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INTENSITY DATA FOR EARTHQUAKES AT LANDOR (17 JUNE 1969) AND CALINGIRI (10 MARCH 1970) AND THEIR RELATIONSHIP TO PREVIOUS WESTERN AUSTRALIAN OBSERVATIONS

by

I.B. Everingham and A. Parkes

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SUMMARY

Intensity data for earthquakes at Landor (17 June 1969) and Calingiri (10 March 1970) are presented and discussed along with previous Western Australian results.

The data show that the Meckering (1968), Landor (1969), and Calingiri (1970) earthquake intensity radiation patterns were similar, but different from those of the Nourning Spring (1963) and Meeberrie (1941) earthquakes. Intensities at Landor may have been increased by geological or source effects.

Examination of the relationships between isoseismals and focal depths, propagation efficiency, and magnitudes suggests that it is not possible to predict accurately intensities for use in earthquake risk analysis.

It is strongly recommended that networks of strong-motion instruments be established in Western Australia.

1. INTRODUCTION

The purpose of this report is to present macroseismic data from larger Western Australian earthquakes which occurred during the period January 1968 to June 1970, and to discuss these observations along with previous results obtained from the W.A. earthquakes which took place at Meeberrie (1941), Nourning Spring (1963), and Meckering (1968); See Clarke, Prider & Teichert (1955); Everingham (1968); Everingham & Gregson (1970). Localities are shown in Plates 1 and 2.

The results are of interest, because of the relationship of earthquake risk to the depth and magnitude of the events, and to geological structure.

The distribution of the macroseismic effects, i.e. the earthquakes' effects observed on a large scale without instrumental aid, is represented by isoseismals, which indicate boundaries between regions of successive ratings of intensity estimated on the Modified Mercalli (MM) scale described by Richter (1958).

During the period 1968 through June 1970, the three earthquakes listed below were felt over wide areas of the State.

DATE	ORIGIN TIME (UT)	EPICENTRE LAT °S	EPICENTRE LONG °E	DEPTH km	m CGS	m	MS
1969 Jun 17	195434	25.0	116.8 (Landor)			5.7	
1970 Mar 10	171511.2	31.11	116.47 (Calingiri)	1	5.7*	6.2	5.1
Mar 24	103522*	22.0*	126.7* (East Canning Basin)	33R*	6.2*	5.9	5.9*

In this list the USCGS data are starred; the MS value for the Calingiri event was determined from the Port Moresby and Riverview WWSSS seismograms; and the remaining data were determined at the Mundaring Observatory.

Isoseismals for the largest event of the three were not obtained, because the epicentre was in a remote and uninhabited area of the State, from which very little observational data were available. The maximum known intensity of MM5 was observed at Fitzroy Crossing, which is about 500 km from the epicentre. The earthquake was also clearly felt in tall buildings at Perth (distance 1500 km) (MM1 or 2).

Isoseismal surveys were conducted for the Landor and Calingiri earthquakes, both of which occurred in Precambrian regions with a recent history of seismic activity. The active regions as outlined by Everingham & Gregson (1970) are shown, slightly modified, in Plate 1, and the main tectonic units for Western Australia are shown in Plate 2 together with epicentres of the earthquakes under discussion.

2. ISOSEISMAL MAPS

The isoseismal questionnaire used for the Calingiri earthquake is shown in Appendix A. The same questionnaire was used for the Landor shock, but with appropriate changes in the general remarks section.

Both events occurred during darkness in the very early morning when most people were sleeping. The ratings of intensity were difficult to assess, because too few people were awake or else they were awakened during the tremor too dazed to know just what was happening. Furthermore, the damage, being very slight, could not be used as a criterion. To assist in evaluating intensities, a chart was designed (Appendix B) to obtain average intensities from what had been felt or heard and according to the proportion of people awakened at any point. It was most useful for estimating intensities of less than MM6 where damage was negligible. Where several reports were assessed for small areas around a particular township the intensity range obtained from this method was rarely more than one and a half units. Normally a range of at least one unit of intensity could be expected because of sub-soil variations, so that the results tend to show the consistency of the averaging method using the chart.

Places at which observers reported that the earthquake was not felt are marked in Plates 3 and 4, because the ratio of 'not felt' reports to 'felt' reports provides a factor for comparison with other results.

The Landor earthquake

The isoseismal map is shown in Plate 3.

Fifty-two replies were received from about seventy questionnaires sent to every homestead (H.S.) and township within a 300 km radius of the epicentre.

Reports of damage were: Moorarie H.S., lightly cracked old brick wall; Yinnietharra H.S., mud brick chimney fell in an abandoned hut; Dairy Creek H.S., ceiling shifted; Meekatharra, tank slightly cracked. The maximum intensity was assessed as MM5+. However, because of the large distance between homesteads (usually 30-50 km) a zone of high intensity could have remained undiscovered.

The largest aftershock (presumably in the same position as the main event) was heard at Landor and at four homesteads to the south, which suggests that the instrumentally determined epicentre indicated in Plate 3 is too far north. The epicentre could have been situated in the centre of the region with greatest intensities.

The Calingiri earthquake

The isoseismal map is shown in Plate 4.

Three hundred and sixty replies were received from about 420 questionnaires circulated within a 300 km radius of the earthquake epicentre. Each intensity rating is shown in Plate 4.

Although the earthquake caused an arcuate shallow east-dipping thrust fault over a distance of about 5 km, where the surface was uplifted by as much as 30 cm. Major damage to buildings did not occur at Calingiri only 3 km from the fault. No building straddled the fault, where the only damage was the shortening and misalignment of wire fences and a bump in a road where the fault scarp crossed it.

Close to the epicentre individual intensities rated from questionnaires were in the range MM4+ to MM6+. The authors, on a very brief visit to Calingiri, concluded that the intensity there was MM6. The 1968 Meckering earthquake had caused some slight cracking of walls in the area, so that it was not easy to assess the damage effects from the Calingiri event.

Here it should be noted that the authors' rating of intensity (MM6) is based largely on cracking of walls in older homes, which because of their age, were considered to be in the 'Masonry D' group as defined by Richter. However, G.A. Eiby (DSIR, NZ) (pers. comm.) considered that, because the local standard of building was generally higher than in areas described by Richter, these types of buildings could be classified as 'Masonry C', and that accordingly the authors' rating would tend to be too low.

