DEPARTMENT OF MINES
SOUTH AUSTRALIA

REPORT ON SEISMIC OPERATIONS - WESTERN AND CENTRAL ARCKARINGA BASIN - 1969

by

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Rept.Bk.No. 70/2
G.S. No. 4390
D.M. No. 28/70.

6th January, 1970.

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ABSTRACT

A programme of seismic reflection and refraction profiling was undertaken by the South Australian Department of Mines between late March and mid-September, 1969, in the central and western portion of the Arckaringa basin. Geophysical investigations of this basin have been carried on by the Department since 1961. Results of the 1969 seismic survey have been integrated with previous work, as well as information from four shallow stratigraphic wells drilled in 1969 on seismic targets.

The region has been divided into three sectors for interpretation. The area south of the Coober Pedy basement ridge contains narrow, fault bounded troughs in which shallow Cretaceous sediments are underlain by up to 5,500 feet of Permian sediments resting on crystalline basement. North of the Coober Pedy ridge and south of the latitude of Wintinna H.S., crystalline basement is at a shallow depth, deepening to the north. Depths range from less than 100 feet below surface over the Coober Pedy ridge to about 3,500 feet in the vicinity of Mount Willoughby. The sedimentary cover is similar to that of the southern troughs, except over the Coober Pedy ridge where the Permian appears to be absent. Crystalline basement in these areas has been identified with a high speed refractor by stratigraphic drilling.

The third sector, north of Wintinna H.S., has revealed a high speed refractor of more than 20,000 feet per second at a depth of about 2,000 feet. Its origin is at present unknown but could be dense carbonate rocks. This interpretation is supported by the calculated depth to magnetic basement of 6,000 feet in this vicinity, coincident with a gravity high feature.

Recommendations for further work in the southern and northern sectors have been made.

INTRODUCTION

The Arckaringa basin has been the target for intermittent geological and geophysical exploration by the South Australian Department of Mines since 1961. In 1968, seismic investigations of the Boorthanna trough of the eastern Arckaringa basin demonstrated the hydrocarbon potential of that region (Milton, 1969a). After the completion of this survey, it was decided to divert attention to the central and western Arckaringa basin during the 1969 field season. This area, situated in the central north of South Australia (fig. 1), is not held under petroleum tenement.

Very little geological information exists in this region and the seismic programme was planned on the basis of gravity and aeromagnetic coverage together with some scattered seismic data obtained in 1964 (Milton, 1964) and 1968 by the South Australian Department of Mines.

The survey was carried out between the 27th March and the 13th September, 1969, and consisted of isolated refraction "depth probes", some continuous refraction profiling, and reflection profiling where this type of shooting gave usable results. Statistical details of the operation are set out in the Appendix to this report. Four stratigraphic wells were drilled on seismic targets, primarily to identify the high speed refractor, and in each case intersected crystalline basement.

As a result of the survey, the region has been divided into three sectors of differing geological conditions, and conclusions made on the potential of these areas.

Recommendations have been made for further exploration of the northern and southern sectors.

PREVIOUS GEOPHYSICAL EXPLORATION

Aeromagnetic:

The area to the east (formerly O.E.L. 20, 21) of the region of operation was flown on behalf of Delhi-Santos by Aero Services Corporation in 1961, and to the west (formerly O.E.L. 28) for Exoil N.L. by Aero Services Corporation in 1964/65. The southern and northern sections were flown by the Bureau of Mineral Resources for the South Australian Department of Mines in 1966 and 1967 respectively, while the central sector was surveyed by the Geophysical Resources Development Co. on behalf of the South Australian Department of Mines in 1968. An integration of the interpretation of this data has been carried out by the Exploration Geophysics Section of the South Australian Geological Survey.

Gravity:

A helicopter survey with stations on a 4-mile grid pattern was undertaken by the Geological Survey of South Australia in 1968 (Hall and Townsend, 1969) over a large part of the Arckaringa basin. A further helicopter survey in 1969 has extended the gravity information to the south and west of the area discussed in this report. Gravity values were established in 1969 at the seismic shot points and these data have been integrated with the results of the helicopter surveys.

Seismic:

Refraction depth probes were shot from north of Welbourn Hill H.S. to Coober Pedy along the Stuart Highway by the Department of Mines seismic party in 1964 in an initial reconnaissance of this area. Experimental reflection shooting in the vicinity of an aeromagnetic feature located near Mount Willoughby H.S. was carried out in 1968 to determine the best approach for the 1969 operation.

