Report 294

Australian Seismological Report, 1986

Peter J. Gregson & Yvonne Moiler

Bureau of Mineral Resources, Geology and Geophysics

Department of Primary Industries and Energy

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

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ABSTRACT

Seismicity in the Australian region in 1986 was about average with 148 earthquakes of magnitude 3 or more being located. The largest earthquake, of magnitude Ms 5.8, occurred near Marryat Creek, SA, on 30 March and produced a 13 km long fault scarp with a maximun throw of 0.6 m. Three earthquakes exceeded ML 5 and 31 were ML 4 or greater. Isoseismal maps were drawn up for the Somerset Dam Qld, Augusta WA, Upper Colo NSW, Temma Tasmania, Marryat Creek SA, Ravensthorpe WA, Arthur River WA, Meckering WA and Kangaroo Island SA earthquakes. Accelerograms were recorded close to the foci of small earthquakes near Cadoux in southwest WA, Dalton NSW and Thomson Dam Victoria.

The nuclear monitoring group established by the BMR during 1984 continued to monitor underground nuclear explosions. During 1986 a total of 23 presumed underground nuclear explosions were detected, 15 by the USA and 8 by France. This compares with 30 in 1985. The USSR maintained a self-imposed moratorium on testing throughout the year.

INTRODUCTION

This report contains information on all earthquakes of Richter magnitude 3 or greater that were reported in the Australian region during 1986. It is the seventh in an annual series compiled by the Bureau of Mineral Resources, Geology & Geophysics (BMR), using data provided by various seismological agencies in Australia (Denham & Gregson, 1984, Denham & Gregson, 1985, Gregson & Denham, 1986, Gregson & Denham, 1987, McCue, 1988, and McCue 1989). Their purposes are to aid the study of seismic risk and provide background information for scientists and the general public.

The report comprises five main sections: 'Australian earthquakes', which contains a summary of the 1986 seismicity and brief descriptions of the more important earthquakes, 'Accelerograph data' contains the results of the accelerograph network, 'Network operations', gives details of the seismographs that operated in Australia during 1986, 'Principal world earthquakes, 1986' lists the largest and most damaging earthquakes that took place during 1986, and 'Monitoring nuclear explosions' describes the operation of the Nuclear Monitoring Group, BMR and lists underground nuclear tests.

In the report we refer to *magnitudes* of earthquakes and *intensities* caused by earthquakes. These terms are defined below.

Magnitudes

The magnitude (M) of an earthquake is a measure of its size, and is related to the energy (E) released at its focus. The magnitude scale is logarithmic, thus a magnitude 6 earthquake produces ground amplitudes 10 times as large, and an energy release about 30 times as large, as a magnitude 5 earthquake.

A rule of thumb relation between magnitude and energy (in joules) is

$$\log E = 4.8 + 1.5M$$

A shock of magnitude 2 is the smallest normally felt by humans, and earthquakes of magnitude 5 or more can cause major damage if they are shallow and close to buildings. The following magnitude scales are in common use.

Richter magnitude (ML)

This scale was defined by Richter (1958, 340)

$$ML = \log A - \log A_o$$

where A is the maximum trace amplitude (zero to peak) in millimetres on a standard Wood-Anderson seismogram and $\log A_o$ is a standard value given as a function of distance (0-600 km). Richter's reference earthquake of ML 3.0 produces a trace amplitude of 1 mm, 100 km from the epicentre.

If standard Wood-Anderson instruments (Anderson & Wood, 1925) are not available, an equivalent Richter magnitude can be determined by correcting for the differences in magnification (see Willmore, 1979, para. 3.1.1).

Surface-wave magnitude (Ms)

The surface-wave magnitude is normally applicable only to shallow earthquakes in the distance range 20-160°, and in the period range T = 20 ± 3 s. When these conditions hold, Ms values are calculated from the IASPEI (1967) formula (McGregor & Ripper, 1976)

$$Ms = \log \frac{A}{T} + 1.66 \log \Delta + 3.3$$

where A is the ground amplitude in micrometres, T is the period in seconds, and Δ the epicentral distance in degrees (see Båth, 1981).

Body-wave magnitude (mb)

The body wave magnitude scale was developed for earthquakes beyond the range of ML and deep enough or small enough that no significant surface waves were produced. The scale is a poor measure of energy release or seismic moment above magnitude 6.5.

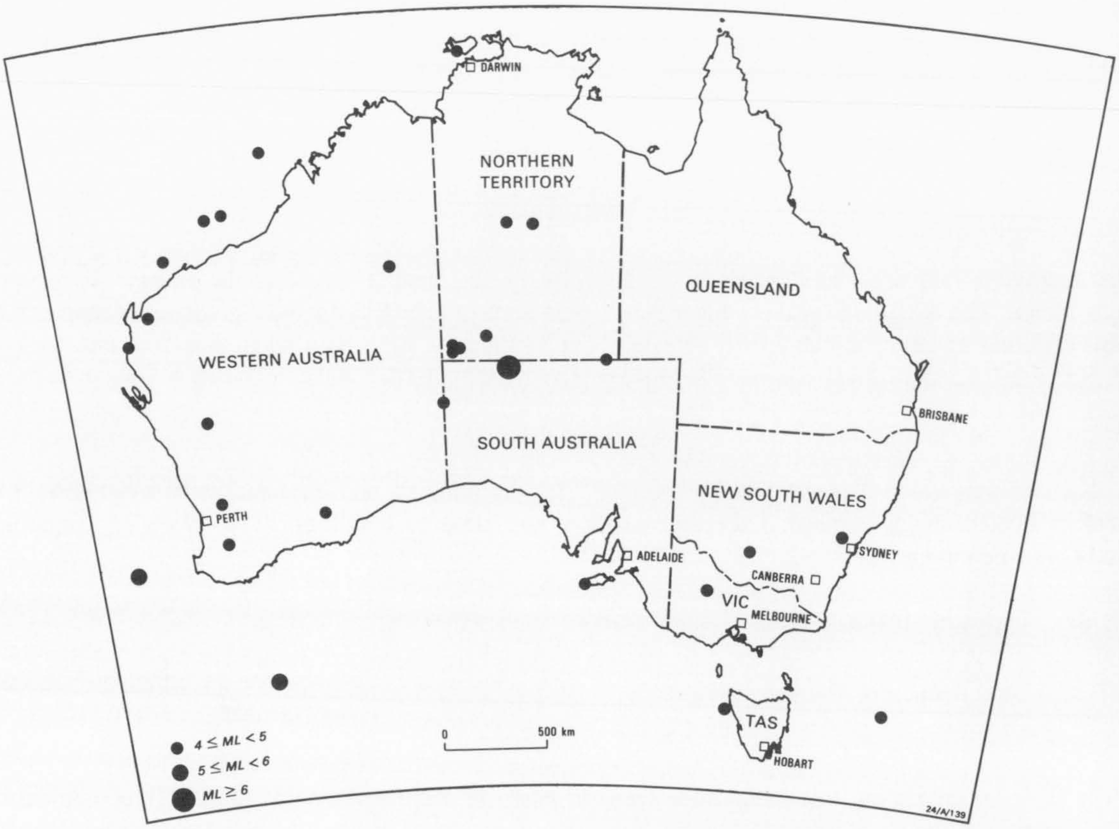

Fig. 1. Australian region earthquakes, magnitude 4 or greater, 1986

The equation derived by Gutenberg (1945) is given by

$$mb = \log \frac{A}{T} + Q\ (\Delta, h)$$

where A is the maximum mean-to-peak ground amplitude in microns of the P, PP, or S-wave trains, T the corresponding wave-period (seconds), and Q (Δ, h) a depth/distance factor (Richter, 1958, 688-9).

Duration magnitude (MD)

This scale is equivalent to ML and is related to the duration (t) of the seismogram coda measured in seconds from the P arrival

$$MD = a \log t + b\,\Delta + c$$

where Δ is the epicentral distance, and a, b, and c are constants for a particular recording station.

Seismic moment magnitude (Mw)

This magnitude scale was proposed by Kanamori (1978)

$$Mw = \frac{\log M_o}{1.5} - 6.0$$

where M_o is the seismic moment (in Nm) and defined as

$$Mo = \mu\, AD$$

where μ is the rigidity, A the surface area displaced, and D the average displacement on that surface.

Magnitude from isoseismals

In some cases where reliable magnitudes cannot be determined instrumentally (from seismograms), it is possible to calculate magnitudes from macroseismic data, using McCue's (1980) formula

$$M(Rp) = 1.01\ ln(Rp) + 0.13$$

where Rp is the radius of perceptibility (in kilometres) of the MM(III) isoseismal. M(Rp) is equivalent to ML below magnitude 6 and Ms at magnitude 6 and above. Magnitudes found by this method should be treated as approximate only, and may be revised as a result of further research. Further information on magnitudes is available in McGregor & Ripper (1976), Båth (1981), and Denham (1982).

Intensity

The intensity of an earthquake is determined from its effects on people, buildings, and the Earth's surface. In this report we use the Modified Mercalli scale (MM) as presented by Eiby (1966) for New Zealand conditions and listed in the Appendix. The MM scale is essentially an assessment of how severely the earthquake was felt and what damage was caused at a particular place. Some earthquakes are large enough to be felt over a wide area, and an isoseismal map can then be prepared. These maps indicate in detail the extent of the shaking. They are prepared mainly from information compiled from questionnaire canvasses, newspaper reports, and personal interviews and inspections. Isoseismal maps for many pre-1984 earthquakes have been collated in Everingham & others (1982) and Rynn & others (1987). A third atlas is in preparation (McCue, in prep.).

(DAVID DENHAM, PETER GREGSON & KEVIN McCUE)

AUSTRALIAN REGION EARTHQUAKES, 1986

Table 1 lists the parameters of all 148 earthquakes of ML 3.0 or greater that were detected in the Australian region in 1986. The largest occurred on the 30 March at Marryat Creek, SA. It had a magnitude of ML 6.0. Three earthquakes of ML 5 or greater and 31 of ML 4 or greater were recorded during the year. This compares with the annual average of 3.7 for ML 5 or greater earthquakes since 1960 and 23 for ML 4 or greater earthquakes since 1980. For these periods all earthquakes in the stated magnitude ranges should have been recorded.

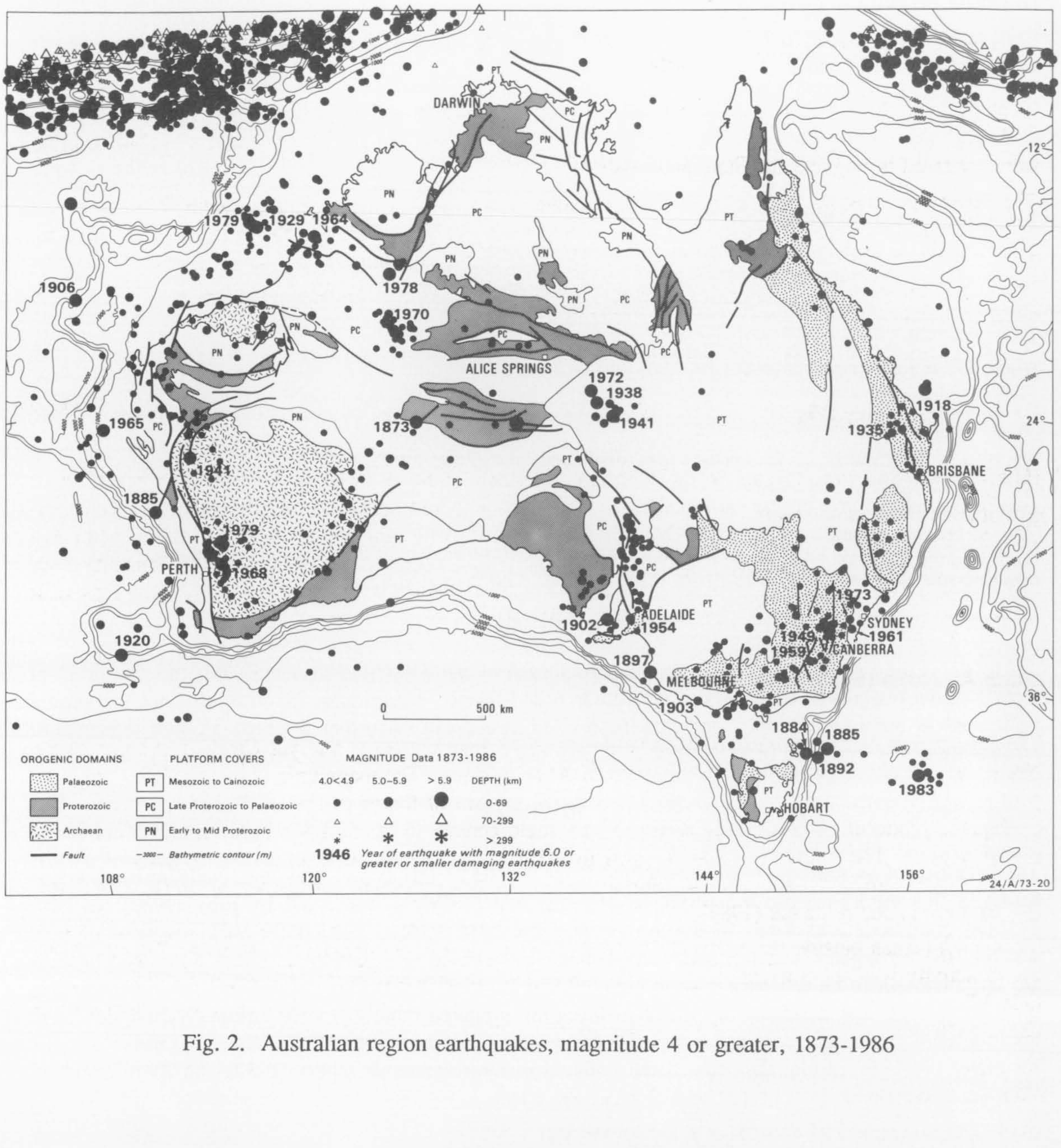

Fig. 2. Australian region earthquakes, magnitude 4 or greater, 1873-1986

Figure 1 shows earthquakes of magnitude ML 4 or greater in the Australian region during 1986. Figure 2 shows the epicentres of earthquakes for magnitude 4 or greater for the period 1873-1986. Earthquakes of magnitude ML 6 or greater in the period 1873-1986 are listed in Table 2.

For a comparison of seismic activity by State, epicentres of earthquakes exceeding ML 2.4 are plotted in Figures 3 to 5 and 7 to 10, though coverage down to this magnitude is probably complete only in Tasmania, Victoria, southeastern New South Wales and the Australian Capital Territory, southwestern Western Australia and southeastern South Australia.

Western Australia (Fig. 3)

Western Australia continued to be one of the most seismically active States. Two of the four earthquakes of magnitude ML 5 or more occurred off the southwest coast. Eleven others of ML 4 or more were scattered throughout the State and offshore.

The Southwest Seismic Zone east of Perth remained one of the most active areas with 80 earthquakes of magnitude ML 2 or greater located. The level of activity was similar to that of 1985. The Cadoux region was the most active area as it has been since the 1979 earthquake of magnitude ML 6.2 (Gregson & others, 1979). The rest of the activity was spread throughout the zone from Denmark in the south to Wongan Hills in the north and Merredin in the east.

Thirty-four earthquakes were located offshore, most within the 200 m isobath.

Northern Territory (Fig. 4)

Fifteen epicentres were located in the Northern Territory, eight of which had magnitudes of ML 4 or greater. All but three of the earthquakes were widely scattered across the southwest of the Territory. The largest earthquake, magnitude ML 4.5, occurred on 17 August on Melville Island, 100 km northwest of Darwin. Two earthquakes of magnitude ML 4 occurred within 100 km of Tennant Creek to the west. Some of the earthquakes in the southwest may be in the same zone as the Marryat Creek earthquake in South Australia (see below).

South Australia (Fig. 5)

The largest Australian earthquake to occur during 1986 was located at Marryat Creek, just south of the Northern Territory border and 500 km south of Alice Springs. The magnitude (Ms) was 5.8. Only one poorly located earthquake has been recorded within 100 km of the epicentre in the past 30 years. The earthquake produced a 13 km long arcuate thrust fault, convex to the northwest with a maximum throw of 0.6 metres. The fault scarp was mapped by AISLIG and is shown in Figure 6. Details of a fault plane solution are given in Table 4. Further details of the earthquake are given by Barlow & others (1986) and McCue & others (1987).

Most earthquakes outside the Marryat Creek area occurred in the Adelaide Geosyncline Seismic Zone, where activity was about average. No earthquakes were located within 200 km of Adelaide. A magnitude ML 4.6 earthquake occurred on 16 December, located 30 km offshore from the western end of Kangaroo Island. It was strongly felt underground at Kelly Hill caves (Figure 19).

Victoria (Fig. 7)

Only one earthquake exceeded magnitude 3.9 in Victoria, on 24 April, in the northwest of the State. Activity was about average for Victoria in 1986 and most was in the Highlands northeast of Melbourne. No earthquake warranted distribution of intensity questionnaires.

New South Wales (Fig. 8)

All the larger earthquakes in NSW were in the southeastern part of the State except for a single small event in the extreme northwest. The largest earthquake during the year, near Upper Colo on 20 February, was felt throughout the Sydney metropolitan area. The intensity in the epicentral area did not exceed MMIV and there was no structural damage. Within a few days of the earthquake, water was

