UNDERGROUND WATER INVESTIGATION

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ASPECTS OF THE GEOLOGICAL STRUCTURE OF THE MURRAY BASIN IN NORTH-WESTERN VICTORIA

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*By M. W. Johns, B.Sc. and C. R. Lawrence, B.Sc.**

INTRODUCTION.

The Murray Basin is an area of over 100,000 square miles which partly covers New South Wales and South Australia, as well as Victoria, but this report deals with that part of the basin which lies in north-western Victoria.

It has been necessary to rely largely on bore logs and bore samples for information on the structure and stratigraphy of the basin, because most of the area is covered by a veneer of quaternary unfossiliferous sediments.

Bores used for this purpose are mainly official exploratory bores sunk for underground water and of which thirty-four have penetrated the pre-Tertiary land surface (here referred to as bedrock). The data available from the few private bores which have penetrated bedrock, or which have been sunk in areas devoid of official drilling, were also examined. Other lines of enquiry used to arrive at the geological structure included the study of geophysical surveys, both gravity and magnetic, the geochemistry and movement of underground waters, the trends of streams and the positions of lakes.

It appears that movement along ancient lines of weakness in two or three directional trends (approximately north-west, north-east and north) within the basement rocks, have been dominant in the formation of the basin. Sporadic movements, both positive and negative, have occurred in these directions from the earliest Tertiary and possibly from late Mesozoic times. These relative land movements, combined probably with eustatic changes of sea level, have allowed different environments of deposition, varying from marine to fresh water, to prevail over large areas of the basin at different times.

CONTOURS OF THE BEDROCK SURFACE OF THE MURRAY BASIN IN VICTORIA.

Several rock types have been met in the bores in north-western Victoria beneath the Tertiary sediments. These rock types and localities are given in Table 1.

TABLE 1.—TYPES OF BEDROCK, DEPTHS AND LOCALITIES.

Rock Type.	Depth Struck.	Reduced Level of Bedrock.	Bore Name.	Parish.	Position of Bore.
	feet.	feet.			
Glacial sandstone[1] and tillite (Permian ?)	978	− 588	Netherby No. 1 ..	Warraquil ..	3 miles west of Netherby
Quartz porphyry[1] ..	2,175	− 1,785	Netherby No. 1 ..	Warraquil ..	3 miles west of Netherby
Porphyry	272	+ 127 (approx.)	Mitre	Arapiles	Allotment 34A
Granite	409	− 60 (Approx.)	Apsley	Boikerbert ..	Township of Apsley. Adjacent to allotment 5, Section 9
Granite	82	+ 433 (Very approx.)	Douglas	Toolongrook ..	Adjacent to allotment 72
Granite[1]	148	+ 214 (Approx.)	Glenloth ..	Glenloth ..	Adjacent to Allotment 19, Section 7
Granite	745	− 212	Goroke	Goroke	Allotment 8
Granite	705	− 172	Gymbowen ..	Gymbowen ..	School grounds
Granite	592	− 355 (Approx.)	Lake Boga ..	Kunat Kunat ..	Allotment 2, Section 4
Granite	271	+ 67 (Approx.)	Langkoop ..	Meerek	Allotment 4A
Granite or micaceous sandstone[1 2]	863	− 579	Marlbed	Towma	Water Reserve
Granite	1,098	− 672	Netherby No. 2 ..	Warraquil ..	Township of Netherby. Public Building Reserve

* Manuscript prepared 12th July, 1961.

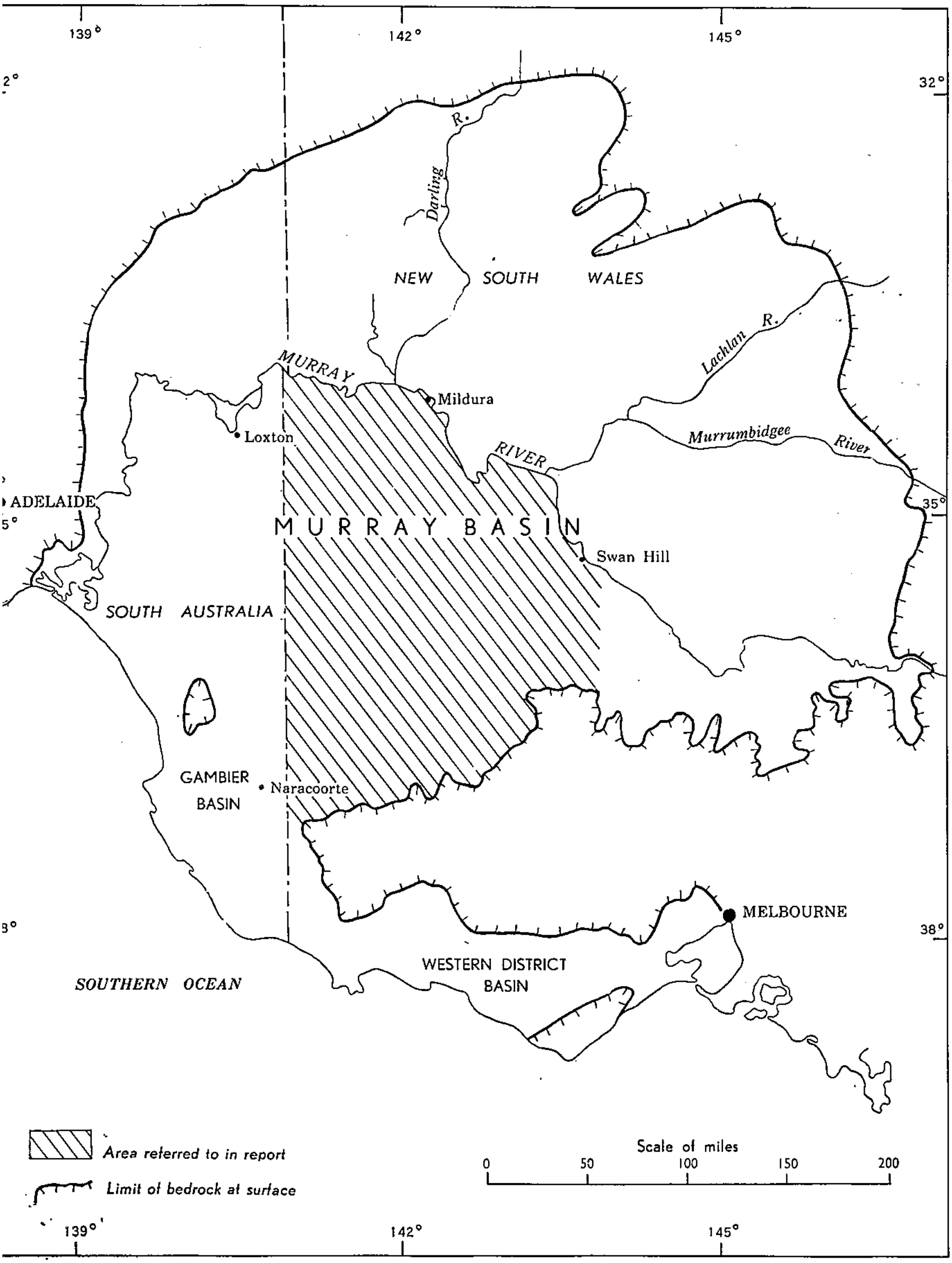

Fig. 1. Locality plan of Murray Basin area.

Most of the rock types encountered in these bores may be matched with similar rocks outcropping at the edges of the basin. As no fossils are known in outcrops of shale, slate and sandstone near the basin, they have been provisionally dated as Lower Ordovician on lithological grounds although they are possibly part of the Kanmantoo Group of South Australia.

