problem of the removal of fluorides from drinking water is discussed under " domestic supplies ".

POTASSIUM.

Attention has previously been drawn to the paucity of potassium salts in the ground waters of the Union, even in the case of those issuing from rocks like the Red granite which contain more K_2O than Na_2O. In the highly mineralised Old granite waters of the North West Cape and North-East Transvaal the potassium content seldom exceeds 1 part K. per 10^5 while the percentage of K. in terms of the total salts seldom exceeds 0·4 per cent. The highest potassium content found in these granitic waters was that of a borehole water at Alldays in the North-Eastern Transvaal, with 2·6 parts K. per 10^5 (or 2·2 per cent. K. in terms of total salts.) In the Old granite itself Na_2O generally slightly exceeds K_2O.

In the spring or borehole waters from other formations the potassium content seldom exceeds 0·5 parts K. per 10^5. A few of the medicinal springs contain more than the above amount of potassium. For example, the Lilani spring in Natal contains 2·3 parts K. per 10^5 or 5·8 per cent. K. in terms of salts, while the Caledon spring contains 2·1 parts K. per 10^5 or 12·3 per cent. K. which must be one of the highest percentages of K. recorded in the Union. Now this " Thermal spring " issues from the Table Mountain series, but, as already pointed out, the Table Mountain series is entirely non-felspathic in the Cape Province, hence it would be very difficult to account for the potassium content. It is possible therefore that the water has it origin in some deep-seated pre-Cape rock mass, possibly the Cape granite. This theory is supported by the fact that the temperature of the water is 120° F. The complete analysis of these two medicinal springs is given in Geological Survey Memoir 32 (70).

Even the highly concentrated brines in the salt pans in Kimberley and Bloemhof district contain only a small quantity of potassium salts and this applies also to the brine of the Matsap " Nitrate " pan in which the potassium content is only 1·4 per cent. K. The potassium content of the brine in the Kimberley–Bloemhof salt pans is not usually determined and therefore the following complete analyses carried out by the author many years ago may be of interest as they show the relation between sodium and potassium. Two of the analyses have already been given in connection with the Dwyka salt pans but are reproduced here. The Dwyka tillite in the pan in the Christiana district is very thin and there are exposures of Ventersdorp lava with large porphyritic felspar crystals. This may account for the different type of brine in this latter pan and for its much higher potassium content :—

	Brine in Britten Pan Borehole No. 1. % on Dry Salts.	Brine in Britten Pan Borehole No. 2. % on Dry Salts.	Brine from Pan North of Christivna. % on Dry Salts.
NaCl	77·50	76·52	70·70
KCl	3·24	6·08	13·00
(K)	(1·6)	(3·2)	(6·85)
$MgSO_4$	12·00	9·76	—
Na_2SO_4	7·10	5·60	6·60
$CaSO_4$	—	0·48	Nil
$NaHCO_3$	Nil	Nil	5·00
Na_2CO_3	Nil	Nil	4·70
Moisture	0·20	0·47	Nil

The brine in the soda caldera, Salt Pan, Pretoria district, notwithstanding its great concentration contains only 11·9 parts K. per 10^5, or only 0·09 per cent. K. in terms of total salts : now this brine, as previously shown in primarily derived by concentration from Red granite ground waters, and in the Red granite K_2O sometimes exceeds Na_2O.

To turn now to the reason for the paucity of potassium salts in the ground waters and concentrated brines in the Union.

Analyses of fresh and weathered granite indicate that K_2O and Na_2O are removed in *more or less the same proportions from the parent rock* during the process of weathering, but it is a well established fact that *potassium and sodium compounds pass unequally into solution in the ground water.* This is on account of the fact that clayey soils tend to retain potash by " adsorption ".

The investigation of Crawley and Duncan (71) have shown that a layer of certain clayey soils only 6″ deep will adsorb 98 per cent. of the potassium salts from solution, but will let practically all the Na salts through.

It is therefore not surprising that even the granitic waters in the Union contain only very small quantities of potassium salts.

Dickenson (89, p. 43) in a discussion of the saline ground waters of the Moonaree Station, S. Australia, is puzzled apparently by the fact that, though the ground waters of this region are situated in a porphyry with a K_2O content of over 5 per cent., they contain very little potassium. He makes the following statement :—

> " If the saline matter found in the ground water were derived, at least in part from the weathered country rock, would there not be a high potassium content in the ground water of an alkali rich rock region compared with the potassium content in the ground water of a region not characterised by the presence of alkali rocks. "

However, the porphyry would give rise to a clayey soil and this could adsorb the bulk of the potassium, so that the position would appear to be analogous to that of the granitic waters of the Union of South Africa.

Sodium Carponate.

Reference has already been made to the abundance of soda carbonate waters in the Union and it has been shown that, in most of them, $NaHCO_3$ rather than Na_2CO_3 is present.

It has also been stated that soda carbonate waters are to be expected in granitic and other igneous rocks like the Stormberg lavas which contain a fair amount of *fresh* soda felspars. On the other hand the consistent and appreciable Na_2CO_3 or $NaHCO_3$ content of waters rising in the upper Beaufort and Stormberg *sandstones* is at first sight rather surprising in view of the fact that the felspar in felspathic sandstones *being usually of detrital origin,* is normally far from fresh, since the felspar grains have had a good deal of their Na_2O or K_2O content removed during transportation. It was suggested previously that in view of the probable aeolian origin of these sandstones, the felspar in the sandstones may be comparatively fresh, as it would be in granitic rocks and would therefore tend to give a rise to soda alkaline waters. Lindgren (35, p. 53) states that Na_2CO_3 waters are not common in sedimentary rocks and suggests that alkaline carbonates in these waters are probably derived from a reaction between Na_2SO_4 and $CaCO_3$ or between NaCl. and $CaCO_3$. However, this explanation could not apply to the aforementioned waters since chlorides and sulphates are generally very low indeed.

As aforementioned the waters with the highest (average) soda alkalinity are those arising in the upper Beaufort and Stormberg sediments. The maximum percentage found was that of a borehole at Hobhouse in the upper Beaufort beds with 60 per cent. (as Na_2CO_3), but the highest absolute figure so far recorded (excluding the " brine " in the soda caldera at Salt Pan) was that of a borehole in the Old granite at Alldays, Northern Transvaal, with 43·5 parts (as Na_2CO_3) per 10^5 (35·5 per cent.).

Kenny (77, p. 150) furnishes several complete analyses of the characteristics of soda carbonate waters (Jurassic age) in the Great Australian Artesian Basin. The percentage of Na_2CO_3 (or $NaHCO_3$) vary from 8 to 80 per cent., the majority being over 50 per cent. The highest absolute amount is 137 parts Na_2CO_3 per 105.

It is interesting to note that sodium carbonate or bicarbonate waters are very rare in Canada (Leverin 87).

As will be shown that the absolute amount of Na_2CO_3 or $NaHCO_3$ present in ground waters is a matter of some importance if the water is to be used for irrigation or for human consumption.

IRON.

The iron content of ground waters in the Union (excluding of course acid mine waters) is generally very low. Even the so-called "Chalybeate Springs" do not contain much iron.

It has been previously stated that certain waters, particularly some of the waters issuing from the Table Mountain series, Malmesbury and Cape granite formations in the Cape Peninsula and the Old granite along the Natal coast, show a tendency to deposit iron oxide on standing, though perfectly clear when freshly drawn.

Dealing with waters issuing from the Table Mountain series, it was pointed out that this does not necessarily indicate a high iron content and further, it had been observed that this characteristic appears to be confined to slightly acid waters with a pH. of 7 or under. The probable reasons for this were discussed.

