DEPARTMENT OF NATIONAL RESOURCES

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Record 1976/103

SEISMIC INVESTIGATIONS OF CRUSTAL STRUCTURE IN SOUTHEAST AUSTRALIA, MARCH-MAY 1976: OPERATIONAL REPORT

by

C.D.N. Collins

Record 1976/103

SEISMIC INVESTIGATIONS OF CRUSTAL STRUCTURE IN SOUTHEAST AUSTRALIA, MARCH-MAY 1976: OPERATIONAL REPORT

by

C.D.N. Collins

CONTENTS

	Page
SUMMARY	
INTRODUCTION	1
GEOLOGICAL AND GEOPHYSICAL SUMMARY	
FIELD WORK	3
Survey operations	3
Communications	4
SHOTS	4
Shot locations	4
Shot details	5
Shot timing	6
RECORDING STATIONS	8
Recording site positions	8
Rock samples	9
EQUIPMENT	9
Akai recording systems	9
PI recording systems	10
Three-component systems	11
Battery and Tape life	11
Shot-timing recorders	12
COMMENTS	12
ACKNOWLEDGEMENTS	14
REFERENCES	14

APPENDIX

Personnel and vehicles	16

Page

TABLES

1. Participating quarries 17
2. Shot statistics
3. Station statistics

FIGURES

1. Locations of shots and stations
2. Geological provinces in New South Wales
3. Shot size and frequency
4. Recording success

SUMMARY

During March, April, and May 1976, a deep crustal seismic survey was conducted between Bass Point and Ardlethan in southern New South Wales. Sixty-six recording sites were occupied along a traverse across the Lachlan Geosyncline and part of the Sydney Basin. Routine blasting at thirteen quarries was used as the source of seismic energy. Seventy-three shots were fired during the survey, of which 64 were recorded by at least one station. A total of 269 usable records was obtained, and interpretation of these is proceeding.

INTRODUCTION

During four weeks in March, April, and May, 1976, a deep crustal seismic survey was conducted in southern New South Wales (Fig. 1). The aim of the survey was to define the crustal structure, and upper-mantle relief, across the strike of the Lachlan Geosyncline, and beneath the southwest Sydney Basin.

This survey was part of a program of crustal studies in southeast Australia using quarry blasts as seismic sources. Quarry blasts provide a cheap source of seismic energy, however, survey design is restricted by the positions of the quarries, and by the size and frequency of the blasts.

Originally it was planned to record along the strike of the Lachlan Geosyncline between Marulan (NSW) and Dartmouth (Victoria). Regular blasting at the Marulan limestone quarry and the Dartmouth dam construction site would have provided good seismic sources at both ends of the traverse. However, when industrial disputes closed down the Dartmouth Construction site, it was decided to postpone this survey, and record along a traverse through Marulan, perpendicular to the original traverse.

The survey traverse lies mainly across the Lachlan Geosyncline (Fig. 2) which forms the tectonic province of the Lachlan Fold Belt (Scheibner, 1973), also called the Central and Southern Highland Fold Belt (Packham, 1969). At the eastern end, the traverse terminates in the southernmost extension of the Sydney basin. The Singleton/Muswellbrook area, from which the northern shots were recorded, lies in the Sydney Basin adjacent to the New England Fold Belt of northeast New South Wales.

The Lachlan Geosyncline extends from Victoria to northern New South Wales, where it disappears under the sediments of the Great Artesian Basin. Sedimentation extended from the early Ordovician, and possibly late Cambrian, to the Carboniferous. Folding of the sediments occurred during four orogenic periods, with associated granitic intrusions. These were the Benambran orogeny of the early Silurian, the Bowning orogeny of the Late

Silurian and early Devonian, the Tabberaberan orogeny of the late Devonian and, finally, the Kanimblan orogeny, which occurred during the middle Carboniferous. Between each of these orogenies, sedimentary deposition and volcanic activity prevailed.

The Permo-Triassic Sydney Basin extends from the New South Wales coast, near Sydney, to the northwest, where it is overlapped by sediments of the Great Artesian Basin (Fig. 2). The Basin may extend southeastwards as far as the continental slope, and northwards, beneath the younger cover, to the Bowen Basin in Central Queensland. Permian marine beds form the basal outcrop at the southern and western margins of the Basin. The Triassic sequence comprises fluviatile, deltaic and some brackish marine sediments.

Previous investigations of crustal thickness and structure across the Lachlan geosyncline in the region of this survey include the surface wave studies of Thomas (1969). For a two layer crust, Thomas found the depth to the intermediate layer to be about 20 km and the depth to the Mohorovicic discontinuity to be about 40 km. Recordings from quarry blasts in the Snowy Mountains and shots off the central NSW coast have been interpreted by Doyle, Everingham, & Hogan (1959) and Doyle, Underwood, & Polak (1966). The depth of the intermediate layer varies from about 10 km beneath the Sydney area to about 20 km beneath the Snowy Mountains. The interpreted depth to the Mohorovicic discontinuity varies from about 25 to 42 km. Quarry blast recordings in the Sydney area show the sediments to be 1.5 to 2.5 km thick, with a basement velocity of 5.88 km/sec (Bolt, 1962). Other recordings of quarry blasts have been made in the area by the Australian National University, but the data have not been interpreted.

FIELD WORK

Survey operations

The shot sites and station locations are shown in Figure 1. Sixty-six recording sites were occupied on a line between Bass Point on the New South Wales coast, south of Wollongong, and Ardlethan, 370 km to the west. Records were also obtained at the permanent observatories at Cooney near Armidale, Riverview in Sydney, and Kowen Forest near Canberra, and at a temporary station south of Singleton.

Routine blasting at thirteen quarries provided the seismic sources for the survey. Along the traverse line, shots were recorded from the blue-metal quarries at Bass Point, Albion Park, and Dunmore at the eastern end; the Marulan limestone quarry, 65 km from the coast; and the Ardlethan tin mine, at the western end. Records were also obtained from the open-cut collieries in the Singleton/Muswellbrook area and quarries in the Sydney area, north of the traverse line, and from blue-metal quarries at Queanbeyan and Hall, south of the traverse line. A total of 73 shots was fired during the recording period.

All temporary stations were occupied by BMR remote recording seismic systems. Sixty stations along the recording line were occupied by systems with a single vertical component seismometer, the other six being occupied with a three component system. A station interval of 5 km was aimed at, but owing to lack of time, some sections have a 10 km spacing.

Field work was carried out between the following dates:

29/3/76 to 15/4/76
3/5/76 to 7/5/76

A total of 21 days of recording was achieved during this period. After the initial three weeks field work, an assessment

of the results was made and the final week of recording planned accordingly. Survey personnel and vehicles are listed in Appendix 1.