It is to be noted that no sandstone similar to the Grampian sandstone has been encountered in any of the bores sunk in the Murray Basin, and moreover, that no Grampian sandstone is known further north than Mount Arapiles.

Although bedrock bores have not been sunk in large areas of the Murray Basin, some general features of its structure emerge from a consideration of contours of the pre-Tertiary land surface. (See Figure 3).

The main feature of these contours in the southern part of the basin is that they demonstrate the greater depth of the basin and also the much greater thickness of Cainozoic sediments to the west of a line running approximately north–south through Lake Hindmarsh than to the east of this line. The lithological sequences on each side of the line are different. From Upper Oligocene to Middle Miocene times deep clear water marine conditions, predominated to the west of this line and creamish-white limestones and some marls were deposited. To the east of the line muddy conditions favouring the formation of glauconitic clays and marls prevailed during this time. The difference in elevation of the bedrock surface on either side of the line appears to diminish in a northerly direction to the Pinnaroo–Ouyen railway line. However, both sections of the basin, deepen to the north, the deepest portion probably being in the far north-west corner of Victoria.

Because of the separation of the basin into large regions of dissimilar lithology and depth, it is proposed to discuss the geology of these regions seriatim.

THE GEOLOGY OF THE WESTERN PORTION OF THE MURRAY BASIN IN VICTORIA.

In the south-western part of the basin, the warping which caused the uplift of the Dundas highlands in Victoria and the Padthaway Ridge in South Australia apparently began in pre-Mesozoic times, and further movements have taken place intermittently throughout Cainozioc times. In South Australia the non-existence on the horst block of Mesozoic sediments which occur to the north and south of the block and the thinning of the Tertiary sediments over it provide evidence of this.

This unwarped region in the counties of Dundas and Lowan appears to have been the main structural ' high ' in the western part of the Murray Basin which gradually deepened to the north of it. It is possible, however, that the latest period of uplift in the formation of this basement ' high ' may have been quite recent.

At Goroke and Gymbowen on the northern edge of the upwarp in bedrock which was responsible for the Dundas highlands, granitic rocks were struck in bores at 212 and 172 feet below sea level respectively (all depths to bedrock are with reference to low water mark at Hobson's Bay). In general the Murray Basin deepens to the north from these bores. As well as a general deepening of the basin from Goroke northwards, there is also a general deepening from west to east from Bordertown, just across the South Australian border. At Bordertown bedrock is about 300 feet below sea level whereas at Nhill bedrock is at 586 feet below sea level. The bryozoan limestone which was deposited there during Lower Miocene times under fairly deep, clear water conditions thickens as one travels north to the Murrayville district.

These limestones grade laterally into marls and clays towards the southern structurally high region, suggesting the proximity of a source of terrestrial sediment to the south. Also, wherever they occur the limestones grade into marls with depth.

In the county of Weeah and the northern part of the county of Lowan the general lithological sequence of Cainozoic sediments is fairly constant. The generalized sequence in the " Mallee " bores near Murrayville has been described by Chapman (1916). Later work by geologists of the South Australian Mines Department Ludbrook, 1957, 1958, 1961, *et alia*) has established the general stratigraphy for an equivalent part of the Murray Basin across the South Australian border. It appears likely that most of the formations already named in South Australia, are to be found in bores near Murrayville in north-western Victoria.

To the south of Yanac towards the highlands the formations possibly become diachronous. The Pliocene estuarine sands recorded near Murrayville appear to be replaced by fluviatile deposits further south. Also, in the most southern part of the county of Lowan the Bookpurnong Beds are absent.

Chapman (1916) demonstrated the existence of a monocline in the Cainozoic sediments near Murrayville, the upwarped section to the west probably being due to a fault in bedrock. The Bookpurnong Beds thicken on the downwarped side of the structure but there also appears to be an exceptional accumulation of Pleistocene and Recent sands and Loxton sands or their equivalents just east of Murrayville. Uplift, therefore, apparently began in the Upper Miocene and continued in sporadic movements during Upper Miocene to Pleistocene times.

TABLE 2.—GENERAL STRATIGRAPHIC COLUMN FOR THE WESTERN PART OF THE MURRAY BASIN IN VICTORIA.

Age.	Stratigraphic Unit.	Lithology.
Pleistocene ? to Recent	.. ..	White, yellow and brown fine and coarse grained sand, and clay, soil and layers of ironstone and kunkar
Pliocene ?	Loxton Sands or equivalents ..	Yellow and brown micaceous sands, fossiliferous in part
Upper Miocene	Bookpurnong Beds	Green, grey and brown sands, marls and clays with mollusca ; often glauconitic towards the base
Middle Miocene to Lower Oligocene	Murray and Glenelg Groups. Probably including the Pata Limestone, Morgan Limestone, Mannum Formation, and Ettrick Formation	Grey, white and cream limestone, usually containing abundant bryozoa, and marls. Some thin layers of clay and occasional bands of flint
Eocene	Knight Group	Brown to black carbonaceous clays, silts and sands, with some lignite. White and yellow sand and gravel beds.
Pre-Tertiary	.. ..	" Bedrock "

Hills (1939) postulated that this monoclinal fold trends in a north westerly direction through Murrayville and coincides with an uplift which Howchin (1919) had shown to have occurred in South Australia to the north of Pinnaroo. This uplift probably altered the course of the Murray River during fairly recent times, causing it to flow further north-west from the Great Pyap Bend in South Australia, before cutting a course southward to the coast.

However, structure contours of the upper limits of both the Bookpurnong Beds and limestones of the Murray Group in the county of Weeah, as drawn by Gloe (1947) and independently confirmed by the writers, show a distinct monoclinal flexure passing approximately in a north-easterly direction through Murrayville and apparently dying out near the southern boundary of the county of Millewa (See Figures 3 and 6). To the west of Murrayville the Cainozoic sediments have a fairly flat dip north, but a north–south section through the bores in the parish of Carina to the " Rock Holes " bore shows a slight monoclinal fold to the north. This fold may be a weak expression in Victoria of a monoclinal fold in the Cainozoic sediments, caused by a bedrock fault with a north-westerly trend, which has affected the course of the Murray River in South Australia. There appears to be little evidence in Victoria for a continuation of this structure south-eastwards towards Dimboola as postulated by Hills (1939).

This Murrayville structure has probably been caused by a bedrock fault the effect of which has been transmitted to the over-lying sediments as a monocline. The probable extent of this fault, the Danyo Fault, is shown in Figure 3. Between Murrayville and Underbool, about 40 miles further east, the structure contours of the upper limits of the Bookpurnong Beds show several gentle anticlinal and synclinal folds pitching with low angles to the north–north-easterly trend. As Hills (1939) has pointed out, it is difficult to conceive of a mechanism capable of folding these realitively unconsolidated sediments by lateral compression. Gloe (1947) considers that these gentle structures may be due to minor adjustments of folded bedrock as a result of tectonic uplift further south and west. It appears, however, that these minor structures in the Cainozoic sediments have not had much effect upon the present topography.

The east-west section through Walpeup in Figure 6 shows that the prominent surface ridges which have trends varying from north to north-west in north-western Victoria (Hills, 1939) are probably not related to structures in the underlying Cainozoic rocks or buried bedrock " highs ".

Ludbrook (1961) has shown that the " Company " bore and the Loxton oil bore in South Australia struck Lower Cretaceous (Albian) sediments at 1,475 and 1,207 feet below sea level respectively (South Australian datum). That is, Mesozoic partially marine sedimentation, occurred both to the north and south of the Padthaway Ridge. In the northern part of the basin these sediments are greenish-grey glauconitic shales and dark grey carbonaceous mudstones. The glauconitic shales carry an impoverished micro-fauna with arenaceous foraminifera which permit tentative correlation to be made with the Tambo Formation on the margin of the Great Artesian Basin.

