SOUTH AUSTRALIA.

DEPARTMENT OF MINES.

Geological Survey of South Australia.

BULLETIN No. 14.

Geological Structure and other Factors in Relation to Underground Water Supply in Portions of South Australia.

By R. LOCKHART JACK, B.E., F.G.S., Deputy Government Geologist.

Issued under the authority of
The Honorable R. S. RICHARDS, M.P., Minister of Mines.

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LETTER OF TRANSMITTAL.

Geological Survey of South Australia,

Adelaide, May 13th, 1930.

Sir,—

I have the honor to submit to you a report prepared by Mr. R. Lockhart Jack, B.E., F.G.S., Deputy Government Geologist, on the relation of geological structure to underground water supply.

This report, with the explanatory sections that accompany the text, will be found to serve a dual purpose:—

(*a*) In the first place, the sections supplement in a useful way the geological map of South Australia published in 1928. There are many portions of the State in which nearly horizontal rock formations or shallow deposits of the youngest sediments extend continuously over wide areas. The sequence of the formations at many individual places was indicated on the geological map by columns of figures, but it was not found possible to show the thickness of each nor the variations of structure from one point to another. The sections printed with this Bulletin reveal these structural features and have been so located as to afford the maximum information obtainable from the records and samples from a large number of boreholes. The coloring of the successive formations corresponds with the coloring used on the geological map of the State, in order that the sections may be read easily in conjunction with the map.

(*b*) Secondly, the sections provide a useful source of reference for the use of those who are developing underground water supplies. In the majority of cases the sections traversed areas that are utilized by the pastoralist, but in a portion of the Murray River Artesian Basin the sections traverse agricultural country.

I have, &c.,

L. KEITH WARD, Government Geologist.

Submitted for approval to print as a Bulletin of the Geological Survey of South Australia.

Approved,

R. S. RICHARDS, Minister of Mines.

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UNDERGROUND WATER SUPPLY.

INTRODUCTION.

The development of the pastoral industry of South Australia hinges on the provision of adequate and reliable water supplies, as the vegetation of the interior, though sparse, is largely edible, and practically any of the country could, in normal years, be lightly stocked, as far as fodder is concerned.

Throughout the pastoral regions natural surface waters are, as a whole, very poorly developed. Under suitable conditions waterholes may be present in creek channels, but those that can be regarded as absolutely permanent are very few in number, and serve but a trifling proportion of the pastoral country. Both the large and the small waterholes are of very great use in fair to good seasons, and they are supplemented by tanks or dams excavated to depths of 20ft. or more. Even with this provision for surface storage the danger of failure of the water supply is not wholly removed, and underground resources have been sought and are being increasingly developed.

The writer has found that a great deal of misconception, or even ignorance of the natural laws controlling the origin, distribution, and quality of underground water exists, and that, in consequence, a great deal of useless and expensive work has been done which would have been saved if these laws had been better understood. An endeavor has been made in this Bulletin to give a brief account of the structural and other principles controlling the presence, quality, and supply of underground water in South Australia, so as to enable a prospective searcher to make the best possible selection of a site, and to form some idea of his prospects of obtaining water.

The sparse stocking that is judicious in the driest areas means that only a small herd or flock can permanently utilise one watering point, and consequently the capital expenditure on providing such water, including the waste on failures, must be reduced to a minimum if development is to proceed on sound lines. The north-eastern portion of the State may be cited as a good example of the commercial limits imposed by depth and light stock-carrying capacity, for although it is known that the Artesian water of the Great Basin underlies it at depths up to 6,750 feet, and can be got with certainty, the tapping of this water in the area of 5in. of annual rainfall has not been carried out by private enterprise to a greater depth than about 2,200ft. Any considerable depth in excess of this makes the utilization of the water a non-commercial proposition, unless—as is seldom the case in a region where dust and sand storms are prevalent—the water can be led through open drains to serve a considerable area.

The writer has, during the past 18 years, seen a considerable proportion of the drier portions of the State in connection with the provision of water supply, and has endeavored to elucidate the factors governing the occurrence of useful or useless water as a guide to the selection of bore or well sites. Much of the State has perforce not been seen, owing to the area, the absence of demand for water, and the lack of opportunity. At the same time there is no very large geological province that has not had some portion of its area examined in some detail with regard to its water-bearing possibilities. Such known areas range in size from a few hundred to several thousand square miles. Information has been collected in them of practically all the holes sunk, successful or otherwise, and an endeavor made to understand the conditions affecting each site.

THE LIMIT OF USEFUL WATER.

One of the disabilities that South Australia suffers in common with other parts of the south of the continent is the poor quality of much of the ground water, and even of the lesser artesian basins.

Salinity is in places very pronounced, and consideration must always be given to the possibility of excessive salinity in seeking a water supply.

The writer, in 1912, when on Eyre Peninsula, found the water problem acute. Farmers were carting water many miles from rain water tanks, and mixing it with well water of poor quality for the use of their stock. Naturally enough, as the carriage of fresh water was very costly the dilution was the minimum possible. From the proportions used it was possible to construct the following table showing the maximum salts that could be tolerated:—

Sheep	2½oz. per gallon
Cattle	1½oz. per gallon
Horses (at grass)	1¼oz. per gallon
Horses (in work)	1oz. per gallon
Man	½oz. per gallon

Water of 1.44oz. (Petina Well) was stated by the users to have been drunk exclusively by them for a period of three months.

The amount of salts given above on which stock can live is applicable to grass country, and the concensus of opinion among sheep men is that, in saltbush country 2oz. should be regarded as the upper limit. At the same time, in saltbush country, water with 2.38oz. of salts (Chowilla) has been used throughout the year, and 2.47oz. water (Five Mile Well, Quondong Vale) in a period of drought. Other highly saline waters are used, but only in emergency, and in default of better adjacent to available pasturage.

Less information has been collected as to the limit of tolerance for cattle. Pan Well (1.63oz.) has carried cattle through a dry summer, and Old Ediacara Well (1.69oz.) for six weeks, on good but dry herbage.

The accumulation and examination of analytical data and records of the utilization of these waters and of the conditions of pasturage led the writer to the conclusion that it was desirable to reduce analyses of various types of water to a common basis, so that the effect on stock could be approximately forecast, and make it possible to determine whether a water could be equipped and used with reasonable security.

All water analyses made for the Department of Mines by Mr. W. S. Chapman show the ions and the "assumed salts" calculated from the ionic analysis. To get a comparable basis, the writer, on empirical grounds based on the reaction of waters on stock, set out a table of factors for each of the "assumed salts" to express the toxicity of such salts in terms of sodium chloride. A paper was read by the writer on this subject before the Australian Association for the Advancement of Science (1926) in the hope of causing a discussion that would result in more accurate factors. Subsequently a joint discussion by the Chemical and other Societies of Western Australia took place, and it was the consensus of opinion that it was desirable to be able to make such comparisons, and the suggestion was made that experimental work be done to determine the relative toxicity of different salts.

The factors proposed and still used by the writer, in default of better, are:—

Calcium carbonate	$CaCO_3$	x 0
Calcium sulphate	$CaSO_4$	x .8
Calcium chloride	$CaCl_2$	x 2.0
Magnesium carbonate	$MgCO_3$	x .2
Magnesium sulphate	$MgSO_4$	x 2.0
Magnesium chloride.	$MgCl_2$	x 2.0
Sodium carbonate	Na_2CO_3	x 1.0
Sodium sulphate	Na_2SO_4	x 1.8
Sodium chloride	NaCl	x 1.0
Silica	SiO_2	x .0

With these factors the analysis is reduced to grains "equivalent to NaCl" (salt) per gallon, and then calculated as a percentage of the worst water known to be in regular use over a period of 12 months. While the results may not be exact, the waters hitherto compared fall into order with their observed effect on stock, and the comparison is certainly much more reliable than that of the mere summation of total salts that is generally used.

The quality of the water governs the use which may be made of it. In farming districts an ounce to the gallon is generally regarded as the limit of utility, as horses are largely used and cannot work satisfactorily on more highly mineralised water. Again, in parts of the eastern portion of the Nullarbor Plain the water is too bad for cattle, but is suitable for sheep.

ORIGIN OF THE WATER.

The ground water within the State has a local source in the rainfall falling directly above it or being brought to the spot where the ground water exists by creeks or rivers of no great magnitude. Some of the pressure water, however, enters the earth beyond the limits of the State and travels laterally to enter South Australia. Chief of this is the Queensland and the Central Australian Artesian waters which cross the eastern and northern boundaries of South Australia and travel towards the line of mound springs, extending from Dalhousie through the Coward to the north-eastern extremity of the Flinders Range.

The useful water of the Murray Basin comes from south-western Victoria, and the small Border Basin, superimposed on the southern edge of the Great Basin to the north of Cockburn, derives its waters from the slopes of the Barrier Range in New South Wales.

THE ORIGIN OF SALINITY.

The writer in 1912 had his attention called to the work of Gray (A.A.A.S., vol. I.) on the salts brought down by rainfall in New Zealand and has become more and more certain that this so-called "cyclic salt," in the absence of surface run-off and with high evaporation from the soil, is the major cause of the high salinity of so much of the saline ground waters of the State.

Samples taken by the writer, on Yorke Peninsula, from rain water tanks fed from iron roofs, gave chlorine equivalent to 8.54lbs. of salt per acre-inch of rainfall.

Two similar suites of samples of rain water collected from Eyre Peninsula in 1929 gave chlorine equal to 12.8lbs. and 6.5lbs. of sodium chloride per acre-inch, the latter figure, owing to the incidence of the rainfall caught, being subnormal

Many more isolated analyses could be given showing the existence of salt in rainfall in South Australia.

Ground water, being the residue left after soil evaporation and run-off, in the absence of the latter, must carry all the cyclic salts brought to the earth by rain, and this, in areas of high evaporation and low rainfall, explains sufficiently the condition of saline ground water that is normal in South Australia except under exceptional conditions where surface accumulations of rain water can enter the earth before being concentrated by evaporation, in such bulk as to dilute to harmless proportions the salts stored in the soil.

The existence of cyclic salt and high evaporation must ever be borne in mind considering the development of ground waters in the drier portions of the State.

EXPLANATION OF SECTIONS—PLATES II., III., AND IV.

While the Geological Map of the State delineates the surface areas occupied by each geological series, it cannot fully embody the particulars that have been recorded as to structure in depth or the limits and relationship of the various minor aquifers that have been disclosed by bores. For the purpose of showing these relationships in depth, lines of sections have been prepared through the basins and other aquifers, and are reproduced in this bulletin on a horizontal scale of 16 miles to the inch and a vertical scale of 2,000ft. to the inch. On these sections the color scheme closely follows that of the Geological Map (1928 edition) where color is used.

Heights have been obtained from railway and other surveys and aneroid readings where available, but a good deal of the profile has had to be estimated from topographic features and stream channels and their relation to points of known height. They can thus only be regarded as approximate, though sufficiently close not to seriously distort the sections.

Records and personal examinations of many bores and wells and of samples from others have been used to determine the materials penetrated. Depths and qualities are given for the various waters cut where such information is available, but unfortunately, in the case of many of the older bores sunk in search of flowing water, there is reason to believe that waters were cut between the ground water and the main flow and not recorded, or even recognised, owing to the upper waters not being cut off by casing so long as it could be inserted freely, or until it was necessary to shut off as the main water was approached. Where the information is available the horizon at which water was cut, and whether it is under pressure or not, is shown on the sections, and flowing bores are also indicated. Where information as to quality is available the content of salts is shown in ounces per Imperial gallon. When the salinity is expressed in decimals of an ounce, the water has been analysed, but if in fractions, the salinity has only been determined by a salinometer.

Colors have been used in these sections to indicate the geological sequence, and it will be noted that boundaries of formations are indicated with varying degrees of accuracy. Where the junction is definitely established by a bore or bores in reasonable proximity to one another, a solid line is used, but where, though there is no doubt as to the continuity of the series, the position in depth is only approximately correct, broken lines are used. In places where the formation is in all probability continuous, but the depth cannot be even approximately given, the colors are not separated by any line Thus, in using the sections as a guide to future boring, it will be possible to estimate with reasonable accuracy the prospects of obtaining useful water, the depth to the water desired, and to determine at what depth it would be advisable to cease boring in case the hole is a failure.

The conditions governing the occurrence of underground water in South Australia may be most conveniently discussed under two main heads—those of Pressure waters and those of Ground waters.

THE PRESSURE WATERS.

THE GREAT AUSTRALIAN ARTESIAN BASIN.

A considerable portion of this basin has been traversed by the writer and its boundaries crossed, but by far the greatest amount of information as to its vertical structure has been gained by examinations of bore samples preserved in the Engineer-in-Chief's Department and elsewhere, and by the correlation of many bore logs.

Nothing is known of the formations on which the Jurassic sands which constitute the main aquifer rest, except on the margins and from bores adjacent thereto. The known relationships are as follows:—

(1) In Central Australia, on the Finke River south of Crown Point, the Jurassic overlies and dies out on the Permo-carboniferous glacial beds [1] and is overlapped by the Lower Cretaceous formations.

(2) On the Upper Hamilton and Alberga the underlying rocks are the gneisses and granites which extend eastward from the Musgrave Range.

(3) East of Mount Johns the sands rest on the series of sediments to which an Ordovician age has been provisionally assigned.

(4) The Lake Phillipson Bore gives the deepest available section of the sub-Jurassic sediments. Beneath the sands are the coal measures, presumably Triassic; a large thickness of unidentifiable shales, with erratics in the shale between 2,000ft. and 3,100ft. On the evidence of the erratics this material may be classed as Permo-carboniferous. The hole finished in granite.

(5) From Commonwealth Hill to the vicinity of Kingoonya the Jurassic sands rest on a Pre-Cambrian complex made up of gneisses and highly metamorphosed sediments. Jurassic outliers are very close to masses of intrusive felspar porphyry, which penetrate the still older granites and sediments.

(6) Between Wirraminna and Lake Torrens the basin is bounded by an extensive series of flat-lying quartzitic rocks, overlain by residual patches of limestone and underlain by a thinbedded shaly slate. This series is presumed to be of Ordovician age.

(7) Thence, past the Flinders Range through Lake Frome the basin is underlain by rocks of the type of the Adelaide series, with the exception of an area at the north-eastern extremity of the Flinders Range. Here the edge of the basin is formed by faults which bring the Jurassic and Cretaceous beds against granitic rocks.

Two inliers of Pre-Cambrian rocks occur in the Basin:—The Denison Ranges and a group of small outcrops to the south-east of Stuart's Range Opal Field. [2]

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(1) L. Keith Ward, Trans. Roy. Soc. of S.A., vol. XLIX., p. 67.

(2) Geological Map of S.A., 1928.

Bores near the western group show this series to underlie the Jurassic sands.

There is a measure of doubt as to the age of the formations penetrated by the Duff Creek (Boorthanna) Bore west of the Denison Range. The log shows the last bed of sand to be present at 197ft., and thence to 2,088ft. blue shale with thin layers of limestone is reported. If this shale is Lower Cretaceous, and it may be, as it contains thin limestone beds, the depth is abnormal for the locality. Inflammable gas was recorded from this bore, a phenomenon that is not characteristic of the Cretaceous marine shale. It is possible that this bore has penetrated the lower pre-Jurassic beds exposed in the Lake Phillipson Bore.

The Jurassic Water-bearing Beds.

The main aquifer extends as a practically continuous body under the whole of the basin and underlies the driest areas of three States and of Central Australia. In Queensland and New South Wales it contains lenticular shale beds, but in South and Central Australia such beds have not been recognised near the margins where the sands have been penetrated, nor in the main area, possibly because very few bores have had to be sunk more than a few feet into the sand to get a sufficiency of water. At Charlotte Waters, just north of South Australia, the No. 1 Bore entered the sand at 614ft. and had not passed out of it at 1,474ft. Clayey sand and "soft micaceous rock" between 925ft. and 1,233ft., which interpose a sufficient barrier to hold the water in the lower sand under a pressure that enabled it to rise 10ft. above the waters of the upper sand, is the nearest approach to shale beds so far recorded.

The grain of the water-bearing beds and their coherency is variable. In Queensland, at Whetstone, east of Goondiwindi, they outcrop as a soft sandstone of medium grain, very absorbent, and so loosely cemented that it disintegrates in water. On the western margin some of the sands are much coarser and may be best described as grits. This grit consists essentially of quartz with a bluish grey tinge, and in places quartz pebbles up to 2in. in diameter occur on the exposed surface of the Jurassic beds. In the bulk of the South Australian portion of the basin the sands are considerably finer grained, as shown by a sizing test, made by W. S. Chapman, of sands from a number of bores. The results of the tests are recorded in detail in the Government Geologist's Annual Report for 1927. The power of water to travel through a sand bed—other factors being equal—is dependent on the size of the sand particles, and the "effective size" of the grains is the size at which 90 per cent. is retained on and 10 per cent. passes through a sieve of that aperture. From the table in the Annual Report the following effective sizes are arrived at by interpolation:—

Effective Sizes of Sand Grains.

Bore.	Sand Stratum. Depth in Feet.	Effective Size. Inches.
Mirra Mitta	3,529—3,534	.0035
Cannuwaulkaninna	2,838—2,847	.0030
Clayton	1,704	.0120
Charlotte Waters	1,263—1,363	.0058
Stevenson	1,150—1,170	.0054
Stevenson	1,192—1,193	.0060
Tmbitcha	255—345	.0037
Raspberry Creek	260—280	.0093
Arboola	1,015—1,060	.0044
Currawarra	1,065—1,075	.0047
Yandama	1,600—1,625	.0055

For the most part the water-bearing sands occur as a very soft sandstone or sandrock that may disintegrate with the flow of water, but silicified sands are not unknown. Associated with these sands are brownish to black pieces of lignitic wood, which have been thrown out by some of the bores, and are recorded in the logs of others.

The limits of the Jurassic sands are approximately indicated below.

South of Crown Point they rest upon the Permo-carboniferous outcrop, but do not outcrop owing to the existence of an overlap of the Lower Cretaceous shales. (1) To the north-eastward, but still in Central Australia, their presence at the surface may be inferred from the dying out of considerable stream channels leading from the eastern Macdonnell Ranges. The hydraulic gradient also indicates the presence of an intake in this region.

They are exposed west of Charlotte Waters and are fed by the Goyder and Coglin Rivers. (2)

On and south of the Wintinna Creek headwaters there is an extensive tract of sandy country that must, in part, represent the outcrop of the Jurassic series, but there is a merging into the Recent sands that are the predominant surface feature to the westward, so that the boundary must remain very indefinite. The presence of Cretaceous remnants resting on the flank of the Ordovician tablelands establishes the overlap of the Cretaceous on the Jurassic east of Mount Chandler.

Still farther to the south the Jurassic sand is known to be fed by Woorong, Long's, and Carringalana Creeks.

Thence, to the Transcontinental railway near Kingoonya and Tarcoola, its outcrops have been recognised by their relation to the overlying patches of shale and by the typical bluish-grey quartz grit.

Some of these areas appear to fill valleys and depressions in the Pre-Cambrian terrain.