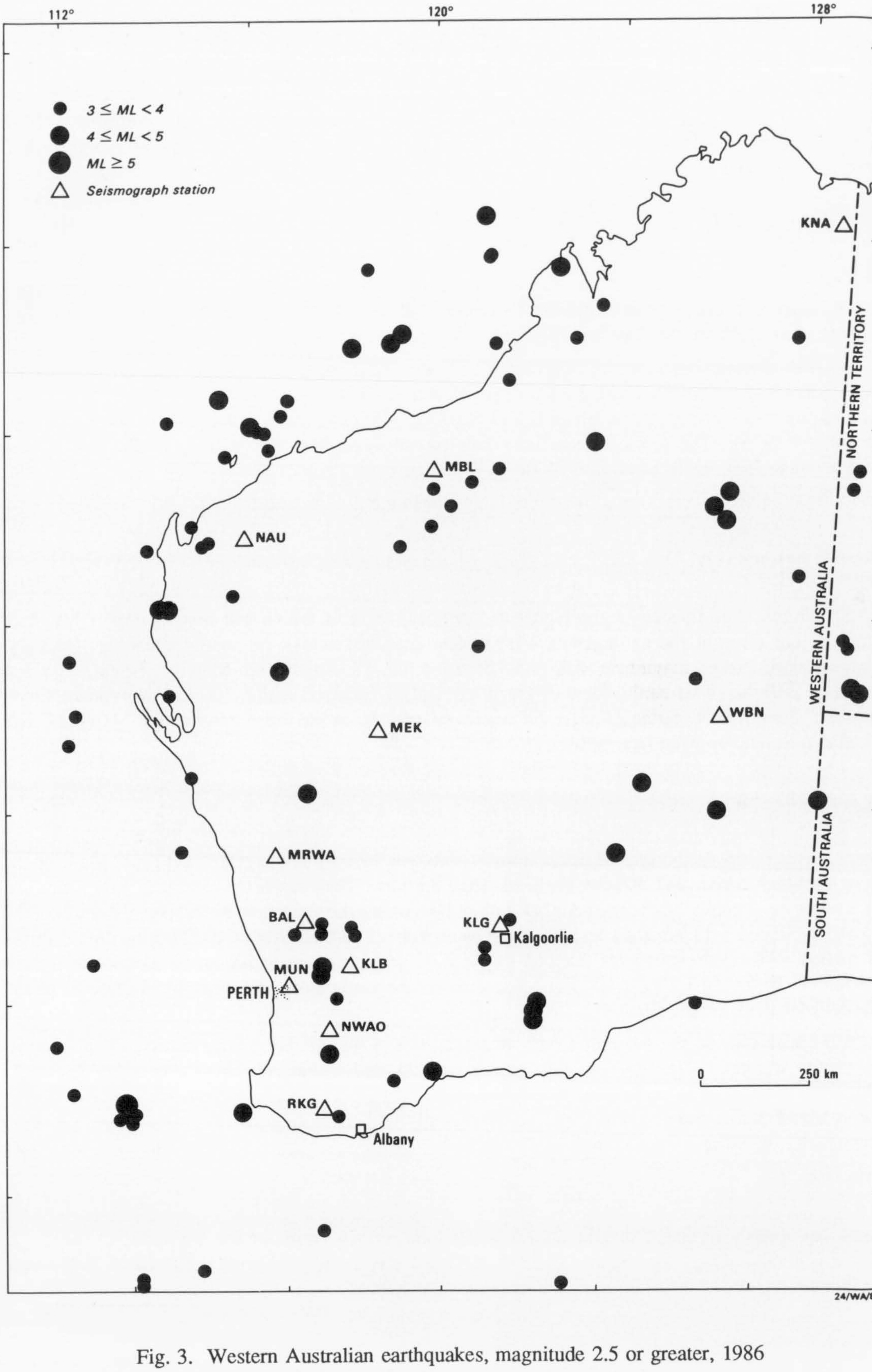

Fig. 3. Western Australian earthquakes, magnitude 2.5 or greater, 1986

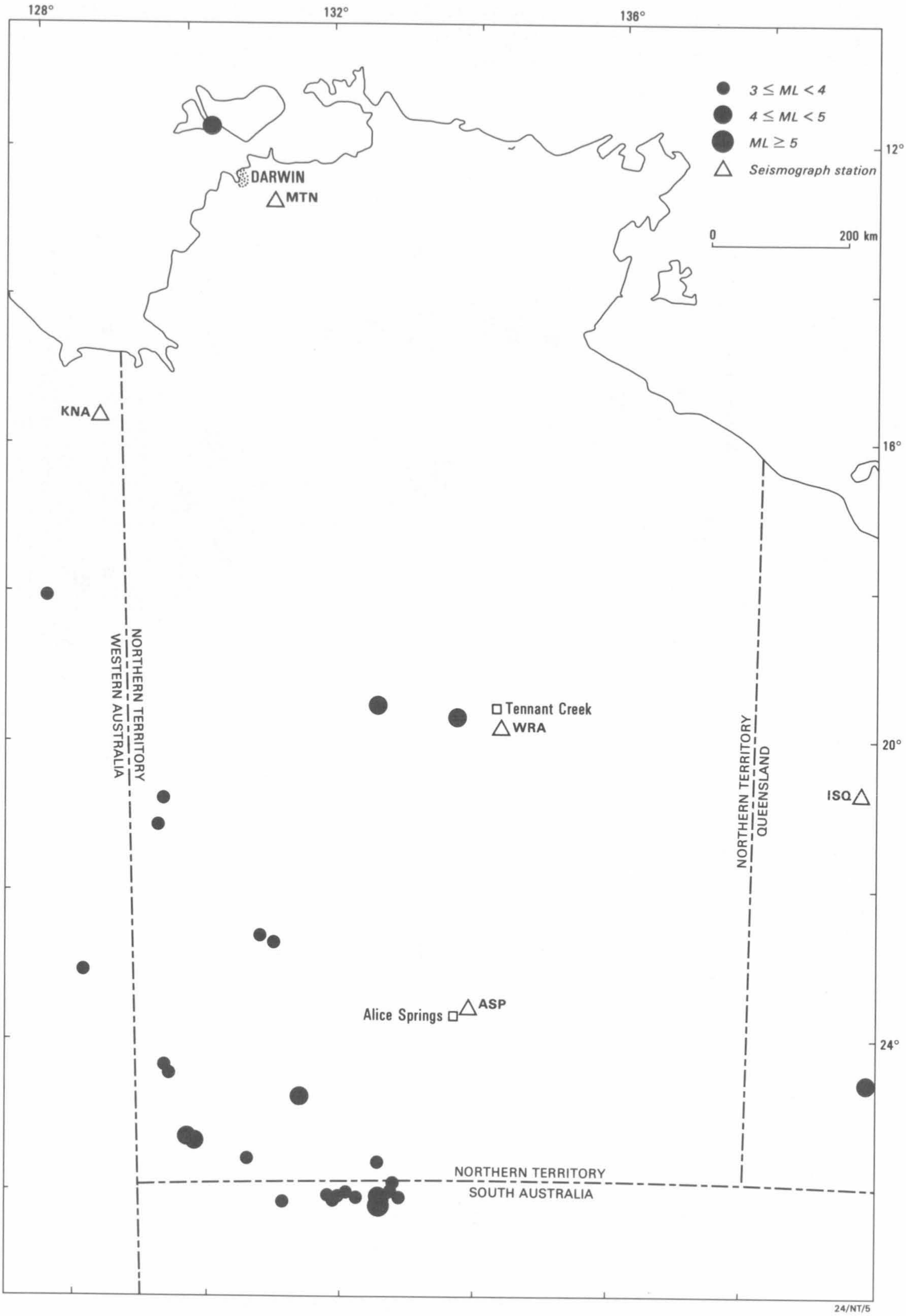

Fig. 4. Northern Territory earthquakes, magnitude 2.5 or greater, 1986 6

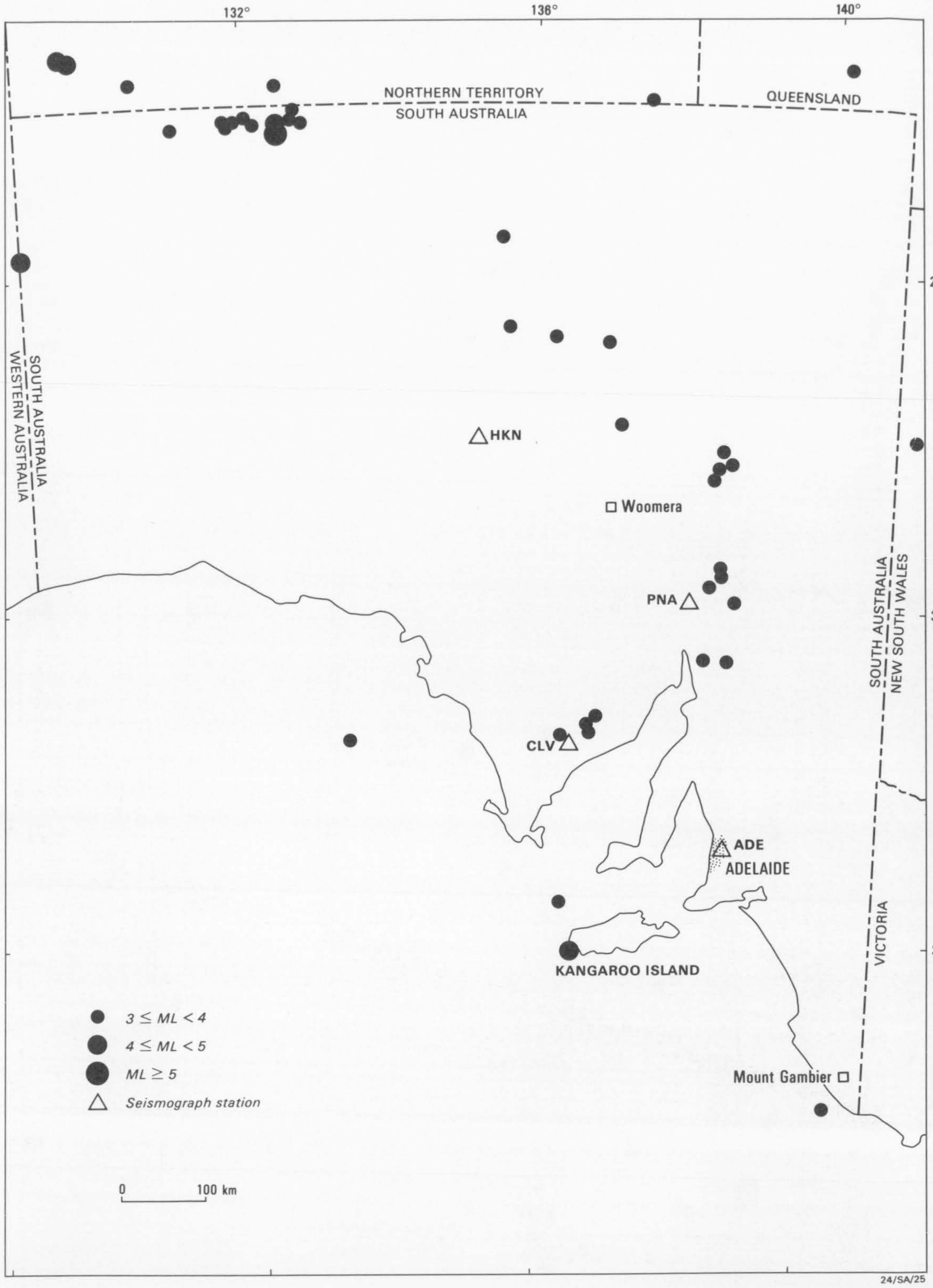

Fig. 5. South Australian earthquakes, magnitude 2.5 or greater, 1986

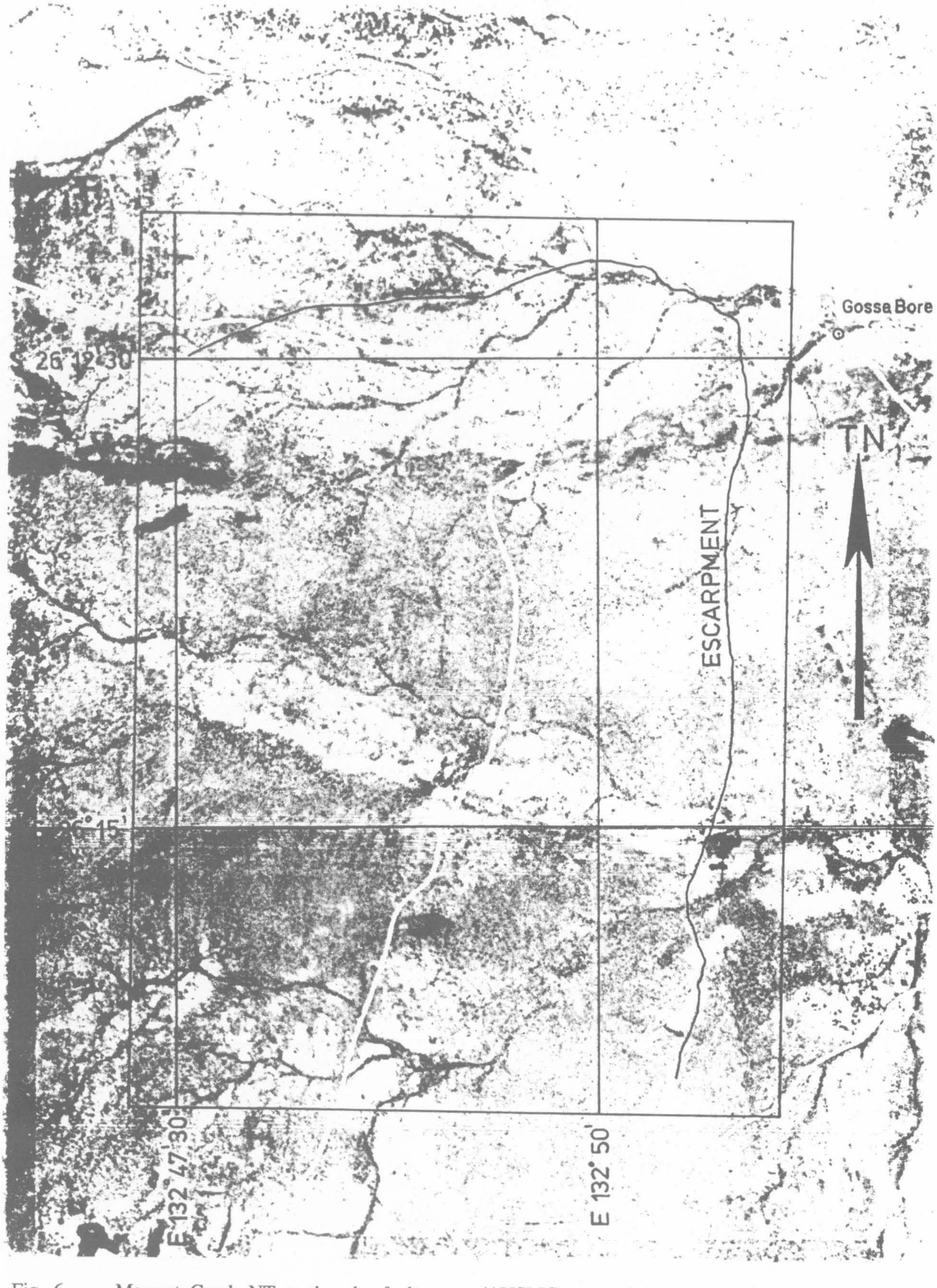

Fig. 6. Marryat Creek NT earthquake fault scarp (AUSLIG mapped the scarp and provided the figure which is reproduced with permission)

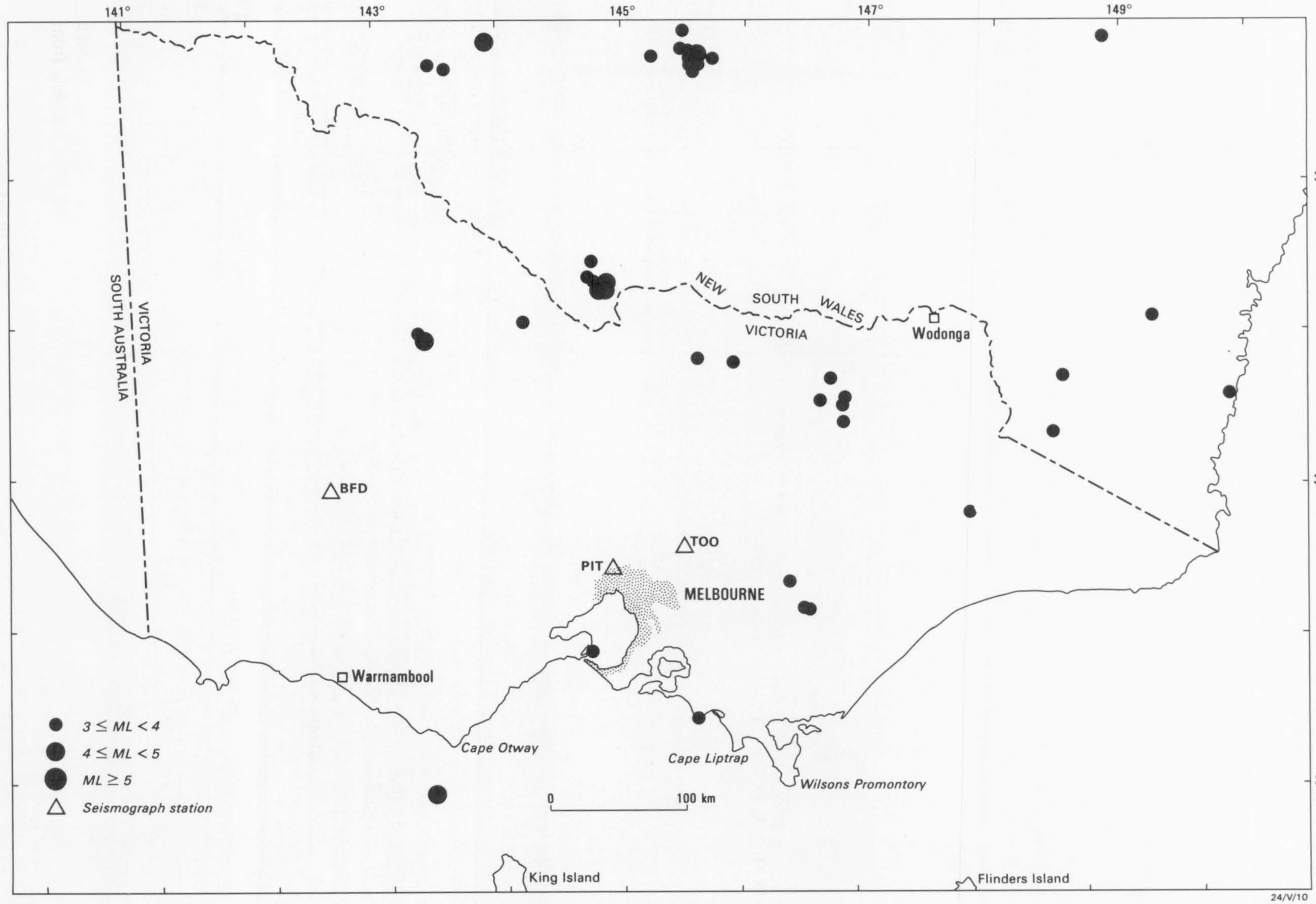

Fig. 7. Victorian earthquakes, magnitude 2.5 or greater, 1986

observed emerging from an old investigation drill hole below the embankment of Windamere Dam near Mudgee. This is attributed to shaking during the earthquake causing some foundation settlement in a highly fractured, fine grained conglomerate underlying the dam.

There were three swarms of earthquakes in NSW, in southeastern NSW north of Echuca on the Murray River in April and June/July, the other north of Hay on 22 September. All the events were magnitude 3.0 to 4.0 (Table 1) and in neither case did a mainshock or significantly larger earthquake occur.

The largest earthquake in the Dalton/Gunning region occurred on 7 January, it had a magnitude of ML 3.1 which is the modal magnitude for that area.

Tasmania (Fig. 9)

Only three earthquakes were recorded in Tasmania as well as one off the east coast of King Island. The largest, magnitude ML 4.1, was located 10 km offshore from Temma, on the west coast. This was the largest Tasmanian earthquake in the 1980s compared with the expected 10 year earthquake of magnitude 4.7. It was felt widely enough that an isoseismal map could be drawn (Fig. 14).

Queensland (Fig. 10)

Activity in Queensland was similar to that of 1985. Five earthquakes of magnitude greater than 2.5 were located. The two largest were magnitude 3.2 on 8 January and 27 June. An isoseismal map for the former is referred to below (Fig. 11).

(KEVIN McCUE, PETER GREGSON & GARY GIBSON)

ISOSEISMAL MAPS

Isoseismal maps based on the Modified Mercalli scale were prepared for nine earthquakes, four in Western Australia, two in South Australia and one each in Queensland, New South Wales and Tasmania.

Somerset Dam, Queensland (Fig. 11)

An earthquake of magnitude ML 3.2 occurred at 19:55 local time (09:55 UTC) on 8 January near Somerset Dam in southeastern Queensland. The earthquake occurred only 5 km from a seismograph in the Wivenhoe Dam network. Six more seismographs within 55 km ensured an accurate location.

Staff of the Queensland Department of Mines conducted an isoseismal survey of the affected area two days after the event. Over 70 intensity reports were used to draw the isoseismal map, which indicates a radius of perceptibility of 20 km. There were some unconfirmed reports of damage to buildings.

Two aftershocks (ML 1.0 and -0.6) occurred within two days of the main shock, the larger of which was felt by some residents of Somerset Dam. Another (ML 0.2) occurred on 28 January.

Augusta, WA (Fig. 12)

Residents in the southwestern corner of Western Australia experienced a magnitude ML 3.8 earthquake on 15 January at 06:11 (22:11 UTC). The epicentre was 24 km southwest of Augusta (Gregson, in prep.)

The isoseismal map was prepared from about 50 questionnaires. The response from the northeast of Augusta was not good, probably due to the relatively low population and the early hour of the morning. The maximum intensity experienced was MM V at Karridale, 30 km from the epicentre. Intensity MM IV was experienced within a radius of 40 km, and the earthquake was felt at Busselton, 100 km from the epicentre.

Several other earthquakes that have occurred in the area and have been felt are listed below. All except the 1978 earthquake occurred offshore in two areas, one about 300 km west of the coast and the second about 70 km west near the 200 m bathymetric line. The earthquake of 15 January 1986 was in neither area and was the closest ever recorded to the coast.

