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A

SEISMIC SURVEY AT MARALINGA, SOUTH AUSTRALIA

(1955-56)

by

W.A. Wiebenga and L.V. Hawkins

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SUMMARY

The seismic survey described in this report was carried out at the request of the U.K. Ministry of Supply. The purpose of the survey was to disclose the geological structure and, if possible, the physical rock characteristics at the Maralinga testing ground. The report is a continuation of, and includes, the work described in an earlier Record. It confirms the preliminary findings in that Record.

The 11,000 ft/sec layer at a depth of about 200 ft, probably a sandstone-shale formation, and the 19,000 ft/sec formation at a depth of about 1350 or 1800 ft (according to the method of computation used) were successfully mapped.

The subsurface information to a depth of about 200 ft was derived mainly from shallow drill holes and up-hole shots. An experimental spread indicated a very low Poisson ratio for the sandstone-shale formation.

1. INTRODUCTION

This survey was carried out by the Bureau of Mineral Resources at the request of the U.K. Ministry of Supply. The main object of the survey was to obtain information on the geological structure at the Maralinga testing ground in South Australia. As it is intended that the results are to be used for model experiments, an effort was made during the survey to estimate, and collect information on, the physical characteristics of the rock types in the area.

Maralinga is situated in South Australia, north of Watson, which is on the railway line from Port Augusta to Kalgoorlie. The survey started on the 1st December 1955 and ended in March 1956, with a break during the Christmas period. The geophysical party consisted of W.A. Wiebenga, party leader, L.V. Hawkins, geophysicist, F. Halls, driller, and G. Woad, radio technician. Five assistants were supplied by the Commonwealth Department of Supply.

A preliminary report (Wiebenga, 1956) has already been issued and described the work carried out during the first three weeks of the survey. This report covers the complete survey.

2. GEOLOGY

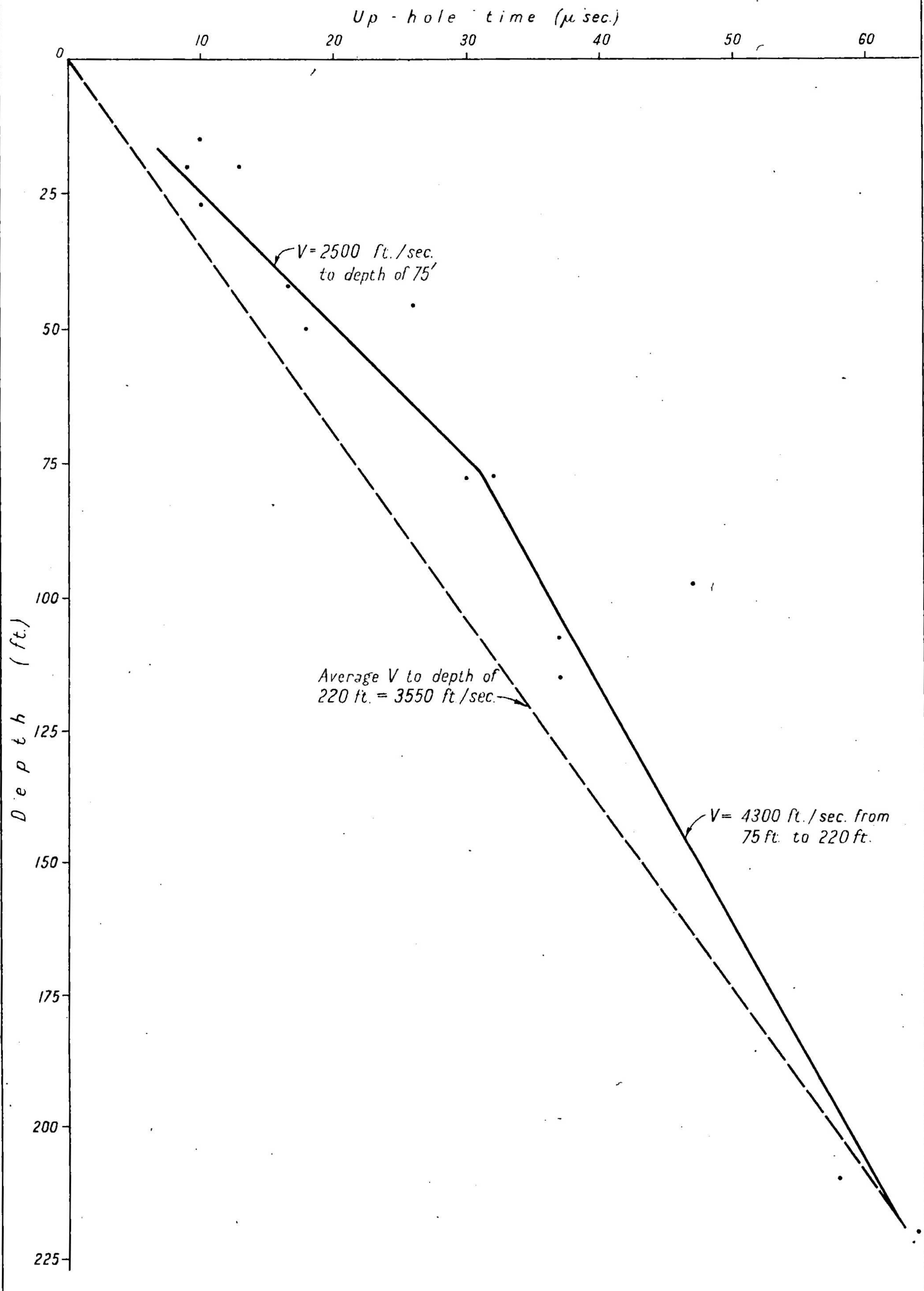
The area, situated north of the Nullarbor Plain, is fairly flat, with gently sloping hills of low relief.

