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DEEP CRUSTAL REFLECTION SEISMIC TEXT SURVEY, MILDURA, VICTORIA AND BROKEN HILL, N.S.W. 1968

by

J.C. Branson, F.J. Moss and F.J. Taylor

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SUMMARY

Techniques for recording deep crustal reflections were developed on an experimental seismic survey at Mildura, Victoria and Broken Hill, N.S.W., during September to December 1968. The survey was carried out preparatory to a seismic reflection survey on the 'Geotraverse' project, a project initiated by the Australian Upper Mantle Committee to study the Earth's crust and upper mantle along a line across the Precambrian shield in Western Australia.

Noise tests, expanded reflection spreads, and continuous reflection profiles mutually at right-angles, with split-spreads 1080-0-1080 m, were recorded at both Mildura and Broken Hill. Arrays of up to 48 geophones per station and shot-hole patterns of length 100 metres or more were used to attenuate random and coherent noise. Seismic energy return from within the crust and the upper mantle was fair at Mildura when charges of 115 kilograms of Geophex explosive were used; at Broken Hill, however, charges of about 4500 kilograms were necessary. Although it was considered that the survey techniques would be suitable for use on a reflection survey on the Geotraverse, additional experimental work was recommended to test the practicability of using long spreads and common-depth-point profiling techniques for deep crustal reflection surveys.

Fair-quality events at about 8.2 (average), 10.1, and 14.7 seconds' record time at Mildura are considered to be primary reflections from an intermediate layer within the crust, from the Mohorovicic Discontinuity at the base of the crust, and from a sub-Mohorovicic layer in the upper mantle. These may be correlated with events at Broken Hill at about 5.0, 11.3, and 14.6 seconds' record time.

Reflection data from the expanded spreads were analysed to provide velocity and depth estimates to reflecting horizons. Notwithstanding the inherent inaccuracies in timing the reflection events and in the method of analysing the expanded-spread data, the seismic reflection results indicate a possible model of the structure of the crust and upper mantle at Mildura and Broken Hill. The crust, relative to sea level, appears to thicken from about 31 kilometres at Mildura to about 36 kilometres at Broken Hill. An intermediate layer, with an interval velocity of about 7.0 kilometres per second, is at depths of about 23 kilometres and 15 kilometres in the two areas respectively. In the crust above, the average vertical velocity is about 6.1 and 5.9 kilometres per second at Mildura and Broken Hill respectively. There is also evidence of shallow layering in the crust at Broken Hill at depths of about 7.1 and 10.5 kilometres. A velocity reversal is evident at the latter depth, with a velocity of about 5.8 kilometres per second in the layer immediately below one of 6.5 kilometres per second.

The difference in the gravity effect between the two areas, obtained from a comparison of the proposed crustal columns, is in reasonable agreement with the difference in observed free-air anomalies at the Mildura and Broken Hill pendulum stations.

1. INTRODUCTION

Following recommendations made by the International Union of Geodesy and Geophysics in 1960, many countries throughout the world initiated projects to study the Earth's upper mantle. The Australian Upper Mantle Committee, which was formed to foster and if necessary co-ordinate national projects, has reported on the work in this field up to the end of 1967 (Australian Academy of Science, 1965, 1967). In 1965 the Committee recommended that a national project should be undertaken to study the Earth's crust and upper mantle along a line, designated the 'Geotraverse', across the Precambrian shield in the southern part of Western Australia. The Bureau of Mineral Resources (BMR) undertook to assist in this project by carrying out seismic, gravity, and magnetic surveys along the Geotraverse.

Seismic refraction methods have been used for most major seismic deep crustal investigations throughout the world; Project BUMP (Underwood, 1970) is an example of a large-scale co-operative effort using seismic refraction methods for deep crustal study in Australia. In some areas, however, seismic reflection surveys have been carried out successfully to obtain information on the structure and nature of the deeper parts of the crust and the upper mantle (Dohr & Fuchs, 1967; Clowes, Kanasewich & Cumming, 1968; Clowes, 1969). The reflection method has considerable advantages over the refraction method in its precision, greater resolving power, and ability to distinguish low-velocity layers beneath high-velocity layers. The reflection data may also yield vertical-velocity information from which fairly accurate depth determination may be made.

The criteria for recognizing primary reflected energy in deep crustal seismic reflection studies have been specified by Kanasewich & Cumming (1965). The basic principles for recording deep crustal reflection events have been described by Steinhart & Meyer (1961). However, little information was available on the field recording techniques used by workers in this field.

For several years, attempts to record deep crustal reflections have been made by BMR seismic parties working on conventional sedimentary basin exploration. These have usually been one-shot attempts, with no prior experimentation to determine an optimum recording technique in a particular area. Deep crustal reflection events were recorded in some areas at reflection times down to that expected for the Mohorovicic (Moho) Discontinuity (Moss, in prep). The best reflection records obtained by BMR were from near Mildura, Victoria, in 1960, where several distinct deep crustal reflections were recorded between 8.5 and 10.5 seconds' record time.

The recordings made at Mildura suggested that this would be a suitable area in which to carry out experimental work to develop recording techniques applicable for major deep crustal reflection studies. BMR carried out an experimental deep crustal reflection seismic test survey at Mildura, Victoria, and at Broken Hill, N.S.W. (Plate 1), from September to December 1968 to develop recording techniques prior to the work on the Geotraverse project in Western Australia.

The results of the experiments and details of the techniques developed for recording deep crustal reflections are presented. S.P. Mathur assisted in the interpretation of the results and in deriving the possible crustal structure in the two test areas.

2. GEOLOGY OF TEST SURVEY AREAS

Mildura lies in the Murray Basin, which covers an area of about 500,000 sq km in southeastern Australia. Tertiary and Cretaceous sediments about 800 m thick are present in the deepest part of the basin, near Mildura. The basin was formed by regional downwarp with associated minor faulting and tilting of the basement complex, which is mainly of Lower Palaeozoic age. The geology of the Murray Basin is described in detail by Pels (1959) and Parkin (1969).

The surface and immediate subsurface conditions in the Mildura area differ generally from those of the Geotraverse on the Precambrian shield in Western Australia. Thus, although the Mildura area was considered to be suitable for developing deep crustal reflection recording techniques generally, it was not considered to be a representative area for testing the actual techniques which could be applied on the Geotraverse project. For this reason a second test location was selected 230 km north of Mildura on the Precambrian Willyama Complex near Broken Hill, N.S.W. This is an area of high-grade metamorphics with outcrops of schist, gneiss, and quartzite. The geology of the area is described by Binns (1964) and Lewis, Forward & Roberts (1965).

3. EXPERIMENTAL RECORDING - MILDURA, VICTORIA

Techniques used for recording deep crustal reflections in the Mildura area in 1960 were not specifically designed for that purpose. The reflections were recorded from two reflection shots at the centre of a split-spread and from two refraction shots, 13.8 km in opposite directions from the centre of the same spread, by allowing the records to run on beyond the time for recording from the sedimentary section.

The objective of experimental work in this area during September to mid-November 1968 was to determine whether the quality of the deep crustal reflections could be improved by a well controlled program of experimentation. The program included noise test recordings, up-hole shooting and charge size, geophone type, and geophone and shot-hole pattern comparison tests prior to attempts to record continuous deep crustal reflection profiles.

The locations of traverses in the Mildura area are shown in Plate 2. Details of the recording equipment are given in Appendix 1 and operational statistics are given in Appendix 2.

Noise tests

Three noise tests were recorded with geophone stations 20 m apart along a spread with a maximum shot-to-geophone distance of 4880 m (Plates 4, 5, and 6). The tests were recorded with eight 4.5-Hz geophones bunched at each geophone station, with eight 4.5-Hz geophones 6 m apart in line, and with eight 14-Hz geophones 6 m apart in line. The most complete suite of noise events was recorded on the first test. Filtering was introduced for the other tests by the use of linear geophone patterns and by using higher-frequency geophones. The velocities and frequencies of the coherent noise events and the frequency of the apparent deep crustal reflection events were measured (Plate 4).

The events recorded fall into four categories. Shallow refraction events marked (1), (4), and (5), which have apparent velocities of about 2000 m/s and frequencies of 15 to 50 Hz, are rapidly attenuated with increasing distances from the shot-point. Refraction events (2) and (3) and noise events (6) and (8) have velocities in the range of 1550 to 4200 m/s with frequencies in the range 6 to 50 Hz. The highest-amplitude events recorded at times greater than 8 s are coherent noise events with velocities in the range 480 to 540 m/s with frequencies of 4 to 9 Hz. The events with apparent infinite velocities, recorded at times greater than 8 s, have apparent frequencies of 15 to 40 Hz. These are considered to be probable deep crustal reflections.

Analysis of the noise test (Plate 4) indicated that a low-cut electrical filter of 14 Hz would attenuate the most significant noise events, (9) to (12), in the zone of interest and improve the signal-to-noise ratio of the apparent reflections. The minimum wave number of the residual noise was 5 cycles per 1000 m, which indicated that effective attenuation could be achieved by linear filtering with geophone and source patterns of length 100 m.

The other noise tests (Plates 5, 6) indicated that the troublesome noise events in the area of interest were attenuated by extending the geophone groups and by the use of 14-Hz geophones. The results of the expanded spread (Plate 11), which was recorded later in the survey using 14-Hz geophones, shot and geo-patterns of length 90 m, and a record filter of K14-K125, indicated that these noise events are of low amplitude beyond 12 km offset distance from the shot-point and do not seriously affect the quality of probable deep crustal reflection events recorded on the expanded spread.

Up-hole survey

An up-hole survey was shot at Traverse A, SP190. Charges of 18 kg were detonated at depths ranging from 76 to 3 m and recorded on a 1080-0-1080 m split-spread with geophone stations at 90 m intervals. Shot-hole depth comparison records are shown in Plate 7. Eight 4.5-Hz geophones 6 m apart in line were used at each station for this test. The energy return was very poor at shooting depths less than 35 m.

The best shooting depth was considered to be between 35 and 55 m.

Charge size comparisons

Charge size comparisons were made in a single shot-hole at Traverse A, SP190 (Plate 8), using the same spread configurations as for the up-hole survey. Charges of 4.5 to 91 kg were fired at a depth of about 52 m. The results indicated that the minimum acceptable charge was about 23 kg. Smaller charges gave insufficient return of energy.

Geophone type and pattern comparisons

Comparison tests were carried out at Traverse A, SP187, with HSJ 14-Hz and HSI 4.5-Hz geophones and two types of geophone pattern with various shot-hole depths, charge sizes, and patterns.

The comparison records are shown in Plate 9, and Table 2 gives details of the relevant parameters.

TABLE 1. Geophone and shot-hole pattern comparisons, Mildura, Traverse A, SP187.

Record	Geophones			Shot-holes			
	Type	Pattern		Depth (m)	Charge (kg)	Pattern	
(a)	4.5 Hz	8	6 m apart in line	45	10 x 4.5	10	10 m apart in line
(b)	14	"	"	"	"	"	"
(c)	4.5	"	"	"	4 x 11.1	4	20 m apart in line
(d)	14	"	"	"	"	"	"
(e)	4.5	"	"	6	9 x 2.5	9	10 m apart in line
(f)	14	"	"	"	"	"	"
(g)	14	"	"	45	10 x 4.5	10	"
(h)	14	16	"	"	"	"	"
(i)	14	8	"	"	10 x 9.1	"	"
(j)	14	16	"	"	"	"	"
(k)	14	8	"	6	10 x 4.5	"	"
(l)	14	16	"	"	"	"	"

A slight improvement in random noise cancellation occurred when the number of geophones in the pattern was increased from 8 to 16. The increase in the geophone pattern length from 42 to 90 m gave more effective linear filtering of the coherent noise and resulted in an increase in the signal-to-noise ratio. The results also indicated that the apparent deep crustal reflections were recorded with a higher signal-to-noise ratio with 14-Hz geophones.

Shot-hole pattern comparisons

Shot-hole pattern tests were carried out at Traverse A, SP186. Shot-holes used for the tests were limited, by available drilling power, to 20 holes in 2 rows of 10 in line with rows 20 m apart and holes 10 m apart. The comparison records are shown in Plate 10 and Table 2 gives details of the relevant parameters.

TABLE 2. Shot-hole pattern comparisons, Mildura, Traverse A, SP186

Record	Shot-holes		
	Depth (m)	Charge (kg)	Pattern 10 m
(a)	36	20 x 9	x x x x x x x x x x - 20 m x x x x x x x x x x -
(b)	36	5 x 9	o x o x o x o x o x o o o o o o o o o o
(c)	36	17 x 2.3	x x x x o x x x o o x x x x x x x x x x
(d)	36	3 x 16	o o o o o o o o o o o x x o o x o o x o
(e)	24	6 x 7	o o o o o o o o o o o o x x o x o x x x
(f)	15	4 x 14	x x x x o o o o o o o o o o o o o o o o
			x Holes shot o Holes not shot

The record with the highest signal-to-noise ratio in this test, (a), was obtained with a pattern of 20 holes and a total charge of 180 kg. Reduction in charge size resulted in a slight deterioration of the record quality as shown in (c). Reduction in the number of holes in the pattern, keeping approximately the same total charge as for (c), resulted in further deterioration of the record quality in (b) and (d). The records (e) and (f) illustrated that poor results may be expected from a reduction of the number of holes in the pattern coupled with a decrease in the depth of the shots.

Experimental recording techniques

As a result of the experimental work it was concluded that the equipment and the shooting and recording parameters most likely to give the best-quality deep crustal reflections in the Mildura test area were as follows:

Geophone type	-	HSJ 14-Hz
Geophone pattern	-	16 geophones, 6 m apart in line
Shot-hole depth	-	36 m
Shot-hole charge	-	23 kg per hole
Shot-hole pattern	-	20 holes in 2 rows of 10 in line Rows 20 m apart Holes 10 m apart
Recording filter	-	K14-K125

The observation that the apparent frequencies of the probable deep crustal reflection events are greater than 15 Hz is consistent with results obtained since the present survey elsewhere in the world. Fuchs (1969) states that deep crustal reflections possess a lower cutoff frequency at about 10 Hz, and refers to special studies with low-frequency instrumentation which concluded in a failure to record low-frequency reflections from the deeper parts of the crust. Davydona, Kosminskaya & Michota (1970) discuss the results of tests which indicate that subcritical deep crustal reflections were recorded with the highest amplitude at a peak reflection frequency of 16 Hz. 14-Hz geophones and a low-cutoff filter of K14 were chosen for reflection recording in preference to 4.5-Hz geophones, and the low-cutoff filter was out for recording.

A slow drilling rate, mainly due to drilling deep holes in clay, would have imposed a practical limitation on the progress of the survey; therefore it was not possible to use the preferred number of holes in the pattern. The greatest number of geophones available during the tests was 16 geophones per station. After the tests, however, more geophones became available, and it was possible to increase the number considerably to improve random noise cancellation and to obtain a more effective linear filter without impeding the progress of the survey.

The following modifications to the proposed recording parameters were used in detailed deep crustal reflection work in the Mildura area, as a result of these considerations:

Shot-hole pattern	-	5 holes, 20 m apart in line or 3 holes, 33 m apart in line
Geophone pattern	-	48 geophones in 2 rows of 24 in line Rows 6 m apart Geophones 6 m apart

4. DEEP CRUSTAL REFLECTION PROFILES - MILDURA, VICTORIA

The objectives of the experimental profiling were to test the effectiveness of the recording techniques established as a result of the preliminary experimental work and to determine practicable seismic reflection profiling techniques to provide information on the deep part of the crust and the upper mentle in the test area. An expanded spread, two continuous split-spread reflection traverses, and an offset reflection traverse were shot in the Mildura area.

Expanded spread - Traverse A, SP180 (Plate 11)

An expanded spread (Musgrave, 1962) was shot using the recording parameters established from the initial experimental work. A split-spread was recorded on Traverse A, SP180, with a similar spread configuration as for the comparison tests. The same subsurface was covered with subsequent shots. This subsurface was as close as practicable to that of the earlier experimental work, but in a position where a long shot-to-geophone offset was possible. The spread was shot out to a maximum shot-to-geophone offset of 27 km. A long offset was necessary to allow noise from the source to decay below the signal level (Dix, 1965) and to permit fairly accurate determinations of the average vertical velocities to any groups of deep crustal reflections which could be recorded (German Research Group for Explosion Seismology, 1964).

The events recorded on the expanded spread were classified broadly into three groups as shown in Table 3.

TABLE 3. Seismic Events Recorded on Expanded Spread, Mildura, Traverse A, SP180

Group	Event	Velocity (m/s)	Frequency (Hz)	Wave number (cycles/1000 m)	Remarks
1	S	-	20	-	Sedimentary reflections
	R1	1900	50	2.6	Refraction events from sediments and basement
	R2	5700	-	-	"
	R3	5700	-	-	"
	R4	5700	-	-	"
2	N1	3400	10	2.9	Noise - basement
	N2	2700-3900	15-17	3.8-6.5	Noise - sediments
3	I	-	20		Apparent reflection
	M	-	20		Apparent reflection

The events in Group 1 do not affect the records in the zone of interest for deep crustal reflections. The noise events in Group 2 were not attenuated significantly by the electrical and spatial filters used. However, these events decay in amplitude with increasing offset distance and do not seriously affect probable reflection events recorded at times greater than 8 s. These noise events were masked at short offsets by other more prominent noise events recorded on the noise test records shown in Plate 4.

Suites of events exhibiting curvatures were recorded between 8 and 12 s. The most prominent events, I and M in Plate 11, are in Group 3; however, other less prominent events with similar curvature are evident, on the section in Plate 11, between the I and M events. The curvatures indicated are considered to be normal for primary reflections at these record times. The absence of high-amplitude reflection events in the interval from 1 to 8 s precludes the possibility of the curved events being multiple reflections.

The events I and M are variable in both amplitude and continuity, and individual phases of the events could not be correlated across the expanded spread. The apparent moveouts for these events across the spread were determined at particular points where local increases in amplitude were detected. These points are indicated on the cross-section in Plate 11.

Velocity and depth information derived from the I amd M events on the expanded spread using the VELSPRED computer program (Pettifer, 1972) are presented in Plate 12 and summarized in the following table.

TABLE 4. Velocity and depth information, expanded spread, Mildura, Traverse A, SP 180

Event	Recorded time (s)	Average velocity (km/s)	Interval velocity (km/s)	Depth (km)
-	0.80	2.00 (Average)		0.80
I	7.86	5.70 ± .17	6.15	22.51 ± .58
M	10.15	5.99 ± .06	6.98 ± .86	30.65 ± .27

The selection of particular points, from which velocity and depth information are derived, tends to imply lower standard deviations than would otherwise be the case if more doubtful points on the curved events were timed.

The results of offset shooting on the expanded spread indicated that the M event was recorded with the highest amplitude and good continuity at near-vertical incidence, and that the I event was recorded most effectively at a shot-to-geophone offset of about 12 km. Similar variations in the amplitude and continuity of deep crustal reflections were observed by Fuchs (1969), when he recorded deep crustal reflections using wide-angle reflection techniques. Fuchs considered that the variations with increasing offset distance may be due to changes in the angles of incidence of plane waves at laminated transition zones at the Intermediate layer and Moho Discontinuity. However, it is probable that variations may also be caused by lateral changes in the basement configuration and in the composition of the upper part of the crust.

The results of the expanded spread suggested that split-spreads should be used in the Mildura area for continuous profiling of the M event and that a shot-to-geophone offset of about 12 km would be desirable for continuous profiling of the I event.

Continuous reflection profiles

James & Steinhart (1966) stipulated that deep crustal reflection observations must be repeatable over short distances with both shot and geophones having been moved, before the reflections can be accepted as valid. They must also be proved to have been reflected from deep within the crust and not to have been the result of backscattering from obstacles and heterogeneities within the shallow part of the crust. It was proposed that an appropriate method of satisfying these requirements would be to record a continuous reflection profile over a considerable length of traverse and to shoot at least one cross-traverse.

Continuous reflection profiles were recorded at Mildura, as close as possible to the site of the initial experimentation, in a location where two traverses could be surveyed perpendicular to each other (Plate 2). It was not possible to extend Traverse A westwards to the centre of the expanded spread because of the limited time available for the survey in this area.

Split-spread profiles were recorded on Traverses A and B using 1080-0-1080 m spreads as for the comparison work and for the expanded spread. Part of Traverse B was re-recorded with a shot-to-geophone offset of 10.8 to 12.96 km, in an attempt to obtain continuous coverage of the I event. Recording parameters were as determined from the preliminary experimental work, modified as noted to take the drilling situation and the increased number of available geophones into account.

<u>Traverse A - Split-spread</u> (Plate 13). A broad band of discontinuous probable reflection events was recorded between 8 and 11 s record time. In addition a horizontal event was recorded at a time of 14.7 s over 2-km subsurface coverage at the eastern end of the traverse. No distinct events were recorded in the section between 1 and 8 s, which indicates that the events were probably primary reflections.

The probable reflection events at 10 to 10.3 s record time appear generally to dip gently to the west.

<u>Traverse B - Split-spread</u> (Plate 14). The amplitude and continuity of probable deep crustal reflection events recorded on Traverse B were better than those recorded on Traverse A. A copy of the original record from Traverse B, SP1202, which shows the highest-quality probable deep crustal reflections obtained during the survey, is shown in Plate 15. A narrow band of high-amplitude, probable reflection events was recorded at about 10 s. The horizontal event recorded at a time of 14.7 s at the eastern and of Traverse A at its intersection with Traverse B was also recorded as a horizontal event at this position on Traverse B.

