AGSO

AUSTRALIAN SEISMOLOGICAL REPORT, 1990

compiled by

Kevin McCue and Peter Gregson

RECORD 1993/52

AGSO
AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

Department of Primary Industries and Energy

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Kevin McCue and Peter Gregson

(Australian Seismological Centre)

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SUMMARY

The year was an average one as measured by the size and frequency of Australian earthquakes. The largest earthquake was near Meckering WA on 17 January, just 3 weeks after the similar sized earthquake near Newcastle NSW which was so destructive. Only minor damage was caused in Meckering, a tribute to both the post-1968 Meckering earthquake building code for domestic construction written by the WA Local Government, and the building quality and workmanship used in the town's reconstruction.

Twelve earthquakes were felt widely enough that intensity questionnaires were distributed and isoseismal maps compiled. Of these, one was at Meckering WA, seven occurred in South Australia, four in the South-east, two in the mid-north and another on Eyre Peninsula, and the others were at Innisfail and Rubyvale Qld, and Montague Is and Bega in NSW. Only the Meckering earthquake caused damage.

Seven accelerograms were obtained during the Meckering earthquake, from Cadoux in the north to Canning Dam in the south over the distance range 75 to 110 km. Other important accelerograms were recorded at Newcastle and Oolong NSW from small close earthquakes, the recorded acceleration in the epicentral region near Oolong exceeded 0.3g.

During 1990, 16 presumed underground nuclear explosions were detonated. This compares with 26 in 1989 and 38 in 1988.

INTRODUCTION

This report contains information on earthquakes of Richter magnitude 3 or greater that were reported in the Australian region during 1990. It is the eleventh of an annual series compiled by the Australian Geological Survey Organisation, using data from AGSO and various seismological agencies in Australia. Its purposes are to aid the study of earthquake risk in Australia, and to provide information on Australian and world earthquakes for scientists, engineers and the general public.

The report has six main sections: **Australian region earthquakes**, which contains a summary of the 1990 seismicity, a State by State breakdown and a brief descriptions of the more important earthquakes; **Isoseismal maps**, describing those that were widely felt; **Network operations**, which gives details of the seismographs that operated in Australia during the year; **Accelerograph data,** which tabulates recordings from the accelerograph network; **Principal world earthquakes,** which lists the largest and most damaging earthquakes that took place world-wide during 1990; and **Monitoring of nuclear explosions,** which describes the operation of the Nuclear Monitoring Section and lists known underground nuclear explosions.

In the report we refer to the *magnitude* of an earthquake and *intensity* caused by an earthquake. These terms are defined below.

Magnitude

The magnitude of an earthquake is a measure of its size and is related to the energy released at its focus. It is calculated from the amplitude and period of seismic waves recorded on seismograms. The magnitude scale is logarithmic: 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 M and energy E (joules) is

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

A shock of magnitude 2 is the smallest normally felt by humans, whereas earthquakes of magnitude 5 or more can cause significant damage if they are shallow and close to buildings. Great, major, large, and moderate are terms used to describe earthquakes above magnitude 8, 7, 6 and 5 respectively whilst small and micro-earthquake are for magnitudes below 4 and 3 respectively. The following magnitude scales are in common use.

Richter magnitude (ML)

Richter (1958) defined a scale to determine the relative size of local earthquakes in California

$$ML = \log A - \log A_0$$

where A is the maximum trace amplitude (zero-to-peak) in millimetres on a standard Wood-Anderson seismogram, and A_0 is the attenuation of amplitude with distance out to 600 km. In California, Richter's reference earthquake, magnitude ML 3.0, causes a trace amplitude of 1 mm on the Wood-Anderson seismogram, 100 km from the epicentre.

If standard, horizontal Wood-Anderson instruments (Anderson & Wood, 1925) are not available, an equivalent Richter magnitude can be determined by correcting for the difference in magnification (see Willmore, 1979, para. 3.1.1) between the seismometer used and the Wood-Anderson, and for a seismometer mounted vertically, rather than horizontally. Allowance must also be made for differences in attenuation from that in California.

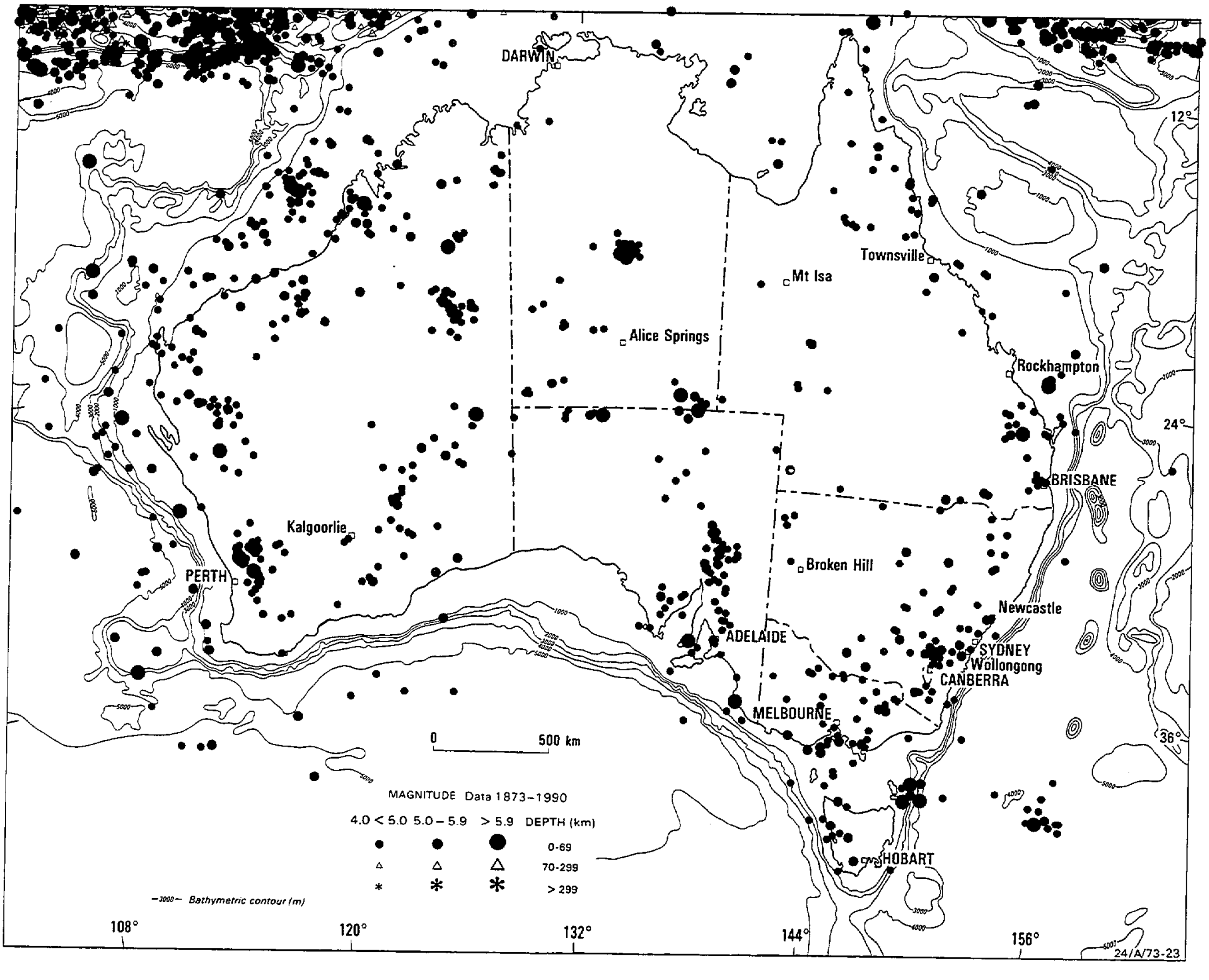


Figure 1 Epicentres of Australian earthquakes, 1873-1990, magnitude ML ≥ 4.0.

Surface-wave magnitude (Ms)

The surface-wave magnitude was originally defined for shallow earthquakes in the distance range 20–160°, and in the period range $T = 17–23$ s. When these conditions hold, Ms values are calculated from the 1967 IASPEI formula (see Båth, 1981)

$$Ms = \log A/T + 1.66 \log \Delta + 3.3$$

where A is the ground amplitude in micrometers (10^{-6} m), T is in seconds and Δ is the epicentral distance in degrees. Marshall & Basham (1973) extended this formula to distances as close as 1°, and periods as short as 10 s.

Body-wave magnitude (mb)

For deeper earthquakes with negligible surface waves, or shallow earthquakes outside the distance range defined for ML or Ms, Gutenberg (1945) defined a body-wave scale

$$mb = \log A/T + Q\ (\Delta, h)$$

where A is the maximum mean-to-peak ground amplitude in microns of the P, PP, or S-wave train, T is the corresponding wave-period (seconds), and Q is a function of focal depth h and distance Δ. The Q factors were derived by Gutenberg (1945) and are listed in Richter (1958). This definition was subsequently modified to limit the amplitude measurement to the first 20 s of the P or S phase for moderate sized earthquakes and the first 60 s for large earthquakes.

Duration magnitude (MD)

When an earthquake is close to the seismograph, the wave amplitude on the seismogram may be clipped, in which case no measure of magnitude is possible. To counteract this, another scale was devised (Bisztricsany, 1958), based on the recorded duration of the seismic wave train on short-period seismograms

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

where t is the length of the earthquake coda in seconds (usually from the initial P onset), Δ is the distance from the epicentre, and a, b, and c are constants for a particular recording station. Many other forms of this equation have been used.

Seismic moment magnitude (Mw)

Kanamori (1978) defined another magnitude scale from the seismic moment M_0

$$Mw = (\log M_0) / 1.5 - 6.0$$

$$\text{and} \quad M_0 = \mu A d$$

where μ is the rigidity of the bedrock, A the fault surface area displaced, and d the average displacement on that surface. M_0 is proportional to the amplitude of the far-field displacement waveform at low frequencies. Bolt & Herraiz (1983) suggested a way of computing the seismic moment (N-m) from Wood-Anderson seismographs

$$\log M_0 = 9.74 + 1.22 \log (CDE)$$

where C is the maximum peak-to-peak amplitude in mm, D the duration in seconds from the S-wave onset to the last point where the peak-to-peak amplitude exceeds $C/3$ and E is the epicentral distance in kilometres.

Magnitude from isoseismals

In some cases, where reliable magnitudes or moments cannot be determined from seismograms, it is possible to estimate magnitudes from macroseismic data. In this report, the formula of McCue (1980) is used

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

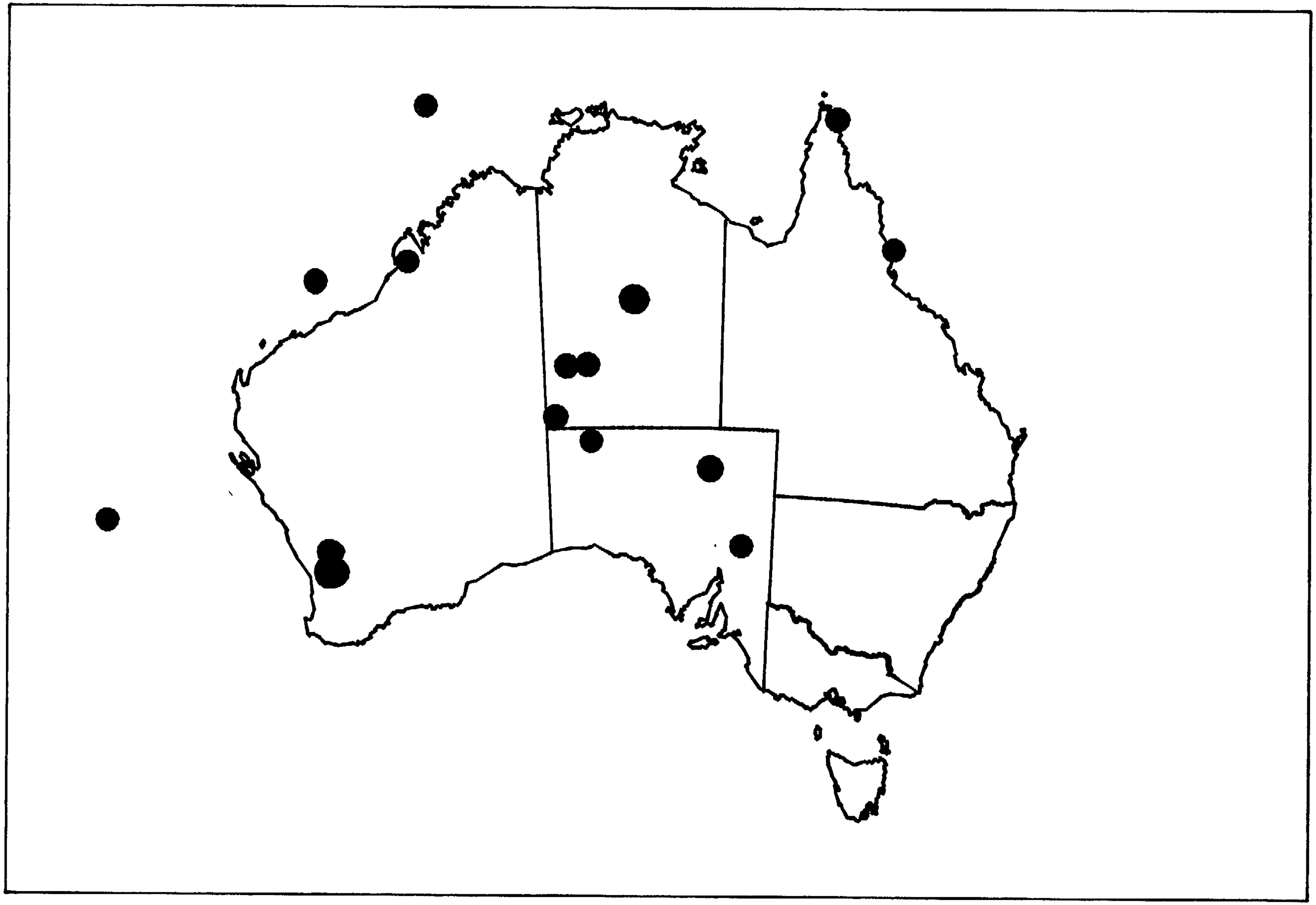


Figure 2 Epicentres of Australian earthquakes, 1990, magnitude ML ≥ 4.0.

where *Rp* is the radius of perceptibility (km), the distance equal to the radius of a circle with an area equal to that enclosed by the MM(III) isoseismal, and *ln* is the natural logarithm. *M(Rp)* is equivalent to *ML* below magnitude 6, and to *Ms* above magnitude 6. Magnitudes so determined are approximate. Greenhalgh & others (1989) modified the equation using a larger data set and extended the method to other intensities, but at the expense of simplicity in application. Additional information on magnitudes is available in McGregor & Ripper (1976), Båth (1981), and Denham (1982).

Intensity

The intensity of an earthquake is a measure of its effects on people and buildings and should not be confused with magnitude which is a measure of the energy release. In this report we use the modified Mercalli (MM) scale as presented by Eiby (1966) for New Zealand The scale is listed in the Appendix. Essentially the MM scale is an assessment of how severely the earthquake was felt and of the degree of damage caused at a particular place. Some earthquakes are felt over a sufficiently wide area that an isoseismal map can be prepared using information compiled from questionnaires, newspaper reports, and personal interviews and inspections.

David Denham, Peter Gregson & Kevin McCue

AUSTRALIAN REGION EARTHQUAKES, 1990

The largest earthquake during 1990 was on 17 January. Its epicentre was 10 km from Meckering WA, 100 km east of Perth. At magnitude ML 5.5, it was only slightly smaller than that at Newcastle NSW only 3 weeks earlier (McCue & others, 1990), which caused extensive damage and loss of life. There was no building damage, nor were there injuries at Meckering. The only other earthquake that exceeded magnitude 5 was at Tennant Creek NT on 27 November, one of the extensive aftershock sequence following the January 1988 mainshocks (Jones & others, 1990). Earthquakes of magnitude 3 or more are listed in Table 1, 22 of them had magnitudes of at least 4.0.

In terms of numbers of earthquakes in the different magnitude ranges, it was an average year. The modal, or most frequent, maximum magnitude in Australia is ML 5.5 and the average number of earthquakes of magnitude ML 4 or more is 22.

There was no apparent change in the long-term rate of earthquakes in Australia in 1990 but the earthquake risk is steadily increasing as the population and building stock grow and buildings age.

Although the level of seismicity in Australia is low compared with countries on plate boundaries such as Western North America, Japan, Papua New Guinea and New Zealand, it is high compared with other ancient (Precambrian) continental regions such as eastern North America, Siberia, Africa or southern India.

Publication of the latest re-evaluation of earthquake hazard in Australia during the year (Gaull & others, 1990), established a baseline for an overdue revision of the Australian Earthquake Code, AS2121-1979. Standards Australia established a (voluntary) committee in late 1989 prior to the Newcastle earthquake, to draft a new code and at the same time convert it to a loading code (it specifically excludes materials which are covered in separate materials codes) for limit-state rather than working-state stresses.

A sub-committee BD/6/4/1, including R Cuthbertson (DRI, Qld), G Gibson (PIT, Vic), G Horoshun (ACS Canberra), D Love (SADME, SA), K McCue (AGSO-Chair), M Michael-Leiba (AGSO) and J Rynn (UQ, Qld), was also established to revise the earthquake zoning map in AS2121-1979. This committee was assisted also by P Gregson (ASC WA).

