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Seismic Travel-Times from Explosions, Western Australia, 1966-1968·5

by

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I.B. EVERINGHAM

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ILLUSTRATIONS

SUMMARY

Local seismic travel-time data obtained from recordings of explosions and rockbursts by the Mundaring Geophysical Observatory during the period 1966 - 1968.5 are presented. Useful results have been obtained from recordings of explosions in rock quarries, iron ore quarries, oil prospecting marine surveys, harbour dredging operations, and in a water filled quarry.

Results indicate that (a) under-sea explosions are about 20 times as effective as explosions on land, (b) depth charges exploded at depths of from 50-100 fathoms have proved the most efficient source, (c) under the best conditions typical quarry blasts of about 3 tons of ammonium nitrate and dieselene can be recorded to a maximum distance of about 300 km, and (d) it will be difficult to obtain accurate reversed P_n velocities for the inland areas because instantaneous explosions of the order of 20 tons or more are needed for recordings where P_n is the first-arrival i.e. at distances greater than about 300 km.

1. INTRODUCTION

As opportunities have arisen the Mundaring Geophysical Observatory has gathered seismic data for studies of the earth's crust and upper mantle. The object of this report is to present refraction data obtained during 1966, 1967, and part of 1968 from artificial sources; data collected before 1966 have been presented by Everingham (1969). Most of the information has been obtained from seismograph recordings of explosions used for harbour deepening, quarrying, and oil prospecting. Results from three small charges exploded by the Observatory and from Kalgoorlie rockbursts are included. Interpretations of data listed here will be presented separately; a preliminary interpretation of the earlier results has been given by Everingham (1965).

This Record does not include data from the Fremantle Region Upper Mantle Project (FRUMP) which was carried out during the same period, because it has been presented separately by Gregson & Woad (1968). Also unlisted here are data recorded from over three thousand 66 pound H.E. seismic reflection shots which were exploded at 40-second intervals during firing runs in off-shore regions of the Perth Basin, late in 1967, by Western Australian Petroleum Pty Ltd (WAPET). These data will be presented separately.

Locations of shots and recording stations are displayed on Plates 1-4 and these and other details are listed in Tables 1 and 2. Travel time data associated with the various series of explosions and with Kalgoorlie rockbursts are listed in Tables 3 -10.

2. METHOD AND RESULTS

Shot instants

The timing of shots was achieved by the methods outlined in the Appendix. Equipment used varied with the circumstances of the shooting and availability. Generally the timing procedure had to be arranged so that it did not in any way hinder the routine of the operating company.

Methods are referred to below by the letter denoted in the Appendix.

Poor reception of time signals marred shot instants determined at sea more often than on land. Ship's electrical noise was one definite contributing factor.

Seismic recordings

At Mundaring recordings of vertical component ground motions are made simultaneously on the World Standard (WWSSS) and Benimore (Benioff seismometer, Willmore recorder) seismographs. To obtain explosion data the Benimore was used because it has high paper-speeds (2 or 4 mm/sec.), high magnification (approximately 150,000 at 0.2 sec), and 10-second time - marks from a crystal clock. Vertical component Willmore seismographs with magnification 50,000 at 0.2 sec, 4 mm/sec paper speed, and 1-second radio-controlled time-marks were used in the field. The instruments are described by Gregson & Woad (1968).

Accuracy

From several series each of up to ten recordings the standard error of a single travel-time measurement was found to be about 0.04 sec when clear seismic phases were recorded. Therefore where good quality multiple readings were obtained, as from the Kwinana and WAPET shots described later, the standard error of the mean is less.

The accuracy of listed travel-times is indicated by the number of decimal places given in the Tables 6 -10. Where two decimal places, one decimal place, or whole numbers of seconds are given, times are estimated to have errors less than 0.05 s, 0.20, and 1.0s respectively.

Maximum errors due to uncertainty of position are dependent on the plotting accuracy of latitudes and longitudes on the WA lands and Surveys 80 chain/inch lithographs. They are probably within ± 0.5 km but could not be definitely ascertained at the time this Record was written (August, 1968). In all cases stations and shot-points could be located with an accuracy of ± 0.1 km on the maps.

Kwinana marine explosions

During May 1966, Dredging Industries Pty Ltd commenced a harbour deepening project which required blasting in Cockburn Sound in order to soften rock before dredging.

Blasting operations were carried out spasmodically for about 18 months. Charges of up to 350 pounds of ammonium nitrate and dieselene were fired at about 4-minute intervals over several 1 to 2 hour periods throughout the days when blasting was in progress. Charges were exploded in about 10 m of water over an area of roughly 4 sq km, centred about 1.5 km from the shore.

Sixty-two field seismic stations were occupied along northerly, easterly, and southeasterly traverses, at distances from explosions in the range 2-270 km (Tables 3, 4, 5). First-arrival P-phases from 350-pound shots were clearly recorded at distances up to about 150 km and were indiscernible at 270 km.

Shot-instants were determined by methods A (on a barge about 150 feet from the explosion) and C.

Series of explosions such as these were ideal for refraction work because field stations could record several events before being shifted. In this way doubtful or emergent seismic phases were easily checked by inspecting the seismogram for each explosion. Usually about five explosions were recorded at each site and errors in travel-times shown in Tables 7, 8, 9 are less than 0.05 seconds.

The data in Table 7 were collected specifically for estimating the basement depth and seismic velocity in the Perth Basin, whereas data in Tables 8 and 9 should provide evidence about the deeper structures beneath the Basin and the adjoining shield.

WAPET marine explosions

WAPET carried out two refraction traverses which provided useful data.

In the first, running south from Rottnest Island (Traverse BE), two shot-points were used for explosions of 200-500 lb of H.E. detonated on the sea-bed where the depth of the sea was about 30 m. Method B was employed for shot-instants and seismic recordings were made at Mundaring.

An east-west traverse (BY) was made later off the coast between Geraldton and Dongara. Here at four shot-points, 100 - 2000 lb H.E. were detonated at various depths in water roughly 40 m deep.

Methods B (August 1967) and C,F, and A (February, March 1968) were used for shot-instant determinations; seismic records were obtained at Mundaring at distances of 352-362 km, Meekatharra (483 km), Kalgoorlie (683 km), and several field stations at distances in the range 22 - 605 km.

In conjunction with FRUMP times, the data from the more distant recordings of northern shots may be used for determining a reversed Pn velocity; remaining results will provide material for studies of the Perth Basin basement and of crustal structure.

Extensive data from Walkaway recordings of the explosions near Dongara proved that seismic amplitudes of P-waves were directly proportional to charge size (apart from near-surface explosions).

Quarry blasts

Results are listed in Table 6.