3. DISCUSSION

Useful formulas

Several useful relationships between intensity, magnitude, and distance from the hypocentre are given below:

Formula 1 (Gutenberg & Richter, 1956)

$$Io = 1.5\ (M-1)$$

(For crustal shocks, fits formula 2 for h = 20 km)

Formula 2 (Shebalin, 1956)

$$Io = 1.5\ M - 3.5 \log h + 3.$$

Formula 3 (see Ergin, 1969)

$$Io - I = n \log \left[\frac{(x^2 + h^2)^{1/2}}{h}\right] + \text{(absorption term)}$$

where Io = maximum MM intensity

I = intensity at horizontal distance x from epicentre

M = magnitude MS

h = focal depth

n = empirical constant

log = log arithon to the base 10

Formula 1, a standard formula used for many years, relates magnitude and maximum intensity. It applies to events with hypocentres in the mid-crustal region (i.e. about 20 km deep). However, it is obvious that maximum intensity is a function of focal depth, and formula 2 should be used for earthquakes with depths appreciably different from 20 km. For a magnitude 3.0 event at a depth of 1.0 km, formula 2 suggests that Io = 7.5; which appears to be unrealistic. Possibly formula 2 is not applicable for depths less than 10 km or 'log h' should read 'log (h + c)' where c is some small constant (see later discussion).

Formula 3 relating intensity, distance from hypocentre, and focal depth may be used for depth determination, and for comparing intensity effects in differing regions, or from different events (Ergin, 1969). The equation is the equivalent of an expression given by Blake (1941), which has been used for the determination of depths of a few Australian earthquakes, including one at Nourning Spring (Everingham, 1968).

Geological effects

Plate 5 shows that the mean radii of the MM3 and MM4 isoseismals observed from the Calingiri earthquake are almost equal to those obtained from the Landor event. Normally this would indicate equality of magnitudes, but instrumental evidence clearly suggests a smaller magnitude for the Landor event. Therefore it must be assumed, that either the sub-soil conditions for the region around Landor (relative to those on the shield near Calingiri) resulted in increased intensities or that the mechanisms at the sources were different.

An effect definitely associated with geological structure, which may be seen by reference to Plates 2 and 3, is the elongation of Landor earthquake isoseismals in the SE-NW direction parallel to the regional geological strike of the northern Gascoyne Block and western part of the Bangemall Basin. A similar effect occurred with the 1941 Meeberrie earthquake, 200 km to the south of Landor. In this event the isoseismals were elongated in the NE-SW direction roughly parallel to the contact between Yilgarn and Gascoyne Blocks.

For higher intensities, the propagation from the Calingiri earthquake was more efficient to the east. A similar phenomenon was observed from the 1968 Meckering earthquake (Everingham & Gregson, 1970). As for the Meckering event, propagation at lower levels of intensity was more efficient to the south southwest.

The explanation for these features could be that more energy was radiated to the east, because of the mechanism at the source, but attenuation was least to the southwest and therefore at distances of, say, 200 km; this effect outweighed the source effect. Further explanation in terms of geology would be highly speculative.

Intensity/distance, maximum intensity

Ergin (1969), using sets of curves derived from formula 3 with various values of the constant (n) and depth (h) found that the intensity/distance relationship for a number of earthquakes indicated values of either 3 or 5 for n. He concluded that the difference in his observed values of n could be the result of different types of motion at the focus or the different crustal structure of the regions. In obtaining his value of n Ergin ignored the 'absorption factor', which, particularly at small distances, was considered negligible.

Plate 6a shows a set of Ergin's master curves for n = 3 for various focal depths and with intensity data for the Landor, Calingiri, and Meckering earthquakes. The latter were scaled from intensity/distance curves based on mean isoseismal radii as plotted in Plate 5. These Western Australian results fit the n = 3 curves well, but the depths indicated appear to be too great for the Calingiri and Meckering events. Both were extremely shallow, possibly less than 5 km deep, whereas depths of 15 km or more are suggested by Ergin's curves.

The discrepancy may be explained if the local values of Io were too low; alternatively formula 3 may require modification for Western Australian conditions.

The master curve for h = 1 indicates how rapidly intensities decrease in moving away from the epicentre of shallow events. At a distance of about 2 km the intensity decreases by one unit. Accordingly, the maximum intensity for the Calingiri event could easily have been underestimated by this amount, because the nearest building was about 3 km from the centre of the earthquake fault (the epicentre). This type of underestimate does not apply for the Meckering earthquake, where many buildings were close to the fault trace. Increasing the Calingiri Io for the above reason results in a better agreement between the Calingiri and Meckering curves, but depths of 15 km are still indicated.

It has been suggested previously (Everingham & Gregson, 1970) that intensities experienced from earthquakes on the western Yilgarn Block are lower than from similar earthquakes in other regions, because of the different sub-soil conditions. The Western Yilgarn Block is commonly covered by only a few feet of soil and clay above solid granite, whereas the average sub-soil layer elsewhere is likely to be thicker and underlain by layers of unconsolidated or weakly consolidated sedimentary rock. However, even if intensity ratings were all raised by some amount to allow for this, the curves would still remain in the same position, when plotted in Plate 6a; and to make the observed data fit Ergin's curves for very shallow depth, an increase of Io alone by two units would be required. The experimental results do not justify such an increase of Io, and to fit the observed data of the Calingiri and Meckering events, formula 3 would require modification to:

$$Io - I = 3 \log \left[(x^2 + (h + 4)^2)^{1/2} / (h + 4) \right] + (\text{absorption term}).$$

This formula would give a depth of about 15 km for the Landor earthquake.

It is interesting to compare these results with results of the Meeberrie (1941) and Nourning Spring (1963) isoseismal surveys carried out independently. Isoseismal radii for these events are shown in Plate 5 and values of (Io - I) along with Ergin's curves of formula 2 for n = 5 are shown in Plate 6b.

The curves for each event are different from those for the three earthquakes plotted in Plate 6a, and indicate an n value nearer 5 than 3. Depths suggested by the Plate 6b plots are 20 km and 60 km respectively for the Nourning Spring and Meeberrie events. If Ergin's standard curves are modified as suggested by the Plate 6a results, depths would be about 13 km and 60 km. The depths determined from the seismograms were 18 km (from possible **pP** phases) for the Nourning Spring earthquake and 32 km (from travel-times) for the Meeberrie earthquake (Everingham, 1968).

