

DEPARTMENT OF MINES
SOUTH AUSTRALIA

GEOLOGICAL SURVEY
ENGINEERING DIVISION

UNDERGROUND WATER RESOURCES OF SOUTH AUSTRALIA

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UNDERGROUND WATER RESOURCES OF SOUTH AUSTRALIA

INTRODUCTION

In 1968 an assessment of the underground water resources of Australia was requested by the Technical Committee on Underground Water of the Australian Water Resources Council. As part of this assessment the Department of Mines provided all available information and estimates of underground water resources in South Australia for inclusion in the report*.

The South Australian contribution, with some additions, is presented in this report. Four maps, at a scale of 1:5 000 000, are presented, together with a number of plans and sections. The maps cover groundwater resources in the following environments : Unconsolidated Sediments (Map 1); Sedimentary Basins (Map 2) and Fractured Rocks (Map 3). Map 4 shows the distribution of best available water. The maps and these notes should only be used as a general guide, particularly for the fractured rocks, because of local variations in salinity resulting from differing geology, topography and groundwater recharge. Advice should be sought from the Department of Mines on any particular area.

*From this point the term "underground water" is shortened to "groundwater". It refers to all water contained in the saturated zone and does not include soil moisture.

HISTORY OF GROUNDWATER DEVELOPMENT IN SOUTH AUSTRALIA

Shallow groundwater was developed by Aborigines long before the advent of Europeans, mainly by digging in the alluvium of stream beds to tap underflow, and also in areas of shallow unconfined aquifers, where there are no streams but where the presence of water is indicated by vegetation.

The first use of groundwater by white man in this State is believed to have been in the Adelaide area, and very probably within a short time of the founding of the State. At that time the main supplies were obtained from the River Torrens but as the population increased it was necessary to obtain supplementary supplies, particularly during the hot dry summers.

Originally shallow wells were dug in the vicinity of the various streams to tap underflow. These generally yielded only small supplies and salinity varied considerably, rising in the western part of the Adelaide Plains to 3,000 milligrams per litre (mg/l) and to more than 15,000 mg/l in the estuarine plains adjacent to the coast. As settlement proceeded in other parts of the State it was found that shallow groundwater was often highly saline, particularly in areas of low rainfall. An exception to this is in the southeast of the State where rainfall is relatively high and shallow groundwater over much of the area is suitable for most general purposes.



Hand drilling plant used for test wells, hundred of Perlubie, near Wirrulla, 1912.

Photo: R. Lockhart Jack
Neg. 562



Cable tool drilling plant, operated by steam engine (background) about 1912.

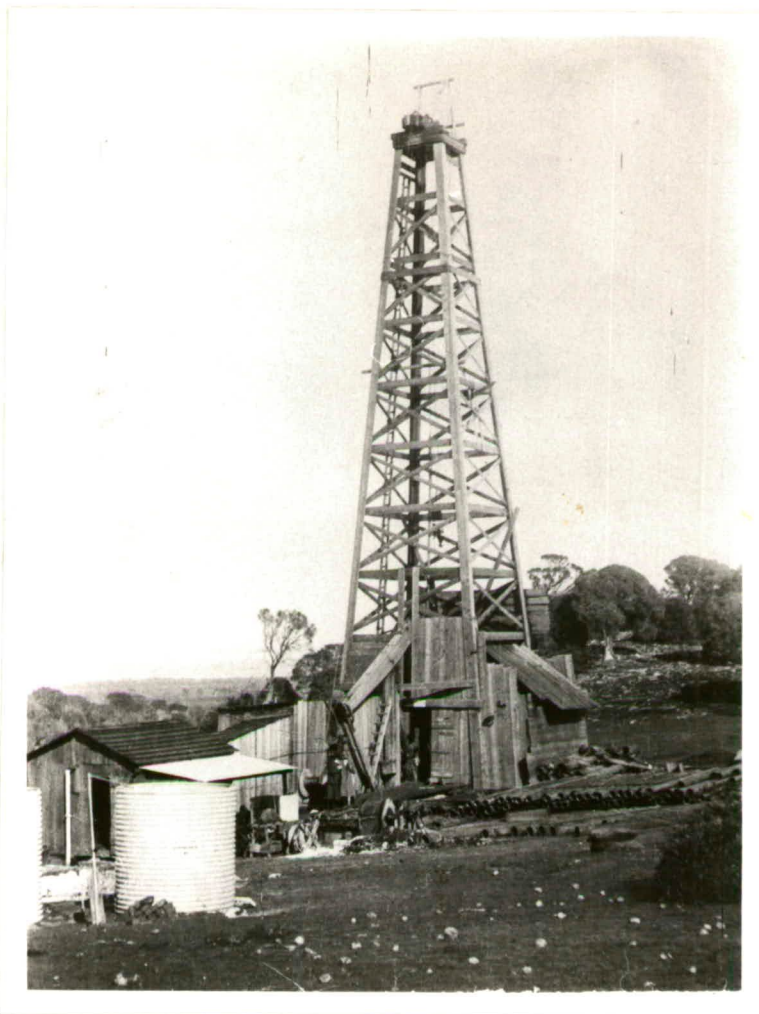
Photo: R. Lockhart Jack
Neg. 4612

In the lower rainfall areas some wells were sunk to deeper aquifers in the search for better quality groundwater. For example, in the Adelaide Plains it was found that good quality water occurred in sand or limestone at a depth of 100-150 metres (m). Gradually, the extent of good quality groundwater became more defined in the Adelaide Plains and elsewhere and is now relatively well known.

Exploration of the Great Artesian Basin in South Australia commenced in 1881 with the drilling of a successful flowing well near mound springs at Anna Creek. Several years prior to this the existence of natural mound springs had been observed giving indications of artesian aquifers occurring in the area.

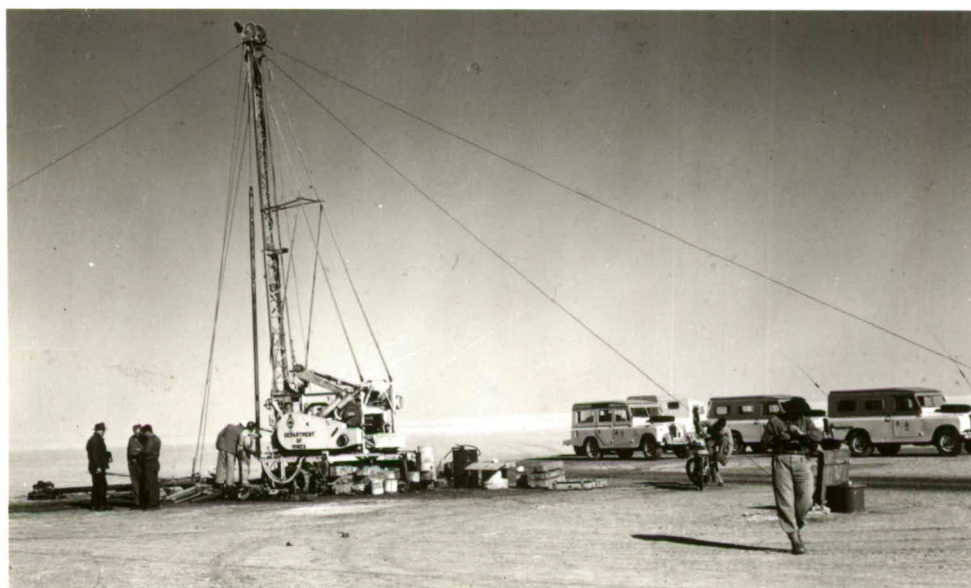
Exploration for groundwater in the Murray Basin commenced with the drilling of a deep well at Coonalpyn in 1886. This proved the existence of salt water but a well at Ki Ki in the following year yielded good quality pressure water. This led to drilling over a wide area of the Murray Basin, and this continued as development of the area proceeded.

In the Eucla Basin several wells were drilled before 1900 but because of the high salinity groundwater which was encountered, few deep wells have been drilled for stock water supplies since that time. However, a number of test wells were drilled in addition to wells for railway purposes along the Transcontinental Railway.



Californian drilling plant on Walkwine Dune near Robe,
1916. Final depth 1 369 metres. Height of Derrick
24 metres.

Photo: South Australian Oil Wells Co.
Neg. 28775



Ruston Bucyrus cable tool drilling plant, Lake Torrens,
1962.

Photo: R.R. Hancock
Neg: 12471

Development of the smaller basins proceeded gradually but there were often stages of intensive development, e.g. in the Adelaide Plains in 1915 and 1945. Such development followed or occurred during years of drought when water was required to augment mains supply. A large volume of groundwater is now withdrawn from the southern part of the St. Vincent Basin including the Adelaide Plains sub-Basin and Willunga Embayment. The quantity pumped is estimated to be 30×10^6 Kilolitres (kl) per year, used for irrigation and industrial purposes. Increasing quantities are being withdrawn from other basins for irrigation, industrial and town supply purposes (Fig. 6). Among these is the Padthaway area in the southeast of the State, where total withdrawal is now estimated to be 36×10^6 kl per year for irrigation.

Many towns rely entirely on groundwater, particularly in the South Australian portions of the Murray and Otway Basins (Fig. 6). Groundwater contributes significantly to the total water used; for example, on Eyre Peninsula an average of 50% of the water consumed is from groundwater sources and this average is maintained for the whole State.

Total quantity of groundwater withdrawn for all purposes is now estimated to be approximately 355×10^6 kl per year. The number of pumping or flowing wells throughout the State is now estimated to be approximately 150,000. There are records in the Department of about 80,000 wells, but it is known that there are many which are not recorded. Since introduction of the Water Resources Act on 1st July 1976, covering the whole State, details of all wells drilled to a depth of 2.5 metres or more are supplied to the Department of Mines. Field surveys are in progress to locate wells drilled before the Act came into force.

ESTIMATED GROUNDWATER STORAGE, RECHARGE AND EXTRACTION

As part of a review of water resources of Australia estimates were made of recharge, the volumes of groundwater in storage and the rate of extraction. Because of a lack of data the figures derived for South Australia are necessarily approximate. The only area where the extraction rate is known is the Northern Adelaide Plains, part of the St. Vincent Basin, where meters were installed in 1970.

Table I shows estimates for the various groundwater basins and the fractured rocks of the State.

PHYSICAL FEATURES

Physiography

South Australia is generally flat to gently undulating with most of the land surface lying at less than 100 m above mean sea level. There are a number of extensive plains in which there is very little variation in relief : the more important of these are the Great Artesian Basin, the Nullarbor Plain and the Murray Mallee. In these areas the only significant relief to an otherwise monotonous plain is provided by sand dunes, in places rising to 30 m or more above plain level. These dunes are roughly parallel and trend generally in a northwesterly direction.

The drainage divisions and basins of the State are shown in Fig. 2.

8.

TABLE 1

ESTIMATES OF STORAGE, ANNUAL RECHARGE AND EXTRACTION

BASIN	AREA OF AQUIFER(S) (km ²)	STORAGE (kl x 10 ⁶)	RECHARGE (kl x 10 ⁶ /year)	EXTRACTION (kl x 10 ⁶ /year)	REMARKS
OTWAY (GAMBIER EMBAYMENT)	7 000	260 000	500	150	All normal water supplies in the area are obtained from groundwater.
MURRAY (S.A. PORTION)	75 000	1 900 000	400	70	Includes Angas-Bremer area where extraction estimated to be 20 x 10 ⁶ kl/year. Also Padthaway where gross extraction is estimated to be 36 x 10 ⁶ kl/year, but 12 x 10 ⁶ kl/year returns to the aquifer from flood irrigation.
G.A.B. (S.A. PORTION)	310 000	12 000 000	0.1	77	Extraction is estimated total discharge from approximately 150 flowing wells; probably less than 1% used. Average discharge per well is 1 400 kl/day. Natural discharge from mound springs is estimated to be 30 x 10 ⁶ kl/year.
ST. VINCENT	4 000	70 000	16	30	Volume of water less than 1 000 mg/l in storage estimated to be 30 000 x 10 ⁶ kl in Adelaide Plains, Noarlunga and Willunga Sub-basins.

PIRIE-TORRENS	10 000	200 000	8	4.0	Extraction for stock supplies; with irrigation restricted to the Nelshaby-Napperby area.
ULEY AND LINCOLN	300	230 000	6	4.0	Town water supplies.
POLDA, ROBINSON AND KAPPAWANTA	450	23 000	8	0.4	Town water and stock supplies.
WILLOCHRA AND WALLOWAY	1 700	15 000	0.6	0.3	Mainly stock supplies; irrigation in southern part of Willochra Basin.
EUCLA (S.A. PORTION)	42 500	1 100 000	0.005	0.0005	Stock supplies only.
OFFICER (S.A. PORTION)	80 000	1 200 000	0.007	0.0001	Stock and minor domestic supplies. For estimation purposes considered to include alluvial aquifers south of Musgrave ranges.
FRACTURED ROCKS (FLINDERS-MT. LOFTY RANGES)	150 000	3 000 000	58	20	Includes Myponga, Hindmarsh Tiers and Barossa Valley Tertiary Basins, Permian sediments of Fleurieu Peninsula; Yorke Peninsula and Kangaroo Island.
TOTALS	670 000	20 000 000	1 000	355	Total number of wells estimated to be 150 000. Storage estimates include fresh and saline groundwater and are based on an average porosity of 25%.

There are no really significant mountain ranges in South Australia; areas of high ground include the Mt. Lofty-Flinders Ranges and the Musgrave Ranges. Within these ranges elevations generally exceed 500 m above sea level rising to a maximum of 1,440 m at Mt. Woodroffe in the Musgrave Ranges. The ranges have an important orographic effect. With the prevailing westerly winds areas of relatively high rainfall occur along the ranges in the southern part of the State. The Musgrave Ranges, because they are located in an arid area have only a minor influence on the rainfall pattern.

Climate

Climate is arid in the northwestern part of the State (Great Victoria Desert) and in the northeast (Simpson Desert), but is wetter and cooler and more typically Mediterranean in the southern and south eastern regions.

Average rainfall in the arid areas is generally not more than 150 mm per year but the term "average" has little meaning in these areas. Rainfall in many years may be almost zero and conversely it may be 750 mm or more during some years, e.g. 1973 and 1974.

Because of the general weather pattern affecting South Australia rainfall over most of the State is low - more than 80% receiving less than 250 mm per year (Fig. 1). In addition evaporation greatly exceeds rainfall over the most of the State, rising to about 3,000 mm per year in the north. As a result surface water supplies are often inadequate in normal years and need to be supplemented by River Murray water and groundwater.

THE HYDROLOGIC CYCLE

There is a continuous movement of water from the ocean, or other exposed bodies of water, to the atmosphere from where it returns to the land and eventually the sea. This is known as the hydrologic cycle and during the various phases water may be either in vapour, liquid or solid form (Fig. 3). The cycle may take a very long period to complete depending on the path taken. Rainfall may result in direct run-off to the sea in which case the cycle is short, but that part of surface water which becomes groundwater may take many thousands of years to reach the sea.

Water evaporated from the oceans is carried over the land masses by winds. Mountain ranges cause the air masses to rise which results in condensation of the water vapour, which finally falls as rain, hail or snow. Part of this precipitation is evaporated before reaching the ground. The remainder may be intercepted by plants where it evaporates or it may reach the ground surface. In this case it will follow four paths but the proportions in each will vary considerably from place to place. The four paths are Evaporation, Run-off, Transpiration and Groundwater Re-charge. Evaporation occurs from water intercepted by plants or from the ground surface and from the run off portion of the cycle. Depending on soil or rock type it may also be effective to a depth of 1-2 metres.

Part of the water reaching the ground will enter the soil zone but much of this may be transpired by plants and returned to the atmosphere. A proportion of water (generally quite small) entering the soil may penetrate below the root zone and beyond the influence of evaporation to become groundwater. This proportion will vary widely depending on such factors as vegetative cover and permeability of sediments in the unsaturated zone above the water table.

HYDROGEOLOGY

Groundwater Occurrence

Groundwater constitutes only about 0.6% of the total volume of water in the hydrosphere, but this is considerably greater than terrestrial surface waters (0.017%). These figures indicate the potential importance of groundwater but salinity and availability are two of the more important factors governing the use of groundwater.

The proportions of water in the hydrosphere are given in the following table:-

Oceans	97.2%
Icecaps and Glaciers	2.15%
Groundwater	0.62%
Surface Water	0.017%
Atmosphere	0.001%

Groundwater may occur in many different rock types ranging from unconsolidated materials such as sand or gravel to dense fractured rocks such as quartzite. In these notes groundwater is considered to occur in three main groups : Unconsolidated sediments; Sedimentary rocks; and

Fractured Rocks. There is, however, some overlap in this rather broad definition, particularly with regard to the sedimentary rocks of the basin areas. Many of these may be regarded as unconsolidated sediments while other rock types in this group may exhibit some characteristics of the fractured rocks. On an age basis the unconsolidated sediments are regarded generally as Pleistocene-Recent in age, the sedimentary rocks as Mesozoic to Tertiary and the fractured rocks as Precambrian to Lower Palaeozoic.

Groundwater may be stored in various ways including : intergranular space, solution cavities and fractures or joints. There are, in addition, two broad divisions - unconfined and confined aquifers. In the former the water is under atmospheric pressure and does not rise when intersected in a well. Many aquifers within unconsolidated sediments fall into this division.

In confined aquifers the water is under pressure and rises above the depth at which it is intersected, in some cases rising to the surface as a flowing well. Well known examples of the latter are the flowing wells of the Great Artesian Basin. In this division the aquifer is overlain by a confining bed of very low permeability, which, however, is often sufficient to result in significant upward leakage from the confined or pressure aquifer, particularly if a large area is involved.

The porosity, or void space, of aquifers varies over a wide range - from less than 1% for dense crystalline rocks such as granite to more than 30% for certain sandstones and limestones. However, porosity is not the factor which determines the availability of water in a rock. For example, clay may have a porosity of up to 55% but its water yielding properties are very low. On the other hand the porosity of a poorly sorted sand and gravel aquifer may be 20% or less, yet this material when suitably developed may yield large supplies.

The factor which is important is permeability which determines the rate at which water is transmitted through the aquifer. Coarse sand or gravel yields water readily and therefore is highly permeable whereas clay yields water only very slowly and has a very low permeability.

There are three main types of groundwater - Magmatic, Connate and Meteoric. Magmatic, which is only of academic interest in Australia, is water derived from magma or molten rock. Connate water is water of deposition of the sediments. Such water is usually highly saline because in many cases it was originally sea water. In addition soluble material has been dissolved from the sediments because of the very long periods of contact with the water. Saline groundwater occurring in Tertiary sediments of the north-western part of the Murray Basin in South Australia is believed to be connate.

Meteoric groundwater (derived from rain) is the most common form. Water contained in practically all unconfined and confined aquifers is of this type. However, some of this water is very old and is then regarded as "fossil".

A glossary of the more common terms used in groundwater is given in Appendix I.

The South Australian Situation

There are a number of groundwater basins in South Australia which are significant, not necessarily because of their size, but because they are highly productive of good quality water (Fig. 5). Included in these are parts of the Murray and Otway Basins, the St. Vincent Basin, and small basins on Eyre Peninsula. The Great Artesian Basin is of considerable importance in providing stock water supplies in the arid northeastern part of the State in an area where surface water is available for only short periods following the infrequent but often heavy rain.

Unconsolidated sediments are important sources of groundwater particularly where there is rapid recharge in areas of high rainfall or rapid run-off from impervious basement rocks. Included in this group are shallow sand or gravel beds and aeolianite aquifers, the latter including the Lincoln and other fresh water basins of Eyre Peninsula.

The sedimentary basins fall into two main groups according to the various types of deposits. These include:-

(1) Non-marine (fluvial or lacustrine). In this group are included the following basins : Cummins, Cowell, Pirie-Torrens, Walloway, Willochra and Barossa.

(2) Alternating marine and non-marine, usually with paralic conditions occurring in the early Tertiary. Basins in this group are : Eucla, Great Artesian, Murray, Officer, Otway and St. Vincent.

Marine sediments now form very important aquifers in major basins such as the Murray Basin.

Groundwater in fractured rock is generally less well known than in the basin areas but it is extensively developed for irrigation in parts of the Adelaide Hills and for stock supplies in other areas where these rocks occur.

Origin of salts in groundwater

Groundwater contains essentially seven ions - those of Sodium, Potassium, Calcium, Magnesium and Chloride, Sulphate and Bicarbonate. Total salinity may range from less than 100 mg/l to very saline water (probably connate) exceeding 300,000 mg/l.

There are several sources of dissolved solids, as follows:-

Rain - sampling of rainwater in southern Australia has shown that it contains significant chloride at distances of up to 50 km from the coast. Beyond that distance chloride and sodium decrease markedly.

Weathering - the breakdown of the mineral constituents of rocks during weathering processes produce soluble salts which are carried by the groundwater.

Aquifer - the aquifer may include connate salts remaining from deposition in a marine environment and such salts would be re-dissolved by meteoric groundwater.

Evapotranspiration - processes of evaporation and transpiration are not the cause of salt in groundwater. However, they are considered here because they result in increased concentrations of salt. It has been shown that even in an area of high rainfall salinity of recharge water increases four times in its passage to the groundwater. In arid regions the salinity increase may be much greater.

GROUNDWATER RESOURCES OF SHALLOW UNCONSOLIDATED SEDIMENTS (MAP 1)

Shallow unconsolidated sediments are widespread and consist generally of two distinctive types. The first is alluvial in origin and consists of gravel, sand, silt and clay and secondly there are deposits of aeolian or wind blown origin, consisting mainly of sand or aeolianite.

Alluvial aquifers show a number of contrasts with dune and aeolianite type aquifers and as a result there are considerable contrasts in salinity patterns. Generally, alluvial aquifers have relatively rapid facies variations both horizontally and vertically. In addition, few of these aquifers receive direct recharge from runoff except those favourably situated close to streams. As a result there may be wide variations in salinity of these aquifers especially if a part of them is located where runoff is large and infiltration rate is high. On the other hand aeolianite aquifers generally have a relatively uniform salinity over large areas, because they receive direct recharge from rain.

Shallow unconsolidated aquifers are important sources of groundwater in South Australia - total extraction for all purposes is estimated to be approximately 40×10^6 kl per year; about 10% of this is pumped into water mains for domestic use, the remainder is used for irrigation and stock purposes.

ALLUVIAL AQUIFERS

Alluvial deposits range in composition from boulders, gravels and sands to clays and silts. These deposits are well developed adjacent to and within the ranges, occurring as valley fill, outwash fan or flood plain deposits.

Aquifers in the form of sand or gravel beds occur within alluvial deposits. In plan, the shape of these aquifers varies widely, particularly in the valley fill type where the ratio of length to width may exceed 20 to 1. In flood plain deposits this ratio is generally closer to 1 to 1. Thickness of these aquifers also shows marked variations and they are commonly lenticular in shape. Facies changes occur commonly in this type of deposit.

In dry areas of the State, notably in the northern Flinders and Musgrave Ranges these aquifers are important sources of groundwater. In some areas of impervious basement, such as in the Gawler Ranges, they are the only source of groundwater.

Following the often heavy but infrequent rain in the far north, runoff may occur in considerable volume for a short period. Infiltration adjacent to the ranges occurs relatively rapidly and as a result salinity of the groundwater is low and often suitable for human consumption, even in very arid areas. These aquifers store a proportion

of the runoff which would otherwise be lost by evaporation.

Shallow aquifers are extensively developed for stock water supplies, particularly adjacent to the main ranges of the north and northwest.

In several areas alluvial aquifers are developed for irrigation purposes; for example Booborowie Valley, Padthaway and the southern part of the St. Vincent Basin (Adelaide Plains Sub-Basin). In the latter where there is extensive development of groundwater, total withdrawal from shallow aquifers is 2.0×10^6 kl per year. Wells entering shallow aquifers total approximately 600 but only 150-200 are used for irrigation.

Groundwater occurring in a rubbly limestone aquifer at Padthaway is of low salinity and yields are high. Over an area of approximately 180 square kilometres the gross extraction of groundwater for irrigation purposes is estimated at 36×10^6 kl per year. This is greater than the estimated safe yield of the basin and it has been recommended that water use be restricted to 95% of the gross water use in a year of average rainfall. Because the aquifer occurs at shallow depth a proportion of the groundwater used for irrigation returns to the aquifer. It has been estimated that the volume involved is 12×10^6 kl/year. However, this causes an increase in salinity and it has been estimated that the average annual increase in salt content is 10 mg/l in the present situation. Under the recommended restrictions the rate of salinity increase would be less and should remain satisfactory for many years.

The characteristics of shallow aquifers vary over wide ranges, as would be expected for flood plain or river deposits. Transmissivity ranges from 46.5 to 8,020 m³/day/m and permeability ranges from 3.95 m/day to 1,395 m/day; the higher value of transmissivity is exceptional as it is about 5 times greater than the next highest value.

BOOBOROWIE VALLEY

The hydrogeology of the Booborowie Valley (Fig. 5, 6) is presented as a typical example of alluvial aquifers within the ranges. The valley is of low relief and bounded on either side by low to moderately hilly terrain. It is infilled with approximately 30 m of poorly sorted piedmont gravels, silts and clays. The underlying Adelaidean rocks consist of slate, siltstone, tillite, sandstone and quartzite with a steep westerly dip. The hydrogeology of the valley is summarised in Table II.

The water table declined rapidly during the early part of this century and was apparently related to changes in land use. The relatively recent establishment of irrigation probably contributes to the decline to a small extent.

AEOLIANITE AND DUNE AQUIFERS

Aeolianite or wind blown sand, generally calcareous, occurs over wide areas of Eyre Peninsula, on Yorke Peninsula, Kangaroo Island and in the Southeast (Fig. 4). It consists essentially of sand and calcareous shell fragments, usually capped by a dense limestone (calcrete). Sand dunes and sand sheets occur on the extensive inland plains but this sand is almost entirely composed of quartz grains often coated with iron oxide.

TABLE II

BOOBOROWIE VALLEY - SUMMARY OF HYDROGEOLOGY

AGE	UNIT, LITHOLOGY	MAXIMUM THICKNESS	HYDROGEOLOGY
QUATERNARY RECENT	Unnamed. Undifferentiated clays, silts, sands and gravels with a gravel basal unit characteristic. Poorly sorted.	30 m	Water table aquifer, depth to water ranging from 6-9 m on flat increasing to over 15 m on valley slopes. Salinity range 880-3 400 mg/l increasing towards the south which is the direction of groundwater movement. Water used for stock purposes and limited irrigation.
TERTIARY	Unnamed. Minor outcrop of Tertiary sands and grits.		Insignificant.
UPPER PROTEROZOIC ADELAIDEAN	<u>Burra Group/Umberatana Group:</u> Dominantly grey to black laminated shales, and siltstones, calcareous in part with interbedded quartzites, arkoses and dolomites. Minor tillites. General steep westerly dip.		Yields and water quality vary over a wide range and reflect the rock type. Some irrigation wells penetrate both the overlying sediments and basement rocks and obtain water from both. Generally used for stock purposes on the flanks of the valley.

Inland sand dunes and sand sheets are widespread in South Australia and in some areas yield small but useful supplies of stock water. These include the upper Southeast, and in parts of the Murray Basin. Small supplies are occasionally derived from sand dunes in the north and northwestern part of the State. Yields from these aquifers are small and uncertain, particularly after long dry periods.

Sand dunes may yield low salinity groundwater in areas of high rainfall or where recharge occurs readily but elsewhere salinity is high. For example, sand dunes and sand sheets on the Padthaway Ridge of the upper Southeast yield groundwater with salinity ranging from 1,700 to 14,000 mg/l. Direct recharge apparently occurs only where the water table lies at a depth of less than 4 m or where there is a recharge path of relatively high hydraulic conductivity. The sediments are generally fine grained and have a low hydraulic conductivity. As a result yields are low, generally sufficient for only small windmills and salinity usually increases with depth.

EYRE PENINSULA BASINS

For convenience discussion of these basins includes comment on Tertiary and Jurassic sediments which would normally be included in sedimentary basins.

The supply of water for Eyre Peninsula is very dependent on the availability of groundwater. In 1973/74, the total consumption of water from the Engineering and Water Supply Department reticulated schemes was 8.4×10^6 kl, of which about 4.4×10^6 kl was obtained from groundwater basins. Eighteen groundwater basins have been outlined on



Mayhew rotary drilling plant County Musgrave, Eyre Peninsula, 1968.

Photo: D.H. Stapledon
Neg. 11518



Polda Basin, Eyre Peninsula. Pumping station and trench with exposed water table, 1962. Trench is approximately 60 metres in length and is now covered.

Photo: R.G. Shepherd
Neg. 4086

the peninsula (Fig. 7). The boundaries of the basins are not distinct geological boundaries, but are defined on the basis of water salinity being less than 1,000 mg/l. In general, water salinity increases with depth.

At present only 8 basins are being utilised for domestic supplies - these include the Lincoln A, B, C, Uley-Wanilla, Uley South, Polda, Bramfield, and Robinson Basins.

A summary of the hydrogeology of Eyre Peninsula is given in Table 3.

In the Lincoln Basin (Fig. 7) low salinity groundwater has been proved to extend below sea level to a depth of 40 m. Groundwater occurrence in this area follows the Ghyben-Herzberg principle of lower density fresh water "floating" in high salinity water. The sea occurs on two sides of part of the basin and the deeper water below 40 m has a salinity equivalent to that of sea water. In many respects other basins on Eyre Peninsula are similar, except that the Lincoln Basin has the greatest depth of low salinity groundwater.