Several quarries along the Darling Scarp use up to 10-ton charges for their mining operations. Co-operation with Australian Blue Metal Ltd (ABM) enabled the observatory staff to make nine field recordings of quarry blasts at distances up to 114 km. Methods D and F were used for shot-instant timing. In most cases the seismographs were set up to record the ABM quarry blasts and Kwinana explosions on the same record.

During routine seismograph interpretation it was deduced that events frequently recorded at Mundaring and Kalgoorlie were blasts at the Koolyanobbing iron-ore quarry. The shot-instant of one such 3-ton explosion (28th June 1967) was obtained by method E and seismic recordings were obtained at Mundaring (340 km), Kalgoorlie (186 km), and in the field (170 km).

Later (24th August 1967) travel times to Mundaring (309 km) and Walkaway (137 km) were obtained in a similar manner from a similar blast at the Koolanooka iron-ore quarry.

At Mount Tom Price up to about 50 tons of explosive slurry (details not yet known) are detonated about twice weekly in the iron-ore quarry. Occasionally during 1968 the blasts were recorded clearly at Mundaring and at Meekatharra. A shot instant has not been measured, so the travel time differences between the first arrival and all subsequent phases at each station are shown at the end of Table 6. All values are the means of several measurements made before July 1968.

Three test explosions (maximum 150 lb of ammonium nitrate and dieselene) were fired in about 10 m of water in a quarry on the shield close to the Darling Fault near Byford. They were recorded only weakly at MUN (30 km) and two closer stations. Unless the explosive was incorrectly mixed, results indicated that one ton charges would be needed here for recordings at distances up to about 200 km and such explosions would therefore have little advantage over large quarry blasts at Kelmscott. Shot instants were obtained by methods C, D, and E.

Kalgoorlie rock-bursts

Since the installation of a seismograph at Kalgoorlie in November 1964 the three strongest seismic events (commonly referred to as rock-bursts) which occurred in the mined area have been recorded at Kalgoorlie and Mundaring; good recordings of similar events had also been obtained previously at Mundaring during March 1964. Details of the rock-bursts are given by Gregson (in preparation). Times of prominent phases common to all Mundaring seismograms were measured, then travel times were calculated by reference to the events as recorded at Kalgoorlie. Because the Kalgoorlie seismograph is only 4 km from the mining area and on a line between the active zone and the Mundaring station the Mundaring - Kalgoorlie travel times could be corrected so that the event could be assumed to have taken place at the Kalgoorlie seismic station.

The averaged travel times of clearly recorded phases are given in Table 10.

The Tennant Creek seismic array (WRA) recorded one Kalgoorlie rock-burst on 17th March 1966. An epicentre and depth for this event were assumed on the basis that it occurred in the centre of the mining zone (Golden Mile) in which numerous others had been located with reasonable accuracy. An origin time was then derived from the Kalgoorlie arrival time using a suitable velocity for the path between the rock-burst and seismograph. The travel-times to Tennant Creek are also listed on Table 10.

3. CONCLUSIONS AND RECOMMENDATIONS

From the results, the ranges at which the various types of explosions can supply useful data when recording with the standard Willmore field recorder have been determined. Listed below are the ranges R1, at which iP phases are most likely to be recorded, and R2 beyond which useful recordings are highly unlikely. W represents the approximate maximum explosive weight used by the operators and would be required for R1 and R2.

TYPE	W (pounds)	R1 km	R2 km
KWINANA (Depth 10 m)	350	150	270
WAPET (Depth 35 m)	2,000	300	450
KELMSCOTT (Delay fuses used here)	10,000	100	150
KOOLANOOKA	6,000	200	300
KOOLYANOBBING	6,000	200	300
TOM PRICE	100,000	400	600
DEPTH CHARGE (Depth 150 m)	300	320	470

With more sophisticated recorders it is possible to obtain better results: for example, Tom Price explosions are recorded at Mundaring, more than 1000 km distant, on a Benimore with a DC amplifier added. However, although similar equipment may be used in the field, it is difficult to do so in a routine manner and microseismic noise commonly limits the maximum usable magnification.

Depth charges exploded at depths from 50 - 100 fathoms have proved the most efficient source to date. Large regional amplitude variations in the seismic signal were observed from WAPET's off-shore 100 lb reflection shots although each was exploded under identical conditions. Indeed it was possible to recognize from seismograms certain areas in which shooting was proceeding because amplitudes of seismic phases increased fourfold and it would be feasible to explode large charges in such areas to obtain increased recording ranges.

For interpretations of data more results from explosions on land are also desirable. Detailed traverses using Tom Price, Koolanooka, and Koolyanobbing sources are obvious requirements, but other shot-points will be essential. For the latter it would be inefficient and, partly because of the current mining boom, hard to arrange for large, say 5 ton, charges to be exploded in old mines. Instead, any large shots exploded on land specifically for seismic purposes should consist of a series of 250 lb (H.E.) charges in suitably spaced drill holes in a clay medium (commonly beneath laterite) because (a) the seismic effects of charges are directly proportional to charge weight up to about 250 lb, and proportional to the cube root of charge weight for larger charges, and (b) longer period seismic waves are generated far better in clay than in harder rocks, granite in particular. O'Brien (1967) describes methods needed for efficient use of large charges.

4. ACKNOWLEDGMENTS

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APPENDIX

METHODS FOR MEASURING SHOT-INSTANTS

A. Marine shots

The arrival time of the water-wave from the explosion was recorded on board ship along with radio time-pips. This was corrected for the travel time of the wave from the explosion point to the ship, to give the shot-instant (S.I.). The correction is D/V where

D = (ship's velocity) x (apparent shot-instant - time overboard)

V = velocity of sound in water (1.5 km/sec)

Refer to Gregson and Woad (1968) for further details.

B. Marine shots

Commercial marine survey parties transmit an audible tone break from a recording vessel to trigger the shooting mechanism on the shooting ship. The time interval between the tone break and the S.I. is usually 0.5 to 1.0 seconds and is fixed for each set of instruments.

The tone-break and shot-instant (which sounds like a soft 'pop') were recorded on land via VHF transceivers on a normal commercial tape recorder. Time-pips were also recorded simultaneously and S.I.'s were measured from a visual play-back record. The S.I. could be determined from either the direct S.I. pip or, if this was not clear, the tone-break could be used once the time interval between it and the S.I. was established. Generally the tone-break was most clearly recorded.

27 MHz radio transmission was reliable at 50 km range and fairly reliable to 100 km with a receiver at a height of about 30 metres above M.S.L.

C. Marine or land shots

The detonation impulse (S.I.) was arranged to start an audible tone which was recorded simultaneously with radio time-pips on a magnetic tape recorder. The S.I. was measured off a play-back record.