GEOLOGY

Very little geological work has been undertaken in this region apart from detailed investigations in the vicinity of Coober Pedy (refer S.A. Department of Mines Mining Review indices) related to opal mining in that area. A photogeologic intepretation (V. Zay Smith, 1964) was made for the lease-holder of O.E.L. 31 in March, 1964. The lease was relinquished and later taken up as O.E.L. 34. A geological and geophysical appraisal was made on scanty data in 1965/66, but apart from a very limited amount of geological work in the north, no other surveying was carried out, and the lease lapsed.

The area is bounded to the south by the Gawler Platform and to the west and northwest by the eastern Officer basin. The eastern limit of shallow crystalline basement within the Arckaringa basin is at present unknown, although a northwesterly trend on the gravity contour plan (fig. 2) suggests that this lies well to the east of the survey area. The cover consists of shallow Cretaceous sediments underlain by Permian of unknown extent and thickness, except where investigated by drilling and seismic exploration. Several regions of deeper sediments were indicated by the gravity data, and most of these features investigated by seismic exploration and shallow stratigraphic drilling.

PHYSIOGRAPHY

The westerly and southerly sections of the area are generally sand covered with east trending dunes and scattered to dense mulga and mallee scrub. In the north and east, the topography is tableland or mesa type with the Stuart Range extending north from Coober Pedy. The eastern slopes of the Stuart Range drain into the Lake Eyre basin, while westerly drainage in the south of the area feeds to Lake Woorong and Lake Phillipson (fig. 1). The average rainfall of the region is about five inches per annum and the only surface water exists for short periods in water holes and the ephemeral lakes after the occasional heavy rains.

With the exception of the central western section, the area is held under a number of pastoral leases for the raising of sheep and cattle. Most of the 1969 survey was carried out along the Stuart Highway, vermin fences and station tracks, an extensive network of which exists, particularly on the sheep properties in the south. Some track making was necessary over the Karkaro anomaly and at the eastern end of the Mount Willoughby gravity feature, and a total of 65 miles of line and access tracks were bulldozed in these areas.

EXPLORATION METHODS

Targets for detailed seismic exploration were chosen from the results of the 1968 helicopter gravity survey of the Arckaringa basin. Continuous reciprocally shot refraction profiling with 300 feet station spacing was shot at right angles to the major axes of gravity anomalies and in-line spreads shot to penetrate to a high speed refractor, assumed to originate from basement. Away from the negative gravity features, "depth probes" (Vale and Smith, 1961) with 200 or 300 feet geophone spacing were shot along the Stuart Highway, station tracks, etc. at about 5 mile intervals to obtain spot depths to the high speed refractor. Information from weathering spreads and uphole shooting was obtained at regular intervals to establish values of weathering thickness and velocities for correction to datum. Wherever it appeared that basement was at a depth greater than about 1,000 feet, reflection profiles were shot at intervals along the refraction spreads to determine if usable reflection results could be obtained. Reflection records of poor to fair quality have been obtained over the Mount Willoughby trough, where one short line of six old stack was shot in 1968; in the vicinity of the Mount Furner No. 1. well; over a short profile in the northern sector between Wintinna and Welbourn Hill H.S.; and over the southern troughs. No reflections were recorded at Karkaro, although a considerable amount of experimental shooting was carried out, and this may be due to the presence of very large granite boulders which overlie the basement (Demaison, 1969).

The contour plan of depth to basement (fig. 2) has been constructed from the results of the 1964 and 1969 surveys. Depth values have been calculated from 17 depth probes shot in 1964, from 40 depth probes laid down in 1969 and from 173 miles of refraction and 31 miles of reflection profiling shot in 1969, the latter mainly located south of the Coober Pedy basement ridge.

Where the corrected values of refraction times could be used to fit a time-distance curve with little scatter, i.e. where the surface could be assumed to be a plane refractor, depths, true velocities and dips were calculated using an algebraic method for dipping, plane refractors (Dooley, 1952). Where it was evident that the refraction events were originating from an horizon with small scale structure sufficient to cause considerable scatter of values about any fixed line, one of several more complex methods was used, depending on the depth to basement and the distribution of the intermediate refractors (e.g. Hawkins, 1961).