The *iron content of the majority of waters is well under* 0·5 *parts Fe per* 10^5. It is interesting to note the iron content of the "chalybeate medicinal springs", the analyses of which are shown in Geological Survey Memoir 32 (70) :—

	Parts Fe per 10^5.	*Percentage on Dry Salts.*
Zwartkops, C.P.	1·3	3·5
Toverwater Poort, C.P.	0·3	2·4
Balmoral	4·8	11·4
Caledon, C.P.	1·4	7·3
Inungi, Mount Currie	5·3	3·2

MANGANESE.

Manganese does not appear to be present in any waters except in traces.

The concentration of manganese in the waters from the Table Mountain series was discussed previously.

XXV.—UTILISATION OF UNDERGROUND WATER FOR TECHNOLOGICAL, OTHER PURPOSES AND CHEMICAL METHODS FOR IMPROVEMENT OF THE WATER.

The utilisation of the 5 main types of water will be considered together with the corrective chemical treatments necessary to render those waters suitable for various technological purposes.

It has been shown that the underground water supplies of the Union fell under 5 main groups, as summarised in Table 27, viz. :—

(A) *Highly Mineralised Chloride-Sulphate Waters.*—Tota solids > 100 parts per 10^5, Cl. > 27 per cent., SO_4 > 5 p cent., Permanent Hardness > 12 per cent. (as $CaCO_3$).

(B) *Slightly Saline Chloride Coastal Waters.*—Total solids > 30 < 50 parts per 10^5, Cl. > 27 per cent., $SO_4 > 3$ per cent.

(C) *Temporary Hard (Carbonate) Waters.*—Total solids < 80 parts per 10^5. Total Hardness (as $CaCO_3$) > 70 per cent. Temporary Hardness > 67 per cent. (as $CaCO_3$). Permanent Hardness < 7 per cent. (as $CaCO_3$), Cl. < 7 per cent. pH. $> 7 \cdot 6$ per cent.

(D) *Alkaline Soda Carbonate Waters.*—Total solids < 100 parts per 10^5. Na_2CO_3 or $NaHCO_3 > 15$ per cent. (as Na_2CO_3). SiO_2 sometimes > 12 per cent. Total Hardness > 30 per cent. (as $CaCO_3$). Permanent Hardness nil.

(E) *Pure Waters.*—Total solids < 15 parts per 10^5. pH. generally less than $7 \cdot 0$.

It is proposed to take each of these water groups in turn and consider their adaptability for each of the following purposes :—

(1) Domestic Supply (General and Potable).
(2) Agriculture (Irrigation and Watering of Livestock).
(3) Technological :—
    (*a*) Power Production.
    (*b*) Industrial use.

DOMESTIC SUPPLY.

It is assumed that the waters under study are uncontaminated by sewerage and bacteriologically pure. Each of the groups will be considered in turn.

(i) *Group A.—Highly Mineralised Chloride-Sulphate Waters.*

It is difficult to lay down a hard and fast rule regarding the limit of salinity for potable waters. Obviously much depends on the combination of ions, e.g. whether magnesium and sodium sulphates (purgative salts), nitrates and fluorides, are present in excess. Other factors have also to be considered, e.g. humidity and temperature of the atmosphere. The higher the temperature and lower the humidity, the greater will be the quantity of water drunk.

Investigations are being carried out at Onderstepoort Veterinary Research Laboratory (Steyn and Reinach, 79) regarding the effect on human beings and stock of the continued ingestion of highly saline waters. Steyn and Reinach do not set a definite limit to the degree of salinity of drinking water, but appear to agree (79, p. 220) with certain authorities in England and the U.S.A. that the extreme limit of salinity of drinking water for human consumption should be 57 parts total salts per 10^5 ($\cdot 057$ per cent. salts), much depending on the combination of ions.

It appears to the author, however, that this limit is far too low. If applied, it would mean that a very large number of borehole waters in the Union would be condemned as being too brack. Certainly all the waters in this Group A would be condemned.

However, all authorities are not agreed on this point, and much higher limits have been suggested, even when a large proportion of the salts are the sulphates and chlorides of sodium and magnesium. The author therefore suggests that a salinity of 150 parts total solids per 10^5 be regarded as the upper limit of salinity for human consumption.

Taking this figure of 150 parts per 10^5 as the maximum, it will be observed that many of the waters in this Group are therefore far too saline for human consumption, particularly some of the waters rising in the Cretaceous and Bokkeveld formations, and in the Old granite of the North-West Cape and North-East Transvaal. Further, many of the Old granite waters of the North-West Cape contain over 1 part fluorine per million (as F.), a fact which renders these waters even less suitable as drinking water. In fact these highly mineralised waters are actually poisonous to stock and man when ingested over a long period Steyn and Reinach, (79). There is no *economic* treatment, short of distillation which will render these brack waters fit for human consumption.

In spite of this fact, such waters, supplemented by a limited quantity of rain water, form the sole drinking water supply of a large number of farmers and small town inhabitants of the Union.

It is true that human beings develop a certain degree of tolerance to such waters. Newcomers to these districts are of course, immediately affected. Steyn and Reinach (79, p. 220) point out however that, after apparent tolerance has developed, men and animals may after a long period, exhibit the more chronic effects from drinking these highly mineralised waters ; for example, retarded growth, stuntedness, decrease in productivity and deposition of urinary calculi.

Most of the waters of this group are far too hard for general domestic use, and since they generally contain in addition, very large amounts of magnesium chloride, are also particularly corrosive and may cause rusting of pipes and hot water installations, as well as scale. Some of the less saline waters in this group could be softened by putting them through a Base Exchange (Zeolite) softening plant, but it will be found that in the case of a good many of these waters the cost of maintenance makes softening uneconomic.

It has been previously mentioned that many of the towns and villages in the Southern Cape Province, located on formations giving rise to highly saline waters, are fortunately able to obtain their water supplies from pure mountain streams arising in the Table Mountain series. However, this does not apply to many centres in the Karroo and in the North-Western Cape, which are dependent entirely on highly mineralised waters for domestic supply.

(ii) *Group B.—Slightly Saline Chloride Coastal Waters.*

These waters generally have a total solid content of under 50 parts per 10^5, and fluorides are absent or present in mere traces; they can therefore be used for all domestic purposes.

(iii) *Group C.—Temporary Hard (Carbonate) Water.*

Since chlorides and sulphates are very low and the waters are composed almost entirely of $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$ all the waters in this group can be regarded as potable. For general domestic use some of the waters are not altogether suitable if untreated, for not only are they very hard, but the hardness is practically all temporary, leading to deposition of scale in hot water systems, or even in pipe lines, due to the decomposition of the unstable $Ca(HCO_3)$ and $Mg(HCO_3)_2$ with rise in temperature. However, most of these waters can be economically softened by zeolite treatment.

(iv) *Group D.—Alkaline Soda Carbonate Waters.*

As regards potability, Steyn and Reinach (79, pp. 175, 216, 220) have pointed out that the continued ingestion of strongly alkaline water (Na_2CO_3 or $NaHCO_3$) will tend to render the gastro-intestinal juices abnormally alkaline, thus leading to serious digestive and other disturbances, and even to the causation of urinary calculi. It has also been shown that Na_2CO_3 is more harmful than $NaHCO_3$. However, absolute amounts of $NaHCO_3$ or $NaCO_3$ in this group of waters seldom exceeds 24 parts per 10^5, and it is not considered likely that this amount of alkali will affect the suitability of the water for human consumption.

Therefore, excluding the Red granite waters, all the waters in this group are potable.