D. Land shots

A seismometer was placed near the explosion point and the S.I. was timed from the seismograph recording of the P-wave and radio-time pips. A correction for travel time from shot-point to seismometer was applied.

E. Land shots

A commercial tape recorder was placed close to the shot and the air-wave from the explosion was recorded simultaneously with radio time-pips. The arrival time of the air-wave was measured from a play-back record and an allowance was made for the travel time from the shot-point to the microphone in order to determine the S.I. This method can only be used when the microphone is very close to the shot because of the inaccuracy of the sound wave-velocities used for the correction of the air-wave arrival to the S.I.

F. Marine or land shots

Where several shots were exploded at the same position, a P-wave travel-time to Mundaring say, was determined using a S.I. found by the methods described above. Other S.I.'s were then calculated from the times of arrival of the relevant P-waves from the other explosions.

SHOT-POINT DATA

SHOT POINT	LATITUDE °S	LONGITUDE °E	ELEV'N (metres)	REMARKS
KWINANA A	32 12.31	115 44.73	-10	1966
" B	32 12.51	115 45.26	"	Mar 1967
" C	32 12.31	115 45.00	"	1-19 Apr 1967
" D	32 12.29	115 45.16	"	20 Apr 1967
" E	32 12.59	115 45.48	"	28 Apr 1967
" F	32 12.50	115 45.37	"	3, 4 May 1967
" G	32 12.59	115 45.37	"	12 May 1967
" H	32 12.31	115 44.73	"	Jul 1967
ABM QUARRY A	32 04.27	116 01.59	150	1966-68.5
KOOLYANOBBING A	30 47.85	119 30.73	500	Jun 1967
KOOLANOOKA A	29 11.98	116 12.18	500	Aug 1967
BYFORD	32 13.14	116 01.03	100	Sep 1967
WAPET BE-2N	32 05.67	115 31.65	-33	Oct 1966
" BE-16S	32 14.54	115 33.58	-32	" "
" BY-G	29 05.25	114 41.89	-36	Aug 1967
" BY-F	29 05.36	114 39.36	-39	" "
" BY-B	29 05.47	114 28.01	-45	" "
" BY-C	29 05.40	114 30.50	-43	Feb, Mar 1968
TOM PRICE A	22 45.1	117 45.5	1200	28 Jan 1968
" " B	22 45.4	117 45.7	"	Centre of quarry

TABLE 2

RECORDING STATIONS - MISCELLANEOUS SHOTS

STATION	CODE NAME	LATITUDE °S	LONGITUDE °E	SHOT POINT	DISTANCE km
GOSNELLS POOL	GOP	32 03.76	116 02.17	ABM-A	1.12
THORMANS	THO	32 04.91	116 00.85	ABM-A	1.70
PICKERING BROOK	PIC	32 01.93	116 05.87	ABM-A	8.00
GLENEAGLE NORTH	GLN	32 16.41	116 09.89	ABM-A	25.95
GLENEAGLE SOUTH	GLS	32 22.72	116 14.90	ABM-A	39.20
MUNDARING	MUN	31 58.69	116 12.47	ABM-A	20.00
LAKES B	LAB	31 54.52	116 20.81	ABM-A	35.23
LAKES A	LAA	31 52.79	116 24.36	ABM-A	41.67
MURESK	MUR	31 45.16	116 40.12	ABM-A	70.26
MECKERING WEST	MEW	31 36.71	116 58.24	ABM-A	102.87
MARRADONG T.O. B	MTB	32 55.93	116 41.43	ABM-A	114.06
TRAYNING SOUTH B	TSB	31 13.06	117 47.81	KOOLYANOBBING A	170.31
KALGOORLIE	KLG	30 47.02	121 28.47	KOOLYANOBBING A	186.24
MUNDARING	MUN	31 58.69	116 12.47	KOOLYANOBBING A	340.44
"	"	"	"	KOOLANOOKA A	308.05
WALKAWAY	WAL	28 55.07	114 49.26	KOOLANOOKA A	138.15
MEEKATHARRA	MEK	26 36.75	118 32.70	KOOLANOOKA B	367.78
MUNDARING	MUN	31 58.69	116 12.47	BYFORD	32.20
GLENEAGLE NORTH	GLN	32 16.41	116 09.89	BYFORD	15.50
GLENEAGLE SOUTH	GLS	32 22.72	116 14.90	BYFORD	28.06
MUNDARING	MUN	31 58.69	116 12.47	BE-2N	65.50
"	"	"	"	BE-16S	67.80
"	"	"	"	BY-G	351.71
"	"	"	"	BY-F	353.23
"	"	"	"	BY-C	359.34
"	"	"	"	BY-B	361.07
WALKAWAY	WAL	28 55.07	114 49.26	BY-G	22.29
"	"	"	"	BY-F	24.92
"	"	"	"	BY-B	39.49
MARRADONG T.O.-B	MTB	32 55.93	116 58.24	BY-G	466.79
"	"	"	"	BY-F	468.26
KALGOORLIE	KLG	30 47.02	121 27.47	BY-F	683.05
DEWAR'S POOL	DEW	31 26.98	116 23.37	BY-C	318.11
MEEKATHARRA	MEK	26 36.75	118 32.70	BY-C	483.25
LEE FARM	LEE	34 06.78	116 59.94	BY-C	605.03
MUNDARING	MUN	31 58.69	116 12.47	TOM PRICE A	1033.8
"	"	"	"	" " B	1033.3
MEEKATHARRA	MEK	26 36.75	118 32.70	" " A	435.06
"	"	"	"	" " B	434.5