For some distance to the eastward in this south-western region the shale cover is very thin and the Jurassic sands have been exposed in the flat valleys where the shale has been eroded. From near Kingoonya to near Lake Eyre there is no evidence of outcropping sands, but beyond this to as far as the border of New South Wales they are definitely absent. In the last-named portion the sands have thinned out to a feather-edge and been overlapped by Cretaceous shale, except in the vicinity of Petermorra Springs, where the sands are down-faulted relatively to the granite. At these springs artesian water of carbonate type issues, not through the line of fault which is blocked by the plastic shale, but through the fissures of the granite. The normal ground water in this granitic area is sulphated and not carbonated.

In the south-eastern corner of the South Australian portion of the basin the sands thin out and are deeply overlapped by the Cretaceous formation, but the position of the edge of the water-bearing sands is known with reasonable accuracy as a result of the boring that has been done.

Lower Cretaceous ("Blue Shale").

Overlying the Jurassic beds is the marine Lower Cretaceous formation, attaining in South Australia a maximum known thickness of 2,714ft. at Goyder's Lagoon Bore. Towards the west and south it overlapped the

(1) L. K. Ward, Trans. Roy. Soc. of S.A., vol. XLIX., p. 67.

(2) H. Y. L. Brown, Geological Explorations in the West and North-West of South Australia, pp. 71/1905.

Jurassic beds for a considerable distance, weathered remnants being recognised as far to the west as Mount Chandler, where they rest directly on rocks of the Ordovician (?) and Adelaide series. (1) This western extension has suffered a large amount of erosion, and weathering has converted it into a white or light-colored shale to depths of 150ft. to 200ft.

F. W. Whitehouse (Queensland) has divided the Lower Cretaceous series into the Tambo, Roma, and Morven formations in Queensland, and, on the fossil suites submitted from South Australia, has been able to correlate some of the fossil localities. (2)

The lowest or Morven formation is the transition series above the Jurassic beds, and, in South Australia, is represented by beds, about 50ft. to 100ft. thick, of sandy shale and clayey sands. The normal color is somewhat more greyish than the overlying Roma formation. Bores may get small supplies of artesian water in it before striking the Jurassic aquifer.

Above the Morven lies the Roma formation, containing, as do the overlying marine shales, thin fossiliferous limestone beds. With the possible exception of the Morven formation, the Lower Cretaceous series is a very poor aquifer. A little salt water is occasionally recorded in it, and in the high and weathered portions in the west small supplies of useful water have been found where conditions are favourable.

There is, however, a point of structural interest provided by the presence of erratics in the area occupied or formerly occupied by the Cretaceous formation. Recorded as evidence of ice action by H. Y. L. Brown in 1894, they were seen by the writer in 1914 west of Warrina. (See Bulletin 5, G.S.S.A., p. 42.) The writer suggested that they were transported by ice in Lower Cretaceous time.

At Lake Phillipson Bore these Lower Cretaceous erratics are strewn over the surface of the weathered Lower Cretaceous shale, while the bore (a diamond drill) proved the existence of pieces of felspar porphyry and granite embedded in shale beds, presumed to be of Permo-carboniferous age, at depths between 2,000ft. and 3,100ft. As these Cretaceous erratics are composed of resistant quartzite, felspar porphyry, and granite, they remain on the surface as the shale is eroded beneath them. From examination of bores and logs and of the erratic-strewn country, the writer considers them to be not more than 400ft., and possibly 300ft. above the Jurassic sands, if the latter are present.

In the western and more elevated portion of the basin this Cretaceous shale has suffered very complete oxidation, so that there is no resemblance to the unweathered shale. The weathered material shows white, yellow, pink, mauve, and ochreous colors and a considerable variety of texture. It may be "chalky," shaly, indurated with conchoidal or dice-like fractures, or may be hardened to a porcellanite. The ancient surface became silicified in the form of a widespread crust, but this type of alteration appears to be now less active than when the undissected and ill-drained surface must have had to dispose of almost all its rainfall moisture by evaporation, the dropping of dissolved silica resulting in the formation of an almost complete siliceous crust. With the erosion of the region this crust has broken up to form the typical mantle of gibbers. This white shale, with its silicified crust, was long regarded as a separate formation, but the occurrence of fossils of the Roma facies associated with the erratic boulders *in situ* at Stuart Range, has enabled the formation to be assigned to its geological position.

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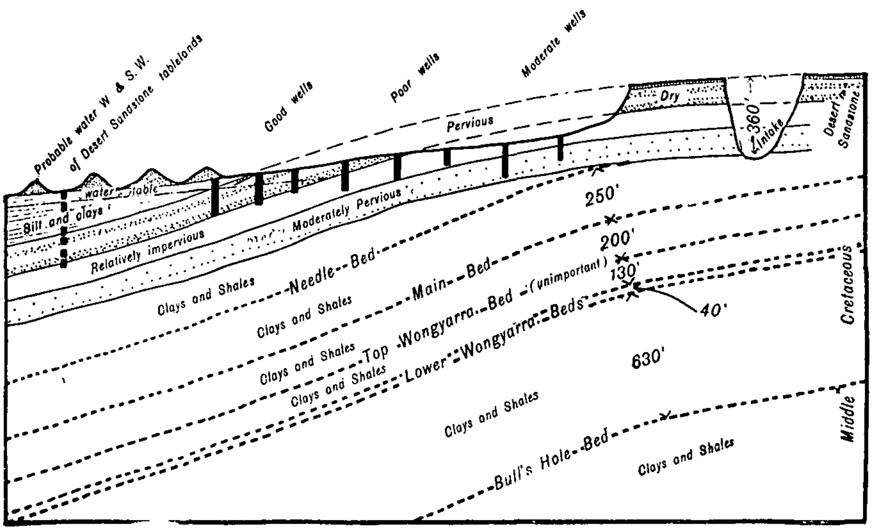
(1) Bulletin 5, G.S.S.A.

(2) Trans. Royal Soc. S.A., vol. XLIX., 1925.

Upper Cretaceous or Winton Beds.—To the eastward of the exposures of the Lower Cretaceous beds, boring has demonstrated the existence of the great fresh water Upper Cretaceous series known in Queensland as the "Winton Beds." They contain lignitic and carbonaceous formations, and at Kuntha Hill, near Kopperamanna, some prospecting of these coal beds was done many years ago. Only three small areas in South Australia are known as outcrops of the Winton beds, in part because of the difficulty of recognition, but chiefly by reason of the Recent to Eyrian cover. At Patchawarra Bore the Winton series has a thickness of 3,695ft., but thins out to the west and south, and does not overlap the marine shales except in the extreme south-east of the South Australian portion of the basin. The beds are a little more arenaceous than the underlying marine shale, while the colour is a grey-green rather than the grey-blue of the marine shale. The formation contains a number of sandy beds that may carry water, and the basal bed is so distinctly sandy that it has been identified in the bore samples with certainty. This series is, for reasons given later, of considerable importance as a source of water, and the known areas will be discussed as separate basins.

Eyrian.—Overlying the Winton beds is the series that has been named Eyrian by Woolnough and David. (1) Lithologically it closely resembles the weathered Lower Cretaceous seen by the writer on the Alberga, Arckaringa, and Evelyn ("Desert Sandstone" of Bulletin 5). The formation described as "Desert Sandstone" in Bulletin 5 is the northern extension of the beds carrying Lower Cretaceous fossils at Stuart's Range, whereas at Cordillo and Murnpeowie the Eyrian is definitely unconformable on the Winton beds.

At Cordillo Downs, where topographical features are pronounced and the deeper beds have been penetrated by a number of bores, it was possible to work out the structure in detail and to establish the unconformity with the Winton beds. On Murnpeowie the unconformity covers the Winton beds and the marine "blue shale."



Section on Cordillo Downs, showing the unconformity between the Eyrian (Desert Sandstone) and the Winton Beds (Cretaceous) and their aquifers.

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(1) W. G. Woolnough and Sir T. W. E. David, Cretaceous Glaciation in Central Australia, Q.J.G.S., vol. LXXXII., Part 3, 1926.

The Eyrian beds are about 360ft. thick at Cordillo. (1) The upper third is fairly arenaceous, and where topographical conditions permit the absorption and retention of water, yields important supplies. The middle third, being essentially argillaceous, is a very poor aquifer, and also in most localities prevents the entrance of water to the rather more open-textured lower third. The upper crust became silicified, prior to the dissection of the formation, to form a dense superficial quartzite. The silicification is less pronounced with increased depth.

The breaking down of this crust forms the characteristic "gibbers" that cover so much of the artesian basin. The water-bearing potentialities of the series are discussed later.

The Attitude of the Beds of the Great Basin.—The topography and the flexures of the beds must be considered together. The highest portions of the basin are along the western side of the Dividing or Coastal Ranges of Queensland, where in places the elevation is over 1,400ft. The north-western margin in Central Australia is about 700ft. to 800ft. above the sea, while in South Australia the elevation ranges from nearly 1,000ft. at the head of Evelyn Creek to about 500ft. near Kingoonya, with probably a somewhat lower area near Lake Phillipson.

South of the watershed of the Flinders River in Queensland the surface has a general slope in all directions towards the low-lying area extending from Lake Eyre to Lake Frome.

Broadly speaking, the edge of the Jurassic series has the same general altitude, but the deepest portion is believed to be in the vicinity of Lake Yamma-Yamma, in Queensland, where the series is estimated to lie 7,000ft. below the surface. In South Australia the greatest depth so far known is at Patchawarra Bore, about 60 miles south-west of Lake Yamma-Yamma. As this bore entered the marine blue shale at 4,040ft., and as the thickness of the shale was proved in Goyder's Lagoon Bore, to the west, to be 2,714ft., it seems as if the aquifer at Patchawarra must be in the vicinity of 6,750ft., or about 1,290ft. below the point at which boring had to cease, owing to mechanical difficulties.

Boring near the North Flinders Range has shown that the axis of the range has a subterranean northward prolongation. This prolongation appears to have resulted in holding at the surface certain Eyrian exposures, probably as a very flat anticline. The Denison Range is a similar mass of old rock, and the basin has sagged west of the Denison Range, between it and the prolongation of the Flinders Range, and to the east of the latter. While this has had a prejudicial effect in the case of the Great Basin, by increasing the area that is too deep for economic exploitation, it has affected the Eyrian beds in such a way that the upper portion becomes an aquifer, carrying, under favourable conditions of feeding, water of useful quality.

Associated with these flexurings a good deal of faulting has taken place in the vicinity of the old rock horsts and their underground extension.

Faulting is strongly suggested (2) by the collinear attitude of the south-western shores of Lakes Gregory, Blanche, and Callabonna. The faulting at Petermorra Springs has already been mentioned by the writer. Some little evidence of the age of this faulting is afforded by the presence of a mound, resting on the granite, similar in composition and type to the great extinct mound springs of Mount Hamilton and Beresford Hill, near Coward Springs.

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(1) Bulletin 11, G.S.S.A. (2) David and Woolnough.

An interesting and important economic effect of these faults is to enable the carbonated water, which is characteristic of the Great Basin in the Jurassic sands east of the belt of mound springs, to reach porous beds above or even in the marine shale. Apart from numerous mound springs that reach the surface, there are three localities where analyses have shown the lower water to have migrated to a higher horizon. They are:—

(1) At Meteor and Petermorra Bores, where the water occurs in a sand about 800ft. above the depth at which it should be present.

(2) East of Paralana Springs, which yield water of deep seated artesian type, a group of shallow bores in the piedmont plains basin of Wooltana, between the Flinders Range and Lake Eyre, also yield carbonated waters, the normal water of Wooltana being sulphated.

(3) Three bores near the north boundary of Mulyungarie Station, south-east of Lake Frome, tap carbonated water lying above the blue shale, in an aquifer which, to the south, contains sulphated water. As the Jurassic sands have cut out some 15 miles to the northward, this water can only have risen through a fault line cutting the sands, and then come southward, displacing, by virtue of superior pressure, the normal sulphate water.

The Inlets and Outlets of the Artesian Water.—The areas of intake of the water are known, from the topography, the geological structure, and the isopotentials that have been determined, to be along the western flank of the Coastal Range of Queensland and New South Wales, near Boulia in Queensland, and along the Central and South Australian margins.

Development of water supply by the Government and pastoralists undertaken and in progress has thrown much light on the structure of the south-west of the basin, and on the quality of the water. Here there are outcrops of the Jurassic series which, in the south-westernmost portion, is very flat-lying, and is exposed by denudation of the deeper valleys cut through the thin shale cover. To the north the shale becomes thicker, then thins off or is totally removed in the vicinity of the low-lying area containing Lakes Phillipson, Woorong, and Wirrida. North of this, between the western intake and the opal field (Coober Pedy), it again becomes thicker, so that a zone of unweathered shale remains above the water-bearing sands.

Near the south end there is a chain of salt lakes, extending from Lake Labyrinth to Lake Younghusband. North of these lakes and on slightly higher ground it was noted that where bores had been sunk through the weathered shale rises into the Jurassic sands, or where the bores had been sunk on wide Jurassic flats, the water, which is not under pressure, contained 2oz. or more of salts per gallon. The good wells, without exception, in this area (the south part of Bon Bon Station) were found to occur where water had been shed in some bulk from the impervious shale rises and had sunk into the underlying sands at the edge of the shale to displace or dilute the saline water. It is notable that some of the wells show good water resting on saline water.

To the north on Bon Bon and on Mount Eba the shale cover is continuous, and the water comes from higher ground to the west, where the Jurassic sands rest on the Pre-Cambrian rocks, and are at such an elevation that there is a free circulation of ground water. This water travels easterly and north-easterly beneath the blue shale, and gradually deteriorates in quality. There is a local freshening where Kalybyng Swamp depression has cut through the shale and allows the swamp waters to drain into the Jurassic sands.

The Lake Phillipson area is, on the surface, a basin of internal drainage, and acts as an evaporating pan in which the salinity of the groundwater is as much as 10oz. per gallon. It is probable that this low area on the western edge of the Great Artesian Basin receives the very scanty and highly saline underflow from the sandy areas to the west, as the collinear arrangement of lakes in this little-known area along an east and west line suggests the presence of a depression which can only drain to the eastward. The saline groundwaters of the Lake Phillipson area have been proved by bores through the Cretaceous shales to extend as pressure water for part of the distance to Lake Cadibarrawirracanna, and may reasonably be assumed to find an outlet in the salt springs on the southern shores of that lake.

Northwards, where the Jurassic sands are traversed by the high level portion of Woorong Creek, and there is such a slope that there must be a free circulation of underground water, the quality again becomes good, and good water should be got in these sands between the head of Lang's Creek and the Arckaringa.

Outlets.—The isopotential lines or lines drawn through points of equal elevation on the artesian water surface, prove that a proportion of the Queensland water escapes by submarine vents into the Gulf of Carpentaria, but the bulk of the water that escaped under natural conditions has done so by way of the mound springs within the basin. The map published by the Fourth Interstate Conference on Artesian Water in 1924 (Plate I.) shows these isopotentials, and clearly demonstrates the profound influence of the mound springs in destroying the hydrostatic head and so modifying the isopotentials.

The great extinct mound springs seen by the Interstate Artesian Conference in 1921, which stand over 100ft. above the present springs, and the similar one at Petermorra Springs seen by the writer, point to a former much greater escape and greater head due to the existence of intake beds at levels now denuded.

The Movement of the Water in South Australia.—The writer has shown, by plotting the iso-chlors and the iso-salts (1) that there is a very definite circulation towards the natural outlets and that the zones of active circulation along which the water has thus been changed more often contain water of better quality than that in the areas of stagnation between the vents.

Even more important as throwing additional light on the origin or source of the water was the recognition that all the waters of eastern, and north-eastern origin were carbonated, while those from northern, western, and south-western sources carry sulphates.

This difference in composition was noted by A. L. du Toit (2), who expressed the opinion that the sulphates were connate salts being pushed out to the westward. The slope of the hydraulic surface, in this western region, has since been established as being from the west towards the mound springs, and renders this explanation untenable. Further, the hydraulic grade and the exposure of bedrock by boring has proved the impossibility of an escape of water from the Great to the Eucla Basin. The inevitable conclusion which must be faced is that, prior to the disturbance of the balanced conditions by boring, the intake of water was disposed of by the leakage from a part of the Great Basin into the Gulf of Carpentaria, and by the effluent of the mound springs. Consequently, as the natural flows cannot be blocked,

(1) Trans. Royal Soc. S.A., vol. XLVII., p. 316.

(2) Proc. Roy. Soc. N.S.W., vol. LI., 1917, pp. 183-184.

every bore adds to the draft and tends to lower the head, and so reduce the flows. Probably the lowering of the water level in the intake beds will add slightly to their efficiency.

As the loss of head is going on beyond dispute, it follows that, when a sufficiency of bores to serve the area of the basin has been sunk, this loss of head and of flow must continue until the head has fallen so far that the higher level bores will cease to flow, while the low-lying flowing bores and the mound springs will yield smaller supplies.

Ultimately a new state of balance will be reached, as much less water will be drained from the basin when a very large proportion of the bores only yield by pumping the supply required. But in view of the expense of pumping, which will steadily increase with the loss of head, the desirability, from an Australian viewpoint, of doing everything possible to conserve the water and the head cannot be too strongly emphasised.

SUBSIDIARY PRESSURE WATERS OF THE GREAT BASIN.

Much of the area of the Great Basin is too deep for commercial development, and shallower waters must be searched for. In the north-east corner of the State a good deal of boring had been done by the pastoral lessees, and the correlation of these logs and inspection of the area was carried out by the writer, and the results embodied in Bulletin No. 11. In this region several of the beds are water-bearing in the upper portion of the Winton formation, and the correlation of bore logs, which was confirmed by comparisons of the types of water indicated by the analyses of the waters contained in the sandy beds showed that the beds form a series of superimposed anticlines pitching to the south-west at rates of from 20ft. to 40ft. per mile.

The deeper sand beds of the Winton series do not outcrop in South Australia but flatten out towards the northern border, but must outcrop in Queensland and be fed by the Diamentina or its tributary, Farrar's Creek, to yield the good water in the deeper Cordillo Downs Bores.

The northern extension of the Bull's Hole Bed will ultimately have to be tapped close to the north boundary of Cordillo Downs, at depths not exceeding 600ft., as the surface in this locality is occupied by the impervious middle third over the slightly pervious lower third of the Eyrian formation, which portions are negligible as aquifers.

Dripie and Patchawarra Bores on Innamincka Station tap aquifers in the Winton Beds, and it is so probable that Cooper's Creek crosses and feeds the outcrop of porous members of the Winton series that boring to the west of Innamincka township would be justified where water is not supplied by the Cooper and its waterholes.

On these Winton beds the Eyrian beds were deposited with a slight unconformity, and the continuance of the warping has given these beds a similar attitude, though to a lesser extent. The Eyrian beds, having a considerable proportion of shale, seal to some extent the outcrops of the sandy members of the Winton beds. They themselves, however, receive some feed and yield useful supplies.

The upper third of the Eyrian is distinctly pervious, and, though, where best seen in the eroded anticline of Cordillo, it is drained by the dissection, where the bed dips beneath the surface it yields good wells along the feeding creeks. An inspection of the geological map shows, along the Birdsville-Marree track, areas of the Eyrian formation. This is on the prolongation of the axis of the Flinders Range, and it is very probable that these patches are along an Eyrian anticlinal axis, with synclines filled with silt to the east and to the west. The existence of the eastern limb of the eastern syncline is fairly clearly seen on the ground between Innamincka and the northern boundary of the State. The importance of this unexploited syncline as a possible aquifer fed by the Cooper is such as to justify boring between latitudes 27° and 28° 30′ S. and from the 139° of east longitude to the Strezlecki. South of this region, until the useful waters of subsidiary basins fed from the north and east flanks of the Flinders Range and the west side of the Barrier Range are reached, there does not appear to be much likelihood of useful pressure water other than the deep main water, and creek channels and flood swamps will have to be searched for isolated subterranean pools of useful water, while wells of the sandhill type, such as the Box Flat Well west of Montecollina Bore, will probably be found in some places.

