DEPARTMENT OF NATIONAL RESOURCES

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Record No. 1977/29

CANAWAY RIDGE, QUEENSLAND, GEOPHYSICAL SURVEY, 1973

by

E.J. POLAK & D.C. RAMSAY

Record No. 1977/29

CANAWAY RIDGE, QUEENSLAND, GEOPHYSICAL SURVEY, 1973

by

E.J. POLAK & D.C. RAMSAY

CONTENTS

ILLUSTRATIONS

SUMMARY

The Bureau of Mineral Resources, Geology & Geophysics (BMR) carried out an experimental geophysical survey with the aim of identifying and resolving fresh and saline aquifers at depths up to 300 m, using bore logging and resistivity depth probing methods, along with chemical analysis of water samples. The survey was conducted in the area around Yaraka in central southwest Queensland, this location being chosen because of favourable geological conditions.

Eight bores were logged and twenty-seven depth probes recorded, as many as possible close to bores from which water samples were taken and for which, in some cases, geological logs existed. Geological and geophysical logs of deep oil wells in the area were also used in correlation of results.

The results indicated two major faults in the survey area, permitting the circulation of water from different beds. Freshwater and saltwater aquifers were differentiated by resistivity, but it was felt that the complexity of interpretation would prevent the method from being used as a regular field tool without access to expert geophysical services. The depth to basement interpreted from a deep probe was correct within the limits of experimental accuracy.

1. INTRODUCTION

The Canaway Ridge area is in central Queensland, about 150 km southwest of Longreach (Pl. 1). The area is flat and covered by scrub which provides shelter and food for beef cattle and sheep. Life in the area is centred at Yaraka and a rail service connects it twice weekly with Rockhampton.

The aim of the Canaway Ridge geophysical survey was to test the usefulness of the resistivity method in locating aquifers at depths up to 300 m. The area was chosen because the geology is reasonably well known and appears favourable for the application of the method. The freshwater aquifer zone is reasonably thick in relation to the overlying sediments which are relatively uniform, impermeable, and saline. It was hoped that the method would give a fairly reliable and inexpensive guide to depths to aquifers and perhaps some indication of aquifer quality.

The first stage of the survey was carried out in May 1972 by the Difficult Bore Logging Party of BMR, with G.S. Jennings as party leader. Eight bores were logged using gamma, temperature, differential temperature, and continuous collar locator tools.

The resistivity survey was carried out between 30 April and 13 June 1973 by a party from the Engineering Geophysics Group of BMR, consisting of E.J. Polak, D.C. Ramsay (geophysicists), R.C. Watson (draughtsman), M.J. Dickson (technical assistant) and S.J. Hall (fieldhand). Twenty-seven depth probes were recorded, using the Schlumberger electrode configuration with a maximum spacing between current electrodes varying from 2 to 12 km.

Samples of water were collected from all the pumping bores in the area and chemical analysis of the samples was arranged by the Irrigation and Water Supply Commission of Queensland.

2. GEOLOGY AND HYDROLOGY

Plate 1 shows the geology of the area of the survey. The plate is a composite of four 1:250 000 geological maps: Windorah, Adavale, Blackall, and Jundah. Plate 2 shows the gravity contours and a geological section through the area.

2.1 Stratigraphy

Quaternary. Alluvial, colluvial, and aeolian gravel, sand, silt, and clay occupy land depressions and river valleys.

Tertiary. Only the early Tertiary or so called Glendower Formation is present in the area. It consists of poorly sorted, medium-sized quartzose sandstone with a white clay matrix, quartz pebble conglomerate, and interbedded siltstone and mudstone. These rocks form prominent table hills generally silcrete-capped.

Cretaceous. Cretaceous rocks underlie unconformably the Tertiary. They consist of five geological subdivisions of the Rolling Downs Group.

Winton, the top formation, consists of labile sandstone, siltstone, and mudstone. The total thickness of these beds may be more than 300 m.

The Mackunda Formation is much thinner (10 to 150 m) but is composed of similar rocks; the basic difference is the presence of volcanic detritus.

Allaru Mudstone, Toolebuc Formation, and the Wollumbilla Formation are the three lower sequences and are marine: fossiliferous mudstone, siltstone, and limestone are the main components. The Toolebuc Formation is a marker horizon indicated clearly on the gamma logs of deep bores. The total thickness of the Lower Cretaceous is about 400 m.

The Hooray Sandstone forms a boundary between the Cretaceous and Jurassic. It consists of pebbly sandstone, conglomerate, and siltstone and is the major aquifer in the Great Artesian Basin.

Jurassic. Canaway No. 1 bore (location shown in Plate 2) near the top of the Canaway Ridge (Alliance Oil, 1963) did not indicate the presence of Jurassic rocks.

Budgerygar No. 1 bore (Alliance Oil, 1969), which is much closer to the area of investigation, included about 100 m of siltstone, mudstone, and fine sandstone of Jurassic age. The possibility of the existence of Jurassic rocks in the area of investigation will be discussed later.

Triassic. Budgerygar No. 1, Yongala No. 1 and 2 wells established the presence of quartzose sandstone, siltstone, mudstone, and minor coal belonging to Lower Triassic. These beds were not found in Cothalow No. 1 well.

Permian. Permian exists on both sides of the Canaway Fault. It consists of coal-bearing sandstone and mudstone.

Carboniferous (?). The Buckabie Formation belonging to Upper Devonian-Carboniferous (?) age has been located in all wells drilled on the downthrown side of the Canaway Fault. It consists of sandstone, siltstone, and shale.

Devonian. In Yongala No. 1 bore (Alliance Oil, 1965) metamorphosed sediments incorporating trachyte flows and belonging to the Gumbardo Formation if Middle Devonian age were found.

2.2 Structure

Consideration of the structure is very important in the discussion on the hydrology of the area. Generally the structure controls the water regimes, and this is the case in the survey area.

As the basis for discussion the gravity map (Pl. 2) of the area is used. The gravity high is an expression of the Canaway Anticline, the eastern side of which is formed by the Canaway Fault. The surface expression of the Canaway Fault is clearly identified on geological maps. The inset in Plate 2 shows the profile from Bothwell, through Budgerygar and Yongala No. 1 to Cothalow bore. The profile is adapted from Alliance Oil (1969) and is based on geological, drilling, gravity, and resistivity evidence. On the western side of the anticline a smaller fault was indicated by the Welford seismic profiles (Phillips-Sunray, 1967). The Bothwell bore proved the deepening of the strata towards the north. The Hooray Sandstone produces water in the Bothwell bore from a depth of 1481 m (4860 ft) (IWSC), while if it existed in the resistivity survey area on Canaway Ridge it would be at a depth of about 900 m (2950 ft). Hooray Sandstone

Farther east across the Canaway Fault the Lower Carboniferous and Devonian appear on the profile (Pl. 2) and the thickness of the upper formations increases indicating continuation of the fault movement during the depositional history. (Alliance Oil, 1965, 1967). The top of the basement? is not uniform, ? as indicated clearly on the gravity profile and proved by the section of the Cothalow No. 1 bore (Tanner, 1965), drilled on the Cothalow Anticline (inset, Pl. 2). It is possible that the Cothalow Anticline extends into the eastern part of the area of investigation. The seismic work (Tanner, 1965) suggests the existence of a fault cutting the structure in the southeast direction. The same fault may also cut the northern end of the Canaway Anticline. This is also a possible interpretation of the gravity map.

2.3 Hydrology

2.3.1 Main Aquifers

Although we are primarily concerned with groundwater to a depth of only 300 m a short note on the deep, main aquifer of the Great Artesian Basin is necessary. The main aquifers in the area are of Upper Jurassic to Lower Cretaceous age and are, in descending order: Hooray Sandstone, Adori Sandstone, and Hutton Sandstone. These aquifers are tapped by only a few bores in the area, most of which produce water from the Winton Formation (Upper Cretaceous). These latter supplies are restricted and the quality varies from fresh to saline. On Canaway Ridge the bores produced brackish water from the Winton Formation, and fresh water when deepened.

2.3.2 Use of Stiff Patterns

During the BMR surveys samples of water were collected from flowing bores and subsequently analysed by the Queensland Irrigation and Water Supply Commission. Plate 3 shows the Stiff patterns (Stiff, 1951) of the water samples analysed. Each of the symbols indicates the chemical composition of the salts from a particular bore. The method of presentation using a Stiff pattern was used as it gives a clear, visual, but not sophisticated method of comparison of water samples. The method was successfully applied in oil-well drilling to distinguish between brines from different horizons. The method may best be illustrated by an example from the Canaway No. 1 well, shown in Plate 3 and listed in Table 1.

A different sample pattern is found in the Yongala No. 2 well (Pl. 3, inset) which draws water from the Triassic at a depth of 1797-1812 m (5896 - 5946 ft).

TABLE 1. WATER SAMPLES FROM CANAWAY NO. 1 WELL

Sample No.	Depth metres	Depth feet	Local name	Standard name
DST 1	902 - 923	2962-3031	Transition	Hooray
DST 2	985 - 997	3234-3271	Mooga Sandstone	Hooray
DST 3	1203 - 1213	3948-3980	Gubberamunda	Adori
DST 4	1407 - 1417	4618-4652	Unnamed	Permian
DST 5	1464 - 1490	4804-4891	Unnamed	Permian

The only deep bore in the Yaraka district is No. R1057 which produces water from the main aquifer. Unfortunately the geological log of the bore drilled to 1282 m (4205 ft) was never recorded and the gamma log reached only 172 m (564 ft) where a blockage was encountered. Chemical compositions of water from R1057 and Canaway No. 1 give similar Stiff patterns, but with different concentrations.

All other samples in Plate 3 come from wells bottomed in the Winton Formation. The three samples (R3950, R3945, R3947) from the top of the Canaway Anticline show patterns similar to that from the Hooray Sandstone (DST 1 and DST 2) of the Canaway No. 1 well with some addition of NaCl, suggesting that water from the main aquifer is leaking along the fault plane and mixing with saline water of the Winton Formation. Similar modified sample patterns were found to the east (R3767 and R3941) roughly along a fault postulated in part 2.2. The three samples (R3063, R5983, R3060) to the west of the Canaway Ridge seem to indicate saline water of the Winton Formation.

In the Yaraka central area the patterns indicate a considerable increase in NaCl content. There are some modifications in the pattern probably owing to water coming from separate porous zones of the Winton Formation.

In the northeast corner of the area the patterns change again. These bores are generally deeper and also the rocks are uplifted in a steep anticline centred on Emmet (shown by gravity contours in Pl. 2).

3. METHODS AND EQUIPMENT

In the Canaway Ridge groundwater survey two methods of investigation were used: bore logging and resistivity depth probing.

