Report 303

Australian Seismological Report, 1987

Marion Michael–Leiba & Vic Dent

Bureau of Mineral Resources, Geology and Geophysics

Department of Primary Industries and Energy

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

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Compiled by

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ABSTRACT

Seismicity in the Australian region in 1987 was above average due to the occurrence of foreshocks of the three large (magnitude 6 to 7) earthquakes near Tennant Creek in January 1988. There were 173 events of magnitude 3 or more, but 64 of these were Tennant Creek foreshocks. There were 37 events with magnitudes of 4 or more, and six of these had magnitudes of at least 5 on the Richter scale. Of the six, four were Tennant Creek foreshocks occurring in January 1987, and the other two were off the coast of Western Australia. The largest event was a Tennant Creek foreshock with Richter magnitude ML 5.5. A magnitude ML 4.9 event in December 1987 near Nhill, Western Victoria, caused minor damage in the epicentral region and was felt over a relatively wide area. Lithgow, NSW, incurred tens of thousands of dollars worth of minor damage from a magnitude ML 4.3 earthquake very near the town in June 1987. Isoseismal maps were drawn up for earthquakes at Tennant Creek (NT), Cadoux (WA), Bega (NSW), Dampier (WA), Lithgow (NSW), Wooroloo (WA), for three events at Oolong (NSW), and for a Banda Sea earthquake.

The nuclear monitoring group established by the BMR during 1984 continued to monitor underground nuclear explosions. The Alice Springs Seismic Array Processor, developed by the Australian Seismological Centre in conjunction with US agencies, was dedicated by the Minister for Resources and Energy on 24 June 1987.

During 1987 a total of 47 presumed underground nuclear explosions, 23 by the USSR, 15 by the USA, eight by France and one by the Peoples Republic of China, were detected. This compares with a total of 23 in 1986.

INTRODUCTION

This report contains information on all earthquakes of Richter magnitude 3 or greater that were reported in the Australian region during 1987. It is the eighth 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, McCue, 1989a, and Gregson & Moiler, 1990). 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 1987 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 1987, 'Principal world earthquakes, 1987' lists the largest and most damaging earthquakes that took place during 1987, 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.

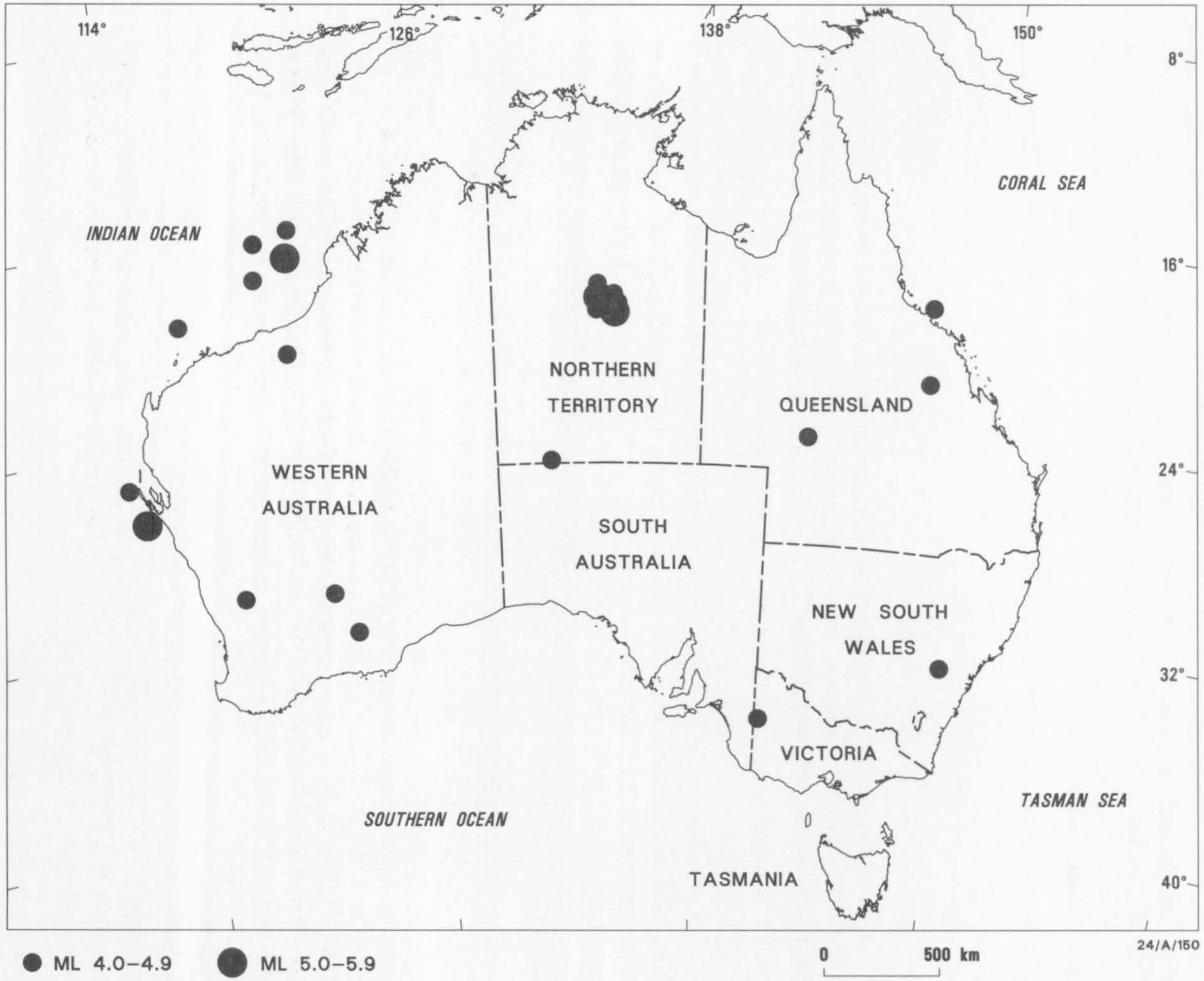


Figure 1. Australian region earthquakes, 1987, ML > 3.9

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. However, the Oolong, NSW, intensities were assessed using Richter's (1958) version of the MM scale which differs only slightly from that of Eiby (1966). 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, 1987

Table 1 lists the parameters of all 173 earthquakes of ML 3.0 or greater that were detected in the Australian region in 1987. The largest occurred on the 9 January at Tennant Creek, NT, and had magnitude ML 5.5. Six events of ML 5 or greater and 37 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, 1960-1986, and 23 for ML 4

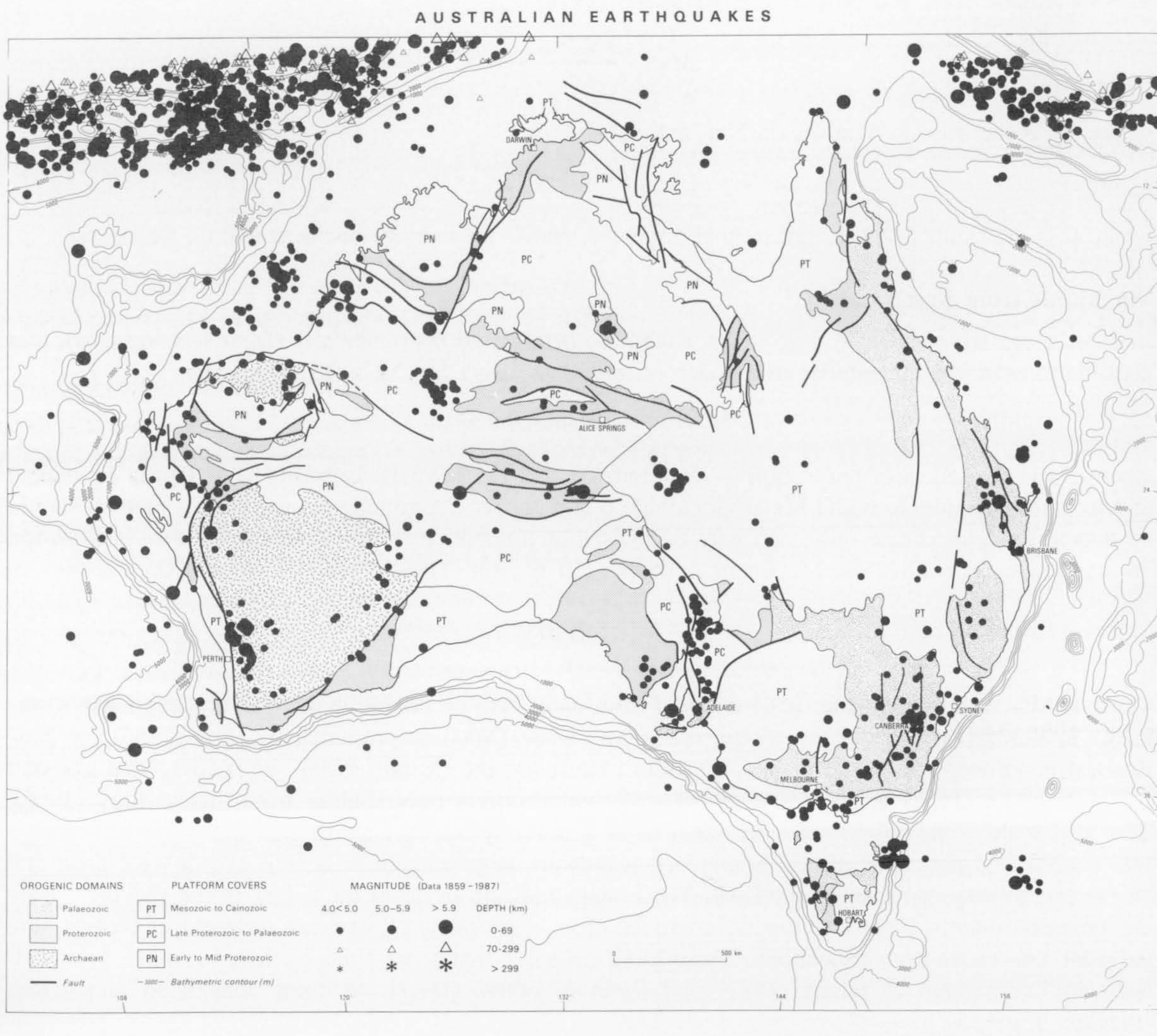


Figure 2. Australian region earthquakes, 1859-1987, ML > 3.9

or greater earthquakes, 1980-1986. For these periods the record of earthquakes in the stated magnitude ranges should be complete.

Australian seismicity during 1987 was, like 1986, above average. The most significant 1986 event was a magnitude 6 earthquake near Marryat Creek, in far northern South Australia. In January 1987, a foreshock series commenced southwest of Tennant Creek in the Northern Territory as a prelude to the three large earthquakes (magnitude 6-7) which occurred there a year later. The series included 64 events with magnitude ML 3 or greater, 19 with ML 4 or greater, and four with ML greater than or equal to 5. Other significant events were a magnitude ML 4.9 event near Nhill, in Western Victoria, and a magnitude ML 4.3 event which caused minor damage at Lithgow, NSW. Figure 1 shows earthquakes of magnitude equalling or exceeding ML 4 in the Australian region during 1987, and Figure 2 shows their epicentres for the period 1859-1987. Earthquakes of magnitude ML 6 or greater in the period 1859-1987 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 9, 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)

The number of Western Australian earthquakes in 1987 was relatively high, with 152 events of magnitude ML > 1.6 being located. The majority of these (56%) originated in the Southwest Seismic Zone. Significant activity occurred in the Wyalkatchem area, 170 km ENE of Perth, with 24 events being located there during the year (none in 1986). This activity continued into 1988 (Dent, 1990).

The Meckering area was also relatively active, with 15 events being located. The largest of these (ML 3.8) occurred on 2 March 1987, approximately 3 km east of Meckering. This is close to the epicentre of an ML 4.1 event on 1 September 1986, which was the largest Meckering event since the ML 6.9 event of October 1969.

The Cadoux area was also active, but not as many earthquakes were located there as in previous years (12 in 1987 as against 39 in 1986). The largest Southwest Seismic Zone earthquake for 1987 (ML 4.5 on 7 March) occurred there. Details of a fault plane solution (McCue, 1989) are given in Table 4 and the isoseismal map is shown in Figure 11.

The Dumbleyung area, 240 km southeast of Perth, was also unusually active, with 12 events being located there during the year.

On July 5, a relatively large (ML 2.7) event was recorded at Wooroloo, which is unusual for this area. This event is significant in that it is one of the closest recorded to Perth, only 50 km to the west.

In the rest of the State, a significant number of events (10) were recorded from a region approximately 60 km southeast of Norseman. This was part of declining activity following an ML 5.6 earthquake there in July 1985 (McCue, 1989).

Two events of magnitude > 4.9 occurred in Western Australia during 1987, and these were both offshore (120 km WNW of Kalbarri, ML 5.0, and 200 km WNW of Broome, ML 5.0).

Three moderate earthquakes occurred approximately 10 km ENE of Coolgardie in October 1987. The first event was the largest, ML 4.5, on 9 October. This was the second largest event ever to be recorded in the area. An ML 4.6 event occurred approximately 150 km east of this location in April 1977.

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

Northern Territory (Fig. 4)

The seismicity of the Northern Territory during 1987 was dominated by a sequence of earthquakes, approximately 30 km south-west of Tennant Creek. Seventy-five earthquakes of magnitude ML > 2.4 were located in this area during 1987. Most of these occurred in January and February 1987. This area was aseismic until the occurrence of two magnitude 4 events in 1986 (February and December). The 1986-1987 activity was a precursor to a much more significant series, which commenced on 22 January 1988 with three major earthquakes, each of magnitude greater than 6.0.

South Australia (Fig. 5)

Seismicity in South Australia returned to a more normal level in 1987, after a period of above average activity in 1986, which was due to the magnitude Ms 5.8 event at Marryat Creek on 30 March 1986, and its aftershocks (McCue & others, 1987).

The largest events in 1987 were both of ML 3.4, and occurred on 26 and 30 March. The first of these events was in the vicinity of Kangaroo Island, and not far from an ML 4.6 event on 16 December 1986. The event on 30 March was poorly located, but was close to the location of the Ms 5.8 event at Marryat Creek, which occurred exactly 12 months earlier.

Victoria (Fig. 6)

Almost 400 earthquakes were located within Victoria in 1987, but only 10 of these were reported felt. Almost 100 of the located earthquakes were small, shallow reservoir-induced earthquakes under Thomson Reservoir. These were all within 3 km of the surface, and under or near the reservoir.

An earthquake of magnitude ML 3.9 occurred near Seaton, 10 km east of Walhalla, on May 30 at 1444 UTC. The epicentre was in an uninhabited area, and the earthquake was quite deep, so only low intensities were reported. The earthquake was felt at many places within a radius of 40 km of the epicentre.

Two earthquakes of magnitude ML 3.0 were felt near Point Hicks in the far east of the State on November 11 and December 7.

The largest Victorian earthquake for several years occurred near the small town of Yanac in the far west of Victoria, north of Nhill at the southern boundary of the Big Desert (McCue & others, 1990). It was on December 22 at 1506 UTC (December 23 at 0206 am EDST). The magnitude was ML 4.9. The nearest seismograph was over 100 km from the epicentre, so there was little control over the depth. The focal mechanism parameters are given in Table 4.

The earthquake was widely felt over western Victoria and southeastern South Australia, from Portland to Mildura, and east to Bendigo (Figure 20). Considerable minor damage was caused within 50 km of the epicentre, including broken windows, cracked brickwork and concrete, and small items shaken from shelves. Minor damage was reported from Bordertown in South Australia at a distance of 80 km. Much of the epicentral area was in the uninhabited Big Desert.

A temporary network of five seismographs was installed by the evening of December 23, with the closest station being approximately 20 km from the epicentre. However, few aftershocks were recorded. Seven of the ten recorded aftershocks occurred within 15 hours of the mainshock, before this network was installed, and the last three were very small. The aftershocks larger than ML 1.5 were felt in the Yanac area.

No earthquakes had previously been located within 75 km of the epicentre. This was partly due to the poor seismograph coverage of the area, but there is no doubt that the area has fewer earthquakes than average for Victoria. None of the local residents interviewed could recall having previously felt any earthquake.

New South Wales (Fig. 7)

Twenty-four earthquakes with magnitude ML 3.0 or greater occurred in New South Wales in 1987. All except two were in the eastern part of the State.

The largest event was the magnitude ML 4.3 Lithgow earthquake in June which was felt from Mudgee in the north to Mittagong in the south, had several aftershocks, two within 24 hours of the mainshock having magnitudes greater than ML 3, and a maximum epicentral intensity of MM VII (Figure 17). It caused tens of thousands of dollars worth of minor damage to buildings in Lithgow. Details of a fault plane solution for the mainshock are given in Table 3 (McCue, K.F., personal communication).

After 16 months of comparative quiet, the Dalton-Gunning area experienced a magnitude ML 2.6 earthquake on Saturday 16 May followed by about 20 aftershocks. The next weekend, a swarm of another 20 events occurred, including two of magnitude ML 2.5. These were followed in June by the three largest earthquakes in the area for 17 months (Michael-Leiba & others, in prep.); their magnitudes were ML 2.9, 3.0 and 3.1 and they were felt with maximum intensities in Dalton of MM V, V and VI respectively (Figures 13, 16 and 18).