The events at about 10 s record time appear generally to dip gently to the north.

Traverse B - Offset-spread (Plate 16). Three offset spreads were shot on Traverse B. The quality and continuity of a probable reflection event at about 8.6 s record time is shown to be an improvement over that recorded on the split-spread profiles. The quality of other events recorded later is not significantly different from that of the split-spread profiles.

Reflection results

The main events recorded at about 10 s record time on Traverses A and B are nearly horizontal, indicating that these are probably reflections recorded at near-vertical incidence and hence are from deep within the crust. The absence of reflections from 1 to 8 s record time rules out the possibility of the events being multiples. The same criteria also apply to the other events recorded between 8 and 15 s. A number of low-amplitude dipping events, with continuity extending over more than one record, were recorded at times of 11 to 14.5 s on Traverses A and B; however, insufficient data were available to define the source of these events.

A prominent reflection recorded on the offset reflection profile at 8.6 s does not correlate with the I event on the expanded spread to the west of Traverse B. This reflection time does correspond, however, to that of one of the less distinct probable reflection events recorded on the expanded spread between the I and M events.

Depth and dip estimates for the reflections at the intersection of Traverses A and B have been made by assuming average vertical velocities derived from the expanded spread and assuming a vertical velocity of 8.05 km/s below the M horizon (Doyle & Everingham, 1964). These are shown in Table 5.

TABLE 5. Depth and dip information, Mildura, Traverses A and B

Event	Recorded time (s)	Average velocity (km/s)	Dip (°)	Depth (km)
I	8.6	5.7	8 S	24.5
M	10.1	6.0	3.5 NNW	30.3
-	14.7	6.6	1 N	48.8

The deep crustal events recorded satisfy the criteria stipulated by James & Steinhart (1966). They are considered to be primary reflections from deep within the crust and the upper mantle. The modified recording techniques established as a result of the preliminary experimental work were used successfully to record fair-quality deep crustal reflections in the Mildura area. It was possible, using velocity information obtained from the expanded spread, shot with a maximum shot-to-geophone offset of 28 km, to estimate the depths to the principal reflectors recorded on the reflection profiles.

5. EXPERIMENTAL RECORDING - BROKEN HILL, N.S.W.

The objective of experimental work in the Broken Hill area, from mid-November to mid-December 1968, was to determine whether deep crustal reflections could be obtained there using recording techniques similar to those used on the Mildura area. The Broken Hill area, which lies on the Willyama Complex, was selected on a test location because it is fairly close to the Mildura area but has a geological environment somewhat similar to that of the Geotraverse in Western Australia.

The program included a noise test, up-hole survey, some charge size and shot-hole and geophone pattern comparisons, and an experimental transverse spread test in addition to two reflection profiles and an expanded spread.

The locations of traverses in the Broken Hill area are shown in Plate 3, and operational statistics are included in Appendix 2.

Noise test (Plate 17)

A noise test was recorded with geophone stations 20 m apart along a spread with a maximum shot-to-geophone distance of 2480 m. The test was recorded with eight 14-Hz geophones 6 m apart in line. Filtering was introduced by the high-frequency geophones and the use of linear geophone patterns as for the noise test (Plate 6), which had been recorded at Mildura. The velocities and frequencies of the interfering noise events and the frequency of an apparent deep crustal reflection event were measured.

The refraction event (1) has a high velocity and a high apparent frequency and does not affect the records in the zone of interest for deep crustal reflection events. Events (2), (4), (5), and (6) are noise events which are attenuated with increasing shot-to-geophone distance. Refraction event (3) may be attenuated by electrical filters and is not considered to extend into the zone of interest. Event (7) is considered to be a probable deep crustal reflection.

Analysis of the noise test (Plate 17) indicated that a low-cut electrical filter of 14 Hz and a linear filter with source and geophone patterns of length 138 m (k_c = 3.4 cycles/1000 m), identical to those used for reflection profiling at Mildura, would be acceptable for profiling in the Broken Hill area.

Up-hole survey

An up-hole survey was shot at Traverse A, SP500. Charges of up to 45 kg were detonated at depths ranging from 70 m to 2 m and were recorded on a normal spread. The drilling at this shot-point was easy, and a weathering velocity of 1500 m/s was established in the section to the total depth of the hole. The energy return was very poor for all shots although an apparent reflection event was just discernible at about 4.8 s on the records from most deep shots.

The best shooting depth at SP500 was considered to be between 30 and 45 m. However, as the drilling was in unconsolidated material to the bottom of the hole, it is probable that if the hole had been drilled deeper into fresh bedrock shooting conditions would have been improved.

Charge size and pattern comparisons

Charge comparisons were not made specifically at a particular shot-point. However, the results from various shots on Traverse A, SP494-500 were compared in an attempt to determine an optimum shooting technique for the Broken Hill area.

Initially comparison records were obtained, from shots at SP500, between a 23-kg charge in a single shot-hole at a depth of 30 m, and a 920-kg charge distributed in 40 holes in a pattern, at the same depth. The 40-hole pattern gave better results, probably because of the increase in total charge and the distribution of the large charge, for which the 40 holes were in 4 rows of 10 holes in line, with holes 10 m apart and rows 10 m apart. The probable deep crustal reflection event at 4.8 s record time was of better quality than that recorded for the single charge, and an event at 9.1 s record time was also discernible. This latter event could be a multiple of the earlier event.

The principal charge comparisons were shot between SP494 and SP500 using total charge sizes ranging from 227 kg to 907 kg in various shot-hole patterns from 5 holes 20 m apart in line at depths up to 5.5 m, to 20 holes 10 m apart in line at depths of 30 m. Because of the variable near-surface geological conditions along the traverse, the results of the comparison tests were inconclusive. However, it was proposed that a large charge distributed in as many holes as possible, to a depth of about 30 m, would be best, and that a charge of at least 454 kg distributed in 10 holes 10 m apart in line, at depths of about 30 m, would be a practicable arrangement. This distributed charge and pattern was used generally for shots on Traverse A, SP490-493, and on the expanded spread centred on SP490½.

Two very large charges were shot at Traverse A, SP493, and at Traverse C, SP1499, respectively, to determine whether a large increase in charge size would improve the energy penetration and by so doing improve the quality of the results. At SP493, 7100 kg ammonium nitrate, equivalent to 4500 kg Geophex, was distributed in 49 holes arranged in a diamond pattern with 15 m between holes. At SP1499, 7800 kg ammonium nitrate, equivalent to 4900 kg Geophex, was distributed in 36 holes in 6 rows of 6 holes in line, with holes 20 m apart and rows 15 m apart. A copy of the original record from the large shot at SP493, the best record obtained in the Broken Hill area, is shown in Plate 18.

Geophone pattern comparisons

Comparisons were obtained at Traverse A, SP496 and SP497, between spreads shot with 48 geophones per station in 2 rows of 24 in line, with 6 m between geophones and rows, and 48 in 6 rows of 8 in line, with 6 m between geophones and rows. As expected, the geophone pattern of 2 rows of 24 in line of length 138 m (k_c = 3.4 cycles/1000 m) gave better coherent noise cancellation than the patterns of length 42 m (k_c = 10 cycles/1000 m).

Experimental transverse spread

An experiment was done at SP499 and SP500 to determine whether an event recorded with fair continuity and amplitude at SP500, at a record time of about 4.8 s, was arriving at near-vertical incidence. A short transverse spread, length 600-0-600 m, was laid through SP500, perpendicular to Traverse A. Geophone patterns were laid at stations on the transverse spread with each pattern laid radially towards SP499 to maintain the same linear filtering as for normal reflection shooting. A shooting diagram for the transverse spread shot from SP499 is shown in Plate 19, and copies of the records from SP499 Experimental and SP500 are shown in Plate 20.

The record from SP499 Experimental shows a near-horizontal, fair-quality event at about 4.8 s record time similar to that recorded from SP500, indicating that this is a probable deep crustal reflection arriving at near-vertical incidence. Other less clearly defined events with similar characteristics, recorded from SP499 Experimental and SP500, are also probably deep crustal reflections.

6. DEEP CRUSTAL REFLECTION PROFILES - BROKEN HILL, N.S.W.

The objective of experimental profiling in the Broken Hill area was to test the effectiveness of the recording techniques developed at Mildura and during experimental work at Broken Hill, and to determine whether these techniques could be used to provide information on the deep part of the crust in the Broken Hill area. Split-spread reflection profiling, using 1080-0-1080 m spreads, was done along a 9 km traverse and a 4 km cross-traverse, and an expanded spread was shot out to a maximum shot-to-geophone offset of 15 km.

Traverse A - Split-spread (Plate 21). The energy return along this Traverse was very low despite the use of larger charges than those used at Mildura, and large charges were found to be necessary for deep penetration. The best record was obtained, late in the survey, at SP493, using the equivalent of 4500 kg Geophex; it was not practicable, however, to reshoot the whole traverse using such large charges. The charges and shot-hole patterns used on Traverse A for records in Plate 21 are shown in Table 6.

TABLE 6. Charge and shot-hole patterns, Broken Hill, Traverse A

SP	Depth (m)	Total charge (kg)		Pattern
490	15.2	145	4	10 m apart in line
493	24.4	4500	49	15 m apart in diamond pattern
494	30.5	454	20	2 rows, holes 10 m apart in line Rows 10 m apart
495	32.0	113	5	20 m apart in line
496	36.6	227	10	10 m " " "
497	36.6	204	9	10 m " " "
498	45.7	454	10	10 m " " "
499	54.9	454	10	10 m " " "
500	30.5	907	40	4 rows, holes 10 m apart in line Rows 10 m apart

No clearly defined probable deep crustal reflections, either showing continuity over considerable sub-surface coverage or in discontinuous bands, were recorded along the entire traverse. However, an ill-defined near-horizontal event was recorded at about 4.8 s along most of the traverse, and at SP493, several suites of strong near-horizontal events are evident at record times down to 15 s. The highest-amplitude, most continuous event recorded at SP493 was from 14.3 s record time.

Traverse C - Split-spread (Plate 21). Traverse C was shot with larger charges than those generally used on Traverse A, and the energy return appears to have been better than on Traverse A. The charge at SP1499 was about the same as that at SP493: 4900 kg Geophex equivalent at SP1499 compared with 4500 kg at SP493. Penetration appears to have been equivalent, but fewer suites of events were recorded and the events lack the continuity of those from SP493.

The highest-amplitude suite of events was recorded at about 11.3 s record time at SP1499.

Expanded spread - Traverse A, SP490½ (Plate 22). The expanded spread was recorded, centred on SP490½, using the same basic parameters as for the spread at Mildura, but with an increased charge size of 454 kg per shot.

Only poor-quality reflection events were recorded to about 15 s record time. The events were timed, as on the Mildura expanded spread, at particular points where local increases in amplitude of the possible reflection events were evident (Plate 22). Velocity and depth information derived using the VELSPRED computer program are presented in Plate 23. The low standard deviations are again the result of selecting particular points from which to determine velocities rather than other more doubtful points. The information at Broken Hill, elevation 220 m, is summarized in Table 7.

TABLE 7. Velocity and depth information, expanded spread, Broken Hill, Traverse A, SP490½

Event	Record Time (s)	Average Velocity (km/s)	Interval Velocity (km/s)	Depth (km)
I1	2.49	5.72 ± .16		7.30 ± .10
			6.52 ± .90	
I2	3.60	5.96 ± .17		10.68 ± .22
			5.81 ± 1.25	
I3	4.95	5.92 ± .22		14.75 ± .48
			6.97 ± 1.04	
M1	11.28	6.51 ± .48		36.71 ± 2.68
			8.05 (assumed)	
M2	14.60	6.86		50.07

The results of the expanded spread indicate that coherent noise was not troublesome but that energy penetration was a major problem. The probable deep crustal reflection events, in the analysis, were not recorded as continuous events out to the maximum shot-to-geophone offset distance but were recorded as reflection segments only. The same order of observational errors were found as for the expanded spread at Mildura, and it is considered that the depths and velocities found can be used to provide a first approximation of the deep crustal structure in the two test areas.

Reflection results

The results on Traverses A and C are generally of low amplitude and poor continuity; however, from these results and from those on the experimental transverse spread shot at Traverse A, SP499, it is concluded that deep crustal reflections have been obtained by continuous reflection profiling in the Broken Hill area, at record times of about 4.8 s, 11.3 s, and 14.3 s.

The event at 4.8 s record time at SP499 appears to correlate with the event at 5.0 s record time on the expanded spread centred at SP490½. The other main events at 11.3 s and 14.3 s record time appear to correlate with events at about those record times on the expanded spread.

7. CONCLUSIONS

Deep crustal reflection profiling techniques were developed on the experimental survey at Mildura, Victoria, and Broken Hill, New South Wales.

The results indicated that reflection events were recorded from deep within the Earth's crust and probably from within the upper mantle in both areas. Although the M event at Mildura, and the M1 event at Broken Hill, could not be said to be definitely from the Mohorovicic Discontinuity, the events were recorded from depths which must place them close to the Discontinuity.

Deep crustal reflection recording techniques

Details of the equipment used and recording parameters found to be effective for deep crustal reflection surveys at Mildura and Broken Hill are given in Appendices 1 and 2.

As expected from the work at Mildura in 1960, fair-quality deep crustal reflections could be recorded using relatively simple techniques. However, it was established by experimental shooting that large numbers of geophones in spatial patterns of length 100 m or more were necessary to satisfactorily attenuate random and coherent noise, and that relatively small charges of 23 kg per hole distributed in 3 or 5 holes, in a linear pattern of 100 m in length, gave effective energy penetration.

Similar recording techniques made it possible to record deep crustal reflections at Broken Hill also, but there large charges of the order of 4500 kg Geophex equivalent, distributed in a large number of holes at the shot-point, were found to be necessary to give effective energy penetration.

The amplitudes of the deep crustal reflections recorded at both Mildura and Broken Hill varied widely within the same general areas, as found elsewhere by Kanasewich & Cumming (1965) and others. The appearance of the deep crustal reflections differed considerably from that of reflectionsfrom shallow sedimentary formations. They generally correlate only over short distances, seldom more than a few kilometres, and are recorded usually with many phases or legs. This agrees with the findings of Dohr & Fuchs (1967).

The seismic program, consisting of reflection profiling along a considerable length of traverse and on a cross-traverse, and an expanded spread, was found to be satisfactory for deep crustal reflection probes at both Mildura and Broken Hill. However, the quality of the seismic information at Broken Hill could probably have been improved by the use of large charges for all shots, and the velocity information could have been improved by recording the expanded spread out to a considerably greater shot-to-geophone offset distance than that used.

Deep crustal structure at Mildura and Broken Hill

The crustal columns based on the seismic reflection results in the Mildura and Broken Hill areas are compared in Table 8. Densities have been assigned to the different layers on the basis of a velocity-density relationship by Nafe and Drake (Talwani, Sutton & Worzel, 1959), and values of 3.32 g/cm^3 and 3.25 g/cm^3 for the density of the material below the Moho Discontinuity and sub-Moho level respectively. These latter densities are based on determinations of Woollard (1970) in areas of sub-Moho layering in the United States.

TABLE 8. Comparison of crustal columns

	Mildura (Elev. 50 m)				Broken Hill (Elev. 220 m)			
Possible level	Depth (km)	Thickness (km)	Velocity (km/s)	Density (g/cm^3)	Depth (km)	Thickness (km)	Velocity (km/s)	Density (g/cm^3)
Surface	-0.05				-0.22			
		0.80	2.00	1.90				
Basement	0.75							
		22.70	6.15	2.80		14.75	5.92	2.75
Intermediate	23.45				14.53			
		7.15	6.98	3.06		21.96	6.97	3.06
Moho	30.60				36.49			
		18.15	8.05 (ass.)	3.32		13.36	8.05 (ass.)	3.32
Sub-Moho	48.75				49.85			
		1.10		3.25				
	49.85							
Mass/unit area to 49.85 km (x10^5 g/cm^2)		150.79				152.11		
observed free-air anomaly (mgal)*		-8.0				+45.9		

* From Dooley, McCarthy, Keating, Maddern & Williams (1961)

The mass per unit area to the level of the deeper sub-Moho layer at Broken Hill (49.85 km) has been computed for the two columns. From the difference in the two masses per unit area (1.32 x 10^5 g/cm^2), an estimate of the difference in the gravity effect between the two areas, $2\pi\gamma\Delta R\Delta\rho$ where γ is the gravitational constant and $\Delta R\Delta\rho$ is the difference in mass per unit area between the crustal columns in the two areas, is calculated to be (41.85 x 1.32) = 55.2 mgal. The difference in the observed free-air anomalies at the Mildura and Broken Hill pendulum stations is 53.9 mgal. Although the difference in the regional free-air anomalies in the two areas may differ somewhat from this value, the close agreement suggests that the depths and velocities of the deep crustal and mantle layers obtained from the seismic work and the assigned densities are reasonable.

From observations made in some areas of the United States, where sub-Moho layering has been detected seismically, Woollard (1970) concludes that isostasy, in these areas, is related to the column above the sub-Moho level rather than that above the Moho Discontinuity. The results at Mildura and Broken Hill indicate that, in these areas, the depth of equal mass corresponds approximately to that of the sub-Moho level (approximately 50 km). Woollard (1970) also found a direct relationship, in areas of sub-Moho layering, between the depth of the Moho, the refraction velocity of the Moho horizon, and the velocity and depth of the sub-Moho layer. No such relationship could be established in the Mildura and Broken Hill areas, because of lack of refraction velocity information on the Moho and sub-Moho layers in these areas.

A fence diagram indicating the possible crustal structure from Mildura to Broken Hill, as determined from the deep crustal reflection work, is shown in Plate 24.

8. RECOMMENDATIONS

The experimental survey at Mildura and Broken Hill indicated that large charges, possibly of the order of 4500 kg Geophex equivalent, would probably be required for the deep crustal reflection survey on the Geotraverse in Western Australia. Further experimental work was recommended, prior to the Geotraverse survey, with objectives as follows:

1. To determine the practicability of using spread lengths of 4320 m with geophone stations at 180 m (twice the length of spreads at Mildura and Broken Hill), to reduce the cost of using large charges for profiling by a factor of two.

2. To investigate the use of Common Depth Point (CDP) profiling techniques (Mayne, 1962) with charges of the order of 500 kg, as an alternative to the use of large charges with single coverage.

A possible model of the structure of the deep part of the crust and the upper mantle in the Mildura and Broken Hill areas has been proposed from an interpretation of the reflection results of the experimental survey. Further geophysical work, to test the validity of this model, is recommended as follows:

1. A deep crustal refraction survey, to the Moho, between Mildura and Broken Hill.

2. Further reflection profiling at several locations between Mildura and Broken Hill.

3. Interpretation, in terms of deep crustal structure, of the regional gravity information over the two areas, when this information becomes available.