Kevin McCue

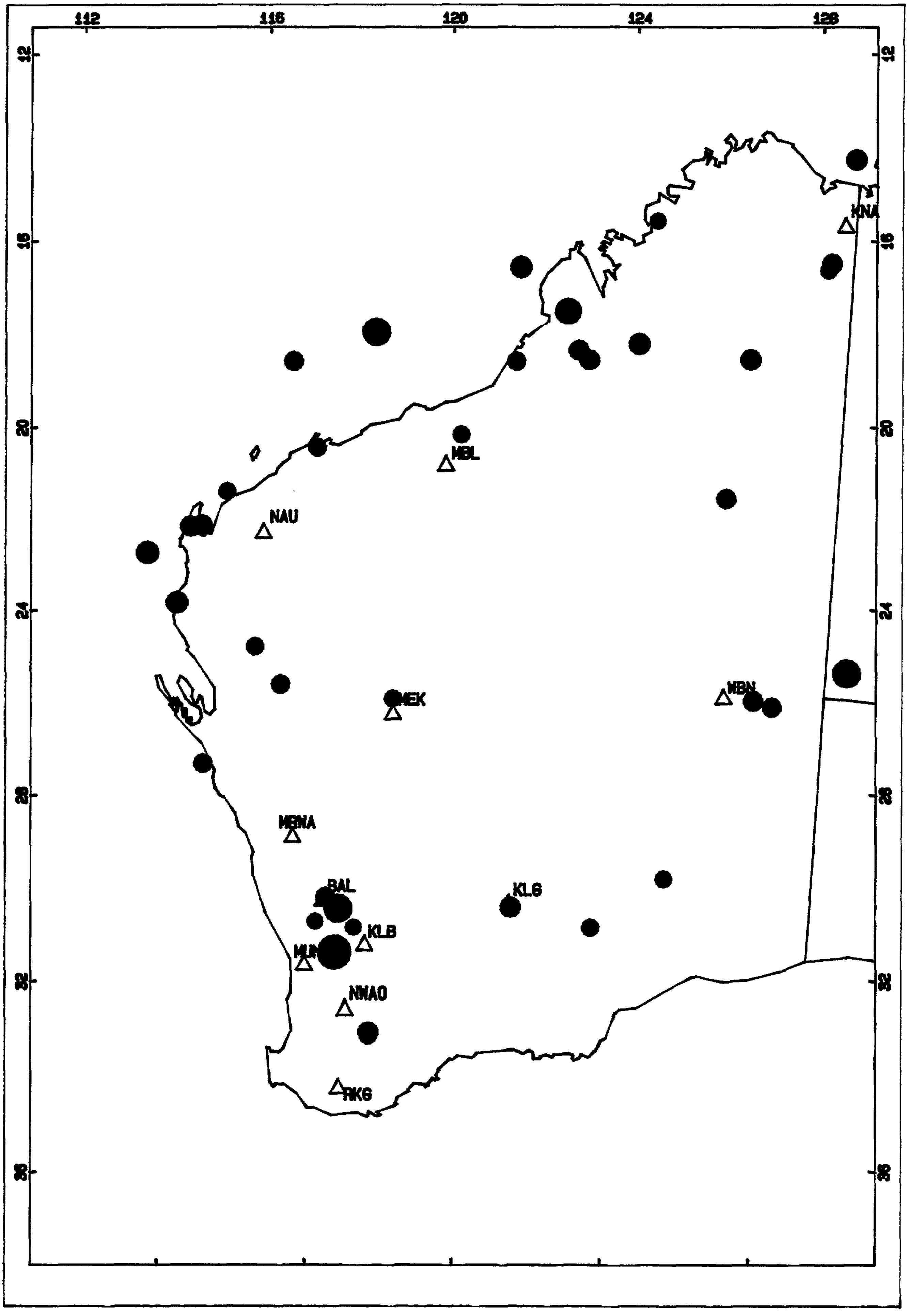


Figure 3 Epicentres of earthquakes in Western Australia, 1990, magnitude ML ≥ 2.5.
In figures 3 to 8, the dots are epicentres (ML2.5 to 5.5), the triangles are seismographs.

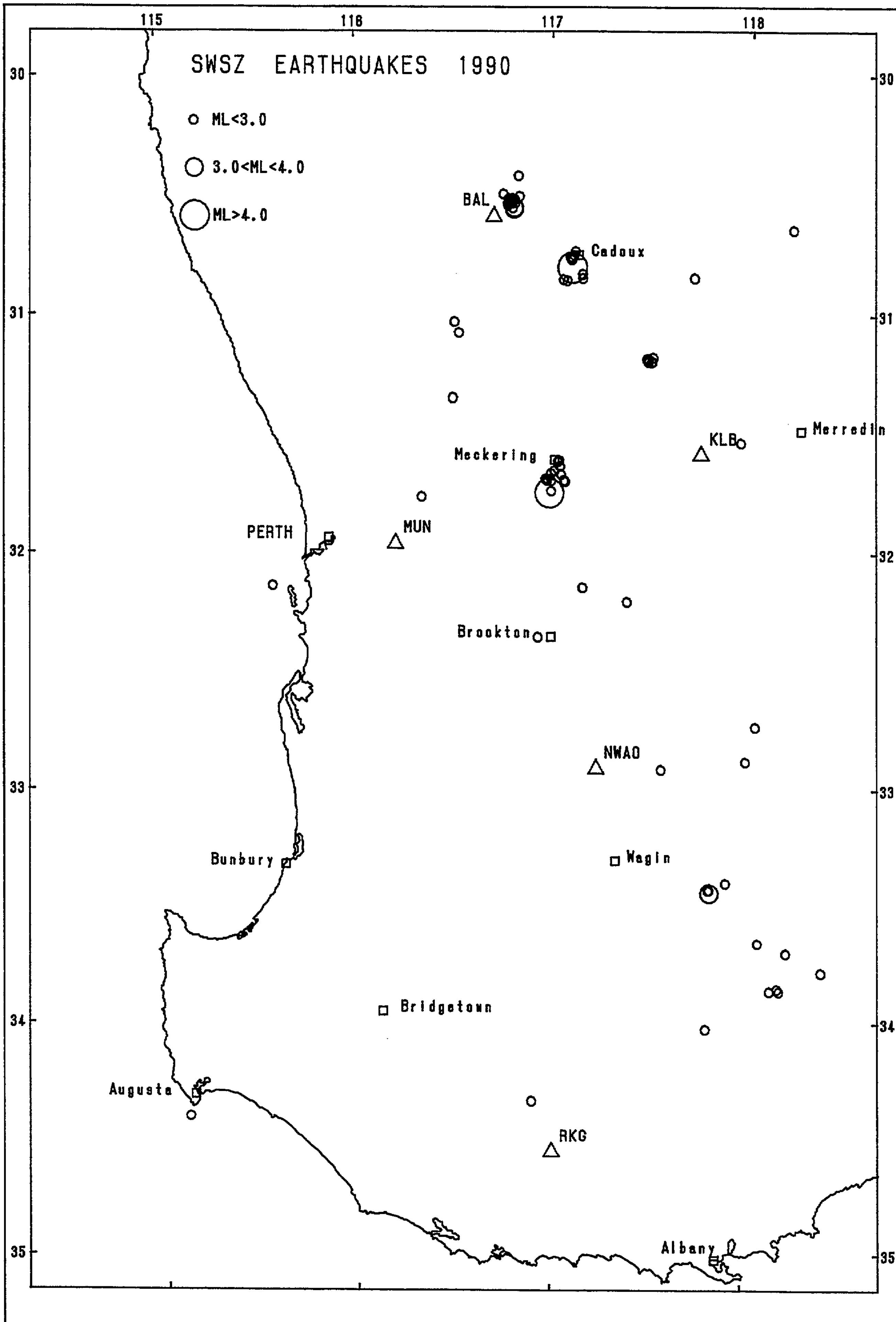


Figure 3b Epicentres of earthquakes in Southwest WA, 1990.

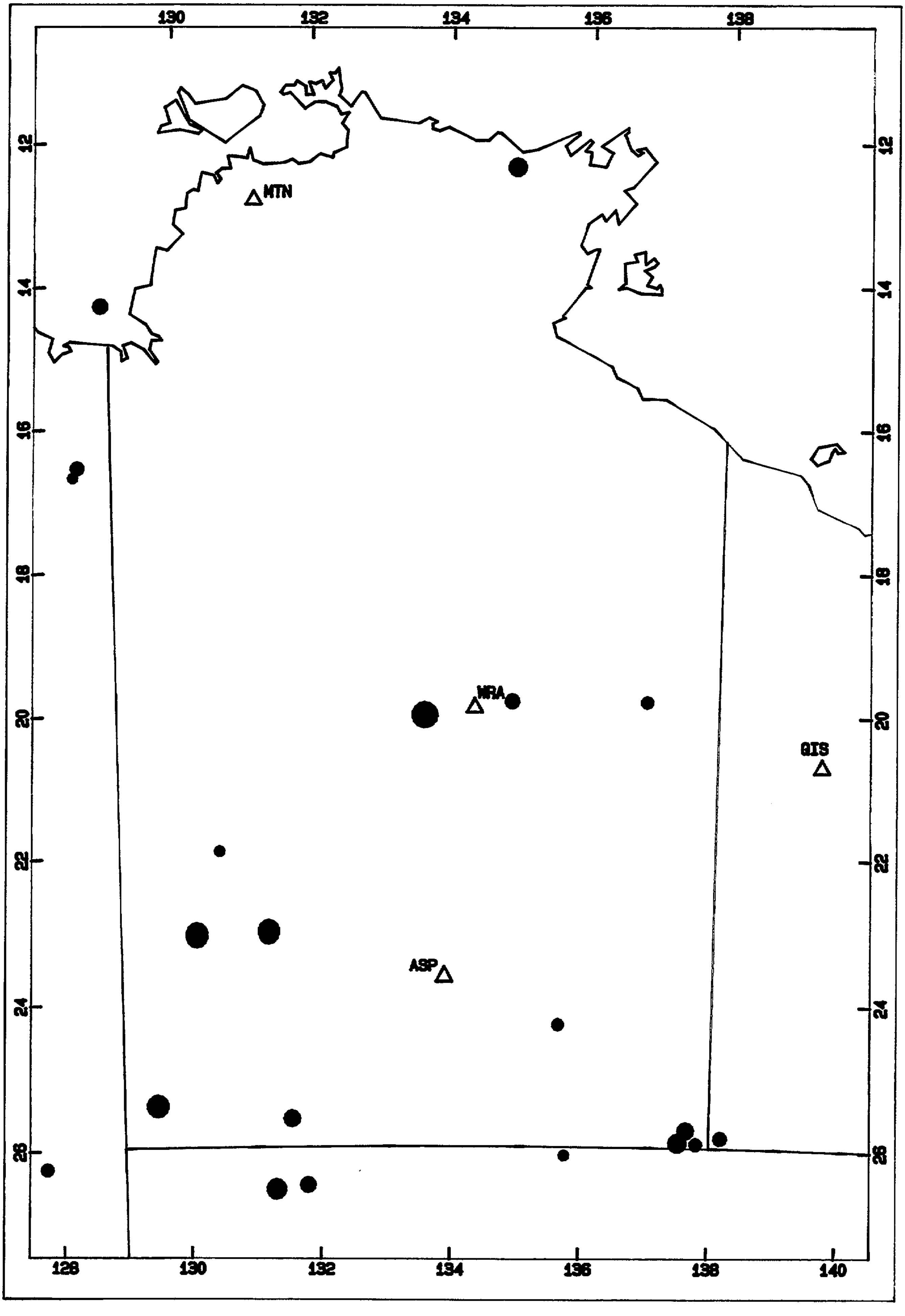


Figure 4 Epicentres of earthquakes in the Northern Territory, 1990, magnitude ML ≥ 2.5.

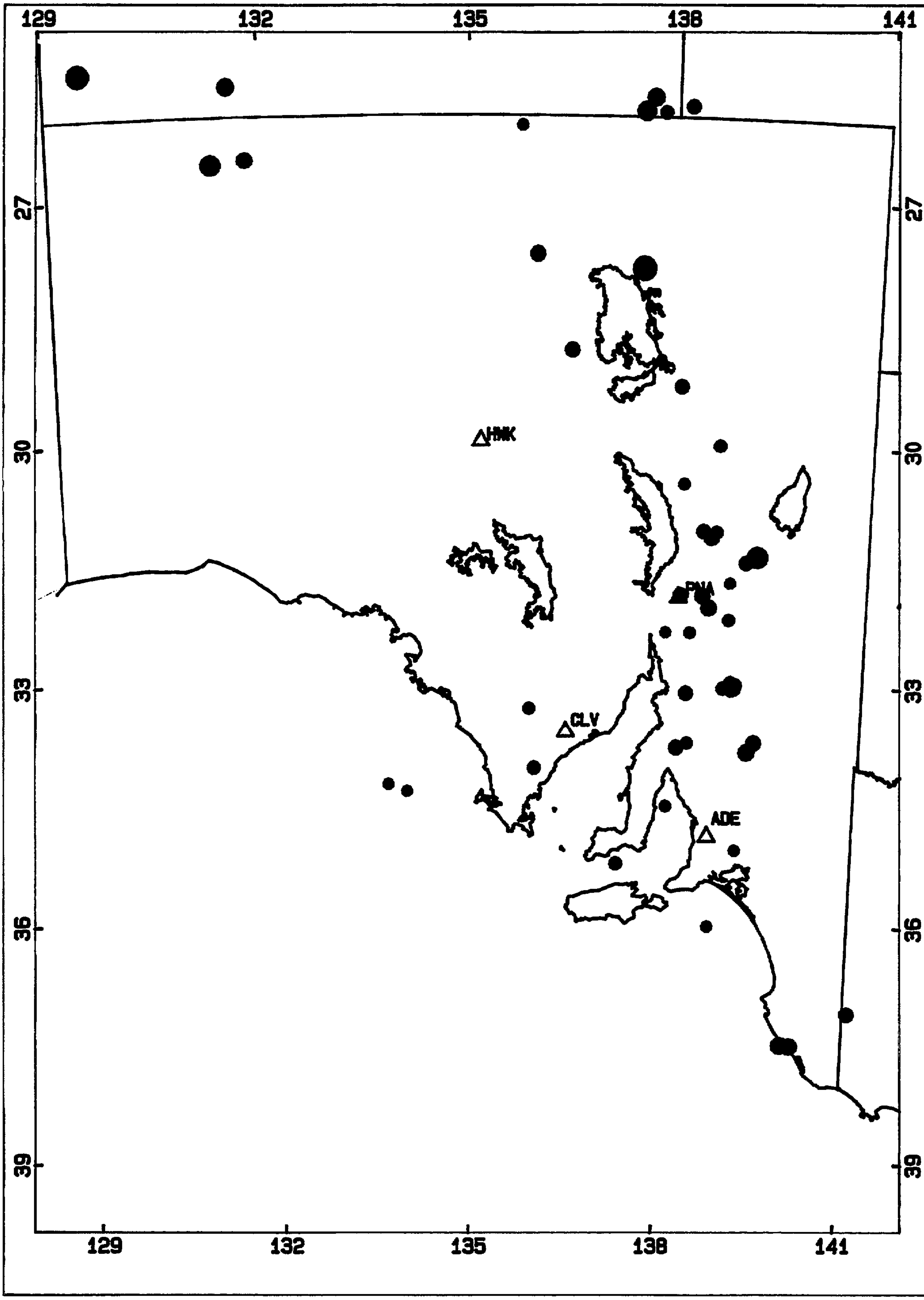


Figure 5 Epicentres of earthquakes in South Australia, 1990, magnitude ML ≥ 2.5.

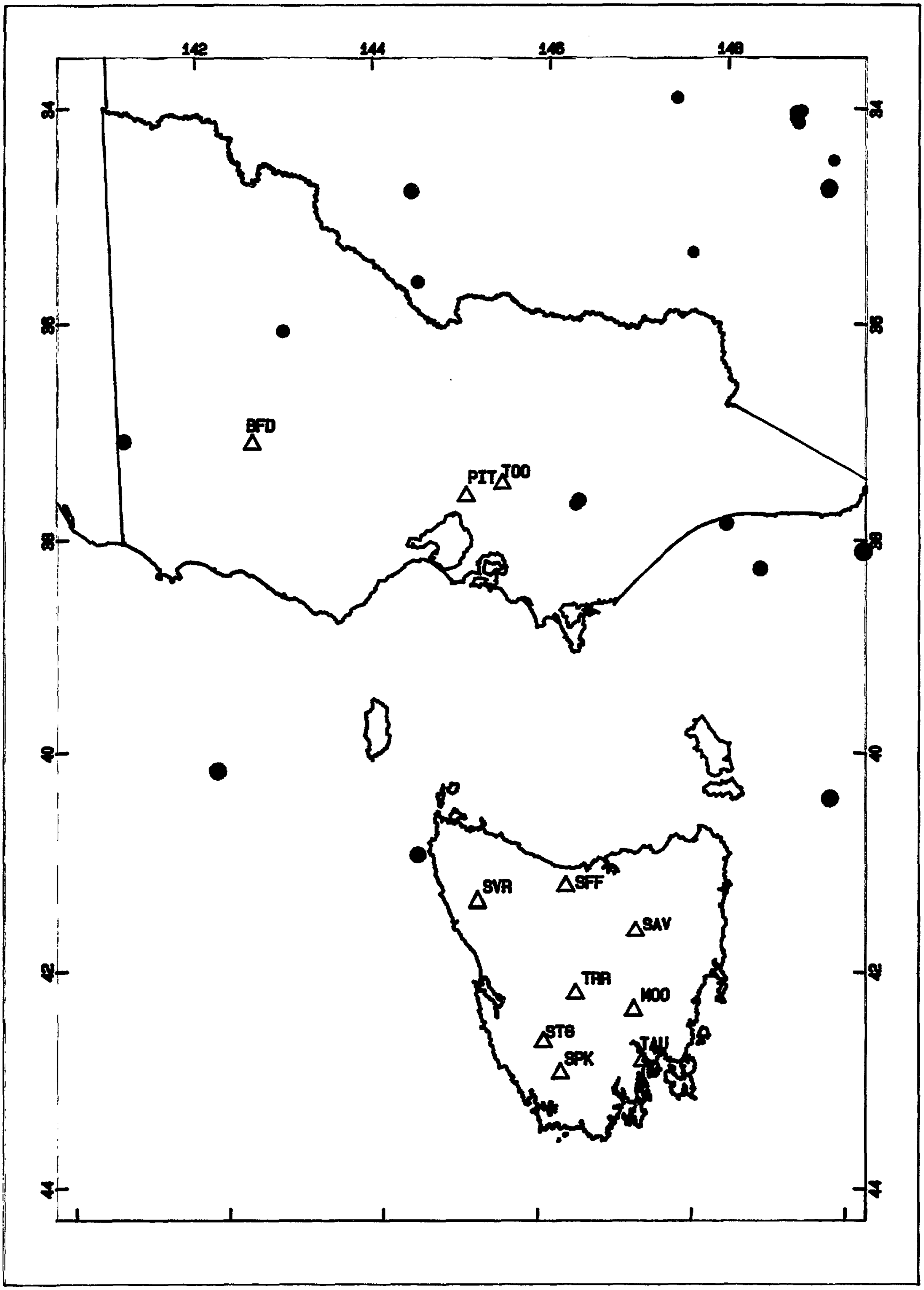


Figure 6 Epicentres of earthquakes in Victoria & Tasmania, 1990, magnitude ML ≥ 2.5.