In the region between the Flinders and Barrier Ranges two basins containing useful water and overlapping the Great Basin occur, and they may be regarded as being connected by a third area which, however, does not overlap the Great Basin. Structurally they are more or less connected.

The Eastern basin, referred to in Bulletin No. 11 as the Border Basin, is Pleistocene to Recent in age, and rests to the north on the "blue shale" and the Winton beds and to the south on the Adelaide series. The surface has a slope of about 7ft. to the mile to the north-west and the hydraulic surface is approximately parallel. The basin is filled for the most part with clays, and in its South Australian portion contains several thin sand beds. Some of this sand is extremely fine and has to be shut out by fine gauze screens in the bores. Four water-bearing beds are recognised, and it has been found that the proportion of salt decreases as the deeper beds are struck. The reason for this is that the deepest bed outcrops nearest to the efficient watershed of the Barrier Range, and so receives the most abundant and best quality feed waters. The upper beds receive their supplies at progressively greater distances from the Range, and consequently are not so efficiently fed. The log of Furlough Bore on Mulyungarie Station illustrates the structure and is given below:—

	Feet.	
Recent to Pleistocene	0— 14	Red and yellow parti-coloured clay with gypsum.
	14— 76	Yellowish-pink clay.
	76—101	Yellowish-brown clay with some white clay.
	101—160	Whitish clay with iron stains and streaks.
	160—170	*Very fine white siliceous sand, containing water with 4.09oz. salts per gallon, which rises to 140ft.*
	170—201	Light grey very fine textured clay.
	201—202	Yellow iron-stained clay. *At 201ft. 2.61oz. water rising to 141ft. was struck.*
Winton	202—204	*Very fine-grained white sand.*
	204—237	Grey clay.
	237—242	Fine siliceous sand reported as moist only.
	242—279	Whitish clay with traces of lignite particles.
	279—283	*Fine-grained clean siliceous sand, with 1.66oz. water rising to 140ft.*
	283—325	Grey clay, carbonaceous in parts.
	325—333	Light grey clay.
	333—355	Greenish-grey clay.
	355—358	*Medium-grained siliceous sand with .70oz. water rising to 145ft.*

Though this particular bore does not touch the underlying formations, the lowest water-bearing bed is proved by other bores to rest, in the south of the basin, on the Adelaide series, and in the north on the Lower Cretaceous shales. The normal water of the basin is a sulphate water, but a group of three bores (Banavie, Birksgate, and Lake Charles) get the carbonated artesian water of the Great Basin in the aquifer that normally contains

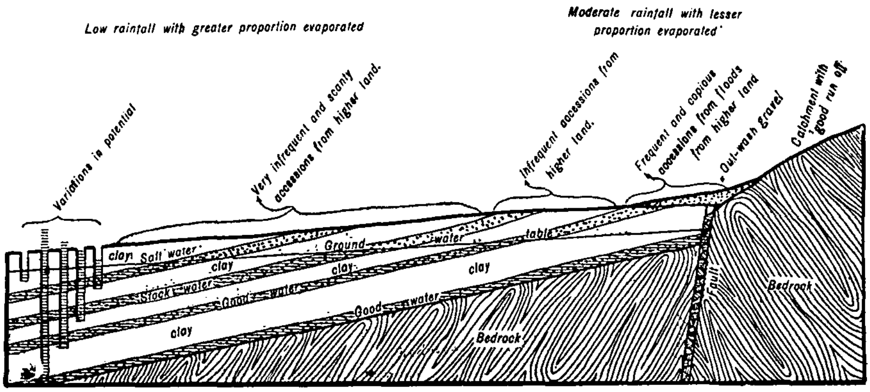


Diagram showing the influence on Quality of distance of Intake from the Effective Catchment Area.

sulphate water. As this is on the top of the blue shale, proved near these bores to rest on the Adelaide series, it follows that there must be a leakage through a break in the blue shale to the north, and that the carbonate water has spread laterally to these bores and displaced the sulphated water that should be the normal type.

On the south-west of this basin a subterranean ridge of older rock has formed a shore line and cut off the deeper beds, but even before this the quality of the water has degenerated with increasing distance from the intake and under the influence of a saline feed from the south-west until it is too bad to use.

For this area, lying to the north of the Boolcoomatta Ranges, the intakes are ineffective and the pressure water developed hitherto is of poor quality until, towards the western side, the filled valley of the ancient Siccus River affords somewhat better conditions. A bore on Curnamona reached a depth of 577ft. in this filled valley, the water, of 1¾oz. salinity, rising to within 90ft. of the surface.

West of the Siccus and along the eastern flank of the Flinders Range a large extent of piedmont plain has been built up, and is fed by the steep and good creeks of the Range. Useful waters occur along this plain. Some is ground water and some flows, but in the majority the rise is not great.

Intensive boring has been carried out in this region with very satisfactory results, and the influence of the feeding creeks is clearly indicated by the variations in the quality of the water, tongues of good water extending out farthest opposite the largest creeks. Towards the western shore of Lake Frome the waters are shallow and of poor quality, and it appears to the writer that these waters are from a higher geological horizon than those nearer the Range. A bore to a depth of 500ft. at most is required to prove whether this is the case, and is justified on the grounds that it may solve the problem of providing good water along the western shore of Lake Frome.

The northern portion of this area contains the Woolatchi Bore, west of Lake Callabonna. From the log it appears probable that the following formations were penetrated:—

Recent piedmont plain deposit, 0—128ft., with 300galls. per hour of stock water at 110ft.

Eyrian series, 128—277ft., with 600galls. per hour of water at 243ft., rising to 143ft. from the surface.

Winton beds of the Cretaceous, from 243ft. to 857ft., or possibly 903ft.

Cretaceous (blue shale), 857ft. or 903ft. to 1,746ft., with salt water rising to 80ft. from the surface at 1,177ft.

Jurassic sands and sand rock, 1,746—1,872ft. A flow of 280,000galls. per day, when boring ceased, was obtained. The water had a temperature of 158° Fahr., and contained 0.32oz. of total salts per gallon.

The conclusion arrived at is that the piedmont plain and Eyrian waters exist in the vicinity of Woolatchi Bore and can be developed over a fairly large area.

To the north and north-west of Woolatchi several bores cut saline water at about 800ft. to 900ft. above the Jurassic sands. The best of this water is that of Lake Crossing: a sulphate water containing 1.67oz. of salts per gallon. The horizon, however, is important, as it appears from the sections on Plates II. and III. to be very widespread and a noteworthy "marker" as to the depth to the main water. Lake Crossing, Yerilla, and Petermorra bores all get their water from this bed. The first two have normally saline water, the last gets the typical Great Basin water that should be several hundreds of feet deeper. The explanation of this anomaly is the occurrence of fault planes (manifested by lines of mound springs) through which the water has entered the upper aquifer.

Section C.C., Plate II., including the bores along the Birdsville track, shows that the water of this horizon is salt in the south, but at Mount Gason Bore the bed carries ¾oz. water. Water of such quality could not enter from the south or from the west, where this water-bearing horizon contains more highly saline water, and, unless its presence is due to the existence of a fault, can only have come from a northern source, so that there is a possibility of this bed being of use in Queensland, to the north of the South Australian border. It appears to be beyond the economic depth in South Australia, but to the north may save 700ft. to 900ft. of boring to the main supply.

The Eyrian series west of Lake Frome, where fed by good creeks from the Flinders Range, yield some useful waters.

West of this again, on the north part of Mount Lyndhurst Station, is the water-bearing area referred to by the writer in Bulletin 11 as the "Lyndhurst Area." The boring and well-sinking that has been done shows that here the deepest rocks are of the Adelaide series, that the Jurassic sands are missing, and that the Cretaceous shale overlaps far to the south, to be still farther overlapped by the Eyrian beds.

The basal bed of the underlying blue shale is somewhat sandy, and it and the plane of unconformity between the shale and the Adelaide series provide an aquifer that yields useful pressure water in the case of Woodgate and Junction Bores. In each case the water is of sulphate type, indicating that it is making its way downwards along the base of the blue shale towards the Jurassic sands and not coming from them, in which case it would be carbonated.

The Eyrian (referred to in Bulletin 11 as "Desert Sandstone") is composed of white and yellow clays and somewhat siliceous beds. It forms flat-topped hills and "Tablelands," and its surface is covered by a great development of quartzite stones or "gibbers" formed by the breaking down of its silicified crust. This Eyrian formation has filled the valleys in the older formations for some distance up them. Subsequent erosion has left residual table hills and formed channels or valleys in the Eyrian in the northern portion of the Mount Lyndhurst Station. These channels have in their turn filled with Recent alluvium, and are now little more than flooded flats. Useful ground and pressure water occurs in the alluvial and in the porous Eyrian members, where suitably fed by flood flows from the Ranges.

SECTIONS.

Several lines of sections have been drawn across the Great Basin to show the succession of these formations, the position of the water-bearing beds, and the quality of the waters, and are briefly described below.

The sections are drawn on Plates II. and III., and their positions are shown on Plate I.

Section A.A. (Tarcoola to Charlotte Waters) shows the good groundwater in the exposed Jurassic sands resting on the high level ancient rocks, and the low level saline area of Lake Phillipson. Lake Phillipson Bore shows Triassic coal measures and a very deep trough in the Pre-Cambrian complex, the bottom of which is filled with shale containing glacial erratics. The depth of Jurassic sands proved at Charlotte Waters and the extremely saline groundwater are of interest.

Section B.B. (Kingoonya to Andado No. 1 Bore) shows two points of interest: the Cretaceous erratics strewn on the surface and an aquifer, containing salt water, recorded in Mount Sarah and Opossum Bores that is in the same position relatively to the Jurassic sands as the bed developed in Sections C.C., D.D., E.E., F.F., G.G., and H.H.

Section C.C. (Lake Torrens to Goyder's Lagoon) includes part of the Torrens Basin and the variable bedrock waters in the Willouran Range.

Section D:D. shows the great depth to the main water at Patchawarra, the great development of the Upper Cretaceous, and how it has been possible to develop non-flowing artesian waters in these beds.

Section E.E. (Mingary to Tilcha) is of much interest by reason of the successive overlaps, and the development of the Border Basin at Mulyungarie, in the Upper Cretaceous beds. There appears to be a very reasonable chance of this water being developed as far north as Coonanna, as the good water cut in the porous bed of the blue shale probably enters the bed from the water at the base of the Upper Cretaceous series. It may, of course, come from New South Wales, as Section H.H. shows that the porous bed rises in this direction, and so may outcrop in a position where it could receive an influx of water.

The Sections on Plate III. intersect those of Plate II., and have a general west to east trend.

Section F.F. calls for no comment; but

Section G.G. shows the influence of the Denison Range—Mount Dutton horst—as an anticline at Woodduck Bore. The influence of the prolongation of the axis of the Flinders Range shows at Chapallana Bore and at Yarra Hill Bore. There have been very definite sags between and on either side of these two axes of old rock masses.

Faulting affects this section and brings the deep-seated Jurassic type of water into Meteor Bore, the bottom of which is far above the Jurassic sands.

Section H.H. shows the same thing to have happened at Petermorra.

Section I.I. crosses the piedmont plain east of the Flinders Range and shows the good and shallow groundwater developed in the superficial beds. Paralana Spring brings up water that certainly contains a proportion of the waters of the Jurassic sands. This water coming up along the Paralana fault plane has an opportunity to enter any porous beds present in the Eyrian or Upper Cretaceous series, and a bore on the western margin of Lake Frome might easily give much better water than is known at present in that locality.

Section J.J. crosses the Siccus and the Border Basins, and shows the variation in the quality of the waters cut.

With the aid of these two series of intersecting sections it is possible to determine very closely, for any point within the network of section lines of Plate I., the depths at which the main structural changes and aquifers occur and to form a fair idea as to the quality of water that may be expected in such aquifers. With the aid of bore records off the lines of sections that have been drawn a still more accurate forecast can be made as a guide to future boring at any defined locality.

THE MURRAY ARTESIAN BASIN.

This is one of the most important of the South Australian basins, in that it provides good and shallow water for a considerable area of farming land and makes possible the keeping of stock. The water-bearing beds are Recent to Miocene in age and have been laid down in a wide basin, floored in places by granite, Lower Pre-Cambrian, Upper Pre-Cambrian (or Adelaide series), Permo-carboniferous and Jurassic rocks. The greatest depth of Tertiary material so far proved is 2,110ft., and the beds are very little disturbed. Between Kingston and the Murray Bridge-Serviceton Railway outcrops of the Archaean rocks have been mapped, and there are some exposures between the Murray and the Mount Lofty Ranges. Subsequent folding has been very slight, as evidenced by the section cut by the Murray River through the Polyzoal limestone which is the dominant feature in the geological structure.

The lowest members of the Tertiary series are sandy (siliceous) and lignitic clays with lignite. In some localities the change to the overlying Polyzoal limestone is abrupt; in others there are alternations of the carbonaceous clays and sands with limestones and sands carrying marine fossils before the main bed of the Polyzoal limestone attains its full development.

In the south of the State this limestone is exceptionally pure and open-textured; south of Renmark it is recorded as being argillaceous in the log of Company's Bore, while in the northern portion the limestone merges into a calcareous clay carrying the typical marine fossils. Above the Polyzoal (Janjukian) and the overlying Kalimnan limestone there is in places an appreciable thickness of sands of Recent to Pleistocene age.

Water enters these formations from three directions, west, north, and south-east. The last is by far the most important source by reason of the high head, over 400ft., and the rainfall of 23in. in the vicinity of Casterton and Coleraine in Victoria. The abundant intake from this source has resulted in good quality, and the head has caused a widespread distribution of the good water. The water occurs in two main horizons, the sandy members of the lignitic series and the Polyzoal limestone.

The deeper water is in general of somewhat better quality and is under pressure, while the Polyzoal limestone water may be either ground or pressure water. The quality of these waters gradually deteriorates to the north and west until it is possible to draw a line showing the incidence of 1oz. water, the limit for horses used in farm work. Within this area the provision of water supply resolves itself into avoiding the inliers of bedrock and sinking the necessary hole.

To the north of the Murray the catchment feeding the basin is much less effective, and the water is of poor quality. It is collected along the ridge on which is the Peterborough—Cockburn railway, and on which the rainfall averages about 8½in.

The principal feeders are Olary Creek and Winninninie Creek, and it is notable that the best water is obtained from bores nearest to the outfalls of these creeks. A number of wells tap the ground water, which is of very poor quality except along the main watercourses on the north and west rims of the basin. Such wells exist on Sturt Vale, and the southernmost in use are the 5-Mile Well on Quondong Vale (2.47oz.) and Pine Valley H.S. Well (2.06oz.). South and east of this no ground water is of use north of the influence of the Murray.

The pressure water occurs below the calcareous clays that here represent the Polyzoal limestone, and is found in a bed of drift containing marine shells.

This bed was tapped in the following bores:—

Name of Bore.	Locality.	Depth to Water.	Quality oz. per Gallon.	
		ft.		
Kruger Dam	Lilydale	374	1·29	200 g.p.h.
Brooks'	Oakvale	420	1·59	
Cockatoo	Pine Valley	573	1·71	
Triangle	Calperum	525	1·97	
Oak Tank	Calperum	644	1·95	
Calloden	Calperum	575	2·09	
Gunyah	Chowilla	650	2·29	Flows.
Company's	S. of Murray in Hd. of Gordon	712 1,102	2¼ 7·52	
North West	Oakbank	402	1·79	
Postmark	Oakbank	517	1·60	
Dick's Paddock Bore	Pine Valley	487	1·57	
Mulga Bore	Oakvale	388	1·63	
Billing	Oakvale	467	1·59	

Kruger Dam and Dick's Paddock Bores are so placed as to be benefited by the intake from Winninninie Creek, while Brook's Bore is similarly placed in reference to Olary Creek. The others are not so well fed or are farther from the intake.

West of the Murray, and west of the meridian of Morgan north of the Murray, the basin is fed by creeks from the eastern slopes of the Mount Lofty Ranges. To the north of the Burra Creek the low rainfall and the poor feeders combine to render the feed scanty and inefficient, and the pressure water is too saline to be of use except in local patches close to the ranges. The Burra Creek supplies a sufficient volume to influence the pressure water, so that a tongue of useful pressure water extends from the intake, beneath Florrieton to Nor-West Bend. At the last-named locality a bore in search of lignite cut 1.30oz. water at a depth of 375ft. and yielded a flow of 210,000galls. per day, but as the water was of no use in the locality the bore was blocked to prevent wastage of the stored water. This useful water is proved by the Bower bores, which tap salt water both in the Polyzoal limestone and in the lignitic series, not to extend far to the southward. It does, however, extend into Eba and Hay, the hundreds to the south of Morgan, and occurs at or just below the base of the Polyzoal limestone, but at shallower depths. In the vicinity of Sedan and Cambrai good water is found near the foot of the ranges in the Polyzoal limestone, but to the east the quality falls off. In the hundred of Finniss two aquifers have been proved, the lower carrying pressure water of useful quality in places at depths of 80ft. to 100ft. below the ground water.

Still farther to the south, south and east of Strathalbyn, the Angas and Bremer Rivers act as feeders to a small artesian basin that may be named the Milang Basin. Many bores have been sunk to depths of 90ft. to 400ft. and some of them flow. The quality deteriorates with distance from the intake, and it is possible that there is a scanty feeder of bad water from intakes in the vicinity of the Archaen inliers in the hundred of Strawbridge. The point is not established, but it is noteworthy that bores at Narrung on the south side of Lake Alexandrina and one on Hindmarsh Island have failed to get any useful pressure water. The latter bore reached a depth of 600ft., the last 100ft. being in Permo-carboniferous (?) glacial pyritic clay

A matter of considerable interest is the possible escape of the excess water of the Murray Basin. The line of 1oz. of salts to the gallon runs for a little along the western rim of the basin near Mannum, and though the complete water analyses are fewer than is desirable, there is no doubt but that a tongue of good water extends from the main body to the western rim. The hydraulic grades and the geological structure make it impossible for the poor water north of the line of 1oz. salts to escape by subterranean passages to the sea. Everything very strongly suggests that the good water and the scanty northern saline water escape into the bed of the Murray in the vicinity of Bowhill, though this appears to be incapable of proof save by the determination of the hydraulic slopes by accurate levelling in the district and by additional knowledge of the composition.

A deep bore has recently been completed by the Railway Department at Karoonda, between the Walsh and Sherlock bores on Sections N.N. and O.O. respectively (Plate IV.). This bore throws additional light on the structure of this portion of the basin and is of considerable interest, as it has penetrated the full depth of Tertiary material, and the analyses of the different water passed through have been recorded.

By the courtesy of the Railway Department it is possible to give the log and the quality of the waters.

Record of Samples from Karoonda Railway Bore.