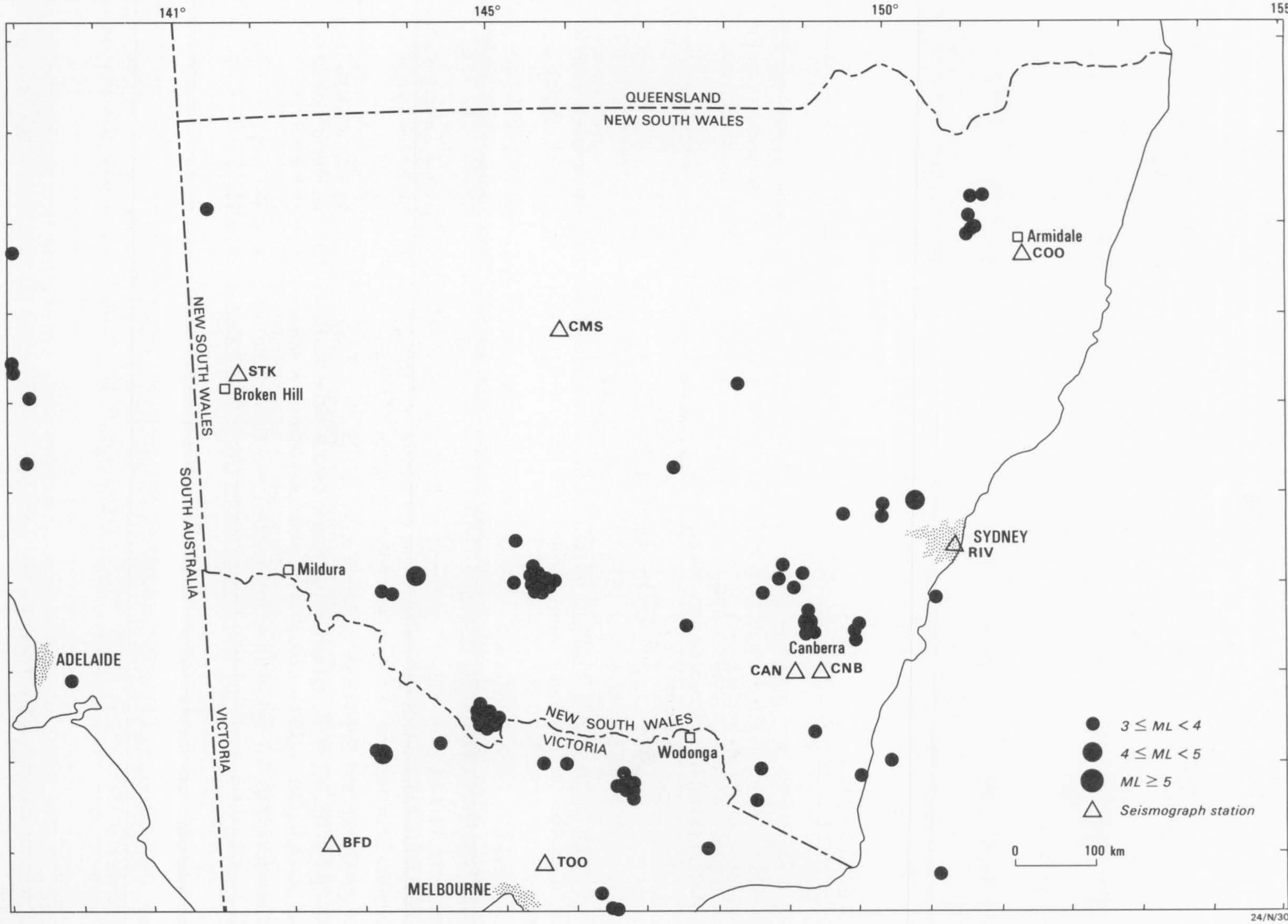

Fig. 8. New South Wales and ACT earthquakes, magnitude 2.5 or greater, 1986

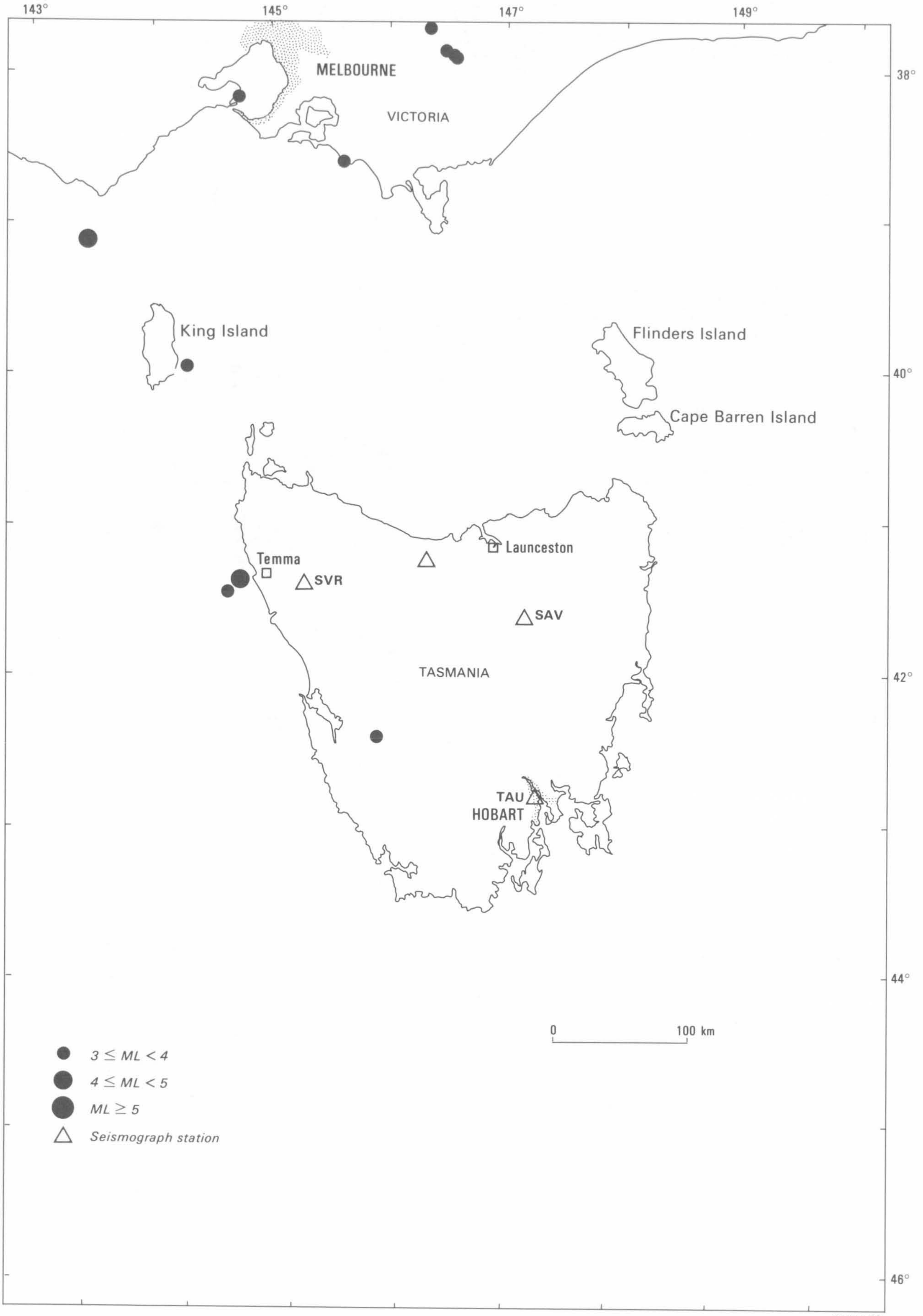

Fig. 9. Tasmanian earthquakes, magnitude 2.5 or greater, 1986

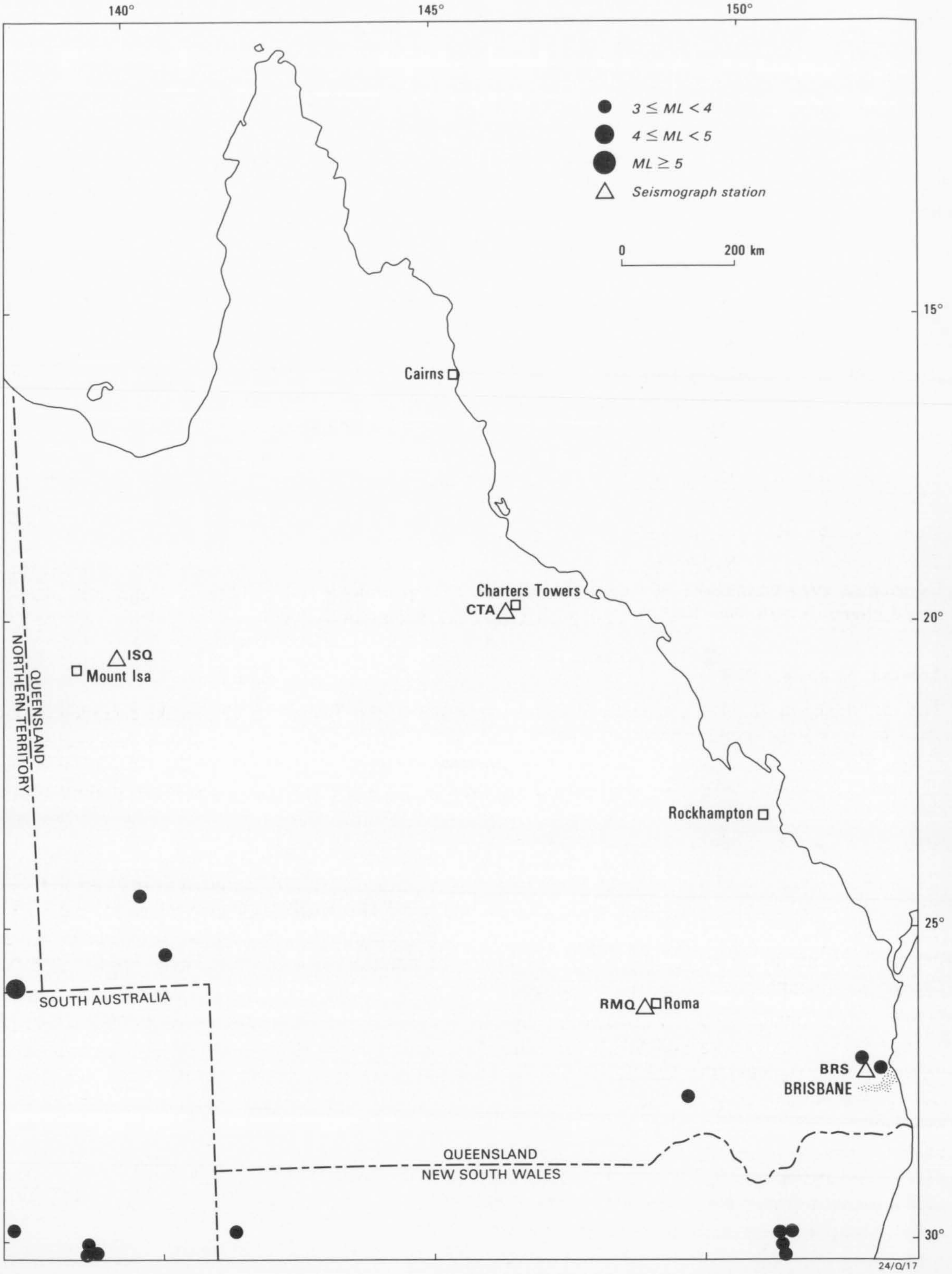

Fig. 10. Queensland earthquakes, magnitude 2.5 or greater, 1986

Earthquakes that were felt in the Augusta area, WA

1920 Feb 8	0524UTC	35 S	111 E	Ms 6.2	(Everingham, 1968)
1946 Apr 19	2113UTC	33.5 S	114.5E	ML 5.7	Felt at Yallingup and Busselton (Everingham & Tilbury, 1972)
1959 Oct 3	1207UTC	34.5 S	114.5 E	ML 4.2	Felt Busselton, Yallingup, Margaret River, Bunbury, C. Naturaliste and C. Leeuwin (Everingham, 1968)
1961 Jun 12	1800UTC	3.2 S	114.5 E	ML 4.1	Felt (Everingham, 1968)
1978 Jun 9	1231UTC	33.93 S	115.20 E	ML 3.0	Isoseismal map prepared (Everingham & others, 1982)

Upper Colo, NSW (Fig. 13)

On the morning of 21 February at 8:44 local time (21:44 UTC on 20 Feb) an earthquake occurred which was felt widely throughout the Sydney region. The magnitude of the earthquake was 4.0 on the Richter scale. Its epicentre was about 30 km northwest of Richmond, or about 90 km northwest of the Sydney GPO. There were no reports of damage. The earthquake was felt over an area of approximately 25 000 km ^{2}, from the central coast to Wollongong, and from the eastern suburbs of Sydney to Mudgee in the west. Typical effects were a rumbling and shaking of windows and doors which were quite severe in the epicentral region.

The area northwest of Sydney has not been particularly seismically active in recorded history apart from the August 1919 earthquake of magnitude ML 4.6 near Kurrajong and a shock of magnitude ML 4.3 near Lithgow in February 1985, both of which were felt widely in Sydney.

Temma, Tasmania (Fig. 14)

The earthquake of 16 March, magnitude ML 4.1, was the largest Tasmanian earthquake recorded during the 1980's. It caused minor non-structural damage at Temma on the northwest coast and was felt at Queenstown and Devonport, 200 km away. Staff at the Geology Department, University of Tasmania, distributed the questionnaires which were used by McCue (in prep.) to draw up the isoseismal map.

Marryat Creek, SA (Fig. 15)

On 30 March at 08:54 UTC (18:24 local time) a large earthquake (Ms 5.8) occurred near Marryat Creek by De Rose Hill in the Musgrave Ranges, South Australia. The main shock was followed in the next seven days by five aftershocks which were large enough (magnitude greater than 3) to enable instrumental locations to be made (Table 1). A further 12 unlocatable aftershocks were recorded at the closest seismographic station, at Alice Springs.

Intensity questionnaires were distributed by Flinders University to homesteads and post offices covering a large area of the centre and South Australia (Barlow & others, 1986). Of the 227 questionnaires returned, 88% reported that the earthquake was not felt. Because of the sparsity of the population, damage was minor, being confined to cracked walls in the nearest homesteads at De Rose Hill and Victory Downs. The maximum intensity was MM VI. Several localities, as far away as 150 km, reported effects consistent with intensity MM V. Minor shaking was reported at Alice Springs, 300 km to the north, and Cooper Pedy, 350 km to the south, although towns such as Oodnadatta which were closer to the epicentre experienced no felt effects. There were isolated reports of the earthquake being felt (MM II/III) from places as distant as Olary and Quorn.

Ravensthorpe, WA (Fig. 16)

At 22:57 (14:57 UTC) on 17 May, a small earthquake of magnitude ML 3.5 occurred 21 km southwest of Ravensthorpe near the south coast of Western Australia (Gregson, in prep.)

The majority of the population in the area is almost entirely confined to the two towns Ravensthorpe and Hopetoun with farms mostly along the highway east and west of Ravensthorpe. Questionnaires distributed through the local high school, supplemented by information obtained through phone calls were used to prepare the isoseismal map.

The maximum intensity reported was MM V at Hopetoun with the boundary between MM III and IV along the east-west highway about 15 to 30 km from the epicentre.

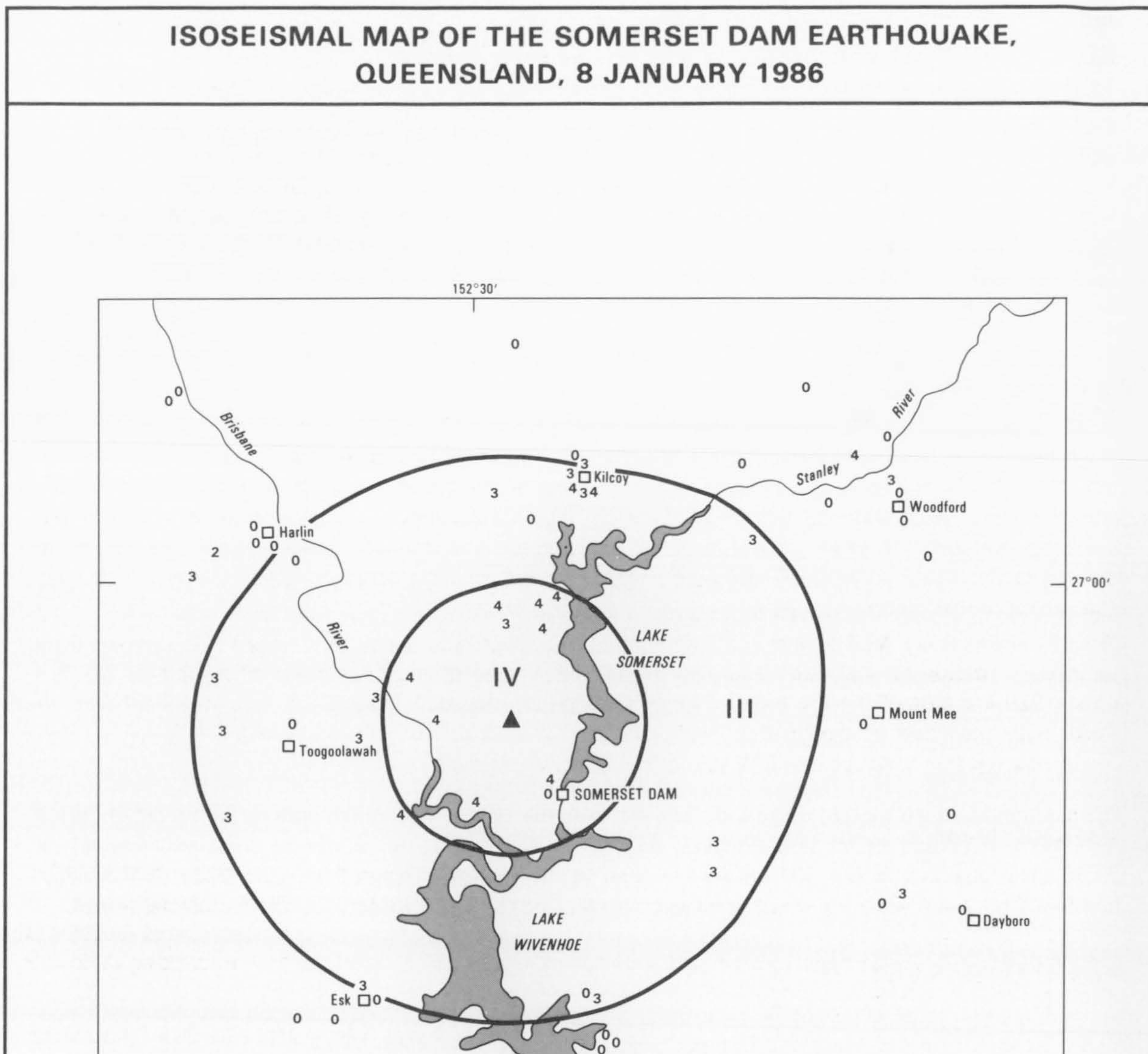

Fig. 11. Isoseismal map, Somerset Dam earthquake, Queensland, 8 January 1986

Arthur River, WA (Fig. 17)

At 12:41 UTC (20:41 local time) on 17 May, an earthquake of magnitude ML 4.2 occurred near Wagin, 200 km south-east of Perth in the South-West Seismic Zone of Western Australia (Gregson, in prep.)

Earthquake questionnaire forms were distributed over an area bounded by Narrogin, Darkan, Kojonup and Dumbleyung. An officer from the observatory then visited the area 10 days after the event, and interviewed approximately 50 families in 2 days. In almost all cases, a significant noise was reported with the tremor, and in about half of those cases people reported hearing it although they could not recall feeling the tremors. Descriptions likened it to an explosion or thunderclap in localities near the epicentre, and to rumbling like a truck or a roar from a chimney in other localities.

Small pockets of intensity MM V were experienced near the epicentre; the MM V isoseismal was about 25 km in radius. The earthquake was felt up to 70 km from the epicentre.

Meckering, WA (Fig. 18)

At 21:54 WST (13:54 UTC) on 1 September, an earthquake of magnitude ML 4.1 occurred 5 km east-southeast of Meckering in Western Australia. It was the most severe earthquake in the area since 29 October 1976, and frightened many residents who recalled the magnitude ML 6.9 of 14 October 1968 (Everingham & others, 1982).

The earthquake was felt over 70 000 km ^{2}. The maximum intensity reported was MM VI near Meckering in the vicinity of the epicentre. Plaster cracked and small objects fell from shelves. Effects consistent with intensity MM 5 were reported up to 50 km from the epicentre. The MM IV isoseismal had an average radius of 110 km. There were isolated reports of the earthquake being felt at Southern Cross, 220 km east of the epicentre. Numerous reports warranting intensity V were received from the Perth Hills area east of the Darling Fault, 100 km west of the epicentre. Very few felt reports were received from the Perth area west of the fault (Gregson, in prep.)

Kangaroo Island, SA (Fig. 19)

At about 15:00 local time on 16 December, a magnitude 4.6 earthquake occurred approximately 30 km southwest of Cape du Couedic, Kangaroo Island. There were isolated reports of it being felt as far away as Adelaide. One group near the epicentre was on a guided tour of Kelly Hill Caves (southwest Kangaroo Island). No damage to stalactites was noticed, but after 14 to 15 seconds of shaking their tour was abruptly terminated and they made a hasty exit.

A portable seismograph was installed in Kelly Hill Caves in February 1988. This has detected 3 small, close events which suggest that the 1986 epicentre may have been much closer to Cape du Couedic.

(PETER GREGSON, KEVIN McCUE, RUSSELL CUTHBERTSON & DAVID LOVE)

NETWORK OPERATIONS

Table 3 gives the co-ordinates of seismograph stations and the types of seismographs in operation during the year (Fig. 20). The network includes two arrrays at Alice Springs and Tennant Creek in the Northern Territory, five Worldwide Standard Seismograph Stations at Adelaide, Charters Towers, Mundaring, Sydney, and Hobart, and two Seismological Research Observatories at Narrogin and Charters Towers. Another ninety-three short period vertical seismographs were in operation throughout Australia. At Mawson in Antarctica, the seismographs included a three-component set of short period recorders and one long period vertical instrument. Two new stations were commissioned, at Glen Eva (GVA) in Queensland and Bell's Track (BEL) in Victoria. Kalgoorlie (KLG) and Meekatharra (MEK) in Western Australia were re-sited to reduce industrial noise. Stations at Mount Graham, Bungobine and Glendon Crossing in Queensland, Mount Gambier in South Australia, and Boolarra South and Yinnar South in Victoria were closed during the year.

Regional epicentres (Table 1) were located by the main institutions listed on page iii. BMR maintains the definitive Australian earthquake datafile and provides basic earthquake data for the Australian region on request to scientists, insurance companies, engineers, and the general public.

