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Record No. 1968 / 97

Mundaring Geophysical Observatory Annual Report 1966

by

I.B. Everingham

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CONTENTS

TABLES

ILLUSTRATIONS

SUMMARY

During 1966, basic observatory programmes were continued in geomagnetism, ionospherics, and seismology at the Mundaring Geophysical Observatory, the main instruments being the Eschenhagen normal-run magnetograph, a Cosser ionosonde, and a World-wide Standardised Seismograph system. A seismograph was operated continuously at Kalgoorlie.

Annual lists of Western Australian earthquakes and seismic events at Kalgoorlie, and provisional lists of Australian shocks prior to 1967 were compiled; seismicity maps were drawn. The latter show that undersea shocks are more frequent beneath the Indian Ocean off the west coast of the continent than beneath the Pacific off the east coast.

In the course of the year crustal structure and upper-mantle investigations proceeded with the gathering of travel-time data from explosion recordings and the calculation of P-wave station-residual values.

1. INTRODUCTION

The Mundaring Geophysical Observatory came into being on 18th March 1959, and now controls operations at Mundaring (seismological and ionospheric recording), Gnangara (magnetic recording), and Kalgoorlie (seismological recording). Descriptions of the observatory and an outline of activities there to the end of 1965 have been given in previous Records (see McGregor, 1967a). This Record summarises the work during the calendar year 1966.

Discussions of non-routine projects are limited as they will be presented in separate reports.

2. STAFF AND VISITORS

Staff

Observatory staff are listed in Table 7 and other personnel associated with the observatory's operations in Table 8. Staff absences, for other than recreation leave, are summarised in Table 9.

I. B. Everingham took part in Project CRUMP in Queensland during 15th September - 15th October. P. M. McGregor transferred to Canberra Head Office early in November to perform higher duties; I. B. Everingham commenced acting as Observer-in-Charge during his absence. Staff members visited the Japanese Antarctic Research Expeditions ship M.V. Fuji in December.

Visitors

Notable visitors included R. W. Boswell, R. H. J. Thompson, L. Lee (Department of National Development); K. Svendsen, B. Hill (USCGS); J. M. Rayner, L. S. Prior, M. A. Condon, K. M. Kennedy (BMR); P. J. Milne (SEATO); scientific members of the M.V. Fuji crew (JARE).

3. GEOMAGNETISM

Normal magnetograph

The Eschenhagen 20-mm/hour magnetograph continued in operation. Nine days of recording were lost largely (7 days) because of inefficiency of an attendant who was subsequently replaced. The two-hour rate gears were removed from the recorder to eliminate record losses due to meshing of the wrong gears.

H and Z baselines were restored to the record (July 7th) in compliance with a headquarters request designed to facilitate scaling. The Z variometer was also moved about 50 cm northwards to increase its recording range.

Abrupt changes in the H, D, and Z baseline values were noted after the adjustments on July 7th, and H and Z values drifted for about a month before stabilising. During the remainder of the year,

baseline value changes were small and the D values showed their normal tendency to decrease (westwards) with temperature. H scale values were also consistent during the year whilst Z scale values drifted from about 5.1 to 5.2 gammas/mm after the July adjustments. The standard deviations of observed values from adopted values are:

Element	Baseline value	Scale value
D	0.19 minutes	-
Z	1.7 gammas	0.02 gamma/mm
H	1.1 gammas	0.01 gamma/mm

Magnetograph tests

Orientation. Tests made on July 11th indicated that the Z variometer magnet was accurately levelled and the D magnet was correctly orientated (N end 0.1°W). The position of the H trace indicated that the H magnet was also orientated correctly.

D scale-value. This was found to be 7.45 gammas/mm (1.073 min/mm) on July 13th (Helmholtz coil method).

Magnetometer comparisons

Results are listed below:

May 2nd and 3rd. BMZ 120 was compared with proton precession magnetometer Elsec 271 (giving total force, F) and QHM 293 + 1 gamma (giving H); these values of F and H yield Zp:

Zp = BMZ 120 + 306.4 gammas (18 observations)

May 13th. BMZ 120 was compared with the Elsec-vector coil system (giving Zs directly):

Zs = BMZ 120 + 305.3 gammas (6 observations)

Assuming Zp and Zs are equivalent, the weighted mean of the two sets of comparisons was:

Zp = BMZ 120 + 306.1 gammas

October 12th. BMZ 120 and Elsec 271 were read and H was derived from the magnetogram using routine baseline values:

Zp = BMZ 120 + 308 gammas (5 observations)

No other intercomparisons were made. Preliminary corrections used for the magnetometers were:

QHM 291	-14 gammas
QHM 292	-20 gammas
QHM 293	+ 1 gamma
BMZ 120	+304 gammas
Askania 509319	+0.5 minute

Data, reductions, and publications

The only change in the distribution of data (see Mcgregor, 1967a)was that microfilms of magnetograms for WDC A were made on 16-mm instead of a 35-mm film from September onwards.

Mean-hourly-value programme sheets 1965, for Head Office use, were completed.

Listed in Table 1 are the monthly and annual mean values of H, D, and Z for Gnangara 1966. Values are derived from magnetogram ordinates on the five local quiet days each month. They suggest that D has started to become more westerly, Z is not changing significantly, and H is continuing the decrease which started about 1958.

Miscellaneous requests attended to were primarily for magnetogram copies (Dr Akasofu, Iowa; Dr Muller, Hungary; Dr J. Everett, A.N.U.; P. Stephen, Czechoslovakia) and data on local declination and field strength.

Accessory equipment

The Mundaring visual recorder power supply was relocated at the recorder site and the recorder re-wired (February). Later (November 15th) the scale value was doubled to eliminate frequent re-adjustments during disturbed periods. It had been run at low scale value (about 1 gamma/mm) from the beginning of IQSY to provide data on very quiet periods (MAGCALMES). The induction loop daily recordings continued, but analysis of records was not carried out.

Time was spent designing and building a control panel for the Gnangara magnetograph but it was not installed because modifications to the ammeters were required.

QHM elastic after-effect

Measurements of the elastic-after-effect in QHMs indicated how errors of up to 5 gammas in H can arise from non-standard reading of the instrument. The effect was described and a routine for reading QHMs suggested by McGregor (1967b)

4. IONOSPHERICS

Equipment

The ionosonde performance was good and major troubles were not experienced. Minor record losses were caused by failures of the power supply (January, February) and in the programming circuitry. During November, the Landis programmer was shifted from the seismic vault to the ionosonde hut and the circuitry was adjusted so that it could be driven from WWSS or chronometer minute pulses.

Publications

In accordance with IPS procedures, parameters measured as from January 1st were f min, foE, foEs, foF2, and M(3000)F2. These were published by the IPS and BMR in the form of the IPS-D Series.

In addition, monthly medians and f-plots of E, F2 and M(3000) F2 are currently being published by the United States Department of Commerce in their Ionospheric Data series CRPL-FA.

5. SEISMOLOGY

Notes on instrumentation

The WWSS equipment at Mundaring functioned well apart from a drive motor failure, and no difficulties arose in the running of it. The magnifications were unchanged, i.e. 25,000 at 2.0 sec (SP) and 750 at 15 sec (LP). Calibrations of the KLG and MUN seismographs were carried out (Gregson, 1967).

At Kalgoorlie, frequent changes in sensitivity were caused by poor contacts and wiring joints in the Benioff recorder. To overcome these defects it was finally necessary to insert fixed attenuator and damping resistor networks for all components and bypass the recorder control panel. The modified circuit is described by Gregson (1967).

The sensitivities of the KLG horizontal component seismographs were changed slightly during March and July (as a result of the control panel trouble) but maximum magnification remained at about 40,000 throughout the year. During March, the Z magnification was increased from a maximum of 40,000 at T = 0.5 sec to 105,000 at T = 0.25 sec in order to record smaller local events. The increased sensitivity resulted in a big increase of teleseismic and local P-wave recordings, even though the records were noisier.

During the year, the Kununurra station (operated by the Western Australian Public Works Department) gave unsatisfactory results and could not be used for routine interpretations. The troubles were due to (a) changes of operating staff, (b) operators having no technical knowledge, (c) insufficient communication with Mundaring. All were beyond the control of the observatory.

Throughout the period May to August, the Lake View and Star seismograph was operated to obtain cross-bearings on Kalgoorlie seismic events (when combined with KLG data). The instrument consisted of two Willmore MK II seismometers (horizontal) recording via 14-sec galvanometers on a Benioff recorder. Recording ceased when seismometers were required for CRUMP.