Feet.	
0—22	Yellow-brown siliceous sand and marly limestone.
22—150	Yellowish siliceous sand and polyzoal limestone.
150—235	Greyish polyzoal L.S., dense and crystallised in parts.
200	*Water cut, rising to 177ft. Salinity .37oz. per gallon.*
235—292	Greyish polyzoal L.S., dense and crystallised in parts.
292—360	Fine grey sand, mostly limestone.
360—381	Fairly hard fossiliferous L.S., crystallised (polyzoal).
381—395	Greyish sand, clay, and soft limestone (marly).
395—463	Grey calcareous clay.
463	*Water cut, rising to 200ft. Salinity .41oz. per gallon.*
475	*Water cut, rising to 200ft. Salinity .42oz. per gallon.*
463—482	Fine quartz sand, with shell fragments.
482—580	Dark lignitic clay with some lignite.
580	*Water cut, rising to 200ft. Salinity .42oz. per gallon.*
580—586	Coarse sand of quartz and polyzoal L.S. fragments.
586—598	Lignitic sandy clay (coherent).
598—688	Dark lignitic sands.
688—709	Lignitic clay.
709—750	Coarse to medium coherent quartz sand with pyrite and blackened by lignitic matter.
760	*Water cut, rising to 200ft. Salinity .38oz. per gallon.*
750—802	Coarse to medium coherent quartz sand, less pyrite and lignite.
802—828	Coarse angular quartz grit.
828	*Water cut, rising to 200ft. Salinity .40oz. per gallon.*
828—894	Greenish clay-like semi-decomposed slate.
894—900	Quartzitic schist.

Analyses of Waters, Karoonda Bore.

Grains per gallon.	200ft. rising to 177ft.	463ft. rising to 200ft.	475ft. rising to 200ft.	580ft. rising to 200ft.	760ft. rising to 200ft.	828ft. rising to 200ft.
Calcium carbonate	18	8	25	4	22	4
Magnesium carbonate	14	5	7	5	13	6
Magnesium sulphate	12	—	3	—	1	—
Magnesium chloride	—	—	1	—	—	—
Sodium carbonate	—	28	—	25	—	24
Sodium sulphate	6	14	—	18	14	18
Sodium chloride	109	125	124	125	117	121
Undetermined	3	1	23	9	1	6
Total salts—grains per gall.	162	181	183	186	167	176
Oz. per gallon	.37	.41	.42	.42	.38	.40
Hardness						
Total	45	14	37	9	38	10
Temporary	35	14	33	9	37	10
Permanent	10	nil	4	nil	1	nil
Due to calcium	18	8	25	4	22	4
Due to magnesium	27	6	12	5	16	6

The bore is situated on the probable track of the water to the presumed outlet near Bowhill, and shows that good water immediately overlies the bedrock in this portion of the basin for some distance, as the Cotton Bore to the east-south-east in the Hundred of Bews (Section Line O.O., Plate IV.) shows the continuity of the lignitic beds, and yields water of better quality.

The hydraulic surface only rises above the land surface in a few localities (near Chowilla, on the low ground near the Murray at Morgan, near Mannum, Milang, the vicinity of Tintinara, and at Kingston). Thus there is only a small number of flowing bores and the water has to be pumped as required. Consequently there is no wasteful draught upon the basin as is the case where flowing bores are uncontrolled. The hydraulic surface is exposed as the Blue Lake at Mount Gambier, and Dr. C. Fenner has proved the inter-relation of the rainfall on the intake beds and the level of the lake, and in so doing has established the meteroic origin of artesian water in a basin of considerable magnitude, as against the theories of plutonic water and rock pressure.

Sections.—Several sections have been drawn through bores in this basin to show the relation of the water-bearing beds. The position in plan of these sections is shown on Plate I., while the sections themselves are on Plate IV., K. to P.

The principal section is K.K., extending from Mingary on the Broken Hill railway through Mount Gambier and roughly parallel to the eastern border of the State.

At the northern end the rocks of the Adelaide series are exposed and yield ground water of variable quality. These rocks occupy high land, the drainage from which forms a scanty intake into the younger formations to the south. As the section is followed south the superficial cover consists of sands, soft sandstones, and associated argillaceous deposits, which show as far as Naracoorte.

Ground water occurs in these beds, but is saline in the northern portion of the section. To the south the heavier rainfall has resulted in useful ground water.

Below this is the Janjukian marine limestone series, which attains its maximum thickness in this section of 584ft. at Company Bore. No good water is cut in this formation in this section to the north of Meribah, but to the south there is no trouble on the score of salinity. The water may or may not be under pressure. Near the base is a glauconitic clay overlying a sand carrying marine fossils. This sand bed is the main aquifer north of the Murray and is recognised as far south as Company Bore, where it carries 2½oz. water. Its presence not far below the bottom of Pinnaroo Bore may be inferred from the recognition of the superincumbent strata. Company, Cotton, and Coonalpyn Bores show that these lowest Janjukian sands overlie the lignitic series. This series is made up of sands, some marine limestones in the upper portions, clays, lignitic clays, and lignites. Towards the southern end of the section the Janjukian Polyzoal limestone gives way to the sands of the lignitic series at comparatively shallow depths in the two bores shown near Penola. East of the section, in Victoria, the land surface rises, and this aquifer must also rise correspondingly. As a whole it dips very gently to the north as far as Company Bore, and thence rises again. The only hole that has penetrated beneath it to any considerable depth on this section is Company Bore, which got 7.52oz. water at a depth of 1,102ft. The bore log shows that the recognisable lignitic series was passed through at 1,596ft., and from this point, to the bottom at 1,805ft., the bore passed through a blue shale, to which it is impossible to assign an age.

The chief value of the deeper sinking of the bore is a negative one, indicating over a considerable area that it is useless to penetrate beneath the main aquifer.

Sections have also been drawn from the north-western and western side of the basin to connect with the main section K.K.

Section L.L. from Faraway Hill in a south-easterly direction to Company Bore, in the hundred of Gordon, shows that the Recent cover contains very little useful water, the exception being a well in a wide watercourse at Sturt Vale Station, with stock water at 40ft. The controlling factor in this case is the occasional floods in the watercourse.

The waters in the limestone series, which is exceedingly argillaceous here, are also salt until the main aquifer at the base is tapped. The supply of good water cut in Farmer's Dam Bore was trifling and the bore was abandoned, but the other bores in this section all cut the same aquifer, and yield considerable supplies. The quality deteriorates with increasing distance from the edge of the basin.

Section M.M., from Sutherlands to Gunyah Bore, crosses section K.K. Bores at Bower get salt water below the limestone and above the lignite beds proved in this locality, and finish in schistose rocks. No. 2 Bore, near Morgan, cut a flow of 210,000galls. per day of 1.3oz. water in the main aquifer and was then stopped as it was being sunk in search of lignite, and this flow rendered the possible future working of any underlying lignite bed inpracticable. This water is abnormally good for this portion of the aquifer, and this can only be ascribed to the influence of that large and efficient feeder, the Burra Creek, which injects into the main aquifer a tongue of good water, extending beneath Florrieton as far as the No. 2 Bore and apparently bordered on either hand by distinctly more saline water.

Section N.N. extends from the railway near Palmer through Meribah. The bore on section 179 cut .45oz. water near the base of the Polyzoal limestone in a valley of the granitic bedrock, and this water may very possibly represent the main aquifer which has not been reached by any of the other bores on the line of section. The position of the main aquifer beneath Meribah may be deduced with reasonable certainty from section K.K. The quality of the water in it beneath Meribah is unknown, as the section K.K. from north to south shows that the water from the north is much more saline than that from the south and that the line of demarcation between them must lie between Pinnaroo and Company Bores. On section N.N. the waters cut by the bores are all in the Polyzoal limestone at a considerably higher horizon than the main aquifer.

Section O.O. shows saline water in the westernmost bores and salt ground water at Sherlock with ⅔oz. water in the main aquifer. The eastern bores in this section show the Recent sands and associated clays with good quality ground water in the limestones a little below the Recent formations. Cotton Bore cuts the main aquifer and finishes in granite.

Section P.P., from Strathalbyn to Cook's Plains and thence along the Adelaide-Melbourne railway, presents several features of interest. On the west two bores prove that the bedrock is comparatively shallow and that the depression is occupied by sands and Tertiary sediments. The porous members of this series are well fed by the Bremer and Angas Rivers, and so form the small but useful Milang Artesian Basin.

Cook's Plain, Coomandook, and 1A hundred of Kirkpatrick Bores tap saline waters, evidently from scanty feeders not far to the west. Many water-bearing horizons have been cut by the Coomandook Bore which has disclosed a great depression in the bedrock. The bottom portion, judged from the log, has passed into material that may reasonably be co-related with the Permo-carboniferous tillite proved at Currency Creek, Hindmarsh Island, and near Victor Harbor. It is shown in the section as a glacial deposit. South-easterly the water improves, the saline and shallow ground water gradually becoming of better quality as the section is followed in this direction.

Tintinara and Emu Flat Bores both cut the main aquifer and get very good water.

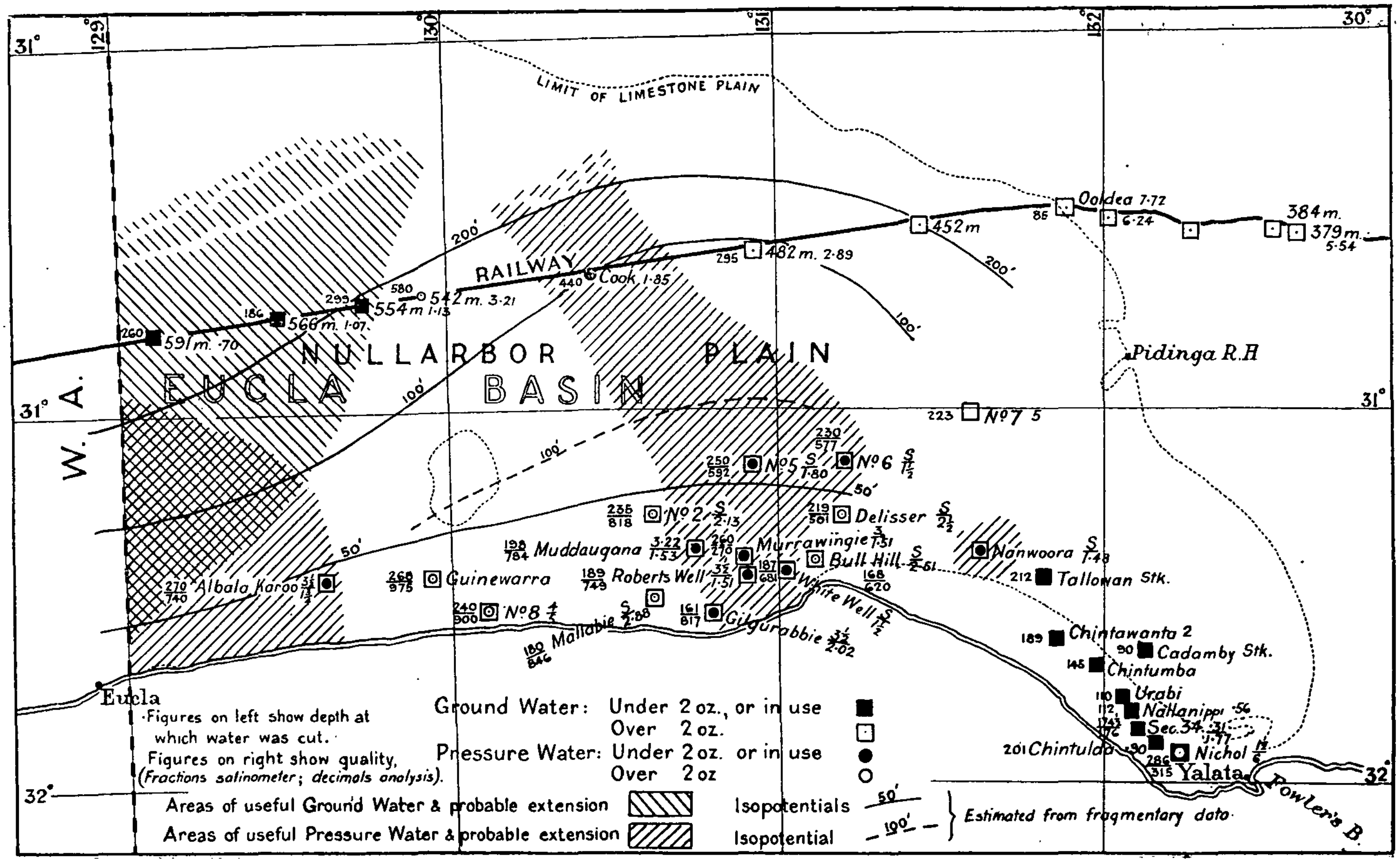
EUCLA BASIN.

Though only a little has been seen by the writer of this area, most of the known information as to structure and water is contained in the records of Government and private bores and analyses that have been collected into the files of the Geological Survey.

The South Australian portion of this basin has an area of about 17,000 square miles.

The bottom of the basin, wherever known from the records of bores and by outcrops on its margin, consists of granitic and gneissic rocks.

Upon this base were laid down the Miocene sands, lignitic clays, and clays that underlie the Janjukian limestone. The latter overlaps the lignitic series on the eastern end, but the lignite outcrops in the vicinity of the granite of Pidinga. To the northward Recent siliceous sands overlie the Janjukian limestone and conceal its extension. It is, however, certain that there is a dying out in this direction, not only of the limestone, but of the underlying clays, which must, in their turn, die out to permit the entrance into the underlying sands of the pressure water developed by the bores nearer the coast.



Eucla Basin, showing the quality of the Ground and Pressure Waters,

Little warping appears to have taken place during the laying down of the lower beds, but there is evidence of a Post-Tertiary fault scarp along the Hampton Range, just north of Eucla and west of the South Australian boundary. ([1])

To the south, along the coastline, the Tertiary limestone is covered by a small accumulation of sandy soil, supporting a stunted arboreal vegetation. and so contrasting sharply with the normal travertine plain, which is sparsely clad with saltbush and blue bush.

To the north of the Plain very little is known until the area far to the north mapped by the Elder Expedition in 1891-1892, and of which a part was seen by the writer in 1914 (Bulletin 5, G.S.S.A.) is reached. The records of explorers show that the intervening space is very sandy, with salt lakes in parts, and that there are no ranges or elevated ground capable, with the low rainfall, of running water into the intake bed of the Eucla Basin in any quantity. These salt lakes are believed, by the writer, to mark an east-west depression into which the very scanty ground water of the region between it and the Musgrave Ranges drains, and from which this water, with a salinity of up to 10oz. per gallon, escapes in an easterly direction beneath the Lake Phillipson area into the Jurassic sands of the Great Artesian Basin. Ross' Salt Springs, ([2]) which escape from horizontally bedded quartzite and grit rocks, are probably a manifestation of this water traversing the Jurassic grits and superficially indurated sands. As these sands surround granite inliers to the east-north-east of the Springs, the granite is probably so shallow as to be the cause of the emergence of the spring water.

Salt though the deeper water of the Eucla Basin has been proved, it is far less so than the water escaping under the Lake Phillipson area, and this suggests that the salt lake depression does not contribute an overflow to the Eucla Basin.

The inefficiency of any possible feeding area is a sufficient explanation of the poor quality of the pressure water, and of the even worse quality of the ground water occurring in the Polyzoal limestone. This salinity can only be due to the unevaporated residue of a 10in. to 6in. rainfall, carrying the cyclic salts down to ground water. The suggestion that it is connate salt is, in the writer's opinion, untenable, in view of the porosity, the abundant solution cavities in the limestone, and the length of time the beds must have been above the sea to permit the formation of these cavities. The removal of so much limestone in solution implies that the much more soluble connate salts have been thoroughly leached.

Two sections Q.Q. and R.R. (Plate IV.) have been drawn to show the geological structure, the quality and the position of waters cut by bores.

Section Q.Q. extends in an east-north-easterly direction from Albala Karoo Bore to Pidinga Rockhole. Four of the six bores in the section have proved the existence of granitic or gneissic bedrock. The greatest depth recorded to bedrock is 1,120ft. at Guinewarra Bore, while granitic rocks outcrop at Pidinga.

Sands and lignitic clays of Tertiary age were laid down upon this base, and beds of this series constitute the principal aquifer of the Eucla Basin. The lignites are exposed at Pidinga, the overlying strata having thinned out. At the other end of the section the lignite cannot be recognised in the bore log of Albala Karoo, and the impression formed is that it has thinned out in this direction also.

([1]) L. K. Ward.

([2]) H. Y. L. Brown, Geol. Explorations in the W. & N.W. of South Australia, 1905.

Overlying these beds is a wide expanse of clay or shale, generally bluish, which dies out near No. 7 Bore, and probably also along the northern and eastern sides of the Basin.

It is not an aquifer, though a little 1½oz. water was cut near its upper limit in Albala Karoo Bore, but forms the cover rock that confines the lower water. It has a maximum known thickness of 400ft. at Albala Karoo.

Overlying this is the Janjukian Polyzoal limestone, which forms the cliffs to the west of the Head of the Bight, and underlies the widespread Nullarbor Plain traversed by the Port Augusta-Kalgoorlie railway. Its greatest recorded thickness, at Guinewarra, is 570ft. After its emergence from the sea the upper portion has developed very extensive solution cavities, both vertically and horizontally, so that any percolating water readily reaches the ground water table. But as the limestone overlaps the bluish clay towards Pidinga, and probably also on the north, some of the northern rainfall, in part percolating through the limestone, and in part falling directly on the outcrop of the lignitic series, goes to produce the pressure water of the Eucla Basin.

Levels and bores along the Transcontinental Railway establish the isopotentials of both ground and pressure water with fair accuracy, but the levels of the coastal line of bores are based on aneroid readings. Sufficient levels are available to show a hydraulic grade nearly normal to the coast line, for both waters, of approximately 3ft. per mile.

In the western part of the South Australian portion of the Basin three railway bores proved useful ground water (from the point of view of stock keeping), ranging from .70oz. to 1.13oz. of salts per gallon, in the Polyzoal limestone and above the shale.

Below the shale, Albala Karoo Bore proved a small supply of 1½oz water at a depth of 740ft. This is probably nearly at the eastern limit of the better quality pressure water known to exist west of the State boundary.

Towards the Head of the Bight there is a group of eight bores tapping pressure water, of quality ranging from 1½oz. to 2.13oz. per gallon, in the carbonaceous series. The presence of salt water in bores to the east and to the west, and the direction of the hydraulic slope, prove the existence of a north-north-westerly intake through a gap between the saline pressure waters proved by the bores along the Railway. The bore at Cook, with its 1.85oz. pressure water, is on the only possible line of intake for this group of bores, and this belt of useful water should be traceable to the north-west or north-north-west of Cook, with reasonable expectation of some slight improvement of quality towards the north-westwards.

An analysis on record of 1.48oz. of pressure water at Nanwoora is of interest. No. 7 Bore gets salt unconfined or ground water in the horizon which, when under cover, yields the pressure waters, and this salt water precludes the possibility of Nanwoora being fed from the north. On the other hand, No. 6 bore with 1½oz. pressure water extends the area of useful water so far to the east that there is apparently shown a sharp constriction due to the salinity of Delisser and Bull Hill Bores. It is within the bounds of possibility that the saline top waters of Delisser and Bull Hill Bores get down outside the casing and contaminate the lower water. A hole between Bull Hill and Nanwoora might be justified on this reasoning. Again, the general suggestion of the hydraulic grade makes it possible that the salt water of No. 7 Bore escapes towards the sea between the useful waters of Bull Hill and Nanwoora. In this event the Nanwoora pressure water could only come from the north-east, and a hole in this direction would be a justifiable speculation.