TABLE 3

RECORDING STATIONS - PERTH-BASIN AND SHIELD MARGIN - KWINANA SHOTS

STATION		CODE NAME	LATITUDE °S	LONGITUDE °E	SHOT POINT (KWINANA)	DISTANCE km
	EASTERN STATIONS WITHIN BASIN					
KWINANA	A	KWA	32 12.74	115 45.55	A	1.51
"	B	KWB	32 12.83	115 45.70	A	1.80
"	C	KWC	32 12.21	115 46.25	A	2.40
"	D	KWD	32 11.76	115 46.95	A	3.63
"	E	KWE	32 10.69	115 49.01	A	7.36
"	F	KWF	32 08.20	115 53.63	A	15.92
"	G	KWG	32 06.21	115 58.01	A	23.73
	NORTHERN STATIONS WITHIN BASIN					
NORTH BEACH "A"		NBA	31 50.68	115 45.62	C	39.99
NORTH BEACH "B"		NBB	31 50.68	115 46.12	C	40.01
GNANGARA		GNA	31 46.75	115 56.75	A	50.89
	SOUTHERN STATIONS WITHIN BASIN					
PIKE ROAD		PRO	32 20.16	115 47.34	G	14.49
MANDURAH NORTH		MAN	32 24.34	115 45.91	C	22.28
MANDURAH		MAH	32 29.35	115 44.63	E	31.00
RAVENSWOOD		RAV	32 34.11	115 48.51	C	40.66
	SHIELD MARGIN NORTH					
ARMADALE		ARM	32 09.53	116 00.66	B	24.82
THORMANS		THO	32 04.91	116 00.85	A	28.80
GOSNELLS POOL		GOP	32 03.82	116 02.02	A	31.39
GOOSEBERRY HILL		GOH	31 56.05	116 02.48	F	40.61
MIDDLE SWAN		MSW	31 50.90	116 03.68	C	49.30
CHITTERING		CHI	31 37.60	116 05.05	C	71.51
	SHIELD MARGIN SOUTH					
BYFORD		BYD	32 13.23	116 00.94	E	24.32
NORTH DANDALUP		DAN	32 30.83	116 00.51	D	41.88
PINJARRA EAST		PIB	32 42.23	115 57.80	F	58.30
WAROONA		WAR	32 49.95	115 56.80	C	71.98
	MUNDARING DATA					
MUNDARING		MUN	31 58.69	116 12.47	A	50.38
		"	"	"	B	49.85
		"	"	"	C	50.22
		"	"	"	D	49.78
		"	"	"	E	49.63
		"	"	"	F	49.69
		"	"	"	G	49.78

TABLE 4

RECORDING STATIONS, EAST-TRAVERSE-KWINANA SHOTS

STATION	CODE NAME	LATITUDE °S	LONGITUDE °E	SHOT POINT (KWINANA)	DISTANCE km
ARMADALE	ARM	32 09.53	116 00.66	B	24.82
THORMANS	THO	32 04.91	116 00.85	A	28.28
GOSNELLS POOL	GOP	32 03.82	116 02.02	A	31.39
PICKERING BROOK	PIC	32 01.93	116 05.87	A	38.39
MUNDARING	MUN	31 58.69	116 12.47	A	50.38
MUNDARING OFFICE	MUO	31 54.17	116 09.93	A	51.93
LAKES B	LAB	31 54.52	116 20.81	A	65.62
LAKES A	LAA	31 52.79	116 24.36	A	72.06
LAKES C	LAC	31 50.30	116 26.22	G	76.38
LAKES D	LAD	31 52.81	116 33.56	H	84.91
LAKES E	LAE	31 50.80	116 37.51	H	92.11
TALBOT BROOK	TAB	32 03.10	116 38.65	A	86.50
MURESK	MUR	31 45.16	116 40.12	A	100.65
MT DICK	MDI	31 35.84	116 41.47	A	112.00
MECKERING W	MEW	31 36.71	116 58.24	A	133.26
MECKERING E	MEE	31 31.58	117 03.67	A	145.96
CUNDERDIN	CUN	31 37.11	117 13.83	A	154.84
TAMMIN	TAM	31 36.36	117 29.89	A	178.60
WYLCATCHEM	WYL	31 09.66	117 23.70	A	194.59
DOODLAKINE	DOO	31 34.74	117 51.32	A	211.32
TRAYNING SOUTH	TRS	31 13.47	117 47.25	A	222.01
TRAYNING	TRA	31 06.72	117 47.10	A	227.27
KUNUNOPPIN	KUN	31 04.92	117 56.40	A	242.42
MERREDIN	MER	31 26.53	118 16.05	A	253.33
POPES HILL A	PHA	30 55.95	118 17.55	A	279.97
WARRACHUPIN	WAR	31 00.60	118 42.85	A	311.32

TABLE 5

FIELD STATIONS, SOUTH-EAST-TRAVERSE-KWINANA SHOTS

STATION	CODE NAME	LATITUDE °S	LONGITUDE °E	SHOT POINT (KWINANA)	DISTANCE km
BYFORD	BYD	32 13.23	116 00.94	E	24.32
GLENEAGLE NORTH	GLN	32 16.41	116 09.89	B	39.35
GLENEAGLE SOUTH	GLS	32 22.72	116 14.90	A	51.12
MT COOKE	MTC	32 26.95	116 18.76	A	59.87
MARRADONG T.O. A	MTA	32 55.56	116 43.45	A	121.81
MARRADONG T.O. B	MTB	32 55.93	116 41.43	B	119.03
WILLIAMS WEST	WIW	33 05.32	116 46.37	A	137.44
ARTHER RIVER	ARR	33 21.52	117 01.16	A	174.93
MARTUP HILLS	MAR	33 31.05	117 04.14	A	191.12
BOSCABEL STH A	BSA	33 42.48	117 05.73	A	209.08
KOJONUP	KOJ	33 50.09	117 07.57	A	222.05
LUMEAH	LUM	33 59.88	117 14.51	A	242.20

TABLE 6.

TRAVEL TIMES

MISCELLANEOUS SHOTS

Station	Shot	Distance (km)	P Travel times (sec) 1	2	3	4	S Travel times (sec) 1	2	3	4
GOP	ABM-A	1.12								
THO	ABM-A	1.70	(0.35)							
PIC	ABM-A	8.00	1.39				2.6			
GLN	ABM-A	25.95	4.27				7.2			
GLS	ABM-A	39.20								
MUN	ABM-A	20.00	3.45				5.75			
LAB	ABM-A	35.23	5.67	6.1	6.4		9.5			
LAA	ABM-A	41.67								
MUR	ABM-A	70.26	11.38	11.6	12.0		19.8	20.2		
MEW	ABM-A	102.87	16.26	16.67	18.0			31.6		
TSB	K'NG A	170.31	27.22	27.77	28.27	29.4	48.0	49.0	50.0	
KLG	K'NG A	186.24	(29.5)	30.2	(30.4)		51.8	52.7		
MUN	K'NG A	340.44	47.45	47.93	51.2	55.0	83	84	92	98
MUN	K'KA A	308.05	45.80	46.30	48.0	48.6	78.0	80.5	83	
WAL	K'KA A	138.15	22.78	24.20	26.0		38.3	39.8	43.5	44.5
MEK	K'KA A	367.78	-	59.6						
MUN	BYFORD	32.20	5.28				8.85			
GLN	BYFORD	15.50	2.59							
GLS	BYFORD	28.06								
MUN	BE-2N	65.50	12.70	13.5						
MUN	BE-16S	67.80	12.93	13.2						
MUN	BY-G	351.70	50.61	50.9	51.8		88	99		
MUN	BY-F	353.23	50.63	51.0	52.1	61.4	90	98		
MUN	BY-C	359.34	51.35	51.5	52.6	58.5	85.2	89	93	99
MUN	BY-B	361.07	51.43	51.9	53.8	58.3				
WAL	BY-G	22.29	4.58	5.3	8.5					
WAL	BY-F	24.92	5.00	6.0	6.8					
WAL	BY-B	39.49	7.62	8.1	8.8	14.8				
DEW	BY-C	318.11	46.77							
MTB	BY-G	466.79	64.44	65.0	76.0					
MTB	BY-F	468.26	(63.00)	(64.0)	64.5	65.1				
MEK	BY-C	483.25	65.58	66.4	67.6	81.6	109.8	110.1	120.1	128.6
LEE	BY-C	605.03	82.28	86.5	114.9					
KLG	BY-F	683.05	90.0	92			160	191		
MUN	TOM P A	1033.8	0.0 dt 71.2	2.3	4.5	7.0	(93.0)	94.1	100.7	152
MEK	TOM P A	435.06	0.0	2.2	9.1	10.2	(38.7)	39.8	58.5	61.5