The Landis pendulum clock, which had been operating at the seismic vault for standby timing, was removed for repairs. They were unsuccessful. Two Eddystone receivers were fitted with crystal-controlled tuning for WWV and VNG frequencies.

A log of VNG time signal reception was maintained for the PMG Department during October.

Major improvements were made to four Willmore recorders by fitting of larger recording lamps and 250V/6V transformers and by the replacement of drive motors (with 4-rpm Philips AU5050 250V-volt 50-c/s with gearbox AU5300/80DMO). This permitted an increase in paper speed from 60 mm/min to 240 mm/min and subsequently resulted in much better recordings of explosion-generated seismic waves.

Notes on seismicity

Western Australian earthquakes. 1966 earthquakes are listed in Tables 2 and 3 and plotted in Plates 2 and 3. The lists are a continuation of previous ones (McGregor, 1967a) and give similar data. Some KLG m_b (body-wave magnitude) values are shown in addition to data in previous lists. Values of M_S (surface-wave magnitude) could not be determined for any 1966 shocks, which were all too small.

In Table 2, values of m_b in columns headed (b) are determined by using new more realistic values of the attenuation function, A_2. The provisional curve of A_2 versus distance adopted by Everingham (1966) has given values of m_b which are generally too high in the 100 to 1500 km range of epicentral distances and a revised curve (curve B in Plate 1) was used to rectify this effect. It was subsequently found that this curve agrees with Evernden's (1967) average results for first arrival P-waves in the USA.

During 1966, larger Western Australian shocks occurred off the west coast and in the south-west region of the shield.

One shock (No.65 in Table 2) west of Carnarvon was recorded by many Australian and overseas stations, and an epicentre was determined by the USCGS. Another shock (No.58) off the coast near Broome was recorded at several Australian stations but did not appear on the PDE sheets. Three earthquakes (Nos. 56, 57, and 62) occurred west of Perth beneath the Indian Ocean, where an oceanic type crust could be expected.

Several tremors (Nos. 53, 54, 55, 63, and 64) occurred along the flanks of the Yandanooka/Cape Riche Lineament and show that this zone may be broader (east-west extent) than previously believed. A shock 250 km east of Mundaring and felt at Hyden (No. 59) is the most

inland shock nown to occur in the south-western part of the State, to date. It was also unusual in that fore-shocks and after-shcoks did not occur as they do with larger shocks along the Yandanooka/Cape Riche Lineament.

Minor tremors (Table 3), with three exceptions, were in the Yandanooks/Cape Riche Lineament region, several swarms being associated with larger shocks amongst those listed in Table 4. The exceptions were a shock of magnitude 3.2 felt near Cape Naturaliste (June 9th), a small event 50 km south-east of Kalgoorlie which could possibly have been a natural tremor, rock-burst, or explosion, and a similar event 100 km north of Mount Magnet.

Australian earthquakes. Provisional lists of all larger Australian earthquakes are given in Tables 4 and 5; their epicentres are shown in Plates 4 and 5. The division into two tables at 1959 was made because the effects of modern seismic instruments became apparent then. Prior to 1969, publications such as Gutenberg and Richter (1954) and Burke-Gaffney (1951) listed only three shocks on or around the western region of the continent (see Plate 4), whereas they show numerous shocks to the east. Since then, because of the increase in number and sensitivities of seismograph stations, a different seismicity pattern has emerged (Plate 5).

The source of data for each shock pre-1959 is given in Table 4. Only those shocks recorded at three or more stations are listed and the smallest events had magnitudes m_b of about 5.5. It is probable that all shocks since the early 1900s with magnitudes greater than this would have been recorded at more than one Australian station, regardless of the location of epicentres, whereas many smaller shocks would have been undetected.

Magnitude data in Table 5 were obtained from: Cleary and Doyle (1962); Cleary, Doyle, and Moye (1964); Everingham (1966); Fisher, Baker, and Guidroz (1964); Fisher and Guidroz (1964); Green et al (1967); and USCGS Earthquake Data Reports. All magnitudes were converted to m_b via the standard equations (Everingham, 1966), and re-determined wherever possible using the A2 values of curve B, Plate 1.

It is apparent that activity occurs around the extreme western and north-western parts of the continent, on the adjoining continental shelf areas, and beneath the Indian Ocean.

These shocks apparently do not occur in sharply defined areas as they do in South Australia along the 138°E meridian, although the total number of shocks in each region is not vastly different. Again, the relative aseismicity of the Pacific Ocean immediately to the east of Australia compared with the Indian Ocean region adjacent to Western Australia is noteworthy and indicates tectonic differences in the sub-oceanic mantle regions east and west of the continent. Geology, heat-flow data, and P-wave station-residual data suggest differences in the crust or upper mantle of the eastern and western regions of the Australian continent, so that it would not be surprising to find that

features of the mantle beneath adjoining Pacific and Indian ocean areas are also dis-similar.

Very small earthquakes. Another interesting study commenced during 1966 related to very small earthquakes (commonly termed tremors when the magnitude is in the range M_L = 2 to 4 and microtremors when M_L is less than about 2).

To start investigations of minimum magnitudes, relationship to local geology, depth and other features of these events, a rapid-run Willmore was installed and run for several hours during an active period at Talbot Brook, 45 km east of Mundaring.

Results were as follows:

(a) Four micro-tremors were recorded, the magnitude (M_L) of the smallest being -0.5.

(b) The SP intervals indicated that epicentres were about 2 km from the recorder.

(c) It is probable that, normally, events with magnitudes as small as zero may be heard.

(d) Residents suggested that the seismic events were most frequent between 12 noon and 2 p.m. local time, but analysis of instrumental recordings of tremors over several periods did not confirm this.

A full description of the results is being written by Everingham and Gregson (in preparation).

Kalgoorlie events

During 1966, 71 events believed to be 'rock bursts' were recorded from the mining area at Kalgoorlie. More than half of these were felt and some caused damage in the mines.

Events are listed in Table 6, which also includes abstracts of mining company reports. The shock on March 18th was recorded at Mundaring and was clearly felt around Kalgoorlie, but caused no known damage in the mines.

The relative strain release curve (Plate 6) shows a steady trend since recording started in 1964. This pattern is unlike the natural release pattern of local small tremors in regions along the Yandanooka/Cape Riche Lineament; there, earthquakes usually occur in swarms, followed by long periods of inactivity. The fairly uniform release of energy is probably caused by the steady continuity of mining operations.

Work was commenced on a Record to present all data pertaining to the Kalgoorlie seismic events during the period from November 1964 to the end of 1967 (Gregson, in preparation).

Explosion recordings

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

Blasting operations were carried out spasmodically over a period of approximately twelve months. Charges of up to 350 lb of ammonium nitrate and dieseline were fired at about four-minute intervals over several one-to-two-hour periods (throughout the days when blasting was in progress). Charges were exploded in about 30 ft of water in an area of roughly one square mile.

The observatory made use of these explosions to study crustal structure of the Perth Basin and the western-most region of the Precambrian shield.

About 30 field stations were occupied at distances from explosions in the range 2 to 270 km. First arrival P-phases were clearly recorded at distances up to about 150 km, but were undiscernible at 270 km. The work was still in progress at the end of 1966, and travel-time data and interpretations will be presented separately.

Six field recordings of quarry blasts (up to 10-ton charges) were also made during the year. These were up to 130 km from the quarry. These data will be tabulated with 1967 data as above.

P-wave residuals

P-wave station-residuals were determined for Western Australian permanent and field seismograph stations, and for the major Australian stations. Everingham (in preparation) co-ordinated them with published results and discussed features of the Western Australian residuals.

Western Australian shield station residual values are more negative (earlier arriving P-waves) than other regions of the continent and values apparently become more negative to the east or north-east of Mundaring towards the central Archaean shield region. These variations of station residuals on the Archaean shield area tend to confirm previous interpretations of gravity anomalies, seismicity patterns, and geomagnetic variations, which show that the structure of the lower-crust/upper-mantle beneath the south-western part of the Archaean shield may differ from that beneath its central or eastern region.

6. NOTES ON OPERATIONS

Department of Works jobs

Repairs and maintenance and alterations were:

(a) New drain on Lot 74 dug

(b) Porches at vault and ionosonde hut constructed

(c) Ceiling put in machine shop

(d) Office electrical distribution board replaced

(e) Annual fire precautions carried out including clearing undergrowth at the weir site. Routine inspection of fire-fighting equipment organised.

(f) Extension to seismic vault commenced (November)

(g) Concrete cable entry installed at seismic vault (for drainage)

(h) Access road into Gnangara Observatory paved

Archives storage

Scientific records, data reports, early library holdings and old files were transferred to the Archives Office store at Karrakatta. This relieved the observatory storage problem particularly of seismic records.

