

REPORT ON EXPLORATORY
DRILLING FOR UNDERGROUND
WATER AT MANDURAH, PERTH BASIN, W. A.

by

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ABSTRACT

Five exploratory water bores, ranging in depth from 504 feet to 2,001 feet, were drilled by the Mines Department in a general west-east direction across the Perth Basin, between Mandurah and Pinjarra, some 40 miles south of Perth. These bores, together with several private bores recently drilled in the area, provided new stratigraphical and hydrological information.

The sediments penetrated are of Upper Jurassic, Lower Cretaceous and Quaternary age, Upper Cretaceous and Tertiary sediments being locally absent. The Upper Jurassic non-marine sediments are considered to be the Claremont Sandstone equivalent, whereas the Lower Cretaceous deposits are correlated with the South Perth Formation. The latter can be subdivided into three different units. In the western part of the drilling area, the upper and middle units are predominantly marine, and the lower is paralic to non-marine. Towards the east, non-marine influences are noticed higher in the South Perth Formation. The general dip of the strata intersected between Mandurah and North Dandalup seems to be towards the west, although there are some indications that structural complications might occur at depth west of Bore No. 4. Aquifers were encountered in the Upper Jurassic, Lower Cretaceous and Quaternary sediments. The shallow Quaternary aquifers are unconfined and yield only insignificant supplies of usable water. The Lower Cretaceous aquifers are of two types, the upper one being subartesian, and containing mainly salt water, recharged from surface intakes in the middle part of the Perth Basin. Below a green, glauconitic, clayey marker, another aquifer system is capable of yielding large supplies of artesian water, the water quality being suitable for stock and selected irrigation purposes in the west part of the Perth Basin, whereas towards the east, it is of

domestic quality. The main intake area for this artesian aquifer, as indicated by the hydraulic gradient and the salinity pattern, appears to be near the Darling Scarp. In the westernmost part of the drilling area, near the coast line, there are some indications of a possible component of recharge from a southerly direction.

Several other aquifers are present in the deeper Lower Cretaceous sediments, and, in Bore No. 1, the Upper Jurassic Claremont Sandstone is another good one. However, these different aquifers have not been further investigated, as the results of electrical logging indicated a general increase in water salinity with depth.

INTRODUCTION

Drilling in the Mandurah area was done at the request of the Public Works Department, to find water for the township. It was done by the Mines Department between August, 1962, and January, 1964, with an interruption from October, 1962 to April, 1963, and consisted of five bores, totalling 4,600 feet, the depths of individual bores varying from 504 feet to 2,001 feet. These bores were drilled by a rotary plant, and extended across the coastal plain in a general west to east direction.

In addition to these five bores, this report discusses the results obtained from several private bores drilled recently by percussion methods in the area, or being drilled simultaneously with the Mines Department programme. (See Plate 1.) They include a bore drilled for the Mandurah Shire Council on the Mandurah Golf Course, about $\frac{3}{4}$ mile west of Mandurah Bore No. 1; a private bore located along the Murray River (Hill's Bore, about $1\frac{1}{2}$ miles south of Mandurah Bore No. 3); and three bores drilled in the North Dandalup area, northeast of the Mines Department line.

Mandurah No. 1 Bore was commenced in the town itself in August 1962, and was drilled to 2,001 feet to obtain as much geological and hydrological information as possible in an area where no deep subsurface data were available, although its primary purpose was to supply Mandurah as well as the North and South Yunderup areas. The bore penetrated an unusual thickness of the South Perth Formation (1,593 feet) overlying the Upper Jurassic Claremont Sandstone equivalent (1,670 feet to 2,001 feet). Electrical logging showed that the aquifer zone between 442 feet and 631 feet contained the freshest water. Above this section poorer quality water was present, and below it, the salinity gradually increased with depth. A pump test on the section 442-631 feet indicated the presence of a large supply of artesian water, the salinity however being too high for human consumption (112 grains/gallon NaCl, and 143 grains/gallon total dissolved solids).

In view of these results, as it was considered likely that the intake area for the subsurface aquifers of the Perth Basin is situated along the Darling Scarp, the exploratory drilling programme was extended in an east-south-easterly direction towards Pinjarra, the distance between successive bores varying between 2 miles and 2½ miles.

In siting these bores, consideration had to be given to such matters as access to the sites and the fact that reticulation to Mandurah and the area around North and South Yunderup was in view. The bores were therefore sited as close as possible to the main road from Mandurah to Pinjarra.

Use of the Mines Department rotary plant was expected to reduce drilling time to a minimum, but in the first few bores difficulties were experienced in collecting proper water samples by the method of running a casing line and bailing. In the Mandurah area the presence of a salt water body overlying an aquifer system containing fresher water, often resulted in contamination of one zone by the other.

This sometimes required long operations in an attempt to obtain a reliable water sample (for example Bore No. 2). To overcome those difficulties, the Department acquired a Johnston Formation Tester, which was first used in Bore No. 5 and which, combined with the results of electrical logging, considerably facilitated the work, although still not enabling the frequent collection of samples of water from any aquifer as drilling proceeded.

The Resistivity and Gamma Ray Logs gave very useful indications on the rock types and were used to accurately define the boundaries in the Composite Logs (Plates 7-11). They are also very important means of establishing correlations between the different bores. The best example is the green glauconitic clay marker and the calcareous beds complex (Plate 2) which appear very distinctly on the Gamma Ray and Resistivity logs respectively. As a rule, the general salinity trend (increase or decrease) could be deduced from the Resistivity and Spontaneous Potential logs, but accurate calculations of salinities were often not possible because the drilling mud could not always be brought to the appropriate resistivity.

Electrical logging of Bores No. 1 to No. 3 was carried out by West Australian Petroleum Pty. Ltd., an assistance which was greatly appreciated. Bores No. 4 and No. 5, and the Golf Course Bore, were electrically logged by Geophysicist D. Rowston, of the Geological Survey, using the Mines Department newly arrived logging unit. The advices and useful suggestions given by WAPET'S geologists and D. Rowston, regarding the interpretation of the electric logs data, are gratefully acknowledged.

Palaeontological examination of sludge samples was made by H. S. Edgell, Palaeontologist. His detailed study of the microfloral and microplankton assemblages in Bore No. 1 enabled him to give very helpful advice while the subsequent

bores were being drilled, and to establish valuable stratigraphic correlations between the various bores. This help is gratefully appreciated.

Wellsite geologists were J. R. Passmore and C. Emmenegger for Bore No. 1, C. Emmengger for Bores No. 2 to No. 5 and the Golf Course Bore. The work was under the general supervision of Mr. E. P. O'Driscoll, Chief Hydrogeologist of the Geological Survey, Mr. E. Brisbane, State Mining Engineer, being responsible for the drilling, casing and testing operations.

PHYSIOGRAPHY

The geomorphic elements of the area are described by McArthur and others (1959) and McArthur and Bettenay (1960). Westwards from the Darling Plateau and Scarp, these authors subdivide the Swan Coastal Plain into several entities which are subparallel to the present coastline. They include the Ridge Hill Shelf (lateritic soil forming the foothills of the Darling Scarp), the Pinjarra Plain, and the sand dune systems. The Pinjarra Plain is itself subdivided into several distinct depositional systems, including the estuarine deposits bordering the Peel Inlet. The dune systems consist of three generations of dunes, the oldest and most easterly being the Bassendean Dune System, followed by the Spearwood System and finally the Quindalup System along the present coastline. At the boundaries between the different dune systems there is generally a series of depressions occupied by swamps or lakes, the most typical in the Mandurah area being the depression occupied by the Serpentine River, at the boundary between the Bassendean and the Spearwood Systems. The Peel Inlet and the estuary cut across the Spearwood System and the Quindalup System.

The vegetation depends largely upon the soils of

the geomorphic element with which it is associated.

The natural drainage system comprises the Serpentine and Murray Rivers, and the North and South Dandalup Rivers, which reach the sea by way of Peel Inlet and the estuary.

Average rainfall varies from about 35 inches at Mandurah to about 37 inches at Pinjarra.

GEOLOGY

GENERAL

The Perth Basin is an elongated sedimentary trough, 600 miles long, bounded at its eastern margin, along the Darling Scarp, by the Precambrian West Australian Shield. The Mandurah drilling area is situated in its southern part, where the basin's width, from the Darling Scarp to the Coastline, is about 17 miles.

In the drilling area, the Mesozoic sediments are covered by Quaternary deposits, and apart from this superficial material, there is no exposure of sedimentary rocks. About twenty miles further northeast, Proterozoic sediments (the Cardup Shale) are exposed along the Darling Scarp.

The general geology of the Perth Basin is described by McWhae and others (1958).

SUMMARY OF PREVIOUS DATA

Prior to the drilling of the Mandurah programme, the subsurface geology of the area had to be inferred from two sources: geophysical work, and water bores to the north around the Perth Metropolitan area.

Recent geophysical work of significance with regard to the Mandurah area consists of a Gravity Survey of the Perth Basin (Thyer and Everingham, 1956) a Seismic Reflexion

Survey between Rockingham and Mundijong (Moss, 1962), and a Gravity Survey of the central part of the Perth Basin (Felcman and Lane, 1963). Seismic work is currently being carried out in the Mandurah-Pinjarra area by West Australian Petroleum Pty. Ltd.

From geophysical evidence, it appears that the Perth Basin is a deep trough, some 20,000 to 25,000 feet deep in the drilling area, bounded to the east by a normal fault along the Darling Scarp. The gravity maps indicate that the deepest part of the basin is situated about half way between the Darling Scarp and the coast line.

The Rockingham-Mundijong seismic traverse was interpreted as indicating two major fault zones west of the Darling Fault, and also an easterly dip of the sediments at depth, whereas the top 1,000 feet are horizontal or subhorizontal.

Apart from the geophysical work, valuable stratigraphical and structural information was available from numerous water bores in the Perth Metropolitan area, on Garden Island, at Point Peron (near Rockingham), and the Byford exploratory bores. From the Metropolitan bores, (Budovskis, 1962) it was known that the depth to the Jurassic Claremont Sandstone was in the order of 2,500 feet in the deepest part of the Basin. Along the coast line (Hampton Road Bore, Fremantle), and in the Garden Island and Point Peron Bores, the Jurassic was reached at about 1,100-1,200 feet. The South Perth Formation intersected in the Byford Bores in unconformably overlain by the Osborne Formation in the western part of the Basin (Bores Nos. 5 and 6), no Tertiary deposits being present. The latter are known to occur in the Garden Island and Point Peron bores, as well as in the Metropolitan Bores. Byford Bores Nos. 1 and 2, towards the Darling Scarp, reached Lower Jurassic deposits at shallow depth, thus confirming the presence of one of the fault zones indicated by the Rockingham-Mundijong seismic traverse.

The complete stratigraphic sequence intersected in these different bores is as follows:

- Quaternary : Superficial deposits
- Tertiary : King's Park Shale
- Upper Cretaceous : Osborne Formation
- Lower Cretaceous : South Perth Formation
- Upper Jurassic : Claremont Sandstone
- Lower Jurassic : Cockleshell Gully Sandstone equivalent

STRATIGRAPHY - LITHOLOGY

The age of the formation drilled in the Mandurah area is established on palaeontological data supplied by H. S. Edgell. The sediments penetrated are of Upper Jurassic, Lower Cretaceous and Quaternary age. No Upper Cretaceous (Osborne Formation) nor Tertiary (King's Park Shale) sediments were intersected between the Quaternary deposits and the Upper part of the South Perth Formation. Plates 7-11 present the composite logs of Bores Nos. 1-5. Plate 2 shows the correlations based on lithology, and Plate 3 the stratigraphic correlations based on data supplied by H. S. Edgell. Plates 12-23 give the results of electrical and Gamma Ray Logs of Bores Nos. 1-5 and the Golf Course Bore.

The Formations penetrated are given below:

Age	Stage	Formation	Maximum Thickness
Quaternary	Recent to Pleistocene	Superficial deposits	220 feet (Bore No.3)
----- unconformity -----			
Lower Cretaceous	Aptian Neocomian	South Perth Formation	1593 feet (Bore No.1)
----- unconformity -----			
Upper Jurassic	Portlandian to Kimmeridgian	Claremont Sandstone Equivalent	331 feet+(Bore No.1)
----- unconformity -----			

Appendix 2 includes the detailed sample logs of Bores Nos. 3, 4, 5, the Golf Course Bore, and the private bores (these last based mainly on driller's logs). Only a summary of the logs of Bores Nos. 1 and 2 is given, as detailed information was included in previous reports.

The specific lithological characteristics of the formations penetrated were described in the reports on Mandurah No. 1 and No. 2 Bores, and the discussion below refers mainly to the general character of these formations, and their correlations across the Basin.

Quaternary.

The superficial deposits comprise dune sands, coastal limestone, estuarine clays and sands and residual sands. In Bore No. 2, from 26 feet to 48 feet, there is a mottled zone of claystone and siltstone, in places very consolidated. Bore No. 3 is a special case, because it intersected a deep Quaternary channel cut to a depth of 220 feet, filled with very permeable material.

The Quaternary deposits unconformably overlies the South Perth Formation, the boundary usually being easy to determine on a lithological basis, although it is uncertain in the North Dandalup bores.

Lower Cretaceous.

Sediments of this age are correlated with the South Perth Formation (McWhae and others, 1958) and consist of an interbedded sequence of sandstone, siltstone and claystone containing carbonaceous material, pyrite and mica. In the middle part, there is a development of calcareous beds with shells and pebbles, together with glauconitic beds.

On the evidence of lithology, Gamma Ray and Electric Logs, it is possible to divide the South Perth Formation of

the Mandurah area, into three different units, the two upper ones being separated by a green, glauconitic clay horizon, which is an excellent marker all over the area (Plate 2). Table 1 gives the thickness of these units in the different Mandurah Bores.

Table 1

In Bore No. 1, it is possible to further subdivide the middle unit into a sequence of interbedded sandstone, claystone and siltstone, often glauconitic, with numerous hard calcareous beds (406 feet to about 731 feet), and a thinly interbedded sequence of claystone and siltstone with minor sandstone (731 feet to 966 feet). In Bore No. 3, the upper unit is reduced to 19 feet because of the presence of a quaternary channel. In Bore No. 5, it is considered that the lithological change at 652 feet (also clearly seen on the Gamma Ray Log) is equivalent to that occurring at 966 feet in Bore No. 1.

A description of these different units follows:

(a) Upper unit. Above the green clay marker, there is a complex of interbedded claystone, siltstone and sandstone which, because of a regional westerly dip, has its maximum thickness in the Golf Course Bore (383 feet). In this unit, the quartz sandstone is grey, dark grey and brown, coarse to very coarse, with mostly subrounded to rounded grains. The bedding is well differentiated, and the sandstone is very well sorted in Bore No. 2, whereas the amount of siltstone and claystone increases in the direction of Bore No. 1 and the Golf Course Bore. The claystone and siltstone is black, dark grey and dark brown, often very silty, carbonaceous, micaceous and pyritic.

