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RECORD No. 1964/3

CABBAGE GUM BASIN GEOPHYSICAL INVESTIGATION FOR UNDERGROUND WATER,

TENNANT CREEK, N.T. 1958

by

W.A. WIEBENGA and D.F. DYSON

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SUMMARY

This Record gives the results of a geophysical survey for underground water at Cabbage Gum Basin, south of Tennant Creek,NT.

A magnetic survey indicated the zone of Warramunga Group slates, which occur as 'roof pendants' in granite.

Resistivity contour plans suggest the presence of a subsurface drainage system or zones of deeper weathering.

Cross-sections constructed from resistivity depth-probes, together with resistivity measurements of bore water, indicate formations characterised by certain porosity ranges. These formations may be correlated with the rock types occurring locally.

1. INTRODUCTION

The Cabbage Gum Basin is situated about 10 miles south of the township of Tennant Creek, NT. In 1954 the Mines Branch of the Northern Territory Administration began investigations in the Basin for an underground water supply suitable for Tennant Creek township (Hays, 1958a). Fourteen wells were put down and tests on some of these have indicated that there would be sufficient potable subsurface water available to span the longest recorded period of effective drought, viz. three years.

In 1958, at the request of the Director of Mines, the Bureau of Mineral Resources, Geology and Geophysics made a geophysical survey in the Basin to assist in the search for a suitable water supply. The resistivity survey consisted mainly of 21 depth probes and constant-electrode-spacing traversing in an area extending roughly two miles west, one mile east, and two miles north from the Cabbage Gum Bore (Plate 3) and also six depth probes along the Stuart Highway between Ghans Bore and Well 6 (Plate 1). Magnetic measurements were made in the area around the Cabbage Gum Bore.

The geophysical party consisted of D.F. Dyson (party leader and geophysicist), R.J. Goodchild (geophysicist), and field assistants. To check the field results, a Failing-750 rotary drill was assigned to the party, with L. Sprynskyj as driller. The field work was done between 22nd April and 5th June 1958.

Before this report was completed, D.F. Dyson, the original author, left the Bureau of Mineral Resources, Geology and Geophysics. Most of the information originally sought by the geophysical survey has since been obtained by drilling and is reported by Crohn (1961) and Bracewell, Crohn and Hays (1962). Thus the interpretation of the geophysical data has now become a matter of interest mainly in connexion with an assessment of the possibilities and limitations of geophysical work in underground water search.

2. GEOLOGY

Hays (1958 a and b) described the geology and gave detailed geological logs of the holes drilled by the Failing drill.

The area is covered by windblown sand with occasional outcrops of silicified sediments and travertine.

Underneath the windblown sands are the younger sediments, probably of Tertiary age. In many places the younger sediments overlie a clay formation of unknown origin and age.

The bedrock consists of decomposed or weathered granite with sediments (slate) of the Warramunga Group. The latter rocks are probably remnants of what may be considered roof pendants overlying intrusive granites.

Two or more laterisation periods may be distinguished. The oldest laterisation zone marks the tops of the old bedrock surface on which the younger sediments were deposited. This laterisation is characterised by ferruginous, mottled, pallid, and siliceous zones.

The more recent laterisation, also characterised by ferruginous, mottled, and pallid zones, took place in the younger sediments. Formation of sinter and travertine is common.

Apparently the ferruginous zones in the near-surface sediments act as good fresh-water aquifers. Deeper, within the weathered bedrock, the aquifers grade into low-yield aquicludes. Along certain zones the deeper bedrock has been brecciated by faulting and the rocks are completely decomposed. Some faults or shear zones are silicified.

3. METHODS AND EQUIPMENT

The following methods and techniques were used :

Method	Technique
Resistivity	Constant-electrode-spacing traversing Depth-probing Determination of bore and well-water resistivity Single-point logging
Magnetic	Traversing

Resistivity Method

The resistivity method is described by Dobrin (1960) and Wiebenga (1955).

Traversing. A constant-electrode-spacing 'Wenner' arrangement is moved along a traverse and the apparent resistivity is plotted as a profile. In the surveyed area the bedrock is not deeper than 50 to 100 ft. By using electrode spacings of 100 and 200 ft, information about the depth and nature of the bedrock is obtained. Low-resistivity zones may indicate the location of deep unweathered bedrock, subsurface drainage channels, or decomposed rocks in brecciated fault or shear zones.

Depth probing. For the resistivity depth-probes an expanding Wenner configuration was used. It may be useful to point out the ambiguities of the interpretation.

Following Hummel's principle (Wiebenga, 1955) a layer with resistivity ρ_1 and thickness h_1 may be represented as a resistance R_1, where $R_1 \simeq C\rho_1/h_1$, C being a non-dimensional constant. It follows that if $R_1 = C\rho_1/h_1 = C\rho_{1'}/h_{1'} = C\rho_{1''}/h_{1''}$ etc.

$$\rho_{1'}/h_{1'} = \rho_{1''}/h_{1''}$$

Hence, in the interpretation one may assign to a layer a range of values ρ with a corresponding range of values h as long as the above relations are used. This means that both resistivity and depth may vary between relatively wide limits, i.e. the depths estimates are not very accurate unless some controls are used. Nevertheless, valuable qualitative information or estimates may be obtained, especially if the curve-fitting technique is applied consistently in the same way.

It is usually difficult to distinguish thin layers with the resistivity method.

A valuable parameter which may be computed from resistivity depth-probing data is the total conductance of the ground (α), defined as :

$$\alpha = h_1/\rho_1 + h_2/\rho_2 + \text{-----} = \Sigma h/\rho \qquad \text{------} (1)$$

If h is in feet, ρ in ohm-metres, and α in mhos, (1) becomes:

$$\alpha = 0.3 \ \Sigma h/\rho \qquad \text{------} (1a)$$

Determination of bore and well-water resistivity. For saturated unconsolidated sediments and very weathered, decomposed granites (Wiebenga, 1955, p.44) the following relation may be used (all logarithms are to the base 10):

$$\log(\rho_x/\rho_1) = -1.25 \log V_1 \qquad \text{------} (2)$$

in which ρ_x is the resistivity of the rock measured in situ, ρ_1 the resistivity of the pore solution, and V_1 the porosity. Equation 2 is plotted in Plate 8. Hence, it is important to measure the resistivity ρ_1 of bore or well-water wherever possible. To reduce ρ_1 measured at temperature t°C ($\rho_{1,t}$) to ρ_1 at 20°C ($\rho_{1,20}$) the formula

$$\log\rho_{1,20} = \log\rho_{1,t} - 0.9\,(20-t)/100 \qquad \text{------} (3)$$

may be used. To estimate the total dissolved salt content from the water resistivity the formula

$$\log T + 0.92 \log\rho_{1,20} = 3.68 \qquad \text{------} (4)$$

may be used (Dyson and Wiebenga, 1957) in which T is the total dissolved salt content in p.p.m.