Communications

Radio communication was maintained between all mobile field parties, and between the field parties and survey headquarters in Canberra. A 100 watt Codan Type 6801 single-side-band transceiver was employed at Canberra and six 25 watt Codan Type 6924 single-side-band transceivers were used by the six mobile field parties. Single wire aerials approximately 12 metres long were used. A Codan Type 7208 Antenna Tuner was used to tune the 100 watt base station.

After initial tests using frequencies of 4630 kHz and 2140 kHz, it was found that 2140 kHz was unsatisfactory due to poor reception and excessive interference. As a result 4630 kHz was used throughout the survey. Regular radio schedules between all parties were held daily at 0900, 1200 and 1700 hours. Communication at other times was by prior arrangement between individual parties. The furthest distance over which radio communication was required was about 400 km, and this was achieved.

Communication between headquarters and the various quarries was usually done by telephone and the planned shooting program was passed on to the field parties by radio.

SHOTS

Shot Locations

The location of quarries from which shots were recorded is shown in Figure 1. A list of quarries is given in Table 1.

The quarries can be grouped as follows:

(i)	Eastern:	Bass Point, Dunmore and Albion Park blue-metal quarries.
(ii)	Central:	Marulan limestone quarry.
(iii)	Western:	Ardlethan tin mine.
(iv)	Northern:	Ravensworth, Swamp Creek, Foybrook and Howick open-cut collieries and the Prospect and Wallgrove blue-metal quarries.
(v)	Southern:	Queanbeyan and Hall blue-metal quarries.

A single shot from the blue-metal quarry at Cootamundra was fired outside the time slot for which the recording stations were programmed and was not recorded.

The latitudes and longitudes of shots were found by scaling the positions on 1:100 000 topographic maps. The positions of shots from Ravensworth, Swampy Creek, Howick, Foybrook and Marulan were marked on local quarry maps supplied by each quarry. These positions were then transferred to the 1:100 000 maps. The positions of the Foybrook and Howick mines were first identified on aerial photographs. For all other shots, the area of the quarries in which they were fired was small, and their exact positions were identified directly on the 1:100 000 maps. The co-ordinates were found to the nearest 0.1 minute of arc. Approximate elevations above mean sea level of shots were obtained from the contours on the topographic maps.

All relevant information on shots is listed in Table 2.

Shot details

All the shots recorded during the survey were from routine blasting operations. The explosives used were mainly ANFO and Quarigel, with the normal boosters, primacord and detonators.

The explosive was placed in up to 69 drill holes per shot. Most shots were fired with delays between holes, or rows

of holes. The total delay between the first and the final detonations in a particular shot was variable, but was usually about 100 milliseconds. In some cases however the delay exceeded 1000 milliseconds.

The size of the shots ranged from 332 to 46 000 kg (Fig. 3). The smaller shots were not well recorded to any great distance (Fig. 4).

In a period of 22 days, 73 shots were detonated. Of these, seven shots were fired on a Saturday and one on a Sunday.

Shot timing

The exact times of detonation were obtained either by recording the shot on site, with a visual recorder, or by recording on a tape recorder set up close to the mine. In the latter case, a correction was made to allow for the distance of the recorder to the shot. This was estimated by recording at least one shot on-site and on the tape recorder, thus obtaining the travel time from the mine to the recorder.

The on-site recording was done by using two shot-timing recorders. A Sprengnether portable seismograph was used at Ardlethan.

Marulan, Bass Point, Dunmore, Albion Park

Station 8 at Fitzroy Falls was used for timing shots at these quarries. It was left running throughout the survey. Some difficulty was experienced early in the survey with equipment at the site, and during this period stations 13 at Wingello and 16 at Marulan were used for shot timing.

The following shots were recorded on site: shot 31, Marulan; shots 28 and 45, Bass Point; shot 26, Albion Park; shot 39, Dunmore.

Ardlethan

A Sprengnether MEQ-800 portable seismograph with a Mark L-4C 1 Hz geophone was used for timing Ardlethan shots. It was set up in the mine to run continuously when a shot was expected. The seismograph was being run as an ink-pen recorder, but this was found to be unsatisfactory, owing to blockage of the pens. It was then run as a smoked paper recorder by smoking the recording paper with paraffin and using the pen as a stylus. The records were fixed with a coating of shellac.

Ravensworth, Swamp Creek, Foybrook, Howick

An Akai seismic recorder was placed at station 74, Bulga, 29.5 km south of Ravensworth, and left running for the first three weeks of the survey. Shots were timed at each quarry, and the travel time to Bulga computed. Corrections to times of other shots recorded at Bulga could then be made. Cooney observatory was used for timing shots in the final week of recording when Bulga was unoccupied. Travel times to Cooney were obtained in the earlier recording period.

The following shots were recorded on site: shot 7, Ravensworth; shot 22, Howick; shot 23, Foybrook; shot 48, Swamp Creek.

Prospect, Wallgrove

Shot-time recordings were made on-site for one shot at Prospect (shot 40) and one shot at Wallgrove (shot 63). Other shot times were calculated from Riverview observatory records.

Hall, Queanbeyan

Shot 14 at Hall was timed on-site by the Engineering Geophysics section of BMR. Previous work at Queanbeyan quarry had established the travel time to Kowen Forest station, and this

was used for timing the two Queanbeyan shots.

RECORDING STATIONS

Sixty-seven recording sites were occupied by BMR remote recording stations. Records were also obtained at the permanent observatories at Riverview, Cooney and Kowen Forest. Sixty six stations between Marulan and Bass Point and between Marulan and Ardlethan were occupied. A single station was occupied at Bulga, 29.5 km south of Ravensworth, principally for shot timing purposes.

Recording site positions

The sites for the recorders were initially selected at 5 km intervals along the traverse. Considerations in choosing the final sites included accessibility, rock outcrops, protection from livestock and permission from the property owner. Most sites were placed close to their initially chosen positions.

Where possible, the seismometer was placed on a rock outcrop. Otherwise it was buried in soil to provide better ground coupling and protection from wind and livestock. The recorder and battery were covered by plastic sheeting.

A total of 15 recording systems was available at the time of the survey, and to occupy all the sites it was necessary to shift them along the traverse. The stations were left at each site until at least one shot was recorded from the major quarries. They were then moved further along the traverse. The sites were visited, when necessary, to change batteries and tapes.

Six stations (stations 17, 20, 23, 26, 29 and 32) were occupied by a three-component recording system. Three-component recordings were also made at the Riverview and Cooney observatories, operated by Riverview College and the University of New England respectively. All the other stations were occupied by

vertical component systems.

The position of each site was marked on 1:100 000 topographic maps when the station was set up. Bearings and, where possible, distances, to objects recognizable on the maps were noted. The latitudes and longitudes to within 0.1 minute of arc were found by scaling off the positions on the topographic maps. Elevations of stations were found from the contours on the maps. The positions of the three observatories were known previously.