Most of the area is capped by a travertine limestone, which is often concretionary in structure and ranges between zero and fifteen feet of thickness, but may be slightly thicker over the hills. The northern, north-western and western parts of the area are covered by sand-dunes. Beneath the limestone is a layer of unconsolidated sand to an average depth of 75 to 80 feet. Below the unconsolidated sand is a formation of sands and clays, underlain by solid sandstone and/or shale. The exact nature of the latter formation is not known because of lack of drilling information. Apart from what has been inferred from the results of the present survey no information is available on the nature and depth of the basement rocks in the Maralinga area.

3. METHODS AND EQUIPMENT

Considerable difficulty was experienced in the drilling of shot holes. The circulation of the drilling mud was frequently lost between depths of 60 and 80 feet. Caving in of drill holes, both in the limestone and in the loose sand, sometimes necessitated redrilling the holes. As drilling progress was slow in the hard limestone the number of shot holes was restricted to the minimum requirements, and holes were used for both reflection and refraction shooting. A 'Failing 1500' - foot drill was used to drill the shot holes.

FIG. I



SEISMIC SURVEY, MARALINGA, S.A.

UP-HOLE TIMES VS. DEPTH OF SHOT HOLES

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GEOPHYSICISTS

The 24-channel T.I.C. seismograph (model 621) covered a frequency range of 5 to 350 c.p.s. for 70% response. High and low-cut filters, A.V.C. and pre-suppression controls were available, but the frequency ranges above 80 c.p.s. were not used because of the appearance on the traces of a persistent 100 to 200 c.p.s. hash from the recorder. Six-cycle vertical component T.I.C. geophones were used, and as an experiment, one-cycle horizontal-component Wilmore seismometers were used to obtain transverse wave velocities.

The only reflections observed were from shallow reflectors and were partly masked by the high noise level of the travertine limestone. The vertical travel times of these reflections could not be determined accurately from the records. The results of the refraction method were used to map the two main refractors. Depth determinations by both the 'intercept time method' and the 'method of differences' were in agreement.

To enable rough estimates to be made of the 'energy of ground movement' two T.I.C. geophones were calibrated on a shaking table.

4. RESULTS

In Figure 1 the vertical travel times of events from shots in shallow drill holes are plotted against the depth of the charge. The slope of a line through the vertical travel times indicates velocity. At an average depth of 75 to 80 feet the vertical velocity increases from 2500 to 4300 ft/sec. This discontinuity was not shown by the time distance curves plotted from the refraction results because energy from the higher velocity surface limestone completely masked any arrivals from this discontinuity. The 2500 ft/sec layer consists of unconsolidated sand; the 4300 ft/sec layer consists of clay and sand.