TABLE 1

Mandurah Water Bores - Lithological Subdivisions of the South Perth Formation

BORE	SOUTH PERTH FORMATION								
	Upper Unit			Middle Unit			Lower Unit		
	From (feet below sea level)	To (feet below sea level)	Thickness (feet)	From (feet below sea level)	To (feet below sea level)	Thickness (feet)	From (feet below sea level)	To (feet below sea level)	Thickness (feet)
Golf Course Bore	31	414	383	414	670+	256+	-	-	-
Mandurah No. 1	71	402	331	402	962	560	962	1666	704
Mandurah No. 2	28	280	252	280	551+	271½	-	-	-
Mandurah No. 3	(212)	231	(19+)	231	676	445+	-	-	-
Mandurah No. 4	29	89	60	89	493	404+	-	-	-
Mandurah No. 5	8	53	45	53	625	572	625	810+	188+
Hill's Bore	42(?)	164	122(?)	164	173+	(9)+	-	-	-
Anderson's Bore	+26(?)	39(?)	65(?)	39(?)	131+	92½(?)	-	-	-
Runciman's Bore	+51(?)	17(?)	68(?)	17(?)	159+	1 142+(?)	-	-	-
Giles' Bore	+55(?)	16	71(?)	16	141+	125+	-	-	-

It contains a few beds of consolidated calcareous sandstone. In Bore No. 3, below the Quaternary Channel, the unit is represented by only a few feet of silty sandstone, whereas in Bores Nos. 4 and 5, where it thins as a result of the westerly dip, the unit consists only of about 45 feet to 60 feet of silty sandstone, carbonaceous, micaceous and pyritic. In the North Dandalup area the thickness of this unit is not certain because the Quaternary-Lower Cretaceous boundary is not established with accuracy. Several conglomeratic horizons are present above the green clay marker in these easternmost bores.

(b) Middle unit. The green clay horizon is the top of a distinctive unit, in which the lithological characters differ noticeably from the upper unit. The green clay itself is a good lithological marker, 15-19 feet thick in the western part of the drilling area. It has been recognised in all the Mandurah bores, and as far east as the North Dandalup area, where where it reaches a thickness of about 11 feet in Gile's Bore. Lithologically it consists of a green, sandy and silty, clay, glauconitic, pyritic and carbonaceous. Its top part is often indicated by a thin zone of light brown, or whitish soft and greasy clay. Below this marker is a sequence of interbedded sandstone, siltstone and claystone, very often glauconitic, containing numerous hard beds of calcareous sandstone, fragments of pebbles and numerous shells. The number and size of pebbles increases towards the east (at North Dandalup) some of them exceeding 8 to 10 inches in diameter. These pebbles are usually well rounded, and consist mainly of quartz, quartzite, granite, gneiss. At North Dandalup numerous pebbles of dolerite were noticed, often weathered to a greenish, clayey product. Special mention should be made of a pebble horizon which can be fairly well traced from the Golf Course Bore to the Bore No. 3. Above it, and up to the green clay marker, there is a higher concentration of pebbles and calcareous beds with shells, and also the glauconite content is

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usually higher. In Bore No. 3 immediately below this horizon, there is a clear change in lithology, the green, glauconitic sandstone being suddenly replaced by a brown to light brown sandstone. This minor break in lithological conditions is also to be seen on the gamma ray logs, and could possibly represent an erosion surface, as tentatively indicated on Plate 2. In Bores No. 4 and No. 5 this break is still clearly shown on the Gamma Ray Log, although not very evident from the lithology.

A second lithological marker, at some depth below the above mentioned green clay, consists of a grey, dark grey and light grey claystone, rich in pyrite, usually 10 to 20 feet thick (Plate 2). Though not as distinct as the first one, it can be followed from Bore No. 2 to Bore No. 5. Its equivalent in Bore No. 1 was previously considered to be at 630-666 feet (Emmenegger, 1963) but palaeontological evidence (Plate 3) suggests a correlation with deeper strata.

In Bores No. 1 and No. 5, the middle unit extends down to 966 feet and 652 feet respectively, whereas Bores No. 2, No. 3 and No. 4, at their final depths, did not fully penetrate this unit, nor did the North Dandalup Bores. In the Golf Course Bore, it seems that the calcareous beds and shells are less well developed than in Bore No. 1.

As suggested earlier, the middle unit in Bore No. 1 can be further subdivided into a glauconitic clay-calcareous beds complex (406-731 feet approximately) and a thinly interbedded clayey, silty and sandy sequence (731-966 feet).

(c) Lower unit. In Bore No. 1, this unit is described by J. R. Passmore (1962) as an interbedded sequence of claystone, sandstone and siltstone containing relatively abundant carbonaceous material. As is apparent from the Composite Log (Plate 7) and the Gamma Ray Log (Plate 13) the bedding is better differentiated than in the overlying unit. In Bore No. 5 the top of this unit was penetrated at 652 feet, and is represented by a well sorted coarse sand, with minor

beds of claystone, often with mottled colours.

The age of the South Perth Formation in the Mandurah area (Plate 3) ranges from Neocomian to Aptian. From the frequency of microplankton, H. S. Edgell suggests a marine depositional environment in Bore No. 1 for the section 75 feet to about 460 feet, a strongly marine facies for the section 460 feet to about 770 feet, a marine facies from 770 feet to 966 feet and a non-marine to paralic facies from 966 to 1,670 feet.

It is interesting to note that in Bore No. 5, below a beach sand containing ilmenite from 513 feet to 546 feet, non marine influences are deduced from the absence of microplankton in some samples and also from the presence of mottled sediments. At North Dandalup, non marine influences are apparent at the shallower depth of 240 feet. Thus, it would appear that the marine character of the deposits decreases very quickly east-northeast of Bore No. 5.

Noteworthy is also the fact that the glauconitic clay--calcareous beds complex (with pebbles and shells), is not recognisable as such in stratas of similar age in bores along the Byford cross section. In the Mandurah area, this might indicate a slightly different province of sedimentation, perhaps shallower than at Byford, and closer to a coast line. In the metropolitan bores, fossiliferous beds containing Pelecypods are also described, but, unlike at Mandurah, their stratigraphic position is at the base of the South Perth Formation (Pudovskis, 1962).

With reference to the subdivision of the South Perth Formation into the "Leederville Sandstone" and the "South Perth Shale" (Fairbridge, 1951, 1953), H. S. Edgell suggests that, on a time stratigraphic evidence, the corresponding boundary between these two units in Mandurah No. 1 Bore should be placed at about 770 feet, i.e., at the top of the Neocomian.

In the Perth Metropolitan bores, Pudovskis (1962) lithologically subdivided the Lower Cretaceous sequence into

the "Leederville Sandstone Member" and the "South Perth Shale Member". In Mandurah No. 1 Bore, it seems that the lithological equivalent to the Leederville Sandstone Member would include the strata from 75 feet to about 731 feet, and that the sequence from 731 feet to 966 feet would correspond to the South Perth Shale Member as defined by Pudovskis. Thus, at Mandurah, there is a considerable thickness of Lower Cretaceous sediments developed between the South Perth Shale and the top of the Claremont Sandstone equivalent (966-1,670 feet). In the metropolitan bores, this thick interval is either missing or partly represented by the "transition beds" to the Claremont Sandstone, described by Pudovskis. On the evidence of considerable variations in thickness of these "transition beds", this author suggested a possible ~~dis~~conformity between the South Perth Shale Member and the Claremont Sandstone Member.

Upper Jurassic.

The Claremont Sandstone equivalent intersected in Bore No. 1 consists of non marine claystone, siltstone and sandstone from 1,670 feet to 1,847 feet, and of non marine sandstone from 1,847 feet to 2,001 feet. Both units are described by J. R. Passmore (1962).

STRUCTURE

The correlations shown on Plate 2 indicate, for the glauconitic clay marker, a general dip to the west, very slight from North Dandalup to Bore No. 4, more pronounced west of Bore No. 4 (assuming that the gradually higher position of this marker towards the east and south is not only due to facies variations reflecting successive phases of a marine transgression). The dip value is only about $\frac{1}{2}^{\circ}$ - 1° , and on Plate 2, no dip corrections are shown although the bores are not situated along a straight line across the Basin. Plate 4

shows a tentative contour map at the top of the green glauconitic clay markers, which indicates also a steeper slope west of Bore No. 4. The position of the green clay marker in Hill's Bore is important, because it is indicative of a probable northerly component of the general westerly dip.

The correlation based on palaeontological data supplied by H. S. Edgell (Plate 3) confirms this general dip to the west, the top of the Neocomian showing a greater displacement between Bores No. 2 and Bore No. 1 than between any other bores.

From lithological correlations it would appear that, at some depth below the green clay marker, the dip is slightly reversed to the east from Bore No. 2 to Bore No. 3, thus suggesting that Bore No. 3 could be structurally lower than Bore No. 2 and Bore No. 4. However, the palaeontological data indicated on Plate 3 do not seem to support this interpretation.

West of Bore No. 4, below the green clay marker and the possible erosion surface mentioned earlier, there are still insufficient data to enable definite correlations, and hence, to establish the true structural relationships between the different bores. For instance, assuming that the correlations, indicated at depth on Plate 2, are correct, they have not necessarily to be interpreted as reflecting a dip to a given direction. Block faulting at depth could be responsible for the relative displacement of corresponding strata. The possible erosion surface below the green clay marker might represent a disconformity, or possibly an unconformity near the Neocomian-Aptian boundary, depending on the structural interpretation given for the underlying stratas.

In Bores No. 4 and No. 5, the whole section penetrated seems to have a uniform slight dip to the west. Between Bore No. 5 and the North Dandalup Bores the absence of deep bore data precludes a structural interpretation at depth, but the shallow green clay marker shows a slightly westerly dip.

It is interesting to note that if the fault zone intersected near Byford No. 2 Bore and shown also on the Rockingham-Mundijong seismic traverse, were to be prolonged towards the south, parallel to the Darling Scarp, it would be located at depth somewhere between Bore No. 5 and the North Dandalup Bores. In the alluvial Plain from Pinjarra northwards, several spring mounds occur in a relatively straight line parallel to the Darling Scarp. This feature was interpreted by McArthur and others (1959) and McArthur and Bettenay (1960) as indicating possibly the presence of a deep fault.

HYDROLOGY

AQUIFER SYSTEMS

Aquifers have been intersected in formations of Quaternary, Lower Cretaceous and Upper Jurassic age.

Quaternary.

The shallow, unconfined Quaternary aquifer system consists of superficial sands, aeolinites, and coastal limestone, except in the case of Bore No. 3, where a deep channel cut contains very permeable material down to 220 feet. In this bore, a thin zone of blue clay separates the uppermost part of the aquifer from the channel filling itself. In the other bores, the unconfined quaternary aquifer is separated from the deeper system by aquicludes of Lower Cretaceous or Quaternary age. Towards the east, as shown on Plate 2, there is in places a direct connection between the two systems.

Lower Cretaceous.

Two distinct aquifer systems were identified in the Lower Cretaceous sediments (Plate 5). They are separated by the green clay marker described earlier, and are considered

to have no hydraulic connection. There is a noticeable difference in the piezometric surface of these two systems, the upper one being described here as subartesian, the lower one as artesian.*

(a) Subartesian system. It comprises the strata extending from the top of the Lower Cretaceous to the top of the green clay marker, and is thus identical with the "upper unit" described earlier in this report, in the Stratigraphy section. Developed mainly in the westernmost part of the Basin it must be considerably influenced by the deep Quaternary channel of Bore No. 3.

(b) Artesian system. Its top is marked by the green clay horizon, and its lithology is characterized by the presence of hard beds, shells, pebbles and glauconite. This aquifer was the main target for drilling because electrical logging of Bore No. 1 indicated that it contained the best quality water.

Below the aquifer section developed in Bore No. 1, there is quite a number of other potential aquifers in the Lower Cretaceous deposits which would yield artesian water but they were not investigated because of their poorer quality water. In Bore No. 5 domestic quality artesian water was intersected down to 546 feet.

Upper Jurassic.

The Upper Jurassic aquifer extending from 1790 feet to 2,001 feet in Bore No. 1 has not been fully penetrated. It has no hydraulic connection with the Lower Cretaceous aquifers, from which it is separated by a thick aquiclude (1,670 feet - 1,790 feet). The shallow depth of the other bores makes it impossible to establish the lateral extension of this system.

* In the Perth metropolitan bores, there are also two aquifers systems with different piezometric surface, in the corresponding strata of the Leederville Sandstone Member (Forman, in Pudovskis, 1962).

YIELD

No pump tests were carried out for the Quaternary aquifers ^{for} nor/the Lower Cretaceous subartesian system. The Cretaceous artesian aquifer however, is able to produce a considerable supply. The results of pump tests on Bore No. 1, the Golf Course Bore, and the North Dandalup Bores, are given in Appendix 1. Supplies of 12,000 gallons per hour to 16,300 gallons per hour were obtained from pump tests on Bore No. 1 and the Golf Course Bore respectively. Bores Nos. 2 to No. 5 were not pump tested, but the capacity appears to be very large. At North Dandalup, where only the uppermost part of this aquifer is producing, supplies of up to 20,000 gallons per hour (even more in Anderson's Bore) were tested for a drawdown of about 40 feet (Giles and Runciman's Bores). Flows of a magnitude of 4,000 to 10,000 gallons per hour were recorded from this aquifer system. In the Golf Course Bore because of its location on a dune high, the water level is 6 feet below surface. Giles Bore, the closest to the Darling Scarp started to flow slightly in August ~~after heavy rains in July~~ after heavy rains.

GROUND WATER MOVEMENT AND INTAKE AREAS

Quaternary.

The study of the ground water movement in the shallow aquifers of the Mandurah area will be included in a general report currently being prepared by K. H. Morgan, following a census covering a more extensive part of the Perth Basin. The Quaternary aquifers are recharged either by direct precipitation or by infiltration from surface rivers, estuaries or swamps. The channel cut in Bore No. 3, below a blue clay zone from 15 feet to 35 feet, is hydraulically connected with the Lower Cretaceous subartesian aquifer, with which it will be included in discussion.

Lower Cretaceous.

(a) Subartesian System. The piezometric surface (Plate 5B) is between 20 and 30 feet below surface in Bore No. 2, and about 4 feet below surface in Bore No. 3 (channel filling). In Bore No. 1 and in the Golf Course Bore, the piezometric surface, although not accurately measured is known to be well below the surface. Thus, the water movement seems to take place in a general east to west direction, at least from Bore No. 3 towards Bore No. 2.

The recharge area for this system is considered to be located on the coastal plain, somewhere near the locations of Bores No. 3 and No. 4. This is supported by the fact that the aquifer beds, if produced to surface, would reach the surface in this same area. Furthermore, the occurrence of several swamps and lakes, some permanent, some temporary, along the Serpentine River in that particular zone, might be indicative of a saturation zone on the eastern margin of this hydraulic system. The recharge of this aquifer could be done mainly through direct infiltration from the surface waters. On the other hand, the deep quaternary channel of Bore No. 3 could likewise be an important source of recharge, and in its lower part, which is more than 200 feet below sea level, sea water encroachment is not precluded.

(b) Artesian aquifer system. When considering the data illustrated on Plate 5B, which shows the piezometric surface of this system, some reservations should be made. The aquifer thickness tested below the green clay horizon is not constant throughout the area; in the western part of the drilling area, only Bore No. 1 and the Golf Course Bore have been pump tested; in Bores No. 2 to No. 5, the head level was measured when the bores were bailed or were flowing for a reasonably long time, while at North Dandalup only the uppermost part of the aquifer was penetrated and pump tested. In Bore No. 5, the piezometric surface indicated on Plate 5 is

representative of the section between the green clay and the light grey clay markers. Below the lower marker, several good aquifers caused a subsequent rising of the water level.

Despite these limitations, the general shape of the hydraulic surface is good evidence of the direction of the water movement. From North Dandalup to Bore No. 3, the piezometric surface has a slope to the west. The hydraulic gradient is about 5 feet per mile from Runciman's Bore to Anderson's Bore, 13 feet per mile from Anderson's Bore to Bore No. 5, 1½ feet per mile from Bore No. 5 to Bore No. 4, and about 1 foot per mile from Bore No. 4 to Bore No. 3. From Bore No. 3 to the Golf Course Bore, however, the slope of the piezometric surface is slightly reversed, with a gradient of less than 1 foot per mile to the east.

