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KIMBERLEY DIVISION, WESTERN AUSTRALIA

by

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SUMMARY

This report contains the results of a seismic survey on the Nerrima Dome, a major structure within the Fitzroy Basin and near its south-western boundary. The dome is situated near the Fitzroy River about 100 miles south-east of Derby in the West Kimberley district of Western Australia.

The Nerrima Dome has been mapped at the surface in Permian sediments and is a complex structure. It was desired to determine if the dome existed at depth and, if not, the structure at depth, with a view to locating a site for a deep drilling test. The target beds for such a test are Devonian and/or Ordovician sediments over which the Permian sediments are believed to lie unconformably. Reflection methods were tried and proved unsuccessful and the survey was carried out using refraction methods.

Although the structure underlying the dome has not been clearly shown, the refraction method has indicated that it is complex and does not conform with the domal structure at the surface. There appears to be a major unconformity at comparatively shallow depth (2000 ft). The deep structure (7000 ft) although apparently less complex than that immediately below the unconformity, also bears no obvious relation to structure at surface. The results so far obtained are reasonably conclusive in showing that no simple dome-like structure of large magnitude exists under the Nerrima Dome.

1. INTRODUCTION

The oil possibilities of the Kimberley district of Western Australia were first recognised in 1919 when Harry Price, a well sinker, reported traces of oil in the area now known as Prices Creek. Subsequently, four bores were drilled in the Prices Creek area by Freney Kimberley Oil Company and three were reported to have disclosed traces of oil. Further traces of oil were reported in bores put down later by the same Company on the Mount Wynne and Poole Range Domes.

Regional geological mapping in connexion with the search for oil has been carried out mainly by Dr Arthur Wade (1924 and 1934), Kraus and Findlay (1941-42), Dr Frank Reeves (1947-48) and more recently by a party of Bureau geologists (1948-1952). Other investigators have been in the area and contributed to the total knowledge but in general they have devoted their efforts to the study of particular problems or particular areas. The Nerrima Dome was located by Dr Wade. In 1939, the Freney Kimberley Oil Company commenced drilling on the Nerrima Dome at a site selected by Dr Wade. Owing to drilling difficulties and the war, the boring was stopped at 4271 ft. An attempt to deepen the well after the war was unsuccessful.

In 1948, the Bureau carried out detailed geological mapping of the Nerrima Dome (Guppy, Cuthbert & Lindner, 1950) and in 1952 geophysical work was undertaken. A detailed gravity survey over the Nerrima Dome was completed and a regional gravity survey of the Fitzroy Basin was commenced. A refraction seismic survey of Nerrima Dome was also completed and forms the subject of this report.

The seismic survey was confined to the Nerrima Dome and covered an area of approximately 100 square miles between latitudes 18° 22'S and 18° 32'S and longitudes 124° 11'E and 124° 33'E. Some additional test shooting was done outside this area in order to determine if conditions for the recording of reflections were similar to those within the area.

Headquarters were maintained at the drilling camp vacated by the Freney Kimberley Oil Company.

The party consisted of two geophysicists, a surveyor, a driller and drill assistant, a mechanic, six field assistants, a cook and cook's off-sider. The senior author (K.R. Vale) supervised the work in the field for the first three months and directed the programme from the Melbourne office during the remainder of the survey.

The party was supplied with one 24-channel recording truck, one shooting truck, one drill, one water tender, one workshop truck, one supply vehicle, and two Land Rovers.

The central area of Nerrima Dome is a slight depression bounded on the north, south, and west by sandstone ridges but open to the east. The largest ridge is Nerrima Ridge to the north and it rises some 80 ft above the surrounding plains. The surface of the depression is composed of a clayey soil derived from soft shale facies of the Noonkanbah Formation. Parts of the Nerrima area have no vegetation; elsewhere the vegetation consists of treeless patches of grass or spinifex or sparse to thick and rather tall scrub with occasional larger trees. The entire area except the bare patches is dotted with generally small ant hills. The operations were easily conducted in the bare areas and those covered in grass and spinifex. In the scrub-covered areas, traverse lines had to be cleared.

The survey occupied the winter dry period. Although temperatures were high, the humidity was low, and in general living conditions were comfortable. Both early and late in the season, however, high temperature and humidity made living conditions uncomfortable. It would not be reasonable to attempt to extend the field working season. No trouble was experienced from rain and only occasionally was the wind so high that work had to be suspended entirely, although on a few occasions it was necessary to modify the daily programme because the wind noise level was too high for long shots.

2. GEOLOGY

The following notes on the geology of the Fitzroy Basin have been drawn mainly from the work of Wade (1936), Guppy, Cuthbert and Lindner (1950), and Schneeberger (1952) and from discussions with field officers of the Bureau's Kimberley Geological Party.

The Fitzroy Basin, which is actually the north-eastern part of the Desert Basin, has now been mapped in semi-detail by surface geology and photo-geology as far north-west as Derby where it is believed to continue under King Sound, and to the south-east as far as the 126° meridian of longitude. Its farthest south-eastern extension is not definitely known. The north-eastern and south-western boundaries are fairly well defined by two major faults of regional significance; namely, Pinnacle Fault to the north-east, and Mount Fenton Fault to the south-west. It is believed that the throw of these faults is such that the Fitzroy Basin at least in one section is actually graben. However, there is some evidence that the Fenton Fault is a hinged fault and it probably would not be correct to classify the entire basin as a graben.

The Fitzroy Basin, as bounded by the two faults referred to above, is believed to be a basin of Devonian sediments, possibly underlain by Ordovician sediments, but completely overlain and concealed by Permian sediments and, in a few localities, by Mesozoic sediments. The cycle of erosion is at an advanced stage, and Quarternary erosional products mask a large portion of the area.

On the north-eastern side of the Pinnacle Fault both Devonian and Ordovician rocks crop out. These are mostly fossiliferous limestones, and include reef formations. The Ordovician rocks have been observed in only one locality and it may be that they exist only as erosional remnants in pre-Ordovician valleys within the Precambrian basement complex. However, the Devonian rocks are quite extensive and Middle and Upper Devonian sediments are represented.

None of the abovementioned pre-Permian rocks crop out on the south-western side of the Pinnacle Fault. However, it is definitely established, at least to the south-east of Fitzroy Crossing, that the fault has a down throw of several thousand feet on the south-western side, and in several places in this area Permian sediments overlap the Devonian on the north-eastern side of the fault. It seems probable that Devonian sediments extend into the Fitzroy Basin under the overlying Permian sediments but no prediction can be made as to the extent of post-Devonian erosion which could affect their distribution. It can be expected that progressive facies changes in the Devonian sediments have occurred basinward.

The Permian section is composed of four groups or formations; these have been observed in outcrops. The lowermost or Grant Formation is mostly composed of glacial sandstone, tillite, etc., and is overlain unconformably by the Poole sandstone. Above this lie the Noonkanbah Formation, which consists mainly of shale and claystone beds, and the Liveringa Formation, which consists mainly of fine-grained sandstone and siltstone.

The Mesozoic, Tertiary, and Quarternary rocks are unimportant as far as the present survey is concerned, although it should be noted that leucitite plugs probably of Cretaceous age occur within fairly local areas of the Fitzroy Basin.

Oil occurrences reported to date have been in the Ordovician at Prices Creek and the Permian (Grant Formation) at Poole Range and Mount Wynne. It is believed that the oil at Poole Range and Mount Wynne originated below the Grant Formation and, presumably, came from the Devonian rocks.

The Devonian succession is by far the most promising for oil. It has within it types which, if their probable deep water equivalents are considered, present a favourable succession of possible source, reservoir, and cap rocks. The absence of surface showings of oil in the outcrop area does not preclude the possibility of occurrence within the basin. Erosion of the Devonian rocks has been considerable in the outcrop area, but may not have affected the deeper portions of the basin and Devonian oil may still be retained there.

Although the right conditions for the occurrence and accumulation of oil exist in the Ordovician and traces of oil have been observed in it, the limited area of outcrop eliminates it as an immediate target. Unless evidence of its widespread occurrence in the basin is shown in future boreholes, the primary target beds for future oil search will be those of Devonian age.

Although there are a number of domal structures at the surface within the Fitzroy Basin, they have been mapped only in Permian sediments and the possibility exists that they do not persist beneath the angular unconformity between the Permian and Devonian sediments. If it can be shown that an unconformity eliminates the possibility of the surface structures persisting at depth, it is pointless to establish a test location on the evidence of near-surface structure.

In the outcrop areas to the north and east of the Fitzroy Basin, there is ample evidence that the Precambrian surface is not a perfect peneplain but has a rugged topography. Within the basin there may be basement 'highs' giving rise to the larger structures present and the structures may have comparatively shallow basement cores. On the other hand, reef-forming organisms established around islands in the Devonian seas may have kept pace with the rate of subsidence of the basin and under the main anticlinal structures there may be reef formations corresponding to the deeper water facies in the synclines. It is important to determine to what extent the structures are due to basement 'highs'. If a basement core is shown to be present at a comparatively shallow depth, the test location would have to be moved down flank to avoid it.

The major Permian structures show at the surface considerable faulting for which there are two possible explanations :-

(1) The faulting affected both the basement and the overlying rocks, or

(2) The faulting is an expression of the competence of the upper beds at the time they were folded.