3.1 Bore logging

In logging, physical properties of the rocks penetrated by the bore are continuously recorded in terms of depth. The logs obtained give relatively detailed information on some properties of the rocks and of the fluids contained both in the bore and in the pores of the rocks. Further, an accurate cross-section of the area can be obtained by correlating the logs between drill holes; incomplete geological logs may be made more detailed by the use of bore logs.

Some bore logging techniques may be used in uncased bores, others in both cased and uncased. As all the bores in the Canaway Ridge area are cased, only methods applicable to cased bores were used. These methods were: gamma, temperature, differential temperature, and continuous collar location.

3.1.1 Gamma logging

Most rocks and soils contain small quantities of radioactive material, mainly potassium, uranium, and thorium. The radioactivity of clay and shale, mainly due to potassium, is several times that of the other common types of sedimentary rocks so gamma logs can be used to distinguish clay from other types of rocks or soils. The increase in gamma ray intensity is nearly proportional to the clay content of the rock. Gamma logging can be carried out in an open or a cased borehole, whether full of mud or water or empty.

3.1.2 Temperature and differential ~~temperature~~ logging

The interior of the earth is very hot but its surface temperature is only slightly affected by this heat. The thermal conductivity of rock is a characteristic property of the rock type and is generally very low: igneous rocks have much higher thermal conductivity than sedimentary rocks. The temperature in a shallow hole is equal to the mean annual air temperature; at greater depths, the temperature increases with a temperature gradient measured in Celsius degrees of temperature change per kilometre. This temperature gradient depends on the thickness of sedimentary rocks above the igneous basement. Superimposed on the general gradient are small changes in temperature due to the thermal conductivity of the particular rock type in the wall of the hole. Heat convection caused by the circulation of groundwater also perturbs this temperature gradient. These small changes are measured in differential temperature logging.

3.1.3 Continuous collar location

The continuous collar locator is an electromagnetic device able to measure the quantity of iron in the casing of the bore. Therefore the log indicates the position of the externally upset collar of the casing and also the positions of excessive corrosion of the casing. In hydrology this latter feature may show the location of corrosive groundwater.

3.2 Resistivity depth probing

3.2.1 Rock resistivity

The resistivity of rock depends on the resistivity of the rock matrix and of the fluid that occupies the spaces within the rock matrix. If the resistivity of the interstitial fluid is constant, the resistivity that is measured depends mainly on the porosity of the material. Even above the water-table there is normally sufficient moisture present for the resistivity measured to be substantially lower than that of the rock matrix. Below the water-table the resistivity of unconsolidated material will be even lower in areas where the water contains salts.

3.2.2 Depth probing techniques

Depth probing is used to determine vertical variations in electrical resistivity. There are several arrangements of electrodes which can be used in electrical surveying (Heiland, 1946). In the Schlumberger arrangement, which was used on the survey, the separation of potential electrodes is kept small compared with the separation of the current electrodes. The current electrodes are moved until the reading of potential drop between the potential electrodes becomes too small to measure accurately. The distance between the potential electrodes is then increased and the outward movement of the current electrodes is continued to reach the maximum spacing required: this will be roughly six times the required depth of investigation. The apparent resistivity in ohm-metres at any spacing is calculated from measurement of the potential drop, current applied, and by a factor depending on the geometrical arrangement of the electrodes. A graph of a depth probe is then obtained by plotting, usually on a log-log scale, the apparent resistivity value against half the distance between the current electrodes i.e. AB/2.

3.2.3 Interpretation techniques

There are several methods of interpretation of the resistivity data, some only qualitative, others quantitative. In the interpretation of the Canaway Ridge data, considerable difficulties were met owing to very small differences in resistivity between separate layers. The initial interpretation was done in the field by the use of BMR precalculated two-layer curves superimposed on the field curve (van Nostrand & Cook, 1966). The process of interpretation was repeated for underlying resistivity layers using the Hummel (1931) equivalence principle. The values of resistivity and thickness obtained in this interpretation were fed, on return to the office, into a Wang 600 computer to obtain a model curve for comparison with the field curve. A program based on the method of van Dam (1965) and developed by F.J. Taylor, a geophysicist from the Engineering Geophysics Group was used. If the matching between the field data and theoretical calculated curve was not perfect the thicknesses and resistivities were adjusted and the process was repeated.

Later, an automatic inverse method of interpretation (Zohdy, 1975) became available and was used to produce the final interpretative models shown in this record; these computer models have been included without any adjustments. In order to define the field curve as accurately as possible, increases in electrode spacing were carried out in much closer steps than normally. This could result in the smoothed curve having some sections steeper than theoretically possible for a horizontally layered model. In trying to match such a curve, the computer would fit geologically improbable layers of either very high or very low resistivity. The cause of measured points which could produce these anomalies could be either lateral resistivity inhomogeneities or errors in measurement. Nevertheless, the computer-produced interpretation has been presented in all cases, being the most accurate fit to the field curve measured, independent of any corroborating evidence. This must be borne in mind in using the interpretations.

3.2.4 Equipment

During the survey an induced polarization transmitter manufactured by Geotronics Pty Ltd was used. This instrument transmits a square wave at constant current amplitude which may be varied up to 20 amps peak to peak with a maximum of 850 volts potential difference between the current electrodes. A square wave frequency of 0.1 Hz was used throughout the survey. The received signals were measured with a Fluke type 845AB high impedance voltmeter coupled to a BMR-designed device to back-off self potential, and recorded on a Hewlett Packard type 7100B 10-inch electro-write recorder.

4. RESULTS

4.1 Results from logging of bores

The physical properties of rocks in any layer may be laterally constant and therefore the logs obtained in neighbouring bores have similar characteristics. The correlation between bores generally depends on vertical changes in character of the rocks in the different geological formations (see: resistivity and SP logs in Pl. 9). Unfortunately when the logs are confined to one geological formation, vertical changes in physical properties are generally very small and correlation may be very difficult and often impossible. The matter is still more complicated if there is lensing of some beds, as is the case with the Winton Formation.

BMR logging techniques obtain logs on two scales: 1 in. = 100 ft and 1 in. = 20 ft. Correlation is generally done on the larger-scale logs, where subdivisions of strata are more clearly defined. The correlation is later transferred to the other scale for easier illustration. The correlation of the Canaway Ridge bore logs was done according to this procedure.

4.1.1 Gamma-log correlation

Suggested correlation of nine gamma logs is shown in Plate 4. The logs were taken in a single geological formation which is characterised by large lateral changes in bed composition. Therefore the suggested correlation may contain errors, but the supporting geological and seismic evidence suggests that the errors are small. Eight bores were logged with a time constant of 2 seconds, while in logging bore R1057 a 5-second time constant was used. The longer time constant gives a clearer record but some boundaries may be lost because of the longer averaging period. The gamma-ray curve obtained in cased bores may be modified by absorption of the radiation in the casing, and one of the most obvious indications in Plate 4 is the length of the surface casing. The correlation in Plate 4 supports the geological and seismic evidence for two faults; one between bores R3950 and R3767 (the Canaway Fault) and the other north of bore R1057. The latter is indicated by the presence of displaced strata in the log of bore R3938.

4.1.2 Temperature logs

Plate 5 shows the temperature logs recorded in nine bores of the survey area; the locations of the bores are shown in the inset of the plate.

With horizontal sedimentary layering the geothermal gradient is constant laterally. When the basement rocks are not horizontal or the surface of the ground is not parallel to the basement the value of the temperature gradient is not constant laterally, and the near-surface temperature may be affected by geological conditions existing in the area. The temperature of the ground just below the surface is also affected by meteorological conditions and as a result it is roughly 2^{o}C higher than the annual mean air temperature. The Climatic Averages, Australia (Bureau of Meteorology, 1969) gives the mean annual air temperature for Windorah as 22.9°C and for Longreach as 23.3°C; therefore a surface temperature of 25°C has been accepted for all bores. From Plate 5 it can be seen that bores R3942, R6362, R1077, and R3767 have a logged surface temperature of about 25°C, indicating that they have not been affected by the flow of hot water, as is the case for the remaining bores shown in Plate 5.

Table 2 gives temperature data from logs obtained in the area. The data from three other flowing bores are added, namely Bothwell (R1473), Warbreccan (R4782), and Bulgroo (R1728). All these bores were logged by BMR, and locations are shown in Plate 2. The bores in Table 2 are discussed in two groups.

1. Flowing bores. In the calculation of the geothermal gradient some assumptions have to be made. As an example of the calculation, the case of bore R1057 will be detailed. The bore was drilled to a depth of 1282 m and subsequently logged to 172 m where it is partly blocked although the flow of water is not affected. The temperature at the blockage was 84°C and at the surface 82.5°C giving an apparent geothermal gradient of 8.7° C/km. This apparent gradient may be distorted due to release of pressure in the water and to flow of heat from the water to the country rock. Extrapolating this apparent gradient to the drilled depth of the bore (1282 m) the temperature at the level of water inflow into the bore is calculated to be 93.5°C. The geothermal gradient is then calculated from the depth of the bore divided by the difference between the calculated bottom temperature and the top of the bore temperature, 25°C. This equals 53.5°C/km. The same procedure has been applied to bores R1473, R3950, and R4782; in bore R1728 the bottom temperature was measured. The geothermal gradient for the five flowing bores varies between 46.1 and 57.1°C/km.

TABLE 2. GEOTHERMAL GRADIENTS

Bore		Lower level temp.	Lower level depth	Upper level temp.	Upper level depth	Gradient °C/km interval	Gradient °C/km mean
R1057	FL	93.5	1282	25.0	0		53.5
R1473	FL	107.0	1481	25.0	0		55.2
R1728	FL	121.0	1681	25.0	0		57.1
R3950	FL	38.5	236	25.0	0		57.1
R4782	FL	87.0	1326	25.0	0		46.7
R1077	P	35.0	253	25.0	0		39.5
R3767	P	51.0	613	36.0	91	28.7	42.4
		36.0	91	25.0	0	120.5	42.4
R3938	P	32.5	168	31.5	59	9.2	36.0
		31.5	59	27.0	15	102.0	36.0
R3944	P	32.0	167	25.0	0		41.8
R3947	P	44.0	202	36.5	0		37.2
R6362	P	32.0	146	25.0	0		47.8
R3942	P	29.5	161	25.0	0		27.9
Yongala No. 1	OW	111.0	3108	25.0	0		27.7
Yongala No. 2	OW	98.0	2028	25.0	0		36.1
Cothalow	OW	63.0	1831	25.0	0		20.7
Budgerygar	OW	85.0	1628	25.0	0		36.9
Canaway No. 1	OW	56.0	1504	25.0	0		20.6

FL - flowing bore; P - pumping bore; OW - oil well.

A surface temperature of 25°C has been accepted for all bores.