The equipment used with the above-mentioned resistivity techniques included :

a D.C. resistivity meter made by the Bureau of Mineral Resources,

a Geophysical Megger with ranges 0 to 0.3, 0 to 1, 0 to 3, 0 to 10, and 0 to 30 ohms, manufactured by Evershed and Vignoles Ltd,

a low-resistance Megger with a maximum range of 0 to 1000 ohms, manufactured by Evershed and Vignoles Ltd., and

a specially designed container or mudcell for measuring the resistivity of bore-water or mud.

Single-point resistivity logging. Several shallow holes were drilled with the Failing drill and, when possible, single-point electrical logs were taken. If it is assumed that the borehole has a constant diameter, the logs indicate variations in resistivity. Assuming that the variations in groundwater salinity are small within the drilled section, the resistivity variations represent variations in porosity. However, with this type of logging no quantitative estimates can be made; also it is not possible to correlate the many thin layers of varying resistivity shown on the logs with the 'resistivity layers' found by resistivity depth-probing. The 'resistivity layers' usually represent thick formations of average resistivity; the ambiguities in resistivity depth-probing have already been explained. Further, no direct correlation is possible between the resistivity variations shown on the logs and the variations in permeability within the drilled section.

For the logging a Widco 1000-ft single-point resistivity logger was used.

Magnetic method

The magnetic method depends on susceptibility contrasts between formations or rock types. In the Cabbage Gum area the magnetic intensity anomalies, indicating zones of higher magnetic susceptibility, may probably be correlated with the sediments of the Warramunga Group, which occur as roof pendants within the granites. Measurements were made of the vertical magnetic intensity with a Watts variometer.

4. RESULTS

Basin area

Plates 2, 3, and 4 show the traverse plans, with the locations of the resistivity depth-probes. The traverses are too far apart for the contours to be accurate between the traverses.

Plate 2 shows a vertical-magnetic-intensity contour plan on which the boundary of the Warramunga Group sediments (after Bracewell et al., 1962) is superimposed on the magnetic contours. It may be observed that the zone of higher magnetic intensities largely coincides with the locality of the Warramunga slates, as found by drilling.

Plates 3 and 4 show the resistivity contour plans made from resistivity traversing with 100 and 200-ft electrode-spacing respectively. The patterns of the two plans are very similar, as could be expected over shallow bedrock. The low-resistivity zones (the main axis of each indicated by a broken line) suggest the presence of a subsurface drainage system or zones of deep weathering.

Plate 5 shows the interpretation of the depth-probe data as histograms, together with a few resistivity logs.

In Plate 6 the histograms of Plate 5 are arranged in diagrammatic cross-sections, following the same section lines as Hays (1958b, Plate 2).

The geological names shown on Plate 5 are largely taken from Hays (1958b). Although the depth estimates in Plate 5 are probably not very accurate, this presentation gives a very good insight into the structure of the area in terms of resistivity.

The appendix gives the results of a limited number of resistivity measurements of bore and well-water, indicating the 'total dissolved salt content' (a bore is a few inches in diameter, and a well is a few feet in diameter). Generally, the well water shows lower resistivities than the bore water, probably because in wells the water has been subjected to evaporation from an open surface, thereby increasing the salinity. The water resistivity measured in the bores follows a certain pattern. It is high near S5, (21.4 ohm-metres) where the bedrock is weathered granite and the water is probably well- drained; it is between 13 and about 16 ohm-metres near S4, S7, S8, S11, S15, and S16, indicating a higher salinity but still relatively good drainage conditions.

Low groundwater resistivities within or above weathered granite bedrocks may be caused by low permeabilities and poor drainage conditions. Such conditions may prevail at S12 and in the zone containing S13, S14, S20, and S18, where the bore-water resistivities range between 7 and 11 ohm-metres.

On the diagrammatic cross-sections of Plate 6 the layers with similar resistivities found in resistivity depth-probing (Plate 5) are correlated and the geological names known at the time of the survey are inserted. The cross-sections show near-surface layers of sediments, generally with the depth to bedrock less than 60 ft. In the search for near-surface water supplies those places where the bedrock depth is maximum offer the best chances for success, <u>i.e.</u>:

along Cross-section A-B near S5 and S11,
along C-D near S20 and possibly near S18,
along E-F near S15, and
along G-H near S10.

Places near S11, S19, S13, and S14 do not form very suitable targets because of the presence there of known clay deposits.

Above each cross-section the total-conductance profile is plotted. At places where resistivity depth-probing and geological observation have indicated deep weathering or the presence of decomposed rock in uncemented shear zones, the total conductance is comparatively high or maximum, <u>viz</u>. near S1, S7, and S15 on A-B, near S21 on C-D, near S15 and S16 on E-F, and near S9 and S12 on G-H.

The porosities of the different layers (estimated from formula (2), page 3) are indicated on the cross-sections. These porosity figures, which should be considered as average values over the layer, are probably not very accurate; they indicate broadly the porosity variations, however, and hence are an aid in suggesting drilling targets. The following examples may illustrate the principles.

At S7 (Plate 6, A-B) an intermediate layer of 224 ohm-metres resistivity has an average porosity of 0.12; this relatively low porosity value is consistent with the geological concept of a travertine or laterite layer. Underneath the travertine or laterite is a very thick layer of 13 ohm-metres resistivity. Assuming that the decomposed granite has the porosity of 0.50, which is as high as can be expected, the water resistivity must be equal to, or less than, 5 ohm-metres, <u>i.e</u>. the water is probably saline. Summarising, resistivity depth-probing at S7 indicates that although the water near the surface is fresh, saline water must be expected at depth. Further, the low-porosity layer confirms the presence of a laterite or travertine zone. Not much can be deduced about the 'transmissibility' within the bedrock, but geological evidence shows that in decomposed granites, even if the porosity is high, the 'transmissibility' is usually very low unless an open or fractured shear zone is present.

