COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

RECORD No. 1962/181

RAILTON GEOPHYSICAL SURVEY,

TASMANIA 1959-60

by

E. J. POLAK

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SUMMARY

This Record describes seismic refraction, magnetic, gravity, and resistivity surveys of a proposed extension of the limestone quarry belonging to the Goliath Portland Cement Works at Railton, Tasmania.

The purpose of the surveys was to determine the thickness and nature of the overburden over the limestone. Seismic results indicated that the overburden is from 50 ft to 170 ft thick and consists of residual clay, gravel, and dolerite boulders.

Later drilling information has shown that seismic results are in error by over 100 percent in places. The discrepancies are apparently due to pinnacle formations in the surface of the limestone. Refracted seismic waves arriving from the steep slopes lead to erroneous depth calculations.

1. INTRODUCTION

The Goliath Portland Cement Company obtains limestone for cement production from a quarry next to its plant in Railton, Tasmania. The Company proposed to extend the quarry towards the west. The Department of Mines requested the Bureau of Mineral Resources to make a geophysical survey in this area to determine the depth to the limestone.

The survey was made in November 1959 and February 1960 by a geophysical party consisting of E.J. Polak (party leader), and M.J.W. Duggin and D.J. Harwood (geophysicists). The Company provided additional assistants and surveyed the traverses.

2. GEOLOGY

The general geology of the area was mapped by Hughes (1957). A detailed investigation of the existing quarry was made by Jennings (1957). Six drill holes were put down, three of which are in the area covered by the geophysical survey.

The quarry is located in a broad limestone valley (Plate 1), about 14 miles south of Devonport. The whole area is covered with alluvium, with only a few outcrops of limestone.

Table 1 shows the general stratigraphy of the area (Hughes, 1957).

Table 1

Age	Rock type
Recent	Residual clay
Tertiary	Basalt and agglomerate
Jurassic	Dolerite?
Permian	Mudstone, sandstone, coal measures, conglomerate, and glacial till.
Ordovician	Gordon Limestone

Gordon Limestone

The limestone is mostly solid, although much of it is sheared and folded. The weathering is irregular. In places the limestone has been dissolved by surface water, which has resulted in the formation of caves. Some of these have been proved by drilling, though not in the area of the geophysical survey.

Residual clay

The limestone is covered with residual clay and alluvium. In some places the clay is in situ and of uniform consistency, but in others it is mixed with alluvium and dolerite boulders. The thickness of residual clay proved by drilling in the area of survey ranges from 51 to 130 ft. This residual clay is used as a source of alumina in the production of cement.

The existence of dolerite in the area of the survey, as shown on Plate 1, is doubtful (Hughes, 1959).

3. METHODS AND EQUIPMENT

Resistivity method (Heiland, 1946, p.707)

Differences in the structure and composition of rocks produce variations in their electrical resistivity. Hard, non-porous, and unweathered rocks have a high resistivity. Shearing and fracturing result in narrow weathered zones, with relatively saline pore-water, and these zones show low resistivity. In general the resistivity of a rock is inversely proportional to the product of its porosity and the salinity of the pore solution.

The equipment used was a Megger Earth Resistivity Tester, manufactured by Evershed and Vignoles.

The Wenner arrangement of electrodes was used for measuring resistivity. This is shown in Figure 1 of Plate 2. Four electrodes C1, P1, P2, C2, are equally spaced along a straight line. An alternating current is introduced into the ground through the current electrodes C1 and C2, and the difference in potential is measured across the potential electrodes P1 and P2. The depth of penetration of the current is controlled by the distance 'a' between the electrodes.

Resistivity can be measured in the following ways:

(a) Constant-spacing traversing The four electrodes are moved along a traverse as a unit (Wiebenga, 1955). Readings are taken with the array centred on consecutive stations. In the interpretation, absolute values of resistivity are not as important as sudden changes, which usually indicate a change in rock type. In this survey, constant electrode-spacings of 50 ft and 100 ft were used.

(b) Depth probes. The distance 'a' between electrodes is increased between successive readings, while the centre of the array remains in one place. Values of apparent resistivity are then plotted against the distance 'a' between electrodes (Plate 2, Fig. 2). From the graph, the depth to a horizontal interface between two formations with different resistivities can be computed, and the resistivities can be determined (Wiebenga, 1955).

(c) Drill-hole resistivity log. The assembly of three electrodes (Plate 2, Fig. 3) is lowered down the hole, the fourth electrode remaining at the surface. Readings of apparent resistivity are taken at consecutive depths. The plotted curve shows the changes in the resistivities of the rocks, and may indicate the boundaries of different strata.

<u>Magnetic method</u> (Heiland, 1946, p. 293)

The measured magnetic intensity at any point on the Earth's surface may be expressed as a vector. An anomaly in the Earth's magnetic field caused by local variations in the magnetism of rocks may be considered as the resultant of two vectors, viz. an induced magnetic-intensity vector in the direction of the Earth's magnetic field, and a remanent magnetic-intensity vector, which may lie in any direction.

In certain areas magnetic measurements may indicate such features as faults and boundaries between near-surface formations. In some instances an estimate can be made of the depth to the feature causing the anomaly.

In this survey both the horizontal and the vertical components of the magnetic field were measured. The variometers used were manufactured by Hilger and Watts.

<u>Gravity method</u> (Heiland, 1946, p.67)

The gravity method depends on the density contrast between different types of rocks. A subsurface structure with lateral variations in density will give rise to variations in the force of gravity at the surface. This variation can be measured with a gravity meter. During this survey a Worden gravity meter was used.

<u>Seismic method</u>

The seismic method of exploration depends on the contrast in the velocity of elastic waves through different rock formations. The fastest wave is the longitudinal wave, which consists of a forward and backward movement of particles along the direction of propagation. Only the longitudinal waves are considered in this Record.

When an explosive charge is fired in a shallow hole, the seismic waves radiate in all directions. Geophones, placed in the ground, detect these waves and send electrical impulses along a cable to the recorder truck, where they are amplified and photographically recorded by an oscillograph.

Figure 1 on Plate 3 shows a sample record obtained during the survey. The vertical lines are timing lines at 10-msec intervals. The shot instant, marked S.I., is on the bottom trace. Following the shot instant, the first deflection on each trace indicates the arrival time of the longitudinal wave; this time may be measured relatively to the shot instant. The arrival time of the longitudinal wave at each geophone is plotted against the distance of the geophone from the shot-point, giving the time/distance curve. Figure 2 on Plate 3 shows the time/distance curve derived from the seismic record in Figure 1. The slope of a section of the curve is proportional to the reciprocal of the seismic wave velocity in a corresponding layer (Fig. 3, Plate 3).

An analysis of the paths of various seismic rays of the longitudinal wave indicates the following pattern for the first impulse recorded by successive geophones (Plate 3, Figs. 2 and 3):

Geophone G_1 indicates a low velocity V_1, which cannot be determined from this graph; special 'weathering spreads' must be used for this purpose. The seismic wave travels from Shot-point A to point B with velocity V_o, and thence along the interface with velocity V_1. The position of B is determined by the critical angle of incidence i_{o1} where $\sin i_{o1} = V_o/V_1$. As this refracted wave travels along the interface, part of its energy is continually refracted back at the critical angle i_{o1}. This wave reaches geophone G_1 through point C.

Geophones G_2 to G_8 indicate a velocity V_2 of 5000 ft/sec. The wave travels from A to B with velocity V_o, then to D with velocity V_1. At D it is critically refracted, and travels with velocity V_2 to E. A refracted wave from E travels to C_1 with the velocity V_1, and thence to geophone G_2 with velocity V_o.

Geophones G_9 to G_{12} indicate a velocity of 33,000 ft/sec. This is the wave that penetrates still deeper, and is refracted from the fourth horizon. The very high apparent velocity indicates that the depth to the fourth layer decreases away from the shot-point. The true velocity can be calculated from records obtained by firing shots at both ends of the spread.

For the field arrangement and calculation the 'Method of Differences' was used (Heiland, 1946, p.548). The technique is illustrated in Figure 4on Plate 3. A shot is fired at A and the travel times are recorded at B and C. A shot is then fired at C and the travel times are recorded at A and B. The depth d measured to the refracting horizon below point B is calculated from the formula:

$$d = \tfrac{1}{2} (T_{AB} + T_{CB} - T_{AC}) \ V_a$$

where

T_{AB} = time of travel of refracted wave from A to B

T_{CB} = " " " " " " " C to B

T_{AC} = " " " " " " " A to C

V_a = the apparent velocity of the seismic wave within the overlying rocks.

The following types of spreads were shot:

(a) Weathering spreads. These were used to obtain the thickness and seismic velocity of the soil and surface layer. Geophones were spaced 10 ft apart and shots were fired 5 ft and 100 ft beyond each end of the spread and in line with it.

(b) Normal spreads. Geophones were spaced 25ftor 50 ft apart, and shots were fired 25ft and 200 ft or more beyond each end of the spread and in line with it.

(c) Drill-hole velocity logs. Seismic velocities were recorded in three drill holes. A small charge of explosives was detonated at several depths in each drill hole, and the resulting waves were detected by a geophone at the ground surface adjacent to the drill hole. The vertical velocities were calculated from the depth of the shot and the travel times. These velocities were measured in a direction approximately normal to the direction in which velocities are measured in seismic refraction work.

The equipment used in the survey was an SIE 12-channel refraction seismograph with SIE geophones having a natural frequency of 8 c/s.

Application of methods

The total lengths of traverses surveyed with each geophysical method were:

Table 2

Resistivity, constant spacing	7300 ft
Vertical magnetic intensity	7650 ft
Horizontal magnetic intensity	7650 ft
Gravity	7900 ft
Seismic refraction	6100 ft

4. RESULTS

Resistivity

Depth probes. The results of the two depth probes done in the survey are shown in Figure 2 on Plate 2. The depth probes were located over drill holes DD5/59 and DD4/59. The depth probe over DD5/59, in which the overburden is about 71 ft thick, shows a higher apparent resistivity than the depth probe over DD4/59, in which the overburden is about 51 ft thick. This means that the overburden is of higher resistivity than the limestone.