(PETER GREGSON & KEVIN McCUE)

ISOSEISMAL MAP OF THE AUGUSTA EARTHQUAKE, WESTERN AUSTRALIA
15 JANUARY 1986

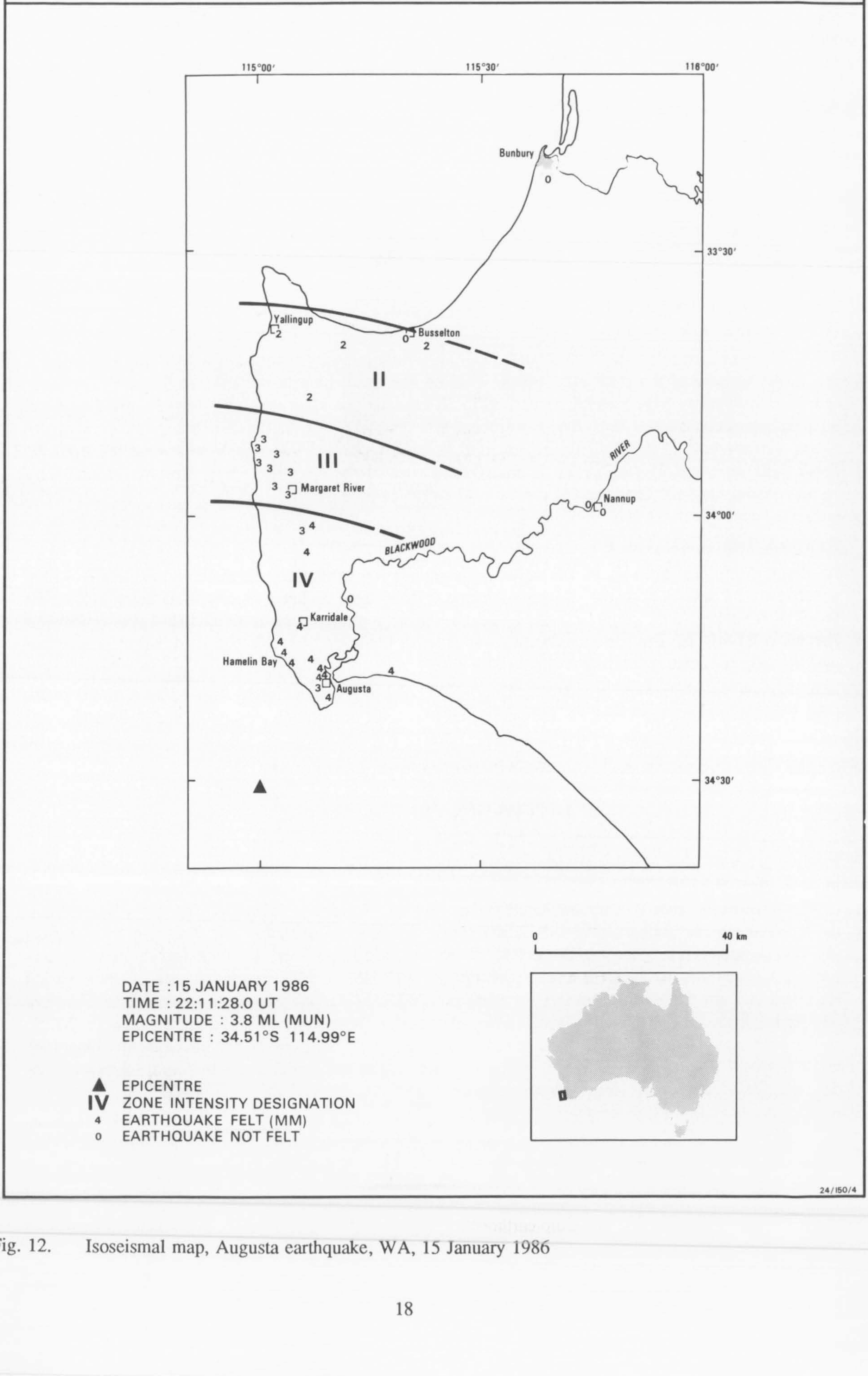

Fig. 12. Isoseismal map, Augusta earthquake, WA, 15 January 1986

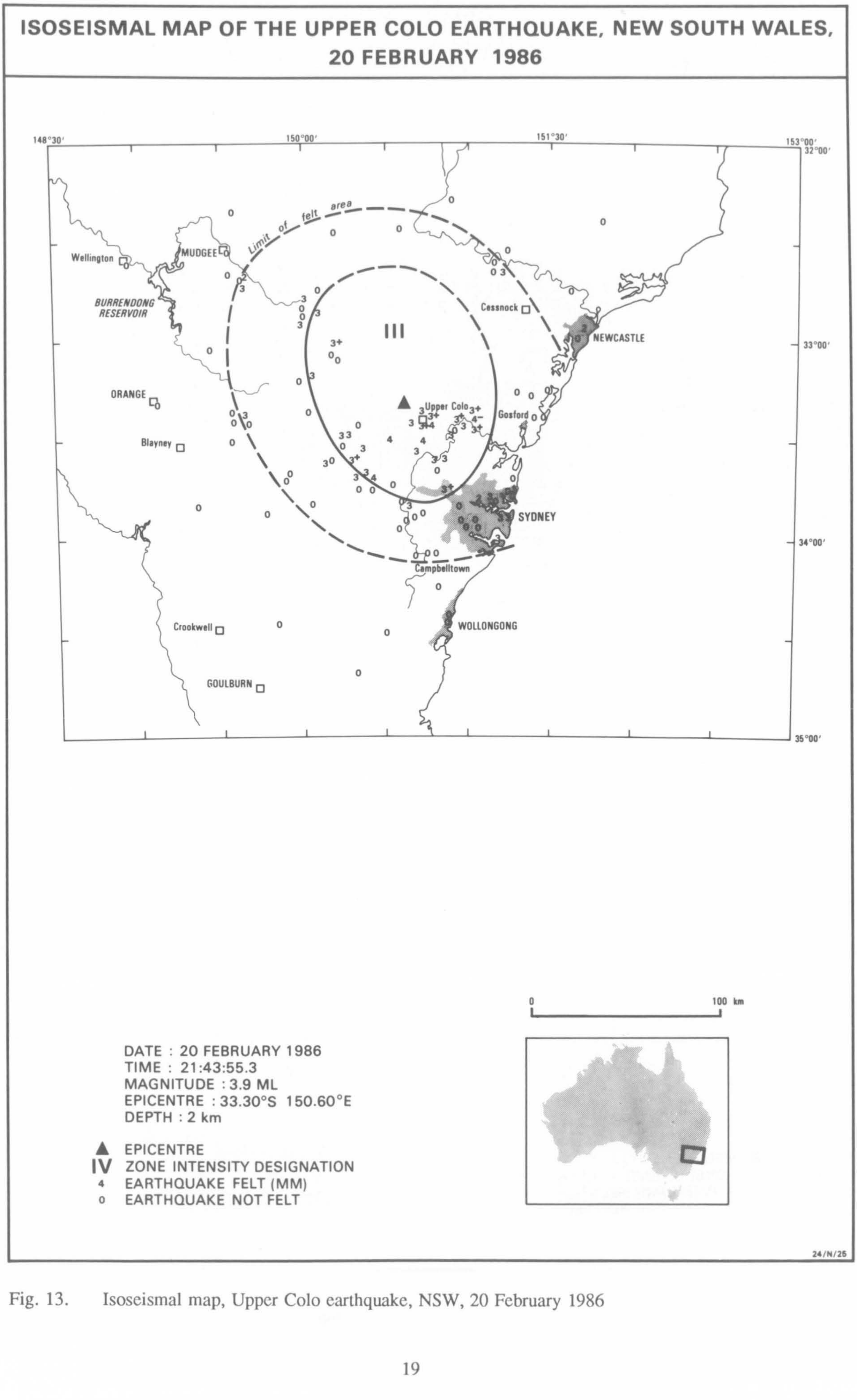

Fig. 13. Isoseismal map, Upper Colo earthquake, NSW, 20 February 1986

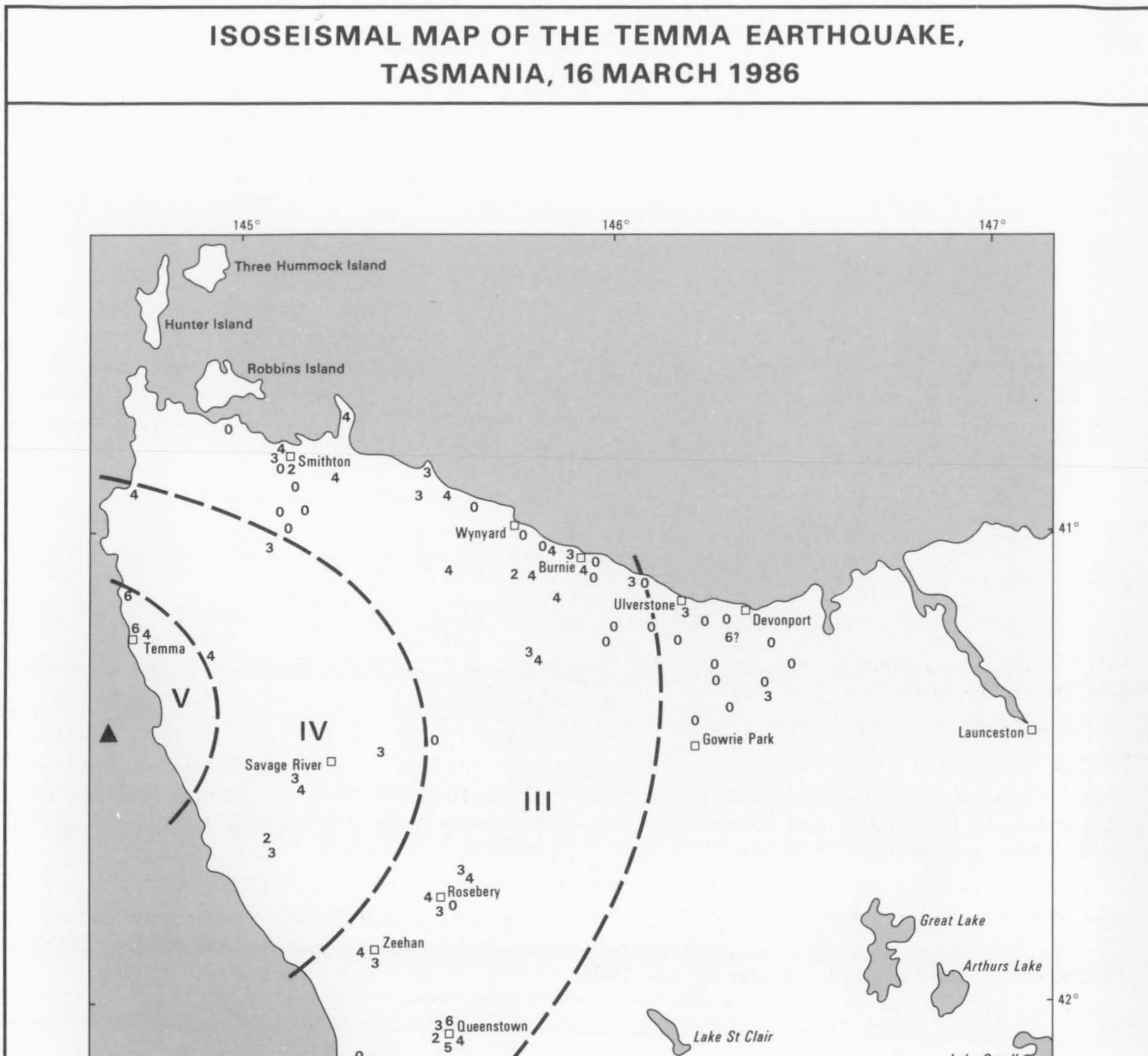

Fig. 14. Isoseismal map, Temma earthquake, Tasmania, 16 March 1986

ACCELEROGRAPH DATA

An accelerograph is used to record the strong ground motion near an earthquake source where a seismograph, being much more sensitive, would be saturated. The records or accelerograms are useful to both the seismologist and earthquake engineer. Accelerometers may be permanently installed in a building or engineered structure, such as a dam or tower, to record its response during an earthquake, or set up at temporary field sites wherever the seismicity is currently active. Table 5 lists the details of accelerographs in operation during 1986.

Fifty-five accelerograms were recorded in the Cadoux area in southwestern WA and thirty-five in the Dalton/Gunning NSW seismic zone. The Seismological Centre at Phillip Institute of Technology, Victoria recorded 24 accelerograms, 12 of them at Thomson Dam. The largest acceleration recorded was in the Dalton area on 7 January where a magnitude ML 3.1 earthquake resulted in a peak ground acceleration of 1.15 $m.s^{-2}$ at a distance of 4 km. The maximum recorded accelerations in the Cadoux area were 0.05 $m.s^{-2}$. Table 5 lists parameters read from the accelerograms and the causative earthquakes. Figures 21 and 22 are examples of accelerograms recorded at Cadoux.

No accelerograms were recorded in Tasmania, South Australia or Queensland during 1986.

(KEVIN McCUE, BRIAN GAULL, GARY GIBSON & VAUGHAN WESSON)

PRINCIPAL WORLD EARTHQUAKES, 1986

Table 7 lists all earthquakes of magnitude 7.0 or greater, and damaging earthquakes of lesser magnitude, that occurred throughout the world in 1986. Figure 23 shows the locations of these earthquakes and the numbers of casualties.

Worldwide deaths in 1986 were more than 1090, compared with 9838 and 73 in 1985 and 1984 respectively. The most disastrous earthquake was in El Salvador on 10 October where more than 1000 people were killed, 10 000 injured and 200 000 left homeless. Severe damage occured in the San Salvador region. The magnitude of this earthquake, Ms 5.4, was relatively low. By comparison the largest earthquake, which occured on 20 October in the Kermadec Island region, had a magnitude of Ms 8.3. Apart from objects being knocked off shelves on Raoul Island, damage was very minor. These data are based on 'Earthquake Data Reports' published by the United States Geological Survey and the SEAN Bulletin of the Smithsonian Institution (SEAN, 1984).

(PETER GREGSON & KEVIN McCUE)

MONITORING NUCLEAR EXPLOSIONS

Ken Muirhead was recruited to head the Nuclear Monitoring Group and take over the role of Australian representative at the meetings of the Group of Scientific Experts (GSE) at Geneva.

The Australian Seismological Centre (ASC) was created in 1986, with the transfer of the Earthquake Seismology (HQ section) and Nuclear Monitoring Groups from the BMR building to a separate building (Jamieson House) in Canberra.

A new SUN computer and another donated by the United States Defence Advanced Research Projects Agency (DARPA) were installed and a Telecom landline established to Alice Springs to enable direct telemetry of the Joint Geological and Geophysical Research Station (JGGRS) array data to the ASC Canberra. Array processing software was provided by the Center for Seismic Studies under contract to DARPA.

Table 8 lists the 23 nuclear explosions detected during 1986, compared with 30 in 1985, 15 by the USA and 8 by France. The USSR maintained a self-imposed moratorium on nuclear weapons testing throughout 1986.

(PETER GREGSON & KEVIN McCUE)