The pattern of the hydraulic gradient suggests that the hydraulic surface of the artesian aquifer is approximately as illustrated on Plate 4. Thus it appears that the main recharge area for this aquifer system takes place near the Darling Scarp and that the water moves in a westerly direction from the Darling Scarp to the area of Bores No. 5 and No. 4. The green clay marker probably lenses out towards the Darling Scarp and the recharge of the artesian aquifer system could result from direct infiltration of rain water through the lateritic soils of the "Ridge Hill Shelf". However, for the area under consideration, the main recharge is considered to be from the North and South Dandalup Rivers, close to the Darling Scarp.

From Bores No. 5 and No. 4 westwards, it seems that the water movement takes a southeast-northwest trend, possibly because of a structural complication between Bore No. 4 and Bore No. 3. As can be seen from the contour map (Plate 4), the green clay marker must be truncated by quaternary deposits towards the south southeast, probably in the area around the south and southwest of Pinjarra. It is therefore quite probable

that in Bores No. 3 and No. 2 the artesian aquifer is recharged partly from the south-east rather than directly from the east. As a consequence, it is not precluded that waters from the Murray River may enter the aquifer system around Pinjarra, influencing the water quality in the central part of the drilling area. Also, the slope of the hydraulic gradient has a minimum value in Bore No. 3 and No. 2, which could mean that the water recharging the aquifer has a relatively low head. The fact that towards the coastline, from Bore No. 2 to the Golf Course Bore, the slope of the hydraulic surface is slightly reversed to the east further confirms the probability of a southerly component of the recharge direction. For the westernmost part of the Basin this recharge component could come from an area situated south or perhaps south southwest of Pinjarra. There is also a possibility that this component might be influenced directly or indirectly from the south, but this cannot be established before the structural conditions of the Perth Basin south of Mandurah are better known.

In conclusion, the data illustrated on Plate 4 suggest that the recharge of the artesian aquifer of the Mandurah area comes from two different sources, the major recharge being along the Darling Scarp with the water moving in a general east-west direction up to the area of Bores No. 5 and No. 4. From this point westwards, a probable south-easterly component of the recharge takes effect, and the water moves towards the north northwest.

QUALITY OF THE UNDERGROUND WATER

Salinities for the various aquifers in the different bores are tabulated in Appendix 1. Appendix 3 shows the results of analyses done by the Government Chemical Laboratories. A graphical representation of these analyses on semilogarithmic graph is given on Plate 6.

Quaternary.

In almost every bore, there is some good quality water in these aquifers, except in Bore No. 1 where the estuary is a direct cause of contamination. In the Golf Course Bore, a fresh water layer lies directly on the top of a salt water body in connection with the sea and possibly the estuary.

Lower Cretaceous.

From Bore No. 1, it was established by electrical logging that the salinity gradually increased with depth in the Lower Cretaceous pressure water system, and that this trend was apparently maintained in the Jurassic aquifer. In the subsequent bores, therefore, only the middle part of the South Perth Formation was investigated (except Bore No. 5).

(a) Subartesian aquifer: This system contains only very saline water, and in Bore No. 2, the chemical composition of the water is practically identical with that of sea water (Plate 6). Because of the location of intakes and the particular conditions of the recharge, there seems to be no prospect of obtaining any good quality water from the aquifer in the Mandurah area itself.

(b) Artesian aquifer system: (1) Concentration of Total dissolved salts. Plates 5A and 6 show the variations in total salinities across the Basin and the following comments can be made:

The concentration of total dissolved salts generally increases with depth in each particular bore, and also from east to west, from Anderson's Bore to Bore No. 2.

Within the artesian aquifer, the concentration of total dissolved solids varies according to the permeability of the formation. For example, in Bore No. 5, immediately below the green clay marker (80-94 feet) there is another aquiclude (135-150 feet) which is not present in Bore No. 4.

The glauconitic sequence between these two horizons has little permeability, and, as a result, the water salinity is higher than below 150 feet (Plate 6, Bore No. 5, water No. 1, 89-113 feet).

The highest salinity occurs in Bores No. 2 and No. 3, West of Bore No. 2 the quality of water improves slightly towards Bore No. 1 and the Golf Course Bore, which in conjunction with the hydraulic properties, supports the interpretation that Bore No. 1 and the Golf Course Bore are partly recharged from another direction, probably the south southeast. In Hill's Bore, south of Bore No. 3, the water is reported by the landowner to be coming from immediately below the green clay (or from a sandy zone within the green clay). The water quality in this bore shows considerable variations from one season to another. (See Appendix 1). This is possibly due to periodical salt water intrusions from the Peel Inlet and the estuary.

It is possible there has been a contamination of the artesian aquifer system in Bores No. 3 and No. 2 by salt water filling the Quaternary Channel intersected in Bore No. 3, which may not be fully penetrated in this bore. However, as has been discussed previously, the contour map (Plate 4) rather suggests that the general east-west movement of the water is in some way restricted between Bore No. 4 and Bore No. 3, and that Bores No. 3 and No. 2 are possibly influenced by intake of surface water from the Murray River. (The total soluble salts in the latter vary from a minimum of about 30 grains per gallon in summer, to a maximum of about 190 grains per gallon in winter, the mean content being about 130 grains per gallon).

As is apparent from Plate 5A, the major break in water quality occurs between Bore No. 3 and Bore No. 4. From Bore No. 4 eastwards, the water is of suitable quality for domestic purposes. From Bore No. 3 westwards it is more

saline than the accepted limit for domestic use, but is of good stock quality, and can be used for irrigation purposes for salt tolerant plants in well drained areas. Plate 5A shows that the thickness of aquifer containing domestic quality water increases markedly from Bore No. 4 to Bore No. 5 (310 feet to 546 feet). Isohaline curves between the two bores indicate that the good quality water "wedges out" rapidly towards the west.

(2) Chemical Composition. The graphical representation of Chemical analyses (Plate 6) shows the variations in chemical composition of the waters across the Basin from the east to the west, and also the variations in composition with depth in Bores No. 4 and No. 5.

With regard to the absolute values of ion concentrations, it is apparent that all waters are dominated by the sodium and chloride ions. The evolution of the calcium and magnesium content is of particular interest. Comparison between waters occurring in similar aquifers strata (i.e. excluding the waters numbered No. 1 and No. 4, Bore No. 5 Plate 6) shows that the magnesium content is very high in Giles and Runciman's Bores, decreases towards Bore No. 5, increases again from Bore No. 5 to Bores No. 3 and No. 2, and finally, decreases towards Bore No. 1 and the Golf Course Bore. The calcium content varies in an almost inversely proportional way from North Dandalup to Bore No. 4. It is fairly constant from Bore No. 4 to Bore No. 2 and decreases towards Bore No. 1 and the Golf Course Bore.

Among the different ratios, those of Na/Mg and Cl/SO_4 generally increase with an increase of total concentration. The chloride-alkalis disequilibrium index, $\text{Cl}-(\text{Na}+\text{K})/\text{Cl}$ (Schoeller, 1962) is positive in Giles and Runciman's Bores, negative or positive from Anderson's Bore to Bore No. 2, and negative in Bore No. 1 and the Golf Course Bore.

The ratio Mg/Ca will be discussed in more detail. Theoretically, it should be low near the intake area and show a gradual increase with increasing general concentration, because of the higher solubility of the magnesium salts. However, in the Mandurah area, the ratio Mg/Ca is exceptionally high in the two easternmost bores, compared to the other Bores. In the case of the North Dandalup area, it could be concluded from the different compositions and concentrations of waters in the different bores, that, because the intake area extends on a broad north south line, waters of different type enter the aquifer (high Mg/Ca ratio in Giles and Runciman's Bores, low Mg/Ca ratio in Anderson's Bore and Bore No. 5). However, it seems that a high Mg/Ca ratio in shallow underground waters close to the Darling Scarp is not only a local phenomenon. Further north, close to the Darling Scarp, a Mg/Ca ratio well above unity has been observed in shallow waters from Westphield No. 1 Bore and from Byford No. 2 Bore. This raises the question of the origin of the high Mg content of these different waters.

A first possible explanation could be that there is a source of Mg in the soils of the intake area. However, the soils of the Hill Ridge Shelf (and possibly also the Coolup System) which form the surface deposits of the presumed intake area are described by McArthur and Bettenay (1960) as having a very low exchange capacity, the clay fraction being almost entirely of the kaolin type.

Another explanation for this high Mg/Ca ratio near the Darling Scarp is possibly that the river waters recharging the artesian aquifer have already a high Mg/Ca ratio. On Plate 6, the maximum, minimum and mean contents of the Ca, Mg and Na ions of the Murray River waters (analyses in McArthur and others, 1959) are compared with the concentration of the corresponding ions in Runciman's and Giles Bores. There is a great similarity between the Mg/Ca ratio of the bores water

and the Mg/Ca ratio of the river water (mean content). In superficial waters concentrated by evaporation (such as interior lakes) the ratio Mg/Ca is always very high, the reason being that the CaCO_3 and the CaSO_4 of such waters precipitate when saturation is reached, whereas the Mg concentration keeps increasing because of a higher solubility (Schoeller, 1962). The Murray River shows a maximum Mg/Ca ratio (and a maximum total concentration) in winter, presumably when the high rainfall causes the river to carry away very concentrated solutions formed inland by evaporation during the summer months. A careful sampling and complete analyses of waters from the North and South Dandalup Rivers at different periods of the year could establish whether this explanation is applicable to the North Dandalup case.

Concerning this high Mg/Ca ratio of the waters near the Darling Scarp, it is perhaps worthwhile to add that because of the proximity of the Ocean, the composition of the Perth rainwater (as given in Anderson, 1940) shows also a Mg/Ca ratio above the unity, and a positive disequilibrium index. This could also have a bearing on the composition of the underground water close to the intake area.

It was noticed earlier that the Mg content decreases from North Dandalup to Bore No. 5, while at the same time the Ca content is increasing in an almost inversely proportional way. If a high Mg/Ca ratio is a general characteristic of waters near the Darling Scarp, it is possible that the Mg-rich waters entering the artesian aquifer are quickly affected by base exchange at the contact with the Ca-rich beds of the green clay-calcareous beds complex.

West of Bore No. 5 and No. 4 it is probable that the variations in Mg and Ca contents are influenced by a slightly different chemical composition of the water entering the aquifer from the south-southeast. Noteworthy is the increase in Mg from Bore No. 5 to Bore No. 2, and the decrease of both the Mg and the Ca from Bore No. 2 to the

Golf Course Bore.

In conclusion, the examination of the salinity patterns of the artesian aquifer in the Mandurah-Pinjarra area tends to confirm the existence of two distinct water provinces. The first one, in the eastern part of the Basin contains the best quality water because of the proximity of a major recharge area. The second one, from Bore No. 4 to the coast line contains poorer quality water because the conditions of recharge are different, and because for the westernmost part of the Basin, the distance from the intake is probably greater.

CONCLUSIONS

From an overall geological viewpoint, very useful information has been obtained in an area where no previous subsurface data were available. In conjunction with the results of the Byford exploratory drilling programme, this should prove to be of help in future search for water in that part of the Perth Basin. The main practical results and the questions still unresolved are summarised below.

Geological results

Tertiary and Upper Cretaceous sediments are absent at Mandurah, and if they were ever deposited, must have been removed by subsequent erosion. Lower Cretaceous beds occur, but the youngest part of the sequence is recorded only in the westernmost part of the Basin, which could mean that the axis of sedimentation during Upper Cretaceous and Tertiary times was not situated under the center of the coastal plain, but farther westwards. In support of this is the known occurrence of sediments of Upper Cretaceous or Tertiary age farther north, in the Garden Island Bores, the Point Peron Bore and Byford Bores No. 5 and No. 6. Palaeontological and

lithological correlations have established a probable general westerly dip for the shallow Lower Cretaceous stratas, whereas at depth, in the western part of the drilling area, the structural relationships between the different bores are not yet definitely established. It is interesting to note that the structural position of the Upper Jurassic in Bore No. 1 is lower than at Garden Island and Point Peron, but higher than in the Jandakot Bore.

Hydrological results

The recognition of several aquifer systems with different hydraulic properties and salinity patterns, should be a valuable guide in the future search for water. In particular, the presence of an easily recognisable green clay marker at the top of a potential artesian aquifer will be of assistance in future drilling programmes.

The Mandurah exploratory work has shown that on the Mandurah area itself, the underground water from the Lower Cretaceous artesian aquifer is suitable for stock and selected irrigation purposes, but suggests that a town water supply can only be obtained with safety in the eastern part of the drilling area, nearer the major intakes.

Future investigations

On a more regional scale, several questions of interest could be the subject of future investigations.

A comparison between the results of the Mandurah and Byford cross sections suggests that, in these two areas, there is little prospect of obtaining supplies of domestic quality water from the Cretaceous aquifers, beneath the western half of the coastal plain south of Perth. More drilling will be needed before it can be established whether this is a general feature, or whether, in places, the "fresh water front" might extend farther towards the coastline.

The possibility that near Mandurah the groundwater is moving from the southeast rather than the east needs further investigations. Also, very little is known about the structural and stratigraphical conditions along the coastline, south and north of Mandurah.

It is apparent, from electrical logging, that the Jurassic Claremont Sandstone in Bore No. 1 (1,847-2,001 feet) contains only salt water. North of the Byford line, the Jandakot Bore reached the Jurassic at about 2,500 feet, and only salt water was found, but at Point Peron and on Garden Island, the Jurassic is much shallower and contains fresher water. This good quality water appears quite anomalous if a general east to west movement of groundwater from intakes along or near the Darling Scarp is postulated, and it is obvious that more exploratory drilling is needed if the matter is to be elucidated.

While on this matter of intakes, the discovery of a deeply incised (220 feet) Quaternary Channel near Bore No. 3 is of particular interest, as it is quite possible that similar deep but as yet undiscovered channels occur elsewhere on the coastal plain. Filled with permeable material, such channels could provide plentiful if localized intake of surface water into the underlying aquifer system and this would complicate the salinity pattern considerably, possibly for all aquifers including the Jurassic. They could also in themselves be valuable local sources of water especially in the eastern part of the Basin where no salt water intrusion is expected, and geophysical investigations, if practicable, could be of assistance in locating such channels.

RECOMMENDATIONS

Although the drilling has shown that water suitable for domestic use and probably in sufficient supply is avail-

able some miles eastward of Mandurah, there is as yet, insufficient evidence to determine whether the water is of sufficient areal extent, and has enough recharge available, to warrant the rather large capital cost of development. Saline waters occur to the westward, and the salinity pattern to the north and the south is unknown.

Before development work is undertaken, therefore, further drilling has been recommended to test the extent, thickness, and salinities of the water within the Lower Cretaceous artesian aquifer system, in the vicinity of Bores No. 4 and No. 5.