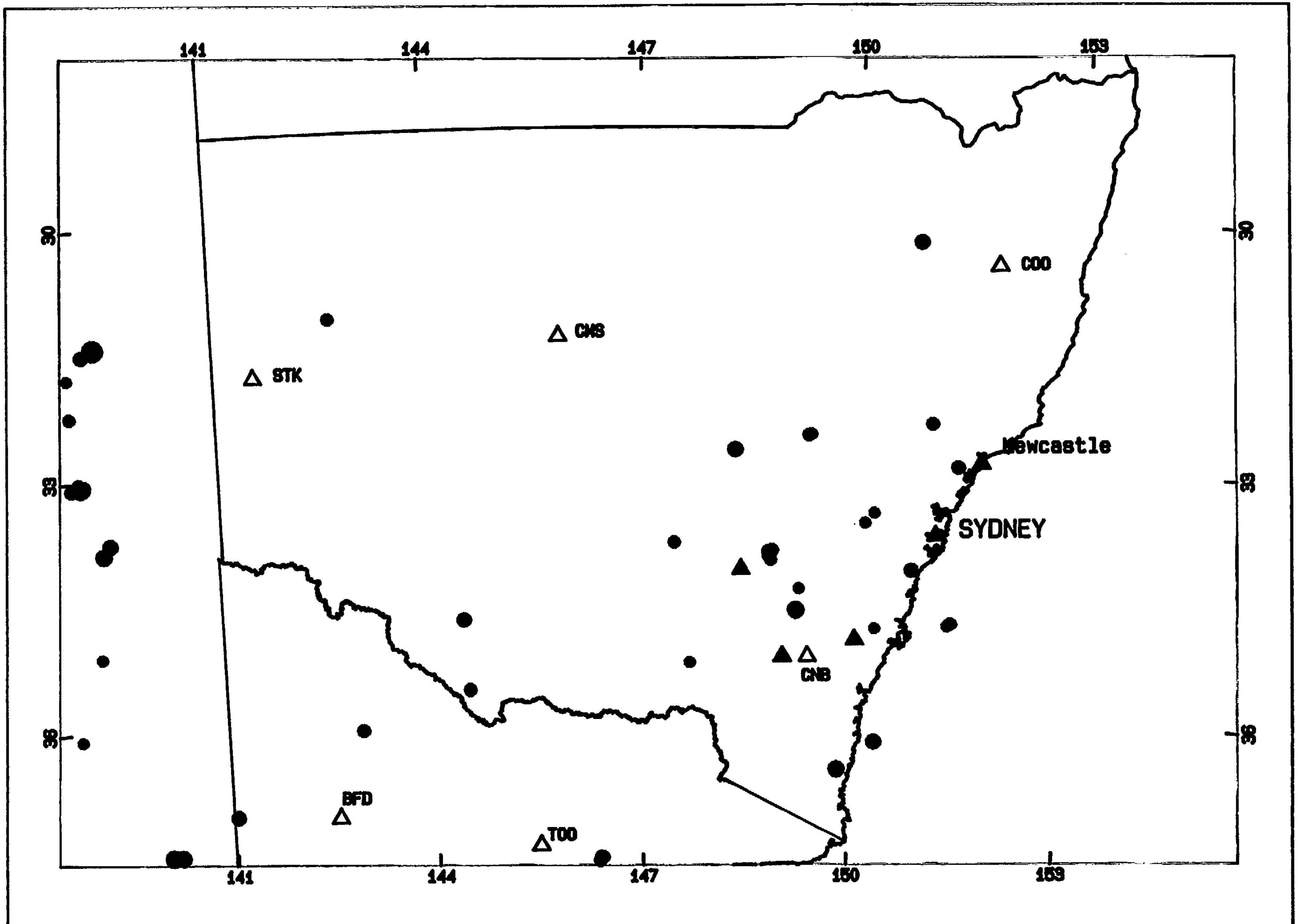


Figure 7 Epicentres of earthquakes in New South Wales 1990, magnitude ML ≥ 2.5.

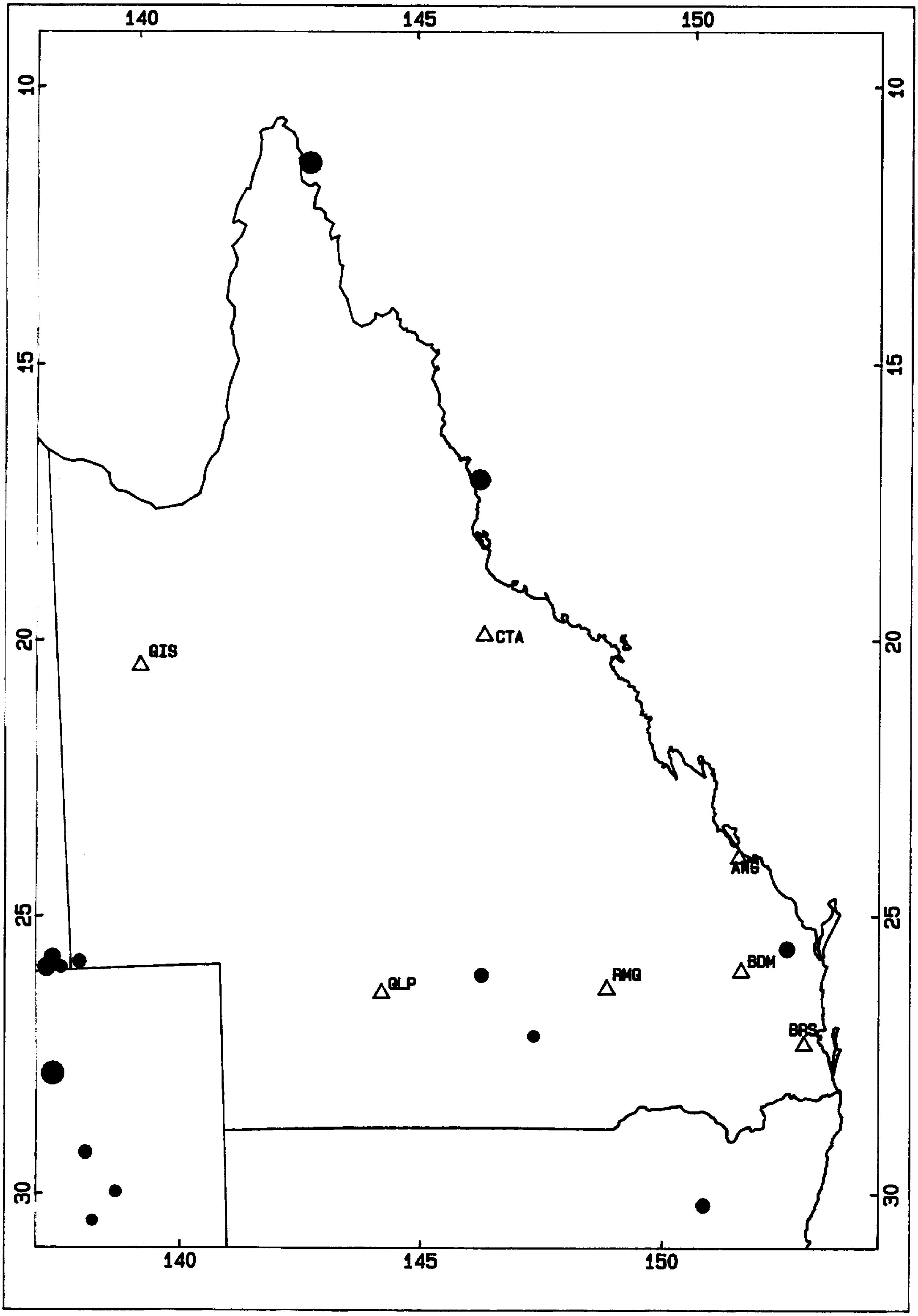


Figure 8 Epicentres of earthquakes in Queensland, 1990, magnitude ML ≥ 2.5.

Western Australia (Figure 3)

Five earthquakes of magnitude ML 4 or greater occurred in Western Australia, the same number as in 1989.

The largest ML 5.5, occurred on 17 January, 10 km south of Meckering. The ISC rated its magnitude as Mb 5.2 and listed 80 stations which reported the event. By comparison, the ISC gave the 1989 Newcastle NSW earthquake a magnitude of Mb 5.4 and and it was reported by 253 stations worldwide. The 1990 Meckering earthquake was obviously the smaller of the two.

Of the 138 earthquakes recorded in WA, the majority occurred within or close to previously defined zones. The notable exception was a magnitude 2.9 earthquake offshore and about 150 km north of Geraldton on 28 May. This is in the same area as a group of offshore earthquakes between Geraldton and Shark Bay between 1987 and 1989 (Gregson, 1991).

Magnitude 4 or greater earthquakes outside the South-West Seismic Zone occurred 230 km N of Port Hedland (ML 4.5) on 18 February; 45 km NE of Broome (ML 4.2) on 17 August and 900 km W of Dongara (ML 4.1) on 9 May.

Seventy-eight earthquakes were located in the South-West Seismic Zone, compared with 62 in 1989. The most significant activity occurred near Meckering (14 events) where the largest earthquake was recorded. Other areas of activity were Cadoux (10); Ballidu (23); Wyalkatchem (6) and Dumbleyung (6). Minor activity occurred near Bencubbin (3); Calingiri (2); Gnowangerup (10); Brookton (7); Corrigin (8); Nyabing (9); Quairading (5); Bolgart (1); Beverley (6); Kellerberrin (4) and Newdegate (11).

An isoseismal map was prepared for the Meckering earthquake.

Northern Territory (Figure 4)

Aftershock activity continued throughout the year at Tennant Creek with the largest event, magnitude ML 5.2, on 27 November. Apart from a single small earthquake east of Darwin, the remaining seismicity was in the southwest and in the Simpson Desert in the southeast overlapping the South Australian and Queensland borders.

South Australia (Figure 5)

During 1990 about 300 earthquakes were located in South Australia by the Sutton Institute, SADME. This was down on the unusually high 380 the previous year, but the number of events over magnitude 3 doubled, resulting in 7 isoseismal maps. Most activity was again in the Flinders Ranges but there were interesting events in many other areas as well, giving a greater spread of epicentres than usual. There were a number of aftershocks to the Beachport (8 Nov 1989) event in the South East of the state, two events in the far north-west (largest ML 4.1 near Amata but not felt) and the largest event of ML 4.5 was at the top of Lake Eyre (also not felt). There were more events than usual in the Simpson Desert and also around Cleve on Eyre Peninsula. There was an interesting swarm of earthquakes on the eastern edge of the Flinders Ranges near Peterborough, with nine events between magnitude ML 2 and 3.

The first 4 digital seismographs were installed during 1990, with a number of other analogue stations being opened, moved or closed. The additions to the network in the South-East of the State were as a result of a grant to study any correlation with oil strandings that occur regularly on the beaches, in the hope of finding an economic oil field.

Victoria & Tasmania (Figure 6)

Over 350 earthquakes were located within Victoria in 1990, but only fourteen of these events were reported felt.

On 25 January at 13:33 UTC an earthquake of magnitude ML 2.9 occurred in East Bass Strait some 24 kilometres east of the Marlin oil rig. The event was felt between Marlo and Cape Conran. One week after the event an oil slick was washed up on the Ninety Mile Beach, possibly related to this earthquake.

Between 08:38 EDST on 12 March and 07:17 EDST on 13 March, a total of six separate events were felt southwest of the town of Maldon in central Victoria, just east of Cairn Curran Reservoir. The largest of these had a magnitude of ML 2.3, and was felt strongly at the property of Mr Michael Coles near Welshmans Reef, but did not cause any damage. Events as small as ML 0.3 were also felt on the property, so they must have been very shallow and not more than one or two kilometres away.

On 20 March at 07:36 UTC an earthquake of magnitude ML 2.4 occurred near Officer, 48 kilometres south east of Melbourne. This event was felt by many people between Pakenham and Narre Warren, especially about Berwick. No damage was reported.

On 22 April two separate events of magnitude ML 2.5 and ML 1.6 were felt at 16:59 UTC and 21:03 UTC respectively in the town of Glenloth, near Wedderburn. The first of these was of sufficient intensity to wake people from their sleep and to rattle windows. The second, though smaller, was also widely felt. No damage was reported.

A swarm of five separate events occurred at Digby 50 km west of Hamilton on 5 May. Two of these were at 09:59 UTC while the rest occurred at 10:00, 10:12, and 10:17 UTC. They ranged in magnitude from ML 2.3 down to ML 1.0. A resident of Rifle Downs just west of Digby felt three of these events, but no damage was reported.

At 02:22 UTC on 11 May an earthquake of magnitude ML 3.0 occurred at Thomson Reservoir, followed by four smaller aftershocks between 02:41 UTC and 03:34 UTC. These were reservoir induced earthquakes, and were very shallow, occurring at a depth of about 2.5 km. The ML 3.0 event was the largest reservoir induced earthquake experienced in Victoria. It was felt by MMBW staff working at Bell's Portal who were within one kilometre of the epicentre, but no damage was caused. Another similar event of magnitude ML 3.0 occurred at Thomson Reservoir on 19 May at 17:09 UTC, but was not felt as it occurred in the middle of the night.

In Tasmania, magnitude ML 3.6 earthquakes occurred in the east and west Tasman Sea Seismic Zones and a magnitude ML 3.3 earthquakes was centred in the Otway Basin off the northwest coast of Tasmania. A magnitude ML 3.5 earthquake was detected in an unusual location west of King Island on 27 November.

New South Wales and ACT (Figure 7)

Most of the earthquakes were in the southeast of NSW, in an area stretching from Newcastle west to Parkes and south to Bega. Six of the eight ML 3 or greater earthquakes were in this quadrant as was the largest, ML 3.5, at Oolong on 13 January. Isoseismal maps were drawn for small earthquakes at Bega on 1 April and Montague Island on 4 May following intense interest from the affected communities and the media.

A single small earthquake was felt at Cessnock, 30 km west of Newcastle on 23 February. It was apparently shallow and is not considered to be an aftershock of the December 1989 Newcastle earthquake.

Queensland (Figure 8)

Innisfail and Cape York were the epicentral regions of the 2 earthquakes that were of magnitude ML 4 or more in Queensland. The offshore magnitude ML 4.2 earthquake on 20 July was felt in Innisfail with an intensity of MM IV but there were no reports that the larger ML 4.5 earthquake on 9 June near the site of the proposed spaceport on York Peninsula was felt. Only three other small events could be located, all in the south of the State but none of these excited sufficient interest to distribute questionnaires.

Kevin McCue, Peter Gregson, David Love, Gary Gibson & Wayne Peck

ISOSEISMAL MAPS

There were 12 earthquakes either important enough or widely felt, that warranted further investigation or the distribution of questionnaires. Apart from the ML 5.5 Meckering WA earthquake on 17 January, the other earthquakes studied were all small. Details of the earthquakes and maps are discussed below.

Meckering WA, 17 January (Figure 9)

An earthquake occurred 10 km south of Meckering (100 km east of Perth) at 2.38 p.m. WST (Gregson, 1992; Dent, 1990). This was the largest earthquake in the Meckering area since 14 October 1968 when a magnitude Ms 6.9 earthquake destroyed the townsite. An aftershock of magnitude ML 5.7 occurred several hours after the 1968 mainshock (Everingham & others, 1982).

Isolated reports of MM VI were received from near the epicentre of the 1990 earthquake. It was felt strongly at Meckering (MM V) with reports of crockery and other items being thrown from shelves. In Northam the earthquake was reported as 'sounding like an explosion then violent shaking of buildings and extreme noise'. There were no reports of structural damage and no injuries. The effects of the earthquake were felt throughout the Perth Metropolitan area and over an area of 200 000 km^2 at distances of 280 km from the epicentre. The mean radius of the IV and III isoseismals were 180 and 270 km respectively.

M(Rp) was calculated as 5.6 which is consistent with the Richter magnitude of ML 5.5. Most of the intensities reported from Perth were consistent with MM IV which is the same intensity as at towns on the Yilgarn block at a similar distance.

Only four aftershocks were recorded, ranging from ML 2 to 2.3, and all of them were within 2 days of the main earthquake.

Beachport SA, 26 January (Figure 10)

This ML 3.7 event at 9:55 am on Saturday 27 January (local time) was a small reminder of the ML 3.9 earthquake in November the previous year. Most people commented that the effects were much less. A portable digital recorder near Southend produced the first digital seismogram in the State. The data was used to compute a more accurate epicentre location, which turned out to be offshore as previously suspected. Isoseismal lines were somewhat difficult to draw.

Beachport SA, 21 February (Figure 11)

This ML 3.4 event at 3:20pm was the last felt in the sequence of aftershocks from the November 1989 shock. It was not felt widely, but the reports suggested that this one may have been a little closer to shore.

Terowie SA, 5 March (Figure 12)

From 4 - 10 March 1990, the Peterborough - Terowie area was hit by a swarm of earthquakes. Nine had magnitudes over ML 2 with the two largest being magnitude ML 3.0 about 1 minute apart on 5 March at 5:25pm.

There were 69 questionnaires distributed and the map was produced from 39 replies. Most respondents noted a number of the events, and particularly noted the noises which varied from loud cracks to rumbling with some people regularly hearing both P and S arrivals.

Penola SA, 8 March (Figure 13)

At 8:27 pm on Thursday 8 March an earthquake of magnitude ML3.0 occurred south of

Naracoorte and Penola. It was felt over a wide area with no clear centre of high intensity. The map was produced from questionnaires and a few phone calls.

The event was well recorded on the newly installed digital instrument near Naracoorte, which was the first digital to be permanently installed in the State.