9. REFERENCES

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APPENDIX 1

STAFF AND EQUIPMENT

STAFF

Party Leader	J.C. Branson
Observer/Geophysicist	F.J. Taylor
Shooter	R.D.E. Cherry
Surveyor	P. Simpson, Department of the Interior
Toolpusher	B. Findlay
Drillers	E.D. Lodwick
	K. Reine
Drill Assistants	K. Huth
	E. Reid
Mechanic	D.K. McIntyre
Clerk	G.B. Handley
Field Hands	13

EQUIPMENT

Seismic amplifiers	TI 8000
Oscillograph	SIE TRO-6, SIE VRO-6
Magnetic recorder (AM)	DS7-7 (24 s tapes)
Geophones	Hall-Seers HSI 4.5-Hz, HSJ 14-Hz
Drilling rigs	Mayhew 1000 (2)
	Fox Mobile
Other vehicles	International recording truck
	Bedford workshop
	Bedford water tankers (5)
	Bedford flat-tops (2)
	Landrovers, 109" (4)
	Landrover, 88"
	Holden station wagon
	Trailers (4)

Miscellaneous office equipment

APPENDIX 2

OPERATIONAL STATISTICS

Area of operation	Mildura, Victoria	Broken Hill, N.S.W.
Surveying commenced	3 September 1968	7 November 1968
Surveying completed	7 November 1968	14 December 1968
Traverse surveyed	51.8 km	24.8 km
Topographic survey control	Department of the Interior road traverses	
Total number of holes drilled	304	388
Total footage drilled	11570 m	9481 m
Explosives used	8119 kg	16 121 kg
Number of detonators used	375	175
Shot-point interval	1080 m	1080 m
Geophone station interval	90 m	90 m
Common geophone group	48/trace in 2 rows of 24 in line	
	Rows 1 m apart	Rows 6 m apart
	Geophones 6 m apart	Geophones 6 m apart
Other geophone groups	See text and plates	See text and plates
Common hole pattern	3 holes, 33 m apart in line	10 holes, 10 m apart in line
Other hole patterns	See text and plates	See text and plates
Common hole depth	37 m	See text and plates
Common charge size	23 kg/hole	45 kg/hole
Other charge sizes	See text and plates	See text and plates
Normal tamping	Solid	Solid
Normal recording mode	A.G.C. slow	A.G.C. slow
Normal recording filters	K14-K125	K14-K125

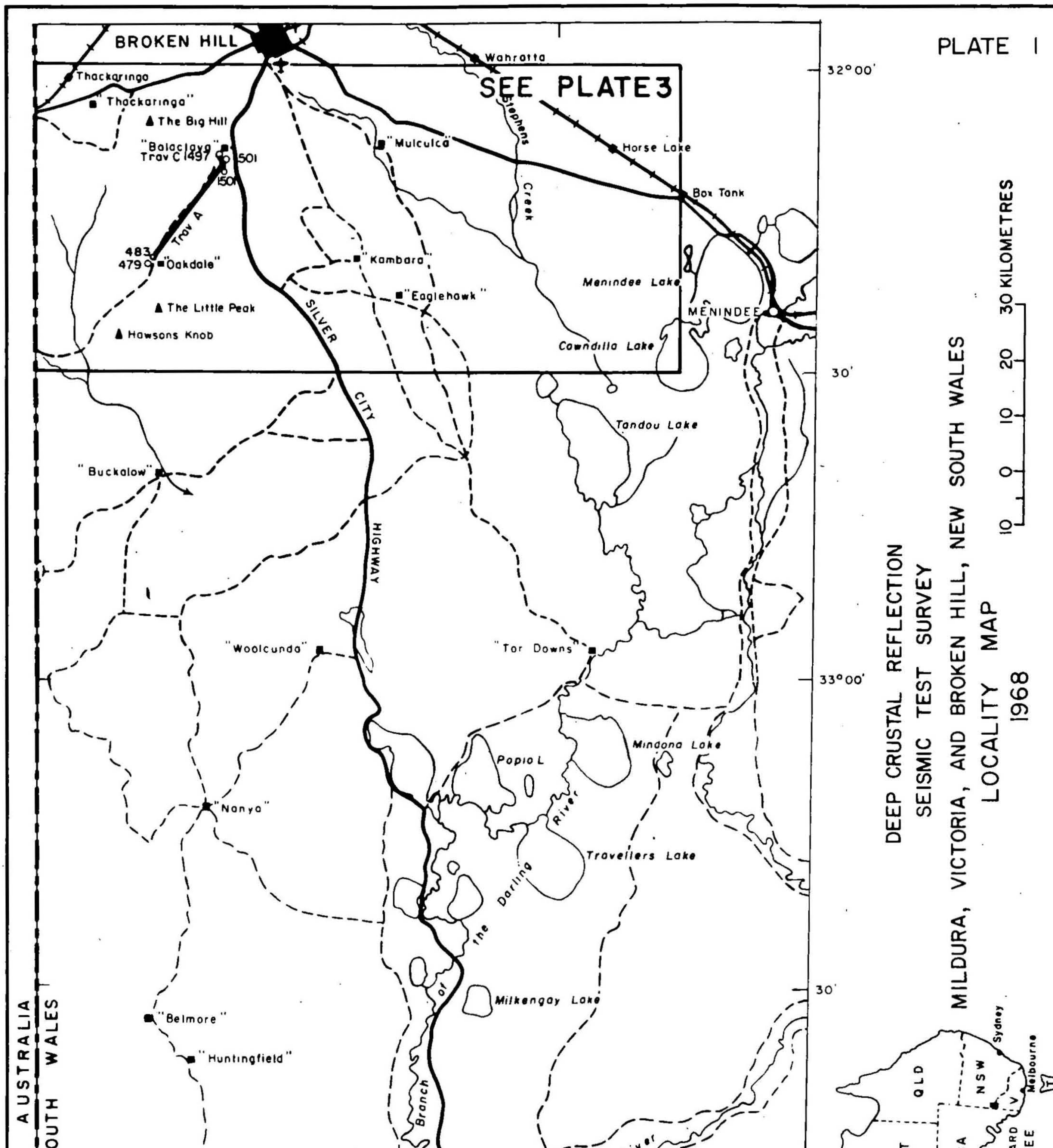
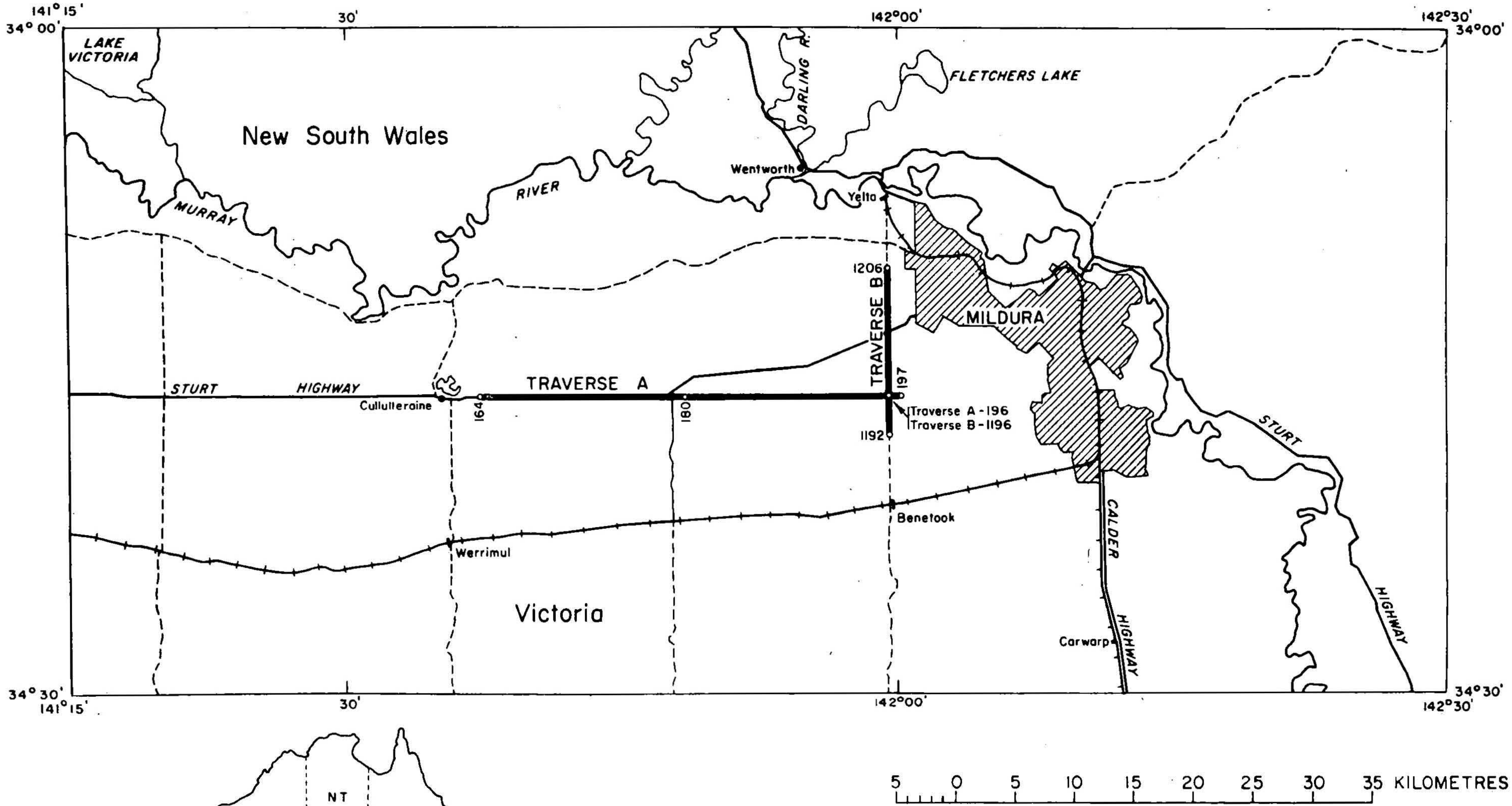


PLATE I
DEEP CRUSTAL REFLECTION SEISMIC TEST SURVEY
MILDURA, VICTORIA, AND BROKEN HILL, NEW SOUTH WALES
LOCALITY MAP
1968
10 0 10 20 30 KILOMETRES
SEE PLATE 3
SEE PLATE 2
BROKEN HILL
Thackaringa
"Thackaringa"
The Big Hill
"Balaclava"
Trav C 1497
1501
Trav A
483
479
"Oakdale"
The Little Peak
Hawsons Knob
Wahratta
Stephens Creek
"Mulculca"
Horse Lake
Box Tank
"Kambara"
"Eaglehawk"
Menindee Lake
MENINDEE
Cawndilla Lake
Tandou Lake
SILVER CITY HIGHWAY
"Buckalow"
"Woolcunda"
"Tor Downs"
Mindona Lake
Popio L
"Nanya"
Travellers Lake
the Darling River
Milkengay Lake
"Belmore"
"Huntingfield"
Ana Branch of the Darling
Darling River
"Lake Victoria"
Lake Victoria
SOUTH AUSTRALIA
NEW SOUTH WALES
MURRAY RIVER
VICTORIA
WENTWORTH
Yelta
MILDURA
MERBEIN
1206
CSIRO
1202
Irymple
STURT HIGHWAY
Cullulleraine
Lake Cullulleraine
KOORLONG
"Taparoo"
164
Trav
180
A
Trav B 1192
Trav A 196
Trav B 1196
REDCLIFFS
Morkalla
Karween
Yarrara
Werrimul
Merrinee
Benetook
Meringur
Bambill
32°00'
30'
33°00'
30'
34°00'
141°00'
30'
142°00'
142°30'
To accompany Record No 1972/127
I54/B3-23A
QLD
NSW
NT
SA
WA
V
T
Sydney
Melbourne
REFERENCE TO AUSTRALIA STANDARD 1:250,000 MAP SERIES MENINDEE

To accompany Record No 1972/127

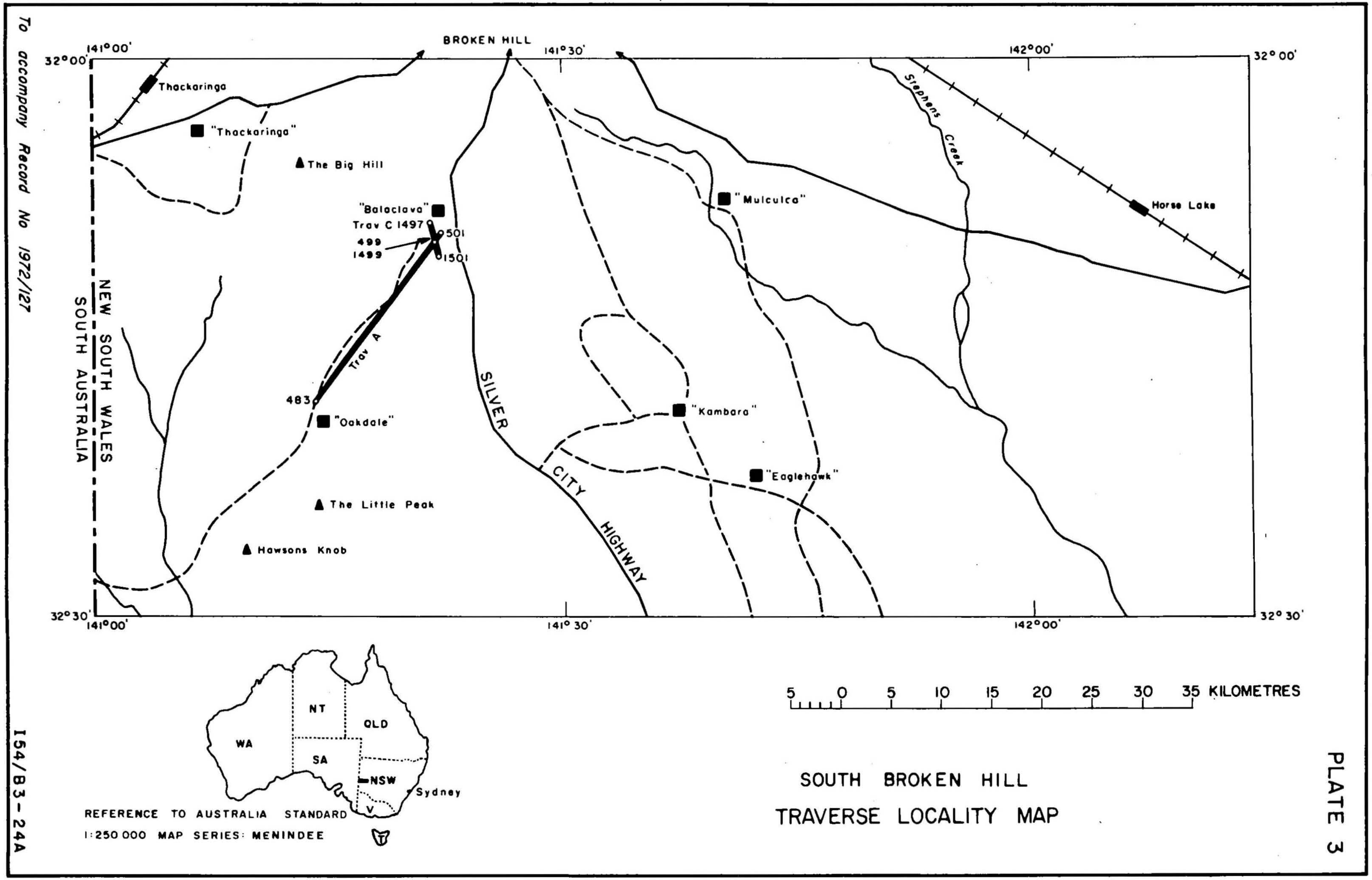


REFERENCE TO AUSTRALIA STANDARD
1:250,000 MAP SERIES : MILDURA

MILDURA, VICTORIA
TRAVERSE PLAN

PLATE 2

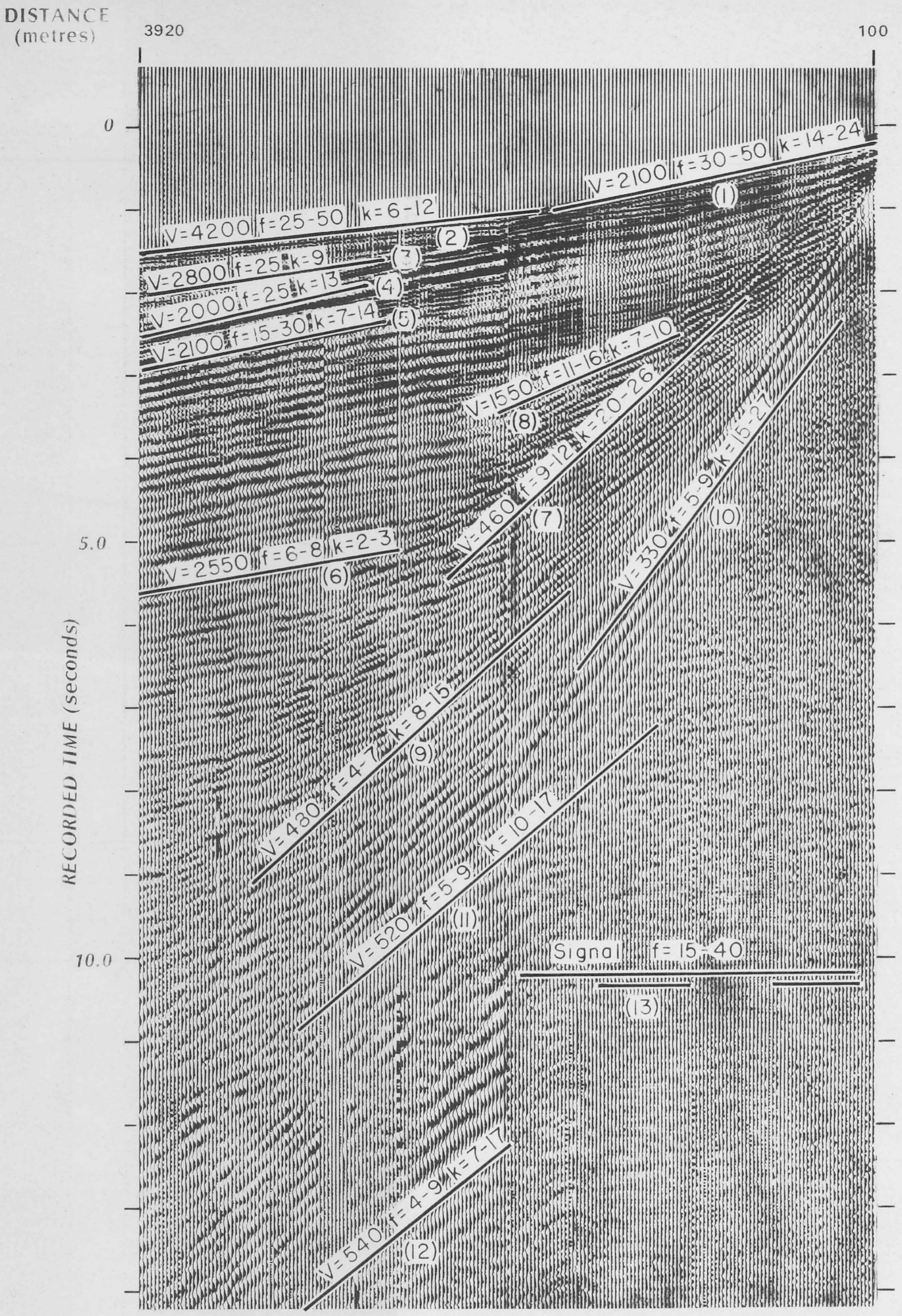
I54/B3-22A

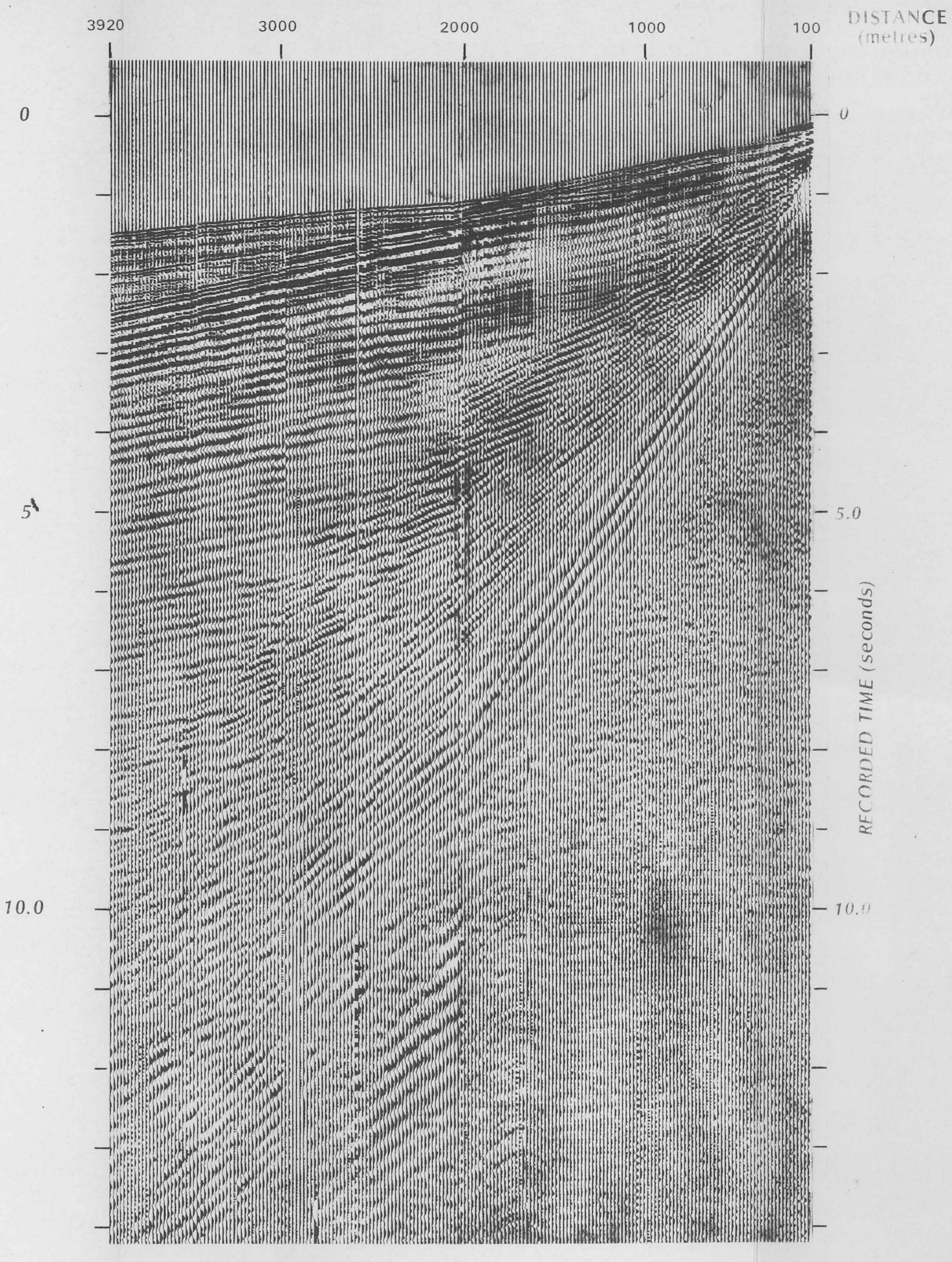


SOUTH BROKEN HILL
TRAVERSE LOCALITY MAP

PLATE 3

RECORD SECTION





RECORDING INFORMATION

Magnetic Recorder: DS7–700
Amplifiers : TI–8000
Prefilters: Nil
Filters : 0–K125
AGC : 1/1–20
Gain Initial: –50
Final : 8μV
Geophones: HSI 4.5Hz
Geophone Station Interval: 20m
Geophone Pattern:

8/trace, bunched

Shot Hole Pattern:

Single
Depth 36–37m
Charge 4.5kg Geophex

PLAYBACK INFORMATION

Filters: Out–Out
AGC : S.S
Gain Initial: –40
Final : –40
Trip Delay: 0
Compositing: Nil

VELOCITY INFORMATION

Nil

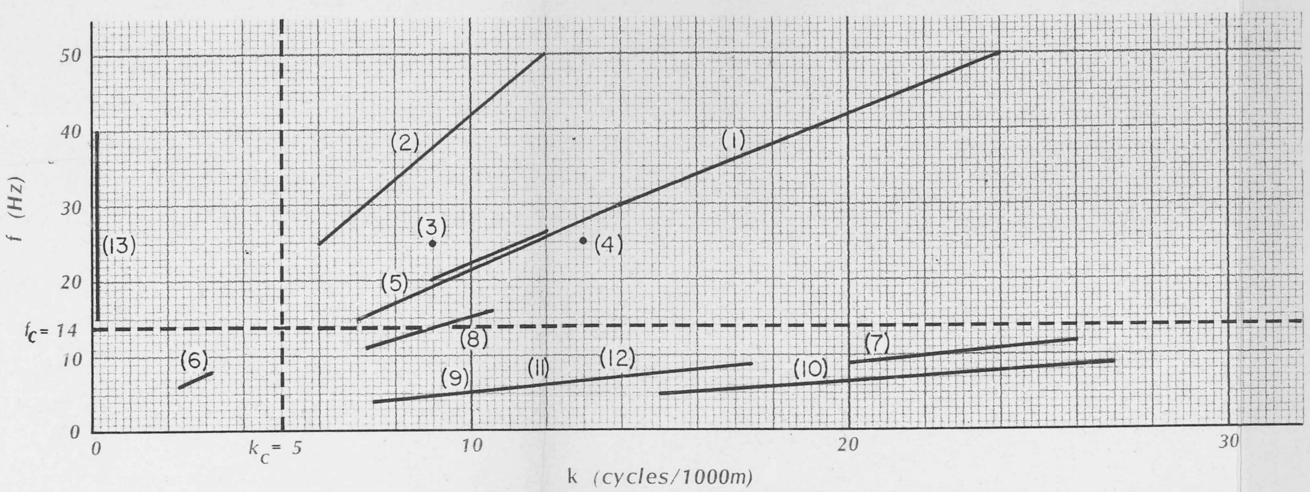
HORIZONTAL SCALE

As indicated

MILDURA, TRAVERSE A, SP187½
NOISE TEST
(8x4.5Hz Geophones, Bunched)

154/B3-11

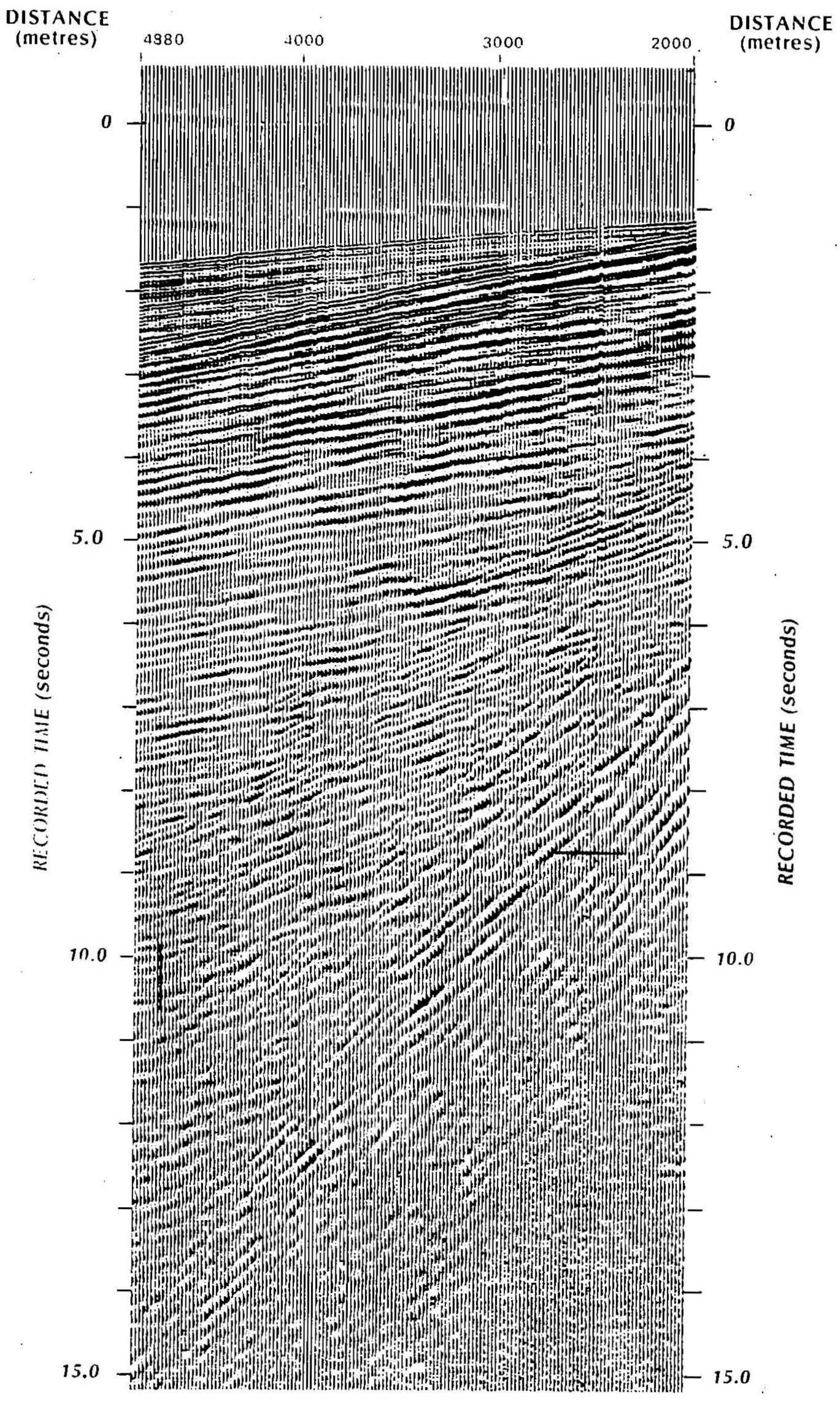
V = *Velocity (m/s)*
f = *Frequency (Hz)*
k = *Wave number (cycles/1000m)*



Frequency — Wave Number Graph

To accompany Record No 1972/127

PLATE 5



RECORD SECTION

RECORDING INFORMATION

Magnetic Recorder: DS7 – 700
Amplifiers : TI – 8000
Prefilters: Nil
Filters : 0 – K125
AGC : 1/1 – 20
Gain Initial: –50
Final : 8 μV
Geophones: HSI 4.5Hz
Geophone Station Interval: 20m
Geophone Pattern:

8/trace, 6m apart in line

Shot Hole Pattern:

Single
Depth 36–37m
Charge 4.5kg Geophex

PLAYBACK INFORMATION

Filters: Out – Out
AGC : S.S
Gain Initial: –40
Final : –40
Trip Delay : 0
Compositing: Nil

VELOCITY INFORMATION

Nil

HORIZONTAL SCALE

As indicated

MILDURA, TRAVERSE A, SP187½
NOISE TEST
(8x4.5Hz Geophones, 6m apart in line)

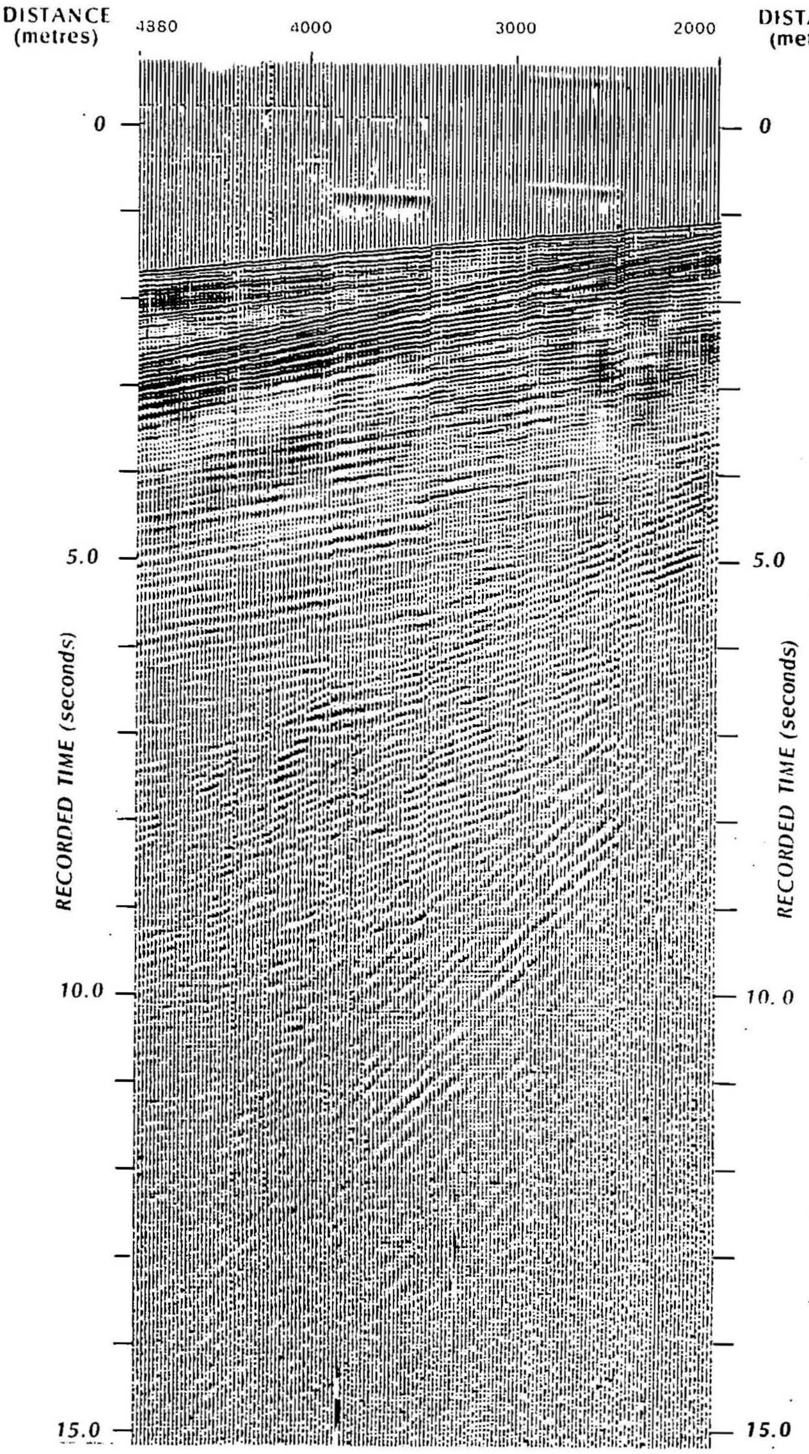
RECORDED BY Seismic Party No. 2
SECTION BY Bureau of Mineral Resources
Playback Centre SIE 115
TO ACCOMPANY RECORD No
(Based on G85 3 115 4)

154/B3–13A

To accompany Record No 1972/127

PLATE 6

RECORD SECTION



RECORDING INFORMATION

Magnetic Recorder: DS7 – 700
Amplifiers: TI – 8000
Prefilters: Nil
Filters: 0 – K125
AGC: 1/1 – 20
Gain Initial: –50
Final: 8μV
Geophones: HSJ 14Hz
Geophone Station Interval: 20m
Geophone Pattern:

8/trace, 6m apart in line

Shot Hole Pattern:

Single
Depth 36–37m
Charge 4.5kg Geophex

PLAYBACK INFORMATION

Filters: Out – Out
AGC: S.S
Gain Initial: –40
Final: –40
Trip Delay: 0
Compositing: Nil

VELOCITY INFORMATION

Nil

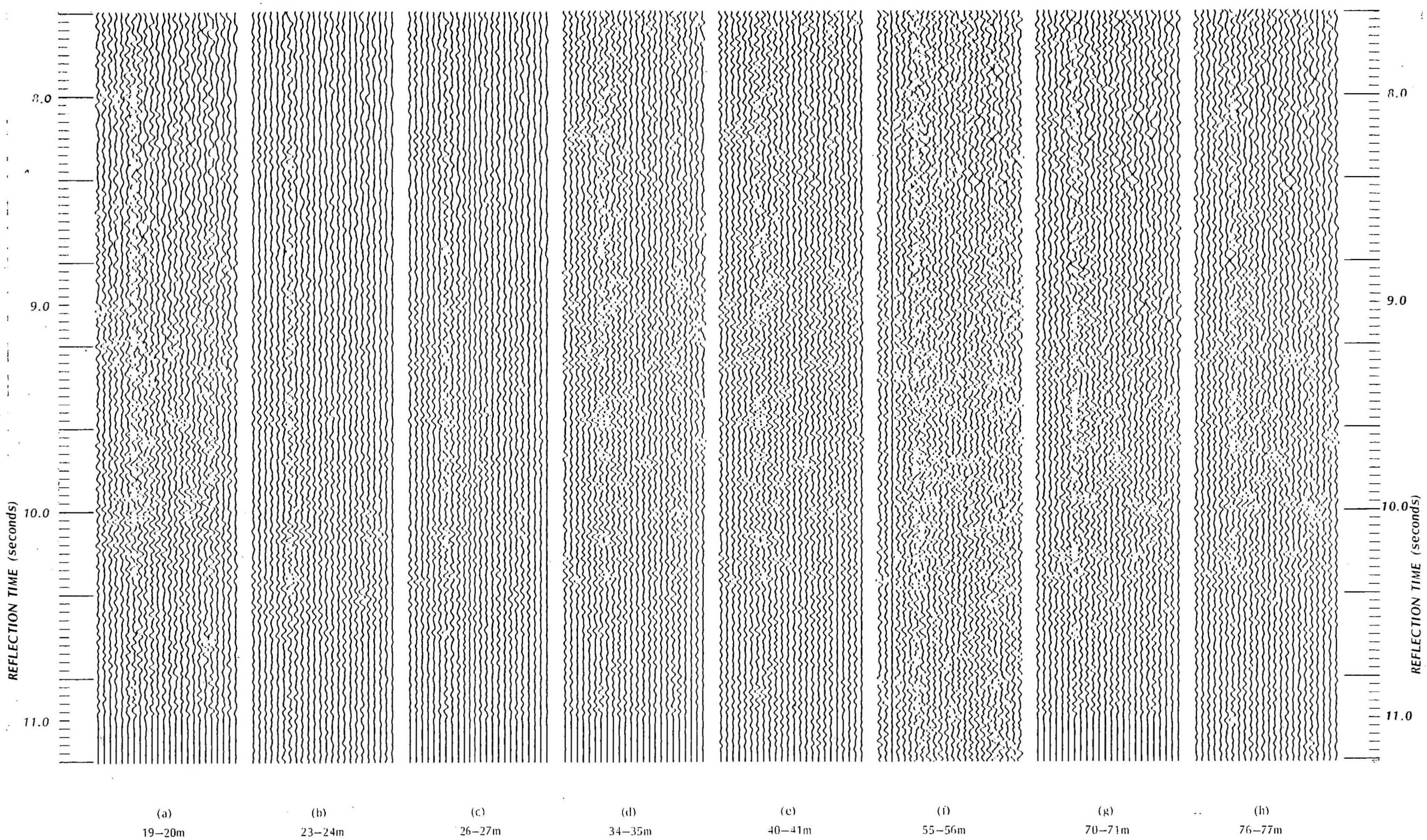
HORIZONTAL SCALE

As indicated

MILDURA. TRAVERSE A, SP187½
NOISE TEST
(8x14Hz Geophones, 6m apart in line)

154/B3–12A

To accompany Record No 1972/127



UNCORRECTED RECORD SECTION

PLATE 7

RECORDING INFORMATION

Magnetic Recorder: DS7–700
Amplifiers : TI–8000
Prefilters: Nil
Filters : 0–K125
AGC : 1/1–80
Gain Initial: –50
Final : 1μV
Geophones: HSI 4.5Hz
Geophone Station Interval: 90m
Geophone Pattern:

8/trace, 6m apart in line

Shot Hole Pattern:

Single
Depth as indicated
Charge 18kg

PLAYBACK INFORMATION

Filters: 1/12–1/55
AGC : Off
Gain Initial: –40
Final : –40
Trip Delay : 0
Compositing: Nil

VELOCITY INFORMATION

Nil

SPREAD

1080 0 1080 Metres
24 13 12 1 Trace

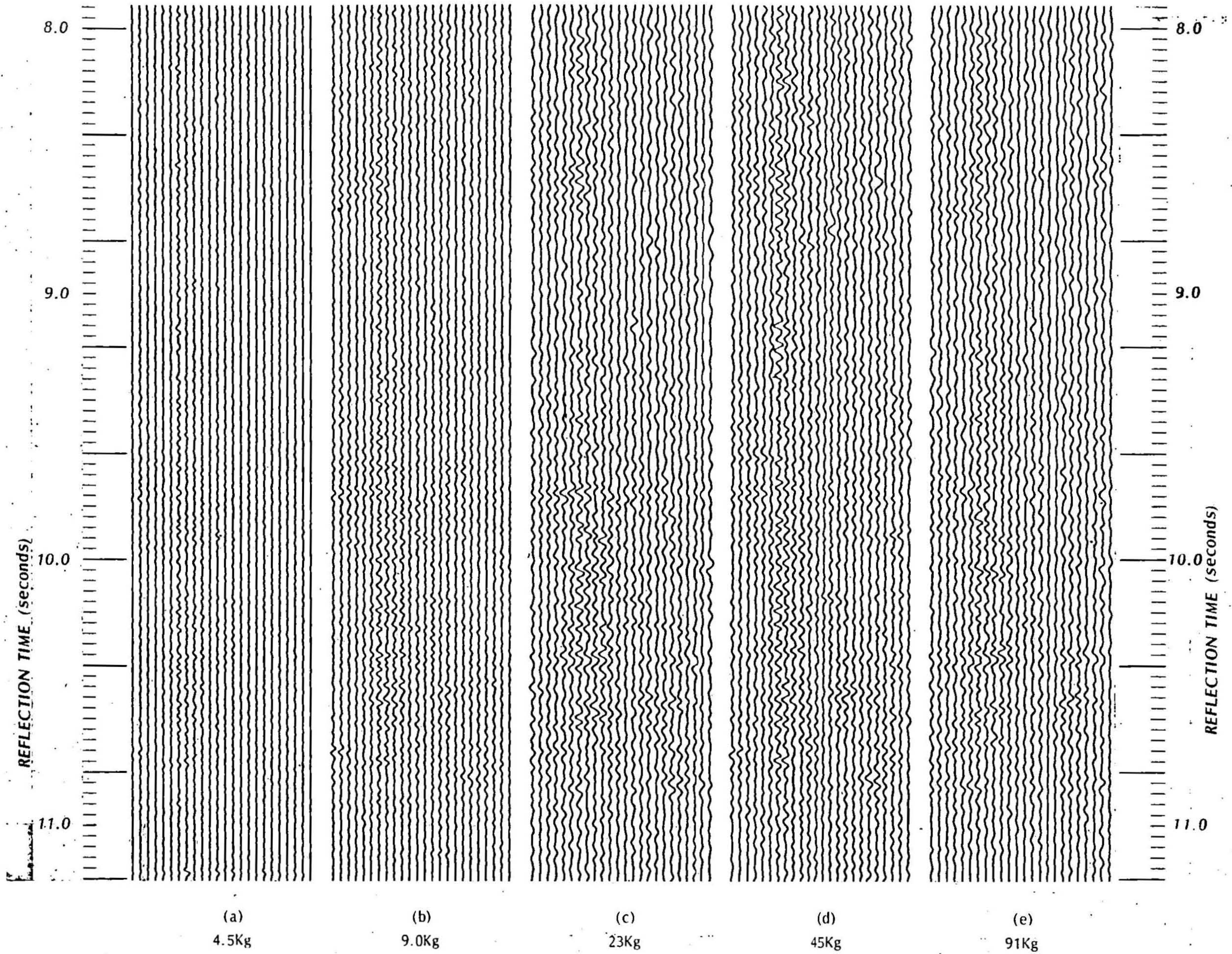
MILDURA, TRAVERSE A, SP190
SHOT HOLE DEPTH COMPARISONS

154/B3–15

To accompany Record No 1972/127

[redacted]LATE[redacted]

UNCORRECTED
RECORD SECTION



RECORDING INFORMATION

Magnetic Recorder: DS7 – 700

Amplifiers : TI – 8000

Prefilters: Nil

Filters : 0 – K125

AGC : 1/1 – 80

Gain Initial: –50

Final : 8 μV

Geophones: HSI 4.5Hz

Geophone Station Interval: 90m

Geophone Pattern:

8/trace, 6m apart in line

Shot Hole Pattern:

Single
Depth 52–64m
Charge As indicated (Geophex)