NOTES:

( ) doubtful phase

dt first-arrival travel-time difference MUN-MEK

TABLE 7

TRAVEL TIMES

KWINANA SHOTS - PERTH BASIN AND SHIELD MARGIN

Station	Shot KWINANA	Distance (km)	P Travel times (sec) 1	2	3	4	S Travel times (sec) 1	2	3
EASTERN STATIONS WITHIN BASIN									
KWA	A	1.51	0.60						
KWB	A	1.80	0.74						
KWC	A	2.40	0.98	1.7					
KWD	A	3.63	1.48						
KWE	A	7.36	2.66	3.3					
KWF	A	15.92	4.80	5.7	6.3				
KWG	A	23.73	6.56	7.6	9.1	9.7			
NORTHERN STATIONS WITHIN BASIN									
NBA	C	39.99	9.49	9.65	10.5	11.5			
NBB	C	40.01	(9.49)	9.65					
GNA	A	50.89	(11.00)	11.95	14.8	16.0			
SOUTHERN STATIONS WITHIN BASIN									
PRO	G	14.49	4.37	4.8	5.8	6.5			
MAN	C	22.28	6.16	7.8	8.2				
MAH	E	31.00	7.72	11.0	13.0				
RAV	C	40.66	9.57	10.4	15.6				
SHIELD MARGIN NORTH									
ARM	B	24.82	6.06						
THO	A	28.80	8.78						
GOP	A	31.39	7.15						
GOH	F	40.61	8.65						
MSW	C	49.30	9.98	10.7	12.0	12.8			
CHI	C	71.51	13.73	13.8					
SHIELD MARGIN SOUTH									
BYD	E	24.32	5.97	6.1	8.2	10.5			
DAN	D	41.88	8.98	10.0	12.0	17.5			
PIB	F	58.30	11.35						
WAR	C	71.98	(13.44)	13.87					

( ) = Doubtful Phase

Station	Shot KWINANA	Distance (km)	P Travel time 1
MUNDARING DATA			
MUN	A	50.38	(9.98)
MUN	B	49.85	9.90
MUN	C	50.22	(9.96)
MUN	D	49.78	9.89
MUN	E	49.63	(9.86)
MUN	F	49.69	(9.87)
MUN	G	49.78	(9.89)
MUN	H	50.38	(9.98)

( ) Based on travel-time to KWINANA-B

TABLE 8

TRAVEL TIMES

KWINANA SHOTS - EAST TRAVERSE

Station	Shot KWINANA	Distance (km)	P Travel times (sec) 1	2	3	4	S Travel times (sec) 1	2	3
ARM	B	24.82	6.06						
THO	A	28.28	8.78						
GOP	A	31.39	7.15						
PIC	A	38.39	8.11	8.8	9.1	10.6			
MUN	A	50.38	9.98						
MUO	A	51.93	10.22						
LAB	A	65.62	12.41						
LAA	A	72.06	13.40	13.8					
LAC	G	76.38	14.20						
LAD	H	84.91	15.35	15.52	16.1	17.0			
LAE	H	92.11	(16.56)	16.76	17.3	19.3			
TAB	A	86.50	15.58						
MUR	A	100.65	17.74						
MDI	A	112.00	19.43						
MEW	A	133.26	22.52						
MEE	A	145.96	(24.17)	24.38					
CUN	A	154.84	25.83						
TAM	A	178.60	29.41						
WYL	A	194.59	31.98						
DOO	A	211.32	34.36						
TRS	A	222.01	35.12	35.3	35.9				
TRA	A	227.27	36.82						
KUN	A	242.42	37.90						
MER	A	253.33	(38.26)	40.02					
PHA	A	279.97	(42.46)	43.01					
WAR	A	311.32	47.83	41.10	45.42				

( ) doubtful phase

TABLE 9

TRAVEL TIMES

KWINANA SHOTS - SOUTH-EAST-TRAVERSE

Station	Shot KWINANA	Distance (km)	P Travel times (sec) 1	2	3	4	S Travel times (sec) 1	2	3
BYD	E	24.32	5.97	6.1	8.2	10.5			
GLN	B	39.35	8.13						
GLS	A	51.12	9.93						
MTC	A	59.87	11.37						
MTA	A	121.81	20.97						
MTB	B	119.03	(20.83)						
WIW	A	137.44	23.52						
ARR	A	174.93	29.43	29.63					
MAR	A	191.12	(31.71)	32.05					
BSA	A	209.08	34.11						
KOJ	A	222.05	35.48						
LUM	A	242.20	37.83						