The location of this event was originally assumed to be Peterborough a few hundred kilometres north, as it occurred in the middle of a swarm of events there.

Bega NSW, 1 April (Figure 14)

The Bega District News of Tuesday 3 April 1990 headed its front page story with:

Not an explosion, not a crash, not something falling on the roof

Earthquake rocks Bega

The story included the following extracts:

> The first reaction of most residents to the earthquake was that a truck or semi-trailer had either hit the house or crashed nearby.
> Others thought it was an explosion of some sort, gas or petrol, or that a bomb had gone off.
> Residents have reported the whole house shaking, while others only felt tremors.
> The loud bang heard elsewhere was not reported in Bermagui.
> Police were inundated with calls.
> No damage was reported but in Merimbula and Pambula objects fell from shelves.

Most of the reports from which this isoseismal map was drawn were from letters from residents responding to a request for information carried by the local newspaper. The one surprising report was from Mallacoota, a Victorian coastal town some 10 km from the NSW border and more than 100 km from the epicentre of this ML 3.4 earthquake.

An isoseismal maps was drawn for a previous earthquake in the area on 13 June 1987 (ML 2.6).

Montague Is NSW, 4 May (Figure 15)

This small earthquake 10 km southeast of Montague Island was felt along the coastal strip from Moruya to Bega NSW. The epicentre is poorly constrained but felt reports are consistent with the computed location. Questionnaires were not distributed, the reports were obtained by phone and from the local media.

Innisfail Qld, 13 May (Figure 16)

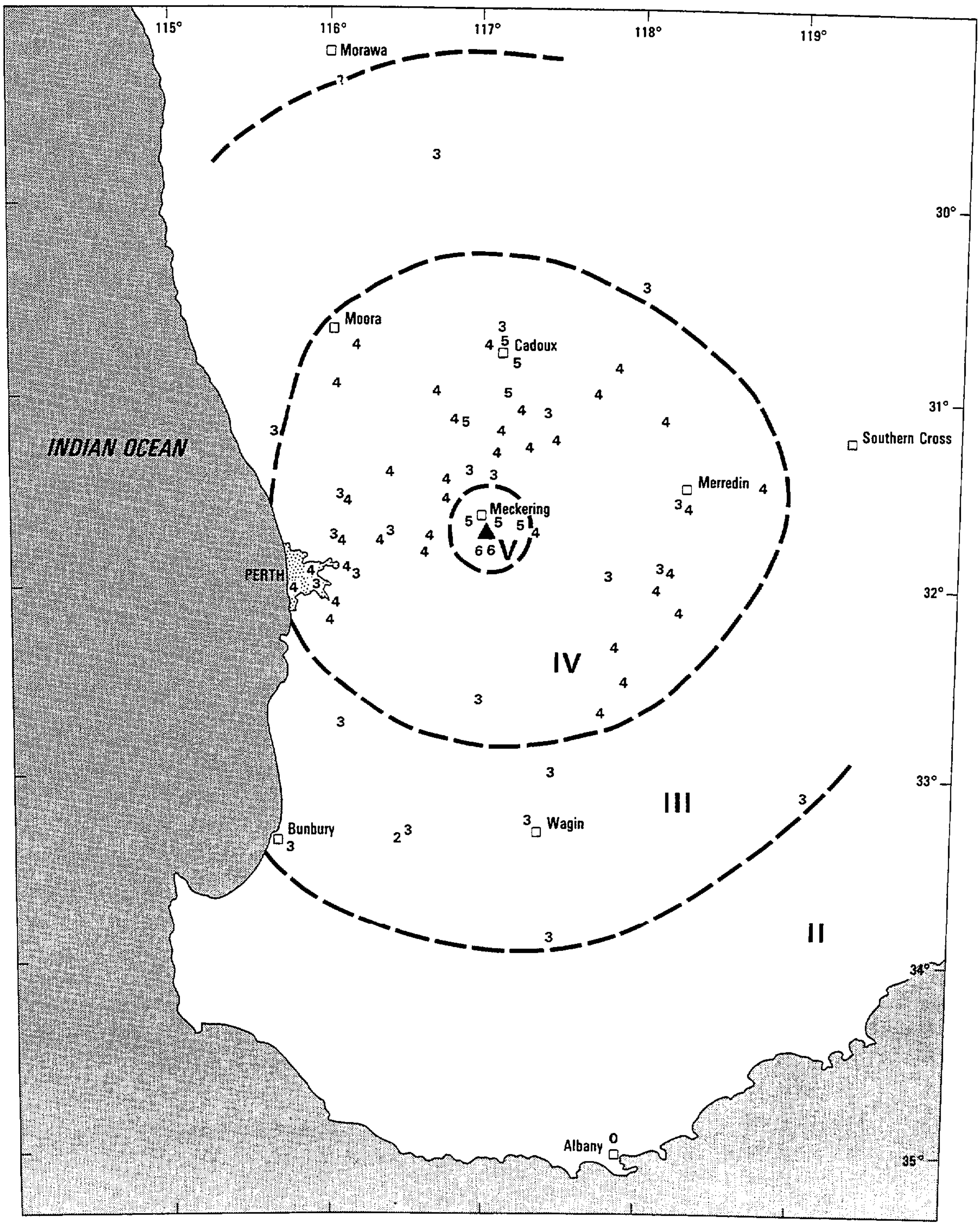
On 13 May at 3:30 pm (AEST) an earthquake was felt in the Innisfail region. A survey of the felt effects was conducted by Department of Minerals and Energy seismologists and several Queensland Electricity Commission personnel in Ravenshoe. This ML 4.5 event was located offshore, in the same area as a magnitude ML 4.0 earthquake on 16 November last year. The offshore location limited the area over which the earthquake was felt to 2000 km^2. No damage was reported and the maximum assessed intensity was MM IV.

Over 60 aftershocks were recorded on the nearby Tully-Millstream network over the next 2 years. An aftershock on 15 August 1990 (ML 2.6) was felt by several people at Flying Fish Point near Innisfail.

Rubyvale Qld, 9 June (Figure 17)

This ML 2.9 earthquake was felt in the gemfields of Rubyvale and Sapphire, 50 km west of Emerald in Central Queensland. The event was felt underground in the mines

ISOSEISMAL MAP OF THE MECKERING EARTHQUAKE, WESTERN AUSTRALIA, 17 JANUARY 1990



DATE :	*17 January 1990*
TIME :	*06:38:08 UTC*
MAGNITUDE :	*5.5 ML (MUN)*
EPICENTRE :	*31.70°S, 117.00°E*
DEPTH :	*6 km*

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

0 — 200 km

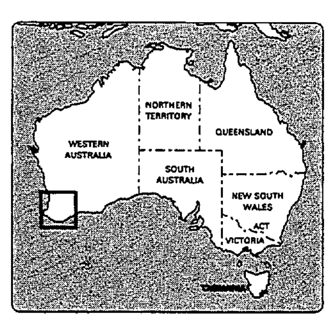
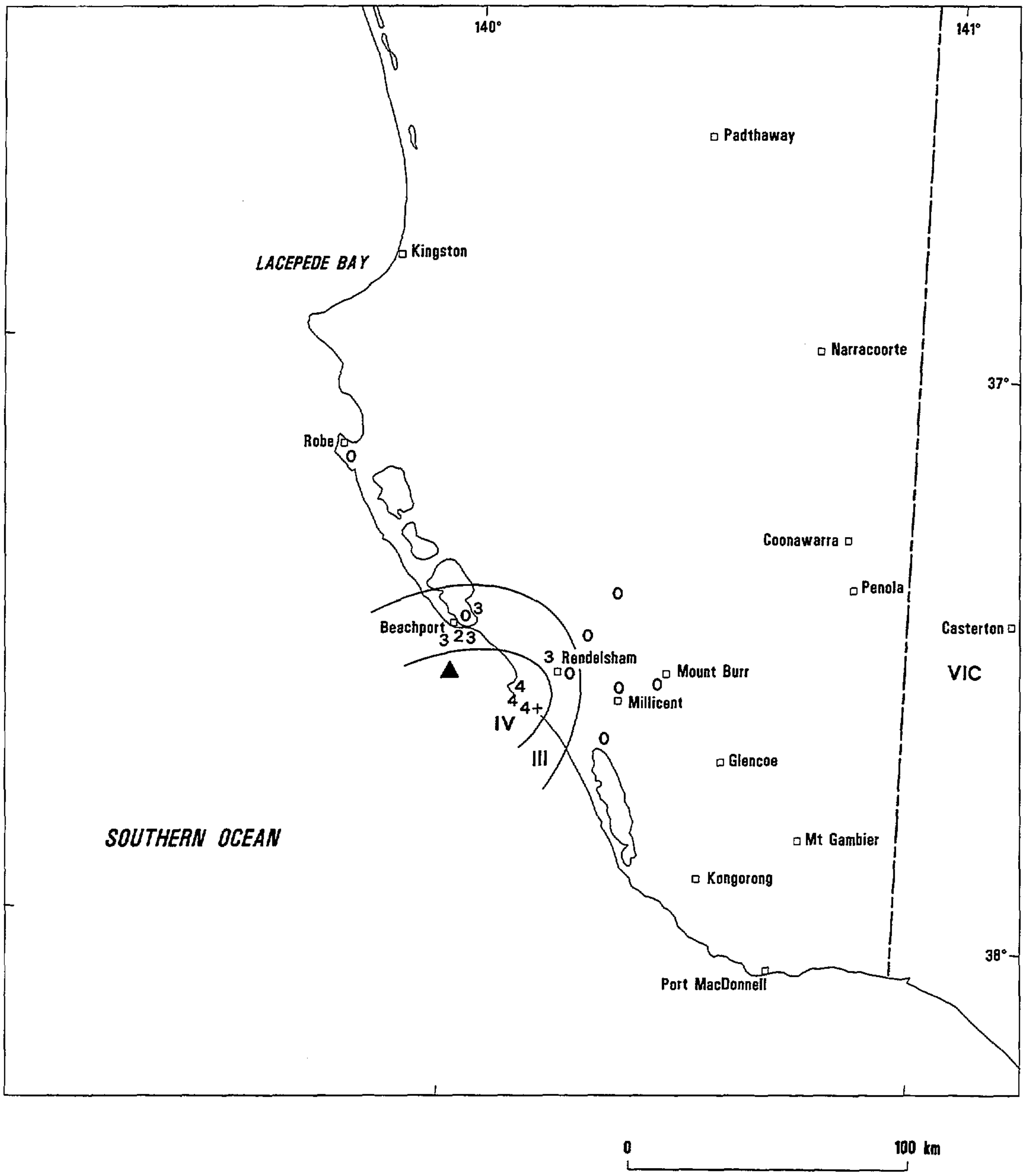


Figure 9

24/WA/88

ISOSEISMAL MAP OF THE BEACHPORT EARTHQUAKE SOUTH AUSTRALIA
26 JANUARY 1990



DATE:	26 January 1990
TIME:	23:25:11.9 UTC
MAGNITUDE:	3.7 ML
EPICENTRE:	37.55°S 139.99°E
DEPTH:	3.8 km

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

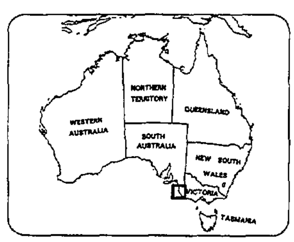
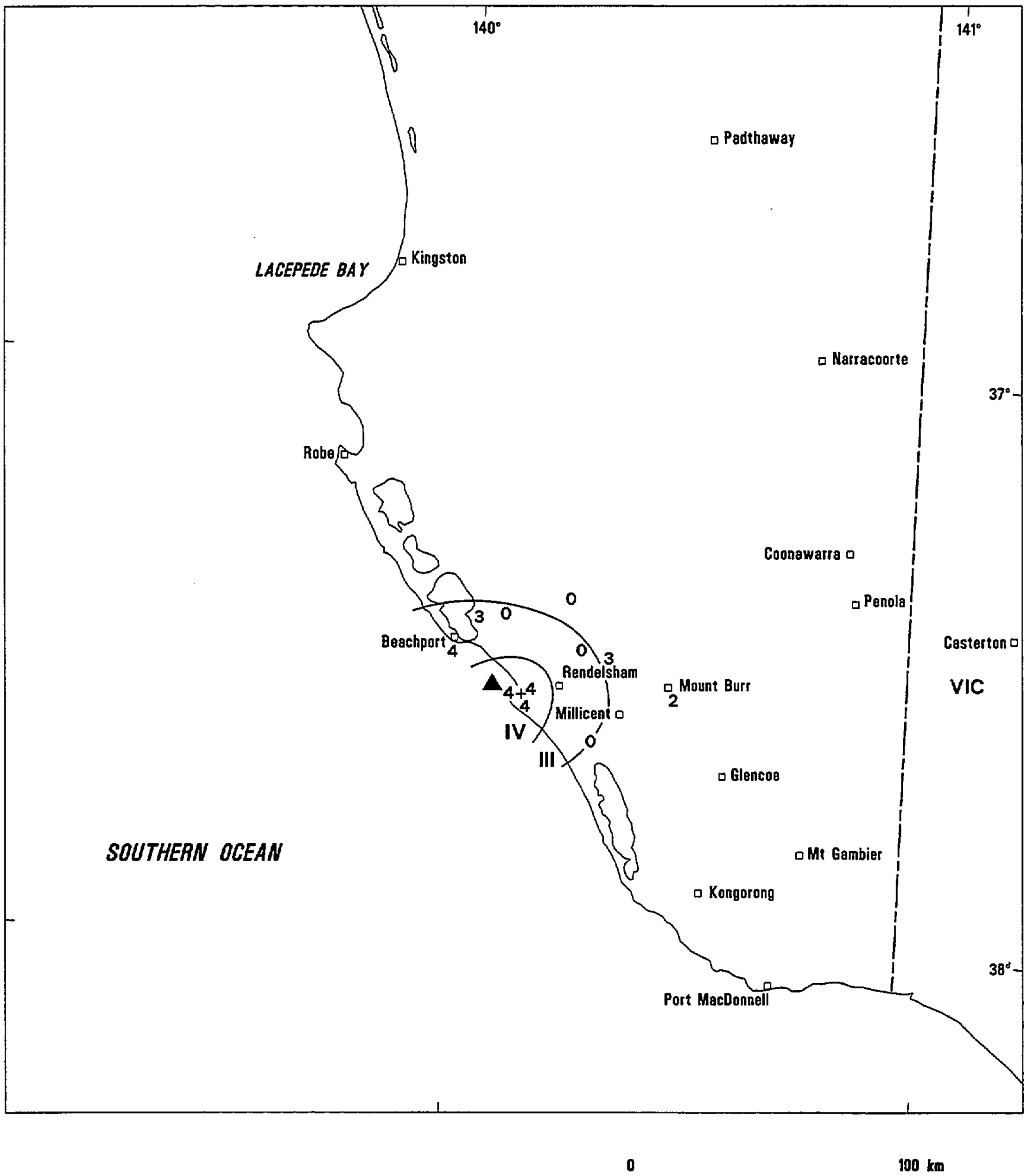


Figure 10

24/J54-6/2

ISOSEISMAL MAP OF THE BEACHPORT EARTHQUAKE, SOUTH AUSTRALIA, 21 FEBRUARY 1990



DATE: 21 February 1990
TIME: 04:52:16.4 UTC
MAGNITUDE: 3.4 ML
EPICENTRE: 37.54°S 140.07°E
DEPTH: 11.7 km

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

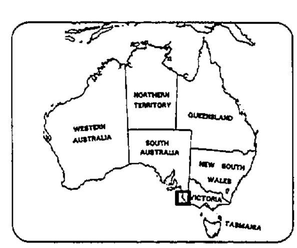
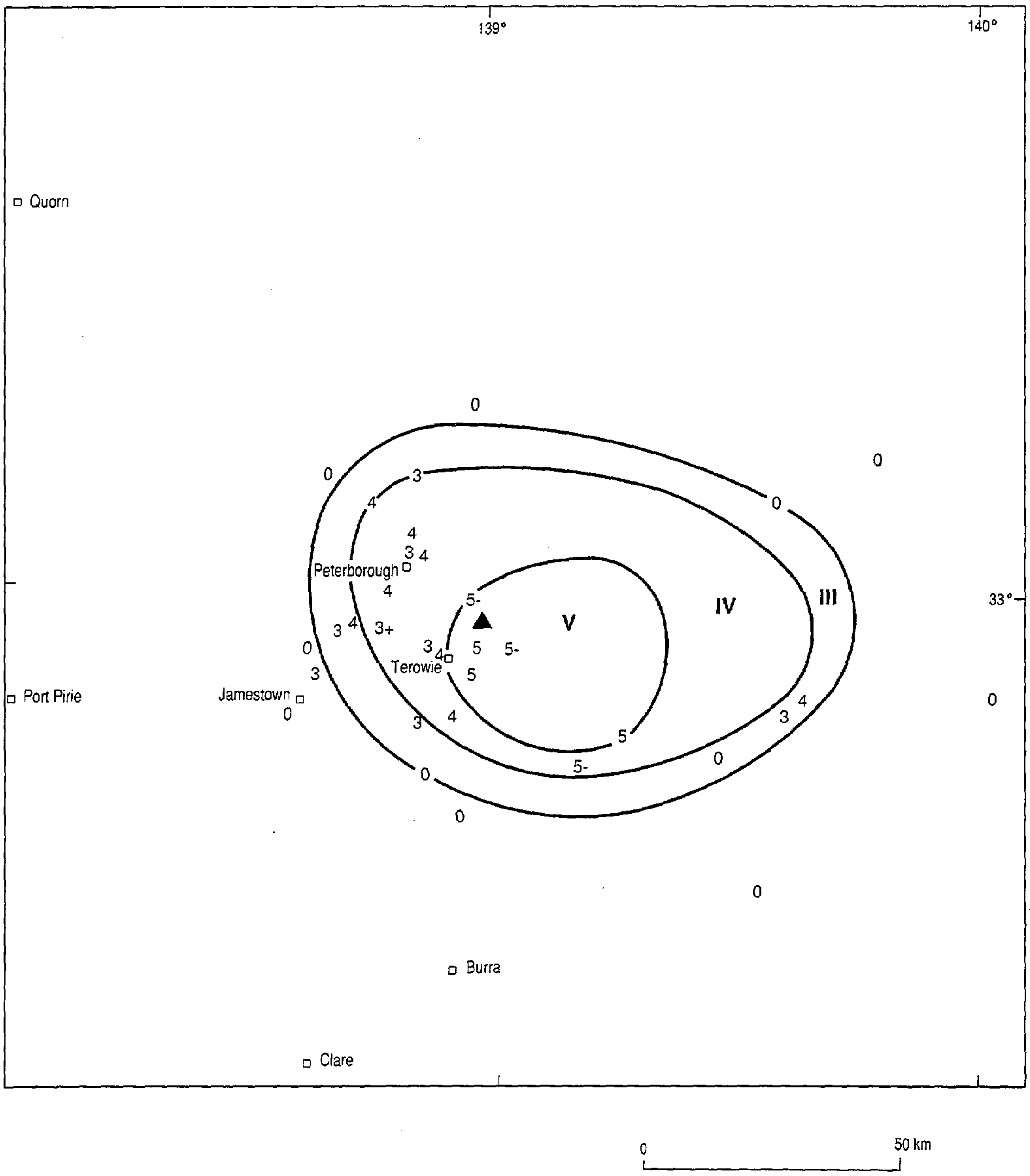