2. Non-flowing bores. The geothermal gradient for pumped bores R1077, R3767, R3938, R3944, R3947, and R6362 varies from 36.0 to 47.8°C/km, with an average for the six of 40.5°C/km. Comparison of the geothermal gradient for the flowing and for the pumped bores suggests that the water entering the flowing bores comes from greater depths and increases the bottom temperature of the bore, thus increasing the gradient. Bore R3942 shows the lowest geothermal gradient of 28°C/km. A possible explanation for this is that the bottom of the bore is being cooled by water entering from a fault. Part 2.2 of this report suggests the existence of a fault in this location. While the geothermal gradient for bore R3767 falls within the limits of gradients for non-flowing bores, the shape of the log suggests that there may be a warm water circulation at 115 m, increasing the rock temperature to this depth. The bore had not been operative for more than one year.

In the inset of Plate 5 temperatures of each bore at a depth of 140 m below the surface are shown. This is the deepest common depth for all the bores, and it is deep enough to be confident that no cyclic near-surface variations will affect the values. On the basis of these temperatures the area is clearly divided into three sections:

1) West of the Canaway Fault a temperature of 42°C in R3947 indicates the proximity to the basement on the top of the anticline, whereas in bore R3950 on the flank of the anticline the temperature is lower (36.7°C).

2) In the Yaraka area the temperatures are between 31 and 34°C.

3) In the depression near Merrigal, bore R3942 shows a temperature of 29°C. In bore R3767, where the circulation of warm water is suspected, the temperature at 140 m depth calculated from the surface temperature and the geothermal gradient also equals 29°C. This area is different geologically from neighbouring areas, as shown in Plates 2 and 3; additional geological formations are included in the section above the Devonian.

Thus the interpretation of the temperature zones agrees with the structure and geology as described in 2.2; it also conforms with the results of water analyses (Pl. 3).

4.1.3 Differential temperature log correlation

Eight differential temperature logs are shown in Plate 6. The differential temperature logs are affected by the condition of the bore both during and for some considerable time before the logging operation. A bore standing idle for a period of time allows the temperature of the water and rock to reach equilibrium. On the other hand, a bore where pumping of water is interrupted to allow logging shows the temperature of the rock modified by the exchange of heat between the water and the rocks forming the walls of the bore. The temperature of water and rock will slowly move towards equilibrium. Porous rocks containing water have higher qualities of heat retention, and so higher-temperature beds may indicate the existence of aquifers cut off by the casing. Such aquifers are indicated on the logs of bores R6362 and R3938. It is necessary to note that they represent two different aquifers, supporting the evidence that the Cretaceous aquifers are of limited lateral extent. The logs of bores R3944 and R3942 may indicate several thin aquifers.

Differential temperature logs have been correlated with each other in Plate 6 and if compared with Plate 4 (gamma logs) it can be seen that the correlations on the two plates agree reasonably well. The same reservations as expressed in correlation of gamma-logs apply to the differential temperature logs. Unfortunately correlation between the differential temperature logs of R3950 (defective log) and R3767 (bore standing idle) is impossible.

4.2 Resistivity depth probing interpretation

The locations of all resistivity depth probes are shown in Plate 7. To facilitate the discussion of the results the area of the survey was subdivided into four sections the results from which are shown in Plates 9 to 12.

4.2.1 Aquifer and rock resistivities

Before the results of the survey are explained in the form of rock types it is necessary to assign resistivities to characterise some specific types. Table 3 was prepared listing aquifers containing fresh or salty water intersected in bores, and values of resistivity indicated by the interpretation of depth probes located close to the bores. This information is taken from Plates 9 to 12.

TABLE 3. CHARACTERISTICS OF WATER SAMPLES AND INTERPRETED RESISTIVITIES OF ROCKS CONTAINING THE WATER

Bore	Fresh water Resistivity (ohm-m)	Salt or brackish water Resistivity (ohm-m)	Plate
R3945	5.6		9
R3948	4.2	2.4	9
	5.0		9
R3950	5.3	2.0	9
	5.6		9
R3060	4.4		9
R3949		2.0	10
		2.8	10
R3967	3.5	2.8	10
	4.0		11
R3942	6.0		11
R3937	3.8		11
R3938	3.7		11
R6362	4.8		11
R3944	4.2		11
	4.3		11
R1078	4.8		12
R1077	12.0	1.7	12

Table 3 clearly indicates that the resistivities of aquifers containing fresh water vary from 3.5 to 6 ohm-m (16 cases) with one exceptional value of 12 ohm-m, and aquifers containing salty or brackish water from 1.7 to 2.8 ohm-m. Higher resistivities probably indicate dry rocks. There are several layers of rocks characterised by resistivities similar to those of freshwater aquifers although these are not indicated on the drilling logs as containing fresh water. It is impossible to deduce from the drilling logs (where available) whether the rock contained water but only in small quantities or whether the water was cut off by the drilling mud or the rocks were dry. However, the resistivity method seems to provide an indication of resistivity layers which may carry fresh water.

4.2.2 Area west of the Canaway Fault (Pl. 8 and 9)

Six resistivity depth probes were located in this area (see inset, Pl. 9), including Budgerygar No. 7.

4.2.2.1 Budgerygar No. 7 - discussion of a deep probe.

The Budgerygar No. 7 depth probe was surveyed reaching a maximum spacing of AB = 12 km. Plate 8 shows the field data and the interpretation of the depth probe on a logarithmic scale. The field results were processed by computer using the Zohdy program giving an interpretation of 17 layers. Some difficulties were experienced with the bottom part of the field curve, as the points for 10 to 12 km spacing lie on a line which is inclined to the distance axis at an angle greater than 45^{o}. This inclination, which is greater than theoretically possible for a horizontally layered model, may indicate a sloping interface, near-surface inhomogeneity effects, or instrumental errors. In this case, all factors may influence the readings, as a seismic survey (Phillips-Sunray, 1965) indicated a sloping bedrock surface in this area. Also, a large spontaneous potential drift was experienced during this part of the depth probe measurements and consequently recordings were not of high quality. The depth to bedrock may therefore be in error but will probably lie between 1400 and 1600 m from the surface.

The Budgerygar No. 7 depth probe is also shown in Plate 9. In this case it is plotted on a linear scale and compared with the Budgerygar No. 1 bore geological log and electrical logs (Alliance Oil, 1969) and with the seismic reflection results (Phillips-Sunray, 1967). For the geological subdivision of the Budgerygar No. 1 bore the standardized nomenclature was used (Vine & Day, 1965; Exon, 1966). Electrical logs in the general area of the Eromanga Basin were previously discussed by Laing (1969).

In the comparison of a resistivity depth probe with an electrical log it is necessary to remember that the resolution of the depth probe decreases with depth. Thus, while at shallow depth thin layers of different resistivity will be shown (for example in the Winton and Mackunda Formations, Pl. 9), multiple resistivity layering will not be shown in the deeper sections (for example, the Jurassic). Likewise the Triassic and Permian are not separated because they are too thin in this area. Notwithstanding this, there is one discrepancy existing between the log of Budgerygar No. 1 bore and the interpretation of the depth probe, namely, the depth probe shows a low-resistivity bed at the base of the Cretaceous which is not indicated on the bore log. A fault cutting the area close to the depth probe is a possible explanation. The existence of a small fault here is suggested by a seismic section (Phillips-Sunray, 1967).

A comparison between the Budgerygar No. 7 depth probe interpretation and the seismic reflection results (Phillips-Sunray, 1965 and 1967) is given in Table 4.

TABLE 4. COMPARISONS OF SEISMIC AND RESISTIVITY INTERPRETATIONS

Formation	depth to top in metres	
	Seismic	Resistivity
Mackunda	380	335
Toolebuc	720	not shown
Jurassic	853	890 Hooray Sandstone
basement	1600	1400 - 1600

4.2.2.2 General characteristics of depth probes in the area

The other five depth probes in this area were recorded to a maximum spacing AB of 2 km and therefore the investigation was confined to the Winton and Mackunda Formations. These formations consist of alternate layers of aquifers sandwiched between impermeable layers.

The six depth probes in the area west of the Canaway Fault all show similar characteristics (see Plate 9). The near-surface layers are of low resistivity overlying rocks of higher resistivity. Five bores in this vicinity intersected salt-water aquifers before penetrating freshwater rocks. Thus the resistivity method is capable of determining the minimum depth to a freshwater horizon.

4.2.3 Area of the Canaway Fault (Pl. 10)

Eight depth probes were recorded in this area, three of which (Bona Vista 4, Budgerygar 1 and 2) were located west of the fault, on the upthrown side. Two bores are located in this area. Budgerygar No. 1 and 2 depth probes show similar characteristics with about 300 m of layered but lower-resistivity rocks, similar to those shown in Plate 9. Bona Vista No. 4 shows uniform low resistivity, possibly owing to its location in the shear zone of the Canaway Fault.

On the downthrown side of the fault the low-resistivity salt-water (brackish) horizon overlying fresh water is indicated on 3 depth probes, Budgerygar No. 3, and Bona Vista Nos. 2 and 3, and was proved in Bona Vista 2 bore R3935. Resistivities interpreted from Bona Vista No. 1 and Budgerygar No. 9 are too low overall to represent the freshwater horizon. In fact, bore R3934 produces small quantities of relatively fresh water, and pumping of R3949 was discontinued due to the poor quality of the water produced.

4.2.4 Central area: Yaraka (Pl. 11)

Eight resistivity depth probes were measured in this area, six of which were located close to bores.

Merrigal No. 2 depth probe was located south of the postulated fault (indicated by the seismic results and temperature logs) and the resistivities found there were lower than for most other depth probes in the area. Merrigal No. 1 and Vacy No. 1 show similar resistivities with layered formations and the interpretation suggests the possibility of fresh water underlying the salt water. The other depth probes in Plate 11 (with the exception of Bellevue No. 3) show only small variations in resistivity between different beds, while the bores in this area pump water which is drinkable but contains some salt. This lower-resistivity water appears to impart a more uniform resistivity character to the depth probes. Bellevue No. 3 depth probe showed more contrasts in resistivity and nearby bore R6362 produced only fresh water.

4.2.5 Eastern area (Pl. 12)

Two depth probes were located to the east of the central area; both were close to bores. Greenlaw No. 1 depth probe is close to Bellevue No. 3 depth probe and interpretation shows a section of brackish water overlying the freshwater layer. The log of bore R1077 supports this interpretation. Emmett Downs No. 1 depth probe indicated resistivities in the same range as Greenlaw No. 1 but bore R1078 does not record any brackish water, although the resistivities indicate the possibility of brackish water there.