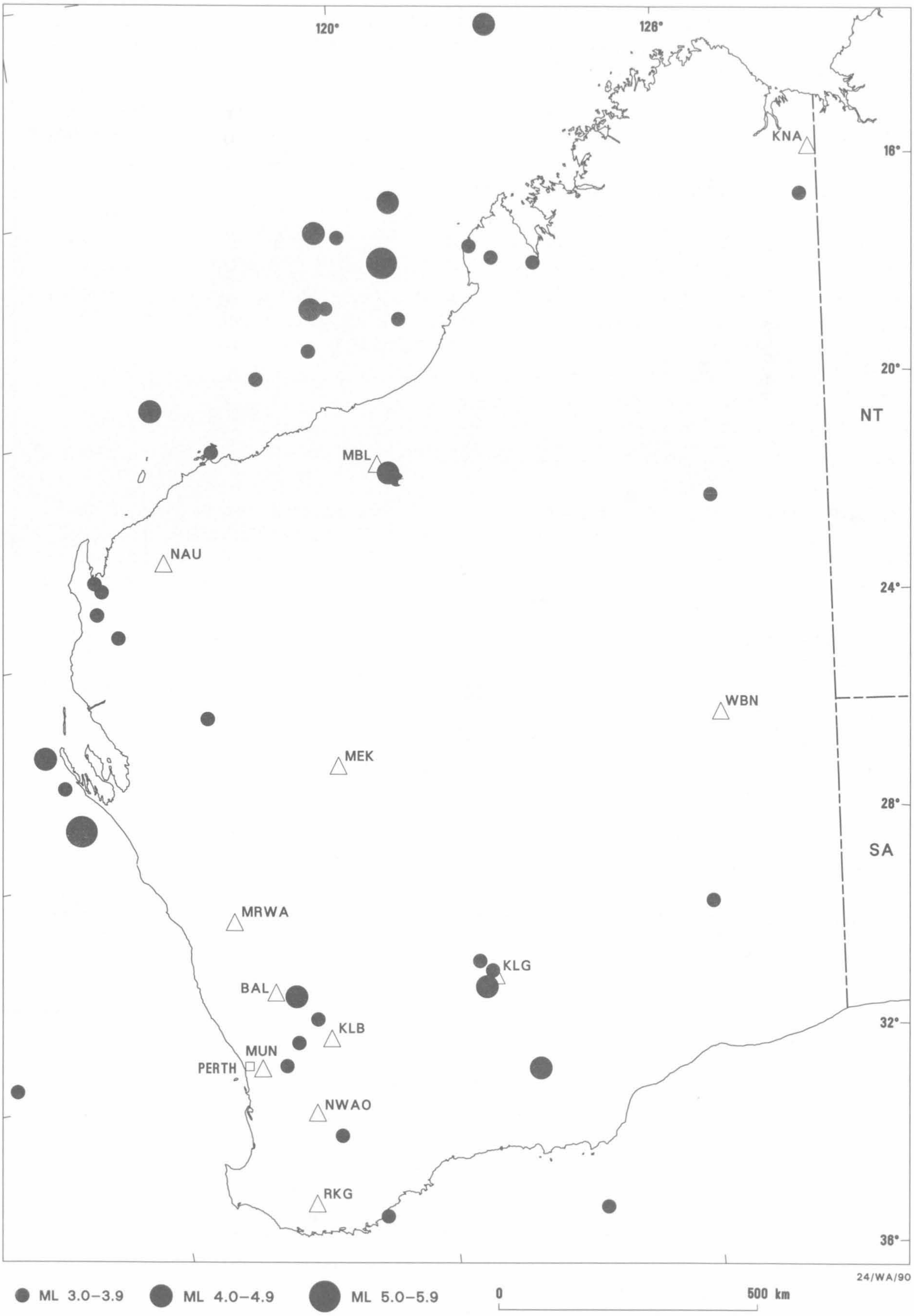


Figure 3. Western Australian earthquakes, 1987, ML > 2.4

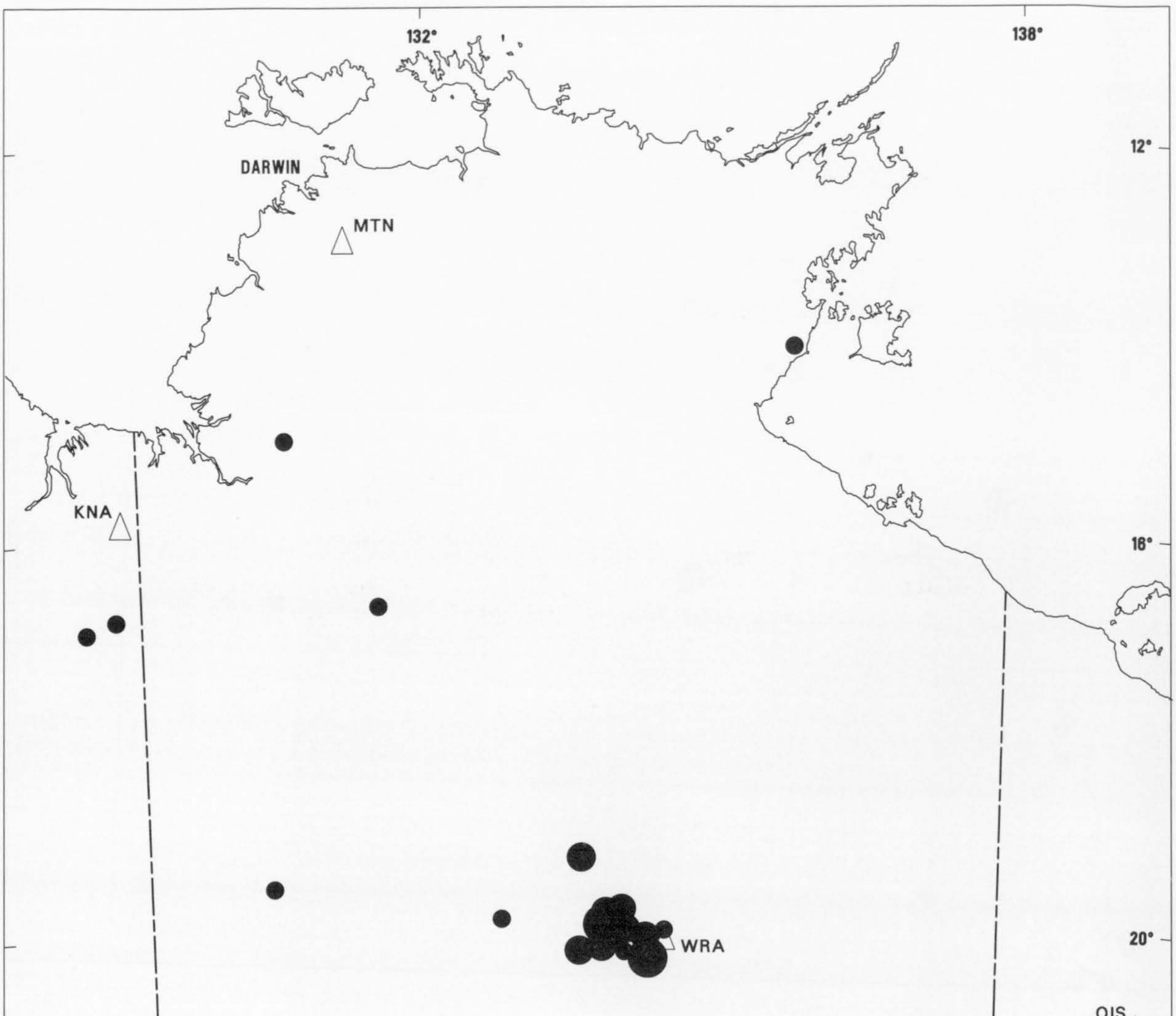


Figure 4. Northern Territory earthquakes, 1987, ML > 2.4

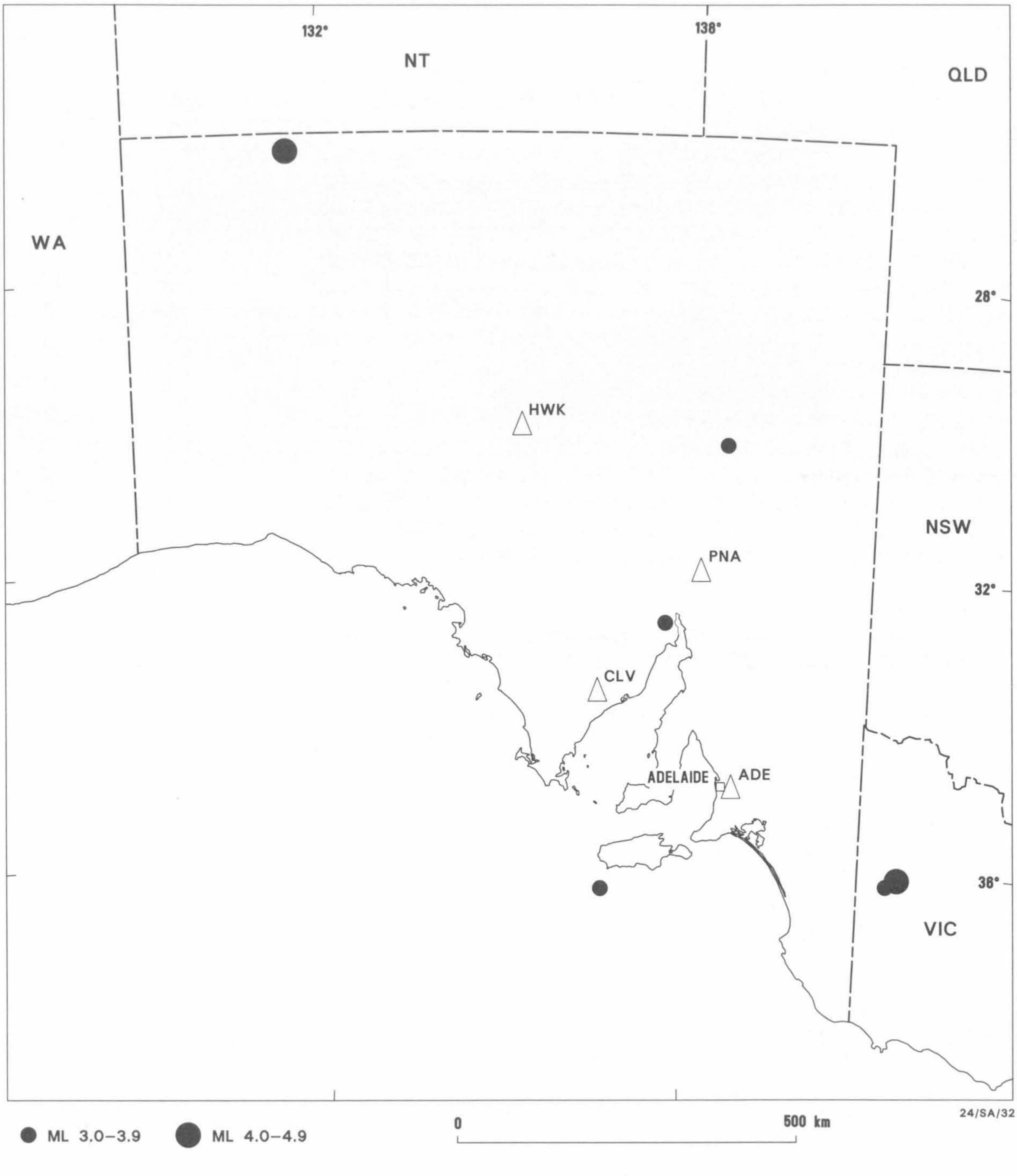


Figure 5. South Australian earthquakes, 1987, ML > 2.4

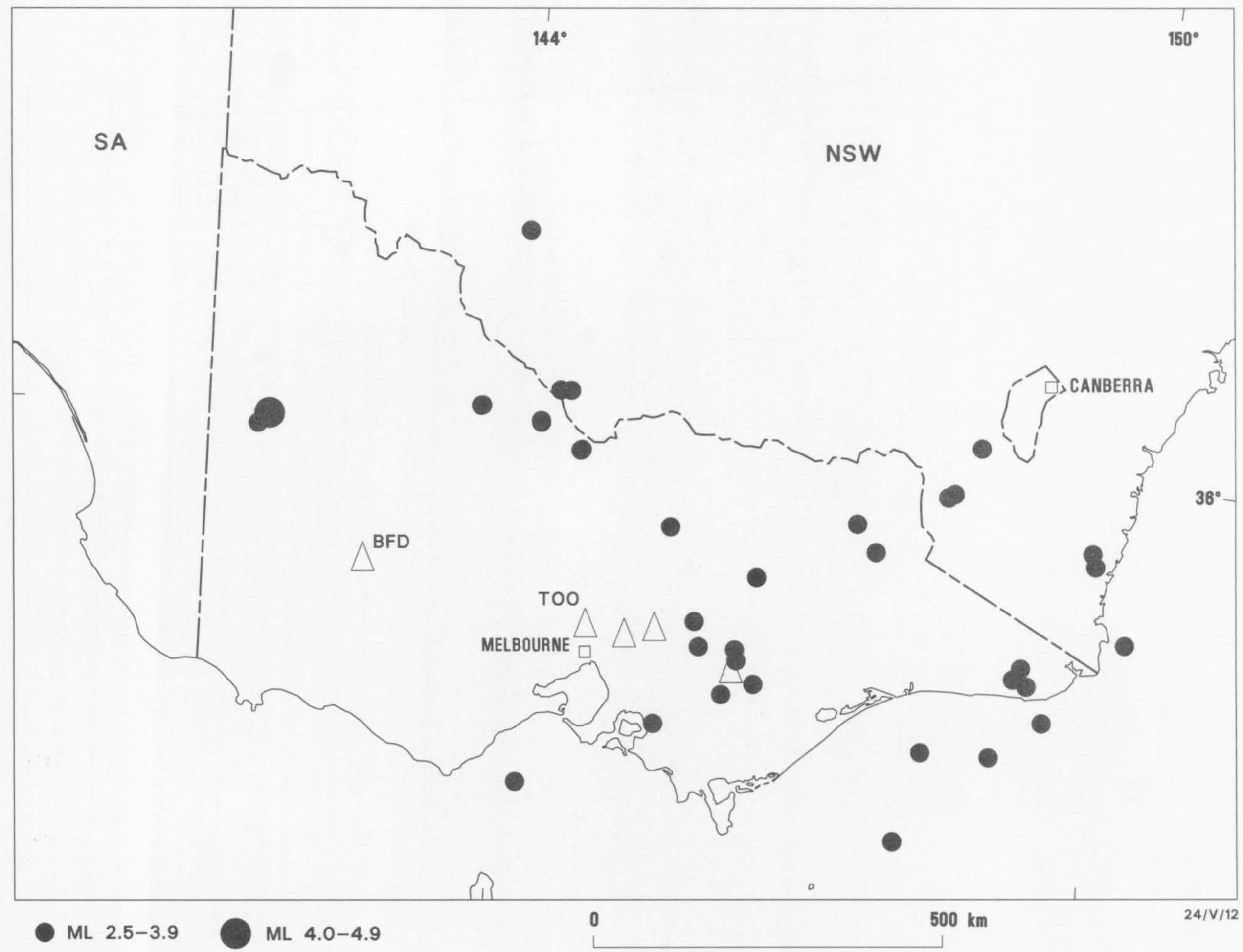


Figure 6. Victorian earthquakes, 1987, ML > 2.4

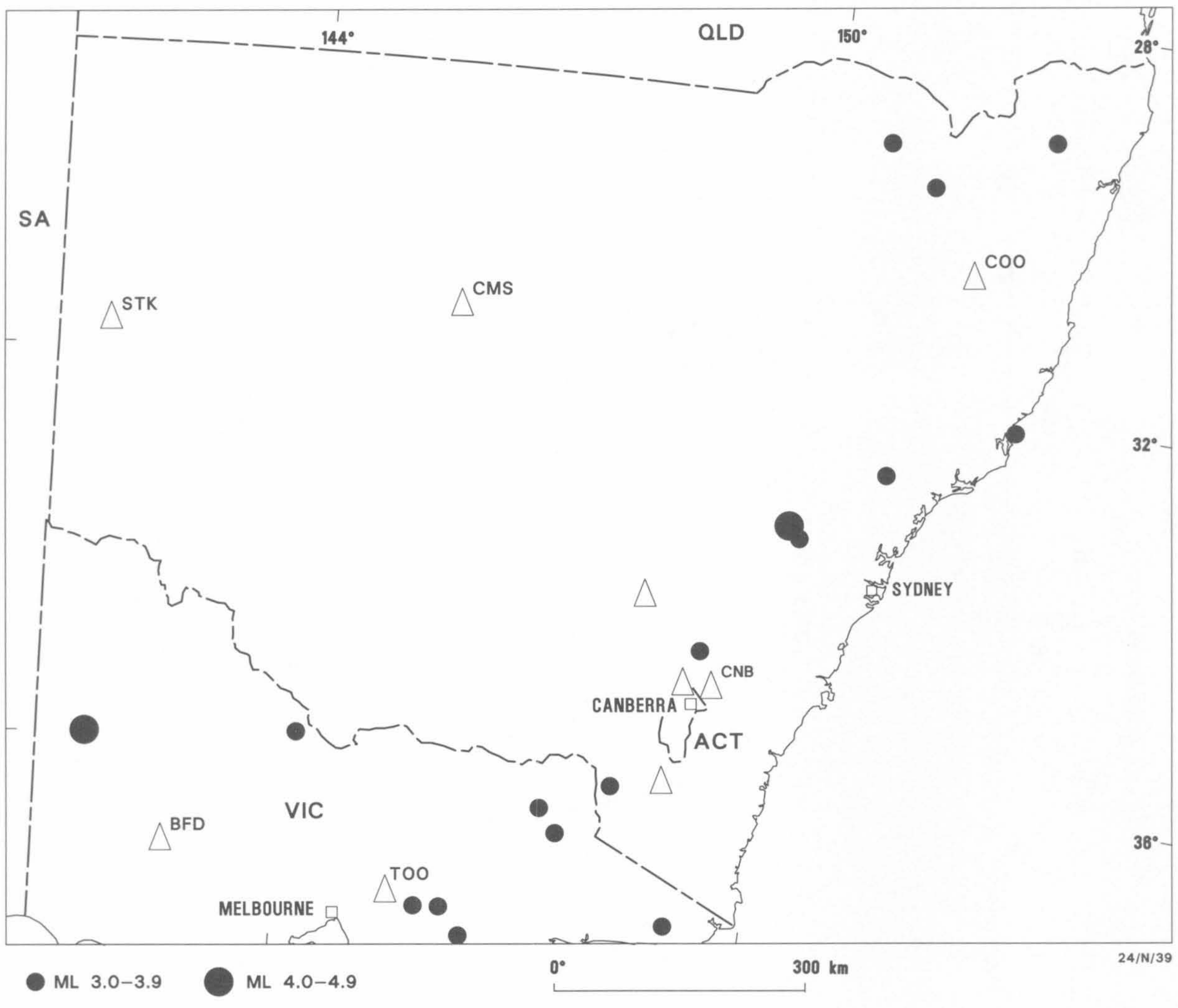


Figure 7. New South Wales and ACT earthquakes, 1987, ML > 2.4

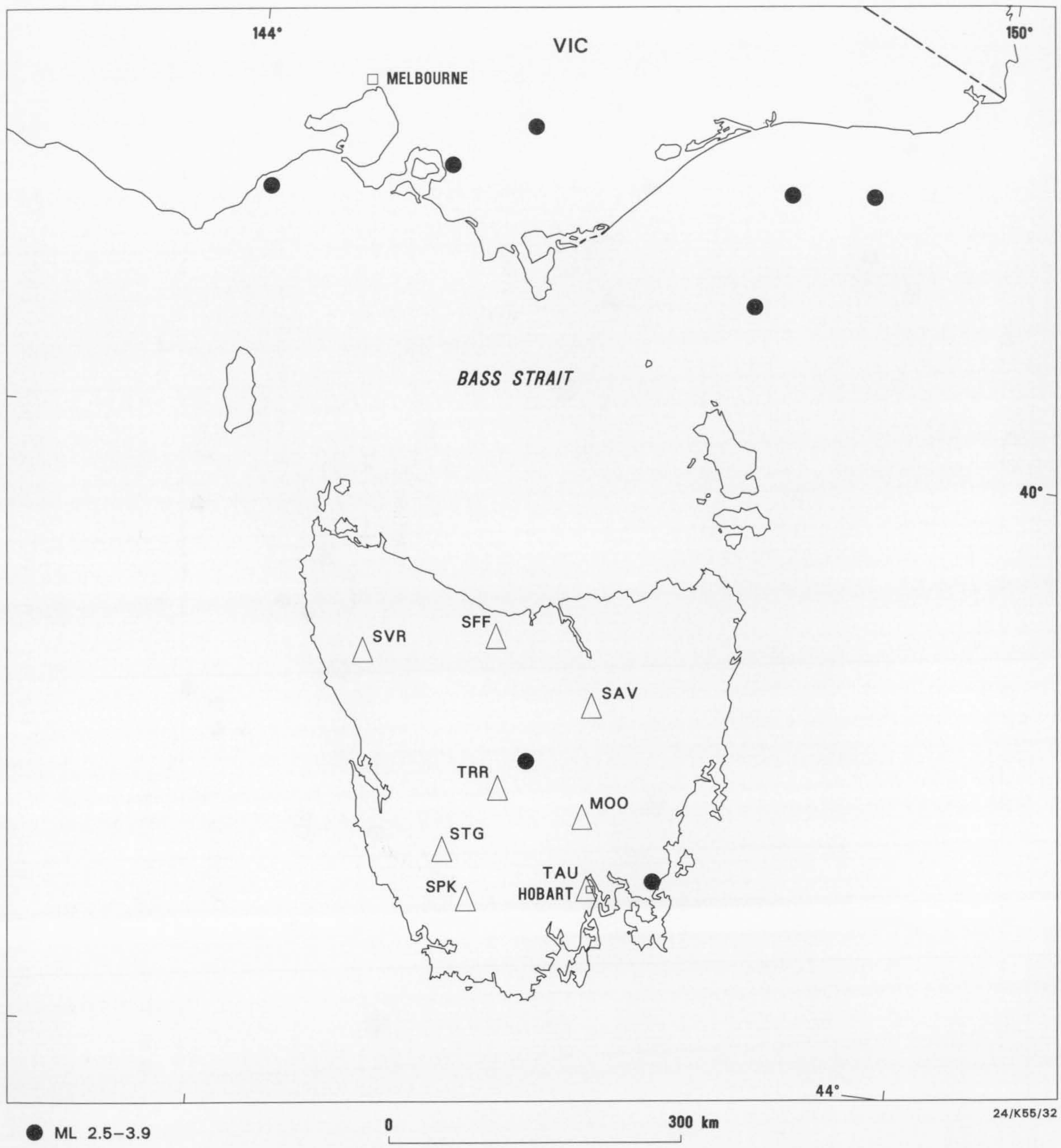


Figure 8. Tasmanian earthquakes, 1987, ML > 2.4

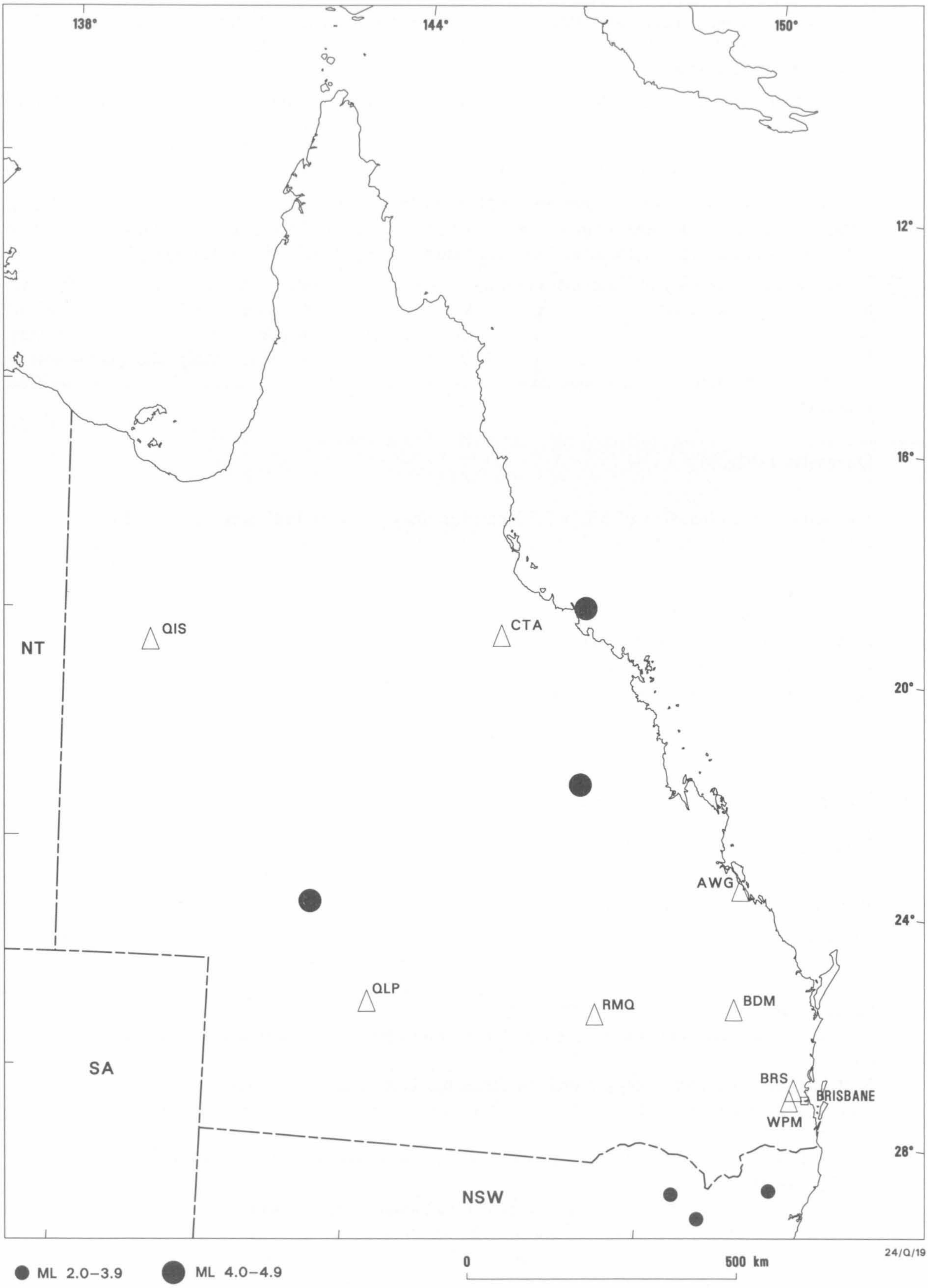


Figure 9. Queensland earthquakes, 1987, ML > 2.4

Tasmania (Fig. 8)

No earthquakes with magnitudes ML 3.0 or greater were recorded in Tasmania during 1987, and only nine had magnitudes of ML 2.0 or more. The largest event, of magnitude ML 2.7, occurred on 26 January in central Tasmania.