As previously shown, many of the Red granite waters contain more than the maximum quantity of fluorides deemed permissable by Public Health Authorities, i.e. more than 1 part F. per million, and the continued ingestion of such water will give rise to severe mottling of the teeth in children and perhaps to even more serious chronic disease. Steyn, for example (53, p. 59) suggests that the prevalence of goitre in the Kenhardt district may probably be due to a superabundance of fluorides in the drinking waters of the district, but there does not appear to be any direct proof of this theory. Ockerse (78, pp. 6–13) states that fluorides stimulates osteoblasts, producing ostephytic growths and calcification of muscles and describes cases at Kalkheuvel in the Pretoria district.

It has been pointed out that a very small amount of fluorine in drinking water appears to be beneficial rather than otherwise.

There is really no satisfactory treatment for the removal of fluorides from drinking water, though several methods have been proposed. Klein, Adler and Lindsay (72) propose the use of tri-calcium phosphate and state that 1·8 grams of F. are removed per kilogram of tri-calcium phosphate.

Van der Merwe (69 and 73) suggests the use of commercial superphosphate instead of $Ca_3(PO_4)_2$ as a defluorinizing agent and states that 1 kilogram of superphosphate can remove 9–10 grams of F. solution. This treatment apparently does result in a reduction in the total amount of fluorides, but as aforementioned, no treatment has proved entirely satisfactory.

The solution of the problem may lie in the recent discovery and development of "organic zeolite" treatment (i.e. complete removal of *all cations and anions* by filtration through beds of synthetic resins). This process is, however, as yet, not fully developed. It is discussed later.

For general domestic use all the waters in this group are quite satisfactory, though cases have been observed of corrosion of pipe lines conveying $NaHCO_3$ waters, the corrosion being due to liberation of the excess CO_2 even in the cold.

(v) *Group E.—Pure Waters.*

These waters are all potable, but since they lack calcium they would benefit from the addition of small amounts of lime.

For general domestic use all the waters in this group, with the exception of the dark coloured spring waters from the Table Mountain series, are very suitable.

As previously shown, the coffee coloured mountain spring water from the Table Mountain series is distinctly acid, pH. figures of as ow as 4·5 being common. An ernormous amount of damage has been caused to hot water systems and even to metal pipe lines by the use of untreated water from the Table Mountain series. The corrosion of pipe lines results in the trouble known as "red water" which is a serious matter as far as municipal supplies are concerned.

However the acidity of water from the Table Mountain series can easily be corrected by the addition of a small quantity of lime, care being taken to avoid excess of lime, which otherwise might lead to scale in the pipe line. An even more efficient chemical to inhibit the rusting of pipe lines is sodium hexametaphosphate (Calgon). With pure waters only about 0·5 to 2 parts of this salt per million parts of water is necessary for this purpose. Sodium silicate in small doses is also used to protect pipe lines against corrosion by such waters, and does not affect the potability of the water in any way. The organic colouring matter in the water can only be removed by coagulation with $Al_2(SO)_2$ and alkali.

AGRICULTURE, IRRIGATION AND WATERING OF LIVE STOCK.

From the point of view of irrigation, the injurious salts which may be present in water are, in order of toxicity—

Na_2CO_3
$MgCl_2$
$NaCl$
$CaCl_2$
Na_2SO_4
$MgSO_4$

For watering livestock, Na_2SO_4 and $MgSO_4$ in excess and Na_2CO_3 and NaCl in large excess, are to be avoided.

(i) *Group A.—Highly Mineralised Chloride-Sulphate Waters.*

There appears to be a divergence of opinion among agricultural authorities regarding limits of salts permissible in irrigation waters. Much of course depends upon the nature of the soil, i.e. whether the soil is light, sandy and well drained or of a heavy clayey impervious nature, as well as the nature of the salts.

The Bureau of Soils, U.S.A. (74) states that it is unsafe to use a water having a concentration greater than about 250–300 parts per 10^5 for irrigating land. Perkins (75) states that, although waters highly charged with saline matter have sometimes been used on light well drained soils, a combined total of 143 parts per 10^5 or over of *chlorides* of any type, together with the carbonates and sulphates of sodium and magnesium, may be regarded as excessive.

In view of the foregoing statements, it will be observed that many of the waters in this group, more particularly the Bokkeveld and Cretaceous waters and the granitic waters from the North-West Cape, are quite unsuitable for irrigation unless the soils are exceptionally well drained.

As in the case of human beings, the effect of saline water upon livestock depends on the quantity of water drunk daily, the concentration of salts in the water, and the nature and relative proportion of salts present in rhe water.

Certain species of animals are, however, more sensitive than others to saline waters. Steyn and Reinach (79, pp. 199–200) point out that the order of susceptibility to saline water is as follows: poultry and pigs, horses, cattle, sheep.

Sheep can tolerate far more saline water than any other domestic stock. Stock generally can tolerate far more saline water than human beings, but there is disagreement among authorities as to the safe limit of salinity. Certain authorities suggest 1,500 parts per 10^5 (1·5 per cent.) as the upper limit.

Steyn and Reinach (79, pp. 190–197) consider that concentration of salts much lower than 1,000 parts per 10^5 are harmful to livestock if they partake of it daily and over long periods. They mention several cases from the Kenhardt district.

If we take 600 parts solids per 10^5 as the upper limit, it will be observed that some of the waters in this group, particularly those from the North-West Cape, are unsuitable for watering stock. The majority could, however, be used.

As regards the fluorides that often occur in the saline waters of the Old granite in the North-West Cape, Steyn (53, p. 17) points out that from all available information cattle and sheep are far less susceptible than human beings to fluorine, and that their drinking waters have to contain 4–6 parts F. per million before their teeth are affected. Therefore, provided that these granitic waters of the North-West Cape do not exceed the maximum limit in salinity, they could be used for watering livestock, since fluorines are generally under 5 parts per million.

(ii) *Group B.—Slightly Saline Chloride Coastal Waters.*

The concentration of injurious salts in the waters of this group are so low that the waters are very suitable for irrigation and the watering of livestock.

(iii) *Group C.—Temporary Hard (Carbonate) Waters.*

There are no injurious salts present in these waters, so that they can all be used with impunity for watering livestock and for irrigation.

(iv) *Group D.—Alkaline Soda Carbonate Waters.*

Since Na_2SO_4 is present in these waters only in exceedingly small amount, the only injurious compound is " black alkali " (Na_2CO_3 or $NaHCO_3$) which is highly injurious to vegetation when present in appreciable amount.

Perkins (76) states that few crops can tolerate 100 parts Na_2CO_3 or $NaHCO_3$ which is highly injurious to vegetation when present in appreciable amount.

Hilgard (75) states that few crops can tolerate 100 parts Na_2CO_3 per 10^5 *in any type of soil* while on heavy soils smaller amounts are injurious.

Simpson (57, p. 145) states that upwards of 37 parts per 10^5 of Na_2CO_3 are injurious to plant life.

Although in some waters of this group in the Union the percentage of Na_2CO_3 or $NaHCO_3$ is extremely high (more particularly in the upper Beaufort waters) the absolute amounts of alkali are generally under 35 parts per 10^5 (as Na_2CO_3), so that the majority of the waters of this group could be used for irrigation provided the soil is not too heavy.

The prevalence of soda carbonate waters in the Union no doubt *accounts for the fact that so many of our soils are deflocculated*, for apart from injurious action on plant life, $Na\ CO_3$ has deflocculating action on the clay present in soils, with the possible formation of a hard pan beneath the surface of the soil which cannot be penetrated by plant roots.

The waters of this group are suitable for watering livestock, though the high fluoride waters in the Red granite and Pilansberg rocks may have some effect on teeth of cattle, since the fluorine content is sometimes over 5 parts F. per 10^5.

(v) *Group E.—Pure Water Group.*

The waters belonging to this group are all suitable for watering of livestock and irrigation purposes.

POWER PRODUCTION.