4.3 Structural deductions

4.3.1 Major E-W fault

The geological map (Pl. 1) shows that the area of the survey is divided into two parts (western and eastern) by the Canaway Fault. The present geophysical work supports the interpreted results of a seismic survey carried out by Phillips-Sunray (1965), suggesting a second major fault cutting the area in an east-west direction. The postulated fault is shown in Plate 7. The area of the survey can therefore be divided into three distinct zones:

A. Canaway Anticline
B. Yaraka
C. Merrigal.

Evidence for the second fault consists of:

1. The character of the water (Pl. 3). Water bores R3767 and R3941 indicate a Stiff pattern which is different to the patterns of water from water bores further north.
2. The correlation of gamma logs (Pl. 4) of bores R3767 and R3942 suggests a steep gradient in the strata between these bores. Some reservations as to the accuracy of correlation of bores from one geological formation were expressed in the record.

3. The temperature at a depth of 140 m (Pl. 5) in bores R3767 (estimated) and R3942 is at least two degrees lower than in bores at Yaraka and eight degrees lower than in those on Canaway Anticline.

4. Resistivity depth probes Merrigal 1 and 2 and Vacy No. 1 show different resistivity layering from other depth probes in Plate 11.

4.3.2 Other possible faults

The correlation of gamma logs (Pl. 4) suggests the existence of a third fault cutting off water bore R1057. No other measurements were taken in this area so no supporting evidence is available, and the strike of the fault is unknown.

Interpretation of Budgerygar No. 7 depth probe also suggests the existence of a fault.

4.3.3 Water flow along faults

The fault zones of the two faults discussed in paragraph 4.3.2 above are open allowing the circulation of water. The evidence is:

1. The character of water (Pl. 3) indicates a similarity between water of the Hooray Sandstone and near-surface water in bores close to the faults.
2. The character of depth probe Bona Vista No. 4 (Pl. 10) is different from the others in the area having a more consistent resistivity (about 4 ohm-m) with depth indicating uniformity in salt content of the water.

5. CONCLUSIONS

5.1 Applicability of resistivity technique for water exploration

(i) Interpretation of depth probes indicates that in the Canaway Ridge area the resistivity of salt-water saturated rocks is 1.7 to 2.8 ohm-m, while the resistivity of freshwater saturated rocks is 3.5 to 6 ohm-m. Dry rocks have resistivities generally greater than 6 ohm-m.

(ii) Of the shallow depth probes recorded, the correlation between the interpretation and borehole evidence is good in 21 out of 22 cases (see Table 3).

(iii) The results of the survey indicate that it is possible to predict the presence of salt and fresh water at shallow depths using the resistivity method.

(iv) It is apparent that the complexity of the interpretation techniques for shallow and deep probes would require expert knowledge of resistivity theory; thus the method would not be applicable as a general-purpose field tool for use by water-drilling contractors or similar bodies.

(v) In the large spacing (12 km) depth probe interpretation, very good correlation with the log of a bore has been obtained and the depth to basement has been estimated within 10 to 15 percent of depth obtained by the seismic method.

5.2 Structural conclusions

(i) Interpretation of groundwater patterns and the existence of a low-resistivity zone in the Canaway Fault indicate that the fault is open to water circulation.

(ii) The existence of several faults in the area is suggested from the survey results:

(a) An east-west fault cuts the area close to bore R3962.

(b) A fault is suggested west of bore R1057; the strike of the fault is unknown.

(c) A fault is suggested close to the Budgerygar No. 7 depth probe.

(iii) Interpretation of the Budgerygar No. 7 depth probe suggests that it is possible to determine the depth to the basement with a high accuracy by use of the resistivity method.

6. REFERENCES

ALLIANCE OIL, 1963 - Completion report for Alliance Oil Development Australia N.L. Canaway Well No. 1, AP98 P, Queensland. Oil Subsidy Rep. 63/1018 (unpubl.).

ALLIANCE OIL, 1965 - Well completion report Alliance Yongala No. 1. AP 98P. Q. Oil Subsidy Rep. 65/4150 (unpubl.).

ALLIANCE OIL, 1967 - Completion report Yongala Well No. 2 AP 98P, Q. Oil Subsidy Rep. 67/4254 (unpubl.).

ALLIANCE OIL, 1969 - Completion report Budgerygar No. 1 Well AP 129P Q. Oil Subsidy Rep. 68/2051 (unpubl.).

BUREAU OF METEOROLOGY, 1969 - Climatic averages Australia; temperature, relative humidity, rainfall. 1969.

EXON, N.F., 1966 - Revised Jurassic to Lower Cretaceous stratigraphy in the SE Eromanga Basin, Q. Qld. Govt. Min. J. May 1968, 1-7.

HEILAND, C.A., 1946 - GEOPHYSICAL PROSPECTING. Prentice Hall, New York.

HUMMEL, J.N., 1931 - A theoretical study of apparent resistivity in surface potential method. Am. Inst. Min. Metall. Eng. Tech. Publ. 418.

IRRIGATION AND WATER SUPPLY COMMISSION - Water Bore Index.

LAING, A.C.M., 1969 - Review of geology and case history of petroleum exploration in central Eromanga sub-basin. APEA J. 1969, 88-96.

PHILLIPS-SUNRAY, 1965 - Geophysical report reflection seismograph, Yaraka Area. Oil Subsidy Rep. 65/11046 (unpubl.).

PHILLIPS-SUNRAY, 1967 - Final report Welford area seismic survey. Authority to Prospect 129 P, Queensland. Oil Subsidy Rep. 67/11178 (unpubl.).

STIFF, H.A., 1951 - The interpretation of chemical water analysis by means of pattern. J. Petrol. Techn., Oct. 1951.

TANNER, J.J., 1965 - Phillips-Sunray Cothalow No. 1, well completion report. Oil Subsidy Rep. 65/4139 (unpubl.).

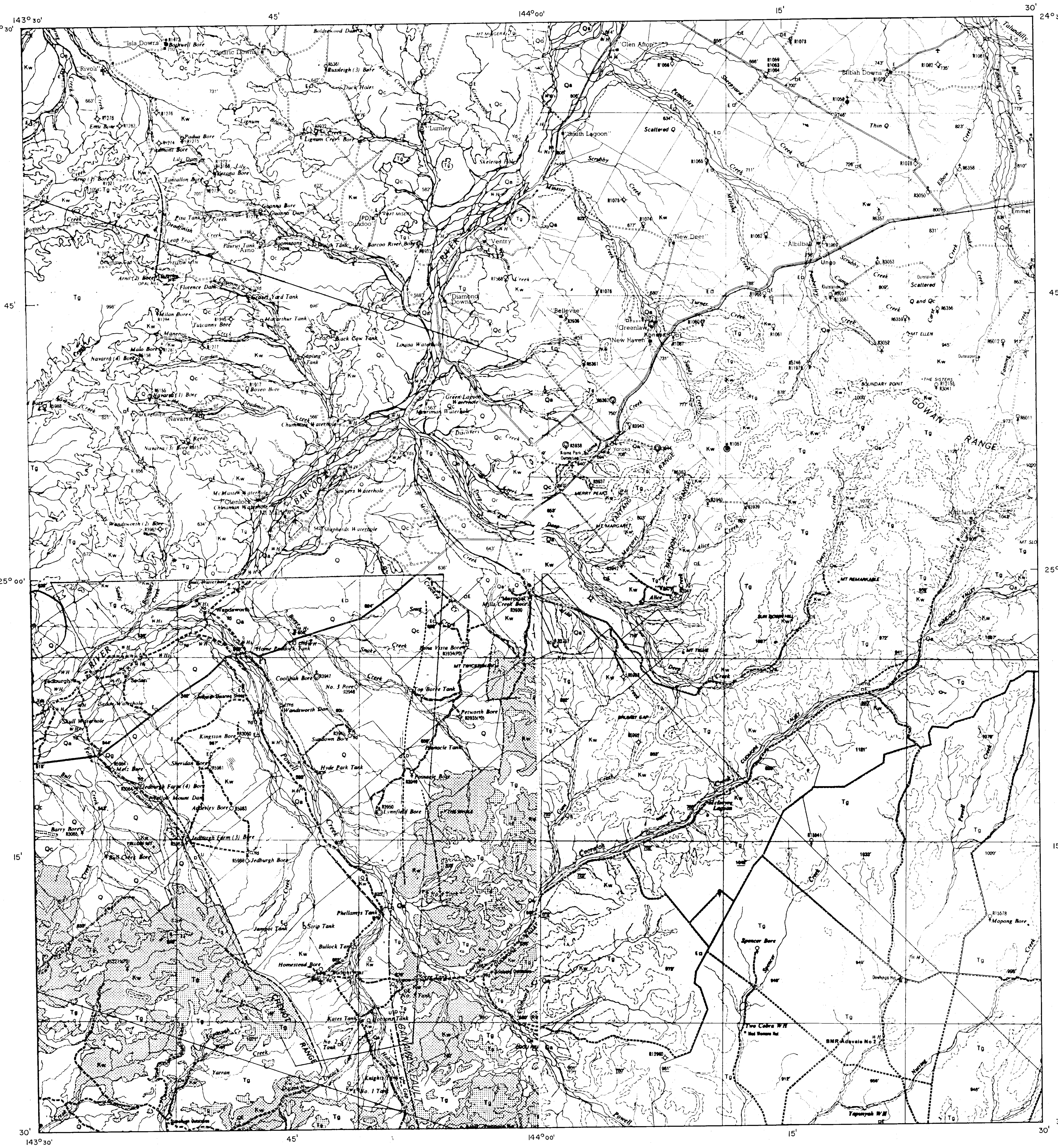
van Dam, J.C., 1965 - A simple method for the calculation of standard graphs to be used in geo-electrical prospecting. Geophysical Prospecting, 13 (1), 37-65.

van Nostrand, R.G., & Cook, K.L., 1966 - Interpretation of resistivity data. U.S. Geol. Surv. Prof. Pap. 499.

VINE, R.R., & DAY, R.W., 1965 - Nomenclature of the Rolling Downs Group, northern Eromanga Basin, Q. Qld. Govt. Min. J., September 1965, 3-6.

ZOHDY, A.A.R, 1975 - Automatic interpretation of Schlumberger sounding curves using modified Dar Zarrouk functions. U.S. Geol. Surv. Bull. 1313 - E.