However, swarms of small earthquakes, which started in late 1986, under Bream Creek in southeastern Tasmania, continued into April 1987, with the activity virtually dying out by mid year. Although none of the events was very big, the largest in 1987 being only ML 2.5 (on 19 January), a number of them were heard and felt quite strongly (up to MMV).

The seismic activity peaked in January 1987 when approximately 100 events including the ML 2.5 occurred, the maximum number in a single day being around 30. This swarm continued into February. Other swarms occurred in November 1986 and March and April 1987 (Jones & others, 1988).

BMR and the University of Tasmania ran a network of four portable seismographs in the Bream Creek area for five weeks during March-April 1987. Most of the 20 events located using stations in this network had epicentres within 2 km of Bream Creek, and the focal depths of all were no greater than 4 km. Their duration magnitudes ranged from MD 1.0-1.7 (Jones and others, 1988). The shallowness and proximity to the town explains why some of the earlier, larger events caused alarm to Bream Creek residents.

Queensland (Fig. 9)

The number of earthquakes of ML > 2.5 located in Queensland in 1987 was relatively low. The largest was an ML 4.7 earthquake which occurred approximateley 100km east of Townsville on 28th September (local time). It was felt in the Townsville and Bowen areas with a maximum intensity of MM IV. A similar sized event (ML 4.7) occurred in the same region 2 years earlier (2 August, 1985). Two other events greater than magnitude 4 occurred in Queensland during 1987. These were an ML 4.2 event, approximately 200 km south-west of Mackay on 17 May, and an ML 4.1 event near Jundah, in the central south-west of the State, on 16 December.

(VIC DENT, MARION MICHAEL-LEIBA & GARY GIBSON)

ISOSEISMAL MAPS

Isoseismal maps based on the Modified Mercalli scale were prepared for 11 earthquakes, five in New South Wales, four in Western Australia, and one each in the Northern Territory and Victoria. Seven out of the 11 events occurred in June 1987.

Tennant Creek, Northern Territory (Fig. 10).

Between 5 and 9 January, four earthquakes in the range magnitude 4.9 to 5.4 rocked Tennant Creek and the surrounding region. Trevor Jones, ASC, installed three temporary seismographs in the area during the following week, and collected information on the distribution and degree of effects. The largest of the four earthquakes, at 2001 UTC on 7 January, caused minor damage in Tennant Creek 35 km northeast of the epicentre, and was felt at Alroy Downs homestead more than 200 km west of the epicentre.

A preliminary isoseismal map prepared by Jones has been updated and shows an asymmetric radiation pattern, extended in an eastwest direction. There were no reports from west of the epicentre, reflecting the lack of population.

Typical of the reports from Tennant Creek is the following which was added to a questionnaire distributed by Jones.

> A roar like thunder woke us up at 5.35 am we thought maybe it will rain in Tennant Creek! But within seconds we knew it was an earthquake. As the roar stopped the ground rumbled the same sound and we felt instantly the shock of the ground movement and the rumbling coming from due west towards us. The house shook so much we thought a lot of damage had to be done to the structure but fortunately only a few cracks occurred.

An extensive aftershock sequence was recorded on the temporary network and nearby Warramunga array. This included 349 events to 21 January 1988 when three large earthquakes occurred (Jones & others, in prep).

Cadoux, Western Australia (Fig. 11).

At 1.38 p.m. WST, on 7 March, an earthquake of Richter magnitude 4.5 occurred 4 km WSW of Cadoux, 170 km northeast of Perth. It was the largest earthquake in the area since November 1985 (ML 4.5), and was felt at a ground intensity of up to MM VI near the epicentre where cracks up to 2 mm wide appeared at Hopkins farm along the Robb Fault (which was produced during the destructive ML 6.2 earthquake of 2 June 1979). The average radii of the MM V and MM IV isoseismals were 21 km and 100 km respectively, and the earthquake was felt (MM III) in the outer suburbs of Perth. The isoseismal map is similar to that for the magnitude 4.3 earthquake which occurred near Cadoux on 10 October 1985.

Two kilometres from the surface cracks, the greatest ground acceleration (3.0 ms $^{-2}$) yet measured in Western Australia was recorded on an A700 digital accelerograph. It also triggered two newly-installed digital accelerographs in the wall of Canning Dam, which is 35 km southeast of Perth and 175 km south of the epicentre.

Bega, NSW (Fig. 12)

On 13 June an earthquake of magnitude ML 2.6 took place near Bega. It was felt over an area of approximately 650 km ^{2} and the reports of the shaking, which were all obtained from telephone interviews, indicated that the maximum felt intensity was equivalent to MMIV.

The area of felt shaking was well defined. In the east an observer near Tanja, who was seated in the house at the time, reported that she did not think she could have felt the shaking if she had been outside. In the north, reports from Margaret Park and Honeysuckle indicated that the sound of an explosion was heard and that "all the birds flew off" but the observers were outside and did not feel any shaking.

The highest intensities were experienced in and around Bega. At Milton Park and Scotland Yard the property owners reported feeling a jolt which vibrated the houses and hearing a sound like an explosion. The walls creaked and crockery rattled. It was reported as being felt by a horserider near Scotland Yard.

Several reports in the town of Bega indicated the rattling of crockery and shaking of houses, but there were also some 'not felt' reports. In the hospital it was felt by some, but not all.

To the east of Bega a report from a resident in a house 4 km west of the town described his house shaking and a sound like a large explosion.

The map was compiled from approximately 35 reports.

The epicentral determination is poor because of the absence of stations to the east and south but the instrumentally determined solution coincides reasonably well with the area of maximum shaking.

Oolong, NSW (Fig. 13)

The Oolong earthquake of 16 June was the largest in the Dalton-Gunning-Oolong area for 17 months. In the seven hours preceeding the event there were eight foreshocks and, in the 11 hours following, 13 aftershocks, with Richter magnitudes of 0.9 or more. This magnitude ML 2.9 earthquake could itself be considered a foreshock of the ML 3.0 event which occurred on 20 June, and the ML 3.1 event on 26 June.

The earthquake of 16 June occurred at 11.26 p.m. local time. It woke people at Dalton but did not cause any damage. The isoseismal map (Michael-Leiba and others, in prep.) was compiled from felt reports obtained by personal interview and over the telephone. The points assessed as intensity MM II on the map were places where the earthquake was heard but not felt.

At a digital accelerograph 5 km to the north, a peak ground acceleration of 0.20 ms $^{-2}$ was recorded.

Banda Sea (Fig. 14)

Large earthquakes from the Banda, Timor or Arafura Sea regions are usually felt in Darwin.

An earthquake of magnitude mb 6.7, occurred at 0133 UTC on 17 June in the Banda Sea, 740 km north of Darwin. The maximum intensity experienced in Australia was MM V in Darwin. No damage was reported. Intensities of MM V were experienced over an area of 90 000 km ^{2} in Australia up to 800 km from the epicentre.

Isolated reports of MM II were reported from Brisbane where gentle swaying was observed generally on the second floor of buildings. About 100 questionaires were distributed across the northern part of Australia. Response was poor from the remote areas.

The previous Indonesian earthquake that was felt strongly in northern Australia occurred on 23 October 1985 (Gregson & others, 1987).

Dampier, Western Australia (Fig. 15)

This earthquake occurred at 9.32 p.m. local time (1332 UTC) on 19 June. The maximum intensity experienced was MM IV at Dampier and Karratha, 10 and 25 km respectively from the epicentre. The earthquake was felt weakly up to 100 km from the epicentre.

Apart from Dampier, Karratha and Roebourne, the area is sparsely populated and therefore isoseismals are sketchy.

Reports of a bright light the size of the moon, travelling down towards the horizon north west of Roebourne occurred several minutes after the earthquake and were not related. The light could have been a meteorite.

Oolong, NSW (Fig. 16)

This magnitude ML 3.0 earthquake occurred at 6.23 p.m. local time on 20 June (Michael-Leiba and others, in prep.). The events of 16 June, the largest of which had magnitude ML 2.9, can be regarded as foreshocks, and the ML 3.0 event was followed by 16 aftershocks, with Richter magnitudes of 0.9 or more, within 36 hours. The 20 June earthquake may be considered to be a foreshock to the magnitude ML 3.1 event on 26 June (27 June, local time).

The isoseismal map was compiled from felt reports collected by phone or by personal interview. Where the earthquake was heard but not felt, it was assigned an intensity of MMII.

A peak ground acceleration of 0.94 ms^{-2} was recorded by a digital accelerograph 3 km to the northwest.

Lithgow, NSW (Fig. 17)

At 1505 UTC on 24 June (1.05 a.m. local time on 25 June) a magnitude ML 4.3 earthquake struck Lithgow, where it cracked walls and ceilings and damaged chimneys. In one house, the chimney collapsed through the roof and ceiling. The intensity at Lithgow was assessed as MMVI-VII. It was high because the epicentre was less than 5 km north of the town and the focus was shallow (5 km).

The earthquake was felt as far afield as Wollongong, Sydney, Newcastle and even Canberra, over 200 km from the epicentre.

This was the second damaging earthquake in Lithgow in less than three years. On 13 February 1985, a magnitude ML 4.3 event there caused an estimated $65 000 worth of damage. (Michael-Leiba and Denham, 1987). The total damage bill for the 1987 event was not assessed, but it was almost certainly greater.

The event of 24 June was preceded by a magnitude ML 2.5 foreshock on 23 June and an ML 3.1 earthquake 12 minutes before the main shock. It was followed within an hour by two aftershocks large enough (ML 3.4 and 3.5) to be located by BMR's regional network. The Australian Seismological Centre operated two portable seismographs in the Lithgow area from 25 June to 4 July 1987. A magnitude ML 1.8 aftershock on 27 June, located with the aid of these stations, had a depth of 5 km, and an epicentre at 33.46°S, 150.17°E, within 5 km of that of the main shock.

Oolong, NSW (Fig. 18)

This earthquake (Michael-Leiba and others, in prep.), with magnitude ML 3.1, occurred at 2328 UTC on 26 June (9.28 a.m. local time on 27 June). The ML 2.9 event on 16 June and the ML 3.0 earthquake on 20 June may be regarded as foreshocks of this event, which was the largest to occur in 18 months in the Dalton-Gunning-Oolong area. The event of 26 June was followed by 24 aftershocks, with Richter magnitudes of 0.9 or more, within 24 hours.

Felt reports for the isoseismal map were gathered by personal interview and by phone. The earthquake was felt most strongly at Dalton where things were rattled violently and some objects fell off a shop shelf. The intensity MM II points on the map represent reports of the earthquake having been heard but not felt.

The event triggered the accelerograph at Oolong, 4 km to the west, where a peak ground acceleration of at least 1.0 ms^{-2} was recorded. A similar acceleration (0.98 ms^{-2}) was recorded by a digital accelerograph 4 km to the northwest.

Wooroloo, Western Australia (Fig. 19)

This earthquake was located 3 km northeast of Wooroloo and occurred at 0528 UTC (1.28 p.m. WST) on 5 July.

Information was obtained from reports from residents in the area, and an on-site survey by staff of the Mundaring Geophysical Observatory.

The maximum intensity felt was MM IV over an area of 20 km^2 with intensity MM III being felt up to 10 km from the epicentre. An isolated report (MM II) was received from Bakers Hill, 13 km from the epicentre.

Although the earthquake was relatively small (magnitude ML 3.0), it is significant as it is the most westerly earthquake to be recorded in the Southwest Seismic Zone. Its epicentre was 25 km northeast of the observatory and 40 km from the centre of Perth. Previous tremors close to Perth have been at Clackline and Talbot Brook, 70 km east of Perth (Gregson & others, 1987).

Nhill, Victoria (Fig. 20)

On 22 December, a shallow magnitude ML 4.9 earthquake occurred in western Victoria where there is no previous record of seismic activity.

An excellent response was received to the intensity questionnaires distributed to residents of Victoria, southeastern South Australia and southwestern NSW. These were used to compile the isoseismal map. Minor damage occurred in brick and mud-brick houses in the closest towns, Yanac and Nhill, and reports of damage were also received from towns further afield as far as Bordertown in South Australia, 80 km from the epicentre. The earthquake was felt over an area of 145 000 km^2 which is large for an earthquake of this size. The Nhill earthquake was one the most widely felt in Victoria this century.

Its focal mechanism (Table 3), a thrust with a principal stress directed east-west, is typical of earthquakes in the Lachlan Fold Belt (McCue, Gibson and Wesson, 1990).

(MARION MICHAEL-LEIBA, PETER GREGSON, KEVIN McCUE, DAVID DENHAM, & VIC DENT)

NETWORK OPERATIONS

Table 4 gives the co-ordinates of seismograph stations and the types of seismographs in operation during the year (Fig. 21). The network includes two arrays, 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-six 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 Fig Tree (FGT) in Queensland and Dromana (DRO) in Victoria. Seismographs at Mt Isa (ISQ) and Awoonga Dam (AWG) in Queensland, and Nanutarra (NAU) and Warburton (WBN) in Western Australia were re-sited to reduce industrial noise. The station at Glen Eva (GVA) in Queensland was 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 & MARION MICHAEL-LEIBA)

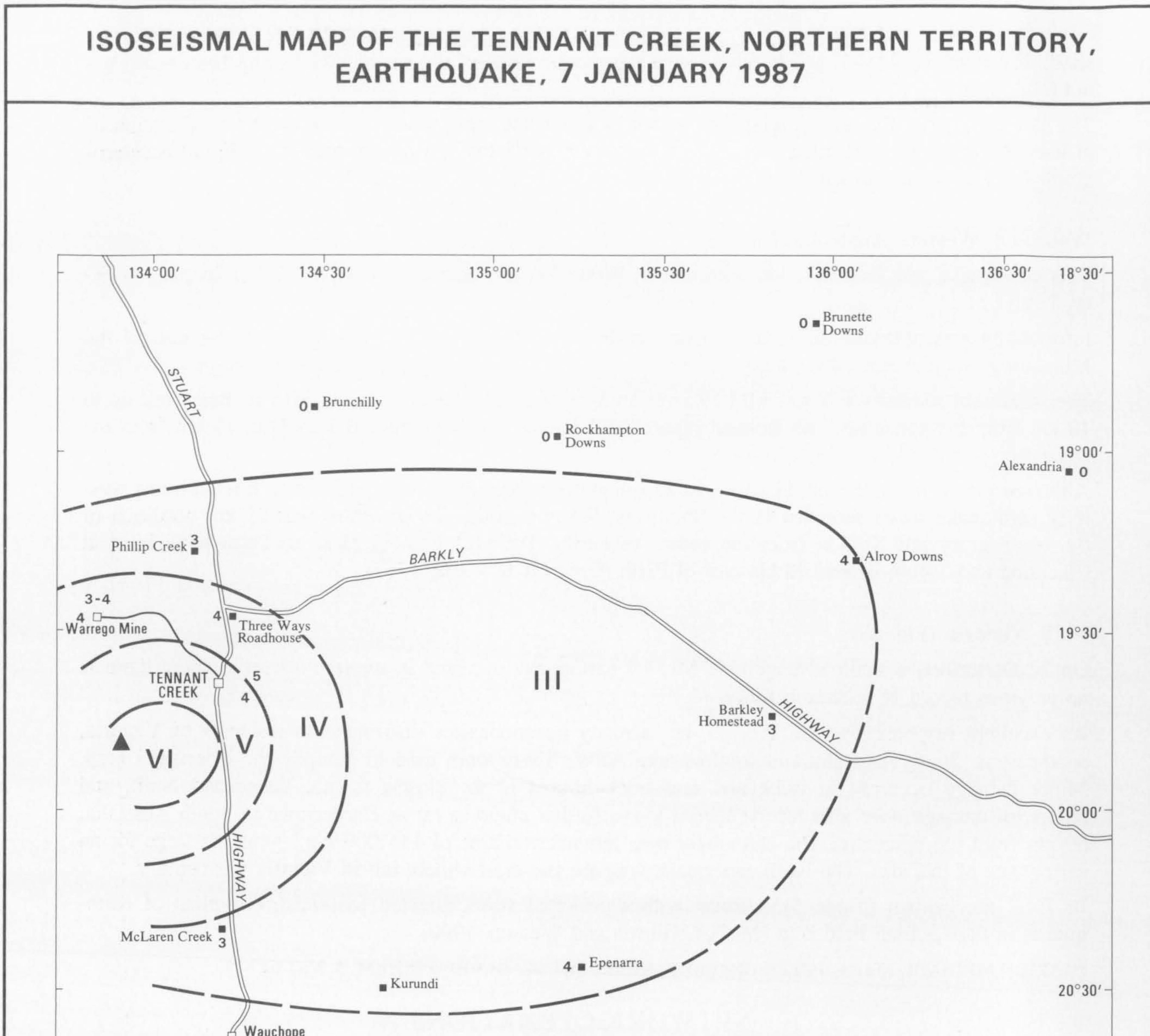
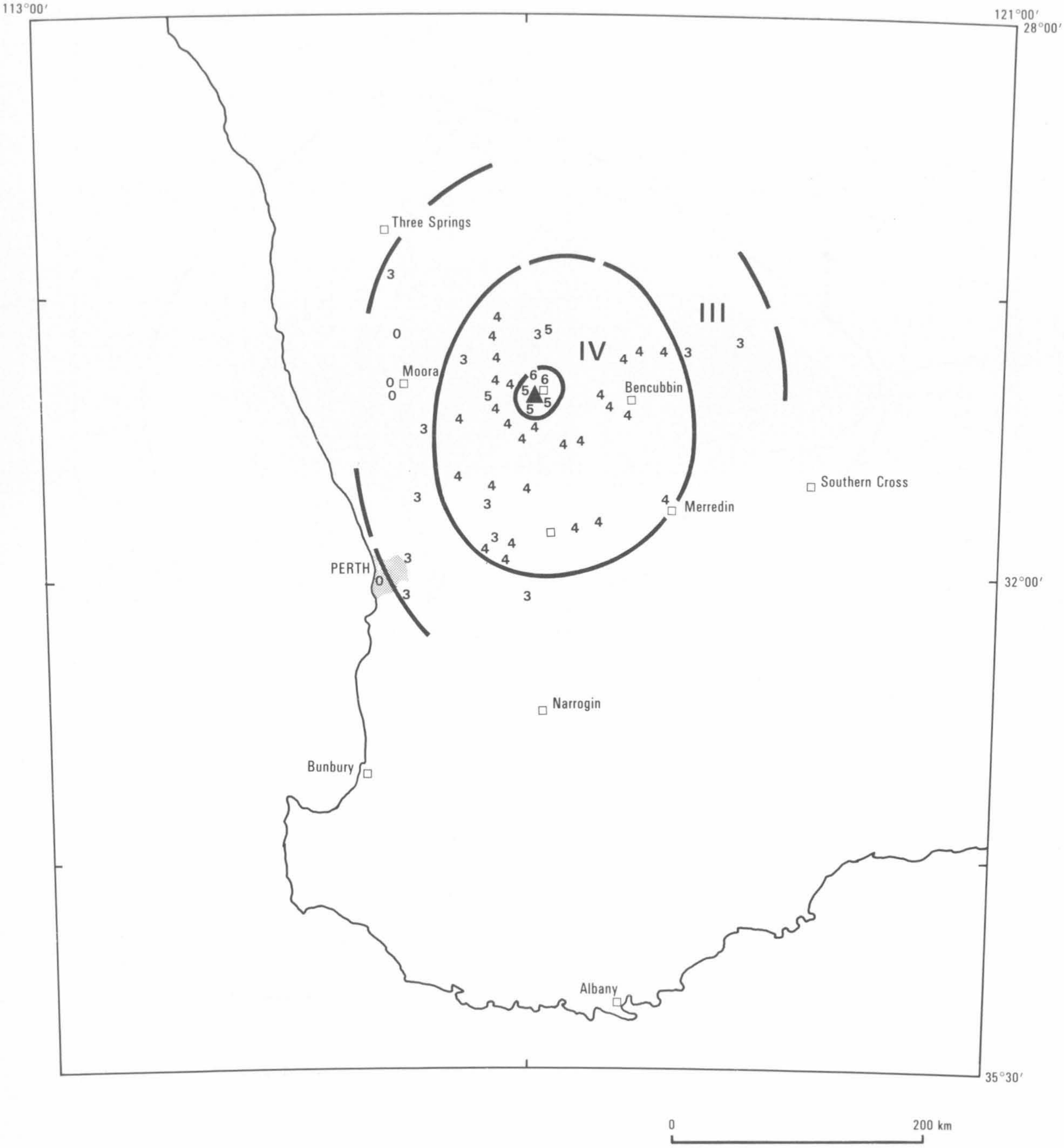