In aeolianitic aquifers the quality of the groundwater is almost uniform over large areas, for example, in the Polda Basin (Fig. 7). This is a reflection of the homogeneity of the rock type and a shallow groundwater depth combined with rapid and uniform intake over the area.

TABLE III

EYRE PENINSULA - SUMMARY OF HYDROGEOLOGY

AGE		UNIT, LITHOLOGY	MAXIMUM KNOWN THICKNESS (m)	HYDROGEOLOGY
QUATERNARY	PLEISTOCENE	<u>Bridgewater Formation:</u> Aeolianite, fine to medium grained, weakly to moderately cemented. Grains are calcite and shell fragments mainly 0.1 to 1.5 mm and cross bedded. Generally calcreted at surface.	180	Unconfined aquifer generally low salinity. Permeability ranges from low to very high, mainly moderate. Transmissivity ranges from $2.0 \times 10^3 \text{ m}^3/\text{day/m}$ to $8.0 \times 10^3 \text{ m}^3/\text{day/m}$.
?TERTIARY		<u>Unnamed:</u> Clay, ranging from stiff to soft, sandy and highly plastic. Becoming sandier near base.	12	Confining bed.
TERTIARY	EOCENE	<u>Vanilla Formation:</u> Clay, sand gravel with thin lignites. Sand is generally fine grained, less than 0.5 mm, uncemented or weakly cemented.	116	Aquifer with permeability low to moderate but with marked variations vertically and laterally. Salinity variable and generally higher than upper aquifer.
MESOZOIC	JURASSIC	<u>Unnamed:</u> Sand, silt, and clay. Sand consists of quartz grains usually less than 0.5 mm, occasionally up to 3 mm. Sediments generally carbonaceous and contain lignite beds.	60	Aquifer with permeability very low and salinity high, generally exceeding 14 000 mg/l.
	LOWER CRETACEOUS	<u>Flinders Group, Middleback Group, Hutchison Group:</u> Schist, gneiss, and quartzite intruded by granite and volcanics. Deeply weathered in places.	-	Usable groundwater obtainable in the southern part of the peninsula - generally at least 7 000 mg/l but in a few localities salinity is lower.



Sinkhole in Bridgewater Formation, south of Elliston,
Eyre Peninsula, 1967.

Photo: C. Bleys
Neg. 20600



Same sinkhole as above, after heavy rain in July, 1968.

Photo: C. Bleys
Neg. 20601

Frequently in this type of deposit sink holes or solution channels are developed above the water table allowing rapid ingress of surface water. Where direct intake does not occur because permeability is lower at the surface, salinity is generally higher; this situation may also occur where the water table is very shallow and evapotranspiration causes a salinity increase.

GROUNDWATER RESOURCES OF SEDIMENTARY BASINS

The various basins are considered in two groups, the first are non-marine followed by a second group dealing with the more complex marine and non-marine sedimentation.

NON-MARINE SEDIMENTARY BASINS

Barossa Valley Basin

This is an intermontane basin which is not part of the St. Vincent Basin but sedimentation in the early Tertiary period was contemporaneous. Sediments of the basin are Miocene to Recent in age and consist of sand, gravel, clay and occasional lignites, with a maximum thickness of approximately 200 m close to the eastern margin.

The basin has an area of 186 km² and is elongated in a north-northeasterly direction (Fig. 5). The North Para River, source of much of the recharge to the groundwater, enters the basin east of Nuriootpa. The river trends southerly through the basin, eventually leaving it through a gorge in Adelaidean rocks.

Groundwater in relatively large supply is obtained in some areas where coarser sands occur but supplies are quite variable because of the variable nature of the sediments. Yields of up to 1,700 kl/day have been reported, but only in areas where permeability is highest and where the best recharge conditions occur. Yields generally range from 150 to 850 kl/day. There are several aquifers within the basin but they tend to be lenticular and in many cases there is no certainty of obtaining an adequate water supply from a particular bed. Geology and hydrogeology of the basin are summarised in Table IV.

Salinity of groundwater within the basin ranges from 400 to 2,000 mg/l with the better quality water occurring in recharge zones close to the North Para River.

Aquifer characteristics are unknown but as with other non-marine deposits they are expected to vary considerably over the basin. It is considered that transmissivity has a minimum value of about $8.0 \text{ m}^3/\text{day}/\text{m}$, possibly rising to $200\text{--}300 \text{ m}^3/\text{day}/\text{m}$ in the more permeable zones.

Pirie-Torrens Basin

This is an elongated basin, occupying the plains east of the northern part of Spencer Gulf and generally considered to extend between the Flinders Ranges and Lake Torrens (Fig. 5), although the lake itself is actually part of the basin. It is approximately 400 kilometres long, varying in width from 0.8 to 40 kilometres with a total area of approximately $10,000 \text{ km}^2$. The basin is oriented almost north-south and extends from latitude 30°S to $33^\circ 50'\text{S}$.

TABLE IV

BAROSSA VALLEY - SUMMARY OF HYDROGEOLOGY

AGE		UNIT, LITHOLOGY	MAXIMUM THICKNESS (m)	HYDROGEOLOGY
QUATERNARY	PLEISTOCENE - RECENT	<u>Pooraka Formation</u> : Undifferentiated silts, clays and gravels, orange-brown mottled with brown to grey gravels. Outwash deposits (fans etc.) fluvial. May contain carbonate of the Loveday Soil.	20	Unconfined aquifer used mainly for stock supplies with occasional small scale irrigation. Yields range from 8 to 150 kl ³ /day and salinities from 200-14 000 mg/l. Depth to water-table ranges from 2 to 30 m. Recharge from North Para River and scarp streams.
TERTIARY	EOCENE? - PLEISTOCENE	<u>Unnamed sequence</u> : Basal units characterised by conglomerates (white quartz) and fine to very coarse sands showing medium and large scale deltaic bedding. These grade up into carbonaceous sands and clays tentatively classed as Eocene. A fine white sand unit is recognisable in the Light Pass area.	200	Unconfined and confined aquifer, used extensively for irrigation, especially vines. Sand screens are generally required. Well yields range from 150 to 830 kl/day and salinities from 400 to 2 000 mg/l. Groundwater movement is to the south. Recharge from overlying unconfined aquifer.
LOWER-MIDDLE CAMBRIAN		<u>Kanmantoo Group (Inman Hill Strangway Hill Formation)</u> : Metamorphosed greywacke, arkose siltstones. Underlies southeastern portion of Valley. <u>Angaston/Kapunda Marbles</u> : White, blue, pink marble, amphibolitic marble. Underlies Barossa Valley sediments in parts of northern area and on eastern margin. Minor solution features recorded.	-	Moderate yields from arkoses. Otherwise limited supplies of stock quality. Limited in extent but generally high yield and good quality water obtainable. Water used for irrigation and industrial purposes.
UPPER PROTEROZOIC	TORRENSIAN - STURTIAN	<u>Burra Group/Umberatana Group</u> : Siltstones, shales, phyllites, etc. with interbedded quartzites and dolomite.	-	Well yields are generally low and salinity high, limiting it to stock purposes. Best yields and quality obtained from the interbedded quartzites. Salinity range 500-10 000 mg/l. Recharge from 150-4 000 kl/day.

Natural boundaries to the basin are formed by Cambrian and Precambrian basement rock of the Mount Lofty-Flinders Ranges in the east and by Spencer Gulf and Lake Torrens in the west. The northern boundary is determined by basement rock outcrops but the southern boundary is somewhat indefinite as stratigraphic evidence is lacking. It is regarded as being near Pt. Broughton on geomorphological grounds. There is possibly a tenuous connection with non-marine sediments of the St. Vincent Basin near Crystal Brook. However, no definite evidence of an actual connection between the two basins has been established but if it occurs, it is considered to be insignificant in the hydrological sense.

Surface drainage of the basin is westerly from a series of short steep watercourses originating in the ranges east of the basin. Two relatively large streams, the Broughton River and Willochra Creek, traverse the basin in the southern and northern part, respectively, but catchment areas for these streams lie mainly outside the Pirie-Torrens Basin.

Quaternary sediments consist of clay, gravel, sand, with some areas of surface limestone and aeolian sands. The thickness of these deposits is variable and in places up to 180 metres has been recorded.

Tertiary sediments occur at a minimum depth of about 80 m to a maximum of about 270 m as recorded in a test well drilled on Lake Torrens. Tertiary sediments consist of sands, sandy clays, and sandstones occasionally with thin carbonaceous clay beds. Geology and hydrogeology are summarised in Table V.

TABLE V

PIRIE-TORRENS BASIN - SUMMARY OF HYDROGEOLOGY

AGE	UNIT, LITHOLOGY	MAXIMUM KNOWN THICKNESS (m)	HYDROGEOLOGY
QUATERNARY	<u>Hindmarsh Clay</u> : Poorly sorted clays, clayey sands and clayey gravels. Confined to the basin south of Port Augusta.	180	Unconfined aquifer, partly confined in limited areas. Salinity and yields highly variable. Sands and gravels used mainly for irrigation but salinity may increase with heavy pumping. Salinity ranges from 900 to 30 000 mg/l, the highest salinity occurring near the coast. Confining bed to Tertiary aquifer.
	<u>Avondale Clay</u> : The northern equivalent of the Hindmarsh Clay - dominantly red clay with mottled grey, yellow and brown clays.	50	Unconfined aquifer used mainly for stock supplies in the northern part of the basin. Salinities 1 400 to 10 000 mg/l. Forms a confining bed to Tertiary aquifer.
	Unnamed alluvial sands, gravels and calcrete.	20	Forms an aquifer in local areas, particularly at foot of Flinders Ranges. Used mainly for stock water supplies.
TERTIARY	Unnamed fine grained yellow to white sands overlying basement. Not known in outcrop. Includes multicoloured sandy clays. Pyrite and marcasite found in the southern part of the basin.	40	Sands comprise a confined aquifer which is used for irrigation supplies in the southern part of the basin. Salinity ranges from 800 mg/l near the ranges to 30 000 mg/l near the coast or Lake Torrens. Very little exploitation of this aquifer in northern part of the basin.
UPPER PROTERO- ZOIC	Adelaidean sequence of quartzites, sandstones, limestones and siltstones. Forms the basement to the Pirie-Torrens Basin.		Groundwater contained in fracture porosity. Stock supplies obtained on the edge of basin at the foothills of the Flinders Ranges. Salinity is variable.

In addition to groundwater occurring in shallow Quaternary sands and gravels Tertiary sands form a confined aquifer. Most of the wells drilled into this aquifer were for stock water supplies but in the southern part, mainly near the foothills east of Port Pirie, there is considerable use of groundwater for market gardening purposes.

Contours of the potentiometric surface of the pressure aquifers are approximately parallel to the basin margins with an average gradient to the west of about 1 to 80. The groundwater contours and salinity indicate that the main recharge occurs along the range front where the streams reach the plain. The lowest salinity groundwater within Tertiary aquifers occurs near the major sources of intake along the eastern margin of the basin but with distance from intake areas salinity increases markedly. In the Port Augusta area salinity increases from less than 3,000 mg/l near the foothills to more than 30,000 mg/l on the plain to the west, over a distance of about 16 km.

Yields vary over wide ranges but the average would be less than 200 kl/day. In some areas yield is only about 1 kl/day rising to 1100 kl/day where the aquifer is more permeable. Rarely, higher yields have been obtained; up to 3,000 kl/day has been reported for a well in the southern part of the basin.

No controlled pump tests have been performed in the basin, but it is considered that aquifer characteristics range over wide limits, as indicated by the range of yields.

Walloway Basin

Located about 260 km north of Adelaide, the Walloway Basin is a north-south orientated intermontane basin, approximately 80 km long and maximum width is 16 km, with an area of about 650 km² (Fig. 5).

Average rainfall over the basin is about 330 mm per year and there are no permanent streams. Maximum known thickness of basin sediments is 200 m which include at the base fine grained sands, clayey sand and clay with minor lignite, of Middle to Upper Eocene age (Table VI). The overlying sediments include up to 70 m of clay with coarse gravel beds, often lenticular. These overlying sediments possibly range in age from mid-Tertiary to Quaternary. Obscuring the Quaternary and older deposits are beds of Recent alluvium and outwash material, derived from the surrounding Precambrian rocks.

Pressure and non-pressure groundwaters are available from various aquifers in the basin. The pressure aquifers are more uniform and apparently extend throughout the basin in contrast to shallow aquifers. The latter are lenticular and occur mainly along old drainage lines. The best quality groundwater of the Tertiary aquifers occurs near Orroroo where salinities of less than 3,000 mg/l are recorded and in the most favourable area salinity is 1,500-1,700 mg/l.

Flow rates for the artesian wells are generally low, normally less than 300 kl/day. In a number of wells the flow rate has declined considerably, possibly through

partial collapse of the fine silts and sands in the aquifer or of the overlying clay. In properly developed bores, suitably screened in the aquifer, yields of up to 1,600 kl/day may be obtained. Development to this extent may result in a drawdown of up to 46 m.

Aquifer characteristics are almost unknown, but the results of one pump test indicate a transmissivity of 123 m³/day/m. This test was done in a relatively low salinity area where the sands are probably coarser and more permeable than elsewhere. For this reason, it is considered that this transmissivity value is tending towards a maximum.

Willochra Basin

This is an intermontane basin approximately 345 km north of Adelaide and with an area of 1,165 km² (Fig. 5). The basin is bounded by Upper Proterozoic-Cambrian rocks of the Adelaide geosyncline forming a line of rugged hills particularly along the western margin. Prominent hills include Mt. Brown (965 m) and Mt. Remarkable (959 m). The basin is drained by the Willochra Creek which flows north-erly, eventually traversing a gorge through Precambrian rocks before entering the northern part of the Pirie-Torrens Basin and subsequently Lake Torrens. Average gradient northward along the Willochra Creek is approximately 1 in 750.

Maximum known thickness of sediments within the basin is 140 m and details are given in Table VI.

TABLE VI
WALLOWAY BASIN - SUMMARY OF HYDROGEOLOGY

AGE	UNIT, LITHOLOGY	MAXIMUM KNOWN THICKNESS (m)	HYDROGEOLOGY
RECENT	Loam: Brown, silty. Calcareous. Outwash and alluvial sandy clays and gravels.	2 30	Unconfined aquifer, over most of the basin yielding stock supplies. Salinity 1 000-1 500 mg/l. Irrigation supplies available over a limited area from gravels at 25 m.
TERTIARY (upper undiff.)	Unnamed. Mainly sandy clays, yellow and mottled with thin sandy beds. Lacustrine and fluvial.	40	Not exploited for groundwater. Forms part of the confining bed for artesian aquifer below.
	"Walloway Sands and Clays". Fine grained sands and clayey sands.	50	Not exploited for groundwater. Forms part of the confining bed for artesian aquifer below.
	"Walloway Sands and Clays". Fine grained sands, white to pale brown with minor clay interbeds.	25	Artesian aquifer used for town water supply and irrigation purposes. Salinity approximately 1 500-1 700 mg/l. Some development problems because of fine sands.

WILLOCHRA BASIN - SUMMARY OF GEOLOGY AND HYDROGEOLOGY

RECENT	Unnamed mottled sandy clays and thin sandy clays and thin sandy beds, overlain by a hard marly limestone.	90	Comprises an unconfined aquifer over part of the basin where more sandy facies occur. Yields generally low. Groundwater varies from stock quality to saline - unsuitable for domestic use or irrigation.
TERTIARY?	Unnamed white to creamy clays, sandy clays and clayey sands, slightly pyritic, lignitic in part. Aquifer consists of fine clayey sand overlying basement rocks at base of Tertiary.	50	Confined aquifer is in sandy section overlying basement. Yields generally moderate, 200-300 kl/day. In southern half of basin groundwater is generally suitable for irrigation purposes (1 000-2 000 mg/l). Salinity higher in northern part of basin. Recharge by runoff from flanks. Measured permeability is 3 m/day.
PRE-CAMBRIAN	Adelaidean phyllites and slates.		Small supplies occur in fractured and folded rocks. Salinity generally similar to that of confined aquifer (Tertiary).

Quaternary sediments consist of mottled clays, with frequent thin sand and gravel beds, particularly near the drainage lines. The underlying Tertiary sediments consist of clay and sandy clay with carbonaceous silts and low grade lignite or lignitic sand. The pressure aquifer within the Tertiary succession is a relatively fine grained sand bed of maximum thickness 15 m as recorded in the south. This aquifer decreases in thickness to approximately 6 m in the north, but it is apparently continuous over the whole basin, yielding pressure water which has a potentiometric level above the surface in the northern part of the basin.

Contours of the potentiometric surface indicate that the main intake is in the south near Mt. Remarkable where average annual rainfall is 559 mm in contrast to less than 305 mm in the central part of the basin. Salinity of water in the pressure aquifer is lowest in the vicinity of intake areas, being less than 1,400 mg/l near Mt. Remarkable. Salinity is less than 2,000 mg/l over much of the southern half of the basin rising to more than 7,000 mg/l in the north. It has been estimated that the safe yield of the basin is 0.4×10^6 kl per year.

There is adequate water suitable for stock available from the confined aquifer. Although the quality in the southern half of the basin is suitable for pastures, depletion of the aquifer would probably occur if large scale irrigation were carried out.

Permian Sediments

Permian sediments occur in the southern part of the Mt. Lofty Ranges, on Kangaroo Island and Yorke Peninsula (Fig. 19). Only within the ranges do they contain low salinity groundwater; in the other localities salinity exceeds 14,000 mg/l.

The sediments in the southern Mt. Lofty Ranges occur as a thick succession of uniformly fine sands infilling ancient valleys. A thickness of approximately 300 m has been recorded in Back Valley, near Victor Harbour.

Water quality is good, but well yields are usually small due to poor development and the low permeability of the sediments. The groundwater is usually unconfined, although some flowing wells have been reported. Transmissivity has been determined from a pumping test at one site (Mt. Compass) where it was found to be $3 \text{ m}^3/\text{day}/\text{m}$, but this is not necessarily representative of these sediments generally.

Cowell Basin

With an area of $1,600 \text{ km}^2$ this basin is located near Cowell on eastern Eyre Peninsula (Fig. 5). Sediments are of Tertiary-Recent age with a maximum known thickness of 114 m. The groundwater is invariably of high salinity; at only one locality near Yeldulknie Creek on the margin of the basin the groundwater could be used for sheep. The recharge rate is unknown but is probably quite small. Surface water entering the basin generally has a relatively high salinity, e.g. Salt Creek.

Cummins Basin

Sediments of Tertiary-Recent age occupy a central basin extending northward from Wanilla to beyond Cummins (Fig. 5). The sediments consist of clay, sand, gravel and thin lignites with a maximum thickness recorded at Cummins of 136 m. The maximum known thickness of early Tertiary (Eocene) carbonaceous silty sands with lignite is 116 m. Groundwater occurs in thin sand or gravel beds and varies considerably in yield and salinity. Stock wells drilled in the Wanilla area during 1949-1950 had a success rate of about 50%. In some wells salinity was found to exceed 20,000 mg/l and yields were as low as 3 kl/day.

Northward towards Cummins salinity increases probably because of poorer recharge conditions and lower rainfall.

There are other similar but smaller Tertiary basins in the northern part of Eyre Peninsula, notably near Caralue, Kimba, Kyancutta, Rudall and Warrambo. These basins invariably contain highly saline groundwater.

BASINS OF MARINE DEPOSITION

These include all basins where there has been alternating periods of marine and non-marine deposition. The larger basins, including Great Artesian, Murray, Eucla, Otway and St. Vincent Basins are included in this group. They are characterised by a thick succession of fossiliferous marine limestone, sandstone, sand and shale or clay.

Great Artesian Basin - South Australian Portion

The Great Artesian Basin occupies a total area of 1.74 million km² over parts of three States and the Northern Territory, covering approximately 22 per cent of the Australian continent. The basin in South Australia covers an area of 310,330 km² which is less than 18% of the total area and it extends from the Northern Territory as far south as Kingoonya, Marree and Lake Frome and to the west of Coober Pedy (Fig. 8). It includes, as inliers, the Peake and Denison Ranges and the Mt. Woods area.

Topographic Setting

Topography over the basin area in South Australia is monotonously flat and broken only by dissected table lands and residual mesas. A large proportion of the area is covered by mobile sand dunes, their orientation controlled by prevailing winds; and also by desolate crab hole and stony desert country.

The principle drainage pattern feeds into the large Lake Eyre depression which is fed by such major channels as the Diamantina River and Cooper Creek from the northeast and by the Finke, Macumba and Neales Rivers from the northwest. Subsidiary drainage systems to the west of the Peake and Denison Ranges feed into Lake Cadibarrawirracanna and the Lake Phillipson-Lake Woorong system. Lake Frome takes much of the drainage south of the Cooper and provides a further local base level and evaporation pan.

The South Australian part of the basin is far removed from the major intake areas in eastern Queensland and New South Wales, apart from minor subsidiary intake areas along the western rim. For this reason it is of added importance to South Australia, providing a reliable source of stock water and town water supplies over a very extensive arid region at considerable distances from areas of more plentiful rainfall.

Geology

Sediments recognised as belonging to the artesian basin system overlie three sub-basins containing sediments of pre-Jurassic age. In the northeast part of the State, artesian sediments overlie Triassic and Permian sediments of the Cooper Basin (Fig. 5) which form the hydrologic basement in this area. To the west of the Cooper Basin, artesian sediments overlie thinner Permian sediments of the Pedirka Basin (Fig. 5). West of the Peake and Denison Ranges, thinner equivalent artesian sediments overlie rocks of Permian and Devonian age of the Arckaringa Basin (Fig. 5). It is not known precisely just how widespread Permian sediments are throughout the basin but hydrologically speaking, they can generally be regarded as basement rocks.

The Flinders, Willouran and Peake and Denison Ranges provide an almost continuous Proterozoic basement outcrop marginal to the basin, except for that subsidiary part of the basin to the west of the Peake and Denison Ranges. In the southwestern lobe of the basin itself, the margin is formed by granite, either outcropping or occurring at

shallow depth and also by occasional outcrops of lower Proterozoic quartzite or conglomerate. The occasional granite outcrops in the Mt. Woods area are regarded as inliers although these and other shallow subsurface hard rocks are presumed to control the hydrology within basin sediments over a wide area.

Sediments of the Great Artesian Basin in South Australia are predominantly Jurassic and Cretaceous in age. Triassic rocks which have a limited areal extent within the Basin contain no useful aquifers and are regarded hydrologically as basement.

A geological section is given in Fig. 10, hydrogeology is summarised in Table VII.

Jurassic

The freshwater Hutton Sandstone of lower to middle Jurassic age is generally coarse grained to conglomeratic, loosely cemented and exhibits good porosity and permeability. It is an excellent artesian aquifer both in respect to yield and quality, but because of its great depth of burial, it has not been extensively developed in South Australia.

The Birkhead Formation, consisting predominantly of micaceous and carbonaceous shale, immediately overlies the Hutton Sandstone and is a confining bed.

The Algebuckina Sandstone of Upper Jurassic age is the most widespread of the Jurassic sediments and forms a continuous blanket from the subsurface in the northeast corner of the State to where it outcrops along the southern and western margins of the basin. The lithology of



Great Artesian Basin. Duck Hole Well, 1971.

Photo: R.G. Shepherd
Neg. 12582

PLATE V

this unit consists of a fine to medium grained kaolinitic sandstone grading upwards to a coarser grained conglomeratic sandstone.

The Algebuckina Sandstone forms the main artesian aquifer in the South Australian part of the Great Artesian Basin where it has been extensively developed for pastoral purposes; individual bores may produce more than 4.3×10^3 kl/day of good quality water.

Cretaceous

Sediments of this age occur over the whole of the South Australian portion of the Great Artesian Basin. The sedimentary record clearly demonstrates that Cretaceous deposition in the basin took place following a major transgression. Predominantly comprised of marine shale, these relatively impermeable sediments provide a confining bed for the pressure water of the main aquifer of the basin. In some parts, however, a sandy horizon (Cadna-Owie Formation) occurs at the base of the Cretaceous section and is of sufficient thickness and areal extent to be important hydrologically. No continuous aquifer is known in the Cretaceous, however, and it is likely that such sandy horizons are only local lenses.

Tertiary to Recent

Sediments of this age are of less importance hydrologically than Jurassic aquifers. However, in the northeast corner of the State useful supplies of stock quality water may be obtained from Tertiary sediments.

Tertiary to Recent sediments occurring in the southeastern parts of the basin and extending into the Frome Embayment are of importance as they include aquifers yielding water suitable for stock.

Hydrogeology

The extent of pressure water occurrence is controlled by the continuous distribution of the aquifers, by the extent of Cretaceous shale cover and by the relative differences in elevation of the intake zone and the aquifer at any one locality. Pressure within the aquifer results not only from elevation of intake areas but also from the pressure of overlying formations. The latter is of considerable importance for those portions of the aquifer system located at great distances from intake areas.

Lack of pressure data and accurate levels within the basin prevents the drawing up of isopotentials which could enable true direction of water movement to be determined. However, isohalsines show that direction of movement in the South Australian portion of the basin are mainly south-westerly from Queensland and New South Wales, but with small intake along the western margin of the basin in this State.

Sands of the Cadna-Owie Formation and Algebuckina Sandstone form an unconfined aquifer to the west of the limits of artesian water (Fig. 8). In places the aquifer is overlain by relatively permeable white siliceous leached mottled clay shale which enables direct percolation of fresh water into the sands. Where these sands contain free groundwater, whether covered by the mottled shale or not,



Great Artesian Basin, McEwin's Well, 1971. Stone Wall approximately 1.5 metres high

Photo: R.G. Shepherd
Neg: 12576



Great Artesian Basin. Almost extinct mound spring near Coward Springs, 1958.

Photo: A.R. Crawford
Neg: 1411

there is usually a fresh skin of water overlying more saline water and the supplies of fresh water available depend on the degree of local recharge. Highly saline water occurs in places of ineffective intake where downward percolation of fresh waters cannot reach the groundwaters contained in confined aquifers. Good examples of this are found in the Coober Pedy area.

Saline water has been obtained in several deep artesian wells from near the base of the Cretaceous sediments. Some wells on the Birdsville Track are reported as having obtained reasonable quality stock water from sands within Cretaceous shale. Upper Cretaceous non-marine shale and sandy beds are important in the northeast of the State where their thickness is greatest. Artesian water from these beds was obtained in Patchawarra well and sub-artesian water has been developed at other places to the south adjacent to the New South Wales border.

In the Frome Embayment, and around the northern end of the Flinders Ranges and in the Lyndhurst area, shallow water is obtained from Tertiary-Recent sediments as a result of intake from the adjacent ranges.

Water Quality

The quality of the pressure water in the Great Artesian Basin deteriorates in a southwesterly direction towards the natural outlets (mound springs). In the northeast, Birdsville well and Goyders Lagoon well, with salinities of 450 and 600 mg/l, respectively, yield some of the best quality water within the Great Artesian Basin in this State. Water quality in the main aquifer is remarkably uniform over wide areas in parts of the basin remote from the margins.

TABLE VII
GREAT ARTESIAN BASIN - SUMMARY OF HYDROGEOLOGY

AGE		UNIT, LITHOLOGY	MAXIMUM KNOWN THICKNESS (m)	HYDROGEOLOGY
CAINOZOIC	TERTIARY- QUATERNARY	Unnamed: Aeolian sands, alluvium lacustrine and fluvial sands, silts and clays, occasional limestone beds. May be cemented at surface by silica, iron or gypsum.	400	Usually unconfined aquifer. Stock and domestic supplies only. Salinity variable from 1 000 mg/l to >100 000 in desert areas. Transmissivity probably <100 m ³ /day/m. Water table contours probably focus on Lake Eyre. Groundwater in this area is concentrated brine. Recharge is from low rainfall. Depth to water table up to 90 m.
MESOZOIC	CRETACEOUS	Winton Formation: fresh water fluvio-lacustrine sequence of fine grained sands, silts and clays and lignite. Predominantly grey-green, little quartz, mostly feldspathic (salt and pepper sandstone).	500	Confining bed in part - may be an unconfined aquifer. Very low transmissivity as formation is tight. No information on aquifer parameters in South Australia.
		Oodnadatta Formation: marine sequence of sand, silt and clay inter-fingering with above formation. Predominantly fine grained. Basal sandstone, gritty, in marginal areas.	300	Confining bed (similar to Winton Formation. May be an unconfined aquifer around margins of basin.
		Bulldog Shale: similar to Oodnadatta Formation mainly shale with occasional calcareous nodules.	200	As for Oodnadatta Formation.
		Cadna-owie Formation: variable lithology, more sandy towards basin margin.	100	Confined aquifer - insignificant compared with Algebuckina Sandstone - hydraulically connected to it. Unconfined aquifer on extreme margin of Great Artesian Basin. Salinity varies 600-10 000 mg/l. Supplies up to 850 kl/day. Aquifer parameters unknown.