Constant-spacing traverses. Plate 4 shows a contour plan of resistivity values with 50-ft electrode spacing. In areas where the thickness of the overburden is greater than the spacing of the electrodes, the resistivity values depend on the resistivity of the overburden. The variations in resistivity shown on Plate 4 indicate that the overburden is not homogeneous. In areas of residual clay the resistivity is lower than in areas of residual clay with boulders and gravels. Only in the northern corner of the area do the low resistivity values suggest that the limestone is within 50 ft of the surface.

Plate 5 shows the resistivity contour plan with 100-ft electrode spacing. In the northern part, resistivity readings have been influenced by the limestone, and the decrease in the thickness of the overburden in a north-easterly direction is reflected in a decrease of apparent-resistivity values.

Drill-hole resistivity log. The three-electrode resistivity log of the drill hole at the bottom of the quarry is shown in Figure 3 on Plate 2. This hole was drilled entirely in limestone, and it indicates that the apparent resistivity in limestone ranges between 8000 and 25,000 ohm-cm with an average value of about 18,000 ohm-cm.

The very jagged appearance of the log above 172 ft may be an indication that the rock is jointed and that the higher apparent-resistivity values occur at joints filled with relatively fresh water. Below 172 ft the values are much lower; this may indicate that the permanent water-table has been reached, as below the water-table the water would be expected to contain more dissolved salt, and therefore to show a lower resistivity.

Magnetic

The profiles of vertical and horizontal magnetic intensity along the traverses are plotted on Plates 8 to 12. Plate 6 shows a contour map of the vertical magnetic intensity.

The magnetic susceptibility of limestone is generally low and uniform but the susceptibility of the overburden depends on its constitution. On areas of pure residual clay it may be expected to be low, but where the clay is mixed with boulders of dolerite and products of dolerite weathering, the magnetic susceptibility should be higher.

The steep gradients of the anomalies suggest that the origin of the magnetic features is located at shallow depth Near drill hole DD4/59, grains of highly magnetic material were picked up by magnets The zone of lowest magnetic values seems to follow the axis of a subsurface valley that was interpreted from the seismic work (see Plate 13).

Gravity

A contour map of the gravity results is given on Plate 7. The specific gravity of dense limestone (about 2.76) is much higher than that of the overburden (2.4). The areas where the limestone comes close to the surface would therefore be expected to show as gravity 'highs'. The gravity values decrease from north to south, possibly indicating that the depth to the limestone increases towards the south. The gradient could also be due to a deeper-seated effect. It is also possible that local gravity 'highs' correspond to high limestone features. Caves in the limestone could cause negative anomalies. However, no corrections have been made for irregular terrain, and this may affect the pattern significantly, particularly as the anomalies are not very large.

Seismic

Velocities In the interpretation of the seismic data the following velocities were assumed as characteristic for different rock types:

Table 3

Rock type	Seismic velocity (ft/sec)
Soil	1000
Overburden consisting of residual clay and alluvium, gravel, and boulders in different proportions.	2000 to 3000
Unidentified rock; may be weathered mudstone, sandstone, wet sand, or glacial till.	5000 to 5600
Limestone	12,000 to 13,000

Interpretation. Plates 8 to 12 show the depth to limestone as calculated from the seismic results. South-east of Traverse E the seismic work indicates a bed in which the velocity is 5000 to 5600 ft/sec, between a near-surface layer in which the velocity is 2200 ft/sec, and the bedrock in which the velocity is 13,000 ft/sec. The presence of this bed may account for the lower gravity values in the south-eastern part of the area. The bed may extend north-west of Traverse E as a bed too thin to be recorded by the seismic refraction method.

The depth to the limestone has been calculated from the seismic data using an apparent velocity. The apparent-velocity values were determined from weathering spreads.

A bedrock contour plan is shown on Plate 13; this plan was prepared from the seismic data on Plates 8 to 12. The valley mentioned in the discussion of the magnetic results is clearly shown.

Plate 14 shows the thickness of the overburden above the limestone. The thickness increases from less than 50 ft in the northern corner of the area to more than 170 ft in the southern corner.

5. CONCLUSIONS

After the geophysical survey had been completed, further holes were drilled. The results obtained are compared with the seismic results at the same points in Table 4.

Table 4

Drill hole No.	Location	Depth from drilling (ft)	Depth from seismic results (ft)
1/60	A200	140	70 to 90
2/60	F100	138	90 to 110
3/60	C 80	189	50 to 70
4/60	C200	133	100 to 120

Hole 4/59, 80 ft away from hole 3/60, showed limestone at 71-ft depth.

This drilling information suggests that the limestone surface consists of a series of sharp pinnacles and valleys, rather than the gently undulating surface suggested by the seismic refraction work.

The reason for the large discrepancies between the true and calculated cross-sections is illustrated on Plate 15. Figure 1 shows a possible cross-section in an area such as this, with a series of sharp pinnacles and deep valleys. The path of the first wave to arrive at each geophone is shown through the overburden. On Plate 3 (Fig. 4) the simple case is shown on which the seismic interpretation is based; the depth d is calculated. It can be seen from Figure 2 on Plate 15 that the depth calculated by the seismic method to a bedrock surface as depicted in Figure 1 will be incorrect. The narrow valley beneath G3 does not show up at all on the calculated profile, and the wide valley between G4 and G9 shows up as a much shallower valley. If the geophones marked on Plate 15 were spaced at 50-ft intervals, then the valley under G3 would be 130 ft deep and 100 ft wide at its widest point, yet the seismic profile indicates only a small inflexion at 60 ft depth. The wide valley between G4 and G9, which would be 180 ft deep, appears to be only 90 ft deep in the calculated profile.

The seismic data do not give any indication that such a complicated bedrock profile might be expected. It is not considered that the use of other geophysical methods would help to solve the problem because:

(a) variations of resistivity in the overburden are too large,

(b) gravity, magnetic, and resistivity measurements cannot resolve sub-surface features whose distance apart is less than two or three times their depth,

(c) variations of magnetisation in the overburden are greater than the average difference between overburden and limestone,

(d) the gravity method could not distinguish broad, shallow features from deep, sharp features,

(e) possible gravity anomalies due to caves in the limestone could not be allowed for in the interpretation.

6. REFERENCES

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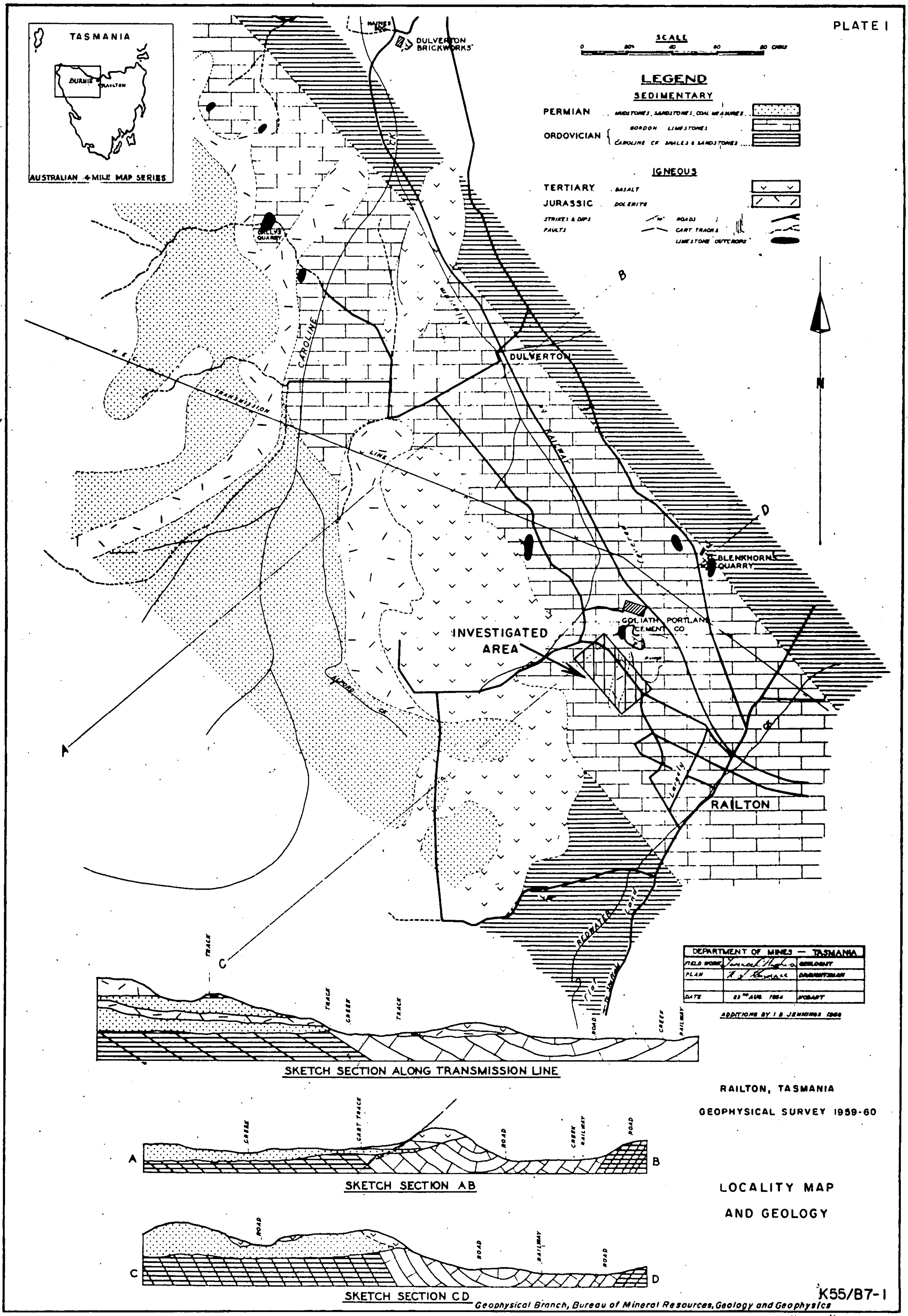
WIEBENGA, W.A.	1955	Geophysical investigations of water deposits, Western Australia. Bur. Min. Resour. Aust. Bull. 30.