ISOSEISMAL MAP OF THE TENNANT CREEK, NORTHERN TERRITORY, EARTHQUAKE, 7 JANUARY 1987
134°00′
134°30′
135°00′
135°30′
136°00′
136°30′
18°30′
19°00′
19°30′
20°00′
20°30′
21°00′
0 Brunette Downs
0 Brunchilly
0 Rockhampton Downs
Alexandria 0
STUART
Phillip Creek 3
BARKLY
4 Alroy Downs
3-4
4 Warrego Mine
4 Three Ways Roadhouse
TENNANT CREEK
5
4
III
IV
V
VI
Barkley Homestead 3
HIGHWAY
HIGHWAY
McLaren Creek 3
4 Epenarra
Kurundi
Wauchope
Wycliffe Well 0
0
100 km
DATE : 7 January 1987
TIME : 20:01:51 UTC
MAGNITUDE : 5.4 ML (BMR)
EPICENTRE : 19,8°S, 133,9°E
DEPTH : Shallow
Epicentre
IV Zone Intensity Designation
4 Earthquake Felt (MM)
0 Earthquake Not Felt
WESTERN AUSTRALIA
NORTHERN TERRITORY
QUEENSLAND
SOUTH AUSTRALIA
NEW SOUTH WALES
ACT
VICTORIA
TASMANIA
24/E53-14/2

Figure 10

ISOSEISMAL MAP OF A CADOUX EARTHQUAKE, WESTERN AUSTRALIA
7 MARCH 1987



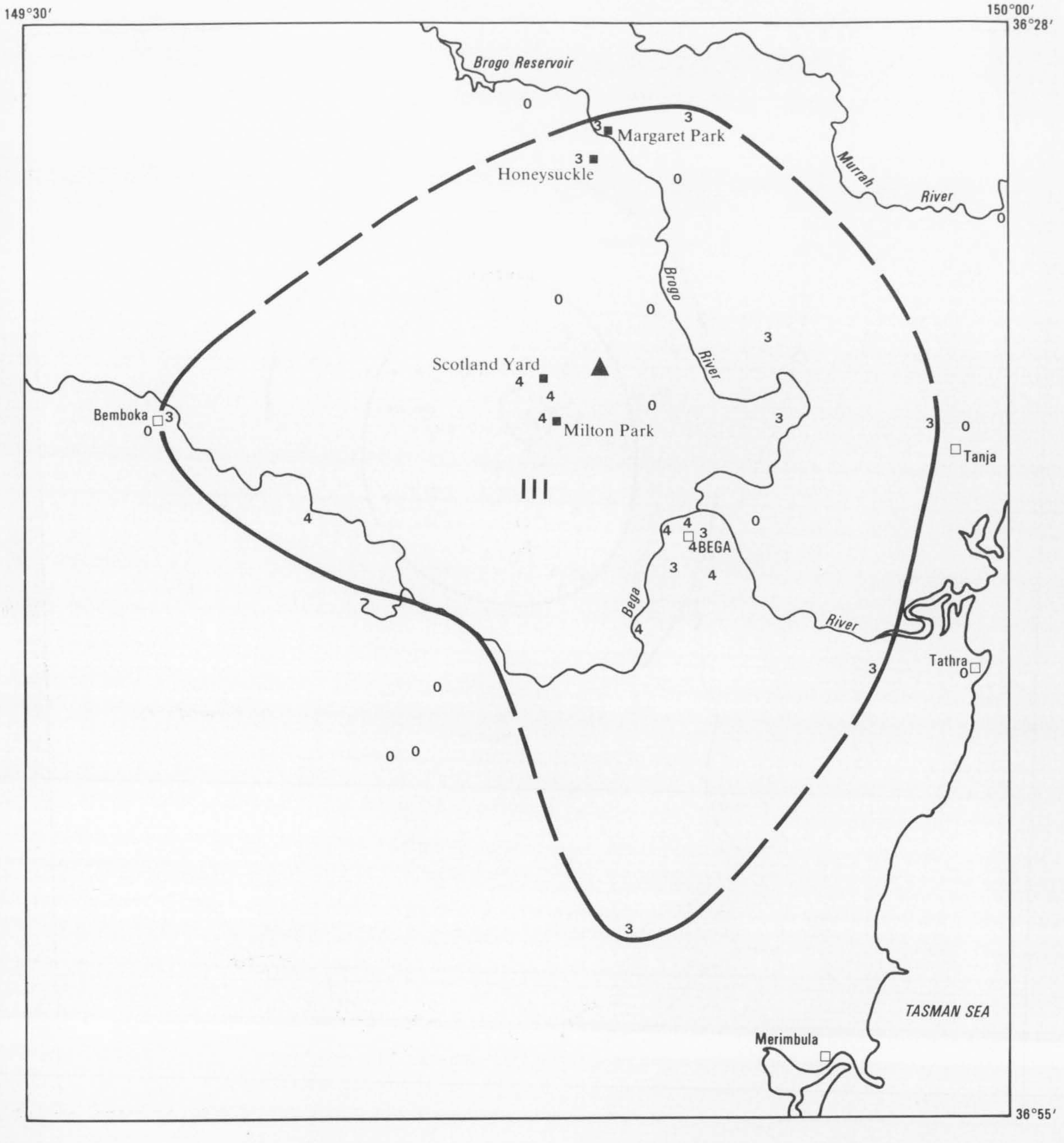
DATE : *7 March 1987*
TIME : *053807.7 UT*
MAGNITUDE : *4.5 ML (MUN)*
EPICENTRE : *30.77°S, 117.09°E*
DEPTH : *5 km*

▲ *Epicentre*
IV *Zone Intensity Designation*
4 *Earthquake Felt (MM)*
0 *Earthquake Not Felt*

24/H50/21

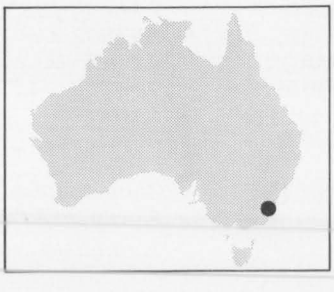
Figure 11

ISOSEISMAL MAP OF THE BEGA EARTHQUAKE, NEW SOUTH WALES, 13 JUNE 1987



DATE : 13 JUNE 1987
TIME : 04:34 UT
MAGNITUDE : 2.6 ML
EPICENTRE : 36.61°S 149.80°E
DEPTH : Crustal

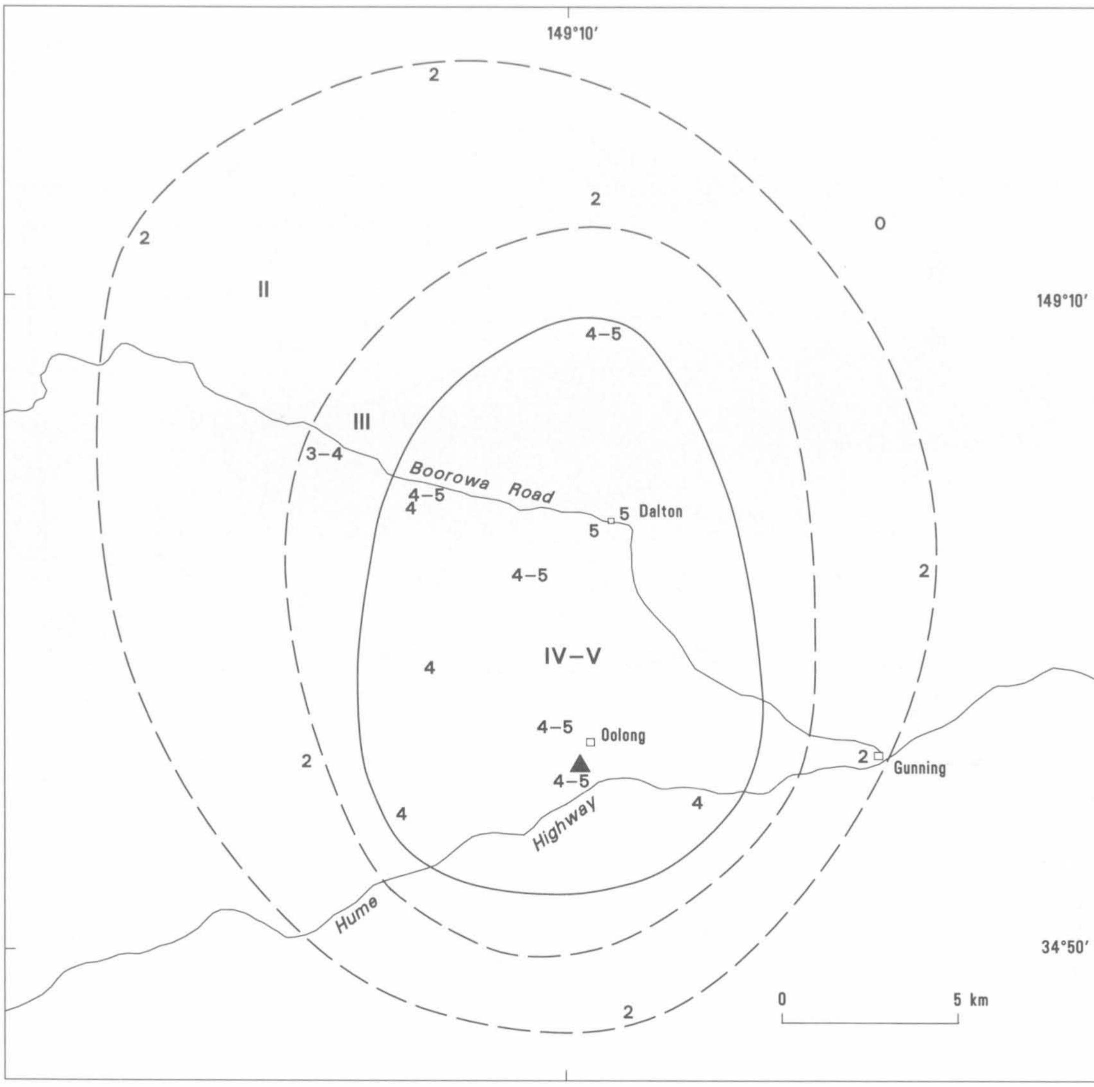
▲ *Epicentre*
IV *Zone Intensity Designation*
4 *Earthquake Felt (MM)*
0 *Earthquake Not Felt*



24/J55-4/1

Figure 12

ISOSEIMAL MAP OF THE OOLONG EARTHQUAKE, NSW, 16 JUNE 1987



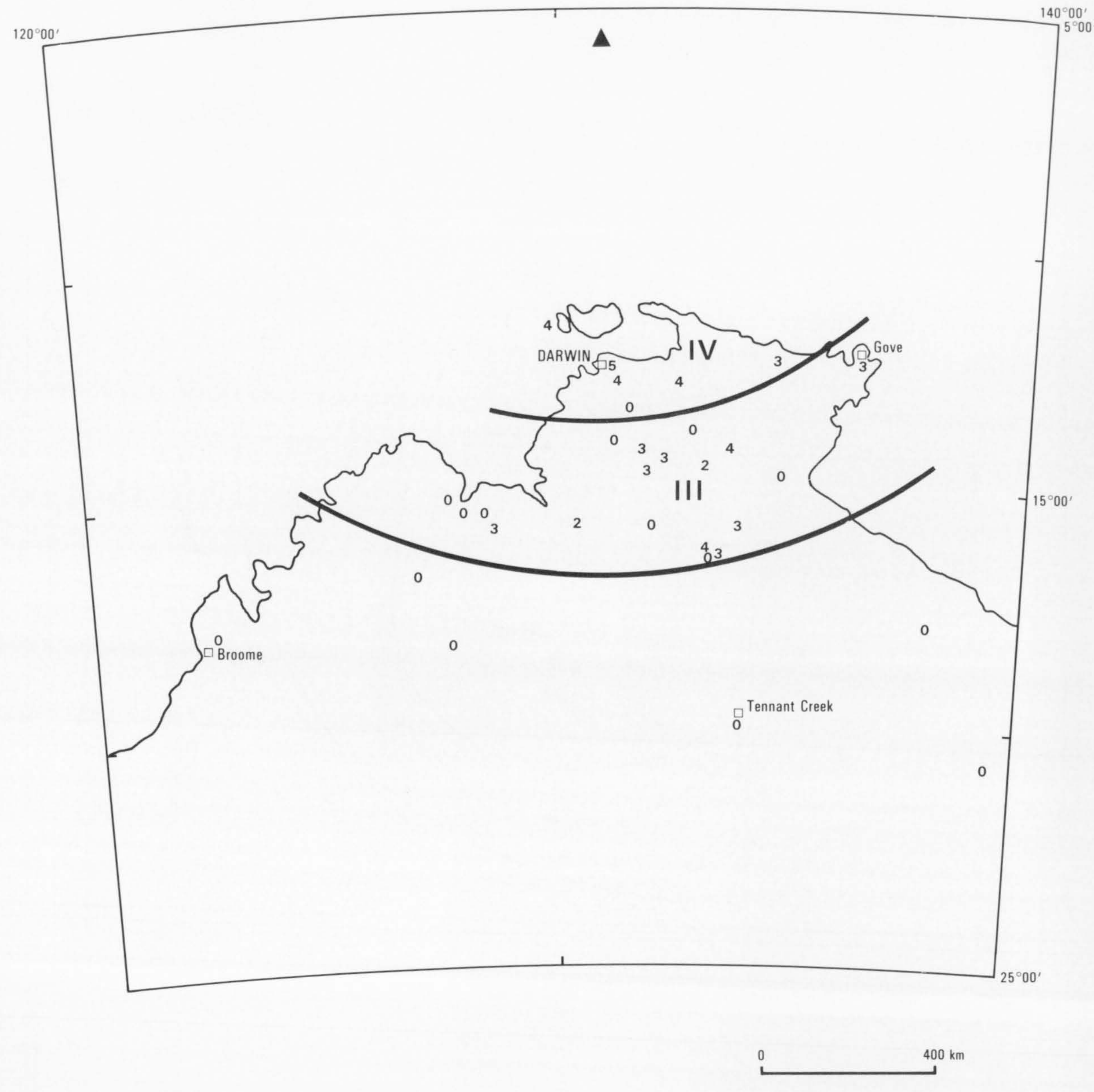
DATE: 16 June 1987
TIME: 13:26:40.6 UT
MAGNITUDE: 2.9 ML (BMR)
EPICENTRE: 34.79°S 149.17°E
DEPTH: 0 km

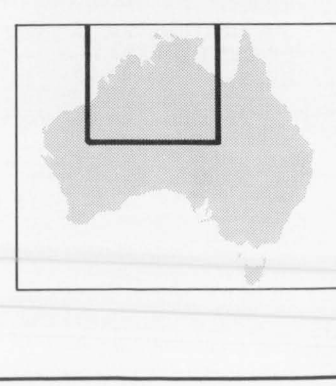
▲ *Epicentre*
IV *Zone intensity designation (MM)*
4 *Earthquake felt (MM)*
0 *Earthquake not felt*

24/I55/26

Figure 13

ISOSEISMAL MAP OF THE BANDA SEA EARTHQUAKE, 17 JUNE 1987





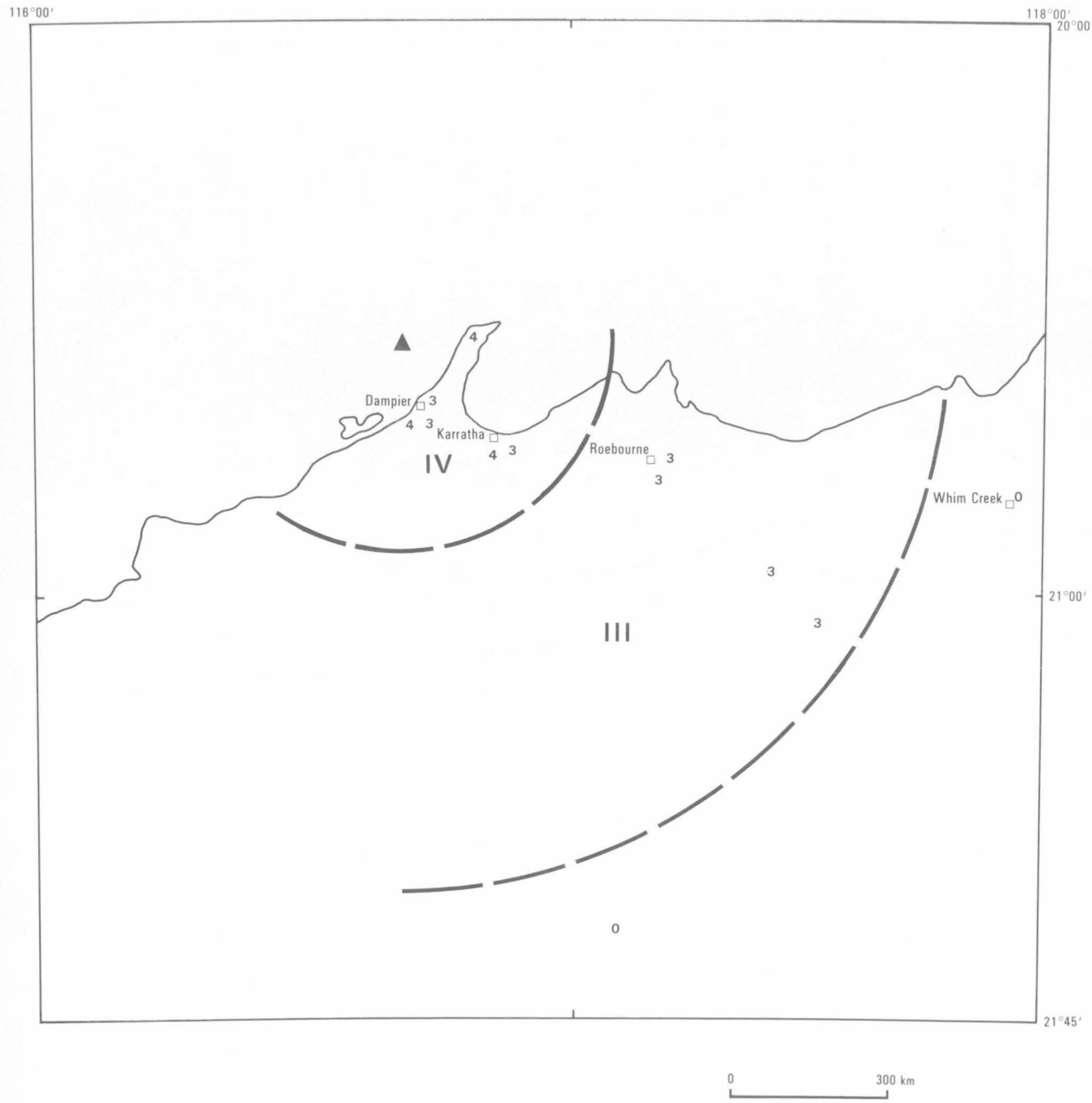
DATE : 17 June 1987
TIME : 013255.6 UT
MAGNITUDE : 6.7 MB
EPICENTRE : 5.583°S, 130.882°E
DEPTH : 84 km