Refraction shooting over the narrow, fault bounded troughs of Wallira and Lake Phillipson was not successful in penetrating to the high speed (basement) refractor. The depth of the troughs, e.g. greater than 5,000 feet at Wallira, and the distance between the bounding faults, e.g. about five miles between the north and south faults at Wallira east, prevented shooting within the trough at a sufficient offset distance from the seismic spread to reveal the high speed refractor. Shooting along the major axis may enable penetration to be attained, but this will require a fairly precise knowledge of the location of the major axis, to avoid seismic events from the fault zones interfering with the refracted energy from below the spread.

Reflecting horizon depths were obtained by computing a velocity-time function from a T-delta-T analysis of reflection moveout times, but due to the limited number of usable reflections and the steep dips of the reflectors, this function must be considered an approximation.

Gravity values were obtained at seismic shot points, and tied to helicopter gravity permanent stations, as well as South Australian Department of Lands bench marks along the main tracks. The Bouguer values on the seismic lines have been incorporated in the 1:250,000 contour plans of Bouguer anomaly. Although the patterns resulting from the helicopter survey contours have not been greatly modified by inclusion of data along the seismic lines, errors of up to 10 milligals, e.g. at Karkaro, have been revealed, necessitating a drastic revision of depth estimates. The source of these errors in Bouguer anomaly has not been determined, as it has not been possible to re-occupy the helicopter stations which are in error. It is possible that the error may be in the barometric levelling of the helicopter station, rather than in the observed gravity value.

Calculations of depth from gravity anomalies in the central and southern sectors have been made using a density contrast obtained from a determination of specific gravities of cores from five wells, each of which penetrated crystalline basement (refer Table 1 below). The contrast is between 0.6 and 0.7 grammes per cubic centimetre, the density of the crystalline basement lying between 2.62 and 2.70 grammes per cubic centimetre.

INTERPRETATION OF RESULTS

Results are presented as a contour plan of depths relative to Mean Sea Level of a high speed refractor and basement reflector, with depths to basement from five stratigraphic wells included (fig. 2); a north-south section north of the Coober Pedy basement ridge showing depth to the high speed refractor, depth to magnetic basement, surface elevation and the gravity profile (fig. 3); and seismic cross sections through the Wallira and Lake Phillipson troughs constructed from refraction and reflection profiling (fig. 4). Gravity contours at 10 milligal intervals are also shown on figure 2.

The only sub-surface geological information available prior to 1969 and directly applicable to petroleum exploration, apart from that obtained from shallow water bores, was recorded from Lake Phillipson bore and Stuart Range Nos. 1, 2 and 3 (Ludbrook, 1961 and 1965). The latter three wells are located east of the boundary of the survey area and were not drilled to basement.

Four stratigraphic wells (Demaison, 1969; Townsend, 1970) were drilled in 1969, viz. Karkaro No. 1, Mount Furner No. 1, and Wallira Nos. 1 and 2. A summary of the geological logs is set out in Table 1, with emphasis on the relationship of geological discontinuities to seismic refracting horizons. Depths are given in feet below the surface, and refraction velocities in feet per second.

TABLE 1

	Top of Cadna-owie Sandstone	Top of Permian	Top of Unit 1 Lower Permian	Lower Permian Boulder Beds	Basement
Refraction Velocity	7-7,500	8-9,000	11,000		18-19,000
North of Coober Pedy Basement Ridge					
Karkaro No.1	100	230	990	1,330	1,550
Mt. Furner No. 1	200	435	1,714		1,802
Stuart Range No. 1		447			
No. 2		248			
No. 3		490	910	1,660	
South of Coober Pedy Basement Ridge					
Lake Phillipson		166		2,438	3,140
Wallira No.1		185	420	670	710
No. 2			195	605	1,096

From the information obtained from the geophysical exploration and the wells, it is evident that the region can be divided into three areas for interpretation.

The central area extending north from and including the Coober Pedy basement ridge to the latitude of Wintinna H.S. is one of shallow crystalline basement overlain by Permian sediments to within a few hundred feet of the surface, except over the Coober Pedy ridge, where the Permian appears to be absent. The shallowest depth to basement recorded is less than 100 feet below surface over the Coober Pedy ridge, and the deepest about 3,500 feet at the Mount Willoughby gravity low.