Rock samples

Rock samples were collected from each site where rock was exposed. The samples were identified by a geologist at BMR and the P-wave velocities and densities determined. These are listed in Table 3 with other relevant information for each recording site.

EQUIPMENT

Fifteen BMR remote recording seismic systems were used on the survey. Of these, twelve used modified Akai tape decks and three used Precision Instruments (PI) tape decks. One PI system was run as a three component system.

Akai recording systems

The Akai recording systems used on this survey were improved versions of the Akai systems employed on previous BMR crustal surveys. The electronics and tape deck were re-packaged into a single case, and power was provided from a single 12 volt DC supply. This survey was the first in which the new versions of these systems were used.

The seismic recording system consisted of a seismometer, amplifier, tape recorder, calibrator, clock and radio, as well as ancillary equipment such as power supplies. Willmore Mk IIIA or

Willmore MK II Seismometers, fitted with calibration coils, were used. The free periods were adjusted to 0.75 seconds. The high and low gain seismic signals were frequency modulated by a BMR Type TMF-2 modulator before recording.

BMR Type TAM5 amplifiers were used in all recorders. The gain of these was adjustable in 6 dB steps from 48 dB to 120 dB. In addition, a low gain level 24 dB below the selected level was also recorded. Five switchable filters were provided, with passbands of 0.01 to 0.2 Hz, 0.01 to 20 Hz, 0.1 to 10 Hz, 1 to 5 Hz and 1 to 100 Hz. The 0.01 to 20 Hz filter was used during this survey.

The tape recorders were modified Akai 4 channel Type 1730D-SS tape decks which used $\frac{1}{4}$ inch tape.

A BMR Type SSC-1 calibrator, with current outputs ranging from 1/128 mA to 4 mA in ten steps, was used to calibrate the recording systems.

A BMR Type NCE-1 clock provided a coded time signal to the recorder and also switched the recorder on and off at pre-set times. The system was initially programmed to switch on at 1100 hr and switch off at 1800 hr E.S.T. However, to take advantage of earlier shots, the program was modified to switch the recorder on at 0900 hr. VNG time signals were received on modified Labtronics Model 20 radios. Reception was usually good on a frequency of 12 MHz. The clock and radio signals were recorded directly on tape.

PI recording systems

The PI recording systems were similar to the Akai systems, but employed a separated Precision Instruments Type 5107 seven track tape deck which used $\frac{1}{2}$ inch tape.

The radio channel and two seismic channels were frequency modulated, while the clock signal was recorded directly on tape. The modulators were contained in the tape deck.

Two 12 volt DC supplies were needed to power the system.

Three-component system

A PI recording system was modified to a three-component system. Two additional TAM5 amplifiers, power supplies and cabling were added to provide two extra seismic channels.

Three Willmore Mark II seismometers were used, two in the horizontal mode and one vertical. The horizontal seismometers were aligned along north-south and east-west axes when setting up.

Six channels were recorded. These were the clock and radio signals, the high and low gain vertical seismic component and the two high gain horizontal components.

Battery and tape life

A single 80 amp-hour lead-acid battery was used to power each Akai system. Each PI system was powered by two batteries.

When the Akai system was recording the current drain was approximately 1.65 A. The current drain on stand-by was approximately 0.9 A.

With the system programmed for nine hours each day, the reliable life was found to be about 2½ days, i.e, about 20 hours recording time and 40 hours on standby. This was variable, and apparently depended on the initial state of charge of the batteries.

For the last week of the survey two batteries in parallel were used for each Akai. They were therefore able to operate unattended for five days.

The tapes normally used were 1200 feet long. With a record speed of 15/256 inches per second, the tape life was 68.3 hours. Tapes 1800 feet long were also used in some cases.

Shot-timing recorders

Two shot-timing systems were constructed prior to the survey. The output from an SIE 2 Hz geophone was amplified by a TAM5 amplifier, and was recorded on a Hellige Hellcoscript chart recorder. VNG time signals from a Labtronics Model 20 radio receiver were recorded alongside the geophone output.

The Sprengnether portable seismograph used for timing Ardlethan shots has been described in the section on shot timing.

COMMENTS

At the time of writing this report, most of the field tapes have been played back, and arrivals picked on the records. However, the data have not been analysed and the comments given here are therefore preliminary.

Out of a total of 73 shots, nine were not recorded by any station. Of these, one was fired outside the recording time slot, five were less than 1000 kg, and three were small shots (less than 4000 kg) from the northern quarries.

The overall recording success is shown in Figure 4. All possible recordings of shots are shown as squares. The shaded squares represent records on which arrivals have been picked. The rest showed no evidence of a seismic arrival, or were so poorly recorded that arrival times could not be picked. There was a total of 921 possible recordings, of which 269, or about 29%, were

sufficiently large for an arrival time to be picked.

It is difficult to draw conclusions, from the results of this survey, about the maximum useful recording distance for a particular shot size. The variables involved include shot delays and shot pattern, the local geology of the shot and recording site, instrumental factors such as gain and frequency response, and the noise level at the site.

An analysis was made of shot size versus distance at which useable records were obtained. The results are inconclusive because the picture is distorted by exceptional shots being recorded to anomalously large distances, and non-uniform distribution of recorders during the survey.

Failure of the clock was the most common instrumental fault. One PI and one Akai system failed to record any seismic information during the first three weeks of the survey, resulting in the loss of recordings at seven stations. Four of these stations were re-occupied in the final week of recording.

The three-component PI system suffered tape transport problems and the clock time code signal was incorrect for most of the recording period. One Willmore MK III seismometer was found to contain water. In eleven cases, the recording system was not operating when the site was visited. Eight malfunctions were due to the battery being flat, one due to a broken power cable, one due to accidental activation of the automatic stop switch on the tape deck, and one due to the tape running out.

It is proposed that future surveys of this type be conducted on a similar basis to that used on the last week of this survey. The stations would be left at each site with sufficient batteries to last for a week of programmed recording. This would require less manpower for operating equipment. Also, the probability of recording at least one large shot at each site would be increased thus providing a more uniform coverage along the recording line.

ACKNOWLEDGEMENTS

The cooperation of the management and staff of the various quarries is gratefully acknowledged. In particular, thanks are due to the following:

D. Merz and J. Taber, Albion Park; Mr. Wood and J. Dooley, Bass Point; K. Gore and D. Park, Dunmore; J. Teague, T. Pearson and A. Johnson, Marulan; A. Baxter, Prospect; R.D. Humphries, C. Randle and J. Braddock, Ravensworth; R.C. Moore and J. Bowen, Swamp Creek; C.G. Turner, N. McMillan, M. Wilton and J. Botton, Foybrook and Howick; Mr. Tittiom and P. Reynolds, Ardlethan; I. Fraser, Wallgrove, and I. Haddow, Queanbeyan.

Thanks are also due to the many property owners who gave permission to place recording equipment on their properties, and to Dr. L.A. Drake for providing the Riverview Observatory records.