MESOZOIC	UPPER JURASSIC	<u>Algebuckina Sandstone</u> : Fluvio-lacustrine sequence - mainly fine to coarse sandstone. Sequence thickens basinwards.	400	Confined aquifer. Artesian flows may exceed 4.3×10^3 xkl/day. Salinity 600 to 4 000 mg/l. Water discharge temperature up to 99°C. Very corrosive near margins. Dominant ions Cl^- with varying SO_4 and HCO_3 . Aquifer parameters unknown. Natural outlets in form of mound springs, total discharge being about 30×10^6 kl/year. Discharge from uncontrolled wells is estimated to be 77×10^6 kl/year.
	LOWER-MIDDLE JURASSIC	<u>Birkhead Formation</u> : micaceous and carbonaceous shale. Recognised beneath Simpson Desert and further east.	150	Confined bed.
		<u>Hutton Sandstone</u> : Coarse grained, conglomeratic, loosely cemented. Occurs in eastern part of the basin in South Australia.	200	Confined aquifer: good quality water, high yielding. Not generally used in this State because of its depth, generally exceeding 1 500 m.
TRIASSIC	<u>Nappamerrie Formation</u> : Green dolomitic siltstone and sandstone.	200	Confining bed to the Gidgealpa Group.	
PALAEOZOIC	LOWER-UPPER PERMIAN	<u>Gidgealpa Group</u> : Sandstone shale, siltstone and coal.	300	Confined aquifer generally containing highly saline groundwater. In the southern Cooper Basin flushing by pressure water of Jurassic aquifers has occurred in areas where Triassic sediments are missing. Salinity in this area is generally less than 5 000 mg/l.
	LOWER PERMIAN	<u>Merrimelia Formation</u> : Sandstone conglomerate, shale, siltstone.	360	No known aquifers.

48a.

PALAEO-ZOIC	ORDOVICIAN - CAMBRIAN	Unnamed sandstones, carbonate rocks and volcanics.	-	No known aquifers.
PRE-CAMBRIAN	ADELAI-DEAN	Undifferentiated sediments and volcanics.	-	No known aquifers.

Salinities in the southwestern areas, north of Kingoonya, reflect some local intake where Cretaceous shale is absent and regional isolation from the main pressure basin occurs. On the fringes of the sub-basins, the water quality is sometimes locally potable but it often fluctuates seasonally.

In the main basin and in the western areas, the quality of the water is illustrated by the types of ions contained in it. A high bicarbonate content in the eastern parts of the basin provides soft water which is suitable for domestic use, but generally unsuitable for irrigation. The high sulphate content of the western waters however, imparts to them a highly corrosive activity and renders them hard for domestic use.

In parts of the basin it is known that at the base of the Cretaceous or in the upper portion of the Jurassic sediments there is a hard band of pyrite, often sufficient to separate two horizons of water. In addition, the weathered outcrop of Cretaceous shale is often associated with abundant gypsum. These are two possible sources of the sulphates predominant in the groundwaters west of Lake Eyre.

Yields

Individual wells in the basin flow at rates ranging from less than 22.5 kl/day in some marginal areas to more than 4,300 kl/day in the central zone.

Total quantity flowing or pumped from wells in the basin in this State is estimated to be 77×10^6 kl/year. There are known to be approximately 150 flowing wells in the basin and the average flow rate is approximately 1,400 kl/day. Flow from mound springs is estimated to be approximately 30×10^6 kl/year.

Only a small proportion of this water is effectively used; more than 95% is considered to be lost by evaporation or seepage into shallow sands. Some towns along the western margin obtain their supplies from artesian wells but such usage would represent only a small proportion of the total output.

MURRAY BASIN - South Australian portion

The Murray Basin extends through New South Wales, Victoria and South Australia with a total area of 277,780 km². Its area in South Australia is 73,220 km².

Permian and Cretaceous sediments occur in the deepest part of the basin, for example at Loxton, Monash and Renmark in South Australia. However, the Murray Basin is not regarded as having formed as a unit of sedimentation until the early Tertiary. Marine sedimentation was continuous over most of the basin during the mid-Tertiary. Rocks deposited at this time consist mainly of bryozoal limestone as described in the Tertiary stratigraphy of the Murray Basin (Ludbrook, 1961). Hydrogeology of the Murray Basin and Gambier embayment are described by O'Driscoll (1960). Maximum known thickness of Tertiary sediments within the basin is 641 m. A north-south section (Fig. 11) along the South Australian - Victorian border shows the general succession with Tertiary sediments resting on Palaeozoic rocks south of Pinnaroo.

The Knight Group of the central basin area, which includes brown and grey sands with carbonaceous sand and lignite are referred to in part as the Renmark Beds (Harris, 1966) with a maximum known thickness of 305 m. From palaeontological evidence the age of the beds is Palaeocene to Eocene.

Tertiary hydrogeology of the Murray Basin is summarised in Table VIII.

The potentiometric surface of the pressure water of the Renmark Beds (Knight Group) falls from about 60 m above sea level in the Naracoorte area to less than 15 m in the Waikerie-Blanchetown area. Over the Murray Basin the potentiometric surface is generally about 8 m above groundwater levels in sediments of the Murray Group. Salinity increases in a general northwesterly direction from less than 1,000 mg/l near Pinnaroo to more than 14,000 mg/l in the Renmark-Morgan area. In the northern part of the Murray Basin, where salinities of at least 7,000 mg/l are recorded in Renmark Beds the water is regarded as being at least partly connate.

Beds of the Buccleuch Group which overlies Renmark Beds have a maximum thickness in the western part of the basin where they represent an incursion of the sea during the Upper Eocene, the extent of which has not been determined. The Group is mainly developed in County Buccleuch but it has been intersected in a bore near Waikerie. Salinity of groundwater occurring in the Buccleuch Group is high; over 15,000 mg/l being recorded in the top part of Buccleuch B which, however, is a useful aquifer in some areas.

TABLE VIII
MURRAY BASIN - SUMMARY OF HYDROGEOLOGY

AGE		UNIT, LITHOLOGY	MAXIMUM KNOWN THICKNESS (m)	HYDROGEOLOGY
QUATERNARY	PLEISTOCENE -RECENT	Fluvial sands, clays and silts including calcretes. Includes <u>Blanchetown Clay</u> , yellow to white sandy clay; <u>Chowilla Sand</u> , yellow to pale grey calcareous sands, pale yellow sand; southern part.	40	Unconfined aquifers. Contains groundwater only in local areas - occasionally exploited for stock water supplies. Quality variable. Blanchetown Clay acts as confining bed to the Parilla and Loxton Sands.
TERTIARY	UPPER PLIOCENE	<u>Norwest Bend Formation</u> : fossiliferous sandstones, sandy limestones and calcareous sands - extends from Tailem Bend to Waikerie.	15	Not largely exploited as a source of groundwater because of the availability of river water. Used mainly for stock supplies because of indifferent quality. Salinity range 3 000 to 14 000 mg/l.
	PLIOCENE	<u>Parilla and Loxton Sands</u> : Parilla Sand in part equivalent to Norwest Bend Fm. Cross bedded micaceous sands, grits and silty sands commonly containing oyster beds.	60	Partly confined where Blanchetown Clay confining bed occurs. Porous to permeable beds, devoid of groundwater in the western part of the basin. Exploited as an aquifer in the eastern part of the basin in South Australia.
	MIO-PLIOCENE	<u>Bookpurnong Beds</u> : extend over the northeast part of the basin; marl, glauconitic, shelly in part.	15	Act partly as a confining bed to the underlying Morgan and Pata Limestones.
	LOWER TO MID MIOCENE	<u>Morgan Limestone and Pata Limestone</u> : Bryozoal Limestones, richly fossiliferous sandy in part with clayey lenses - e.g. <u>Cadell Marl</u> and <u>Finniss Clay</u> . Morgan Lst. gypsiferous in part, equivalent in part to the Gambier Limestone of the Otway Basin.	90	With the Mannum Formation, (hydraulically continuous) forms the main aquifer of the Murray Basin. Transmissivity measured at 200 kl/day/metre. Salinity values range from 700 to 14 000 mg/l with the best quality water occurring in the southeast part of the basin in South Australia. Yields of up to 1 700 kl/day available from individual wells. Exploited for irrigation, stock and domestic supplies.

TERTIARY	LOWER MIOCENE	<u>Mannum Formation</u> : yellow limestone with abundant solution cavities and highly fossiliferous. Transgressive onto bedrock on western margin of basin.	40	Subsidiary aquifer in the basin and hydraulically continuous with the Morgan Limestone. Salinity values similar. Aquifer parameters unknown.
	OLIGO- CENE	<u>Ettrick Formation</u> : 'Sandy' marls, glauconitic marls and limestone. Equivalent in part to the Gambier Limestone.	15	Limited mainly to the southwest part of the basin - not important as an aquifer and may act in part as a confining bed in local areas.
	UPPER EOCENE	<u>Buccleuch Group</u> : Marine glauconitic marl, fossiliferous limestone, carbonaceous sands and clays.	60	Not important as an aquifer. Occurs only in the southern part of the basin - generally contains brackish to saline groundwater. May act in part as a confining bed to the Renmark Beds.
	PALAEOCENE- EOCENE	<u>Renmark Beds</u> : brown to dark brown, fine to medium sands with bands of carbonaceous clay and lignites. Equivalent to Knight Group sediments of the Otway Basin.	300	A confined aquifer over almost the entire basin. Good quality water obtainable in the southern part of the basin. Not greatly exploited because of its depth and poor yield in some areas - better yields and quality obtainable from shallower aquifers.

The overlying Ettrick Formation is of Oligocene-Lower Miocene age and consists of glauconitic marls and sandy marls with limestone at the top. The Ettrick Formation grades upward into limestone indistinguishable from the Mannum Formation. The latter is well exposed in cliffs of the River Murray at Mannum, where it is a yellow limestone, highly fossiliferous with numerous solution cavities. Near the margin of the basin the Mannum Formation is overlain by the thin (2 m) Finniss Clay.

The overlying Morgan Limestone, together with the Cadell Marl Lens, described from the type section near Morgan attains a maximum thickness of 91 m in deeper parts of the basin.

In certain parts of the basin, particularly the deeper sections where the Finniss Clay may be absent, it is difficult to distinguish between Morgan Limestone and Mannum Formation without palaeontological evidence. In such cases the undifferentiated sequence is referred to as Murray Group.

The Morgan Limestone and Mannum Formation are significant aquifers as they consist of porous limestone. Permeability is both interstitial and cavernous and the aquifers are unconfined. Direction of movement of the groundwater in these aquifers is in a general northwesterly direction. Reference to the groundwater map shows that salinity also increases by 11,000 mg/l over a distance of little more than 16 km. The pattern of salinity is similar to that shown by the Knight Group or Renmark Beds of the basin.

The Pata Limestone which occurs above the Morgan Limestone in the Waikerie-Loxton area, is a bryozoal limestone of Lower to Middle Miocene age. Following deposition of Pata Limestone there is a gap in sedimentation until late Miocene or early Pliocene when Bookpurnong Beds, a glauconitic sandy and micaceous marl, were deposited. These beds form a confining bed above the Pata Limestone.

The overlying Loxton Sands, which are 15 m thick at Loxton are yellow micaceous sands, laid down in littoral - marine conditions and lower Pliocene in age. The Norwest Bend Formation is in places lithologically similar to Loxton Sands, particularly where they contain oyster shells.

The Parilla Sands (Firman, 1966) which are partly equivalent to and probably younger than Norwest Bend Formation, are fluvial-lacustrine.

In general, limestones of the Murray Group are the most productive source of groundwater in the Murray Basin. The other major aquifer - sands of the Renmark Beds (Knight Group) occur throughout the area but are not generally developed except for town water supplies. Thinner and less persistent aquifers are developed in some areas for stock water supplies, e.g. Buccleuch B.

Few pump tests have been done on Murray Group limestones of the Murray Basin and only one of these is useful for obtaining aquifer characteristics. A controlled pump test, conducted at Wanbi in 1959 showed transmissivity to be approximately $3.2 \times 10^2 \text{ m}^3/\text{day/m}$. This is a value for the aquifer of that area, which is not necessarily representative of the aquifer as a whole. However, conditions were

apparently fairly uniform during deposition of the Murray Group Limestones and the value of transmissivity might be considered an average value over a wide area.

There would be considerable variations in areas where the limestone is highly cavernous and locally transmissivity may range up to $8.0 \times 10^3 \text{ m}^3/\text{day/m}$ or even higher.

Although pumping tests have been done for town supplies on Renmark Beds (Knight Formation) these were mainly designed to check the available yields and Transmissivity has not been calculated.

Angas-Bremer Area

With an area of about 390 km^2 this area is located on the northern shore of Lake Alexandrina (Fig. 5). It is part of the area of deposition of the Murray Basin but is considered separately on the basis of salinity, the boundary being taken as the 3,500 mg/l isohaline. Groundwater is used for irrigation of lucerne and vines and where salinity is too high for these purposes it is used for stock. Cereals are also grown in the district.

The area is underlain by flat lying Upper Eocene to Quaternary sediments resting on phyllites of the Kanmantoo Group (Cambrian). The maximum known thickness is north of Milang where 146 m of sediments (mainly sand) occur above basement rock.

Formations and their lithologies in the basin are shown in Table IX.

The Mannum Formation is the main source of irrigation water in the basin, yields of up to 2,600 kl/day being obtained. The water is under pressure and bores formerly flowed in low lying areas near Lake Alexandrina. The underlying Buccleuch Group also contains water under pressure which so far has not been utilised. Because this aquifer is a fine sand with marly horizons there could be considerable problems in development, and it may not be a significant aquifer.

There are two rivers traversing the basin, the Bremer and Angas and in a broad zone on either side of these rivers salinity of the pressure aquifers is less than 2,000 mg/l. In general, salinity increases with increasing distance from the rivers.

Average annual withdrawal from the basin is estimated to be 20×10^6 kl per year and this results in the formation of a cone of depression which extends over an area exceeding 100 km^2 at the end of summer.

Aquifer characteristics of the Mannum Formation as determined from pump tests are as follows:-

Transmissivity ranges from 5.0×10^2 to 2.0×10^3 $\text{m}^3/\text{day}/\text{m}$ and Storage Coefficient is 2.5×10^{-4} .

Total discharge from the two rivers has been estimated at 43×10^6 kl per year, but the proportion which recharges the aquifers is unknown.

TABLE IX

ANGAS-BREMER AREA - SUMMARY OF HYDROGEOLOGY

AGE	UNIT, LITHOLOGY	MAXIMUM KNOWN THICKNESS (m)	HYDROGEOLOGY
QUATERNARY	RECENT	8	Not known as an aquifer.
	PLEISTOCENE	50	Unconfined aquifer: Stock and domestic supplies. Yields up to 50 kl/day and salinities 1 000-9 000 mg/l. Vertical hydraulic conductivities measured on silts and clays showed results of 10^{-3} - 10^{-5} m/day. Forms confining bed over main pressure aquifer. Recharge from rivers, swamps and ?Lake Alexandrina. Water levels 5-10 m below surface.
TERTIARY	UPPER PLOIOCENE	20	Confined aquifer: rarely used as it is often too fine and thin. Salinity usually <3 000 mg/l. Hydraulic conductivity of samples tested are similar to above.
	LOWER MIOCENE	30	Confined aquifer: main groundwater supply for the area. Yields of 1 500-2 600 kl/day. Salinity 1 000-3 500 mg/l. Low salinity zones correspond with Bremer and Angas rivers. Wells have shown some increase in salinity - probably due to upper saline water leaking through corroded casing. Cone of depression developed.

TERTIARY	OLIGO-L. MIOCENE	Ettrick Formation: similar to above - some marly and silty bands, fossiliferous - boundary detected on palaeontological grounds.	30	May partially confine lower aquifer (Bucclleuch Beds) as more silty and marly. Water quality similar to Mannum Formation. Hydraulically connected to above aquifer. Penetrated by most wells.
	EOCENE - OLIGO-CENE	Bucclleuch Beds: sands, limestones and thin lignitic beds, often richly glauconitic; basal pebbly bed.	30	Confined aquifer - generally too deep and fine to be economically developed. Salinity ranges similar to Mannum but may be higher with depth.
CAMBRIAN		Kanmantoo Group: metamorphosed siltstone, phyllite and greywacke. May be deeply weathered. Steeply dipping, jointed, cleaved. Some sandstone interbeds.		Used as aquifer outside basin. Varies from unconfined to confined aquifer. Supplies 50 kl/day, greater in sandstone. Salinity 750-1 500 mg/l, outside Angas-Bremer area.

Otway Basin

General Configuration

The Otway Basin consists of an east-west elongate marginal basin extending from the Mornington Peninsula-King Island basement high in the east (along the eastern side of Port Phillip Bay, Victoria) to Lacepede Bay in South Australia. From King Island to west of Robe, the basin is rounded on its southern margin by a well defined basement ridge on the upper part of the continental slope. Basement rocks, ranging in age from Cambrian to Lower Permian outcrop along the northern margin of the basin in Victoria. The South Australian portion of the basin is known as the Gambier Embayment and is subdivided from the remainder of the basin in Victoria by the Merino uplift.

In South Australia the Upper Cretaceous-Tertiary sedimentary section attains a maximum known thickness greater than 4,000 m as shown by drilling at Geltwood Beach and the thickness of Mesozoic-Tertiary basin fill is considered to be in excess of 6,000 m in the vicinity of Robe.

Physiography

The onshore part of the Otway Basin in South Australia (Gambier Embayment) shows very little surface expression and over most of its area lacks an integrated surface drainage system. Apart from the extinct Pleistocene to Recent volcanoes between Mount Gambier and Millicent, the only other features of this coastal plain are a series of sub-parallel northwest trending dune ridges. The ridges average 15 to 30 m in height and are each associated with stranded Pleistocene

shore lines which extend inland as far as the Kanawinka escarpment, just east of Naracoorte. The escarpment forms the boundary between the coastal plains and the slightly higher plains inland.

The direction of drainage varies from southwest in the southern part of the basin to northwest in the northern part. Drainage is predominantly normal to the coast. Due to the very gentle gradient ranging from 1 to 5,000 to 1 in 500 surface water courses tend to be somewhat random and many shallow lakes and swamps occur throughout the area. The Pleistocene ridges form a barrier to drainage toward the coast and the natural drainage system has been augmented by the construction of numerous artificial drains, without which swampy conditions would prevail over much of the area during and after the winter rainfall season.

Annual rainfall ranges from approximately 560 mm in the vicinity of Naracoorte to 790 mm in the vicinity of Mt. Gambier. Annual evaporation exceeds precipitation throughout.

Stratigraphy

The oldest dated sediments are of Lower Cretaceous age. These sediments have been encountered subsurface but are nowhere exposed at the surface. The pre-Tertiary section from oldest to youngest is:-

Lower Cretaceous

Otway Group : Grey to green lithic and feldspathic siltstones and generally fine to medium grained sandstones overlain by a sequence of mud stone and greywacke sediments, probably 3,000 m thick.

Upper Cretaceous

Sherbrook Group : This unit, which does not outcrop in South Australia, is interpreted from sub-surface data to occur in the area south of the Beachport-Kalangadoo high. Three sub-units are recognised:-

Belfast Mudstone : Carbonaceous siltstones with minor medium to coarse grained feldspathic sandstones.

Paaratte Formation : This unit consisting of mudstone, siltstone and sandstone extends much further up the northern flank of the Upper Cretaceous basin than the Belfast Mudstone.

Curdies Formation : Consists almost entirely of slightly feldspathic and pyritic quartz sandstone with occasional coal lenses.

Tertiary

The oldest Tertiary sediments belong to the Knight Group which are visible at only one site - a quarry north west of Mt. Gambier. They are known principally in the subsurface. These units are recognised:-

Bahgallah Formation : Brown and green oolitic grit containing chamosite.

Dartmoor Formation : A sequence of grey and brown silty sandstone with occasional dolomite sands.

Tartwaup Formation : Poorly sorted dark brown and brownish grey silty coarse sand. The Burrungule Member consists of a highly carbonaceous micaceous claystone and siltstone.

Kongorong Sand : This unit, which immediately overlies the Knight Group consists of a thin bed of yellow brown limonitic quartz grit. Although thin, this unit is extensive and is useful as an aquifer in the hundred of Mayurra and elsewhere.

Lacepede Formation : This unit consists of fossiliferous brown carbonaceous silt and dark grey sandy clay, rich in glauconite pellets and greenish brown shelly marl. North of what is regarded as the Tartwaup Fault, the Lacepede Formation and Kongorong sand are missing as a result of erosion.

Gambier Limestone : The section of this unit consists of a thin glauconitic marl at the base followed by a siliceous member with abundant sponge spicules. Above this the limestone is often sugary in appearance and recrystallised, finally giving way to a richly fossiliferous porous limestone with chert or flint nodules. It is composed almost entirely of the remains of bryozoa with abundant foraminifera.

As an aquifer it is an important source of groundwater. Fresh water is reported to persist in the aquifer for some distance offshore, apparently emerging from submarine springs off Port MacDonnell.

Quaternary

Coomandook Formation : This is a fine grained, grey, shelly sand or sandy limestone, silty in part and overlies the Gambier limestone.

Bridgewater Formation : Consists of aeolian calcarenite forming stranded coastal dunes and beach deposits.

For details of stratigraphy see Fig. 14 showing a geological section from Mt. Salt to Kingston and a summary of the geology and hydrogeology of Tertiary formations is presented in Table X.

Hydrogeology

Sediments of Cretaceous age in the Gambier sub-basin have no value as aquifers. Saline waters have been reported from the Paaratte Formation in petroleum exploration wells. Some of the Upper Cretaceous sands have been invaded by fresh waters along the onshore margin of the basin but this effect diminishes rapidly inland.

The Otway Group sediments contain formation waters with salinities generally ranging from 10,000 to 27,000 mg/l, and which, because of the low regional permeability, are thought to be connate waters.

The oldest aquifer of any practical importance is one of the main sand interbeds in the Tartwaup Formation which underlies the Burrungule Member. This aquifer yields good pressure water at flow rates up to 6,500 kl/day. The salinity of the water is relatively low, ranging up to 2,000 mg/l and is suitable for irrigation, domestic and stock purposes.

The Kongorong sand of Middle Eocene age, which although thin, is useful as an aquifer in the Mayurra-Millicent area. Yields are moderate and salinities generally fall within the range 500-1,000 mg/l. The overlying Lacepede Formation acts as the upper confining bed.

TABLE X

SOUTH EAST PROVINCE - SUMMARY OF TERTIARY-QUATERNARY HYDROGEOLOGY OF OTWAY BASIN AND PADTHAWAY RIDGE

AGE		UNIT, LITHOLOGY	MAXIMUM KNOWN THICKNESS (m)	HYDROGEOLOGY
QUATERNARY	PLEISTOCENE -RECENT	Molineaux Sand, pale yellow unconsolidated sand of the sand sheets (aeolian).	-	Shallow stock bores in some area. Restricted distribution.
		"Padthaway Formation", rubbly limestone silty in parts. Occupies interdunal flats, first recognised in the Padthaway irrigation area. Fresh water sediment.	14	Good unconfined aquifer. Transmissivity 1 000-10 000 m ³ /day/m and Storage Coefficient (S) 0.03-0.2. Salinity range 800-1 500 mg/l. Contains a clayey unit (Keppoch Member) at its base acting as a confining bed.
	PLEISTOCENE	Bridgewater Formation. Stranded coastal dunes, beach ridges and beach deposits. Calcareous sands, calcarenites and sandstones. Yellow-brown.	100	Unconfined aquifer. Hydraulic coefficients vary depending on grain size distribution and development of solution features. T is 300 to 3 000 m ³ /day/m. S is 0.1-0.3.
Coomandook Formation: Sand, partly cemented in places, fine grained pale brown to grey, calcareous.		20	Minor unconfined aquifer in some areas; not generally used for water supply.	
TERTIARY	UPPER EOCENE	Loxton Sands, Parilla Sands: Sand, yellow, micaceous silty and gritty, in parts and in some areas contain oyster shells.	30	Unconfined aquifer, low yielding; not generally used for water supply.
	UPPER EOCENE-MIOCENE	Gambier Limestone. Marine calcarenites, bryozoal, shelly, marly in parts, especially towards base.	300	Unconfined aquifer throughout the South East. Developed for stock, domestic, industrial and irrigation purposes. T is 300-10 000 m ³ /day/m and S is 0.05-0.2. Karstic in some areas, especially in the Mt. Gambier area. Two possible sub-aquifers within unit.

TERTIARY	UPPER EOCENE	Lacepede Formation: Fossiliferous brown carbonaceous silt and dark grey sandy clay rich in glauconite pellets, and greenish brown shelly marl with brown and green glauconite and limonite pellets.	15	Acts as a confining bed with the basal marls of the Gambier Limestone.
	MIOCENE - UPPER EOCENE	Kongorong Sand brown to yellow-brown limonite quartz grit, clayey in parts. Sharks teeth found occasionally.	20	Unconfined aquifer used in town water supply wells at Kingston and by a paper mill at Snuggery. At Snuggery $T = 126 \text{ m}^3/\text{day}/\text{m}$ and $S = 1.2 \times 10^{-4}$.
	MIDDLE PALAEOCENE - MIDDLE EOCENE	Knight Group. Quartz silts, sands and gravels with interbedded lignitic clays (Burrungule Member) Paralic, mixed marine and deltaic. Sharks teeth found. Includes Bahgallah, Dartmoor and Tartwaup Formations.	800	Confined aquifer. Upper sandy units developed extensively for town water supplies and for limited industrial supplies (Mt. Gambier area). T is $180-500 \text{ m}^3/\text{day}/\text{m}$. S averages 10^{-4} . Wells flow in the Kingston-Beachport area and used extensively for flood irrigation of pasture.



Lower South East. Sinkhole in dolomitized Gambier Limestone south of Mt. Gambier, 1961 (hundred of Caroline).

Photo: R.K. Johns
Neg; 12914



Groundwater flowing into Glenelg River (Victoria) from a joint controlled cave (200 metres in length) in Gambier Limestone, 1974.

Photo: J.D. Waterhouse
Neg: 11504

The Gambier Limestone is an aquifer of considerable significance over large areas of the Gambier embayment. It yields plentiful supplies of water by pumping and rates exceeding 2,100 kl/day have been obtained. The quality of the water is good with salinities generally falling in the range of 500-1,000 mg/l. It is used extensively for irrigation, stock and domestic purposes. In some areas, however, e.g. along the western side of the interdunal flat areas, salinities can range up to 14,000 mg/l.

The Coomandook Formation is a moderate aquifer occurring in the northern part of the Gambier embayment. It is not generally exploited for irrigation because the upper aquifers are higher yielding.

St. Vincent Basin

This is an elongated basin extending northward from Adelaide for approximately 160 km (Figs. 5, 15). Maximum width in the vicinity of Port Wakefield is approximately 48 km and land area of the basin is approximately 5,200 km², and includes three sub-basins. These are the Adelaide Plains Basin and the Willunga and Noarlunga Embayments. The basin is a graben structure, down faulted along the Para and other faults and extending beneath St. Vincent Gulf which is a remnant of a much larger area of marine inundation.

Marine sediments of the St. Vincent Basin outcrop at intervals along the southwestern shore of St. Vincent Gulf, and are probably continuous beneath the Gulf. Sediments of the basin are mainly Tertiary-Quaternary in age.

Permian glacial sediments occur within or adjacent to the southern part of the basin and have been penetrated in a deep bore in the Adelaide area. Marine lower Permian sediments are known to occur on Yorke Peninsula, particularly at Minlaton, Stansbury and Troubridge Shoal, and also near Cape Jervis.

A geological section is presented of the St. Vincent Basin from Kingston Park, on the coast southwest of Adelaide, to Dublin a distance of about 72 km (Fig. 16). This shows the gentle dip of the sediments to the south with an average gradient of about 1 in 350. The various formations thicken in a southerly direction; for example, the Port Willunga beds thicken from about 27 m at Dublin to almost 198 m at Grange, west of Adelaide. Table XI shows the stratigraphic succession of basin sediments in the St. Vincent Basin.

The oldest non-marine sediments are sands with some lignites succeeded by paralic clays, silts and sands. The oldest aquifer within the system is represented by the North Maslin Sands of Lower Eocene age, which are mainly non-marine. South Maslin Sands which are regarded as partly marine were probably deposited under estuarine conditions and form part of the deepest aquifer.

A significant marine transgression occurred during Middle-Upper Eocene times in the southern part of the St. Vincent Basin - marked by the Tortachilla Limestone. A thickness of 30 m was intersected in Troubridge Shoal bore, off the coast of Yorke Peninsula. Following this the

TABLE XI

ST. VINCENT BASIN - SUMMARY OF HYDROGEOLOGY

AGE		UNIT, LITHOLOGY	MAXIMUM KNOWN THICKNESS (m)	HYDROGEOLOGY
QUATERNARY	RECENT	<u>Semaphore Sand</u> . White, fine grained silica sand occurring as dunes near the coast.	15	Unconfined aquifer: contains groundwater in some areas. Yields generally are quite small and salinity variable. Small quantities used for gardens in Grange-Semaphore area.
	RECENT	<u>Fulham Sand</u> . Red brown quartz sand of fossil dunes.	8	Not known to contain groundwater.
		<u>Molineaux Sand</u> . Pale yellow. Occurring as southeasterly trending dunes mainly in the Balaklava area.		
	RECENT	<u>St. Kilda Formation</u> . Shallow marine deposits including shell beds, sand and clay. Occurs in coastal areas.	5	Unconfined aquifer: groundwater is highly saline with a salinity generally at least equal to sea water.
	RECENT	<u>Lipson Formation</u> . Estuarine clay, silt and fine sand occurring in the Port Adelaide area.	4	Probably contains only highly saline groundwater.
	LOWER PLEISTOCENE	<u>Pooraka Clay</u> . Alluvial clay, silt and sand generally red brown in colour.	3	Confining bed.
MIDDLE PLEISTOCENE	<u>Glanville Formation</u> . Shallow marine deposits including sand and shell beds, adjacent to coast.	5	Contains highly saline groundwater.	