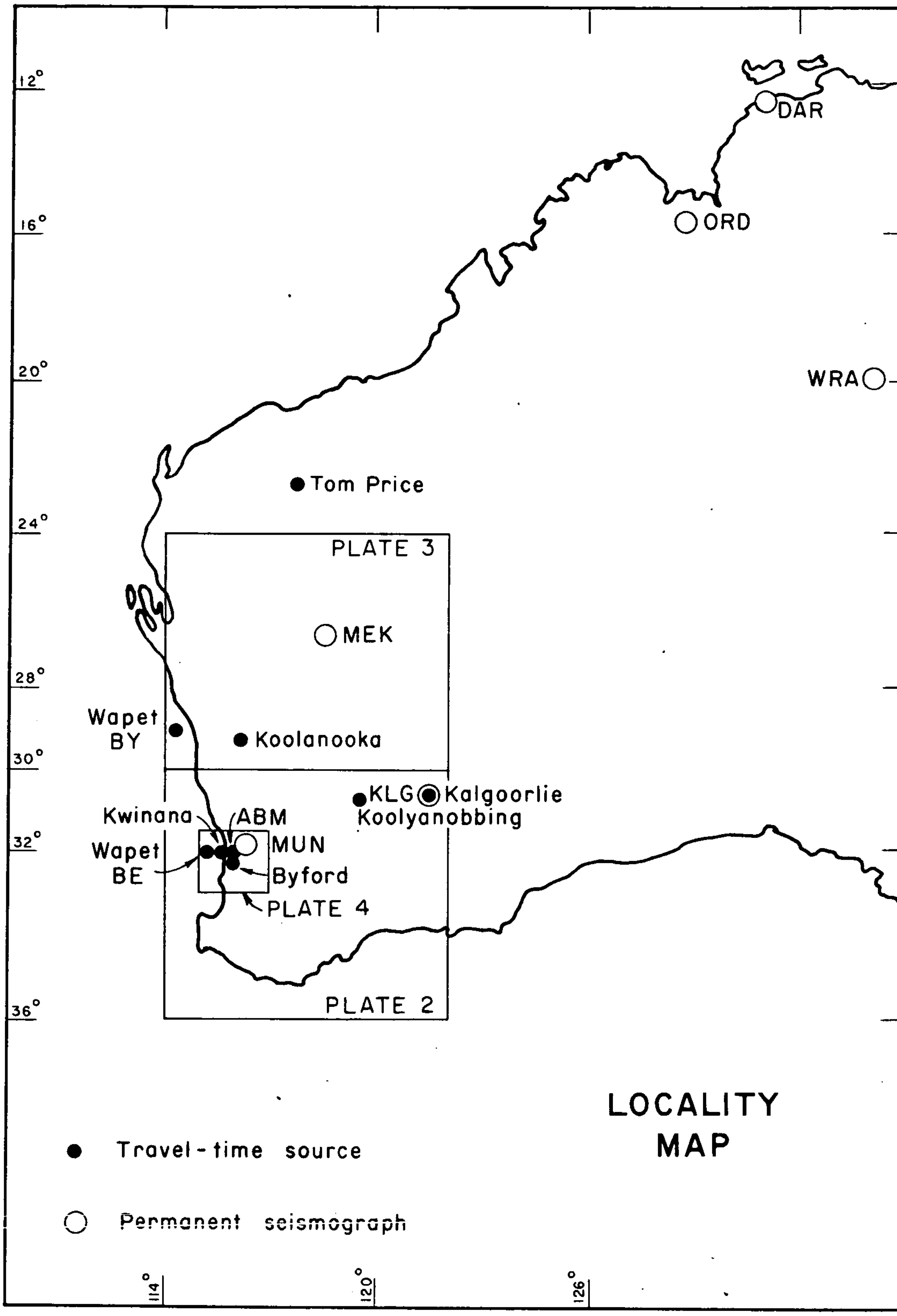
( ) doubtful phase

TABLE 10

TRAVEL TIMES

FROM KALGOORLIE ROCK-BURSTS

Station	Shot Point.	Distance (km)	P Travel times (sec) 1	2	3	4	S travel times (sec) 1	2	3
MUN	KLG	516.7	(68.1)	68.3	74.5	80	117	131	140
			83	85			143	146	
			LR phase (T = 2.3 sec) 161						
			Times are meaned for 3 events						
WRA		1760.5	216.6				383.1		
			17th March 1966 event.						
			H = 180227.4 ± 0.2						
			Epicentre : 30° 46.7' S, 121° 30.1' E (accuracy 1 km)						
			Depth: 0.6 ± 0.6 km						
			Recorded at WRA pit R2						
			Location 19° 57'S 134° 22' E						


12°
16°
20°
24°
28°
30°
32°
36°
114°
120°
126°
DAR
ORD
WRA
Tom Price
PLATE 3
MEK
Wapet BY
Koolanooka
KLG
Kalgoorlie
Koolyanobbing
Kwinana
ABM
MUN
Wapet BE
Byford
PLATE 4
PLATE 2
LOCALITY MAP
Travel-time source
Permanent seismograph