PLATE I



Reference

CAINOZOIC	QUATERNARY		Q	Undifferentiated
			Qa	Alluvium
			Qs	Sand and silty sandstone, poorly consolidated
			Qc	Gravel, mostly silcrete
	TERTIARY		T	Quartz sandstone, quartz pebble conglomerate
		Glendower Formation		Silcrete (silicified quartz sandstone)
			Tg	Quartz sandstone, quartz pebble conglomerate, sandy conglomerate, siltstone, mudstone
MESOZOIC	LOWER TO UPPER ? CRETACEOUS	Winton Formation		Chemically altered (kaolinized and ferruginized) sediments
			Kw	Labile sandstone siltstone, mudstone, in part calcareous, minor coal, peat, intraformational conglomerate
	LOWER CRETACEOUS	Rolling Downs Group: Mackunda Formation	Klm	Labile sandstone, siltstone mudstone, in part calcareous; coquinite
		Rolling Downs Group: Allaru Mudstone	Kla	Mudstone, minor siltstone, in part calcareous, minor limestone
		Rolling Downs Group: Toolebuc Limestone	Klo	Limestone, calcareous shale
		Rolling Downs Group: Wallumbilla Formation	Klu	Mudstone, siltstone, minor labile sandstone
	UPPER JURASSIC TO LOWER CRETACEOUS	Hooray Sandstone	J-Kh	Quartzose to labile sandstone, pebbly in part: conglomerate, siltstone
	UPPER JURASSIC	Injune Creek Group	Ju	Undifferentiated
	MIDDLE TO UPPER JURASSIC	Injune Creek Group: Westbourne Formation	Juw	Siltstone, mudstone, very fine-grained quartzose and sublabile sandstone
		Injune Creek Group: Adori Sandstone	Ja	Labile to sublabile sandstone, pebbly in part, siltstone
	MIDDLE JURASSIC	Injune Creek Group: Birkhead Formation	Jmb	Sublabile to labile sandstone, calcareous in part: carbonaceous siltstone and mudstone; minor coal
	LOWER JURASSIC		Jl	Quartzose to sublabile sandstone; scattered pebbles; minor siltstone and mudstone (section only)
	LOWER TO MIDDLE TRIASSIC	Clematis Sandstone	Re	Quartzose to sublabile sandstone, pebble conglomerate, minor siltstone (section only)
PALAEOZOIC	LOWER PERMIAN		Pl	Siltstone, mudstone, minor interbedded sandstone (section only)
	UPPER DEVONIAN TO LOWER ? CARBONIFEROUS	Adavale Group: Buckabie Formation	D-Cb	Siltstone, sandstone, mudstone and conglomerate (section only)
	MIDDLE DEVONIAN	Adavale Group: Etonvale Formation	Dme	Shale, siltstone, sandstone (section only)
		Adavale Group: Cooladdi Dolomite Member	Dmc	Dolomite, in part argillaceous, minor limestone (section only)
		Adavale Group: Log Creek Formation	Dml	Shale, siltstone, with some labile sandstone: sandstone common at top (section only)
		Adavale Group: Gumbardo Formation	Dmg	Vitric crystal tuff, agglomerate, minor silty shale and sandstone (section only)
	LOWER PALAEOZOIC		Pzl	Low-grade metamorphics (section only)

Geological boundary

Anticline, showing plunge

Syncline, showing plunge

Fault (section only)

Where location of boundaries, folds and faults is approximate, line is broken; where inferred, queried; where concealed, boundaries and folds are dotted; faults are shown by short dashes

Dip 15°, air-photo interpretation

Trend lines, air-photo interpretation

Abandoned dry oil exploration well

Abandoned bore or well

Artesian bore — of post-Allaru aquifer system

Artesian bore, ceased flowing — of post-Allaru aquifer system

Sub-artesian bore

Artesian bore, flowing — of pre-Wallumbilla aquifer system

Artesian bore, ceased flowing — of pre-Wallumbilla aquifer system

refers to bore registered number of Queensland Irrigation and Water Supply Commission records

Earth tank or dam

Dam on stream

Waterhole

Wireline log available

Highway

Road

Vehicle track

Railway with station

Fence

Town

Mons Homestead

Outstation

Building

Airfield

Landing ground

Height in feet; datum: mean sea level

(PD) Position doubtful

Gravity station

Bouguer anomaly (milligals)

Isogals

Bouguer anomaly—relative high

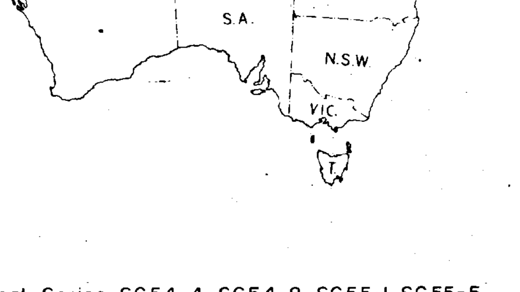
Bouguer anomaly—relative low

Bouguer anomalies are based on the 1962 observed gravity values at pendulum gravity base stations in and near the area

For the calculation of Bouguer anomalies 1.9 g/cm³ has been adopted as an average rock-density

Station Bouguer Anomaly reliability: standard deviation <1 milligals

Published by the Bureau of Mineral Resources, Geology and Geophysics, Department of National Development, in conjunction with the Geological Survey of Queensland. Issued under the authority of the Hon. David Fairbairn, Minister for National Development. Base map compiled by the Division of National Mapping, Department of National Development. Aerial photography by the Royal Australian Air Force; complete vertical coverage at 1:48,000 scale.
Transverse Mercator Projection.



INDEX TO ADJOINING SHEETS

Showing Magnetic Declination

MACKUNDA SF 54-11	WINTON SF 54-12	MUTTABURRA SF 55-9	GALILEE SF 55-10	CLERMONT SF 55-11
BRIGHTON DOWNS SF 54-15	MANEROO SF 54-16	LONGREACH SF 55-13	JERICHO SF 55-14	EMERALD SF 55-15
CONNEMARA SG 54-3	JUNDAH SG 54-4	BLACKALL SG 55-1	TAMBO SG 55-2	SPRINGSURE SG 55-3
CANTERBURY SG 54-7	WINDORAH SG 54-8	ADAVALE SG 55-5	AUGATHELLA SG 55-6	EDDYSTONE SG 55-7
BARROLKA SG 54-11	EROMANGA SG 54-12	QUILPIE SG 55-9	CHARLEVILLE SG 55-10	MITCHELL SG 55-11

ANNUAL CHANGE 2'30"E

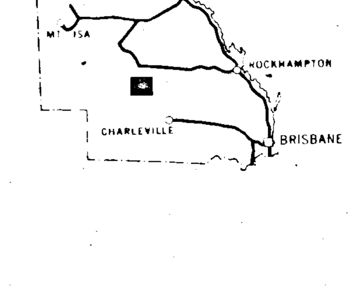
Scale 1:250,000

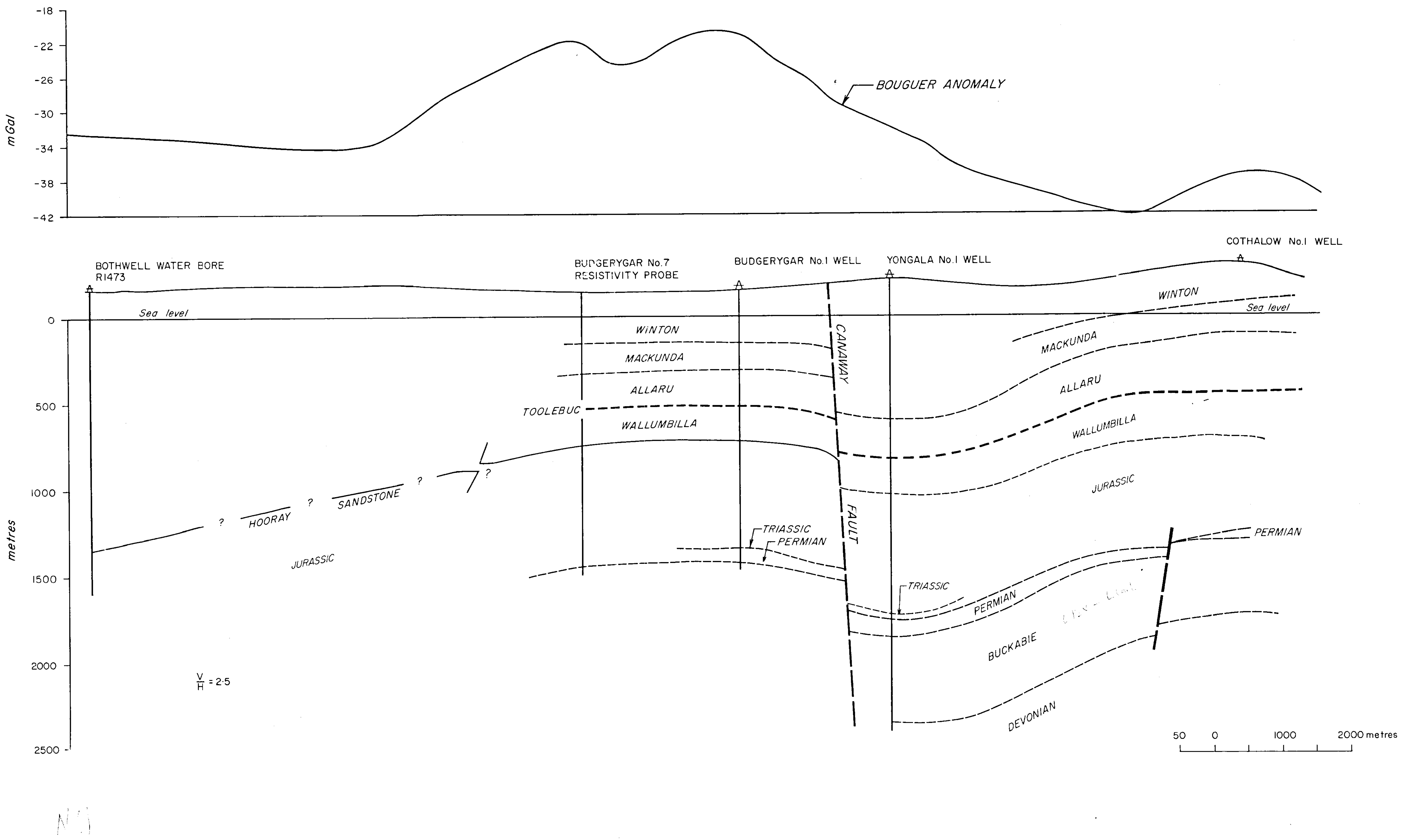
5 0 5 10 15 MILES

5 0 5 10 15 20 25 KILOMETRES

GREY NUMBERED LINES INDICATE THE 20,000 YARD TRANSVERSE MERCATOR GRID, ZONE 7 (AUSTRALIA SERIES)