REFERENCES

- Anderson, W. G., 1940, Old and new systems for reporting the inorganic constituents in natural waters. Melbourne. Australian Chem. Inst. Journ. and Proceed., vol. 7.
- Berliat, K., 1963, Report on exploratory Drilling for Under-ground Water in the Perth Basin West of Byford, W. A.: West. Australia Geol. Survey, Record No. 1963/33.
- Emmenegger, C., 1963, Report on G.S.W.A. Mandurah No. 2 Water Bore, Mandurah, W. A.: West, Australia Geol. Survey, Record No. 1963/31.
- Fairbridge, R. W., 1953, Australian Stratigraphy: University of Western Australia, Text Books Board.
- Felcman, F. L. & Lane, E. P., 1963, Central Perth Basin Gravity Survey (North Portion Augusta-Moora Gravity Survey): West Australian Petroleum Pty. Ltd., company report.
- McArthur, W. M. & Bettenay, E., 1960, The development and Distribution of the Soils of the Swan Coastal Plain, W. A.: C.S.I.R.O. Soil Publication No. 16.
- McArthur, W. M., Bettenay, E. & Hingston, F. J., 1959, The Soils and Irrigation Potential of the Pinjarra-Waroona Area, W. A.: C.S.I.R.O. Soils and Land Use Series No.31.

- McWhae, J. H. R., Playford, P. E., Lindner, A. W., Glenister, B. F. & Balme, B. E., 1958, The Stratigraphic of Western Australia: Geol. Soc. Aust. Journ. v. 4, pt. 2.
- Moss, F. J., 1962, Rockingham-Mundijong Seismic Survey 1955-1956: Bur. Min. Resour. Aust. Record 1962/107.
- Passmore, J. R., 1962, Report on G.S.W.A. Mandurah No. 1 Water Bore, Mandurah, W. A.: West. Australia Geol. Survey. Record No. 1962/18.
- Pudovskis, V., 1962, Subsurface Geology of the Perth Metropolitan Area: West Australian Petroleum Pty. Ltd., company report.
- Schoeller, H., 1959, Arid Zone Hydrology - Recent Developments: Arid Zone Research, XII, Paris, UNESCO.
- 1962, Les Eaux Souterraines, Hydrologie dynamique et Chimique, Recherche, Exploitation et Evaluation des Ressources: Masson & Cie, Editeurs, Paris.
- Thyer, R. F., and Everingham, I. B., 1956, Gravity Survey of the Perth Basin, Western Australia: Bur. Min. Resour. Aust. Bull. 33.

APPENDIX 1 DRILLING RESULTS

DRILLING RESULTS - G.S. No. 1 TO

MISCELLANEOUS DATA

- (a) Electrical logging unit: Widco Logger, Western Australian G.S. Petroleum Pty. Ltd. (Mandurah Bores No. 1, No. 2 and No. 3.) Widco Logger, Mines Department (Bores No. 4 and 5, and Golf Course Bore).
- (b) Drilling Rate Log (rotary): Drilling time measured for each 2 feet drilled. For the composite logs (Plates 7 - 11), averaged over 51 feet.
- (c) Ditch samples (rotary): Collected from shale shaker every 5 feet and examined; Measured Volume of each sample sieved and results plotted on a percentage lithological log (Composite Logs, Plates 7-11). 10 feet samples retained.
- (d) Coring (rotary): Only in Mandurah No. 1 Bore. 16 core runs with NX diamond bit, 9 feet 6 inches core barrel. Core 2 1/2" diameter.
- (e) Water samples: Collected by running a casing string and bailing (Mandurah Nos. 1-4 Bores). In Mandurah No. 5 Bore, the Mines Department Johnston Formation Tester was used. (383-411 feet and 684-714 feet).
- (f) Salinity tests: Apart from the samples sent to the Government Chemical Laboratories for standard or partial analyses, the salinities were determined in the field by titration (for NaCl) and with the Philipps Conductivity Bridge (for total dissolved solids).
- (g) Bore elevations: Accurately surveyed by the Mines Department (Except Hill's Bore): 442 feet to 631 feet. Slots 12" x 3/32" / 412 feet to 576 feet 12" x 1/8" / 375 feet to 631 feet. 108 slots per 20 feet.

DRILLING RESULTS - G.S.W.A MANDURAH No.1 TO
NO. 5 BORESG.S.W.A. MANDURAH NO. 1 BOREGeneral Data.

Location: South West Division.
W. A. Lands Department Litho. 380A/40, Crown Reserve 859.
Lat. $32^{\circ}32'8''$ S., Long. $115^{\circ}42'37''$ E.
Elevation: Ground Level: 3.7 feet above sea level.
Datum: Ground Level. (On Plates 7, 12 and 13, datum = drill floor, 4'6" above ground level)
Commenced: 10th August, 1962.
Drilling completed: 23rd September, 1962.
Testing completed: 19th October, 1962.
Total depth: 2001 feet.
Status: Fitted with valve, ready for use.

Drilling Data.

Drilling contractor: J. F. Grill.
Drilling Plant : Mines Department Failing MI Rotary.
Bore diameter : $9.7/8''$ from surface to 87 feet.
 $7.1/2''$ from 87 feet to 426 feet.
 $6.3/4''$ from 426 feet to 2001 feet.
Casing: 8" O.D. from surface to 88 feet.
6" O.D. from $1/2$ foot to 426 feet.
5" O.D. from +2 feet to 631 feet.
(6" casing cemented from 426 feet to surface)
Perforations: 5" casing slotted from 442 feet to 631 feet. Slots $12'' \times 3/32''/442$ feet to 576 feet
 $12'' \times 1/8''/576$ feet to 631 feet, 108 slots per 20 feet.
Cement Plug: Set at 631 feet to 686 feet.

Logging and Testing:

Bore site geologists: J. R. Passmore and C. Emmenegger.

Coring: 16 core runs with NX diamond bit, 9 ft 6 ins. core. barrel. Core 2½" diameter. Total recovery 49%.

Logs Run: Spontaneous Potential, Resistivity - 16" Short Normal, Resistivity - 64" Long Normal, Point Resistivity, Gamma Ray.

Logged by: M. H. Johnstone and J. W. Burdett, W.A.P.E.T.

Date of logging: 3rd September, 1962 (0-1200 feet)
20th September, 1962 (0-1874 feet).

Hydrological Data:

Developed aquifer zone: 442 feet - 631 feet.

Static water level: 20 feet 4 inches above ground surface.

Flow : 6820 gallons per hour.

Date of Pump Test : 17th-19th October, 1962.

Yield : Pumped for 48 hours at 12,000 gallons per hour.

Drawdown : 19 feet.

Quality of water : Total Dissolved solids: 2040 parts per million (143 grains/gallon).

G.S.W.A. MENDURAH NO. 2 WATER BORE.

General Data:

Location: South West Division.

W. A. Lands Dept Litho. 380A/40, Cockburn Sound Loc. 16, Lot 120.

Lat. 32°32'13"S., Long. 115°45'0"E.

Elevation: Ground surface 20 feet above sea level.

Datum : Ground surface.

Commenced: 30th April, 1963.

Completed: 1st June, 1963.

Testing completed: 17th July, 1963.

Total Depth : 571 feet.

Status: Abandoned with 8 inch casing from 2 feet above surface to 351 feet 10 inches below surface. Static water level: about 30 feet below ground level. (Quality: 330 parts per million (2,275 grains per gallon) total dissolved solids.)

Aquifer Capped. 310 feet (green clay)

(a) Sample from zone 340-360 feet obtained on 10/8/63: Static water

Drilling Data:

Drilling contractor: J.F.C. Griffin 2 feet above surface.

Drilling Plant : Failings MI Rotary. 10 parts per million

Bore diameter : 12 1/4 inch/0-22 feet; 9 7/8 inch/22-571 feet.

Casing : 11 inch O.D./0-22 feet; 8 inch O.D./2 feet above surface to 351 feet 10 inches below surface. Ground surface.

Perforations : One length of 8 inch casing plotted from 310 feet to 331 feet (20 inches). Slots: 12 inches x 1/8 inch (20-260 feet)

Pump Test: None. Cement plugs : Set at 350-353 feet and 329-332 feet. Third plug set at 307-316 feet and

G.S.G.A. MANURAU No. 5 drilled out inside 8" casing. The hole has been backfilled to 353 feet and again from 350 to 332 feet.

General Data:

Location: South West Division. Logging

Bore site geologist: W. A. Lands Department No. 380A/40. C. Emmenegger.

Logs Run : Spontaneous Potential, Point Resistance, Gamma Ray. Lat. 32° 33' S, Long. 150° 50' E.

Elevation: Ground surface. Logged by: M. H. Johnstone. 300 level.

Date logged : 1st June, 1963.

Drilling commenced: 1st July, 1963.

Drilling completed: 20th August, 1963.

Hydrological Data:

Total Depth: 571 feet. Aquifer 89-130 feet: Static water level: 20 feet below

Status: Abandoned. all ground surface. Quality: 17,700 parts per million (1,239 grains per gallon) total dissolved solids.

Aquifer 220-260 feet: Static water level: about 30 feet below ground level. Quality: 32' 500 parts per million (2,275 grains per gallon) total dissolved solids.

Aquifer below 316 feet (green clay) : (a) Sample from zone 340-360 feet obtained on 10/6/63: Static water level about 2 feet above surface. Quality: 2350 parts per million (165 grains/gall.) total dissolved solids.
(b) Sample from zone 320-330 feet collected on 17/7/63: Static water level: 8 feet below ground surface. Quality: 34,500 (2'415 grains/gall.) total dissolved solids. (contamination from aquifer zone 220-260 feet)

Pump Test: None.

G.S.W.A. MANDURAH No. 3 BORE.

General Data:

Location: South West Division.

W. A. Lands Department Litho. 380A/40.

Cockburn Loc. 16, Lot 177.

Lat. $32^{\circ}33'24''$ S., Long. $115^{\circ}46'58''$ E.

Elevation: Ground surface 8 feet above sea level.

Datum : Ground surface.

Drilling commenced: 31st July, 1963.

Drilling Completed: 29th August, 1963.

Total Depth: 684 feet.

Status: Abandoned, all casing withdrawn. Two cement plugs set (see drilling data).

Drilling Data:

Drilling Contractor: J. F. Grill.
Drilling Plant : Failing MI, Rotary.
Bore diameter : 6 $\frac{3}{4}$ -inch, reamed to 9 $\frac{7}{8}$ -inch/O-243
feet, 6 $\frac{3}{4}$ -inch/243-684 feet.
Casing : 8-inch O.D./O-243 feet, withdrawn.
Cement Plugs : (1) at 20-35 feet (to separate salt
water at 30-239 feet from the top
fresh water).
(2) at 243-254 feet (to separate
salt water at 30-239 feet from
better quality water below 254 feet.)

Logging:

Bore Site geologist: C. Emmenegger.
Logs Run : Spontaneous Potential, Resistivity
- 16" short normal, Resistivity
- 64" long normal, Point Resistivity
Gamma Ray.
Logged by : S. P. Wilmott.
Date Logged : 9th September, 1963.

Hydrological Data:

Aquifer zone 0-15 feet : Static Water Level 2 feet below
surface. Salinity 15 grains/gall.
NaCl.
Aquifer zone 30-239 feet: (Sample at 37-54 feet). Static
water level 4 feet below surface.
Salinity 840 grains/gall. NaCl.
Aquifer zone below 253
feet (green clay) : (a) 270-290 feet: salinity 120
grains/gall. NaCl and 154 grains/
gall. T.D.S.
(b) 290-684 feet: salinity re-
mained at 120 grains/gall. NaCl
and 154 grains/gall. T.D.S.

Aquifer zone 253-684 feet together : Flow at about 7,000 gallons/hour, Static water level 13 feet above surface, salinity 154 grains/gall. NaCl.

Pump test : None.

G.S.W.A. MANDURAH No. 4 BORE

General Data:

Location: South West Division
W. A. Lands Dept Litho. 380A/40, Cockburn Sound Loc. 16, Pt. 1. (50 chains N.W. of Ravenswood Bridge).
Lat. $32^{\circ}34'22''$ S., Long. $115^{\circ}49'04''$ E.

Elevation: Ground surface 11.3 feet above sea level.
Datum : Ground surface.
Drilling commenced: 26th September, 1963.
Drilling completed: 23rd October, 1963.
Total Depth: 504 feet.
Status: Observation Bore and top of 5-inch casing capped and fitted for a pressure gauge.

Drilling Data:

Drilling Contractor: J. F. Grill.
Drilling Plant : Failing MI, Rotary.
Bore Diameter : $6\frac{3}{4}$ -inch, reamed to $9\frac{7}{8}$ -inch/0-112 feet. $6\frac{3}{4}$ -inch/112-504 feet.
Casing : 8-inch O.D. from +3'6" to 113 feet. (Bottom part cemented opposite the green clay extending from 100-114 feet; top sealed around the 5-inch casing line.)
5-inch from +5'2" to 293 feet.

Perforations : 5-inch casing slotted from 154' -
192'9" and from 231'9" to 293'.
Cement Plugs : (1) 450-504 feet.
(2) 293-325 feet.
(3) Cement plug from 100-115 feet
drilled out inside 8-inch casing.

Logging:

Bore Site geologist: C. Emmenegger.
Logs Run : Spontaneous Potential, Resistivity
-16" Short Normal, Resistivity - 64"
Long Normal, Point Resistivity,
Gamma Ray.
Logged by : D. L. Rowston.
Date Logged : 24th October, 1963.

Hydrological Data:

Aquifer zone 0-100 feet: (Sample collected at 40-60 feet):
Static Water level 2-3 feet below
surface. Salinity 70 grains/gall.
NaCl.

Aquifer zone below
114 feet (green clay) : (a) 114-300 feet: salinity
(samples at 130-150 feet and 270
-290 feet, water level: 5-7
feet above surface): 40 grains
for gallon NaCl and 49 grains/gall.
T.D.S. (a partial analysis gave
first 57 grains/gall. T.D.S.)
First yielded: 3,000-5,000 gall-
ons per hour. Yield reduced to
2,000 gallons per hour after
completion of bore (sand at 293-
310 feet cemented off). Static
water level for the section 114-

-300 feet: 8'6" above surface.

(b) 324'-384' (sample at 336-341 feet): salinity 58 grains/gall. NaCl and 75 grains/gall. T.D.S.

(c) 394-448' (sample at 440 feet). Salinity 70-90 grains/gallon NaCl. and 104 grains/gall. T.D.S. Flow of 7,000 gallons/hour.

(d) 466'-504' Salinity higher than 104 grains/gall. T.D.S. (from electrical logging)

(e) for the section 114-488 feet together: Flow of 7,000-9,000 gall/hour. Static water level 13'1" above surface. Salinity 60-70 grains/gall. NaCl.

Pump Test: None.

G.S.W.A. MANDURAH No. 5 BORE.

General Data:

Location: South West Division.

W. A. Lands Dept Litho. 380A/40. Cockburn Sound Loc. 16, Pt. 2 (alongside Road No. 785, 73 chains N. W. of the Murray River, measured from the mouth of the North and South Dandalup Rivers).

Lat. $32^{\circ}34'34''$ S., Long. $115^{\circ}51'12''$ E.

Elevation: ground surface 27.2 feet above sea level.

Datum : Ground surface.

Drilling commenced: 14th November, 1963.

Drilling completed: 22nd December, 1963.

Total Depth : 837 feet.

Status : Left with 8-inch casing O.D. from
+1 foot 10 inches to 141 feet 6 inches
Bore filled with drilling mud. Bought
by the landowner for irrigation purposes.

Drilling Data:

Drilling Contractor: J. F. Grill.
Drilling Plant : Failing MI, Rotary.
Bore Diameter : 6-inch, reamed to 9 $\frac{7}{8}$ -inch from sur-
face to 141 feet 6 inches.
6-inch, from 141 feet 6 inches to
837 feet.
Casing : 8-inch O.D. from +1 foot 10 inches to
141 feet 6 inches (Bottom part cemen-
ted from 125 feet to 141 feet).