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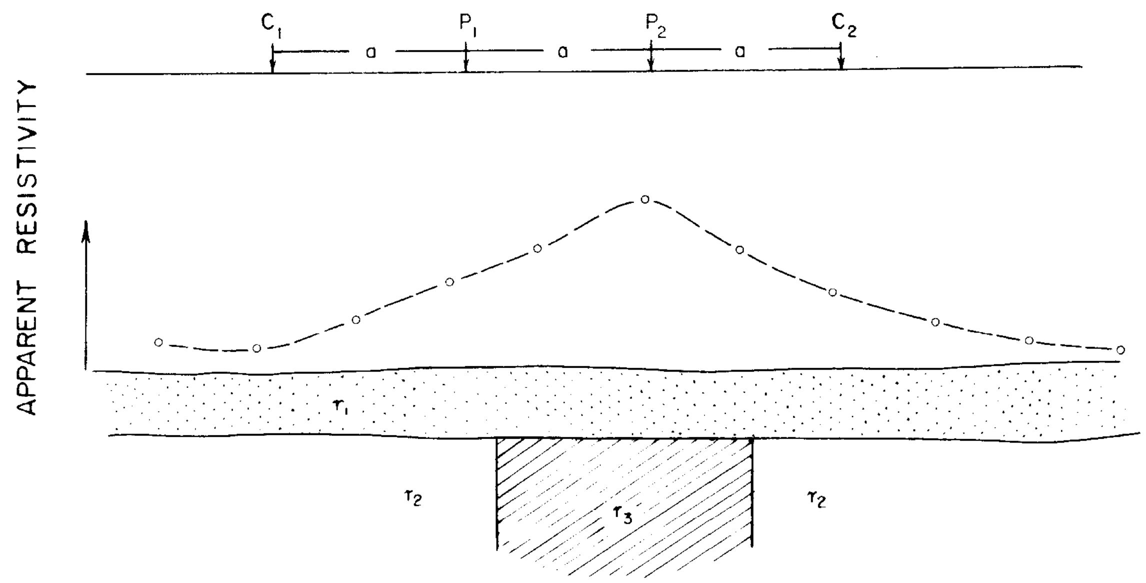