Another interesting example of interpretation is the depth-probe at S19 (Cross-section C-D). Assuming that the low-resistivity (8 ohm-metres) clay formation has a porosity of about 0.50, the pore water must have a resistivity less than 4 ohm-metres, <u>i.e</u>. the pore water is saline. The underlying formation (weathered granite) must have a porosity of less than 0.10 if the pore water has a resistivity of less than 4 ohm-metres. This agrees with the finding that Bore MM2 met silicified hard rock below the clay formation (Hays, 1958b).

Summarising, the cross-sections of Plate 6 show the following :

(a) near-surface layers of varying thickness overlying the weathered bedrock. According to Hays (1958b) this layer is also the site of the top laterite zone. Drilling targets for near-surface water supplies should be located at places where this near-surface layer is thickest, e.g. near S5, S11, S20, S15, and S10,

(b) a clay formation between the bedrock and the near-surface layers (Hays, 1958 b, Plate 2) is characterised by a low resistivity of about 8 ohm-metre,

(c) a weathered bedrock of granite or gneiss, and Warramunga Slate. Places of deep weathering within the bedrock are indicated by deep low-resistivity formations and a high total conductance, e.g. at S7, S15, S20, S21, S14, S16, S9, and S12. Deep weathering also occurs within the Warramunga Slate (near S1 and S2). Water resistivity measurements and geophysical evidence indicate that the water in the deep weathered zones has a high salt content. Further, past experience (Wiebenga, 1955) and geological reasoning indicate that the water supplies from weathered zones within the bedrock are usually relatively small (aquicludes).

Depth-probes along Stuart Highway, from Well 6 to Ghans Bore (S17 to S27)

To obtain some insight into the near-surface groundwater conditions outside the surveyed Basin area, resistivity depth-probes (S22 to S27) were made along the Stuart Highway north of Well 6 (Plate 1). Plate 7 shows the interpretation of the depth-probe data as histograms, with a diagrammatic cross-section and total-conductance profile. The cross-section shows comparatively-higher-resistivity rock close to the surface at Well 6 (S17) and from 2 to 3 miles north of Well 6 (S23 to S24). A low-resistivity zone, marked by a high total conductance, separates the two higher-resistivity zones; low-resistivity rock to a depth of about 200 ft probably indicates decomposed granite in a shear zone or fault. Some fresh water may perhaps be expected in the thin surface layers (about 14 ft thick), but at lower level, within the decomposed bedrock, the low resistivity of 17 ohm-metres indicates brackish or saline water, and the geological circumstances suggest that the supply is probably small (aquiclude). In the neighbourhood of the Cemetery, Eldorado, and Ghans Bores (S25, S26, and S27), low-resistivity rock to large depths indicates that the slates are probably weathered and contain saline water. Brackish water in near-surface beds is indicated in Ghans Bore to a depth that ranges from 20 to 69 ft.

At Ghans Bore (Plate 7, S27) two depth-probes perpendicular to each other show appreciable differences in depths to bedrock and to intermediate layers (anisotropy). This may be explained either by the existence of subsurface structural features or by lateral facies changes or depth variations in the two different directions. For instance, a comparison of the north-south and east-west depth probes at S27 may indicate a subsurface valley with a northerly strike.

5. COMPARISON WITH DRILLING DATA

For future water exploration work it is important to compare the geophysical results with geological findings obtained by drilling. This is done in Table 1 for the Cross-sections A-B, C-D, E-F and G-H, by comparing them where possible with the 'summary of bore data' given by Crohn (1961).

TABLE 1

Resistivity depth-probe	Well or bore	Geological data: Water	Depth (ft) to: Basement	Depth (ft) to: Bottom of borehole	Yield (gal/hr)	Dissolved solids (p.p.m.)	Geophysical interpretation
S1	Well 1 and B.H.	39	40+		?800	630	Low-porosity layer between 8-16 ft and 54-64 ft possibly represents lateritic Warramunga slate, overlying weathered Warramunga slate.
S2	Well 14		40+?		?	640	Depth to Warramunga basement about 23 ft, lateritic Warramunga to 96 ft, and weathered or decomposed rock below 96'. Saline seepage water below 96 ft.
S5	Well 13 and B.H.	38	20*	189	2000	540	Depth to weathered granite 44 ft. Chance of good supply of fresh water in top layers, to about 44-ft depth.
S7	Well 10	41	90*	185	3400	450	Low-porosity, lateritic zone between 15 and 29 ft. Unweathered granite over 200 ft deep, covered by decomposed granite or sediments. Probably in shear zone. Estimated water yield low, saline water.
S11	Well 9 and B.H.	43	70+	136	3400	520	Sediments to a depth of about 59 ft; probably a clay layer between about 35 and 59 ft. A good supply of fresh water within the sediments may be expected.
S15	Well 4 and B.H.	51	65*	147	390	630	A surface layer to 27 ft, overlying rock which may be interpreted as decomposed granite. A low yield and saline water may be expected.
S19	B.H. MM2	About 59	33	70		1490	A surface layer of moderate porosity (about 0.25) to 18 ft, overlying a high-porosity layer with saline water to a depth of about 79 ft. This layer from 18-79 ft probably is a clay formation. Underneath is a cemented, weathered granite.
S20	B.H. MM1	About 56	45	158	?	700	A porous layer, clay, to a depth of about 24 ft, and a less-porous layer of about 0.29 porosity to about 80 ft. Underneath a very porous formation, probably, a decomposed granite in a shear zone, with saline water.

\+ Warramunga basement

* Decomposed granite basement

Resistivity depth-probe	Well or bore	Geological data: Depth (ft) to: Water	Basement	Bottom of borehole	Yield (gal/hr)	Dissolved solids (p.p.m.)	Geophysical interpretation
S16	Well 5, and B.H.	About 49	80+	179	2000	820	A porous formation with brackish to fresh water to a depth of about 110 ft, overlying a porous formation with saline water.
S17	Well 6 and B.H.	47	40+	84	300	360	A low-porosity layer of about 0.20 porosity to a depth of about 66 ft (laterite), overlying a moderately-porous layer which is interpreted as a weathered granite (indicated by magnetic contour plan).
S25, S26	Cemetery and Eldorado bores	Probably low-yield bores with brackish and salt water in Warramunga basement					Weathered, porous Warramunga basement with saline water to a depth of 200 - 300 ft, overlying unweathered rock.
S13	Cabbage Gum bore	A low-yield bore with brackish to saline water				2160	Unweathered granite at about 56 ft covered with porous decomposed granite or clay sediments with brackish water. Yield probably low.
S14	Cabbage Gum East bore	A low-yield bore with brackish to saline water	100	195		1010	Unweathered granite at 180 ft covered with decomposed granite or clay sediments, with brackish water, yield probably low.