Waters in connection with the power industry may be considered under the following heads :—

(1) Cooling waters for the water jackets of oil engines, and in cooling systems of turbo-alternator plant.

(2) "Make-up" for boiler feed water in steam plants and water used for evaporators in boiler plant.

(3) Water for steam locomotives.

Cooling Waters.

It is assumed that the water used is recirculated and that it does not pass once only through the cooling system.

At the present time the majority of power plants in the smaller towns consist of oil engines.

Water is used for cooling the cylinders. Though there is an appreciable rise in temperature of the cooling water in the jacket, the maximum temperature under *normal* operating conditions does not exceed 180° F.

A certain amount of concentration of the water takes place in the spray ponds into which the cooling water passes, but the rate of concentration is never excessive under *normal* conditions and the "make up" seldom exceeds 10 per cent.

There is even less rise in temperature in the cooling water in the condensing system of turbo-generator steam plant, the maximum temperature under normal operating conditions being in the neighbourhood of 110° F. The rate at which concentration takes place in spray ponds or cooling towers through which the water passes is, of course, dependent on temperature, humidity and wind conditions but is small compared with the rate of concentration which takes place in steam boilers. The "make up" to the cooling water does not generally exceed 10 per cent.

Therefore in the cooling water systems of both oil engines and steam plant, the concentration factor is small compared with that in boiler waters, while the temperature of the cooling water is *always well below boiling point.*

In spite of this fact, scale problems are common in both types of plant. Scale in the water jackets of oil engines can be a serious matter since it often results in a cracked cylinder head.

In steam condensers the heaviest deposition occurs at the point of highest heat exchange, i.e. the upper banks of tubes in the first pass. The effect of an accumulation of scale in the first pass of a condenser is to reduce the rate of transfer between condensate and cooling water, this increases the rate of deposition of scale. The result is a lowering of vacuum and condenser efficiency.

TABLE No. 28.—ANALYSES OF SCALE FORMED IN COOLING SYSTEMS OF POWER PLANTS AND THE WATER USED FOR COOLING.

1.	2.	3. Ladybrand	4. Lichtenburg	5. Winburg

TABLE No. 28.—ANALYSES OF SCALE FORMED IN COOLING SYSTEMS OF POWER PLANTS AND THE WATER USED FOR COOLING.

	1. Graaff Reinet Plant.		2. Brandfort Power Station.		3. Ladybrand Power Plant.		4. Lichtenburg Power Plant.		5. Winburg Power Plant.	
	Scale Percentage.	Raw Water Percentage on Total Solids.	Scale Percentage.	Raw Water Percentage on Total Solids.	Scale Percentage.	Raw Water Percentage on Total Solids.	Scale Percentage.	Raw Water Percentage on Total Solids.	Scale Percentage.	Raw Water Percentage on Total Solids.
Moisture	0·41	—	1·65	—	0·21	—	1·51	—	0·60	—
SiO_2	2·60	4·20	3·10	7·7	0·84	—	0·80	0·7	6·44	7·7
Al_2O_3 Fe_2O_3	9·2*	0·41	0·26	—	Trace	—	0·31	0·24	3·56*	—
CaO	44·76	14·00	49·91	11·8	53·64	14·4	51·15	26·0	48·0	16·8
$(CaCO_3)$	(78·5)	—	(89·0)	—	(95·0)	—	(90·5)	—	(86·0)	—
MgO	2·60	10·3	2·99	16·2	1·92	2·4	2·00	22·5	2·53	15·8
$(MgCO_3)$	(5·4)	—	(6·3)	—	(4·0)	—	(4·2)	—	(5·3)	—
Cl	Trace	28·3	Nil	9·8	Nil	6·7	Nil	4·5	Nil	8·0
SO_3	0·56	Trace	0·11	5·85	Nil	Trace	0·40	2·70	0·10	8·0
CO_2	36·56	16·4	38·28	36·0	40·8	36·5	42·25	42·05	39·6	25·0
Na_2CO_3	Nil	Nil	Nil	22·5	Nil	49·5	Nil	Nil	Nil	Nil
Organic Matter, etc. (By Difference)	3·31	—	3·70	—	2·59	—	1·58	—	Nil	—
Total	100·00	—	100·00	—	100·00	—	100·00	—	100·83	—
Ratio CaO : MgO	1 : 0·06	1 : 0·74	1 : 0·06	1 : 1·3	1 : 0·04	1 : 0·2	1 : 0·04	1 : 0·85	1 : 0·05	1 : 0·9

* Scale contained rust.

The author carried out the following investigation into the nature of the scale formed in the cooling water system of both oil engines and steam plant in the Union. Samples of scale found on cylinder heads of oil engines and in the condenser tubes of steam plant were analysed. Samples of the raw water used for cooling were also analysed, the results being expressed as a percentage of total salts in order that comparison could be made with the scales. The results are shown in Table 28 and are very striking.

None of the waters used for cooling purposes were treated in any way. As will be observed from Table 28, several different types of waters were used.

Case 1.—*Graaff Reinet, C.P.*

The water used was of a very hard, somewhat saline type with a CaO : MgO ratio of 1 : 0·74. The scale in the cooling system consists of 78·5 per cent. $CaCO_3$ with only 5·4 per cent. $MgCO_3$, the balance consisting of rust from corrosion of the metal. (CaO : MgO ratio in the scale is 1 : 0·06.)

Case 2.—*Brandfort, O.F.S.* (*condenser tubes*).

(For complete analysis of water see 235, Table 22).

This borehole water was of the soda carbonate type; the hardness was therefore all temporary. Na_2SO_4 was appreciable. The CaO : MgO ratio was 1 : 1·3. The scale consisted of 89 per cent. $CaCO_3$ and only 6·3 $MgCO_3$ with but a trace of sulphate. (CaO : MgO in the scale is 1 : 0·06.)

Case 3.—*Ladybrand, O.F.S.* (*condenser tubes*).

(For complete analysis of water see No. 35, Table 24).

This borehole water was also of the soda carbonate type, but sulphates were absent. CaO : MgO 1 : 0·22. The scale consisted of 95 per cent. $CaCO_3$ with only 4 per cent. $MgCO_3$. (CaO : MgO 1 : 0·04).

Case 4.—*Lichtenburg, Transvaal* (*oil engine*).

(For complete analysis of water see No. 36, Table 10).

This spring water was of the carbonate type C and consisted mainly of $Mg(HCO_3)_2$ and $Ca(HCO_3)_2$. Ratio CaO : MgO 1 : 0·85. $CaSO_4$ was present in small amount. The scale consisted of 90·5 per cent. $CaCO_3$ and 4·3 per cent. $MgCO_3$, (CaO : MgO in the scale 1 : 0·04.)

Case 5.—*Winburg, O.F.S.* (*oil engine*).

(For complete analysis of water see No. 546, Table 23).

This water was of a very hard type, with an appreciable $CaSO_4$ content (i.e. Permanent Hardness present). CaO : MgO ratio 1 : 0·9. The scale consisted of 86·0 per cent. $CaCO_3$ with only 5·3 $MgCO_3$, while $CaSO_4$ was only a trace. (Ratio CaO : MgO in the scale 1 : 0·05.)

Two facts emerge from this investigation :—

(1) Whatever the nature of the water, scale, if formed at all, consists almost entirely of $CaCO_3$ with but a very small amount of $MgCO_3$. Calcium sulphate, calcium silicate and other compounds often present in boiler scales, are entirely absent or in traces only.

(2) There is always a partial, sometimes almost complete elimination of magnesium. This being due to the fact that not only is $Mg(HCO_3)_2$ slightly more stable than $Ca(HCO_3)_2$ but $MgCO_3$ is more soluble than $CaCO_3$, so that scale deposition does not occur to the same extent.