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TABLE 1

Provisional Monthly Magnetic Mean Values, 1966

	H (gammas)	D	Z (gammas)
Jan	23 903	2°52.3' W	-53 495
Feb	899	52.1	497
Mar	894	52.1	498
Apr	891	52.9	499
May	894	52.2	499
Jun	888	52.2	501
Jul	881	52.3	495
Aug	886	52.4	498
Sep	870	52.6	507
Oct	885	53.0	500
Nov	889	53.1	499
Dec	888	53.3	500
Year	23 889	2°52.4'W	-53 499

TABLE 2

1966 earthquakes in the region of Western Australia, $M_L > 3.2$

No.	1966 DATE	Origin Time U.T.	Lat. °S	Long °E	Distance (MUN) km	M_L	(m_L)	m_b (a)	m_b (b)	KLG m_b (b)	Unified m	Remarks
53	Jan 23	03 22 13	32.8	117.0	118	3.6	4.5	4.3	3.5		3.8	Felt
54	24	09 49 14	32.8	117.0	118	3.6	4.5	4.4	3.6		3.8	"
55	25	07 06 35	32.8	117.0	118	3.9	4.9	4.5	3.7		4.0	"
56	Feb 23	03 40 13	37.8	106.8	1070			5.2	4.9		4.9	Rec. KLG
57	Apr 26	03 58 17	31.6	111.6	430	3.5	4.4	5.2	4.4	4.7	4.4	Rec. KLG
58	30	03 24 58	16.9	121.0	1790			4.5	4.7		4.6	Rec. KLG, DAR, CTA, ADE
59	May 06	08 57 35	32.3	118.8	245	3.7	4.5	3.8	3.1	3.4	3.2	Rec. KLG, felt Hyden
60	31	16 38 57	28.3	112.7	517	3.5	4.4	4.2	3.4		3.4	" " "
61	Jun 03	11 27 01	24.9	112.0	880	3.6	4.0	4.6	3.7	3.7	3.7	" " "
62	Aug 29	13 01 10	30.0	109.0	690	3.8	4.6	5.8	5.0	5.1	5.0	" " P:S ampl. large
63	Oct 03	21 39 24	30.6	117.2	180	3.6	4.5	4.2	3.5		3.5	

TABLE 2 (Cont.)

No.	1966 Date	H	Lat. °S	Long °E	Distance (MUN) km	M_L	(m_L)	m_b a)	m_b (b)	KLG m_b (b)	Unified m	Remarks
64	Oct 07	10 24 48	30.4	116.7	180	3.3	4.3	4.1	3.4		3.4	
65	Nov 13*	03 41 48*	24.1*	111.9*	970			6.7	5.8	5.5	5.2	PKP well recorded
		h 33 R	23.7	111.5	1030			4.9X				
66	Dec 25	22 34 27	31.0	116.4	110	3.8	4.6	4.8	3.9	4.3	4.0	Rec felt KLG

Notes:

DAR - Darwin, CTA - Charters Towers, ADE - Adelaide

M_L, m_b Determined from MUN records unless designated

m_b (a) Determined from curve A Plate 1

m_b (b) Determined from curve B Plate 1

m Weighted mean from all magnitude values except m_b (a)

* Determined by USCGS

X Mean for WWSS stations, MUN excluded

TABLE 3

1966 earthquakes in the region of Western Australia, $M_L < 3.3$

1966 Date	P-Arrival Time U.T.	M_L	Distance km	Bearing ^oT	Remarks
Jan 23	02 14 44	2.4	118	139	Several
23	13 51 53	2.5	119	139	
23	18 19 00	2.8	118	138	felt
24	23 20 50	3.2	119	138	
25	04 44 52	3.2	120	140	in area
25	11 31 35	3.1	118	138	
25	19 14 42	3.0	118	140	about 10 km
26	01 24 33	2.9	119	(139)	
26	15 06 43	2.6	117	140	north-west of
28	15 12 09	2.8	118	137	
28	23 39 08	3.1	119	140	Narrogin
31	06 22 26	2.6	119	139	
Feb 09	13 31 25	2.1	102	000	
14	10 00 04	1.9	99	000	
14	11 18 19	2.8	159	153	
15	01 56 08	3.1	159	153	
16	16 29 08	2.1	102	003	
18	07 05 21	2.6	114	135	
18	07 52 28	2.6	113	137	
22	07 21 19	2.5	(190)	(072)	Blast?
Mar 01	09 35 11	1.3	43	(090)	
02	05 33 28	2.1	155	(000)	
25	14 40 54	2.0	100	108	
Apr 26	03 29 37*	2.5*	78*	150*	*KLG Values $31.4^oS, 111.6^oE$
26	11 25 xx	1.7	44	(090)	
26	11 34 xx	1.7	44	(090)	
28	05 45 43	2.2	44	092	
28	13 45 10	1.9	44	(090)	
29	20 36 20	2.0	43	(090)	
30	18 36 xx	1.7	43	(090)	

1966 Date	P-Arrival Time U.T.	M_L	Distance km	Bearing $^{\circ}T$	Remarks
May 01	16 02 58	3.2	43	099	Rec KLG
02	02 09 52	2.1	44	(090)	
03	10 35 21	2.1	77	090	
10	10 12 45	(2.5)	580		(27.1°S,118.7°E) Rockburst?
10	10 12 29*		480*		*KLG
12	06 49 26	1.0	43	(090)	
13	12 44 45		(330)		Felt Gnowangerup
17	14 47 49	2.0	97	070	
Jun 09	19 46 44	3.2	225	210	Felt C. Naturaliste, Margaret River area
19	11 05 55	2.5	94	103	
22	10 34 14	2.1	94	(103)	
Aug 25	15 04 59	1.9	43	106	Felt Talbot Brook
Sep 07	13 49 42	1.7	77	090	
09	18 37	1.9	43	090	
21	04 21	2.6	97	012	
30	07 25 57	2.4	170	(020)	
30	14 05 40	3.0	170	020	Rec KLG
Oct 01	03 04 54	3.0	180	030	
Nov 21	18 08 43	2.7	105	090	
25	15 55 10	2.6	93	099	
25	21 44	2.3	93	099	
26	06 05 01	2.6	90	095	
27	05 33 10	2.3	90	098	
30	15 31 15	2.8	118	140	
Dec 13	02 04 xx		(118)	(140)	From KLG record
14	03 02 14				KLG rockburst?
16	19 40 44	2.8	112	(140)	

NOTE: All data relate to MUN unless signified by *
Brackets denote decreased accuracy

TABLE 4

Larger Australian earthquakes prior to 1959

Date	Origin-time U.T.	Lat. (°S)	Long. (°E)	Depth (km)	Magnitude (Ms)	Reference
1897 May 10	- -	37	140		6-1/2	Dodwell (1910)
1902 Sep 19	10 30	35	137		6	" " "
1906 Nov 19	07 18 41	19.1	111.8	60	7-3/4	Stover (1966)
1913 Dec 18	13 54.0	20	147			" " "
1918 Jun 16	18 14 24	24	152		5-3/4	" " "
1920 Feb 08	05 24 30	35	111		6-1/4	" " "
1922 Apr 10	10 47 39	40	147.5		4-3/4	B-G (1951)
1929 Aug 16	21 28 22	17.0	120.9		6-1/4	Bolt (1959)
1929 Dec 28	01 22 53	40	149		5	G & R (1954)
1934 Jul 12	14 24 27.2	14.8	112.3		6	Stover (1966)
1934 Nov 10	23 47 40	34.9	150.0		4-1/2	B-G (1951)
1934 Nov 18	12 58 41	34.5	149.5		5-1/2	" "
1934 Nov 21	06 32 06	34.5	149.2		4-1/2	" "
1935 Apr 12	01 32 24	26	152		5	B & W (1938)
1937 Oct 28	09 34 43	26.0	136.5		6	Bolt (1959)
1937 Dec 20	22 35 02	25.4	136.5		5-1/2	" "
1938 Mar 24	20 03 33	35.5	146.0		5-1/2	B-G (1951)
1938 Apr 17	08 56 22	25.5	137.2		6	Bolt (1959)

TABLE 4 (Cont)
Larger Australian earthquakes prior to 1959 (Cont)