Different focal depth or mechanism could explain the differences in propagation (n values) for the two sets of earthquakes. However, insofar as risk is concerned, we are faced with yet another unknown, namely which type of earthquake propagation data (e.g. those for Nourning Springs or those for Calingiri), should be used in predicting earthquake shaking effects.

In assessing risk from earthquakes, Everingham & Gregson (1970) listed isoseismal radii (based mainly on the Meeberrie, Nourning Spring, and Meckering data) which indicated an n value of 3.3; i.e. the radius of each successive isoseismal is doubled.

Blake (1941) suggested that values were in the range 3 to 6, and it appears that values cannot be predicted with better precision. To be on the safe side, a low value of n should be used in risk estimates and Everingham & Gregson's (1970) tables with a value of 3.3 seem reasonable.

Magnitude/intensity

The magnitude and maximum intensity data for Western Australian earthquakes are tabulated below:

	EVENT	DEPTH (km)	Io (MM)	MAGNITUDE (MS) from seismograms	from Io (a)	from Io (b)
1	Meckering	5	9.5	6.8	5.9	7.2
2	Calingiri	1	7	5.1 (5.7)	2.7	5.0
3*	Smaller Locals	1	5	(3.5)	1.3	3.6
4	Landor	15	5.5	(5.1)	4.4	5.3
5(a)	Meeberrie	60	8.2	6.8 (7.3)	7.7	8.4
(b)	Meeberrie	30	8.2	6.8	6.9	7.7
6	Nourning Spring	15	7.5	4.1 (5.3)	5.7	6.6

Io obtained from Plate 5

() derived from ML or mb

(a) Magnitude determined via formula 2

$$Io = 1.5M - 3.5 \log h + 3$$

(b) Magnitude determined via

$$Io = 1.5M - 3.5 \log (h + 4) + 2$$

* Small events in the Calingiri, Meckering, and Nourning Spring area.

Magnitudes were first determined from Io and depth h using formula 2. Then by means of another formula, in which firstly the observed Io (see Plate 5) was increased by one unit to allow for the lowered intensities caused by the shield sub-soil condition; and secondly, 'h' was replaced by 'h + 4' in accordance with the empirical results discussed in the previous section.

For events 1-4 magnitudes determined from instrumental information agree fairly well with the magnitudes obtained from the modified formula 2; whereas magnitudes found using formula 2, unmodified are far too low. For event 4 (Landor) a reduction of Io by half an intensity unit (i.e. assuming the sub-soil effect is somewhere between that for the shield and for 'normal' conditions) would make magnitudes determined by instrumental data match those obtained from formula 2, modified. The differences between the Calingiri and Landor magnitudes determined in each manner would be consistent.

For the Nourning Spring event magnitudes determined from Io seem too large, which suggests that Io has been over-estimated, or the depth is too great. A reconsideration of the macroseismic evidence along with that from the Calingiri and Meckering events suggests that the maximum observed intensities could have been MM6, much the same as at Calingiri. If this was so, the magnitudes derived from Io from modified formula 2 are still higher than the instrumental magnitudes, and the Nourning Spring event appears to have different propagation characteristics from events 1-4.

The Meeberrie earthquake also appears to have different propagation characteristics from events 1-4. There was not sufficient evidence available to determine whether Io for the Meeberrie earthquake was incorrect, although, as with the Landor earthquake, the maximum observed intensity may possibly have been slightly higher than for a similar event beneath the shield further south. The magnitudes determined from both formula 2 and its modification and the magnitude derived from the body waves are all higher than the magnitude determined from surface waves. This lends support to the assumption of Everingham & Gregson (1970) that the event was deeper than normal, and hence the magnitude determined from surface waves was underestimated.

4. CONCLUSIONS AND RECOMMENDATIONS

The intensity results from the five earthquakes discussed appear to fall into two categories similar to those found by Ergin (1969) for earthquakes in other regions. However, magnitude/intensity, intensity gradient/distance, and depth formulas appear to need modification to fit the Western Australian results. Two provisionally modified formulae are:

(a) $Io = 1.5M - 3.5 \log (h + 4) + 2$

(b) $Io - I = n \log \left[(x^2 + (h + 4)^2)^{1/2}/(h + 4)\right]$ + (absorbtion term) where $n = 3$ or 5

The discussion clearly shows the uncertainty of the intensity information and the difficulty in predicting shaking effects of earthquakes.

Eiby (1965) and others have pointed out that although isoseismals can be drawn to delineate clearly the margin of an area over which a certain intensity level was reached, only the order of the acceleration associated with such an intensity level may be known. Reporters may differ by as much as two units in assessing intensities, because of the quality of the data and the interpretation of the intensity scale. The Western Australian results show that empirical formulas from other regions must not be relied upon.

In order to make the intensity information more reliable and modernize the method of gathering intensity information, it is urgently necessary to set up arrays of strong-motion recorders. For example, a line of say six equally spaced instruments in the area extending about 200 km SSE from Calingiri would provide good intensity/distance data in the event of a larger than normal earthquake happening in this relatively active seismic zone. Consideration should also be given to the installation of strong-motion recorders in larger centres of population in the State and in regions where earthquake swarms are in progress.

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APPENDIX A

EARTH TREMOR REPORT

Please underline suitable words and fill in answers where applicable as soon as possible while your memory is clearest. Also return report if not felt as that information is also important.

1. PLACE (Station.or.township)....................................

   TREMOR FELT Yes No

   and/or HEARD Yes No

2. INTENSITY OR STRENGTH was faint, moderate, strong.

   MOTION - rapid, slow LASTED FOR ....sec.

   FELT LIKE - sudden jolt, passing heavy truck, slow vibration, swaying.

   Remarks ....

3. LOUDNESS (if heard) - faint, moderate, very loud.

   NOISES - low rumbling, passing truck, passing train, thunder, distant explosion, underground explosion, building being struck, creaking of building structure, loud roaring, a bang.

   Remarks ....

4. DIRECTION - tremor appeared to come from N, NE, E, SE, S, SW, W, NW, can't say.

   DIRECTION OF SHAKING was ....