REFERENCES

BOLT, B.A., 1962 - A seismic experiment using quarry blasts near Sydney. Aust. J. Phys., 15, 293.

DOYLE, H.A., EVERINGHAM, I.B., & HOGAN, T.K., 1959 - Seismic recordings of large explosions in south-eastern Australia. Aust. J. Phys., 12, 222.

DOYLE, H.A., UNDERWOOD, R., POLAK, E.J., 1966 - Seismic velocities from explosions off the central coast of New South Wales. J. geol. Soc. Aust., 13(2), 355-372.

PACKHAM, G.H., 1969 - The general features of the geological provinces of New South Wales. J. geol. Soc. Aust., 16(1), 1-17.

SCHEIBNER, E., 1973 - A plate tectonic model of the Palaeozoic tectonic history of New South Wales. J. geol. Soc. Aust., 20(4), 405-426.

THOMAS, L., 1969 - Rayleigh Wave dispersion in Australia. Bull. seism. Soc. Amer., 59, 167.

APPENDIX 1

PERSONNEL AND VEHICLES

The field work was undertaken by the following personnel:

D.M. Finlayson (Party Leader)
J.B. Connelly
B.J. Drummond
C.D.N. Collins
J.W. Williams
D. Denham (part time)
J.P. Cull (part time)

The vehicles used during the survey were:

5 L.W.B. Landrovers
1 Ford Falcon panel van
1 International 1350

The panel van was used mainly for shot-point recording in the Ravensworth and Sydney areas. A number of mechanical faults occurred with the Landrovers and it was necessary to replace one with the International towards the end of the survey.

TABLE 1. - Participating Quarries

QUARRY	OPERATOR	TYPE	No. of Shots
Marulan	Blue Circle Southern Portland Cement	Limestone	19
Ardlethan	Ardlethan Tin NL	Tin	9
Bass Point	Pioneer Concrete	Blue Metal	5
Albion Park	Farley and Lewers	Blue Metal	2
Dunmore	Blue Metal and Gravel	Blue Metal	4
Prospect	Blue Metal and Gravel	Blue Metal	3
Wallgrove	Pioneer Concrete	Blue Metal	2
Queanbeyan	Readymix Cement	Blue Metal	2
Hall	Albion Reid	Blue Metal	1
Ravensworth	Costain Aust. Ltd	Coal	10
Swamp Ck.	Hebden Mining Co.	Coal	4
Foybrook	Clutha Development	Coal	7
Howick	Clutha Development	Coal	4

Notes

1. Two shots from the Ravensworth area have been tentatively identified as Ravensworth shots.

2. Two shots, tentatively identified as Foybrook shots, may be from Howick.

TABLE 2. SHOT STATISTICS.

SHOT NO.	QUARRY	ORIGIN TIME D	H	M	SEC	LATITUDE DEG	MIN
1	MARULAN	29	15	39	00.37	34	47.3
2	RAVENSWORTH	30	12	39	42.08	32	26.3
3	ARDLETHAN	30	16	00		34	20.0
4	MARULAN	30	15	37	41.28	34	46.4
5	SWAMP CREEK	30	17	03	34.51	32	24.3
6	BASS POINT	30	17	30		34	36.1
7	RAVENSWORTH	31	11	55	24.12	32	26.0
8	HOWICK	31	13	45	10.44	32	26.1
9	MARULAN	31	15	40	48.80	34	46.8
10	ARDLETHAN	32	11	44	21.10	34	20.0
11	MARULAN	32	15	15	48.01	34	47.3
12	MARULAN	32	15	34	04.52	34	46.9
13	QUEANBEYAN	32	15	40	08.10	35	23.9
14	HALL	32	16	22	43.80	35	05.4
15	BASS POINT	33	10	27		34	36.1
16	RAVENSWORTH	33	11	45	01.12	32	26.3
17	SWAMP CREEK	33	14	19	17.27	32	24.3
18	MARULAN	33	15	47	43.81	34	47.1
19	ARDLETHAN	34	09	51	23.70	34	20.0
20	COOTAMUNDRA	34	10	02		34	39.4
21	DUNMORE	34	11	54	08.08	34	36.6
22	HOWICK	35	13	02	27.48	32	26.1
23	FOYBROOK	36	13	45	13.12	32	22.9
24	MARULAN	36	15	43	59.95	34	46.4
25	MARULAN	37	15	27	47.88	34	47.3
26	ALBION PARK	38	11	07	00.56	34	35.2
27	SWAMP CREEK	38	11	37	52.48	32	24.3
28	BASS POINT	38	16	25	58.52	34	36.1
29	ARDLETHAN	38	16	28	48.20	34	20.0
30	WALLGROVE	39	13	00		33	48.0
31	FOYBROOK	39	13	45	20.01	32	22.9
32	RAVENSWORTH	39	13	47	47.25		
33	MARULAN	39	15	47	05.93	34	46.8
34	QUEANBEYAN	39	15	39	16.30	35	23.9
35	RAVENSWORTH	40	10	55	17.70		
36	MARULAN	40	15	41	07.80	34	46.9
37	RAVENSWORTH	40	15	45			
38	ARDLETHAN	40	16	25	24.90	34	20.0
39	DUNMORE	41	10	10	00.20	34	36.6
40	PROSPECT	41	10	41	22.30	33	49.4
41	ARDLETHAN	41	12	55	00.40	34	20.0
42	MARULAN	43	15	48	18.03	34	46.4
43	ARDLETHAN	43	16	38	58.30	34	20.0
44	RAVENSWORTH	44	11	43	28.96	32	25.2
45	BASS POINT	44	13	55	05.15	34	36.1
46	MARULAN	44	15	37	43.64	34	46.8
47	RAVENSWORTH	45	12	46	00.14	32	25.3
48	SWAMP CREEK	45	13	39	12.00	32	24.3
49	FOYBROOK	45	13	44	46.42	32	22.9