FIGURE 1 CONSTANT-SPACING RESISTIVITY TRAVERSE

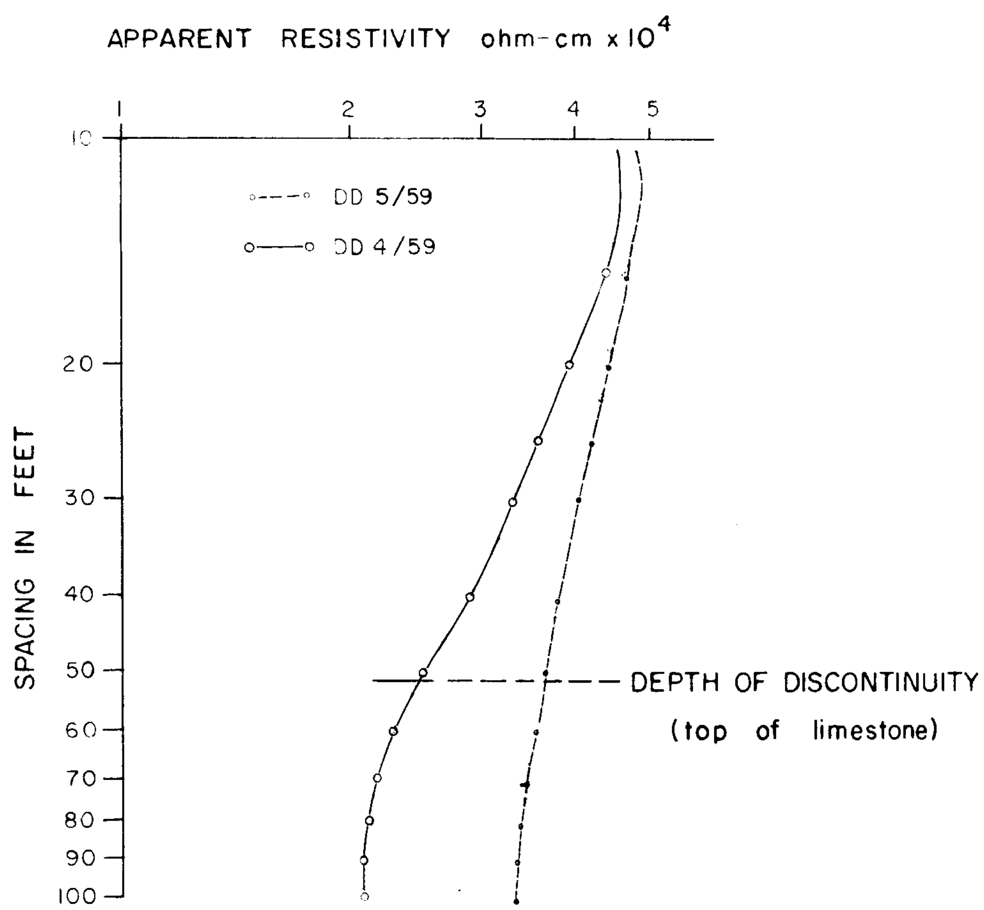


FIGURE 2 RESISTIVITY DEPTH PROBE

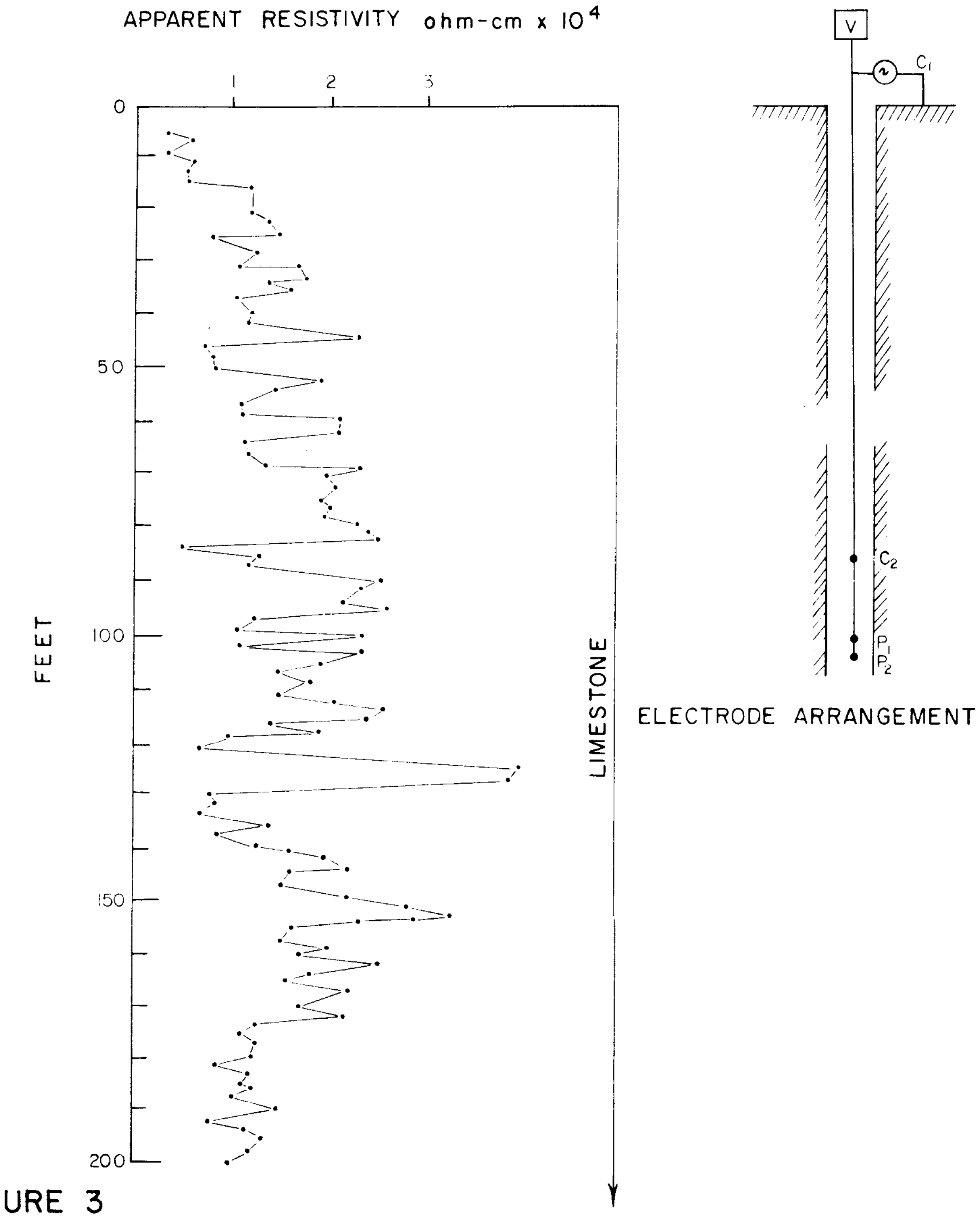


FIGURE 3

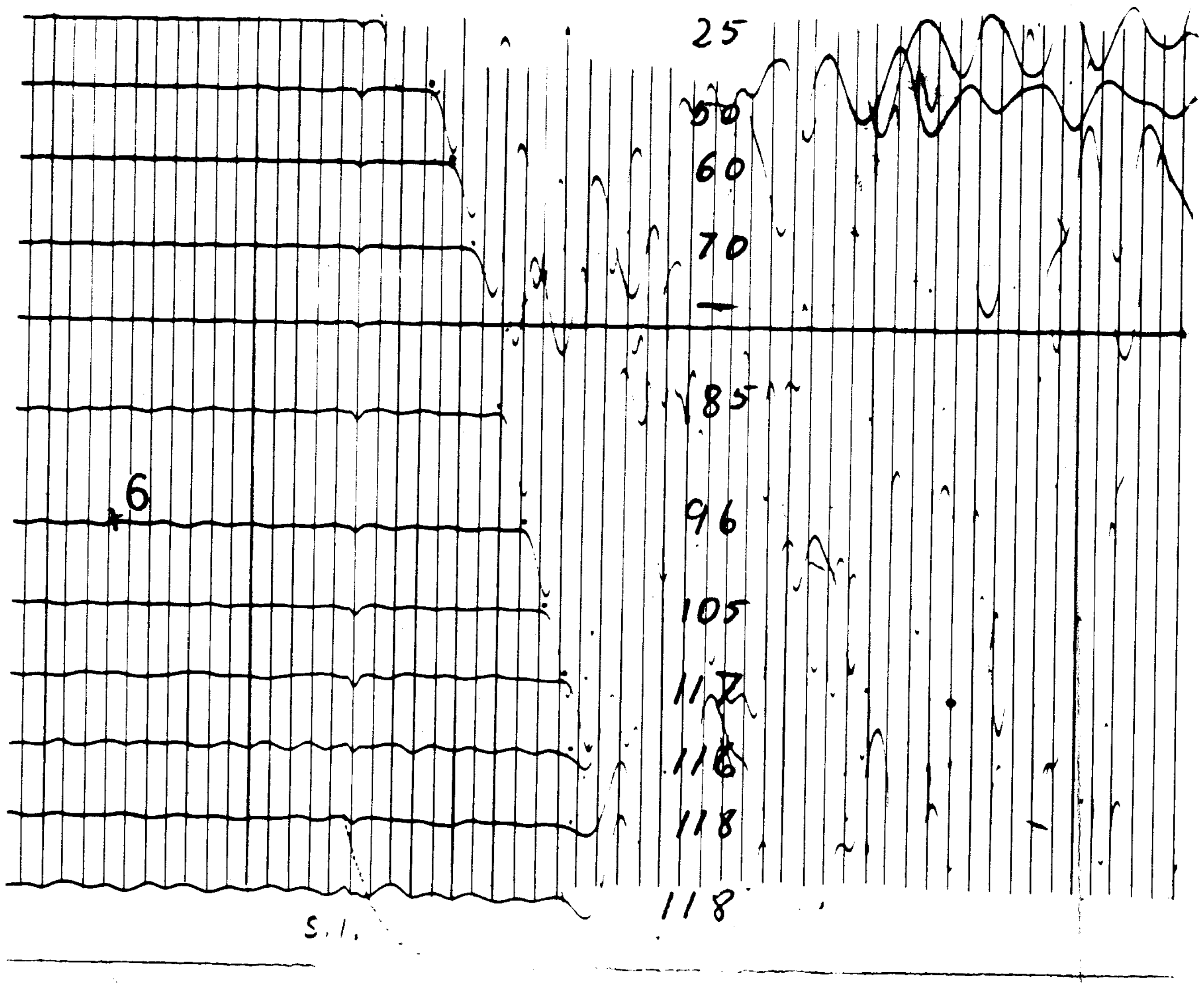
THREE ELECTRODE RESISTIVITY LOG
DRILL-HOLE AT BOTTOM OF QUARRY

RESISTIVITY METHODS ILLUSTRATED

GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES GEOLOGY AND GEOPHYSICS K55/B7-2

TO ACCOMPANY RECORD No 1962/181

RAILTON TAS, 1959-60



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AREA RAILTON RECORD No. 135
TRAV. G INST. S.I.E DATE 5/2/60
SHOT POINT G525 SHOT No. 6
CHARGE 5 DEPTH 2' ft.
SPREAD G_1 500 — G_{11} 0
INTERVAL 50' ft. GAINS 1–15
R.G. G-25' CHANNEL 12
WORKED M.D. CHECKED E.J.P.
~~WEATHERING~~/NORMAL SPREAD

Fig. 1 SAMPLE FIELD SEISMIC RECORD

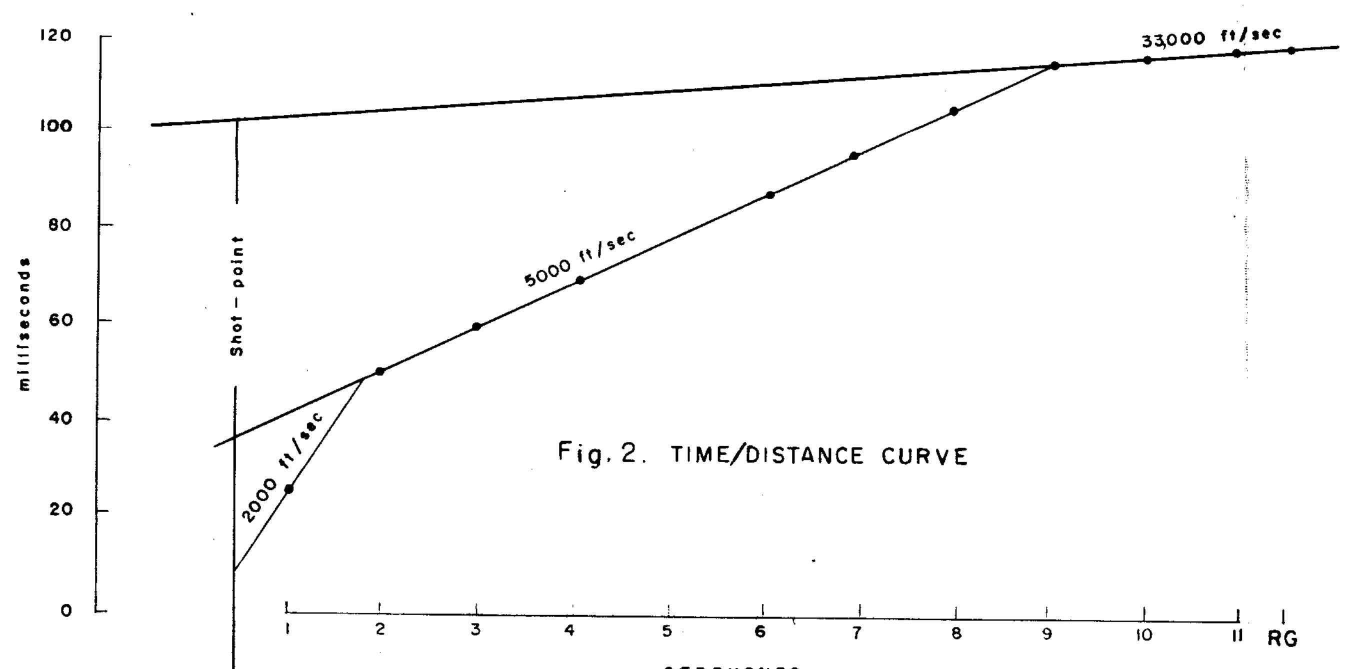

Fig. 2. TIME/DISTANCE CURVE

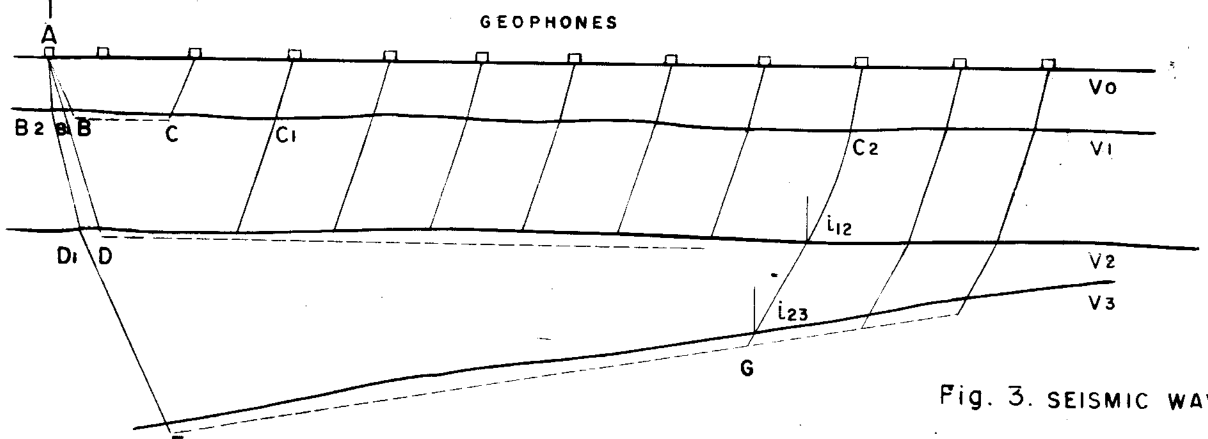

Fig. 3. SEISMIC WAVE PATHS

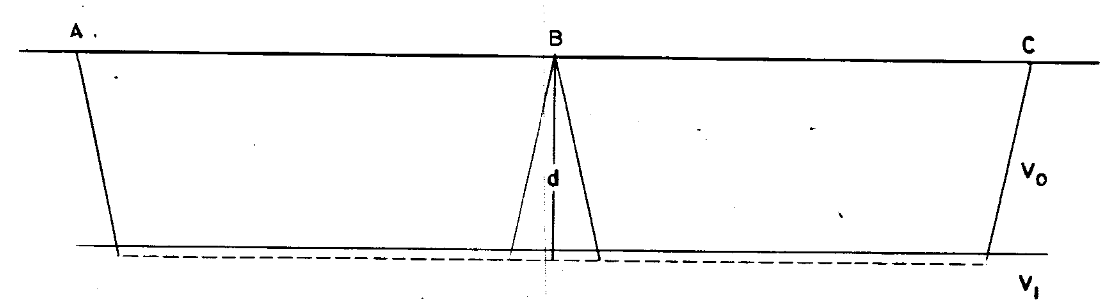

Fig. 4. SEISMIC WAVE PATHS USED IN 'METHOD OF DIFFERENCES'.