   YOUR LOCATION was - outdoors, indoors ....

   walking, standing, sitting, sleeping ....

   Remarks ....

5. TYPE OF BUILDING was - concrete, stone, modern brick, older brick, brick veneer, fibro, weather-board.

6. AGE OF BUILDING - 5, 10, 20, 40, 80, years, more.

7. GROUND BENEATH LOCATION was - rock, soil, sand, loose, compact, filled in, marshy, unknown.

8. NUMBER OF OBSERVERS was - you only, two, several, many, everyone in house, almost whole neighbourhood, everyone.

9. AWAKENED - no one, few, many, everyone.

   Remarks ....

10. EFFECTS ON OBJECTS

Rattling of windows, doors, crockery.

Creaking of walls, frames of buildings.

Swinging produced in lights, doors. Swung N, NE ....

Splashed water out of tank, trough.

Shifted furniture, small objects, vases.

Overturned - furniture, small objects, vases.

Fall of - books, small objects, pictures, plaster, monuments, walls, chimneys.

Cracked - plaster, windows, walls, chimneys, ground.

11. DAMAGE - none, slight, moderate, considerable, great.

to - chimneys, walls, columns, water tanks, plaster, furniture, crockery.

Type of structure damaged - concrete, thick stone, modern brick, older brick, brick veneer, fibro, weather-board.

12. GENERAL REMARKS

Were smaller shocks felt:

(a) before main tremor Yes/No. How many ....

(b) after main tremor Yes/No. How many ....

(c) during previous 12 months. Yes/No ....

(d) describe miscellaneous effects below.

Name ....

Address ....

....

....

APPENDIX B

TABLE FOR EVALUATION OF INTENSITY

EFFECT	M.M. INTENSITY				
	II	III	IV	V	VI
FELT	Probably Nil	Faint	Moderate	Strong	Very strong
HEARD (rumbling)	Faint	Faint but distinct	Moderate	Strong	Very strong
HEARD (other sounds)	Nil or earthquake not recognised	Faint rattle of windows, house creaks	Windows, crockery etc. rattle, building creaks	As for IV objects move	As for V objects fall
AWOKE	No one	Few	Many	All except some children	All, alarm
DAMAGE	Nil	Nil	Nil	Any, light ie. minor plaster falls	Obvious cracks weak masonry

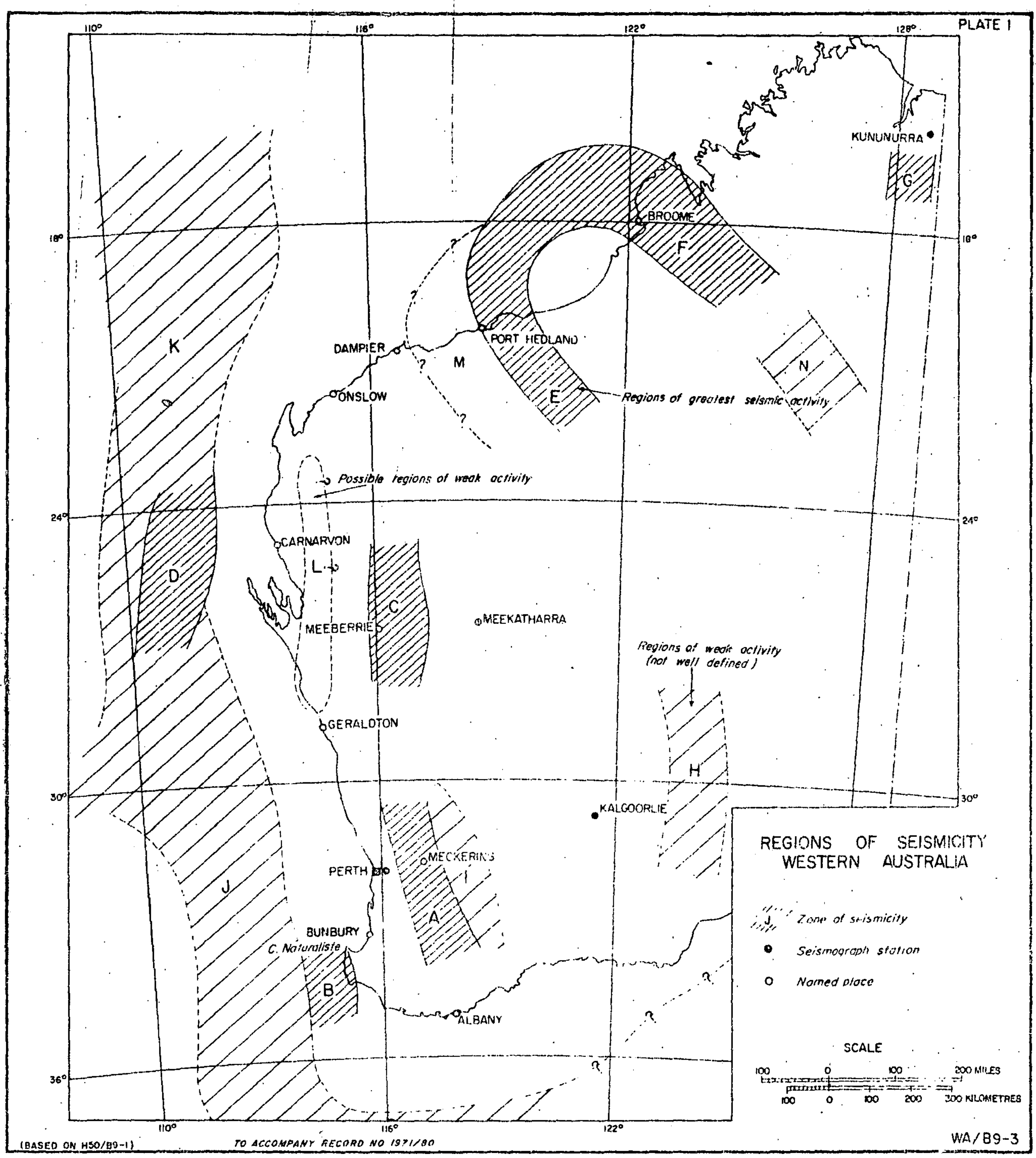
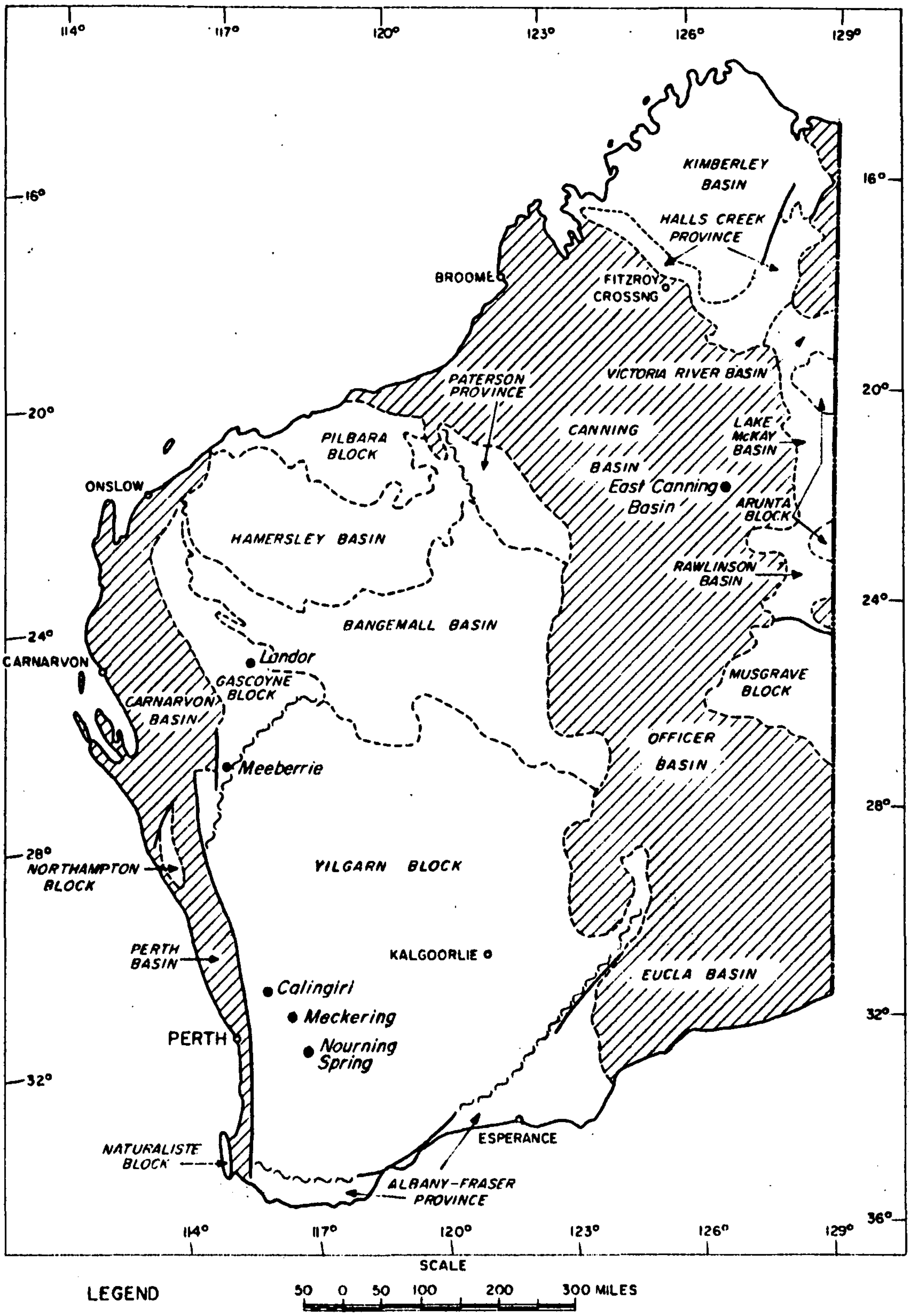