LONGITUDE DEG	LONGITUDE MIN	WEIGHT (KG)	NO.OF HOLES	DELAY (MS)	TOTAL DELAY	DEPTH (M)	WEIGHT/ HOLE(KG)
150	01.5	575	11	10	110		45
151	02.1	28000		25	50		
146	51.2			25/30			
150	01.8	3450	11	10	110		300
151	04.5	10884					
150	53.0	884	18	10	130	9	24
151	02.2	9000		25	100		
150	57.3						
150	01.6	3086	11	10	110		270
146	51.2						
150	01.5	600	14	10	140		45
150	01.5	3800	16	10	160		270
149	13.2						
149	00.5	943	26			12	36
150	53.0	1071	12	10/17			89
151	02.1	22000		25	100		
151	04.5	7710	46				181
150	01.5	1843	7	NIL	NIL		271
146	51.2	1600	40	25/30			40
147	59.9						
150	49.3	725	13		39		76
150	57.3	33815	67	17			1112
151	02.1	8907	49	10			
150	01.8	3076	11	20			301
150	01.5	577	15	10			45
150	48.1						
151	04.5	3810	23				181
150	53.0	934	11	17	187	27	85
146	51.2	4074	67	25/30		9	61
150	49.5						
151	02.1	4916	34	10			
150	01.6	2806	11	NIL	NIL		301
149	13.2						
150	01.5	3860	14	10	140		271
146	51.2	1021	21	25/30		7	49
150	49.3	748	10	NIL	NIL		73
150	55.2	2275	18	10		7	126
146	51.2						
150	01.8	2805	10	20			301
146	51.2	1800	30	25/30		11	60
151	02.1	18000		25	1175		
150	53.0	1744	38	10/17		13	46
150	01.6	2893	9	NIL	NIL		301
151	02.4	13000		25	125		
151	04.5	9070	46				181
151	02.1						

TABLE 2 CONTINUED

SHOT NO.	QUARRY	ORIGIN TIME D	H	M	SEC	LATITUDE DEG	MIN
50	DUNMORE	45	13	55		34	36.6
51	MARULAN	45	15	30	11.13	34	47.3
52	ARDLETHAN	45	16	14	20.30	34	20.0
53	MARULAN	46	15	37	49.05	34	46.9
54	PROSPECT	33	15	36		33	49.4
55	PROSPECT	45	15	34		33	49.4
56	HOWICK	41	11	00	11.74	32	26.1
57	HOWICK	46	12	15		32	26.1
58	FOYBROOK	33	13	04	33.62	32	22.9
59	FOYBROOK	46	12	30		32	22.9
60	MARULAN	03	15	35	00.45	34	46.7
61	MARULAN	03	15	35	26.54	34	46.8
62	MARULAN	04	15	35		34	47.2
63	WALLGROVE	05	12	40	21.13	33	48.0
64	RAVENSWORTH	05	13	21	46.38	32	25.2
65	MARULAN	05	15	31	35.02	34	46.9
66	ALBION PARK	06	14	16	32.90	34	35.2
67	ARDLETHAN	07	12	36		34	20.0
68	BASS POINT	06	16	32	43.92	34	36.1
69	MARULAN	06	15	47	48.73	34	46.8
70	RAVENSWORTH	07	13	45		32	25.8
71	DUNMORE	04	14	46	43.69	34	36.6
72	FOYBROOK	03	13	45		32	22.9
73	FOYBROOK	04	13	45	46.74	32	22.9

NOTES

1. Shot numbers are not necessarily in chronological order.

2. Origin time (time of detonation of shot) is given in days, hours, minutes and seconds. Days increase from 29 (29th March, 1976) to 46 (15th April, 1976), then from 03 to 07 (3rd to 7th May, 1976).

3. Latitudes are south latitudes and longitudes are east longitudes.

4. Weight is the total weight of explosives detonated.

5. No. of holes is the number of drill holes used to load the explosive. The weight of explosive in each hole is also given.

6. The delay, in milliseconds, is the delay between detonation of rows of holes in the shot pattern. The total delay is the delay, in milliseconds, between the first and last detonations in the shot.

7. The average depth of the shot-holes is given in metres.

LONGITUDE DEG	LONGITUDE MIN	WEIGHT (KG)	NO. OF HOLES	DELAY (MS)	TOTAL DELAY	DEPTH (M)	WEIGHT/ HOLE (KG)
150	49.3	657	10	NIL	NIL		63
150	01.5	332	8	10	80	10	48
146	51.2	1070	24	25/30		7	45
150	01.5	3139	13	10	130		301
150	55.2	2270	38	10			60
150	55.2	2555	25	10			102
150	57.3	27501	76	17			
150	57.3	25125	59	17			
151	02.1	3928	60	10			
151	02.1	4390	69	10			
150	01.6	2250	9	NIL			
150	01.6	2250	9	NIL			
150	01.5	870	34				
150	49.5	7193					
151	02.2	46000		25	75		
150	01.5	3420	13	10	100		
150	48.1	961	17	16			57
146	51.2	500					
150	53.0	2768	63	10/17		12	
150	01.6	3798	13	10	130		271
151	02.2	28200		25	1150		
150	49.3	839	10	NIL	NIL		82
151	02.1						
151	02.1						

TABLE 3. RECORDING SITES

No.	ABREV.	NAME	LATITUDE ° '	LONGITUDE ° '	ELEVATION m	SEISMOMETER	ROCK TYPE	DENSITY tm^{-3}	VELOCITY $msec^{-1}$	SET No.	TAPE No.	GAIN dB
1	SH	SIGNAL HILL	34 35.2	150 49.6	140	B	PORPHYRITIC RHYOLITE	2.46	3740	016	3	84
2	WE	WILHOLME	34 35.1	150 46.0	105	R				001	3	84
3	SB	SUNNY BANK	34 35.3	150 42.1	184	B	PORPHYRITIC DACITE (W)	2.65	4610	019	3	84
4	KH	KNAPSACK HILL	34 35.7	150 38.7	710	B				011	2	78
5	RH	RANELAGH	34 36.3	150 36.4	682	B				011	3	84
6	SD	SPRINGDALE	34 36.4	150 34.5	680	B				011	2	72
7	AH	AMELIA HILL	34 37.2	150 31.8	714	B				009	3	78
8	FF	FITZROY FALLS	34 38.9	150 28.3	677	R				013	1,2,3	90
9	RL	RED HILL	34 39.4	150 26.2	657	R	SANDSTONE	2.37	3530,3020	018	3	84
10	MA	MERYLA	34 40.1	150 22.9	580	B				018	2	84
11	BN	BUNDANOON	34 40.1	150 17.9	630	B				P1-6		84
12	TL	TEUDTS	34 41.5	150 14.5	600	R	SANDSTONE (F)	2.03	2720,2480	011	2	78
13	WO	WINGELLO	34 42.5	150 10.9	640	R	TERTIARY FERRUGINOUS GRAVEL (W)	2.34	3610	018	1,2	84
14	BG	BULANGALONG	34 43.9	150 08.1	680	B				P1-6		84
15	HP	HAVEN PARK	34 44.8	150 05.6	660	R	TERTIARY FERRUGINOUS GRAVEL (F)	2.52	5420	011	1	84
16	MN	MARULAN	34 47.4	150 00.9	540	R	DOLOMITE (F)	2.47	3920	001	1	78
17	PO	PRAIRIE OAK	34 46.6	149 57.9	615	R				P1-4	(30)	
18	GS	GLENLOSS	34 46.3	149 55.6	688	B				019	1	84
19	ME	MARIONVALE	34 46.4	149 51.4	700	R				016	1	90
20	BX	BOXERS CREEK	34 45.9	149 48.2	680	B	RHYOLITE (F)	2.55	4570,4420	P1-4	(30)	
21	MG	MOUNT GRAY	34 45.4	149 45.8	797	R	ANDSTONE (F)	2.62	4920,4760	017	1	84