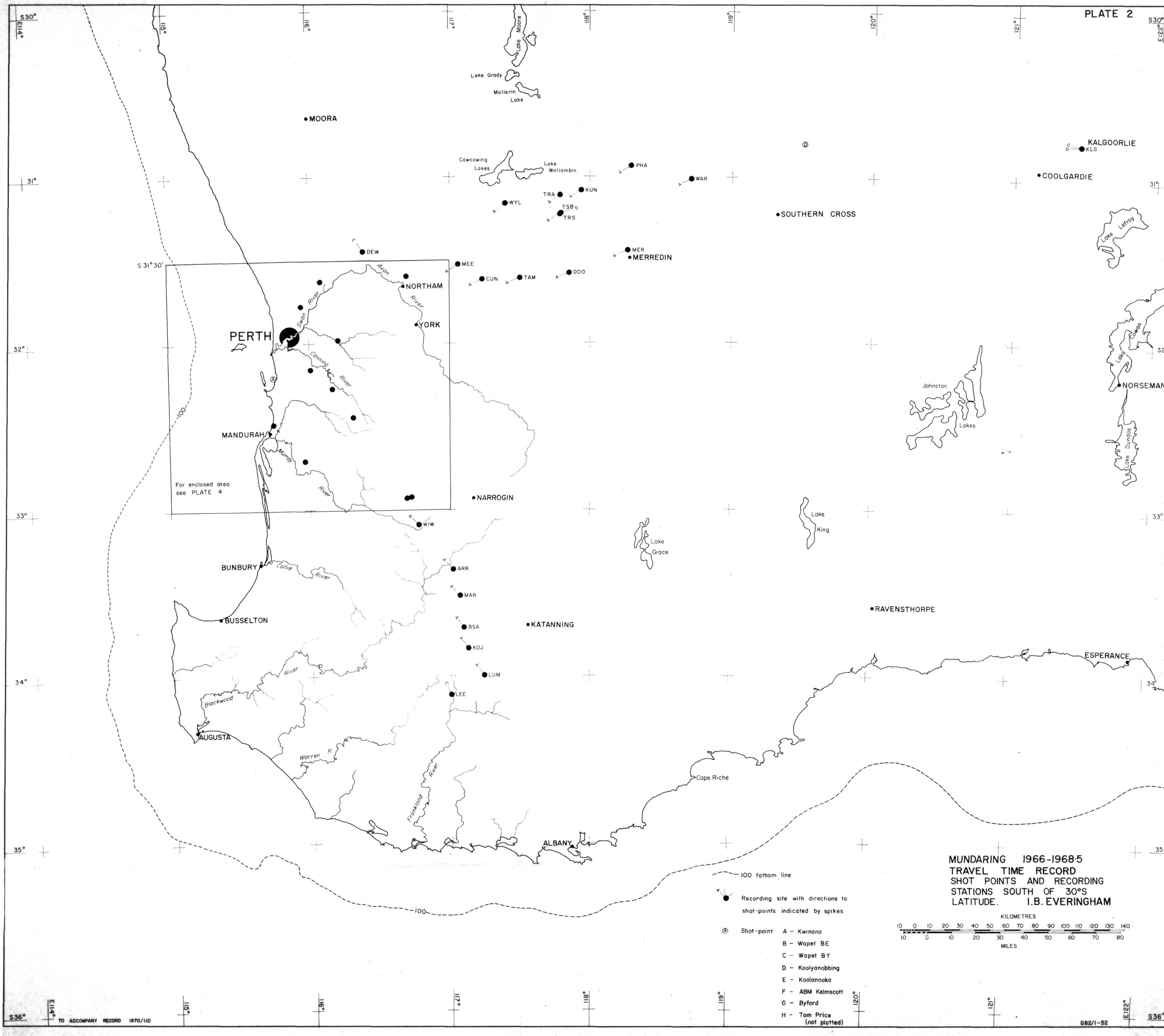


PLATE 2
MUNDARING 1966-1968·5
TRAVEL TIME RECORD
SHOT POINTS AND RECORDING
STATIONS SOUTH OF 30°S
LATITUDE. I.B. EVERINGHAM
100 fathom line
Recording site with directions to shot-points indicated by spikes
Shot-point A – Kwinana
B – Wapet BE
C – Wapet BY
D – Koolyanobbing
E – Koolanooka
F – ABM Kelmscott
G – Byford
H – Tom Price (not plotted)
KILOMETRES
MILES
For enclosed area see PLATE 4
S31°30'
PERTH
MOORA
NORTHAM
YORK
MANDURAH
NARROGIN
BUNBURY
BUSSELTON
AUGUSTA
KATANNING
ALBANY
Cape Riche
RAVENSTHORPE
ESPERANCE
NORSEMAN
COOLGARDIE
KALGOORLIE
SOUTHERN CROSS
MERREDIN
Lake Moore
Lake Grady
Mollerin Lake
Cowcowing Lakes
Lake Wallambin
Lake Lefroy
Lake Cowan
Lake Dundas
Johnston Lakes
Lake King
Lake Grace
Swan River
Avon River
Canning River
Murray River
Collie River
Blackwood River
Warren R
Frankland River
DEW
MEE
CUN
TAM
DOO
MER
WYL
TRA
KUN
TSB
TRS
PHA
WAR
KLG
WIW
ARR
MAR
BSA
KOJ
LUM
LEE
TO ACCOMPANY RECORD 1970/110
G82/1-52