Figure 11

24/J54-6/3

ISOSEISMAL MAP OF THE TEROWIE EARTHQUAKE, SOUTH AUSTRALIA

5 MARCH 1990



DATE: 5 MARCH 1990
TIME: 06:55:10.4 UTC
MAGNITUDE: ML 3.0
EPICENTRE: 33.07° S, 138.98° E
DEPTH: 6 km

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

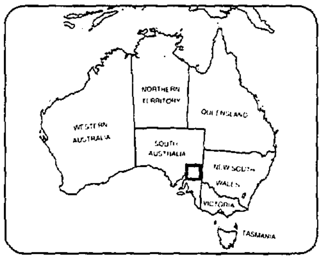
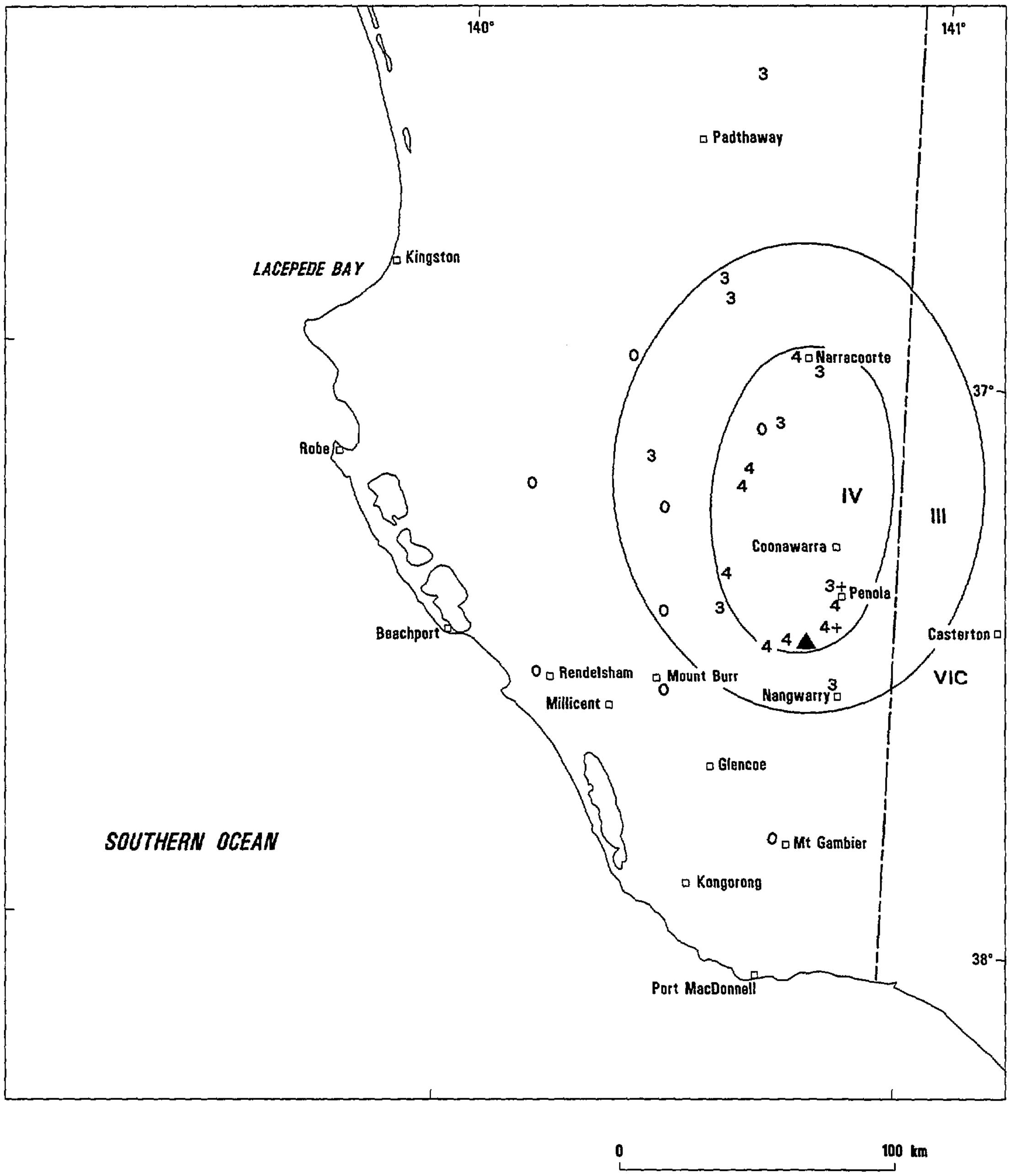


Figure 12

24/SA/59

ISOSEISMAL MAP OF THE PENOLA EARTHQUAKE,
SOUTH AUSTRALIA, 8 MARCH 1990



DATE: 8 March 1990
TIME: 09:55:20.6 UTC
MAGNITUDE: 3.0 ML
EPICENTRE: 37.50°S 140.75°E
DEPTH: 14.5 km

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

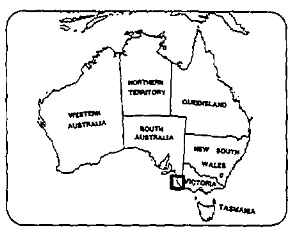
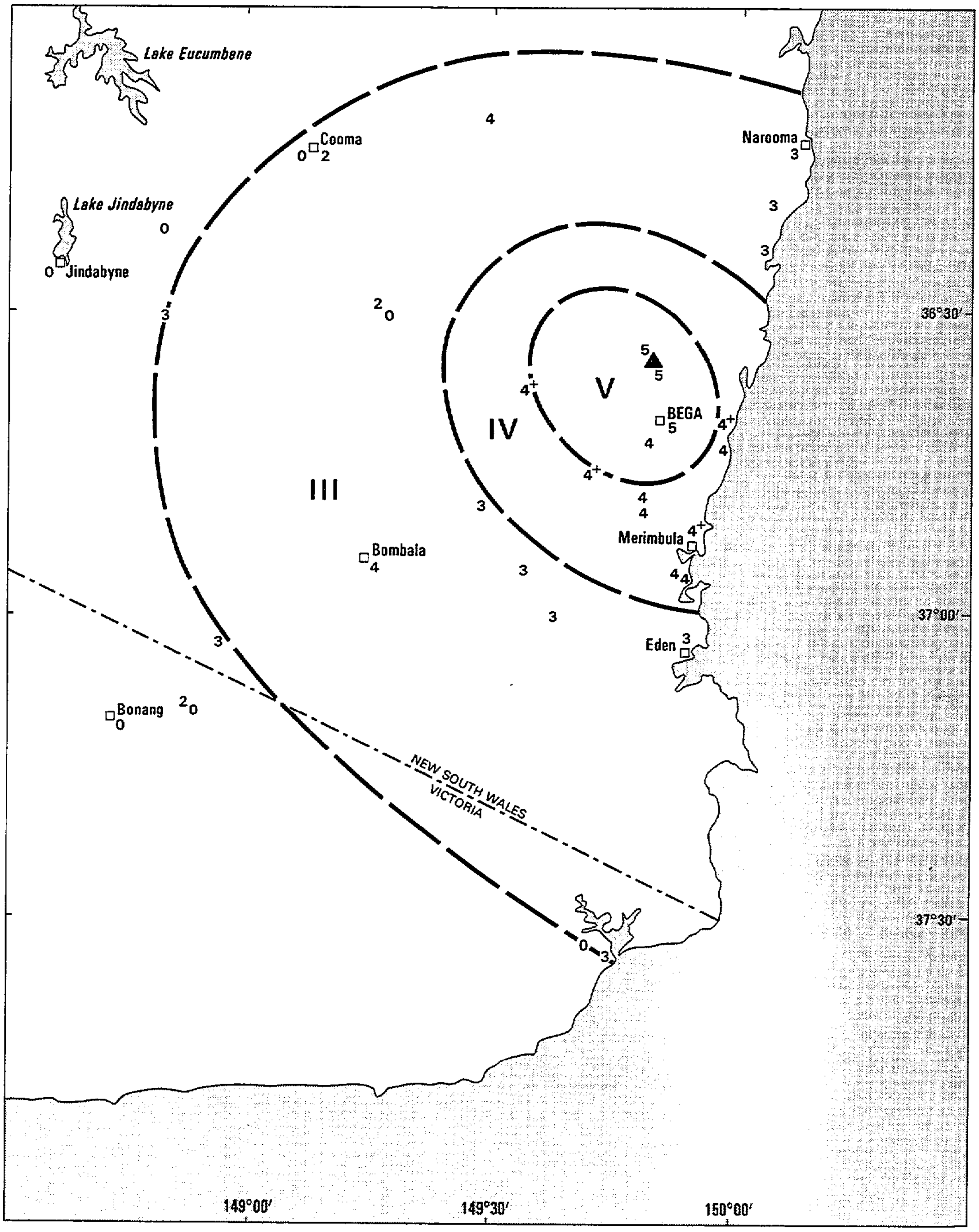


Figure 13

24/J54-6/4

ISOSEISMAL MAP OF THE BEGA EARTHQUAKE, NEW SOUTH WALES, 1 APRIL 1990



DATE : 1 April 1990
TIME : 12:04:30 UTC
MAGNITUDE : 3.4 ML (BMR)
EPICENTRE : 36.59°S, 149.84°E
DEPTH : Shallow

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

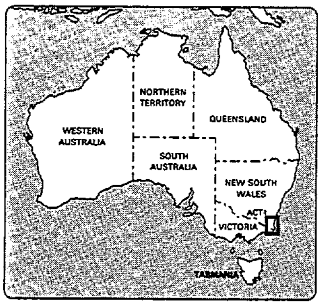
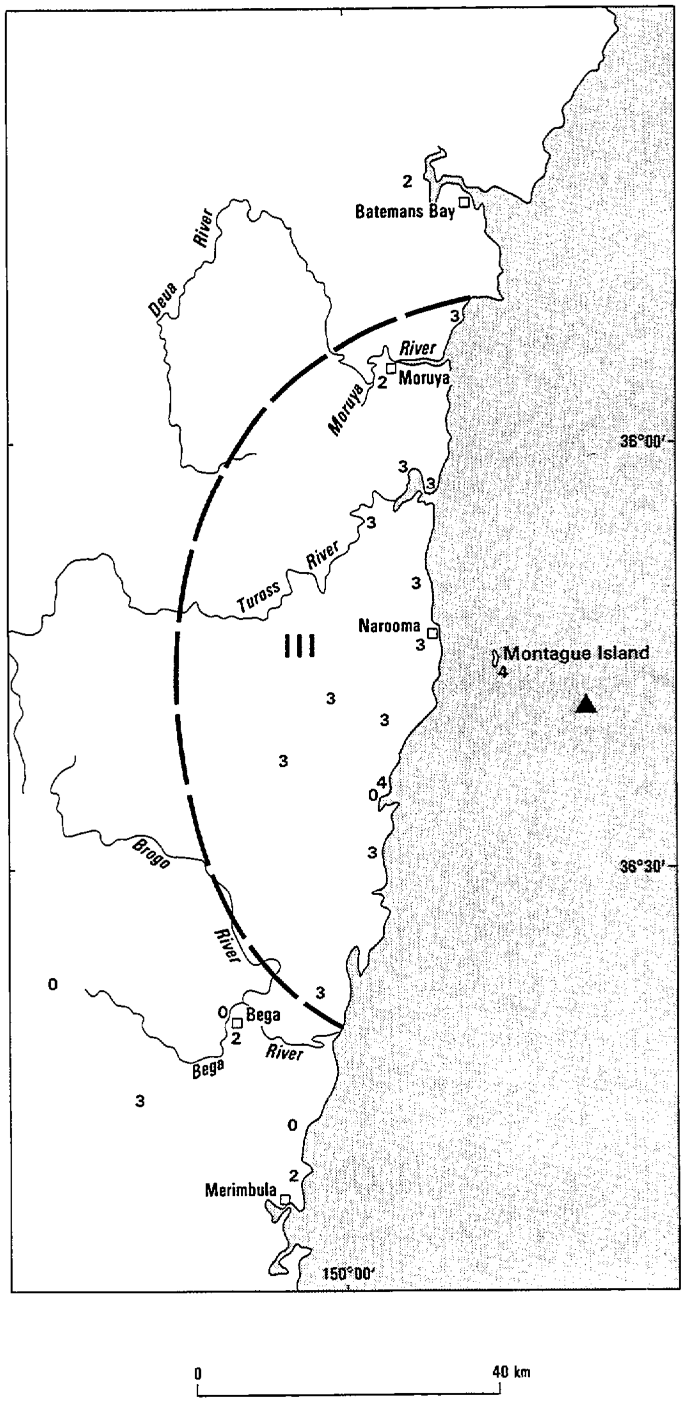


Figure 14

24/N/34

ISOSEISMAL MAP OF THE MONTAGUE ISLAND EARTHQUAKE, NEW SOUTH WALES, 4 MAY 1990



DATE :	*4 May 1990*
TIME :	*12:06:08 UTC*
MAGNITUDE :	*3.3 ML(BMR)*
EPICENTRE :	*36.31°S, 150.36°E*
DEPTH :	*10 km (±50)*

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

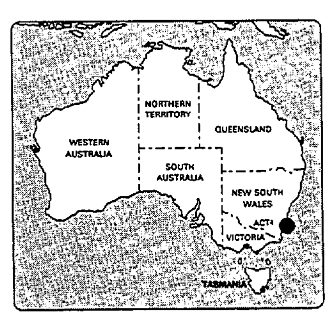
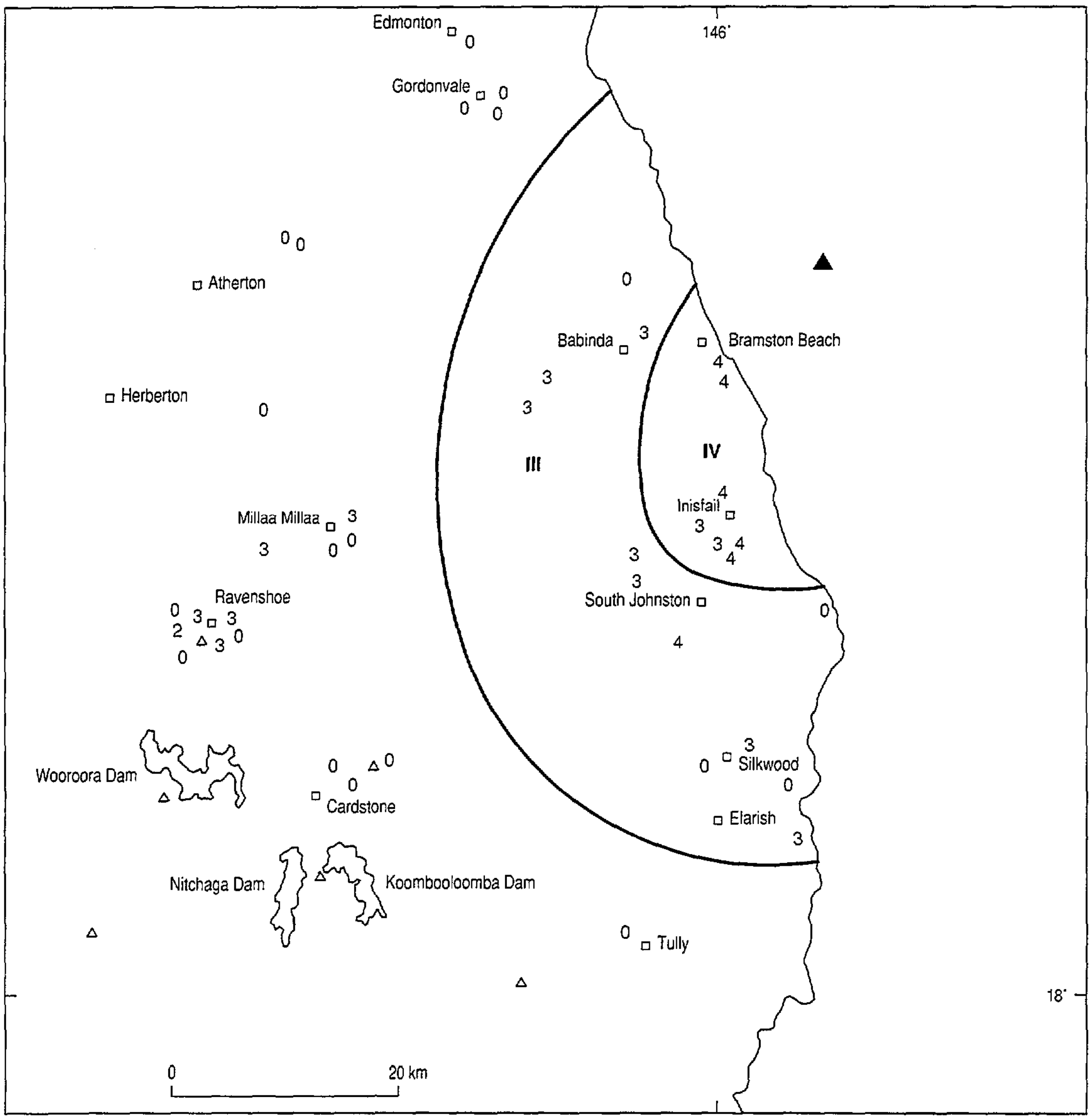