It is most important to decide which of these possibilities is the correct one. If the faulting extends to the basement, it will have affected the possible migration of oil and a number of small and perhaps uneconomic pools may have formed against fault traps, or the faulting may have allowed the oil to escape. On the other hand, if faulting is confined to the near-surface beds, then it may not have had any effect on migration and accumulation and the possibility of a large pool will not be ruled out.

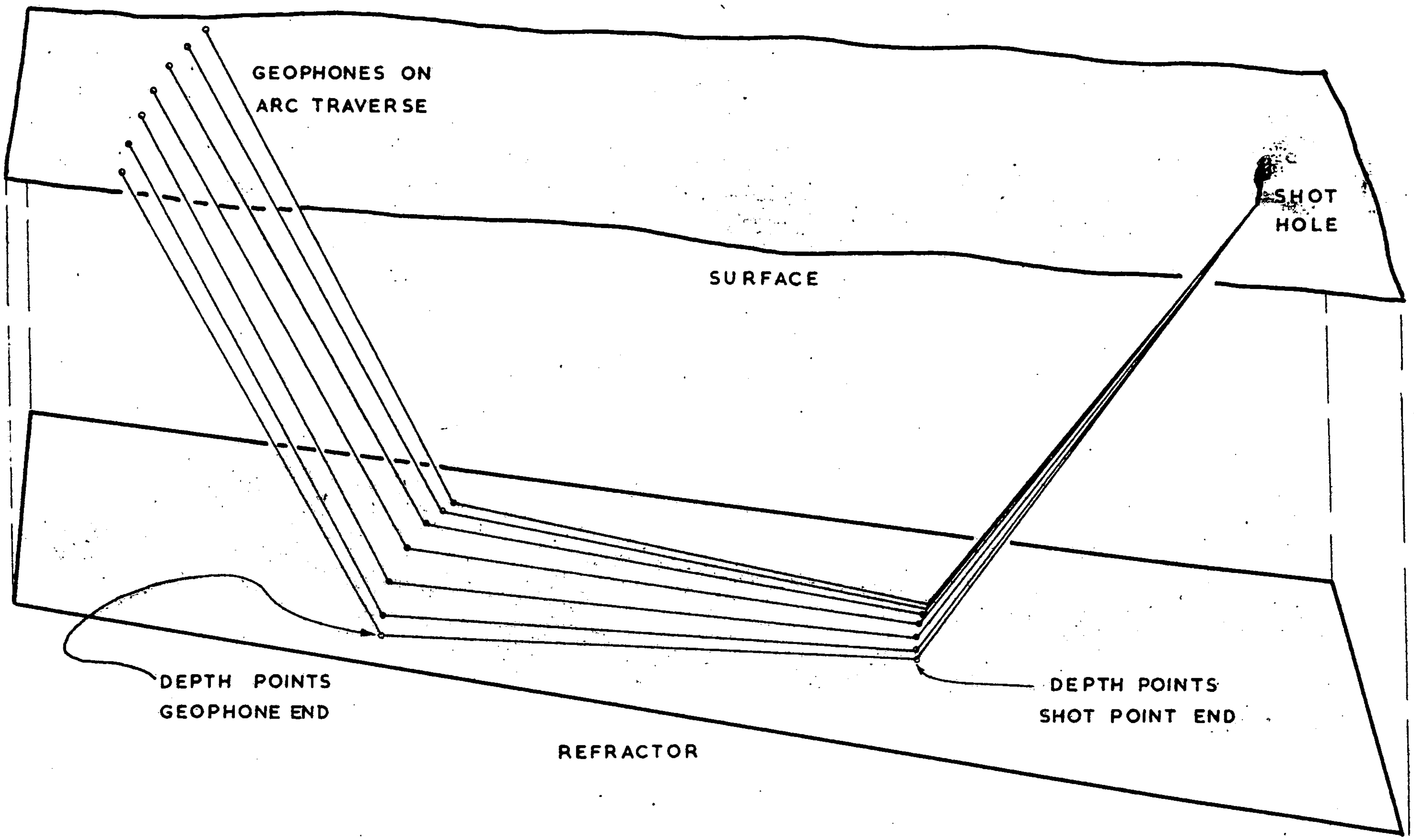
3. APPLICABILITY AND LIMITATIONS OF THE SEISMIC METHOD

The seismic method is commonly used in the investigation of the structure of sedimentary basins. The method depends on the fact that seismic waves are propagated with different velocities in different types of rocks. At the interface between two types of rock having different velocities of propagation, seismic waves undergo reflection and refraction in a manner analogous to that of light waves at the boundaries of optical media. In the practical application of the method, the seismic waves are generated by an explosive charge at the surface. An array or spread of detectors (geophones), suitably placed on the surface in relation to the shot-point, is used to detect the seismic waves, which are then recorded by a set of photographically recording galvanometers. The shot instant and an accurate time scale also are recorded on the same record. Under suitable conditions, waves that have been reflected or refracted at the boundaries of underlying strata can be recognised on the photographic record, their travel times accurately measured and the depths to the boundaries of the strata calculated.

Seismic methods owe their high degree of accuracy compared with other geophysical methods to the fact that they make recordings that are related directly to abrupt changes in the physical properties of the rocks within the stratigraphic section. These changes usually occur at or parallel with the interfaces between members of the formation or at unconformities. Although it is sometimes difficult to evaluate absolute depth accurately, it is often possible to make accurate evaluations of dip and hence structure. Reflection techniques are best suited for structural problems, whereas the refraction techniques are more suited to determining depths to basement and identifying stratigraphic members. Both techniques throw some light on faulting, the refraction method being the more definite.

In some areas the reflection technique fails because of high absorption of reflection energy in near-surface layers, crumpling of shallow beds, or for other reasons, but it may still be possible to apply refraction techniques. In such areas the refraction methods with their comparatively low accuracy become the best available for structural problems also.

A refraction technique frequently used is the fan technique, a modification of which is called arc shooting and is often used for structural problems. This arrangement required a single shot-



GEOPHYSICAL SURVEY AT NERRIMA W.A.
SEISMIC REFRACTION SURVEY

SKETCH ILLUSTRATING

METHOD OF ARC SHOOTING

FIG. 1

(facing page 5)

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point and the geophones are arranged in the form of an arc centred on the shot-point and at a distance from it selected to ensure that the desired refractor is being recorded. The profile obtained is along an arc displaced toward the shot-point from the geophones by a distance depending on the depth of the refractor and the ratio of the seismic velocities in the 'overburden' and the refractor. This technique was used at Nerrima. The ambiguities that may arise in the interpretation of the results are therefore discussed below.

A difficulty in interpretation arises from the fact that two depth points are involved, one at each end of the path through the refractor being mapped. The sketch in Figure 1 shows the relative positions of the shot-point, geophones, and depth points. The depth point at each end is changed when the recording station is changed. Thus, changes in the time profile are not necessarily caused by changes in depth at the recording end only, although the greater portion of the change would normally occur at that end. A fault cutting across the depth points at either the shot-point or the geophone end could cause identical steps in recorded times. Changes in the recorded times could be equally well accounted for by a change of dip of the refractor at either end but the change in elevation at the shot-point end would be required to occur in approximately 1/3 the distance (in the Nerrima set-up) of that in which it would be required to occur at the geophone end. In other words, if a dip is considered to occur at the shot-point end it will necessarily be estimated to be about three times greater than if it is considered to occur at the geophone end.

The above-mentioned ambiguity is not very serious in large and relatively simple structures but assumes increasing importance in mapping small or complex structures. At Nerrima, where the structure is complicated by faults and sharp changes of dip, the method has proved successful in illustrating the degree of complexity but not in giving a clear picture of what is the actual structure. In one example, a fault recorded on Traverse G has been checked by Traverse D with the result that the fault must be placed at the shot-point end and not the geophone end. On the other arc traverses no such check has been made and the location of faults on these traverses may be in error.

4. OUTLINE OF OPERATIONS

Test shooting

In order to establish a standard procedure, where possible, numerous test holes were put down to a depth of 250 ft at widely separated localities on and near the Nerrima Dome. These test holes are indicated on Plate 2 by T. These were shot at short intervals from bottom to top and every effort was made to record usable reflections. At no place on the Dome were usable reflections recorded, although at Shot-point 92 in the syncline south-east of the dome excellent reflections were recorded. Refraction tests were also conducted along the axis of the Dome and a number of definite refractors were indicated.

It was therefore decided to do the entire survey by refraction methods only.

Refraction survey

The refraction survey was commenced by shooting several in-line profiles, along a traverse placed near the axis of the exposed anticline, in order to determine the seismic velocities and approximate depths of refractors present and the optimum distance between shot-hole and geophone for recording the velocities. From the preliminary tests it appeared that a refractor with a velocity of approximately 14,000 ft/sec would be reliably recorded at a distance of 4 miles and would represent a bed at about 4000 ft depth. This refractor was considered to be the best available for checking the structure at depth, having due regard to the operational difficulties and information required. The simple method of placing the geophones round an arc of four miles radius and shooting from the centre was used to obtain values of the component of dip along the arcs. The arcs were set out as far as possible where the surface geology indicated that the least interference from faulting could be expected. In Plate 2 the positions of all traverses are marked on the geological map. Spreads set out along radial lines at various points on the arc and shot from the shot-point served to check which refractor was being recorded and gave an indication of the component of dip along the radius. A general idea of the variations caused by the weathered rocks at the surface was obtained by shooting surface shots with closely spaced geophones at selected points along all traverses, particularly at points where changes in velocity or dip were indicated.