PLATE I
110°
116°
122°
128°
18°
24°
30°
36°
KUNUNURRA
G
BROOME
F
PORT HEDLAND
DAMPIER
M
E
N
K
ONSLOW
Regions of greatest seismic activity
Possible regions of weak activity
CARNARVON
L
D
C
MEEBERRIE
MEEKATHARRA
Regions of weak activity (not well defined)
GERALDTON
H
KALGOORLIE
MECKERING
PERTH
J
A
BUNBURY
C. Naturaliste
B
ALBANY
REGIONS OF SEISMICITY WESTERN AUSTRALIA
Zone of seismicity
Seismograph station
Named place
SCALE
100 0 100 200 MILES
100 0 100 200 300 KILOMETRES
(BASED ON H50/B9-1)
TO ACCOMPANY RECORD NO 1971/80
WA/B9-3

PLATE 2



LEGEND

Phanerozoic basins

Unconformity

Tectonic contact

Metamorphic or igneous contact

Epicentre

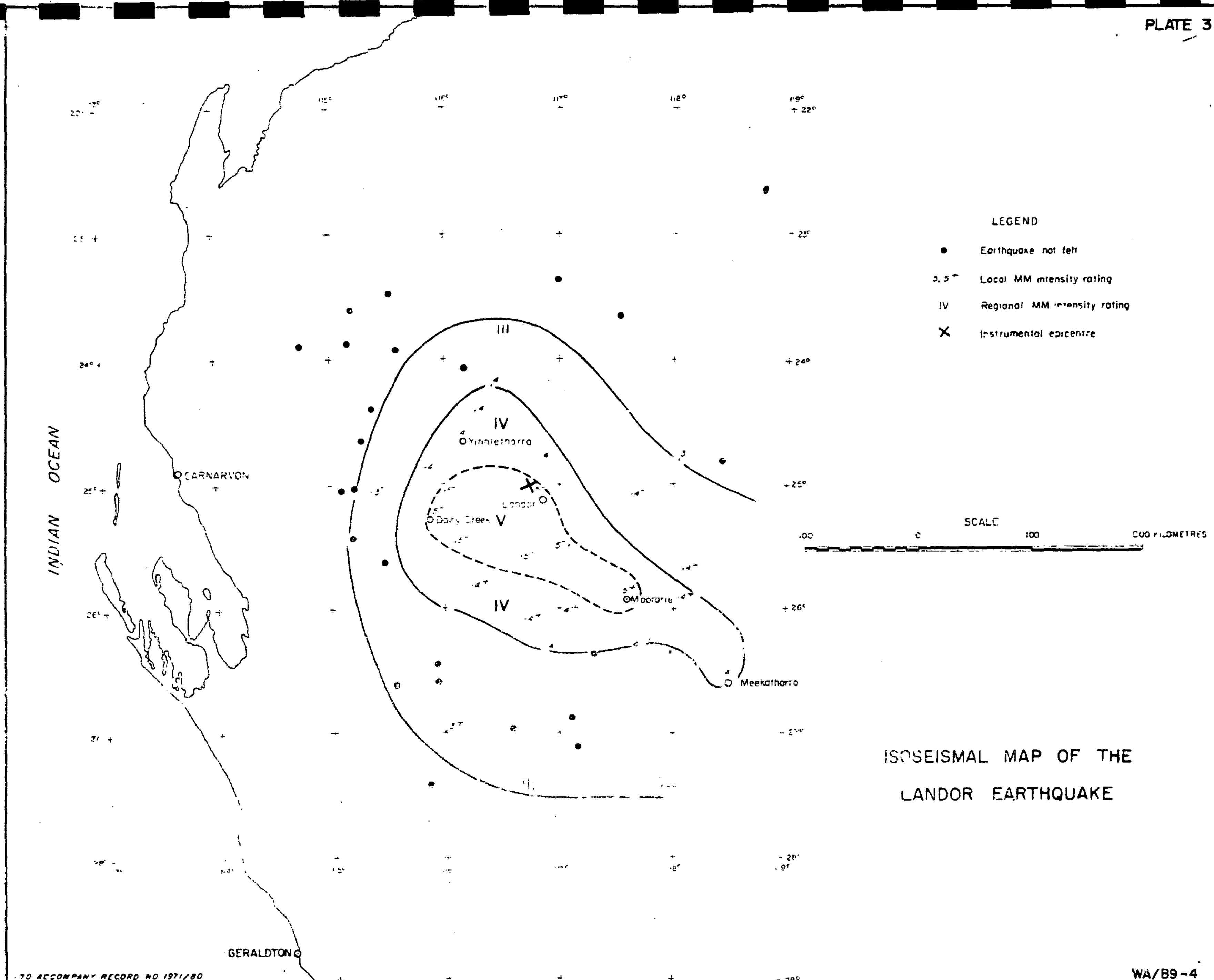
(Precambrian units after Daniels and Horwitz, 1968)