+ Warramunga basement

6. CONCLUSIONS

The geophysical techniques used on this survey gave interesting results. They show that simple geophysical techniques combined with geological knowledge can help considerably in selecting the proper drilling targets for water exploration and development in shallow water deposits.

A vertical-magnetic-intensity contour plan shows that the Warramunga Group is indicated by higher magnetic values. This is of special interest because water within the Warramunga Group appears to be more saline than in the surrounding granite or gneiss areas (Bracewell et al.1962, p.20).

Resistivity contour plans constructed from resistivity-traversing data suggests the presence of a subsurface drainage system or zones of deep weathering. Such plans can be used as guides for test drilling; they also indicate the best localities to carry out resisitivity depth-probing.

Resistivity measurements of bore and well-water should be made wherever possible because these data are used in porosity estimates from rock resistivities found by resistivity depth-probing.

Resistivity depth-probes give an insight into the ground structure in terms of average porosity and average salinity of the pore solutions. Depth estimates without occasional drilling or seismic control are not very accurate, but for the selection of drilling targets a high accuracy is normally not required.

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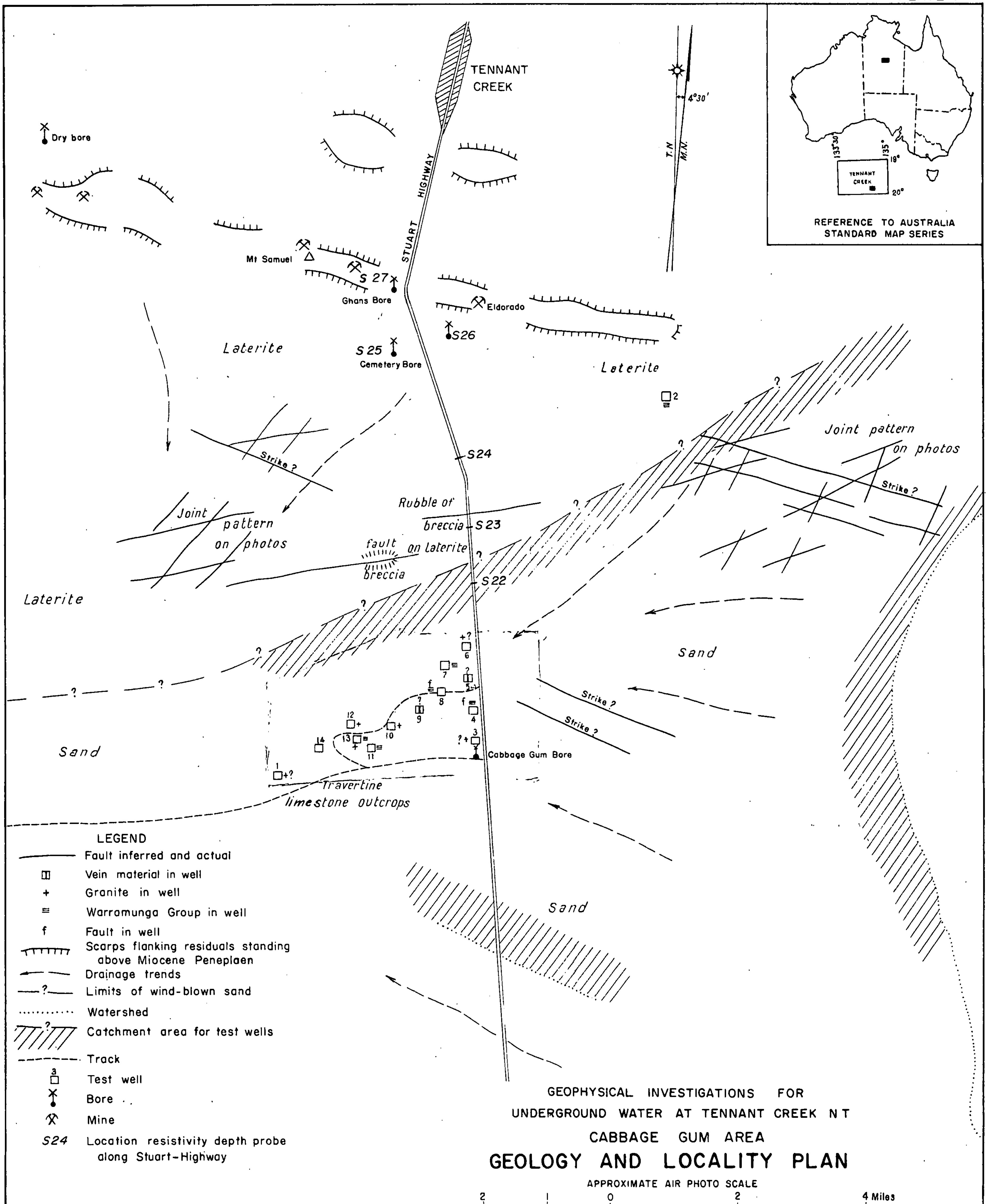
APPENDIX

Table showing measured water resistivities in ohm-metres, reduced to 20°C

Depth probe	Nearby bore or well	Sample depth (ft)	Water resistivity, (ohm-metres)	Estimated total soluble salt content (p.p.m.)	Total bore or well depth (ft)
S1	Bore	40	10.0	587	82
		60	10.6	555	
	Well No. 1	40	13.4	447	43
S4	Bore	35	14.4	420	140
		50	14.8	410	
		65	14.8	410	
S5	Bore	40	21.4	295	189
		100	21.4	295	
		160	21.4	295	
	Well No. 13	40	15.1	407	67
		75	15.8	387	
		110(?)	15.8	387	
S7	Bore 2	40	16.2	380	168
		65	16.2	380	
		90	16.2	380	
	Well No. 10	40	15.3	400	65
		60	15.5	396	
S8	Bore	42 - 74	15.0	406	152
S11	Bore 1	40	13.2	453	136
		80	12.9	465	
	Bore 2	44	14.1	430	95
		60	14.1	430	
		80	14.1	430	
	Bore 3	40	14.1	430	74
	Well No. 9	40	13.3	455	64
		60	13.3	455	
S12	Bore 1	30	9.7	600	148
		70	9.3	630	
		110	9.3	630	
S13	Water tank		1.6	3080	
	Cabbage Gum	55	7.1	710	169
	Bore	80	7.4	690	
S14	Cabbage Gum	60	9.6	612	195
	East	90	9.5	608	
	Bore	120	9.5	608	
S15	Well No. 4	55	16.1	383	70
	Bore	54	14	430	147
		70	14	430	
S16	Bore 1	45	13.4	450	179
		100	11.7	510	
		160	11.7	510	
	Bore 2	50	13.7	440	85
		85	14.4	420	
	Well No. 5	45	9.5	610	64