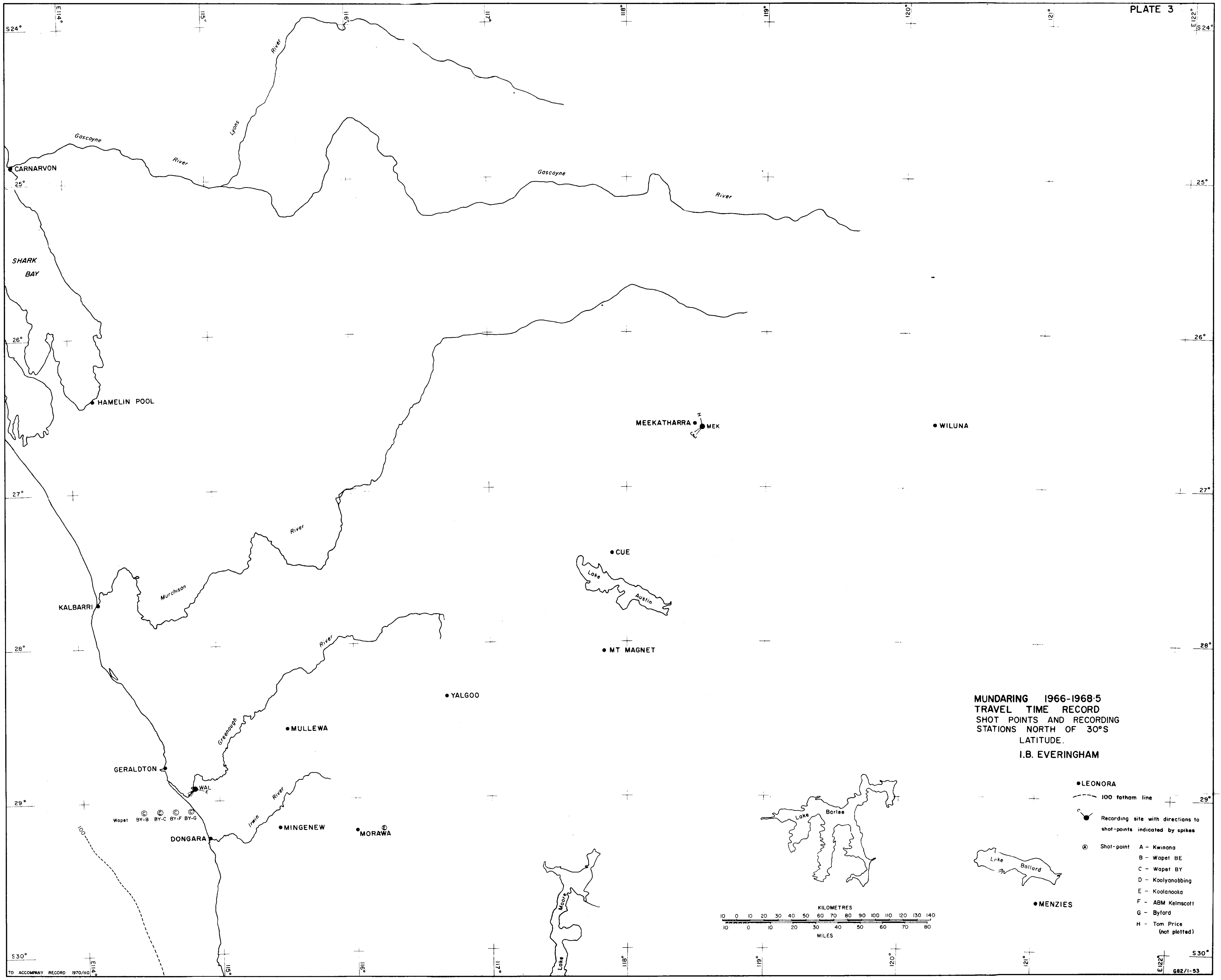


PLATE 3
MUNDARING 1966-1968·5
TRAVEL TIME RECORD
SHOT POINTS AND RECORDING STATIONS NORTH OF 30°S LATITUDE.
I.B. EVERINGHAM
CARNARVON
SHARK BAY
HAMELIN POOL
KALBARRI
GERALDTON
WAL
DONGARA
MULLEWA
MINGENEW
MORAWA
YALGOO
CUE
MT MAGNET
MEEKATHARRA
MEK
WILUNA
LEONORA
MENZIES
Gascoyne River
Lyons River
Murchison River
Greenough River
Irwin River
Moore
Lake
Lake Austin
Lake Barlee
Lake Ballard
Wapet BY-B BY-C BY-F BY-G
100
100 fathom line
Recording site with directions to shot-points indicated by spikes
Shot-point A - Kwinana
B - Wapet BE
C - Wapet BY
D - Koolyanobbing
E - Koolanooka
F - ABM Kelmscott
G - Byford
H - Tom Price (not plotted)
KILOMETRES
10 0 10 20 30 40 50 60 70 80 90 100 110 120 130 140
10 0 10 20 30 40 50 60 70 80
MILES
S24° S25° S26° S27° S28° S29° S30°
E114° E115° E116° E117° E118° E119° E120° E121° E122°
TO ACCOMPANY RECORD 1970/110
G82/1-53

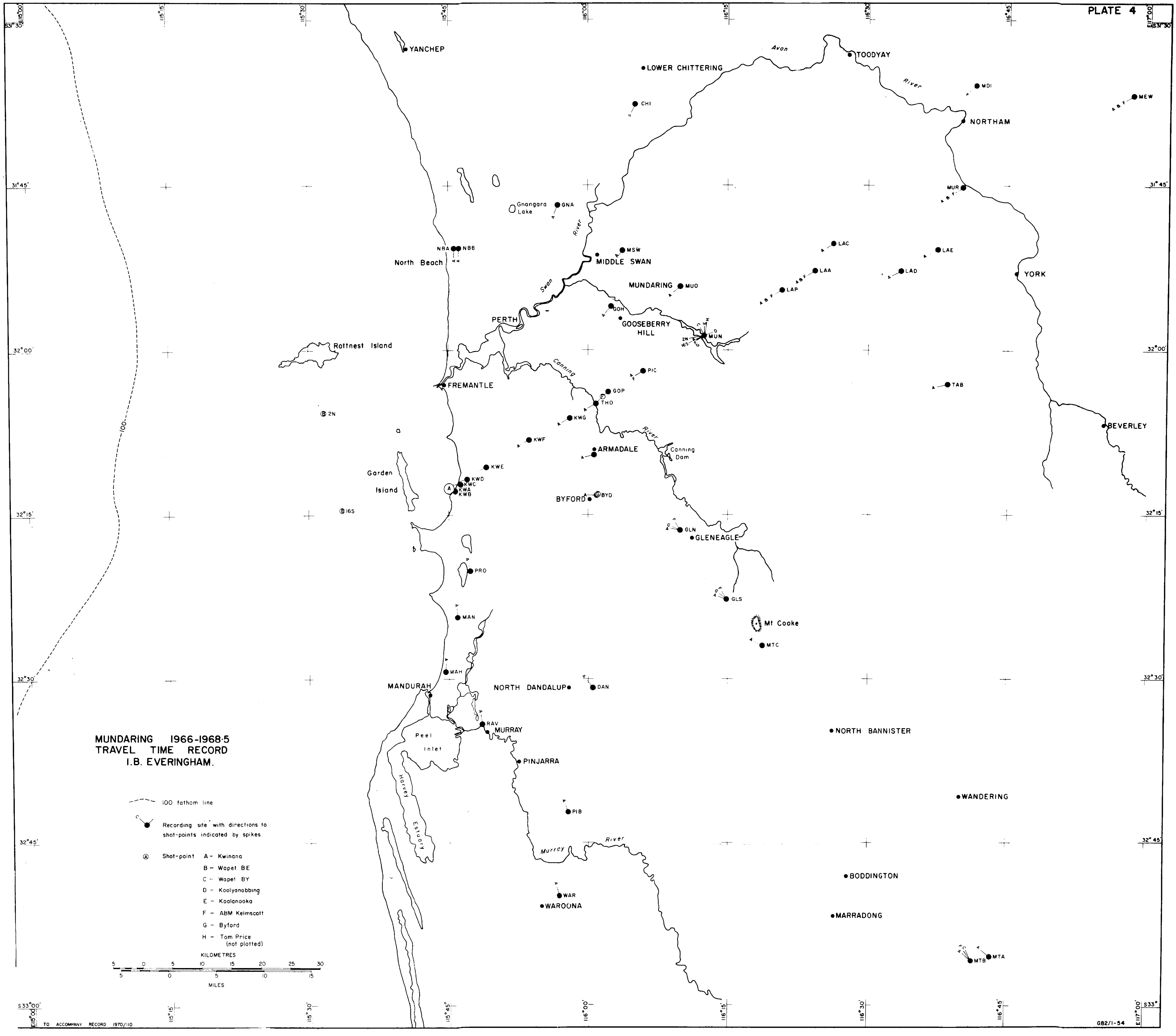


PLATE 4
YANCHEP
LOWER CHITTERING
TOODYAY
Avon
River
NORTHAM
MDI
MEW
CHI
Gnangara Lake
GNA
River
MUR
NBA
NBB
North Beach
MSW
MIDDLE SWAN
LAC
LAE
LAA
LAD
LAP
YORK
MUNDARING
MUO
Swan
PERTH
GOH
GOOSEBERRY HILL
MUN
Rottnest Island
Canning
PIC
FREMANTLE
GOP
THO
TAB
2N
KWG
River
KWF
ARMADALE
Canning Dam
BEVERLEY
KWE
Garden Island
KWD
KWC
KWA
KWB
BYFORD
BYD
16S
GLN
GLENEAGLE
PRO
GLS
MAN
Mt Cooke
MTC
MAH
MANDURAH
NORTH DANDALUP
DAN
RAV
MURRAY
Peel Inlet
NORTH BANNISTER
PINJARRA
MUNDARING 1966-1968·5
TRAVEL TIME RECORD
I.B. EVERINGHAM.
WANDERING
100 fathom line
Harvey Estuary
PIB
Recording site with directions to shot-points indicated by spikes
Murray
River
Shot-point A - Kwinana
B - Wapet BE
C - Wapet BY
D - Koolyanobbing
E - Koolanooka
F - ABM Kelmscott
G - Byford
H - Tom Price (not plotted)
BODDINGTON
WAR
WAROONA
MARRADONG
KILOMETRES
MILES
MTB
MTA
100
TO ACCOMPANY RECORD 1970/110
G82/1-54