Plate 1 shows sections, along the traverses, of the near-surface structure to a depth of about 200 ft. The limestone thickness is taken from shallow drilling data. The limestone velocity as indicated by the refraction results is 5500 to 8500 ft/sec. The 2500 and 4300 ft/sec layers are grouped together on the sections because seismically they could not be distinguished. Below this group of low-velocity layers, at an average depth of about 200 ft, is the 11,000 ft/sec layer, which is interpreted as a sandstone and/or shale formation. The depth to this formation, as indicated on the sections, is determined by the intercept times of the time-distance curves. Seismic evidence indicated that the boundary between the 4300 and 11,000 ft/sec layers is not sharp and that in parts of the area thin high-velocity layers occur towards the base of the 4300 ft/sec layer. The lowest refractor recorded was at an average depth of 1350 ft and has a velocity of approximately 19,000 ft/sec. The results of the seismic survey give no information on any deeper layers. A deeper layer with a velocity less than 19,000 ft/sec would not be detected by the refraction method. However, a deeper layer with a velocity greater than 19,000 ft/sec would be detected, but only if present within certain depth limits, imposed by its velocity and by the length of the geophone spread used. For example, with the maximum shot-point to geophone distance which it was practicable to use at Maralinga, i.e. $2\frac{1}{4}$ miles, a layer with velocity of 23,000 ft/sec (the upper limit of known rock velocities) would have been detected, provided its depth below surface did not exceed about 4000 ft.

From information in geophysical literature on seismic velocities in various types of rocks, it appears that a rock with velocity of 19,000 ft/sec is likely to be igneous or metamorphic basement or a hard limestone. The nearest known outcrops of basement rock are about 40 miles south-east of Maralinga. These outcrops are of pre-Cambrian granite gneiss. About 240 miles west of Maralinga, near Forrest on the Trans-Continental Railway, water bores have shown granite at depths between 1000 and 1400 ft. An east-west aeromagnetic traverse along the railwayline conducted by the Bureau during a reconnaissance of the Eucla Basin, appears to indicate that the depth to basement near Watson is not greatly different from that near Forrest. In view of the above evidence, it is considered that the 19,000 ft/sec layer recorded at Maralinga is most probably the granite basement,

Plates 2 and 3 are contour maps of the top of the 11,000 ft/sec and 19,000 ft/sec refractors, respectively. The elevations of the refractors (relative to MSL), which have been determined from the seismic results and on which the contours are based, are shown by the underlined figures. The velocity of the 11,000 ft/sec layer was determined from time-distance curves and therefore represents a horizontal velocity along the top surface of this layer. From five reflection shots the average vertical velocity within the sandstone-shale section was computed as 13,400 ft/sec with a R.M.S. deviation of 1000 ft/sec. This indicates that the average 'thickness' of the sandstone-shale section may be up to 40 per cent larger than that deduced from Plates 2 and 3. However, the quality of the reflections was not of a high standard.

Assuming a vertical velocity of 11,000 ft/sec, the average thickness of the sandstone-shale formations is 1100 to 1200 ft and the average depth to the 19,000 ft/sec formation is 1300 to 1400 ft. If, however, the vertical velocity is taken as 13,400 ft/sec, the average thickness of the sandstone-shale formation becomes about 1600 ft and the average depth to the 19,000 ft/sec formation about 1800 ft.

As indicated above, it is considered that the 19,000 ft/sec refractor is most probably the granitic or metamorphic basement.

An experimental spread (length 1320 ft) was shot with the two horizontal-component seismometers along traverse A, east of station A5. The two seismometers were placed with their axes perpendicular to the traverse and were moved along the spread after successive shots. The first events indicated a velocity of 8300 to 8600 ft/sec for S waves. Over the same sandstone-shale section a velocity of 11,800 ft/sec was recorded for P waves. These are the velocities of P and S waves travelling along the top of the 11,000 ft/sec layer. Poisson's ratio computed from these velocities and an assumed density of 2.5 is 0.0 ± 0.1, say between 0 and 0.1. For many substances, including most consolidated rocks, Poisson's ratio is in the neighbourhood of 0.25; the value obtained here for the sandstone-shale layer is therefore extremely low. The reason for this low value is not clear but it may be indicative of brittle, incompetent beds near the upper surface of the 11,000 ft/sec layer. It is not necessarily characteristic of the whole layer.