TECTONIC UNITS OF WESTERN AUSTRALIA

TO ACCOMPANY RECORD NO 1971/80

WA/B9-5A

PLATE 3

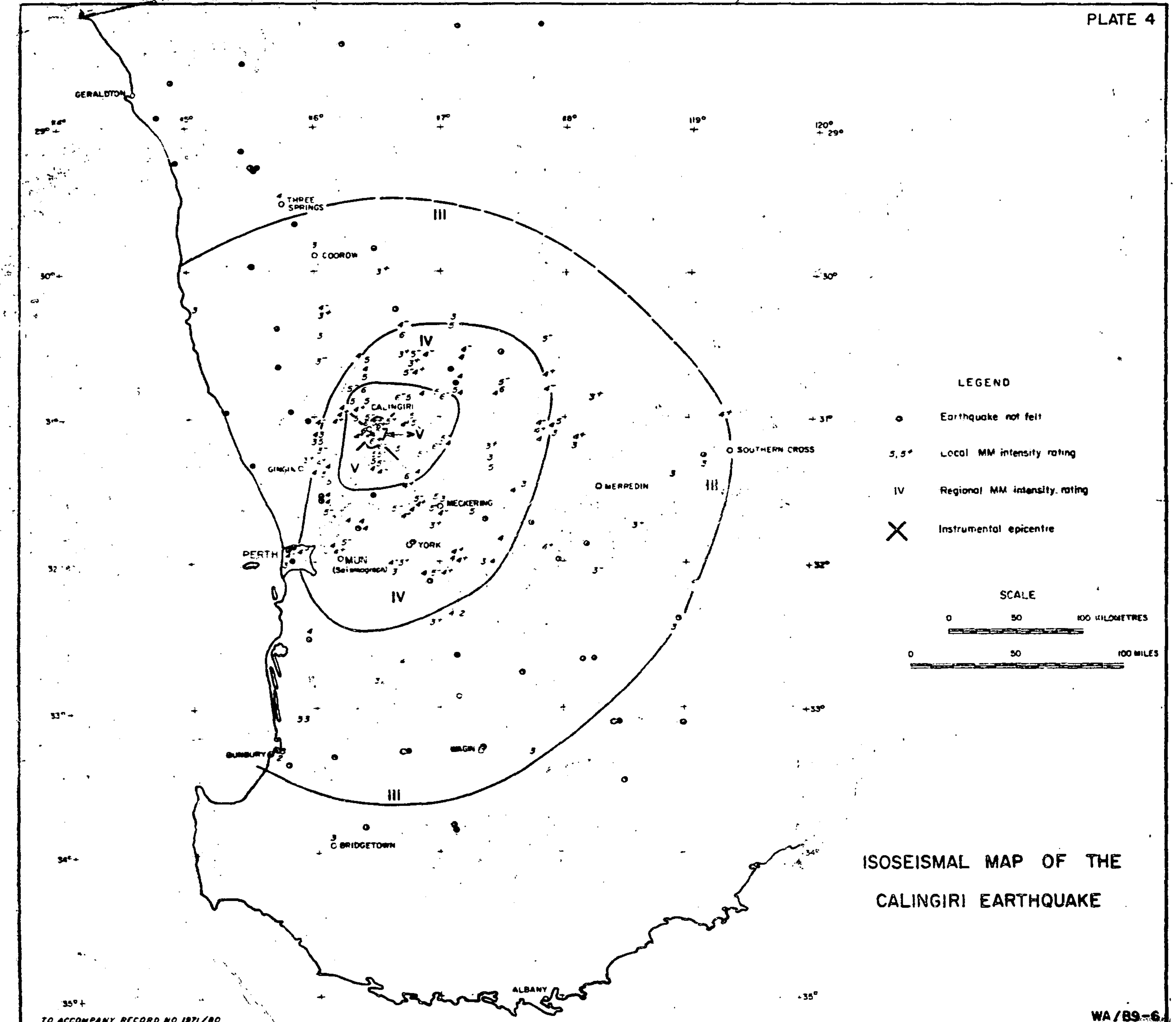


ISOSEISMAL MAP OF THE LANDOR EARTHQUAKE

TO ACCOMPANY RECORD NO 1971/80

WA/B9-4