It is possible that some Mesozoic sediments were deposited in the north-west corner of Victoria where the Murray Basin is relatively deep, but as yet no bores have been sunk to the depth at which these sediments are likely to be encountered.

THE GEOLOGY OF THE SOUTH-EASTERN PORTION OF THE MURRAY BASIN IN VICTORIA.

A bore sunk during 1945 on allotment 38 in the parish of Watchegatcheca, about 6 miles west-north-west from Dimboola, seems to have given the first indication that the creamish-white bryozoan limestone which occurs in the western part of the Murray Basin does not continue across to the eastern part and that bedrock may be considerably shallower to the east.

Bedrock in this bore was struck at 32 feet below sea level beneath 370 feet of Cainozoic sediments. It has been identified as diabase, probably of Cambrian age. Crespin (1946) has carried out a micropalaeontological examination of this bore and has reached the following conclusion regarding the stratigraphic sequence.

The marine clays and marls are the biostratigraphic correlates of part at least of the creamish white limestone found further west and north. There is no evidence of sediments attributable to the Knight Group in this bore.

Another bore about thirteen miles south-east of the Dimboola bore was sunk in 1958–9 by the Mines Department in the parish of Wail. This bore struck diabase at 124 feet below sea level beneath Cainozoic sediments similar to those penetrated by the Dimboola bore except that they included ligneous sands and brown coal seams which resemble the sediments of the Knight Group found in the bores further west and north.

TABLE 3.—GENERALIZED STRATIGRAPHY OF THE DIMBOOLA BORE.
(After Crespin, 1946.)

Age.	Thickness.	Lithology.
Pleistocene to Recent	58 feet	Sandstone, unfossiliferous
Upper Pliocene	19 ,,	Fine dark grey sandstone with glauconite and foraminifera. Estuarine and shallow marine deposits
Mixed (?) Middle Pliocene and Middle Miocene	31 ,,	Friable sandstone and fossils
Middle Miocene	259 ,,	Fossiliferous grey and green marls and clays, glauconitic and pyritic in part Glauconitic sandstones and grits
Palaeozoic	9 ,,	Dark brown basic rocks

A bore at Gerang Gerung township, completed in 1960, also struck diabase beneath 658 feet of Cainozoic sediments. This bore is near the edge of the deeper western part of the Murray Basin in Victoria where the white bryozoan limestone occurs, and a summary of its log is as follows :—

Description.	Depth. From.	Depth. To.
	feet.	feet.
Red and yellow sandstone, sand and some gravels	0	190
Greenish grey sandy marl ..	190	222
Bryozoan limestone	222	360
Limestone and fossiliferous marl ..	360	380
Grey fossiliferous marl	380	500
Ligneous clays, lignite, sands and some gravel	500	658
Decomposed diabase	658	685

A bore in the parish of Quantong, about four miles south-west of the Wail bore, struck Palaeozoic sandstones and slates at 250 feet below sea level after passing through a similar sequence to that at Wail, the difference being that at Quantong the Pleistocene to recent sediments were predominantly clays rather than sands and sandstone.

The results of this drilling appear to indicate the existence of a belt of Lower Palaeozoic, probably Cambrian, diabase trending in a north-north-westerly direction from Horsham and forming a bedrock " high " in the basin. The fact that the considerable thicknesses of ligneous sediments which occur further west (as at Nhill where they are about 430 feet thick) do not occur in the Dimboola bore and are much thinner in the Wail bore, shows the bedrock " high " was in existence in early Tertiary times. Some gravels near the bottom of the bore at Quantong appear to be fairly coarse outwash deposits which were probably deposited on the western slope of this bedrock " high ".