PLAYBACK INFORMATION

Filters: 1/12 – 1/55

AGC : Off

Gain Initial: –40

Final : –40

Trip Delay: 0

Compositing: Nil

VELOCITY INFORMATION

Nil

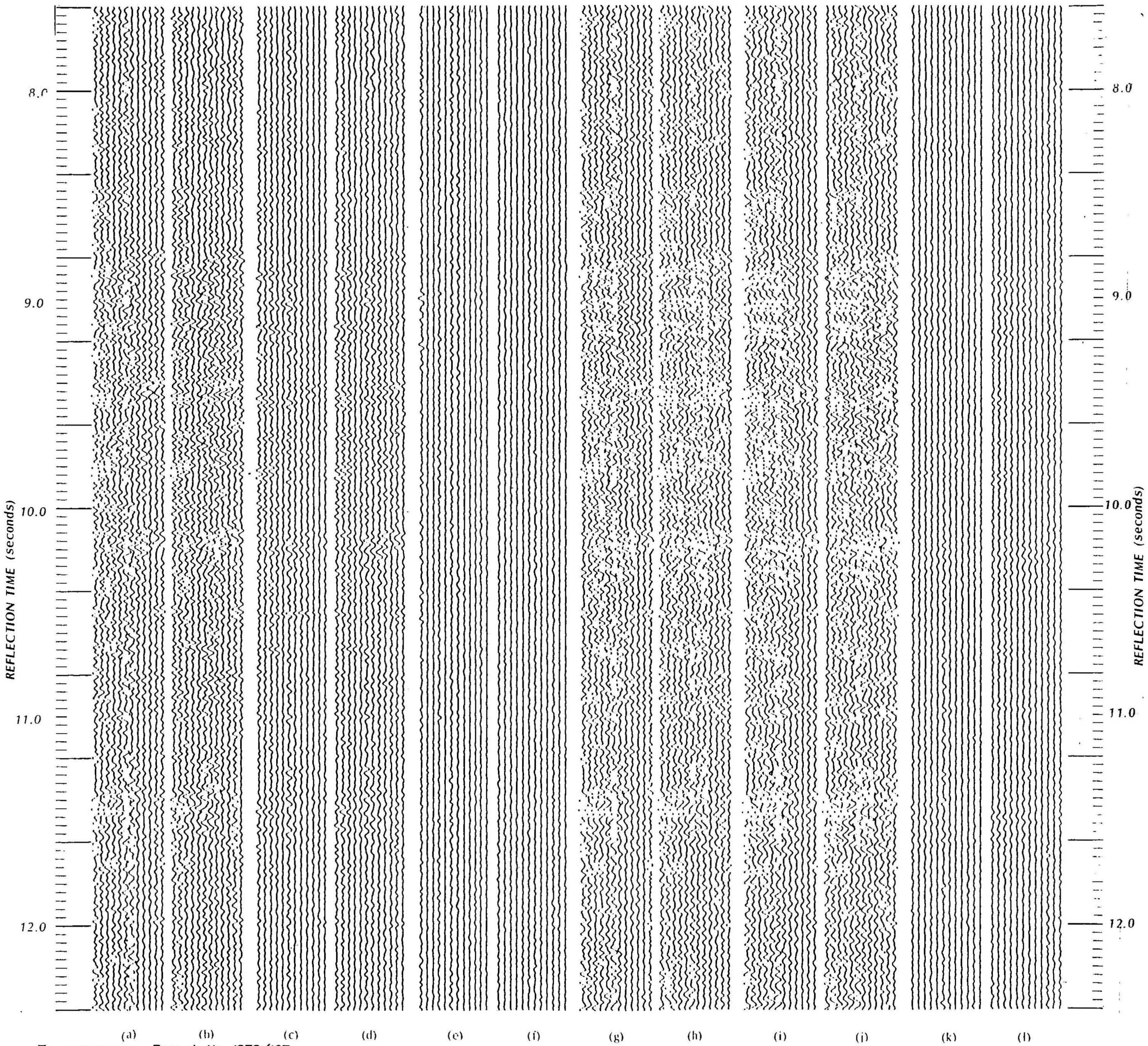
SPREAD

1080 0 1080 Metres
24 13 12 1 Trace

To accompany Record No 1972/127

I54/B3-16A

MILDURA, TRAVERSE A, SP190
CHARGE SIZE COMPARISONS



To accompany Record No 1972/127

PLATE 9

UNCORRECTED RECORD SECTION

RECORDING INFORMATION

Magnetic Recorder: DS7 – 700

Amplifiers : TI – 8000

Prefilters: Nil

Filters : 0 – K92

AGC : 1/1 – 20

Gain Initial: –50

Final : 16 μV

Geophones: HSI 4.5Hz and HSJ 14Hz

Geophone Station Interval: 90m

Geophone Pattern:

See text

Shot Hole Pattern:

See text

PLAYBACK INFORMATION

Filters: 1/12 – 1/55

AGC : Off

Gain Initial: –40

Final : –40

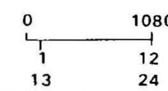
Trip Delay: 0

Compositing: Nil

VELOCITY INFORMATION

Nil

SPREAD



Geophones 1–12 and 13–24 occupy identical stations

MILDURA, TRAVERSE A, SP187

GEOPHONE TYPE AND PATTERN COMPARISONS

154/B3-14A

PLATE 10

UNCORRECTED RECORD SECTION

RECORDING INFORMATION

Magnetic Recorder: DS7 – 700
Amplifiers : TI – 8000
Prefilters: Nil
Filters : K14 – K125
AGC : 1/1 – 20
Gain Initial: –50
Final : 16μV
Geophones: HSI 14 Hz
Geophone Station Interval: 90m
Geophone Pattern:

16/trace, 6m apart in line

Shot Hole Pattern:

See text

PLAYBACK INFORMATION

Filters: 1/12 – 1/55
AGC : Off
Gain Initial: –40
Final : –40
Trip Delay: 0
Compositing: Nil

VELOCITY INFORMATION

Nil

SPREAD

1080	0	1080 Metres
24	13 12	1 Trace

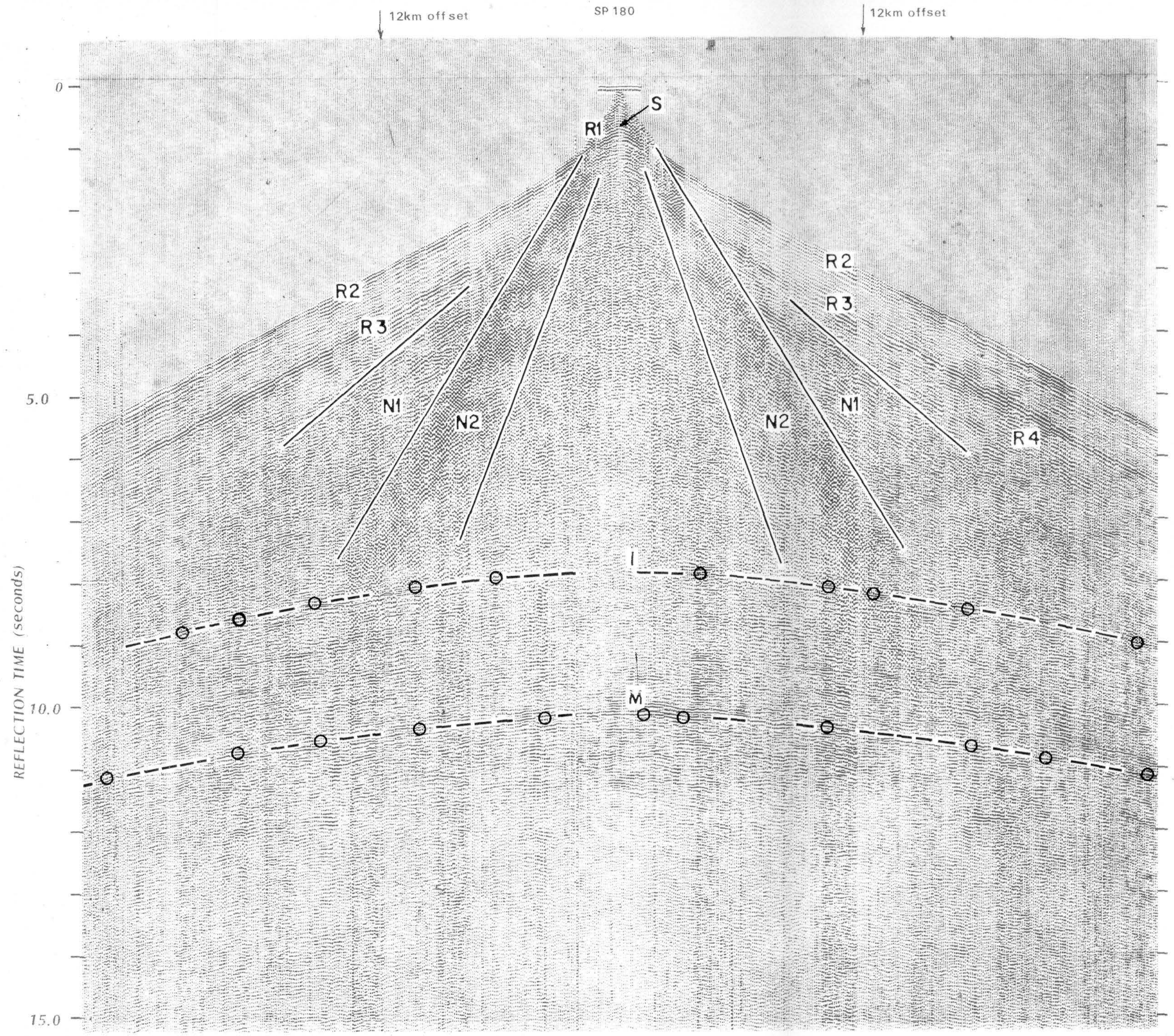
MILDURA, TRAVERSE A, SP186
SHOT HOLE PATTERN COMPARISONS

To accompany Record No 1972/127

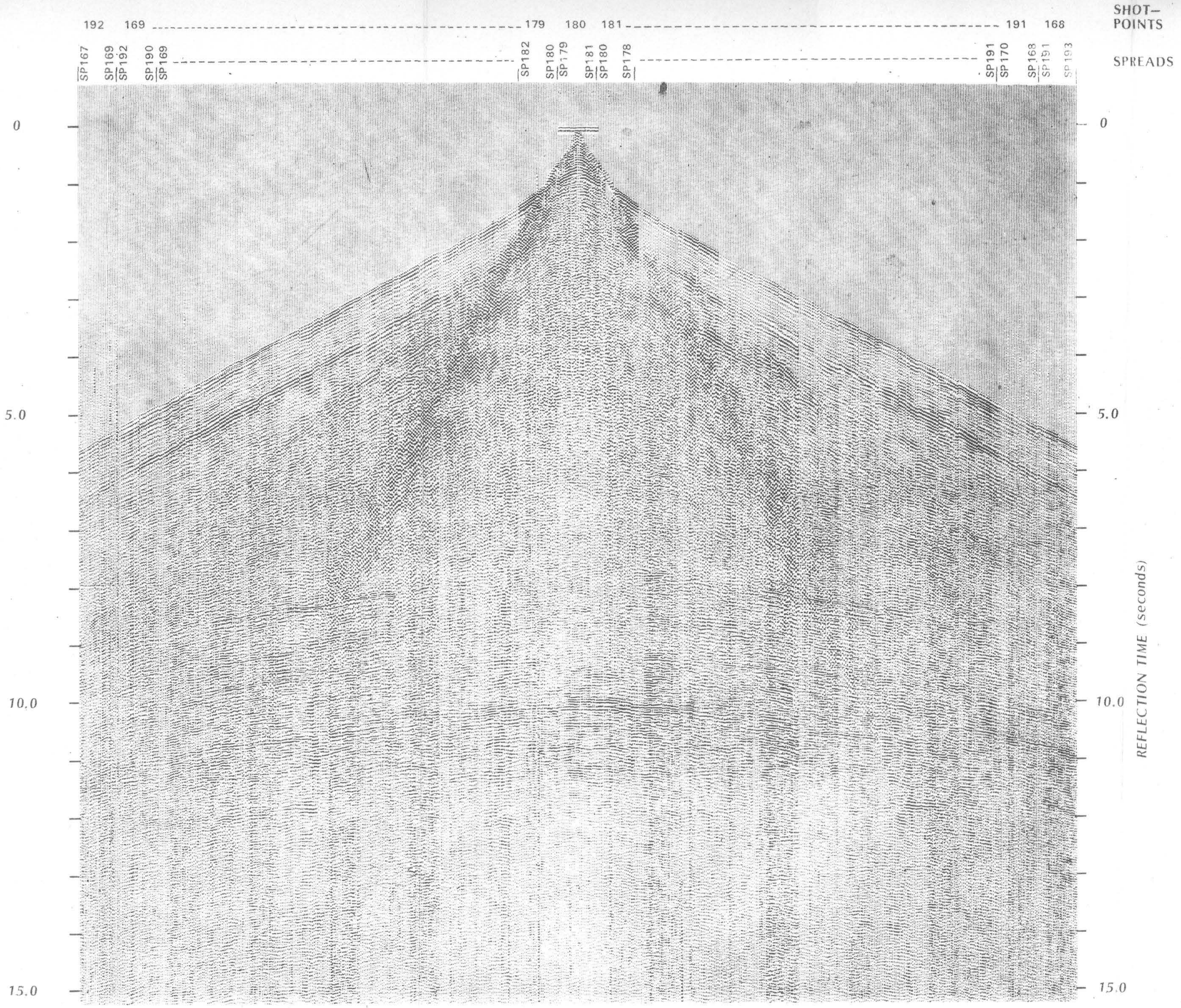
154/B3-17A

PLATE 11

UNCORRECTED RECORD SECTION
Reciprocal Traces Matched
No Other Corrections



S Reflections from sedimentary layers
R1 Refraction at base of weathered layers in sedimentary section
R2 Refraction through basement
R3 Probable second order multiple refraction through basement
R4 Probable third order multiple refraction through basement
N1 Noise events originating from basement
N2 Noise events originating within sediments
I Apparent 'Intermediate' deep crustal reflection event
M Apparent 'Mohorovicic' deep crustal reflection event



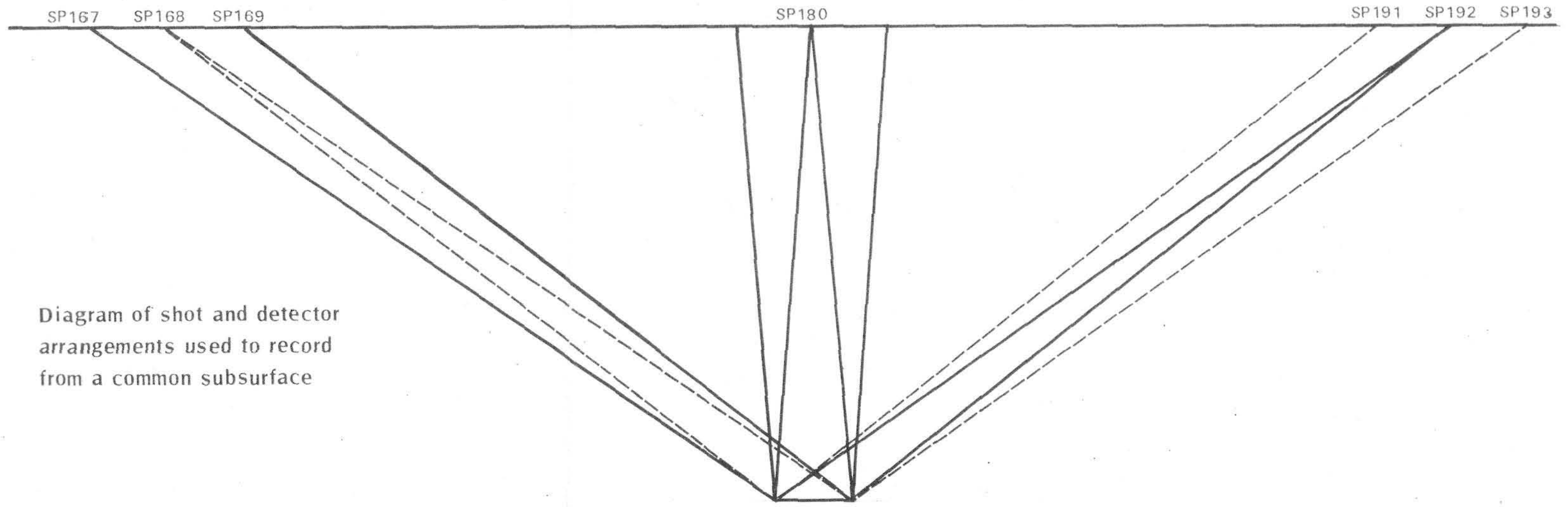


Diagram of shot and detector arrangements used to record from a common subsurface

RECORDING INFORMATION

Magnetic Recorder: DS7 – 700
Amplifiers : TI – 8000
Prefilters: Nil
Filters : K14 – K125
AGC : 1/1 – 20
Gain Initial: –50
Final : 8 μV
Geophones: HSJ 14Hz
Geophone Station Interval: 90m
Geophone Pattern:
16/trace, 6m apart in line

Shot Hole Pattern:
3 holes, 33m apart in line
Depth 34–37m
Charge 23kg per hole Geophex

PLAYBACK INFORMATION

Filters: 1/12 – 1/55
AGC : Off
Gain Initial: –40
Final : –40
Trip Delay : 0
Compositing: Nil

VELOCITY INFORMATION

Nil

HORIZONTAL SCALE
(metres)

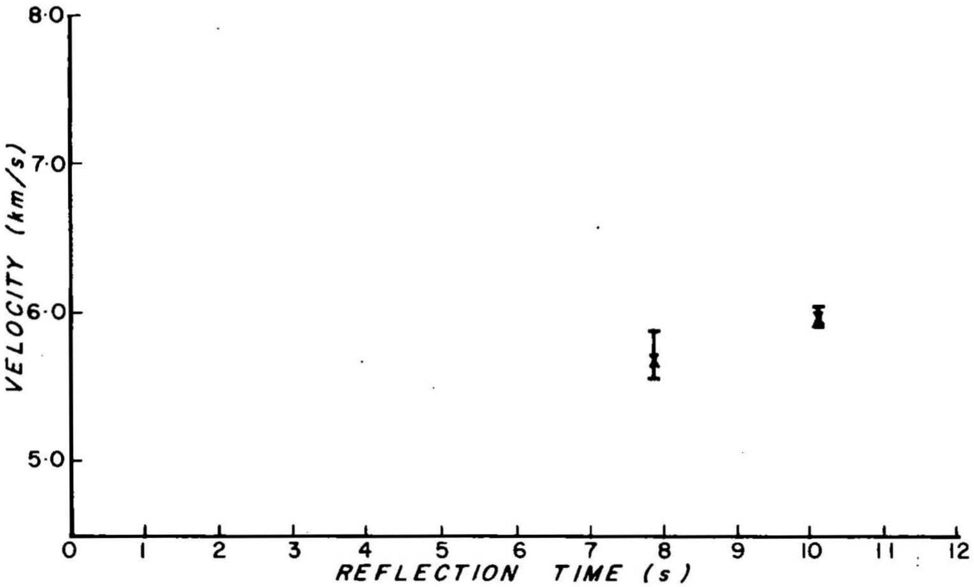
0 2000 4000 6000

MILDURA, TRAVERSE A, SP180
EXPANDED SPREAD

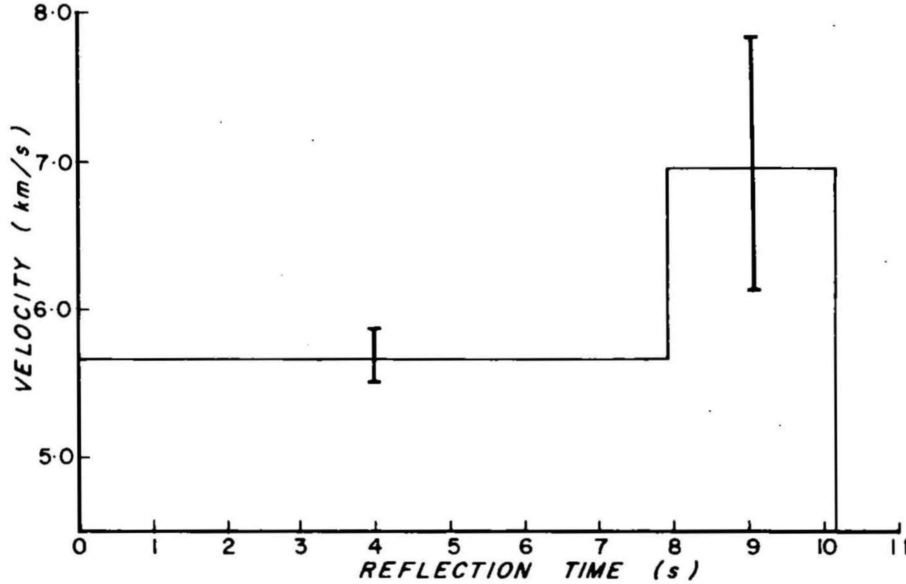
154/B3-6

To accompany Record No 1972/127

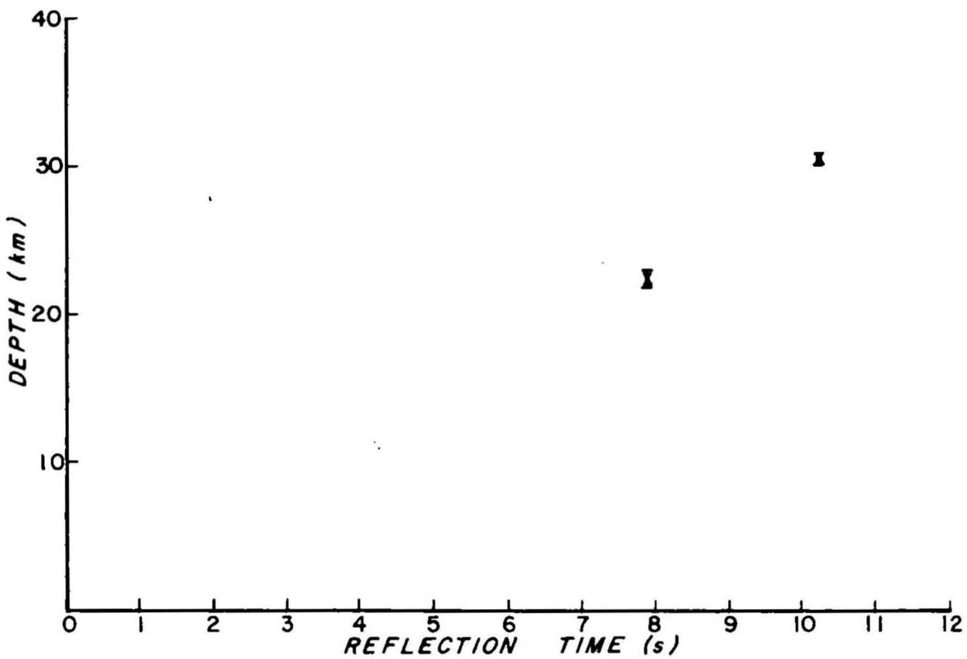
To accompany Record No 1972/127



AVERAGE VELOCITY - REFLECTION TIME



INTERVAL VELOCITY - REFLECTION TIME



DEPTH - REFLECTION TIME

Errors indicated are derived from the standard deviations to the best fitting lines on $t^2 - x^2$ data using a computer programme (Pettifer, 1972)