SEISMIC REFRACTION METHOD
ILLUSTRATED

K55/B7-3

TO ACCOMPANY RECORD No 1962/181

RAILTON TAS 1962

RESISTIVITY CONTOUR PLAN

100 ft ELECTRODE SPACING

RAILTON, TAS, 1962

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TO ACCOMPANY RECORD No 1962/181

VERTICAL MAGNETIC INTENSITY CONTOUR PLAN

GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES GEOLOGY AND GEOPHYSICS K 55/B7-6
TO ACCOMPANY RECORD No 1962/181

RAILTON, TAS. 1962

BOUGUER ANOMALY CONTOUR PLAN

RAILTON, TAS. 1962

GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES GEOLOGY AND GEOPHYSICS K 55/B7-7

To accompany Record No 1962/181

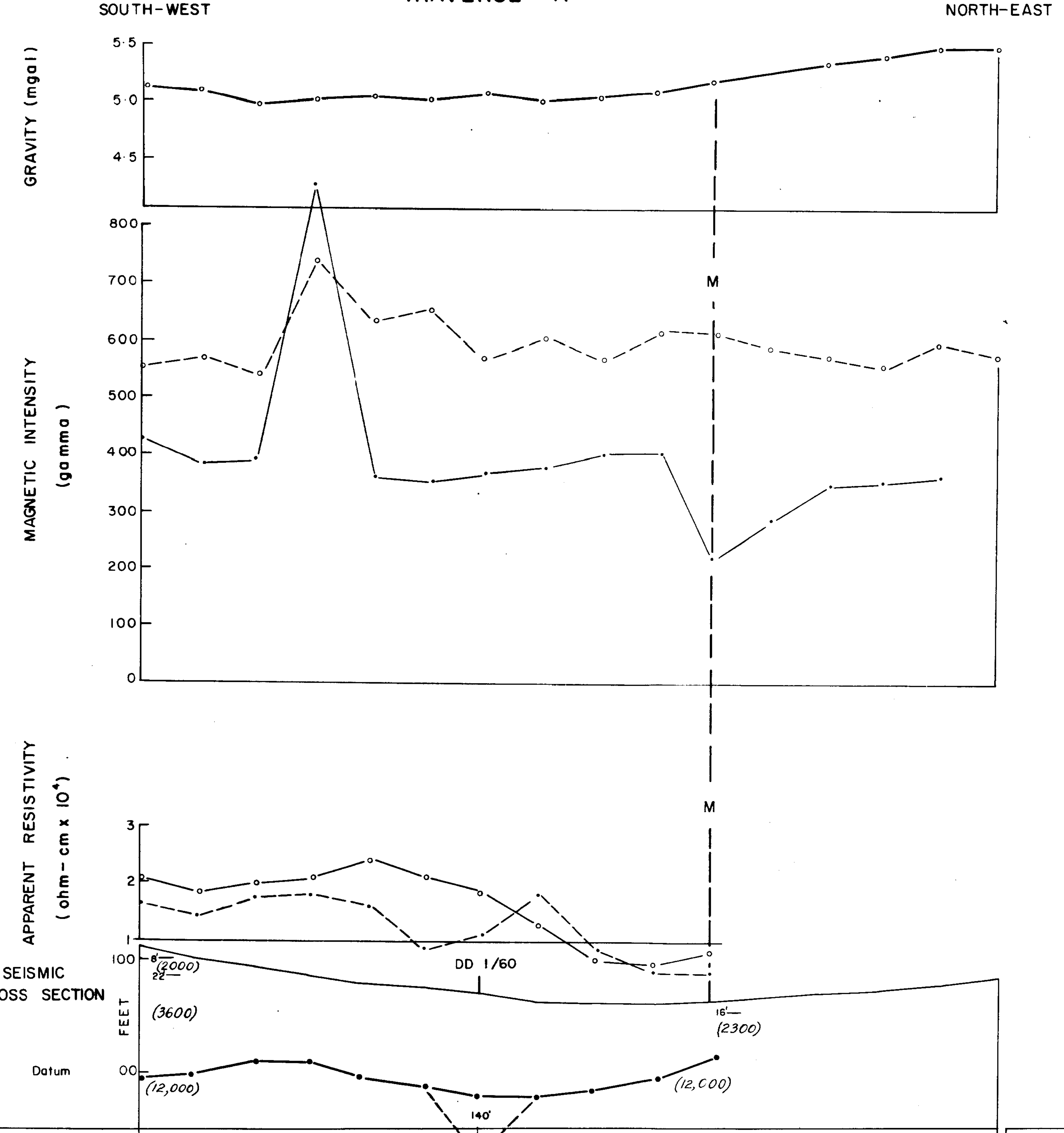
GEOPHYSICAL PROFILES ALONG TRAVERSE M

STATION NUMBER	0	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000
STATION ELEVATION	62	59	55	53	51	49	48	48	47	48	47	46	46	46	47	44	39	38	39	39	36
DEPTH TO BEDROCK	52	56	52	44	49	54	54	49	47	49	56	54	57	59	62	63	55	55	52	52	58

STATION NUMBER	1050	1100	1150	1200	1250	1300	1350	1400	1450	1500	1550	1600	1650	1700	1750	1800	1850	1900	1950	2000	2050	2100
STATION ELEVATION	39	39	39	38	38	36	33	34	39	40	40	39	37	31	29	28	29	30	28	28	29	32
DEPTH TO BEDROCK	61	61	55	55	55	78		82	101	101	99	100	112			108	99	107	109	106	93	