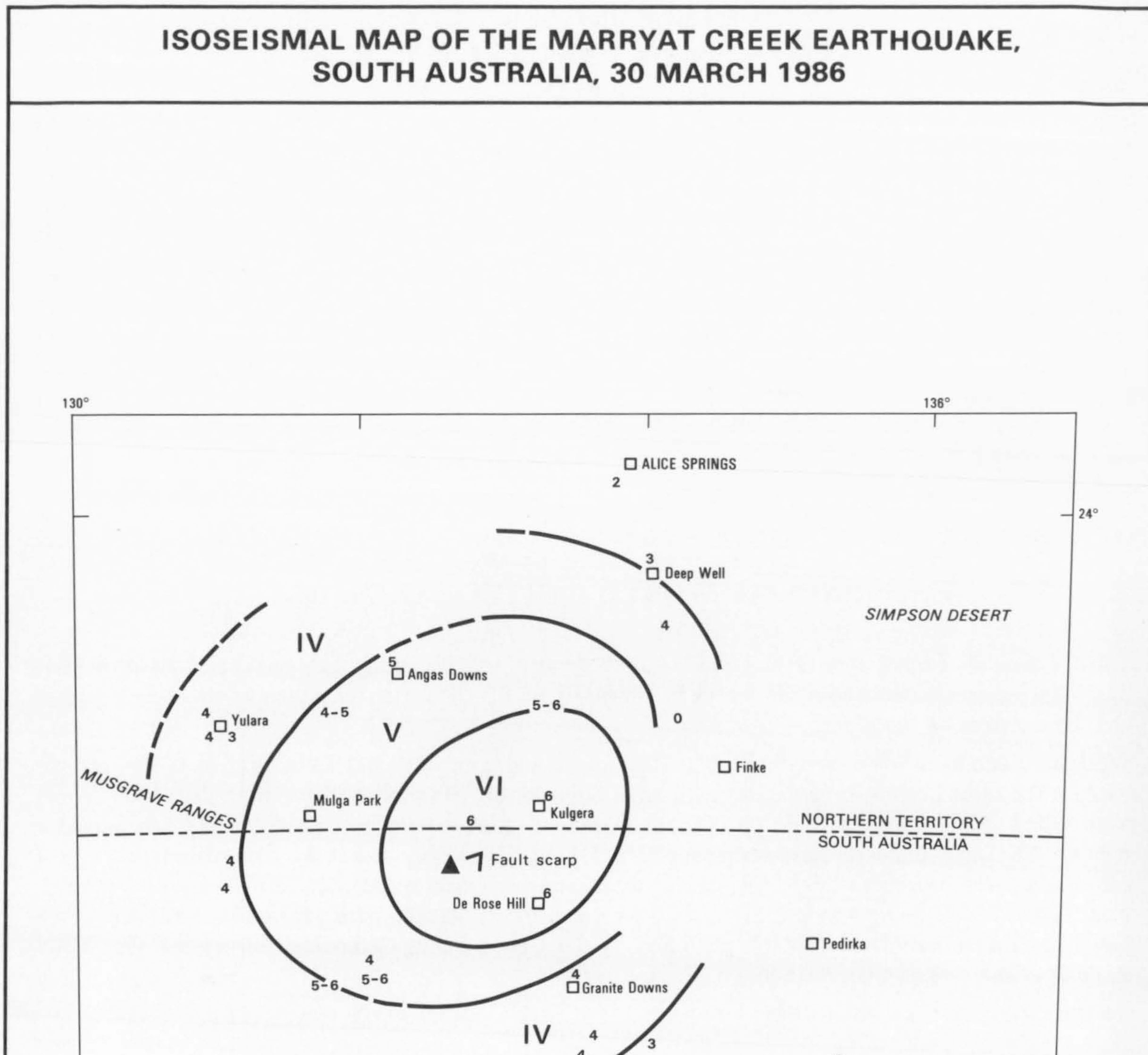

Fig. 15. Isoseismal map, Marryat Creek earthquake, SA, 30 March 1986

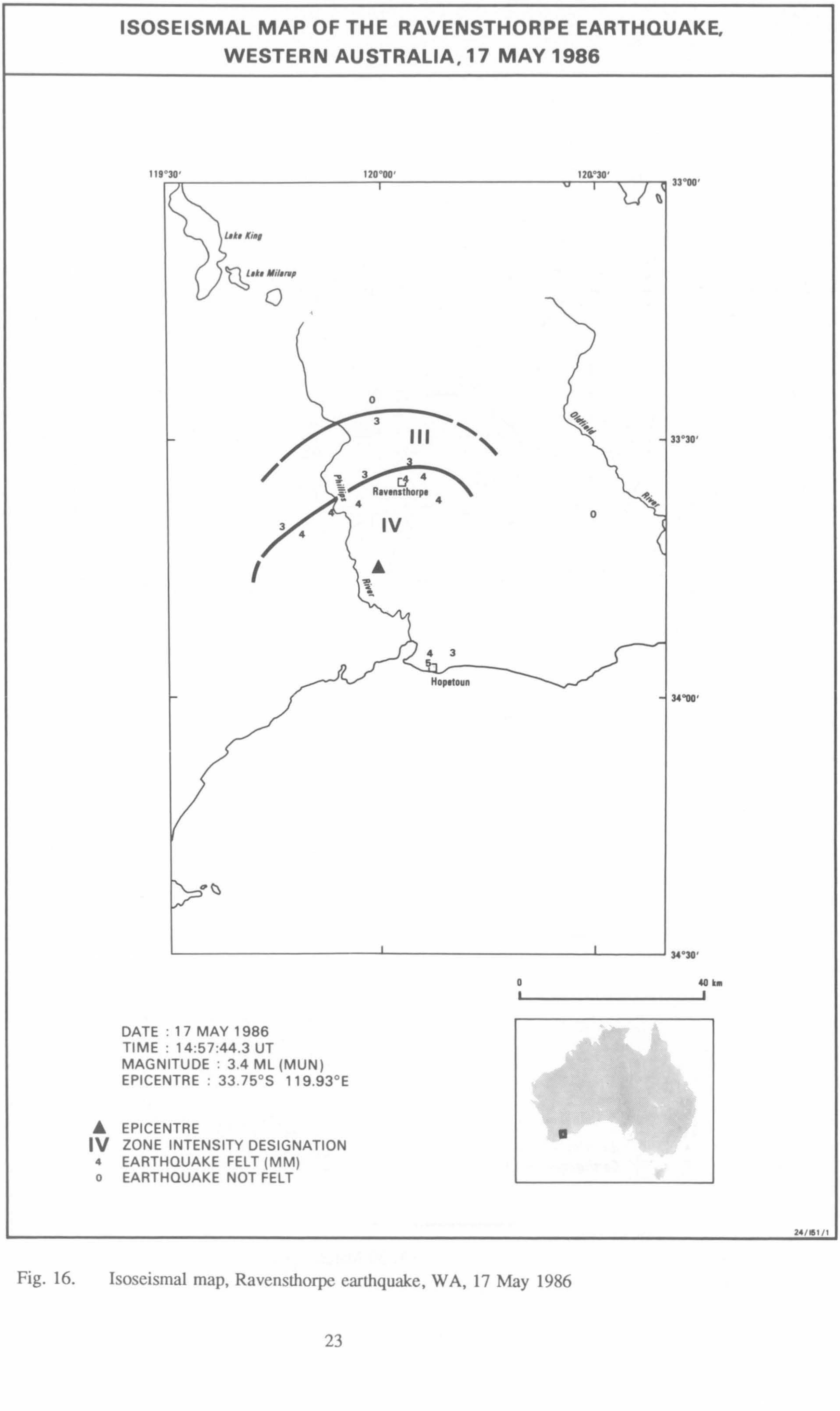

Fig. 16. Isoseismal map, Ravensthorpe earthquake, WA, 17 May 1986

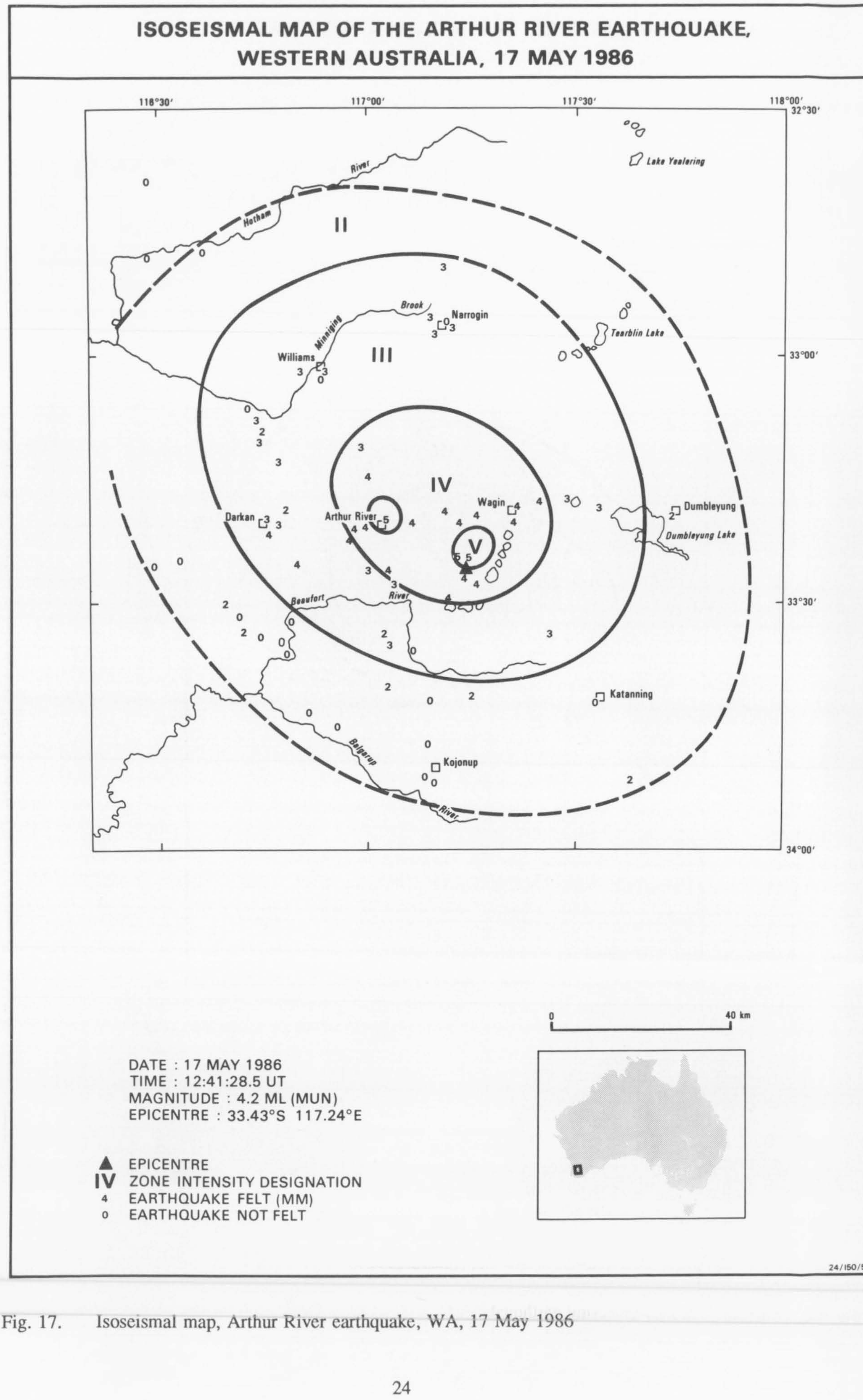

Fig. 17. Isoseismal map, Arthur River earthquake, WA, 17 May 1986

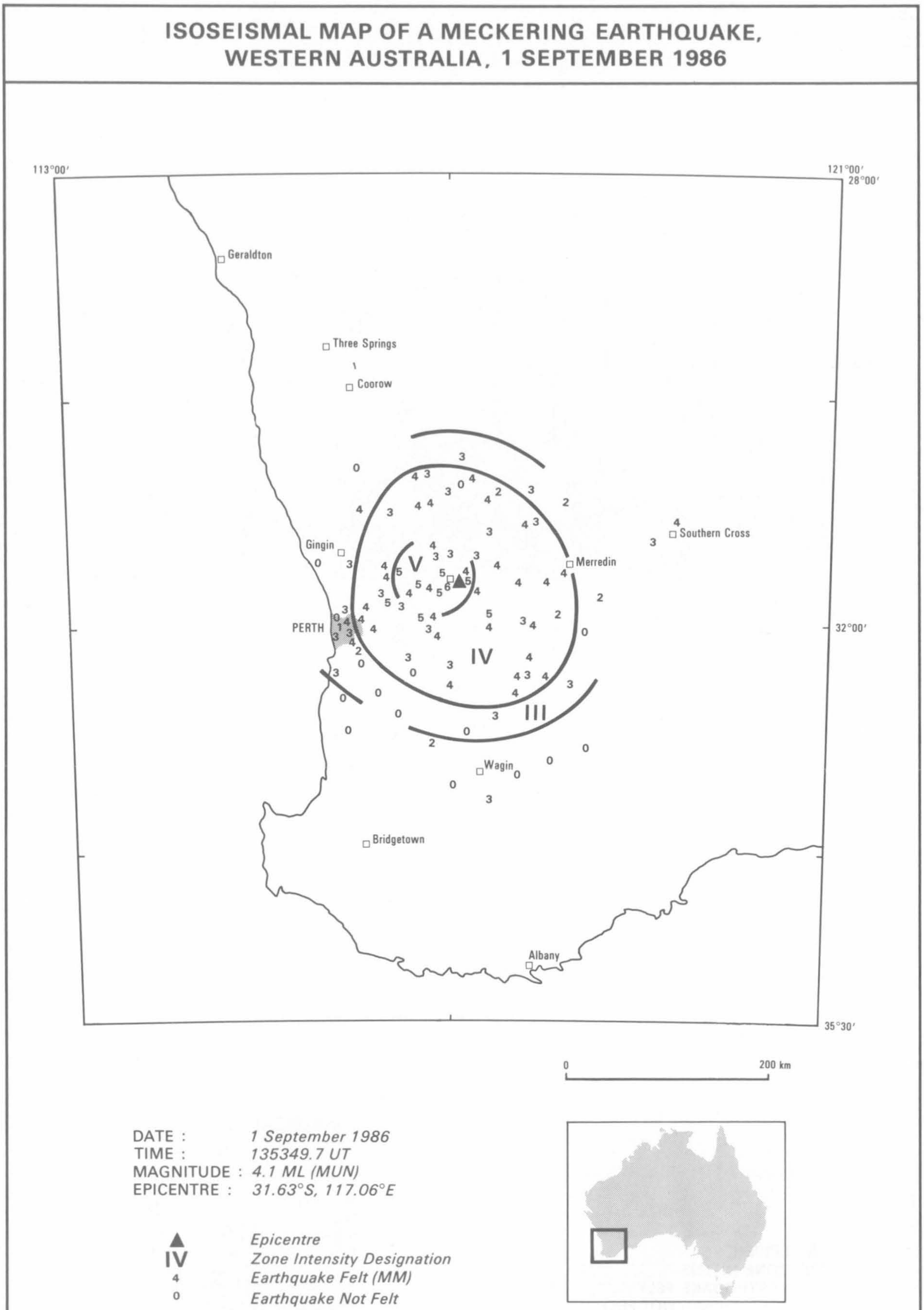

Fig. 18. Isoseismal map, Meckering earthquake, WA, 1 September 1986

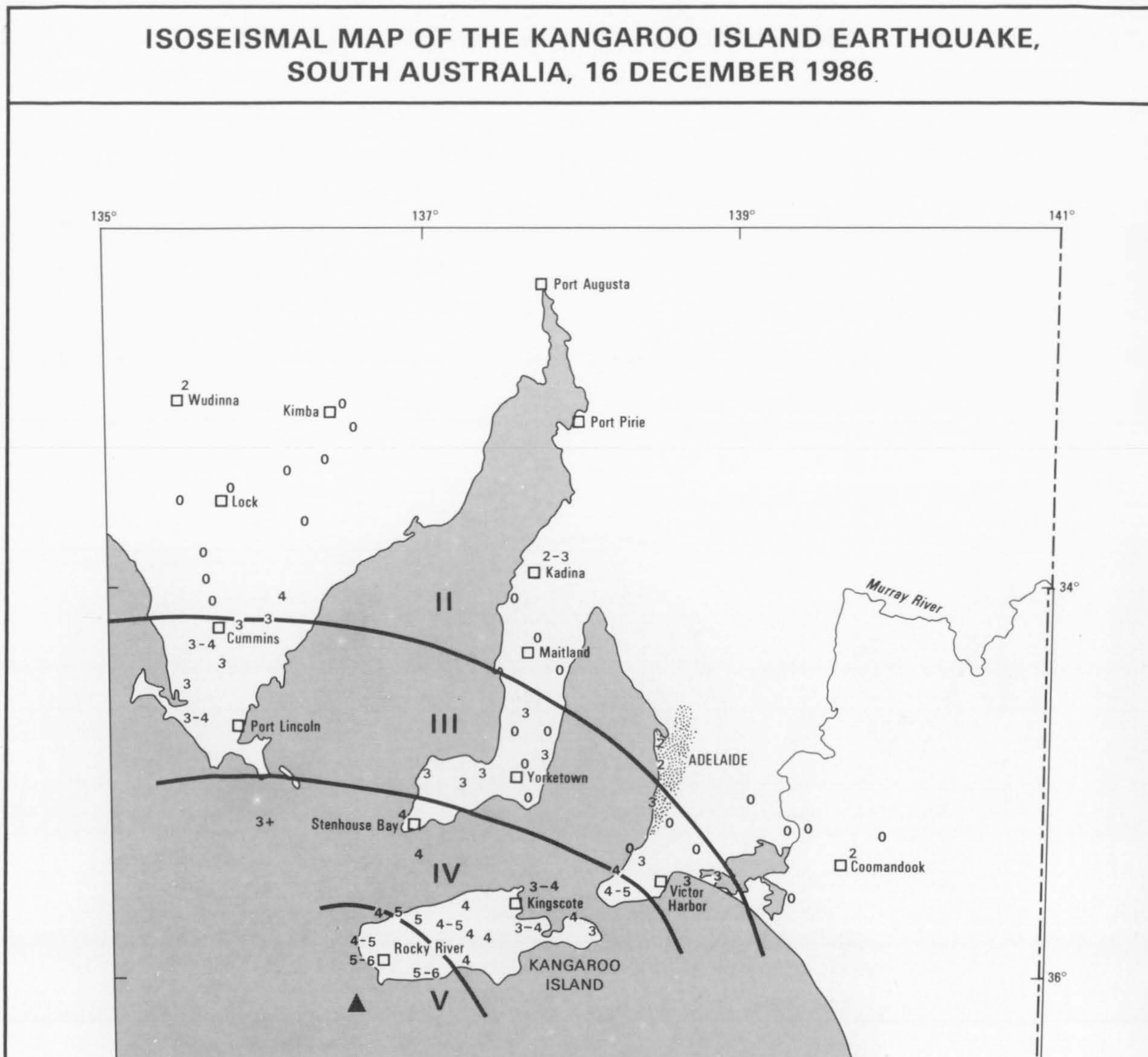

Fig. 19. Isoseismal map, Kangaroo Is earthquake, SA, 16 December 1986

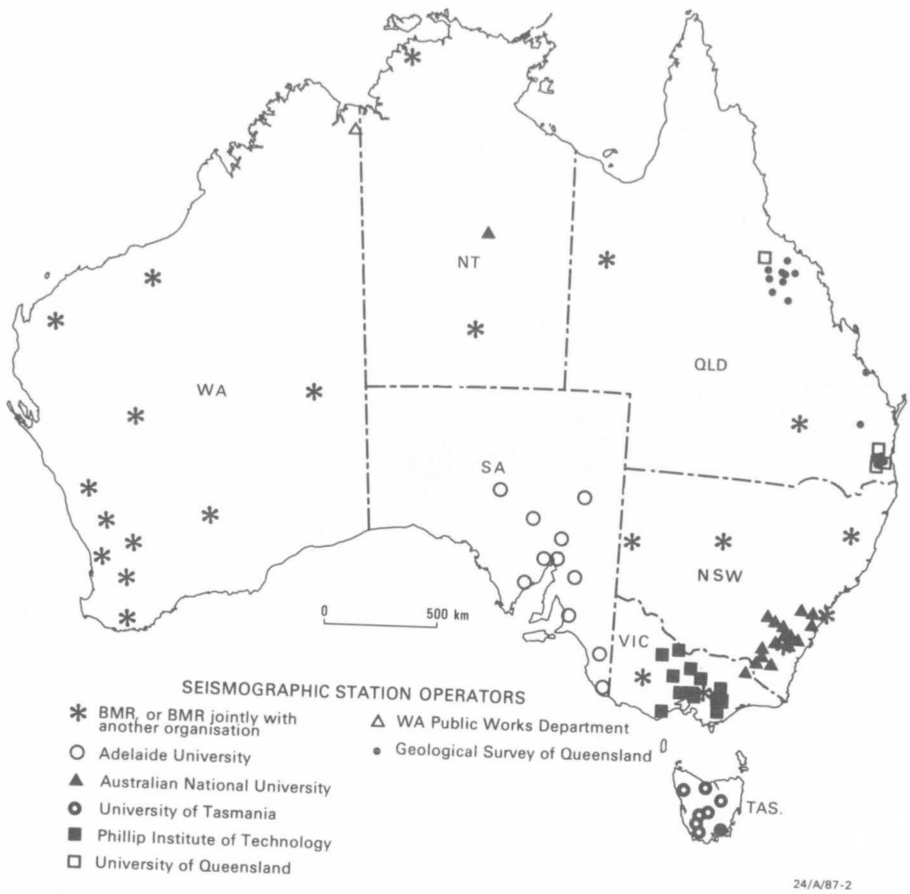

Fig. 20. Australian seismographic stations, 1986

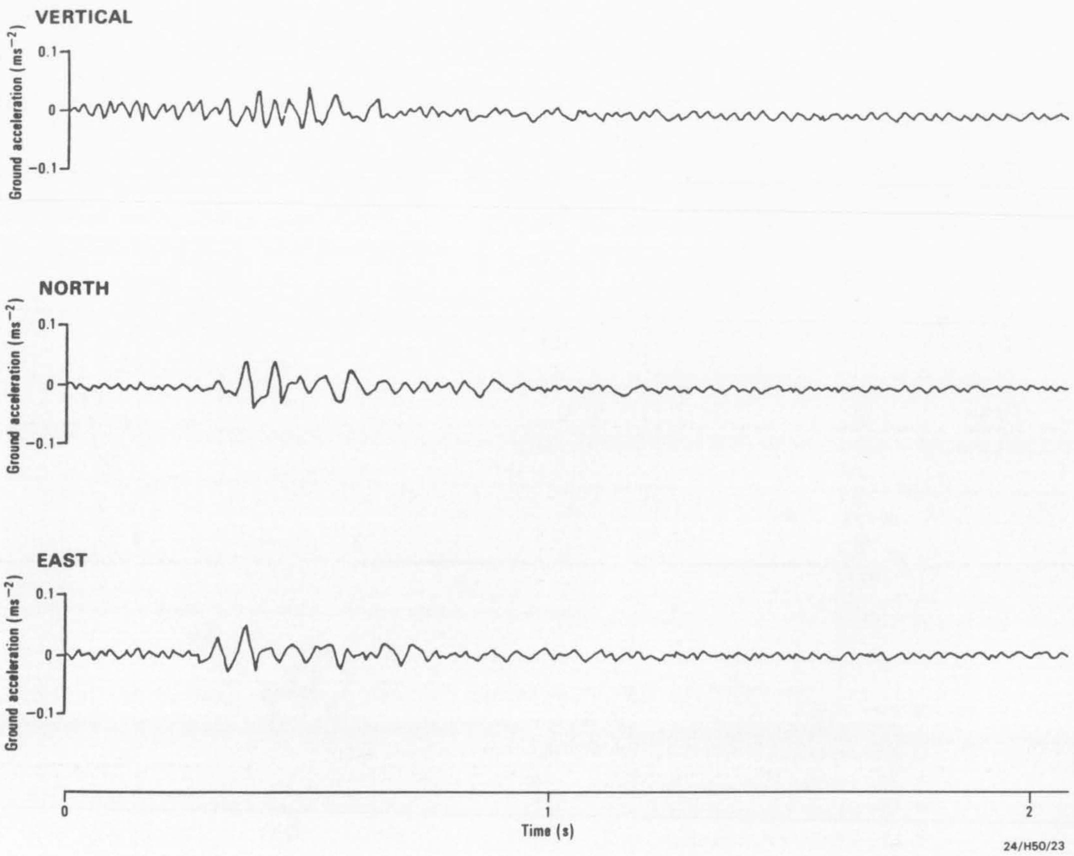

Fig. 21. Accelerogram recorded at Cadoux, WA, 6 February 1986

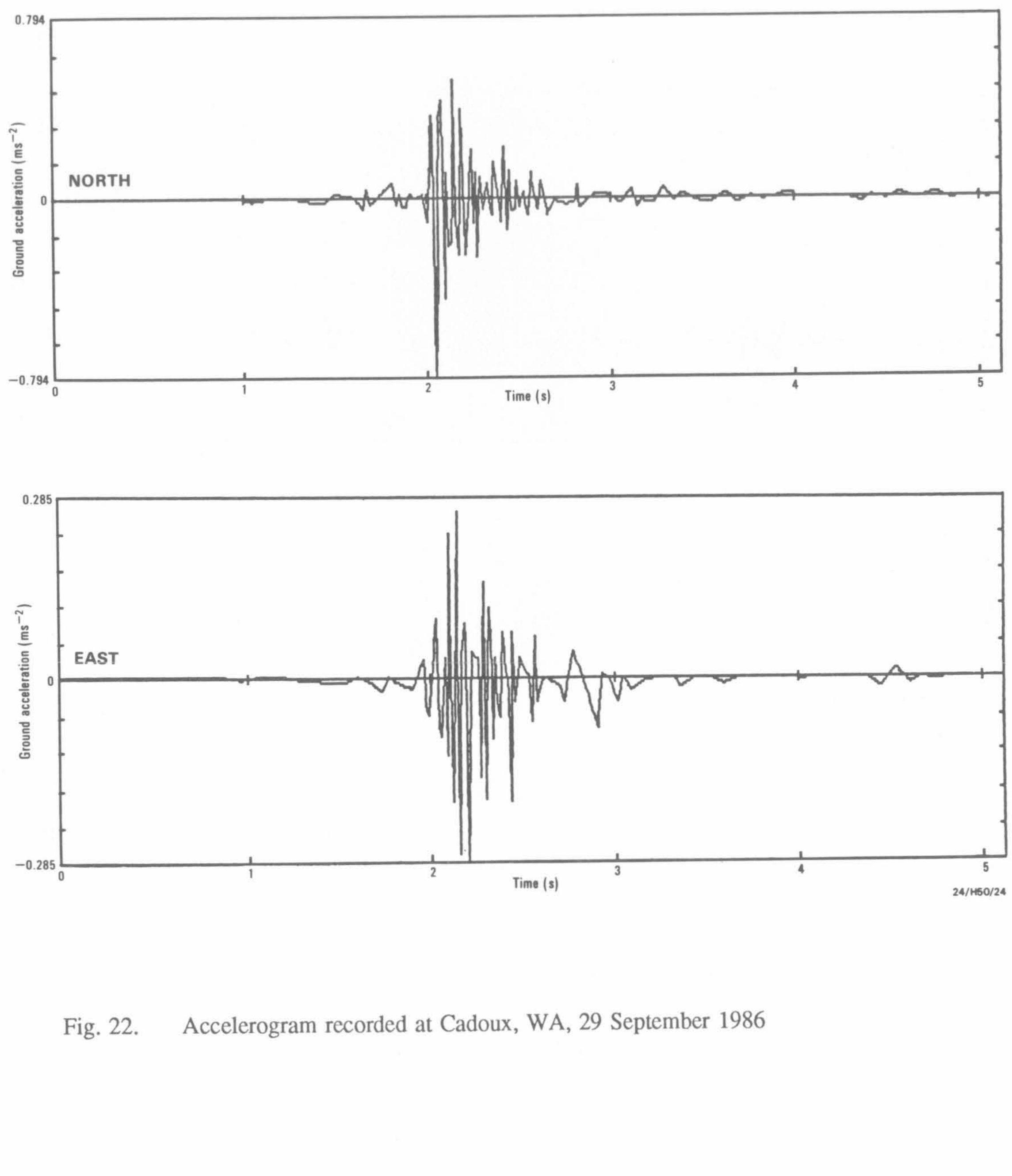

Fig. 22. Accelerogram recorded at Cadoux, WA, 29 September 1986

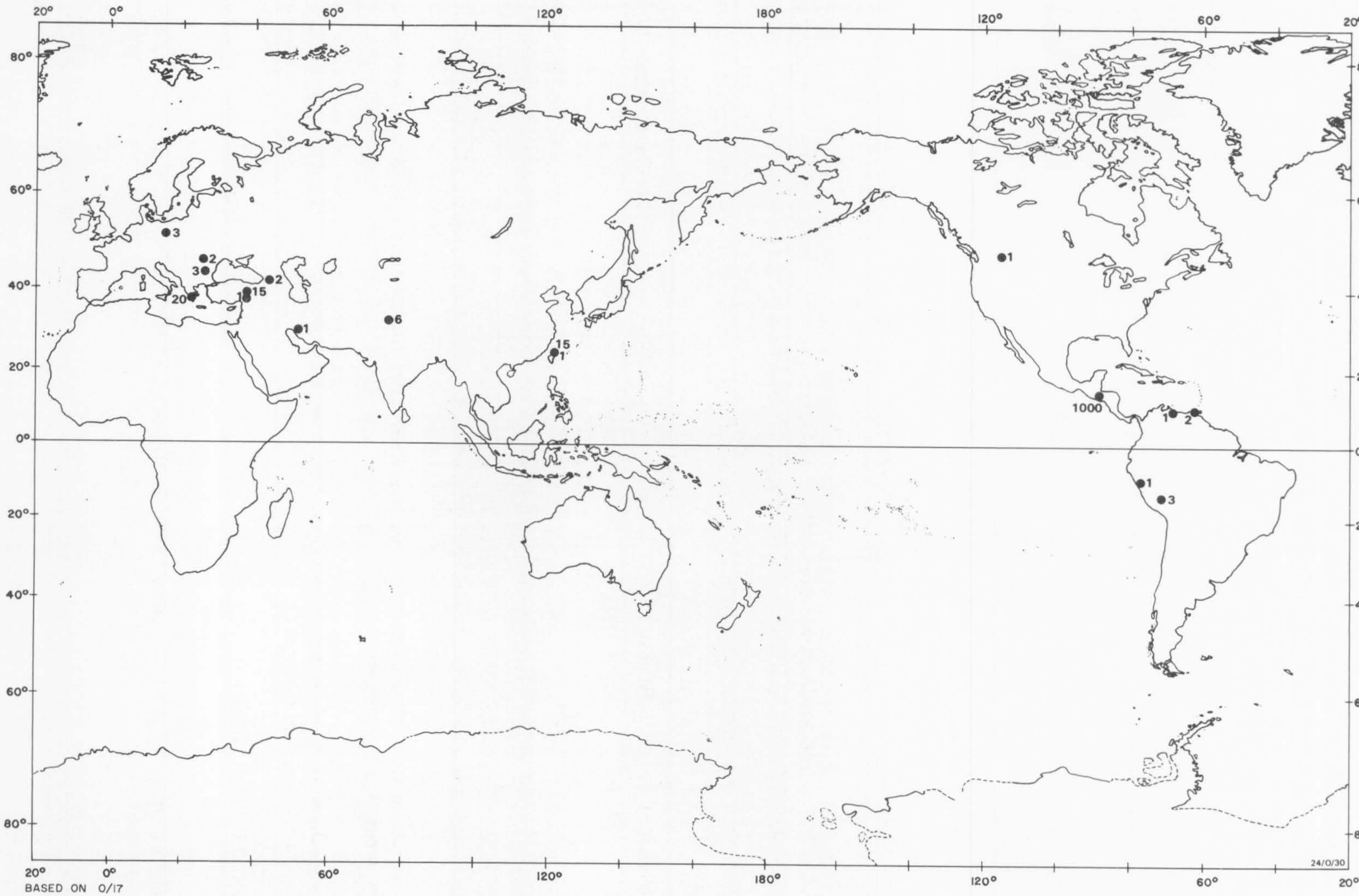

Fig. 23. Principal World earthquakes, 1986 (from USGS Monthly Listing)