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It is known that the stability of the bicarbonates can be broken down by mechanical agitation and a rise in temperature, resulting in the loss of some CO_2, and both factors operate in cooling water systems.

It follows therefore that the waters in which the proportion of $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$ are high, i.e. high temporary hardness (example the Dolomite waters), are more prone to give rise to scale in cooling systems than waters in which the temporary hardness is low and the hardness is mainly permanent (i.e. due to the nitrates, chlorides and sulphates of calcium and magnesium.)

It is proposed to consider the suitability of each group of waters as cooling waters in the light of these facts.

(i) *Group A.—Highly Mineralised Chloride-sulphate Waters.*

In these the temporary hardness is low as compared with the permanent hardness, and in view of this fact they are generally speaking, quite suitable for use in the condensing systems of steam plants, and this applies to a less extent to use as cooling water in oil engine jackets, provided, of course, that undue concentrations is avoided.

However, in some of the more mineralised waters of this group (e.g. the granitic waters of the North-West Cape and North-Eastern Transvaal), the concentration of temporary hardness compounds $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$, though very low in comparison with the permanent hardness salts, may be found to be sufficiently high to lead to scale troubles in oil engines.

In the case of these waters base exchange (zeolite) treatment of the " make up "water of the cooling systems is generally uneconomical in view of the high concentration of Ca and Mg salts other than $Mg(HCO_3)_2$ and $Ca(HCO_3)_2$.

(ii) *Group B.—Slightly Saline Chloride Waters.*

The concentration of all salts in these waters is very low as compared with the previous group. Furthermore, the permanent hardness compounds are relatively high as compared with the temporary hardness forming compounds [$Ca(HCO_3)_2$ and $Mg(HCO_3)_2$]. It follows therefore that these waters are suitable without treatment for the cooling systems of both types of power plant.

(iii) *Group C.—Temporary Hard (Carbonate) Waters.*

Though the concentrations of these waters are generally not very high (except for the dolomitic waters in the Kaap Plateau) the dissolved compounds consist almost entirely of $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$. Hence these waters, if untreated, will invariably give rise to serious scale troubles in the cooling water systems of both types of power plants. However, these carbonate waters are particularly suited for base exchange (zeolite) treatment. It is true that the $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$ are converted by this process into $NaHCO_3$ thus resulting in a highly alkaline water, but this does not matter at all in cooling water systems, however undesirable it might be in boiler feed water " make up ". Therefore base exchange treatment or some other form of treatment is absolutely essential before they can be used for cooling purposes.

Sodium hexametaphosphate (calgon) treatment of the " make up " could possibly be substituted for base exchange treatment, but in most cases the initial concentration of $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$ is too high. This will be discussed hereafter.

(iv) *Group D.—Alkaline Soda Carbonate Waters.*

Since these are similar to the waters of the preceding group, except that there is an excess of Na_2CO_3 or $NaHCO_3$, the same remarks apply as regards suitability for cooling. The concentrations of $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$ are, however, very much less than in the carbonate waters and treatment may not always be necessary. Base exchange treatment of the "make up" to the cooling waters could be used, but treatment with sodium hexametaphosphate will be found to be simpler and require no capital outlay for treatment plant.

In a paper in 1938, the author (80, p. 87) suggested the use of sodium hexametaphosphate for treating circulating waters for condensing systems of steam plant by virtue of the fact that $Na(PO_3)_6$ [or more correctly $Na_2(Na_4P_6O_{18})$] has the unique property of holding up calcium and magnesium in solution in a soluble couplex even up to fairly high concentrations, *provided the boiling point is not reached.*

This $Na(PO_3)_6$ treatment of cooling waters has since been applied and expanded into the so called "Threshold Treatment", viz.: Hatch and Rice (81) and Rice and Partridge (82) in 1939.

The addition of only a very small dose of sodium hexametaphosphate (1–5 parts per million) to the cooling water will prevent precipitation of $CaCO_3$ even on the threshold of crystallisation, hence the term "Threshold Treatment".

It should be pointed out here that the Threshold Treatment is entirely distinct in principle from the treatment of boiler feed waters with $Na(PO_3)_6$. (Calgon).

The Threshold Treatment of cooling waters can be applied to even the highly alkaline waters such as are found in this group *provided the initial $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$ content is not too high.*

The concentration of temporary hardness compounds in the circulating water in this treatment should not exceed 30 parts (as $CaCO_3$) per 10^6 and must be controlled by systematic blow down.

For some years the author has been recommending the addition of $Na(PO_3)_6$ to certain types of cooling waters in this country, and the results up to date, have been satisfactory but more particularly with condenser circulating water. Incidentally it may be stated that this Threshold Treatment is *not satisfactory or economical in the case of the highly mineralised waters of Group A on account of the high initial concentration of calcium and magnesium.*

(v) *Group E.—Pure Waters.*

These waters in view of the exceedingly low concentration of salts are suitable, without treatment, for the circulating waters in condenser systems of steam plant.

Even the spring waters from the Table Mountain series, which have a low pH. due, as already stated, mainly to organic (humic) acids, should not corrode the brass condenser tubing, and should certainly not lead to any scale.

This water would however tend to rust the cast iron or cast steel cylinders in the water jackets of oil engines. The slight acidity could be corrected with lime, care being taken to prevent an excess of lime which would result in scale.

Boiler Feed Water.

During recent years the tendency has been to instal evaporator plant to provide for steam losses in turbo-alternator plants rather than to utilise treated surface or borehole water as " make up " water for boiler feed.

Nevertheless, as far as the Union is concerned, in large numbers of turbo-alternator plants, treated surface or borehole water is still used as " make up " water.

We are not concerned here with surface water, which usually requires a preliminary clarification treatment with aluminium sulphate or a mixture of aluminium sulphate and sodium aluminate [Bond (7), pp. 63–64].

It is assumed here that the borehole or spring water is free from suspended matter.

Changes in modern boiler design have all been in the direction of higher pressures, higher temperatures, higher ratings and larger units, so that the problems of scale, corrosion and priming are becoming increasingly important and consequently our standards regarding purity of water supplies for make up purposes have been radically altered during the past fifteen years.

It is beyond the scope of this treatise to go fully into the highly specialised subject of boiler feed water treatment and conditioning, but it is proposed to take each group of waters in turn, discuss their suitability for boiler feed make up purposes and suggest possible corrective chemical treatment.

(i) *Group A.—Highly Mineralised Chloride-Sulphate Waters.*

These waters are potentially corrosive as well as scale-forming, since the chlorides of magnesium and sodium are appreciable.

A very high chloride and sulphate content is the chief characteristic.

There is no economic treatment for the removal of chlorides, so that even in these cases where the make up is as low as 3–5 per cent., this chloride will concentrate in the boilers and result in excessive primary and other troubles.

The concentration of chlorides in the boiler can be controlled to a certain extent, by " blow down ", but naturally there is an economic limit to the amount of blow down.

In the case of many of the waters in this group, the initial chloride concentration is far too high, and the only remedy is to instal evaporator plant in order to provide distilled water as make up for boiler feed. Some of the highly saline waters in this group would soon scale-up evaporator plant, but scale in evaporator plant is not as serious as in boiler plant, and is more easily removed, and in any case the water could be treated before being evaporated.

Some of the less saline waters in this group are used as boiler feed make up in many of the smaller Karroo towns, but even after elaborate and expensive chemical treatment the results are far from satisfactory. In any case the chloride content necessitates an enormous amount of blow down.

The appropriate chemical treatment for *these less saline waters* is a preliminary softening with lime and soda ash followed by filtration and then conditioning with small amounts of phosphates or phosphotannates in order to remove all the residual hardness left after the lime-soda softening. The phosphate to be used should depend on the boiler alkalinities. The following are commonly used: trisodium phosphate, sodium hexametaphosphate or sodium tetraphosphate.