5. RESULTS

Discussion of velocities

Most of the information on seismic velocities at Nerrima Dome was obtained along Traverse D. Plate 3 shows the time-distance curves, corrected for weathering and elevation, obtained along this traverse. The major profiles that were shot are east from Shot-point 111 (111E), west from Shot-point 95 (95W), east from Shot-point 69 (69E), and west from Shot-point 53 (53W). These form two reversed in-line profiles with four miles between shot-points. Other shot points were drilled and spreads shot from them to obtain specific information at various places.

The time-distance curves show many discontinuities and changes of slope which cannot be attributed to changes in velocity, but must be due to faulting or abrupt changes in dip of the refractors. These conditions make it very difficult to obtain precise values for the seismic velocities and along some traverses even to determine how many refractors are present. The following table sets out the velocities of the more important refractors. Included are those velocities which have been confirmed, and which provide a basis for a reasonable interpretation of the anomalies in the time-distance curves :-

Calculated velocity refractor	Sub-surface portion of refractor where velocity was measured	Apparent Velocities (ft/sec)		Approximate depth (ft)
		Up-dip	Down-dip	
V_1 : 8450	Average of all recorded values			Sub-weathering
V_2 : 9700	SP 103 SP 104	10,000	9400	200-400
V_3 : 11,550	SP 103 SP 105 SP 61 SP 63	12,020 11,490	11,400 11,340	500-1500
V_4 : 12,650	SP 65 SP 67 SP 103	13,250 12,940	12,640 12,500	2000-3000
V_5 : 14,500	Average of all recorded values			= 4000
V_6 : 16,000	This value gives best agreement between profiles obtained from 53W and 99E.			6000-7500

Initial velocities, V_1 (8450 ft sec). The initial velocities recorded are 8580 ft/sec at 111E, 8650 ft/sec at 95W, 7500 ft/sec at 69E, and 9080 ft/sec at 53W. The average of these four values (8450 ft/sec) has been taken as the velocity of the first layer. The variation in the recorded velocities is probably caused by the different thickness of the weathered layer. Although surface shots were fired along Traverse D at intervals and enabled a general idea of the variations caused by weathering to be obtained, their spacing was not close enough to give a detailed knowledge of the weathered layer, or to eliminate entirely the differences in recorded values of V_1 due to weathering.

First refractor, V_2 (9700 ft/sec). The time-distance curves 107E and 101W show up-dip and down-dip values for V_2 from approximately the same sub-surface portion of the refractor under Shot-point 103. These values, V_{2u} = 10,000 ft/sec and V_{2d} = 9440 ft/sec, give a calculated value for the velocity of 9700 ft/sec. The up-dip value of 10,000 ft/sec is based on only 8 or 9 recorded times and could be slightly in error. However, the average of all recorded values for V_2 is 9690 ft/sec, so the calculated velocity would appear reasonably accurate.

Second refractor, V_3 (11,550 ft/sec). Two determinations for the velocity V_3 are possible. Firstly, the portion of the time-distance curve 111E from 660 ft W of Shot-point 103 to Shot-point 100 will have approximately the same sub-surface coverage as the portion of the time-distance curve 95W from Shot-point 106 to Shot-point 104. These portions give a calculated velocity of 11,710 ft/sec. Similarly, the sub-surface portion of this refractor under Shot-point 61 to Shot-point 63 is covered in two directions by time-distance curves 69E and 53W. The calculated velocity here is 11,390 ft/sec. It is probably best to take an average of these two as the velocity, i.e., V_3 = 11,550 ft/sec.

Third refractor, V_4 (12,650 ft/sec). The existence of a refractor with a velocity between 12,000 and 13,000 ft/sec was not suspected until shooting was well advanced along the arcs to the east.

Here, the velocities recorded on the radial spreads for arcs E, F, and G were consistently much lower than the expected up-dip and down-dip values of the 14,000-ft/sec refractor. The time-distance curve 53W between 600'E of 65 and 550'W of 71 is now thought to be recorded from a refractor of velocity 12,650 ft/sec; similar remarks apply to that portion of the time-distance curve 69E from Shot-point 57 to 660'E of Shot-point 81.

Calculations give an approximate depth of 2500 ft for this refractor which means that owing to the angle of emergence of the refracted wave from the refractor, the sub-surface coverage of a spread of geophones which record this velocity is approximately one mile closer to the shot-point than the spread of the geophones. The sub-surface section under Shot-point 66 is covered both up and down dip by time-distance curves 53W and 77E, which give apparent velocities V_4d = 12,640 ft/sec and V_{4u} = 13,250 ft/sec, respectively, giving a calculated velocity of 12,680 ft/sec.

The velocity of this refractor can be calculated also from time-distance curves 111E and 95W, the sub-surface under Shot-point 103 being covered in both directions. The values obtained are :-

V_{4u} = 12,940 ft/sec, V_{4d} = 12,500 ft/sec,
V_4 = 12,620 ft/sec.

However, this calculation has a large possible error since V_{4d} is based only on 6 geophone times. 12,650 ft/sec has been taken as the actual velocity for this refractor.

<u>Fourth refractor, V_5</u> (14,500 ft/sec). Time-distance curves 111E and 95W show apparent velocities of 14,120 ft/sec and 14,950 ft/sec, respectively, from a refractor approximately 4000 ft deep. The offset distance (about 1 mile) for this refractor is such that these recordings are not from the same portion of the refractor. As there is evidence of faulting just east of Shot-point 101 which is near the depth point of the portion of time-distance curve 111E recording V_5, dips of beds in this vicinity are likely to be affected by fault drag, and any calculated velocity not based on reverse direction recordings from the same portion of the refractor would not be reliable.

Other time-distance curves were originally used to calculate the velocity V_5, but it is now thought that these calculations also are unreliable. The first portion of time-distance curve 99E was paired with that portion of 53W near Shot-point 75, but the former has an apparent velocity V_{5d} = 12,650 ft/sec, which is approximately equal to V_4, the intermediate velocity now recognised. This makes it doubtful whether V_{5d} or V_4 is being recorded and under these conditions small errors in reading V_{5d} can cause comparatively large errors in the calculated value for V_5 which thus becomes unreliable. Time-distance curves 64W and 111E were used to calculate a value for V_5, but the former is now also thought to be recorded from the third refractor of velocity 12,650 ft/sec.

Thus there is no means of determining with any accuracy the value of V_5, the failure being due to the complex nature of the areas. Apparent values for this velocity have been recorded by radial spreads on arc Traverses H and I. These, together with the two values recorded on Traverse D, suggest that the velocity of this refractor is approximately 14,500 ft/sec.

Deep refractor, V_6 (16,000 ft/sec). A high-velocity refractor is observed at a distance of seven miles from Shot-point 111 and Shot-point 53. Its depth is about 7000 ft and its velocity between 16,000 and 17,000 ft/sec. The portions of the time-distance curves recording this velocity are not from the same sub-surface part of the refractor and thus no accurate determination of its velocity can be made. At the eastern end of the area the high. velocity is recorded much closer to the shot-point and at much earlier times, indicating that the refractor is much shallower to the east, probably at a depth of about 6000 ft.

Results on individual traverses

Traverse D. It has been possible to plot depth profiles along Traverse D for the refractors represented by velocities V_3, V_4, V_5, and V_6. These profiles are shown on Plate 3A below the time distance curves and their description follows :-

V_3. At the western end several spreads of geophones recording the V_3 refractor have been shot from various shot-points enabling a depth profile of this refractor to be plotted. The main feature is a fault approximately between Shot-points 100 and 101, with an up-throw of 750 ft to the east.

V_4. The time-distance curves 53W and 69E recording the V_4 refractor enable a depth profile of this refractor to be drawn along parts of Traverse D at the eastern end. The main features shown on the depth profile are two faults, one between Shot-points 64 and Shot-points 65 with an up-throw to the east of about 1500 ft, and the other between Shot-point 57 and Shot-point 58 with an up-throw to the west of about 900 ft. Thus there is an uplifted fault-block between Shot-points 65 and 57.

From its depth this refractor must lie within the Permian section and possibly near the top of the Grant Formation. From the results of this traverse and arc Traverses E, F, G, and K there appears to be little conformity between the structure of this refractor and the dome at the surface.

V_5. Using 14,500 ft/sec as the velocity of the V_5 refractor, a short profile of the refractor has been drawn from that portion of the time-distance curve 111E between Shot-point 96 and 660'E of 76. If the velocity assumed is too low then this profile is tilted to the west, or if it is too high the profile is tilted to the east. The maximum error in the dip of this refractor due to the velocity being in error would be approximately 170 ft in 1 mile or about 2°.

The tail-off at the eastern end of the profile caused by the sharp steepening in slope of the time-distance curve is thought to be caused by a fault located near Shot-point 95 and with a down-throw to the east. This steepening in slope can be compared with that in time-distance curves 95W, 69E, and 53W caused by faults in the V_3 and V_4 refractors. As the shooting was not carried far enough beyond the fault, the throw of the fault remains unknown.

V_6. Profiles of this refractor were plotted from the time-distance curves 159E, 116E, 123W and portions of 53W, 99E and 69E, using velocities 16,000 ft/sec, 16,400 ft/sec, and 17,000 ft/sec. It was found that the profiles obtained from 53W and 99E, which overlap slightly agree best when 16,000 ft/sec is used for the velocity. The profile obtained using this velocity is drawn below the time-distance curves of Traverse D on Plate 3A.