Logging:

Bore Site Geologist: C. Emmenegger.
Logs Run: Spontaneous Potential, Resistivity - 16"
Short Normal, Resistivity - 64" Long
Normal, Point Resistivity, Gamma Ray,
Caliper.
Logged by : D. L. Rowston.
Date Logged : 20th December, 1963. Logged from
surface to 715 feet. Bore subsequent-
ly drilled to 837 feet.

Hydrological Data:

Aquifer zone 50-80 feet: (sample at 60 feet): Static water
level near surface. Salinity: 119
grains/gallon. T. D. S.
Aquifer zone below 94 feet (green clay):
(a) 94-135 feet: (sample at 94-114
feet): 75 grains/gall. NaCl and 95

grains/gall. T.D.S. (evaporation).

Water level: 13 feet below surface.

(b) 150-230 feet (sample at 150-178 feet): Static water level 3 feet 10 inches below surface. Salinity: 53 grains/gall. T.D.S. (evaporation).

(c) 240-324 feet. Sample at 250-283 feet: 28 grains/gall. NaCl, 47 grains/gall. T.D.S. (conductivity), Water level at 1'2" below surface. Sample at 294-324 feet. 30 grains/gall. NaCl, 59 grains/gall. T.D.S. (conductivity) Water level: 1'8" below surface.

(d) 354-424 feet (sample at 354-376 feet): 30 grains/gall. NaCl, 55 grains/gall. T.D.S. (evaporation). Water level 1'8" below surface. Sample at 383-411 feet: 40 grains/gall. NaCl and 66 grains/gall. T.D.S. (evaporation) water level at surface.

(e) 434-546 feet. Sample at 434-478 feet: 30 grains/gall. NaCl, 56 grains/gall. T.D.S. (conductivity) Water level 2' above surface. Sample at 478-513 feet: 30 grains/gall. NaCl. 53 grains/gall. T.D.S. (conductivity). Water level 3'10" above surface.

(f) 652-806 feet (sample at 684-714 feet): 80-90 grains/gall. NaCl. 108 grains/gall. T.D.S. Water level 3'10" above surface.

Samples at 383-411 feet and 684-714 feet were collected using the Johnston Formation Tester, the other by bailing through a 5" slotted casing string.

DRILLING RESULTS - PRIVATE BORES

MANDURAH GOLF COURSE BORE.

General Data:

Location: South West Division.

W. A. Lands Dept Litho. 380A/40, Cockburn
Sound Loc. 16, Mandurah Townsite.

Lat. $32^{\circ}31'55''$ S., Long. $115^{\circ}41'35''$ E.

Elevation: ground level 30.2 feet above sea level.

Drilled for: Mandurah Shire Council.

Datum : Ground surface.

Commenced : 22nd July, 1963.

Completed : 29th November, 1963.

Total Depth: 700 feet.

Status: ready for use (irrigation of Golf Course)

Drilling Data:

Drilling Contractor: Westphal Bros. and Co., Abernethy
Road, Belmont, W. A.

Drilling Plant : Ruston-Bucyrus-22 R-W, percussion.

Casing left in Bore: 8" x 9/32" from surface to 75 feet.

6" x 1/2" from surface to 458 feet
and cemented.

4" plastic casing from 434' to 700'
sealed to 6" casing with lead seal.

Lead packer set at 434 feet.

Perforations: 4" casing slotted between 495 and
690 feet (plain from 417 feet to
495 feet).

Logging:

Logs Run : Gamma Ray and Point Resistivity.
Logged by : D. L. Rowston.
Date logged: 15th November, 1963.

Hydrological Data:

Developed aquifer zone: 495-700 feet.
Static water level: 6 feet below ground surface.
Date of Pump Test: 17th-18th December, 1963.
Yield: Pumped for 20 hours at 16,300 gallons per hour.
Drawdown: 11 feet 10 inches.
Quality of water (end of pump test): Total dissolved
solids: 2010 parts per million (141
grains/gallon).
Remarks: Salinity of samples collected on the way down:
70-90 grains/gall. T.D.S. (459-551 feet) 112
grains/gall. T.D.S. (600 feet) 170 grains/gall.
T.D.S. (625 feet).

HILL'S BORE, MURRAY RIVER.

General Data:

Location: South West Division.
W. A. Lands Dept Litho. 380A/40, Cockburn Sound
Loc. 16, Lot 183 (subd.21), 1½ miles south of
Mandurah No. 3 Bore.
Elevation: ground surface, 6 feet above sea level (approx.)
Landowner: H. C. Hill, 102, Holland St., Fremantle W. A.
Date drilled: 1958.
Total Depth: 179 feet.

Drilling Data:

Drilling Plant: Small percussion plant (drilled by the landowner).

Casing left in bore: 6" from surface to 50 feet.

4" from surface to 105 feet.

2" from surface to 179 feet (open hole at the bottom)

Cement filling between 6" and 4" casing, and between 4" and 2" casing.

Status: equipped for limited irrigation purposes (water only good in summer).

Hydrological Data:

(a) aquifer zone 0-8 feet: fresh water.

(b) aquifer zones 14-48 feet, 57-102 feet, 110-170 feet: very salty water.

(c) The bottom of 2" casing is at 179 feet, and it is reported that when the water pipe reached this level, the water level rose to about 3 feet above ground surface, and the bore is flowing since then. The salinity is reported by the landowner as varying greatly over the year ("good water" between November and May, "very salty water" between May and November).

The following samples from this Bore were tested by the Geological Survey:-

(1) Sample collected in September, 1963: 1200 grains/gallon NaCl.

(2) Sample collected in January 1964: 480 grains/gallon NaCl.

(3) Sample collected in February 1964: 400 grains/gallon NaCl.

(4) Sample collected in March, 1964: 200 grains/gallon NaCl.

If the water is really coming from below the green clay (as it would appear, because the subartesian aquifer system does not produce flowing water) such variations in salinities could be related to fluctuations in the balance between a salt water and fresh water system.

ANDERSON'S BORE, NORTH DANDALUP.

General Data:

Location: South West Division.
W. A. Lands Dept Litho. 380A/40, Cockburn
Sound Loc. 16, Lot A32 (234A).
Elevation: ground surface 58 feet above sea level.
Landowner: L. E. Morton, (referred to by the Geological
Survey as Mr. Anderson).
Date drilled: July, 1960.
Total depth : 189 feet.
Status: Nipple and "T" piece fitted to control free
flow for flood irrigation.

Drilling Data:

Drilling Contractor: M. R. Baker, Artesian Well-Drilling
Service, 231 Armadale Rd., Kewdale,
W. A.
Drilling Plant: percussion.
Completion: 6" casing from surface to 183 feet. Open
Hole from 183 feet to 189 feet.

Hydrological Data:

Developed aquifer zone: 183-189 feet.
Flow: 97000 gallons per hour.
Static water level: 22 feet above ground surface (30/10/63)
Pump Test: Pumping at 66 feet yielded approximately 7,000
g.p.h. for 2 hours. Pumping at maximum depth

with centrifugal pump directly/^{coupled} to borehead
yielded about 26,000 gallons/hour.

Water Quality: 28 grains/gallon NaCl and 44 grains/gallon
total dissolved solids.

RUNCIMAN'S BORE, NORTH DANDALUP.

General Data:

Location: South West Division.

W. A. Lands Dept Litho. 380A/40, Cockburn

Sound Loc. 16, Lot a39 (486a).

Elevation: Ground surface, 81 feet above sea level.

Landowner: Mr. E. Runciman, M.L.A., North Dandalup.

Date drilled: June, 1963.

Total Depth: 240 feet.

Status: equipped for irrigation purposes.

Drilling Data:

Drilling Contractor: L. Solomon, Thornlie, W. A.

Drilling Plant : Percussion.

Completion : 6" casing from surface to about
1170 feet. Open Hole from about
1170 feet-240 feet.

Hydrological Data:

Developed aquifer zone: 170 feet-238 feet.

Flow: 4000-5000 gallons per hour.

Static water level: 8 feet above ground surface (30.10.63)

Pump Test: Estimated 20,000 gallons per hour obtained
for drawdown of 40 feet.

Quality of water: 71 grains/gallon total dissolved solids.

GILES BORE, NORTH DANDALUP.

General Data:

Location: South West Division.

W. A. Lands Dept Litho. 380A/40, Cockburn
Sound Loc. 16, Lot a41 (484.20).

Elevation: ground surface 89 feet above sea level.

Landowner: A. B. Giles, North Dandalup, W. A.

Date drilled: January, 1961.

Total Depth: 230 feet.

Status: equipped for irrigation purposes.

Drilling Data:

Drilling Contractor: L. Solomon, Thornlie, W. A.

Drilling Plant : Percussion.

Completion : 6" casing x 3/16" from surface to
190 feet. Open Hole from 190-230
feet.

Hydrological Data:

Developed aquifer zone: 190-210 feet.

Flow: The bore starts flowing slightly in winter. (in
July if particularly wet season, otherwise August).

Pump Test: Pumped at approximately 12,000 gallons per
hour, later testing at 18,000-20,000 gallons
per hour.

Water Quality: 65 grains per gallon total dissolved
solids.

APPENDIX 2 SAMPLE LOGS

(A) G.S.W.A. MANDURAH No. 1 TO No. 5 BORES.

G.S.W.A. MANDURAH No. 1 BORE. (Summary log only. For detailed log, see West. Australia Geol. Survey Record No. 1962/ (18) Datum: ground level

FROM (ft)	TO (ft)	THICK- NESS (ft)	DESCRIPTION
0	68	68	SAND and CLAY SAND: Calcareous, grey, medium grained, shelly, silty, carbonaceous CLAY: silty, grey, shelly.
68	75	7	SAND: quartz, coarse grained, feldspathic, with fragments of wood and coal
75	118	43	CLAY and SANDSTONE CLAY: sandy in part, dark grey to black SANDSTONE: quartz, clayey, medium to coarse grained, slightly feldspathic and micaceous
118	166	48	MUDSTONE: silty, slightly sandy, dark grey to black, micaceous, carbonaceous, slightly pyritic.
166	216	50	SANDSTONE with minor MUDSTONE SANDSTONE: quartz, medium grained, poorly sorted, micaceous, with minor coal and pyrite MUDSTONE: dark grey to black, carbonaceous, pyritic
216	266	50	MUDSTONE with minor SANDSTONE MUDSTONE: dark brown, carbonaceous, micaceous, pyritic SANDSTONE: fine to medium grained
266	406	140	SANDSTONE MUDSTONE and SILTSTONE SANDSTONE: quartz, in part clayey and silty, fine to coarse grained, poorly sorted, feldspathic, carbonaceous and pyritic, with rare

FROM (ft)	TO (ft)	THICK- NESS (ft)	DESCRIPTION
			<p>shells. Two thin beds consolidated with calc. cement.</p> <p>MUDSTONE: silty, dark brown, dark grey and black, micaceous, carbonaceous and pyritic</p> <p>SILTSTONE: light grey, carbonaceous and micaceous</p>
406	425	19	<p>MUDSTONE: very slightly sandy, greenish-black, glauconitic</p>
425	577	152	<p>SANDSTONE with minor CLAY and MUDSTONE</p> <p>SANDSTONE: quartz, clayey and silty, fine to coarse grained, poorly sorted, feldspathic, carbonaceous, with shells. Some white kaolin from decomposed feldspar, and thin beds of light green clay. Thin beds consolidated, with calcareous cement and calcite veins.</p> <p>CLAY: sandy, light green, brown and grey.</p> <p>White kaolin from decomposed feldspar</p> <p>MUDSTONE: black, silty, carbonaceous</p>
577	630	53	<p>SANDSTONE: quartz, coarse to very coarse grained, moderately sorted, feldspathic slightly carbonaceous and micaceous with few shells. Thin beds consolidated with calcareous cement. Minor thin beds of green and brown clay.</p>
630	666	36	<p>MUDSTONE and CLAY</p> <p>MUDSTONE: (638-666) Slightly silty, grey and blue-grey interbedded, greasy texture. Slightly micaceous, carbonaceous and pyritic. Bedding in part contorted</p> <p>CLAY: (630-638) sandy, dark grey, carbonaceous.</p>

FROM (ft)	TO (ft)	THICK- NESS (ft)	DESCRIPTION
666	731	65	<p>SANDSTONE with minor MUDSTONE and CLAY</p> <p>SANDSTONE: quartz, slightly clayey, coarse grained, moderately sorted, feldspathic, with minor coal and pyrite and few shells. Few thin beds of consolidated fine grained sandstone</p> <p>MUDSTONE: grey and blue grey, greasy texture</p> <p>CLAY: sandy and silty, dark grey, micaceous.</p>
731	966	235	<p>SANDSTONE and CLAY</p> <p>SANDSTONE: quartz, clayey, fine to coarse grained, poorly sorted, feldspathic in part with white kaolin from decomposed feldspar, minor pyrite and fine carbonaceous material, and rare shells. Few thin beds consolidated, with calcareous cement.</p> <p>CLAY: sandy and silty, dark grey, green-grey and green, micaceous.</p>
966	1238	272	<p>SANDSTONE and CLAY with minor MUDSTONE and SILTSTONE</p> <p>SANDSTONE: quartz, slightly clayey in places, medium to very coarse grained, well sorted, with minor coal and pyrite</p> <p>CLAY: sandy, grey-brown, black and green-black, slightly pyritic and carbonaceous.</p> <p>MUDSTONE: silty, black, micaceous, carbonaceous with rare pyrite.</p> <p>SILTSTONE: sandy, grey, micaceous.</p>
1238	1338	100	<p>SANDSTONE with minor CLAY</p> <p>SANDSTONE: quartz, coarse to very coarse grained, moderately to well sorted, feldspathic (some decomposed). Pyrite and coal beds.</p>

FROM (ft)	TO (ft)	THICK- NESS (ft)	DESCRIPTION
1338	1424	86	<p>CLAY: grey</p> <p>SANDSTONE and MUDSTONE</p> <p>SANDSTONE: quartz, slightly clayey, coarse to very coarse grained, moderately sorted, rare feldspar and pyrite, and minor beds of coal.</p> <p>MUDSTONE: soft and hard interbedded. Soft mudstone dark brown; hard mudstone silty, grey-brown, micaceous with fine carbonaceous material</p>
1424	1498	74	<p>SANDSTONE with minor MUDSTONE</p> <p>SANDSTONE: quartz, medium to very coarse grained, moderately to well sorted, slightly feldspathic, pyritic and carbonaceous</p> <p>MUDSTONE: grey and brown, mostly soft, some brittle</p>
1498	1596	98	<p>MUDSTONE with minor SANDSTONE and SILTSTONE.</p> <p>MUDSTONE: slightly silty, grey to light greenish-grey, compact, greasy texture, very slightly micaceous and carbonaceous in places shaly</p> <p>SANDSTONE: quartz, medium to very coarse grained, well sorted, feldspathic, with minor fine grained, silty sandstone</p> <p>SILTSTONE: sandy, grey and greenish-grey, micaceous</p>
1596	1670	74	<p>SANDSTONE with minor MUDSTONE</p> <p>SANDSTONE: silty in part, fine to coarse grained, moderately sorted</p> <p>MUDSTONE: grey, greenish-grey, and dark brown</p>

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FROM (ft)	TO (ft)	THICK- NESS (ft)	DESCRIPTION
1670	1790	120	MUDSTONE: slightly silty, light greenish-grey and dark grey, compact, greasy texture, slightly micaceous in places has irregular shearing planes. One 10' bed dark grey shale Minor thin beds grey siltstone and fine grained sandstone
1790	1847	57	MUDSTONE with minor SANDSTONE MUDSTONE: grey and greenish-grey, slightly carbonaceous SANDSTONE: quartz, fine grained, some calcareous. Rare feldspar and carbonaceous material, very rare pyrite and mica
1847	2001	154	SANDSTONE: quartz, slightly clayey, medium to very coarse grained, mostly well sorted, feldspathic (some decomposed to kaolin), slightly pyritic; fragments of coal frequent in places, rare grains of garnet. Minor thin beds of grey and greenish-grey mudstone
TOTAL DEPTH:			2001 feet.