In the case of " closed feed " systems the water is sometimes also conditioned with sodium sulphite to remove residual oxygen and to supply the sodium sulphate concentration deemed necessary by certain alkalinities, as an inhibitor against so called " caustic embrittlement ". The " conditioning " of treated feed water with phosphates and sodium sulphite has been discussed by the author in three previous publications Bond, (80, 84 and 86).

The " base exchange " or zeolite treatment might be used for the preliminary treatment of these waters instead of the lime-soda treatment, since in these waters the permanent hardness is generally far greater than the bicarbonate water, but this base exchange treatment, though yielding zero hard water, does not result in a reduction of total solids, and leaves the water with a high concentration of solids.

At this point it may be stated that the author is cognisant of the recent sensational developments in the " exchange " treatment of water.

The development of synthetic resins which exhibit exchange absorbent properties has opened up a new field of application and promised unique uses in the purification of water. Theoretically it is possible to start off with the most saline of the waters in this group and by means of a hydrogen zeolite process to end up with what is virtually distilled water, but in actual practice the process, which results in the total elimination of both cations and anions, is uneconomic for certain waters under existing conditions in the Union. In the old basic exchange or zeolite treatment Ca and Mg were exchanged for an equivalent amount of Na. In the recent development *all cations* present in the waters are replaced by hydrogen. Briefly the process may be summarised thus :—

$$(1)\quad \begin{matrix}Ca(HCO_3)_2\\ Mg\\ Na_2\end{matrix} + H_2Z = 2H_2CO_3 + \left.\begin{matrix}Ca\\ Mg\\ Na_2\end{matrix}\right\}Z$$

$$(2)\quad \begin{matrix}Ca(SO_4)\\ Mg\\ Na_2\end{matrix} + H_2Z = H_2SO_4 + \left.\begin{matrix}Ca\\ Mg\\ Na_2\end{matrix}\right\}Z \quad \text{(}H_2Z\text{ is the hydrogen ion exchanging material).}$$

$$(3)\quad \begin{matrix}Ca\ Cl_2\\ Mg\\ Na_2\end{matrix} + H_2Z = 2HC. + \left.\begin{matrix}Ca\\ Mg\\ Na\end{matrix}\right\}Z$$

The exchange material is regenerated with H_2SO_4. The next step is the removal of free acids, by passing through beds of acid absorption material, thus leaving what is virtually distilled water. It is this latter stage of the process which still has to be worked out satisfactorily.

CO_2 produced, as in equation (1) can be removed very easily in a degasifier, hence the process would be particularly suitable for carbonate waters. This fact will be discussed later.

The main objection to this process, at the present time, appears to be the high initial cost of the equipment and the fairly rapid deterioration of the organic substances employed. This latter factor would apply more particularly to the treatment of the saline type water found in the Union.

In conclusion it is repeated that the only satisfactory way dealing with this group of waters is by the installation of evaporating plant.

(ii) *Group B.—Slightly Saline Chloride Waters.*

These waters are potentially corrosive since they generally contain magnesium chloride. The salts in these waters do not usually exceed 50 parts per 10^5, but chlorides are relatively high in relation to other salts, so that these waters are not suitable for high pressure boiler plant, with their high steaming rates, for the concentration of chloride would soon become appreciable, necessitating very frequent blow-down even when the make up is only 3 per cent. After appropriate treatment these waters could be used as " make up " for boilers operating up to 250 lb. per sq. ins. provided the make up does not exceed 5 per cent. Temporary hardness is greater than the permanent hardness and consequently these waters are not altogether suited for base exchange treatment.

The appropriate treatment would be a preliminary softening with lime and soda followed by conditioning of the filtered water with small amounts of phosphate, sodium sulphite, and so on.

(iii) *Group C.—Temporary Hard (Carbonate) Waters.*

These waters contain only $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$ and are thus potentially scale forming. The hardness, being temporary, is easily removed, and since chlorides are negligible these waters are very suitable for boiler feed make up. The appropriate treatment is preliminary softening with lime and a little soda followed by conditioning with phosphate. In this case the alkalinity, after lime treatment, is generally high, so that the acid sodium hexametaphosphate would be preferable to the tri- or di-sodium phosphate. Since the preliminary cold lime-soda softening does not reduce the hardness much below 5 parts $CaCO_3$ per 10^5, it is advisable to add a small amount of sodium aluminate along with the lime and soda. This results in a much lower residual hardness, a more rapid settlement of floc, part removal of silica, and prevents the " after precipitation " of $MgCO_3$. As the author has pointed out in previous papers Bond, (80, p. 75, and 84, pp. 3–4) it is necessary that magnesium compounds be present in appreciable quantities in the raw water for sodium aluminate to be effective.

The waters from the basic zones of the Bushveld Igneous Complex offer peculier difficulties, inasmuch as the water contains practically only $Mg(HCO_3)_2$ with a very high silica content. These waters can however, be satisfactorily softened and the silica largely eliminated by the addition of larger amounts of sodium aluminate in the preliminary softening than are normally used.

A base exchange softening is often erroneously applied to these waters. This may result in a zero hard water, but the $Mg(HCO_3)_2$ and $Ca(HCO_3)_2$ are merely exchanged for an equivalent amount of $NaHCO_3$ and the total soluble salts are not reduced. In the boiler the $NaHCO_3$ is decomposed into NaOH and the corrosive CO_2 gas. High alkalinity are to be avoided in boiler water. Of course, base exchange treatment could be combined with an after treatment with H_2SO_4 to convert the $NaHCO_3$ into Na_2SO_4 but this is not altogether satisfactory since the total salt content in the water is not reduced in any way. A very effective treatment would be by means of the hydrogen zeolite referred to previously. This will be discussed under the soda carbonate waters.

(iv) *Group D.—Alkaline Soda Carbonate Waters.*

These waters contain a certain amount of $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$ and are therefore potentially scale-forming. The chief difficulty is in regard to the high soda and silica content of these waters.

It is essential to reduce the $NaHCO_3$ or Na_2CO_3 content for both are decomposed in the boiler into NaOH and CO_2. The NaOH soon concentrates and leads to foaming. Since "antifoam" compounds containing castor oil or other oils, are not suitable for use in high or medium pressure boiler plant, it follows that excessible blow down would be required to control foaming.

The CO_2 evolved will contaminate the steam, corrode superheaters and aggravate corrosion of turbine blades. It reappears dissolved in the condensate, rendering it corrosive. Apart from foaming, there is also the problem of the so called caustic embrittlement in riveted steam boiler drums. This embrittlement is supposed to be inhibited by maintaining a certain ratio of Na_2SO_4 to NaOH, but the author has expressed his doubts, in previous publications Bond (84, p. 11, 85, pp. 75–76, and 80, pp. 76–77) as to the effectiveness of this remedy.

At one time the usual method with soda carbonate waters was a treatment with $CaSO_4$ followed by lime treatment. This was very simple but far from efficacious, owing to the insolubility of $CaSO_4$. The $CaSO_4$ was added in an attempt to convert Na_2CO_3 and $NaHCO_3$ into $CaCO_3$. The author has suggested the following treatment for these waters. Lime plus soda aluminate treatment to reduce the the temporary hardness and silica, filtration, and then conditioning with phosphoric acid to reduce the alkalinity (H_2SO_4 could be used but a certain amount of $CaSO_4$ will be formed). This phosphoric acid treatment is effective, as it results in a water of practically zero hardness and with a considerably reduced alkalinity. It will also prevent the formation of a silica scale. It is, however, expensive with some of the more highly alkaline waters in this group.

It must be emphasised, however, that, in the above methods, one is merely replacing Na_2CO_3 or $NaHCO_3$ by an equivalent amount of other sodium salts, which, though less dangerous than the former, will cause priming in high concentrations.