Figure 15

24/N/35

ISOSEISMAL MAP OF THE INNISFAIL EARTHQUAKE, QUEENSLAND

13 MAY 1990



DATE: 13 MAY 1990
TIME: 05:35:24.9 UTC
MAGNITUDE: 4.2 ML (GSQ)
EPICENTRE: 17.26°S 146.15°E
DEPTH: 0 km

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

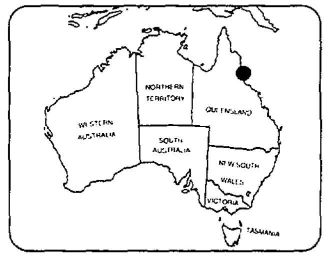
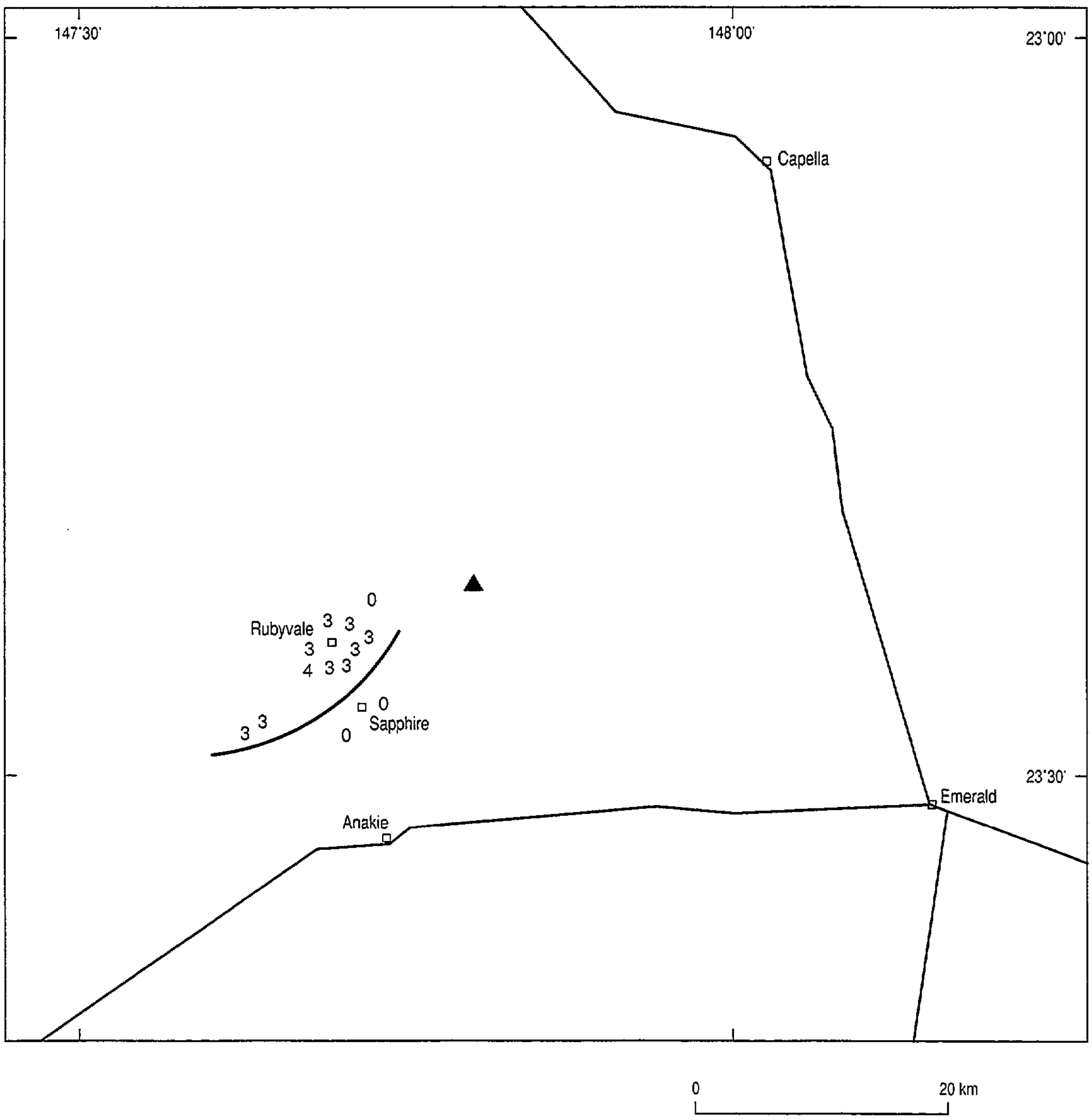


Figure 16

24/Q/26

ISOSEISMAL MAP OF THE RUBYVALE EARTHQUAKE, QUEENSLAND
9 JUNE 1990



DATE: 9 JUNE 1990
TIME: 04:06:10.3 UTC
MAGNITUDE: 2.9 ML (GSQ)
EPICENTRE: 23.36°S 147.82°E
DEPTH: 10 km

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

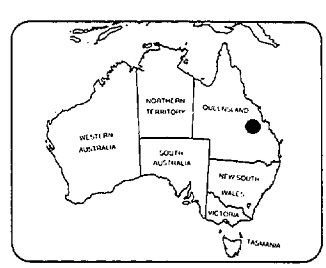
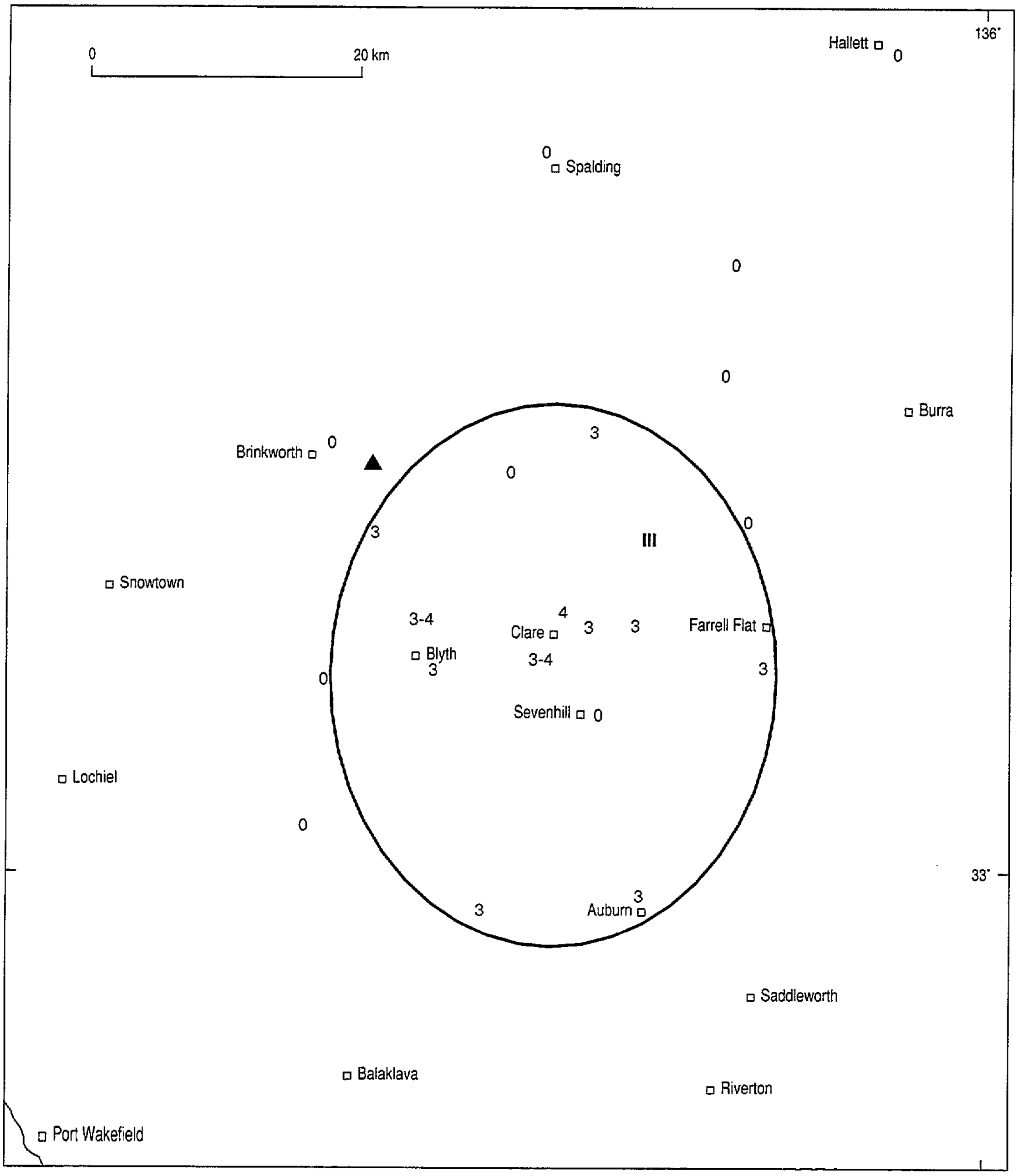


Figure 17

24/Q/25

ISOSEISMAL MAP OF THE CLARE EARTHQUAKE, SOUTH AUSTRALIA

11 JUNE 1990



DATE: 11 JUNE 1990
TIME: 15:08:04.5 UTC
MAGNITUDE: 2.7 ML (ADE)
EPICENTRE: 33.7O˚S 138.45˚E
DEPTH: 18 km

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

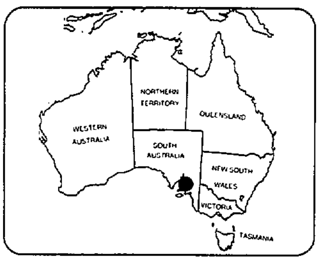
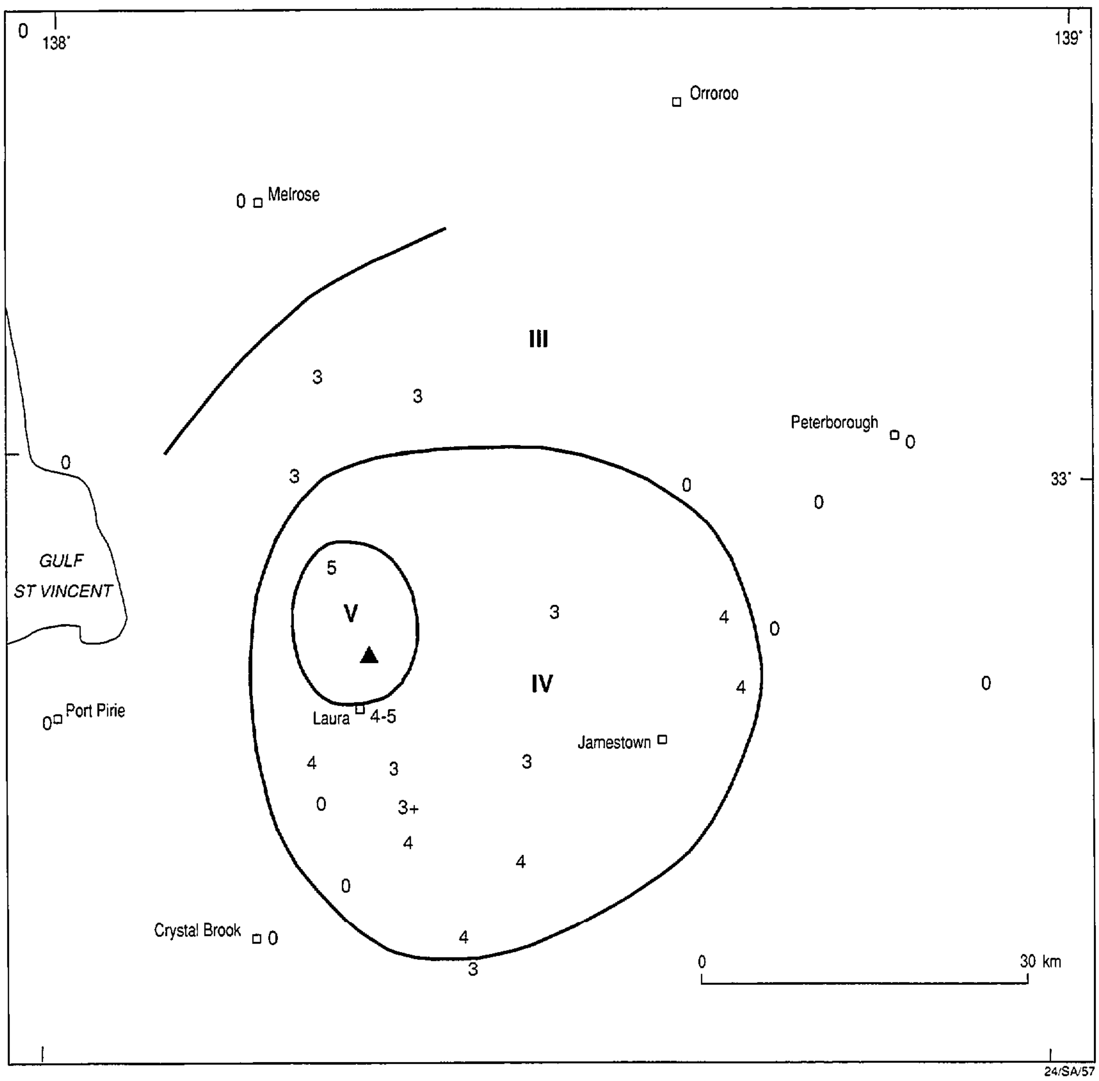


Figure 18

24/SA/56

ISOSEISMAL MAP OF THE LAURA EARTHQUAKE, SOUTH AUSTRALIA
13 JUNE 1990



DATE: 13 JUNE 1990
TIME: 20:23:54.2 UTC
MAGNITUDE: 3.0 ML (ADE)
EPICENTRE: 33.160°S 138.318°E
DEPTH: 14 KM

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

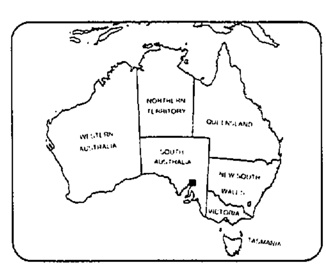
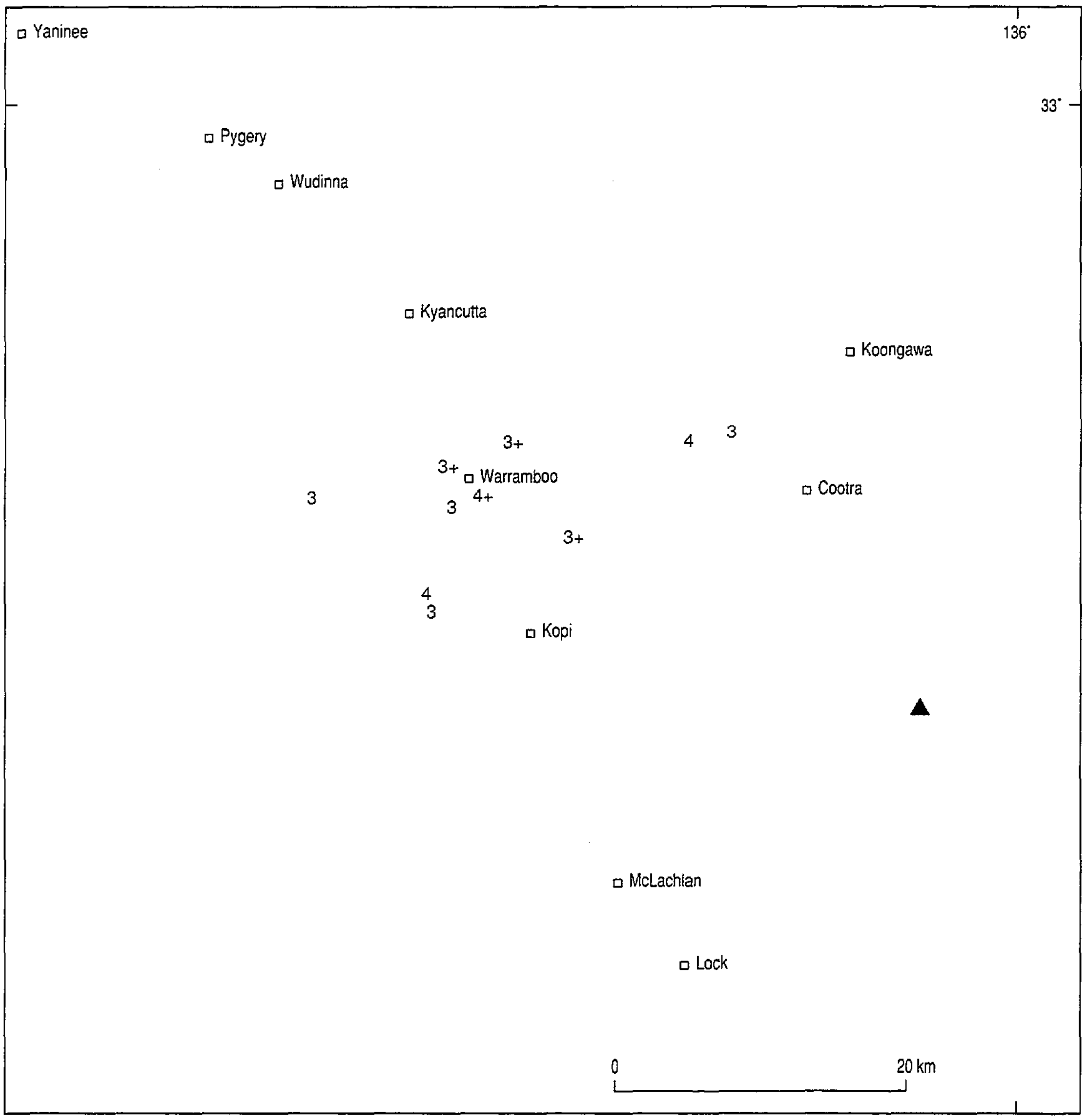


Figure 19

ISOSEISMAL MAP OF THE WARRAMBOO EARTHQUAKE, SOUTH AUSTRALIA
5 OCTOBER 1990



DATE: 5 October 1990
TIME: 22:11:01.3 UTC
MAGNITUDE: 2.7 ML (ADE)
EPICENTRE: 33.39˚S 135.93˚E
DEPTH: 7 km

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

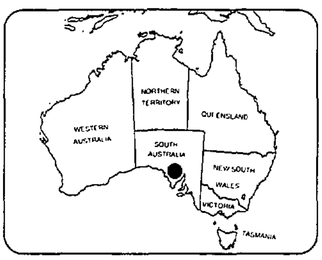


Figure 20

24/SA/58

and there were reports of trees and bushes being shaken to the extent that birds took flight. Unfortunately the nearest seismograph to record the event was 320 km away so it was not possible to accurately determine the epicentre. A limited number of intensity reports with a restricted distribution were obtained by seismologists at the University of Central Queensland, University of Queensland and the Department of Minerals and Energy.