Date	Origin-time U.T.	Lat. (°S)	Long. (°E)	Depth (km)	Mag (Ms)	Reference
1939 Mar 26	03 56 05	32.0	138.0		6	Bolt (1959)
1941 Apr 29	01 35 41	26.8	116.1	32	6-3/4	" "
1941 May 04	22 07 30	26.3	136.9		5-1/2	" "
1941 Jun 27	07 55 51	25.7	137.8		6-1/2	" "
1946 Sep 14	19 48 42	40	148		5	G & R (1954)
1948 Aug 06	03 29 23	37	137		6	B-G (1951)
1954 Feb 28	18 09 52	34.8	138.7		5-1/2	Bolt (1959)

Note: B-G - Burke-Gaffney
G & R - Gutenberg and Richter
B & W - Bryan and Whitehouse

TABLE 5

Larger Australian earthquakes, 1959 - 1966

Date	Origin Time U.T.	Lat. (°S)	Long (°E)	m_b	USCGS PDE Card.	Depth (km)	Remarks
1959							
May 18	06 12 59.2	36.2	148.7	5.5	43/59	17	CDM
Oct 03	12 07 22	34.5	114.5	4.7		18R	MUN
Oct 12	21 25	31	151.5				Doyle H.A. (Pers.comm.)
Nov 02	01 18 00.9	33.4	136.0			0	SW (a)
Nov 27	06 25 22	25.8	116.2	4.9		18R	MUN
1960							
Aug 18	15 04 40	34.0	135.0		106/60	33	
Dec 24	16 42 10.4	38.9	143.6		106/60	0	SW (a)
1961							
May 21	21 40 03.0	34.6	150.5	5.5	45/61	19	CD
Jun 01	09 35 35.7	38.7	144.2		46/61	0	SW (a)
Jun 01	13 19 50.1	38.7	144.3		46/61	0	SW (a)

TABLE 5 (Cont.)

Date	Origin Time U.T.	Lat. (°S)	Long. (°E)	m_b	USCGS PDE Card	Depth (km)	Remarks
1961							
Jun 18	16 13 58	20.1	119.3	5.2	51/61	13	
Aug 23	18 01 33	18.5	119.0	5.0		18R	MUN
1962							
Jan 01	23 29 52	34	126	4.6		18R	MUN
May 16	21 41 37.7	35.5	137.6		43/62	25	SW (a)
1963							
Jan 18	05 49 16.8	32.2	117.1	5.4	10/63	18	MUN
Feb 26	14 10 19	22.2	121.1	4.8		18R	MUN
Mar 14	01 57 35.0	25.6	137.4	5.5	23/63	33	SW (a)
Mar 28	01 31 15.7	16.0	131.9	5.7	29/63	33	
Jun 14	19 23 49.8	38.6	146.5		48/63	0	SW (a)
Aug 27	19 15 38	16.3	128.8	5.4		18R	SW (b)
Sep 07	08 44 35	13.2	122.1		77/63	256	
Nov 03	12 00 44.3	43.3	146.8	5.0	96/63	33	SW (a)

TABLE 5 (Cont.)

Date	Origin Time U.T.	Lat. (°S)	Long. (°E)	m_b	USCGS PDE Card	Depth (km)	Remarks
1964							
Mar 23	22 41 16.1	17.7	123.2	5.5	23/64	33	I.S.C.
May 12	07 08 44.6	11.0	126.0	5.2	42/64	33	
Nov 14	10 53 01	40.0	144.3	4.7	93/64	33R	
1965							
Jan 17	02 48 32.8	28.1	135.7	5.0	13/65	33R	
Jan 25	20 22 53.7	31.9	138.4	4.9	13/65	0	SW (a)
Mar 02	15 18 53.2	30.5	138.4	5.2	28/65	33R	
Mar 14	12 47 42.2	31.9	138.8	5.0	27/65	26	
Mar 18	18 09 31.1	40.2	149.6		33/65	33R	
May 18	10 17 52	17.5	121.0	4.6		18R	MUN
May 19	02 13 47	25.0	112.1	5.5	51/65	33R	
Jun 03	21 59 58.5	28.1	150.1	5.0	52/65	33R	
Jun 04	10 45 13	30.8	138.5	4.6		18R	MUN
Jun 15	06 16 01	19.6	106.3	4.8	64/65	33R	
Aug 28	00 26 38.1	32.3	138.1	4.7	74/65	33R	
Sep 10	12 24 01	18.1	122.2	4.8		18R	MUN
Sep 14	12 53 13	38.7	144.3	5.0	74/65	33R	

TABLE 5 (Cont.)

Date	Origin Time U.T.	Lat. (°S)	Long. (°E)	m_b	USCGS PDE Card	Depth (km)	Remarks
1965							
Sep 14	12 34 36.3	38.7	144.2		75/65	33R	
1966							
Apr 30	03 24 58	16.9	121.0	4.6		18R	MUN
May 03	19 07 55.0	37.1	147.2	4.2	28/66	37	
Nov 13	03 41 48	24.1	111.9	5.2	92/66	33R	
Nov 23	20 48 03	34.2	139.2	4.7	84/66	33R	
Dec 15	19 08 29.1	40.4	155.4	4.8	96/66	33R	

NOTE:

Epicentres determined by USCGS unless designated in "Remarks" column as follows:

CD - Cleary and Doyle (1962)

CDM - Cleary, Doyle & Moye (1964)

MUN - Mundaring Geophysical Observatory determination - Everingham (1966), McGregor (1967a)

SW(a) - Sutton and White (1966)

SW(b) - Sutton and White, personal communication

I.S.C. - International Seismological Centre

R - Depth assumed.

TABLE 6

Kalgoorlie seismic events 1966

DATE	W.S.T.	Relative amplitude (a)	Approx bearing (^{o}T)	Remarks
Jan.				
23	09 45	15.5	085	G.M.K., damage on Perseverence No. 13 level, adjacent to Associated boundary - L.V.S., very strong tremor; stronger in Eastern leases than Western leases - G.B., N.K., strong tremor.
24	23 04	2.0		G.B., slight tremor.
Feb.				
4	03 15	4.2		
14	15 04	1.0		G.B., slight bump.
24	03 57	0.6		G.M.K., Hainault Shaft, fall of rock.
24	04 35			ditto.
Mar.				
3	15 00	1.5		L.V.S., mild tremor - slight movement 227 chains from seismic station on bearing 087^{o}T.
5	09 03	11.0		G.B., heavy bump followed by small bump - no damage.
	09 03	6.5		L.V.S., two sharp tremors felt more strongly on Western leases - damage 203 chains on bearing 89^{o}T from seismic station. N.K., felt, no damage.
6	09 04			G.M.K., Kalgoorlie Enterprise Shaft, Blast followed by tremors. Not recorded.
8	20 20	6.0		G.B., slight bump. G.M.K., felt, no damage.

Date	W.S.T.	Relative amplitude (a)	Approx bearing (^{o}T)	Remarks
March				
10	15 04	11.2		L.V.S., medium tremor minor damage 200 chain bearing 89° from seismic station.
11	11 47	1.9		G.B., slight bump, slight damage 800 ft bearing 64° from Ham. Shaft - L.V.S., slight tremor, no damage.
18	02 02	(290)		Recorded at Mundaring. N.K., very severe, on surface, no damage - L.V.S., extremely heavy tremor, no damage - G.B., heavy bump, no damage.
18	02 17	(0.2)		
18	02 23	3.2		
18	02 23	0.9		
18	02 45	0.3		N.K., very slight - L.V.S., two light tremors - G.B., two slight bumps.
19	21 07	4.4		
20	18 59	3.6		L.V.S., two light tremors, no damage.
21	11 57	0.9		
22	05 33	3.4		L.V.S., two light tremors no damage - G.B., slight bump no damage.
24	20 16	1.0		
25	16 16	3.2		L.V.S., mild tremor, no damage.
Apr.				
7	15 00	1.8		L.V.S., mild tremor, no damage.
14	12 08	5.0	080	L.V.S., strong tremor, ruptured pillar 205 chain bearing 91° from seismic station - N.K., slight on surface.