The recently developed hydrogen zeolite exchange process referred to in a previous page appears to be the ideal treatment for these alkaline waters for, as shown in equation (1), all the cations are removed and the net result is a water containing little else than CO_2. This CO_2 is easily removed in a degasifier, and all that would then be necessary is to add a small amount of Na_3PO_4 to the water to elevate the pH. However, as far as the author is aware, this process has not yet been applied in the Union.

(v) *Group E.—Pure Waters.*

With the exception of spring waters from the Table Mountain series, these waters only require the addition of a small amount of alkali to elevate the pH. of the water to inhibit corrosion. Treatment with sodium silicate is not recommended when the water is used for boiler feed purposes, if the water contains calcium.

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In the case of the dark coloured acid waters from the Table Mountain series in the Cape Province, it is desirable to add a very small amount of lime to neutralise the acidity and precipitate the organic matter, followed by filtration and then a conditioning with a minute amount of phosphate to eliminate the residual hardness due to any excess of lime.

The relatively high chloride content of the waters ariving in the Table Mountain series necessitates far more blow down than would be the case with other waters of this group.

Feed Water for Locomotive Boilers.

Suitability of the various types for use as locomotive feed water will now be discussed.

Locomotive boilers have to work under very different conditions from those existing in the stationary steam plant in power stations.

To begin with no return condensate is available, *the whole of the water having to be obtained from natural resources.*

In addition treated water from many different sources, different widely in composition, often gets mixed in a locomotive boiler.

Furthermore, in comparison with the feed water in a closed feed system of a modern stationary steam boiler plant, the water is far more aerated. The pressures, are however, much lower.

The water capacity of the large locomotive boilers used in this country is about 3,000 gallons, and in a round trip of 400–500 miles, the boiler will evaporate about 30,000 gallons. Thus the salts will have been concentrated ten times. It may be pointed out that a very much higher concentration of solids is allowed in a locomotive boiler than in a stationary boiler, for concentrations up to 1,000 parts per 10^5 can be permitted under certain circumstances in the former boilers, whereas 300 parts would be regarded as excessive in stationary boiler plants of 250 lb. pressure or over.

Owing to this concentration factor, priming and foaming are more serious problems in locomotive feed water practive than in stationary boiler steam plant.

The quantity of water blown off under operating conditions will naturally be dependent on the type of water used but will normally vary from 5 per cent. to 20 per cent. of the total water fed to the boiler.

The treatment given to locomotive feed water does not differ essentially from modern practive in power stations, and it is therefore not necessary to go into this question in detail. It is sufficient to state that there should be a preliminary softening with lime soda and a little sodium aluminate followed by filtration, or a base exchange softener may be used if the permanent hardness is much greater than the temporary hardness.

A zero-hard boiler water is aimed at in the higher pressure boilers in stationary boiler plant, but a boiler water hardness of 2–3 parts $CaCO_3$ per 10^5 is usually deemed satisfactory in locomotive practice.

Phosphate-tannin boiler compounds are added in small quantities to the softened feed water, as internal conditioners. It is preferable that the phosphate should be the hexametaphosphate or the tetraphosphate since the use of di- and tri-sodium phosphate may lead to the deposition of phosphatic sludge in the injectors and feed pipes. If tetra- or metaphosphate be used, then deposition of the soft phosphatic sludge is delayed until the high alkalinity and temperature conditions of the boiler are reached.

Minute quantities of "antifoam" compounds such as castor oil are often added to inhibit foaming, but naturally there are limitations to their use.

Both the pure water Group E and the slightly saline water Group B are very suitable, after appropriate treatment, for locomotive boiler feed.

The temporary hard waters Group C, are suitable for locomotive boiler feed if efficiently treated, but it is essential that the treatment with lime, soda and sodium aluminate be satisfactory, otherwise trouble will occur in the injectors which heat up the feed water to about 150° F. In the injectors loss of CO_2 takes place resulting in the deposition of $CaCO_3$ (and to a much lesser extent, of $MgCO_3$) and this may lead to scaling up of the injector cones, thus causing serious trouble and delay. The silica which, as has been shown, is present in appreciable amount in the magnesium bicarbonate waters from the basic zones of the Igneous Complex will cause very thin hard silicate scale unless inhibited by phosphate conditioners.

The highly alkaline soda carbonate Group D of waters are not easy to treat for locomotive feed water. The $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$ present can be eliminated by efficient lime-soda-sodium aluminate treatment but the high Na_2CO_3 or $NaHCO_3$ content, as well as the usually high silica content, constitute a problem. The Na_2CO_3 or $NaHCO_3$ are converted in the boiler into NaOH and this will rapidly concentrate and cause excessive foaming, apart from the question of caustic embrittlement. Furthermore, highly alkaline water will tend to corrode the copper stays and other copper parts of the older types of locomotive boilers. The addition of an anti-foam compound, and very frequent blowing down will inhibit foaming to a certain extent, but naturally there is a limit to these palliative measures. Adequate phosphates will inhibit scale to a certain extent. Preliminary treatment with gypsum ($CaSO_4$) will bring down the soda alkalinity, but, as has already been stated, this process is not very efficaceous.

Some of the waters of the highly mineralised chloride-sulphate Group A are far too saline for use as locomotive feed water as their use will lead to excessive priming. Some of the less saline waters could be used after lime-soda or zeolite softening, followed by the addition of a suitable "phosphate-tannin" conditioner and an anti-foam compound. It is difficult to generalise with regard to the concentration of total solids at which priming may be expected to take place in a locomotive boiler, for priming is dependent on a number of factors, namely, the design of the locomotive boiler, the load factor, the gradient of the line, the presence or absence of suspended matter, the nature and concentration of the salts in boiler water, and the presence or absence of an "anti-foam" compound. At concentrations of above 300 parts per 10^5, particularly with highly alkaline water (and all softened water will be alkaline) priming and foaming may take place, but by the use of an anti-foam compound a concentration of as much as 700 parts may be reached before the priming or foaming occurs.

Generally speaking, the use of a borehole water with over parts total solids is uneconomical, for even when an anti-foam co pound is present the boiler solids have to be kept down below parts per 10^5 with the result that the amount of blow down

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be excessive. It follows that, though the majority of waters in Group A can be and are used for lack of better waters as locomotive boiler feed in the Union, their use is uneconomical and leads to a number of problems.

INDUSTRIAL USES.

There is hardly any industry or prospective industry in the Union in which the quality of the water is not of paramount importance. The more important are the following :—

(i) *Wool Washing.*

Since soap and alkali are used in the process, it is essential that the water should not be too hard or too saline, otherwise insoluble calcium and magnesium soaps would be formed and deposit in the wool. The hardness should not exceed 8 parts $CaCO_3$ per 10^5. The waters of the pure water Group E are suitable, while some of the waters of the slightly saline Group B could be used. The waters in the carbonate Groups C and D could be used after treatment, but in some cases the cost of softening might be excessive in view of the amount of water used.

Iron is extremely deleterious for wool washing. It has been stated that water from the Table Mountain series and other waters in Groups B and E show a tendency to deposit iron oxides on standing. Provided sufficient time is allowed for these waters to stand before being used, all the ferrous bicarbonate will oxidise and come out of solution, and these waters would then be entirely suitable.

(ii) *Starch Manufacture.*

Starch is sensitive to colouration, and the product must be white. Hence the brown waters from the Table Mountain series would first have to be decolourised. Iron and manganese must be removed, and the water should not be too saline or too hard.

(iii) *Yeast Manufacture.*

There do not appear to be many limitations, though the water should not be too saline, and of course, sterile.