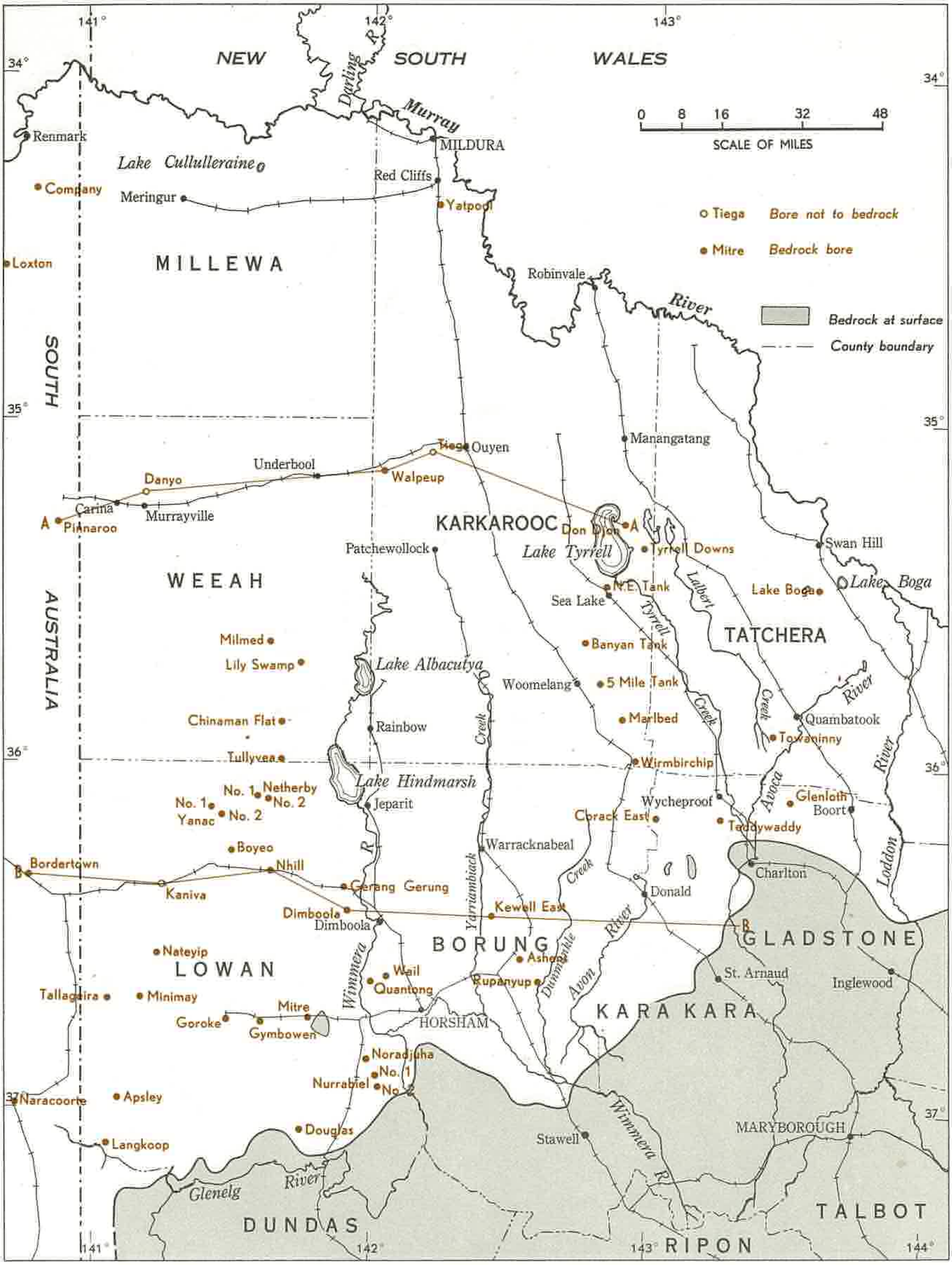

Fig. 2. Locality map showing positions of deep bores and section lines A and B

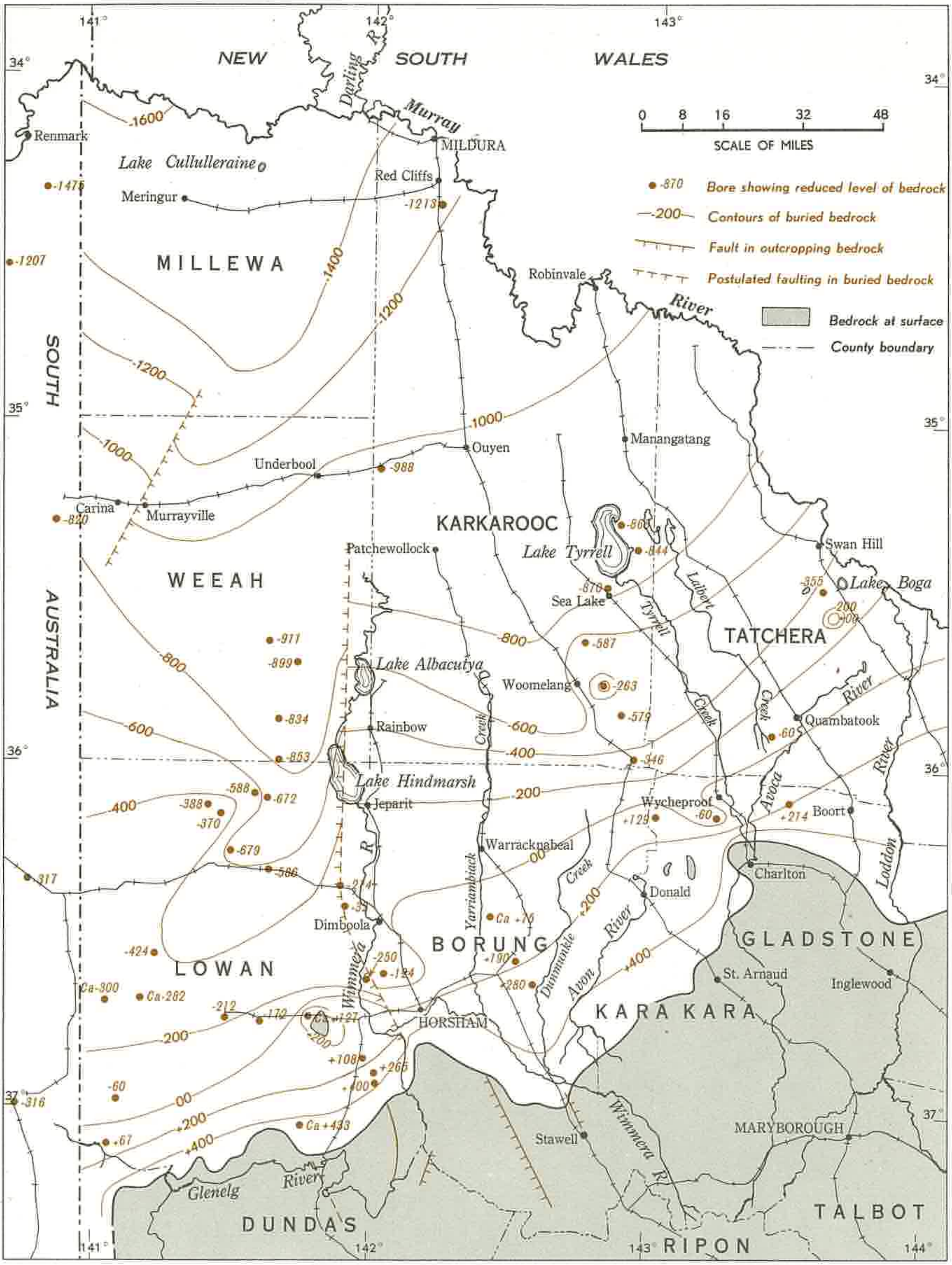

Fig. 3. Contours of buried bedrock surface

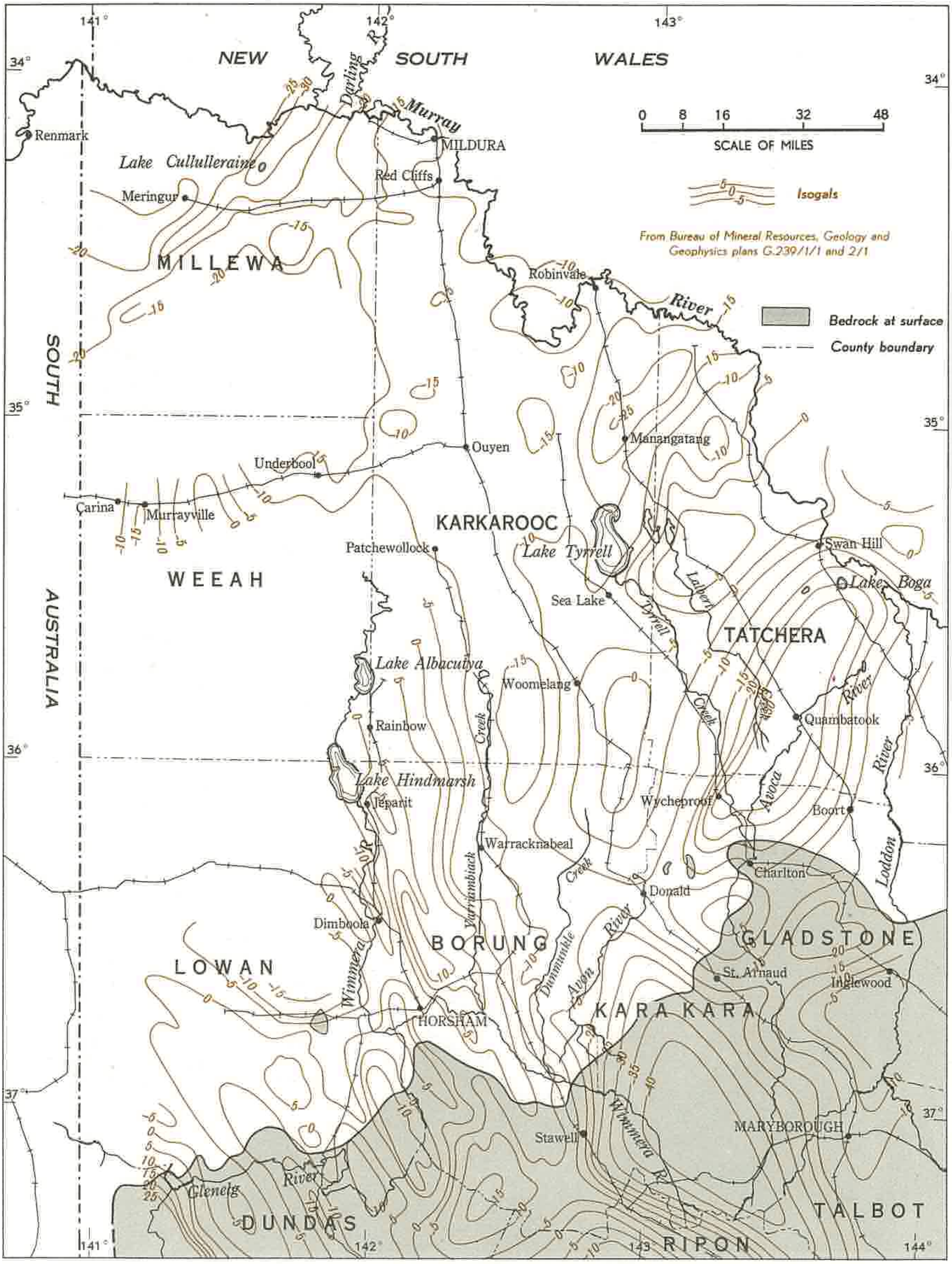

Fig. 4. Bouguer anomaly contours

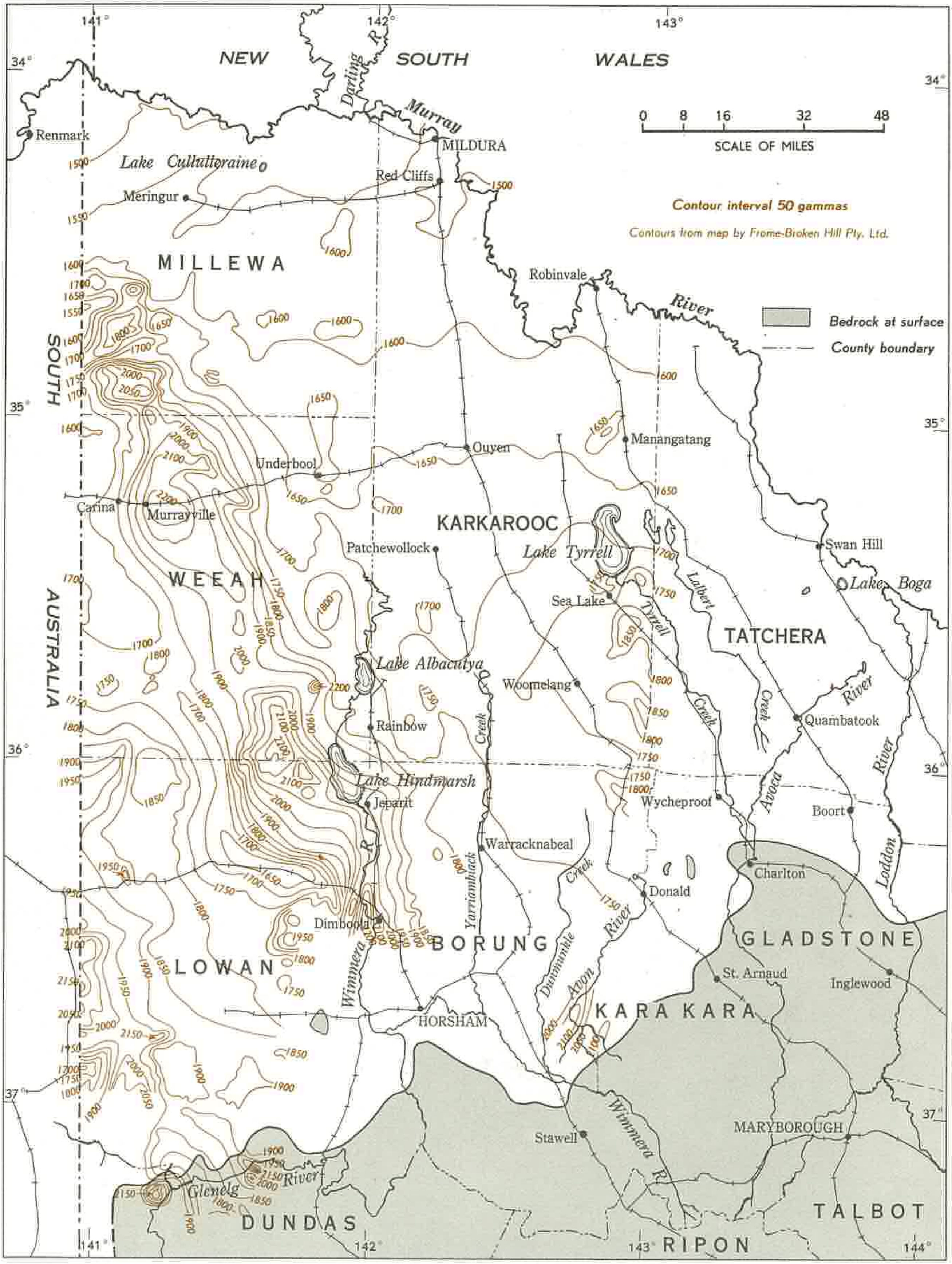

Fig. 5. Aeromagnetic survey of Victorian part of Murray basin

The diabase belt may be related to similar rocks either at Mt. Stavely and Mt. Drummond to the east of the Grampians, or in the central part of the Black Range to the west of the Grampians. Should, however, either of these diabase belts be connected with the Dimboola–Wail diabase, then some change in the trends of their outcrops would appear to be necessary to the north of the Grampians, to allow for alignment with the northern belt.

The discovery of a bedrock " high " at Dimboola ɔver which glauconitic clays and marls were leposited during the deposition of the white imestone further west, promoted the idea Gloe 1947) that perhaps there was an anticline in he Tertiary limestone due to the effects of a buried idge. It was thought that clays and marls replaced he limestone on the ridge because of the different nvironments of sedimentation prevailing there it that time, but that the limestone was deposited igain further east. As will be discussed later, there vere reasons for believing that the sub-artesian vaters to the east and west of this structure had little onnexion with each other and that an anticlinal tructure of this kind containing sediments of elatively low permeability across it would partly it least provide a physical separation of the two ɔortions of the Murray Basin.

As against this, recent private boring for water o a depth of 500 feet at Peppers Plains, about 8 miles ast of Jeparit, and to a depth of 560 feet at Pullut few miles south of Rainbow although not ontinued to bedrock in either case, indicates that he fairly pure limestone occurs in the western ortion of the basin but not further east across the elt of diabase. Marls and glauconitic and arbonaceous clays and silts predominate instead.