Of the alternative possibilities it appears as if there is a balance of probability of the extension north-east of Nanwoora being the more likely, and one or other of these sites, if bored, should extend the area of useful water.

The ground water in the basin proper is too saline to be of use, except for 50 miles east of the Western Australian border, where bores on the railway gave the following results:—

At 554 miles from Port Augusta, 1.13oz. per gallon.
At 566 miles from Port Augusta, 1.07oz. per gallon.
At 597 miles from Port Augusta, 0.70oz. per gallon.

The Tertiary limestone may be regarded as forming the normal surface of the Nullarbor Plain, though it is superficially altered to travertine. The soil is thin and the conservation of surface water presents very great difficulties, by reason of the absence of holding ground and of suitable catchment areas.

Sand encroaches on the plain to the north, and a stretch of barren sands near Ooldea is capable of absorbing and protecting rainfall caught on a watertight bottom. The result is the well-known Ooldea Sandsoak wells that have been so freely utilised during the construction and operation of the Railway. West of Nullarbor Station, and near the coast, some sand overlies the limestone plateau, but yields no water, but at Merdyerrah Sandpatch the cliffs fall back from the sea front and the sands accumulated in the gap yield wells of the coastal sandhill type.

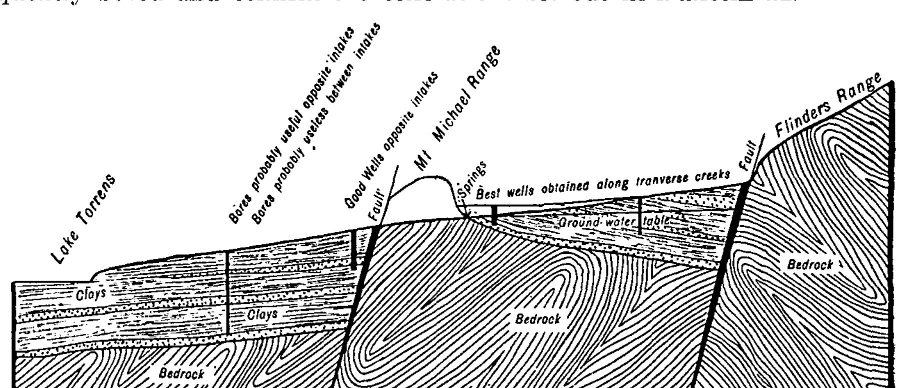
Section R.R., drawn from No. 2 Bore on Section Q.Q. to Nicholl's Well in the hundred of Wookata, shows an additional formation along the south-eastern portion of the section. Nanwoora Well and Bore is reported to have 1.48oz. water beneath salt water, but no depths are available. On this section, at no great distance from the coast, the Miocene limestone is below sea level, and is overlain by a very considerable development of an old dune formation. The sands of this formation are essentially calcareous and slightly consolidated.

They are capped by abundant travertine and are extremely permeable. The water in this formation is discussed under "Ground Water."

THE PIRIE-TORRENS BASIN.

This basin of pressure water extends from the strictly pastoral region on the north-eastern side of Lake Torrens to a little south of the Broughton River in the farming areas.

That portion of the basin lying east of Lake Torrens has been discussed in some detail in Bulletin No. 11, Geological Survey of South Australia, pp. 49-49, and it is unnecessary to go over the same ground. Several of the sites suggested and a number of others to the north have been subsequently bored and confirm the conclusions set out in Bulletin 11.



Generalised Section showing the occurrence of Water in the Pirie-Torrens Basin, east of Lake Torrens.

There has been a good deal of development in the southern portion and much information has been collected as to old bores, and many new ones have been sunk.

Trough faulting in Pliocene time formed a deep trough to the west of the fault scarp of the Flinders Ranges, and this trough has been filled with clays, sands, and gravels from the erosion of the Ranges by the creeks. The deepest portions of the filled area contain lignitic beds predating the faulting. Alluvial fans or cones of dejection have been built up to form the Pliocene plain, and during the formation of these cones and the aggradation of the plain, the channel of each contributory creek debouching from its rock valley in the Ranges must have repeatedly changed its course down the slope of its alluvial cone. Each active channel, when the creek brought debris on to the flatter portion of its course where the cone was forming, dropped boulders, gravels, sands, silts, and clays, and built up its bed till the sands and clays could escape laterally over its banks to form the clay deposits of the cone. Ultimately floods burst the channel and a new one formed, to be in turn built up and deserted by the stream. If it were possible to look down and into a cone of dejection, imagining the clay to be transparent, a fan-like arrangement of old stream beds radiating out from the notch in the rocks of the ranges would be visible at different depths. Further, if the detail of each of the ribs of the fan were studied it would be found that there is a diminution in the size of the particles making up the stick (or old stream channel) from boulders, through gravel, coarse and fine sand down the slope of the stream, and that, further, a cross section shows a diminution in size of particle laterally. The successive cones of dejection along the foot of the Ranges coalesce to form the plain, and the fine sands become less localised with increasing distance from the Range until they, too, coalesce and an aquifer containing a general pressure water is formed.

These old creek channels and their porous margins embedded in the clay are fed by floods from the Ranges and form the water storages that are tapped by boring. It follows from their mode of origin that there are irregularities both in supply and depth, but it may be taken as a working basis that the best chance of cutting these porous beds is opposite the outfall from the Range and sufficiently far from it to allow of storage above the bore site. Furthermore, there is a tendency for the quality of the water to deteriorate with increasing distance from its point of entry, and it has been noted in many instances that bores sunk in the plains between two main creeks debouching from hill country and close to the latter get water much inferior in quality to those sunk down the slope from the point where the main bodies of feed water can enter the ground. These rules are strictly applicable to the Pirie-Torrens Basin, and there is considerable variation in depth, supply, and quality.

Depths range from a few feet to over 600ft. In places, such as Stirling North and Nectar Brook, it has been found that the deepest water cut is much more salt than some of the upper waters. This is probably due to the sealing of the eastern intake by the fault scarp and the consequent exclusion from the deepest beds of the fresh intake water.

The bores near sea level flow, but those to the east yield pumping supplies only. The maximum flow recorded was 750,000galls. per day of 3oz. water on Wilkatana Station, north of Port Augusta, and several pumping bores in the basin yield from 20,000galls. to 50,000galls. per day. Quality is variable, the most favorably situated bores have developed water containing from 0.11oz. of salts per gallon upwards to ¼oz. Many of under 1oz. to the gallon are recorded, but in a few cases total failures, even as sheep waters, occur. As a whole it may be said that there is little difficulty in getting stock water, except in one or two saline areas that are known, and in two outcrops of the old rocks that protrude above the surface of the artesian basin. The best waters have been largely developed in recent years, for town and irrigation supplies, in the vicinity of Port Augusta and Port Pirie.

II. THE GROUND WATERS.

Ground water is water which is free and not under pressure exceeding that of the atmosphere at its upper surface. Consequently, being unconfined by an overlying impervious bed, it is fed by the direct downward percolation of surface water, and is of local origin. This characteristic of local origin, as compared to the distant origin of artesian or pressure water, which has travelled laterally to be present beneath a watertight covering bed, is of importance, as ground and pressure waters cut by the same bore may have sources so far apart and under such widely different conditions that the qualities may be very different. The qualities of ground waters are much more irregular than in the case of artesian water, as may be easily understood if the variability of conditions governing its occurrence at different localities is noted.

Quality.—In the arid and sub-arid portion of the State first consideration must be given to the probable quality. Very few holes that have attained any considerable depth are wholly dry, but very many tap water so saline as to be useless. It may indeed be postulated that with less than 12in. to 14in. of annual rainfall saline ground water is normal and that special conditions must be sought to get supplies of useful quality.

The presence of salts in rainfall has been abundantly proved by analyses in many parts of the world, and South Australia is no exception. With the light rainfall, the small individual showers, the absence of run-off, and the high evaporation characteristic of so much of South Australia, the bulk of the rainfall is dissipated into the air instead of reaching the ground water table, while the soluble salts, the carbonate of lime, and the gypsum remain in the soil until exceptionally heavy rains add their quota to the ground water and carry down all the salts stored in the soil from the evaporation of light rainfalls.

This concentration by evaporation is so great that the direct rainfall in the drier regions is insufficient to provide useful ground water except where the conditions are exceptionally favorable for percolation and for the checking of the subsequent evaporation. Such conditions are provided by the barren siliceous sand dunes along portions of the coast, and to a lesser degree by some of the older calcareous dune formations. They are absent when an appreciable proportion of clay is present in the soil.

Thus the first requisite for the occurrence of useful ground water is that there should be an accumulation of surface water in such bulk that it can enter the ground in quantity sufficient to dilute to harmless proportions the salts contained in the soil and subsoil. This involves an examination of the topography to ensure a quick run-off and accumulation of floodwaters, followed by a geological examination of the course followed by the floodwaters to see if there is any stratum or creviced area into which the waters can freely enter and be stored.

A third condition is that the site must not be in one of the main depressions of the country as the general underflow towards the low ground tends to mingle, with the result that the water under such depressions is too saline to be of use. Thus the extreme heads and the lowest portions of watercourses should be avoided, unless there is evidence of the presence of some especially favorable conditions.

THE GEOLOGICAL FEATURES GOVERNING THE OCCURRENCE OF GROUND WATER.

Assuming that the topographical conditions are such that there is a concentration of surface rainfall water in considerable volume and that there is a reasonable chance of avoiding the lowest portions of the ground water table of the region, consideration must then be given to the geological structure to determine where the surface water can enter the ground most freely. Practically all the older rocks of South Australia, down to and including those of Ordovician age, are, in their fresh unweathered state, so dense that the rocks themselves cannot store or yield water. Such water as is got from them (and it is a very important factor in the pastoral life of the State) is held in and yielded by either the weathered upper portion of these rocks or by the network of joints which is always present, though more or less imperfectly developed, in all the older rocks.

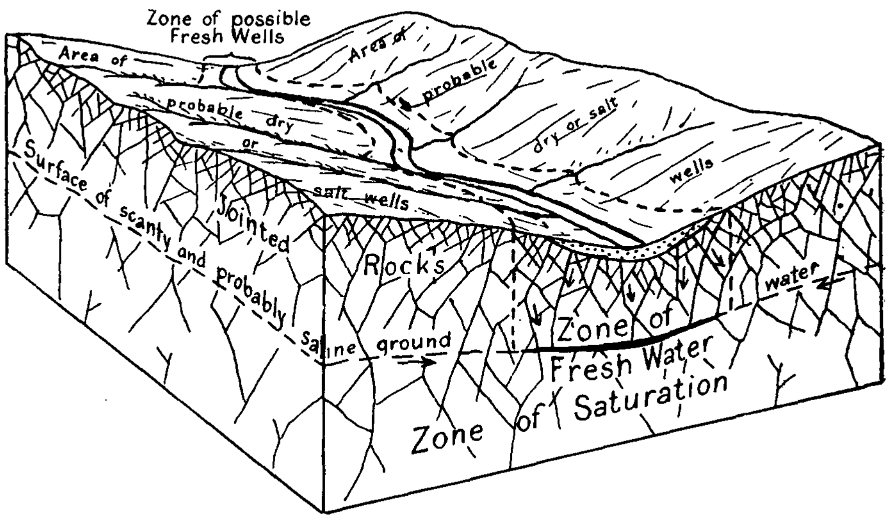


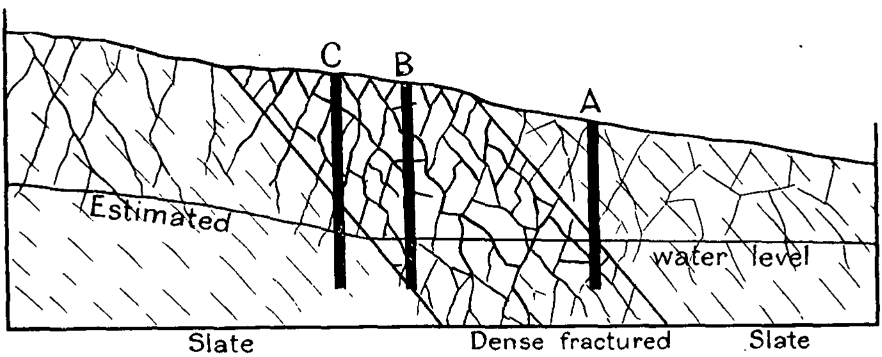
Diagram illustrating the Zonal Occurrence of Useful Water in the Drier Areas in Jointed Rocks beneath Drainage Channels.

The type of rock and the nature of its weathered product influence the supply to be obtained from the zone of weathering. The aluminous rocks, for example, when weathered to clays may contain large quantities of water, but are incapable of yielding it from their pore spaces at an economic rate, while the joints, which in the unweathered rock yield water, have ceased to exist in the weathered rock.

When boring in the weathered aluminous rocks it is generally advisable, if the quality of the water continues satisfactory, to bore into the unweathered zone for a few feet to penetrate the jointing. If a joint of appreciable size (say, ⅛in. or more wide) is cut, the bore is then in all probability in communication with a network of joints, and these joints can collect the water from the overlying weathered material over such an area as to afford a useful supply. Slate and shale, which are the most abundant of the older rocks, are unfavorable aquifers, by reason, not only of their argillaceous weathered zone, but also owing to the tendency of water circulating through the joint system to decompose the walls of the joints, and so to close them by the increase of volume that takes place in the change from slate to clay.

The quartzites are of two types, one being a felspathic quartzite or arkose, which weathers to a soft sandstone with an argillaceous cement. The Mount Lofty freestone is a good example. This type may contain water in considerable amount in the weathered zone, but does not yield it very freely to a well or bore wholly within that zone. If there is reason to believe that the bed has been fractured by earth movements the network of joints in the unweathered zone should be penetrated. Many wells have been sunk in this rock and give good supplies, as the joint system can draw on the water stored in it and in the overlying weathered material over a considerable area.

The other type of quartzite is that having a siliceous cement which consequently does not weather to a soft rock. Its possibility as an aquifer depends upon the abundance of its jointing, and very careful consideration should be given to the jointing before a hole is started. If it is abundant the quartzites may be worth developing, but to sink in them is costly, and it is advisable, if the beds are inclined, to so lay out the site as to penetrate a softer rock (generally slate) and only enter the hard quartzite at the estimated water level. In this section site A would be much less costly than B and equally satisfactory in other respects, while C would be a comparative failure owing to being wholly in the less jointed slate below water level.



Wells depending on Jointed Quartzite.

Among the older rocks the most favorable potential aquifers are the limestones, dolomites, and marbles. These are all sparingly soluble in water, so that once water begins to circulate through a joint the latter is enlarged by solution of its walls until openings of appreciable size are developed, ranging in extreme cases up to large caves. A well or bore, penetrating such a limestone bed, even if it is only 2ft. or 3ft. thick, has a very good chance of cutting a network of very open joints which can not only drain a considerable length of the bed, but are in communication with the smaller and less free-yielding joints of the strata on either side. Where the geological formation is such that limestone beds or even calcareous slates exist, these beds should be sought as favorable to bore into below the estimated water level.

Jointing.—Since the chances of getting water in the granites, gneisses, schists, phyllites, slates, quartzites, and limestones, all of which are non-permeable, depend upon cutting joints, it is necessary to consider the possible distribution and frequency of such joints. It is a matter of common knowledge to those engaged in metal mining that the joints cut in sinking and crosscutting are larger, more numerous, and wetter not far below the water level, and that, as a general rule, after a depth of about 400ft. to 500ft. has been reached crosscuts disclose very little water unless fault planes on which movement has taken place, or the lode channel are cut. The Geological Survey of the United States (Water Supply Paper 489; O. E. Meinzer) has set out the nature of the occurrences of joints in crystalline rocks as the result of a large series of observations. Meinzer points out that there are two types of joints, the vertical and the horizontal. The former are the most important water carriers and feeders, and the mean dip recorded in 75 localities was 74°.

Meinzer states:—

"that the vertical joints have no regularity of spacing, even for the same rock. From a large number of observations it appears that at the places where jointing is well developed the spacing of all joints is commonly between 3ft. and 7ft. to a depth of 50ft.; the average spacing, however, between vertical joints of the same series for the crystalline rocks, excluding trap and limestone, is more than 10ft. for this depth, while the study of well records indicates that this is not far from the average spacing for all joints to a depth of 100ft.

"Although there are many exceptions, joints of this type are generally continuous for considerable distances both along the line of outcrop and that of dip. Faults, however, have the greatest continuity and frequently extend for several miles across the country, occasionally for tens of miles. The sheeted zones of close jointing are probably nearly as continuous as faults, and their dimensions should be measured in hundreds of feet. Where there is a well-defined parallel joint series the prominent joints may extend several hundrd feet, while the minor intersecting joints will be much shorter.

"*Horizontal Joints.*—There is much greater regularity of spacing in the horizontal joints than in the vertical joints. They are apparently surface phenomena and diminish in number rapidly with depth, and it is probable that they do not exist as fractures at 200ft. below the surface. In the first 20ft. below the surface these horizontal joints average 1ft. apart, in the next 30ft. they average between 4ft. and 7ft., and in the next 50ft. they are much more widely spaced, running from 6ft. to 30ft. or more apart.

"The continuity of individual horizontal joints rarely exceeds 150ft., but owing to their intersection of each other a continuous opening might be formed of several hundred feet which would be in the form of a curved sheet approximately parallel to the hill slope, each lower sheet having less curvature than the other. They are probably better developed on the hills than in the valleys, as the pitch of the joints is usually less than the slope of the surface, which consequently cuts across the joints, and as they are wider spaced with depth the horizontal joints which cross the valleys will be widely spaced.

"*Depth.*—Not only do joints become tighter with depth, but they are farther apart. The application of this principle in the drilling of wells is of the utmost importance, as it is frequently asserted that water can always be obtained by going deep enough, whereas, in fact, the deeper the well the less the chance of striking fractures, which are the only passages permitting water transmission in crystalline rocks. It is further evident that owing to the closing of joints with depth, there will be a much greater circulation in the upper half than in the lower half of any individual joint.

"The number of fractures supplying water varies greatly in different wells. In some cases the greater part of the water appears to come from a single opening, while in others the water comes in slowly from a large number of openings. In the average well there are from one to four horizons from which the principal supplies of water come, although the yield from one of them is usually greater than from all the others together . . . .

"If an average inclination of 70° from the horizontal and an average spacing of 10ft. be assumed for the vertical joints for the upper 200ft. of rock, each well 200ft. in depth will intersect seven joints. This is probably not far from the average for all the wells, the small and discontinuous fractures near the surface being neglected. Below 200ft. the average number of joints intersecting would be somewhat decreased for the next 100ft., and greatly decreased at depths greater than 300ft."

In the sedimentary rocks the bedding planes may also yield water, hence the frequent comment by drillers that "the water is held down by bars of rock," either hard or soft. These bedding planes also tend to become less prominent with increased depths.

It is evident from the quotation given above that the chances of cutting large joints decrease with increasing depth, and that by about 300ft. the chances are reduced to cutting major fractures, such as faults, which are comparatively scarce. Some holes must, of course, be sunk on chance when the surface mantle prevents the goelogical structure being seen, and all that can be done in such cases is to ensure that the surface conditions are such as to provide a sufficiency of surface water to enter freely, if there are joints for it to penetrate. In many more cases, however, is it possible to so select a site that the hole may enter a bed of rock of a type known to be habitually well-jointed, and possibly to do the bulk of the sinking to water level through a softer though probably unjointed rock. It may even be possible to find fracture zones into which to sink.