▲ *Epicentre*
IV *Zone Intensity Designation*
4 *Earthquake Felt (MM)*
0 *Earthquake Not Felt*

24/OA/5

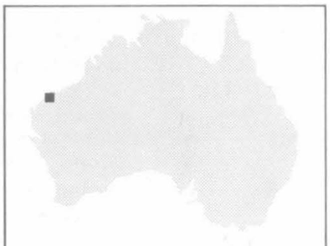
Figure 14

ISOSEISMAL MAP OF THE DAMPIER EARTHQUAKE, WESTERN AUSTRALIA 19 JUNE 1987



DATE : *19 June 1987*
TIME : *133203.0 UT*
MAGNITUDE : *3.7 ML (MUN)*
EPICENTRE : *20.56°S, 116.69°E*
DEPTH : *5km*

▲ *Epicentre*
IV *Zone Intensity Designation*
4 *Earthquake Felt (MM)*
0 *Earthquake Not Felt*



24/F50/3

Figure 15

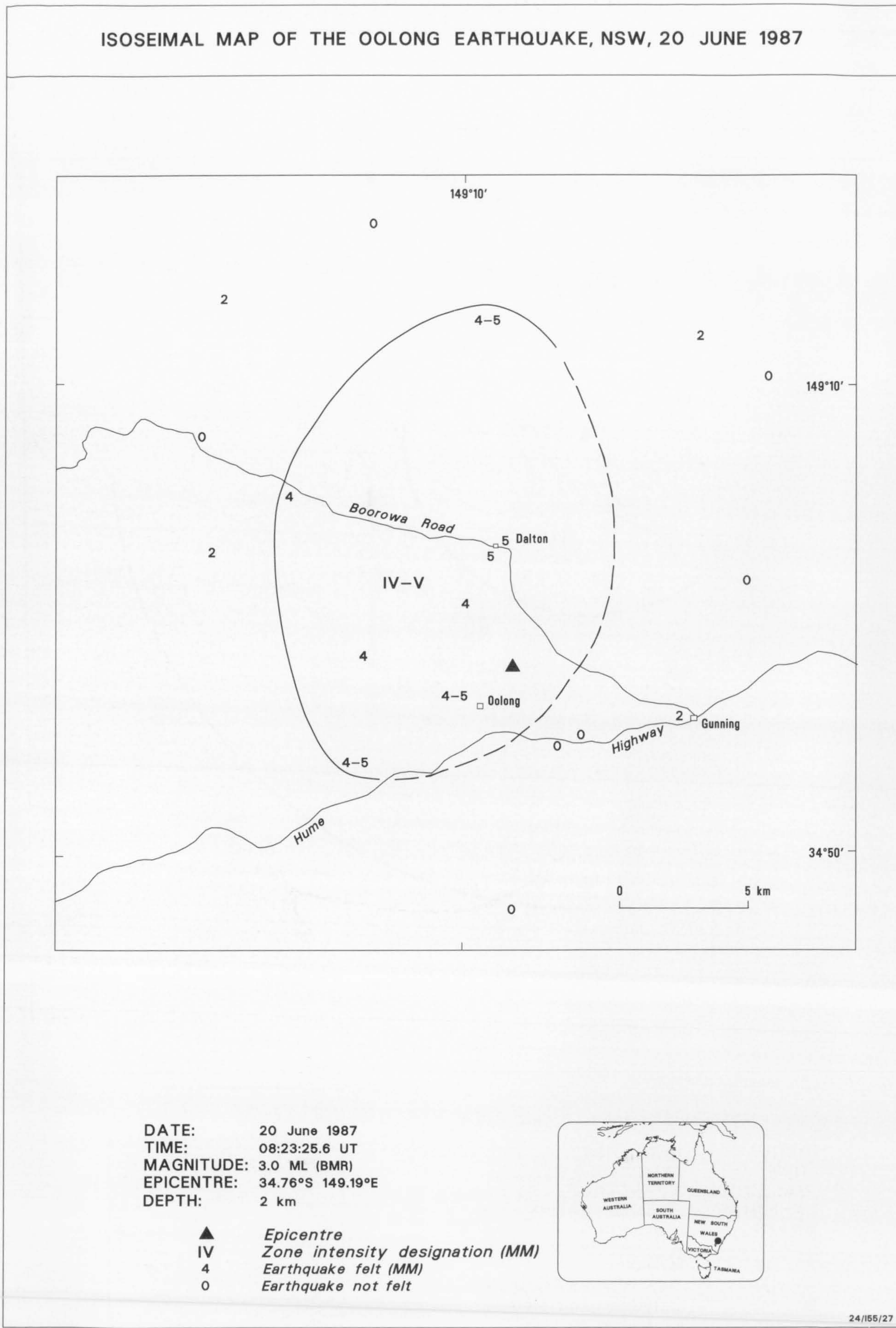
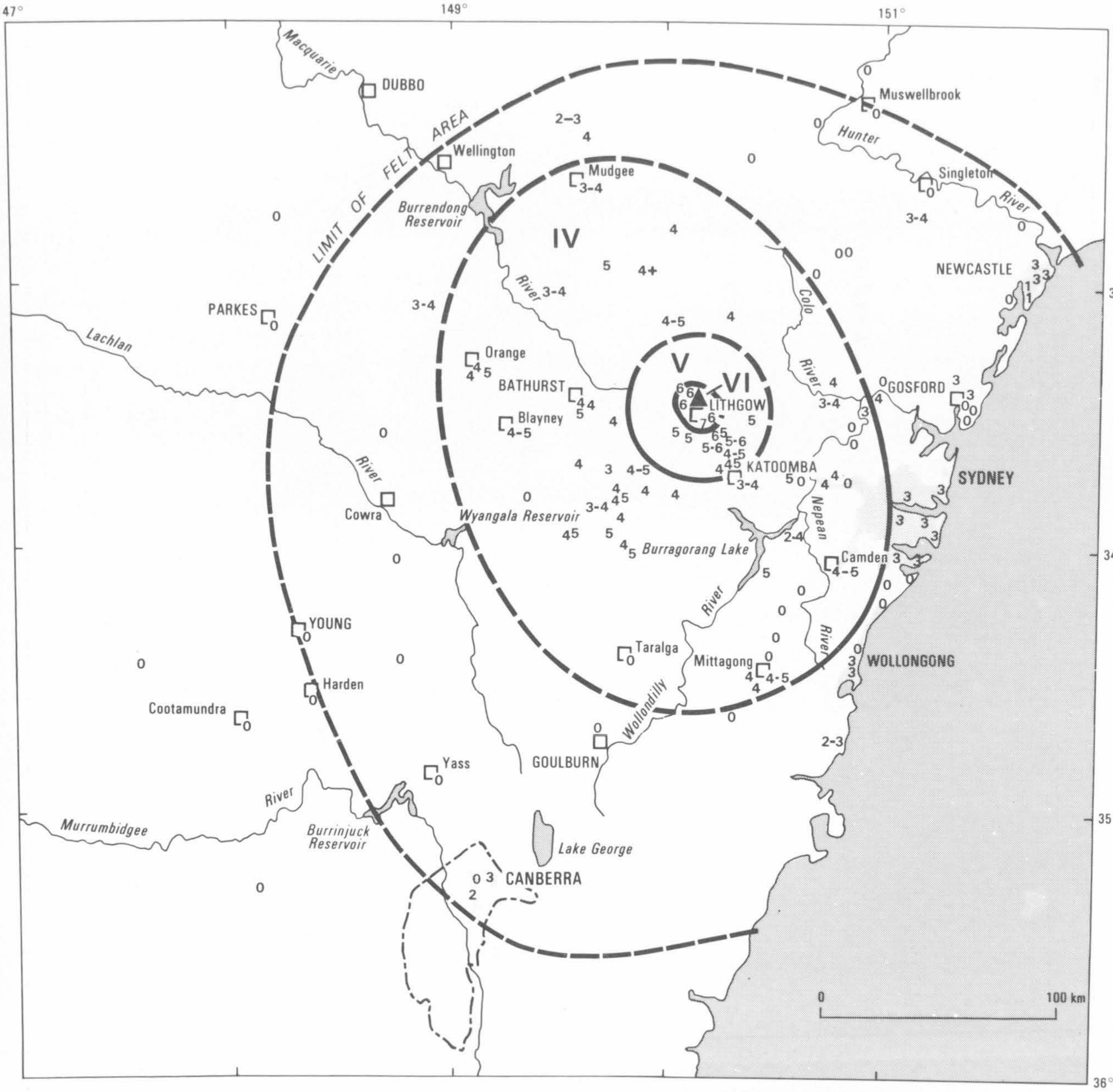

ISOSEIMAL MAP OF THE OOLONG EARTHQUAKE, NSW, 20 JUNE 1987
149°10'
0
2
4–5
2
0
149°10'
0
4
Boorowa Road
5 Dalton
5
2
IV–V
0
4
4
4–5 Oolong
2 Gunning
0
0
Highway
4–5
Hume
34°50'
0
5 km
0
DATE: 20 June 1987
TIME: 08:23:25.6 UT
MAGNITUDE: 3.0 ML (BMR)
EPICENTRE: 34.76°S 149.19°E
DEPTH: 2 km
Epicentre
IV Zone intensity designation (MM)
4 Earthquake felt (MM)
0 Earthquake not felt
NORTHERN TERRITORY
QUEENSLAND
WESTERN AUSTRALIA
SOUTH AUSTRALIA
NEW SOUTH WALES
VICTORIA
TASMANIA
24/I55/27

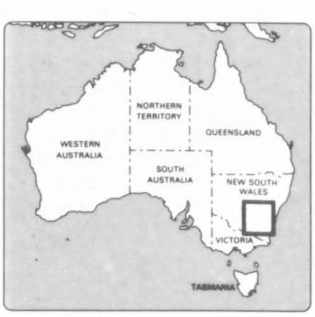
Figure 16

ISOSEISMAL MAP OF THE LITHGOW EARTHQUAKE, NEW SOUTH WALES, 24 JUNE 1987



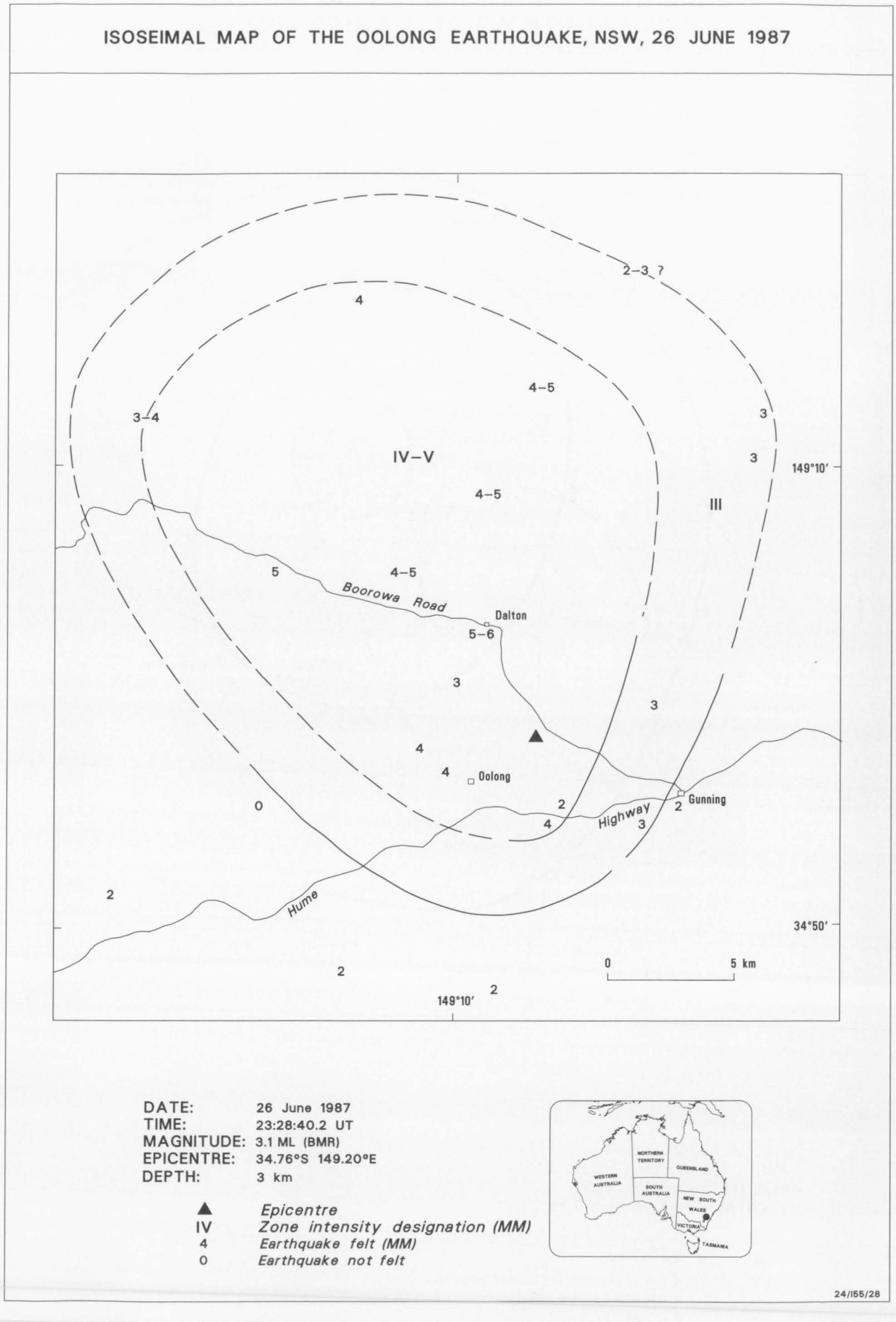
DATE : 24 June 1987
TIME : 15:04:55.4 UT
MAGNITUDE : 4.3 ML (BMR)
EPICENTRE : 33.44°S, 150.15°E

▲ Epicentre
IV Zone Intensity Designation
4 Earthquake Felt (MM)
0 Earthquake Not Felt



24/N/26

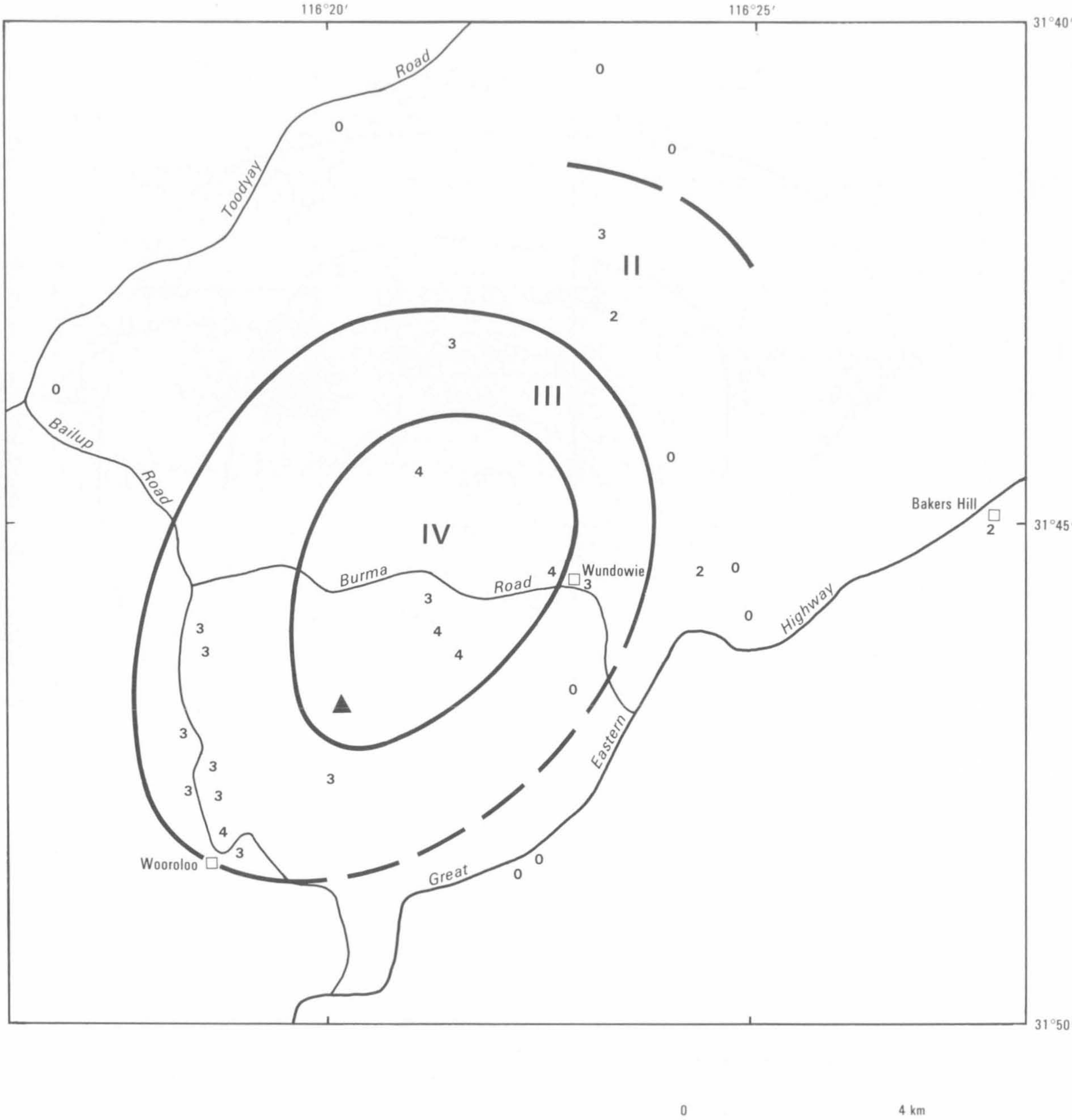
Figure 17



ISOSEIMAL MAP OF THE OOLONG EARTHQUAKE, NSW, 26 JUNE 1987
2-3 ?
4
4-5
3-4
3
IV-V
3
149°10'
4-5
III
5
4-5
Boorowa Road
Dalton
5-6
3
3
4
4
Oolong
0
2
4
Highway
3
2
Gunning
Hume
2
34°50'
0
5 km
2
149°10'
2
DATE: 26 June 1987
TIME: 23:28:40.2 UT
MAGNITUDE: 3.1 ML (BMR)
EPICENTRE: 34.76°S 149.20°E
DEPTH: 3 km
Epicentre
IV Zone intensity designation (MM)
4 Earthquake felt (MM)
0 Earthquake not felt
NORTHERN TERRITORY
QUEENSLAND
WESTERN AUSTRALIA
SOUTH AUSTRALIA
NEW SOUTH WALES
VICTORIA
TASMANIA
24/155/28