Depth probe	Nearby bore or well	Sample depth (ft)	Water resistivity, (ohm-metres)	Estimated total soluble salt content (p.p.m.)	Total bore or well depth (ft)
S17	Bore	45	12.9	465	84
		70	12.9	465	
	Well No. 6	50	22.4	280	
		80	22.4	280	
S18	Bore	60	9.9	592	80
S20	Bore	55	10.6	560	158
		75			

PLATE I



GEOPHYSICAL INVESTIGATIONS FOR UNDERGROUND WATER AT TENNANT CREEK N T

CABBAGE GUM AREA

GEOLOGY AND LOCALITY PLAN

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics.

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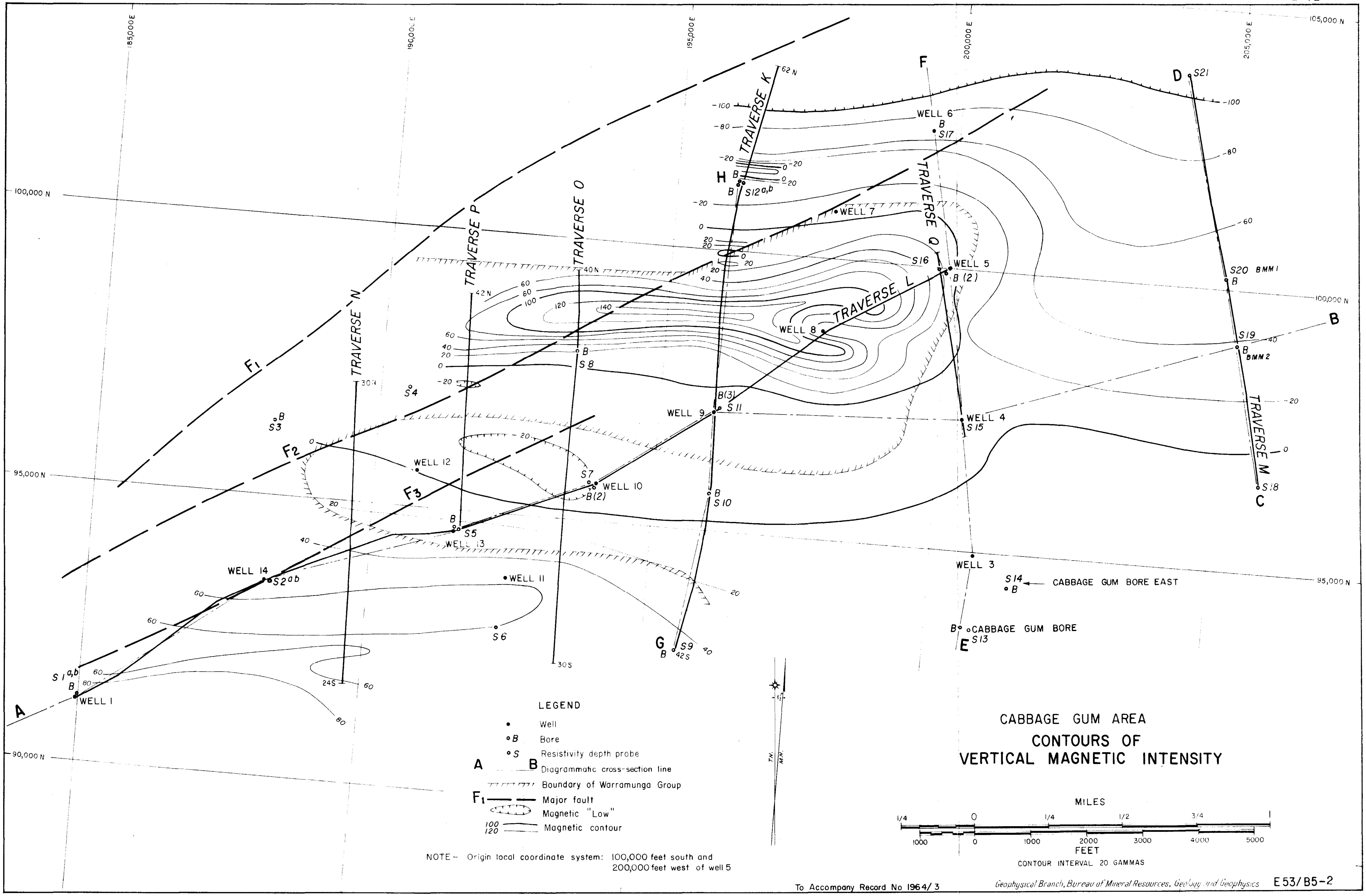
To Accompany Record No 1964/3