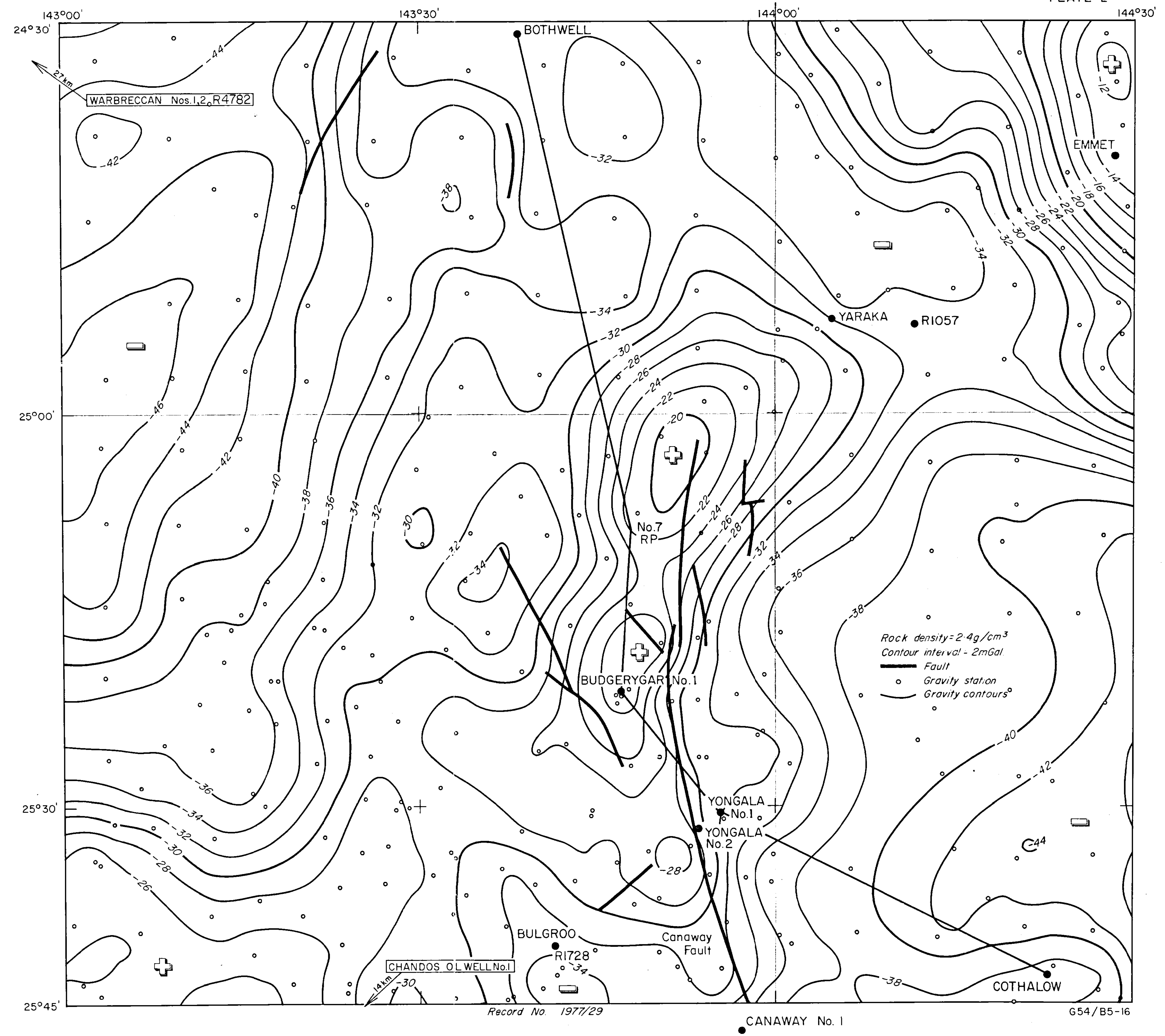
Geology, 1965–66, by D. J. Casey (G.S.Q.), M. C. Galloway
Gravity data, 1963–64, from B.M.R. gravity and microbarometer surveys
Compiled, 1965–66, by D. J. Casey (G.S.Q.), M. C. Galloway, D.R. Williams
Cartography by Geological Branch B.M.R.
Drawn by Geodrafting Services Pty. Ltd., Melbourne
Printed by Mercury Press Pty. Ltd., Hobart