QUATERNARY	LOWER PLEISTOCENE	Hindmarsh Clay: Fluvial and alluvial clay, silt, sand and gravel in outwash areas. Occurs over almost whole of basin.	120	Up to four semi-confined aquifers consisting of thin sand or gravel beds. Forms a confining bed to Aquifer "A". Average transmissivity of aquifers is $250 \text{ m}^3/\text{day}/\text{m}$ and Storage Coefficient 5×10^{-3} to 10^{-1} . Relatively saline groundwater except near streams.
	?PLIO- PLEISTOCENE	Carisbrooke Sand. Fluvial, alluvial yellow fine sand and silt with some clay and thin gravel beds in outwash areas. Occurs over whole area except within 4-5 km of the coast. Restricted occurrence in Willunga Sub-basin.	54	Confined aquifer but very little development because of low yields. May be hydraulically continuous with Aquifer "A" in some areas eg. near Salisbury.
TERTIARY	UPPER PLIOCENE	Hallett Cove Sandstone, Dry Creek Sands. Limestone, calcareous sandstone and sand of marine deposition. Usually abundantly fossiliferous. Occurrence generally restricted to area south of Two Wells and restricted to coastal area in Willunga Sub-basin.	75	Confined aquifer: part of Aquifer "A" which is extensively developed for irrigation supplies in Northern Adelaide Plains.
	MIDDLE- LOWER MIOCENE	Port Willunga Beds (upper part). Fossiliferous sandy limestone, fine grained, occurring south of Two Wells. Restricted to southern part of Willunga Sub-basin.	45	Confined aquifer: with Dry Creek Sands forms Aquifer "A" which has an average transmissivity of $70 \text{ m}^3/\text{day}/\text{m}$ and Storage Coefficient of 8×10^{-4} .
	LOWER MIOCENE	Munno Para Clay. Blue-grey sandy shelly clay, missing in some coastal areas and north of Two Wells.	12	Confining bed between Aquifers A and B.
	LOWER MIOCENE TO J. EOCENE	Port Willunga Beds (lower part). Fossiliferous limestone with sand and sandstone grading to a dense siliceous unit towards the base.	170	Confining aquifer. Developed for irrigation supplies in the Northern Adelaide Plains Aquifer "B" - average transmissivity above siliceous zone is $55 \text{ m}^3/\text{day}/\text{m}$ and storage coefficient 5×10^{-4} .
	UPPER MIOCENE	Blanche Point Marls. Marl, siltstone, limestone, fossiliferous and glauconitic.	130	Generally a confining bed but may be a low grade aquifer in some areas.

TERTIARY	UPPER EOCENE	<u>Tortachilla Limestone.</u> Fossiliferous glauconitic limestone, sand and marl.	30	May form an aquifer with South Maslin Sands.
	UPPER EOCENE	<u>South Maslin Sands.</u> Marginal marine sand, glauconitic and poorly fossiliferous.	40	Confined aquifer. Part of main producing aquifer of Willunga Sub-basin. Aquifer "C" of Northern Adelaide Plains where it is highly saline.
	UPPER-MIDDLE EOCENE	<u>Muloowurtie Clay.</u> Green to blue clay carbonaceous and silty.	40	Confining bed where present.
	MIDDLE-LOWER EOCENE	<u>North Maslin Sands.</u> Pebbly quartz sand, slightly clayey, carbonaceous; fluviatile and estuarine deposition. Contain thin impure lignites in places.	30	Confined aquifer. With South Maslin Sands forms main aquifer in Willunga Sub-basin. Aquifer "C" of Northern Adelaide Plains.
PALEO-ZOIC	LOWER PERMIAN	<u>Cape Jervis Beds.</u> Till, sandstone, and fossiliferous shale of marine and non-marine deposition.	30	Confined aquifer - probably contains only saline groundwater within St. Vincent Basin.
UPPER PROTERO-ZOIC	ADELAI-DEAN	<u>Adelaide System.</u> Slates, quartzite, dolomite, tillite, shale and limestone occurring below younger sediments.	-	Probably contain only salt water beneath basin sediments. Useful aquifers in fractured rocks adjacent to St. Vincent Basin e.g. Willunga Embayment yields of 400-1 200 kl/day and salinities of 1 000-2 000 mg/l.

Blanche Point Marls were deposited, attaining a maximum known thickness of 131 m at Croydon. Marine sedimentation continued with deposition of the Port Willunga Beds, Upper Eocene to Miocene in age. Following this, with a slight angular unconformity, Pliocene Dry Creek Sands and Hallett Cove Sandstone were deposited.

Apart from minor marine transgressions this marked the end of marine sedimentation within the present land area of the St. Vincent Basin. A thick succession of clays (Hindmarsh Clay) with numerous thin sand lenses was formed, the unit attaining a maximum thickness of about 120 m.

The Adelaide Plains Basin is considered as a separate sub-basin on hydrogeologic grounds; aquifers within it contain good quality groundwater, whereas the same aquifers in their continuation northward in the St. Vincent Basin yield only salt water. Salinity of groundwater in Tertiary sediments north of Two Wells increases, within 8 kilometres of the town, to more than 7,000 mg/l.

The Willunga and Noarlunga Embayments are separated by faulting from the main basin; details of the three sub-basins are given below:-

Adelaide Plains Sub-Basin

There are two important pressure aquifers within the basin, the upper consisting of Dry Creek Sands and the upper portion of the Port Willunga Beds (Aquifer A). The lower aquifer which is below a thin clay bed, consists of the lower section of the Port Willunga beds (Aquifer B). The clay bed (Munno Para Clay) has a maximum known

thickness of 12 m and is not continuous throughout the basin. Thus there is hydraulic connection between the two aquifers in places, particularly in the area north of the Gawler River, and west of Virginia.

Salinity of both aquifers has been strongly influenced by intake from the Torrens, Little Para and Gawler Rivers which traverse the plain. Adjacent to the rivers salinity is generally less than 1,000 mg/l but increases markedly to 3,000 mg/l or more in areas of restricted intake, for example at Elizabeth.

Although the transmissivity is relatively low some relatively large yields, up to 3,000 kl/day have been obtained.

The aquifers in the northern part of the Adelaide Plains are currently being pumped at an annual rate of 21×10^6 kl per year. This is a Proclaimed Region under the Water Resources Act, 1976 and all irrigation bores are licensed to be pumped at a certain annual rate.

To the south of the Proclaimed Region in the western suburbs of the City of Adelaide the volume pumped is unknown. However, large quantities are pumped for use in industry and for the watering of golf courses. The Metropolitan Water Supply has been augmented from bores in the Adelaide Plains on six occasions since 1915; the last occasion was in the summer of 1967-68 following an exceedingly dry year. At that time a volume of 9.5×10^6 kl was pumped into the distribution system during a 7 month period.



Northern Adelaide Plains, Little Para River at Carisbrooke Reserve; a groundwater recharge zone, 1968.

Photo: B.M. Harris
Neg: 21167

PLATE VIII

The potentiometric surface of Aquifers A and B in the more heavily pumped parts of the Northern Adelaide Plains Proclaimed Region declined steadily from 1959 to 1967 when restrictions on use were first introduced. Because of the increasing demand for water for irrigation the stage was reached when output greatly exceeded recharge. Total recharge to all aquifers is now estimated at 7.4×10^6 kl per year. Further use of groundwater in this important market gardening area becomes a problem in management of the resources. With the reduction of head in the pressure aquifers there is a possibility of increasing salinity from adjacent or overlying high salinity groundwater. No increases in salinity which can be definitely related to a general increase in salinity of the pressure aquifer have yet been established. However, a group of wells north of Virginia have increased considerably in salinity and is apparently related to downward leakage of saline water or to construction.

Willunga Embayment

This basin is located about 32 km south of Adelaide and has an area of about 155 km^2 , trending in a general northeasterly direction (Figs. 5, 15). The main surface stream of the basin is Pedlar Creek, a small stream rising in the hills to the east.

Mixed farming, including vineyards is carried on in the area. This basin, which is open to St. Vincent Gulf along its western margin, contains sediments which are part of the normal sedimentation of the St. Vincent Basin (Table XI). The basin is faulted in the east against

the Precambrian basement mass by the Willunga Fault. Maximum known depth of the basin is 207 m where North Maslin Sands rest on basement.

The Port Willunga Beds are an aquifer but are little used in the basin. They are limestones or bryozoal sands, equivalent in age to the Gambier Limestone of the Murray-Otway Basin. The Maslin sands are the most important aquifer in the basin providing approximately 75% of the water used for irrigation purposes.

Salinity of groundwater within the basin is generally less than 1,500 mg/l, increasing to 2,000 mg/l or more in the coastal area. Yields are variable, particularly within the Maslin sands in the eastern part of the embayment. No tests to determine aquifer characteristics have been done; apart from the Port Willunga beds they are expected to be quite variable.

Noarlunga Embayment

This is a small tectonic valley, approximately 24 km south of Adelaide (Fig. 19). Sediments range upward in age from Eocene with lignites occurring in association with the North Maslin Sands. Younger marine sediments, including Blanche Point Marls, form cliffs along the coast near Noarlunga. Groundwater in the embayment is not a significant resource - it is used on only a very limited scale for stock and irrigation. Salinity is generally less than 3,000 mg/l.

Yorke Peninsula

Sediments along the east coast of Yorke Peninsula include Tertiary sandstone, limestone and marl of the St. Vincent Basin. Maximum thickness of these sediments is approximately 40 m and they rest on Permian sands, Cambrian or Adelaidean rocks.

The Tertiary sediments contain groundwater of relatively high salinity which is suitable only for stock.

Groundwater also occurs in aeolianite of the Bridge-water Formation in the Carribie and Para Wurlie Basins (Fig. 15). The latter provides a water supply for the township of Warooka. Aeolianite occurs over much of the western part of the "foot" of the peninsula but salinity is highly variable.

Permian and older rocks contain groundwater which is not considered to be a significant resource because of high salinity and low yields.

The hydrogeology of Yorke Peninsula is summarised in Table XII.

Hindmarsh Tiers and Myponga Valley

These two small basins in the southern Mt. Lofty Ranges (Fig. 19) are filled with sediments ranging in age from Palaeozoic to Quaternary. Lithologies of the various units of the Hindmarsh Tiers basin are presented in Table XIII. Sediments occurring within the Myponga Basin are of a similar type but occur over a larger area. Groundwater occurring in the limestone is of low salinity and is used for irrigation of pastures. Groundwater also occurs in the underlying Permian sediments but is little used because of lower yields. The Permian sand has a low permeability and because grain size is relatively uniform there are problems in developing a sand free supply.

TABLE XII

YORKE PENINSULA - SUMMARY OF HYDROGEOLOGY

AGE		UNIT, LITHOLOGY	MAXIMUM KNOWN THICKNESS (m)	HYDROGEOLOGY
QUATERNARY	RECENT	Unnamed aeolian sand: fine grained, white to light brown, possible equivalent to Molineux Sand.	30	Not known as an aquifer.
	PLEISTOCENE	<u>Bridgewater Formation</u> : Aeolianite; calcareous sand and rounded shell grains. Occurs mainly from Corny Point to Cape Spencer.	60	Unconfined aquifer of Carribie and Para Wurlie Basins. Yields 300-1 300 kl/day are obtained but may exceed 2 500 kl/day in some areas. Salinity variable, in basins less than 850 mg/l but rising to 3 000-4 000 mg/l elsewhere. Best quality groundwater generally within 3-4 metres of the surface.
TERTIARY	PLIO-CENE	<u>Hallett Cove Sandstone</u> : Dense sandy limestone, rich in fossils occurring in east coast cliffs, south of Wool Bay.	3	Not known as an aquifer.
	MIDDLE MIOCENE-OLIGOCENE	<u>Port Willunga Beds</u> : Soft bryozoal limestone and sandy limestone, occurring mainly in cliffs along the east coast south of Port Julia.	30	Unconfined aquifer yielding stock water supplies in the Stansbury-Edithburg areas. Salinity in the range 2 000-7 000 mg/l and known yields less than 170 kl/day.
	UPPER PERMIAN	<u>Blanche Point Marls</u> : Shelly clays with discontinuous bands of dense fine grained fossiliferous sandstone. Occurrence confined mainly to east coast near Pine Point.	2	Confining bed where present.

	MIDDLE EOCENE	Muloowurtie Clay: Ochreous sandy clay with lenses of fossiliferous sand (Maslin Sands) the latter having a thickness exceeding 120 m near Price.	5	Confining bed (Muloowurtie Clay). Associated sands (Maslin Sands) probably contain only saline groundwater.
PALAEOZOIC	LOWER PERMIAN	Permian Clay - boulder till and fluvio-glacial sand, occurring mainly near Yorketown in the floor of salt lakes and beneath Tertiary and Quaternary sediments. Occupies depressions in Precambrian basement.	235	Generally a confining bed but sandy variants may contain small quantities of saline groundwater.
	MIDDLE CAMBRIAN	Ramsay Limestone: Blue grey crystalline nodular limestone. Minlaton-Curramulka area	30	The limestone may contain small quantities of groundwater, quality unknown.
	LOWER CAMBRIAN	Unnamed: red beds, clastics, evaporites and shales.	30	Generally an unconfined aquifer in the Minlaton-Curramulka area. Salinity 2 000-3 000 mg/l and yields 85-250 kl/day.
		Parara Limestone: Blue grey crystalline nodular limestone.	290	
	Kulpara Limestone: Blue grey limestone with Archeocyatha. Occurs in the Kulpara-Ardrossan-Urania area.	320	Generally an unconfined aquifer in the Minlaton-Curramulka area. Salinity 2 000-3 000 mg/l and yields 80-250 kl/day.	
PROTEROZOIC	ADELAIDEAN	Adelaide System: Conglomerates, sandstones and shales.	-	Not known as an aquifer.
	LOWER PROTEROZOIC	Gneiss, schist, granite, pegmatite, including Moonta Porphyry.	-	Not known as an aquifer.

TABLE XIII

HINDMARSH TIERS - SUMMARY OF HYDROGEOLOGY

AGE	UNIT, LITHOLOGY	MAXIMUM KNOWN THICKNESS (m)	HYDROGEOLOGY	
QUATERNARY	?PLEISTOCENE	<p><u>Unnamed clays:</u> Stiff mottled clays similar to Hindmarsh Clay. Sandy in part, with some ironstone pebbles. Occurring in floor of the valley.</p>	30	Form confining bed to main aquifer.
TERTIARY	OLIGO-MIOCENE	<p><u>Unnamed:</u> Coarse grained highly fossiliferous limestone. Equivalent to Pt. Willunga Beds of the Willunga Basin, occurring mainly in eastern end of valley.</p>	120	Confined aquifer, high well yields of 2 500-3 500 kl/day, low salinity (750-1 000 mg/l). Transmissivity 10^4 - 10^5 m ³ /day/m. Groundwater discharges into Hindmarsh River 0.5 km upstream of Hindmarsh Falls.
UPPER PROTEROZOIC	LOWER PERMIAN	<p><u>?Cape Jervis Beds:</u> Unconsolidated to well cemented fine quartz sands, pebbly in part, with basal conglomerates. Occur throughout the valley.</p>	100	Confined aquifer with large storage and low permeability. Only developed in western end where limestone absent.
LOWER PALAEOZOIC	CAMBRIAN	<p><u>Kanmantoo Group:</u> impure arkose, phyllite and greywacke.</p>	-	
UPPER PROTEROZOIC	ADELAI-DEAN	<p><u>Torrensian Series:</u> Slate, siltstone, quartzite, arkose and tillite.</p>	-	Cambrian and Precambrian rocks are not developed for water supply in the basin area. Small yields are obtained from wells entering these rocks in surrounding areas.
LOWER PROTEROZOIC		<p>Schist and gneiss, including auger gneiss.</p>	-	

Eucla Basin

A large basin marginal to the Great Australian Bight, the Eucla Basin occurs beneath the flat Nullabor Plain (Fig. 5). Total area of the basin is approximately 176,000 km² of which 41,000 km² is in South Australia. Maximum thickness of sediments occurs in Western Australia and in South Australia Tertiary sediments with a thickness of 423 m were intersected in Yangoonabie Well.

Within South Australia sedimentation in the basin apparently commenced in the Permian; claystone from Yangoonabie Well has been placed as lower Permian in age (Harris and Ludbrook, 1966) on the basis of foraminifera and microflora. No glaciogene sediments were observed in the material from this well. The geological succession is shown in Fig. 17 and Table XIV.

The water table in the Wilson Bluff Limestone is just above or very close to sea level, with a very gentle seaward slope. This indicates an aquifer of high permeability combined with low intake rate. If it were not for the porous and cavernous nature of the limestone there would be very little intake from the very low rainfall over the basin, averaging about 180 mm per year.

There are no data on aquifer characteristics as no pumping tests have been performed. However, in common with limestone aquifers elsewhere, the Wilson Bluff Limestone could be expected to have a high Transmissivity and Storage Coefficient.

TABLE XIV

EUCLA BASIN - SUMMARY OF HYDROGEOLOGY

AGE		UNIT, LITHOLOGY	MAXIMUM KNOWN THICKNESS (m)	HYDROGEOLOGY
QUATERNARY	PLEISTOCENE	<u>Bridgewater Formation</u> : Aeolianite occurring at head of Bight.	-	May contain minor quantities of groundwater. "Soaks" also occur in sandhills of coastal area, quality variable.
TERTIARY	MIDDLE-UPPER EOCENE	<u>Nullarbor Limestone</u> : Dense crystalline limestone with abundant mollusca and foraminifera; frequently cavernous.	52	Unconfined aquifer, comprising Nullarbor Limestone, Wilson Bluff Limestone and Hampton Sandstone; groundwater occurring at 50-85 metres. Lowest salinity is approximately 9 500 mg/l near head of the Bight; exceeding 14 000 mg/l over most of the basin. Low salinity water occasionally found at exposed water table in caves after heavy rain resulting from rapid recharge.
	MIDDLE EOCENE	<u>Wilson Bluff Limestone</u> : Bryozoal chalky limestone, glauconitic at base.	130	
	MIDDLE EOCENE	<u>Hampton Sandstone</u> : Paralic sandstone and conglomerate, limonitic and glauconitic.	25	
	MIDDLE EOCENE	<u>Pidinga Formation</u> : Sand, silt and clay carbonaceous and pyritic.	26	
MESOZOIC	LOWER CRETACEOUS	Unnamed: Coarse sandstone at base overlain by a thick sequence of shales.	190	The sandstone is a confined aquifer; water is under considerable pressure rising to 62 metres from surface at Guinewarra Well. Salinity generally exceeds 14 000 mg/l.
UPPER PALEO.	LOWER PERMIAN	Unnamed: Claystone with foraminifera and abundant microflora.	80	Not known as an aquifer.
PRE-CAMBRIAN		Unnamed: Laminated slates (early Adelaidean) granite and feldspar porphyry (Lower Proterozoic).	-	Not known as an aquifer.



Eucla Basin; Cliffs of the Great Australian Bight.
Grey Nullarbor Limestone overlying white Wilson
Bluff Limestone. Height of cliffs approximately 85
metres. 1973.

Photo: A.F. Williams
Neg: 9978

PLATE IX

Officer Basin

Located in the northwest of South Australia, south of the Musgrave Block, the Officer Basin (Fig. 5) is not regarded as significant from a groundwater view point at the present time. A thick succession of early Palaeozoic sediments occurs in the basin, as revealed by a few exploration wells.

Groundwater occurring within these sediments in the southern part of the basin has a very high salinity, exceeding 35,000 mg/l. Toward the northern boundary of the basin, however, salinity is low in sediments between 60 and 300 m below the surface, as revealed in several wells south of the Birksgate and Everard Ranges. In addition, one well penetrated aquifers where salinity is less than 5,000 mg/l at depths down to 1,220 m.

The Officer Basin is regarded generally as an area of "insufficient data". The relatively low salinity groundwater which has been intersected in a few wells is regarded as fossil water, derived from intakes along the southern margin of the Musgrave Block.

GROUNDWATER RESOURCES IN FRACTURED ROCKS

(MAP 3)

The occurrence of groundwater in basement rocks depends on a number of factors but the most important which affect quality and quantity are:-

-Degree and extent of joints or other openings
-Lithology
-Extent of weathering
-Recharge, which is dependent on quantity and frequency of rainfall or run-off.

The groundwater of fractured rocks is considered in the following six sub-divisions : Musgrave Block, Gawler Block, Olary arc, Flinders Ranges, Mt. Lofty Ranges and Kangaroo Island and locations are shown in Fig. 18.

Musgrave Block

The oldest rocks occurring in the Musgrave Block are lower Proterozoic granulites intruded by basic and ultra basic dykes in addition to granitoid rocks. They outcrop in the Musgrave and other ranges in the North West Aboriginal Reserve.

Overlapping the older rocks are Adelaidean metasediments and Palaeozoic rocks which outcrop at Indulkana. Mesozoic sediments of the Great Artesian Basin occur to the east overlapping the older rocks. Hydrogeology of the northwestern part of the State is presented in Table XV. Salinity of groundwater in the area varies over wide ranges, reflecting differing rock texture and structure and recharge conditions.

Gawler Platform

This is an area of basement rocks extending from Spencer Gulf to the west, generally buried beneath younger sediments towards the west and northwest, and extending northward to the East-West railway. The rocks consist of Adelaidean and older rocks, intruded by the Gawler range volcanics.

Groundwater is exploited almost entirely for stock purposes but there is minor irrigation in the southern part of Eyre Peninsula near Port Lincoln.

TABLE XV
NORTHWEST OF SOUTH AUSTRALIA - SUMMARY OF HYDROGEOLOGY

AGE		UNIT, LITHOLOGY	MAXIMUM KNOWN THICKNESS (m)	HYDROGEOLOGY
QUATERNARY	RECENT	Unnamed: Fluvial silts, sands and gravels of modern drainage channels. Occur in floodplains and areas of internal drainage.	30	Unconfined aquifer: Yields generally of wind-mill proportions with salinity extremely variable, from potable to greater than stock tolerance. Lowest salinity adjacent to drainage lines.
		Unnamed: aeolian sands, generally medium to coarse grained quartz sands fixed by vegetation. Occur in eastern Simpson Desert and western Officer Basin.	Extremely variable	Unconfined aquifer: yields small and water is commonly potable. More saline groundwater at depth
TERTIARY	TERTIARY- QUATERNARY (?PLIOCENE)	Mt. Willoughby, Alberga and Mangatitja Limestones - limestone and dolomitic limestone often with chalcedonic cap. Sporadic occurrence throughout the northwest.	5	Unconfined aquifer: exploited in parts of the Northwest Aboriginal Reserve for low yields of potable water. Limited in areal extent.
MESOZOIC	LOWER CRETACEOUS	Coorikiana Sandstone: fine to coarse grained, glauconitic sandstone, along drainage lines, western margin of Great Artesian Basin.	-	Not confirmed as an aquifer - may be exploited for windmill supplies of stock quality water.
		Bulldog Shale - blue grey shale/claystone when fresh - weathered to mottled red, brown, orange, buff and purple clay/shale. Minor silt and sand lenses. Occurs in Mt. Willoughby area and throughout Great Artesian Basin.	120	Unconfined "fractured rock" aquifer (structurally controlled) in the Mt. Willoughby area, salinity <4 000 mg/l - nitrate may be high up to 70 mg/l. Yields 40-80 kl/day.

MESOZOIC		Cadna-owie Formation - fine to coarse clayey sandstones, micaceous; ferruginised in part. Aquifer of Great Artesian Basin. Outcrops along western margin.	45	Confined aquifer but unconfined along western margin. Salinity approximately 100 000 mg/l (southern part) to 3 000 mg/l. Yields up to 850 kl/day.
	UPPER JURASSIC	Algebuckina Sandstone - poorly cemented, white to pale brown, fine to coarse grained quartz sandstone - kaolinitic with pebble horizons. Occurs over the greater part of the Great Artesian Basin.	30	Similar to the Cadna-owie Formation
PALEOZOIC	ORDOVICIAN	Cartu Beds, Blue Hills Sandstone, Mt. Chandler Sandstone: Sandstones, quartzites with interbeds of silt and shale - commonly feldspathic and kaolinitic. Occur at Indulkana.	200	Unconfined aquifer - local recharge via drainage lines. Salinity variable depending on recharge - from 250 to 2 000 mg/l in the Indulkana area.
UPPER PROTEROZOIC	ADELAIDEAN	Rodda Beds, Tapley Hill Formation: generally siltstones, shales and slates; dolomitic and calcareous with interbeds of dolomite, quartzite and sandstone. Occur from Indulkana to Alberga River and near Tarcoola.	200	Unconfined aquifer: local recharge via drainage lines. Generally stock quality water - salinity dependent upon recharge - 1 000 to 5 000 mg/l. Yields up to 250 m ³ /day.
MIDDLE PROTEROZOIC	CARPENTARIAN	Dolerite and Gabbro dykes, basic and ultra basic intrusives, granitoid rocks, adamellites, charnockites. Occur throughout the Musgrave Block.	-	Unconfined aquifer - Water quality is potable to good stock; nitrate content may be above human tolerance.
LOWER PROTEROZOIC		Granulites - amphibolite to granulite facies. Occur throughout the Musgrave Block.	-	

Salinity generally exceeds 14,000 mg/l but falling to 7,000 mg/l or less in areas of preferred recharge and higher rainfall.

Olary Arc

This area forms a northeasterly arm of basement rocks, extending from the Flinders Ranges through Peterborough to Cockburn and eastward into New South Wales. The rocks are Adelaidean metasediments including quartzites, schists and slates intruded by igneous rocks in the Olary area. Groundwater has been developed almost entirely for stock supplies but has been used occasionally to augment town water supplies and for small scale mining activity. Salinity is generally in the range of 3,000-14,000 mg/l but better quality water may occur in areas of good recharge.

Flinders Ranges

The area included is from Mt. Remarkable to Mt. Painter and the rocks consist of Adelaidean metasediments with Cambrian limestones and dolomites in the northern part. Groundwater is used mainly for stock although it is suitable for limited irrigation in some areas and is used for water supply at Arkaroola, Hawker and Wilpena.

Water with a salinity of less than 3,000 mg/l is obtainable north of Hawker but further south it generally exceeds 7,000 mg/l.

Mt. Lofty Ranges

The ranges are considered to extend from Cape Jervis to Mt. Remarkable and consist mainly of Adelaidean sediments, highly metamorphosed in places. Lower Proterozoic

rocks occur over relatively small areas near Inglewood, Aldgate and Yankalilla (Fig. 19). Cambrian rocks including limestone, sandstone, greywacke and marble occur in the southern and eastern Mt. Lofty Ranges and in the north. Rocks of the Kanmantoo Group, occurring prominently in the eastern part of the ranges generally contain water of high salinity. Groundwater occurring in other rock types is variable in salinity with the best quality, less than 200 mg/l, being obtained near Mt. Lofty. In this area rainfall exceeds 1,200 mm per year over an area of about 5 km².

Two important aquifers are the Aldgate Sandstone and Stonyfell Quartzite, both of which contain low salinity groundwater in the ranges east of Adelaide. Yields of up to 2,000 kl/day have been obtained and the average for Adelaidean rocks is approximately 500 kl/day. Lower Proterozoic rocks are generally lower yielding, averaging 50 kl/day.

The geology and hydrogeology of the southern Mt. Lofty Ranges is presented in Table XVI. In general salinity within Adelaidean rocks is less than 3,000 mg/l as far north as Crystal Brook and Mt. Bryan but increases to 7,000 mg/l further north.

Kangaroo Island

Basement rocks of the island are metasediments of the Kanmantoo Group, intruded in places by granitoid rocks of Palaeozoic age and near Kingscote by basalt of Cainozoic age. Overlying basement rock in a small area near Kingscote is Permian glacial till which is not regarded as a significant aquifer. Tertiary limestone occurs near Kingscote, Cape Willoughby and Flour Cask Bay.

TABLE XVI

MT. LOFTY RANGES - SUMMARY OF HYDROGEOLOGY

AGE	SEQUENCE, LITHOLOGY	SALINITY (mg/l)	HYDROGEOLOGY
PALAEOZOIC	CAMBRIAN Kanmantoo Group: Greywackes, micaceous quartzites, schists and phyllites, with prominent quartzite and limestone beds near base. Zone of pronounced metamorphism from Macclesfield-Angaston. Major rock type of eastern Mt. Lofty Ranges and Fleurieu Peninsula.	5 000- 15 000	Generally impervious rocks containing poor quality water. Yields usually less than 170 kl/day. Better quality water (1 000-3 000 mg/l) and higher yields locally available from limestone, sandstone and some greywacke beds, e.g. Springton-Mt. Pleasant, Rapid Bay-Delamere, Macclesfield.
	LOWER CAMBRIAN Hawker Group Equivalents: Carbonaceous shales, limestone, calcareous shales and siltstones with interbedded sandstones. Metamorphosed to slates, marbles, meta-siltstones and quartzites in Angaston area. Well developed jointing and fissures.	1 000- 3 000	Potentially good sources of low salinity water. Yields up to 700 kl/day.
UPPER PROTEROZOIC	ADELAIDEAN Marinoan Series: Chocolate and grey siltstone and shales with interbedded greywacke. Quartzites developed at top, tillites with feldspathic quartzite and quartzite and greywacke at base of sequence.	1 000- 3 000	Generally low permeability with small yields. Better supplies potentially available from quartzite beds.
	ADELAIDEAN Sturtian Series: Calcareous and laminated siltstones and shales (Tapley Hill Formation), massive boulder tillite (Sturt Tillite), and laminated sandy siltstone with prominent feldspathic quartzite and arkose beds at base (Belair Sub-group).	500- 3 000	Groundwater prospects generally good due to quartzose nature of sediments, and well developed cleavage and jointing. Yields from 170-600 kl/day. Brighton Limestone and basal quartzites are best aquifers, yielding up to 900 kl/day with salinities commonly less than 1 500 mg/l.