The average velocity of the high speed refractor computed from 100 reciprocally shot refraction profiles is 18,650 feet per second with a coefficient of variation of 3.4% (Davies, 1947) and this is correlated with the crystalline basement intersected at Karkaro No. 1 and Mount Furner No. 1. The contour plan discloses shallow elongate basins generally in fair agreement with the gravity features, although a displacement effect appears to be present over a number of the anomalies (refer fig. 3). The displacement may be due to a regional gravity component. Where intermediate refractor velocities are recorded, as indicated in Table 1, it is not possible to correlate any one intermediate horizon over the whole area. The detection of these refractors depends on the relative thickness of the beds from which the seismic event originates, and the velocity distribution. In areas where such beds are present but not recorded, substantial errors can result in the depth calculations to the basement refractor. For example, at Karkaro No. 1, the depth estimate from refraction shooting relative to the depth to basement revealed by drilling is in error by less than 2%, but at Mount Furner No. 1, the error is about 15% due to the absence of the 8,000 - 9,000 feet per second refractor on the time-distance curves. This refractor is equated with the top of the Mount Toondina beds, which are present at both of the above wells. A re-calculation of data in the vicinity of Mount Furner No. 1 using an average velocity of 7,500 feet per second obtained from a well shoot of this hole, gives a depth in good agreement with the depth to basement from the well data. This velocity was therefore used in depth calculations in the Evelyn Downs - England Hill area.

The north-south profile (fig. 3) shows a gradient of the basement refractor deepening to the north at an average rate of about 25 feet to the mile relative to M.S.L. North of Wintinna H.S. the high speed refractor has an average velocity computed from six depth probes of 20,130 feet per second (coefficient of variation 3.3%) and is much shallower than the basement refractor of the central area, immediately south of Wintinna H.S. A profile of depth to magnetic basement is included in the drawing, and a value of about 6,000 feet is derived in this sector, coincident with a gravity high feature. This suggests that the high speed refractor does not originate from crystalline basement, but arises from either dense carbonate rocks (cf. the Devonian dolomite from Cootanoorina No. 1 (Wopfner and Allchurch, 1967) and the dolomitic shale from Munyarai No. 1 (Continental Oil Co. of Australia, 1968), both of which have high seismic velocities) or, less likely, from metamorphic rocks, and these are underlain by crystalline basement of a lower refraction velocity.

The third area for consideration is that lying south of the Coober Pedy basement ridge. Gravity patterns from the 1968 survey indicate the presence of narrow, fault bounded troughs (Hall and Townsend, 1969) and this has been confirmed by the seismic exploration programme. However, the 1969 helicopter gravity survey has revealed the extension of the Wallira trough to the southwest, where it becomes deeper and broader, and of the Lake Phillipson trough to the southeast, with similar characteristics.

The average velocity of the high speed refractor calculated from 19 profiles is 18,920 feet per second (co-efficient of variation 2.3%), which is in good agreement with the value for crystalline basement north of the Coober Pedy ridge. This is confirmed by the informatiom from the shallow stratigraphic wells of Wallira Nos. 1 and 2.

Cross sections have been constructed from an assumed basement reflector and the high speed refractor along a north-south section over the eastern end of the Wallira trough and an east-west section over the northern end of the Lake Phillipson trough (fig. 4). The difficulty of obtaining usable refraction results from basement in this environment has been noted in the section on exploration methods. Fortunately, fair reflection data can be obtained and this exploration method could be employed to investigate the troughs in detail.

The cross sections have been plotted at a natural scale, and demonstrate the loss of reflection quality as the faults are approached. A consistent reflector equivalent to a refractor of 11,500 feet per second is present over the Wallira trough, and this is equated with the top of a shale section in Unit 1 of the Lower Permian (Wopfner and Allchurch, 1967) and is possibly the equivalent of horizon B of the eastern Arckaringa basin and northern Boorthanna trough (Milton, 1969b). If this correlation is correct, about 3,000 feet of Lower Permian shales of Unit 1 and boulder sandstones of Unit 2 exist at the centre of the trough. Reflectors intermediate to the horizon B and basement reflectors can be correlated over part of the trough and these, at about 3,000 feet below M.S.L., could possibly originate from the top of Unit 2.

A similar section exists over the Lake Phillipson trough, but the northern section of this feature so far mapped is much more complex structurally than the Wallira trough.