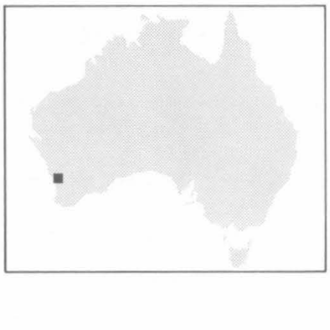
Figure 18

ISOSEISMAL MAP OF THE WOOROLOO EARTHQUAKE, WESTERN AUSTRALIA 5 JULY 1987



DATE : 5 July 1987
TIME : 052840.5 UT
MAGNITUDE : 3.0 ML (MUN)
EPICENTRE : 31.78°S, 116.34°E
DEPTH : 5 km

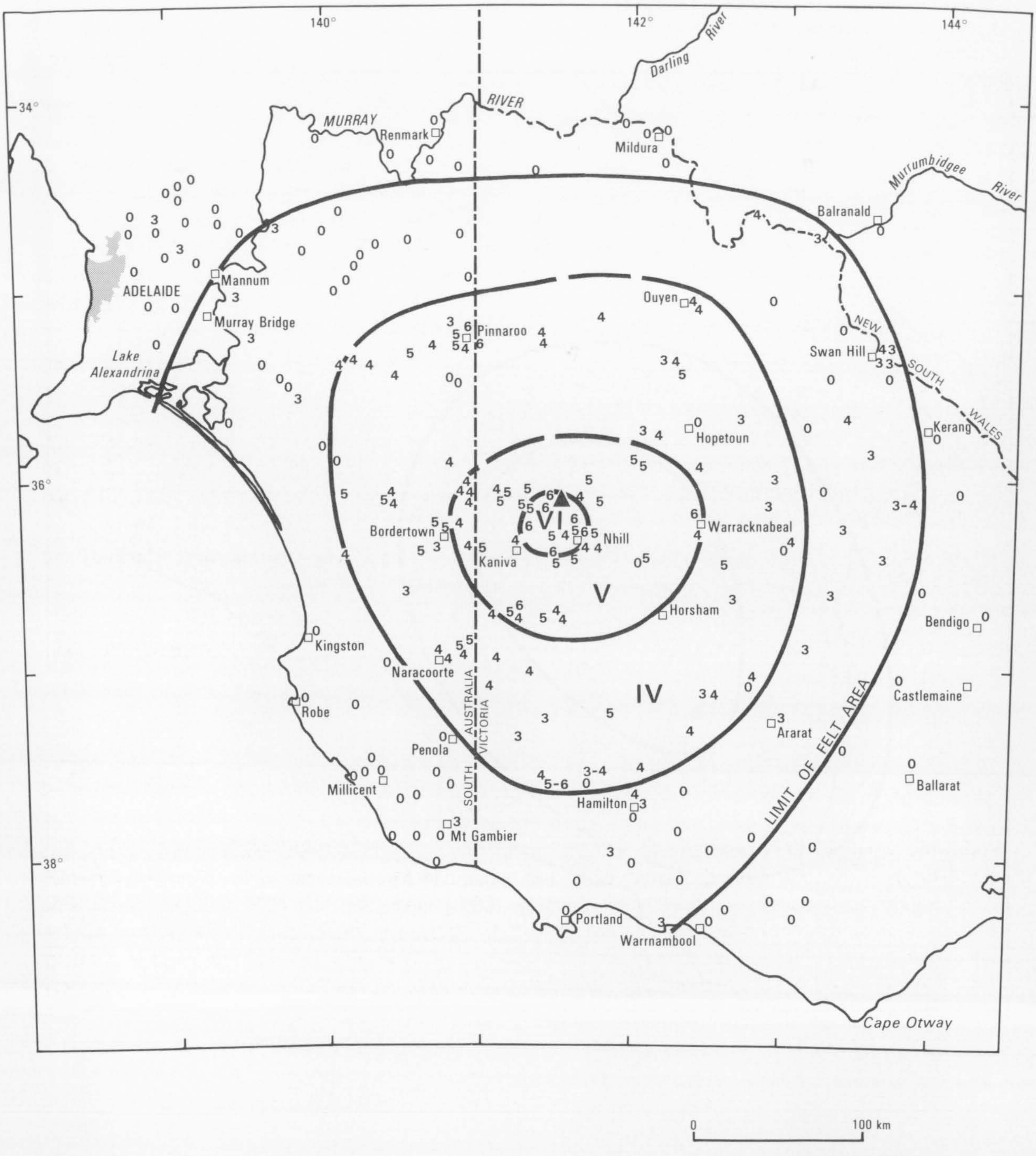
▲ *Epicentre*
IV *Zone Intensity Designation*
4 *Earthquake Felt (MM)*
0 *Earthquake Not Felt*



24/H50-14/2

Figure 19

ISOSEISMAL MAP OF THE NHILL EARTHQUAKE, VICTORIA, 22 DECEMBER 1987



DATE :	*22 December 1987*
TIME :	*15:06:30 UT*
MAGNITUDE :	*4.9 ML*
EPICENTRE :	*36.1°S, 141.5°E*
DEPTH :	*6 (± 25) km*
▲	*Epicentre*
IV	*Zone Intensity Designation*
4	*Earthquake Felt (MM)*
0	*Earthquake Not Felt*

24/A/109

Figure 20

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 1987.

In Western Australia, a total of 55 accelerograms were recorded during the year, all from earthquakes in the Cadoux area (Table 13, Gregson (in prep.)). Only two of these earthquakes had magnitudes (ML) of 2.0 or greater - an ML 4.5 event on 7 March, and an ML 2.6 event on 2 November. Twenty-five of the accelerograms were made on the digital recorder CA-A, a Teledyne-Geotech A700, installed in late 1986. Other A700 recorders at CA-E, CD-L and CD-U were only triggered once during the year, by the ML 4.5 event mentioned above. CD-L and CD-U were located at the Canning Dam, 175 kilometres south of the event epicentre. Eleven of the 25 accelerograms recorded by CA-A occurred between 22 and 30 September. The other 37 accelerograms were recorded on analogue film recorders (MO2's) in the Cadoux area. Data extracted from accelerograms for the ML 4.5 event are shown in Table 6.

In New South Wales and the ACT a total of 74 accelerograms were recorded. Three of the more interesting are listed in Table 6. Two are for magnitude ML 3.0 and 3.1 Oolong events where peak ground accelerations reached 0.94 and 1.00 ms^{-2} at hypocentral distances of 4 and 5 km respectively. The third (Fig. 22) was from an accelerograph newly installed near the top of the inlet tower of the Googong Dam on the Queanbeyan River. It was triggered by a magnitude ML 2.6 earthquake 32 km to the southwest. Useful information provided by the recording included the natural frequencies, 10.8 and 13.3 Hz, of the tower in a southwest and northeast direction respectively (McCue, 1989b).

Five of the more interesting Victorian recordings provided by the Phillip Institute of Technology are listed in Table 6.

No accelerograms were recorded in Tasmania, South Australia or Queensland during 1987.

(VIC DENT, BRIAN GAULL, GARY GIBSON, KEVIN McCUE, MARION MICHAEL-LEIBA & VAUGHAN WESSON)

PRINCIPAL WORLD EARTHQUAKES, 1987

Table 7 lists all earthquakes of magnitude 7.0 or greater, and damaging earthquakes of lesser magnitude, that occurred throughout the world in 1987. Figure 23 shows their locations and the number of fatalities.

Worldwide deaths in 1987 were around 1086, a similar figure to that in 1986. Twenty-two earthquakes caused the fatalities, the most disastrous being the magnitude Ms 6.9 event in the Colombia-Ecuador border region on 6 March. It killed approximately 1000 people, and left 4000 missing and 20 000 homeless. The largest earthquake in 1987 had magnitude Ms 7.6 and an epicentre in the Gulf of Alaska. It occurred at 1923 UTC on 30 November and, although widely felt, it caused only minor damage. These data are based on 'Preliminary Determination of Epicentres' published by the United States Geological Survey.

(MARION MICHAEL-LEIBA)

MONITORING NUCLEAR EXPLOSIONS

Table 8 lists the 47 nuclear explosions detected during 1987: 23 by the USSR, 15 by the USA, eight by France and one by China. The USSR maintained a self-imposed moratorium on nuclear weapons testing throughout 1986, but conducted 17 presumed tests and fired six presumed peaceful nuclear explosions in 1987.

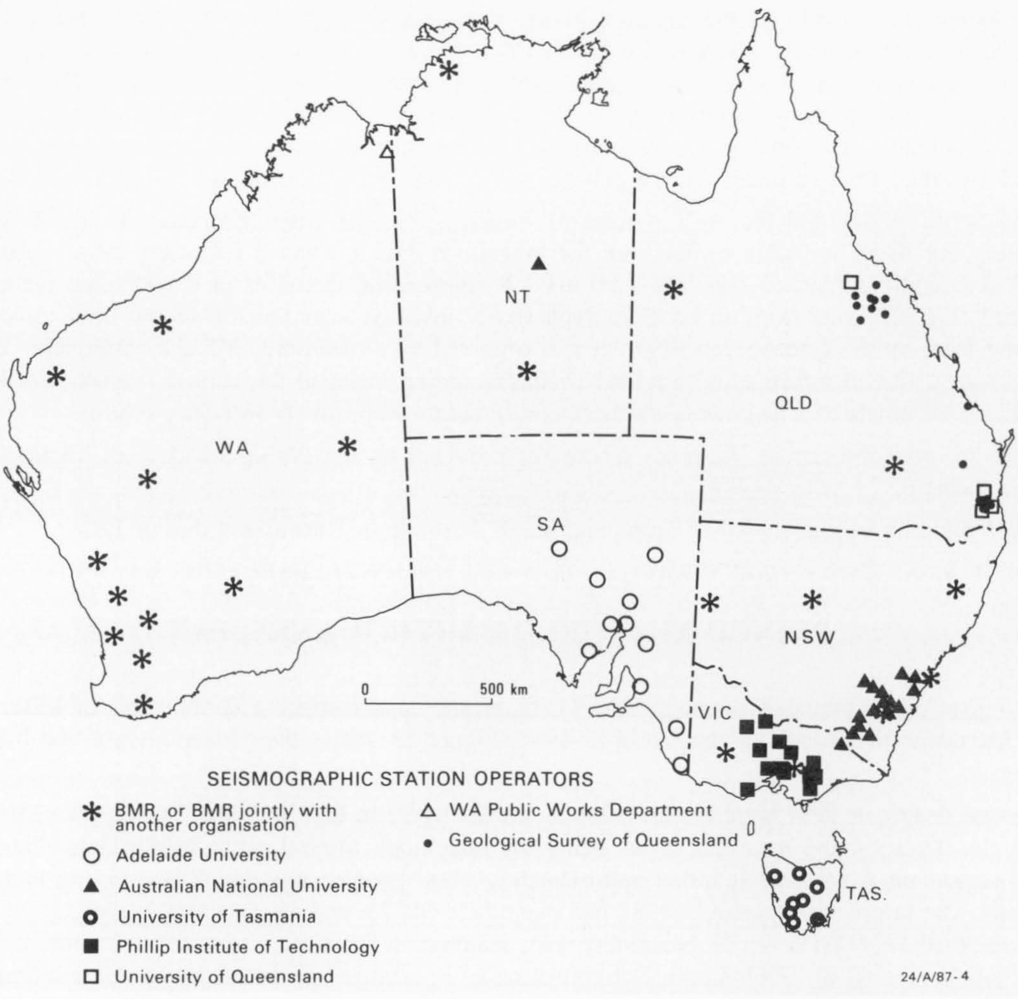


Figure 21. Australian seismograph stations, 1987

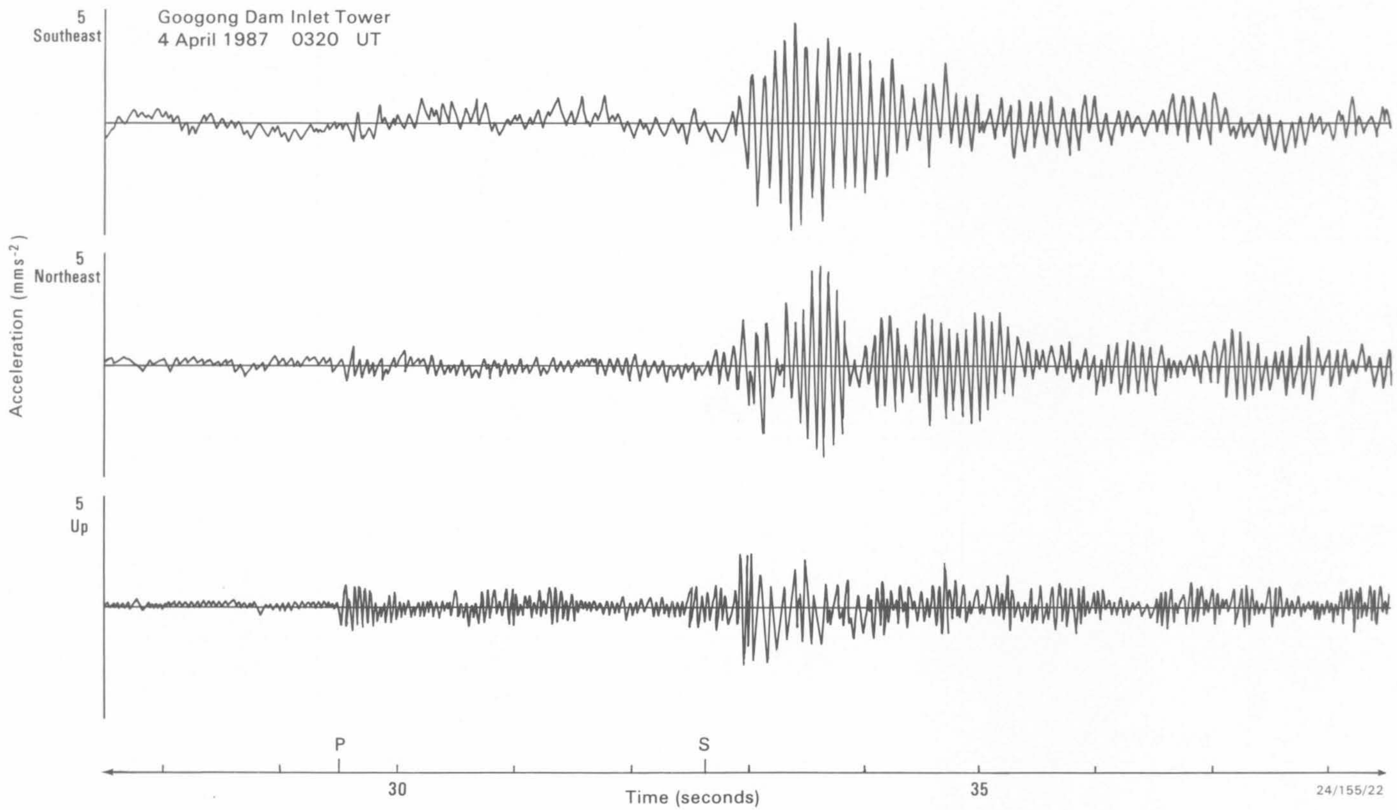


Figure 22. The accelerogram recorded in the Googong Dam inlet tower

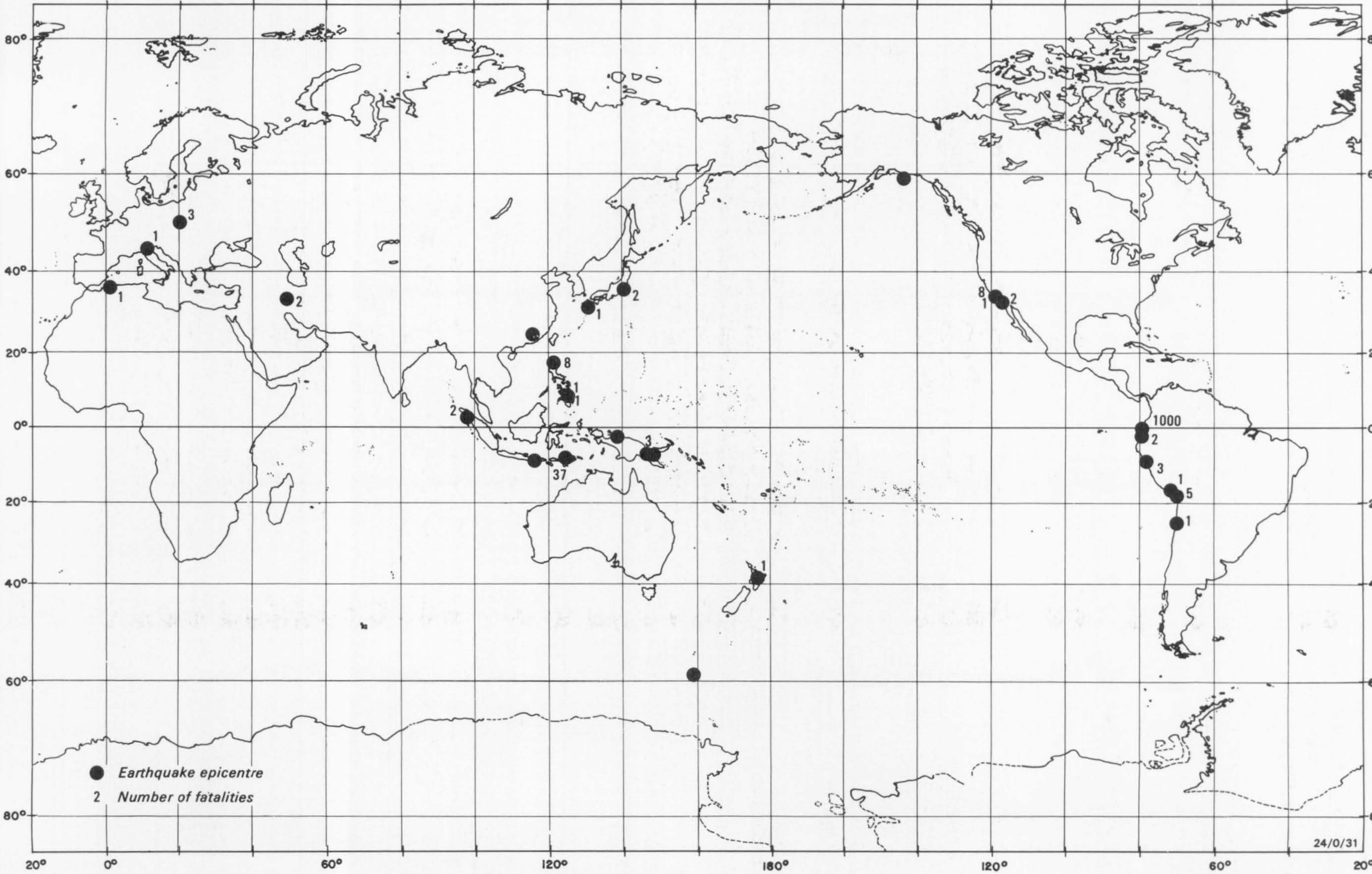


Figure 23. Principal world earthquakes, 1987

The Alice Springs Seismic Array Processor, developed by the Australian Seismological Centre, the United States Air Force Technical Applications Centre, and the United States Defence Advanced Research Projects Agency, was dedicated by the Minister for Resources and Energy, Senator the Hon. Gareth Evans QC, on 24 June 1987.

(MARION MICHAEL-LEIBA)

TIME REFERENCES FOR AUSTRALIAN SEISMOGRAPHS

Telecom Australia's standard frequency and time signal service, VNG, had been used widely throughout Australia for checking seismograph clocks. It broadcast HF time signals from Lyndhurst, Victoria, between 21 September 1964 and 1 October 1987 when the service was terminated. VNG was off the air until the latter part of 1988 when it was re-established on new frequencies at Llandilo, NSW, and AUSLIG agreed subsequently to fund the service, as an interim measure, with partial cost recovery from users (Leiba, 1989).

Around the time of VNG's demise it seemed highly unlikely that it would ever go to air again, and an urgent replacement was essential. The alternative favoured by the Bureau of Mineral Resources, SA Department of Mines and Energy and the Australian National University (which had developed its own receiver) was time derived from Omega navigation signals. These are based on highly accurate caesium atomic frequency standards. Commercial clocks are available which lock into Omega, and these were used at some stations. However, BMR designed a relatively low cost time signal generator based on the unique Australian Omega frequency. This had the advantage of plug-in compatibility which allowed direct replacement of the Labtronics radios commonly used to receive VNG. The BMR unit is a VLF radio to receive and decode the Australian characteristic frequency and extract 10s markers which are adjusted to UTC by means of a programmable digital delay. It provides a composite timing signal of one second and 10s markers. The radio has an active antenna to allow for the long cable required on some installations (Liu and Barlow, 1987).

Other alternatives were also used by Australia's seismologists, but less commonly. One was the HF time signal transmitted by the Royal Australian Navy, initially from Belconnen, ACT, and later from Humpty Doo, NT. These transmissions commenced soon after the closure of VNG at Lyndhurst, and continued until 3 July 1991 when the Navy lent the revived VNG two frequencies. Other time references included phone time pips, used either directly or in conjunction with an accurate travelling clock, and the American standard frequency and time signal services, WWV (Fort Collins, Colorado) and WWVH (Kekaha, Hawaii).