UPPER PROTEROZOIC	ADELAIDEAN	<p><u>Torrensian Series</u>: Calcareous siltstones and shales with minor dolomite beds (Montacute Dolomite). Stonyfell Quarries and Aldgate Sandstone extensively developed in Mt. Lofty region east of Adelaide. Pronounced metamorphism to schists and slates, along eastern portion from Mt. Barker to Greenock. Predominant rock-types of western Mt. Lofty Ranges.</p>	500- 3 000	<p>Less altered rocks, generally permeable with good capacity to transmit and yield water. Metamorphosed rocks generally more clayey and less permeable - water stored mainly in joints and fractures of coarser, more sandy units. Lower salinities (400-500 mg/l) in higher rainfall areas near Mt. Lofty. Yields 170-350 kl/day, up to 2 000 kl/day in strongly fractured areas. Aldgate Sandstone generally yields moderate supplies of good quality water.</p>
LOWER PROTEROZOIC	CARPENTARIAN	<p><u>Barossa Complex</u>: Mica-quartz schist and granitic gneiss of Inglewood-Humbug Scrub; Aldgate; and Yankalilla-Mt. Monster areas.</p>	150-	<p>Limited data available. Not considered to be good aquifers. Small yields of the order 50 kl/day mainly in the near surface zones. Salinities increase with depth.</p>

TABLE XVII

KANGAROO ISLAND - SUMMARY OF HYDROGEOLOGY

AGE		UNIT, LITHOLOGY	MAXIMUM KNOWN THICKNESS (m)	HYDROGEOLOGY
QUATERNARY	PLEISTOCENE	Bridgewater Formation: Calcareous sandstone of aeolian deposition occurring along southern coast.	120	Unconfined aquifer generally with fresh water overlying saline water. Salinities variably may be as low as 700 mg/l but generally at least 1 000 mg/l. Wells yield up to 50 m ³ /day.
		Unnamed: flow basalt of Kingscote and Penneshaw with columnar structure.	Unknown	Not known as an aquifer.
TERTIARY		Unnamed: limestone, fossiliferous. Restricted occurrences at Kingscote, Cape Willoughby and Flour Cask Bay.	20	Unconfined aquifer. Low salinity zones of 600-900 mg/l occur in good recharge areas near the Cygnet River, surrounded by highly saline groundwater, probably connate.
UPPER PALAEO- ZOIC	LOWER PERMIAN	Cape Jervis Beds: Unconfined fine sands and clays - glacial till. Occurs mainly in Kingscote-Smith Bay area with minor occurrences near Penneshaw.	-	Unconfined but a low grade aquifer because of low permeability. Groundwater is highly saline.
PALAEOZOIC	CAM- BRIAN	Kanmantoo Group: Quartzite, greywacke, schist. Occurs over most of island, excluding Stokes Bay-Nepean Bay area.	-	Unconfined aquifer yielding small stock supplies salinity ranging from 8 000 to 15 000 mg/l.
	LOWER CAMBRIAN	Hawker Group Equivalents: Sandstone, conglomerate, shale and limestone with archeocyatha. Restricted occurrence from Stokes Bay to Pt. Marsden on north coast of island.	-	Probably similar to Kanmantoo Group.

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LOWER PALAEO- ZOIC		Granite and related rocks occurring along the south coast of the island.	- Not regarded as an aquifer.
UPPER PROTER- ZOIC	ADELAI - DEAN	Adelaide System: Phyllites and interbedded quartzites near top. Occurrence restricted to a narrow zone extending from Newland Bay to Cape Forbin.	- Probably contain only saline groundwater.

Aeolianite of the Bridgewater Formation occurs along the south coast and in places provides relatively low salinity groundwater.

A summary of the hydrogeology of Kangaroo Island is presented in Table XVII.

DISTRIBUTION OF BEST AVAILABLE WATER (MAP 4)

Reference to MAP 4 shows that the largest area of best available water, with a salinity of less than 1,000 mg/l, occurs in the Great Artesian Basin.

The groundwater of this basin is used for stock and to a limited extent for town water supplies. Although total salinity of groundwater of the pressure aquifers is low it is not suitable for irrigation, because of high bicarbonate content. Along the western margin the waters are highly corrosive and with a high sulphate content. The pressure water, because of its high temperature needs to be cooled before stock can drink it. The present method of cooling is to allow the water to flow in natural channels and consequently the loss is considerable.

Thus the Great Artesian Basin contains an enormous volume of low salinity groundwater in storage but because of its chemistry it is restricted mainly to stock use.

With the exception of the Mt. Lofty Ranges, parts of the St. Vincent Basin and small basins on Yorke and Eyre Peninsula groundwater over the remainder of the State generally has a salinity of at least 3,000 mg/l and there are large areas where it exceeds 14,000 mg/l.

Yields in some of the smaller basins may be very large, for example, on Eyre Peninsula more than 10,000 kl/day was obtained in a pumping test at Uley South. Thus the small basins provide significant volumes of groundwater used for town water supplies, irrigation, stock and for industry.

Map 4, in common with the other maps, is necessarily generalised and isolated occurrences of low salinity groundwater will be found in areas not indicated on the map. For example, a test well in alluvial sediments west of Kimba yielded water with a salinity of approximately 1,200 mg/l but salinity of groundwater in the area generally exceeds 14,000 mg/l. Because of the scale of the map it is not possible to show the relatively low salinity groundwater occurring in scattered alluvial aquifers, for example in the Gawler Ranges.

On Map 4 high and low yields are indicated by depth of colour where salinities are less than 3,000 mg/l. Yields are divided into two groups - greater than or less than 1,100 kl/day (10,000 gallons per hour). In addition, for all salinities greater than 3,000 mg/l yield is considered to be less than 1,100 kl/day.

These divisions are presented to give a general guide to expected yield. However, there will be many variations depending on the geology, particularly in the fractured rocks of the Mt. Lofty and Flinders Ranges.

LEGISLATION

History

Legislation to control the use or contamination of groundwater first came into operation in this State in February 1967. The Act, termed the Underground Waters Preservation Act was applied to a Defined Area of the Northern Adelaide Plains, where increasing use of underground water for irrigation led to declining water levels. Most of the irrigation area was defined in 1967 but it was increased in 1970 and meters were fitted to all irrigation and industrial supply wells, to which quotas were applied.

A small part of the South East was proclaimed as a Defined Area in December 1967 to control waters of the artesian aquifer in the Kingston-Beachport area. In June 1973 the defined areas were increased to cover most of the South East. At the same time a defined area was prescribed on Eyre Peninsula covering Counties Flinders, Musgrave and Robinson.

By 1973 it was recognised that there was a need for legislation to apply to the whole State in order that the groundwater resources could be managed effectively. In that year the Minister of Works announced a new water resources management policy. As part of this policy a Water Resources Branch was established within the Engineering

and Water Supply Department. Its function is planning and management of all the water resources of the State. To enable this to be done a new Act, the Water Resources Act, 1976 was prepared and with associated Regulations and Proclamations came into operation on 1st July, 1976.

The Water Resources Act, 1976

The Act provides that the right to the use and control of all waters in the State is vested in the Crown, and the Minister of Works exercises the right and control in the name of the Crown. "Waters" are defined as all underground and surface waters, including estuarine and waste waters if such waters are declared by proclamation. The Crown is also bound by the Act.

The Act has parts dealing with Surface Waters, Underground Waters and Water Quality. The Underground Waters part of the Act is designed to protect underground water resources from pollution and over-exploitation. It also ensures that supplies are developed efficiently, using approved techniques.

Under the Act a permit must be obtained before any work is done on a well which is or will be of greater depth than 2.5 m. A permit is required in all cases, unless specifically exempted.

"Work" includes : drilling, deepening, backfilling or altering the casing or screen of a well. A permit is also required where a change in use of the well is proposed e.g. from production to drainage.

A licensed driller is required for the work detailed above except when it is done personally by the owner of the land on which the well is situated. However, in this case a permit is still required and the completed depth is restricted to 15 m. There are other exemptions relating to engineering works, details of which may be obtained from the Water Resources Branch of the Engineering and Water Supply Department. Mineral or oil exploration drilling is not subject to this Act but is covered by Mining and Petroleum Acts.

Permits for drilling must be obtained from the Water Resources Branch, E. & W.S. Department and are valid for 1 year. A permit cannot be transferred without permission.

As a permit may carry special conditions it should be obtained before arranging a contract with a driller. This is because the conditions may preclude some drillers from carrying out the work. Wells must be constructed in accordance with general specifications which will be forwarded with each permit.

The permit holder is required to send, within 30 days, a Well Completion Advice to the Engineering and Water Supply Department. The necessary form is supplied with the permit, in addition to a map on which the location of the well must be shown.

Licensed Drillers

With the exception of landholders drilling on their own land to a maximum depth of 15 m all persons who wish to carry out well drilling operations must have a licence.

This applies to wells which are to be used for the production of underground water or for drainage. Wells drilled for other purposes do not require a driller to be licensed under the Water Resources Act.

Before work is commenced on a well the permit holder must ensure that the driller has a licence appropriate to the conditions of the permit.

The following classes of licence are issued to well drillers:-

Class I - Drillers in this class are restricted to work on unconfined aquifers. Such aquifers generally occur at relatively shallow depth and usually involve the simpler type of operation. However, they must be aware of their responsibilities under the Act.

Class II - This applies to drillers of experience and ability and who have attended a course on practical aspects of well drilling and are familiar with all its aspects. This includes their responsibilities under the Act. Class II drillers are authorised to carry out work on confined aquifers, however their licence must carry a special endorsement to construct artesian wells in the Great Artesian Basin.

Licensed drillers are responsible to ensure that work is carried out in accordance with conditions of the permit, and with the general specifications. Water and strata samples must be collected and forwarded in accordance with instructions, unless the permit specifically states that they are not required. A well construction report must be forwarded within 14 days of the completion

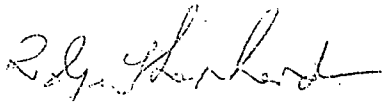
of work on a well. A copy of this report must also be given to the permit holder. The report forms are in a pad and are made available to all licensed drillers.

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RGS:JS
16th March, 1977


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APPENDICES

Appendix I : Definition of Selected Groundwater terms

Appendix II : Suitability of Underground Water for Agricultural Purposes in South Australia

Appendix III : Metric Conversion Table

APPENDIX I

Definitions of Selected Groundwater Terms

Aquifer : A formation, in the saturated zone which is sufficiently permeable to yield significant quantities of water to wells and springs.

Capillary fringe : The zone immediately above the water table in which the interstices contain water at less than atmospheric pressure. The zone may vary in thickness from a few centimetres for coarse materials to a few metres for fine materials.

Cone of Depression : The lowering of the potentiometric surface caused by the withdrawal of water from a well or group of wells. The size and shape of the cone of depression varies with recharge, the rate and duration of withdrawal and the hydraulic characteristics of the aquifer.

Confined Aquifer : An aquifer in which the pressure is significantly greater than atmospheric and is bounded above and below by a confining bed. When a confined aquifer is intersected by a well the pressure is sufficient to cause the water to rise significantly above the upper level of the aquifer. When the pressure is sufficient to cause the water to flow at the surface it is known as artesian.

Confining Bed : A bed of low permeability material occurring above and below a confined aquifer and below an unconfined aquifer or perched groundwater.

Hydraulic Conductivity : In the conditions prevailing in an aquifer, hydraulic conductivity is the rate at which water can move through the interstices of the sediment or rock. It is measured as the flow per unit cross sectional area under unit hydraulic gradient. The units are $m^3/day/m^2$, commonly expressed as m/day. It depends on the size and shape of the interstices and on the viscosity of the water.

Hydraulic Gradient : Expressed as a ratio or percentage, the hydraulic gradient is the change in static head per unit of distance. Unless specified the distance is in the direction of maximum change in static head.

Infiltration : The movement of water from the ground surface through the interstices of the unsaturated zone to the water table.

Perched Groundwater : Groundwater in an unconfined aquifer resting on a bed of low permeability and separated from an underlying aquifer by an unsaturated zone. Its water table is known as a perched water table.

Permeability : A measure of the ease with which an aquifer can transmit water under a potential gradient. It is a property of the aquifer only and is dependent on the size and shape of the pores but is independent of the nature of the fluid.

Porosity : The ratio, usually expressed as a percentage, of the volume of interstices or voids to the total volume of a sediment or rock forming the aquifer. With regard to the movement of groundwater only the system of interconnected interstices is significant. This is known as effective porosity, which is expressed as a percentage of the total volume occupied by interconnecting interstices.

Potentiometric Surface : A surface which represents the static head. As related to an aquifer, it is defined by the levels to which water will rise in tightly cased wells. The water table is a particular potentiometric surface.

Pressure Water : A term used to describe groundwater in confined aquifers, whether water flows at the surface or not.

Safe Yield : The maximum rate at which groundwater can be withdrawn from an aquifer without causing depletion, salinity increase or excessive pumping costs.

Saturated Zone : That part of an unconfined aquifer in which all interstices or voids are filled with water at a pressure greater than atmospheric.

Specific Capacity : The specific capacity of a well is the rate of discharge of water from the well divided by the drawdown of water level within the well. It varies slowly with duration of discharge which should be stated when known. It is expressed as $m^3/day/m$.

Specific Yield : The ratio of (1) the volume of water which the rock or soil, after being saturated, will yield by gravity to (2) the volume of the rock or soil. The definition implies that gravity drainage is complete.

Static Head or Static Level : The height to which water rises in a well which is not being pumped. It is a measure of the head or pressure in that part of an aquifer open to a well at a specified time.

Storage Coefficient (S) Dimensionless : The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. In a confined aquifer the water derived from storage with decline in head comes from expansion of the water and compression of the aquifer. In an unconfined aquifer the volume of water derived from these processes is negligible compared to that derived from gravity drainage as the water table falls. Hence, in an unconfined aquifer the storage coefficient is virtually equal to the specific yield.

Stream, gaining : A stream whose flow is being increased by inflow of groundwater.

Stream, losing : A stream that is losing water to the ground.

Transmissivity (T) : The rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient. It is the product of the hydraulic conductivity and the saturated thickness of the aquifer and is expressed in $m^3/day/m$.

Unconfined Aquifer : An aquifer in which the water level does not rise significantly above the level that it is intersected in a well.

Water Table : The surface of water in a well entering an unconfined aquifer. The water table is at the top of the saturated zone where the pressure is atmospheric.

DEPARTMENT OF MINES
ADELAIDE**Suitability of Underground Water for Agricultural Purposes in South Australia****WATER FOR IRRIGATION**

The use of groundwater for irrigation and domestic gardens is influenced not only by the type and amount of saline matter dissolved in the water, but also by the type of soil, drainage, climate and rainfall. The remarks and tables set out below should therefore be taken only as a general guide. Where the waters approach the maximum salinity for particular plants, or where special conditions of soil type or drainage, rainfall, etc., exist, you are advised to submit the analysis to the Department of Agriculture, or to your local Agricultural Adviser, for more definite guidance.

HORTICULTURAL CROPS AND GARDEN PLANTS

Crops and garden plants may be classified in three groups: low, medium and high salt tolerance. The approximate salinity ranges and some of the plants in each group are shown in the following table:

WATER QUALITY

0—750 mg/l **GOOD.** Water is suitable for growing all plants, especially low salt tolerant plants.
750—1,500 mg/l **MEDIUM.** Water is suitable for most vegetables and fruit trees, except citrus.
1,500—2,000 mg/l **POOR.** Water is suitable for only a limited range of high salt tolerant fruit and vegetables.

TOLERANCE OF PLANTS TO SALT

LOW salt tolerant plants include	MEDIUM salt tolerant plants include	HIGH salt tolerant plants include
Stone fruits Citrus trees French beans Strawberries Flowers Bulbs	Celery Peas Grapes Pome fruits. Cabbages Lettuce Tomatoes Potatoes Pumpkins	Figs Olives Spinach Asparagus Beet

IRRIGATED CROPS AND PASTURES**WATER QUALITY**

0—1,000 mg/l Water is suitable for all types of pastures.
1,000—2,000 mg/l Water is suitable for more tolerant pastures, on well drained soil.
2,000—3,000 mg/l Water is suitable for salt tolerant species on well drained soil.
Over 3,000+ mg/l Marginal water—requires heavy application on well-drained soil. Suitable only for the most tolerant species.

TOLERANCE OF CROPS AND PASTURES TO SALT

LOW salt tolerant crops and pastures	MEDIUM salt tolerant crops and pastures	HIGH salt tolerant crops and pastures
Subterranean Clover White Clover	Strawberry Clover Perennial rye grass Fodder crops	Rhodes grass Prairie grass Lucerne

As the salinity increases, the use of water for irrigation becomes increasingly hazardous. The more saline waters can be used effectively if:—

- The soil has free drainage.
- Heavy and more frequent applications of water are used to wash excess salts through the soil beyond the reach of plant roots; normal winter rains will do this in the higher rainfall areas.
- The water is applied evenly; flooding is more effective than sprinklers, and also reduces the amount of evaporation and risk of leaf damage.
- Salt tolerant plants are used.

WATER FOR LIVESTOCK

Stock vary considerably in their ability to tolerate salt in their drinking water. The more important factors affecting tolerance are:

- (a) Stock can tolerate higher salt levels when on green pastures rather than on dry feed or prepared rations.
- (b) Lactating animals require lower levels than dry stock.
- (c) Young animals have reduced tolerance.
- (d) Changes from low to high salt levels must be made slowly. Stock become adjusted to lower levels and sudden changes can cause toxicity even though below maximum tolerance figures.
- (e) Stock can become accustomed to high salt levels and thrive at above maximum levels quoted.
- (f) When high salt level water is being used, storage tanks and troughs need frequent flushing to prevent excessive build up from evaporation.
- (g) The composition of salts is important and some ions and radicles are much more toxic or unpalatable for stock than others.
- (h) Better quality water is required during periods of high water intake (e.g. hot weather, high salt diets).

The table given, therefore, must be considered only as a guide and not fixed. Tests with the stock must always be done in cases of borderline waters.

Type of Stock	Maximum Total Salts mg/l
Poultry (adults)	4,000
Chickens	3,000
Swine	3,000
Milking Cows	4,000
Horses	7,000
Dry Dairy Cows	7,000
Beef Cattle	10,000
Lambs	10,000
Sheep (dry feed)	12,000
Sheep (green feed)	14,000

SALINITY CONVERSION TABLES

Milligrams per litre (mg/l)	Grains/gallon	Grains/gallon	Milligrams per litre (mg/l)
250	17	25	357
500	35	50	714
1,000	70	100	1,428
2,000	140	200	2,856
5,000	350	500	7,140
10,000	700	750	10,700
15,000	1,050	1,000	14,300

Note—1 grain/gallon = 14.28 Milligrams per litre (mg/l)

1 ounce = 437.5 grains

1 p.p.m. = 1 mg/l

1/2/74

B. P. WEBB
Director of Mines

APPENDIX III
METRIC CONVERSION TABLE

LENGTH

1 inch = 25.40 millimetres (mm)	1 millimetre = 0.03937 inches
1 foot = 0.3048 metres (m)	1 metre = 3.28084 feet
1 chain = 20.1168 metres	1 metre = 0.04971 chains
1 mile = 1.6093 kilometres (km)	1 kilometre = 0.62137 miles

AREA

1 acre = 0.40469 hectares (ha)	1 hectare = 2.47105 acres
1 square mile = 2.58999 ₂ square kilometres (km ²)	1 square kilometre = 0.3861 square miles

VOLUME

1 imperial gallon = 4.54609 litres (l)	1 litre = 0.21997 imperial gallons
1 imperial gallon = 0.00455 kilolitres (kl)	1 kilolitre = 219.97 imperial gallons
1 acre foot = 1233 kilo- kilolitres	1 kilolitre = 0.00081 acre feet

FLOW RATE

1 imperial gallon per hour = 0.00126 litres per second (l/sec)	1 litre per second = 793.63 imperial gallons per hour
1 imperial gallon per hour = 0.1091 kilolitres per day	1 kilolitre per day = 9.168 imperial gallons per hour

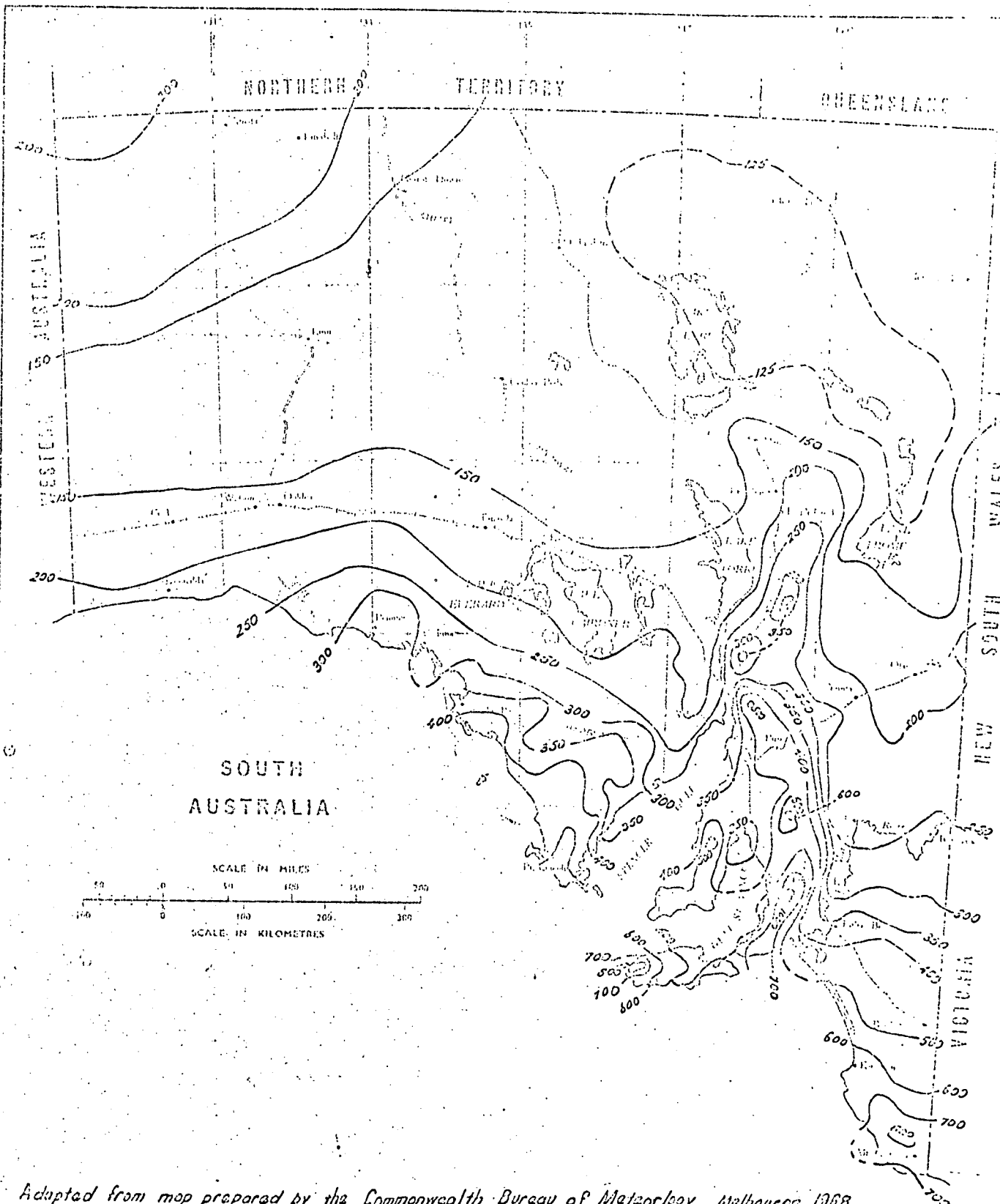
PRESSURE

1 pound per square inch = 6.895 kilopascals (kp)	1 kilopascal = 0.145 pounds per square inch
---	--

SALINITY

1 ounce per gallon = 437.5 grains per gallon	
1 grain per gallon = 14.28 milligrams per litre (mg/l)	1 milligram per litre = 0.07 grains per gallon

Note : milligrams per litre are equivalent to parts per
million.



Adapted from map prepared by the Commonwealth Bureau of Meteorology Melbourne 1968.

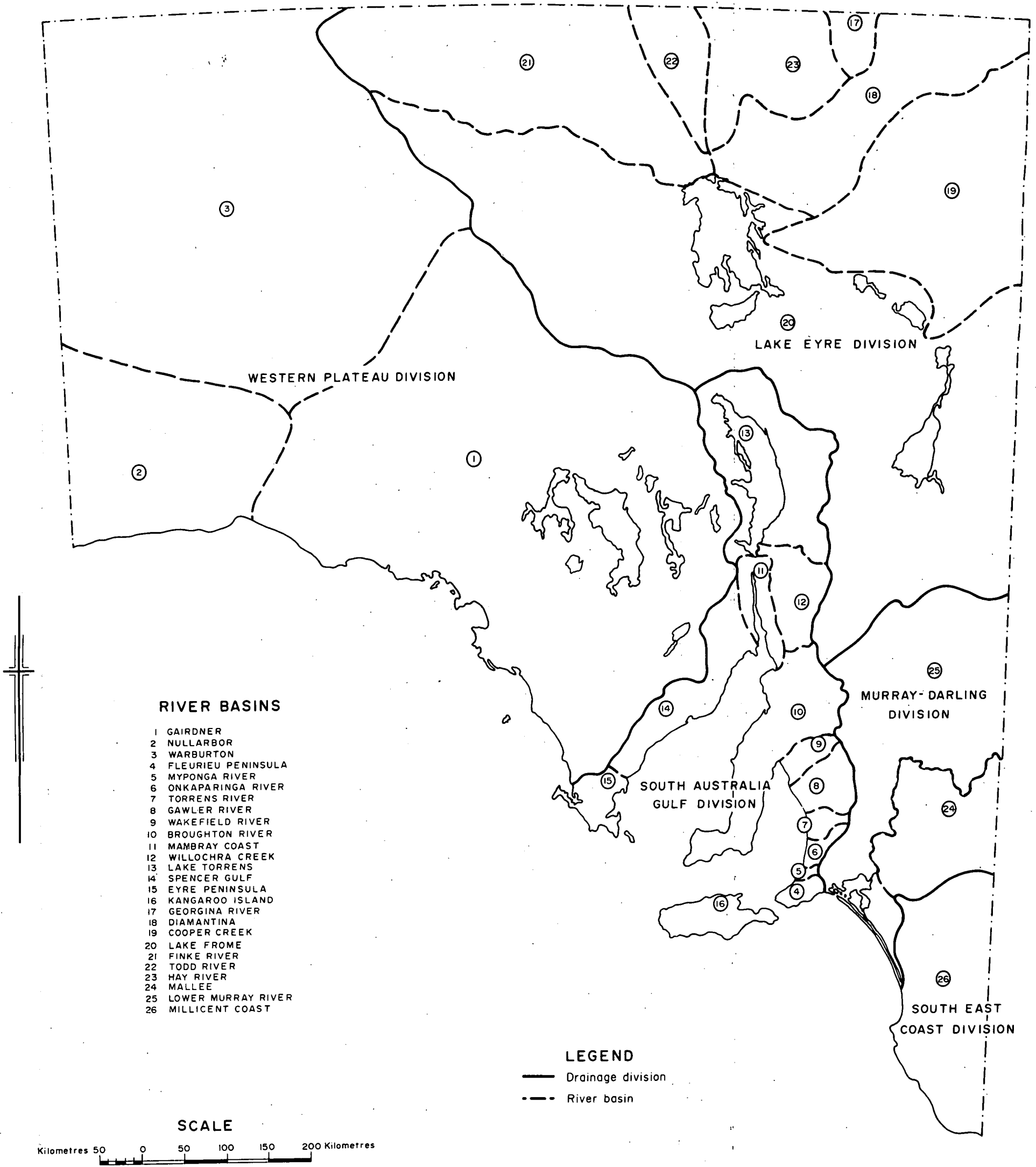
FIG. 1.