At least three private bores in this south-eastern art of the Murray Basin have reached bedrock. t Kewell East, about 12 miles south of Varracknabeal, Palaeozoic slates with quartz eefs were struck at 75 feet above sea level, beneath 44 feet of Cainozoic sediments. The log of this ore in a simplified form is as follows :—

Description.	Depth. From.	Depth. To.
	feet.	feet.
llow sandstones, some gravels	0	121
ey-green to brown fossiliferous marls and clays	121	225
rbonaceous silty clay with fossils	225	345
laeozoic slate	345	348

Two further bedrock bores in the parishes of Ashens and Rupanyup, south-east of the Kewell East bore, struck Palaeozoic slate and biotite schist at about 190 feet and 280 feet above sea level ; in these bores the Cainozoic sediments are only 250 feet and 180 feet thick and are predominantly carbonaceous silty clays with some glauconitic marls. Thus the Cainozoic sediments thin rapidly in the south-eastern portion of the Murray Basin and this suggests that the Tertiary sea here was not as deep as in the western part of the basin. Subsidence in the south-east of the basin more or less kept pace with the rate of deposition of fine-grained sediments, so that at no time were there deep, clear water conditions prevailing there in the Tertiary sea.

Private water bores in the north–south strip of land a few miles west of the Wimmera River from Jeparit to Dimboola give indications that the white bryozoan limestone grades laterally into clays and marls. It appears likely, therefore, that there exists, rather than an anticline in the Tertiary sediments, a bedrock fault—the Hindmarsh Fault—with approximately a north–south trend through Lake Hindmarsh. South of Dimboola the Hindmarsh Fault appears to trend in a south east direction where it has permitted considerable relative movement between the basement blocks to the east and west of it.

At Dimboola and Wail the diabase probably has a similar elevation to the Lower Palaeozoic rocks to the east of it so that it merges into the pre-Tertiary land surface of the uplifted bedrock block in the eastern portion of the Wimmera Region (see Figure 7).