MILDURA

TRAVERSE A, SP 180 VELOCITY

TIME AND DEPTH FROM EXPANDED SPREAD

PLATE 12

154/B3-25A

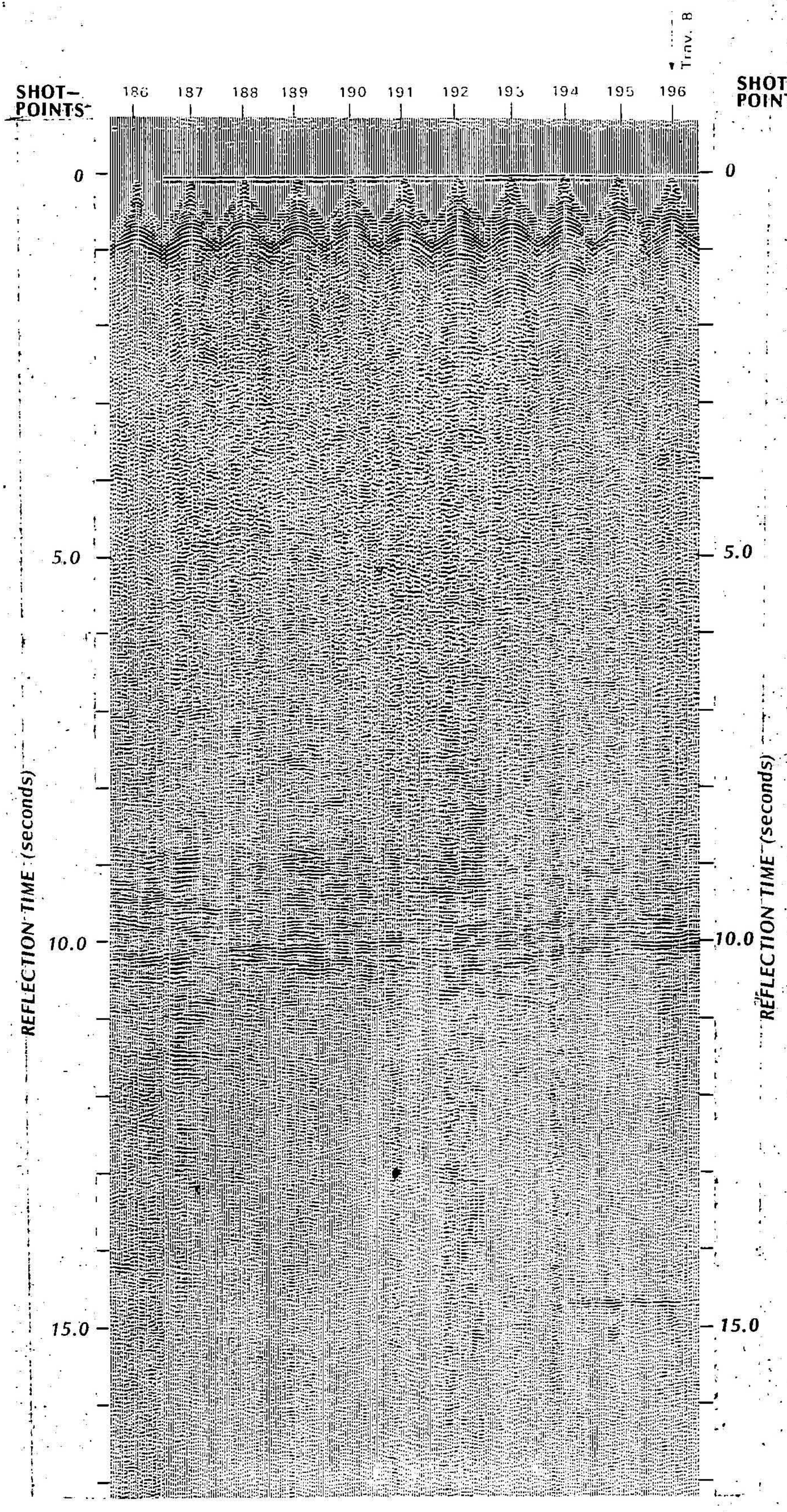


PLATE 13

CORRECTED RECORD SECTION
Reciprocal Traces Matched
No Static Corrections

RECORDING INFORMATION

Magnetic Recorder: DS7 – 700
Amplifiers : TI – 8000
Prefilters: Nil
Filters : K14 – K125
AGC : 1/1 – 20
Gain Initial: –50
Final : 8 μV
Geophones: HSJ 14Hz
Geophone Station Interval: 90m
Geophone Pattern:
48/trace in 2 rows of 24 in line
Rows 1m apart
Geophones 6m apart
Shot Hole Pattern:

5 holes, 20m apart in line
Depth 34–37m
Charge 23kg per hole Geophex

PLAYBACK INFORMATION

Filters: 1/12 – 1/55
AGC Off
Gain Initial: –40
Final : –40
Trip Delay: 0
Compositing: Nil

VELOCITY INFORMATION

Nil

HORIZONTAL SCALE
(metres)

0 2000 4000 6000

MILDURA, TRAVERSE A

RECORDED BY Seismic Party No. 2
SECTION BY Bureau of Mineral Resources
Playback Centre [illegible]
TO ACCOMPANY RECORD No
Based on G85-3 115 41

154/B3–9A

To accompany Record No. 1972/127

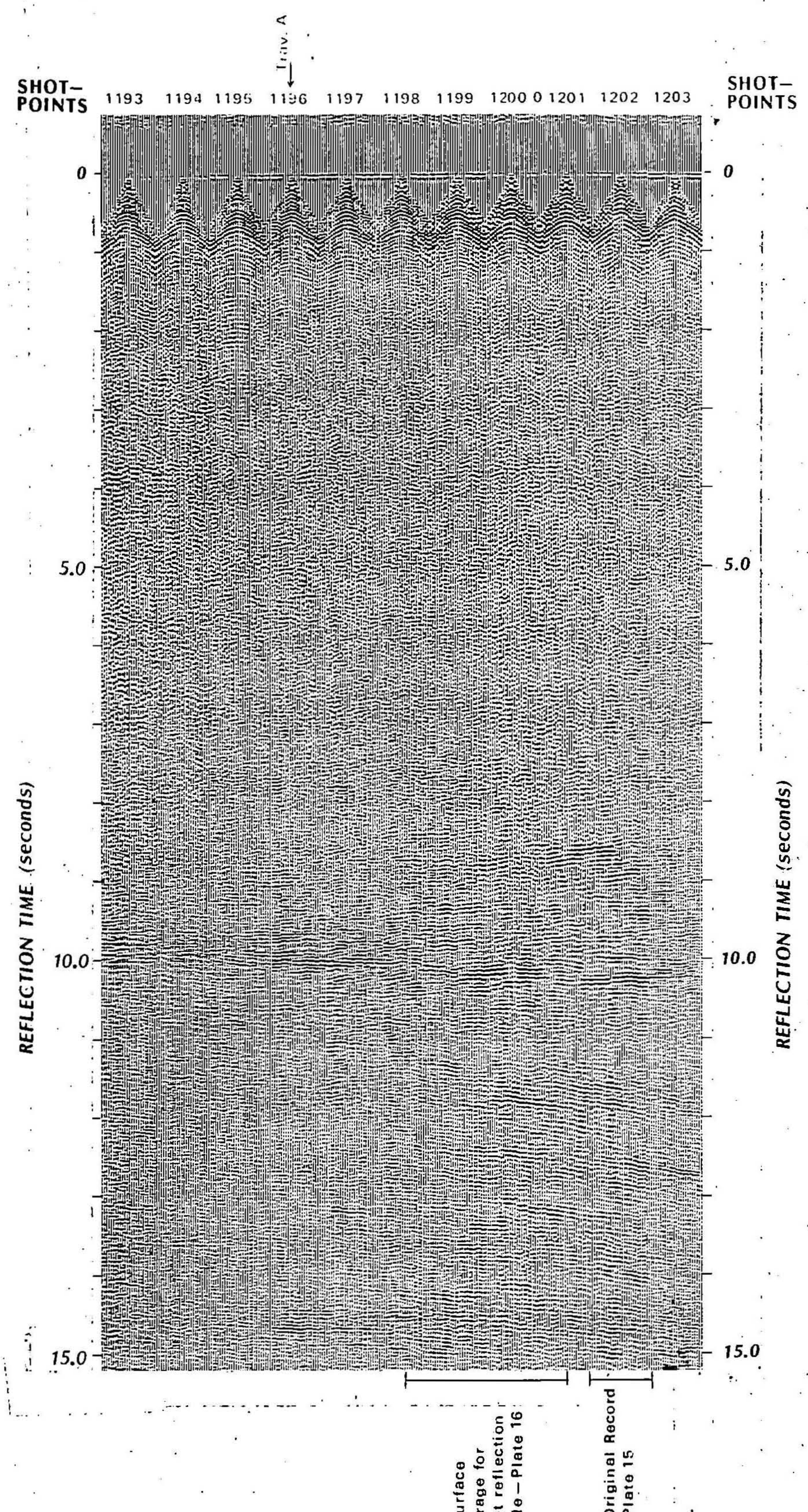


PLATE 14

UNCORRECTED RECORD SECTION
Reciprocal Traces Matched

RECORDING INFORMATION

Magnetic Recorder: DS7 – 700
Amplifiers : TI – 8000
Prefilters: Out
Filters : K14 – K125
AGC : 1/1 – 20
Gain Initial: –50
Final : 8 μV
Geophones: HSJ 14Hz
Geophone Station Interval: 90m
Geophone Pattern:
48/trace in 2 rows of 24 in line
Rows 1m apart
Geophones 6m apart

Shot Hole Pattern:

3 holes, 33m apart in line
Depth 34–37m
Charge 23kg per hole Geophex

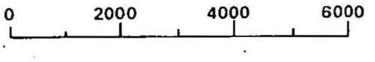
PLAYBACK INFORMATION

Filters: 1/12 – 1/55
AGC : Off
Gain Initial: –40
Final : –40
Trip Delay : 0
Compositing: Nil

VELOCITY INFORMATION

Nil

HORIZONTAL SCALE
(metres)



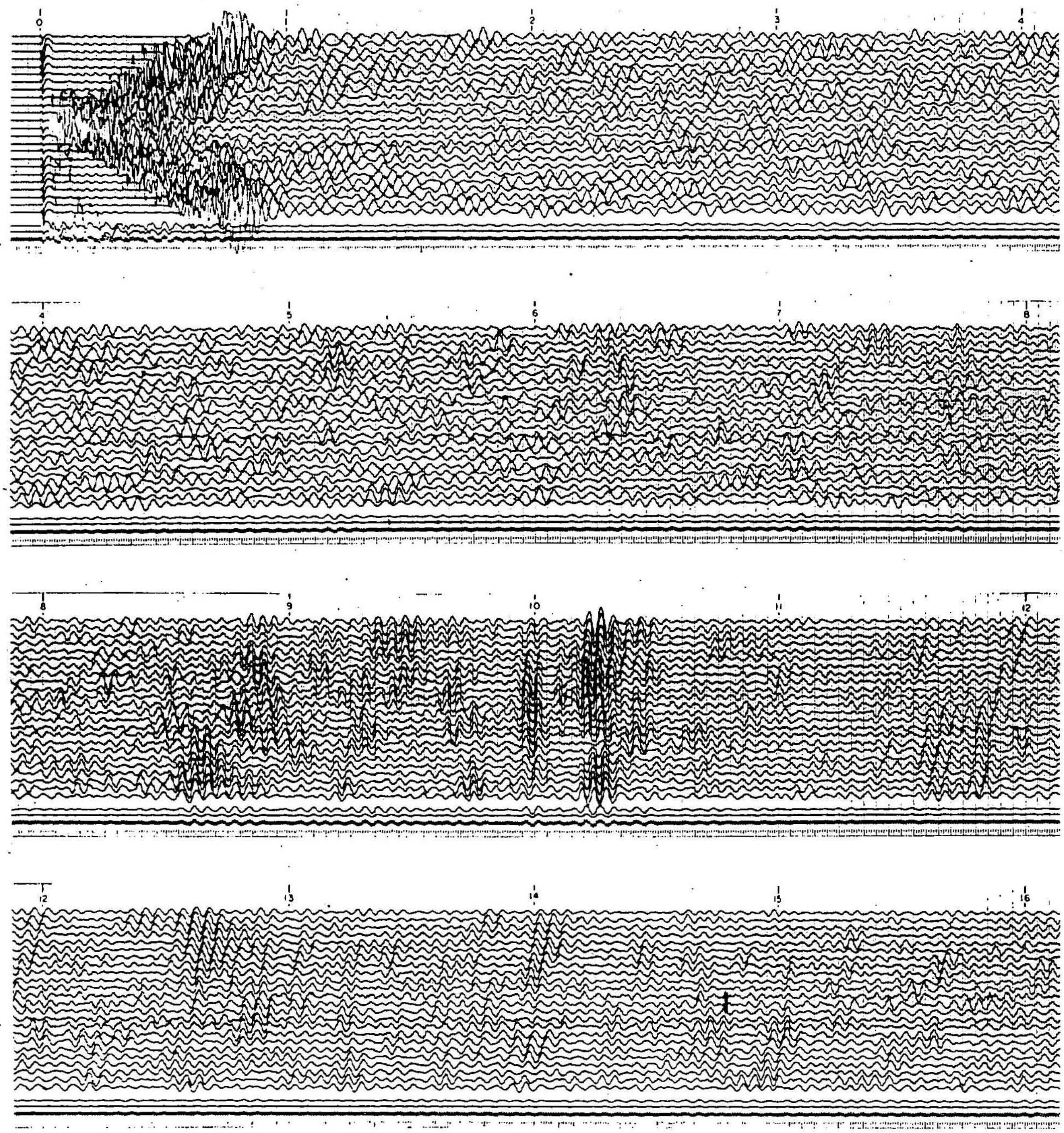
MILDURA, TRAVERSE B

RECORDED BY [illegible]
SECTION BY Bureau of Mineral Resources [illegible]
TO ACCOMPANY RECORD No
[illegible]

154/B3–5A

To accompany Record No 1972/127

PLATE 15



MILDURA, TRAVESE B, SP1202

ORIGINAL RECORD

To accompany Record No 1972/127

I54/B3-18-1A

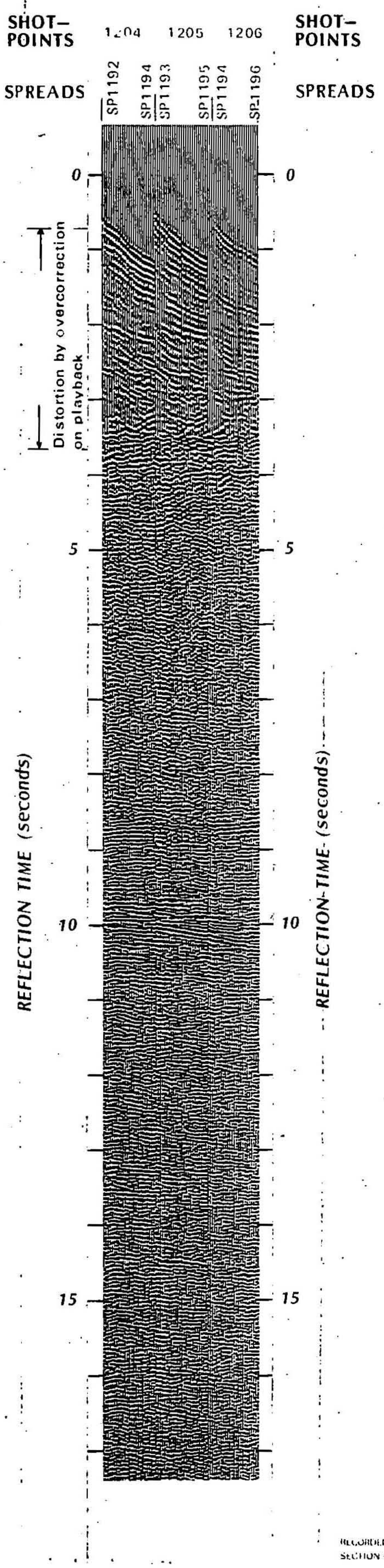


PLATE 16

CORRECTED RECORD SECTION

RECORDING INFORMATION

Magnetic Recorder: DS7 – 700

Amplifiers : TI – 8000

Prefilters: Nil

Filters : K14 – K125

AGC : 1/1 – 20

Gain Initial: –50

Final : 8 μV

Geophones: HSJ 14Hz

Geophone Station Interval: 90m

Geophone Pattern:

48/trace in 2 rows of 24 in line
Rows 1m apart
Geophones 6m apart

Shot Hole Pattern:

3 holes, 33m apart in line
Depth 34 – 37m
Charge 23kg per hole Geophex

PLAYBACK INFORMATION

Filters: 1/12 – 1/55

AGC : Off

Gain Initial: –40

Final : –40

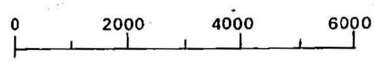
Trip Delay : 0

Compositing: Nil

VELOCITY INFORMATION

Expanded Spread, Mildura 1968

HORIZONTAL SCALE
(metres)



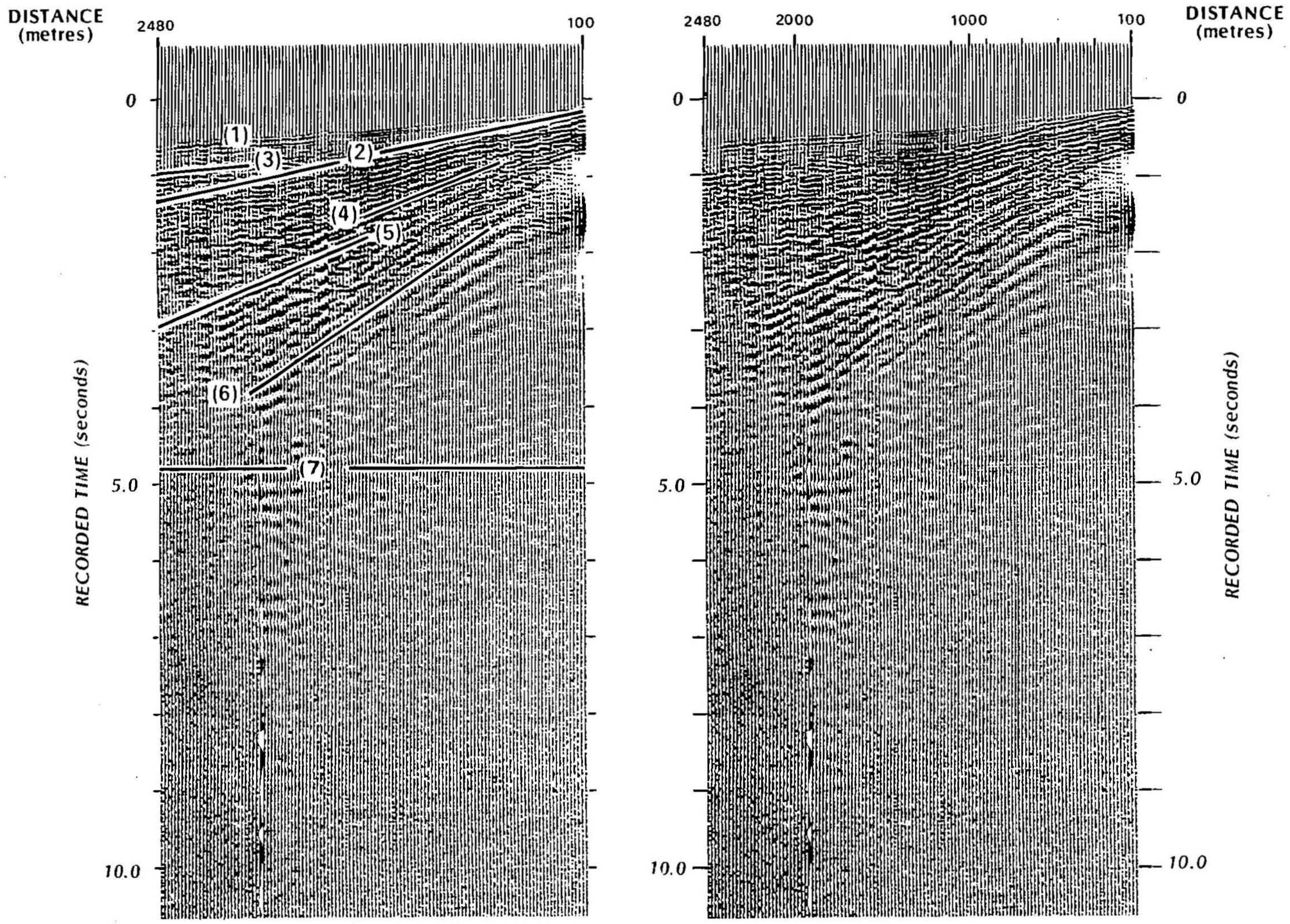
MILDURA, TRAVERSE B
OFFSET RECORDING

RECORDED BY
SECTION BY *Bureau of Mineral Resources Playback Centre*
TO ACCOMPANY RECORD No
(Based on G85 3 115 4)