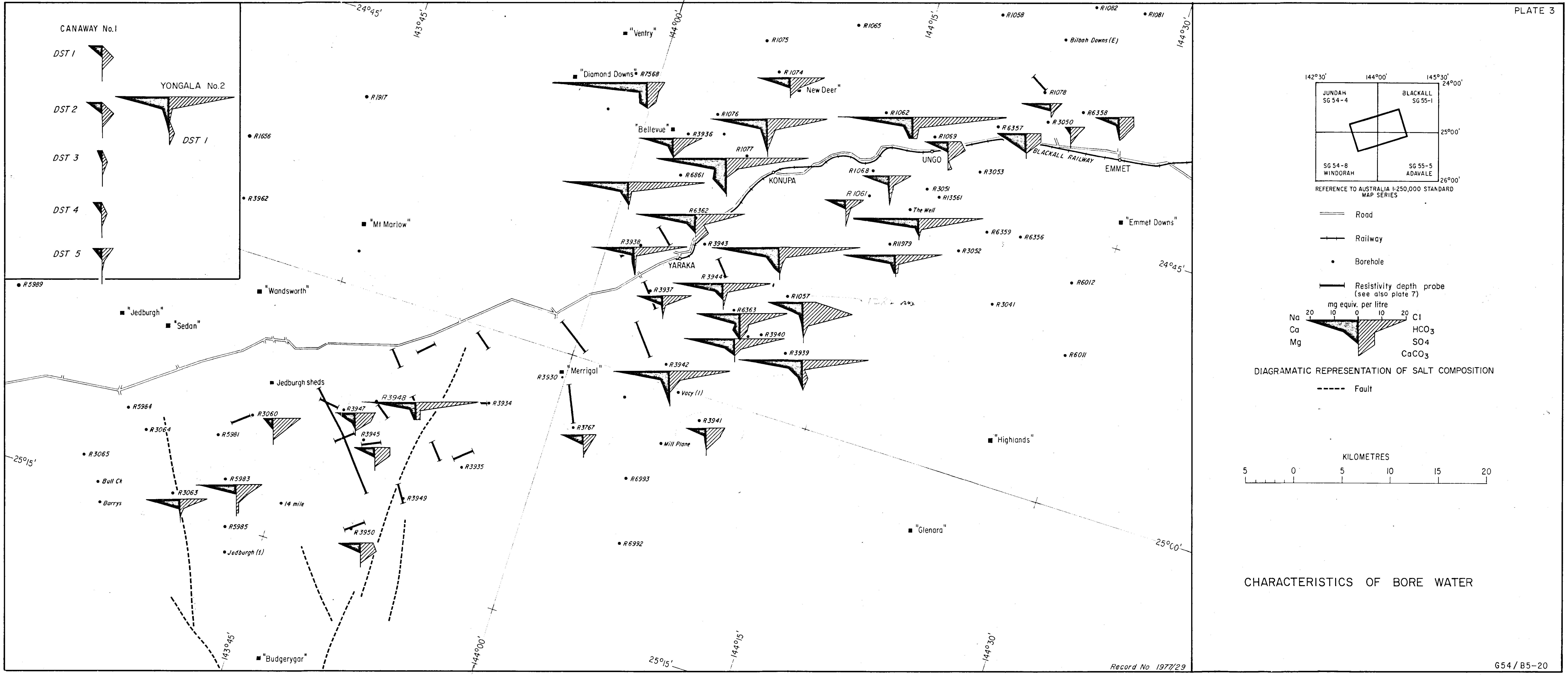




SIMPLIFIED SECTION BOTHWELL-COTHALOW

PLATE 2



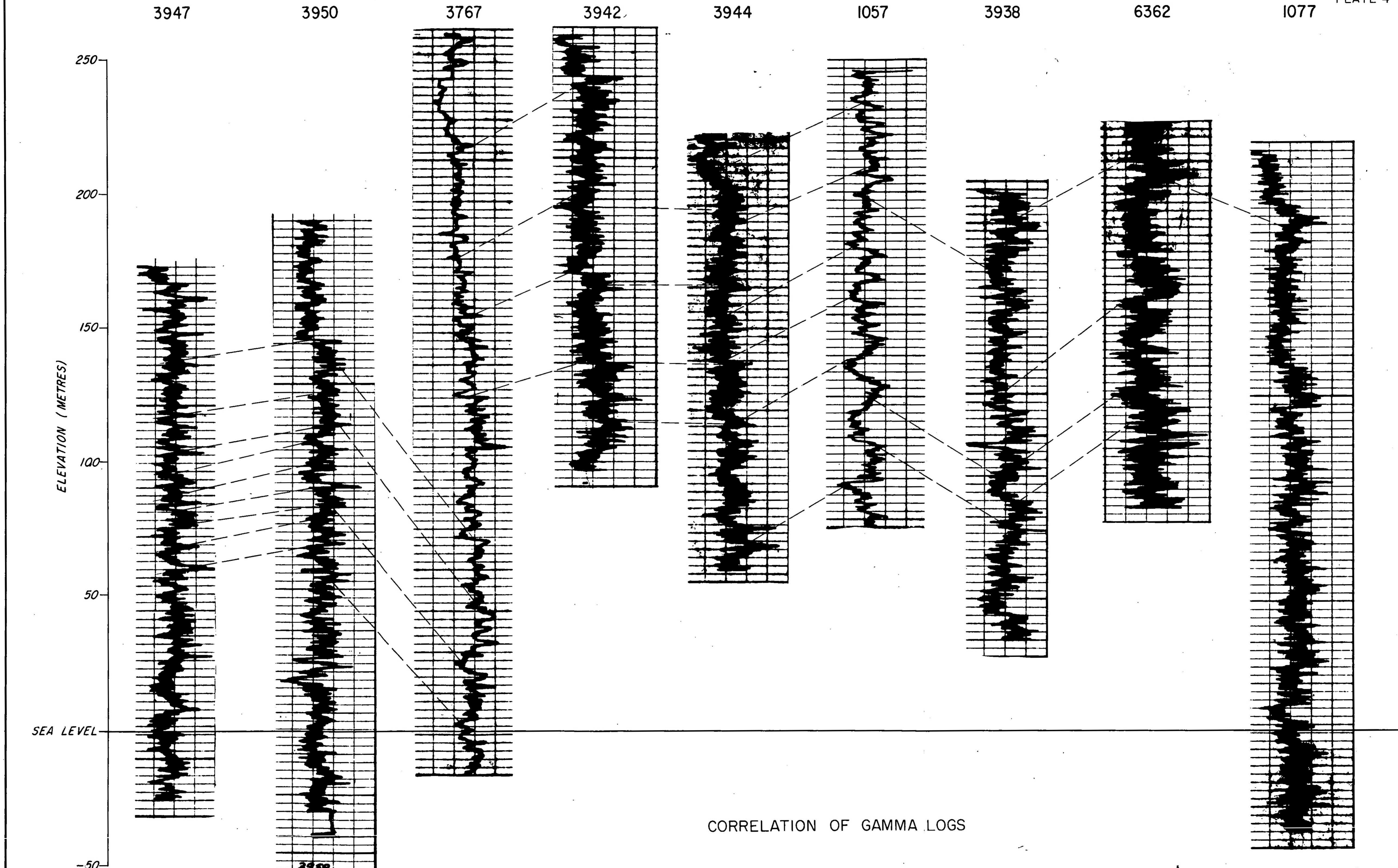


CHARACTERISTICS OF BORE WATER

Record No 1977/29

G54/B5-20

PLATE 4

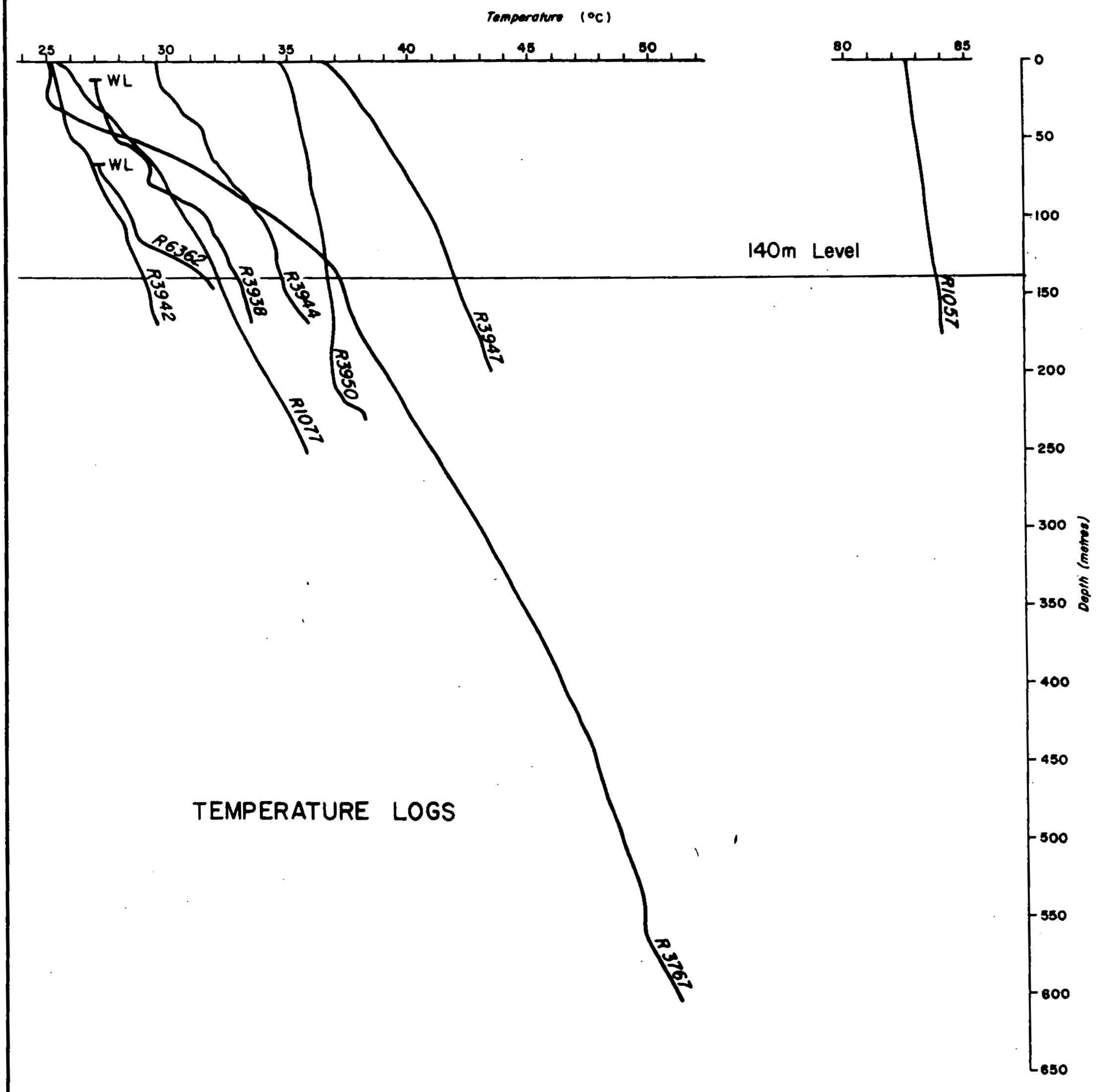


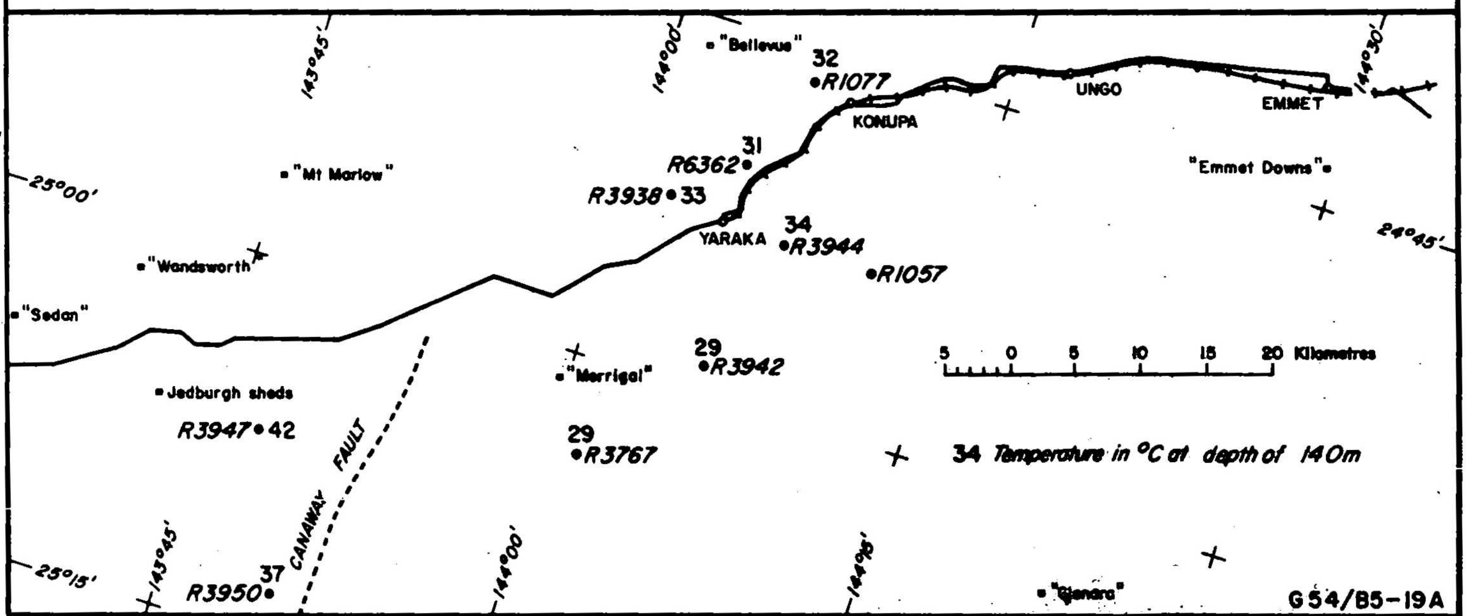
CORRELATION OF GAMMA LOGS

Record No. 1977/29

G54/B5-22

PLATE 5

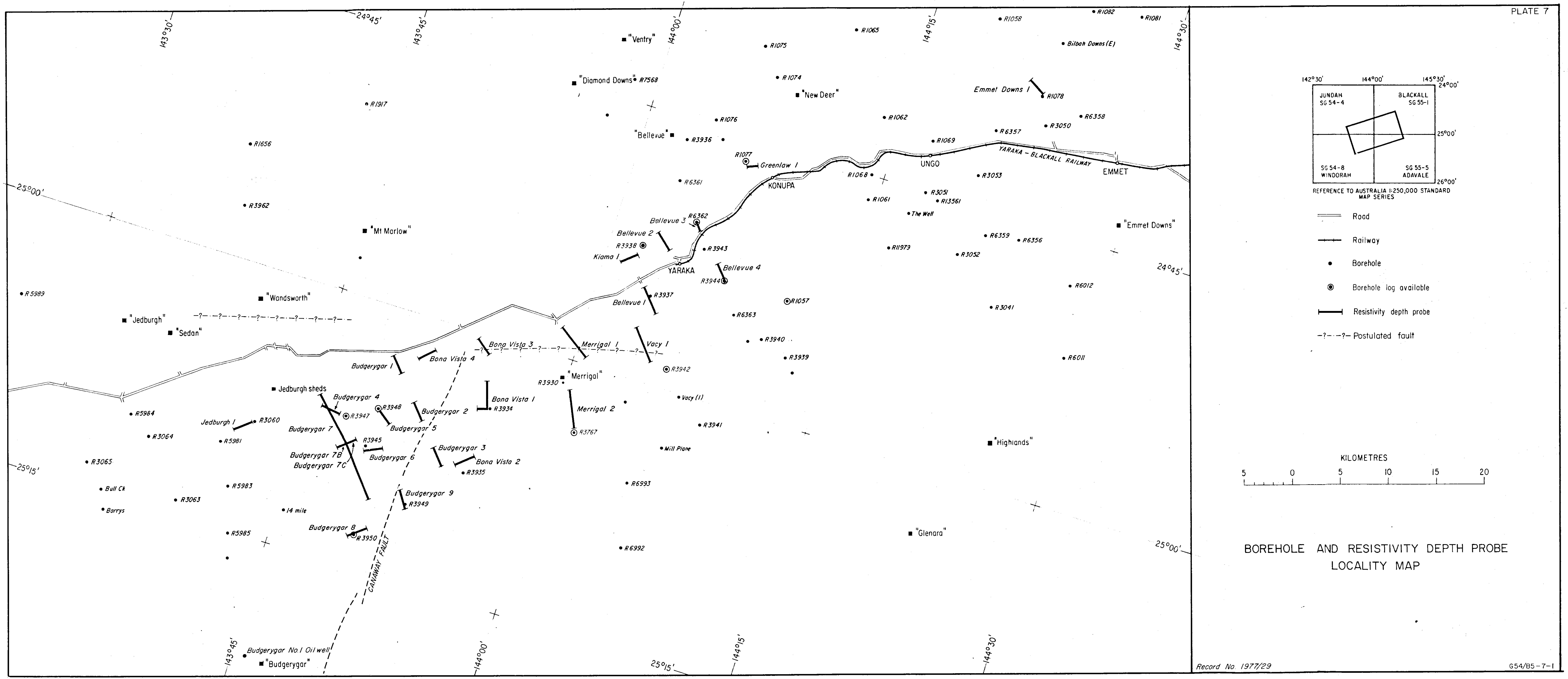




Record No. 1977/29

CORRELATION OF DIFFERENTIAL TEMPERATURE LOGS

PLATE 7



BOREHOLE AND RESISTIVITY DEPTH PROBE LOCALITY MAP

Record No. 1977/29

G54/B5-7-1

(Based on G54/B5-7)