EVIDENCE FOR RECENT UPLIFT IN THE SOUTH-WESTERN PORTION OF THE MURRAY BASIN IN VICTORIA.

In general, the land surface in the county of Lowan to the west of the Hindmarsh Fault is between 400 and 500 feet above sea level whereas further east in the county of Borung it is generally between 300 and 400 feet (see Figure 7).

The Pleistocene to Recent terrestrial and fluviatile deposits which occur over both counties vary between 150 and 250 feet thick to the west of the fault and from 100 and 150 feet thick to the east of the fault. Thus, the greater thickness of sands and sandstones over a large area in the western part of the basin are at a greater elevation than the thinner deposits in the eastern part. One would normally expect the greatest thickness of such deposits to form at the lowest elevations, and

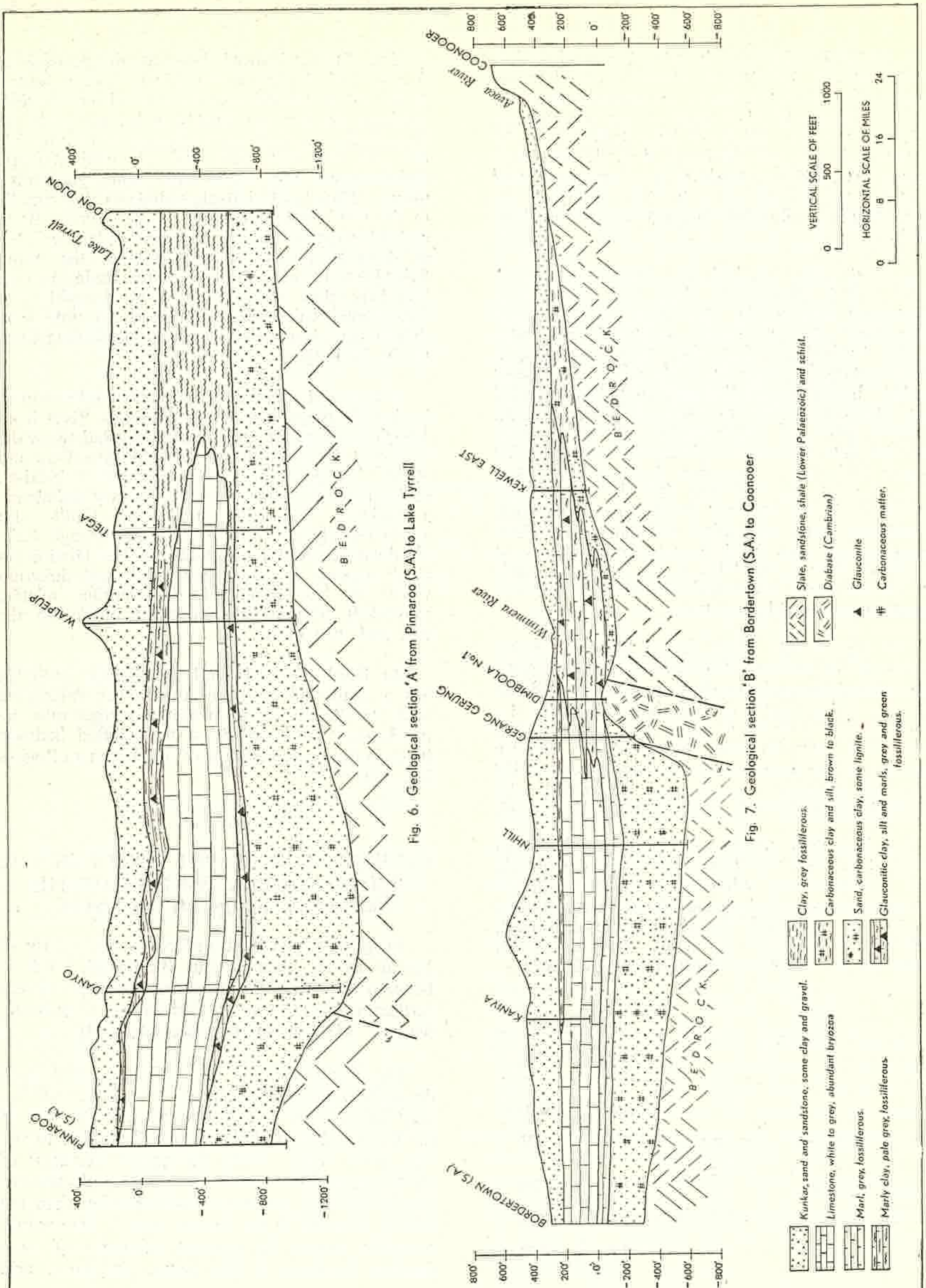

Fig. 6. Geological section 'A' from Pinnaroo (S.A.) to Lake Tyrrell

Fig. 7. Geological section 'B' from Bordertown (S.A.) to Coonooer

Figures 6 and 7, Sections A and B, Murray Basin.

although this difference is not well pronounced, it may indicate a fairly recent uplift along the Hindmarsh Fault of the western block relative to the eastern block.

The abrupt change in the direction of the course of the Wimmera River from south-west to north between Horsham and a point a few miles south of Quantong may be due to such an uplift of the western block of sediments.

This would prevent the river from flowing to the west and cause it to flow northward where its comparatively small flow, dissipated by downward seepage and evaporation, ceases in the series of lakes formed in natural depressions just to the east of the uplifted block.

Such minor movements along bedrock faults appear to have caused the Murray River to change its course in Recent times at the Great Pyap Bend in South Australia and there is little doubt that similar crustal movements have occurred in other parts of the Murray Basin during Recent times.

THE GEOLOGY OF THE NORTH-EASTERN PORTION OF THE MURRAY BASIN IN VICTORIA.

The eastern limit of the Upper Oligocene and Miocene limestone deposition in the north-eastern part of the basin is not accurately known but it is probably mid-way between the Tiega bore and Lake Tyrrell. These limestones then grade laterally into marls and clays.

In the eastern portions of the counties of Borung and Karkarooc the glauconitic marls and clays grade eastwards into carbonaceous clays, silts and estuartine deposits. These in turn grade eastwards into entirely non marine sands and clays against the edge of the bedrock outcrops which mark the eastern margin of the basin from Stawell to Charlton. It is to be noted that the terrestrial, fluviatile, and lacustrine gravels, sands, silts and clays of the Murray Basin sequence extend eastwards to Wangaratta where they are the sole representatives of Cainozoic sedimentation.

The line of bedrock bores north from Corack East to the northern edge of Lake Tyrrell sunk in 1887–88, demonstrated that the Murray Basin deepens to the north of Birchip. For example, at Tyrrell Downs bore about three miles east of Lake Tyrrell, 1,044 feet of Cainozoic sediments were penetrated and Lower Palaeozoic sediments struck at 844 feet below sea level. The log of this bore is as follows :—

Description.	Depth.	
	From.	To.
	feet.	feet.
Clay	0	47
Clay and sand	47	100
Sand	100	268
Carbonaceous clay	268	520
Marl, fossiliferous	520	525
Carbonaceous clay	525	750
Lignite	750	1,044
Shale (Bedrock)	1,044	1,122

During much of the time in which limestones were being deposited further west in the Murray Basin, carbonaceous clays and silts with some fossiliferous marls and clays were being deposited, probably under estuarine conditions, in the eastern part of the county of Karkarooc. Evidently the rate of subsidence in this portion of the Murray Basin roughly kept pace with the rate of deposition so that deep water conditions did not prevail there.

The gradual uplift and the recession of the sea in Pliocene times formed terrestrial and fresh water deposits here as elsewhere in the Basin.