The outstanding feature shown by the profiles along Traverse D is the fault at Shot-point 55, with a down-throw to the east of approximately 1700 ft. It is assumed that if the portion of 69E between 440'W of 84 and 550'W of 118 had been shot, the results would have given an abrupt change in travel times and a steep slope of the time-distance graph as were found when shooting across other faults.

There are other indications that faulting may be present, but they are near the limit of resolution between faults and steep dips. Thus, the change in slope near Shot-point 80 in the time-distance curve of 159E may be caused by a fault with a down-throw to the east between Shot-point 99 and Shot-point 100, but when plotted as a time profile it appears as a gradual change from a westerly dip with a component of 7° along the traverse to an easterly dip with a component of 5°. Similarly, the decrease in slope of the time-distance curve of 116E near Shot-point 72 could be due to a fault with an up-throw to the east, near Shot-point 79, but it can be plotted as a reasonable anticlinal rise in the profile between Shot-point 79 and Shot-point 76. Even if these faults do not exist, this deep refractor represents an irregular surface with considerable relief. Possible leads to a search for comparatively small oil traps are the fault shown under Shot-point 55 and the reversal of dip shown under Shot-point 99 and 100.

<u>Traverse E</u>. Plate 3B shows a graph of the travel times recorded from the third refractor of velocity 12,650 ft/sec around arc Traverse E. The graph corresponds to the profile along an arc situated about 1 mile towards the shot-point from the traverse. Shot-point 140 is structurally the highest point along this traverse. Between Shot-point 140 and Shot-point 128 a uniform south component of dip along the traverse of approximately $4\frac{1}{2}^{\circ}$ is recorded and from Shot-point 140 to Shot-point 215 there is a relatively steep component of dip to the north-west of approximately 12°.

Four radial spreads were shot at intervals around this arc. The apparent velocities recorded and estimated dips at the intersections of the arcs and cross-spreads are shown below.

Location	Apparent Velocity (ft/sec)	Estimated Dip		
		Component along arc	Component along cross-spread	Resultant
SP 119	13,830	30°S	6.0°W	7°WSW
SP 130	12,500	5°S	0.8°E	5°S
SP 135	13,740	2°SSE	5.7°WSW	6°SW
SP 139	13,250	2°SE	3.4°SW	4°S

<u>Traverse F</u>. The time profile of the third refractor V_4 along arc Traverse F is shown in Plate 3C. It relates to depth points displaced from the arc traverse approximately one mile towards the shot-point. This profile demonstrates the apparent rugged outline of the refracting interface. Variations of up to 30 milliseconds in the profile or approximately 500 ft in the depth of the bed, occur within horizontal distances of only half a mile. These variations, when related to depth points at the geophone end, are equivalent to dips with a component of approximately 16° along the traverse. There are several undulations along this profile where dips are of such magnitude. The highest point of the profile occurs midway between Shot-point 158 and Shot-point 217.

Three radial spreads were shot at intervals around this arc. The apparent velocities recorded and estimated dips at the intersections of the arcs and cross-spreads are shown below.

Location	Apparent Velocity (ft/sec)	Estimated Dip Component along arc	Estimated Dip Component along cross-spread	Resultant
SP 62	12,220	8°S	2.6°W	8.5SSW
SP 148	12,500	1°SW	0.8°NW	1.5°W
SP 154	12,500	11.5°SW	0.8°NW	11.5°SW

Traverse G. Plate 3D shows the time profile of the third refractor V_4 along arc Traverse G. It represents a depth profile situated approximately one mile towards the shot-point from the traverse. The western end of the profile is disturbed. From Shot-point 163 to 880 ft east of Shot-point 166 the profile suggests an easterly dip component of approximately 15° along the arc. At 880 ft east of Shot-point 166 it suggests a fault with an up-throw to the east of 400 ft. On the east side of the fault and between the fault and Shot-point 171 the bed is flat. Eastwards from Shot-point 171 it dips to the east (component about 10° along the arc) until a minimum is reached at Shot-point 174. From here to the end of the traverse at Shot-point 183 the refractor rises a total of 35 milliseconds or approximately 500 ft representing a dip component of $6\frac{1}{2}^{\circ}$.

For the first part of this traverse, from Shot-point 181 to Shot-point 168, the depth points lie approximately under a section of Traverse D from Shot-point 62 to Shot-point 57. The fault shown by Traverse G should be under Shot-point 58 of Traverse D. Profile 53W of Traverse D recorded between Shot-point 57 and Shot-point 64 covers very nearly the same sub-surface sections of the shallower refractors without giving any evidence of faulting. Also, profile 69E should record the fault somewhere between Shot-point 56 and Shot-point 53. However, this section is not recorded but, if shot, any fault shown would almost certainly have had a down-throw to the east, and not an up-throw as indicated by Traverse G. Thus, Traverse D and Traverse G appear to show conflicting results.

Although this appears anomalous it is not necessarily so, as the fault indicated by Traverse G has probably crossed the sub-surface depth points at the shot-point end of the travel path. The fault, in our interpretation, has been placed approximately 4000 ft south of Shot-point 180, the shot-point for arc G.

Three radial spreads were shot at intervals around this arc. The apparent velocities recorded and estimated dips at the intersections of the arcs and cross-spreads are shown below.

Location	Apparent Velocity (ft/sec)	Estimated Dip Component along arc	Estimated Dip Component along cross-spread	Resultant
SP 162	12,790	0	0.9°N	1°N
SP 170	12,640	0	0.0°	0
SP 130	12,870	$1\frac{1}{2}^{\circ}$SW	1.1°NW	2°W

Traverse H. Plate 4A shows the time profile along the arc Traverse H. The profile indicates a fault with a down-throw of approximately 800 ft to the south, situated between Shot-point 194 and Shot-point 195. North of the fault, two radial spreads at Shot-point 94 and Shot-point 212 show velocities of 14,100 ft/sec and 14,470 ft/sec, respectively. It is probable, then, that over this part of Traverse H the times recorded are for travel paths along the top of the refractor of velocity approximately 14,500 ft/sec. As this velocity is not known accurately, dips cannot be estimated from the apparent velocity measured on the radial spreads. This part of the profile shows a continuous dip component along the arc to the north and north-west. From Shot-point 193 to Shot-point 209, this component is approximately 3°, but from Shot-point 209 to Shot-point 213 the dip component is relatively large, being about 12°.

South of the fault, radial spreads at Shot-point 196 and Shot-point 202 give velocities of 13,500 ft/sec and 12,860 ft/sec, respectively. It is likely, therefore, that the southern part of the traverse is recorded from the refractor of velocity 12,650 ft/sec. This part of the profile is flat from Shot-point 195 to Shot-point 198, and then dips to the south-west at approximately 17°.

The four radial spreads mentioned above are the only ones shot around this traverse. The location, apparent velocities recorded, and estimated dips at the intersections of the arcs and cross-spreads are shown below.

Location	Apparent Velocity (ft/sec)	Estimated Dip		
		Component along arc	Component along cross-spread	Resultant
SP 94	14,100	0°	-	-
SP 212	14,470	11°N	-	-
SP 196	13,500	0°	4.5°NW	4.5°NW
SP 202	12,860	-	1.2°NW	-

Traverse I. Two radial spreads were shot on this arc at Shot-point 216 and Shot-point 231 and recorded velocities of 14,760 ft/sec and 14,280 ft/sec, respectively, thus indicating that the travel times recorded are probably for the 14,500 ft/sec refractor. Dips cannot be calculated from these apparent velocities are V_5 is not known accurately. The time profile shown on Plate 4B indicates that the refractor rises slightly (about 100 ft) from Shot-point 216 to Shot-point 219, then has a northerly component of dip of about 5½° along the arc to Shot-point 222. It has risen about 100 ft at Shot-point 226, and then remains generally flat to Shot-point 232.

Traverse K. The radial spread at Shot-point 250 on this arc gives a velocity of 12,350 ft/sec, indicating that the 12,650 ft/sec refractor is probably the one recorded here. The time profile shown in Plate 4C indicates a westerly component of dip of approximately 12½°, between Shot-point 248 and Shot-point 252. The radial spread indicates a north dip component of 1.8°. The approximate value of the resultant dip at its intersection with the arc is 12½°W.

Traverses J and L. Each of these traverses consisted of two in-line spreads shot in opposite directions. The distance between shot-point and the centre of geophone spread was four miles. On each traverse the geophone spreads were twomiles apart. Apparent up-dip and down-dip velocities should be recorded from approximately common sub-surface depth points of the refractor and thus enable an accurate determination of the component of dip along the spread midway between the two geophone spreads. The results obtained are shown by Plate 4D and 4E and are listed below.

Traverse J : Centre Point Shot-point 237

V_{4u} = 12,500 ft/sec
V_{4d} = 12,500 "
V_4 = 12,500 "

Zero component of dip along the traverse.

The value obtained for the velocity V_4 agrees reasonably well with the value 12,650 ft/sec calculated on Traverse D.

Traverse L : Centre Point Shot-point 257

V_{4u} uncertain, as record shows possible interferences from V_5.

V_{4d} = 12,360 ft/sec. This indicates a north dip component of 1.8^{o} along the traverse.