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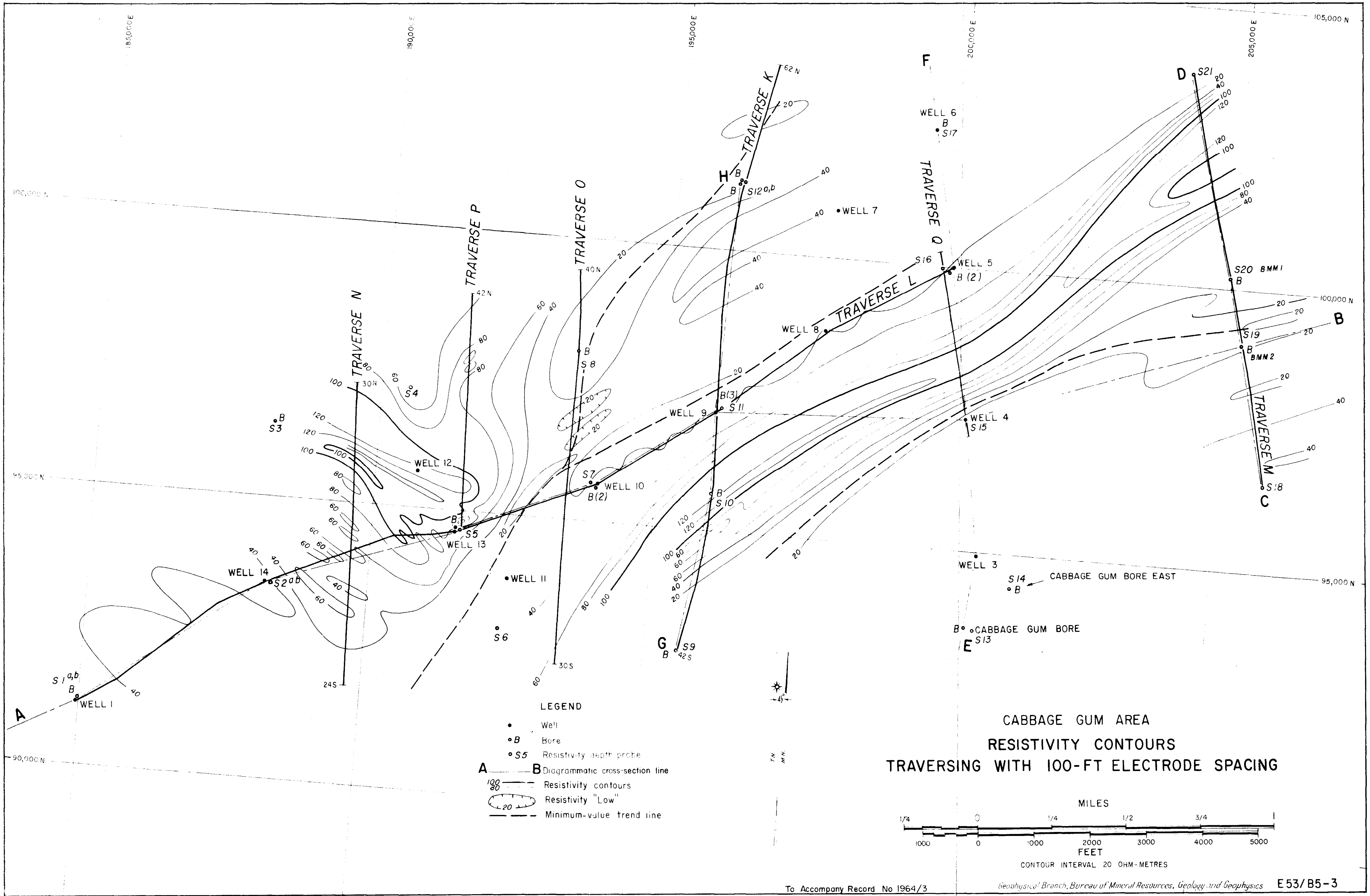
CABBAGE GUM AREA, AT TENNANT CREEK, N.T. 1958



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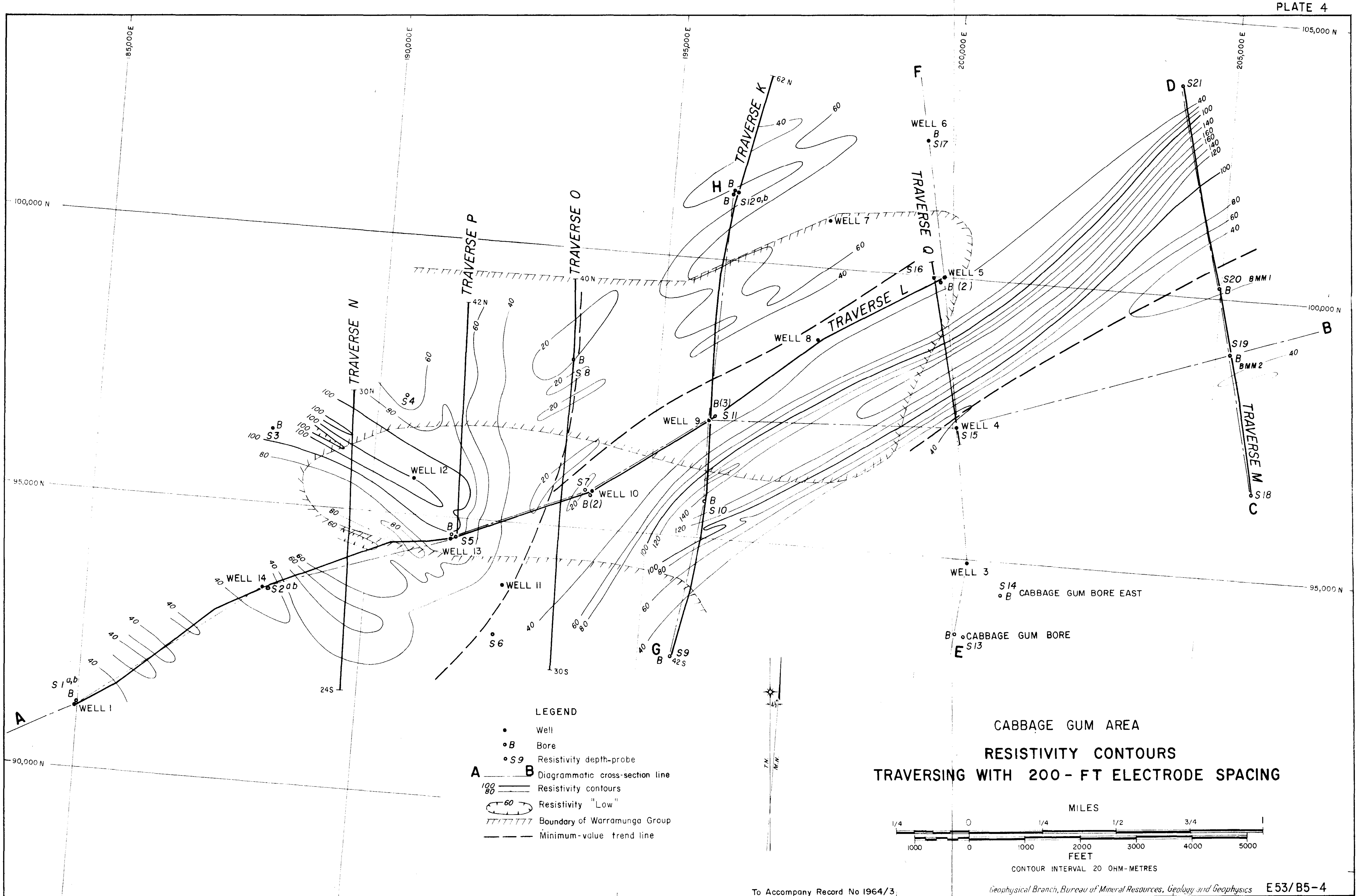