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TABLE 1. AUSTRALIAN REGION EARTHQUAKES, 1986 : HYPOCENTRAL PARAMETERS

DATA# SOURCE	DATE mo dy	TIME(UT) hrmn sec	LAT° S	LONG° E	DEPTH (km)	MAGNITUDE	N*
MUN	1 2	2133 44.2	34.300	112.040	0	5.3	10
MUN	1 2	2159 42.3	34.500	112.010	5	3.4	4
MUN	1 2	2313 50.5	20.790	115.150	5	3.0	3
MUN	1 3	1333 48.0	34.560	111.950	5	3.3	6
BMR	1 4	0626 18.2	31.625	138.610	6	3.4	10
BMR	1 7	1006 50.0	34.746	149.196	0	3.1	15
BMR	1 8	0955 57.0	27.147	152.500	0	3.2	12
MUN	1 9	1454 14.0	24.430	129.350	5	3.1	4
MUN	1 14	0038 7.0	23.870	113.440	5	4.2	11
MUN	1 14	0541 7.0	23.870	113.600	5	3.5	6
BMR	1 14	1410 59.0	31.553	138.603	6	3.2	10
MUN	1 15	2211 28.0	34.510	114.990	5	3.8	9
MUN	1 20	0746 18.0	32.360	122.340	5	4.2	11
MUN	1 20	1016 41.7	32.480	122.300	5	3.6	8
MUN	1 20	2331 45.5	29.050	124.220	10	3.8	9
MUN	1 27	1533 25.0	38.090	123.110	5	3.3	5
MUN	1 27	1717 25.0	18.290	123.000	5	3.3	4
MUN	1 28	1629 57.7	25.750	113.590	5	3.3	4
MUN	2 2	2256 41.0	20.290	115.930	5	3.0	3
MUN	2 6	1017 59.8	30.780	117.080	5	3.5	10
MUN	2 6	1144 13.0	18.250	119.120	5	3.8	5
BMR	2 11	1151 55.9	19.784	133.696	0	4.3	5
MUN	2 17	0206 38.0	32.230	117.410	5	3.2	7
MUN	2 17	1116 46.5	24.530	129.410	5	3.0	3
MUN	2 18	0257 37.0	39.860	118.910	37	5.2	10
BMR	2 20	2143 55.3	33.330	150.604	2	4.0	23
MUN	2 26	0757 40.0	42.460	118.840	5	3.5	3
MUN	3 3	0237 41.0	34.000	110.710	5	3.1	4
CAN	3 13	0129 43.8	36.550	146.820	12	3.0	11
BMR	3 13	0950 17.9	36.418	146.696	0	3.1	9
MUN	3 14	1654 10.0	29.020	113.710	5	3.0	8
BMR	3 16	0153 10.5	41.451	144.632	18	4.1	13
MUN	3 16	0644 50.0	28.100	126.610	5	3.6	6
BMR	3 30	0853 48.4	26.333	132.517	5	6.0	28
MUN	3 30	1836 51.3	37.830	113.820	10	3.7	7
MUN	3 30	2121 42.0	20.020	113.830	5	3.3	4
ADE	3 31	0612 2.5	26.180	132.070	4	3.0	
ADE	4 1	1142 55.6	26.250	131.860	3	3.0	
MUN	4 3	1834 27.8	32.510	122.220	5	3.2	4
MUN	4 3	2230 17.7	32.510	122.220	5	3.4	7
PIT	4 10	1853 4.2	35.798	144.851	5	3.8	36
CAN	4 10	1942 12.0	35.800	144.830	30	3.0	8
CAN	4 11	0346 39.1	35.830	144.850	36	3.1	8
CAN	4 14	0234 55.0	35.650	144.720	0	3.1	9
MUN	4 14	0633 23.0	21.760	126.270	5	3.5	5

Only earthquakes of magnitude 3.0 or more are listed.

Codes denote contributors listed in the text, page iii

* Number of stations used to determine hypocentres.

Table 1 (cont.)

DATA# SOURCE	DATE mo dy	TIME(UT) hrmn sec	LAT° S	LONG° E	DEPTH (km)	MAGNITUDE	N*
BMR	4 14	1932 41.0	24.879	131.345	10	4.2	14
CAN	4 14	2005 2.2	36.570	146.610	15	3.0	12
MUN	4 16	0601 21.0	20.450	123.480	5	3.7	5
CAN	4 16	1413 53.4	35.770	144.720	22	3.2	9
ADE	4 18	2327 20.0	26.230	132.800	35	3.1	
MUN	4 20	1141 23.5	19.590	115.010	5	3.7	5
CAN	4 23	0525 45.0	38.800	153.400	0	3.0	6
CAN	4 23	1224 56.0	41.000	154.000	0	4.0	11
CAN	4 24	0443 46.4	36.150	143.350	13	4.0	12
MUN	4 24	0823 54.0	18.090	127.880	5	3.2	4
MUN	4 29	1924 21.0	32.510	122.220	5	3.2	6
MUN	5 1	1949 27.3	32.590	122.310	5	3.1	8
BMR	5 2	2224 31.0	25.957	137.543	5	4.0	5
BMR	5 8	0818 20.0	36.625	138.384	5	3.7	7
MUN	5 8	1747 4.0	19.620	116.540	5	3.5	3
MUN	5 10	2318 43.6	33.000	110.380	5	3.6	7
MUN	5 15	1205 42.9	30.760	117.100	8	3.4	11
MUN	5 17	1241 26.7	33.360	117.200	5	4.0	11
MUN	5 17	1457 44.3	33.760	119.800	5	3.6	7
TAU	5 17	2352 9.8	41.530	139.580	0	3.4	5
CAN	5 17	2352 22.0	38.500	153.500	0	3.6	8
BMR	5 20	1358 33.1	32.646	138.711	5	3.1	6
MUN	5 21	2042 26.6	25.310	116.220	5	3.6	11
MUN	5 22	2100 33.5	24.920	111.300	5	3.1	4
BMR	5 26	0555 13.5	27.768	128.992	5	4.4	12
MUN	5 26	1034 23.1	17.590	123.550	5	3.3	6
MUN	5 27	1710 35.6	30.830	117.120	5	3.0	9
MUN	5 31	1038 0.0	31.300	111.420	10	3.1	5
MUN	5 31	2038 12.8	18.570	118.020	10	4.1	11
MUN	6 5	1115 45.0	26.280	131.080	5	3.7	7
CAN	6 6	0931 24.8	35.840	144.800	25	3.7	11
MUN	6 16	0442 36.0	21.200	129.360	5	3.5	4
MUN	6 23	1530 27.0	27.590	124.780	5	3.8	11
ADE	6 27	0130 6.2	25.520	140.200	5	3.2	
CAN	7 2	0314 53.1	35.790	144.770	27	3.6	10
CAN	7 3	1410 4.1	35.850	144.780	24	3.3	8
MUN	7 4	1649 57.0	39.630	121.050	5	3.6	7
MUN	7 4	1652 17.5	39.630	121.050	5	3.4	6
MUN	7 4	1725 21.8	39.630	121.050	5	3.4	5
MUN	7 4	1740 32.0	39.630	121.050	5	3.2	4
GSQ	7 7	0627 42.3	29.914	151.188	0	3.1	9
MUN	7 9	1137 10.0	20.840	129.440	5	3.2	4
BMR	7 10	2210 14.5	26.173	132.680	0	4.1	10
BMR	7 11	0613 37.3	25.699	130.555	0	3.3	4
BMR	7 11	0717 54.7	26.262	132.511	5	5.6	32
BMR	7 11	1242 13.8	25.671	132.492	0	3.7	4
BMR	7 12	1353 37.9	26.066	132.727	0	3.2	4
BMR	7 14	1036 42.4	36.046	144.161	36	3.3	16
MUN	7 20	0125 28.2	21.980	126.460	5	3.6	5
MUN	7 26	0841 16.6	31.770	117.050	5	3.0	9
CAN	7 31	1737 20.0	34.180	143.880	0	3.6	9
BMR	8 17	1323 52.7	11.834	130.334	5	4.5	7

Table 1 (cont.)

DATA# SOURCE	DATE mo dy	TIME(UT) hrmn sec	LAT° S	LONG° E	DEPTH (km)	MAGNITUDE	N*
MUN	8 24	0454 39.0	21.410	126.540	5	4.0	11
PIT	8 24	0819 31.9	37.982	146.578	16	3.1	26
GSQ	8 31	1753 56.4	30.260	151.240	9	3.3	8
MUN	9 1	1353 49.7	31.630	117.060	5	4.1	9
MUN	9 2	0557 4.8	38.000	112.200	5	3.2	4
MUN	9 2	1524 53.7	38.000	112.200	5	3.0	3
MUN	9 4	1839 26.7	38.000	112.200	5	3.2	6
ADE	9 4	1910 54.3	33.620	133.330	22	3.0	
MUN	9 5	0618 54.1	37.060	117.000	5	3.1	6
MUN	9 6	1041 5.0	22.730	119.050	5	3.1	6
MUN	9 13	0237 4.5	15.810	120.950	5	4.3	8
MUN	9 13	1323 53.0	18.440	121.200	5	3.1	4
MUN	9 13	1913 33.9	22.680	113.250	5	3.0	4
MUN	9 16	1616 40.2	32.590	122.310	5	3.5	8
MUN	9 21	0439 21.9	38.100	112.200	5	3.4	6
BMR	9 22	0503 10.1	34.362	145.546	12	3.1	8
PIT	9 22	0525 52.1	34.242	145.480	10	3.0	14
CAN	9 22	0526 24.0	34.290	145.550	0	3.3	6
CAN	9 22	0546 24.0	34.270	145.600	29	3.7	9
CAN	9 22	0630 28.0	34.290	145.550	0	3.1	12
BMR	9 22	1421 42.1	34.307	145.550	0	4.0	13
CAN	9 22	1658 4.0	34.290	145.550	0	3.0	5
MUN	9 23	2041 55.6	21.500	119.280	11	3.2	5
MUN	9 29	1509 53.0	16.920	118.330	5	3.0	3
MUN	9 29	2157 22.0	30.730	117.130	7	3.3	9
MUN	10 1	1319 33.0	32.250	126.240	5	3.4	8
MUN	10 2	0343 23.6	30.580	121.600	5	3.0	8
MUN	10 5	1240 40.6	32.430	122.200	5	3.0	9
MUN	10 13	1206 10.2	33.950	118.810	5	3.2	7
MUN	10 16	2136 31.0	22.610	114.590	5	4.1	9
MUN	10 25	0158 49.0	16.620	121.040	5	3.8	6
MUN	10 26	0552 27.0	26.670	111.190	5	3.0	4
MUN	10 27	1708 13.0	23.110	128.220	5	3.3	4
MUN	11 5	0757 56.0	18.470	118.850	5	4.0	10
BMR	11 7	2153 19.1	24.593	139.804	27	3.8	8
BMR	11 28	1540 50.3	25.393	129.656	5	4.2	12
BMR	11 28	1546 1.9	25.433	129.779	5	4.4	12
BMR	11 29	1922 1.8	25.393	129.673	5	4.1	13
BMR	12 2	1713 33.3	19.617	132.549	23	4.4	4
MUN	12 4	1347 16.0	20.250	115.830	5	4.0	7
MUN	12 8	2133 32.0	38.220	112.550	5	3.2	5
MUN	12 14	0932 45.0	19.180	121.510	5	3.6	6
BMR	12 16	0428 46.5	36.171	136.514	1	4.6	18
MUN	12 17	0913 8.0	32.360	122.270	5	3.3	7
MUN	12 18	0126 35.0	16.790	122.590	5	3.9	5
MUN	12 18	0658 51.0	27.830	116.820	5	4.3	11
BMR	12 20	1204 38.2	39.179	143.397	0	3.5	18
CAN	12 23	1529 29.0	39.600	152.700	0	3.5	8
MUN	12 27	0743 58.0	32.510	122.220	5	3.2	9
PIT	12 28	1148 55.2	40.251	154.709	10	3.0	4
MUN	12 30	1700 3.3	20.650	116.090	5	3.0	4

TABLE 2. LARGE AUSTRALIAN EARTHQUAKES, 1873 - 1986

DATA# SOURCE	DATE y mo dy	TIME(UT) hrmn sec	LAT° S	LONG° E	DEPTH (km)	ML	Ms
ET	1873 12 15	0400 0.0	26.25	127.50	0 G		6.0
ET	1885 1 5	1220 0.0	29	114	0 G		6.5
IBE	1885 7 2	1620 0.0	40	150	0 G		6.5
ADE	1897 5 10	0526 0.0	37.33	139.75	0 G	6.5	
ADE	1902 9 19	1035 0.0	35.00	137.40	14 G	6.0	
EDG	1906 11 19	0718 54	19.1	111.8	10 G		7.2
UQ	1918 6 6	1814 24.0	23.50	152.50	15 G	6.2	5.7
EDG	1920 2 8	0524 30	35.00	111.0	0 G		6.0
BMR	1929 8 16	2128 23.4	16.99	120.66	33 N		6.6
EDG	1935 4 12	0132 24	26.00	151.10	0 G	6.1	5.4
BMR	1941 4 29	0135 39.4	26.92	115.80	0 G	7.0	6.8
BMR	1941 6 27	0755 49.0	25.95	137.34	0 G		6.5
BMR	1968 10 14	0258 50.6	31.62	116.98	10 G	6.9	6.8
BMR	1970 3 24	1035 17.6	22.05	126.61	0 G	6.7	5.9
BMR	1972 8 28	0218 56.2	24.95	136.26	10	6.2	
MUN	1975 10 3	1151 1.8	22.21	126.58	0	6.2	
BMR	1978 5 6	1952 19.6	19.55	126.56	17	6.2	
BMR	1979 4 23	0545 10.8	16.66	120.27	10	6.6	5.7
BMR	1979 4 25	2213 57.4	16.94	120.48	1	6.1	
BMR	1979 6 2	0947 59.3	30.83	117.17	6	6.2	6.1
CGS	1983 11 25	1956 7.8	40.45	155.51	19	6.0	5.8
BMR	1986 3 30	0853 48.4	26.33	132.51	5	6.0	5.8

Depths are nominal

* G,N are restrained, or set at normal depth by the locating geophysicist

Source as listed page iv, ET Everingham & Tilbury (1972), IBE Everingham (unpublished data), EDG Everingham & others (1987).

TABLE 3. AUSTRALIAN SEISMOGRAPH STATIONS, 1986

CODE	NAME	LAT° S	LONG° E	ELEV. (m)	OP.*	TYPE**
QUEENSLAND						
AWMQ	AWOONGA DAM	24.046	151.316	125	GSQ	1
BDMQ	BOONDOOMA DAM	26.112	151.444	320	GSQ	1
BFCQ	GLENDON CROSSING	20.614	147.161	160	GSQ	1
BFRQ	GLENROY	20.549	147.105	160	GSQ	1
BMGQ	MT GRAHAM	20.614	147.061	160	GSQ	1
BRS	MT NEBO BRISBANE	27.392	152.775	525	QLD	5
BSL	BRUSLEE	20.275	147.299	185	GSQ	1
CLV	COLINSVILLE	20.590	147.105	160	GSQ	1
CTAO	CHARTERS TOWERS	20.088	146.255	357	QLD	2
DLB	DALBEG	20.151	147.264	70	GSQ	1
DNG	DOONGARA	20.555	146.475	280	GSQ	1
ISQ	MOUNT ISA	20.715	139.553	500	BMR	1
MCP	MT COOPER	20.552	146.806	300	GSQ	1
MHP	MT HOPE	21.396	146.802	200	GSQ	1
RMQ	ROMA	26.489	148.755	360	BMR	1
UKA	UKALUNDA	20.899	147.127	200	GSQ	1
WBA	BUARABA	27.353	152.308	100	GSQ	1
WMB	MT BRISBANE	27.115	152.550	160	GSQ	1
WPL	PLAINLAND	27.606	152.417	160	GSQ	1
WPM	PINE MOUNTAIN	27.536	152.735	35	GSQ	1
WRC	REEDY CREEK	27.187	152.663	190	GSQ	1
WTG	TOOGOOLAWAH	27.146	152.333	130	GSQ	1
WTR	THALLON ROAD	27.528	152.465	100	GSQ	1
WWH	WIVENHOE HILL	27.370	152.587	190	GSQ	1
NORTHERN TERRITORY						
ASPA	ALICE SPRINGS	23.667	133.901	600	BMR	3
MTN	MANTON	12.847	131.130	80	BMR	1
WRA	WARRAMUNGA ARRAY	19.944	134.353	366	CAN	3
WESTERN AUSTRALIA						
BAL	BALLIDU	30.607	116.707	300	MUN	1
KLB	KELLERBERRIN	31.578	117.760	300	MUN	1
KLG	KALGOORLIE	30.783	121.458	360	MUN	1
KLGA	KALGOORLIE	30.718	121.438	390	MUN	1
KNA	KUNUNURRA	15.750	128.767	150	PWD/MUN	1
MBL	MARBLE BAR	21.160	119.833	200	MUN	1
MEKA	MEKATHARRA	26.614	118.534	520	MUN	1
MEK	MEEKATHARRA	26.613	118.545	520	MUN	1
MRWA	MORAWA	29.218	115.996	300	MUN	1
MUN	MUNDARING	31.978	116.208	253	MUN	2
NAU	NANUTARRA	22.544	115.500	80	MUN	1
NWAO	NARROGIN	32.927	117.233	265	MUN	4
WBN	WARBURTON	26.140	126.578	457	MUN	1
RKG	ROCKY GULLY	34.570	117.010	300	MUN	1
NEW SOUTH WALES AND AUSTRALIAN CAPITAL TERRITORY						
AVO	AVON	34.376	150.615	532	CAN	1
BWA	BOOROWA	34.425	148.751	656	CAN	1
CAH	CASTLE HILL	34.647	149.242	700	CAN	1

TABLE 3 (cont.)

CODE	NAME	LAT° S	LONG° E	ELEV. (m)	OP.*	TYPE**
CAN	CANBERRA (ANU)	35.321	148.999	650	CAN	1
CBR	CABRAMURRA	35.943	148.393	1537	CAN	1
CMS	COBAR	31.487	145.828	225	BMR	1
CNB	CANBERRA (BMR)	35.314	149.362	855	BMR	1
COO	COONEY	30.578	151.892	650	BMR	1
IVY	INVERALOCHY	34.972	149.718	770	CAN	1
JNL	JENOLAN	33.826	150.017	829	CAN	1
KHA	KHANCOBAN	36.214	148.129	435	CAN	1
LER	LERIDA	34.934	149.364	940	CAN	1
MEG	MEANGORA	35.101	150.037	712	CAN	1
RIV	RIVERVIEW	33.829	151.159	21	RIV	2
SBR	SOUTH BLACK RANGE	35.425	149.533	1265	CAN	1
STK	STEPHENS CREEK	31.882	141.592	213	BMR	1
TAO	TALBINGO	35.596	148.290	570	CAN	1
WAM	WAMBROOK	36.193	148.883	1290	CAN	1
WER	WEROMBI	33.950	150.580	226	CAN	1
YOU	YOUNG	34.278	148.382	503	CAN	1
SOUTH AUSTRALIA						
ADE	ADELAIDE	34.967	138.713	655	ADE	2
ADT	ADELAIDE	34.967	138.713	655	ADE	1
CLV	CLEVE	33.691	136.495	238	ADE	1
HTT	HALLETT	33.430	138.921	708	ADE	1
HWK	HAWKSNEST	29.958	135.203	180	ADE	1
MGR	MT GAMBIER	37.728	140.571	190	ADE	1
NBK	NECTAR BROOK	32.701	137.983	180	ADE	1
PNA	PARTACOONA	32.006	138.165	180	ADE	1
RPA	ROOPENA	32.725	137.403	95	ADE	1
UMB	UMBERATANA	30.240	139.128	610	ADE	1
WKA	WILLALOOKA	36.417	140.321	40	ADE	1
WRG	WOOMERA	31.105	136.763	168	ADE	1
VICTORIA						
ABE	ABERFELDY	37.719	146.389	549	PIT	1
BEL	BELL'S TRACK	37.761	146.389	545	PIT	1
BFD	BELLFIELD	37.177	142.545	235	BMR	1
BSY	BOOLARRA STH	38.445	146.297	260	PIT	1
BUC	BUCRABANYULE	36.238	143.498	210	PIT	1
DRT	DARTMOUTH	36.590	147.493	950	CAN	1
FRT	FORREST	38.534	144.997	210	PIT	1
GVL	GREENVALE	37.619	144.901	188	PIT	1
HOP	MOUNT HOPE	35.995	144.207	300	PIT	1
JEN	JEERALANG JUNCTION	38.351	146.420	330	PIT	1
MAL	MARSHALL SPUR	37.749	146.292	1076	PIT	1
MEM	MERRIMU	37.637	144.497	160	PIT	1
MIC	MOUNT ERICA	37.944	146.359	805	PIT	1
MLW	MOLESWORTH	37.137	145.510	280	PIT	1
PAT	PLANE TRACK	37.857	146.456	771	PIT	1
PEG	PEGLEG	36.985	144.091	340	PIT	1
PNH	PANTON HILL	37.635	145.271	180	PIT	1
RUS	RUSHWORTH	36.662	144.947	145	PIT	1
TMD	TOMSON DAM	37.810	146.349	941	PIT	1
TOM	THOMSON	37.810	146.348	941	PIT	1

TABLE 3 (cont.)