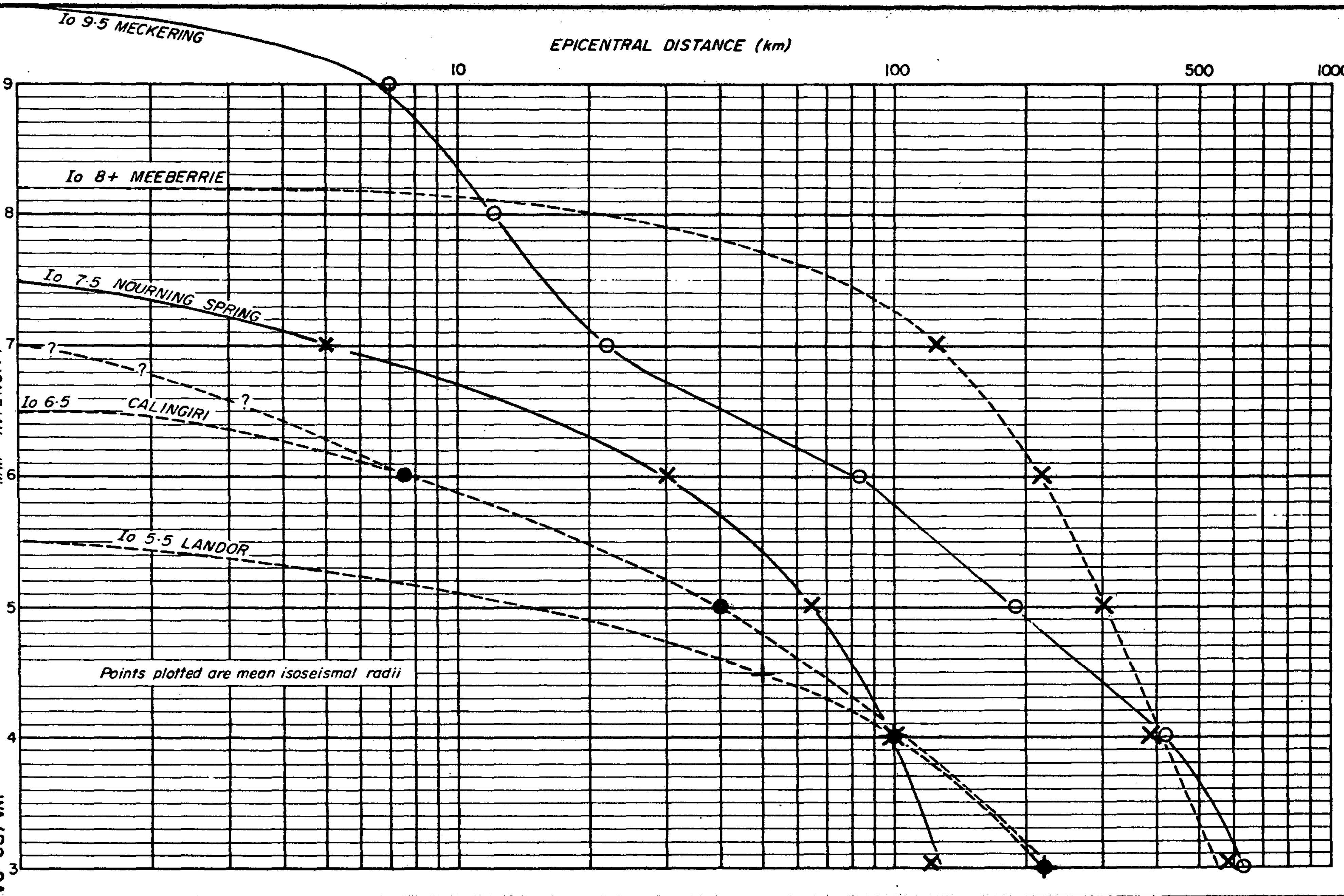
PLATE 4



ISOSEISMAL MAP OF THE CALINGIRI EARTHQUAKE

TO ACCOMPANY RECORD NO 1971/80

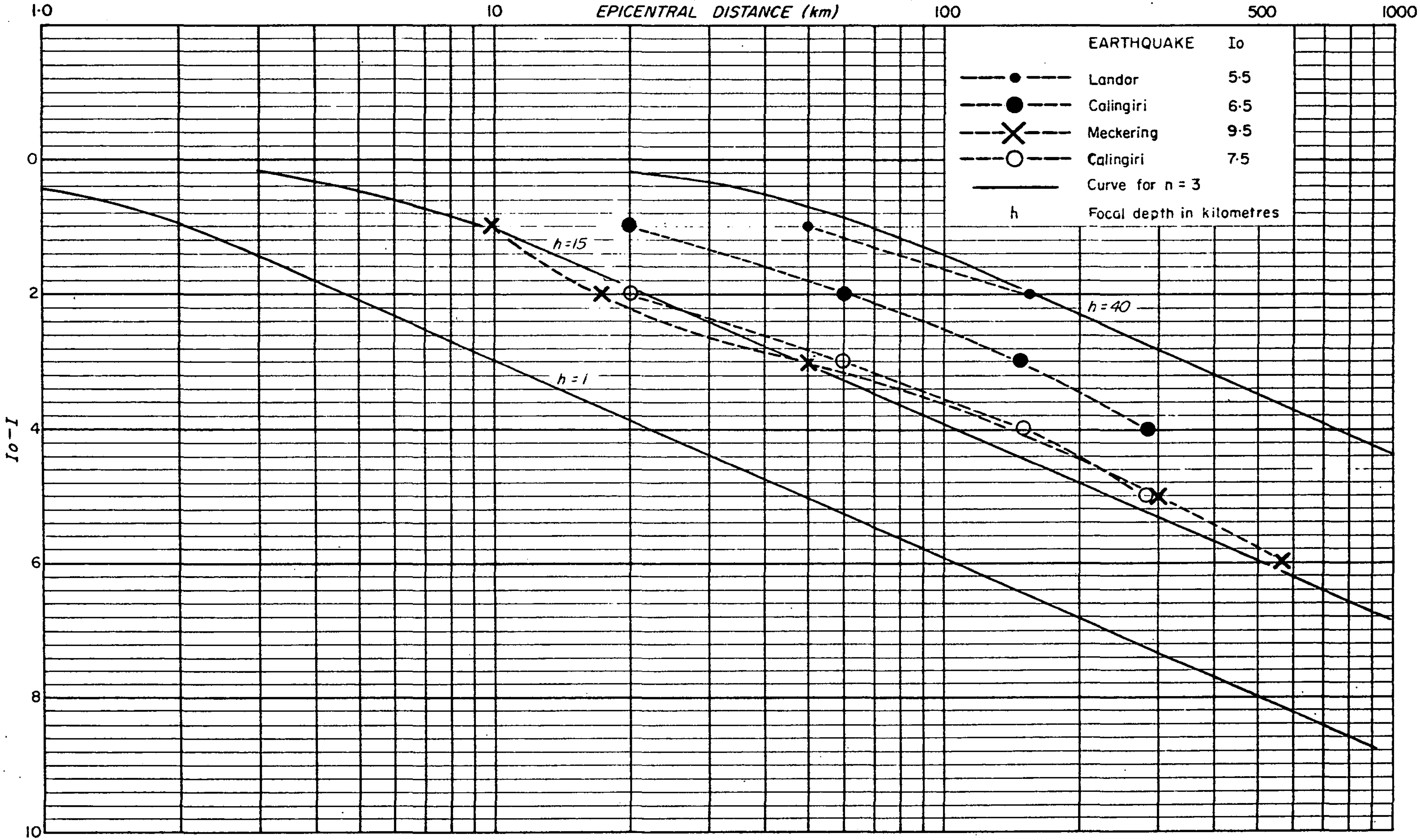
WA/B9-6



INTENSITY VERSUS DISTANCE
FOR WESTERN AUSTRALIAN EARTHQUAKES