Date	W.S.T.	Relative amplitude (a)	Approx bearing (^{o}T)	Remarks
Apr.				
14	19 31	0.6		
18	10 21	1.8		L.V.S., mild tremor, no damage.
May				
3	14 55	2.2		
5	20 51	0.8		G.B., slight tremor, no damage.
6	11 30	(12)		G.B., heavy tremor, no damage - N.K., slight on surface, no damage L.V.S., reported at 10.05 sharp tremor, damage to timbers and minor rock falls, 223 chain bearing 95 1/2^{o} from seismic station.
11	22 40	(0.3)		L.V.S., very strong tremor felt on Western leases.
13	06 30	0.8		
16	23 14	2.2	(045)	Mt. Charlotte?
18	11 38	2.0	(338)*	G.B., heavy tremor, no damage. Recorded at L.V.S.
20	06 15	2.0		G.B., slight tremor, no damage.
24	16 52	4.1	086	L.V.S., medium tremor, damage 235 chain bearing 87 1/2^{o} from seismic station - G.B., slight tremor, no damage. Recorded at L.V.S.
25	23 31	0.7		

T

Date	W.S.T.	Relative amplitude (a)	Approx bearing (°T)	Remarks
May				
27	03 13	(40)	100 176*	Approximate bearing from Chaffers seismograph 176°, distance between 10 and 30 chain. L.V.S., extremely heavy tremor, considerable damage 225 chain 95 1/2° from seismic station (almost directly beneath Chaffers S.S.). Movement appears to have been east side up - G.B., fairly heavy tremor no damage.
30	15 16		(NW)*	Recorded on L.V.S., very small at KLG.
June				
10	23 13	2.2		
27	14 54	0.3	(144)*	Recorded at L.V.S.
28	15 27		144*	Not recorded at KLG
July				
6	15 21	4.2	(086)	G.M.K., tremor, slight damage.
8	15 56	3.4	087 (346)*	G.M.K., remnant blast. Above No. 3 level N.N.E. 11 60 W area. 346° from Chaffers seismograph.
13	08 56	3.0	(094)	N.K., slight on surface, no damage.
25	14 47			L.V.S., light tremor, no damage. Not recorded.
Aug.				
1	16 05	2.6		Blast? Recorded at L.V.S.

Date	W.S.T.	Relative amplitude (a)	Approx bearing (^{o}T)	Remarks
Aug.				
8	15 09	4.0	088	L.V.S., light tremor.
11	23 44	5.6	078 015*	G.M.K., remnant blast No. 9 level Hainault shaft. Recorded at L.V.S.
Sept.				
1	11 45			G.M.K., minor bump, not recorded.
2	15 22	1.4		
3	09 05	2.6		
10	15 48	5.2	(061)	G.M.K., remnant blast No. 8 Paringa Shaft.
14	11 58	1.4		G.B., slight tremor.
16	18 02	2.2		
19	23 15	1.6		
21	04 46	5.6	(093)	G.B., slight tremor.
21	16 24	1.0		
22	22 45	3.4	(094)	
Oct.				
6	12 17	3.8		
11	21 40	11.8	$102^{1}/_{2}$	L.V.S., Floor pillar above 1500 Hannans Star West Lode ruptured when stope face adjacent to the winze was fired out. Considerable damage occured to level timbers etc. G.B., slight tremors.
31	18 28	9.5	105	L.V.S., very strong tremor on Western leases. G.B., slight tremor.
Nov.				
1	00 33	0.6		L.V.S., two light tremors.
9	20 36	0.9		Unusual
10	15 48	2.4	081	

Date	W.S.T.	Relative amplitude (a)	Approx bearing (^{o}T)	Remarks
Dec.				
7	08 44	4.0		G.B., slight tremor, minor damage 2950 level No. 16 lode, cut and fill stope.
13	17 00			L.V.S., mild tremor, not recorded.
14	11 19	(16)		L.V.S., very strong tremor on Western leases - mild on Eastern leases. N.K., sever on surface. G.B., heavy tremor, mild damage 2350 level No. 10 lode. G.M.K., heavy tremor.
17	13 25	0.8		
20	12 12	2.2		
20	16 14	(5.6)		
23	07 05	0.7		L.V.S., mild tremor G.B., light tremor.

NOTES:

* Bearings from L.V.S. Chaffers Shaft seismograph.

a. Relative amplitude is resultant of maximum horizontal trace deflections.

G.M.K. Gold Mines of Kalgoorlie (Aust.) Ltd

L.V.S. Lake View and Star Ltd

G.B. Great Boulder Gold Mines Ltd

N.K. North Kalgurli (1912) Ltd.

TABLE 7

Observatory Staff, 1966.

Officer	Designation	
P.M. McGregor	Geophysicist Cl.3	(Observer-in-Charge) (January - November)
I.B. Everingham	Geophysicist Cl.2 A/g Geophysicist Cl.3	(November - December)
P.J. Gregson	Geophysicist Cl.1 A/g Geophysicist Cl.2	(November - December)
A. Parkes	Technical Officer Gr.2	
G. Woad	Technical Officer Gr.1	
T.D. Dunning (Miss)	Clerical Assistant Gr.1	
N. Keating	Assistant Gr. 1	

TABLE 8

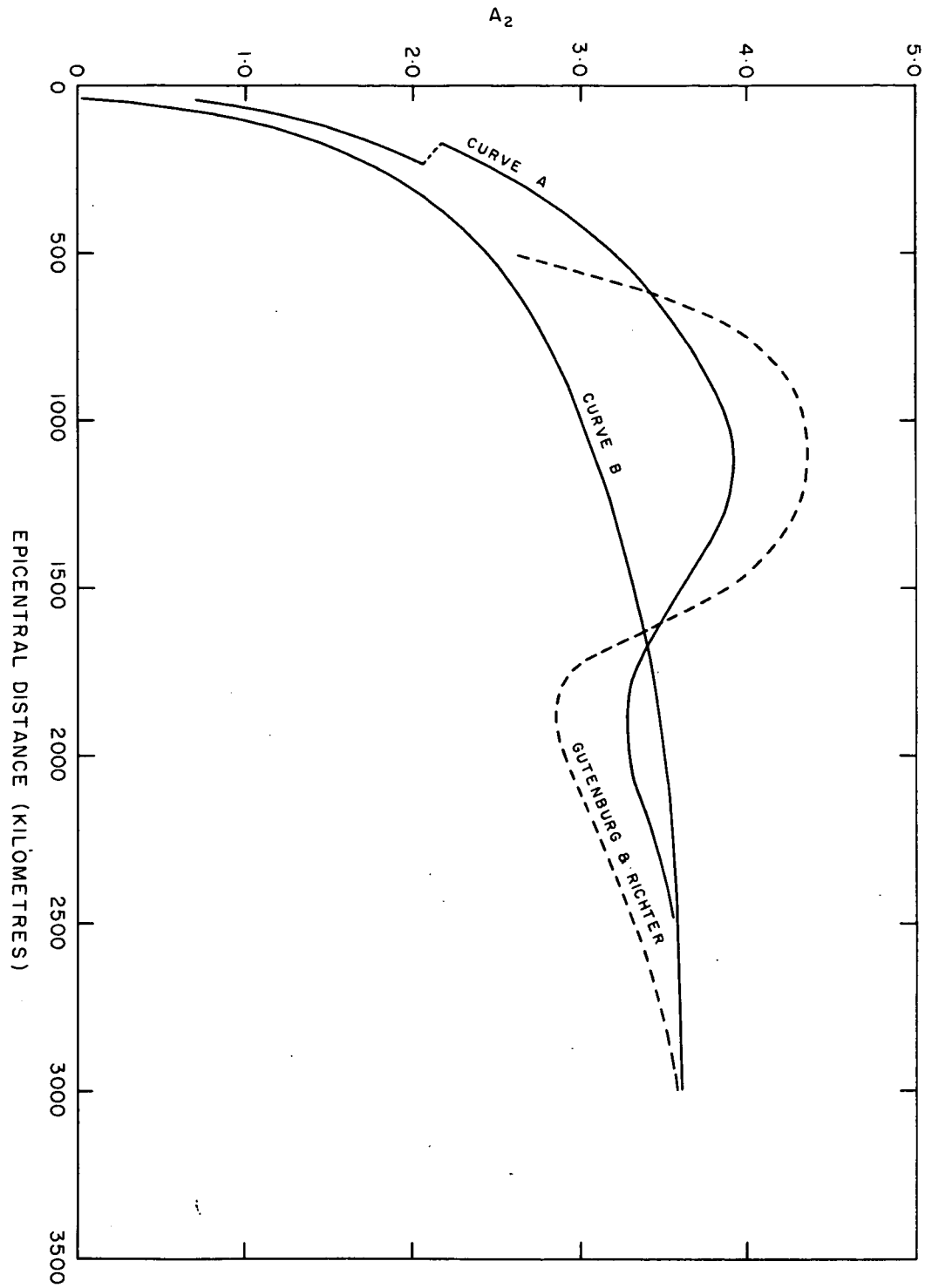
Associated personnel, 1966

Name	Designation or services rendered
D.J. Edmiston	University Student, vacation 1965/66
V.N.E. Robinson	University Student, vacation 1965/66
G. Eichinski	University Student, vacation 1966/67
R.M. Kerr	University Student, vacation 1966/67
V. Dent	Geophysicist Cl.1, Antarctic trainee (5th - 30th September)
G. Hart	Geophysicist Cl.1, Antarctic trainee (5th - 30th September)
J. Major	Geophysicist Cl.1, Antarctic trainee (5th - 30th September)
J. Connolly	Geophysicist Cl.1, Antarctic trainee (11th November - continuing)
A. Wormall	Daily attendant, Gnangara magnetograph
D.H. Eggleston	Daily attendant, Kalgoorlie seismograph