CONCLUSIONS AND RECOMMENDATIONS

Further exploration of the central area does not appear to be justified, except possibly to the east to determine the limits of the Devonian sediments of the eastern Arckaringa Basin as revealed at Cootanoorina No. 1 and mapped geophysically in the Boorthanna trough. A limited amount of work in the southern sector is warranted to determine the nature of the southwestern extension of the Wallira trough and the southeastern extension of the Lake Phillipson trough. This could be carried out by a short programme of reflection and refraction seismic profiling. The hydrocarbon potential of this sector is limited by the volume of sediments contained within these narrow troughs. However, other data, such as source-rock coefficient, formation fluids, etc., will require to be known before the potential of the troughs can be assessed adequately. This information can only be obtained by drilling. This may also disclose the presence of evaporite minerals, the possibility of which is indicated by the gypsum-dolomite cement encountered in the basal Permian in Wallira Nos. 1 and 2.

The northern area requires further investigation, primarily to determine the origin of the high speed refractor by shallow stratigraphic drilling. If this should be of a prospective nature, a seismic programme could be designed to map the surface of this horizon. Penetration to basement by seismic methods, however, may not be easy and multiple reflection coverage or possibly attempts to obtain secondary refraction events may be necessary. A short reflection profile shot in 1964 shows a shallow reflector (.4 second) correlatable with the high speed refractor, and possible reflections at a greater depth (about 1 second). The latter may be capable of improvement by stacking techniques if they are real, primary reflections. Any work in this area would also relate to problems in the sections of the P.E.Ls. to the east and west of the region.

ACKNOWLEDGEMENTS

Acknowledgement is made of fruitful discussions with Dr. H. Wopfner, J. McG. Hall and R.J. Coppin of the South Australian Geological Survey on the interpretation of the geophysical data. Messrs Hall and Coppin with G.W. Kendall, late of the Geological Survey, were largely responsible for carrying out the field operations and for computing of the seismic data.

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APPENDIX

Duration of Survey:	Commenced Karkaro	27/3/69
	Concluded England Hill	13/9/69.

Coverage:
- Reflection profiling - 31.4 line miles
- Refraction profiling - 173 line miles
- Refraction depth probes - 79 line miles

Number of holes shot:
- Reflection - 196
- Refraction - 498
- Weathering - 96

Average depth to base of charge:
- Reflection - 77 feet
- Refraction - 78 feet

Explosives used:
- 2¼" Geophex - 25463 lb.
- Seismic detonators - 1414

Average size of charge:
- Reflection - 10 lb.
- Refraction - 47 lb.

Number of hours drilling: 1087

Total footage drilled: 60,181 feet.

Average rate of penetration: 55.4 feet/hour

Bits used:
- 12 sets Hawthorne 4¾" insert blades
- 2 " " 6½" " "
- 11 Varel hard formation roller bits 4¾"

Personnel:

Party Chief	
Assistant Party Chief	
Observer	
Surveyor	
Shot hole drillers	2
Drill offsiders	2
Shooter	1
Cable layers	3
Chainmen	2
Mechanics	1
Cook	1
Cooks offsider	1
Stores driver/clerk	1
Gravity meter operator	1

Equipment: Seismic recording equipment - Texas 7000B with Techno 401 magnetic recorder-reproducer mounted on an International C1300 truck.

Geophones - Reflection: HS sub-miniature in sets of 10.

Refraction: HS 1 (4½ c/s) in sets of 2.

Shot hole drills - 2 Mayhew 1000 combination rigs mounted on International 190 trucks. Frequently only one rig was used due to slow production from isolated refraction spreads.

Water tankers - 1 camp tanker of 1250 gallons mounted on an International R190 truck.

3 tankers of 800 gallons mounted on Bedford 7-ton trucks - including shooter's truck with explosives box.

3 International AB160 5-ton trucks - 2 flat tops for cartage stores and explosives; one with mobile workshop mounted on tray.

Geophone carriers - 2 International C1300 trucks with cable and geophone boxes.

1 International C1300 tray top for cartage of stores.

4 Land Rovers.

1 Diesel Land Rover with welding plant.

16 caravans and trailers.

A Caterpillar D6B was hired with driver from Keller Earthmovers Pty. Ltd. for constructing 58 miles of access track over the Karkaro gravity anomaly, and 7 miles of access track north of Copper Hills H.S.