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PLATE 5

CABBAGE GUM BASIN, NT, 1958

RESISTIVITY LOGS AND HISTOGRAMS SHOWING RESULTS OF RESISTIVITY DEPTH – PROBING

SCALES

Horizontal 100 0 100 200 300 Ohm-metres

Vertical 100 0 100 200 300 Feet

ELECTRICAL LOG > 25 < OHM-METRES

LEGEND

Depth probe interpretation

Resistivity log (single-point)

S3 Depth probe number. See plates 3 and 4 for locations

$\rho_w = 10 \pm \Omega$ Water resistivity about 10 ohm-metres

V_t Estimated average porosity

$\Sigma \frac{h}{\rho}$ Total conductance in mho

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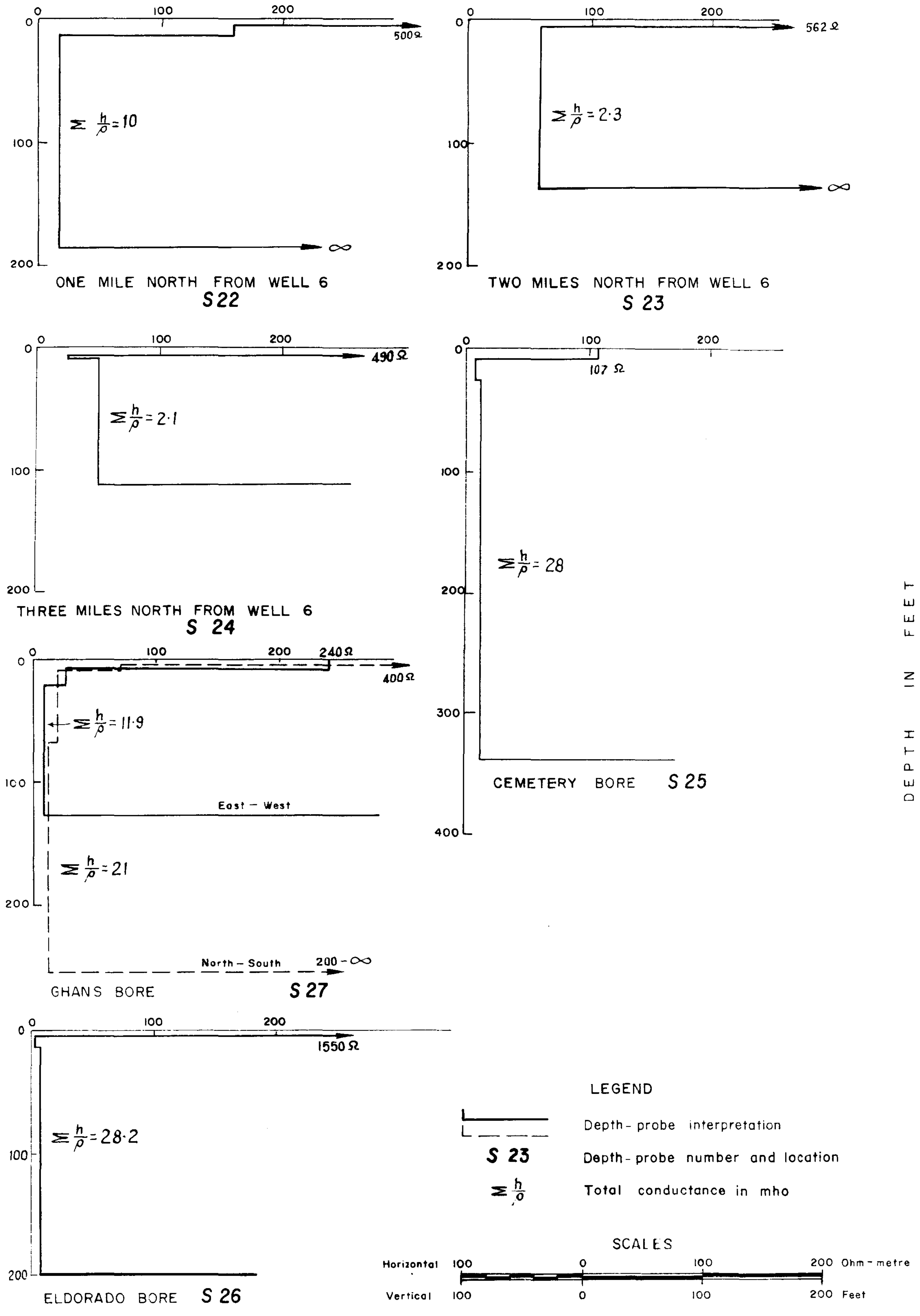
CABBAGE GUM AREA, N.T., 1958.