TABLE 9

Observatory staff absences 1966

Nature of absence	Man-days
Sick, special, repatriation leave	42
Military leave	14
Attendance at outstations	12
Conferences and interstate travel	30
Total	98



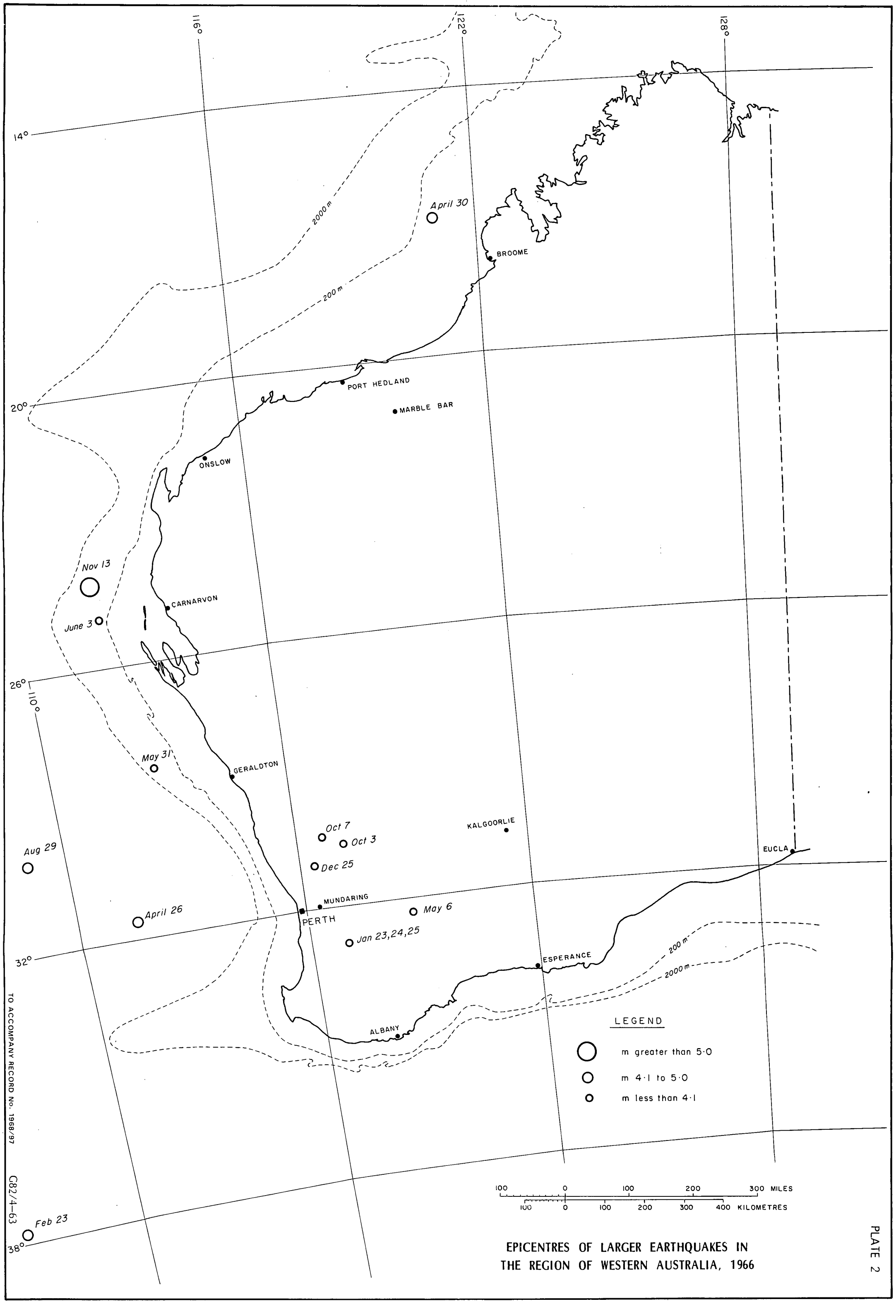
$m_b = \log {}^{A}/_{T} + A_2$

where T = Period in seconds
A = Ground amplitude in milli–microns

CURVES OF A_2 USED FOR MAGNITUDE DETERMINATIONS

TO ACCOMPANY RECORD No. 1968/97 G82/4–59

MUNDARING, WA, 1966

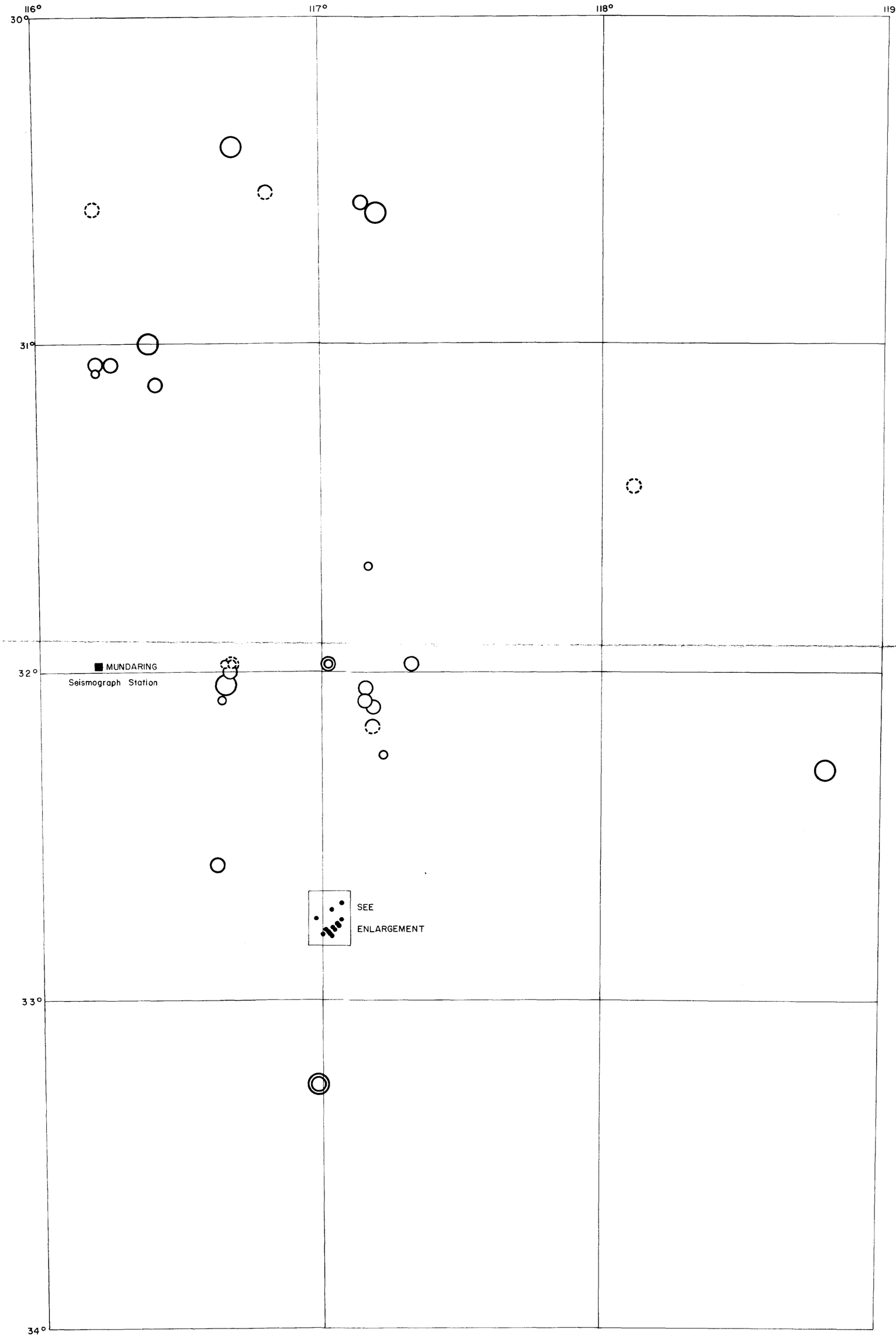


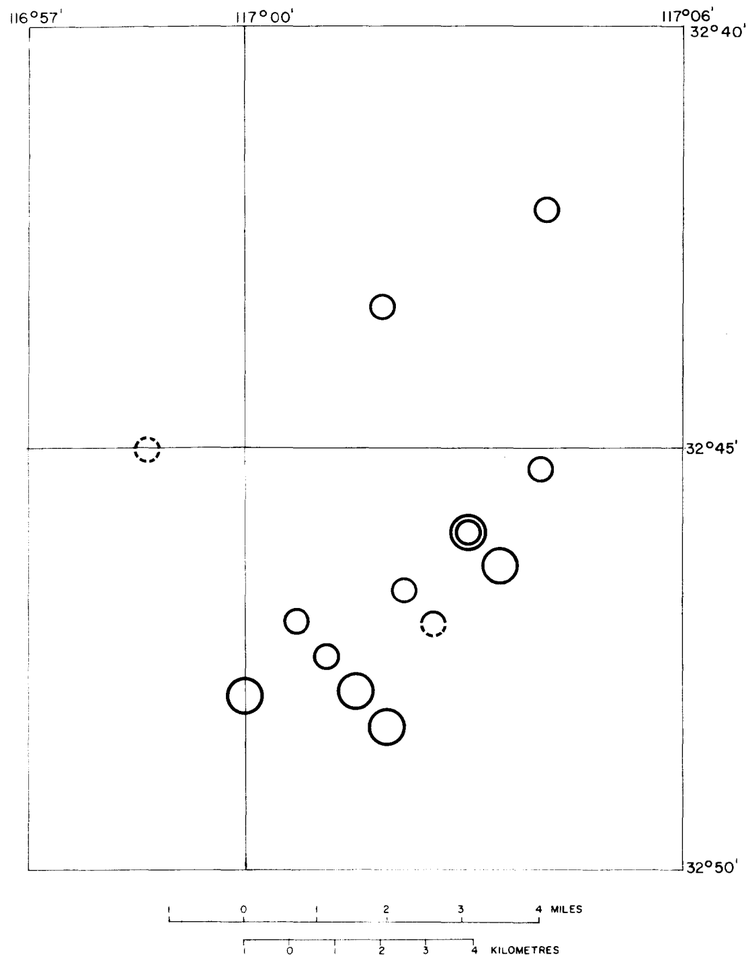