G.S.W.A. MANDURAH No. 2 BORE (Summary log only. For detailed log see West. Australia Geol. Survey Record No. 1963/31) Datum: ground surface

FROM (ft)	TO (ft)	THICK- NESS (ft)	DESCRIPTION
0	26	26	SAND: quartz, brown and yellowish, coarse to very coarse, shelly, with a few hard beds
26	48	22	CLAYSTONE: sandy and silty, light brown, yellow and dark grey. Beds of siltstone, dark grey, in places mottled and hard

FROM (ft)	TO (ft)	THICK- NESS (ft)	DESCRIPTION
48	89	41	<p>CLAYSTONE and SILTSTONE</p> <p>CLAYSTONE: sandy and silty, black and dark grey, rarely yellow and brown, with rare thin beds of consolidated sandstone</p> <p>SILTSTONE: dark grey. In places yellow brown or reddish, consolidated.</p>
89	130	41	<p>SANDSTONE: quartz, brownish and yellowish, unconsolidated, medium to very coarse, well sorted, subrounded to rounded grains. Rare thin beds of consolidated calcareous sandstone. Very rare layers of claystone.</p>
130	220	90	<p>CLAYSTONE and SILTSTONE</p> <p>CLAYSTONE: sandy and silty, black, dark grey, rarely brownish, yellow or slightly greenish, with rare intercalation of thin calcareous sandy beds, consolidated.</p> <p>SILTSTONE: grey and light grey, micaceous, carbonaceous</p>
220	260	40	<p>SANDSTONE: quartz, dark grey, unconsolidated, fine to very coarse grained, well sorted, with subrounded to rounded grains.</p>
260	300	40	<p>CLAYSTONE and SILTSTONE with minor SANDSTONE</p> <p>CLAYSTONE: grey and dark grey, rarely yellow and light grey.</p> <p>SILTSTONE: grey and dark grey. A few thin consolidated beds of sandstone and limestone</p> <p>SANDSTONE: quartz, dark grey unconsolidated, fine to very coarse grained.</p>
300	316	16	<p>CLAYSTONE: (a) silty and sandy, dark grey greenish and light grey to light brown, greasy (300-310 feet) (b) greenish, glauconitic (310-316 feet)</p>

FROM (ft)	TO (ft)	THICK- -NESS (ft)	DESCRIPTION
316	571	255	SANDSTONE and CLAYSTONE with HARD CALCAREOUS BEDS SANDSTONE: quartz, clayey, grey and dark grey fine to very coarse grained, unconsolidated, in places with pebbles and shells CLAYSTONE (from the Gamma Ray log, mostly at 418-420 feet, 442-470 feet, 485-505 feet and 530-550 feet): light grey and blue grey with greasy texture, and black to dark grey, sandy CALCAREOUS BEDS: fine to coarse sandstone, hard, with pebbles and shells
TOTAL	DEPTH:	571 feet	

G.S.W.A. MANDURAH No. 3 BORE. Datum: ground surface

FROM (ft)	TO (ft)	THICK- -NESS (ft)	DESCRIPTION
0	2½	2½	SAND: quartz, white, unconsolidated, fine to very coarse, moderately sorted
2½	15	12½	SAND: quartz, brown, unconsolidated, coarse to very coarse, well sorted, rounded grains.
15	30	15	SAND: quartz, white and brown, unconsolidated coarse to very coarse, well sorted, subrounded to subangular grains, interbedded with blue clay. Numerous brown and black ferruginous concretions, hard
30	220	190	SANDSTONE: quartz, brown and yellow brown, coarse to very coarse, unconsolidated, very well sorted, with angular to subangular grains. Ferruginous concretions, especially at 80 feet, 105 feet, and 130 feet. Rare

FROM (ft)	TO (ft)	THICK- -NESS (ft)	DESCRIPTION
220	239	19	intercalations of carbonaceous material. Rare thin layers of yellow and light grey clay. At 90 feet and 145 feet, fragments of calcareous siltstone with shells (?)
239	253	14	SANDSTONE: silty, dark grey and brown, fine to coarse, unconsolidated, poorly to moderately sorted, with lignite, mica, and rare pyrite.
253	271	18	CLAYSTONE: sandy, at the top light brown to yellowish, soft, greasy, then dark grey and greenish, glauconitic, pyritic, slightly carbonaceous. Thin layers of siltstone, brown, occasionally hard. A few ferruginous concretions, brown, hard. Numerous quartz grains subangular to subrounded, brown and yellow brown.
271	278	7	SANDSTONE: clayey, greenish, very glauconitic unconsolidated, coarse to very coarse, poorly sorted. Minor pyrite and carbonaceous. Quartz grains and granules subangular to subrounded, green and brown stained. A few hard ferruginous concretions. Rare fragments of rounded crystalline pebbles. At 263 feet, thin bed of hard calcareous sandstone
278	320	42	HARD SANDSTONE: calcareous, light grey, with fragments of rounded pebbles of quartzite and granite. Rare glauconite and carbonaceous material. At 275-275½ feet; sandstone, yellow brown, unconsolidated, coarse to very coarse. SANDSTONE, CLAYSTONE and SILTSTONE interbedded. SANDSTONE: quartz, grey and grey-greenish, unconsolidated, fine to very coarse,

FROM (ft)	TO (ft)	THICK- NESS (ft)	DESCRIPTION
			<p>poorly to moderately sorted, grains subrounded to subangular, often yellow brown stained. Rare glauconite, pyrite, carbonaceous material and mica. Fragments of rounded, greenish and dark grey pebbles (granite, gneiss, quartzite) especially between 310-320 feet. At 281-282 feet, 298-299 feet, and 313-314 feet: hard calcareous sandstone, light grey, with pebbles and shells.</p> <p>CLAYSTONE: sandy, grey, grey-greenish, dark grey, and yellow-brown.</p> <p>SILTSTONE: grey and light grey.</p>
320	340	20	<p>SANDSTONE with numerous HARD CALCAREOUS BEDS</p> <p>SANDSTONE: grey-greenish, unconsolidated, coarse to very coarse grained, poorly to moderately sorted, with numerous shells. Numerous pebbles of quartz, quartzite, granite and gneiss. Minor glauconite, pyrite and mica. Carbonaceous material between 335-340 feet. A few ferruginous concretions, hard. Rare thin layers of clay grey and dark grey, and siltstone, yellow brown, in places consolidated</p> <p>HARD CALCAREOUS BEDS: with numerous shells and pebbles, at 320-321 feet, 323-325 feet, 331-332 feet, and 334-339 feet.</p>
340	376	36	<p>SANDSTONE CLAYSTONE and SILTSTONE interbedded</p> <p>SANDSTONE: clayey, grey and dark grey and greenish, unconsolidated, coarse to very coarse, moderately sorted, feldspathic, carbonaceous and micaceous, subangular granules and fragments of quartzite and granite. Minor pyrite and shells.</p>

FROM (ft)	TO (ft)	THICK- NESS (ft)	DESCRIPTION
376	380	4	<p>CLAYSTONE: minor thin beds of grey, dark grey and greenish claystone</p> <p>SILTSTONE: grey</p> <p>SANDSTONE HARD BEDS and PEBBLES</p> <p>SANDSTONE: dark grey-greenish, unconsolidated coarse to very coarse and conglomeratic</p> <p>HARD BEDS: (376-377 feet) Calcareous sandstone light grey, fine to coarse, with shells and pebbles</p> <p>PEBBLES: white-greenish granite and dark grey to black, basic rock</p>
380	430	50	<p>SANDSTONE with minor CLAYSTONE</p> <p>SANDSTONE: grey, light grey and brownish, fine to very coarse, unconsolidated, moderately to well sorted, subangular to subrounded grains, feldspathic. Granules of pink and white-greenish granite, yellow-grey quartzite and chert. Numerous very fine pink and red minerals. Minor pyrite, carbonaceous material and mica. Shells rare to frequent. Hard calcareous beds, light grey and dark grey at 415-416 feet, and 427-428 feet</p> <p>CLAYSTONE: grey and yellow-brown</p>
430	448	18	<p>CLAYSTONE with minor SANDSTONE</p> <p>CLAYSTONE: black, grey and dark grey, occasionally reddish, greenish and whitish, in places hard. Carbonaceous material frequent, rare pyrite and mica.</p> <p>SANDSTONE: coarse to very coarse, feldspathic, with angular to subangular granules of yellow grey chert and feldspar. Hard bed at 431-432 feet; sandstone, calcareous, light grey and brownish.</p>

FROM (ft)	TO (ft)	THICK- NESS (ft)	DESCRIPTION
448	456	8	SANDSTONE: quartz, grey and light grey, unconsolidated, coarse to very coarse, well sorted, angular to subangular grains, feldspathic. A few thin beds of sandstone, hard, light grey, calcareous, and brownish and dark grey, non-calcareous
456	472	16	CLAYSTONE with HARD BEDS CLAYSTONE: in places very sandy, dark grey, black and grey-greenish, occasionally brown, carbonaceous, pyritic and micaceous HARD BEDS: (464-466 feet) sandstone, light grey, calcareous, fine to coarse, and brownish, non-calcareous, fine to coarse. A few shells
472	484	12	SANDSTONE: grey to yellow-grey, unconsolidated, coarse to very coarse, moderately to well sorted, subangular to subrounded grains, feldspathic Minor carbonaceous material, pyrite, and mica. Rare intercalations of black and dark grey clay Hard calcareous bed at 477-478 feet.
484	494	10	CLAYSTONE: silty and sandy, black, dark grey and greenish, with abundant pyrite. A few shells
494	498	4	CONGLOMERATIC SANDSTONE: grey to yellow-grey with granules of quartzite, chert and feldspar angular to subangular grains. Carbonaceous material frequent, a few shells.
498	504	6	CLAYSTONE: sandy, dark grey, pyritic
504	524	20	SANDSTONE: grey and light grey, unconsolidated, coarse to very coarse, subrounded to subangular grains. Numerous granules of whitish quartz and quartzite. At 520-524 feet abundant carbonaceous material, pyrite, and mica. A few thin layers of dark grey to black clay, in places shaly and hard, especially between 515-524 feet.

FROM (ft)	TO (ft)	THICK- NESS (ft)	DESCRIPTION
524	542	18	CLAYSTONE: in places very sandy, grey, dark grey, and grey-greenish, very pyritic, with numerous green stained quartz and feldspar grains. Granules and fragments of quartz and quartzite, yellow-grey and white. A few thin layers of hard sandstone, light grey, calcareous, and brown, non calcareous.
542	555	13	SANDSTONE: quartz, grey to light grey, coarse to conglomeratic, unconsolidated, moderately to well sorted. At 548-549 feet, hard bed of calcareous sandstone, light grey with green minerals, and non calcareous, brown
555	575	20	CLAYSTONE: silty, light grey and grey, in places dark grey or slightly greenish, greasy texture, very rich in pyrite. A few thin intercalations of calcareous sandstone
575	684	109	<p>CLAYSTONE SILTSTONE and SANDSTONE interbedded with numerous HARD BEDS with SHELLS and PEBBLES</p> <p>CLAYSTONE: grey-greenish, dark grey and light grey, occasionally brown and yellow, very pyritic at 575-585 feet, and 635-640 feet. In places abundant carbonaceous material</p> <p>SILTSTONE: grey, in places calcareous</p> <p>SANDSTONE: grey and greenish, coarse to very coarse, poorly to moderately sorted, in places with glauconite.</p> <p>HARD BEDS: sandstone, calcareous, light grey, with green minerals and shells and non-calcareous, brownish. Hard beds at 592-593 feet, 608-612 feet, 616-619 feet, 630-632 feet, 638-642 feet, 663-666 feet.</p>

FROM (ft)	TO (ft)	THICK-NESS (ft)	DESCRIPTION
			<p>PEBBLES: Numerous pebbles throughout the section. 575-684 feet. Rounded fragments of white-greenish granite and gneiss, white and yellow-grey quartz, quartzite and chert.</p> <p>From 670 feet, numerous fragments of pink granite.</p>
TOTAL	DEPTH:		684 feet.

G.S.W.A. MANDURAH No. 4 BORE Datum: ground surface

FROM (ft)	TO (ft)	THICK-NESS (ft)	DESCRIPTION
0	15	15	<p>SAND: quartz, brown, coarse to very coarse, unconsolidated moderately sorted. Rounded grain. A few ferruginous concretions.</p>
15	40	25	<p>SAND; quartz, white and light grey, very silty between 15-30 feet, otherwise fine to coarse, unconsolidated, well sorted, feldspathic and micaceous, slightly carbonaceous. Rounded grains together with angular and subangular grains, very rare shells</p>
40	100	60	<p>SANDSTONE SILTSTONE and CLAYSTONE</p> <p>SANDSTONE: (very silty between 80-100 feet), dark grey and grey, very carbonaceous, slightly pyritic, unconsolidated, coarse to very coarse, feldspathic. Grains mostly rounded to subrounded. From 70 to 100 feet, increasing amount of green stained quartz and feldspar grains.</p> <p>SILTSTONE: grey and light grey</p> <p>CLAYSTONE: silty and sandy, dark grey, brown and light grey, carbonaceous and pyritic. Some grey-greenish clay between 90-100 feet.</p>

FROM (ft)	TO (ft)	THICK- NESS (ft)	DESCRIPTION
100	114	14	CLAYSTONE: Sandy, at the top light grey, whitish and light brown, greasy, then greenish and dark grey, glauconitic, carbonaceous, very pyritic. Green stained grains of quartz and feldspar. Rounded granules. A few thin intercalations of siltstone, brown, slightly consolidated, and some ferruginous aggregates.
114	124	10	CLAYSTONE: very sandy, grey-greenish, glauconitic, pyritic. Numerous quartz and feldspar grains, green and yellow grey stained. Minor dark grey clay. A few chips of ferruginous sandstone, hard, and siltstone, brown, soft.
124	152	28	SANDSTONE: grey-greenish, coarse to very coarse in places conglomeratic, unconsolidated, moderately to well sorted, glauconitic, slightly pyritic and carbonaceous. Numerous quartz and feldspar grains, subrounded to subangular, yellow-grey and greenish stained. A few fragments of crystalline pebbles, white-greenish and black. Minor clay, green, light grey and brown. Some black shale, in places consolidated
152	157	5	CLAYSTONE: green, glauconitic, firm, with minor white kaolin.
157	159	2	HARD BED: sandstone, calcareous, grey to light grey, fine to coarse, glauconitic and pyritic, with numerous shells. A few granules of quartz, quartzite and granite. Minor clay, light green, grey to dark-grey, and brown.
159	165	6	SANDSTONE: quartz, grey-greenish, coarse to very coarse, moderately to well sorted, feldspathic, very pyritic. Numerous green and yellow-grey stained grains. A few thin beds of shale,