6. CONCLUSIONS

The following points summarise the foregoing results :-

(a) Faulting is present right through the section to a depth of at least 7000 ft. It probably follows that the basement is also faulted. A number of faults have been observed, some extending to 4000 ft. On the deep refractor one definite fault (1700 ft throw under Shot-point 55, Traverse D) has been observed and there is evidence that other smaller faults may be present.

(b) With the possible exception of the western end of the area there is no consistent correlation between structure at surface and structure at 2500 to 4000 ft or deeper structure at 6000 to 7000 ft. In many places not only is the direction of dips different on the deeper beds from that on the shallower beds but the amounts of dip are often two to three times greater on the deeper beds than any measured at the surface. This indicates an unconformity within the Permian section, possibly near the top of the Grant Formation. Other unconformities also probably exist. At the western end of the area there is some evidence of conformity between near surface and deeper structure. Traverse H shows evidence of an anticlinal reversal of dip and Traverse D shows evidence of a westerly component of dip. The dips on the deeper beds are considerably greater than those shown at the surface.

(c) It has not been possible to correlate definitely any of the the faults deduced for the deep refractor with those deduced for the shallower refractors, except for the large fault at the eastern end of Traverse D. In general, it has not been possible to correlate definitely the faults deduced from the seismic work with those shown by the exposed geology.

(d) The deep refractor is about 1000 ft shallower at the eastern end of Nerrima Dome under Shot-point 55 to Shot-point 57 than it is at the centre or western end. Whether this is caused by the dip of the refractor or by elevation due to faulting, it precludes the possibility of a simple structural trap at this depth under Nerrima Dome. Although there is a possibility that a reversal of this trend further east may result in closure, the evidence of the gravity results does not support this.

(e) One remote possibility is that the refractor V_6 represents the surface of a reef limestone but there is no evidence of this. The irregular profile of V_6 is what would be expected from a reef. However, if a reef is present it is coincidental and bears no apparent relation to the structure at surface. No known prospecting tool except the drill can give direct evidence as to whether or not a reef does exist although in areas of known reefs that are known to be associated with certain seismic features, indirect evidence can be obtained by the seismic techniques.

From the above points it must be concluded that the structure at Nerrima Dome is complex at depth and bears little obvious relation to the structure at surface. Certainly no simple dome-like structure exists at depth. Oil traps, principally fault traps, may be present but on the known evidence they cannot be predicted and, if present, will probably be comparatively small and perhaps numerous. A drill hole based on the present information could only hope to tap one by chance. The results of the detailed gravity survey covering Nerrima Dome lend support to the above conclusions and suggest that the gravity meter will be a most valuable tool for finding areas where intensive seismic investigation should be carried out to locate sites for test bores.

In assessing the economics of extensive geophysical work before drilling, it should be realised that the estimated cost of a 10,000 ft hole drilled in the Kimberleys is of the order of the cost of ten seasons of seismic work.

7. RECOMMENDATIONS

At this stage no point on the Nerrima Dome can be recommended on the basis of geophysical work as a suitable target for an oil test bore. Any bore put down on Nerrima Dome must be regarded as being principally a geophysical hole for stratigraphic information. However, before such a hole is put down, it would be profitable to do additional seismic work.

It is probable that the complexities of the Nerrima Dome are not peculiar to it but apply to the other major structures in the area. This should first be checked by a seismic survey in the area of, say, Poole Range, where there is some 2000 ft of Permian sediments less than at Nerrima, as a result partly of erosion and partly of the thinning of the Poole sandstones. If it is found that no simple structure exists at depth in the area then the seismic programme should be devoted to the search for deep structure in places not necessarily outlined by structures in the near-surface Permian strata. Any positive gravity anomalies would be the next obvious lead.

If another two or three years of geophysical work in the Fitzroy Basin does not reveal an entirely satisfactory target, it may be wise to drill a hole on the best available target in order to decide to what extent the geophysical investigations should be continued.

If further work in the search for oil at Nerrima should still be considered warranted, it is suggested that consideration be given to scout drilling with electrical logging. It would be desirable to check, by drilling, the main conclusion from the seismic work that a major unconformity exists at about 2000 ft. It would be desirable also to drill holes on either side of the Mount Fenton fault; these might throw considerable light on the stratigraphy of the Fitzroy Basin.

8. REFERENCES

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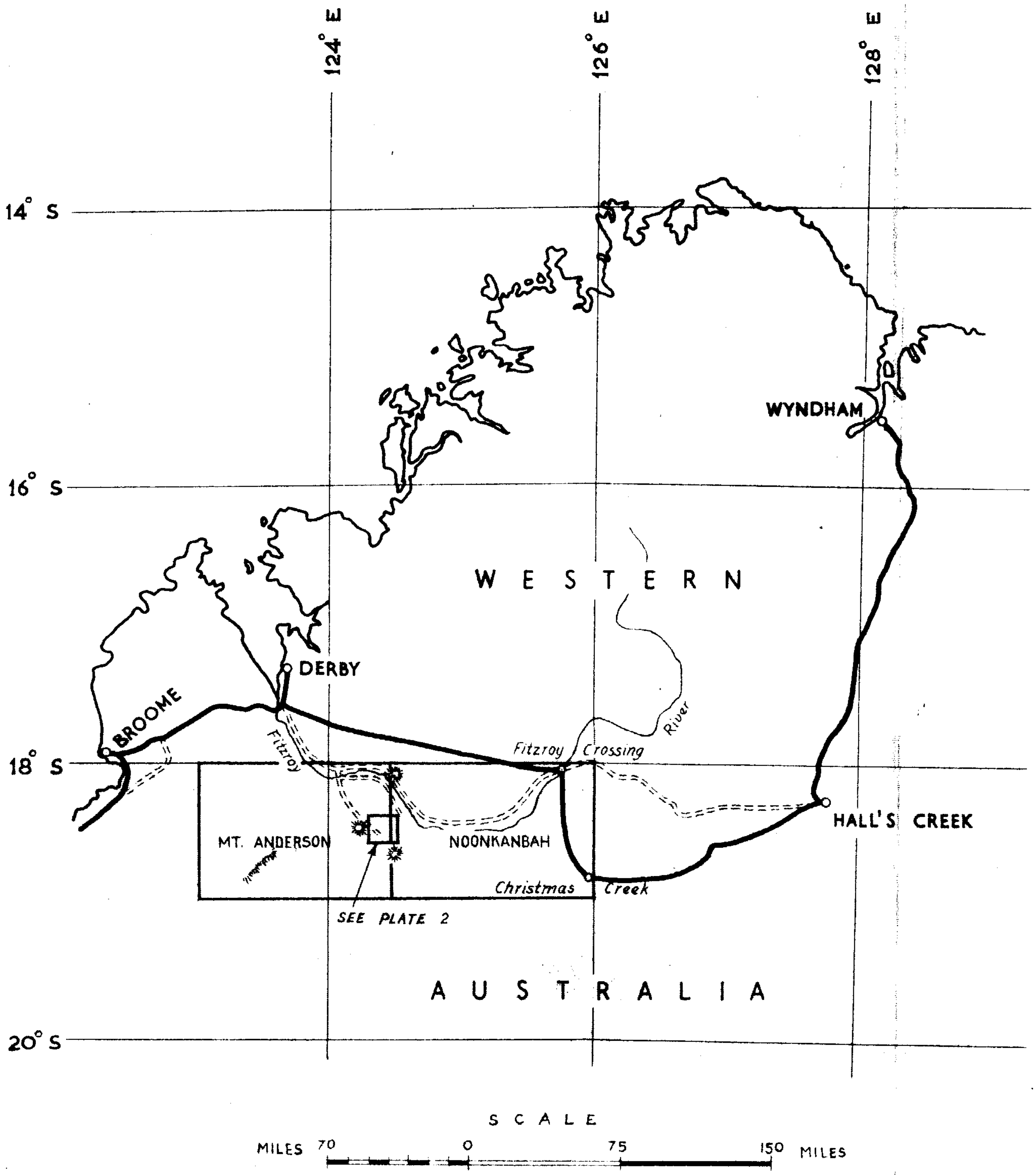
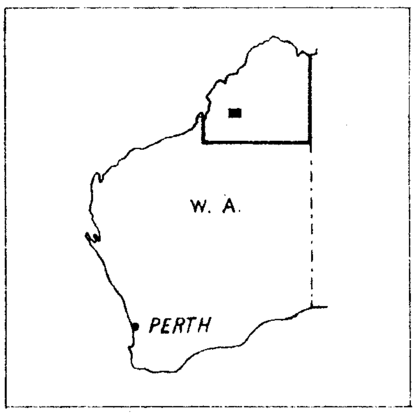




GEOPHYSICAL SEISMIC SURVEY

NERRIMA DOME FITZROY BASIN W. A.

LOCALITY MAP

NERRIMA DOME

SHOWING POSITION OF AREA DEALT WITH IN REPORT AND REFERENCE TO AUSTRALIAN FOUR MILE SERIES

V3, V4, V5, V6 — COLOUR CODE — RESULTS OF SEISMIC SURVEY

13° TRUE, 1° COMPONENT — DIP OF REFRACTORS

DEFINITE / PROBABLE — BOUNDARY BETWEEN LIVERINGA SANDSTONE AND NOONKANBAH SHALE

DEFINITE / PROBABLE (1000' U(UP) D(DOWN) F) — FAULTS AT SURFACE

DEFINITE / PROBABLE — STROPHALOSIA KIMBERLEYENSIS MARKER BED

DEFINITE / PROBABLE — POLYZOAL LIMESTONE MARKER BED

FENCE

TRACK

(FROM GEOLOGICAL MAP)

89 T. — REFLECTION TEST HOLE

SHOT POINT

GEOPHYSICAL SEISMIC SURVEY

NERRIMA DOME, FITZROY BASIN W.A.