EPICENTRES OF LARGER EARTHQUAKES IN THE REGION OF WESTERN AUSTRALIA, 1966

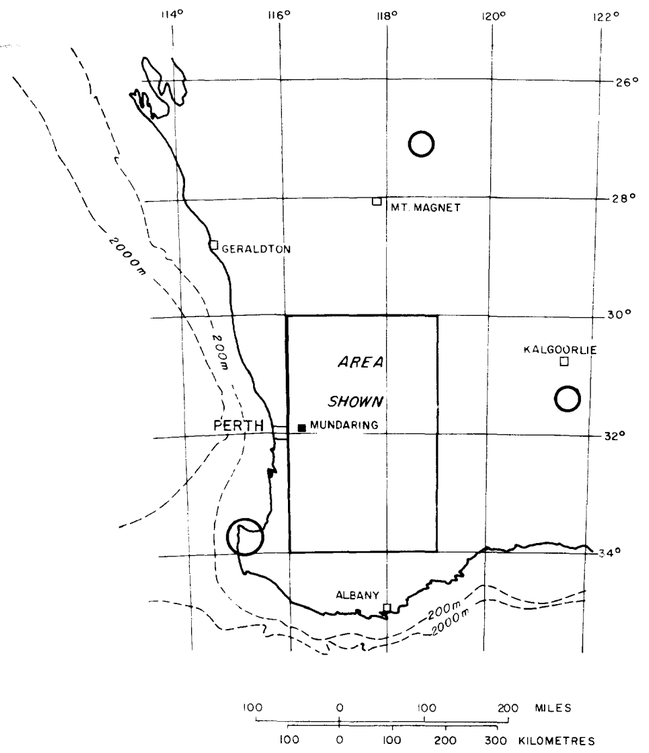
TO ACCOMPANY RECORD No. 1968/97

G82/4–63

PLATE 2







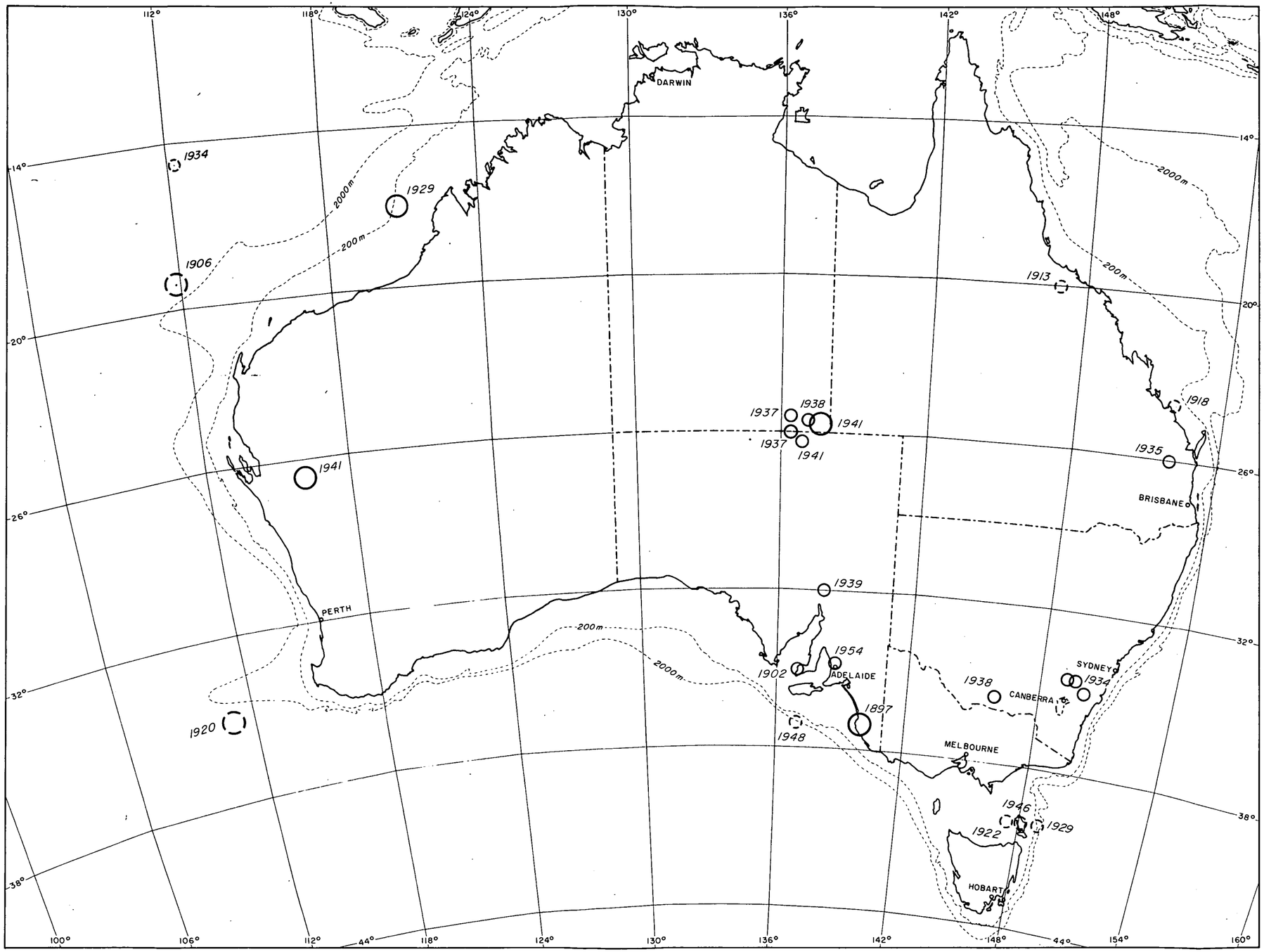
LEGEND

- M_L 3·1 to 4·0
- M_L 2·1 to 3·0
- M_L less than 2·1
- Epicentre less accurate
- Accurate & less accurate epicentres coincident

EPICENTRES OF EARTHQUAKES IN THE REGION OF SOUTH-WESTERN AUSTRALIA, 1966

TO ACCOMPANY RECORD No. 1968/97

G82/4-64



(BASED ON A/BO-13)

LEGEND

- M_S greater than 6
- M_S equal to or less than 6 or undetermined
- Epicentre less accurate