TABLE 3. (Continued)

No.	ABREV.	NAME	LATITUDE ° '	LONGITUDE ° '	ELEVATION m	SEISMOMETER	ROCK TYPE	DENSITY $t m^{-3}$	VELOCITY $m sec^{-1}$	SET No.	TAPE No.	GAIN dB
22	WG	WONGAJONG	34 44.7	149 39.7	640	B				015	1	78
23	KW	KIPPILAW	34 45.1	149 35.9	660	B				P1-4	(3D)	
24	HT	HILLCREST	34 44.9	149 31.9	709	B				014	1	90
25	WV	WILLOVALE	34 44.5	149 27.7	732	R	SHEARED PORPHYRY (W)	2.39	3690,2020	019	1	90
26	MI	MUTHUTBILLI	34 44.8	149 24.9	710	B	GREYWACKE (F)	2.60	4990,3410	P1-4	(3D)	
28	TE	TOLLDALE	34 44.1	149 18.7	620	R	GRANODIORITE (F)	2.69	5620	016	1	84
29	AE	AVONDALE	34 44.2	149 15.4	590	R	GREYWACKE (F)	2.58	3980,1240	P1-4	(3D)	
30	DN	DALTON	34 43.1	149 11.0	540	B				017	1	78
31	DR	DAWES ROAD	34 43.4	149 08.6	550	B				014	1	84
32	BY	BROADWAY	34 42.1	149 05.4	620	B				P1-4	(3D)	
33	CE	CLYDESVALE	34 43.0	149 01.0	661	B	BLACK CHERT (F)	2.57	5030,3350	015	1	78
35	WA	WARGEILA	34 41.7	148 53.7	660	R				016	1,2	84
37	AD	ADARE	34 41.3	148 47.6	556	R				019	1,2	90
39	GN	GLENLOTHIAN	34 40.3	148 41.2	545	B				017	1,2	90
41	GY	GARRYOWEN	34 40.8	148 34.3	440	B				001	2	78
43	CP	CAMPSEE PARK	34 38.8	148 28.1	380	R	GRANODIORITE (F)	2.59	2890	015	2	78
44	TA	TURILAWA	34 38.3	148 25.1	443	R	GRANODIORITE (F)	2.69	4150	015	2	84
45	EE	EULIE	34 38.5	148 21.9	408	R	GRANODIORITE (W)	2.57	1510	014	2	84
46	MM	MOUNT MURRAY	34 37.9	148 18.6	460	R	GRANODIORITE (F)	2.72	5400	014	2	78
47	CD	COLLINGWOOD	34 37.5	148 15.7	442	R	SHEARED GRANITE (W)	2.41	2350	014	2	84
48	ED	EASTWOOD	34 36.9	148 11.5	540	R	AMPHIBOLITE (F)	2.93	3240	017	2	84
49	SE	SUNSHINE	34 36.9	148 8.3	538	R	QUARTZITE (F)	2.61	4680	015	2	78
50	MO	MUNROE	34 36.6	148 5.5	430	R	HORNFELS (F)	2.62	4610,2210	019	2	84
51	RT	ROSEMONT	34 35.5	148 2.2	380	R	SANDSTONE (W)	2.37	4070,2130	019	2	84

TABLE 3. (Continued)

No.	ABREV.	NAME	LATITUDE ° '	LONGITUDE ° '	ELEVATION m	SEISMOMETER	ROCK TYPE	DENSITY $t m^{-3}$	VELOCITY $m sec^{-1}$	SET No.	TAPE No.	GAIN dB
52	WN	WOODBURN	34 36.3	147 58.1	447	R	PORPHYRY (W)	2.49	3810	001	2	84
53	KY	KYOGLE	34 35.6	147 55.6	347	R	PORPHYRY (W)	2.45	3070	017	2	90
54	SV	SPRINGVALE	34 34.9	147 52.4	336	B				016	2	84
55	TO	TRURO	34 34.3	147 49.7	370	R	SHEARED PORPHYRY (W)	2.57		016	2	84
56	GL	GLENLEA	34 33.6	147 46.2	400	R	SANDSTONE (F)	2.53	4170,1420	001	2	84
57	CG	COMBANING	34 33.0	147 42.4	360	B				P1-		
58	SL	SINCLAIRS LANE	34 29.9	147 38.8	280	B				009 007	2 3	84
60	NM	NARNDO MAR	34 30.1	147 32.6	315	R	SILTSTONE (W)	2.35	3730,3830	007	2	
62	TF	TEMORA FOREST	34 29.6	147 24.8	328	B	GRANODIORITE (W) SANDSTONE (W)	2.68 2.44	5400 4150,4650	017	3	84
63	GW	GLENWARREN	34 27.5	147 22.0	300	B	GRANITE (F)	2.64	3200	P1-		
64	GI	GLEN IRA	34 27.4	147 15.7	310	R				009 015	1,2 3	84
65	KA	KOORINGA	34 26.7	147 13.6	300	B				009	2	72
66	KN	KELROAN	34 24.9	147 10.4	292	B				007	2	84
67	BB	BILLABERRY	34 25.0	147 08.3	300	B				P1-		72
68	YY	YARRANJERRY	34 25.5	147 06.3	300	R	GRANITE (F)	2.56	3340	014 009	3 1	90
69	TN	TRACTON	34 22.8	147 03.5	290	R	LEUCOGRANITE (F)	2.56	2220	007 009		
70	GA	GLEN ALLEN	34 22.6	146 59.4	280	R				012 P1-	4	90 72
71	MD	MERALDON	34 20.9	146 55.7	230	R	SANDSTONE (F)	2.54	3250	007	1	84
72	HW	HILLVIEW	34 20.4	146 52.6	240	R	SILTSTONE (F)	2.51	4310,2230	007	1	72

TABLE 3. (Continued)

No.	ABREV.	NAME	LATITUDE ° '	LONGITUDE ° '	ELEVATION m	SEISMOMETER	ROCK TYPE	DENSITY $t m^{-3}$	VELOCITY $m sec^{-1}$	SET No.	TAPE No.	GAIN dB
73	AN	ARDLETHAN	34 19.7	146 51.5	264	R	MINERALISED PORPHYRY (F)	2.78	5700			
74	BA	BULGA	32 42.0	150 58.6	107	R	TUFF (W)	2.17	2590,2360	012	1,2,3	84
75	KOH	KOHEN	35 17.3	149 17.9	792	-						
76	RIV	RIVERVIEW	33 49.8	151 09.5	25	-						
77	COO	COONEY	30 34.7	151 53.5	653	-						
78	OK	OKI	34 23.0	147 01.9	250	B				P1-		72

NOTES

(1) Seismometer placement: B = Buried in soil, R = on rock outcrop.
(2) Rock samples from recording sites. F = Fresh, W = weathered.
(3) More than on velocity indicates anistropy of sample.
(4) Set Numbers are for Akais, unless otherwise indicated.