It seems probable that a bedrock fault or faults may have controlled the formation of this comparatively deep basin, although there is little evidence for accurately locating such a fault on a map. The trend of bedrock outcrops along the eastern edge of the basin from Glenorchy to Lake Boga is north-easterly and this may reflect some bedrock structures.

EVIDENCE OF GEOLOGICAL STRUCTURE FROM THE QUALITY AND DIRECTION OF MOVEMENT OF UNDERGROUND WATERS IN THE MURRAY BASIN.

A feature of the artesian waters found in the Victorian portion of the Murray Basin and one which has played a very big part in their utilization has been the much better quality of water struck to the west of a line running approximately north-south from Dimboola to Underbool and then turning north-west into South Australia, than that generally found to the east and north of this limit (Kenyon 1914, and Gloe 1947).

In the southern part of the Murray Basin in Victoria the transition from water containing from 1000 to 4000 parts per million (p.p.m.) of dissolved solids to water containing between 4,500 and 30,000 p.p.m. or more dissolved solids occurs quite rapidly about 3 miles west of Jeparit (see Figure 8).

Anderson (1941) has shown that much of the dissolved matter in underground water is of oceanic origin. For example, in water from the bryozoan limestone aquifer at Nhill, in the south-western part of the Murray Basin in Victoria, Anderson attributed 86 per cent. of the total millinormality to solids of oceanic origin and 14 per cent. to solids of non-oceanic origin. The salts of non-oceanic origin were present almost entirely as calcium, magnesium and bicarbonate ions derived from the limestone aquifer by solution in carbonic acid. The proportions of chloride to sodium, potassium and sulphate ions were fairly constant and similar to those in average present-day sea water.

This fact has been substantiated for many bore waters in the Murray Basin and elsewhere. Sometimes there have been cation-exchange reactions between the aquifer and the water ; or the presence of soluble evaporites such as gypsum within the aquifer may have increased the proportion of sulphates in the water and so have altered this general relationship. Even then the relation of the water to diluted sea water with minor additions of other salts can usually be seen.

It has also been shown that much of this dissolved matter of oceanic origin in underground water is of cyclic origin. That is, it has been carried inland by rain and wind from the ocean and then concentrated to a certain extent by evaporation and transpiration at the surface before seeping underground (Anderson, 1945).

The amounts of dissolved solids of oceanic origin in non-pressure ground waters and in pressure waters near their intake areas in the Murray Basin can readily be explained in terms of rainfall, evaporation and drainage efficiency.

However, surface concentration of cyclic salts does not explain how, within a given aquifer, the salinity of pressure water increases with the distance it travels from the intake area. The additional salts are not all calcium and magnesium bicarbonates dissolved from the aquifer itself but are the salts which are found in sea water.

The additional oceanic salts must therefore be derived from sea water trapped in the sediments at the time of their deposition, or when they were last in contact with the sea, and which has been incompletely leached from them.

On this basis it would be expected that where the sediments are relatively impermeable the underground water in them would be of highest salinity since leaching of the residual salts would be difficult.

This in fact has been found to be the case in the southern part of the Murray Basin in Victoria, where the poor quality artesian water occurs in relatively impermeable marls and silts to the east of the Hindmarsh Fault. At a similar distance from the intake area for the permeable and porous limestones to the west of this fault the water quality is much better.

Although there are insufficient bores in the eastern part of the Murray Basin in Victoria for which details of static levels are known to draw accurate isopotential lines, enough information is available to determine the general directions of movement of underground waters (see Figure 8).

These isopotential lines show that the intake area for the good quality water in the western portion of the basin is north of the Glenelg River in the county of Lowan. From here the artesian waters move northward and westward. Near Murrayville, in the county of Weeah, the movement is approximately north-westerly.

To the east of the Hindmarsh Fault there are other intake areas associated with deep leads near Stawell. Water passing underground here moves in a north-westerly direction at first and then northward before it turns to the north-west again near Underbool. There is little mixing of the more saline water from the east with the fresh water from the west as far north as Underbool. Thus the line separating good from poor quality water which passes north from near Dimboola to Underbool probably marks the position of a facies change over its whole length as it does near Dimboola. It is postulated that the Hindmarsh Fault, which is responsible for the facies change near Dimboola, has a position similar to this line as far north as Underbool from where it dies out.

Analyses of waters from bores to the north of Underbool show that there is a gradation between the two types of water although the aquifer is a fairly pure limestone in all cases. The deterioration of water quality to the north is probably due to the invasion of saline water from the east as indicated by the isopotential lines there.

GEOPHYSICAL SURVEYS OF THE MURRAY BASIN IN VICTORIA.

(a) Gravity Survey.

A reconnaissance gravity survey of western Victoria has been carried out by the Bureau of Mineral Resources. Dr. D. Spencer-Jones (private communication) has commented on this survey and its relation to the geology of the Grampians area. It shows a strong north-westerly elongation of most of the gravity anomalies consistent with the predominant tectonic trends in the northern part of the Grampian Ranges and the northern end of the Black Ranges.