Clare SA, 11 June (Figure 18)

Soon after midnight on Tuesday 12 June (local time) an ML 2.7 micro-earthquake was felt at Clare. Twenty four questionnaires were sent out. From the 13 replies and a number of phone calls an intensity map was produced. Although one window pane was reported cracked, very few replies exceeded intensity MM3. Many people were still awake, and only a few were awoken, one by a dog pining just before the event.

The epicentre plots just outside the arae of perceptibility at a depth of about 18 km.

Laura SA, 13 June (Figure 19)

Just before 6 am (14 June local time) a small earthquake of magnitude ML 3.0 occurred east of Port Pirie, near Laura and Napperby. Rumbling and vibration were noticed from at least as far north as Murraytown and to Georgetown in the south. People who felt the event contacted the SA Dept of Mines and Energy and were sent questionnaires. The map was produced from 25 replies and a few phone calls. The early hour of the morning made the determination of intensity difficult in a number of cases.

Warramboo SA, 5 October (Figure 20)

At 22:11 UTC on 5 October 1990 (7:41am local time on 6 October), Warramboo was again shaken by a small earthquake. The epicentre was in Hambidge Conservation Park near the previous event on 7 September 1989. The magnitude of the event was ML 2.7, slightly smaller than the previous one.

The Principal at Warramboo Primary School gained a sudden interest in the event as his transportable home twisted, and pictures moved on walls. He distributed questionnaires from which the isoseismal map was compiled. Due to lack of regional coverage, isoseismal lines could not be drawn.

D Love, S Greenhalgh, K Malpas, K McCue, P Gregson, M Leiba & R Cuthbertson

NETWORK OPERATIONS 1990

The National Seismographic Network underwent only minor changes during the year and these are listed in Table 3. A new seismograph was installed at Casey in Antarctica, the data telemetered back to Canberra via ANARESAT. Calibration curves for most of the stations are shown in Figures 21& 21a.

Significant additions and closures were made to regional networks. In Queensland one DRI station was moved, a new station was installed at Cracow and a network of 6 seismographs was installed around the proposed Tully-Millstream dam site north of Cairns. The Applied Physics Department, University of Central Queensland commenced a research program with the installation of a seismograph at Rockhampton and jointly with AGSO, a triaxial digital recorder at Mount Morgan.

In South Australia 6 new stations were installed and 2 closed by SADME. The result is a better monitoring capability and improved epicentre control for earthquakes in Adelaide and the active South-East region.

The Hunter Valley NSW network of 4 seismographs was installed by the ASC on the direction of the then Minister, Senator Peter Cook. Partial funding for one of the seismographs was provided by the Newcastle City Council and Kiwanis International,

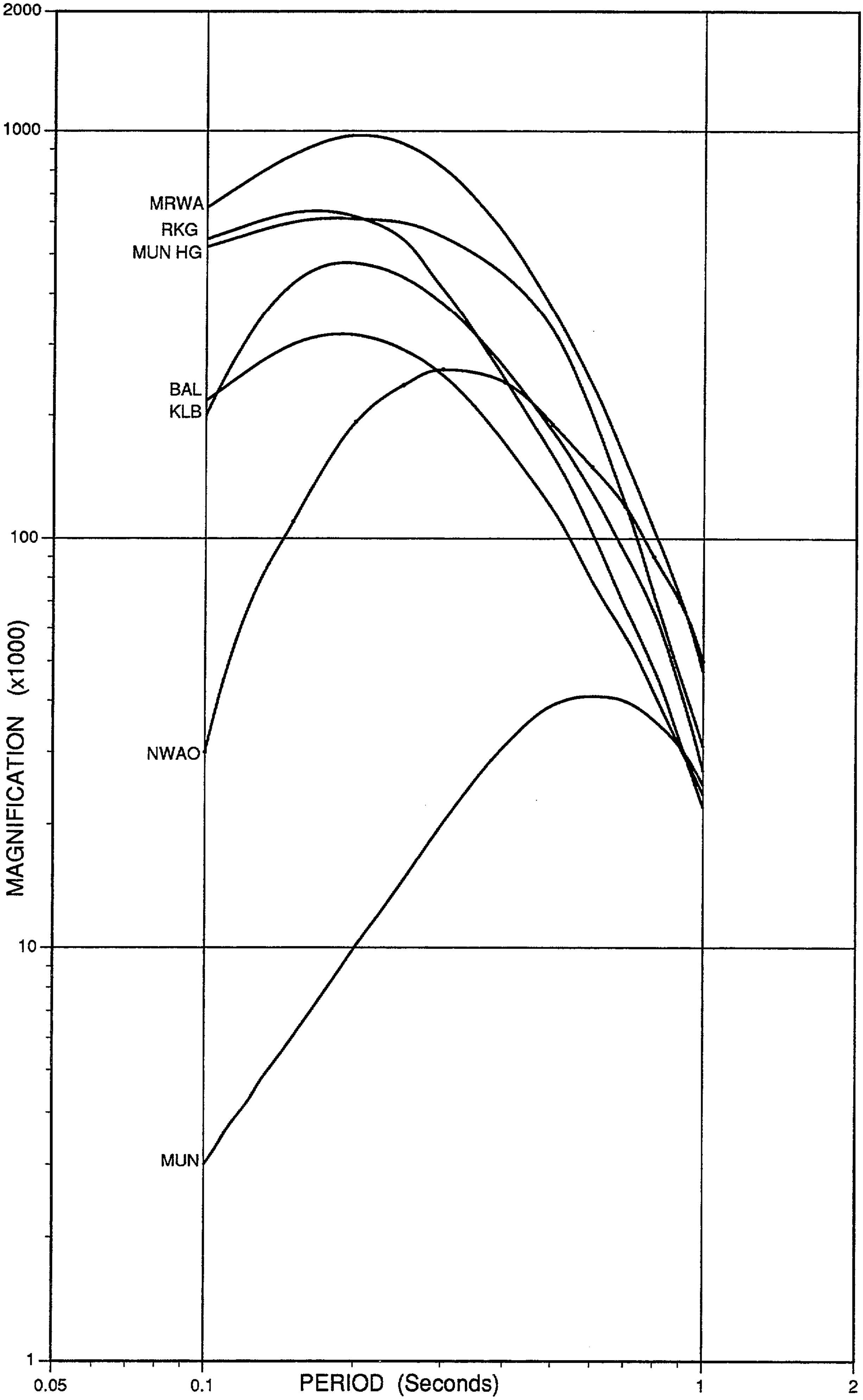


Figure 21a Calibration curves, Western Australian network stations.

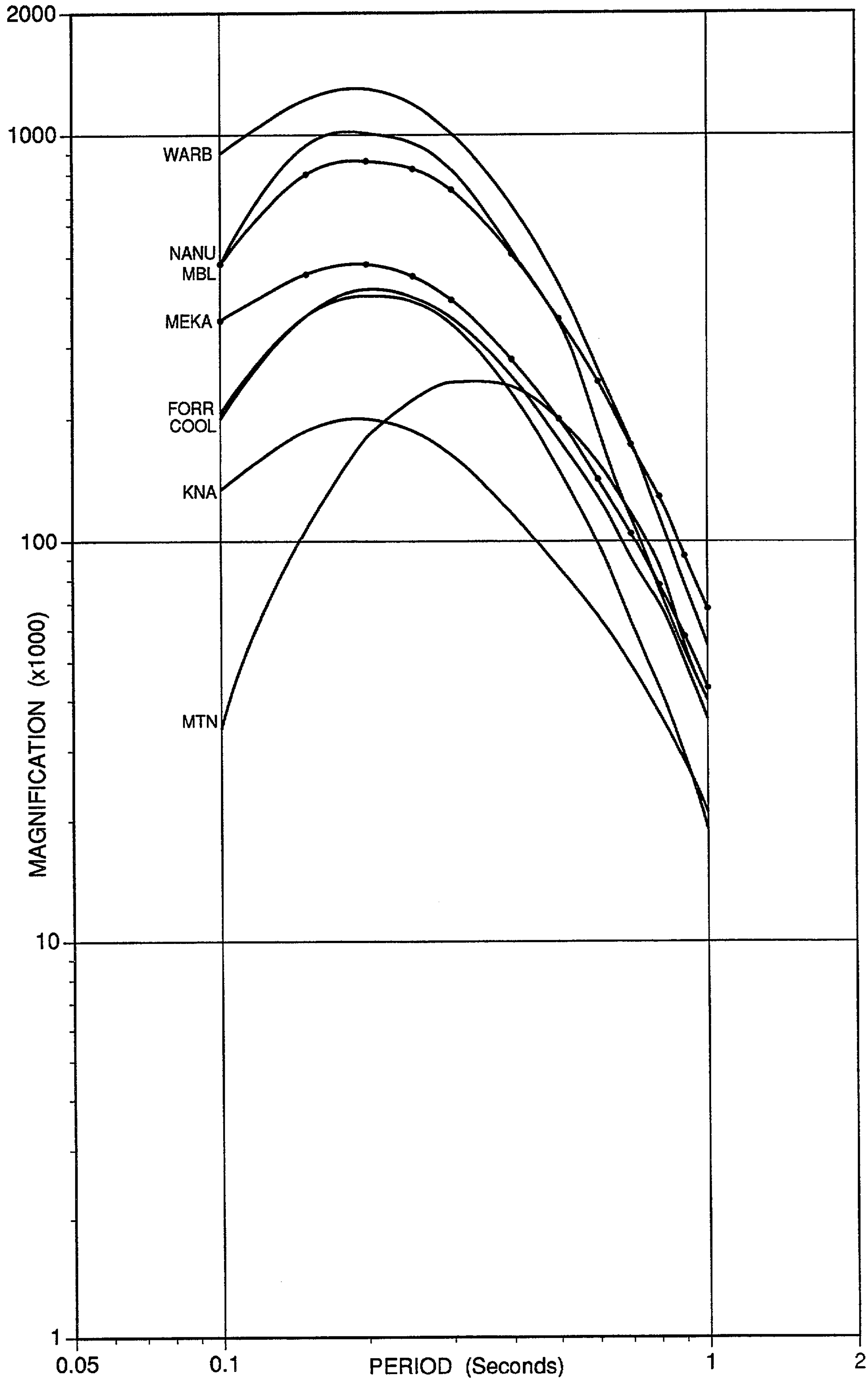


Figure 21b Calibration curves, Western Australian network stations.

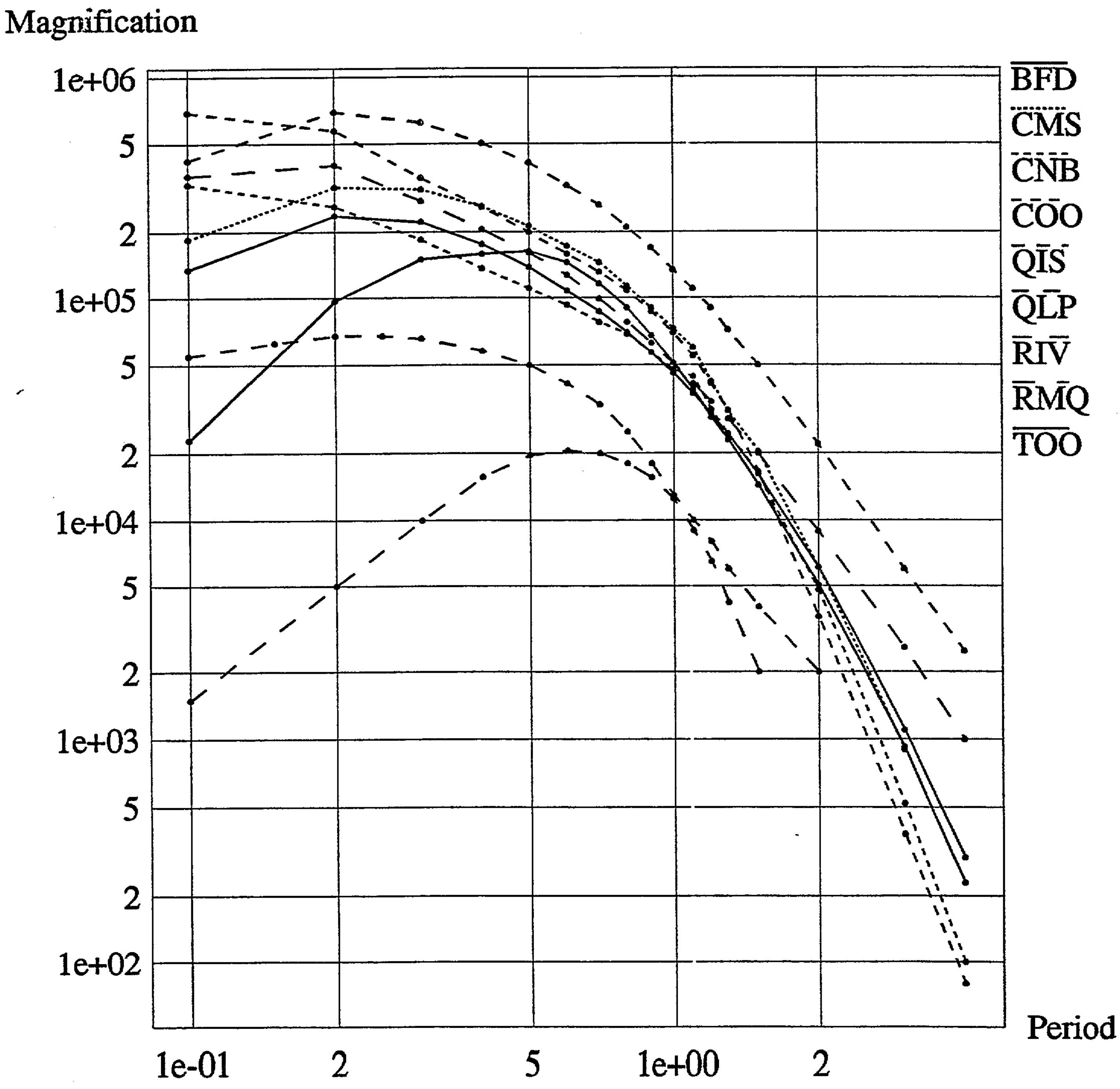


Figure 21c Calibration curves, Eastern Australian network stations.

the rest came from the AGSO budget. Data from one channel of the digital Kelungi at North Lambton is telemetered to the Newcastle Regional Museum where it is recorded on an analogue recorder. The ASC also installed a digital accelerograph at the Police Headquarters building in the Newcastle Central Business District.

A South-eastern Australian network was installed and maintained by the ANU between 1958 and 1972 to monitor the Snowy Mountains, Dalton-Gunning and Sydney Water Board dams at Avon, Werombi and Jenolan. The network has been reduced from 16 stations in 1987 to 10 in 1990 with a substantial loss of detection capability, particularly in the Snowy Mountains.

Graeme Small, Peter Gregson, Kevin McCue & David Love

ACCELEROGRAPH DATA

There were no accelerographs close to either of the magnitude 5^+ earthquakes of 1990.

In Western Australia Twenty accelerograms were recorded by the network in the South-West Seismic Zone during 1990, from 9 earthquakes in the Cadoux area and the ML 5.5 earthquake at Meckering. The latter event was recorded at Dowerin at an epi-central distance of about 75 km (S-P = 8 s) where the peak acceleration was 93 mms^{-2} (Table 6). The accelerogram is shown in Figure 22. Other accelerographs were triggered at Mundaring Weir (90 km) where the peak acceleration was 287 mms^{-2} across the dam wall, compared with 75 mms^{-2} along the wall. It was also recorded at Canning Dam (100 km) and Cadoux (110 km).

In Eastern Australia Accelerograms of 7 micro-earthquakes in a swarm near Oolong NSW were recorded on a digital recorder nearby (FND). Peak horizontal and vertical ground accelerations in excess of 0.3 g were recorded during the close magnitude ML 3.5 earthquake which initiated the swarm on 13 January. Other Dalton/Gunning Zone earthquakes on 23 and 24 March were recorded on an accelerograph installed on the property *Springfield* (SPF).

An accelerogram was recorded at the Newcastle Police Station in the CBD on 23 February 1990. The epicentre of this magnitude ML 2.9 earthquake was about 30 km away near Cessnock, at shallow rather than mid-crustal depth, and too far from the epicentre of the December 1989 earthquake to be considered an aftershock.

Accelerograms, 20 in all from 16 earthquakes, were recorded in Victoria. Four of the records are for magnitude ML 3 earthquakes on 11 and 19 May which are included in Table 6.

K McCue, M Leiba, V Dent, P Gregson & G Gibson

PERTH MICROZONATION STUDY

In August 1989, Brian Gaull visited Hokkaido University, the Tokyo Institute of Technology, the Earthquake Research Institute and Aichi University of Education in Japan with a grant from the Australian Academy of Science and Japan Society for the Promotion of Science. The liaison with microzonation experts in Japan enabled Gaull to set up a study of microzonation effects in metropolitan Perth, WA.

A return visit was made by Drs Kagami and Tanigushi in January 1990 to assist with a pilot study of Perth which was subsequently expanded during the year by Mundaring Geo-physical Observatory staff. A set of 6 simultaneous observations were made along north-south traverses across the coastal plain near Perth to measure the variation in background noise at sites with varying geological foundations compared with a rock site at Mundaring.