BUILT-UP AREA

TOWN

SHOT

STATION

3-COMPONENT STATION

0 50 100 km

N S W

SYDNEY

Fig.1 LOCATIONS OF SHOTS AND STATIONS

Dubbo

Muswellbrook

FOYBROOK

SWAMP CREEK

HOWICK

RAVENSWORTH

Singleton

74

Maitland

Burrendong Reservoir

33°

Newcastle

Parkes

Forbes

Orange

Bathurst

Gosford

The Entrance

Woy Woy

RIVERVIEW

76

WALLGROVE

PROSPECT

SYDNEY

Burragorang Reservoir

34°

West Wyalong

73

ARDLETHAN

70 78 69

Temora

62 60 58

50

COOTAMUNDRA

43 41 39 37 35 33 32 30 29 28 26 23 20 17

Goulburn

10

DUNMORE

ALBION PARK

2 1

BASS POINT

MARULAN

Narrandera

Yass

35°

Lake George

HALL

KOWEN FOREST

75

CANBERRA

QUEANBEYAN

Wagga Wagga

TASMAN SEA

147° 148° 149° 150° 151°

Record No. 1976/103

N/B10-5R

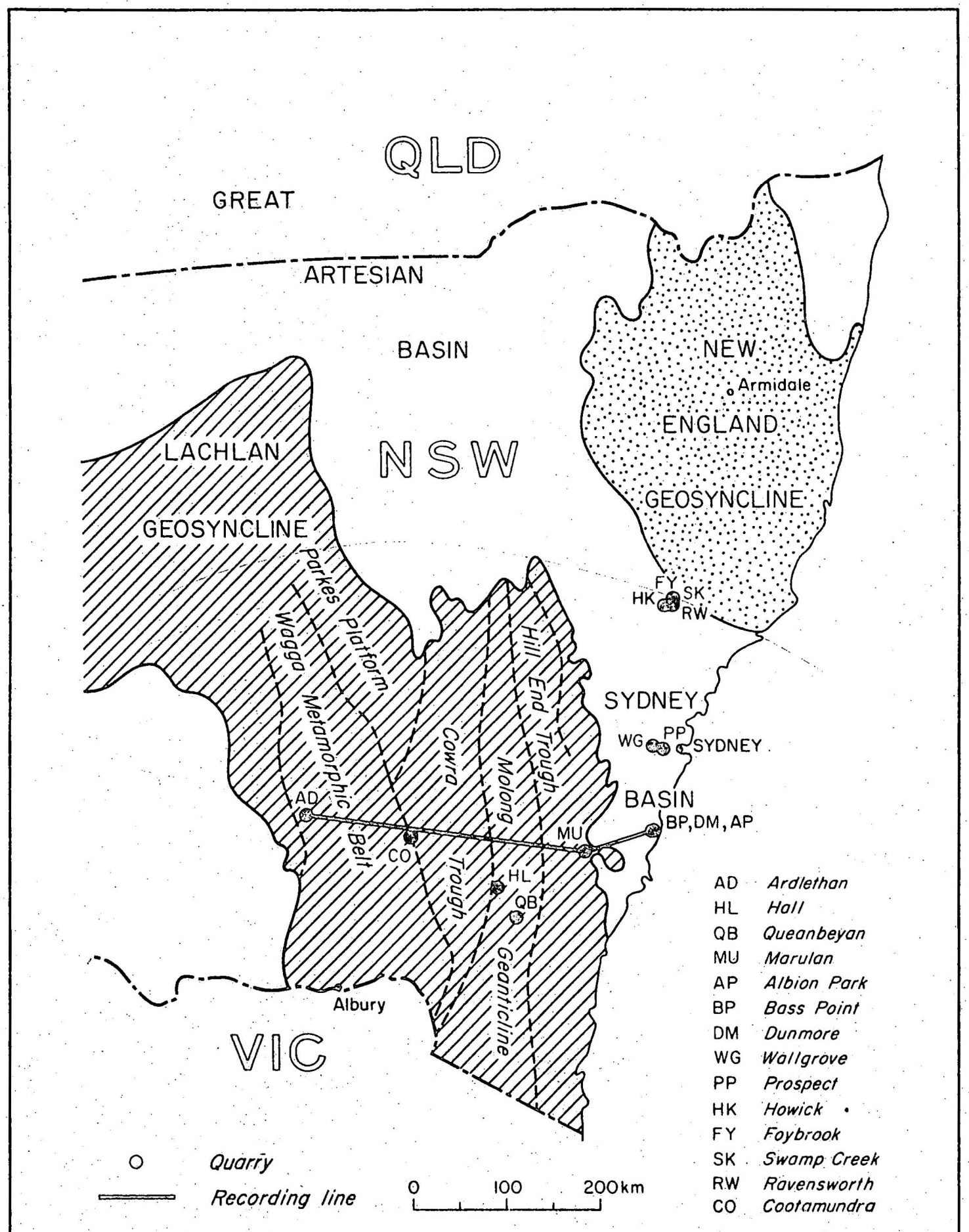


Fig. 2 QUARRIES AND RECORDING LINE USED ON 1976 CRUSTAL SURVEY AND GEOLOGICAL PROVINCES

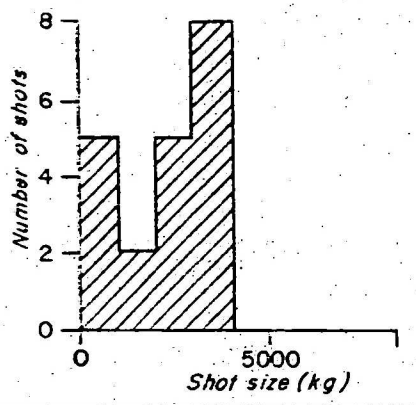
Record No. 1976/103

Fig. 3 SHOT SIZE AND FREQUENCY.

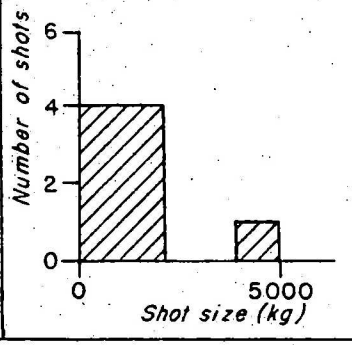
Charge size of shots fired during the survey (over a total period of 22 days).