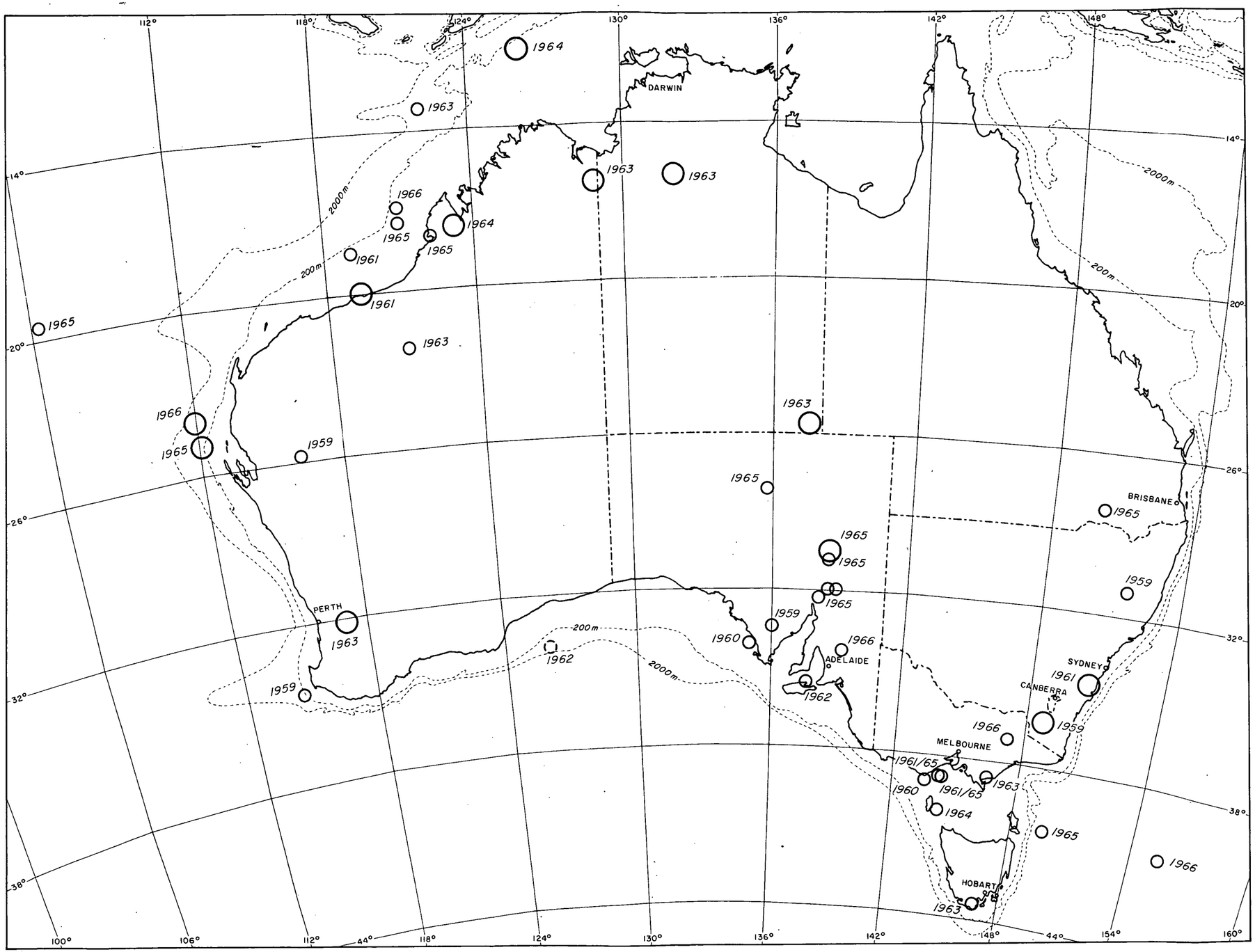
MILES 100 0 100 200 300 400 500

KILOMETRES 100 0 100 200 300 400 500 600 700 800

EPICENTRES OF LARGER AUSTRALIAN EARTHQUAKES PRIOR TO 1959

TO ACCOMPANY RECORD No. 1968/97

G82/4–57



(BASED ON A/80-13)

LEGEND

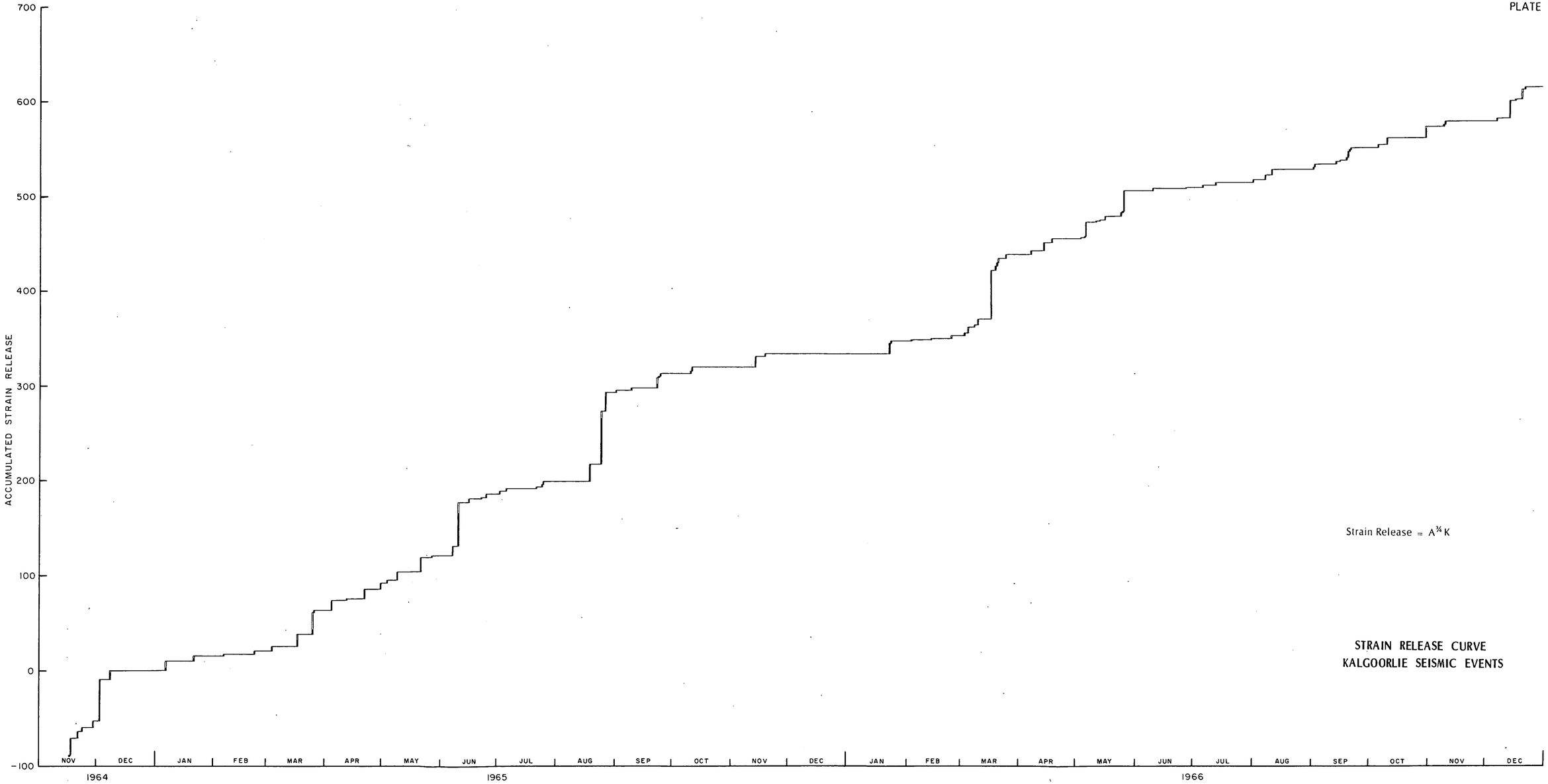
- m_b greater than 5·0
- m_b less than 5·1 or undetermined
- Epicentre less accurate

MILES 100 0 100 200 300 400 500

KILOMETRES 100 0 100 200 300 400 500 600 700 800

EPICENTRES OF LARGER AUSTRALIAN EARTHQUAKES 1959 – 1966

PLATE 6



Strain Release = $A^{3/4}K$

STRAIN RELEASE CURVE
KALGOORLIE SEISMIC EVENTS

TO ACCOMPANY RECORD No. 1968/93 G82/4–60

MUNDARING, WA, 1966