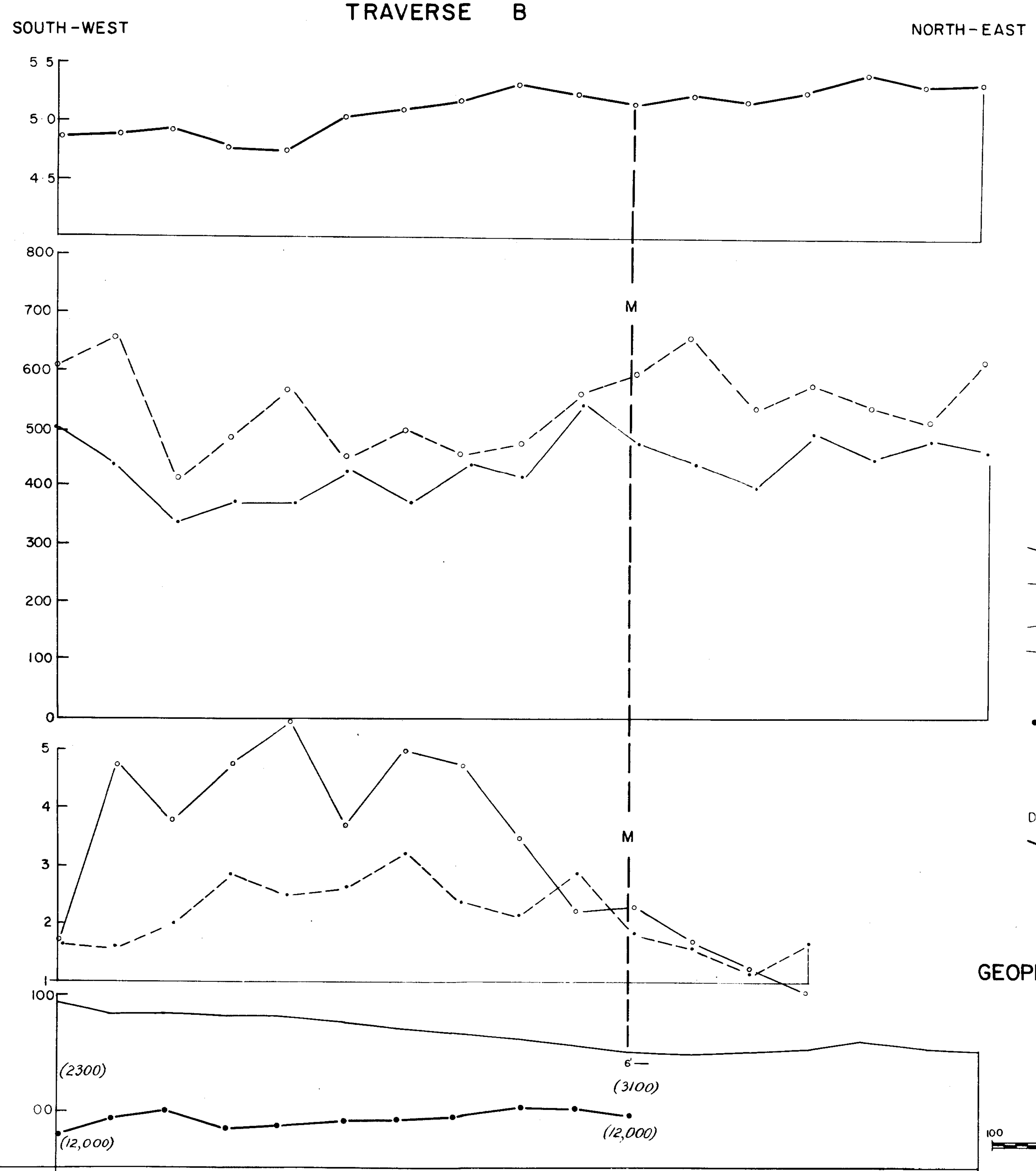
RAILTON TAS 1962

TRAVERSE A

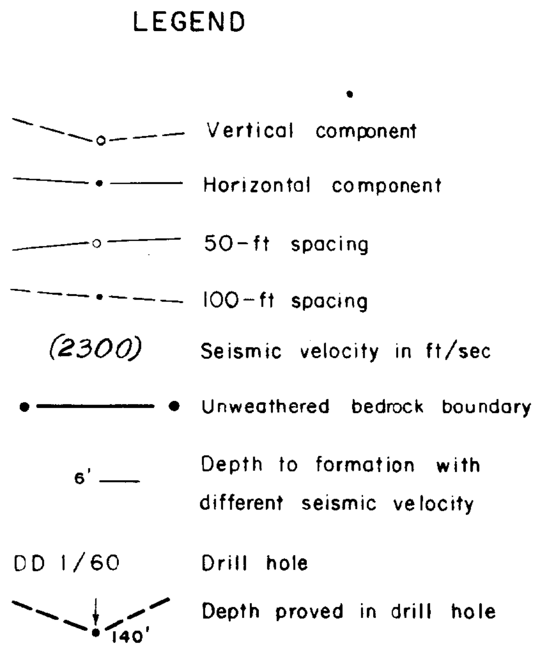


STATION NUMBER	500	450	400	350	300	250	200	150	100	50	0	50	100	150	200	250
STATION ELEVATION	112	103	95	88	81	75	70	64	61	61	62		69	71	76	82
DEPTH TO BEDROCK	114	101	83	76	84	86	90	83	76	67	48					

TRAVERSE B



STATION NUMBER	500	450	400	350	300	250	200	150	100	50	0	50	100	150	200	250	300
STATION ELEVATION	98	86	85	84	81	78	72	66	60	54	48	47	49	53	58	51	50
DEPTH TO BEDROCK	114	90	83	96	95	86	77	69	58	53	54						



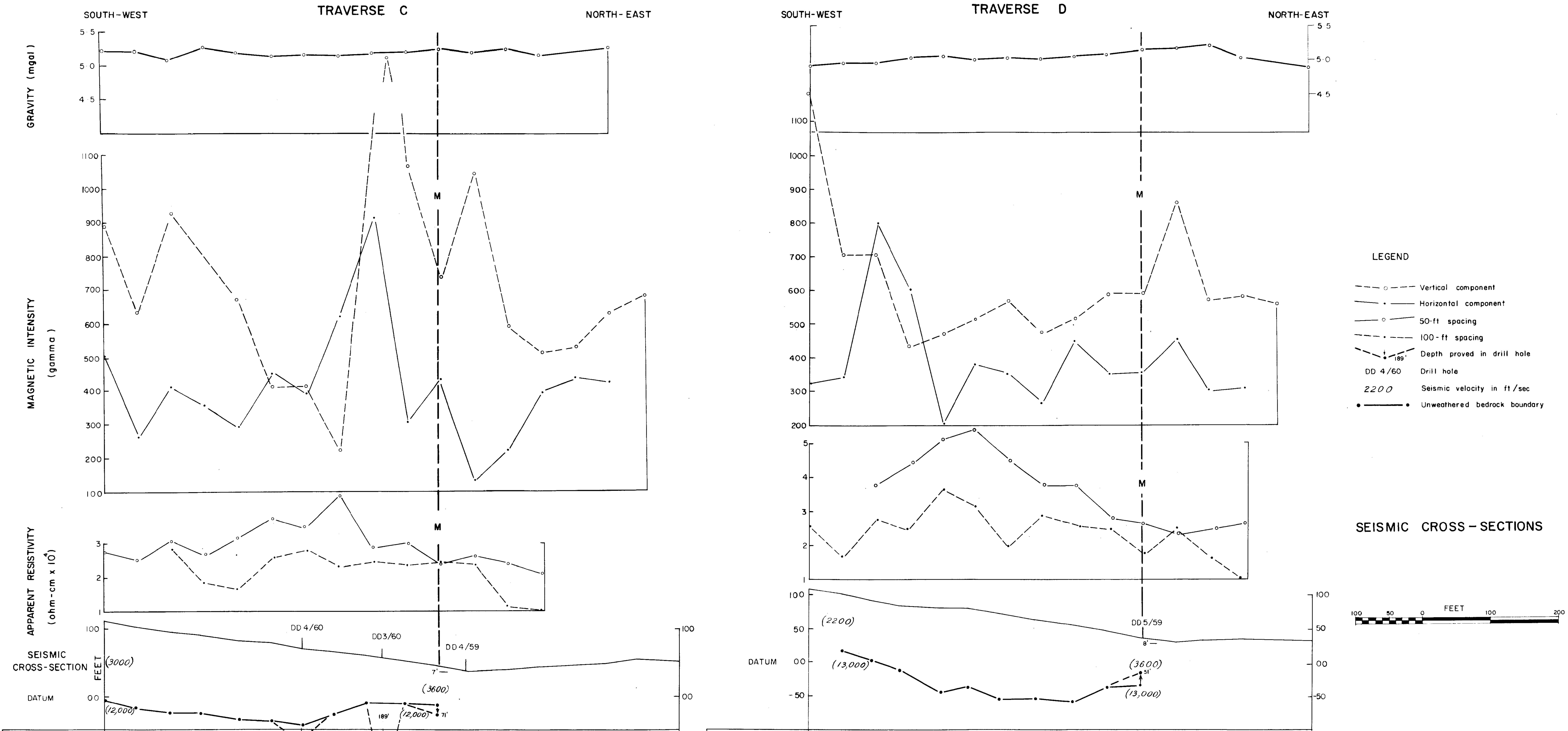
GEOPHYSICAL PROFILES ALONG TRAVERSES A AND B

TO ACCOMPANY RECORD No 1962/181

GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES GEOLOGY AND GEOPHYSICS K55/B7-9

RAILTON TAS 1962

PLATE 10



Traverse C

STATION NUMBER	500	450	400	350	300	250	200	150	100	50	0	50	100	150	200	250	300	350
STATION ELEVATION	110	102	95	89	82	77	72	66	60	53	46	39	40	44		49	56	51
DEPTH TO BEDROCK	115	118	120	114	116	115	112	92	68	61	57							

Traverse D

STATION NUMBER	500	450	400	350	300	250	200	150	100	50	0	50	100	150	200	250
STATION ELEVATION	111	102	94	85	83	84	76	65	59	49	39	34	36	37		36
DEPTH TO BEDROCK		86	88	94	124	116	126	116	114	83	68					