154/B3–21A

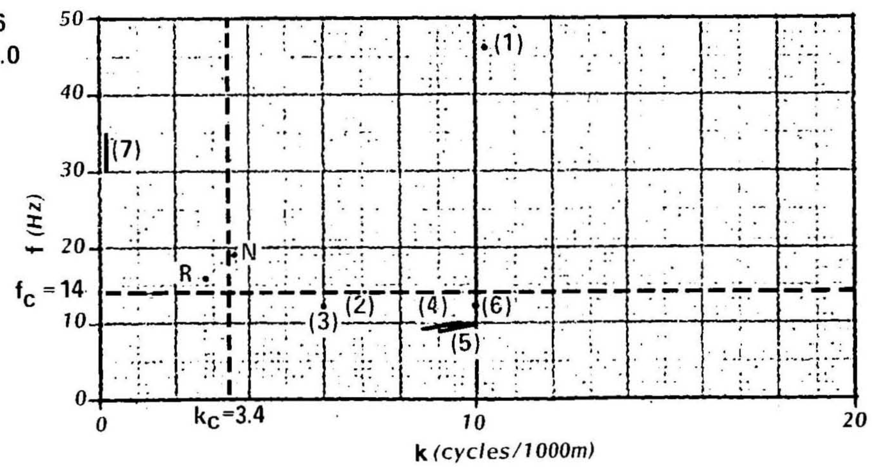
To accompany Record No 1972/127

RECORD SECTION



(1)	V = 4220	f = 46	k = 11.0
(2)	V = 1955	f = 14	k = 7.1
(3)	V = 2000	f = 12	k = 6.0
(4)	V = 1040	f = 9-10	k = 8.6-9.6
(5)	V = 980	f = 9-10	k = 9.2-10.0
(6)	V = 600	f = 12	k = 10.0
(7)		f = 30-35	

V = *Velocity (m/s)*
f = *Frequency (Hz)*
k = *Wave number (cycles/1000m)*
R = *First break from expanded spread*
V = 5700 f = 17 k = 2.8
N = *Noise event from expanded spread*
V = 5400 f = 19 k = 3.5



Frequency – Wave Number Graph

RECORDING INFORMATION

Magnetic Recorder: DS7–700
Amplifiers : TI – 8000
Prefilters: Nil
Filters : 0-K125
AGC : Off
Gain Initial: –40
Final : 4μV
Geophones: HSJ 14 Hz
Geophone Station Interval: 20m
Geophone Pattern:

8/trace, 6m apart in line

Shot Hole Pattern:

Single shot
Depth 27–30m
Charge 23kg Geophex

PLAYBACK INFORMATION

Filters: Out – Out
AGC : S.S
Gain Initial: –40
Final : –40
Trip Delay : O
Compositing: Nil

VELOCITY INFORMATION

Nil

HORIZONTAL SCALE

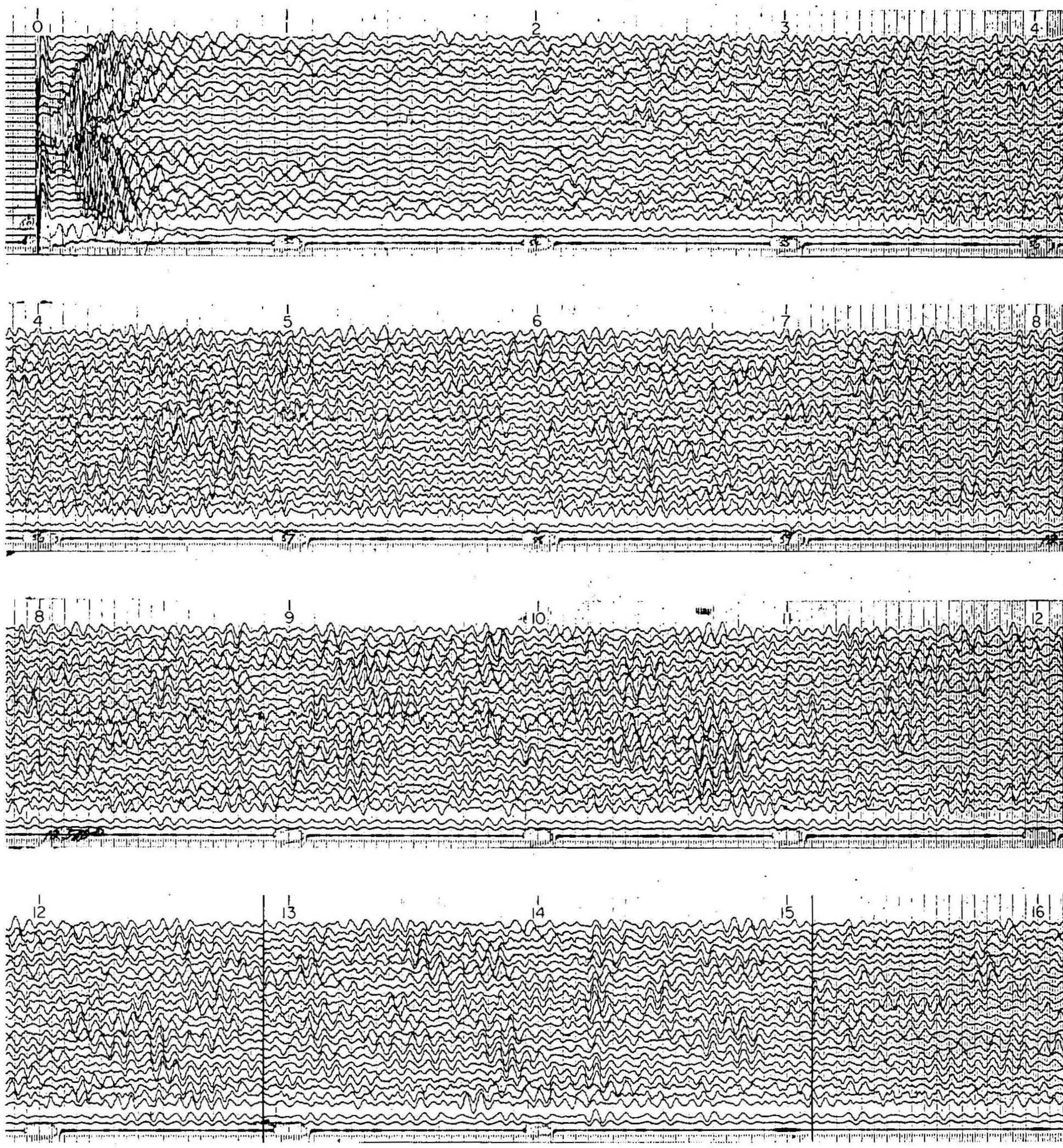
As Indicated

BROKEN HILL, TRAVERSE A, SP500
NOISE TEST

To accompany Record No 1972/127

154/B3-10-1A

PLATE 18



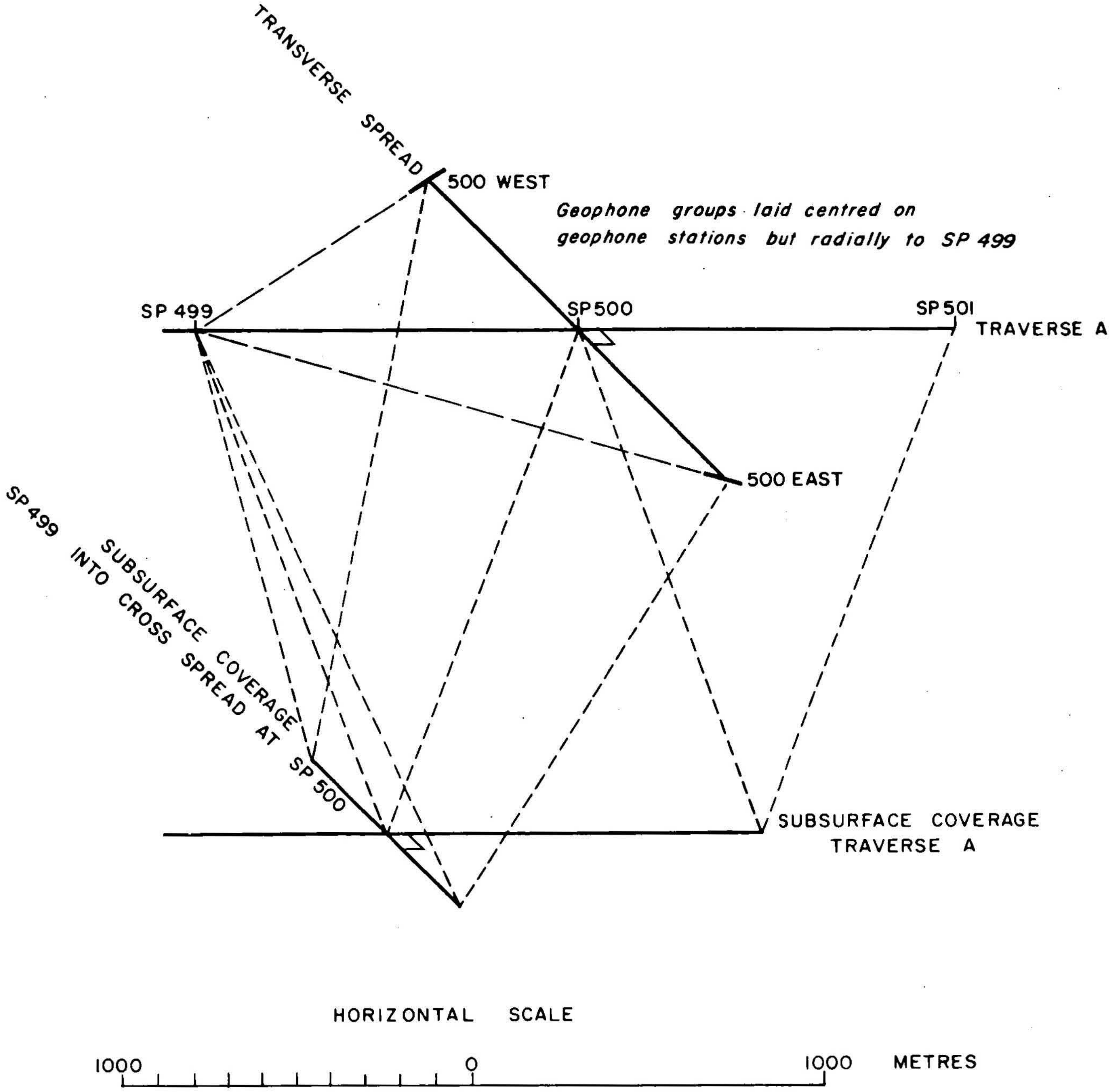
BROKEN HILL TRAVERSE A, SP 493

ORIGINAL RECORD

To accompany Record No 1972/127

I 54/B3-19

PLATE 19



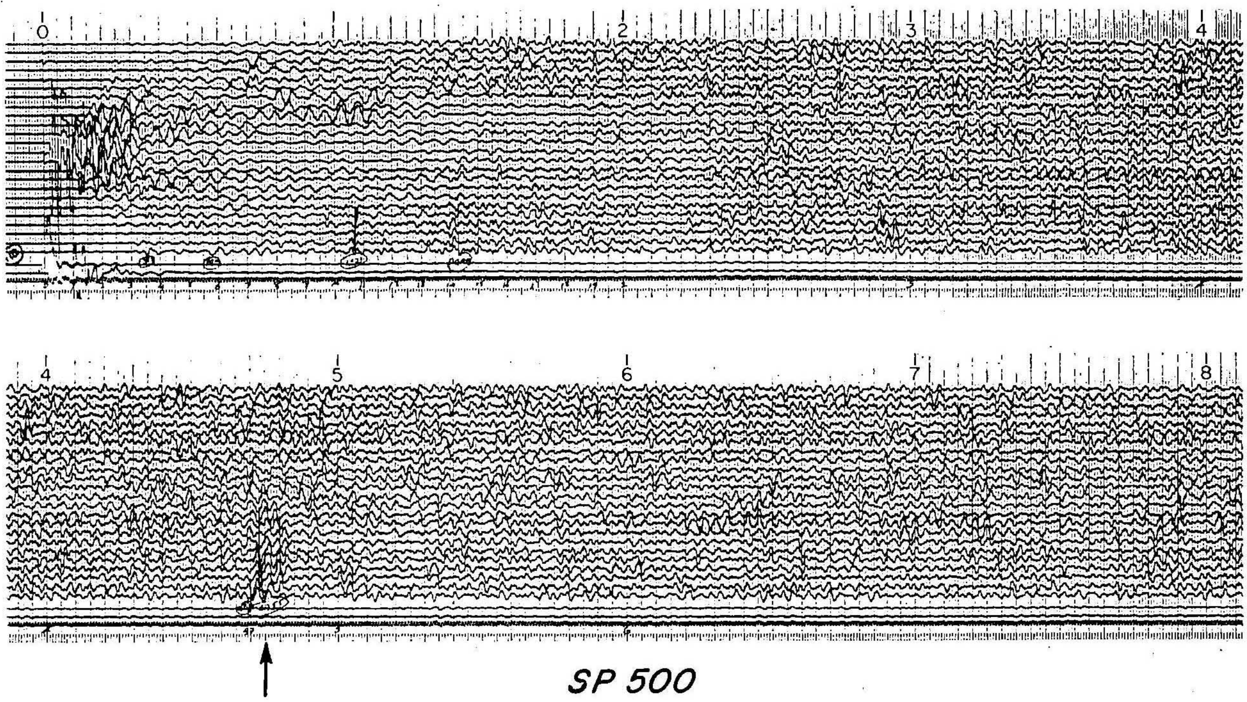
BROKEN HILL , TRAVERSE A

SP 500 AND SP 499 EXPERIMENTAL

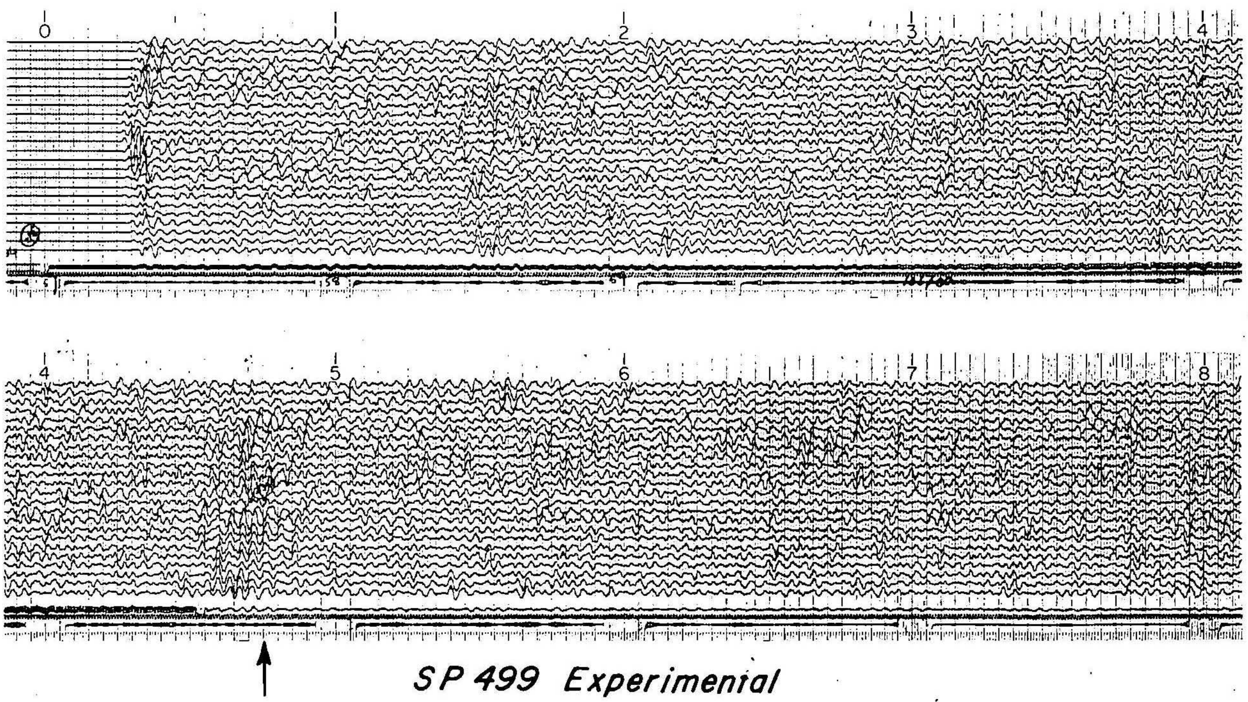
SHOOTING DIAGRAM

To accompany Record No 1972/127

I54/B3-26A



SP 500



SP 499 Experimental

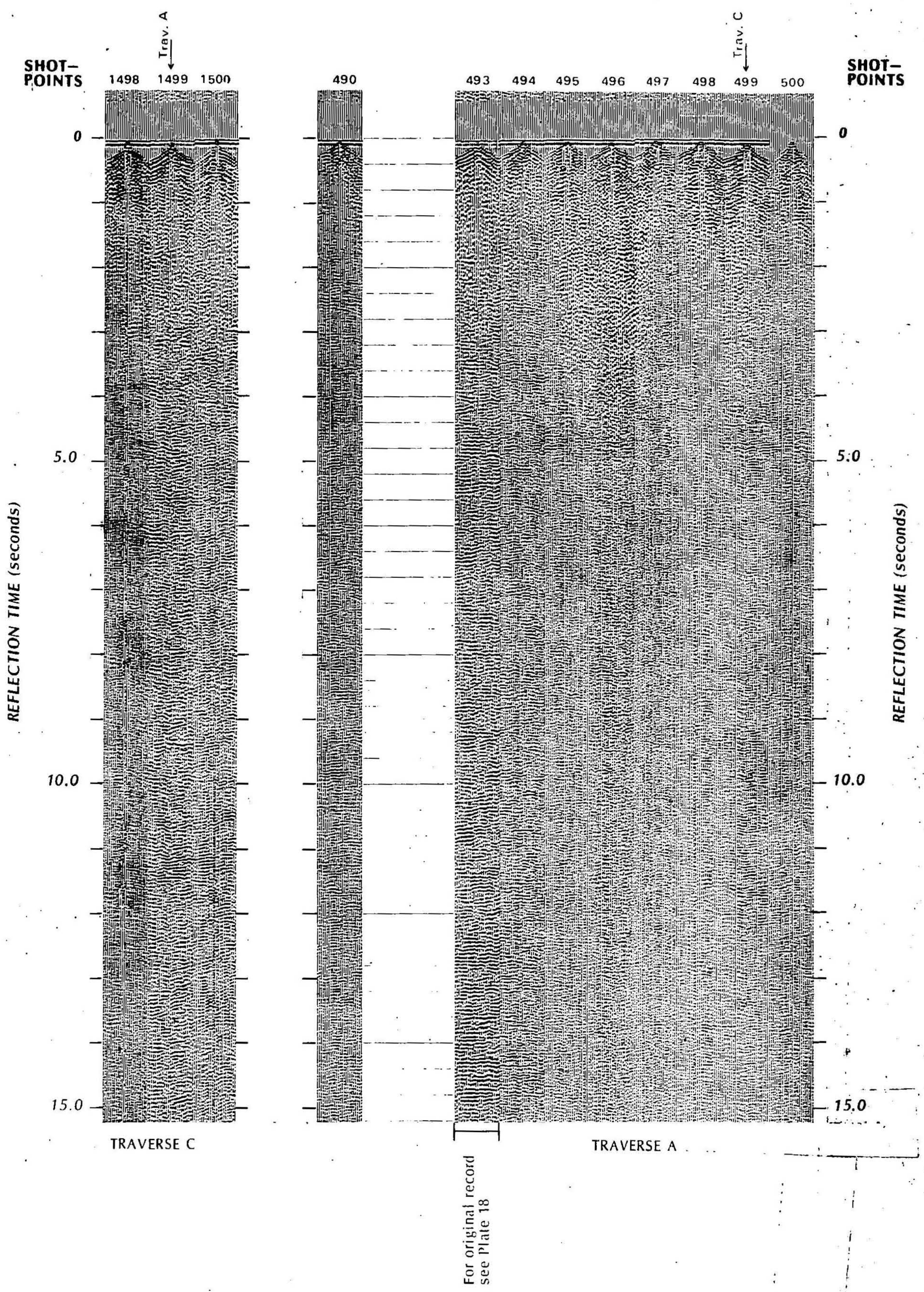
BROKEN HILL, TRAVERSE A

SP 500 AND SP 499 EXPERIMENTAL

ORIGINAL RECORDS (8 seconds only)