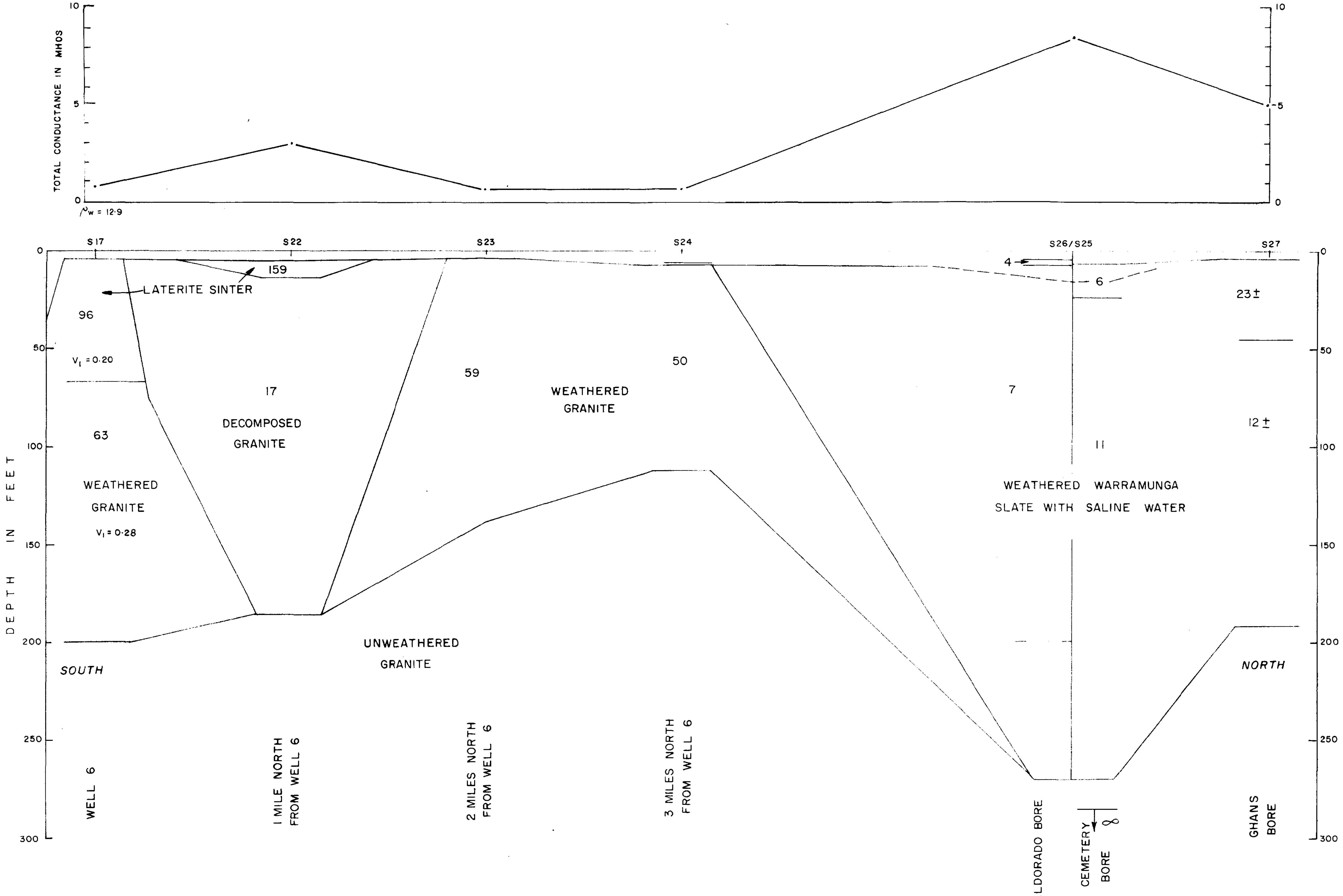
CABBAGE GUM BASIN, N.T, 1958

CABBAGE GUM AREA, AT TENNANT CREEK, N.T., 1958

PLATE 7



RESULTS OF RESISTIVITY DEPTH-PROBING

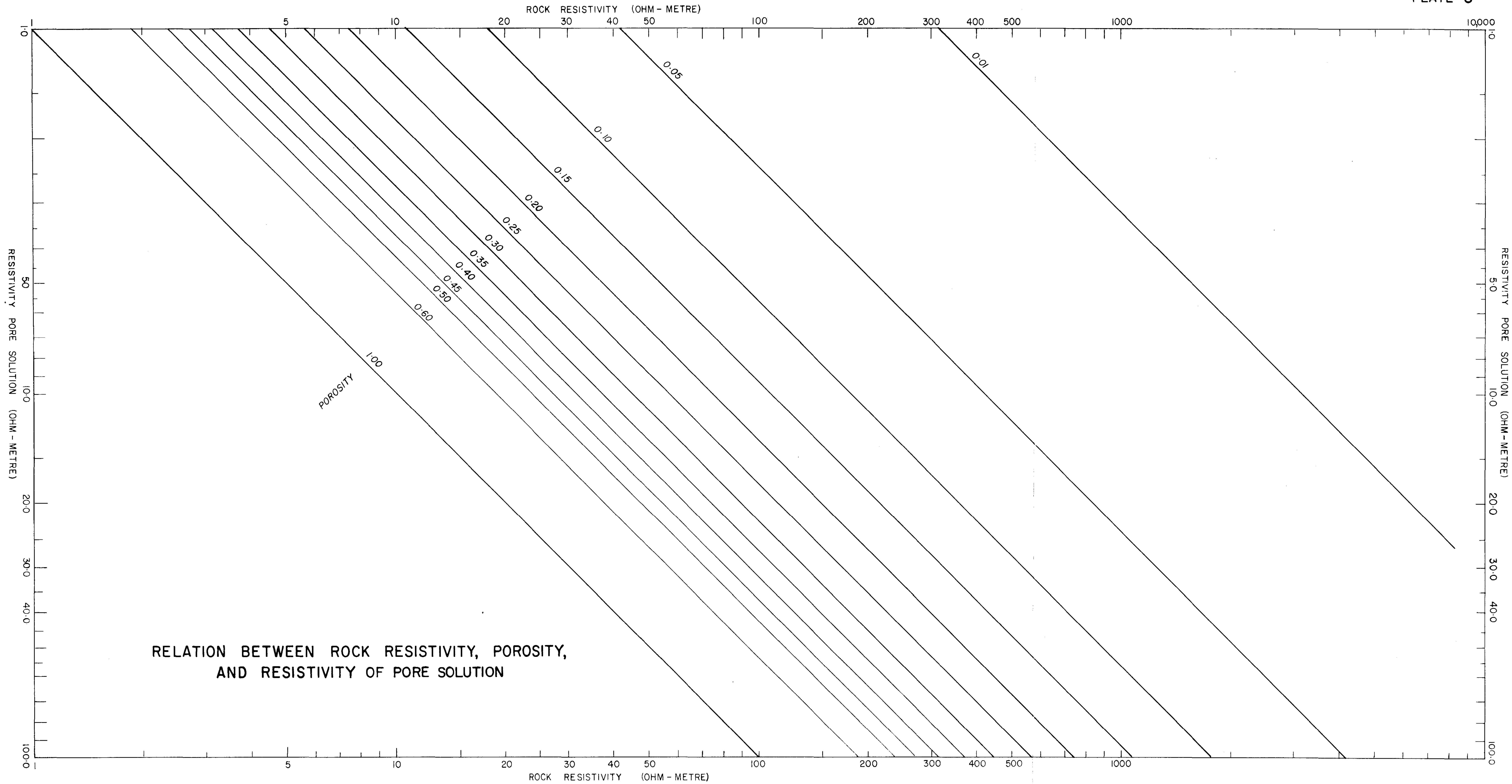


DIAGRAMMATIC CROSS-SECTION, TOTAL-CONDUCTANCE PROFILE, AND HISTOGRAMS SHOWING RESULTS OF DEPTH-PROBING ALONG STUART HIGHWAY BETWEEN WELL 6 AND GHANS BORE

SCALES

Horizontal (approx) ½ 0 ½ 1 mile

Vertical 50 0 50 100 feet



RELATION BETWEEN ROCK RESISTIVITY, POROSITY, AND RESISTIVITY OF PORE SOLUTION

CABBAGE GUM AREA, N.T. 1958

To Accompany Record No 1964/3

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics. G16-6