(MARION MICHAEL-LEIBA)

Table 1. Australian region earthquakes, 1987: Hypocentral parameters

Source	Date	Time UTC	Longitude °E	Latitude °S	Depth km	ML
BMR	1 5	1405 22.6	133.833	19.679	5	4.9
BMR	1 5	1409 50.5	134.223	20.086	5	5.3
MUN	1 7	0526 6.0	117.750	19.310	5	3.4
PIT	1 7	2001 50.4	133.706	20.004	0	5.3
BMR	1 8	0238 5.0	133.815	19.666	0	5.0
BMR	1 9	0102 47.7	133.523	20.031	5	4.8
PIT	1 9	1127 12.9	133.738	19.968	10	5.5
BMR	1 10	1521 53.9	133.902	19.775	3 G	3.9
BMR	1 11	0755 56.8	133.887	19.763	4 G	3.1
BMR	1 11	1150 21.7	133.923	19.801	5	3.0
BMR	1 11	1927 58.5	133.921	19.790	3	3.1
BMR	1 12	0556 57.9	133.889	19.782	3 G	3.6
BMR	1 13	0932 45.7	133.911	19.798	3	3.2
BMR	1 13	2325 44.1	133.900	19.778	2	3.5
CAN	1 16	1308 27.1	148.280	36.270	12	3.0
CAN	1 19	2330 20.9	146.340	37.690	14	3.1
BMR	1 20	0845 29.0	133.896	19.814	4	3.0
BMR	1 20	1142 54.6	133.890	19.794	5	3.2
BMR	1 21	1333 42.6	133.932	19.829	5 N	3.3
BMR	1 22	0607 40.4	133.895	19.795	3 G	4.1
BMR	1 22	0634 28.7	133.906	19.784	4	3.5
BMR	1 22	1209 14.6	133.866	19.770	3	3.1
BMR	1 23	1301 26.9	133.828	19.757	6	3.0
BMR	1 27	0937 40.4	133.833	19.785	6	4.3
BMR	1 27	2340 00.4	133.908	19.791	4	3.3
BMR	1 29	1439 58.7	133.882	19.772	5	3.5
BMR	1 30	1642 58.3	133.915	19.798	2	4.0
BMR	1 30	1742 53.7	133.902	19.806	5	4.7
BMR	1 31	0525 30.6	133.881	19.784	4	3.0
BMR	1 31	0844 35.6	133.954	19.787	8	4.0
BMR	1 31	1755 40.3	133.919	19.789	7	3.7
BMR	2 1	0002 14.9	133.880	19.762	4	3.4
BMR	2 1	0242 55.0	133.903	19.788	4	3.6
BMR	2 6	0004 15.3	133.915	19.781	1	3.1
BMR	2 7	0628 22.6	133.847	19.759	2	3.6
BMR	2 7	0746 26.1	133.885	19.785	2	3.0
BMR	2 7	1054 31.7	133.918	19.770	4	3.0
BMR	2 8	0048 59.2	152.596	29.096	10	3.1
MUN	2 9	0758 21.7	117.080	31.610	6	3.2
BMR	2 11	0636 46.7	133.917	19.797	3 G	3.1
BMR	2 12	0707 15.4	133.872	19.752	3 G	3.5
BMR	2 15	1659 56.6	133.834	19.769	10	3.8
BMR	2 16	1126 33.1	133.830	19.757	8	4.0
BMR	2 16	1146 44.2	133.910	19.826	3	3.4
BMR	2 18	1817 44.6	134.028	19.811	5	3.4
MUN	2 19	1424 45.0	117.500	39.490	5	3.3
BMR	3 2	0612 4.7	133.928	19.779	3	3.1
MUN	3 2	1644 17.1	117.050	31.620	8	3.8
MUN	3 2	2222 13.2	117.490	31.220	2	3.1
MUN	3 2	2222 20.0	117.490	31.220	5	3.0
MUN	3 7	0538 7.7	117.090	30.770	5	4.5
MUN	3 14	1925 38.8	114.100	22.750	5	3.0

Table 1 (cont.)

	Date	Time (UTC)	Long ° E	Lat ° S	Depth	ML
BMR	3 16	2228 53.0	133.875	19.665	5	4.1
BMR	3 16	2239 10.4	133.941	19.623	8	4.5
BMR	3 17	0020 9.5	133.994	19.687	10	3.5
BMR	3 17	0051 40.0	132.896	19.878	9	3.5
BMR	3 20	1128 11.4	133.979	19.596	9	4.2
MUN	3 20	1613 26.6	114.140	22.840	5	3.0
BMR	3 23	1255 50.0	133.938	19.670	11	3.5
ADE	3 26	1214 35.7	136.710	36.460	0	3.1
MUN	3 29	1539 22.0	118.840	18.900	5	3.0
BMR	3 30	0510 54.0	131.519	26.062	33	4.1
MUN	3 31	1013 33.9	112.030	38.110	5	3.6
BMR	4 7	1536 36.1	134.383	19.822	0	3.3
BMR	4 8	2052 30.8	133.528	19.103	5	4.1
BMR	4 9	1038 38.9	151.257	29.716	0	3.3
MUN	4 10	0643 29.0	122.100	17.250	5	3.7
MUN	4 17	1658 22.3	115.980	25.460	23	3.2
MUN	4 19	2241 20.0	122.260	32.610	5	3.2
MUN	5 2	2349 26.0	121.360	30.660	5	3.5
CAN	5 4	1652 10.0	152.750	38.500	0	3.2
MUN	5 5	2324 14.5	116.720	32.040	5	3.8
BMR	5 8	0424 50.9	134.220	19.898	0	4.4
BMR	5 8	0824 21.9	134.049	19.907	27	3.2
BMR	5 8	0904 26.7	133.937	19.800	5	3.5
MUN	5 8	1335 28.0	122.220	32.510	5	3.0
BMR	5 10	0524 8.2	133.992	19.865	0	4.7
MUN	5 10	2336 35.3	117.740	33.390	5	3.2
BMR	5 11	0311 52.8	135.818	13.757	0	3.2
BMR	5 13	0645 62.8	131.430	16.530	5	3.0
BMR	5 15	0405 14.7	148.027	22.363	0	4.2
MUN	5 17	1542 30.0	122.590	17.470	5	3.4
BMR	5 21	0315 53.6	128.348	16.842	0	3.3
PIT	5 28	2318 20.0	146.255	38.055	15	3.0
PIT	5 30	1444 27.4	146.559	37.947	17	3.9
BMR	6 1	1934 93.7	134.011	19.865	5	3.2
BMR	6 2	1302 54.6	134.048	19.852	10	3.3
BMR	6 3	0407 47.8	133.970	20.006	10	3.5
MUN	6 3	15010 0.4	123.590	35.180	5	3.4
MUN	6 4	0333 9.5	122.310	32.590	5	3.5
BMR	6 8	0355 24.9	127.039	21.994	5	3.0
BMR	6 11	1041 59.0	133.883	19.684	14	4.4
MUN	6 11	1218 42.4	117.510	31.200	3	3.5
MUN	6 11	1219 43.1	117.510	31.200	3	3.2
BMR	6 11	1618 12.3	133.799	19.758	15	3.3
MUN	6 11	1711 53.0	117.510	31.210	3	3.2
MUN	6 14	1806 32.5	122.310	32.590	5	3.0
MUN	6 19	1332 3.0	116.690	20.560	5	3.7
BMR	6 20	0823 25.7	149.188	34.760	2	3.0
MUN	6 21	1615 33.7	118.990	18.170	5	4.0
BMR	6 24	1453 19.3	150.173	33.470	0	3.1
BMR	6 24	1504 55.2	150.149	33.432	5	4.3
BMR	6 24	1532 36.0	150.103	33.411	0	3.4
BMR	6 24	1547 68.5	150.179	33.465	0	3.5
PIT	6 24	1853 28.4	144.273	38.900	17	3.0

Table 1 (cont.)	Date	Time (UTC)	Long ° E	Lat ° S	Depth	ML
BMR	6 26	2328 40.2	149.201	34.763	3	3.1
BMR	6 27	0200 24.9	133.936	19.773	30	3.8
MUN	7 5	1105 35.0	120.700	18.470	5	3.3
MUN	7 8	1038 4.5	122.280	32.540	5	4.7
MUN	7 8	1157 57.0	122.280	32.540	5	3.1
MUN	7 12	1951 33.2	122.280	32.540	5	3.3
MUN	7 19	0303 29.2	113.060	27.220	5	5.0
BMR	7 21	2110 34.7	133.765	19.802	1	3.8
BMR	7 24	0019 26.8	129.663	22.573	25	3.5
MUN	7 30	2158 59.0	124.910	36.780	5	3.7
BMR	8 18	1955 22.7	133.935	19.755	6	3.8
BMR	8 19	0325 25.7	138.515	30.239	11	3.2
BMR	8 19	1621 56.2	128.619	24.455	0	3.4
MUN	8 21	0939 39.8	122.370	32.660	5	3.1
BMR	8 26	0138 33.9	151.168	32.732	0	3.3
MUN	8 26	2231 49.0	120.240	21.390	5	3.3
BMR	8 28	1632 10.4	133.989	19.786	8	3.3
BMR	8 30	1423 42.9	128.679	16.739	14	3.0
MUN	8 30	2008 58.0	128.420	37.410	5	3.1
BMR	9 4	0715 35.9	152.585	32.088	0	3.4
BMR	9 15	0237 55.2	145.993	37.687	0	3.3
MUN	9 18	0041 31.0	119.220	16.760	5	4.0
MUN	9 23	0229 31.0	123.380	17.650	5	3.2
BMR	9 24	1039 58.6	133.863	19.776	0	3.5
BMR	9 24	1111 26.4	133.978	19.826	2	3.4
MUN	9 24	1553 19.5	120.240	21.330	5	3.0
MUN	9 24	2046 51.0	115.650	19.670	5	4.0
BMR	9 26	0437 21.4	130.230	19.500	5	3.0
BMR	9 27	1601 26.3	147.825	19.304	9	4.6
BMR	9 28	1937 36.8	150.667	29.357	0	3.4
BMR	9 29	1929 23.8	130.497	14.872	5	3.7
CAN	10 2	0859 40.0	154.000	38.700	0	3.5
CAN	10 4	0630 59.0	147.420	36.580	0	3.1
MUN	10 9	0358 48.6	121.270	30.900	16	4.5
MUN	10 12	0453 15.0	118.470	34.910	5	3.2
MUN	10 16	1055 32.0	112.170	38.760	5	3.3
MUN	10 16	1119 38.0	112.560	25.760	5	4.7
MUN	10 21	0233 21.0	112.840	26.360	5	3.8
MUN	10 21	1832 54.0	121.230	30.920	5	3.3
MUN	10 22	2113 44.0	121.230	30.920	5	3.6
MUN	10 25	2242 35.0	119.220	18.170	5	3.7
GSQ	10 31	0602 50.2	152.841	23.828	10	3.5
MUN	11 1	1527 40.0	126.600	22.080	5	3.6
MUN	11 6	1336 35.0	122.840	13.080	5	4.5
MUN	11 7	0459 16.0	122.840	13.080	5	3.8
CAN	11 7	2054 37.6	147.640	36.780	17	3.1
BMR	11 11	0052 55.2	149.166	37.640	0	3.2
CAN	11 13	1221 7.0	144.240	36.000	0	3.0
MUN	11 15	1227 13.0	122.220	32.510	5	3.1
MUN	11 15	1237 56.9	114.000	23.310	5	3.1
MUN	11 18	0937 19.7	120.180	21.280	11	3.8
MUN	11 19	1800 16.9	120.150	21.300	25	4.1
MUN	11 20	0454 58.9	120.150	21.300	5	3.5

Table 1 (cont.)

	Date	Time (UTC)	Long ° E	Lat ° S	Depth	ML
MUN	12 4	1315 57.0	120.460	17.440	5	5.0
MUN	12 6	2237 36.0	110.890	31.820	5	3.4
CAN	12 7	1054 36.5	149.490	37.980	0	3.7
TAU	12 8	1443 32.2	141.500	41.480	0	3.1
MUN	12 12	1206 56.0	119.570	16.940	5	3.3
MUN	12 13	1529 3.0	126.270	29.610	5	3.5
BMR	12 16	0455 6.6	142.853	24.817	6	4.1
MUN	12 18	1755 49.4	117.500	31.200	3	3.4
BMR	12 20	0802 17.8	145.586	38.326	0	3.3
MUN	12 20	1211 48.0	121.160	30.500	5	3.8
MUN	12 21	2153 56.9	117.510	31.180	4	3.2
ADE	12 22	1202 19.0	138.070	32.710	12	3.0
BMR	12 22	1506 30.7	141.539	36.107	6	4.9
BMR	12 23	0543 53.6	141.440	36.170	6	3.0
MUN	12 25	1936 25.0	120.690	16.340	5	4.6
GSQ	12 27	0716 43.9	153.673	24.111	10	3.2
MUN	12 27	0807 7.0	114.380	23.760	5	3.5

Codes denote the contributors listed in the text, on page iii.
G,N indicate depth Restrained, or set at normal depth, by the locating geophysicist.

TABLE 2. LARGE AUSTRALIAN REGION EARTHQUAKES, 1859-1987*

UTC DATE y m d	TIME h m	sec	LONG E	LAT S	DEPTH km		MAGNITUDE ML	MS
1873-12-15	0400	0.0	127.500	26.250	0	G	6.2	6.0
1884- 7-13	0355	0.0	148.500	40.500	0	G	6.3	
1884- 9-19	1027	0.0	149.500	40.800	0	G	6.4	
1885- 1- 5	1220	0.0	114.000	29.000	0	G	6.6	6.5
1885- 5-12	2337	0.0	148.900	39.900	0	G	6.5	
1892- 1-26	1648	0.0	149.500	40.400	0	G	6.9	
1892- 1-26	1656	0.0	149.500	40.400	0	G	6.0	
1897- 5-10	0526	0.0	139.750	37.333	0	G	6.5	
1902- 9-19	1035	0.0	137.400	35.000	14	G	6.0	
1906-11-19	0718	41.0	111.800	19.100	33	N	7.2	7.2
1918- 6- 6	1814	24.0	152.500	23.500	15		6.0	5.8
1920- 2- 8	0524	30.0	111.000	35.000	33	N	6.3	6.2
1929- 8-16	2128	23.4	120.660	16.990	33	N	6.7	6.6
1941- 4-29	1354	41.0	116.100	26.800	33	N	7.0	6.8
1941- 6-27	0755	49.0	137.340	25.950	0	R	6.3	6.6
1946- 9-14	1948	42.0	149.000	40.200	33	N	6.0	5.4
1968-10-14	0258	50.6	116.980	31.620	10	R	6.9	6.8
1970- 2-16	2120	21.0	111.650	20.070	0	R	6.1	
1970- 3-24	1035	17.6	126.610	22.050	0	R	6.4	5.9
1971- 7-16	0800	1.0	126.560	22.030	0	R	6.4	
1972- 8-28	0218	56.2	136.260	24.950	10		6.2	
1975- 1-10	0820	18.3	126.110	27.740	0		6.2	
1975-10- 3	1151	1.8	126.580	22.210	0		6.2	
1976- 2-19	0232	5.3	114.300	19.410	0		6.2	
1978- 5- 6	1952	19.6	126.560	19.550	17		6.8	
1979- 4-23	0545	10.8	120.270	16.660	39		6.6	5.7
1979- 4-25	2213	57.4	120.480	16.940	1		6.1	
1979- 6- 2	0947	59.3	117.179	30.827	6	R	6.2	
1983-11-25	1956	7.8	155.507	40.451	19		6.0	5.8
1986- 3-30	0853	48.4	132.517	26.333	5		6.0	5.8

* Earthquakes with Richter magnitude of 6.0 or greater, as listed in the BMR earthquake data file.

G,N indicate depth restrained, or set at normal depth, by the locating geophysicist.

TABLE 3. AUSTRALIAN SEISMOGRAPH STATIONS, 1987

CODE	NAME	LAT S	LONG E	ELEV. (m)	OP.*	TYPE**
QUEENSLAND						
AWA	AWOONGA DAM	24.068	151.302		GSQ	1
AWD	AWOONGA DAM	24.078	151.316		GSQ	1
AWG	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
FGT	FIG TREE	20.970	147.776		GSQ	1
GVA	GLEN EVA	21.489	147.483		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
QIS	MOUNT ISA	20.556	139.605	330	BMR	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
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
MRWA	MORAWA	29.218	115.996	300	MUN	1
MUN	MUNDARING	31.978	116.208	253	MUN	2
NANU	NANUTARRA	22.562	115.529	800	MUN	1
NWAO	NARROGIN	32.927	117.233	265	MUN	4
WARB	WARBURTON	26.184	126.643	460	MUN	1
WBN	WARBURTON	26.140	126.578	457	MUN	1
RKG	ROCKY GULLY	34.570	117.010	300	MUN	1

CODE	NAME	LAT S	LONG E	ELEV. (m)	OP.*	TYPE**
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
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
DAL	DALTON	34.726	149.174	570	BMR	1
IVY	INVERALOCHY	34.972	149.718	770	CAN	1
JNL	JENOLAN	33.826	150.017	829	CAN	1
KBH	KAMBAH	35.390	149.080	600	BMR	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
DRO	DROMANA	38.360	144.997	170	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

TABLE 3 (cont.)

CODE	NAME	LAT S	LONG E	ELEV. (m)	OP.*	TYPE**
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	THOMSON DAM	37.810	146.349	941	PIT	1
TOM	THOMSON	37.810	146.348	941	PIT	1
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, CADOUX, LITHGOW AND NHILL EARTHQUAKES

Cadoux WA earthquake: 7 March

	Azimuth	dip
P-axis	296	05
T-axis	173	80
B-axis	026	05
Double couples	A	B
Strike	030	017
Dip	51	40

Lithgow NSW mainshock: 24 June

	Azimuth	dip
P-axis	068	37
T-axis	336	01
B-axis	230	57
Double couples	A	B
Strike	022	107
Dip	74	63

Nhill Vic earthquake: 22 December

	Azimuth	dip
P-axis	264	35
T-axis	008	19
B-axis	120	50
Double couples	A	B
Strike	050	133
Dip	50	80

TABLE 5. AUSTRALIAN ACCELEROGRAPHS, 1987

	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	34.726	149.174	570	Concrete	SMA-1	BMR
Ferndale (FND)	34.745	149.166	580	Granite	PIT	BMR
Wilton (WIL)	34.800	149.221	660	Granite	PIT	BMR
Googong Dam Tower (GGT)	35.423	149.262	650		PIT	ACTEW
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
QUEENSLAND						
Wivenhoe Dam	27.394	152.602	80	Wave crest	A700	BAWB
Wivenhoe Dam	27.395	152.603	28	Instrument hut	A700	BAWB
Wivenhoe Power Stn	27.347	152.631	78	Station floor	A700	QEC
Wivenhoe Power Stn	27.375	152.631	78	Car park	A700	QEC
Splityard Ck Dam	27.379	152.641	170	Dam wall	A700	QEC
Splityard Ck Dam	27.375	152.641	100	Valve chamber	A700	QEC
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
Cousins (CA-I)	30.873	116.928	300	Granite	MO2	BMR
Emmott (CA-E)	30.895	117.123	320	Laterite	A700	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
Canning Dam						
Lower Gallery (CD-L)	32.154	116.126	142	Granite	A700	WAWA
Upper Gallery (CD-U)	32.154	116.126	202	Granite	A700	WAWA
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
O'Conner Museum (MU-C)	31.957	116.162	106	Concrete floor	MO2	WAWA
VICTORIA						
Jeeralong (JNA)	38.351	146.419	330	Mesozoic sediments	PIT	PIT

TABLE 5 (cont.)