DEPARTMENT OF MINES — SOUTH AUSTRALIA

Drawn by	
Drawn	1968

SOUTH AUSTRALIA
ISOHYETS OF AVERAGE ANNUAL RAINFALL

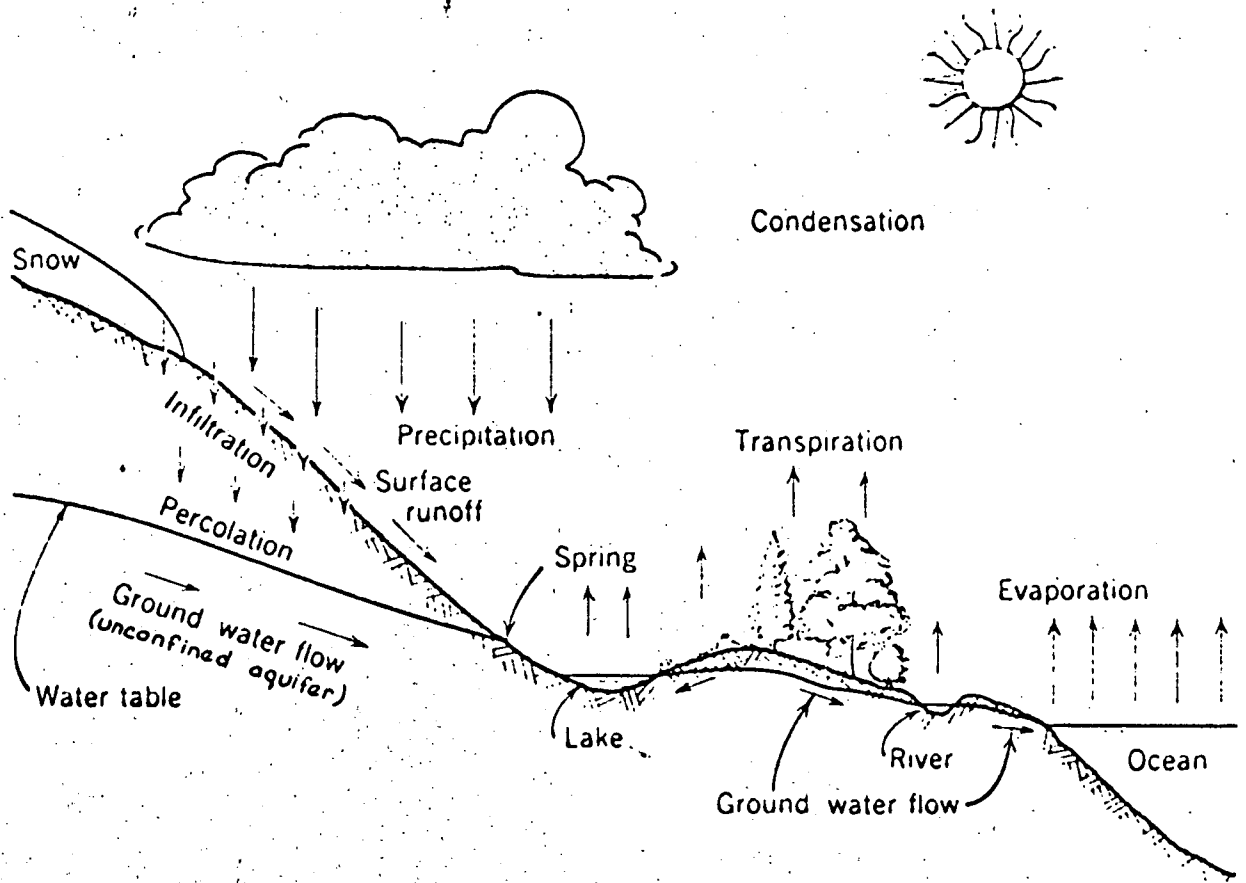
Date:	
Orig. No.	512533



Reproduced from "Surface Water Resources" 1967

Fig. 2

		DEPARTMENT OF MINES—SOUTH AUSTRALIA		SCALE: As shown
COMPILED: R.G.S.		SOUTH AUSTRALIA DRAINAGE DIVISIONS & RIVER BASINS		DATE: January 1977
DRN: L.P.R.	CKD.			PLAN NUMBER:
				77-22



Adapted from "Groundwater Hydrology" (Todd 1959)

FIG 3

		DEPARTMENT OF MINES - SOUTH AUSTRALIA	SCALE: Diagrammatic
COMPILED:		THE HYDROLOGIC CYCLE	DATE:
DRN:	CKD.		PLAN NUMBER:
			512536

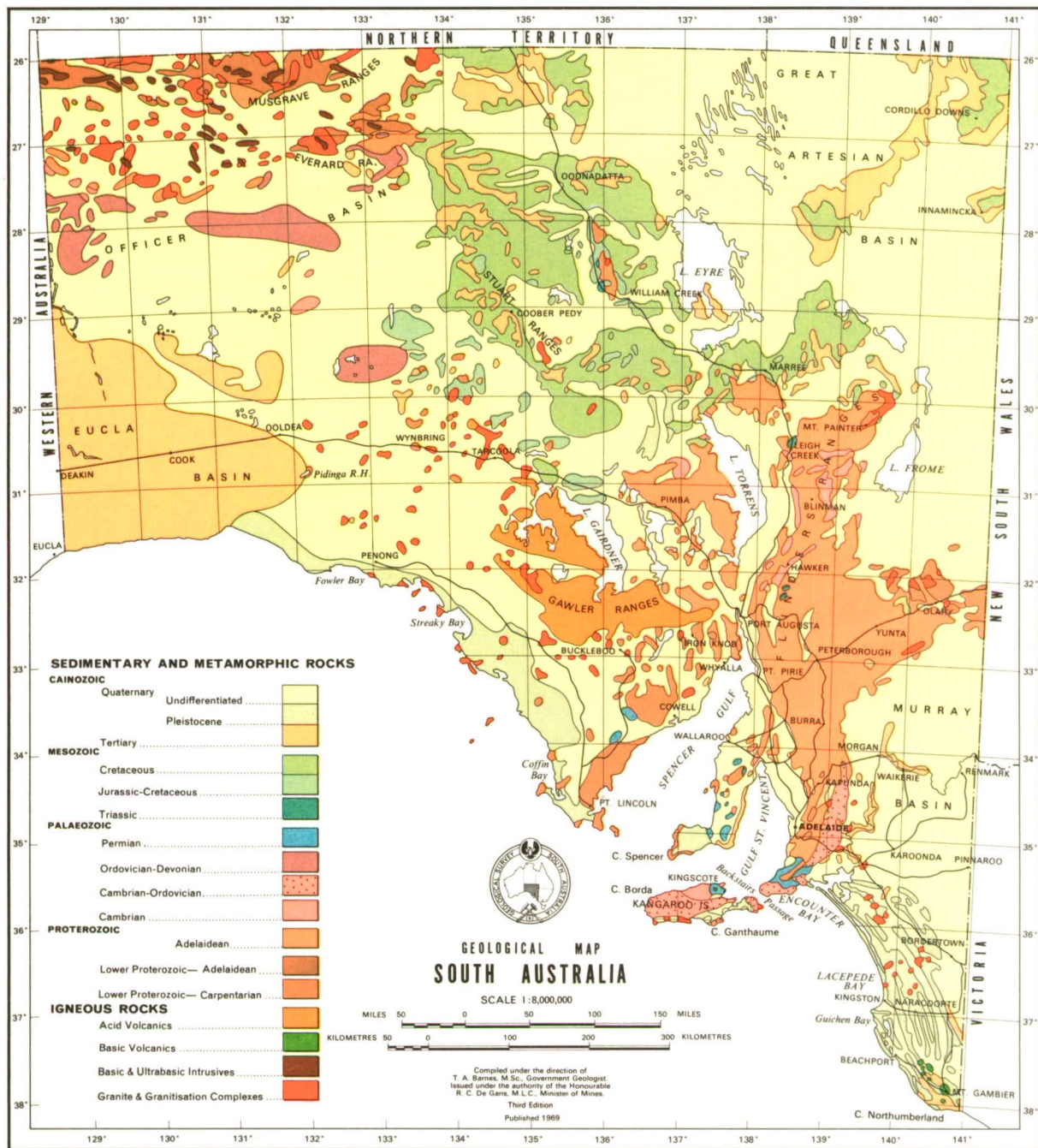


FIG. 4

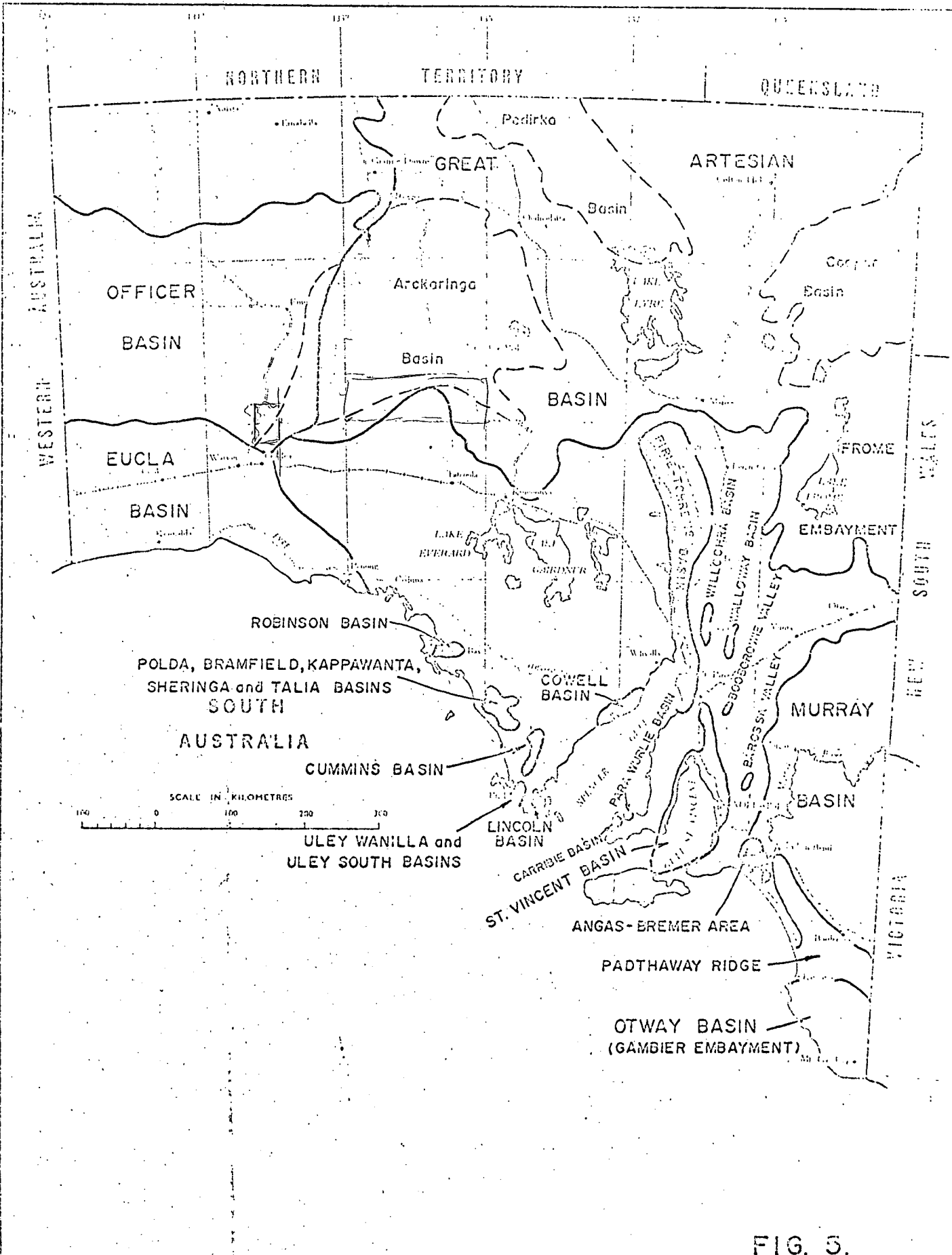


FIG. 5.

DEPARTMENT OF MINES — SOUTH AUSTRALIA

Compiled	
Drawn	CVH

**SOUTH AUSTRALIA
GROUNDWATER BASINS**

Date:	
Dep. No.	S 12633

NORTHERN TERRITORY

QUEENSLAND

WESTERN AUSTRALIA

SOUTHWEST AUSTRALIA

SOUTH AUSTRALIA

SHOWING
IRRIGATION AREAS AND TOWN WATER SUPPLIES
DEPENDANT ON GROUNDWATER

- LEGEND
- Towns on groundwater
 - Town partly dependent on groundwater
 - Intense irrigation areas
 - ▨ Scattered irrigation areas

SCALE
kilometres 0 20 40 60 80 100
miles 0 10 20 30 40

S O U T H E R N O C E A N

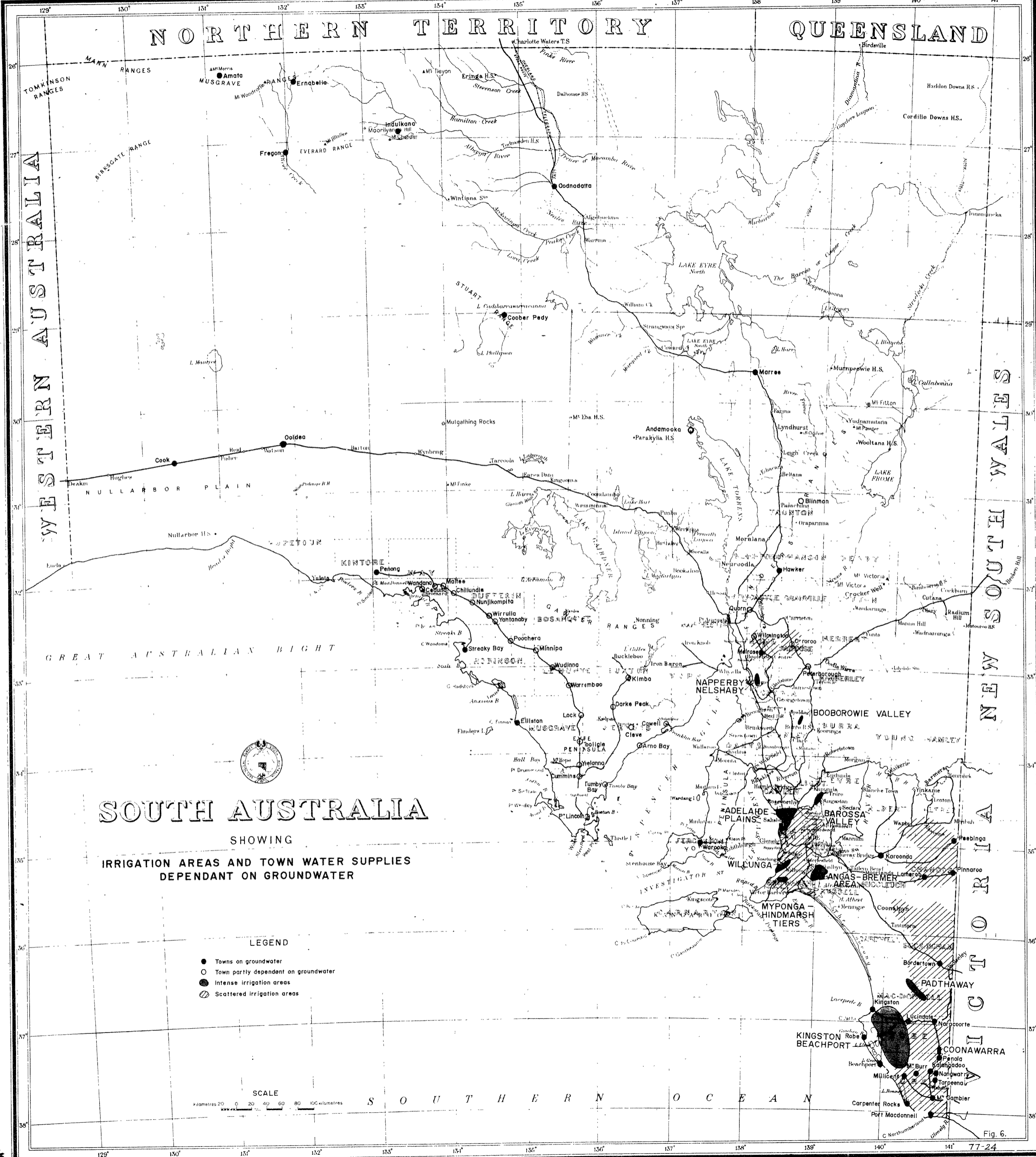
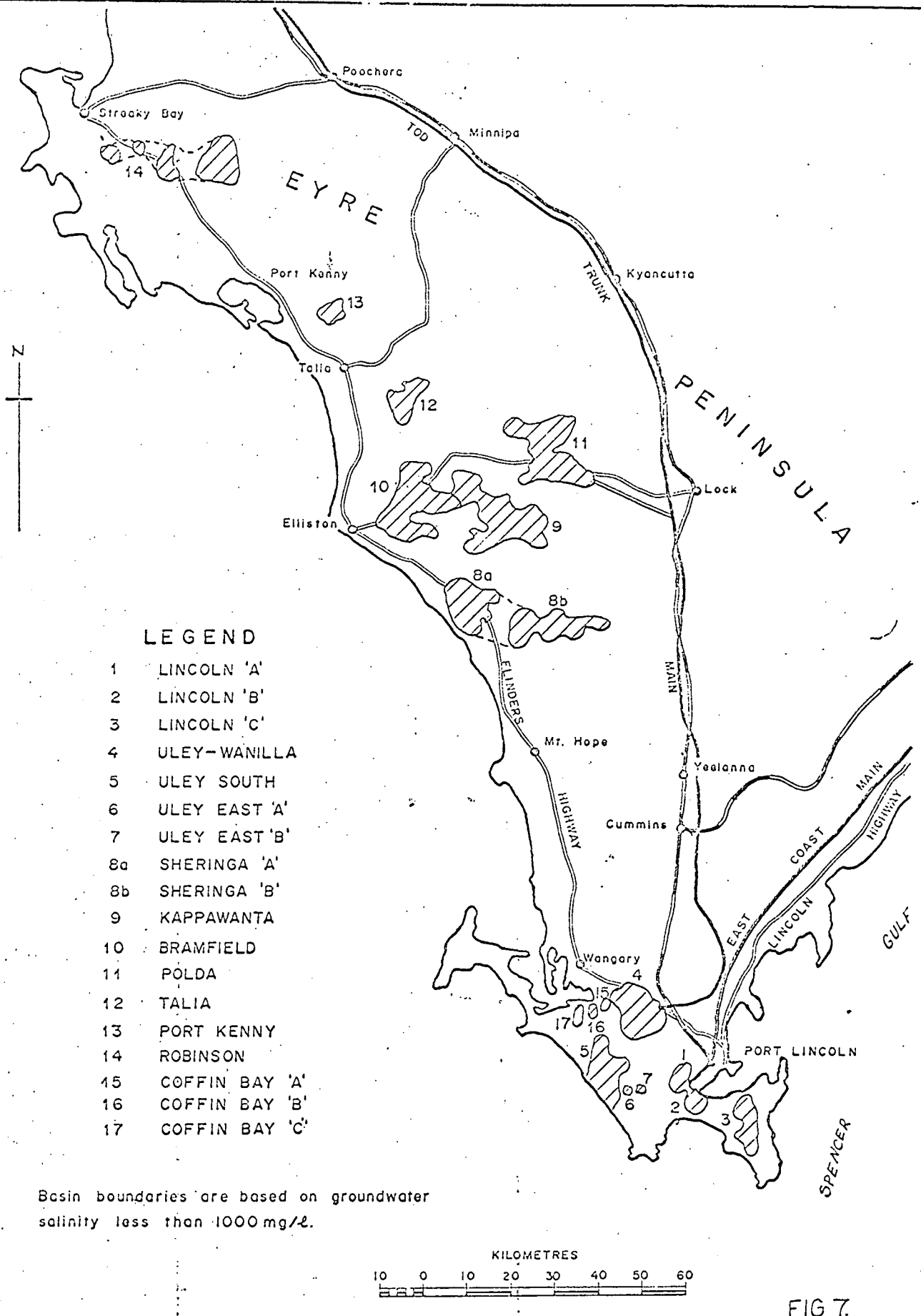


Fig. 6.



LEGEND

- 1 LINCOLN 'A'
- 2 LINCOLN 'B'
- 3 LINCOLN 'C'
- 4 ULEY-WANILLA
- 5 ULEY SOUTH
- 6 ULEY EAST 'A'
- 7 ULEY EAST 'B'
- 8a SHERINGA 'A'
- 8b SHERINGA 'B'
- 9 KAPPAWANTA
- 10 BRAMFIELD
- 11 POLDA
- 12 TALIA
- 13 PORT KENNY
- 14 ROBINSON
- 15 COFFIN BAY 'A'
- 16 COFFIN BAY 'B'
- 17 COFFIN BAY 'C'

Basin boundaries are based on groundwater salinity less than 1000 mg/l.

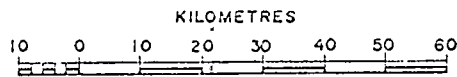
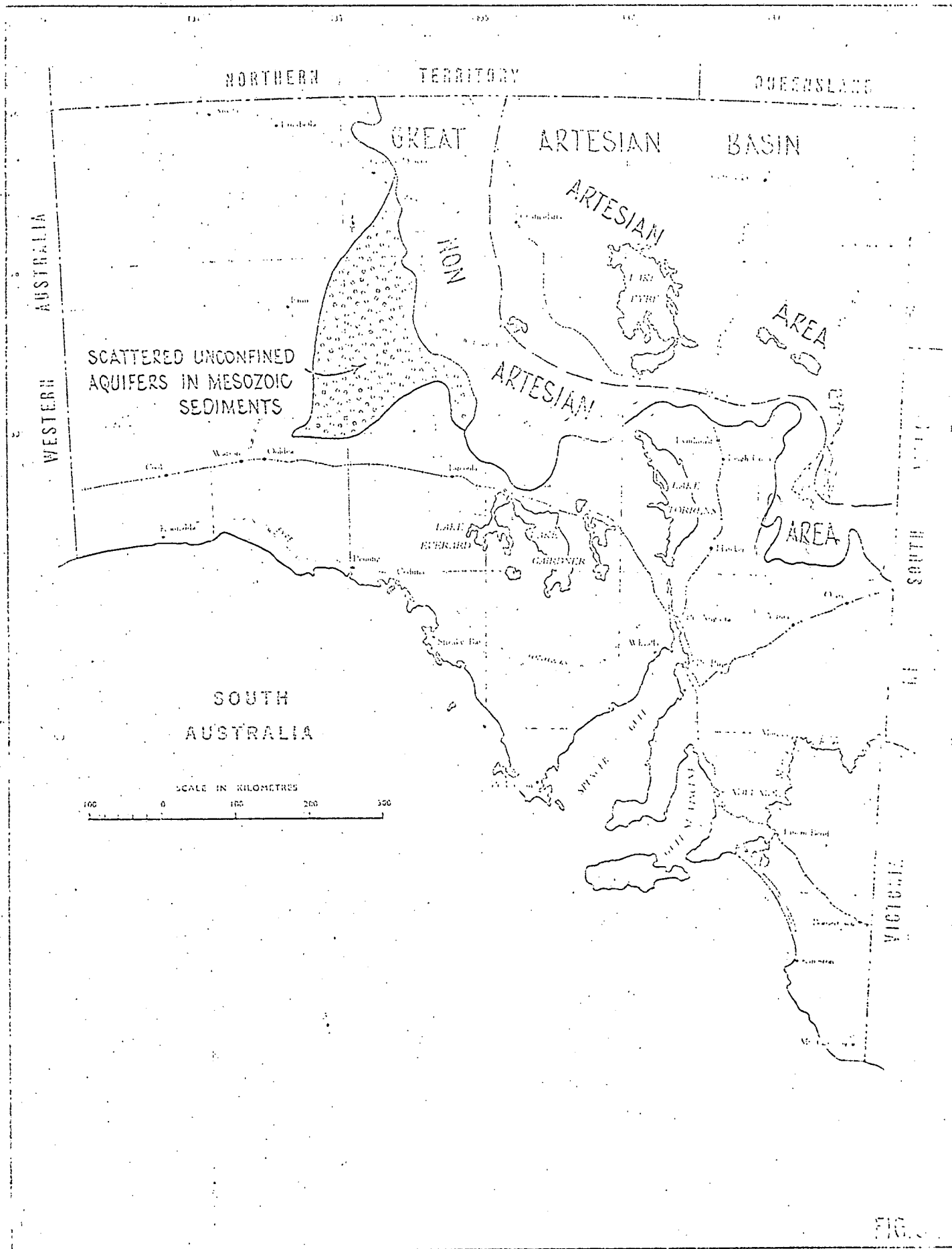


FIG 7.

		DEPARTMENT OF MINES—SOUTH AUSTRALIA	Scale: 1: 800 000
Compiled:		EYRE PENINSULA GROUNDWATER BASINS	Date: 15.12.76
Drn.	Ckd.		Dr. No.
			S 7071



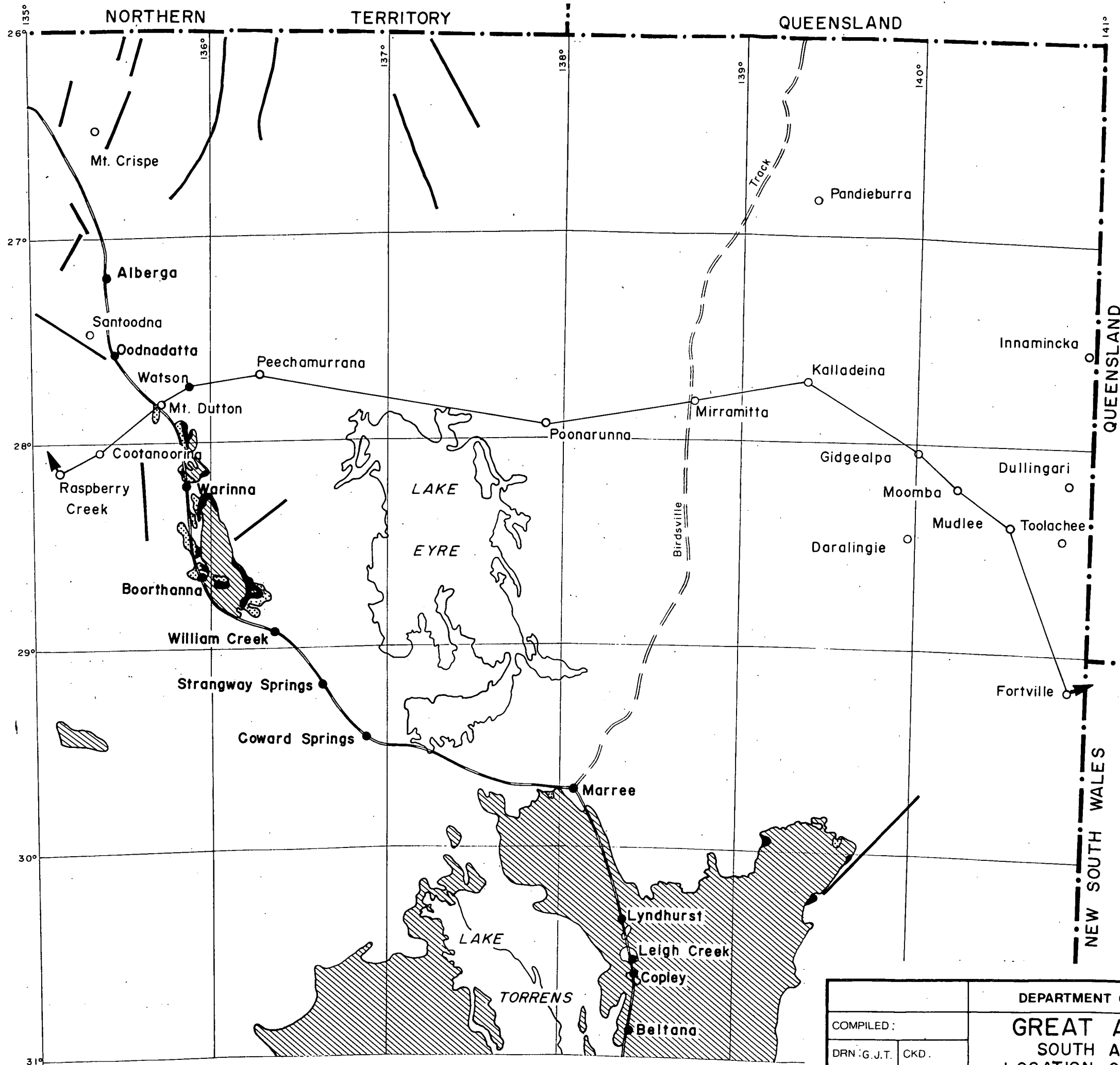
DEPARTMENT OF MINES — SOUTH AUSTRALIA

R.G.S.