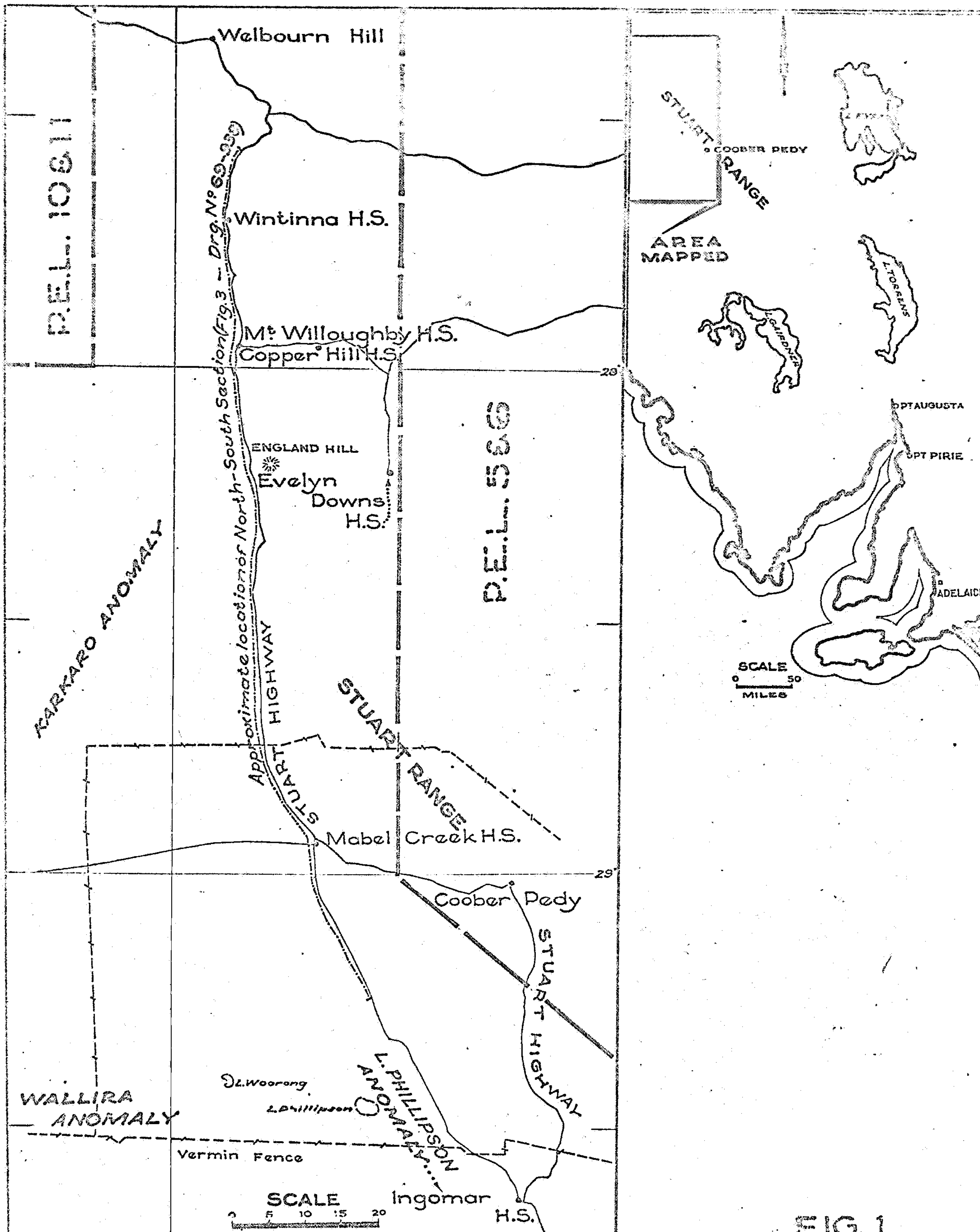


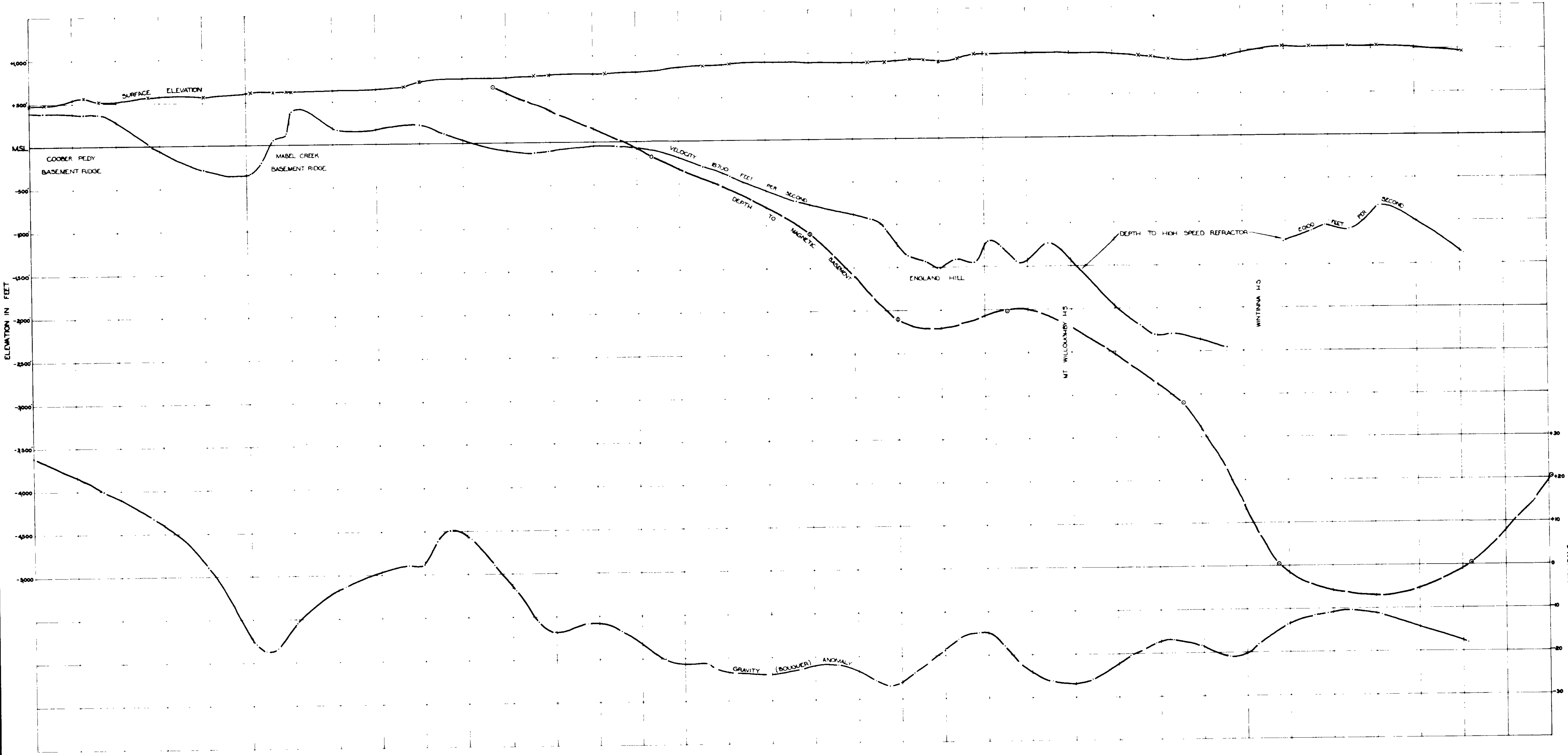
FIG. 1

Compiled: B.M.	DEPARTMENT OF MINES - SOUTH AUSTRALIA	Scale: As above
Drn. G.M. / Ckd. L.V.W.	WESTERN ARCKARINGA BASIN SEISMIC SURVEY LOCALITY PLAN	Date: 10·12·69
		Drg. No S7574 Bob

INTERPRETATION B E MILTON

FIG.2

DEPARTMENT OF MINES — SOUTH AUSTRALIA			
WESTERN ARCKARINGA BASIN CONTOURS OF DEPTH TO BASEMENT REFRACTOR AND REFLECTOR			
PETROLEUM EXPLORATION DIVISION	SEN. GEOPHYSICIST	Drn BEM Tcd AGR	SCALE 1:500,000 69-971
Director of Mines	GEOLOGIST	Ckd LYW Exd.	Bob DATE 20th JAN 1970