TO ACCOMPANY RECORD No 1962 / 181

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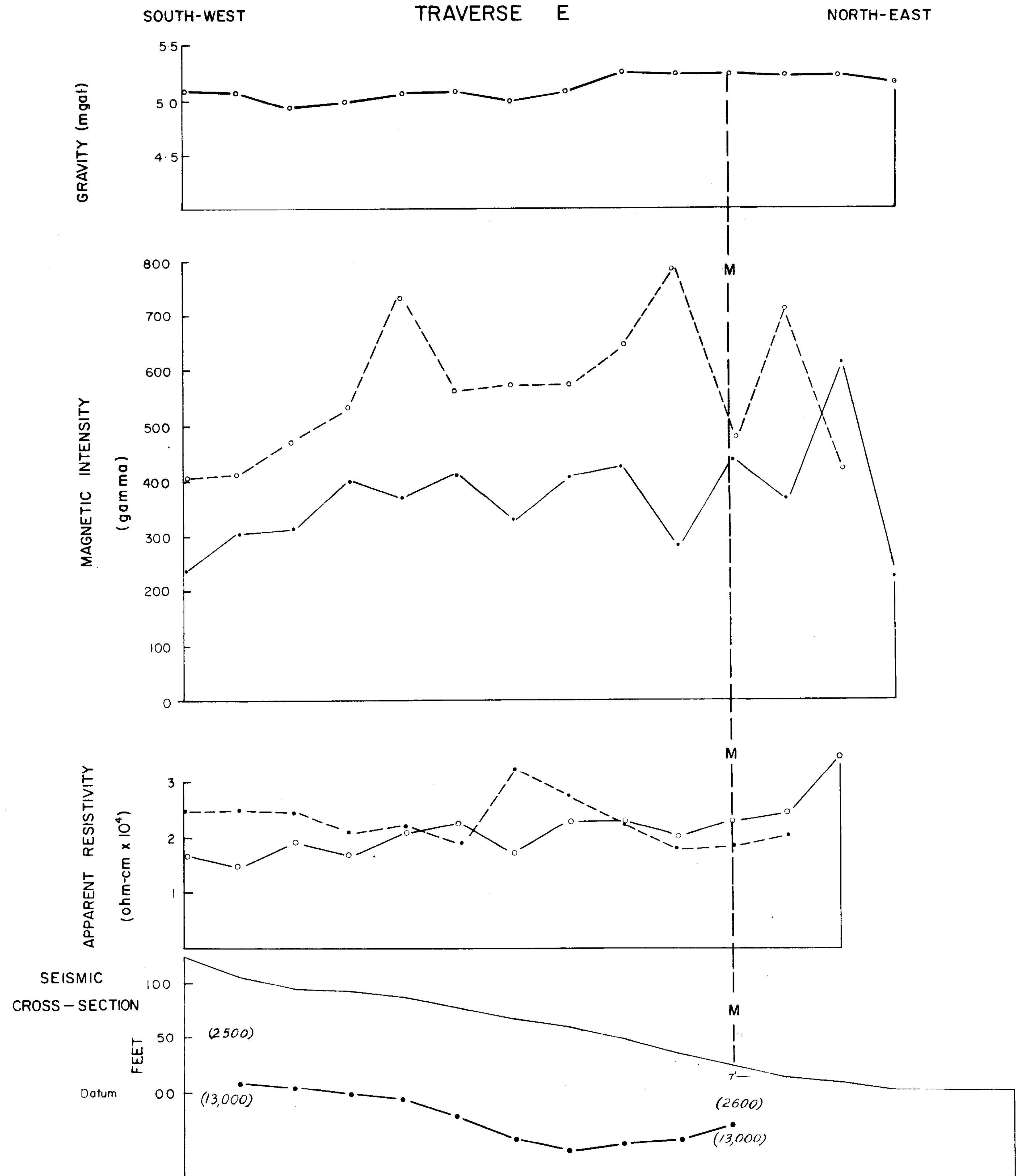
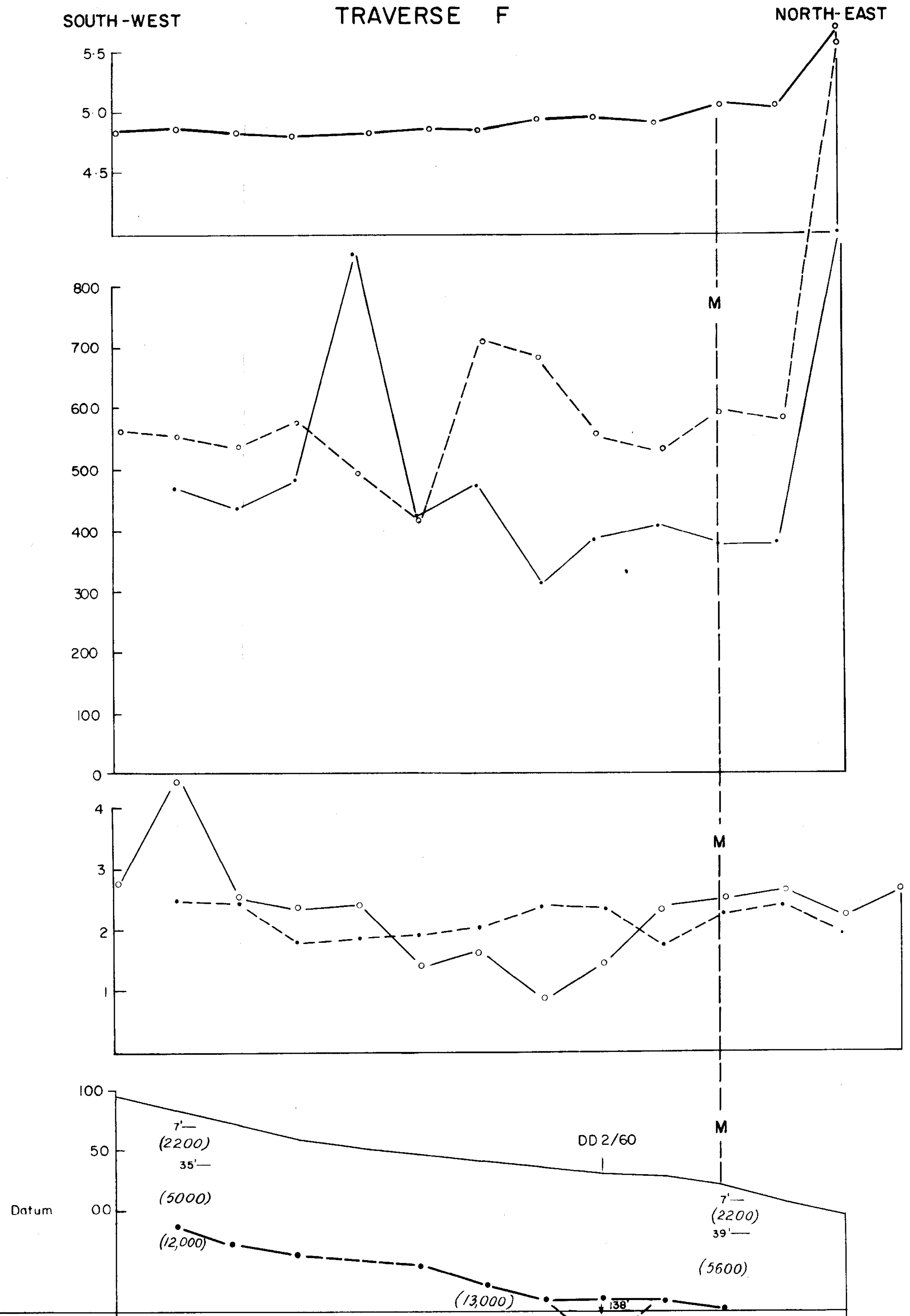
TO ACCOMPANY RECORD No 1962 / 181

RAILTON TAS 1962

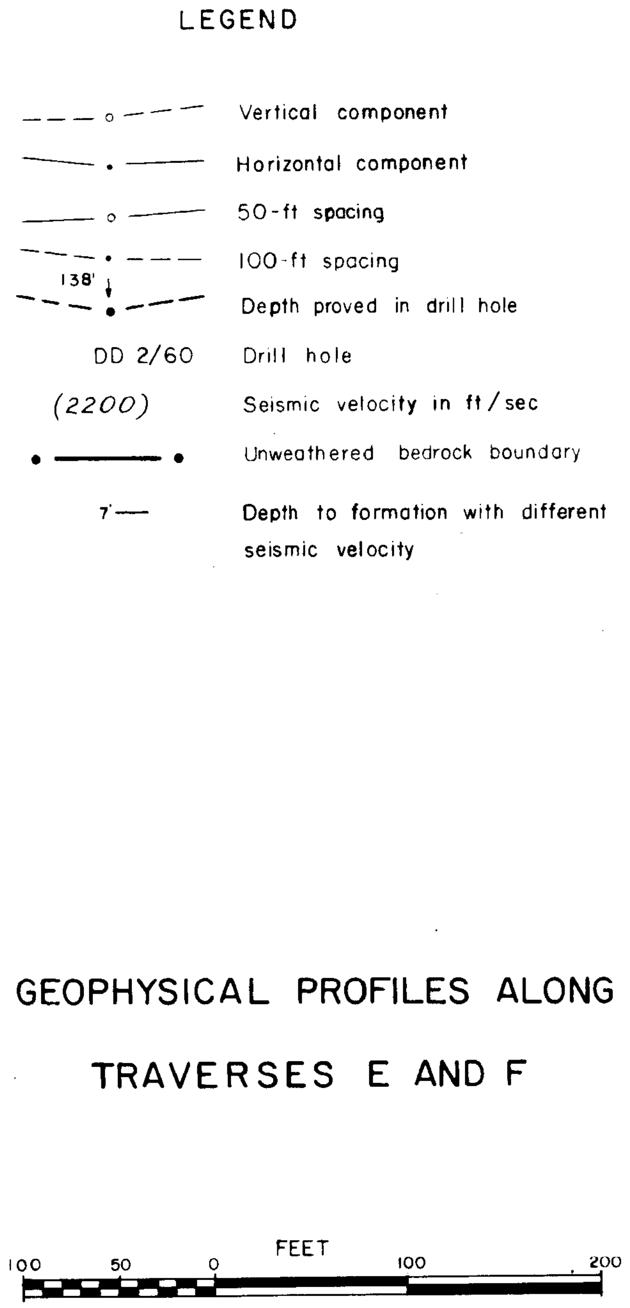
PLATE 11



STATION NUMBER	500	450	400	350	300	250	200	150	100	50	0	50	100	150	200	250
STATION ELEVATION	87	79	73	73	69	64	60	55	50	44	38	33	30	27		26
DEPTH TO BEDROCK		98	90	96	96	99	113	116	94	79	55					



STATION NUMBER	500	450	400	350	300	250	200	150	100	50	0	50	100
STATION ELEVATION	77	69	63	58	54	50	48	45	44	42	40	23	27
DEPTH TO BEDROCK		92	95	94		89	98	108	102	101	100		