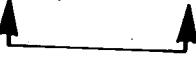
GREAT ARTESIAN BASIN
SOUTH AUSTRALIAN PORTION
LOCALITY PLAN

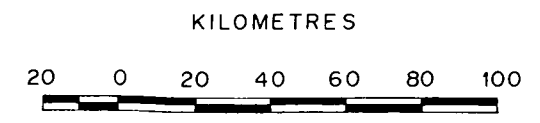
Date March 1937

S12000



LEGEND

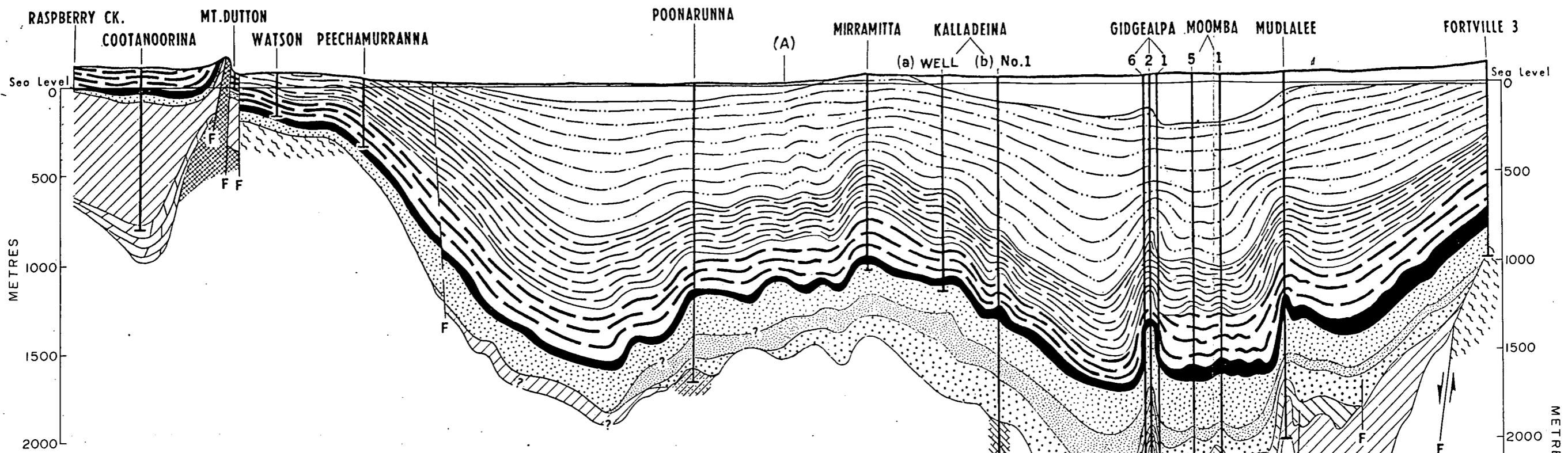
-  Algebuckina Sandstone
-  Cadna-owie Formation
-  Undifferentiated pre-Mesozoic outcrops.
-  Fault
-  Section Line





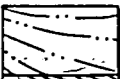
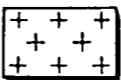

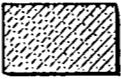



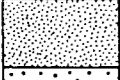

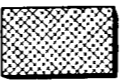
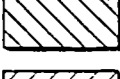

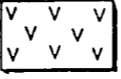

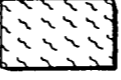


After H. Wopfner, 1968

FIG 9

		DEPARTMENT OF MINES - SOUTH AUSTRALIA		SCALE: 1:2,000,000
COMPILED:		GREAT ARTESIAN BASIN		
DRN: G.J.T. CKD.		SOUTH AUSTRALIAN PORTION		
		LOCATION OF GEOLOGICAL SECTION		
		RASPBERRY CREEK TO FORTVILLE		
				DATE: 28-3-77
				PLAN NUMBER: 77-298



LEGEND

- | | | | |
|---|--|---|--------------------------|
|  | TERTIARY TO RECENT |  | DEVONIAN |
| Undifferentiated | | Unnamed dolomites and anhydrite | |
|  | CRETACEOUS |  | |
| Winton Formation | | Granite in Moomba No.1 | |
|  | Oodnadatta Formation |  | ORDOVICIAN |
|  | Bulldog Shale | Unnamed arenites | |
|  | Cadna-owie Formation |  | CAMBRIAN |
|  | JURASSIC | Unnamed carbonates
some clastics and volcanics. | |
|  | Algebuckina Sandstone |  | ADELAIDEAN |
|  | Birkhead Formation | Undifferentiated sediments | |
|  | Hutton Sandstone |  | Unnamed Volcanics |
|  | TRIASSIC |  | OLDER PRECAMBRIAN |
|  | Nappamerrie Formation | Undifferentiated metamorphics | |
|  | PERMIAN AND PERMO-CARBONIFEROUS | | |
| Gidgealpa and Merrimelia Formations | | | |

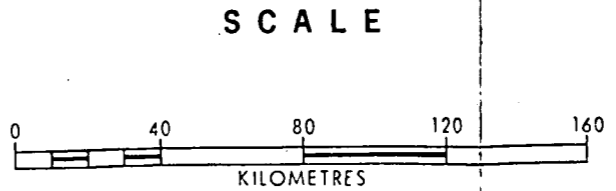


Fig. 10

After H. Wopfner 1968

DEPARTMENT OF MINES - SOUTH AUSTRALIA		SCALE:
GREAT ARTESIAN BASIN		DATE:
SOUTH AUSTRALIAN PORTION		PLAN NUMBER:
GEOLOGICAL SECTION		77-20
RASPBERRY CREEK TO FORTVILLE		
COMPILED:		
DRN:	CKD:	

COMPILED:		DEPARTMENT OF MINES - SOUTH AUSTRALIA	
DHN:		SCALE:	
CKD:		DATE:	
MURRAY & OTWAY BASINS		PLAN NUMBER	
GEOLOGICAL SECTION ALONG		512534	
SOUTH AUSTRALIAN & VICTORIAN BORDER			

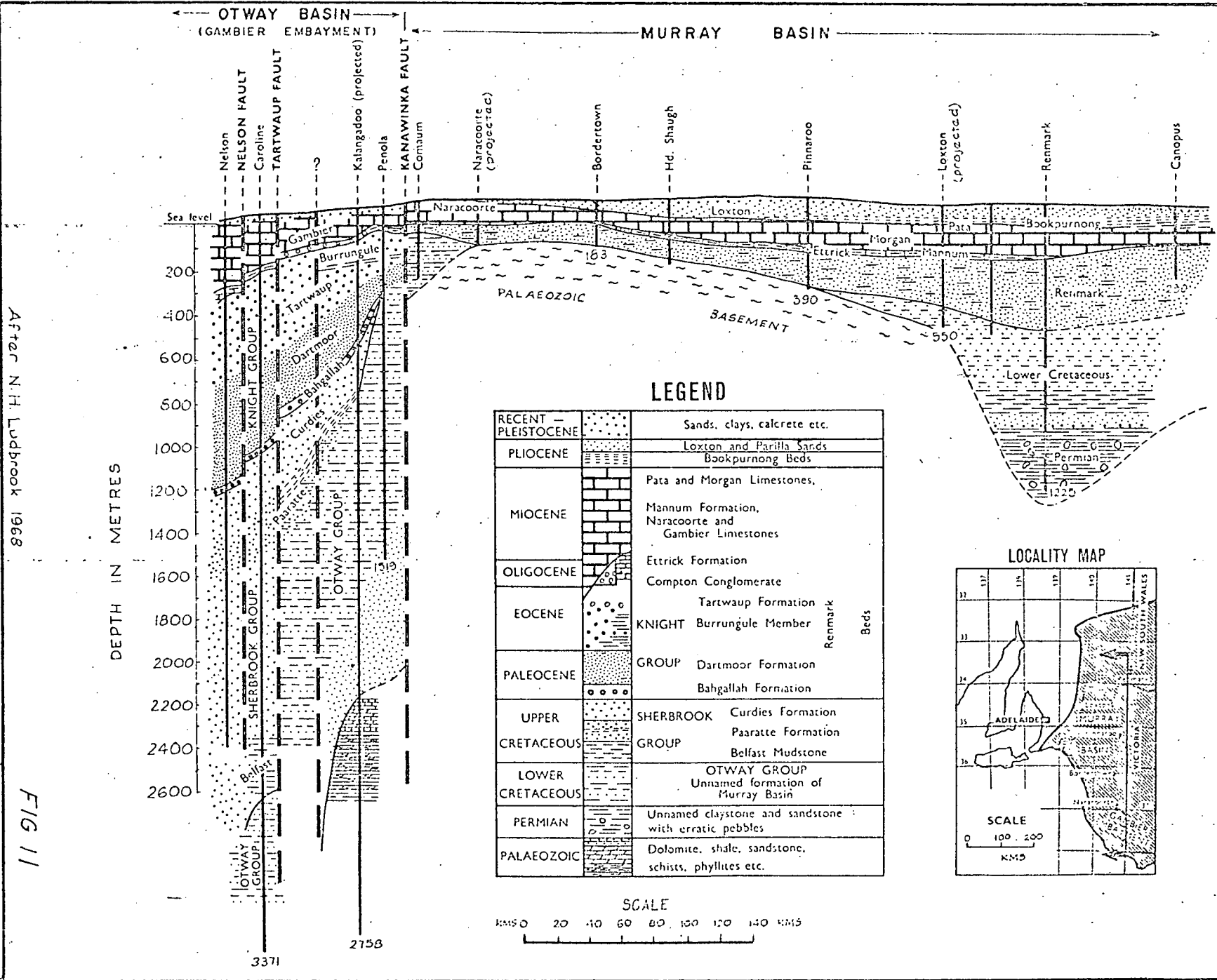


FIG 11

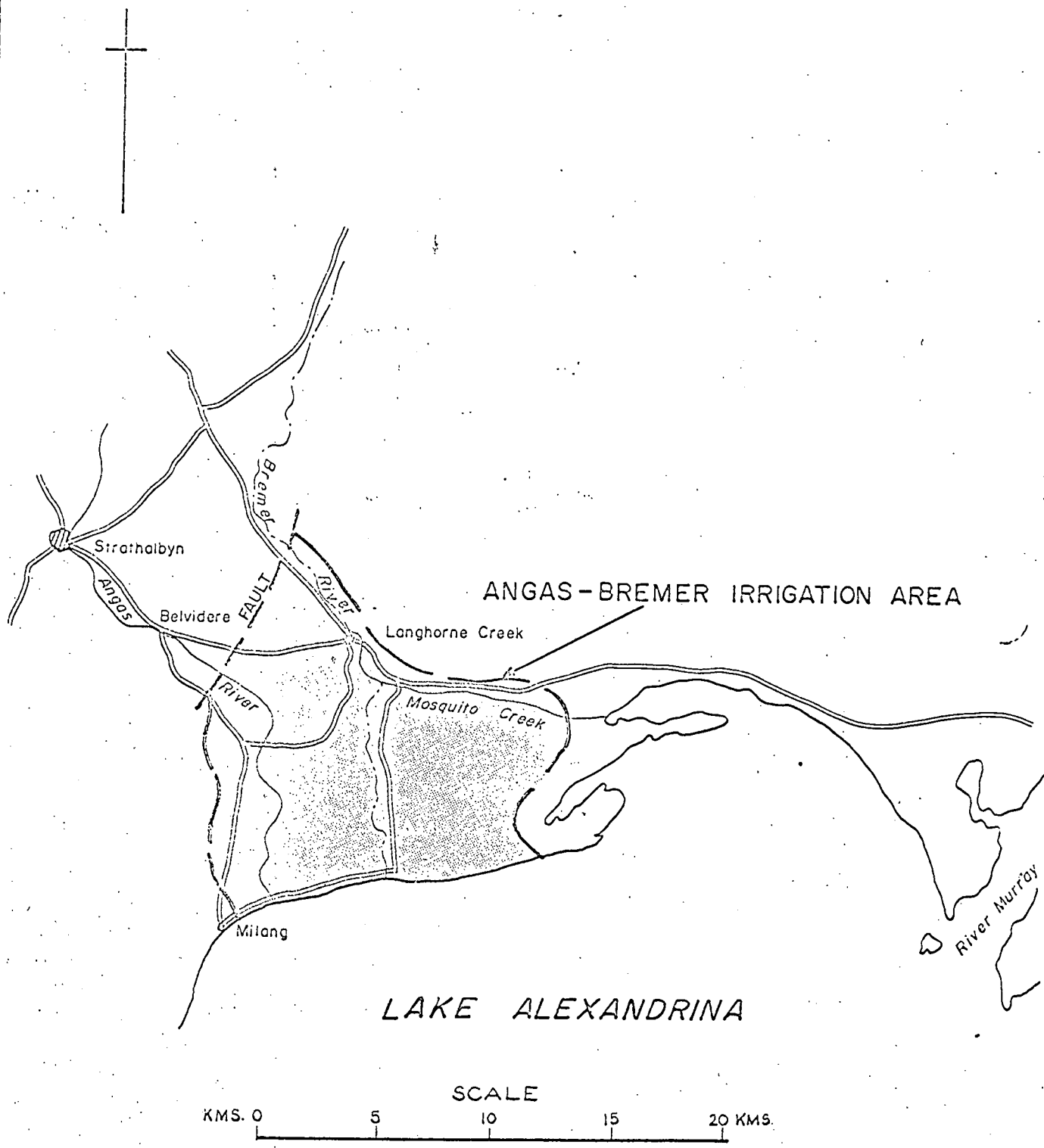


FIG 12.

DEPARTMENT OF MINES—SOUTH AUSTRALIA		Scale: 1:250,000
Compiled:	ANGAS-BREMER IRRIGATION AREA LOCALITY PLAN	Date:
Drn. G. J. J. Ckd.		Drg. No.

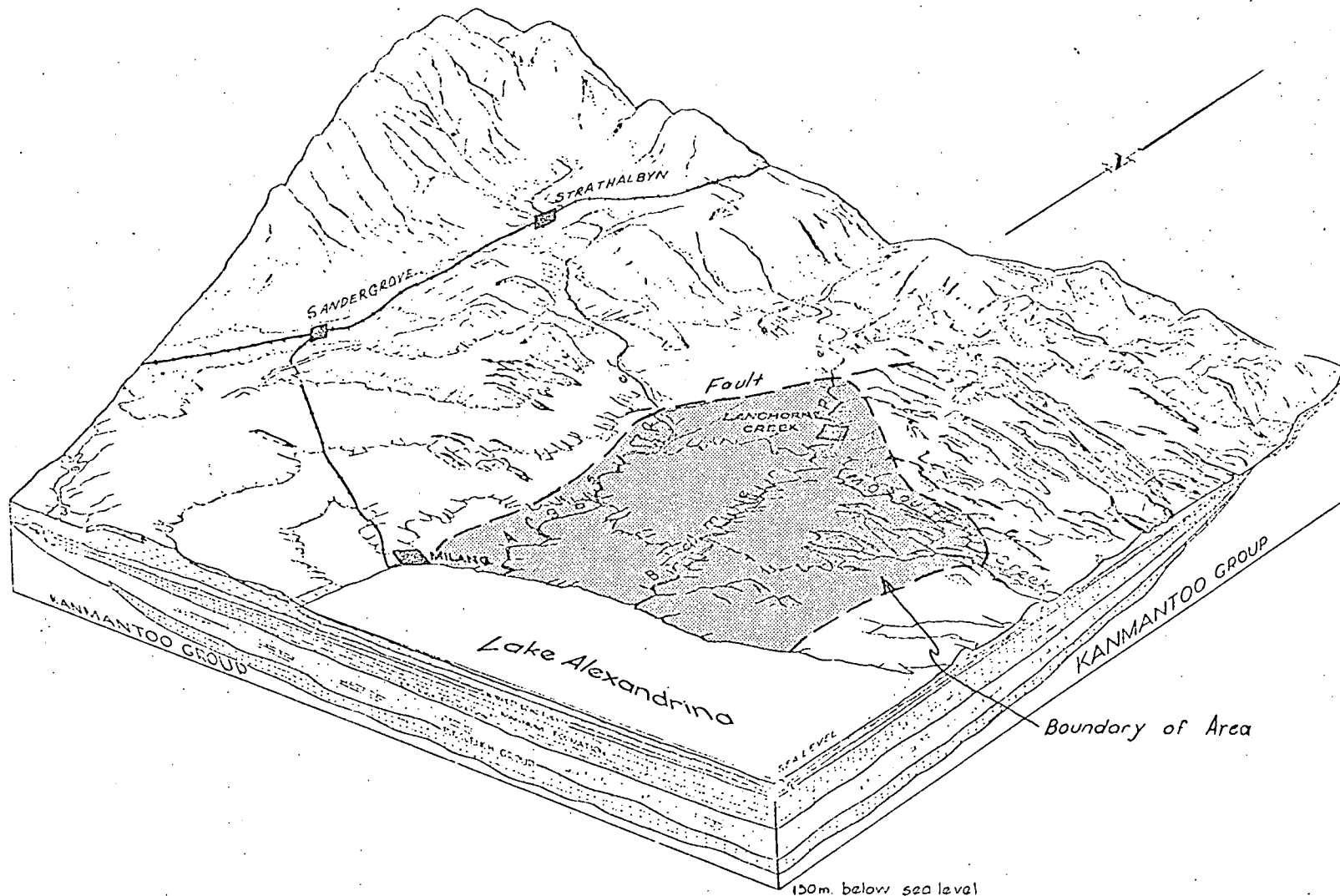
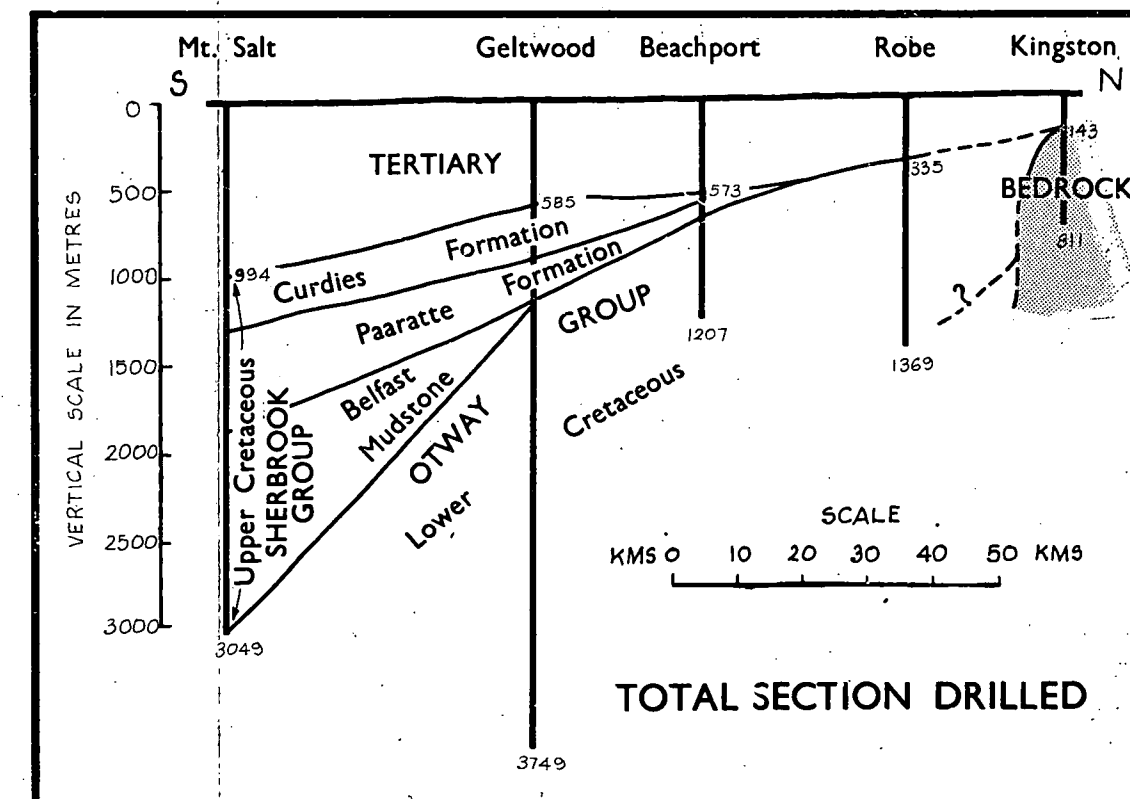
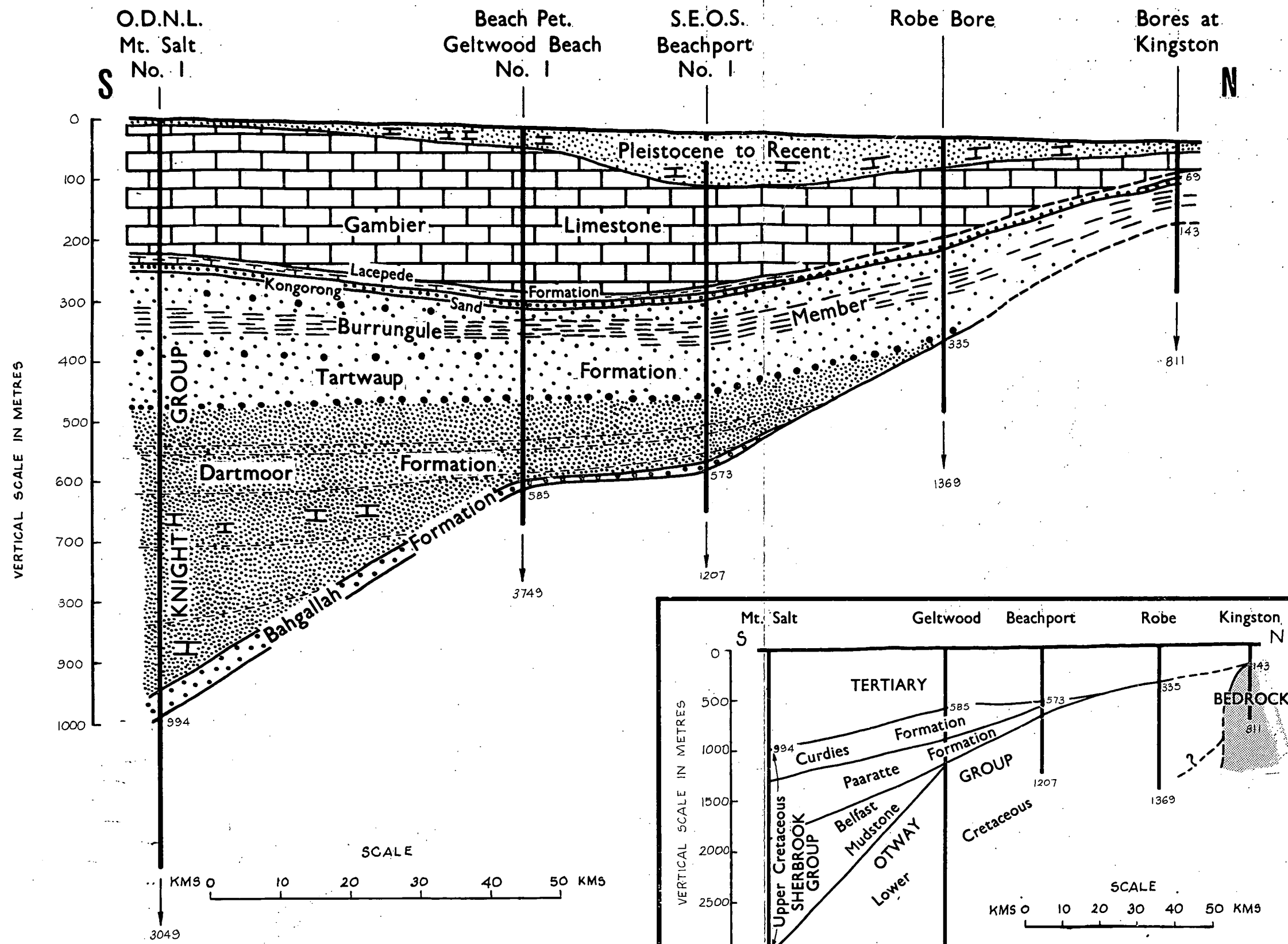
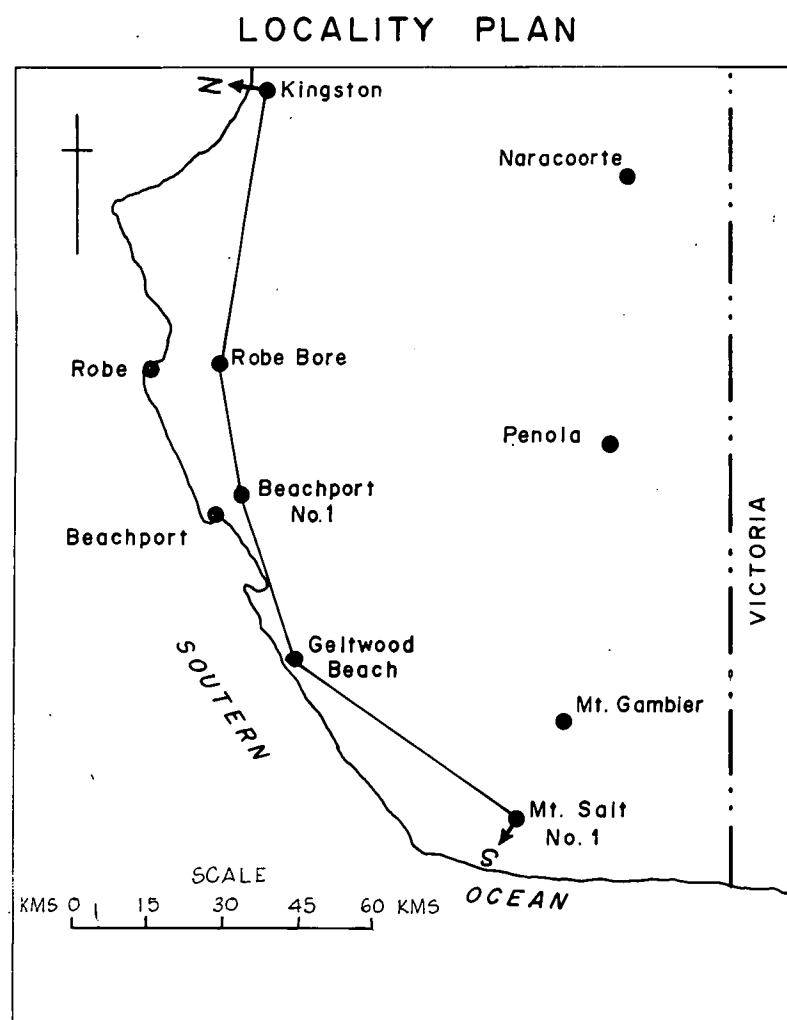


FIG 13

Boundary of area is based on salinity less than 3500mg/l for water in the Mannum Formation

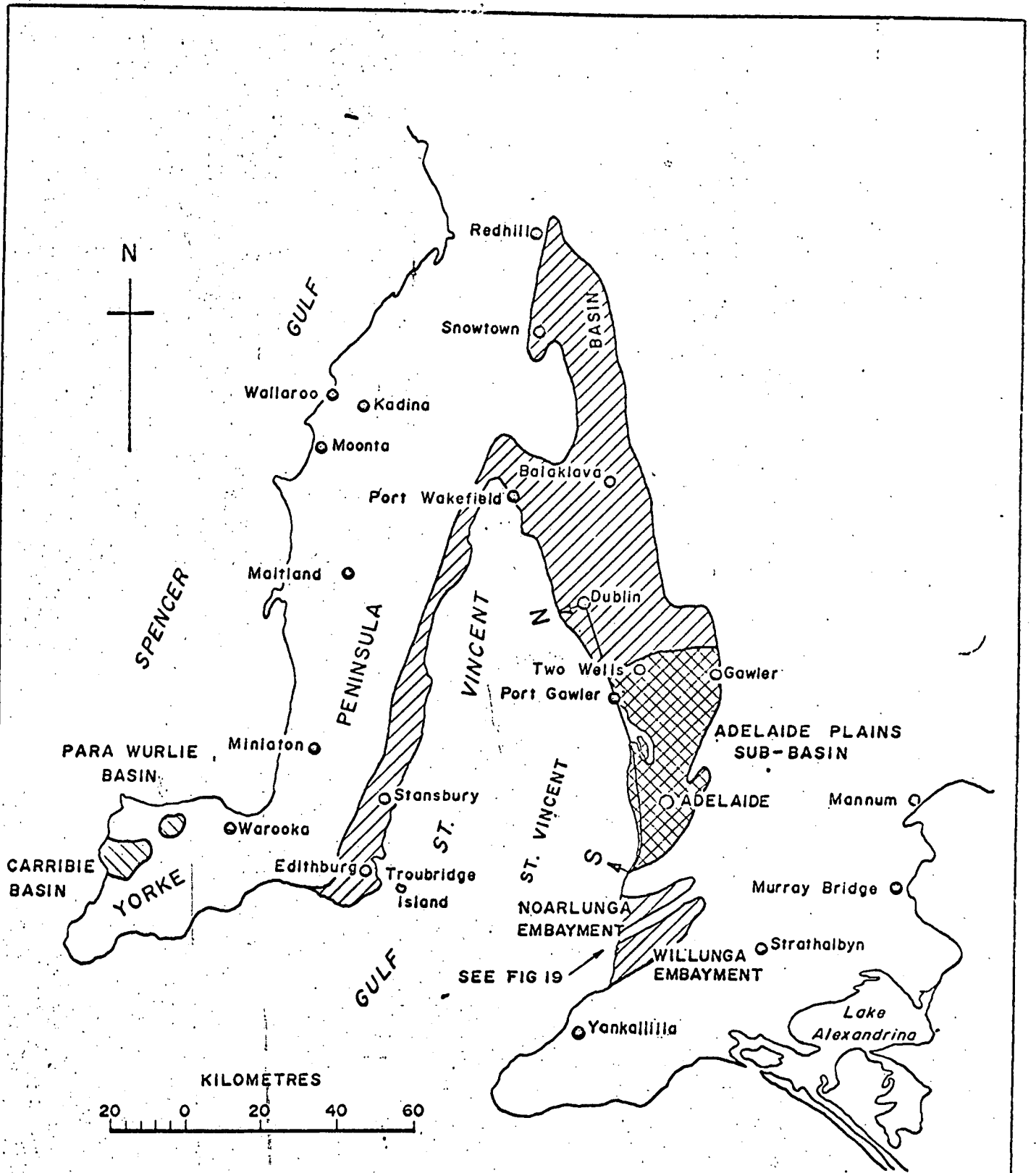
COMPILED A.F.W		DEPARTMENT OF MINES - SOUTH AUSTRALIA	
DRN :	CKD :	ANGAS - BREMER IRRIGATION AREA	
		BLOCK DIAGRAM	
DATE : 14.12.76		SCALE :	
PLAN NUMBER			
S12507			



After N.H. Ludbrook 1968

FIG 14

DEPARTMENT OF MINES—SOUTH AUSTRALIA		SCALE:
OTWAY BASIN—GAMBIER EMBAYMENT		DATE:
COMPILED:	GEOLOGICAL SECTION	PLAN NUMBER:
DRN: CKD.	MT SALT TO KINGSTON	77-21



FOR GEOLOGICAL SECTION S-N SEE FIG 16.