FROM (ft)	TO (ft)	THICK- NESS (ft)	DESCRIPTION
			black, in places hard. A few ferruginous sandy aggregats, brown. Granules and fragments of crystalline rocks, whitish and black@greenish.
165	169	4	HARD BEDS: sandstone, calcareous, grey to light grey, fine to coarse grained, glauconitic, pyritic, with crystalline pebbles and rare shells. Minor brown clay, soft
169	174	5	CLAYSTONE: sandy, green, dark grey, blue-grey and light grey, in places silty, brown and pinkish. Numerous shells. Glauconite fragments . Minor black shale, slightly consolidated. Numerous green, brown and yellow-grey stained grains angular to subangular.
174	178	4	HARD BEDS with PEBBLES HARD BEDS: sandstone, calcareous, grey and dark grey, shelly PEBBLES: white-greenish granite and dark grey-black basic rock
178	190	12	SANDSTONE with minor CLAYSTONE SANDSTONE: grey, yellow-grey and brownish, fine to coarse grained, with granules, moderately sorted, subangular grains. Numerous quartz and feldspar grains, yellow-grey and brown stained. In the fine fraction, numerous pink and red minerals. A few fragments of pebbles. Minor mica and pyrite. Rare chips of ferruginous sandstone, consolidated, brown-reddish CLAYSTONE: grey and brownish
190	203	13	SANDSTONE, SILTSTONE and CLAYSTONE interbedded SANDSTONE: clayey and silty, grey-greenish, fine to coarse, unconsolidated, poorly to moderately

FROM (ft)	TO (ft)	THICK- NESS (ft)	DESCRIPTION
203	216	13	<p>SORTED, with subangular to subrounded grains, feldspathic, carbonaceous and micaceous. At 199-200': hard calcareous bed, grey and brown. Pebbles of quartzite, granite, gneiss and dark grey basic rock. Fish tooth at 190'. Very rare shells. SILTSTONE: grey</p> <p>CLAYSTONE: grey and greenish</p>
216	234	14	<p>CLAYSTONE: in places very sandy, grey-greenish from 214-216 feet.</p> <p>SANDSTONE, SILTSTONE and CLAYSTONE with HARD BEDS</p> <p>SANDSTONE: clayey, grey-greenish, glauconitic fine to very coarse, poorly sorted, feldspathic carbonaceous and pyritic. Fragments of pebbles, white-greenish and dark-greenish. A few pink granite pebbles, Numerous very fine pink minerals SILTSTONE: grey</p> <p>CLAYSTONE: grey, greenish, and brownish, in places black and shaly. White kaolin. HARD BEDS: at 225-228 feet, and 232-234 feet. Sandstone, calcareous, grey, light-grey and brownish, with pebbles and rare shells</p>
234	260	26	<p>SANDSTONE: dark grey to greenish, fine to very coarse, in places conglomeratic, moderately to well sorted, glauconitic. Subrounded to subangular grains. Pink minerals frequent. Numerous fragments of pebbles (pink granite-gneiss, greenish and dark greenish crystalline rock, quartzite). Quartz and feldspar grains often yellow-grey or green stained. Shells very rare. Fine carbonaceous material frequent.</p>

FROM (ft)	TO (ft)	THICK- NESS (ft)	DESCRIPTION
260	270	10	<p>SANDSTONE with HARD BEDS</p> <p>SANDSTONE: grey-greenish, fine to coarse, unconsolidated, well sorted, feldspathic, glauconitic. Subangular to subrounded grains.</p> <p>HARD BEDS: sandstone, calcareous, fine to coarse grained, light grey and brownish, with green minerals. Fragments of pink granite.</p>
270	310	40	<p>SANDSTONE with minor CLAYSTONE</p> <p>SANDSTONE: grey, grey-greenish, and dark grey fine to very coarse grained, unconsolidated, moderately to well sorted, feldspathic. A few thin beds of grey and brown calcareous and non-calcareous sandstone. Numerous pink grains in the fine fraction. Fragments of pebbles, granitic, pink, and greenish to dark grey, lignite and pyrite frequent from 280'.</p> <p>CLAYSTONE: (between 290 and 296 feet): dark grey and black, pyritic and lignitic</p>
310	334	24	<p>CLAYSTONE with minor SANDSTONE</p> <p>CLAYSTONE (310'-324', and 332'-334'): dark grey black and brown, occasionally greenish, very pyritic and lignitic.</p> <p>SANDSTONE: grey and dark grey, coarse to very coarse, unconsolidated, feldspathic, carbonaceous, micaceous. Angular to subangular grains. Hard bed at 327-328 feet, sandstone, partly calcareous, light grey, dark grey and brownish. Few fragments of crystalline pebbles</p>
334	360	26	<p>SANDSTONE: quartz, grey to light grey, coarse to very coarse and conglomeratic, unconsolidated, moderately to well sorted, subangular to subrounded grains, feldspathic and micaceous.</p>

FROM (ft)	TO (ft)	THICK- -NESS (ft)	DESCRIPTION
360	448	88	<p>Numerous white, blue and yellow-grey grains and granules, occasionally with red coating. Pink and red grains frequent in the fine fraction. A few thin layers of calcareous siltstone, light grey. At 348'-350': bed of claystone, black, lignitic.</p> <p>SANDSTONE, CLAYSTONE, SILTSTONE interbedded</p> <p>SANDSTONE: (best sections at 374'-384', 394'-406', 414'-426' and 430'-448'): quartz, grey and dark grey, medium to very coarse and conglomeratic, unconsolidated, moderately to well sorted, feldspathic, grains mostly subangular to subrounded, in places very carbonaceous, micaceous, and slightly pyritic. At 388'-391' hard bed of calcareous sandstone, light-grey and brown, with green minerals. Several granules of pink feldspar. At 410'-415': crystalline pebbles greenish and dark grey.</p> <p>CLAYSTONE: grey, light grey, dark grey and black, occasionally brown and slightly greenish. Abundant carbonaceous material and mica.</p> <p>SILTSTONE: grey and dark grey</p>
448	468	18	<p>CLAYSTONE: silty, light grey, very pyritic, greasy texture. Minor dark grey and whitish clay. A few thin layers of hard calcareous sandstone, light grey and brown. Rare fragments of crystalline pebbles, greenish.</p>
468	504	38	<p>SANDSTONE, CLAYSTONE and HARD BEDS</p> <p>SANDSTONE: clayey and silty, fine to very coarse grained, unconsolidated, poorly to moderately sorted, feldspathic, very carbonaceous, pyritic. Numerous green stained quartz and</p>

FROM (ft)	TO (ft)	THICK- NESS (ft)	DESCRIPTION
			feldspar grains. Pebbles of crystalline rocks, greenish, pink, and dark grey. Rare shells. CLAYSTONE: dark grey, greenish and brown HARD BEDS: at 481-483 feet, and 502-504 feet. Sandstone, calcareous, light grey greenish, shelly at 481-483 feet.
TOTAL	DEPTH:		504 feet

G.S.W.A. MANDURAH No. 5 BORE. Datum: ground surface

FROM (ft)	TO (ft)	THICK- NESS (ft)	DESCRIPTION
0	35	35	SAND: quartz, white (0-10 feet) and brown to light brown (10-35 feet) coarse to very coarse grained, unconsolidated, well sorted, rounded grains, high sphericity.
35	50	15	CLAYSTONE and SILTSTONE CLAYSTONE: dark grey, very sandy, very carbonaceous. SILTSTONE: grey
50	80	30	SANDSTONE: silty, grey and dark grey, unconsolidated, coarse to very coarse, moderately to well sorted, feldspathic and carbonaceous. Subrounded to rounded grains. Increasing amount of green stained quartz grains towards the bottom. Minor brown and light grey siltstone
80	94	14	CLAYSTONE: sandy, green, firm at 87-89 feet, some grey clay, and brown siltstone, in places with dessication cracks (?) Pyrite and glauconite frequent. Minor carbonaceous material. A few fragments of greenish crystalline pebbles.

FROM (ft)	TO (ft)	THICK- NESS (ft)	DESCRIPTION
94	112	18	<p>Numerous green stained quartz grains.</p> <p>SANDSTONE: greenish, medium to very coarse, unconsolidated, well sorted, feldspathic, very glauconitic. Grains subangular to subrounded. Carbonaceous material finely disseminated. A few fragments of crystalline pebbles greenish and dark grey. Rare siltstone, brown and grey and shale, dark grey.</p>
112	135	23	<p>SANDSTONE and HARD BEDS with numerous SHELLS and PEBBLES</p> <p>SANDSTONE: silty, grey-greenish, fine to very coarse, unconsolidated, poorly to moderately sorted, feldspathic, pyritic, glauconitic, carbonaceous. Angular to subangular grains. Some siltstone, brown, slightly consolidated.</p> <p>HARD BEDS: (112'-113', 130'-131', 133'-134'): sandstone, calcareous, grey, shelly and pebbly</p> <p>SHELLS: numerous fragments of pelecypods</p> <p>PEBBLES: white-greenish crystalline rocks, yellowish quartzite, red chert.</p>
135	150	15	<p>CLAYSTONE: silty, grey and light grey, pyritic with greasy texture. Minor siltstone, dark brown, consolidated, and black, shaly. A few thin beds of hard calcareous sandstone with shells and pebbles (quartzite, granite, gneiss)</p>
150	180	30	<p>SANDSTONE and CLAYSTONE</p> <p>SANDSTONE: quartz, silty, grey-brown, and brown medium to coarse grained, moderately sorted, feldspathic, shelly. Numerous brown stained quartz and feldspar grains, angular to subangular. Hard beds at 152-153 feet, 174-175 feet,</p>

FROM (ft)	TO (ft)	THICK- NESS (ft)	DESCRIPTION
180	210	30	<p>and 176-177 feet. Rare sandstone, ferruginous red-brown. A few crystalline pebbles, greenish. In the fine fraction, numerous pink and red minerals.</p> <p>CLAYSTONE: sandy, grey, dark grey, and yellow brown</p>
210	324	114	<p>SANDSTONE and CLAYSTONE</p> <p>SANDSTONE: quartz, silty, grey and grey-greenish fine to very coarse, moderately sorted, with a few shells, especially at 190 feet. Numerous grains of quartz and feldspar grains and yellow-grey stained. Hard calcareous beds at 192-194 feet and 203-204 feet.</p> <p>CLAYSTONE: sandy, grey, dark grey and brownish, occasionally reddish. Minor siltstone, grey and dark grey, and shale, black. Some bluish kaolin</p> <p>SANDSTONE with minor CLAYSTONE</p> <p>SANDSTONE: grey to slightly greenish, medium to very coarse grained, moderately to well sorted, in places conglomeratic, feldspathic, subrounded to subangular grains. Numerous yellow-grey stained grains. Occasionally rich in carbonaceous material and pyrite. A few pebbles, rare shells. Frequent pink and red minerals in the fine fraction. Hard calcareous beds at 213-216 feet, 223-224 feet, 283-284'.</p> <p>CLAYSTONE: (especially between 230-240 feet, and 304-310 feet) black, greasy texture.</p> <p>Minor siltstone, light grey and brown</p>
324	354	30	<p>CLAYSTONE: in places very silty and sandy, black and dark grey, pyritic, carbonaceous and micaeous.</p>

FROM (ft)	TO (ft)	THICK- -NESS (ft)	DESCRIPTION
354	376	22	<p>SANDSTONE: grey, medium to very coarse, in places conglomeratic, moderately to well sorted, subangular grains, feldspathic, carbonaceous and micaceous. A few greenish drystalline pebbles. Frequent pink and red fine grains. At 354-355 feet, hard bed of calcareous sandstone, light grey and brownish, with rare shells.</p>
376	383	7	<p>CLAYSTONE: grey, light grey and dark grey, very pyritic.</p>
383	424	41	<p>SANDSTONE: light grey, medium to very coarse and conglomeratic, well sorted, subrounded to subangular grains, in places very carbonaceous and micaceous. Minor pyrite. Frequent white and bluish quartz grains and granules. A few greenish crystalline pebbles. Thin hard calcareous bed at 410 feet.</p>
424	434	10	<p>CLAYSTONE: grey, light grey and dark grey, pyritic.</p>
434	513	79	<p>SANDSTONE with minor CLAYSTONE</p> <p>SANDSTONE: slightly silty and clayey at the top, grey and grey-greenish, unconsolidated, medium to very coarse, moderately sorted, subrounded to subangular grains, glauconitic, in places with abundant lignitic material. Numerous green stained quartz and feldspar grains, also grey and pink. At 445-448 feet, 477-478 feet and 512-513 feet: hard beds of calcareous sandstone, light grey and brownish with numerous shells at 445-448 feet.</p> <p>CLAYSTONE: silty and sandy, grey and brownish occasionally hard.</p>

FROM (ft)	TO (ft)	THICK- -NESS (ft)	DESCRIPTION
513	546	33	SANDSTONE: quartz, grey-yellow and brownish, medium to very coarse, conglomeratic at the bottom part, very loose, angular to subangular grains, with some well rounded grains. A few rounded pebbles of greenish crystalline rocks, and of granite with grey feldspar and blue quartz. Ilmenite in the fine fraction, with abundant pink and red minerals. A few thin layers of yellow siltstone, hard.
546	556	10	CLAYSTONE: light grey and dark grey, pyritic. Minor yellow, brown, bluish and reddish clay. Some siltstone, bright yellow, and brownish, hard
556	566	10	SANDSTONE: quartz, grey, medium to very coarse moderately sorted, angular to subrounded grains with greenish pebbles. Some kaolinitic clay, blue, reddish, and whitish
566	582	16	CLAYSTONE: light grey and dark grey, pyritic and carbonaceous. Some black shale and hard siltstone, yellow. Thin layers of hard sandstone, partly calcareous, brown and light grey
582	593	11	SANDSTONE with minor CLAYSTONE SANDSTONE: grey and dark grey, medium to coarse unconsolidated, poorly to moderately sorted, subangular grains, very pyritic. CLAYSTONE: black and dark grey. Minor siltstone, yellow
593	652	59	SANDSTONE and CLAYSTONE interbedded SANDSTONE: grey, light grey and yellowish, coarse to very coarse, moderately to well sorted, unconsolidated, feldspathic, subrounded to

FROM (ft)	TO (ft)	THICK- NESS (ft)	DESCRIPTION
			<p>subangular grains. Numerous pink and yellow-grey stained quartz and feldspar grains. Also blue and whitish, milky quartz grains. In places frequent carbonaceous material. Minor pyrite.</p> <p>CLAYSTONE: dark grey, black, in places shaly and consolidated. Minor yellow brown colour. Some siltstone, yellow, slightly consolidated. Abundant lignitic material and pyrite.</p>
652	806	154	<p>SANDSTONE: quartz, light grey, yellow-grey and yellow brown, in places slightly silty, coarse to very coarse and conglomeratic, feldspathic, mostly very well sorted, subrounded grains, fairly high sphericity. Numerous pink and yellow-grey stained grains. At 680-684 feet, and 784-786 feet, beds of claystone, consolidated, chocolate brown, light brown, light grey and dark grey.</p>
806	812	6	<p>CLAYSTONE: bright yellow, olive, chocolate brown, grey to light grey and whitish, minor black and dark grey.</p>
812	837	25	<p>CLAYSTONE: hard, in places shaly, light grey and yellow-olive. Minor grey and dark grey colour. Some white kaolin.</p>
TOTAL DEPTH:			837 feet

B. PRIVATE BORES.

MANDURAH GOLF COURSE BORE

Datum: ground surface

FROM (ft)	TO (ft)	THICK- NESS (ft)	DESCRIPTION
			<u>QUATERNARY</u>
0	30	30	SAND: quartz, light brown, fine to very coarse unconsolidated, well sorted, rounded grains. Some ilmenite in the fine fraction.
30	55	25	SAND with HARD BEDS SAND: quartz, brown and light brown, poorly to moderately sorted, with some ilmenite HARD BEDS: calcareous sandstone and sandy limestone, with granules. Fragments of shells
55	61	6	CLAY: (a) sandy, grey (b) black, micaceous, carbonaceous (c) silty, brown and yellow-brown micaceous.
			<u>LOWER CRETACEOUS</u>
61	110	49	CLAYSTONE: silty, black and dark grey to dark brown, pyritic, carbonaceous, and micaceous. Thin intercalations of sandstone, brown. (salt water).
110	134	24	SANDSTONE: quartz, brown and grey, fine to coarse, in places with pyrite and carbonaceous material (salt water)
134	146	12	CLAYSTONE: silty, dark grey, micaceous, pyritic and carbonaceous
146	152	6	SANDSTONE: silty, brown and grey, fine to coarse
152	196	44	CLAYSTONE: silty, dark grey, pyritic, carbonaceous and micaceous. A few thin layers of brown and grey sandstone
196	285	89	SANDSTONE: quartz, grey and dark grey, fine to very coarse, poorly to moderately sorted.