GEOPHYSICAL PROFILES ALONG TRAVERSES E AND F

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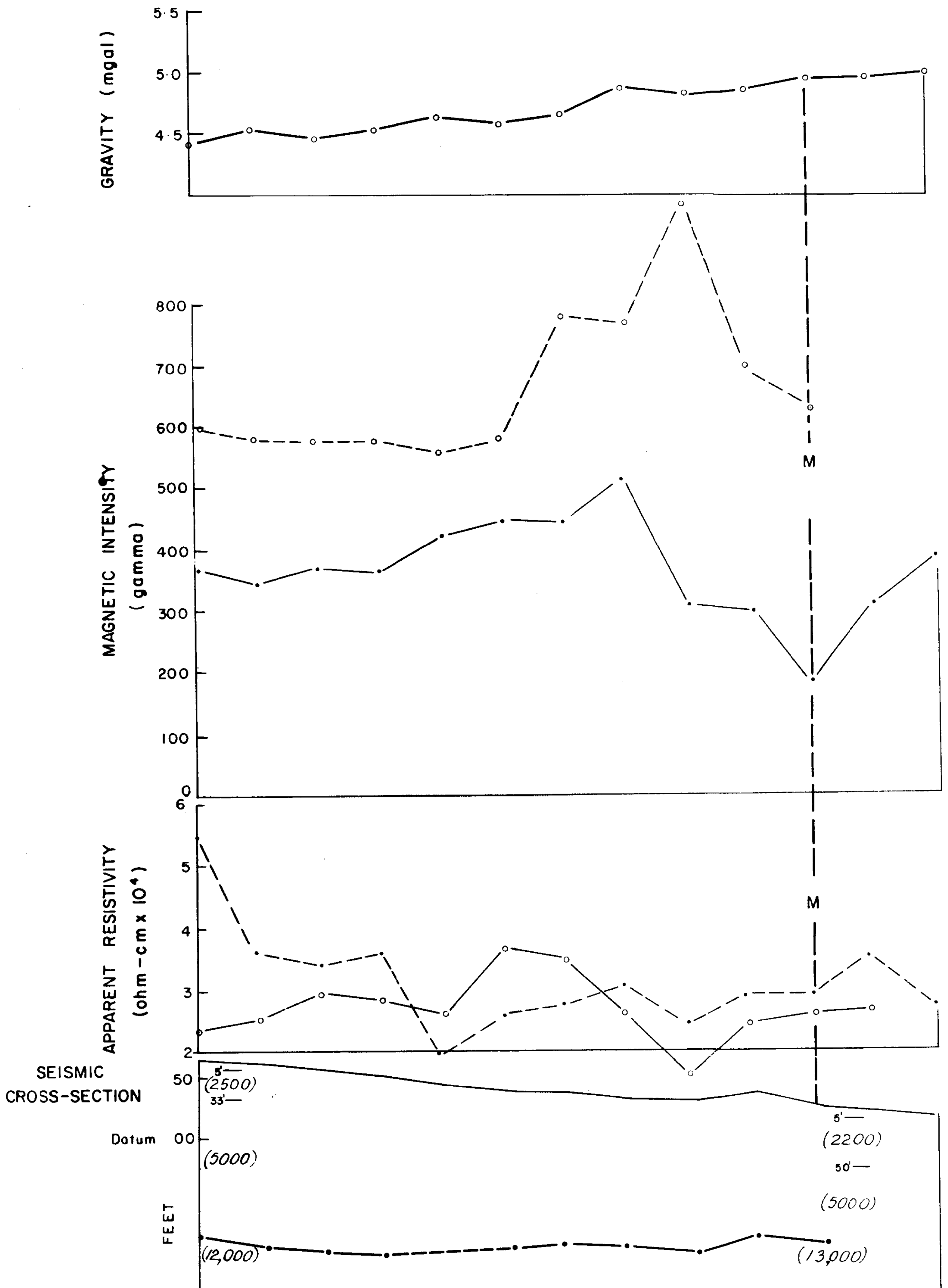
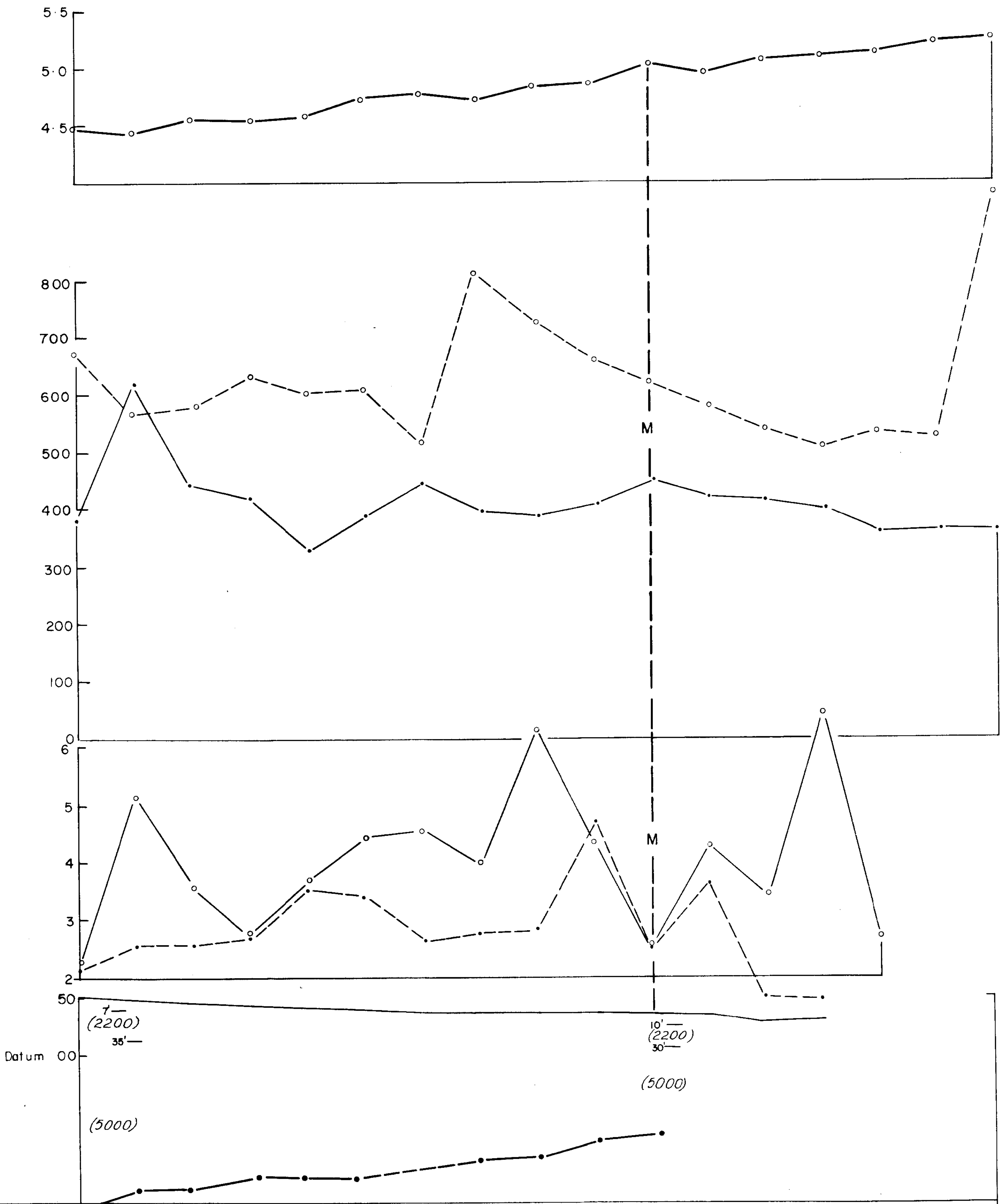
RAILTON, TAS, 1962

TRAVERSE G



STATION NUMBER	500	450	400	350	300	250	200	150	100	50	0	50	100
STATION ELEVATION	64	60	56	51	46	41	38	35	33	31	28	20	23
DEPTH TO BEDROCK	141	148	148	142		128	124	120	124	116	110		

TRAVERSE H



STATION NUMBER	500	450	400	350	300	250	200	150	100	50	0	50	100	150	200	250	300
STATION ELEVATION	50	48	46	43	42	39	37	36	35	33	32	30	28	26	25	23	20
DEPTH TO BEDROCK	183	165	163	149	149	148		131	128	111	106						

LEGEND

- Vertical component
- Horizontal component
- 50-ft spacing
- 100-ft spacing
- (2200) Seismic velocity in ft /sec
- Unweathered bedrock boundary
- 7'— Depth to formation with different seismic velocity

GEOPHYSICAL PROFILES ALONG TRAVERSES G AND H

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K55/B7-12

RAILTON TAS 1962

RAILTON TAS 1962

RAILTON TAS 1962

RAILTON TAS 1959-60

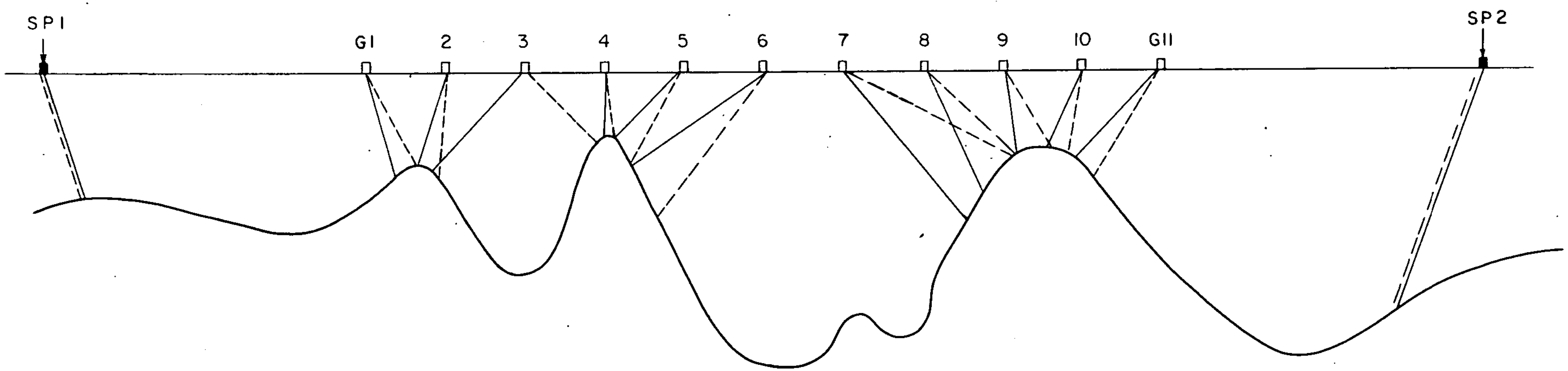

FIG 1 TRUE CROSS-SECTION AND RAY PATHS

Path from Shot-point 1

Path from Shot-point 2

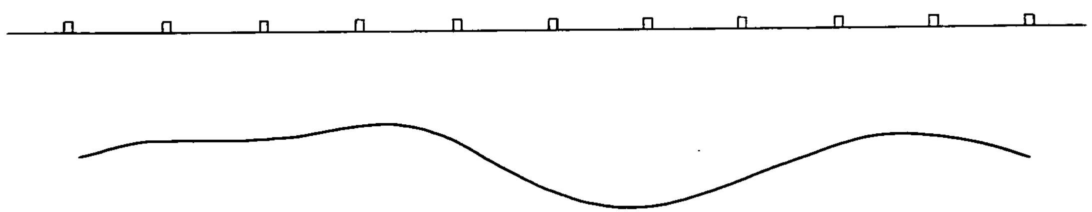

FIG 2 CALCULATED CROSS-SECTION (FROM SEISMIC REFRACTION RESULTS)

TRUE AND CALCULATED CROSS-SECTIONS

PLATE 15

GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES GEOLOGY AND GEOPHYSICS K55/B7-15

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