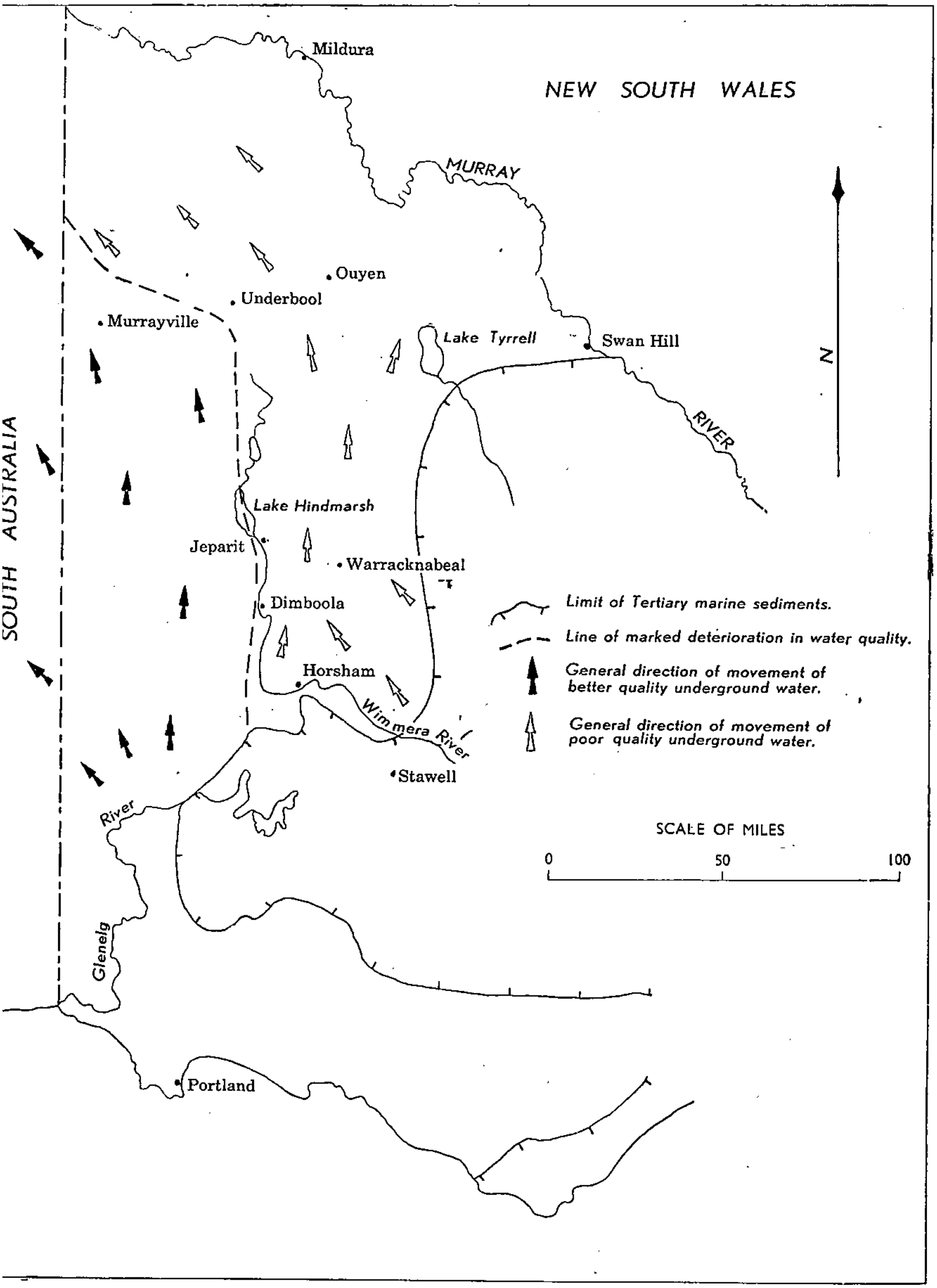

Fig. 8. General directions of movement of underground water. Murray Basin.

Broad positive gravity anomalies coincide with the projection of the Mt. Stavely–Mt. Drummond belt of Cambro–Ordovician rocks and a steep contour gradient on the south-western edge of a positive anomaly west of Mt. Thackeray coincides with a belt of diabases in the Black Ranges. However, to the north of the Grampians area the gravity anomalies trend more in northerly and north-easterly directions. The northern trend is prominent in the southern area of the Grampians also and may be a fairly prominent structural trend in western Victoria in addition to the other major trends in north-westerly and north-easterly directions which Boutakoff (1952) and others consider dominant in south-west Victoria.

Just to the east of Dimboola there is a fairly strong contour gradient with a north–north-westerly trend, which then turns northward through Lake Hindmarsh and Lake Albacutya. This anomaly may coincide with the faulting associated with the diabase struck in the Dimboola bore and other bores.

In the northern portion of the counties of Karkarooc and Tatchera the main trend of the anomalies is north-easterly.

A narrow belt of negative Bouguer anomalies across which there is a steep contour gradient passes from the South Australian border to Yarrara and Lake Culluleraine in a north-easterly direction. This, parallel to, although further north than, a similar belt with a steep gradient of anomalies which coincides with the postulated Danyo Fault. It is possible, therefore, that there are other bedrock faults trending north-east in this part of the basin although there is almost a complete lack of sub-surface information in this area.

To the north of Lake Tyrrell there is a broad positive Bouguer anomaly. Between Charlton and Lake Boga in the north-eastern part of the basin there is a north-easterly trending belt of negative Bouguer anomalies across which there is a fairly steep contour gradient. This coincides with the appearance of bedrock outcrops near Charlton, at Wycheproof and Lake Boga.

(*b*) *Aeromagnetic Survey.*

An aeromagnetic survey of most of the Murray Basin has been carried out by Frome Broken Hill Pty. Ltd. The contours of total magnetic intensity show a strong northerly trend of high intensities west of Dimboola which correspond closely to the diabase struck in the bore there, since this could be expected to be highly magnetic when found so close to the surface. This trend also shows up, but to a less well marked degree going north to Lake Hindmarsh, where a north-westerly trend of fairly high magnetic readings masks it to some extent. This north-westerly trend in magnetic anomalies may coincide with a structure which has been responsible for the preservation of a considerable thickness of Permian glacial sediments encountered in the Warraquil No. 1 bore, 3 miles west of Netherby Township. Further north there is insufficient evidence from deep bores to explain this north-westerly trend since the Tertiary sediments appear to be flat-lying here.

At Murrayville closely spaced contour lines of magnetic intensity trend in a north-easterly direction and coincide with the monocline in the Cainozoic sediments referred to earlier, and presumably with the bedrock fault which has caused this fold. In general, the low gradient of magnetic intensity over the rest of the basin in north-western Victoria indicates that there are few structures in bedrock which could be reflected by Cainozoic structures.

GEOLOGICAL HISTORY OF THE MURRAY BASIN IN VICTORIA.

The conclusions of the foregoing discussion on the geology of the Murray Basin in Victoria may be summarized in a history of the basin as follows :—

Peneplanation occurred in Upper Mesozoic times over most of the Murray Basin in Victoria, although there is a possibility that partly marine Cretaceous sediments exist in the very north-west corner of the State.

During early Eocene times subsidence occurred over a wide area of western Victoria, South Australia and New South Wales. In western Victoria north of the Dundas Peninsula, the main subsidence was of a basement block downthrown to the west of the Hindmarsh Fault trending north and south through Lake Hindmarsh. This was accompanied by the deposition of a thick series of clays, silts, sands and gravels, often carbonaceous or ligneous, under non-marine, paludal and possibly estuarine conditions with periodic marine incursions. These deposits did not extend far to the east of the Hindmarsh Fault in the south, but may have reached nearly to Lake Tyrrell in the north.

During Lower Oligocene till Middle Miocene times continued subsidence enabled the sea to encroach upon the land much farther to the east. In the southern part of the basin the region of deposition of estuarine sediments moved across the Hindmarsh Fault and shallow marine conditions prevailed on a gently sloping shelf there so that glauconitic clay and silts were deposited. To the

/est of the fault the climate and depth of clear /ater in the Miocene sea favoured the deposition f bryozoan limestone.

Maximum marine transgression took place uring Middle Miocene (?) times and the areal ktent of limestone increased. Around the margins f the areas where these conditions prevailed, marls nd clays replaced the limestones. It is probable ıat marine sediments were deposited over the)undas Peninsula which have since been largely ·oded away. The bryozoan limestone extended long the western side of the Hindmarsh Fault from ıis peninsula, north to the Murray River and robably in the north-east of the basin past Ouyen here it graded laterally into marls, clays and stuarine deposits. Glauconitic and carbonaceous ıarls and clays predominated on the sloping shelf to ıe east of the Hindmarsh Fault and reached almost) the foot of the present highlands.

At the end of Middle Miocene (?) times partial plift of some bedrock blocks, such as that to the est of Murrayville, caused the deep water limestone ıcies to recede from certain areas and more lauconitic and sandy deposits to form while mestone continued to be deposited elsewhere.

Gradual uplift over most of the basin occurred uring Upper Miocene times so that the sea receded ıd shallow marine clays and marls were deposited ver the limestone. Thinning of these clays and ıarls over the monocline at Murrayville emonstrates that uplift continued along the Danyo ault.

Uplift continued into Pliocene times when stuarine sands were deposited by a further receding :a. The greater thickness of shallow marine and stuarine sands in north-west Victoria indicate ıat the sea probably receded to the north-west.

During Upper Pliocene and Pleistocene times ıost of the Murray Basin in Victoria was covered y quartz sands laid down under fluviatile, lacustrine nd possibly deltaic conditions. During Pleistocene ıd Recent times sand dunes and large areas of unkar were formed over much of north-western 'ictoria.

Minor earth movements continued into Recent mes and caused changes in the course of the Iurray River as at the Great Pyap Bend in South ustralia and probably elsewhere along the Murray. he Wimmera River probably had its course altered ue to a slight uplift to the west of the Hindmarsh ault, and other minor uplifts in the north of the tate prevented it from reaching the Murray River. he pattern of streams on the Dundas dissected lain was disrupted by a slight upwarping of the eninsula.

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