FIG 15

		DEPARTMENT OF MINES—SOUTH AUSTRALIA	Scale: 1:1650 000
Compiled:		ST. VINCENT BASIN AND YORKE PENINSULA LOCALITY PLAN	Date: 14-12-76
Drn. G.J.T.	Ckd.		Drg. No. S12504

DEPARTMENT OF MINES - SOUTH AUSTRALIA
 EUCLA BASIN
 ALBALA KAROO TO PIDINGA
 GEOLOGICAL SECTION
 COMPILER: CKD
 DATE: 14.12.76
 PLAN NUMBER: S12506

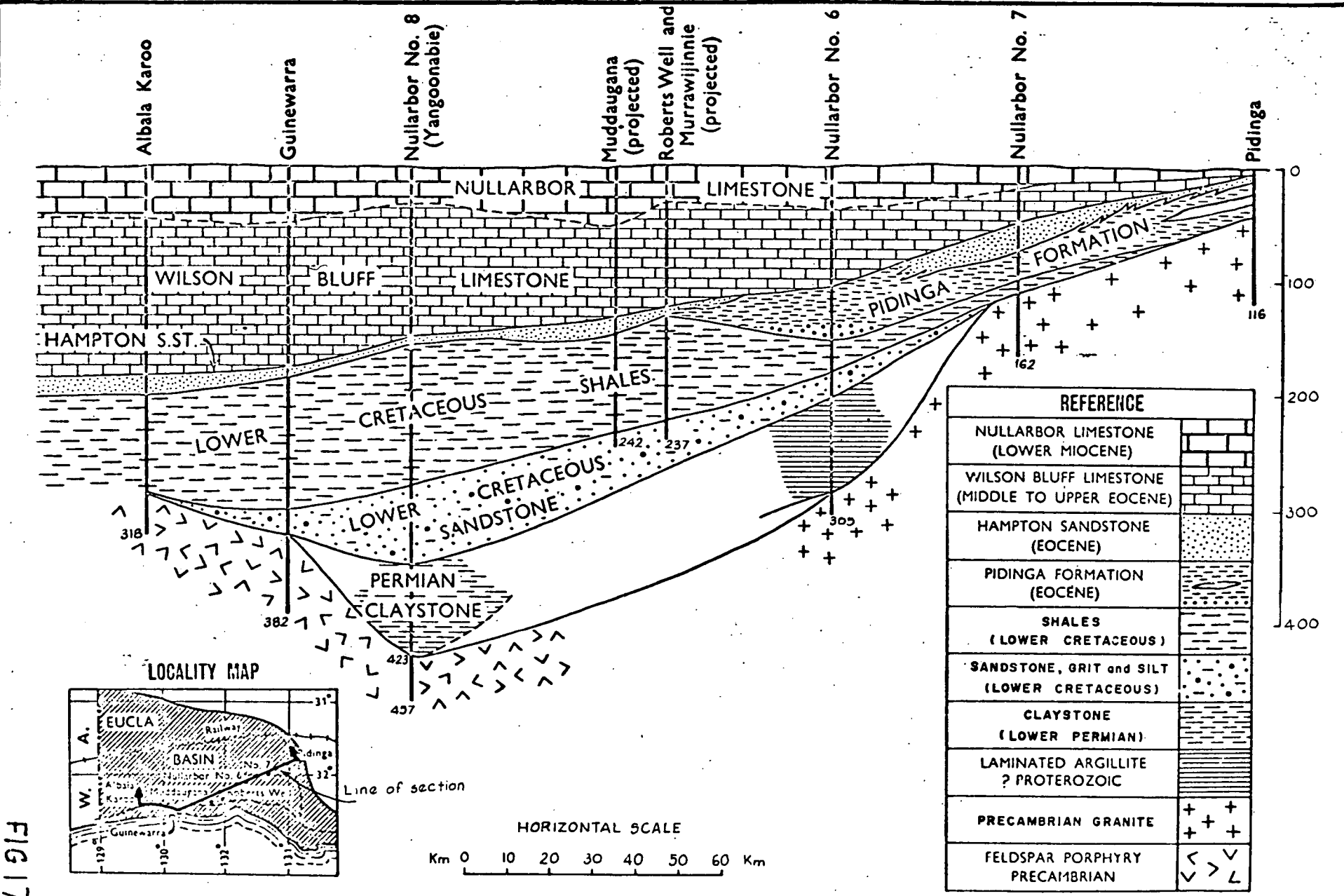
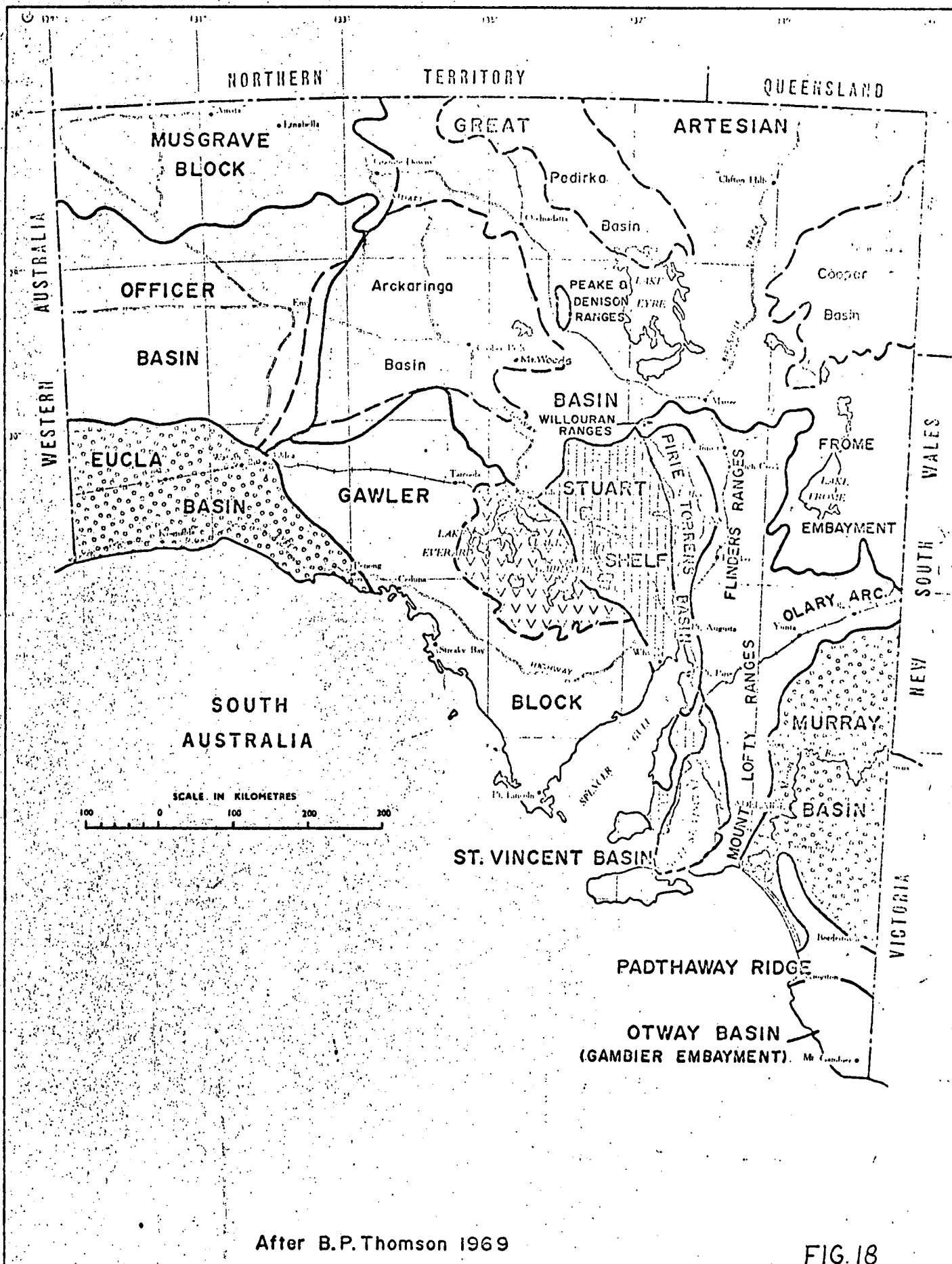


FIG 17

After N.H. Ludbrook, 1968



After B.P. Thomson 1969

FIG. 18

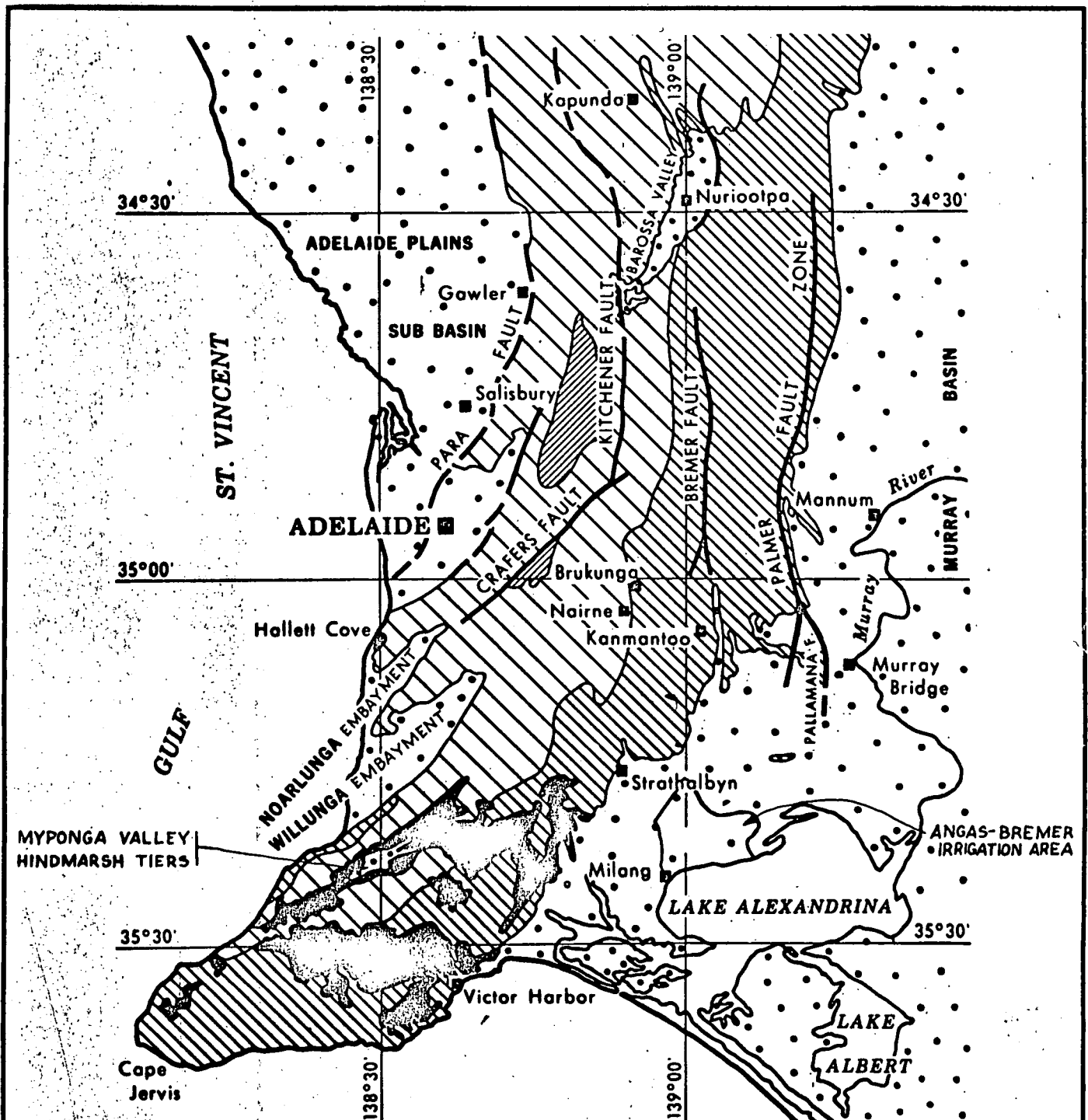
DEPARTMENT OF MINES — SOUTH AUSTRALIA

Compiled.	
Drn.	Ckd.

**SOUTH AUSTRALIA
MAJOR STRUCTURAL UNITS**

Date:
Org. No. **S12626**

1:1 Scale 500'0. 896.2



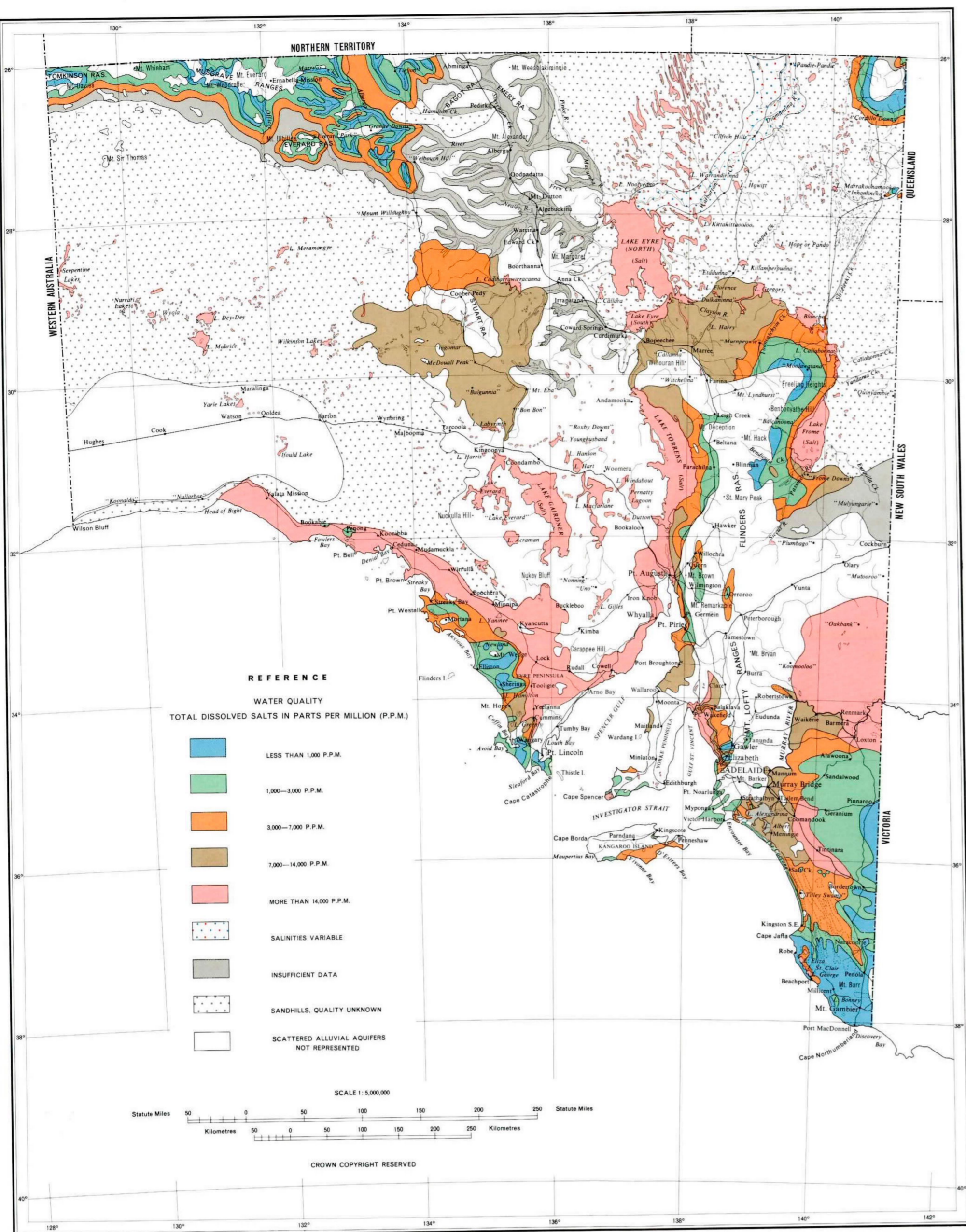
LEGEND

- TERTIARY DEPOSITS
- PERMIAN DEPOSITS
- BASEMENT ROCKS
- CAMBRIAN
- UPPER PROTEROZOIC (ADELAIDEAN)
- LOWER PROTEROZOIC

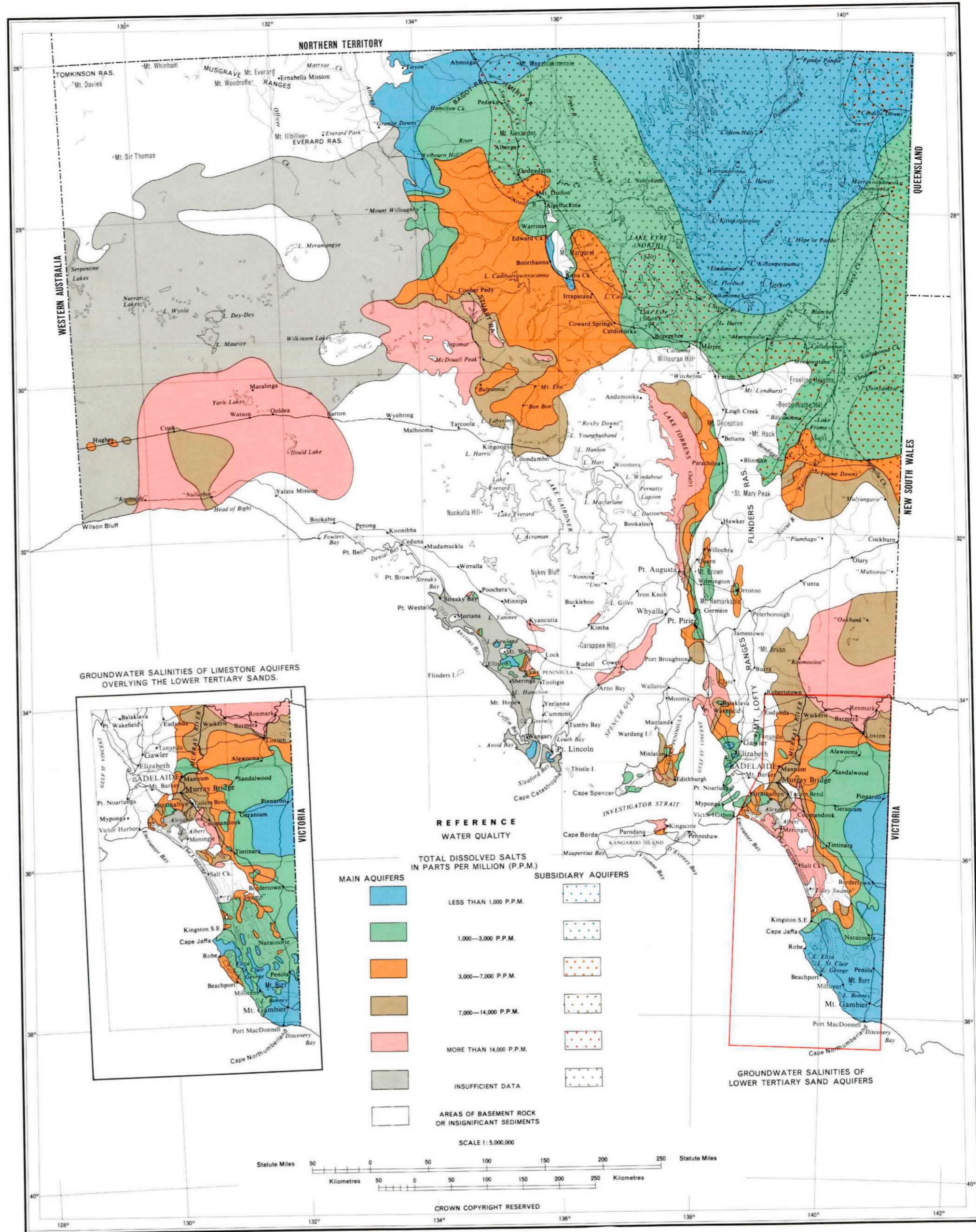
Fig. 19

DEPARTMENT OF MINES - SOUTH AUSTRALIA		SCALE:
SOUTHERN MT. LOFTY RANGES		DATE:
COMPILED:	GENERAL GEOLOGY	PLAN NUMBER
DRN: CKD.		512535

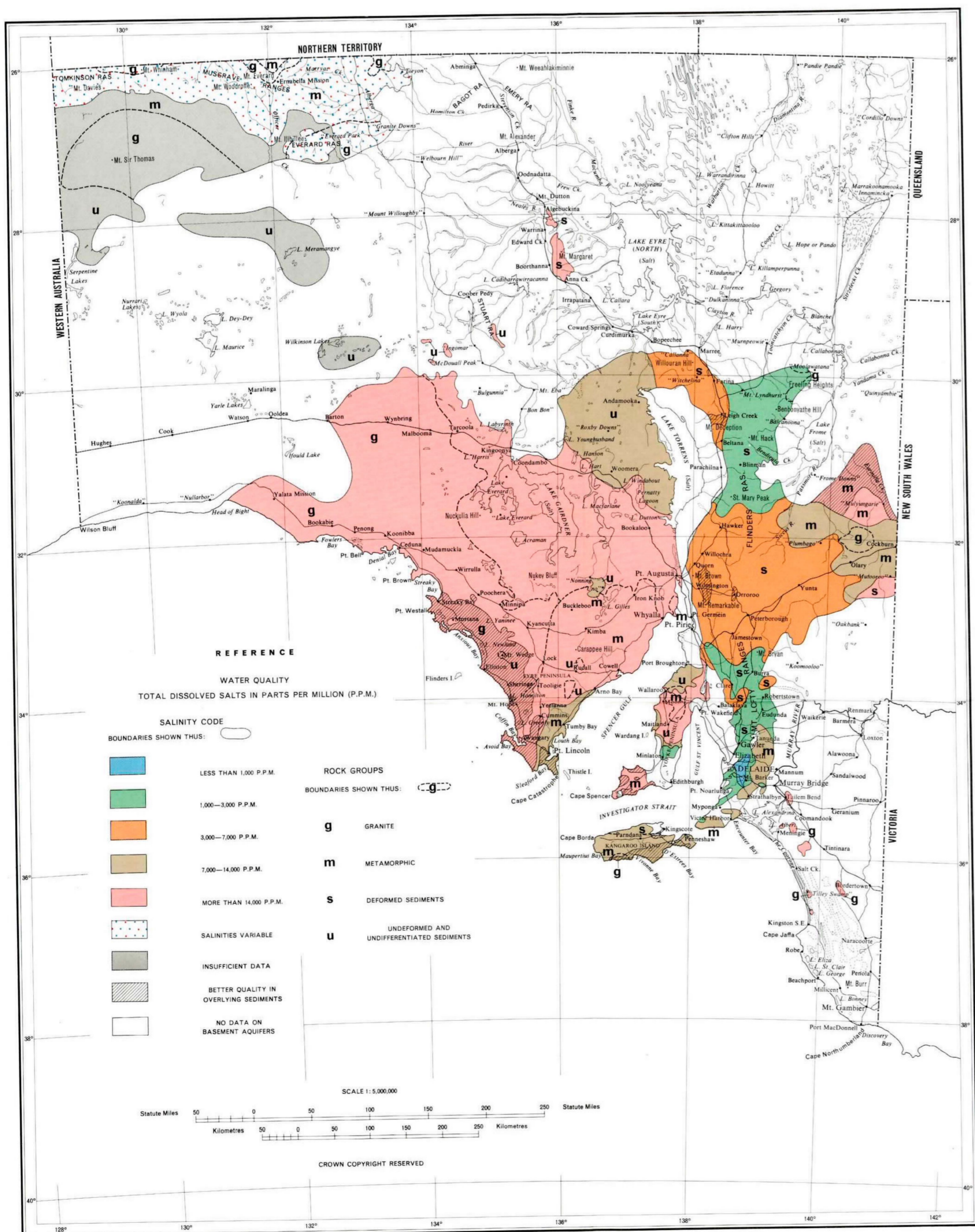
UNDERGROUND WATER RESOURCES OF SOUTH AUSTRALIA



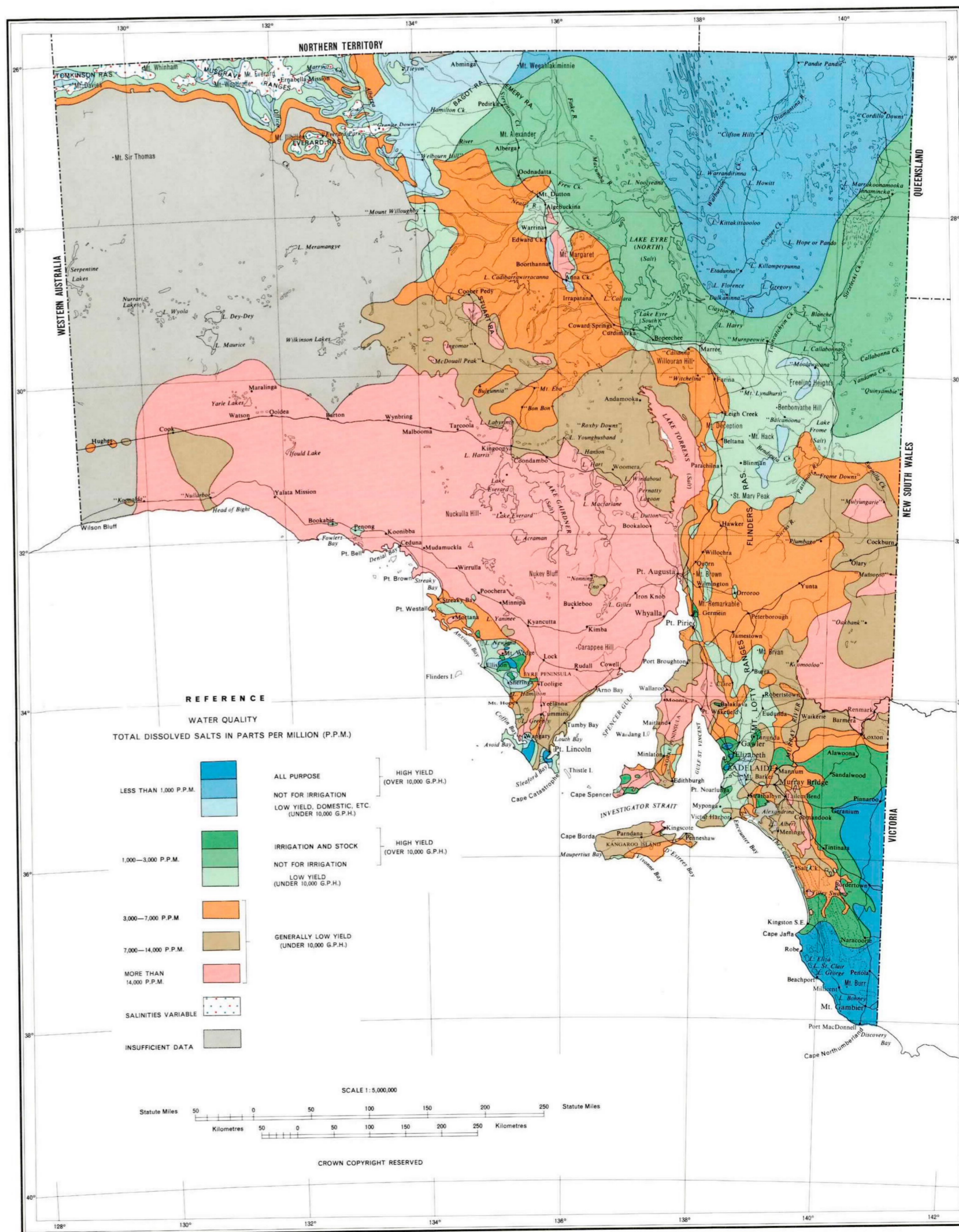
MAP 1—GROUNDWATER RESOURCES IN SHALLOW UNCONSOLIDATED SEDIMENTS



MAP 2—GROUNDWATER RESOURCES IN SEDIMENTARY BASINS



MAP 3—GROUNDWATER RESOURCES IN FRACTURED ROCK



MAP 4—GROUNDWATER RESOURCES—DISTRIBUTION OF BEST AVAILABLE WATER

Maps 1, 2 and 3 portray generalised salinities of groundwater within different geological environments. Usage of groundwater is influenced not only by the type and amount of saline matter dissolved, but also by the type of soil, drainage, climatic conditions, etc.

Map 4 is a comprehensive assessment of best available water, irrespective of source, portraying yield and suitability for irrigation.

All maps are based on available records and do not show local variations in groundwater quality.

SUITABILITY AND TOLERANCE LIMITS

LESS THAN 1,000 P.P.M. GOOD QUALITY—Usually potable and suitable for all stock and most domestic uses including gardens.

1,000-3,000 P.P.M. GOOD QUALITY STOCK WATER—Suitable for all stock and irrigation of salt-tolerant crops under favourable conditions.

3,000-7,000 P.P.M. FAIR QUALITY—Suitable for most stock.

7,000-14,000 P.P.M. POOR QUALITY—Dairy Cattle will tolerate up to 1,000 P.P.M. Beef Cattle and Lambs will tolerate up to 10,000 P.P.M. Sheep on dry feed and salt bush will tolerate up to 12,000 P.P.M.

MORE THAN 14,000 P.P.M. BAD QUALITY—Sheep on green pastures may tolerate up to 15,700 P.P.M.

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Government Geologist, Director of Mines.

Issued under the authority of the Honourable
D. A. Dunstan, M.P., Minister of Development and Mines.

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