In the older sedimentary rocks sharp anticlines (arches), and, to a lesser degree, synclines (troughs) fracture and joint the strata and afford storage space, and several instances of successful wells have been noted where a suitable creek crosses such a structural form and feeds the abundant jointing.

It is apparent that in the older rocks there are many types, differing in their capacity to develop and maintain open fractures. and also that in different localities there have been earth movements of varying magnitude. Thus, some rocks may be satisfactory aquifers in one place and elsewhere be most unpromising.

Consideration must be given to these factors, though in the actual search for suitable well or bore sites attention must also be paid to the topographic conditions which govern (*a*) the accumulation of surface water in bulk sufficient to enable it to reach the ground water table, and (*b*) the probable salinity of the ground water.

If these simple rules are followed and the necessary conditions found, there is little doubt but that in the older rocks of South Australia a bore should be a success before 300ft. is reached from the point of view of supply.

The Igneous Rocks.

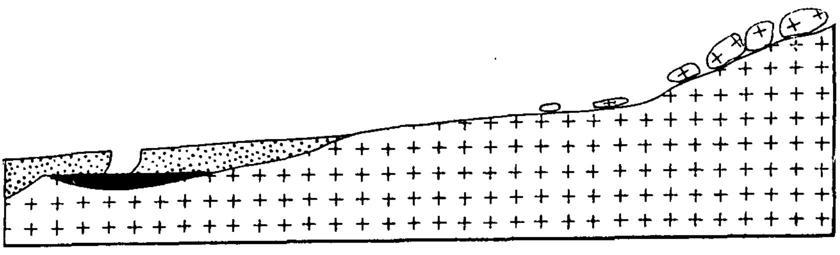
Only two igneous rocks occur in sufficient quantity in South Australia to be taken into account as possible aquifers.

Felspar porphyry is developed in the Gawler Ranges and in the vicinity of Tarcoola over wide areas and appears to have been effusive in type. Consequently a good deal of fine jointing, due to cooling, has taken place and numerous wells and bores have cut supplies large enough to be very valuable to the stock raiser. Many of the waters, however, are salt.

Granite.—The area of granite present in the State above the level of the water table is considerably greater than is indicated on geological maps, in which the mapping of shallow superficial deposits which overlie granite obscures the presence of the latter. The granite may be roughly subdivided into the younger penetrating the sedimentary rocks and showing little or no evidence of strain; and the older in which a more or less pronounced gneissic structure has been developed, and which are in many cases indistinguishable from gneiss of sedimentary origin. The older granites are perhaps a little more favorable, as there is a better chance of joints having been developed.

The granites and gneisses predominate in the Bimbowrie district, over parts of Eyre Peninsula, on either side of the East-West Railway between Wilgena and Ooldea, and in the region of the Everard and Musgrave Ranges in the north-western portion of the State.

Many wells have been developed in the granites where the rock has weathered to a considerable depth. The best water occurs where pockets of decomposed granite close to bare outcrops absorb the run off from the latter.



Section showing a Soak Well below a Granite Hill (Moorilyanna).

The water occurs in these pockets or is intercepted by the well in its slow percolation down the slope of the impervious weathered granite. From their very nature the supplies from these granitic soak wells are small. A more important type is that which penetrates a considerable thickness of decomposed granite. The nature of the products of decomposition vary. In some localities decomposition is complete, the product consisting of the angular quartz grains embedded in a matrix or cement of kaolin derived from the weathering of the felspar. This may be saturated with water, but will yield no supply to a borehole or even to a well. Indeed, the kaolin has a tendency to slump and fill the hole. If the quality of the water is satisfactory the hole should be continued until dense unweathered rock is reached, as it has been found in many bores that the transition zone between the completely decomposed and the fresh granite is open enough to yield water freely, and forms a widespread sheet of pervious material which can drain a considerable area of the overlying saturated kaolin. In this zone incipient decomposition has more or less disintegrated the granite into its component crystals, and so produced openings of appreciable size. The drillings from this zone are coarse, while the fresh underlying granite can only be broken up as a fine powder. When this stage has been reached without getting an adequate supply, and the fresh granite penetrated for 5ft. to 10ft., it is generally advisable to abandon the hole. The writer recognises the fact that some holes have been fortunate enough to cut a fissure after penetrating considerable distances into granite, and to have got useful supplies, but the chances of failure are so great that sinking deeply into fresh granite cannot be regarded as a legitimate commercial risk.

In the drier portions of the State, and especially where gneiss is developed, disintegration rather than decomposition of the rock takes place, and it is possible to form, from surface exposures, some idea of the amount of fracturing. In such cases zones of particularly well-fractured rocks may be traced beneath the watercourse that is expected to feed the ground water, and sites may be selected with reasonable confidence.

In many cases the deep soil mantle prevents an estimate of the water storage capacities of the underlying rock, and the best that can be done is to ensure that the site selected is adequately fed and has a reasonable chance of avoiding saline conditions (*i.e.*, is kept out of the low-lying country). Fortunately these very old rocks are generally fairly well fractured, and the risk of boring is justified, though it is certainly greater than where a known zone of fracturing can be recognised.

The Sedimentary Rocks.

Lower Pre-Cambrian.—These comprise schists, phyllites, quartzites, and altered limestones, including some marble. Speaking broadly, the rocks of this period are characterised by extensive felspathization, and by the presence of intrusive dykes of granites, pegmatites, and, in places, basic rocks.

Their principal occurrences are in Kangaroo Island, Eyre Peninsula, portions of Yorke Peninsula, portions of the Mount Lofty and Flinders Ranges, areas in the vicinity of Olary and Cockburn, and the Denison Ranges.

These rocks are likely to be jointed and fractured. The altered calcareous rocks are perhaps the most promising, but are scarce and difficult to locate. Some of the quartzites are well fractured, and a bore may be reasonably laid out to enter the fractured quartzite below the estimated water level. Owing to the hardness of this rock and the consequent cost of boring, it is advisable, where possible, to so select the site that the bore for the major portion of its depth passes through the softer schists or phyllites that are commonly associated with the quartzite.

Several bores of this type have been successful to the north of Kimba, but they have had to be placed on creeks in very high country to avoid the extremely saline ground water that is so widespread in this region, and the favorable topographical conditions are limited in area. The schists and phyllites are not promising as aquifers.

The Upper Pre-Cambrian (or Adelaide Series).—This series is made up of grits, phyllites, slates, tillite, quartzites, limestones, and marbles.

It forms the bulk of the highlands of the Mount Lofty and Flinders Ranges areas and extends for a considerable distance on either side of the Broken Hill Railway.

While water has been got in more or less satisfactory amount in every one of these rocks, the risk of boring can be greatly reduced by searching for the most promising aquifer within the area to be served. Several easily identified horizons occur in this series, notably the glacial till, the overlying thin-bedded Tapley's Hill slates and the Brighton limestones of the type district described by Professor W. Howchin (Geology of South Australia and Trans. Roy. Soc. of South Australia). The chief aquifers are the limestones, and their position is fairly well known in the geological sequence.

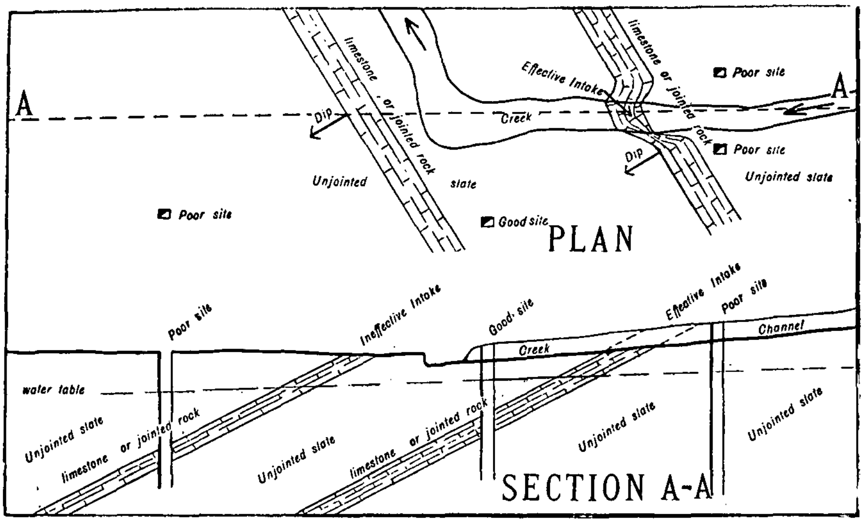


Diagram illustrating the influence of geological structure and topography on well sites.

Small beds occur in the till itself, and one about 6ft. thick is fairly persistent in the pastoral areas, between the till and the overlying Tapley's Hill slate. The Depot Creek Springs, near Port Augusta, derive their water from this source, and near Waukaringa a thin limestone in almost the same relative position has yielded useful supplies. The Tapley's Hill slates are poor water holders, but in some localities a small bed of limestone a few inches thick, or even a slate more calcareous than the normal, is the best available aquifer within the area to be served, and may be sunk to with reasonable prospects of success.

The main aquifer of the series overlies the thin-bedded Tapley's Hill slates and consists of the Brighton limestones. They vary a good deal in purity, but the purer beds afford useful and, in many cases, large supplies. For example, a bore at Depot Creek in this formation has yielded 80,000galls. per day.

Above the Brighton limestone is the great series named by Howchin the Purple Slates, and described by him as comprising slates, shales, flaggy sandstones, quartzites, and limestones. They occupy a large area in the Flinders Range and, as mapped, probably include both the upper portion of the Pre-Cambrian and the Cambrian beds associated with theArchaeocyathinae limestones. The areas occupied by these formations have not yet been fully elucidated by detailed mapping, but between the Brighton limestone and the great beds in which the Archaeocyathinae are so abundantly developed there are many small beds of limestone that afford most useful aquifers.

In many cases, however, it is not possible to find suitably placed calcareous beds, and an endeavor must be made to get the necessary supply from some structural feature. Faults or shatter zones may sometimes be recognised and justify testing. In one case at least (Freeling Well in the

North Flinders Range) a well was seen that appeared to have been intentionally sunk on a sharply folded anticline to get the benefit of the intense fracturing, which was fed by the meanders of a creek across the axis of the fold.

The quartzitic members of the series may or may not be favorable. Some are felspathic or arkose in type and soften superficially to the so-called "freestone." Others have siliceous cement and are very dense. Where folding is seen to have been pronounced or where the rock is well jointed the probability of success is good, but in areas of gentle folding the quartzite is as likely to act as a barrier to the underground water as to be an aquifer. Many instances are to be seen in the Flinders Ranges of quartzite beds acting as underground dams and forcing the underflow of the creeks to the surface. Where this occurs the well should be placed on the upstream side of the quartzite. The effect of the dip of the beds relatively to the proposed site and the intake should always be considered.

Sometimes no structural features can be recognised owing to a widespread soil mantle, and the best that can be done is to select the most favorable topographical site and trust to the underlying rocks being sufficently creviced to store and yield water.

Cambrian.—This series, like the Upper Pre-Cambrian, contains a large development of limestones, and the general conditions are very similar to those governing the occurrence of water in the older series.

Ordovician (?).—This series lies wholly to the west of the Lake Torrens faults, and being on the stable foreland has suffered very little deformation except in the far north-west at Mount Chandler, where it dips at 40°. If it is present to the east of Lake Torrens it has not yet been recognised.

The series, as far as it has been deciphered in the area where it is best developed to the west of Lake Torrens, consists of three main horizons (see Section S.S., Plate IV.).

The deepest member exposed is a slaty rock, chocolate when weathered and greenish in a fresh state. It is exposed in Andamooka Creek, and in the bottom of Yandamdarre Creek to the south of Roxby Downs, where it has been quarried for flagstones. Beda Bore, 48 miles north-west of Port Augusta, penetrated this slate between 281ft. and 439ft., and then entered a rock described as "trap," which persisted to 1,099½ft., the bottom of the bore. This "trap" is a porphyry, not unlike that of the Gawler Ranges.

On this slate, sandstone, probably felspathic, was laid down to a depth of not less than 250ft. and possibly a little more. It was deposited in thin layers, and in shallow water as evidenced by extensive current bedding and ripple marks. Alteration to quartzite and a subsequent decomposition, in part, to sandstone, has taken place since the deposition of this formation. Some limonite occurs over a wide area near the bottom of these beds.

The third and uppermost formation is a greyish buff and, in places, purple limestone of sub-crystalline structure. It contains characteristic cherty aggregations, which, having resisted weathering, remain in parts of the area as evidence of a former greater extension of the limestone. The maximum thickness known to the writer is 120ft.

On Eyre Penisula the Blue Range, west of Arno Bay, consists of a tabular mass of the quartzite, resting unconformably on the Pre-Cambrian rocks. The superior and inferior beds are missing. At Mount Chandler in the north-west the quartzites alone are visible, the underlying slates evidently being concealed by faulting, but they are well developed at Mount John, a few miles to the eastward, and rest unconformably upon the Adelaide series. In their turn they are capped by quartzite, which dips gently under the Jurassic sands to the eastward. How far it extends in this direction is not known, as only Marla Bore (the westernmost hole) has reached it. Outliers of this quartzite have been seen by the writer to the south of the Everard Ranges and they have been mapped by Victor Streich (Geologist of the Elder Expedition) across the West Australian border. The principal area, and that in which there has been the greatest search for water, lies between Whyalla and the north end of Lake Torrens.

These three formations have been slightly folded, so slightly that the synclines are very ill-defined. The general impression that was formed by the writer was that the synclines had axes trending east-north-easterly to west-south-westerly, but there are breaks in the continuity of the residual limestones occupying these troughs. The dips are very small, the maximum noted being 5°, with others of about 2°, but for the most part the order of succession of the beds on a traverse gives the only indication as to dip. Erosion has produced a peneplaned surface and completely removed the limestone from the anticlines, exposing the more resistant quartzite in the higher "tableland" areas. Residual chert from the limestone may be found on these tablelands, but does not indicate the presence of limestone beneath. The typical surface stones of the tablelands are angular and tabular thin-bedded quartzites derived from the breaking up of beds resistant to decomposition.

Upon these formations a very much younger one (the Eyrian) has been laid down wherever the surface was low enough to be submerged. The bulk of this formation consists of whitish and mauve clays with a proportion of waterworn stones from the Ordovician quartzite and fragments of chert from the limestone. This material has suffered a superficial silicification, making a quartzitic crust which also breaks down to "gibbers." that are quite distinct from those derived from the older quartzite. The Eyrian formation is seen most prominently in the vicinity of Andamooka H.S. and on Barber Ridge on Roxby Downs, where bluffs expose a thickness of approximately 100ft. Near the bottom a ferruginous zone leaves a characteristic residue.

Erosion has removed most of the Eyrian formation and exposed the Ordovician slates in the main valleys, but the Eyrian gibbers remain in more or less profusion interspersed with the angular ones of the older quartzite. There are, however, places on the tablelands on which the Eyrian gibbers are associated with *waterworn* stones of the older quartzites. Such localities are worthy of testing for excavated tanks as the Eyrian clay is impervious, and, never having been consolidated, is more easily excavated than the decomposed quartzite of the tablelands. The possibility of sinking tanks in this formation has been discussed owing to the great difficulty of getting useful subterranean water in this region. This difficulty will be realised if the results of well sinking and boring are examined in Section S.S., Plate IV.

From Whyalla to the vicinity of Yorkey's Crossing, eight miles north of Port Augusta, the slate is exposed at intervals, while the partly dissected quartzite bed forms the very striking "tent hills" of this region.

To the north-west of the area shown on the geological map as occupied by the Ordovician rocks it is now known by boring and investigation of the edge of the formation that it dips beneath the superficial cover and the Jurassic sands of the Artesian basin.

The slates are tight and yield but small supplies. Furthermore they are generally exposed only in the low-lying main valleys where the ground water is salt. The formation must be regarded as the impervious bottom beneath which it is useless to go.

The quartzite is the main aquifer of the region, and it is not a good one. The thin bedding providing horizontal joints is in its favor, but the small amount of deformation the series has suffered has not developed vertical jointing to any great extent. Still it is generally the only choice possible so that the best that can be done is to pay special attention to the topographic features; that is, see that the site is out of the main valleys and high enough to bottom if necessary on the slate above the level of salt water, and finally see that flood flows can saturate the site freely. Some of the wells in this formation, such as the Bosworth Wells of Yeltacowie and Myall of Andamooka, yield important supplies, but on the whole the best supplies are provided by the limestone that has escaped erosion in a syncline. The areas of limestone are preserved in troughs, and unless there is reason to suppose that the limestone is very shallow, such areas of limestone justify sinking. The surface generally on these limestone patches is sufficiently low to form extensive but short-lived swamps after heavy rains, and the water of these swamps reaches the ground watertable easily. Even if the limestone proves shallow a hole should be continued in the underlying quartzite until a supply is obtained or the slate or useless water is cut. It must be recognised that in the Ordovician if the water is too saline to be of use there will not be better water beneath it, and the hole should be stopped forthwith.

There is a very definite risk of over-deepening in these formations, as there is a tendency for the fresh water entering from a swamp or watercourse to displace the normal saline ground water both vertically and laterally, and so form a "pool" of useful water. Many wells deepened to increase supply have got the supply at the expense of quality or even the loss of the well through salinity. A bore can be saved by plugging the lower portion of the hole until the bad water is shut out, but it is much more expensive and uncertain to save a well of which the walls have been fractured by blasting.

Triassic.—The only known surface exposures of this age in South Australia are embraced in the Leigh Creek coal field, and all the deeper water that has been cut is too saline to be of use. There are shallow and useful waters where the Leigh Creek crosses these beds, but these waters belong properly to the Recent superficial material along the creek.

Jurassic.—The normal waters of the Jurassic series are the pressure waters of the Great Basin and these are discussed elsewhere. In the south-west corner of the basin the overlying impervious cover is absent or non-continuous, and the water is ground and not pressure water, and is of very variable quality. (See p. 15, Great Basin.)

Lower and Upper Cretaceous.—Very little ground water is known in these formations, which are essentially argillaceous. Some pressure water is found and its occurrence has already been discussed. (See p. 17.)

Eyrian.—This formation has been examined in some detail to the north of the Flinders Range and in the north-eastern corner of the State as a possible aquifer. ("Desert Sandstone" of Bulletin No. 11).

From sections that were examined in the latter area it was found that this formation attained a thickness of 360ft. and was unconformable to the Winton beds. The upper 120ft. is essentially arenaceous and if low enough to be fed by creeks from higher land yields good supplies, but much of this bed is so high that it is dissected and so drained by the creeks rather than fed. It dips from the Cordillo area to the west and south under the Recent alluvium and should be worth exploring for pressure water under this younger cover. (See Bulletin 11). The middle third of the Eyrian is very argillaceous and yields no supplies, so that wells in it are failures. Even if they penetrate it and pass into the lower third, in which there are some pervious beds, the latter may be shut off from supply by the overlying impervious beds.