	LAT S	LONG E	ELEV.(m)	FOUNDATION	TYPE	OWNER
Plane Track (PTA)	37.357	146.357	771	Palaeozoic sediments	PIT	PIT
Thomson Dam Tower (TMT)	37.844	146.396	460		PIT	MMBW
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

AAEC	Australian Atomic Energy Commission
ACTEW	ACT Electricity & Water
BAWB	Brisbane & Area Water Board
BMR	Bureau of Mineral Resources, Canberra/Mundaring
EWSSA	Engineering & Water Supply Department, South Australia
HEC	Hydroelectric Commission, Tasmania
MMBW	Melbourne and Metropolitan Board of Works
PIT	Phillip Institute of Technology
PWDSA	Public Works Department, South Australia
PWDWA	Public Works Department, Western Australia
QEC	Queensland Electricity Commission
RWCV	Rural Water Commission, Victoria
TEL	Telecom (Perth)
WAWA	Water Authority of Western Australia
WRC	Water Resources Commission, NSW

TABLE 6. ACCELEROGRAM DATA, 1987

MN DY	TIME	LAT S	LONG E	ML	LOC	H/E	COM	T(s)	ACC
03 07	0538	30.77	117.09	4.5	CA-S	7/5	PZ	0.034	593
							N	0.031	123
							E	0.031	119
							SZ	0.017	1103
							N	0.016	1053
							E	0.2	1552
					CA-R	7/5	PZ	0.13	212
							N	0.11	65
							E	0.11	216
							SZ	0.16	1100
							N	0.16	646
							E	0.16	1050
					CA-K	9/8	PZ	0.030	119
							N	0.030	81
							E	0.030	57
							SZ	0.037	819
							N	0.049	859
							E	0.043	1141
					CA-A	8/6	PZ	0.023	300
							N	0.04	88
							E	0.04	88
							SZ	0.097	272
							N	0.037	2510
							E	0.044	2860
					CA-A	8/6	PZ	0.05	160
							N	0.04	60
							E	0.04	40
							SZ	0.051	606
							N	0.037	2470
							E	0.044	2150
					CA-E	14/13	PZ	0.05	50
							N	0.04	17
							E	0.04	16
							SZ	0.04	210
							N	0.04	400
							E	0.06	420
04 04	0320	35.61	149.04	2.6	GGT	33/32	SZ	.06	3.0
							S135E	0.06	5.0
							S45E	0.06	5.0
05 15	2103	34.77	149.18	2.6	FND	3/3	SZ	0.029	291
							SN	0.022	239
							SE	0.046	199
06 20	0823	34.76	149.19	3.0	FND	4/3	SZ	0.030	925
							SN	0.030	589
							SE	0.030	683
06 26	2328	34.76	149.20	3.1	FND	5/4	SZ	0.038	947
							SN	0.038	592
							SE	0.042	1125
					OOL	5/4	SZ	0.05	196
							SN	0.05	589
							SE	0.09	1177

TABLE 6 (cont.)

MN DY	TIME	LAT S	LONG E	ML	LOC	H/E	COM	T(s)	ACC
01 19	2330	37.783	146.38	2.7	PTA	11/11	SZ	0.10	11.96
							SN	0.10	10.76
							SE	0.10	9.57
05 28	0237	37.496	145.93	2.9	TMT	56.7/56	SZ	0.05	1.74
							SN	0.05	8.86
							SE	0.05	2.39
05 30	1444	37.947	146.55	3.9	PTA	21/13.2	SZ	0.01	162.7
							SN	0.01	148.3
							SE	0.01	138.8
					TMT	25/18	SZ	0.05	67.0
							SN	0.05	95.7
							SE	0.05	114.8
					JNA	50/46	SZ	0.10	15.4
							SN	0.10	20.3
							SE	0.10	10.7

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, 1987

Earthquakes of magnitude 7.0 or greater, or causing substantial 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
26 Jan	11 11 41.8	Algeria	35.964 N	1.374 E	4.9 mb, 4.3 Ms

Depth 10 km. One person killed, 7 injured and 629 homes damaged in the Mohammadia area. Felt at Oued Fadda and Tissemsilt.

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude
08 Feb	18 33 58.3	East Papua New Guinea Region	6.088 S	147.689 E	7.4 Ms 7.6 Ms (BRK) 7.0 Ms (PAS)

Depth 55 km. Three people killed by a landslide and some damage (VI) on the Huon Peninsula. Several hundred people homeless and moderate damage (VII). Landslides and ground cracks on Umboi Island. Liquefaction occurred in some sands on Malai Island. Felt (VI) in the Cape Gloucester area, New Britain. Felt (III) as far away as Wewak and Port Moresby, New Guinea and Rabaul, New Britain. Multiple event. Observed on broadband displacement seismograms.

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude
02 Mar	01 42 34.1	North Island New Zealand	37.965 S	176.765 E	5.9 mb, 6.6 Ms 6.8 Ms (BRK) 6.4 Ms (PAS)

Depth 19 km. One person died from a heart attack; 25 injured and extensive damage (X) in the Edgecumbe-Kawerau-Whakatane area. Felt throughout much of North Island. Landslides and sandblows occurred. A southwest trending fault scarp 6 km long had extension openings of up to 1 m and as much as 1.5 m of downthrow on the northwest side. Peak ground acceleration of 0.33 g was recorded within 15 km of the epicenter. Depth from broadband displacement seismograms.

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude
05 Mar	09 17 05.2	Near Coast of Northern Chile	24.388 S	70.161 W	6.5 mb, 7.3 Ms 7.2 Ms (BRK) 6.0 Ms (PAS) 6.8 mb(PAS)

Depth 62 km. One person killed and damage VI) in the Antofagasta area. Felt (VI) at Chuquicamata; (V) in Taltal-Taconao-Calama area; (IV) at Arica; (III) at Vallenar. Felt (II) at Arequipa, Peru. Also felt at La Paz, Bolivia. Local tsunami generated with maximum wave heights 22 cm at Caldera, 20 cm at Coquimbo, 14 cm at Valparaiso and 18 cm at Arica. Depth from broadband displacement seismograms.

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude
06 Mar	04 10 41.9	Colombia-Ecuador Border Region	0.151 N	77.821 W	6.5 mb, 6.9 Ms 7.0 Ms (BRK) 6.7 Ms (PAS)

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

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude
Depth 10 km. Approximately 1,000 people killed, 4,000 missing, 20,000 homeless, extensive damage, landslides and ground cracks in Napa Province and in the Quito-Tulcan area, Ecuador. About 27 km of the oil pipeline in Ecuador, between Lago Agria and Balao destroyed or badly damaged. Landslides occurred in the Pasto-Macao area, Colombia. Felt (IV) at Iquitos, Peru. Felt strongly in many parts of Ecuador and southwestern Colombia. Also felt in central Colombia and northern Peru.					
12 Mar	23 07 48.7	Poland	51.37 N	20.21 E	2.6 ML (KRA)
Depth 10 km. Three people killed and three injured in the Slask Mine at Ruda Slaska.					
18 Mar	03 36 30.3	Kyushu, Japan	32.034 N	131.837 E	6.4 mb 6.7 Ms (BRK) 6.6 Ms (PAS)
Depth 54 km. One person killed; also one person died from a heart attack and five people were injured. Damage (V JMA) and landslides in the Miyazaki area. Felt (IV JMA) in the Kumamoto-Nabeoka-Oita-Saga area; (III JMA) in the Fukuoka-Kagoshima area and on southwestern Shikoku. Felt (I JMA) from Naze, Ryukyu Islands to Mita, Honshu. 7 cm tsunami recorded along the coast of Kyushu.					
25 Apr	19 22 07.2	Northern Sumatera	2.244 N	98.866 E	5.9 mb, 6.6 Ms 6.3 Ms(PAS)
Depth 11 km. Two people killed, 22 injured and more than 300 buildings damaged in the Tarutung-Lake Toba area. A hot spring in the area stopped flowing but resumed later. Felt in the Sibolga-Berastagi area. Also felt in the Kuala Lumpur area, Malaysia.					
02 May	20 43 53.0	Northern Italy	44.818 N	10.723 E	4.8 mb 5.2 ML (FUR) 5.0 ML (LDG) 5.0 ML (TTG)
Depth 10 km. One person died from a heart attack at Parma. Several people injured and slight damage (VII) in the Reggio nell'Emilia-Modena area. Felt from Lucca and Genoa to Milan, Verona and Padova.					
18 May	07 27 00.2	Mindanao, Philippine Is	8.302 N	125.362 E	5.5 mb, 5.9 Ms
Depth 16 km. One person killed in Bukidnon Province. Felt (III RF) at Cagayan de Oro. Also felt in the Davao area.					
23 May	17 09 04.4	Mindanao, Philippine Is	8.047 N	125.410 E	5.1 mb, 5.2 Ms
Depth 32 km. One person was killed, two people injured and damage in the Talakag-Malaybalay area. Felt (II RF) at Cagayan de Oro and (I RF) at Butuan and Surigao.					

TABLE 7 (cont.)

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude
29 May	06 27 50.7	Western Iran	34.076 N	48.266 E	4.9 mb, 4.6 Ms

Depth 41 km. Two people killed, 50 injured and damage in the Nahavand- Hamadan-Tuysarkan area.

18 Jun	10 01 07.3	Luzon, Philippine Is	17.291 N	121.356 E	5.5 mb, 5.0 Ms

Depth 43 km. Eight people killed, five injured, one missing and five houses damaged from landslides. Felt (V RF) in the epicentral area; (IV RF) at Baguio; (III RF) at Manila and Cagayan; (II RF) at Santa and Tuguegarao.

02 Aug	09 07 35.5	Near South-Eastern coast of China	24.924 N	115.608 E	4.9 mb

Depth 29 km. Eighty-four people injured and about 37, 000 houses damaged in the Ganzhou-Xunwu area. Felt (IV) at Hong Kong. Also felt at Canton and Macao.

08 Aug	15 48 56.7	Northern Chile	19.022 S	69.991 W	6.4 mb, 6.9 Ms 6.3 mb (BRK)

Depth 70 km. Five people killed, 112 injured and more than 1,000 houses destroyed (VII) in the Arica area. Several landslides occurred along the Chile-Peru border. Damage (VI) at Iquique. Felt (V) at Tacopilla and (III) at Calama and Antofagasta. Felt (III) at La Paz, Bolivia. Felt strongly at Tacna, Moquegua and Lima, Peru. Appears to be two events about 5 seconds apart. Depth from broadband displacement seismograms, based on first event.

13 Aug	15 23 06.9	Near coast of Peru	17.897 S	70.931 W	6.1 mb, 6.4 Ms 6.2 Ms (BRK)

Depth 37 km. One person killed, one injured and additional damage (V) at Arica, Chile. Felt (IV) at Arequipa and Tacna, Peru. Depth from broadband displacement seismograms.

03 Sep	06 40 13.9	Macquarie Islands Region	58.893 S	158.513 E	5.9 mb, 7.3 Ms 7.7 Ms (BRK) 6.9 Ms (PAS)

22 Sep	13 43 37.6	Ecuador	0.978 S	78.050 W	6.1 mb, 6.2 Ms 6.1 Ms (BRK)

Depth 10 km. At least 2 people killed, 12 injured, several houses destroyed or seriously damaged and landslides in the Ambato area. Minor damage in the Latacunga and Riobamba area. Felt in southern Colombia and northern Peru.

01 Oct	14 42 20.0	Southern California	34.060 N	118.080 W	5.8 mb, 5.7 Ms 5.9 ML (PAS) 6.1 ML (BRK)

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude
Depth 10 km. Eight people killed, many injured, about 2,200 homeless and more than 10,400 buildings damaged in the Los Angeles-Whittier- Pasadena area. The earthquake caused 358 million dollars in property damage. Maximum intensity (VIII) at Whittier. Felt strongly in much of Southern California. Felt as far away as Las Vegas, Nevada.					
02 Oct	22 27 55.8	Peru	8.143 S	77.954 W	5.4 mb, 5.1 Ms
Depth 20 km. Three people killed and several homes damaged at Santiago de Chuca. Felt (IV) at Trujillo and (III) at Chimbote.					
04 Oct	10 59 38.1	Southern California	34.070 N	118.100 W	5.2 mb, 4.8 Ms 5.3 ML (PAS) 5.6 ML (BRK)
Depth 8 km. One person died from a heart attack. Some injured and additional damage in the Pasadena-Alhambra-Whittier area. Felt from Ventura County to San Diego to Palm Springs.					
16 Oct	20 48 01.6	New Britain Region	6.266 S	149.060 E	5.9 mb, 7.4 Ms 7.7 Ms (BRK) 7.0 Ms (PAS)
Depth 48 km. Damage (VIII) at Kandrian. Felt (V) at Kimbe and Hoskins, (IV) at Bialla and (III) at Rabaul. Felt (V) at Finschhafen and also felt at Port Moresby, New Guinea. Felt (IV) on Bougainville. Local tsunami generated with 30 meter runup reported at Kandrian. Thirteen cm tsunami recorded at Rabaul. Multiple event.					
25 Oct	16 54 05.6	West Irian	2.323 S	138.364 E	6.2 mb, 7.0 Ms 6.7 Ms (BRK) 6.7 Ms (PAS)
Depth 33 km. Felt at Jayapura.					
24 Nov	01 54 14.5	Southern California	33.083 N	115.775 W	5.7 mb, 6.2 Ms 5.8 ML (PAS) 6.5 ML (BRK)
Depth 5 km. Two people killed in an earthquake-related automobile accident about 80 km east of Mexicali, Mexico. Slight damage (VI) at Calipatria, El Centro, Heber and Westmorland. Felt throughout much of southern California from San Diego and Los Angeles to Las Vegas, Nevada and Yuma, Arizona. Also felt at Mexicali, Tijuana and Ensenada, Mexico.					
24 Nov	13 15 56.5	Southern California	33.010 N	115.840 W	6.0 mb, 6.6 Ms 6.1 ML (PAS) 6.7 ML BRK)

TABLE 7 (cont.)

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

Depth 2 km. Multiple event. At least 94 people injured and an estimated 4 million dollars damage in Imperial County. Additional injuries and damage occurred in the Mexicali area, Mexico, with an estimated 3,000 people temporarily homeless. Maximum intensities (VI-VII) at El Centra and Westmorland, (VI) at Brawley, Calexica, Calipatria, Heber, Holtville, Imperial and Seeley. Felt throughout much of southern California from San Diego and Los Angeles to Las Vegas, Nevada and Tempe, Arizona. Also felt at Tijuana and Ensenada, Mexico. Surface fault rupture and afterslip were mapped by California Division of Mines and geology along a 23 km segment of the Superstition Hills fault. A maximum of 65 cm of right-lateral displacement with a few centimeters of vertical displacement was measured. Strong motion records indicate peak accelerations of 0.21g at Westmoreland and 0.36g at El Centro.

26 Nov	01 43 14.0	Timor	8.247 S	124.155 E	5.8 mb, 6.5 Ms 6.3 Ms (BRK) 6.3 Ms (PAS)

Depth 33 km. At least 37 people killed, 108 injured and 237 buildings damaged on Pantar Island. Landslides also occurred on the island. Mount Sirrung started erupting on December 2.

30 Nov	19 23 19.5	Gulf of Alaska	58.679 N	142.786 W	6.7 mb, 7.6 Ms 7.7 Ms (BRK) 7.4 Ms (PAS) 7.1 ML (PMR)

Depth 10 km. Held to foreshock location. Damage (VI) at Yakutat from earthquake and tsunami. Felt (V) at Anchorage, Copper Center, Gakana, Haines, Homer, Juneau, Levelock, Petersburg, Seward and Skwentna. Also felt (V) in sections of Whitehorse, Yukon Territory, Canada. Felt (IV) throughout southern Alaska from the Ketchikan area to Glennallen and Kodiak Island and (III) as far away as Bethel and Fairbanks. Also felt at Sand Point and (II) at Anaktuvuk Pass. Some damage caused to 2 ships at sea in the epicentral area; felt strongly on 3 other ships in the area. Tsunami generated with wave heights (peak to trough) 85 cm at Yakutat and 25 cm at Sitka, Alaska; 15 cm at Hilo, 12 cm at Nawiliwili, 5 cm at Honolulu, Hawaii and 5 cm at Presidio, California. Complex event, with major subevent occurring about 15 seconds after onset of the foreshock, observed on broadband displacement seismograms.

17 Dec	02 08 19.9	Near East Coast of Honshu, Japan	35.362 N	140.214 E	6.0 mb 6.4 Ms (BRK)

Depth 63 km. Two people killed; 66 injured and damage in Chiba Prefecture and the Tokyo area. Felt (V JMA) at Choshi, Chiba and Katsuura; (IV JMA) in the Tokyo-Yokahama-Mito-Kumagaya area; (III JMA) in the Onahama- Shizouka-Lida area and on Oshima and Hachijo-jima. Felt (I JMA) from Tottori to Sendai.

17 Dec	20 22 58.3	South of Bali Island	9.169 S	114.610 E	5.7 mb, 5.5 Ms

Depth 46 km. Twenty people injured on Bali. Felt (III) on Lombok and in eastern Java. Depth from broadband displacement seismograms.

TABLE 8. NUCLEAR EXPLOSIONS, 1987

DATE	TIME(UTC) h m sec	LAT	LONG	MAGNITUDE mb	Ms	SITE #	REF $	COMMENTS
Feb03	152000.1	37.181N	116.048W			NTS	PDE	"hazebrook"
Feb11	164500.1	37.011N	116.045W	4.5		NTS	PDE	"tornero"
Feb26	045822.1	49.800N	78.100E	5.4	5.3	EKaz	ISC	
Mar12	015717.3	49.900N	78.830E	5.6	3.9	EKaz	ISC	
Mar18	182800.1	37.210N	116.209W	4.3	4.1	NTS	PDE	"middle note"
Apr03	011708.1	49.870N	78.810E	6.2	4.8	EKaz	ISC	
Apr17	010304.9	49.830N	78.670E	6.0	4.7	EKaz	ISC	
Apr18	134000.6	37.248N	116.509W	5.5	4.0	NTS	PDE	"delamar"
Apr19	035957.1	60.620N	57.200E	4.5		Ural	ISC	*
Apr19	040455.9	60.800N	57.500E	4.5		Ural	ISC	*
Apr22	220000.1	36.983N	116.005W	4.2		NTS	PDE	"presidio"
Apr30	133000.1	37.233N	116.423W	5.5	4.4	NTS	PDE	"hardin"
May05	165801.0	21.600S	138.700W	4.8		Mur	ISC	
May06	040205.8	49.800N	78.110E	5.6	6.2	EKaz	ISC	
May20	170458.5	21.870S	138.970W	5.6		Mur	ISC	
Jun05	045958.5	41.550N	88.720E	6.2	4.7	LopN	ISC	
Jun06	023707.1	49.800N	78.090E	5.4		EKaz	ISC	
Jun06	180001.0	21.500S	138.800W	4.7		Mur	ISC	
Jun18	152000.1	37.194N	116.035W			NTS	PDE	"brie"
Jun20	005305.0	49.890N	78.730E	6.1	4.5	EKaz	ISC	
Jun20	160000.1	37.220N	116.178W			NTS	PDE	"mission ghost"
Jun21	175457.9	22.100S	138.700W	5.1		Mur	ISC	
Jun30	160500.1	36.999N	116.043W	4.6		NTS	PDE	"panchuela"
Jul06	235956.6	61.490N	112.784E	5.2		USSR	PDE	C.Siberia *
Jul16	190000.1	37.104N	116.023W	4.8		NTS	PDE	"midland" UK
Jul17	011707.0	49.779N	78.128E	5.8	4.5	EKaz	PDE	
Jul24	015956.7	61.466N	112.721E	5.1		USSR	PDE	C.Siberia *
Aug02	005806.7	49.841N	78.886E	5.9	3.8	EKaz	PDE	
Aug02	015959.6	73.314N	54.709E	5.8	3.4	NovZ	PDE	
Aug12	012956.8	61.426N	112.708E	5.0		USSR	PDE	C.Siberia *
Aug13	140000.0	37.061N	116.045W	5.9	4.4	NTS	PDE	"tahoka"
Sep16	073001.0	49.000N	78.000E	5.0		EKaz	FOA	
Sep18	023209.1	50.180N	78.020E	4.3		EKaz	PDE	
Sep24	150000.0	37.228N	116.375W	5.7	4.3	NTS	PDE	"lockney"
Oct03	151457.5	47.633N	56.218E	5.2		USSR	PDE	W.Kazakh *
Oct16	060608.6	49.780N	78.240E	4.6		EKaz	PDE	
Oct23	160000.1	37.142N	116.079W	5.2		NTS	PDE	"borate"
Oct23	164958.6	21.870S	139.009W	5.5		Mur	PDE	
Nov05	172959.0	21.786S	139.003W	5.8		Mur	PDE	
Nov15	033106.7	49.872N	78.795E	6.0	4.8	EKaz	PDE	
Nov19	163058.3	21.910S	139.008W	5.9		Mur	PDE	
Nov29	175900.0	22.000S	139.000W			Mur	FOA	
Dec01	163000.0	36.996N	116.004W			NTS	PDE	"waco"
Dec02	163000.0	37.235N	116.163W	4.1		NTS	PDE	"mission cyber"
Dec13	032104.7	49.955N	78.852E	6.1	4.5	EKaz	PDE	
Dec20	025506.3	49.753N	78.024E	4.8		EKaz	PDE	
Dec27	030504.7	49.831N	78.744E	6.1	4.5	EKaz	PDE	

NTS: Nevada, USA; EKaz: East Kazakh, USSR; NovZ: Novaya Zemlya, USSR;
LopN: Lop Nor, People's Republic of China

$ ISC: International Seismological Centre, UK
PDE: Preliminary Determination of Epicentres, USA
FOA: National Defence Research Institute, Sweden

* Presumed peaceful nuclear explosion

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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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