FROM (ft)	TO (ft)	THICK- NESS (ft)	DESCRIPTION
285	430	145	<p>Minor claystone, dark grey, pyritic, carbonaceous and micaceous.</p> <p>SANDSTONE, CLAYSTONE and SILTSTONE</p> <p>SANDSTONE: quartz, silty, fine to very coarse grey and dark grey.</p> <p>CLAYSTONE: black, dark grey and dark brown, carbonaceous, micaceous, pyritic.</p> <p>SILTSTONE: grey. At 321-327 feet, hard bed of calcareous sandstone.</p>
430	444	14	<p>SANDSTONE: quartz, very silty, grey and dark grey, fine to medium grained, with brown and white quartz granules.</p>
444	459	15	<p>CLAYSTONE: green-black, glauconitic, pyritic, carbonaceous and micaceous.</p>
459	551	92	<p>SANDSTONE, SILTSTONE and CLAYSTONE with HARD BEDS and SHEELS</p> <p>SANDSTONE: quartz, greenish, glauconitic, in places very silty, in places coarse to very coarse, with fragments of pebbles (quartzite and greenish crystalline rock)</p> <p>SILTSTONE: grey and light grey-greenish, glauconitic.</p> <p>CLAYSTONE: light grey to greenish, glauconitic</p> <p>HARD BEDS: sandstone, calcareous, light grey, fine to very coarse</p> <p>SHELLS: numerous fragments of pelecypods</p>
551	552	1	<p>PEBBLES: fragments of quartz, quartzite, granite and greenish crystalline rock, with shells, and some hard calcareous sandstone</p>
552	617	65	<p>SANDSTONE with minor CLAYSTONE and SILTSTONE</p> <p>SANDSTONE: quartz, grey-greenish, coarse to very coarse, in places conglomeratic between</p>

FROM (ft)	TO (ft)	THICK- -NESS (ft)	DESCRIPTION
			590-617 feet, glauconitic, pyritic, carbonaceous and micaceous. A few shells. Occasionally numerous quartz and feldspar grains with yellow grey and brown coating.
			CLAYSTONE: grey to light grey and greenish, glauconitic, pyritic. Minor dark grey clay.
			SILTSTONE: grey and light grey-greenish.
617	630	13	CLAYSTONE: silty, dark grey, grey and light grey, pyritic, micaceous, and carbonaceous.
630	660	30	SANDSTONE: quartz, silty and clayey, grey to slightly greenish, fine to medium grained, slightly glauconitic.
660	700	40	SANDSTONE: quartz, grey, coarse to very coarse in places conglomeratic. Angular to subangular grains. Minor claystone, grey and slightly greenish.
TOTAL DEPTH:			700 feet

HILL'S BORE, MURRAY RIVER.

Landowner's log.

Datum: ground surface

FROM (ft)	TO (ft)	THICK- -NESS (ft)	DESCRIPTION
0	8	8	SAND (good water)
8	14	6	Blue CLAY
14	48	34	SAND (salt water)
48	57	9	CLAY
57	102	45	SAND (very salt water)
102	110	8	CLAY
110	170	60	SAND (salt water)
170	179	9	CLAY, green
			Total Depth: 179 feet.

Remark: A sample of clay from 170-179 had been retained by the landowner. It is a green, silty and sandy, glauconitic clay, pyritic. Palaeontological examination shows that it correlates with stratas of Aptian age at 240 feet in Mandurah No. 3 Bore, and 450 feet approximately in Mandurah No. 1 Bore. This green clay horizon in Hill's Bore is therefore considered to be equivalent to the glauconitic clay marker in the other Mandurah Bores.

ANDERSON'S BORE, NORTH DANDALUP. Driller's log.

Datum: ground surface

FROM (ft)	TO (ft)	THICK- -NESS (ft)	DESCRIPTION
0	9	9	White SAND (water level at 1'-6")
9	17	8	Yellow sandy CLAY with stones
17	28	11	Yellow and grey CLAY, very sandy
28	32	4	White SAND
32	41	9	Dark grey sandy SHALE
41	53	12	Yellow-grey sandy CLAY
53	58	5	Greenish clay cemented SANDSTONE, firm
58	63	5	Greenish hard granite BOULDER
63	78	15	Black SHALE, micaceous and pyritic
78	82	4	Hard granite BOULDER
82	97	15	Black SHALE, micaceous and pyritic
97	119	22	Greenish brown sandy SHALE
119	124	5	Granite BOULDER
124	135	11	Greenish brown sandy SHALE
135	139	4	Granite BOULDER
139	166	27	Greenish brown sandy SHALE, interbedded with hard dark shale bands

FROM (ft)	TO (ft)	THICK- NESS (ft)	DESCRIPTION
166	171	5	Dark SHALE
171	185	14	Sandy grey SHALE, cemented SANDSTONE
185	187	2	Lightly grey SHALE cemented soft SANDSTONE, medium to fine grained
187	188	1	Coarse green GRAVEL, igneous origin
188	189	1	Very hard granite BOULDER
			TOTAL DEPTH: 189 feet.
			<u>Remark:</u> Correlation between Giles Bore and Mandurah No. 5 Bore indicate that in Ander- son's Bore, the green, glauconitic clay marker is part of the section 97-119 feet.

RUNCIMAN'S BORE, NORTH DANDALUP

From 0-120 feet: driller's log (no sample available)

From 120-240 feet: description of samples collected and stored by the Geological Survey.

Datum: ground surface.

FROM (ft)	TO (ft)	THICK- NESS (ft)	DESCRIPTION
0	15	15	GRAVEL and PEBBLES
15	30	15	CLAY, yellow and brown
30	54	24	CLAY, dark grey
54	120	66	PEBBLES and BOULDERS (quartzite and granite) b with minor CLAY and SAND intercalations. Consolidated formation
120	152	32	PEBBLES and BOULDERS, with CALCAREOUS SAND- STONE, and CLAY PEBBLES and BOULDERS: rounded fragments of dolerite (often weathered to a greenish,

FROM (ft)	TO (ft)	THICK- NESS (ft)	DESCRIPTION
			<p>clayey material), granite, gneiss, micaschist quartzite.</p> <p>CALCAREOUS SANDSTONE: quartz, grey to light grey coarse to very coarse, poorly sorted, very hard, containing carbonaceous material. Angular grains. Rounded pebbles of igneous rock often cemented in the calcareous sandstone.</p> <p>CLAY: grey, dark grey, with white kaolin. In places greenish and sandy, glauconitic.</p>
152	155	3	<p>CLAY and SANDSTONE</p> <p>CLAY: slightly silty, black, micaceous and carbonaceous, with big fragments of lignite</p> <p>SANDSTONE: clayey, grey-greenish, medium grained, with a few pebbles and granules of quartzite</p>
155	160	5	<p>PEBBLES and BOULDERS: quartzite, granite, dolerite, micaschist. A few fragments of hard sandstone: (a) calcareous, light grey (b) non-calcareous, dark grey</p>
160	170	10	<p>SANDSTONE: quartz, very clayey, grey-greenish glauconitic, medium to coarse grained, angular grains. Minor claystone, black-brownish, carbonaceous, micaceous.</p>
170	175	5	<p>SANDSTONE: very clayey, grey-greenish, fine to coarse grained, poorly sorted. Rare granules of quartz.</p>
175	180	5	<p>SANDSTONE: quartz, brownish, coarse to very coarse, poorly to moderately sorted, with a few granules and pebbles. Rare silt, yellow. Rare clay, sandy, dark grey</p>

FROM (ft)	TO (ft)	THICK- NESS (ft)	DESCRIPTION
180	184	4	SANDSTONE: quartz, grey-brownish, coarse to very coarse, poorly to moderately sorted, with numerous pebbles and granules of granite and quartzite. Rare lumps of grey clay.
184	189	5	SANDSTONE: quartz, grey-greenish, coarse to very coarse, with numerous pebbles (granite, gneiss, micaschist, dolerite, quartzite). Rare siltstone, yellow-brown.
189	229	40	SANDSTONE: quartz, brownish, unconsolidated, coarse to very coarse, moderately sorted. Subangular grains. A few granules of quartz and quartzite. Rare clay, grey and brown.
229	238	9	SANDSTONE: slightly clayey, grey-greenish, coarse to very coarse, poorly to moderately sorted. Subangular grains. Numerous granules of granite and quartzite.
238	240	2	CLAYSTONE: black, in places brownish and greenish, micaceous and carbonaceous. A few quartz grains and granules TOTAL DEPTH: 240 feet. <u>Remark:</u> The green glauconitic clay marker, although not specifically mentioned in the driller's log, is considered to be present at about 98-109 feet (lithological correlations between Giles Bore and Mandurah No. 5 Bore). Calcareous beds are present immediately below 120 feet, and the clayey sample at 152 feet correlates, palaeontologically, with the stratas at about 450 feet in Mandurah No. 1 (Aptian age).

GILES BORE, NORTH DANDALUP Driller's log

Datum: ground surface

FROM (ft)	TO (ft)	THICK- NESS (ft)	DESCRIPTION
0	2	2	SAND
2	12	10	Ironstone conglomerate
12	34	22	Firmly packed CLAY with water
34	52	18	CONGLOMERATE and CLAY with water
52	53	1	Granite BOULDER
53	58	5	SILT with SAND, water
58	72	14	10" of water SAND with small BOULDERS (2-3000 gall/hour)
72	78	6	Sticky dark grey SHALE with BOULDERS
78	80	2	Solid granite, probably BOULDER
80	84	4	Break through granite
84	87	3	Dark grey CLAY
87	94	7	Dark grey CLAY with small BOULDERS
94	105	11	Dark grey SHALE with small BOULDERS and pieces of wood
105	107	2	Dark grey SHALE with greenish tinge
107	116	9	Dark grey SHALE with greenish tinge, more SAND and water
116	120	4	Greenish sandy SHALE
120	129	9	Broke through large boulder
129	142	13	Dark grey fine grained SHALE
142	148	6	Dark grey SHALE, hard.
148	152	4	Gritty SHALE, some water
152	157	5	Diorite and granite BOULDER
157	165	8	Hard SHALE
165	172	7	Hard SHALE with small BOULDERS
172	190	18	Sticky dark grey SHALE with small BOULDERS and some coal dust
190	198	8	Sandy SHALE (soft) with water

FROM (ft)	TO (ft)	THICK- NESS (ft)	DESCRIPTION
198	200	2	Coarse SAND with small BOULDERS, water
200	202	2	Small stones and BOULDERS, water
202	210	8	Sandy SHALE, firm
210	226	16	Sandy SHALE, firm, darker in colour
226	230	4	Sticky soft SHALE, very dark
			TOTAL DEPTH: 230 feet.
			<u>Remark:</u> The lithology indicates that in this Bore, the green glauconitic clay marker is at 105-116 feet. Some of the "hard Shale" beds described below the green clay are quite probably hard beds of calcareous sandstone, as in Runciman's Bore.

APPENDIX 3

WATER ANALYSES BY GOVERNMENT CHEMICAL LABORATORIES

(A) G.S.W.A. MANDURAH No. 1 TO No. 5 BORES

	Mandurah No. 1	Mandurah No. 2			Mandurah No. 3		Mandurah No. 4			Mandurah No. 5			
	442-631	89-130	220-260	340-360	37-54	253-684	270-290	336-341	440-445	94-113	354-376	383-441	684-714
Water table section tested (depth in feet)													
Specific Conductivity 20°C (micromhos)	-	22,600	37,600	3,470	19,000	3,280	1,250	1,700	2,460	2,180	1,330	1,430	2,490
	7.7	7.6	7.2	8.9	7.0	7.7	7.7	7.9	7.5	7.7	7.9	7.9	7.6
Temperature (°C)	23			23		22	23	23	24	22	24		
General Matter (p.p.m.)													
Calcium, Ca	58	800	568	88	255	105	89	54	103	76	87	71	31
Magnesium, Mg	25	620	1,150	42	527	28	18	15	26	36	11	11	17
Sodium, Na	671	44,840	9,400	670	4,240	647	141	301	416	379	172	249	548
Potassium, K	25	98	310	39	136	30	17	23	22	8	17	15	23
Chloride, Cl	992	9,490	17,170	1,220	7,500	1,040	301	449	728	650	258	281	736
Sulfate, SO ₄	86	1,530	2,470	120	1,430	102	24	57	67	69	53	173	107
Carbonate, HCO ₃	305	244	226	46	162	305	214	229	244	223	293	253	268
Carbonate, CO ₃	Nil	nil	nil	7	nil	nil	nil	nil	nil	nil	nil	nil	nil
Nitrate, NO ₃	less than 1												
Silicate, SiO ₂	22												
Iron, Fe	0.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	<0.1	0.2	0.2
Aluminum, Al	1												

analyzed by hand

<u>Total</u>													
By summation	2,185	16,000	26,200	2,460									
By evaporation	2,040	17,700	32,500	2,350	14,300	2,200	700	1,010	1,490	1,350	780	940	1,540
By conductivity					13,300		880	1,190	1,720	1,530	930	1,000	1,740
Hardness (calculated as CaCO ₃)													
Total hardness	248	4,550	6,150	393	2,807	376	296	197	364	338	262	222	147
Bicarbonate (temporary hardness)	248	200	185	49	133	250	176	188	200	183	240	207	147
Non-carbonate (permanent hardness)	nil	4,350	5,965	344	2,674	126	120	9	164	155	22	15	nil
Calcium hardness	145	2,000	1,420	220	637	262	222	135	257	190	217	177	77
Magnesium hardness	103	2,550	4,730	173	2,170	114	74	62	107	148	45	45	70

<u>Total</u>				
By evaporation	2,010	630	1,010	920
By conductivity	2,280	710	955	1,050
Hardness (calculated as CaCO ₃) Total hardness	189	203	224	175
Bicarbonate (temporary) hardness	189	203	102	10
Non-carbonate (permanent) hardness	-	-	122	165
Calcium hardness	107	125	43	35
Magnesium hardness	82	78	181	140

(B) PRIVATE BORES

	Mandurah Golf Course Bore	Anderson's Bore	Runciman's Bore	Giles' Bore
Aquifer section tested (depth in feet)	495-700	183-189	170-238	190-210
Specific conductivity (20°C (micromhos)	3,260	1,010	1,360	1,480
pH	7.5	7.1	6.4	6.5
Temperature (°C)	23	20	19	20.5
<u>Mineral Matter (p.p.m.)</u>				
Calcium, Ca	43	50	17	14
Magnesium, Mg	20	19	43	34
Sodium, Na	718	154	283	251
Potassium, K	23	7	8	9
Chloride, Cl	1,030	217	495	488
Sulphate, SO ₄	92	18	46	33
Bicarbonate, HCO ₃	281	271	124	12
Carbonate, CO ₃	nil	nil	nil	nil
Iron, Fe	< 0.1	< 0.1	3.3	0.1