Charge size interval = 1,000 kg

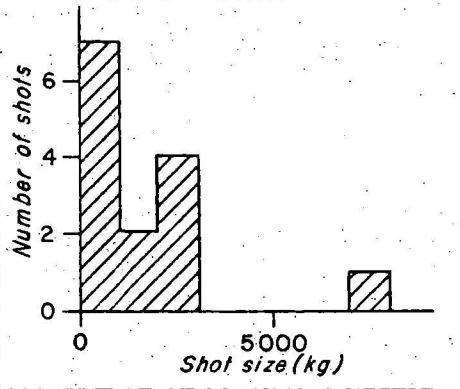
MARULAN



ARDLETHAN



BASS POINT, ALBION PARK, DUNMORE, PROSPECT, WALLGROVE

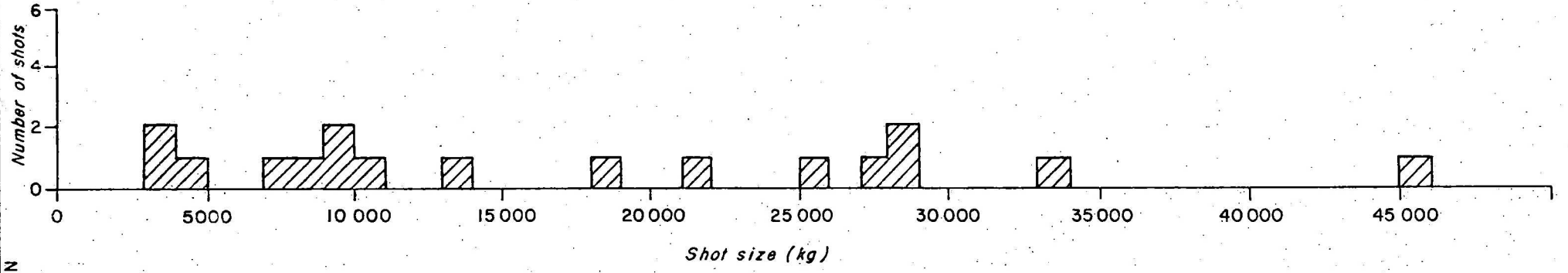


CHARGE SIZE UNKNOWN FOR THE FOLLOWING SHOTS:

Ravensworth Shots		32, 35, 37
Foybrook	"	49, 72, 73
Howick	"	8
Ardlethan	"	3, 10, 41
Wallgrove	"	30
Albion Park	"	26
Cootamundra	"	20

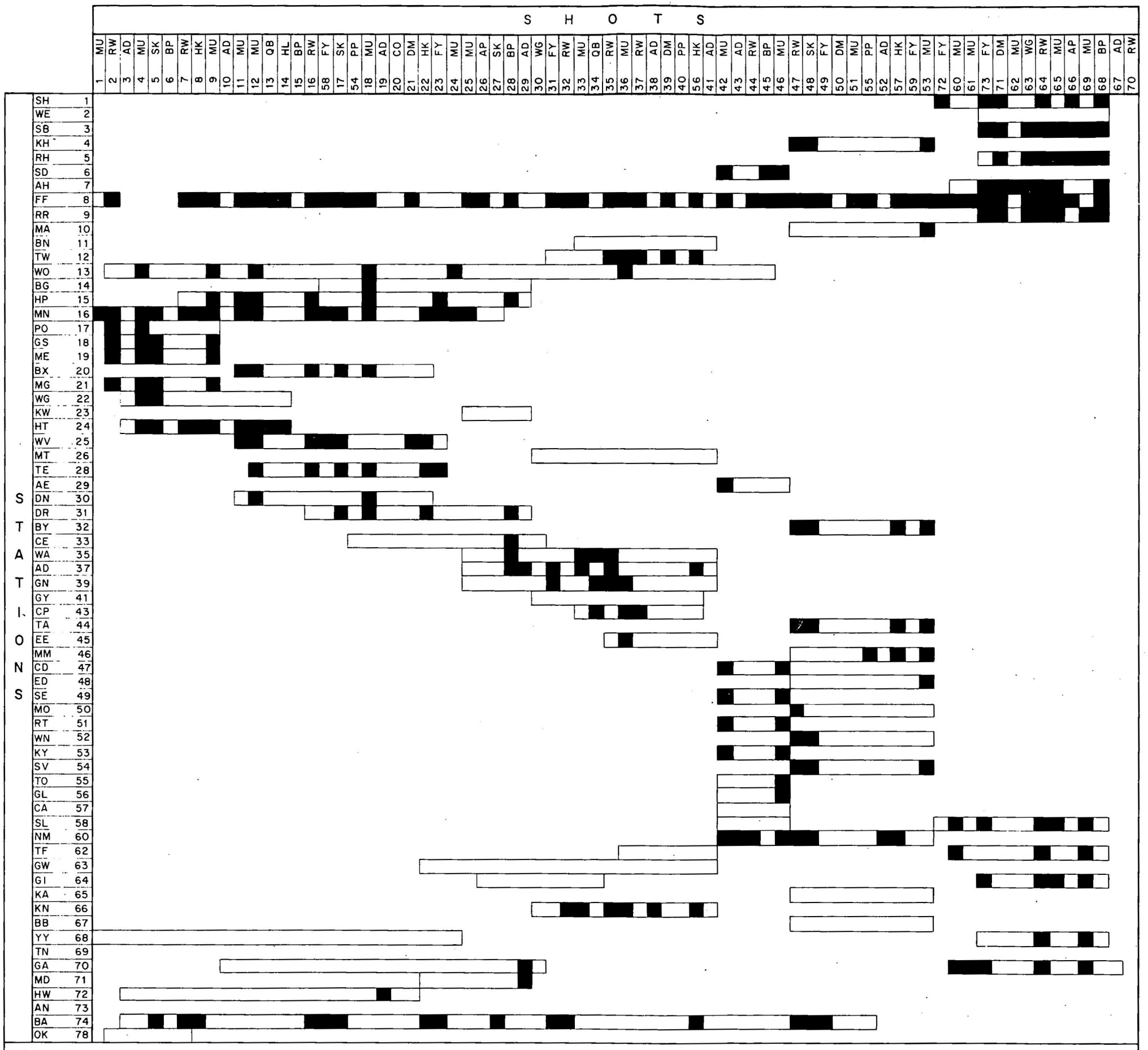
Shots 13 and 34 at Queanbeyan and Shot 14 at Hall were approximately 1,000 kg

RAVENSWORTH, SWAMP CREEK, FOYBROOK, HOWICK



N/B10-6A

Fig.4 Recording Success



No usable arrival recorded

Arrival recorded

For station abbreviations: See Table 3

SHOT ABBREVIATIONS:

RW - Ravensworth
SK - Swamp Creek
HK - Howick
FY - Foybrook
WG - Wallgrove
PP - Prospect
AP - Albion Park
BP - Bass Point
DM - Dunmore
MU - Marulan
CO - Cootamundra
AD - Ardlethan
QB - Queanbeyan
HL - Hall

Record No. 1976/103

N/BIO-7R