The frequencies of the recorded waves ranged between 25 and 75 cycles per second and the average frequency was about 50-55 cycles per second. In the same experiment, the later events recorded by the horizontal geophones consisted of wave packets with a strongly dispersive character and with velocities of 4300 to 4700 ft/sec. It is suggested that these waves were refracted in the 4300 ft/sec layer described previously and could be recognised because the noise level on the transverse horizontal geophones was very low. It is thought that these waves undergo dispersion in the layers between the 4300 ft/sec layer and the surface.

The measured, estimated and derived physical characteristics of the rocks in the area are shown in the accompanying table.

Physical characteristics of the rocks in the geological section.

Type of Rock	Density (gm/cc)	Poisson's ratio	Velocity of P waves (ft/sec)	Velocity of S waves (ft/sec)	Characteristic impedance for P waves (c.g.s units)	Young's modulus (c.g.s units)
Travertine limestone	2.7*	0.15*	5500 to 8500 (ii)	-	5.8×10^5	1.2×10^{11}
Sand underlying travertine	2.0*	0.45	2200 to 2700 (iii)	-	1.5×10^5	0.3×10^{10}
Sand and clay	2.2*	0.35*	4300 ± (iii)	-	2.9×10^5	2.7×10^{10}
Sandstone and/or shales	2.5*	0 to 0.1	11,000 to 12,000 (ii)(iv)	8300 to 8600 (i)	8.8×10^5	3.1×10^{11}
Granitic or metamorphic basement or limestone	2.7*	0.25*	19,000± (ii)	-	15.8×10^5	7.7×10^{11}

* Estimated values.

(i) Measured with horizontal transverse geophones near Marcoo.

(ii) Velocities are derived from time-distance curves of refraction shots.

(iii) Velocities are derived from up-hole shots.

(iv) The vertical velocity of P waves in the sandstone and/or shale, measured from step out times of reflection data, is 13,400 ft/sec with a R.M.S. deviation of ± 950 ft/sec from 5 determinations.

5. CONCLUSIONS

The geophysical investigations carried out on the Maralinga testing ground show several distinct layers between the surface and about 1350 ft. The rocks below this depth are most probably granitic or metamorphic basement which extends to depths of many miles. To a depth of 200 ft the information has been derived mainly from shallow drill hole data. Below that depth, the information depends on measurement of seismic velocities as observed in refraction shooting.

In general it was not possible to determine accurately the elastic properties of the rocks in the section. However, from the observed seismic velocities and by assuming the most likely values for density and Poisson's ratio, approximate estimates have been made of Young's modulus for the different rock formations present in the area.

Calculations are being made of the energy of vertical ground movements as recorded on a second experimental spread, with a small charge at a depth of 75 ft in a drill hole 880 ft north-east of peg P106. The geophone spread was in a north-west direction centred about the shot point.

Preliminary results indicate that the rate of attenuation of the peak energy over the distance range of 110 to 1320 ft is approximately 4 db per 100 ft. It is proposed to include the details of these results and also the results of calculations on the rate of attenuation of total energy, in a further report.