UNCORRECTED RECORD SECTION
Reciprocal Traces Matched

PLATE 21



RECORDING INFORMATION

Magnetic Recorder: DS7–700
Amplifiers : TI – 8000
Prefilters: Nil
Filters : K14 – K125
AGC : 1/1 – 20
Gain Initial: –50
Final : 8µV
Geophones: HSJ 14Hz
Geophone Station Interval: 90m
Geophone Pattern:
48/trace in 2 rows of 24 in line
Rows 6m apart
Geophones 6m apart
Shot Hole Pattern:

See text

PLAYBACK INFORMATION

Filters: 1/12 – 1/55
AGC : Off
Gain Initial : –40
Final : –40
Trip Delay : Out
Compositing: Nil

VELOCITY INFORMATION

Nil

HORIZONTAL SCALE
(metres)

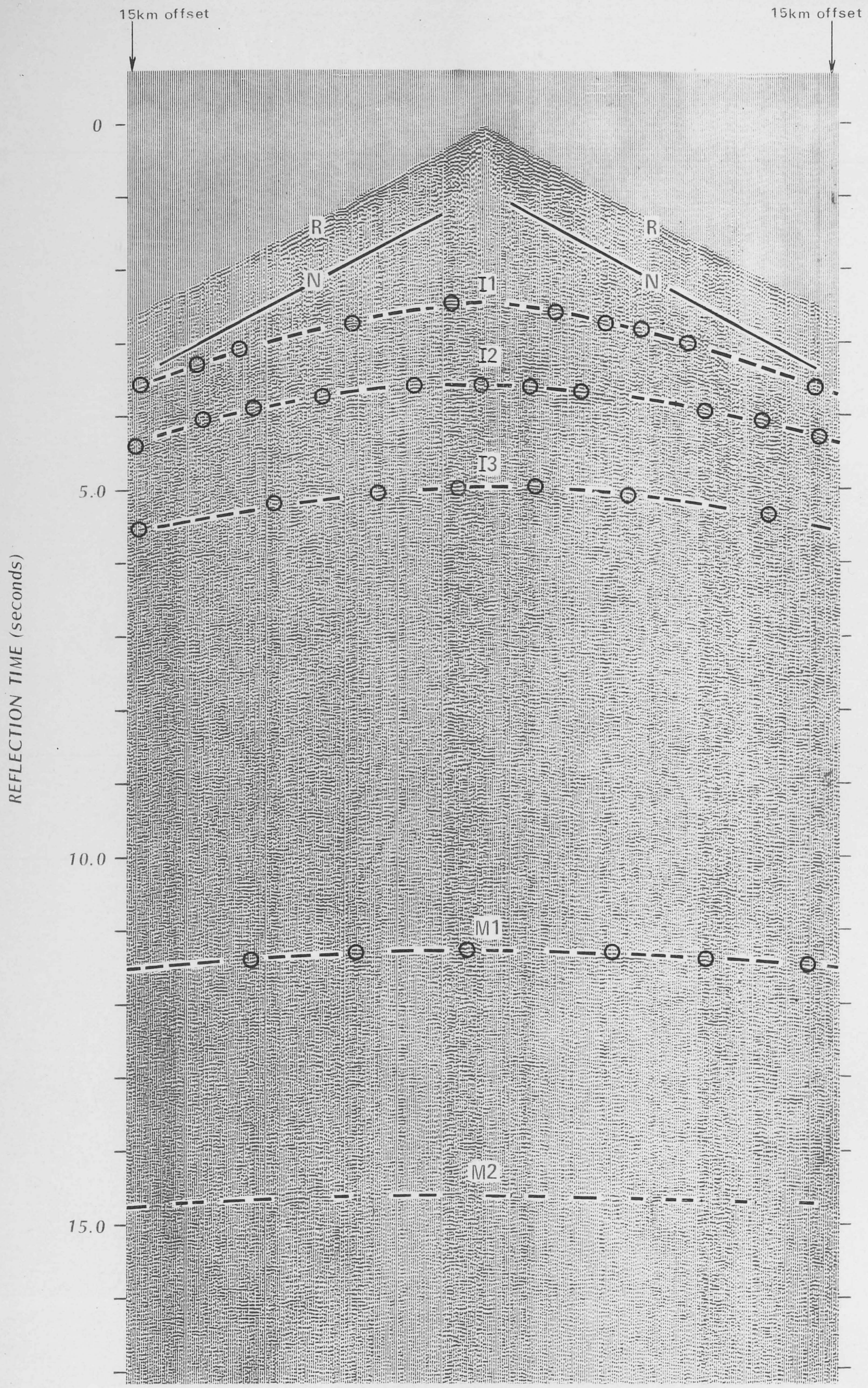
0 2000 4000 6000

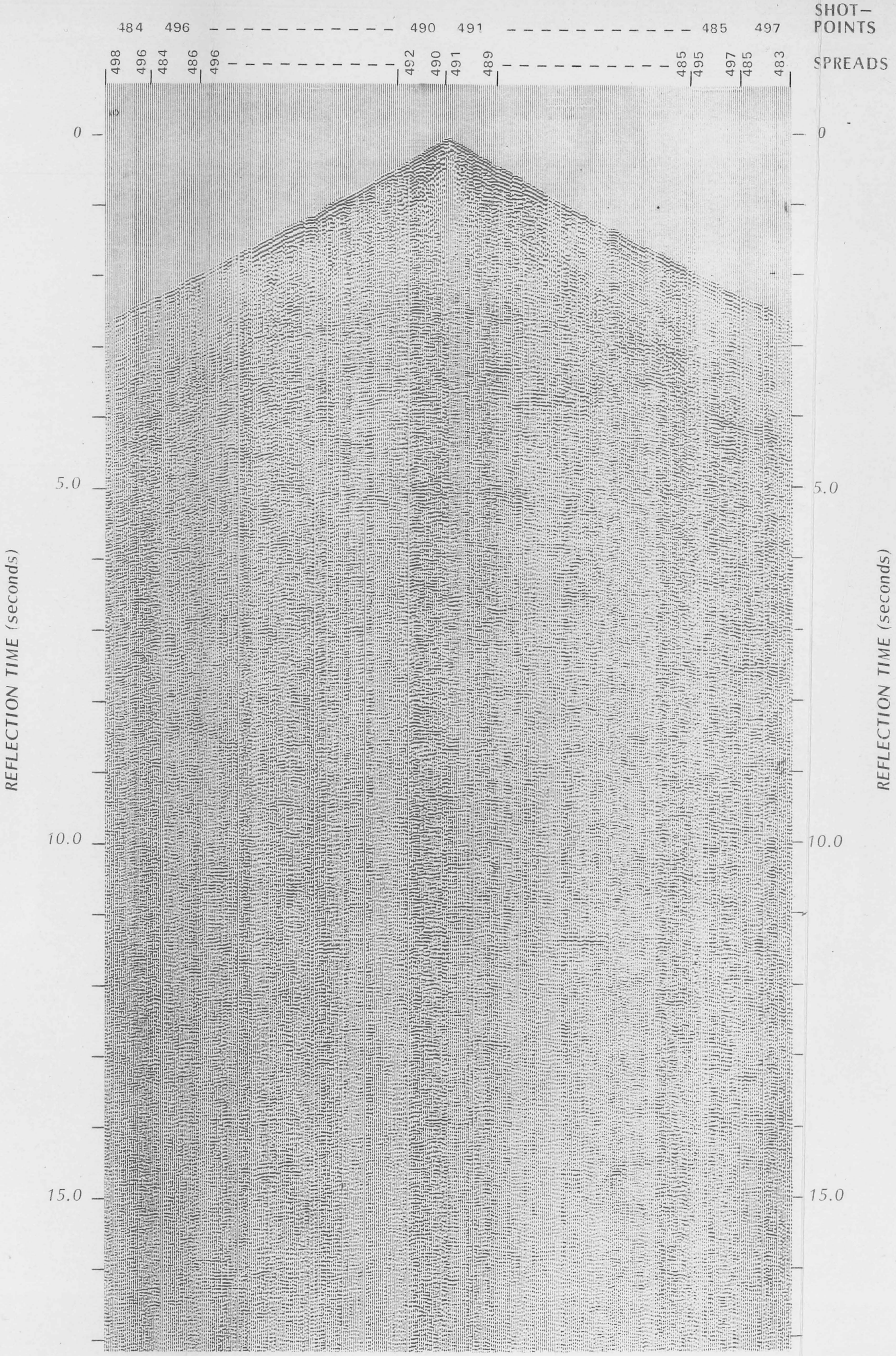
BROKEN HILL, TRAVERSES A AND C

RECORDED BY *Seismic Party No. 2*
SECTION BY *Bureau of Mineral Resources Playback Centre SIE MS 42*
TO ACCOMPANY RECORD No
(Based on G85-3 115 4)

To accompany Record No 1972/127

154/B3–7–1A





R Refraction at base of weathered layers
N Noise events originating within basement
I1
I2 } Apparent Intermediate deep crustal reflection events
I3
M1 Apparent Mohorovicic deep crustal reflection event
M2 Apparent Sub-Mohorovicic deep crustal reflection event

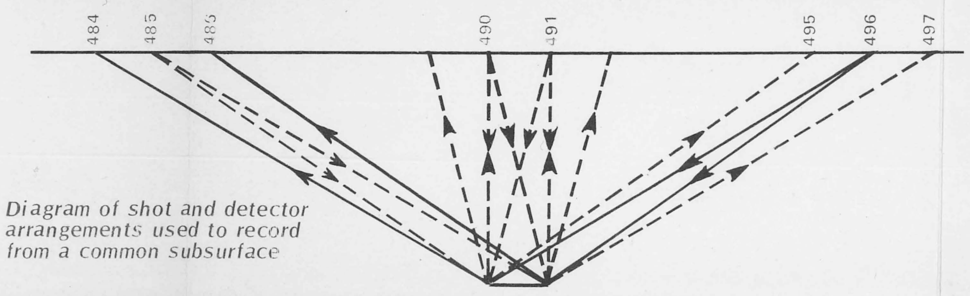


Diagram of shot and detector arrangements used to record from a common subsurface

To accompany Record No 1972/127

RECORD SECTION
Reciprocal Traces Matched
No Other Corrections

RECORDING INFORMATION

Magnetic Recorder: DS7–700
Amplifiers : TI–8000
Prefilters: Nil
Filters : K14–K125
AGC : 1/1–20
Gain Initial: –50
Final : 8μV
Geophones: HSJ 14 Hz
Geophone Station Interval: 90m
Geophone Pattern:
48/trace, 2 rows of 24 in line
Rows 6m apart
Geophones 6m apart
Shot Hole Pattern:

10 holes 10m apart in line
Depth 12–37m
Charge 45kg per hole Geophex

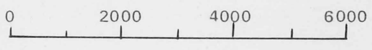
PLAYBACK INFORMATION

Filters: 1/12–1/55
AGC : Off
Gain Initial: –40
Final : –40
Trip Delay : O
Compositing: Nil

VELOCITY INFORMATION

Nil

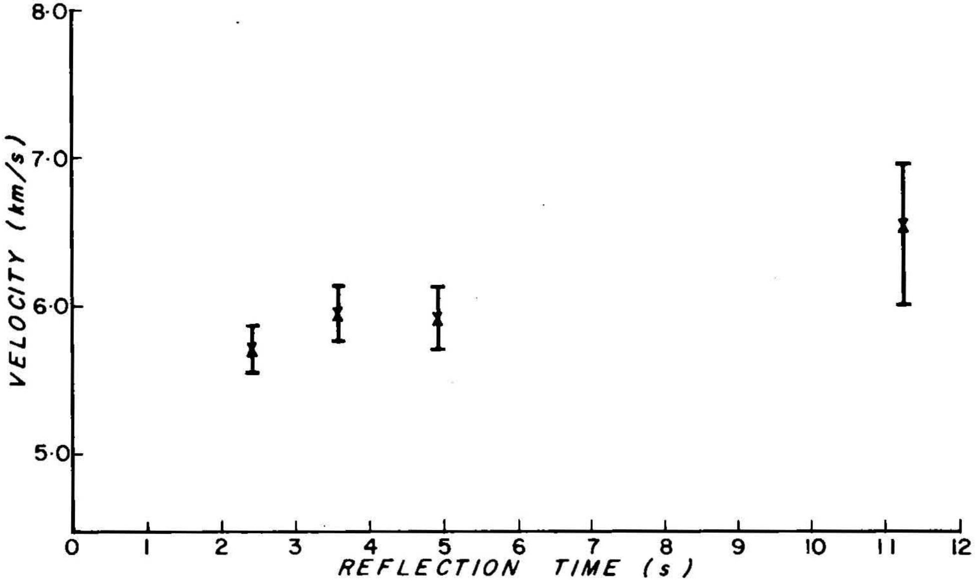
HORIZONTAL SCALE
(metres)



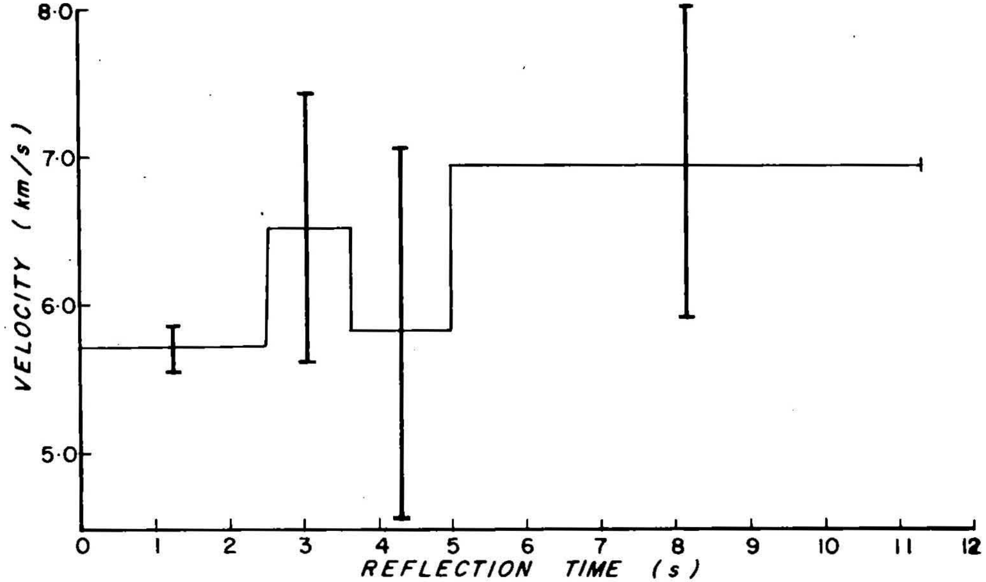
BROKEN HILL, TRAVERSE A, SP490½
EXPANDED SPREAD

154/B3–8–1

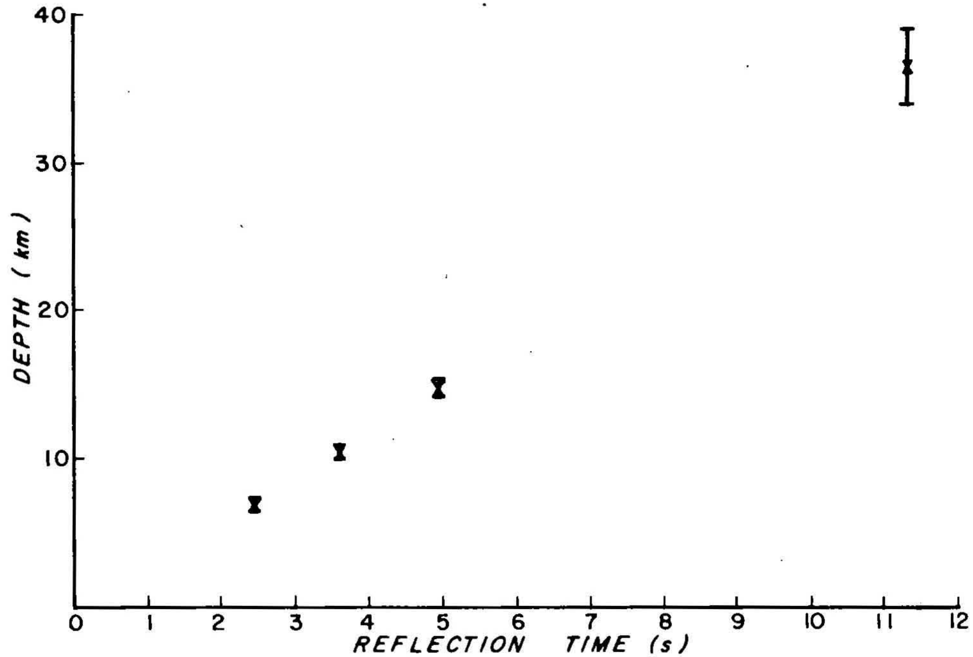
To accompany Record No 1972/127



AVERAGE VELOCITY – REFLECTION TIME



INTERVAL VELOCITY – REFLECTION TIME



DEPTH – REFLECTION TIME

Errors indicated are derived from the standard deviations to the best fitting lines on $t^2 - x^2$ data using a computer programme (Pettifer, 1972)

BROKEN HILL

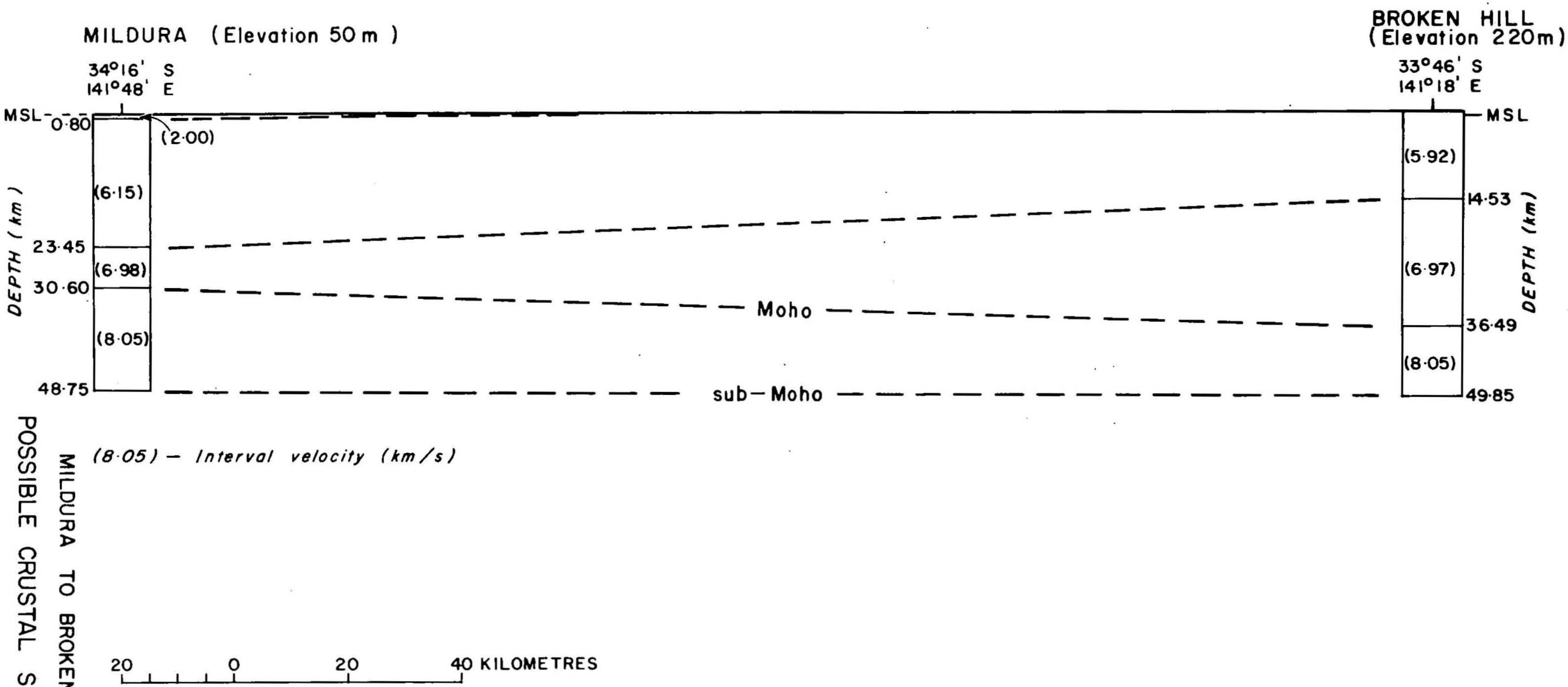
TRAVERSE A, SP 490½ VELOCITY

TIME AND DEPTH FROM EXPANDED SPREAD

PLATE 23

154/B3-27A

To accompany Record No 1972/127



MILDURA TO BROKEN HILL

POSSIBLE CRUSTAL STRUCTURE

PLATE 24

154/B3-28A