CODE	NAME	LAT° S	LONG° E	ELEV. (m)	OP.*	TYPE**
TOO	TOOLANGI	37.572	145.490	604	BMR	5
TASMANIA						
MOO	MOORLANDS	42.442	146.190	325	TAU	1
SAV	SAVANNAH	41.721	147.189	180	TAU	1
SFF	SHEFFIELD	41.337	146.307	213	TAU	1
SPK	SCOTTS PEAK	43.038	146.275	425	TAU	1
STG	STRATHGORDON	42.751	146.053	350	TAU	1
SVR	SAVAGE RIVER	41.489	145.211	360	TAU	1
TAU	TASMANIA UNIV.	42.910	147.321	132	TAU	2
TRR	TARRALEAH	42.304	146.450	579	TAU	1
MCQ	MACQUARIE ISLAND	54.498	158.957	14	BMR	1
ANTARCTICA						
MAW	MAWSON	67.607	62.872	15	BMR	5

* Operator; refers to contributors listed on page iii.

** Type of seismograph

1. Short period (vertical and/or horizontal)
2. World Wide Standard Seismograph Station
3. Seismic Array
4. Seismological Research Observatory
5. Long and short period seismographs

TABLE 4. FOCAL PARAMETERS, UPPER COLO NSW AND MARRYAT CREEK EARTHQUAKES

Upper Colo NSW earthquake: 20 February

	Azimuth	dip
P-axis	353	00
T-axis	262	30
B-axis	082	60
Double couples	A	B
Strike	040	122
Dip	70	70

Marryat Creek SA mainshock: 30 March

	Azimuth	dip
P-axis	220	04
T-axis	314	41
B-axis	122	48
Double couples	A	B
Strike	170	096
Dip	58	67

Marryat Creek SA aftershock: 11 July

	Azimuth	dip
P-axis	332	44
T-axis	230	11
B-axis	130	44
Double couples	A	B
Strike	000	106
Dip	49	68

TABLE 5. AUSTRALIAN ACCELEROGRAPHS, 1986

	LAT° S	LONG° E	ELEV.(m)	FOUNDATION	TYPE	OWNER
NEW SOUTH WALES						
Oolong (OOL)	34.773	149.163	600	Firm soil/granite	SMA-1	BMR
Dalton (DAL)	34.723	149.168	580	Granite	PIT	BMR
Ferndale (FND)	34.745	149.166	580	Granite	PIT	BMR
Hume Weir	36.110	147.043	600	Dam wall	SMA-1	WRC
Hume Weir	36.110	147.043	600	Dam wall	SMA-1	WRC
Hume Weir	36.110	147.043	600	Dam wall	SMA-1	WRC
Hume Weir	36.110	147.043	329	Downstream bank	SMA-1	WRC
Hume Weir	36.110	147.043	600	Left hand abutment	SMA-1	WRC
AAEC	34.053	150.978	80	Reactor basement	SMA-1	AAEC
SOUTH AUSTRALIA						
Kangaroo Ck Dam	34.87	138.78	244	Slates/schists	MO2	EWSSA
Little Para Dam	34.75	138.72	102	Dolomite	MO2	EWSSA
Modbury Hospital	34.83	138.70	50	Marl & clay	MO2	PWDSA
Admin. Centre	34.925	138.608	50	Alluvium	MO2	PWDSA
TASMANIA						
Gordon Dam	42.71	145.97	350	Quartzite	MO2	HEC
WESTERN AUSTRALIA						
Cadoux						
Kalajzic C. (CA-K)	30.810	117.132	300	Sandplain	MO2	BMR
Shankland (CA-S)	30.810	117.132	300	Sandplain	MO2	BMR
Avery (CA-C)	30.851	117.160	300	Tertiary sands/granite	MO2	BMR
Kalajzic M. (CA-A)	30.746	117.151	320	Laterite	A700	BMR
Robb (CA-R)	30.781	117.138	300	Alluvium/granite	MO2	BMR
Mundaring Weir	31.967	116.169	250	Concrete wall	SMA-1	PWDWA
Perth						
Telecom	31.953	115.850	10	Basement	SMA-1	TEL
Exchange	31.953	115.850	40	Middle floor	SMA-1	TEL
Building	31.953	115.850	70	Top floor	SMA-1	TEL
VICTORIA						
Jeeralong (JNA)	38.351	146.419	330	Mesozoic sediments	PIT	PIT
Plane Track (PTA)	37.357	146.357	771	Palaeozoic sediments	PIT	PIT
Phillip Institute (PIT)	37.683	145.061	116	Eocene sediments	PIT	PIT
Dartmouth Dam	36.570	147.580	520	Dam crest	SMA-1	RWCV
Dartmouth Dam	36.570	147.580	520	Hoist house	SMA-1	RWCV
Dartmouth Dam	36.570	147.580	360	Downstream bank	SMA-1	RWCV
Dartmouth Dam	36.570	147.580	420	Downstream face	SMA-1	RWCV
Dartmouth Dam	36.570	147.580	360	Access tunnel	SMA-1	RWCV
Animal Health Lab	38.15	144.39	10		SMA-1	CSIRO
Animal Health Lab	38.15	144.39	10		SMA-1	CSIRO
Animal Health Lab	38.15	144.39	10		SMA-1	CSIRO

TABLE 5 (cont.)

AAEC	Australian Atomic Energy Commission
BMR	Bureau of Mineral Resources, Canberra/Mundaring
EWSSA	Engineering & Water Supply Department, South Australia
HEC	Hydroelectric Commission, Tasmania
PIT	Phillip Institute of Technology
PWDSA	Public Works Department, South Australia
PWDWA	Public Works Department, Western Australia
TEL	Telecom (Perth)
WRC	Water Resources Commission, NSW
RWCV	Rural Water Commission, Victoria

TABLE 6. ACCELEROGRAM DATA, 1986

MN DY	TIME	LAT° S	LONG° E	ML	LOC	H/E	COM	T(s)	ACC
01 04	1311	30.79	117.09	2.7	CA-S	(6)/(4)	PZ	0.04	4.1
							PN	0.04	2.6
							PE	0.05	2.4
							SZ	0.04	8.0
							SN	0.06	6.1
							SE	0.06	14.9
01 05	2140	30.76	117.11	2.3	CA-S	(6)/(4)	PZ	0.03	2.0
							PN	0.03	0.6
							PE	0.03	2.4
							SZ	0.04	1.8
							SN	0.05	4.4
							SE	0.04	3.6
01 06	1346	30.75	117.12	2.5	CA-S	(8)/(6)	SZ	0.03	1.6
							SN	0.07	2.6
							SE	0.09	5.7
01 06	1918	30.80	117.05	2.4	CA-S	(10)/(9)	PZ	0.03	7.2
							PN	0.04	2.6
							PE	0.03	0.6
							SZ	0.03	6.5
							SN	0.04	4.4
							SE	0.05	8.9
01 07	0227	30.77	117.09	2.3	CA-S	(8)/(6)	SZ	0.03	0.4
							SN	0.04	0.6
							SE	0.04	0.6
01 07	0807	30.77	117.09	2.2	CA-S	(7)/(5)	PZ	0.03	2.0
							PN	0.04	0.6
							PE	0.04	1.2
							SZ	0.03	3.1
							SN	0.04	2.9
							SE	0.04	4.8
01 07	1006	34.76	149.18	3.1	DAL	4/-	SH	0.08	1147.
01 07	1113	34.75	149.18	1.9	DAL	4/-	SH	0.08	127.
01 07	1155	34.75	149.18	2.1	DAL	4/-	SH	0.08	99.
01 07	1304	34.75	149.18	1.5	DAL	4/-	SH	0.08	62.
01 07	1417	34.76	149.17	1.6	DAL	4/-	SH	0.08	41.
01 07	1907	34.76	149.18	1.9	DAL	4/-	SH	0.08	43.
01 07	1931	34.76	149.19	1.8	DAL	4/-	SH	0.08	74.
01 07	1954	34.74	149.23	1.9	DAL	4/-	SH	0.08	66.

MN DY	TIME	LAT° S	LONG° E	ML	LOC	H/E	COM	T(s)	ACC
01 07	2006	34.75	149.18	1.7	DAL	4/-	SH	0.08	45.
01 07	2237	34.78	149.18	1.9	DAL	4/-	SH	0.08	83.
01 09	0536	30.75	117.12	2.0	CA-S	(8)/(6)	PZ	0.04	2.0
							PN	0.04	0.6
							PE	0.04	1.5
							SZ	0.03	2.5
							SN	0.05	4.4
							SE	0.05	5.4
01 19	0853	30.77	117.10	1.8	CA-S	(6)/(4)	LZ	0.066	7.8
							LN	0.054	6.9
							LE	0.048	5.9
01 19	1035	30.77	117.10	2.4	CA-S	(6)/(4)	SZ	0.042	2.0
							SN	0.042	1.0
							SE	0.048	3.9
					CA-K	(9)/(8)	LZ	0.027	2.9
							LN	0.030	2.9
							LE	0.042	3.9
02 06	1018	30.78	117.08	3.4	CA-S	(7)/(5)	PZ	0.030	9.8
							PN	0.042	29.4
							PE	0.042	4.9
							LZ	0.042	36.3
							LN	0.077	52.9
							LE	0.071	45.1
					CA-K	(10)/(9)	LZ	0.027	2.0
							LN	0.030	2.9
							LE	0.030	2.0
03 01	0407	34.77	149.16	1.3	DAL	4/-	SH	0.08	36.
03 03	0317	34.76	149.20	1.5	DAL	4/-	SH	0.08	15.
03 03	0318	34.77	149.18	1.5	DAL	4/-	SH	0.08	10.
03 07	1535	34.79	149.19	1.1	DAL	6/-	SH	0.08	4.
03 07	1859	34.76	149.20	2.1	DAL	5/-	SH	0.08	77.
03 22	2204	34.78	149.22	1.1	DAL	5/-	SH	0.08	8.
03 24	1007	34.72	149.20	0.8	DAL	2/-	SH	0.08	22.
04 01	1054	34.79	149.18	2.1	DAL	7/-	SH	0.08	46.
04 01	1129	34.79	149.18	2.1	DAL	7/-	SH	0.08	26.
04 01	1210	34.80	149.18	2.3	DAL	7/-	SH	0.08	44.

MN DY	TIME	LAT° S	LONG° E	ML	LOC	H/E	COM	T(s)	ACC
04 01	1958	34.79	149.19	2.0	DAL	7/-	SH	0.08	56.
04 11	1558	34.77	149.19	1.0	DAL	5/-	SH	0.08	16.
04 27	1617	34.76	149.18	0.9	DAL	3/-	SH	0.08	14.
04 28	0524	34.76	149.20	1.5	DAL	4/-	SH	0.08	15.
03 31	1032	30.72	117.13	1.8	CA-K	6/2	SZ	0.036	4.8
							SN	0.030	1.6
							SE	0.036	2.8
05 15	1206	117.13	30.76	3.4	CA-K	8/6.5	PZ	0.036	1.7
							PN	0.030	2.0
							PE	0.030	1.0
							SZ	0.042	3.4
							SN	0.024	5.3
							SE	0.042	15.0
					CA-S	5.5/4	PZ	0.036	4.2
							PN	0.045	7.0
							PE	0.036	4.0
							SZ	0.036	2.5
							SN	0.088	14.0
							SE	0.072	6.0
							LZ	0.076	6.0
							LN	0.076	14.0
							LE	0.076	7.0
05 17	2244	34.77	149.20	1.6	DAL	5/-	SH	0.08	20.
05 20	0631	34.77	149.18	1.7	DAL	5/-	SH	0.08	44.
05 21	0327	30.78	117.10	2.4	CA-S	4.0/1.0	PZ	0.030	3.3
							PN	0.024	4.2
							PE	0.024	2.4
							SZ	0.030	2.5
							SN	0.036	1.8
							SE	0.052	10.0
05 27	0438	34.78	149.20	1.5	DAL	4/-	SH	0.08	22.
05 27	1711	30.83	117.12	3.0	CA-S	6.5/3.5	SZ	0.042	3.3
							SN	0.042	6.0
							SE	0.048	9.1
05 30	0621	34.78	149.17	1.6	DAL	5/-	SH	0.08	27.
05 31	1748	(30.81)	(117.13)	1.5	CA-S	3.0/0.0	PZ	0.030	0.8
							PN	0.036	1.2
							PE	0.036	1.2
							SZ	0.036	1.3
							SN	0.054	2.4

TABLE 6 (cont.)

MN DY	TIME	LAT° S	LONG° E	ML	LOC	H/E	COM	T(s)	ACC
							SE	0.048	2.4
06 06	2052	34.76	149.21	1.1	DAL	3/-	SH	0.08	25.
06 16	1816	34.75	149.20	1.2	DAL	4/-	SH	0.08	19.
06 23	0629	34.92	149.86	2.8	DAL	67/-	SH	0.08	10.
06 25	0337	34.76	149.18	1.8	DAL	4/-	SH	0.08	33.
07 01	0839	34.77	149.19	1.1	DAL	4/-	SH	0.08	9.
07 05	0820	34.76	149.20	1.2	DAL	4/-	SH	0.08	24.
07 07	1351	34.79	149.19	1.9	DAL	6/-	SH	0.08	9.
07 07	2024	30.83	117.04	2.8	CA-S	9/9	PZ	0.04	4.0
							PN	0.04	0.6
							PE	0.04	1.8
							SZ	0.03	3.2
							SN	0.03	2.8
							SE	0.05	1.8
							LZ	0.03	4.0
							LN	0.05	4.0
							LE	0.03	1.8
					CA-K	15/15	LZ	0.03	1.4
							LN	0.03	1.6
							LE	0.03	2.3
					CA-R	11/11	LZ	0.03	2.8
							LN	0.05	5.4
							LE	0.05	2.8
07 18	1009	30.80	117.06	2.2	CA-K	(10)/(10)	LZ	0.025	1.4
							LN	0.03	1.1
							LE	0.03	1.2
08 09	1342	30.75	117.15	1.0	CA-A	(1)/(0)	LZ	0.065	6.0
							LN	0.020	19.1
							LE	0.026	28.4
08 13	0905	30.78	117.14	1.5	CA-R	(2)/(1)	LZ	0.030	0.6
							LN	0.061	0.6
							LE	0.073	0.6
08 20	2025	30.75	117.15	1.3	CA-A	2/1	SZ	0.025	11.8
							SN	0.025	46.0
							SE	0.035	22.5
08 23	0602	30.76	117.08	2.6	CA-S	8/7	PZ	0.037	6.2
							PN	0.030	4.1
							PE	0.030	3.6
							SZ	0.037	7.0

TABLE 6 (cont.)

MN DY	TIME	LAT° S	LONG° E	ML	LOC	H/E	COM	T(s)	ACC
							SN	0.030	3.5
							SE	0.037	9.5
					CA-A	6/4	SZ	0.067	5.9
							SN	0.030	13.7
							SE	0.030	14.7
08 27	0729	30.75	117.15	1.0	CA-A	(2)/(1)	SZ	0.065	8.3
							SN	0.030	16.6
							SE	0.025	8.8
09 11	0005	30.81	117.08	2.0	CA-K	(3)/(4)	LZ	0.030	0.7
							LN	0.030	1.1
							LE	0.043	1.5
09 18	0702	30.69	117.16	1.5	CA-K	(3)/(4)	LZ	0.024	0.4
							LN	0.030	1.1
							LE	0.043	1.2
09 27	0701	30.72	117.14	2.3	CA-A	(5)/(4)	SZ	(0.18)	3.4
							SN	0.038	11.8
							SE	0.038	6.9
09 28	1718	30.75	117.14	2.8	CA-A	(3)/(1.5)	PZ	0.12	5.4
							PN	0.23	2.0
							PE	0.13	0.8
							SZ	0.038	9.8
							SN	0.038	30.4
							SE	0.038	14.7
09 29	2157	30.73	117.13	3.3	CA-A	5/2.5	PZ	0.13	4.9
							PN	0.17	5.1
							PE	0.13	0.9
							SZ	0.13	16.7
							SN	0.05	64.1
							SE	0.04	26.5
10 01	1921	30.78	117.12	2.0	CA-A	(5)/(5)	SZ	(0.14)	3.4
							SN	0.038	16.2
							SE	0.038	10.8
10 03	0932	30.72	117.14	1.3	CA-K	(2)/(1)	SZ	0.030	1.4
							SN	0.030	2.7
							SE	0.030	5.7
10 04	1628	30.76	117.07	1.8	CA-K	(5)/(4)	PZ	0.021	0.7
							PN	0.021	0.6
							PE	0.021	0.6
							SZ	0.030	6.9
							SN	0.030	9.1
							SE	0.024	5.7
10 05	0132	30.76	117.08	2.6	CA-K	(5)/(4)	PZ	0.030	5.8
							PN	0.030	2.7

TABLE 6 (cont.)

MN DY	TIME	LAT° S	LONG° E	ML	LOC	H/E	COM	T(s)	ACC
							PE	0.030	2.9
							SZ	0.042	22.8
							SN	0.048	18.8
							SE	0.045	28.4
10 05	0132	30.76	117.08	2.6	CA-K	(5)/(4)	PZ	0.030	18.7
							PN	0.030	2.7
							PE	0.030	11.4
							SZ	0.030	21.9
							SN	0.042	21.5
							SE	0.036	22.8
					CA-A	(7)/(6)	SZ	0.16	2.9
							SN	0.051	13.2
							SE	0.05	4.9
10 05	0143	30.75	117.09	2.2	CA-K	(5)/(4)	PZ	0.024	2.3
							PN	0.024	1.1
							PE	0.024	0.3
							SZ	0.030	5.8
							SN	0.042	7.9
							SE	0.030	5.7
10 05	0402	30.73	117.14	0.4	CA-K	(2)/(1)	SZ	0.030	0.7
							SN	0.030	1.1
							SE	0.030	0.9
10 05	1048	30.73	117.13	0.7	CA-K	(3)/(2)	PZ	0.030	0.7
							PN	0.030	0.6
							PE	-	0.0
							SZ	0.030	3.4
							SN	0.024	3.7
							SE	0.030	6.9
10 06	1252	30.76	117.08	1.2	CA-K	(5)/(4)	PZ	0.024	0.7
							PN	-	0.0
							PE	-	0.0
							SZ	0.030	2.7
							SN	0.036	4.3
							SE	0.030	1.7
10 06	1252	30.76	117.08	0.9	CA-K	(5)/(4)	PZ	0.024	3.0
							PN	0.024	0.6
							PE	0.030	0.9
							SZ	0.030	2.1
							SN	0.030	3.2
							SE	0.030	2.3
10 08	1955	30.77	117.08	1.5	CA-K	(6)/(5)	PZ	0.024	0.7
							PN	-	0.0
							PE	0.024	0.3
							SZ	0.024	5.5
							SN	0.024	1.1

TABLE 6 (cont.)

MN DY	TIME	LAT° S	LONG° E	ML	LOC	H/E	COM	T(s)	ACC
							SE	0.024	1.2
10 08	1955	30.77	117.08	1.2	CA-K	(6)/(5)	PZ	0.030	1.7
							PN	-	0.0
							PE	0.036	0.3
							SZ	0.024	2.1
							SN	0.024	0.5
							SE	0.024	1.2
10 09	0156	30.72	117.12	2.7	CA-K	4/1	PZ	0.024	3.4
							PN	0.024	2.7
							PE	0.024	2.4
							SZ	0.048	13.6
							SN	0.045	40.3
							SE	0.045	21.7
					CA-A	6/4	SZ	0.08	4.4
							SN	0.058	17.2
							SE	0.08	7.4
10 19	2036	30.75	117.15	1.8	CA-A	3/1	PZ	0.019	9.0
							PN	0.021	3.1
							PE	0.02	7.4
							SZ	0.029	19.1
							SN	0.029	52.4
							SE	0.03	39.2
10 25	0823	30.75	117.15	1.5	CA-A	2/1	SZ	0.019	12.3
							SN	0.019	14.2
							SE	0.02	20.6
10 27	1036	30.73	117.12	2.0	CA-K	4/2	PZ	0.021	0.7
							PN	0.021	0.5
							PE	0.021	0.6
							SZ	0.024	3.4
							SN	0.030	3.7
							SE	0.024	6.3
11 03	1331	30.73	117.12	1.6	CA-K	(4)/(2)	SZ	0.030	2.0
							SN	0.030	0.5
							SE	0.030	1.0
11 07	2055	30.72	117.13	1.5	CA-K	(3)/(1)	PZ	0.030	0.3
							PN	0.030	0.5
							PE	0.030	0.6
							SZ	0.024	10.8
							SN	0.024	9.7
							SE	0.030	4.6
11 10	2253	30.72	117.14	1.1	CA-K	(3)/(2)	PZ	0.030	0.7
							PN	0.030	0.5
							PE	0.030	0.6
							SZ	0.024	0.7
							SN	0.037	1.6

TABLE 6 (cont.)

MN DY	TIME	LAT° S	LONG° E	ML	LOC	H/E	COM	T(s)	ACC
							SE	0.037	2.2
11 16	0215	30.73	117.12	1.7	CA-K	(4)/(2)	PZ	0.021	3.1
							PN	0.021	0.5
							PE	0.043	0.6
							SZ	0.030	5.1
							SN	0.043	5.4
							SE	0.043	7.4
12 15	0932	30.79	117.09	2.1	CA-R	(6)/(5)	LZ	0.037	2.1
							LN	0.037	(0.6)
							LE	0.037	(0.6)
12 31	2023	30.78	117.12	1.2	CA-R	(4)/(2)	LZ	0.04	(0.4)
							LN	0.04	(0.4)
							LE	0.04	(0.4)

MN Month
DY Day
TIME Universal Coordinated Time (UTC)
ML Richter magnitude
LOC Accelerograph code/location
H/E Hypocentral/epicentral distance (km)
COM Component
T(s) Ground period (s)
ACC Peak ground acceleration ($mm.s^{-2}$)

TABLE 7. PRINCIPAL WORLD EARTHQUAKES, 1986

(Earthquakes of magnitude 7.0 or greater, or causing damage or fatalities.
PAS--Pasadena, BRK--Berkeley, PMR--Palmer, Alaska, PAL--Palisades, New York,
JMA--Japan Meterological Agency, TRI--Trieste, NEIS--US Geological Survey)*

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude
11 Jan	19 42 21.9	Peru	9.51 S	77.51 W	5.3 mb

Depth 39 km. One person killed, about 20 houses destroyed, another 60 damaged and about 100 people homeless in the Huarmey area. About 40 animals killed by landslides. Felt (IV) at Casma and Huaraz and (II) at Chimbote.