(iv) *Soap Manufacture.*

If too hard a water be used in the preparation of the alkaline liquors wastage of alkali results through precipitation of the insoluble calcium and magnesium compounds. If too hard a water be used in the boiling of the soap insoluble calcium and magnesium soaps would be formed, thus resulting in an inferior product. Hence Group C and D waters would first have to be softened. Most waters in the B and E Group would be very satisfactory.

(v) *Textile Industry.*

In the cleaning process, the detergent will combine with calcium and precipitate insoluble soaps that will adhere to the fibre of the fabric.

In the dyeing process, as pure a water as possible should be used since the presence of calcium and magnesium salts cause unevenness of colour deposition. Iron causes rust stains and is thus particularly deleterious. The pure water Group E is suitable provided iron be allowed to settle out before use, but the organic colouring matter in waters issuing from the Table Mountain series would render them unsuitable unless decolourised. The waters of Groups C and D would first have to be softened to eliminate as far as possible calcium and magnesium bicarbonates which would otherwise precipitate on the fibres.

(vi) *Brewing Industry.*

The quality of the water used for brewing is important, as affecting the product. A very pure water is not regarded as suitable. The water should contain a moderate amount of $CaSO_4$, with a small amount of NaCl. Saline waters and waters containing appreciable bicarbonates of calcium and magnesium, such as Groups C and D, are undesirable, as are also those which contain even small amounts of iron. The pure water Group E could be adjusted, if necessary, with $CaSO_4$, etc., but organic matter should be absent, hence dark coloured waters from the Table Mountain series are unsuitable. Group B waters would be suitable.

(vii) *Tanning Industry.*

Tannin precipitates calcium, magnesium and iron in the leaching vats, resulting in the loss of tannin. In addition iron forms dark coloured precipitates with tannin, thus giving rise to discoloured leather. Waters containing sodium carbonate and bicarbonate, cause precipitation of lime in the "liming" process and are to be avoided; likewise those containing organic matter, such as the waters in the Table Mountain series. Therefore Group E waters, with the exception of the waters of the Table Mountain series are very suitable. Group D waters would first have to be softened to remove the bicarbonate of calcium and magnesium, but Group D contain too much soda alkalinity and are to be avoided.

The slightly saline Group B would be quite satisfactory.

(viii) *Paper and Pulp Industry.*

Paper manufacture requires a fairly pure water.

Manganese, iron and organic colouring matters should be absent, hence the dark coloured spring waters arising in the Table Mountain series are not suitable as they would tend to "rust stain" the paper. The other waters in Group E would be satisfactory provided the small amount of iron be allowed to settle out before use. Some of the waters in Group B would be satisfactory, but waters of the Group C and D type would first have to be softened. Naturally highly saline waters would have to be avoided.

(ix) *Cotton Wool Manufacture.*

If the water contains appreciable calcium and magnesium bicarbonates the insoluble carbonates would deposit on the cotton fibres during the "kiering process" and these deposits are very difficult to remove by subsequent washing. Hence Group C and D waters would first have to be softened. Groups B and E would be, in most cases, satisfactory even when untreated.

(x) *Water and Concrete.*

Water used for concrete mixing should conform to certain standards.

Firstly, the water should be non-acidic, but this refers to mineral acids, i.e. acid mine waters. Hence the slightly acid but otherwise pure waters from the Table Mountain series described in Section 15 may be used with impunity, since the acidity in these waters is due to small amounts of the so called "humic acids" and not to mineral acids.

Secondly, the water should be free from a high concentration of organic matter, since it has been shown from the work of Grûn (92, p. 498) and others that concentration of 1 per cent. or over (based on weight of mix) almost completely inhibit the setting and hardening of Portland Cement.

However, in spite of appearance, the dark coloured waters from the Table Mountain series can be used with impunity for concrete mixing, for, as shown in Section 15, the organic content of these waters seldom exceeds 3 parts per 10^5 (·003 per cent.), so that the organic content of the mix would be negligible.

Thirdly, concrete specifications usually state that the mix water should be free from *objectionable* quantities of certain salts, although no fixed limits are set.

It is known from the investigations of Dorsch (91), Grûn (92), Lea and Desch (90, p. 190–191) and others that the chlorides of calcium and magnesium, and the carbonates and bicarbonates of sodium in appreciable amount (1 per cent. or over) lead either to a retardation or acceleration of set. Abrams (93) has shown that the use of sulphate water in concrete mix produces little ill effect until a concentration of 1 per cent. SO_4 is reached, when a 10 per cent. reduction in strength of the concrete results.

However, the concentration of these salts in bore-hole or spring waters in the Union, with the possible exception of a few of the more heavily mineralised waters found in the arid North West Cape, falls far below the concentrations used by the above investigators in their tests, so that the majority of ground waters in the Union can be used with impunity for concrete mixing.

The effect of certain waters on concrete pipes and storage tanks, etc., is however, quite a different problem.

Very pure waters, such as those classified as Group E, tend to leach out the lime from concrete pipes or vessels, if these be unprotected, and several causes of this have occurred recently in the Union.

It has also been found that continued exposure to water containing more than 100 parts per 10^5 of the sulphates of calcium, magnesium and sodium may endanger concrete, through deposition in the pores of the concrete, particularly when the structure is exposed to alternate drying and wetting. Some of the more heavily mineralised waters of chloride-sulphate Group A might cause trouble in this respect.

XXVI.—SUMMARY.

A geo-chemical survey, embracing all the principal geological horizons, has been made of the underground water supplies of the Union of South Africa.

It has been shown that each geological formation yields its characteristic salts to the percolating waters. Certain formations give rise to waters having very striking chemical characteristics.

A chemical classification has been made of the various types of ground water encountered in the Union, and it has been shown that these waters fall naturally within five groups, though there is a certain amount of overlapping.

A water map has been compiled to illustrate the distribution of these various types of ground waters in the Union of South Africa.

The utilisation of these types for various purposes has been fully discussed, but more particularly with regard to utilisation in the power industry.

The corrective chemical treatment necessary to render each of these types of water suitable for various technological uses has also been discussed.

The concentration of certain elements in the natural waters of the Union, and any significance attaching thereto, has also been discussed and comparisons have been made with underground waters of other countries.

It has also been shown that though it is exceedingly difficult and dangerous to generalise on the relation between the composition of ground water and the geological history of the formation in which it arises, nevertheless a study of the composition of the water may occasionally throw light on certain problems connected with the origin of a particular formation, e.g. whether it was laid down in the sea or in fesh water.

The relation between underground water and surface limestone (calcareous tufa) deposits have also been discussed and certain deductions drawn regarding the origin of these deposits.

The origin of the salts in the concentrated soda liquor in the soda caldera near Pretoria and in the brine in the inland salt pans has been discussed and it has been shown that these liquors do not differ basically from the usual ground waters of the geological formations in which they occur.

The effect of climatic conditions on the composition of the underground water is discussed and it has been shown that, though climatological factors play a very important part, the tendency is to exaggerate their importance.

In conclusion, the fact must be emphasised that a very large portion of the Union of South Africa is without supplies of surface water, while perennial streams are few. Hence a chemical survey of the underground water supplies of the Union appears to be a matter of no little importance.

Investigations are being carried out by the Union Department of Public Health into the incidence of dental fluorosis and dental caries, while at Onderstepoort Veterinary Research Laboratory investigations are being made regarding the effect of the continued ingestion of highly saline and hard waters on livestock. It is hoped that this underground water survey will tie up with research of this nature.

In view of all these facts the author sincerely trusts that this treatise may prove to be of some value.

The scope of the subject is so vast that the author has been barely able to touch on the essentials of the subject, and many problems remain to be solved.

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(3) Frommurze, H.
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(5) Juritz, C. F....
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(The names of the farms are printed in italics.)