6. REFERENCE

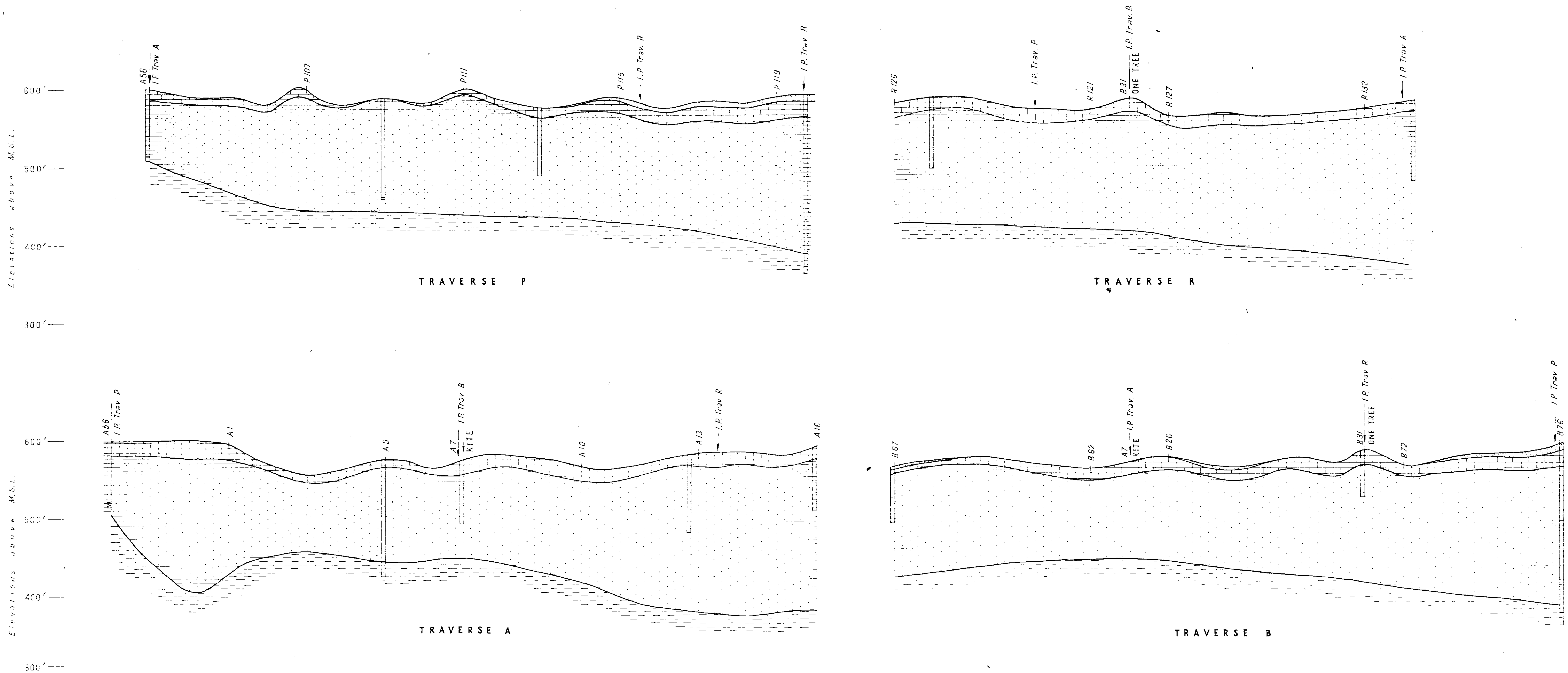
WIEBENGA, W.A.,	1956	Preliminary report on seismic refraction survey at Maralinga, South Australia. Bur. Min. Resour. Aust. Record 1956/11.

APPENDIX

List of Station Elevations

Station	Elevation (ft)	Station	Elevation (ft)	Station	Elevation (ft)	Station	Elevation (ft)
A 60	595	B 69	571	P 100	592	R 126	586
59	596	68	570	101	612	125	590
58	596	67	570	102	627	124	590
57	607	66	575	103	617	123	578
56	598	65	580	104	592	122	575
55	598	64	574	105	590	121	577
54	596	63	569	106	579	127	568
1	595	62	563	107	594	128	567
2	570	26	579	108	579	129	570
3	556	27	569	109	586	130	573
4	563	28	569	110	580	131	573
5	573	29	581	111	599	132	577
6	567	30	573	112	586		
7	573	31	590	113	576		
8	577	72	571	114	584		
9	577	73	581	115	587		
10	564	74	582	116	576		
11	565	75	586	117	585		
12	577	76	597	118	581		
13	582	77	601	119	591		
14	583	78	587	120	597		
15	578						
16	591						

PLATE I



LEGEND

- Sand
- Limestone
- Sand and clay
- Sandstone and/or shale
- Drillhole

NOTE

The thicknesses of sand and limestone were obtained from shothole drilling data.

The depth of sandstone and/or shale was obtained from seismic results.

SCALES

HORIZONTAL ½ 0 ½ 1 1½ 2 MILES

VERTICAL 100 0 100 200 300 400 FEET

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SEISMIC SURVEY, MARALINGA, W.A.