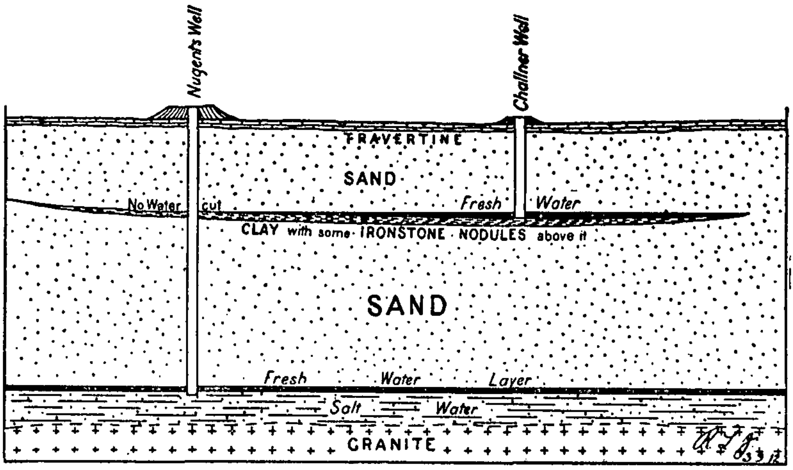
Tertiary.—Two very large areas of Tertiary marine sediments are developed in South Australia, the Nullarbor Plain area and the area east of the Mount Lofty Ranges, between the highlands along the Broken Hill railway and the coast. Of the Nullarbor Plain it can briefly be said that the normal ground water in the Tertiary beds is useless with the exception of an area near the Western Australian border. (See figure on p. 28.)

North of the Murray no good ground water has been found except in flood channels, and these exceptions belong rather to the Recent than to the Tertiary formations. South of the Murray the ground water becomes generally fresh from Pinnaroo southward, while there is a good deal of difficulty in getting useful ground water north and west of a line joining Meribah, Karoonda, and Kiki.

Upper Tertiary.

To the north and east of Streaky Bay, on Western Eyre Peninsula, and west almost as far as Penong, except for wells in the limestone formations close to the coast, salinity is very pronounced, and it is difficult to get useful underground water; but there are some wells where the porous strata have permitted rainfall to percolate to and form a layer on the surface of the ground water. In this region there was an old undulating land surface composed of rocks of granitic and gneissic habit, which was subsequently almost wholly buried beneath Upper Tertiary sediments that are, on the whole, pervious. The old buried granitic valleys are filled with salt water, which, from the hydraulic gradient, is known to be moving slowly toward the sea.

In some cases well and bores have bottomed on the granitic slopes above the level of the saline waters of the valleys, and so intercept fresh water that has penetrated the soil or subsoil, to be deflected in depth by the unweathered and impervious granite. Several wells and bores around Parla Peak are of this type, and it was noted that, though water level might stand high up in the kaolin formed by the decomposition of the granite, the material was so impervious that no useful supply was got until the bore or well entered the transition zone between the completely weathered and the fresh granite.



Section showing the Geological Structure at Challner Wells.

Very occasionally perched water tables, such as that developed by Challner Well, in the hundred of Tarlton, may be found. They depend on the presence of a pervious soil, and subsoil, over an impervious stratum so disposed as to retain the percolating water on its upper surface. At Challner Well the stratum consisted of 3ft. of clay extending over a very few acres, with sands and soft sandstone above and below the clay. The latter was probably a claypan among sand dunes which was subsequently buried. Beyond a thickening of the travertine crust above the shallow water there was no indication of the presence of the water, and waters of this type are very easily missed by boring.

Pleistocene to Recent.—Under this heading are grouped many types of deposits. They may be summarised as:—

(*a*) normal alluvials of stream valleys;
(*b*) outwash alluvial fans and plains flanking the main ranges;
(*c*) the older sand dunes;
(*d*) the Recent sand dunes of the coastal areas;
(*e*) wind-blown sands of the interior.

The Stream Alluvials.

Composed essentially of clays, silts, sands, and gravels these alluvials may yield water when sunk into, or when so shallow that they rest upon a rock bottom above the level of the ground water may perform a useful function by holding in their pervious members the intermittent flood flows and so give them time to sink through the crevices of the rock to the water-table. While very many useful wells derive their supplies from this type, in the drier areas of the State the lower portions of the larger valleys are very apt to be underlain by saline water, and the search in the main valleys must be abandoned in favor of high level tributary valleys where the ground water circulation is more active, and consequently there is less opportunity for an accumulation of salts.

Outwash Plains and Alluvial Fans.

Along the flanks of the Flinders and Mount Lofty Ranges the larger stream channels debouching from the ranges have built up alluvial fans or cones of dejection which, gradually coalescing with increasing distance from the apices of the cones, merge into the plains that flank the ranges. Ground water is found in these deposits, as a general rule of quality proportional to the efficiency of the feeding stream channels. Well out on the plains the quality is generally bad, but these plains are underlain by considerable depths of Pleistocene deposits and pressure water is generally to be found in them below the ground water. Even in the case of this artesian water there may be marked variation in quality.

The Older Sand Dunes.

Prior to the formation of the younger or siliceous dunes the dune sands were much more calcareous and in places consist essentially of wind-blown rounded shell fragments. They are well developed near the coastline of the South-East, on the southern and western shores of Kangaroo Island and Yorke Peninsula, and extend from the south end of Eyre Peninsula to beyond the hundred of Wookata and nearly to the Head of the Bight. They show their aeolian origin by the characteristic slope of the wind-bedded planes, and the large proportion of carbonate of lime present results in the formation of a travertinous crust.

No surface streams exist on this formation, the rainfall being dissipated by evaporation, transpiration, and percolation to the ground water table.

The proportion that is available to form ground water depends largely on the total rainfall, its incidence, and the absence of vegetation.

In the southern and wetter portion of the West Coast of Eyre Peninsula the ground water is good and abundant, and no difficulty is found in getting wells. To the east and east-north-east of Elliston this formation contains three areas of very considerable economic importance as potential water supplies: the Polda, Oakdale, and Wurkagie-Witera basins.

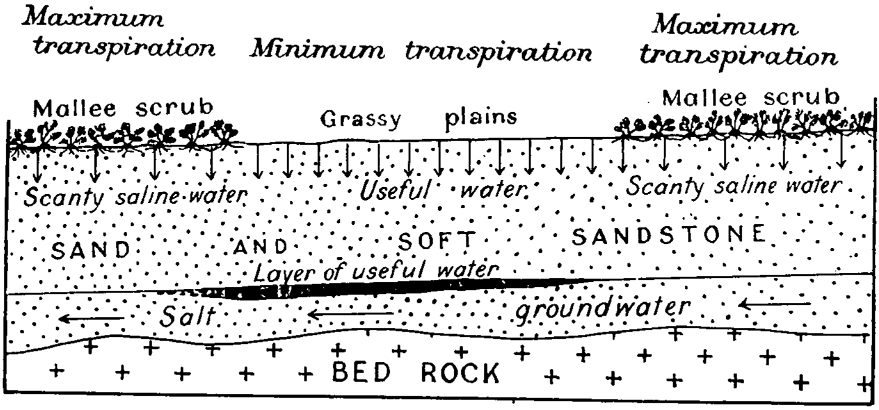
The Polda area has been exhaustively examined by the Public Works Department, and boring and other investigations have proved that there was an older land surface, of valley form, on to which calcareous sands have been blown (Bulletin 1, G.S.S.A.) to form a typical sand dune topography. The high percentage of calcareous material has been dissolved and redeposited until the surface is underlain by massive travertine. This is full of solution cavities, and with the sparse vegetation and thin soil it is probable, from determinations of the chlorine ratio in the rainfall and ground waters, that about two-thirds of an inch out of the annual rainfall of 15¼ inches reaches the ground water table. A very regular hydraulic slope of between 4ft. and 5ft. to the mile gives definite proof that the water is in motion towards the sea, and implies that there is a replenishment due to rainfall falling on the area, since there are no surface feeders from outside it.

While this ground water is of good quality the waters of the underlying and somewhat older sediments are salt and are under pressure. This lower water has, where the impervious stratum between the pressure and ground waters is thin, broken through and mingled with the ground water to the detriment of quality. While this break-through has reduced the area available above a collecting well or line of wells, there is no doubt but that both the quantity of stored water and the annual accession are large.

The Oakdale area to the south appears to be very similar, and a third (Wurkagie-Witera) occurs in the hundred of Campbell, east-south-east of Streaky Bay.

Beyond Penong and towards the Head of the Bight the basal rocks are still of granitic and gneissic types, and are overlain by the fossiliferous Miocene limestones to the west and north, while for some distance inland both the granitic bedrock and the limestone are overlain by the calcareous sand dune series. Examination of the wells in this region has shown that the main mass of the ground water is saline, and that there is a flat hydraulic gradient normal to the coast, so that there is a gradual travel of this saline water towards the coast. A few wells bottom on the bedrock, above the level of the saline water and get useful water on the impervious rock, but the majority of the wells obtaining useful water get it from a thin layer of fresh water lying directly on the saline ground water, and it is extremely difficult to recognise the presence of this superficial layer of ground water by boring. Overdeepening spoils such wells, and it was noted that the depths of water in useful wells of this type ranged from 6in. to 4ft. One notable case of overdeepening was a well on section 34, hundred of Wookata. Sunk to a depth of 174½ft., it got 18in. of water with a salt content of .31oz. per gallon and a daily supply of 2,000galls. As it was desired to get sufficient water to justify piping it to a locality that would serve several farms, the well was deepened 21in. The supply increased to 14,000galls. per day and the salt to 1.77oz. per gallon, and it was only possible to save the well by filling up the lowest portion with plastic clay.

In this region, in which open grassland alternates with areas of mallee scrub, it was observed that every well which derived its water from the fresh layer was in the open country, and that the better ones were, almost without exception, in the southern half of the open areas. No successful well, as far as the writer could learn by investigation and inquiry, has been found in the mallee scrub in this district. The inference drawn is that in the mallee areas of low and moderate rainfall, despite very favorable conditions for downward percolation, the mallee transpires so much moisture that there is an accumulation of the cyclic salts in the soil, and that, when the exceptionally heavy rain does provide an excess over soil evaporation and transpiration to form ground water, the excess is contaminated by these accumulated salts. On the grasslands, and ultimately on cleared and cultivated land, a greater proportion of the rainfall is available for percolation, and consequently the layer of good water is formed. Finally the slow travel of the ground water towards the sea under other belts of scrub results in the destruction of the fresh layer by the tendency to mix during the lateral travel, and by the addition of a scanty saline percolation from above.



The Influence of Transpiration by Vegetation on Ground Waters.

This influence on the transpiration of vegetation upon the quality of the ground water should ever be borne in mind in the search for useful ground water.

The Recent Coastal Sand Dunes.

Wherever the Recent sand dunes have developed from sea level inland there is the possibility of obtaining useful water, and this has been recognised along the South Australian coastline where conditions are suitable. Most of the wells developed in this formation can be spoilt by over-deepening or overdrawing, as the good water generally rests directly on salt water, but in a few cases it rests on a clay bottom.

The water is derived from the direct percolation of rainfall on the dunes, and the sand is capable of retaining it, as capillarity is not present to bring it to the surface to be evaporated. Vegetation, if present, will transpire a proportion of the water, and it follows that there will be least loss with clean sands and non-vegetated surfaces. This has been found to be the case in this State, and the Royal Engineers in Palestine during the War arrived at the same conclusion.

There appear to be very considerable supplies available, in small units, but the barrenness of the surface, though favorable to supply, makes the utilization very difficult by reason of the tendency of the shifting sand to overwhelm pumping appliances and wells. Many drift over in normal years when other waters are available, but in periods of emergency are dug out or a new hole sunk. For example, in the hundred of Keith the Point Bell wells have been sunk at intervals along the landward side of large drifting coastal sand dunes which yield water fairly generally along both their landward and seaward margins. On the inland side these dunes are marching over a saline travertine and gypsum flat. When water is required a hole is excavated at a height of 6ft. to 10ft. vertically above the level of the flat, and to its level.

The Inland Sand Dunes.

Given an impervious bottom, which may be clay, dense rock, or even saline water, the wind-blown sands accumulated on them may absorb and protect the scanty rainfall, and so provide very important supplies. Of these the best known are the Ooldea Soaks on the East-West Railway, which provided a much needed supply for the construction and operation of the railway. Another typical well is Box Flat, on the Innamincka track to the east of Lake Crossing. Here a drift sand formation has been laid down upon the clays and silts deposited by the Strezlecki Creek and contains potable water.

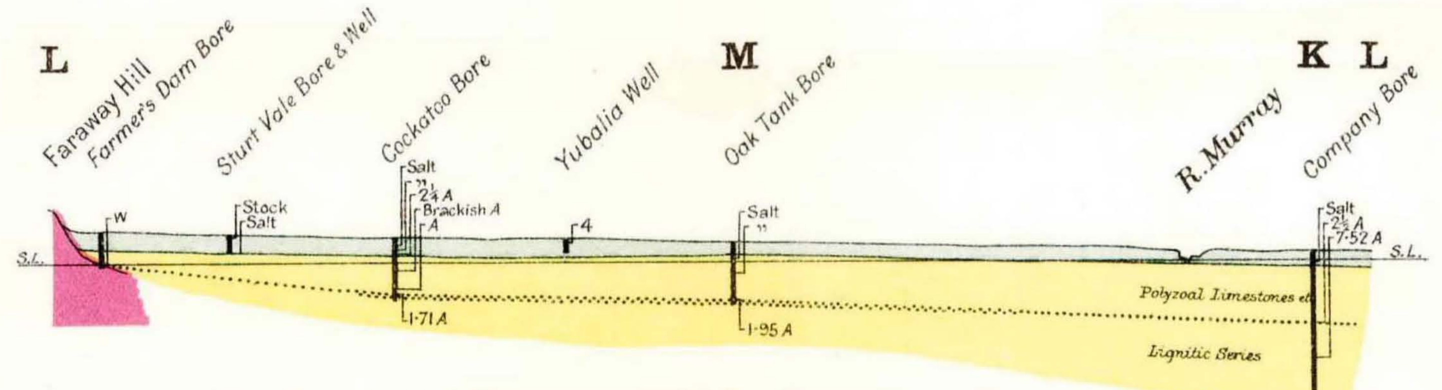
CONCLUSIONS.

The general conditions governing the occurrence, distribution, and quality of underground water have been briefly set out in such a form that it should be possible to see which type or types of occurrence are likely to be present in any particular area. Some conditions are definitely absent in certain places; for example, deep sinking in the old geological formations (from the Ordovician downwards) beneath a saline ground water in search of better water is sheer waste, and many thousands of pounds have been spent in boring foredoomed to failure. On the other hand, as where there is an artesian structure, it is, in many cases, necessary to pass through the upper saline water or waters to obtain useful supplies of good quality.

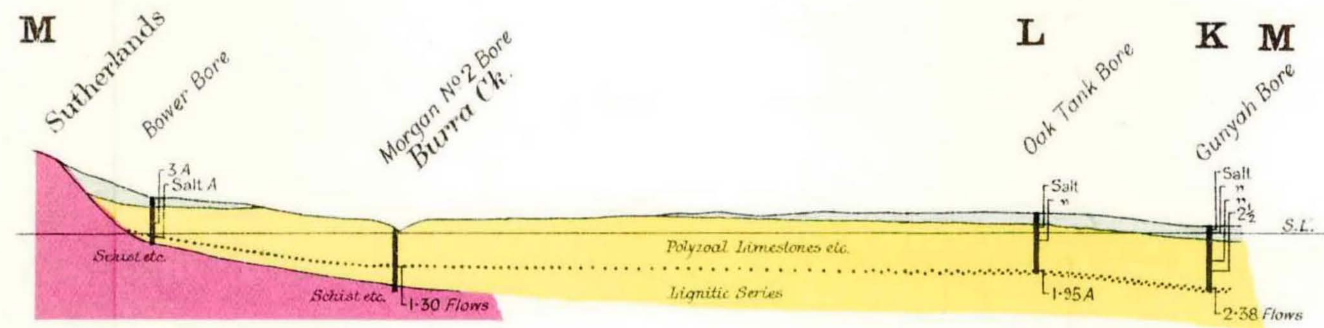
Above all, there is a mass of accumulated and detailed information available which forms an invaluable guide to those desirous of extending the use of subterranean waters. In some districts the conditions are known to be so unfavorable that, unless special and strictly local structural and topographical features exist, it is unwise to waste money on a search for subterranean supplies. Surface conservation may be, and in some places is, infinitely preferable to sinking for water if unfavorable conditions are present.

PLATE IV BULLETIN No 14.

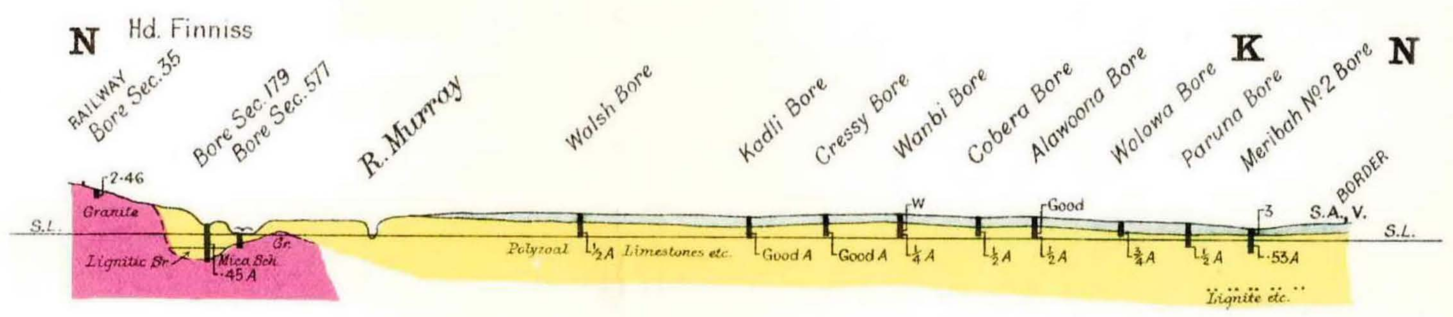
Section K K. Mingary to Mt. Gambier.



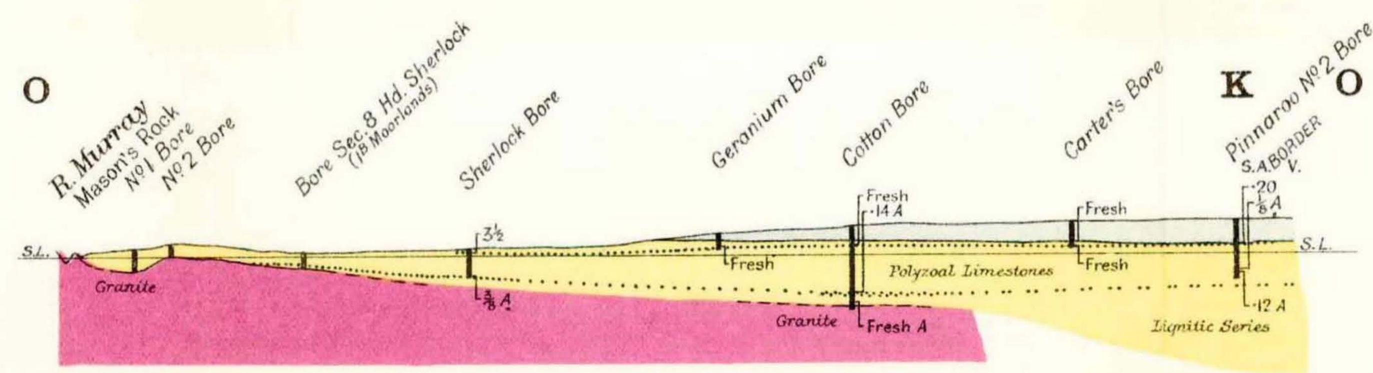
Section L L. Faraway Hill to Company Bore.