HORIZONTAL SCALE 1:500,000
INTERPRETATION B E MILTON

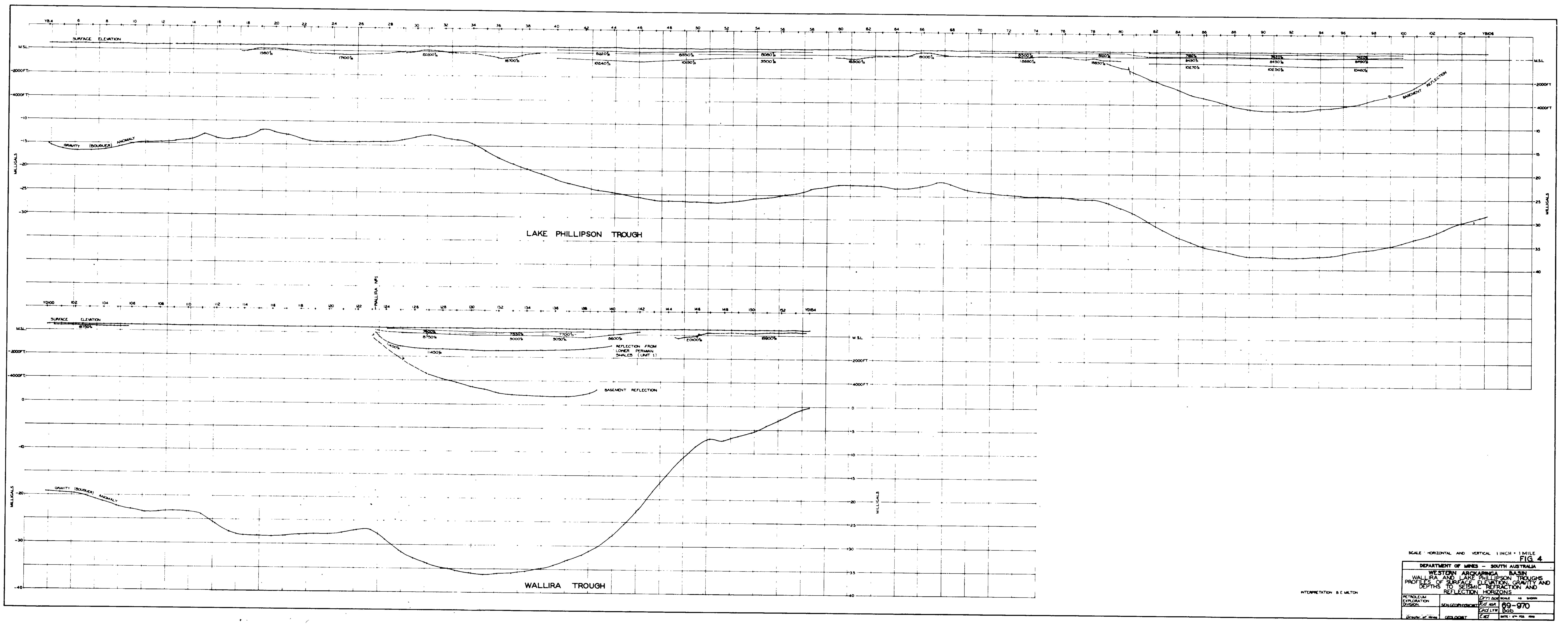
SEE PLAN S 7574 FOR LOCATION OF SECTION

FIG. 3

DEPARTMENT OF MINES — SOUTH AUSTRALIA

WESTERN ARCKARINGA BASIN
PROFILES OF SURFACE ELEVATION, GRAVITY, DEPTHS TO HIGH SPEED REFRACTOR AND MAGNETIC BASEMENT

PETROLEUM EXP DIVISION	SEN GEOPHYSICIST	Drn. BEM	SCALE: AS SHOWN
		Tcd. AGR	69-938
		Ckd. LVW	Bb
Director of Mines	GEOLOGIST	Exd.	DATE 15TH OCT 1969



SCALE : HORIZONTAL AND VERTICAL 1 INCH = 1 MILE

FIG. 4

DEPARTMENT OF MINES — SOUTH AUSTRALIA			
WESTERN ARCKARINGA BASIN WALLIRA AND LAKE PHILLIPSON TROUGHS PROFILES OF SURFACE ELEVATION, GRAVITY AND DEPTHS TO SEISMIC REFRACTION AND REFLECTION HORIZONS			
PETROLEUM EXPLORATION DIVISION	SEN. GEOPHYSICIST	Drn	SCALE AS SHOWN
		Tcd AGR	69-970
		Ckd LYW	Bab
Director of Mines	GEOLOGIST	Exd	DATE : 6th FEB. 1970