VERTICAL SECTIONS TO 11000 FT./SEC. LAYER

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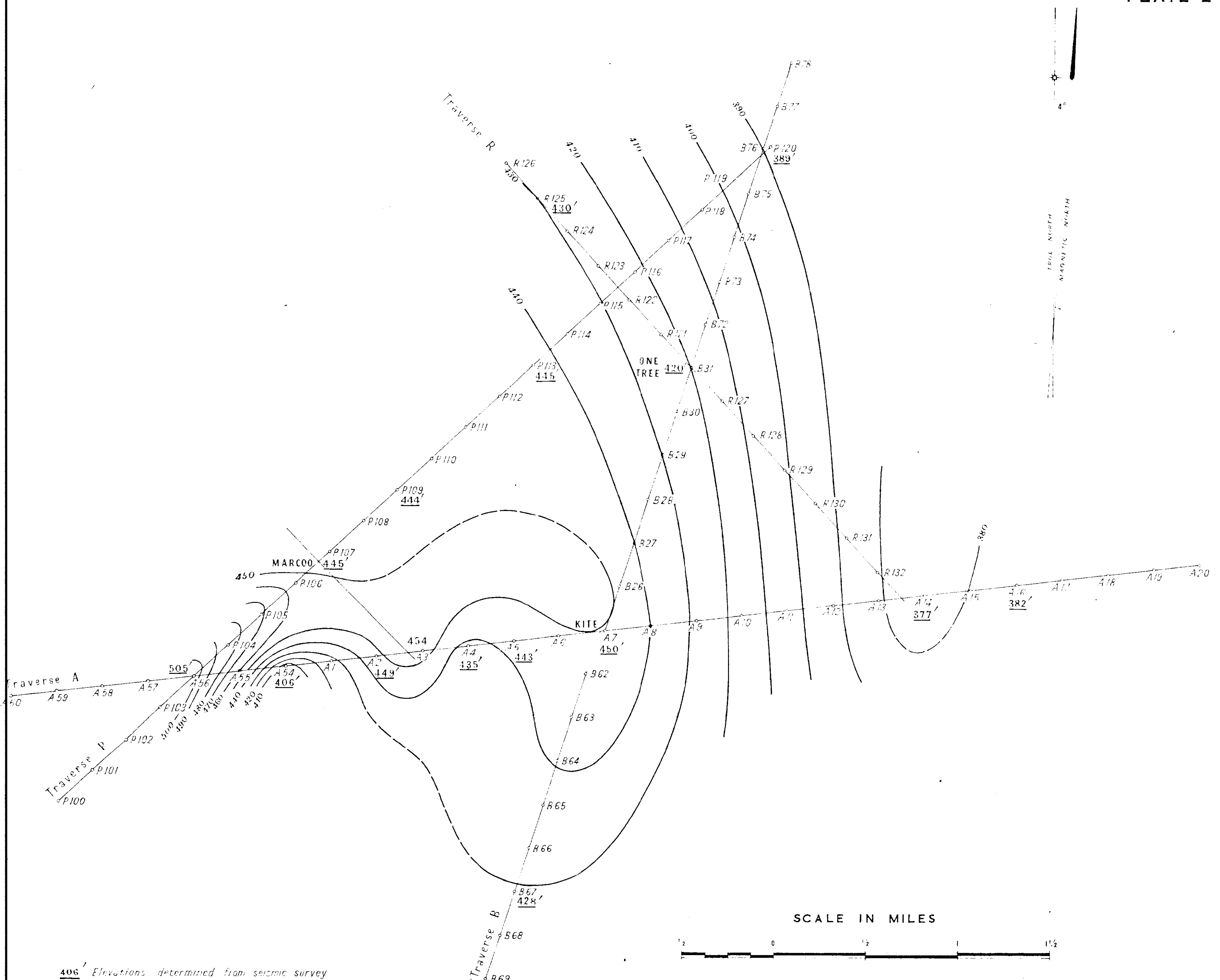
PLATE 2



406′ Elevations determined from seismic survey
Relative accuracy ±20 ft.

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SEISMIC SURVEY, MARALINGA, S.A.

CONTOURS OF THE TOP OF THE 11000 FT./SEC. LAYER RELATIVE TO M.S.L.