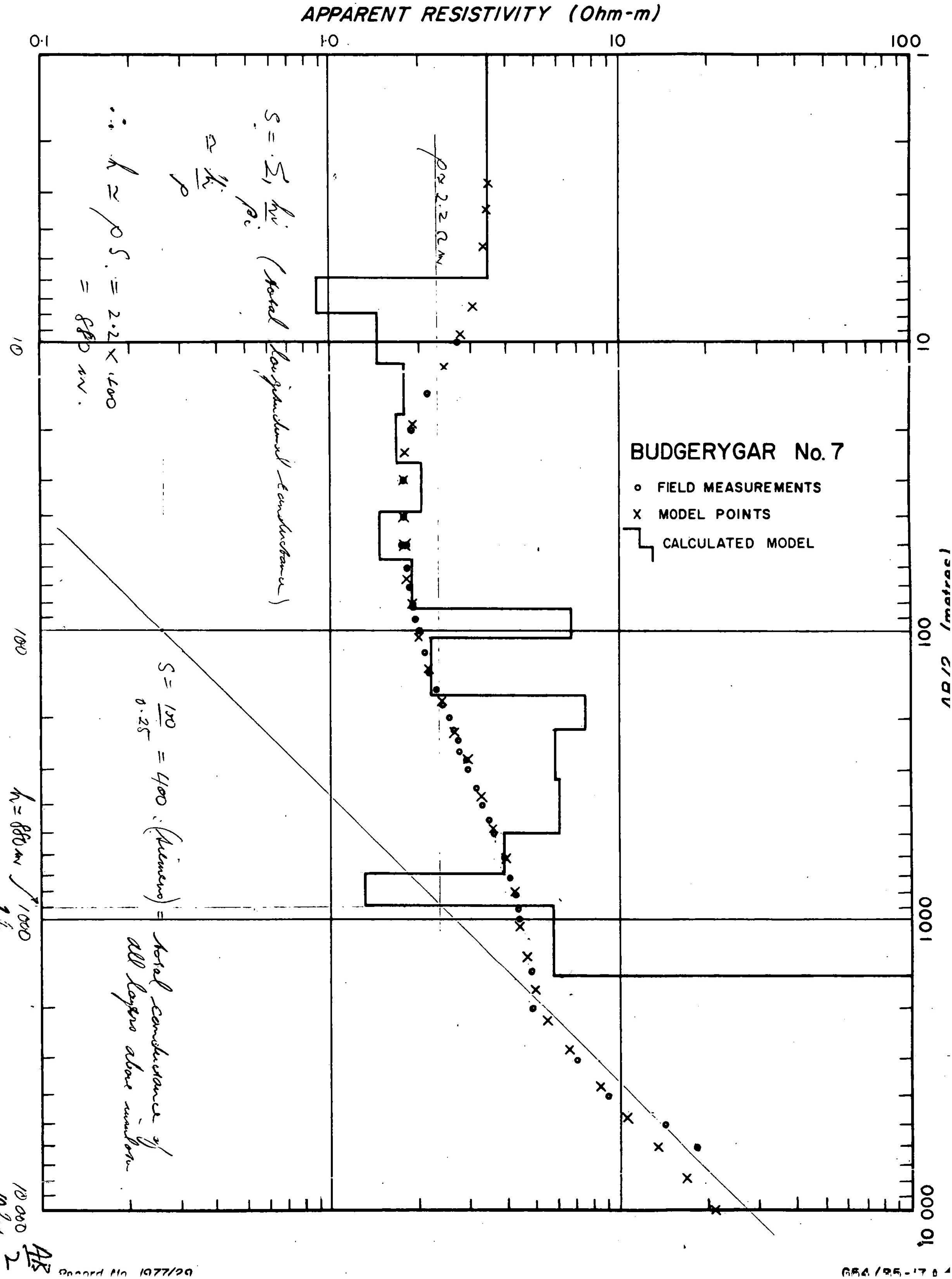

APPARENT RESISTIVITY (Ohm-m)
0·1
1·0
10
100
10
100
1000
10 000
AB/2 (metres)
BUDGERYGAR No. 7
o FIELD MEASUREMENTS
X MODEL POINTS
CALCULATED MODEL
ρ ≈ 2.2 Ωm
S = Σ h_i/ρ_i (total longitudinal conductance)
≈ h/ρ
∴ h ≈ ρS = 2.2 × 400
= 880 m.
S = 100/0.25 = 400 (siemens) = total conductance of all layers above
h = 880 m
1 km
10 km

PLATE 9

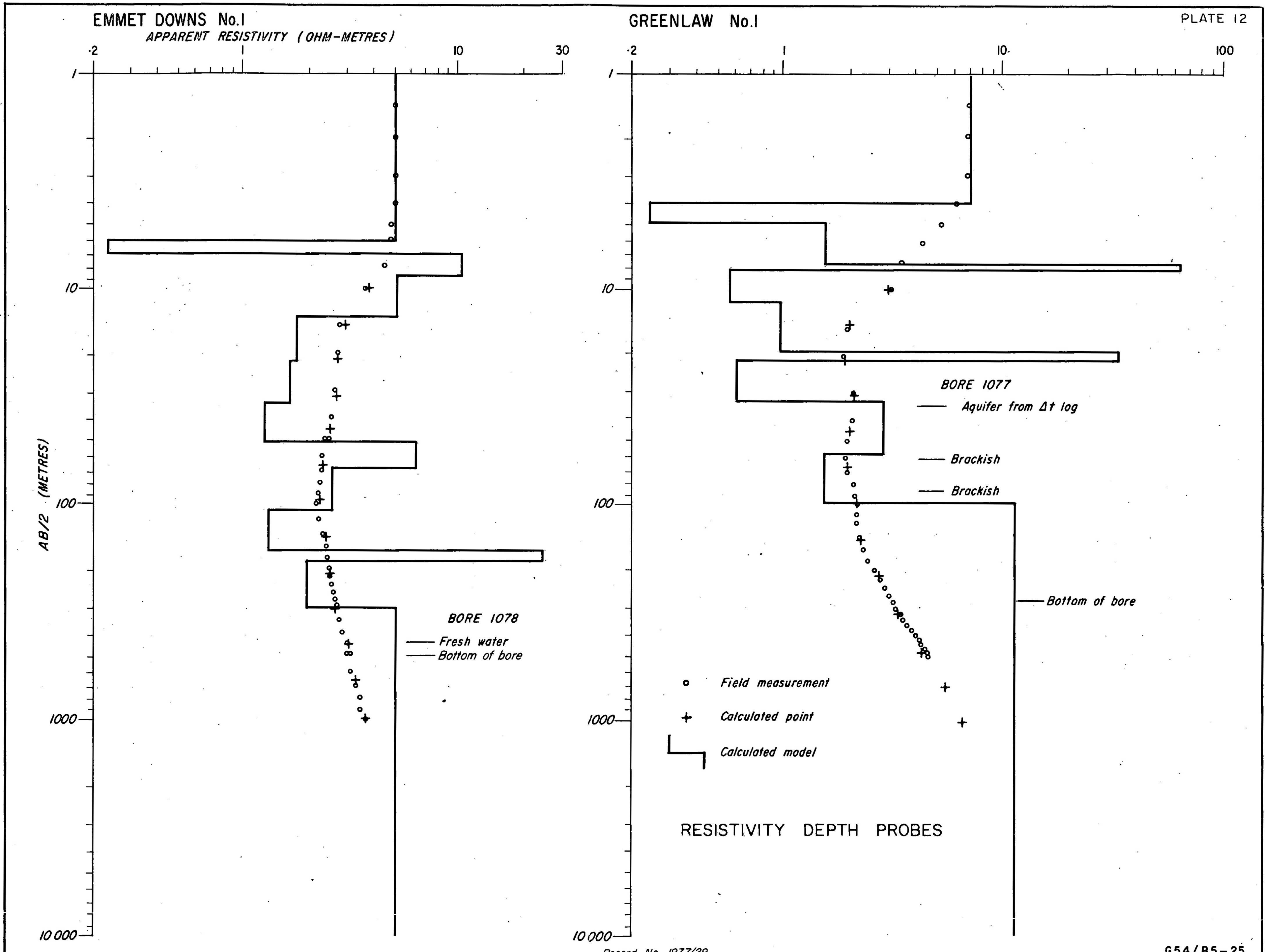
CORRELATION : DEPTH PROBES - BOREHOLES
(AREA WEST OF CANAWAY FAULT)

Record No. 1977/29

G54/B5-18


BONA VISTA No.4
APPARENT RESISTIVITY (OHM-METRES)
BUDGERYGAR No.1
BUDGERYGAR No.2
BUDGERYGAR No.3
BONA VISTA No.2
BONA VISTA No.1
BONA VISTA No.3
BUDGERYGAR No.9
AB/2 (METRES)
DISTANCE (METRES)
BORE 3935
Brackish
Fresh Water
Bottom of the bore
BORE 3934
BORE 3949
DEPTH PROBES ACROSS
CANAWAY FAULT
Field measurement
Calculated point
Calculated model
Record No. 1977/29
G54/B5-23

PLATE 11
MERRIGAL No.2
MERRIGAL No.1
VACY No.1
BELLEVUE No.1
KIAMA No.1
BELLEVUE No.2
BELLEVUE No.3
BELLEVUE No.4
APPARENT RESISTIVITY (OHM-METRES)
DISTANCE (METRES)
BORE 3767
BORE 3942
BORE 3937
BORE 3938
BORE 6362
BORE 3944
Fresh water
Bottom of bore
Aquifer
Fresh water main supply
Field measurement
Calculated point
Calculated model
RESISTIVITY DEPTH PROBES
Record No. 1977/29
G54/B5-24


EMMET DOWNS No.1
APPARENT RESISTIVITY (OHM-METRES)
·2
1
10
30
AB/2 (METRES)
1
10
100
1000
10 000
BORE 1078
Fresh water
Bottom of bore
GREENLAW No.1
·2
1
10
100
1
10
100
1000
10 000
BORE 1077
Aquifer from Δt log
Brackish
Brackish
Bottom of bore
Field measurement
Calculated point
Calculated model
RESISTIVITY DEPTH PROBES

G54/B5-25