PLATE 5

WA/B9-9A

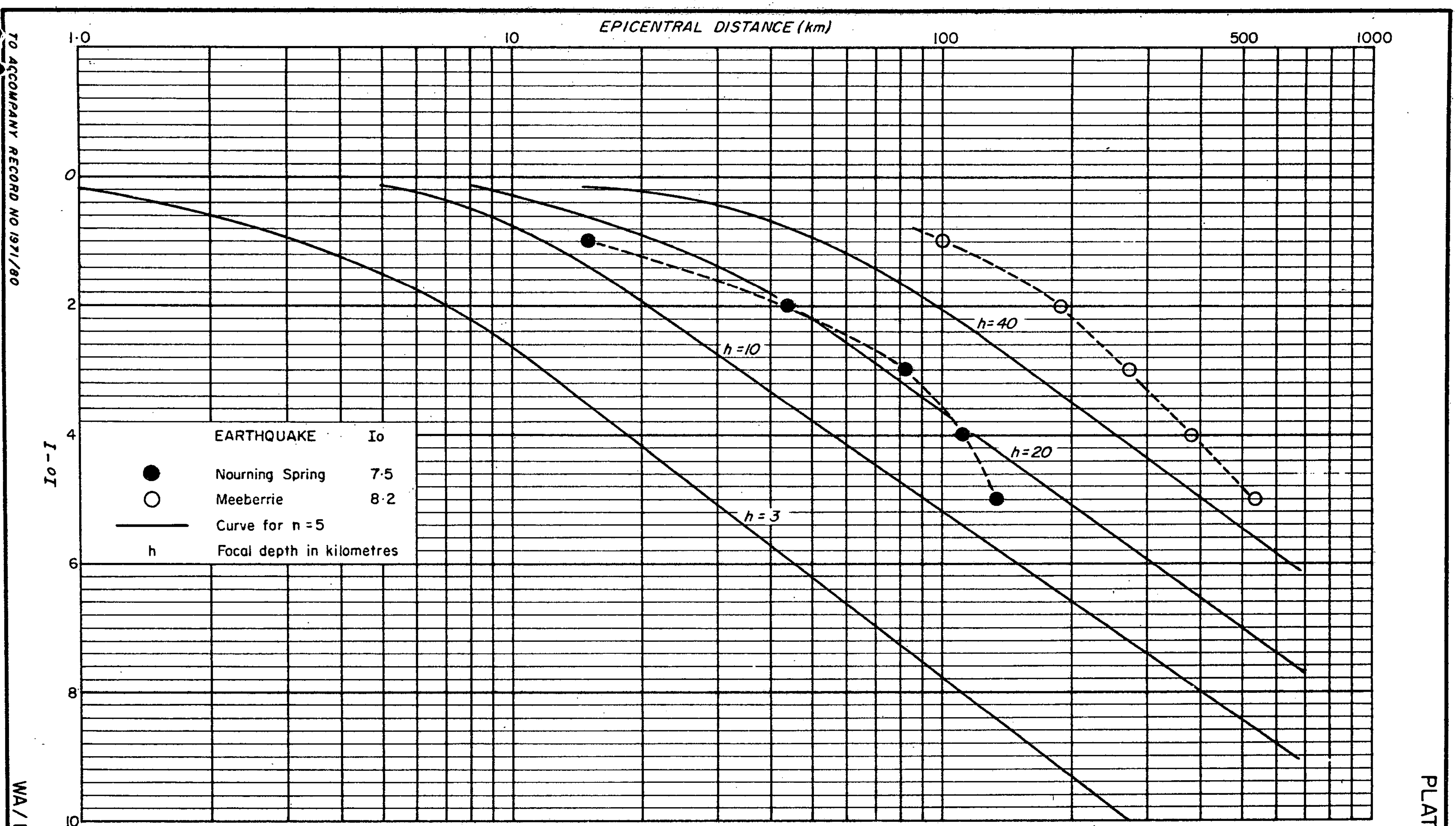


Io — I VERSUS EPICENTRAL DISTANCE

(Master-curves after Ergin 1969)

WA/B9-7A

PLATE 6a



Io − I VERSUS EPICENTRAL DISTANCE
(Master curves after Ergin 1969)