SEISMIC TRAVERSES AND RECORDED DIPS

IN RELATION TO

SURFACE GEOLOGY

(GEOLOGY AFTER GUPPY, CUTHBERT, AND LINDNER)

SCALE

MILES 1 0 1 2 3 MILES

FEET 5000 0 5000 10,000 15000 FEET

T. 92

K. R. Vale
GEOPHYSICIST

Geophysical Section, Bureau of Mineral Resources, Geology & Geophysics.

G132-3

PLATE 3

PLATE 3A
TRAVERSE D

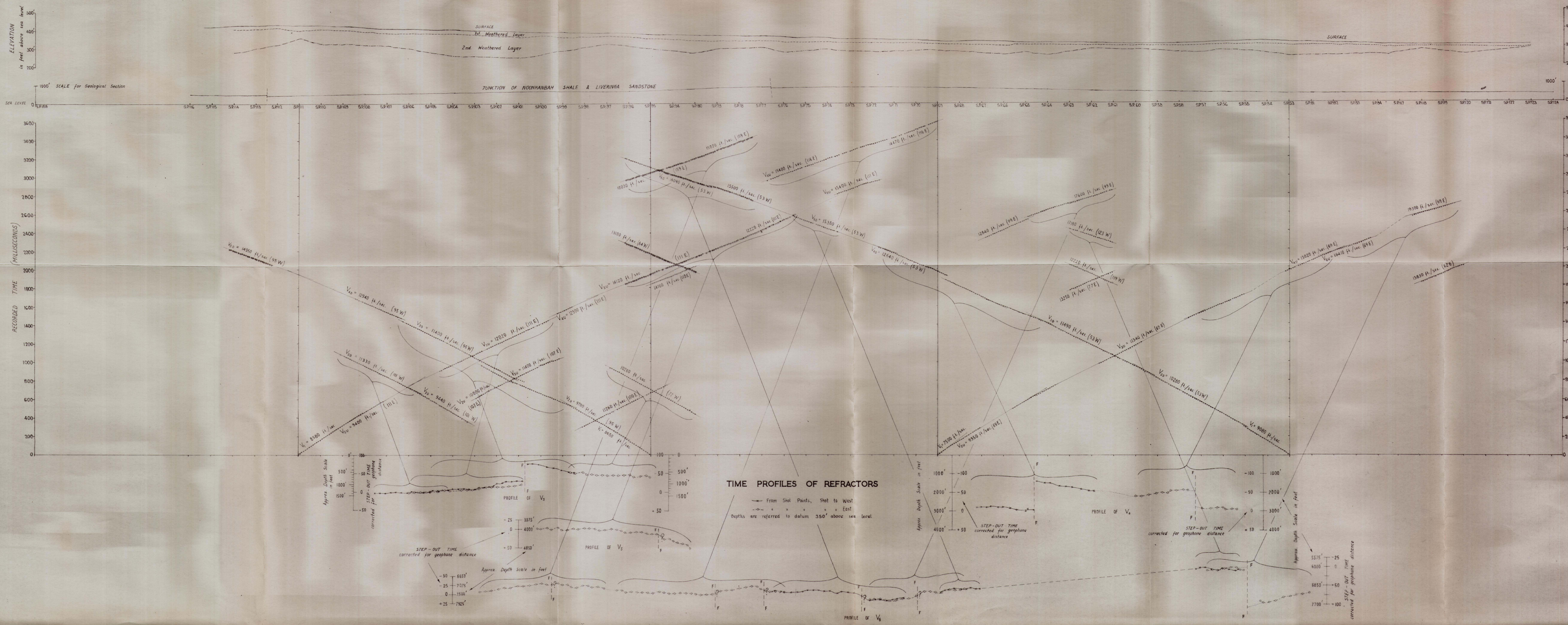


PLATE 3B
TRAVERSE E

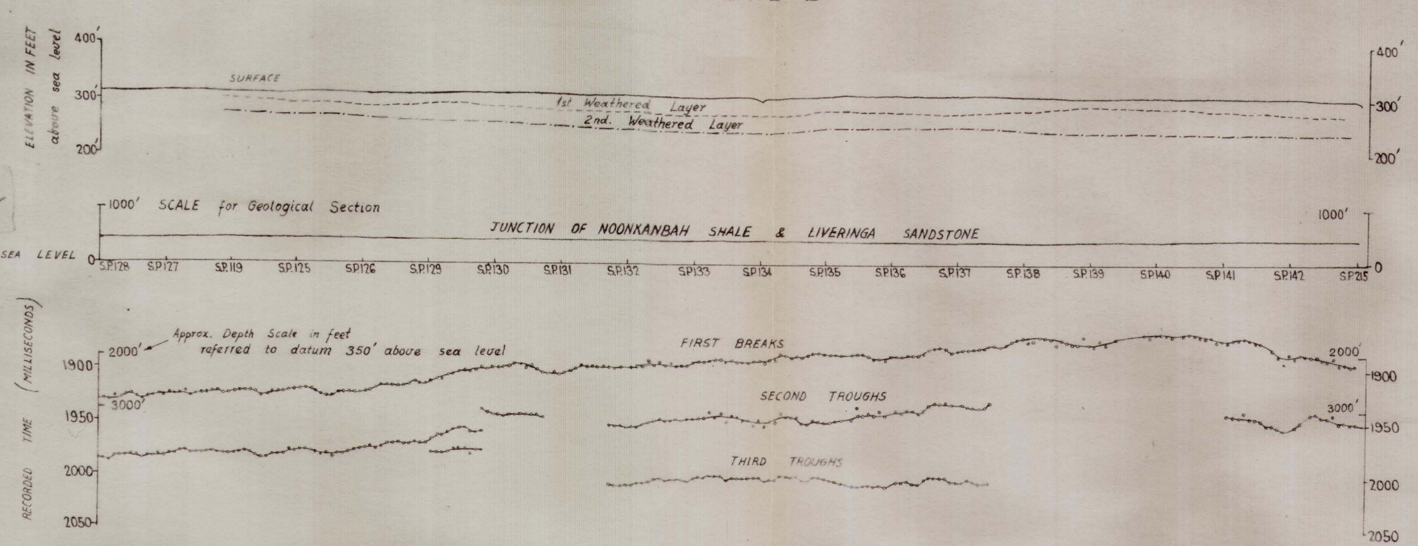


PLATE 3C
TRAVERSE F

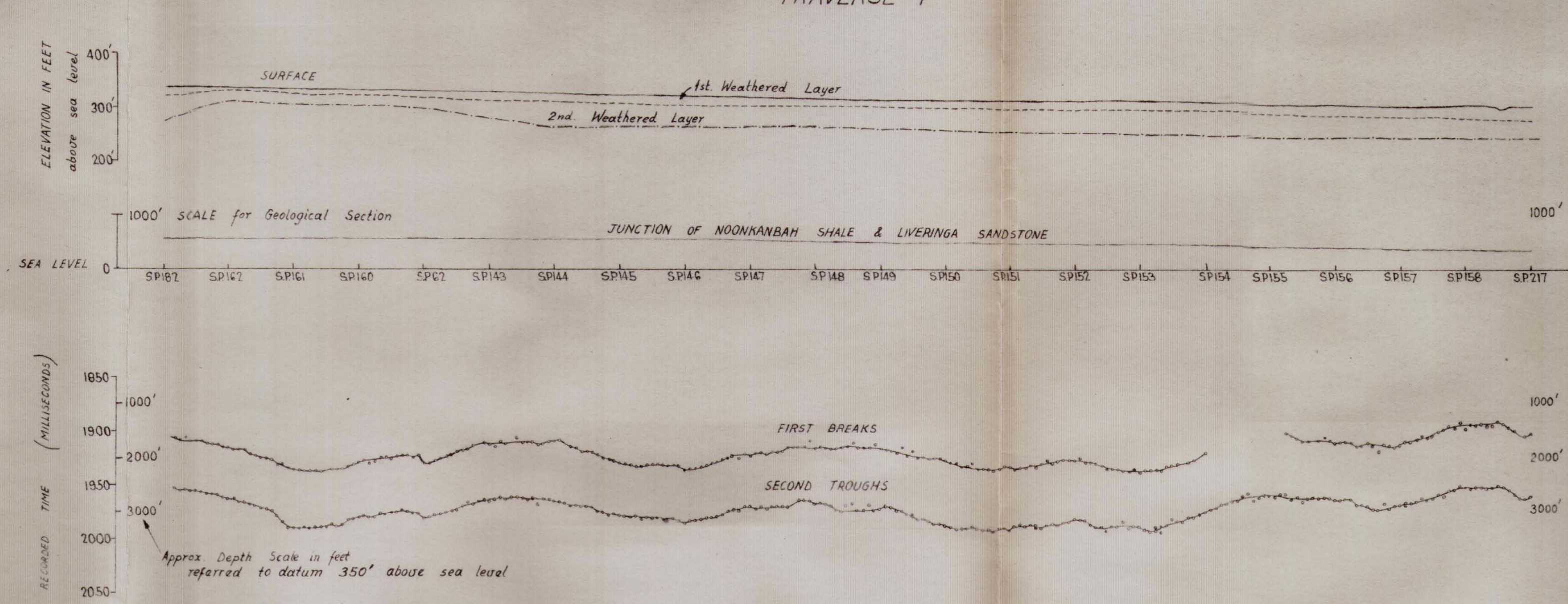
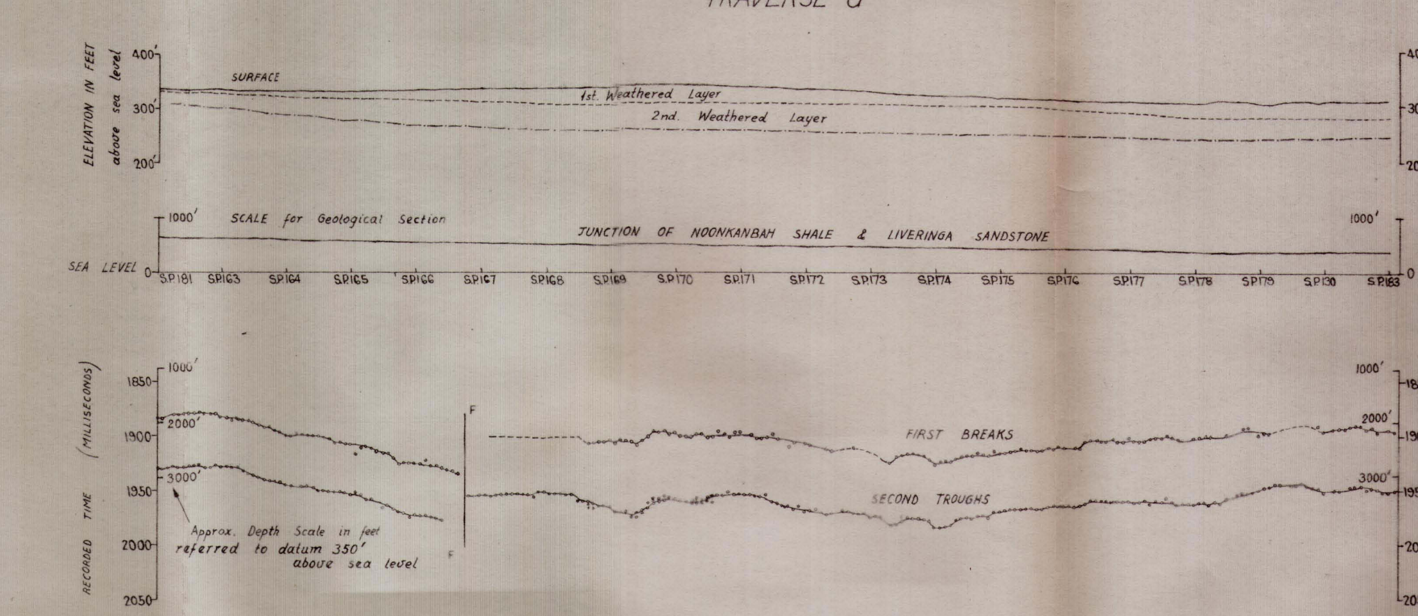


PLATE 3D
TRAVERSE G



GEOPHYSICAL SEISMIC SURVEY