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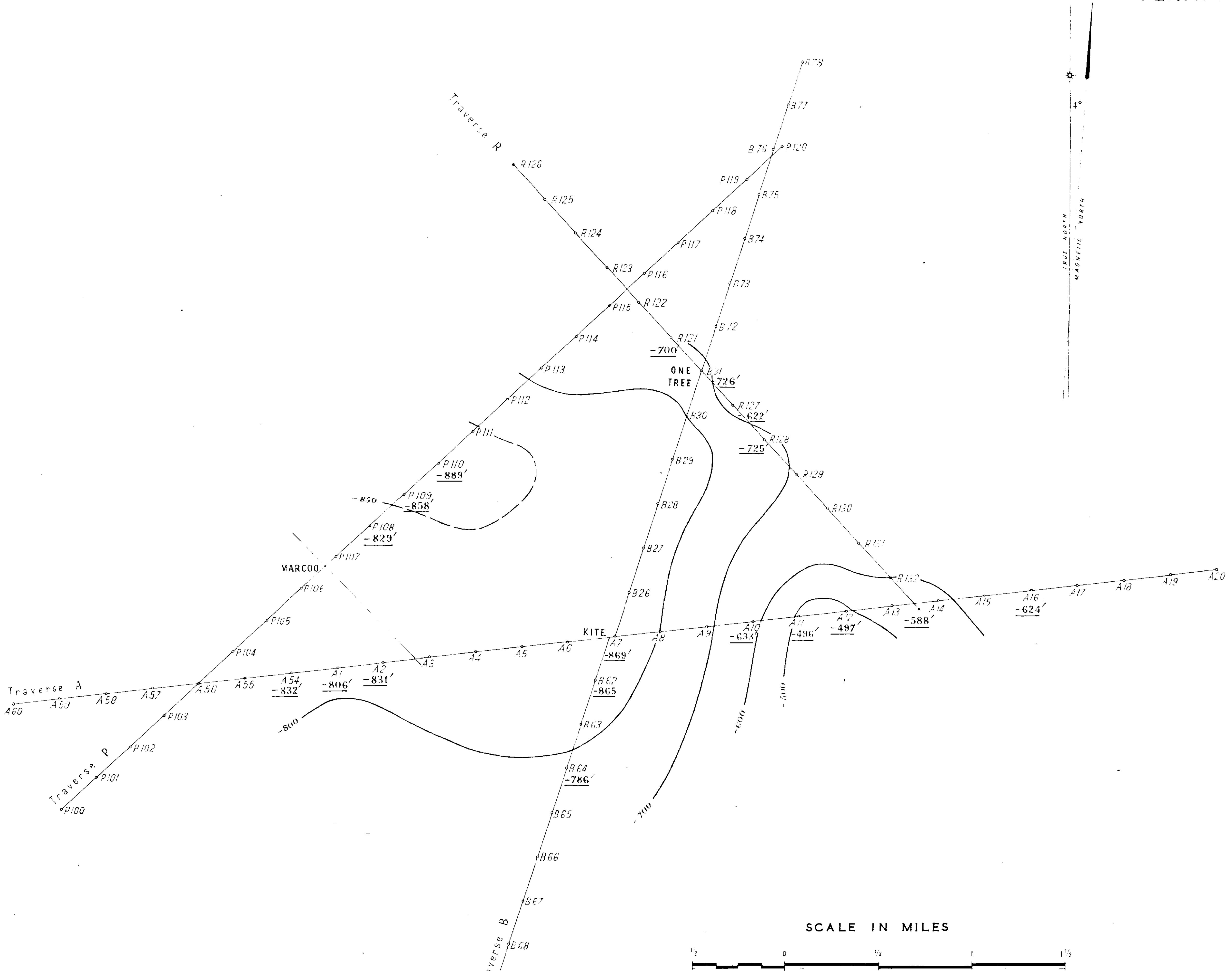
PLATE 3



-832′ Elevations determined from seismic survey
Relative accuracy ± 50 ft.

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SEISMIC SURVEY, MARALINGA, S.A.

CONTOURS OF THE TOP OF THE 19000 FT./SEC. LAYER RELATIVE TO M.S.L.

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