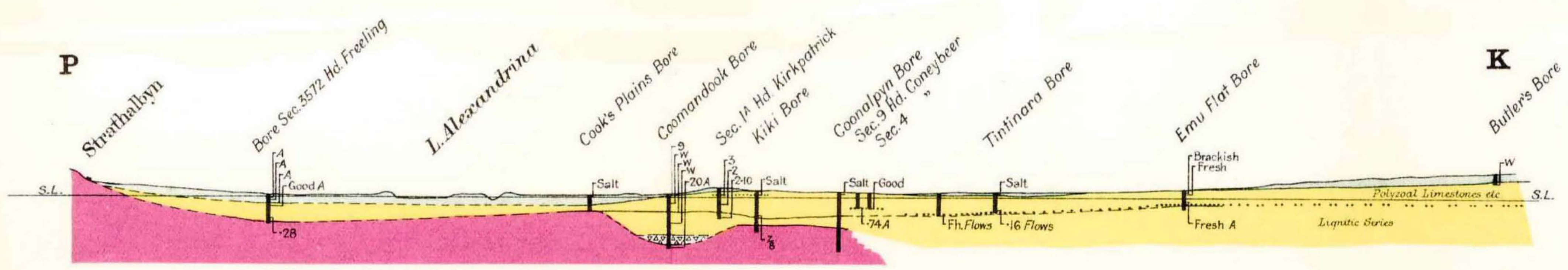
Section M M. Sutherlands to Gunyah Bore.



Section N N. Hd. Finniss to Meribah.

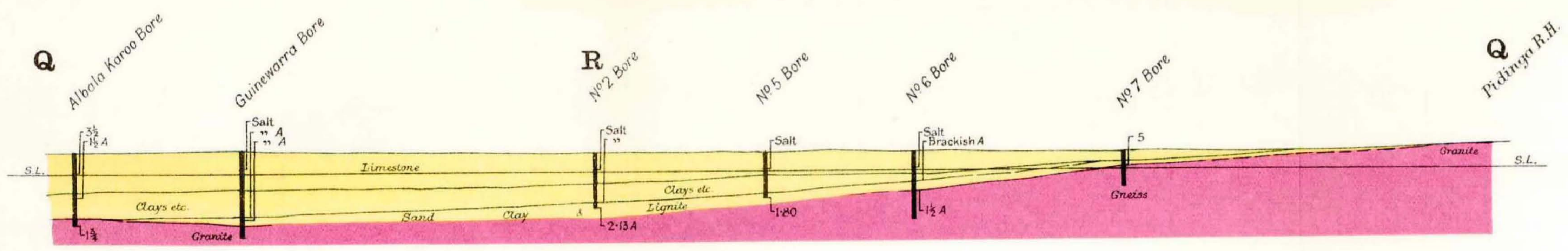


Section O O. Masons Rock to Pinnaroo.

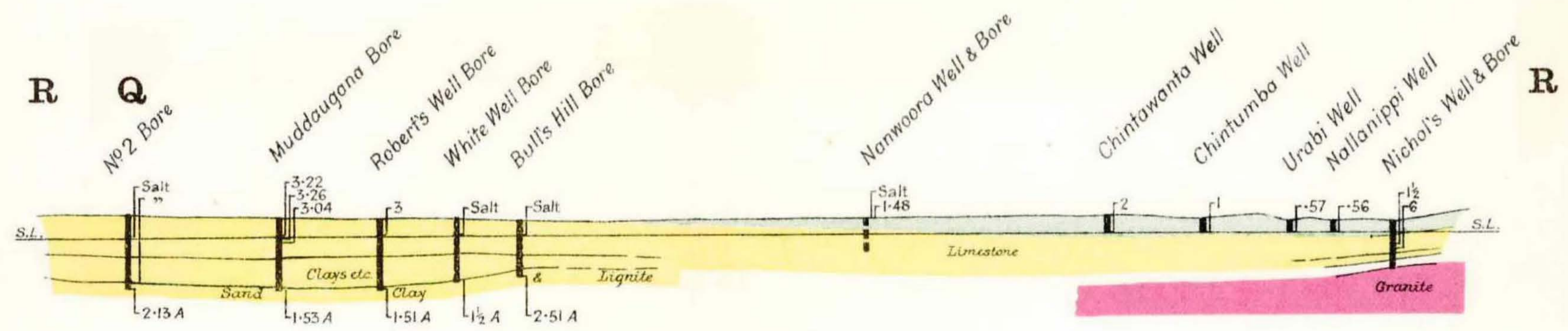


Section P P. Strathalbyn to near Wolseley.

MURRAY RIVER ARTESIAN BASIN.



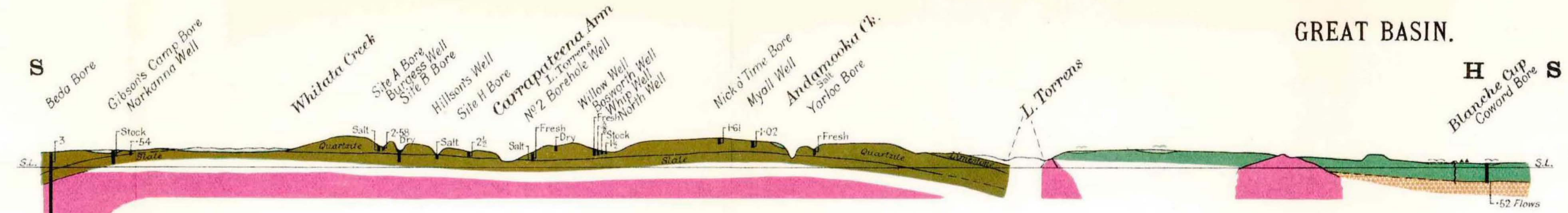
Section Q Q. Near Eucla to Pidinga Rockhole.



Section R R. Nullarbor No. 2 Bore to Hd. Wookata.

EUCLA ARTESIAN BASIN.

GREAT BASIN.



Section S S. Beda Bore to Coward.

WEST OF PIRIE-TORRENS BASIN.

SECTIONS SHOWING THE RELATIONSHIP OF UNDERGROUND WATERS TO GEOLOGICAL STRUCTURE.

LEGEND.

RECENT TO PLEISTOCENE.	*Unconsolidated sand of coast and interior; consolidated sand dunes; river, lake and swamp deposits; gravels of outwash fans; etc.*	
PLIOCENE TO MIOCENE.	*Marine and freshwater sediments; limestones; calcareous and lignitic clays; lignite; sand and shale; sandstone.*	
LOWER CRETACEOUS.	*Bluish-grey clay and shale with thin beds of limestone and occasional boulders of glacial origin; etc.*	
JURASSIC.	*Siliceous sand, loosely compacted or unconsolidated; etc.*	
PERMO-CARBONIFEROUS.	*Glacial deposits. Tillite; clay and sand.*	
ORDOVICIAN. ?	*Dolomitic limestone; quartzite with shaly bands; greenish shale weathering to brown.*	
CAMBRIAN, UPPER PRE-CAMBRIAN, LOWER PRE-CAMBRIAN AND IGNEOUS.	BED ROCK	*Limestone; calcareous slate, marble; tillite; quartzite; slate; phyllite; mica schist; quartz-mica schist; Granite, gneiss, porphyry, etc.*

Definite Geological Boundaries shown thus:	
Approximate Geological Boundaries.	
Formations, the position of which is indefinite, are not delimited by black lines	
Glacial Erratics.	▲▲▲
Sea Level.	S.L.
Water under pressure when cut.	A
Water flowing over surface.	Flows
Water cut—no particulars.	W
Correlated water-bearing horizons shown thus	
Position at which Water was Cut and Quality shown on Sections thus	50
Ounces of Salts per gallon, by Analysis, shown in decimals.	2·25
Ounces of Salts per Gallon, by salinometer, shown in fractions.	2¼
Where a section crosses other sections the letters of the latter are shown	

HORIZONTAL SCALE 1 INCH = 16 MILES. VERTICAL SCALE 1 INCH = 2,000 FT.

R. Lockhart Jack
Deputy Government Geologist.
8·5·1929

R. E. POWELL, GOVERNMENT PHOTOLITHOGRAPHER, ADELAIDE.

Section F F. Oolgelima West to Cordillo Downs.

Section G G. Warrungadinna Bore to Tilcha Bore.

Section H H. Lake Phillipson to Coonanna Bore.

SECTIONS SHOWING THE RELATIONSHIP OF UNDERGROUND WATERS TO GEOLOGICAL STRUCTURE.

GREAT AUSTRALIAN ARTESIAN BASIN.

LEGEND.

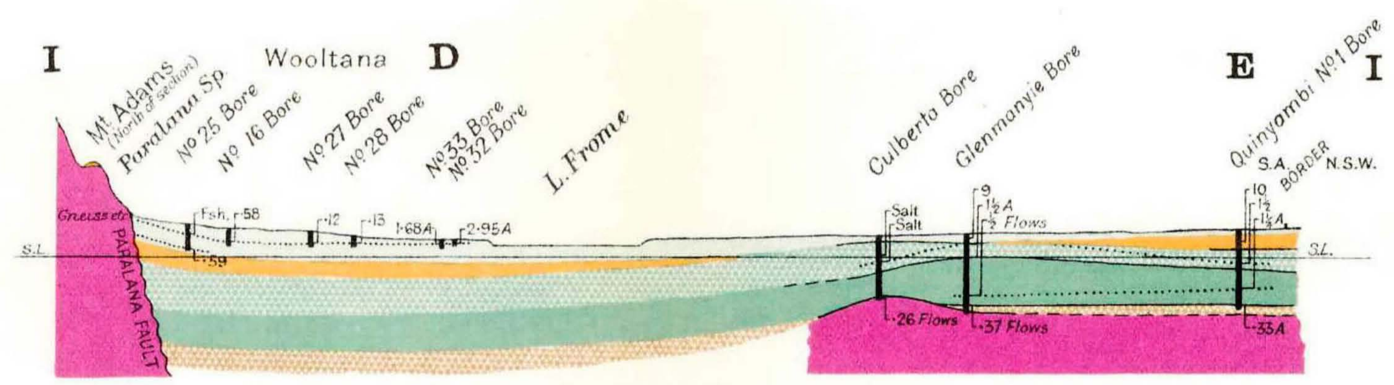
RECENT TO PLEISTOCENE.	*Unconsolidated sand of coast and interior; consolidated sand dunes; river, lake and swamp deposits; gravels of outwash fans; etc.*	TRIASSIC. *Coal measures. Carbonaceous shales with beds of sub-bituminous coal.*
LOWER TERTIARY.	*"Eyrian" series. White, pink and buff argillaceous sandstone and sandy shale and clay. All beds superficially hardened.*	PERMO-CARBONIFEROUS. *Glacial deposits. Tillite; clay and sand.*
UPPER CRETACEOUS.	*"Winton" series. Clay and shale, mostly greenish-grey, with lignitic matter; greenish sandy clay and shale; green sandstone.*	
LOWER CRETACEOUS.	*"Rolling Down" series. Bluish-grey clay and shale with thin beds of limestone and occasional boulders of glacial origin; etc.*	CAMBRIAN, UPPER PRE-CAMBRIAN, LOWER PRE-CAMBRIAN AND IGNEOUS. BED ROCK *Limestone; calcareous slate; marble; tillite; quartzite; slate; phyllite; mica schist; quartz-mica schist. Granite, gneiss, porphyry, etc.*
JURASSIC.	*Siliceous sand, loosely compacted or unconsolidated; etc.*	

Definite Geological Boundaries shown thus: ————
Approximate Geological Boundaries. – – – –
Formations, the position of which is indefinite, are not delimited by black lines
Glacial Erratics. ▲▲▲
Sea Level. S.L.

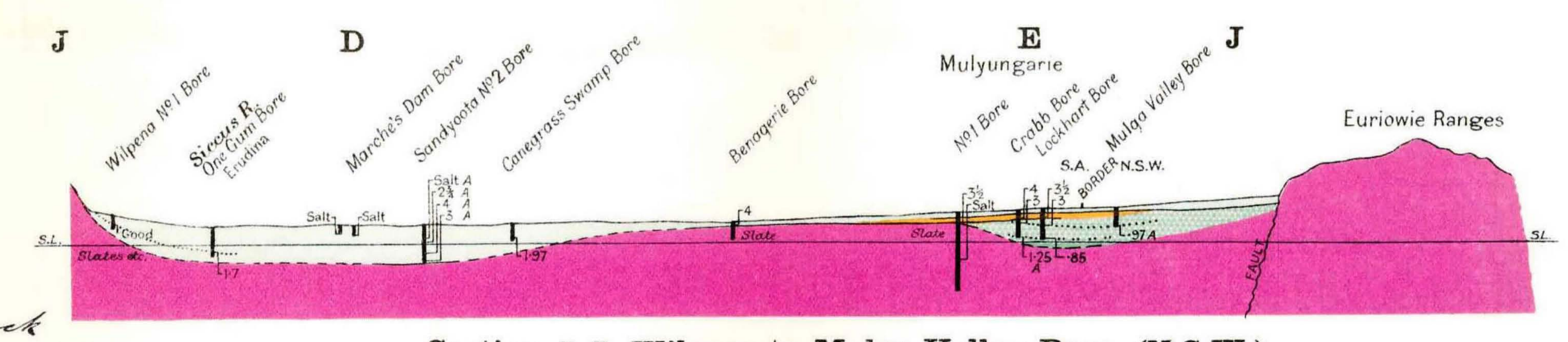
Water under pressure when cut. A
Water flowing over surface. Flows
Water cut—no particulars. W
Correlated water-bearing horizons shown thus: ....

Position at which Water was Cut and Quality shown on Sections thus ·50
Ounces of Salts per gallon, by Analysis, shown in decimals. 2·25
Ounces of Salts per Gallon, by salinometer, shown in fractions. 2¼
Where a section crosses other sections the letters of the latter are shown

HORIZONTAL SCALE 1 INCH = 16 MILES. VERTICAL SCALE 1 INCH = 2,000 FT.



Section I I. Paralana Springs to Quinyambi No. 1 Bore.



Section J J. Wilpena to Mulga Valley Bore (N.S.W.).

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Deputy Government Geologist.
8·5·1929

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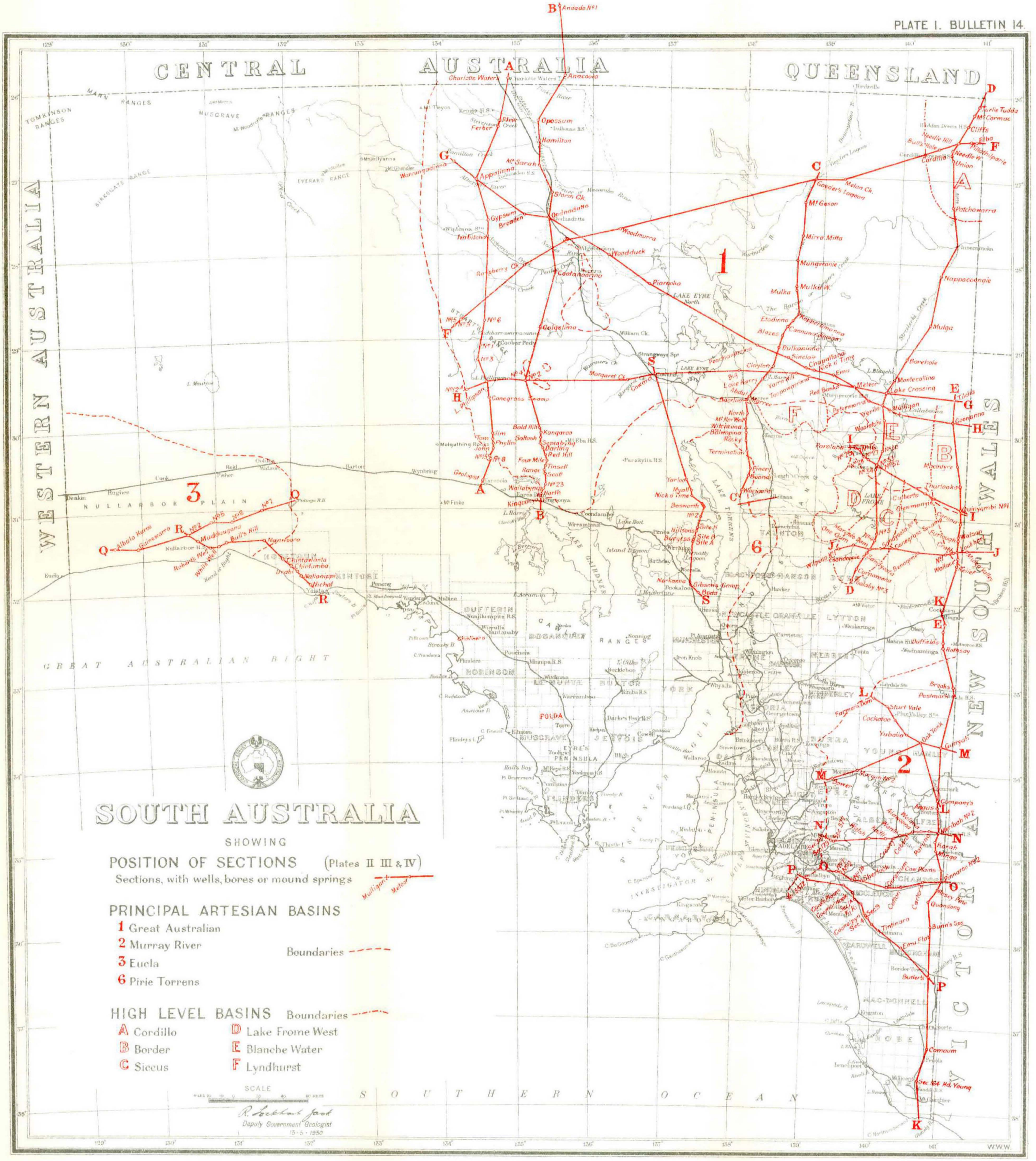
PLATE II BULLETIN No 14

H. E. POWELL, GOVERNMENT PHOTOLITHOGRAPHER, ADELAIDE.


SOUTH AUSTRALIA
SHOWING
POSITION OF SECTIONS (Plates II III & IV)
Sections, with wells, bores or mound springs
Mulligan Meteor
PRINCIPAL ARTESIAN BASINS
1 Great Australian
2 Murray River
3 Eucla
6 Pirie Torrens
Boundaries
HIGH LEVEL BASINS Boundaries
A Cordillo
B Border
C Siccus
D Lake Frome West
E Blanche Water
F Lyndhurst
SCALE
R. Lockhart Jack
Deputy Government Geologist
15-5-1950
CENTRAL AUSTRALIA
QUEENSLAND
WESTERN AUSTRALIA
NEW SOUTH WALES
VICTORIA
GREAT AUSTRALIAN BIGHT
SOUTHERN OCEAN
NULLARBOR PLAIN
LAKE EYRE
LAKE TORRENS
LAKE GAIRDNER
SPENCER GULF
INVESTIGATOR ST.
WWW