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude
3 Feb	15 12 46.7	Mexico-Guatemala border region	15.08 N	92.07 W	4.7 mb

Depth 16 km. About 500 houses damaged at Ixchiguan, San Marcos Province, Guatemala. Damage to adobe houses in Mexico near the Tacana Volcano. Felt at Tapachula, Mexico.

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude
12 Mar	16 32 56.0	Idaho	47.47 N	115.80 W	2.0 ML(NEIS)

Depth 1 km. Rockburst in the Lucky Friday mine near Mullan Idaho. One person killed and two injured.

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude
5 Apr	20 14 28.7	Peru	13.41 S	71.79 W	5.3 mb 4.6 MS

Depth 51 km. At least 16 people killed, 170 injured and 2,000 houses destroyed in the Cuzco area. Landslides occurred near Cuzco.

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude
26 Apr	07 35 16.1	Kashmir-India border region	32.13 N	76.37 E	5.5 mb 5.3 MS

Depth 33 km. Six people killed, about 30 people injured and 85 percent of the houses damaged in the Dharmsala, India area. Felt at Lahore, Pakistan.

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude
30 Apr	07 07 18.1	Near coast of Michoacan, Mexico	18.40 N	102.97 W	6.2 mb 7.0 MS 6.9 MS(BRK) 6.8 MS(PAS)

Depth 27 km. Some minor damage (V) in the Mexico City city area. Slight damage at Ciudad Guzman and Guadalajara. Felt strongly in central and southwestern Mexico. Depth from broadband displacement seismogram.

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude
5 May	03 35 38.8	Turkey	37.99 N	37.81 E	5.9 mb 5.9 MS

* Based on USGS 'Earthquake Data Reports' and the SEAN bulletins.

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude
Depth 10 km. Fifteen people killed, 100 injured and approximately 4,000 houses damaged in the Dogansehir-Colbasi area. Damage to all houses in the village of Kapidere. Slight damage to houses around the cities of Adiyaman and Elbistan. Felt strongly at Gaziantep, Urfa, Kayseri, Sivas, Kahramanmaras Diyarbakie, Antakya and Mardin. Some dangerous cracks in the arch of Surgu Dam. Slight damage to railroads in the epicentral area. Depth from broadband displacement seismograms.					
7 May	22 47 10.8	Andreanof Islands, Aleutian Islands	51.52 N	174.78 W	6.4 mb 7.7 MS 7.9 MS(BRK) 7.8 MS(BRK)
Depth 33 km. Multiple event. Damage (VI) on Adak and Atka. Tsunami generated with observed wave heights 91 to 122 cm at Kapsa, Kauai and 61 to 91 cm at Hanalei, Kauai and along the coast of Washington. Maximum recorded wave heights at selected tide stations were as follows: 175 cm at Adak, 25 cm at Unalaska and 10 cm at Sand Point, Alaska; 55 cm at Hilo, 36 cm at Kahului and 27 cm at Honolulu, Hawaii; 45 cm at Copuimbo and 15 cm at Valparaiso, Chile; 46 cm at Kushiro, Hokkaido; 24 cm at Chichi-shima, Bonin Islands; 40 cm at Port Lyttleton, New Zealand; 12 cm at Crescent City, California; 10 cm at Wake Island and 5 cm at Apia, Samoa. Negative tsunami reports were received from Bering Island, USSR; San Francisco, California and Ponape, Caroline Islands.					
13 May	08 44 02.1	Turkey-USSR border region	41.43 N	43.74 E	5.7 mb 5.4 MS
Depth 10 km. Two people killed and about 1,500 buildings destroyed in the Akhalkalaki area, USSR. Slight damage in the Susuz area, Turkey. Felt (VII) at Akhalkalaki and Bakuriani, (V) at Stepanavan and Tbilisi, (IV) at Abastumani, Leninakan and Gegechkori and (III) at Goris, USSR Also felt at Cildir, Ardahan and Hanak, Turkey.					
20 May	05 25 46.9	Taiwan	24.13 N	121.62 E	6.1 mb 6.4 MS 6.0 MS(BRK) 5.8 MS(PAS)
Depth 19 km. One person killed and 5 injured in the Hua-Lien area. Felt throughout Taiwan. Depth from broadband displacement seismograms.					
6 Jun	10 39 46.9	Turkey	38.08 N	37.88 E	5.6 mb 5.6 MS 5.8 MS(PAS)
Depth 10 km. One person killed, 20 injured and damage in the Surgu area. Additional cracks in the Surgu Dam. A landslide blocked the road between Erkenek and Adiyaman. Felt at Malatya, Diyarbakir, Adiyaman and Urfa.					

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude
11 Jun	13 48 01.3	Near coast of Venezuela	10.60 N	62.93 W	6.0 mb 6.2 MS 5.9 MS(BRK) 6.1 MS(PAS)

Depth 19 km. Two people killed, 45 injured and many left homeless in the Cariaco area. Damage (VII) at Coropano, El Pilar and Rio Caribe. Felt (V) at Cumana and Maturin and (III) at Caracas. Felt at Barcelona, Peurto La Cruz and Valencia. Felt strongly on Trinidad; also felt at Bogota and Bucaramanaga, Colombia. Depth from broadband displacement seismograms.

20 Jun	17 12 46.9	Tibet	31.24 N	86.85 E	5.9 mb 6.1 MS

Depth 33 km. At least 58 houses collapsed and many damaged in the Omba area.

24 Jun	03 11 30.9	Papua New Guinea	4.45 S	143.94 E	6.6 mb 7.1 MS 6.9 mb(PAS)

Depth 102 km. Damage (VII) and landslides occurred throughout the Papua New Guinea highlands. Submarine cables from Madang to Guan and Madang to Cairns were damaged. Preliminary estimate of damage is approximately 500,000 U.S. dollars. Felt on New Guinea from Tabubil to Port Moresby and from Vanimo to Daru. Felt (III) at Arawa and Panguna, Bougainville. Depth from broadband displacement seismograms.

8 Jul	09 20 44.5	Southern California	34.00 N	116.61 W	5.8 mb 6.0 MS 6.0 ML(PAS)

Depth 12 km. At least 29 people injured and some damage in the Palm Springs- Morongo Valley area. Landslides occurred in the area. The most serious damage (VII) occurred at the Devers substation of Southern California Edison Company. Also some residences in the Whitewater Canyon area were badly damaged. Preliminary estimate of damage approximately 4.5 million dollars. Damage (VI) at Angelus Oaks, Desert Hot Springs, North Palm Springs, Palm Desert, Palm Springs and Yucca Valley. Felt throughout much of southern California. Also felt at Las Vegas, Nevada, Lake Havasu City, Arizona and in northern Baja California, Mexico. Depth 8.5 km from broadband displacement seismograms.

12 Jul	07 54 26.8	Southern Iran	29.96 N	51.58 E	5.7 mb 5.6 MS

Depth 10 km. One person killed, four injured and about 300 homes damaged in the Mamasani area. Felt at Shiraz.

13 Jul	13 47 08.2	Southern California	32.97 N	117.87 W	5.6 mb 5.8 MS 5.3 ML(PAS)

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude

Depth 10 km. Twenty-nine people injured, one critically and at least 50 buildings damaged in the Newport Beach-San Diego area. Preliminary estimate of damage 720 thousand dollars. Also some damage reported in the Tijuana area, Mexico. A small landslide occurred near lakeside in eastern San Diego County. Felt throughout the coastal area of southern California, from Santa Barbara to San Diego, east to Palm Springs and as far as Yuma, Arizona.

18 Jul	17 22 38.2	Venezuela	10.77 N	69.43 W	5.9 mb 4.9 MS

Depth 7 km. One person died from a heart attack and about 30 homes damaged in the Churuguara area. Felt in Falcon, Lara, Carabobo, Zulia, Aragua and Miranda. Depth from broadband displacement seismograms.

21 Jul	14 42 26.6	California Nevada border region	37.54 N	118.45 W	6.0 mb 6.2 MS 6.5 ML(BRK)

Depth 9 km. About 20 mobile homes were damaged and a number of others shaken off their foundations in the Chalfant Valley, California. Several buildings were damaged (VI) at Bishop, California. Landslides occurred in the area Fault rupture, maximum of 5 cm of right-lateral slip, occurred along faults in the Volcanic Tableland west of Chalfant Valley and in the White Mountains fault zone. The earthquake was felt throughout a large area of California and Nevada from San Francisco to Reno and south to Los Angeles and Las Vegas. Felt in high-rise buildings as far away as Salt Lake City, Utah. Depth 8.9 km from broadband displacement seismograms.

3 Aug	01 33 20.3	Turkey	37.20 N	37.30 E	5.0 mb 4.1 MS

Depth 12 km. Seventy houses damaged at Yesilce, Ucgoze and Sam, Gaziantep Province and 3 houses damaged at Karabiyikli, Kahraman Maras Province. Felt at Kahramanmaras, Adiyaman and Malatya. Felt also in the Eskisehir area.

14 Aug	19 39 13.6	Molucca Passage	1.80 N	126.52 E	6.6 mb 7.2 MS 7.4 MS(BRK)

Depth 33 km. Felt (IV) at Manado, Sulawesi and (II RF) at Cagayan de Oro, Mindanao.

30 Aug	21 28 35.4	Romania	45.55 N	26.32 E	6.4 mb 6.9 MS(NEIS)

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude

Depth 132 km. Damage (VIII) in the Focsani-Birlad area, including the collapse of a church. Felt (VII) at Bucharest. Two people killed, 558 injured, and about 55 000 homes damaged, leaving more than 12 500 people homeless in the Kishinev-Kagul area, USSR. Felt (VII) in northern Bulgaria; (V) in the Skopje area, Yugoslavia; (IV) at Simferopol and Kiev, USSR and Belgrade, Yugoslavia; (III) at Moscow, USSR and Titograd, Yugoslavia. Felt throughout central and eastern Hungary. Also felt in Greece, Turkey, southern Italy and eastern Poland. Depth from broadband displacement seismograms.

13 Sep	17 24 33.7	Southern Greece	37.03 N	22.20 E	5.8 mb 5.9 MS

Depth 29 km. Twenty people killed, about 300 injured, about 1500 buildings damaged or destroyed and 2500 people homeless in the Kalamai area. Felt in Lakonia and on Zakinthos. Also felt at Athens and in central Greece.

6 Oct	23 28 11.9	Yunnan Province, China	25.50 N	102.35 E	5.3 mb 4.5 MS

Depth 42 km. Several people injured and some houses damaged in the Fumin area.

10 Oct	17 49 23.7	El Salvador	13.83 N	89.13 W	5.0 mb 5.4 MS

Depth 5 km. At least 1000 people killed, 10 000 injured, 200 000 homeless and severe damage in the San Salvador area. About 50 fatalities were the result of landslides in the epicentral area. Some damage at Tegucigalpa, Honduras. Felt strongly in parts of Guatemala and Honduras. Felt throughout Central America.

10 Oct	20 50 14.3	El Salvador	13.81 N	89.39 W	3.9 MC(CCG)

Depth 5 km. Additional damage in the San Salvador area.

20 Oct	06 46 10.4	Kermadec Islands region	28.10 S	176.43 W	6.6 mb 8.2 MS 8.3 MS(BRK)

Depth 33 km. Objects knocked from shelves on Raoul Island. Felt at Napier and Wellington, New Zealand. Tsunami generated with maximum wave heights 22 cm at Hilo, 15 cm at Kahului, 13 cm at Honolulu and 7 cm at Kona, Hawaii; 14 cm at Papeete, Tahiti and 10 cm at Pago Pago, Samoa Islands.

14 Nov	21 20 04.6	Taiwan	23.96 N	121.82 E	6.2 mb 7.8 MS 7.5 MS(BRK)

Depth 33 km. Fifteen people killed, 44 injured and damage in the Taipei- Hua-lien area. Landslides occurred along the highway between Su-ao and Hua-lien. Taiwan to Guam and Taiwan to Okinawa undersea telecommunication cables were damaged. Felt strongly throughout Taiwan. Felt (III JMA) on Yonaguni-jima and (II JMA) on Ishigaki-shima, Ryukyu Islands.

25 Nov	13 59 42.1	Yugoslavia	44.14 N	16.41 E	5.3 mb 5.5 MS

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude
Depth 27 km. At least 12 people injured, damage (VIII) and landslides in the Knin-Grahova area. Felt strongly in many parts of southwestern Yugoslavia. Also felt along the northeastern coast of Italy and felt (III) in the Graz-Klagenfurt area, Austria.					
30 Nov	05 19 48.1	Brazil	5.55 S	35.75 W	5.0 mb
Depth 5 km. Approximately 1500 houses damaged (VII) in the Joao Camara area. Felt at Natal.					
7 Dec	14 17 10.5	Bulgaria	43.29 N	25.85 E	5.1 mb
Depth 28 km. At least 3 people killed, 60 injured and damage (VIII) in the Veliko Turnovo-Turgovishte area. Felt throughout Bulgaria. Also felt at Bucharest, Romania and Istanbul, Turkey.					
18 Dec	20 24 20.9	Poland	51.25 N	15.71 E	3.8 ML(KBA) 3.7 ML(GRF)
Depth 10 km. Three people killed and 5 injured in the Zabrze-Bielszowice Mine near Katowice.					
20 Dec	23 47 09.8	Iran	29.96 N	51.61 E	5.4 mb 5.1 MS
Depth 33 km. About 80 houses damaged in the Mamasani area.					

TABLE 8. NUCLEAR EXPLOSIONS, 1986

DATE m d	TIME (UT) h m s	SITE*	mb	Ms	LAT°	LONG°	REF#	CODE NAME
03 22	1615 00.0	NTS	5.1		37.083 N	116.066 W	PDE	'glencoe'
04 10	1408 30.1	NTS	4.9		37.218 N	116.183 W	PDE	'mighty oak'
04 20	2312 29.9	NTS	4.0		37. N	116. W	PDE	'mogolion'
04 22	1430 00.1	NTS	5.3	4.2	37.264 N	116.440 W	PDE	'jefferson'
04 26	1701 56.6	Mur	4.8		22.150 S	139.120 W	PDE	
05 06	1658 00.0	Mur	4.8		22 S	139 W	NZ	
05 21	1359 00.0	NTS			37.125 N	116.060 W	PDE	'panamint'
05 27	1715 00.0	Mur	4.7		22 S	139 W	NZ	
05 30	1724 58.6	Mur	5.6	4.3	21.860 S	139.030 W	ISC	
06 05	1504 00.1	NTS	5.3	4.2	37.098 N	116.016 W	PDE	'tajo'
06 25	2027 45.1	NTS	5.5	4.2	37.265 N	116.499 W	PDE	'darwin'(UK)
07 17	2100 00.1	NTS	5.7		37.279 N	116.356 W	PDE	'cybar'
07 24	1505 00.1	NTS	4.4		37.143 N	116.071 W	PDE	'cornucopia'
09 04	1609 00.1	NTS			37 N	116 W	NRDC	'galveston'
09 11	1457 00.1	NTS			37.069 N	116.050 W	PDE	'aleman'
09 30	2230 00.1	NTS	5.5	4.5	37.300 N	116.307 W	PDE	'labquark'
10 16	1925 00.1	NTS	5.6		37.220 N	116.462 W	PDE	'belmont'
11 10	1658 00.0	Mur	4.9		22 S	139 W	NZ	
11 12	1701 58.3	Mur	5.3		21.911 S	139.085 W	PDE	
11 14	1600 00.1	NTS	5.8	4.5	37.100 N	116.048 W	PDE	'gascon'
12 06	1710 00.0	Mur	5.0		22 S	139 W	NZ	
12 10	1714 58.3	Mur	5.2		21.926 S	138.917 W	PDE	
12 13	1750 05.1	NTS	5.5		37.263 N	116.412 W	PDE	'bodie'

*NTS Nevada, USA
EKaz East Kazakh, USSR
MUR Muroroa, French Polynesia

ISC International Seismological Centre, UK
NZ Department of Scientific and Industrial Research, New Zealand
PDE Preliminary Determination of Epicentres, USA
FOA National Defence Research Institute, Sweden
NRDC Natural Resources Defense Council, USA

APPENDIX

MODIFIED MERCALLI (MM) SCALE OF EARTHQUAKE INTENSITY (after Eiby, 1966)

MM I — Not felt by humans, except in especially favourable circumstances, but birds and animals may be disturbed. Reported mainly from the upper floors of buildings more than ten storeys high. Dizziness or nausea may be experienced. Branches of trees, chandeliers, doors, and other suspended systems of long natural period may be seen to move slowly. Water in ponds, lakes, reservoirs, etc., may be set into seiche oscillation.

MM II — Felt by a few persons at rest indoors, especially by those on upper floors or otherwise favourably placed. The long-period effects listed under MM I may be more noticeable.

MM III — Felt indoors, but not identified as an earthquake by everyone. Vibrations may be likened to the passing of light traffic. It may be possible to estimate the duration, but not the direction. Hanging objects may swing slightly. Standing motorcars may rock slightly.

MM IV — Generally noticed indoors, but not outside. Very light sleepers may be awakened. Vibration may be likened to the passing of heavy traffic, or to the jolt of a heavy object falling or striking the building. Walls and frame of building are heard to creak. Doors and windows rattle. Glassware and crockery rattle. Liquids in open vessels may be slightly disturbed. Standing motorcars may rock, and the shock can be felt by their occupants.

MM V — Generally felt outside, and by almost everyone indoors. Most sleepers awakened. A few people frightened. Direction of motion can be estimated. Small unstable objects are displaced or upset. Some glassware and crockery may be broken. Some windows crack. A few earthenware toilet fixtures crack. Hanging pictures move. Doors and shutters swing. Pendulum clocks stop, start, or change rate.

MM VI — Felt by all. People and animals alarmed. Many run outside. Difficulty experienced in walking steadily. Slight damage to masonry D. Some plaster cracks or falls. Isolated cases of chimney damage. Windows and crockery broken. Objects fall from shelves, and pictures from walls. Heavy furniture moves. Unstable furniture overturns. Small school bells ring. Trees and bushes shake, or are heard to rustle. Material may be dislodged from existing slips, talus slopes, or slides.

MM VII — General alarm. Difficulty experienced in standing. Noticed by drivers of motorcars. Trees and bushes strongly shaken. Large bells ring. Masonry D cracked and damaged. A few instances of damage to Masonry C. Loose brickwork and tiles dislodged. Unbraced parapets and architectural ornaments may fall. Stone walls crack. Weak chimneys break, usually at the roof-line. Domestic water tanks burst. Concrete irrigation ditches damaged. Waves seen on ponds and lakes. Water made turbid by stirred-up mud. Small slips, and caving-in of sand and gravel banks.

MM VIII — Alarm may approach panic. Steering of motor cars affected. Masonry C damaged, with partial collapse. Masonry B damaged in some cases. Masonry A undamaged. Chimneys, factory stacks, monuments, towers, and elevated tanks twisted or brought down. Panel walls thrown out of frame structures. Some brick veneers damaged. Decayed wooden piles break. Frame houses not secured to the foundation may move. Cracks appear on steep slopes and in wet ground. Landslips in roadside cuttings and unsupported excavations. Some tree branches may be broken off.

MM IX General panic. Masonry D destroyed. Masonry C heavily damaged, sometimes collapsing completely. Masonry B seriously damaged. Frame structures racked and distorted. Damage to foundations general. Frame houses not secured to the foundations shift off. Brick veneers fall and expose frames. Cracking of the ground conspicuous. Minor damage to paths and roadways. Sand and mud ejected in alluviated areas, with the formation of earthquake fountains and sand craters. Underground pipes broken. Serious damage to reservoirs.

MM X Most masonry structures destroyed, together with their foundations. Some well-built wooden buildings and bridges seriously damaged. Dams, dykes, and embankments seriously damaged. Railway lines slightly bent. Cement and asphalt roads and pavements badly cracked or thrown into waves. Large landslides on river banks and steep coasts. Sand and mud on beaches and flat land moved horizontally. Large and spectacular sand and mud fountains. Water from rivers, lakes, and canals thrown up on the banks.

MM XI Wooden frame structures destroyed. Great damage to railway lines. Great damage to underground pipes.

MM XII Damage virtually total. Practically all works of construction destroyed or greatly damaged. Large rock masses displaced. Lines of slight and level distorted. Visible wave-motion of the ground surface reported. Objects thrown upwards into the air.

Categories of non-wooden construction

Masonry A Structures designed to resist lateral forces of about 0.1 g, such as those satisfying the New Zealand Model Building By-law, 1955. Typical buildings of this kind are well reinforced by means of steel or ferro-concrete bands, or are wholly of ferro-concrete construction. All mortar is of good quality and the design and workmanship are good. Few buildings erected prior to 1935 can be regarded as Masonry A.

Masonry B Reinforced buildings of good workmanship and with sound mortar, but not designed in detail to resist lateral forces.

Masonry C Buildings of ordinary workmanship, with mortar of average quality. No extreme weakness, such as inadequate bonding of the corners, but neither designed nor reinforced to resist lateral forces.

Masonry D Buildings with low standards of workmanship, poor mortar, or constructed of weak materials like mud brick and rammed earth. Weak horizontally.

Windows Window breakage depends greatly upon the nature of the frame and its orientation with respect to the earthquake source. Windows cracked at MM V are usually either large display windows, or windows tightly fitted to metal frames.

Chimneys The 'weak chimneys' listed under MM VII are unreinforced domestic chimneys of brick, concrete block, or poured concrete.

Water tanks The 'domestic water tanks' listed under MM VII are of the cylindrical corrugated-iron type common in New Zealand rural areas. If these are only partly full, movement of the water may burst soldered and riveted seams. Hot-water cylinders constrained only by supply and delivery pipes may move sufficiently to break pipes at about the same intensity.

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