NERRIMA DOME, FITZROY BASIN, W.A.

NEAR SURFACE GEOLOGICAL SECTION
AND
TIME PROFILES ALONG SEISMIC TRAVERSES

(GEOLOGICAL SECTION TAKEN APPROXIMATELY VERTICALLY ABOVE SEISMIC DEPTH POINTS)
AND BASED ON STRUCTURAL CONTOUR MAP BY GUPPY et al

SCALE
HORIZONTAL 1 — 0 — 1 MILE

K.R. Vale
GEOPHYSICIST

Geophysical Section, Bureau of Mineral Resources, Geology & Geophysics.

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PLATE 4

PLATE 4A
TRAVERSE H

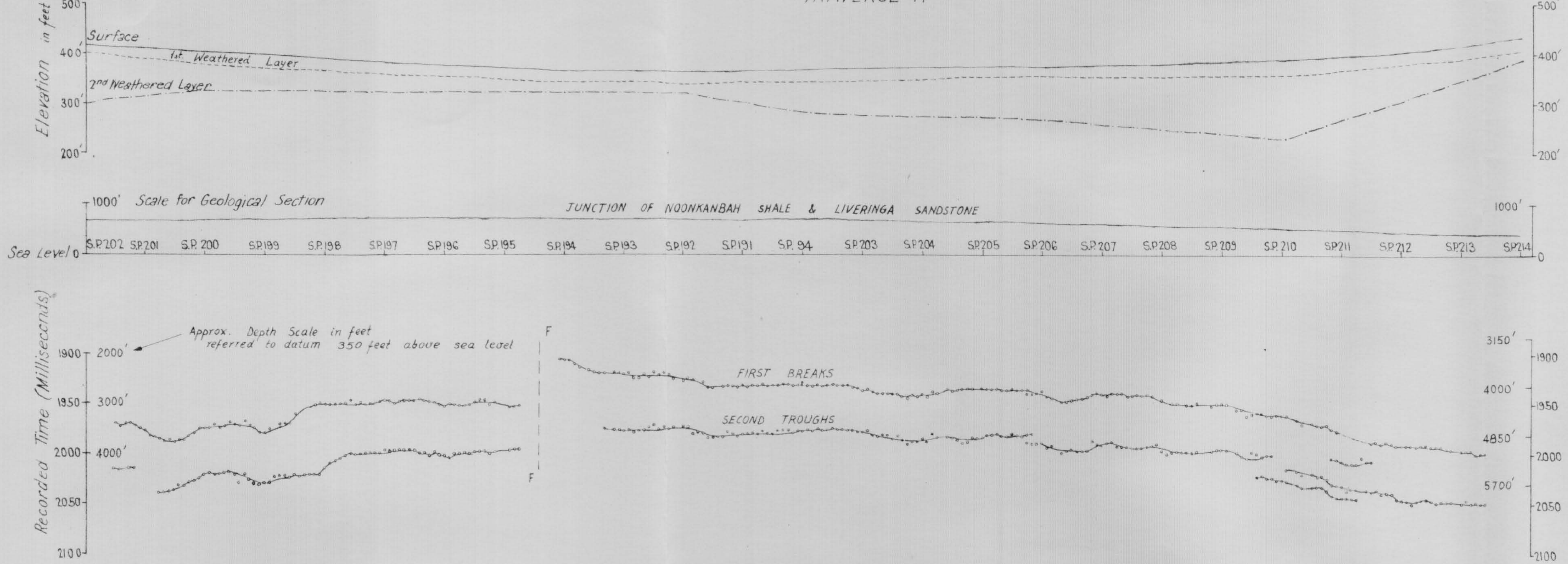


PLATE 4B
TRAVERSE I

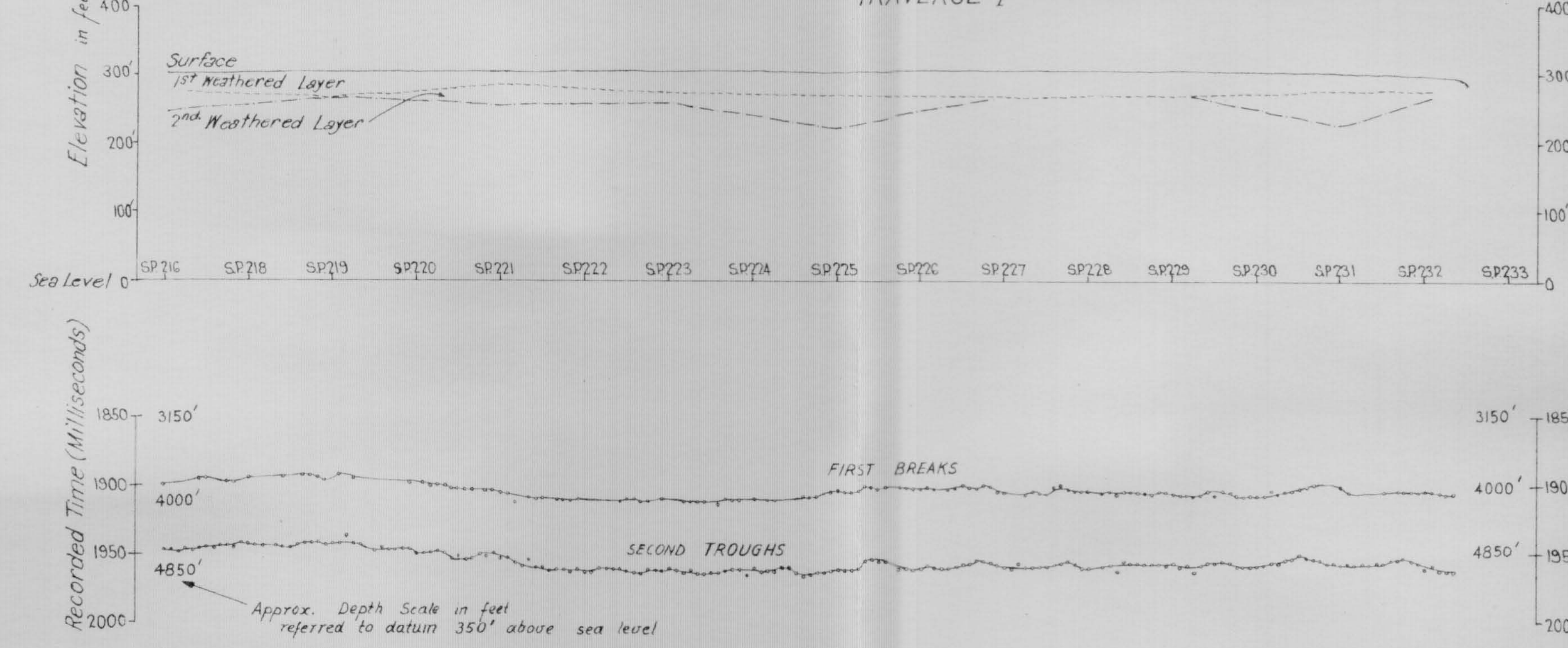


PLATE 4D
TRAVERSE 'J'

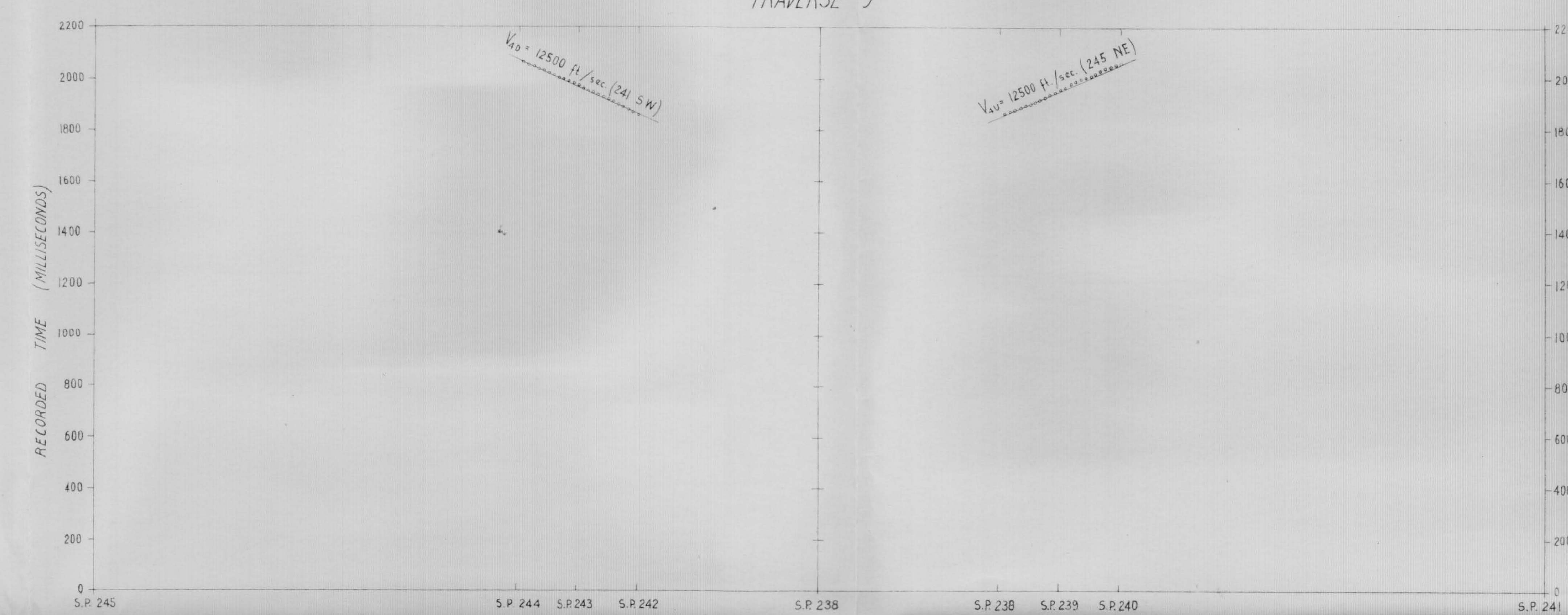


PLATE 4C
TRAVERSE K

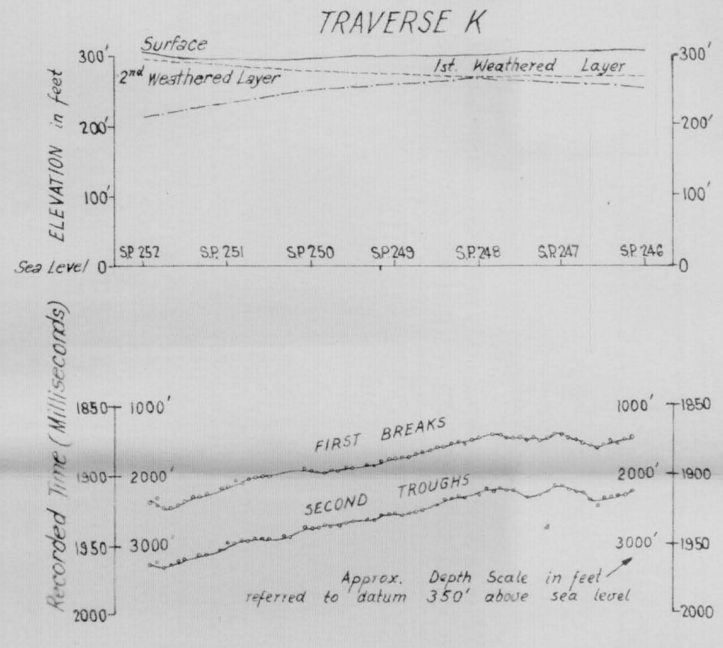
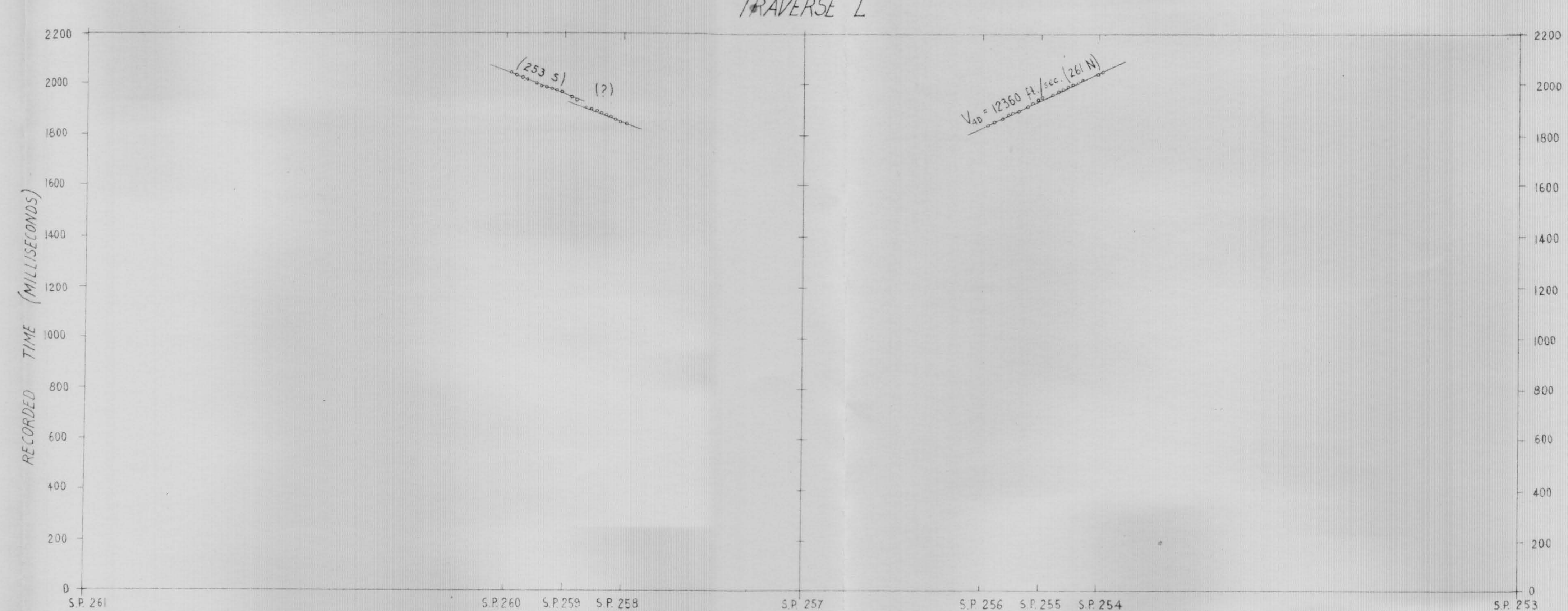


PLATE 4E
TRAVERSE L



GEOPHYSICAL SEISMIC SURVEY

NERRIMA DOME, FITZROY BASIN, W.A.

NEAR SURFACE GEOLOGICAL SECTION

AND

TIME PROFILES ALONG SEISMIC TRAVERSES

(GEOLOGICAL SECTION TAKEN APPROXIMATELY VERTICALLY ABOVE SEISMIC DEPTH POINTS)

AND BASED ON STRUCTURAL CONTOUR MAP BY GUPPY et al

SCALE

HORIZONTAL 1 0 1 MILE

K. R. Vale
GEOPHYSICIST