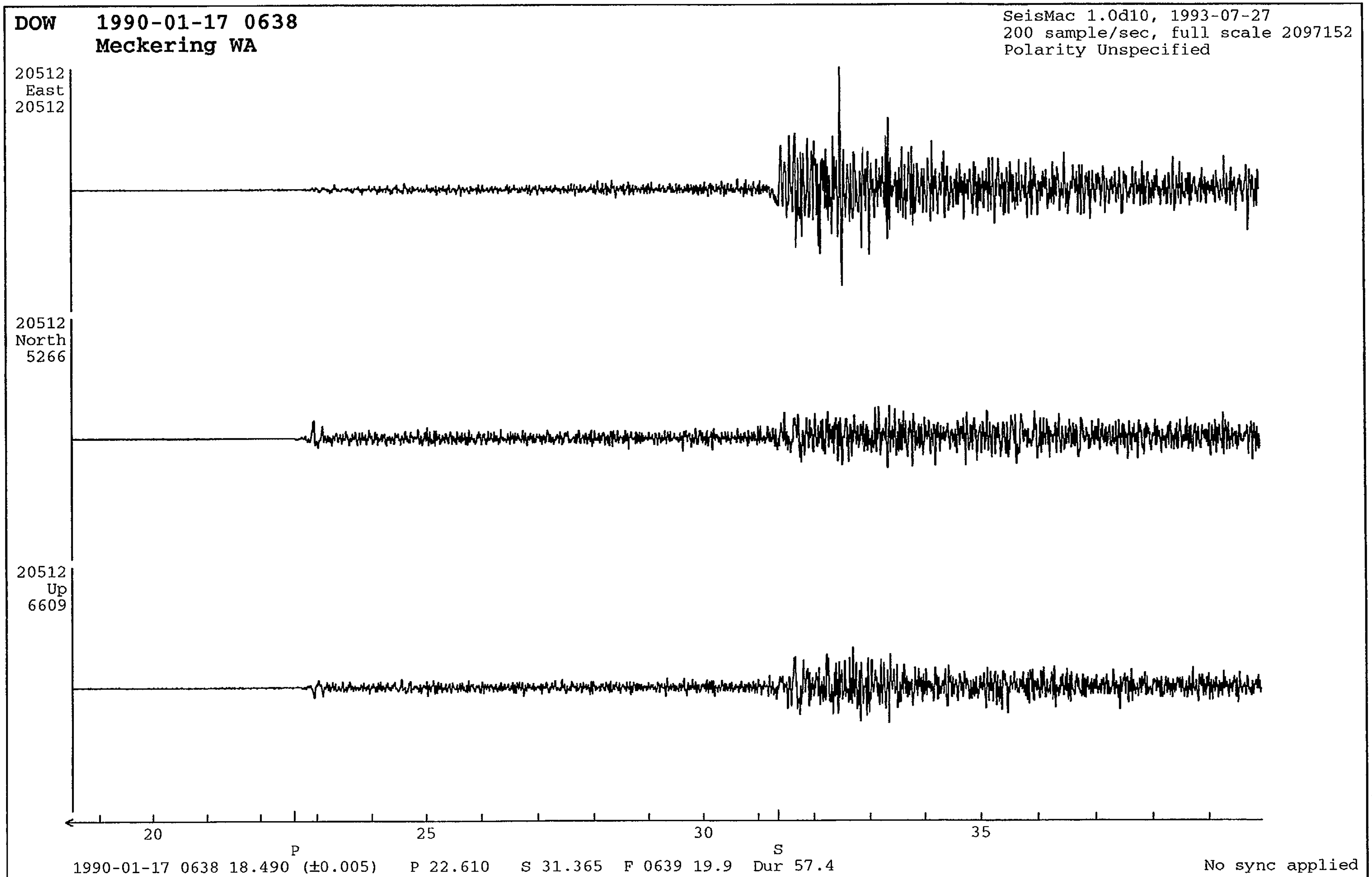


Figure 22 Accelerogram of the Meckering earthquake, 17 January 1990 recorded at Dowerin at an epicentral distance of 78 km. The ordinate scale is in counts where 20 000 counts is about 0.01 g.

Fortuitously, an earthquake occurred on the 8 May 1990 near Cadoux WA whilst the zonation measurements were in progress. It was recorded on sediments in the suburb of Kewdale where the ground motion was ten times that at Mundaring, confirming the observation of considerable magnification in the background noise levels on alluvium compared with those on rock.

The results will be published in a BMR Record.

B A Gaull, P Gregson & K McCue

TIME ZONES IN AUSTRALIA

The Standard Time Act of 1895 introduced Greenwich Mean Time (GMT) to Australia and standardised time zones within the States; Eastern, Central and Western Standard Time, 10, 9:30 and 8 hours ahead of GMT. According to Paul Payne of the Sydney Observatory; prior to 1895 the times of the capital cities for noon in Sydney were: Melbourne 11:45 am, Adelaide 11:10 am, Perth 9:39 am, Hobart 11:45 am, Brisbane 12:07 pm, which times correspond closely to the difference in longitude from Sydney. Towns near the capital cities probably adopted the same time but what standard was adopted in isolated towns is not known.

GMT is a measure of Earth rotation relative to the Sun at the longitude of Greenwich UK. The Coordinated Universal Time (UTC) scale, synonymous with GMT since 1970, is derived from the US National Bureau of Standards atomic frequency standard which emulates the Caesium resonance frequency to within a few parts in 10^{13}. Integral second corrections are applied to UTC as required so that it never differs from UT (the Earth rotation time with respect to the sun and corrected for polar motion) by more than 0.7s (NBS, 1972; J. McK. Luck, 1991).

AUSTRALIAN EARTHQUAKE FOCAL MECHANISM

Meckering WA The epicentre determined by Mundaring seismologists is 2 km east of, and down-dip from, the Meckering Fault scarp caused by the 1968 earthquake (Gordon & Lewis, 1980). First motions at 16 Australian seismographic stations and 7 worldwide stations reporting impulsive P-wave arrivals to the ISC were initially used to study the focal mechanism of the Meckering earthquake.

The solution was poorly constrained but additional data was obtained from South Australian (CLV, PNA & HWK) and ANU stations (BWA & IVY) and some seismograms, including that recorded broad-band at Mawson were reanalysed. The ISC bulletin reported a compression at WRA but a check of WB5 showed it to be a clear dilatation. The Chinese data do not fit the preferred solution but were down-weighted because of their distance and the relatively small size of the earthquake. The preferred mechanism (Figure 23) is a thrust with only a very small dip-slip component. The northerly nodal plane parallels the strike of the closest section of the Meckering fault and its dip is 66° E, strong evidence for concluding that it is the fault plane. The implied principal stress direction is eastwest.

This solution is nearly identical to that of the 14 October 1968 earthquake which produced the fault scarp, indicating that this large earthquake did not release all the crustal stress nor change the long term stress regime in the region of the fault.

K McCue

PRINCIPAL WORLD EARTHQUAKES, 1990

Table 7 lists earthquakes that occurred throughout the world in 1990 of magnitude 7.0 or greater, or that caused fatalities or substantial damage. There were no great earthquakes, and 8 of the 11 earthquakes of magnitude Ms 7 or more occurred around the Pacific rim. The largest at magnitude Ms 7.7 - 7.8, were those in Iran on 20 June

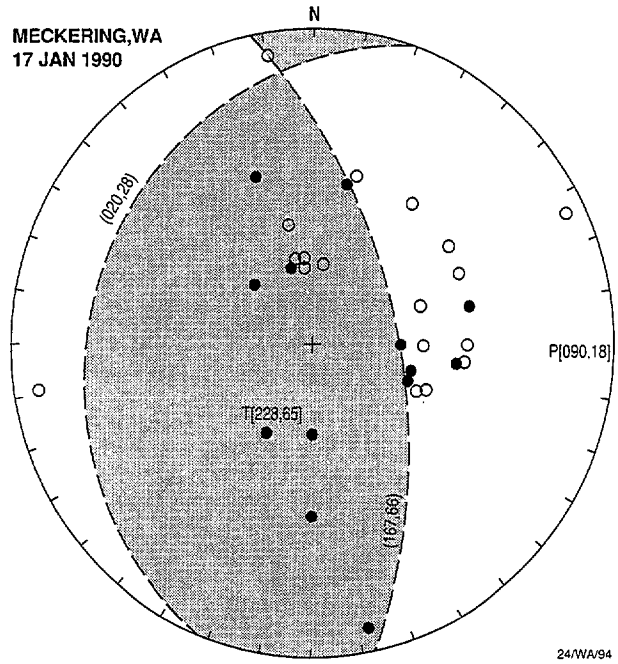


Figure 23 Focal mechanism of the Meckering earthquake, 17 January 1990. A Lambert equal area projection was used. Solid circles are compressions, open circles dilatations. The dashed lines represent the nodal planes with strike and dip as marked.

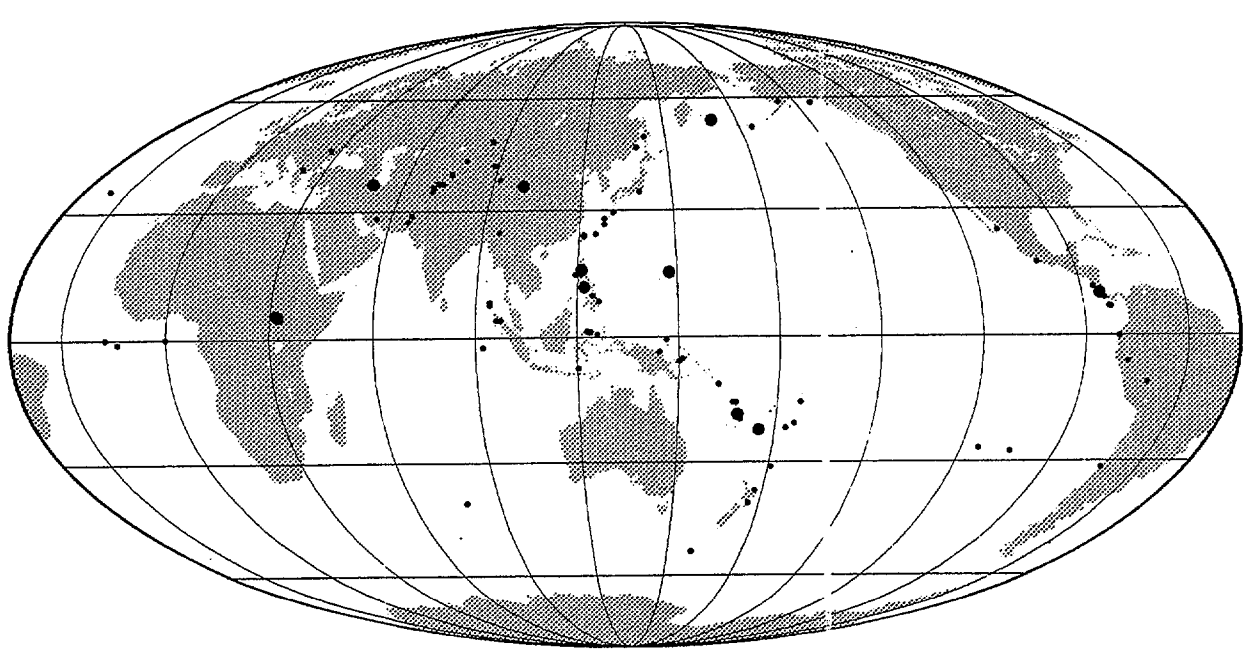


Figure 24 Principal world earthquakes, magnitude 6 or greater. Data extracted from the AGSO/ISC earthquake database.

and the Philippines on 11 July. The most destructive earthquake was that in Iran. Nearly all buildings were destroyed in the Rasht-Qazvin-Zanjan area of north-eastern Iran. Substantial damage occurred as far as Khalkhal and Nor Shahr. A spectacular strike-slip fault was caused during the Philippine Is earthquake, with 5.5 m of left-lateral displacement. Figure 24 shows the locations of these earthquakes.

World-wide, more than 52 000 people died in earthquakes in 1990, compared with 530 and 26 550 in 1989 and 1988 respectively, and the average for the century of 10 000 per year.

Intraplate earthquakes outside Australia included one in the UK of magnitude Mb 4.6 (ML 5.1) on 2 April at 13:46 UTC which caused building damage in Liverpool, Manchester, Wrexham and Shrewsbury. A magnitude 7.2 earthquake in the Sudan on 20 May at 02:22 UTC caused building damage in the Sudan and Uganda.

This information is from the ISC monthly bulletins, 'Earthquake Data Reports' published by the United States Geological Survey, and the SEAN Bulletin of the Smithsonian Institution (SEAN, 1990).

P Gregson and K McCue

MONITORING OF NUCLEAR EXPLOSIONS

Underground nuclear explosions presumed to have been detonated during 1990 are listed in Table 8. Except for 2 small Nevada tests, which are in the core shadow zone, all of the listed events were recorded by Australian seismic stations. Seven nuclear tests were conducted at the US test site in Nevada, whereas the then-USSR performed their solitary test at Novaya Zemlya. China held 2 tests at Lop Nor, the first time China has detonated more than one test in any year. The 2 largest French nuclear devices were exploded at Fangataufa and the remaining 4 were at Mururoa.

The approximate yield (in kilotons) of an underground nuclear explosion can be determined empirically from its average body-wave magnitude mb (Table 9).

In the past few years there has been a dramatic reduction in the number of tests of nuclear weapons (Figure 25).

D Jepson

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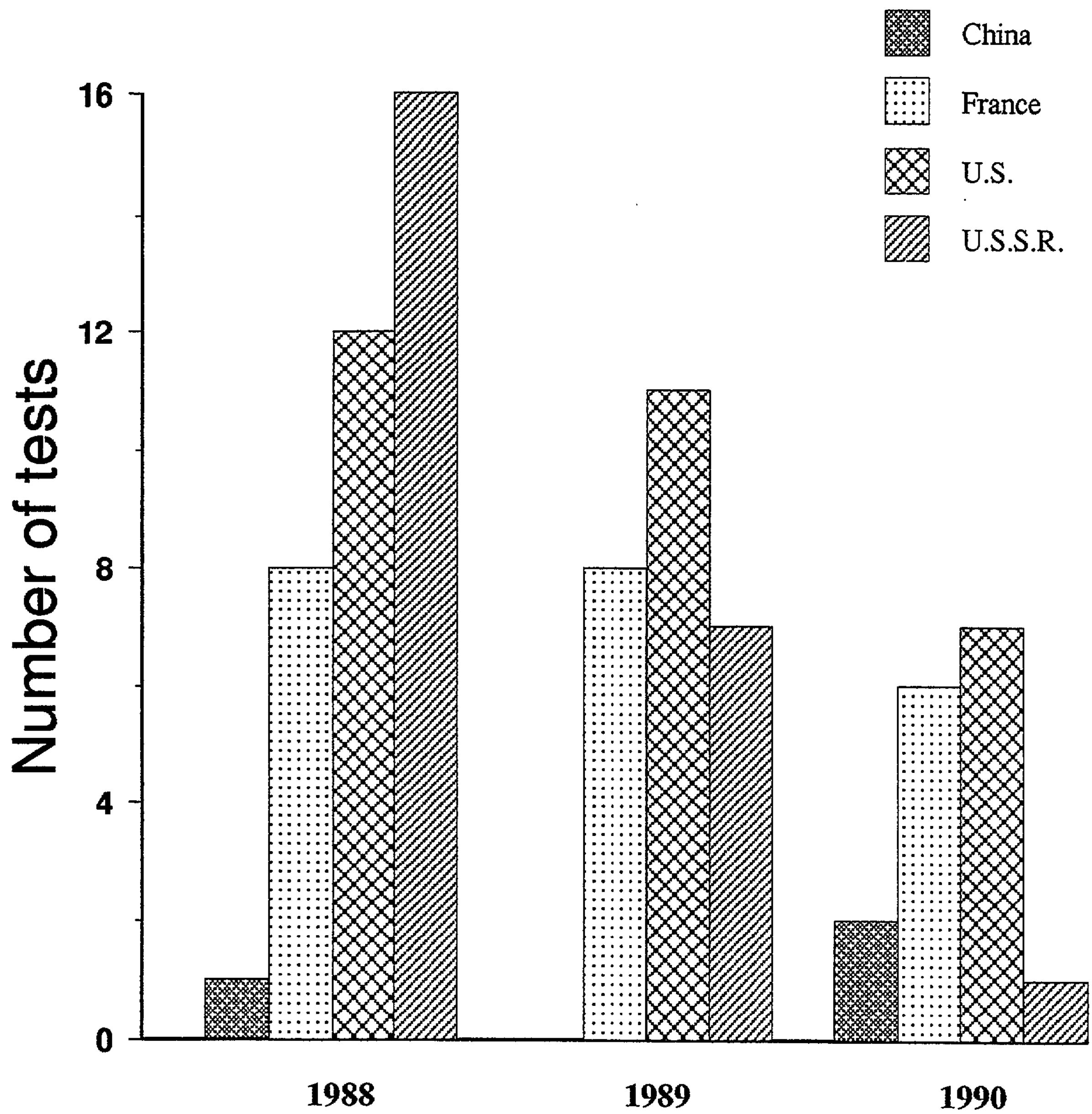

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Table 1 Australian earthquakes, 1990, ML ≥ 3.0

Date	Time (UTC)	Latitude ° S	Longitude ° E		ML	Location
1 12	0549 19.9	-25.621	131.570	5.0 G	3.5	Uluru NT
1 12	0950 58.2	-23.053	131.239	5.0 G	4.4	W Alice Springs NT
1 12	1004 15.5	-23.100	131.200	5.0 G	3.0	"
1 13	1555 59.8	-34.756	149.182	2.0	3.5	Oolong NSW
1 16	0111 6.6	-41.053	144.473	5.0 G	3.3	NW Tasmania
1 17	0638 8.2	-31.720	116.990	6.0	5.5	Meckering WA
1 19	1621 36.2	-33.777	139.370	5.0 G	3.2	Clare SA
1 21	1627 42.4	-19.900	133.800	2.0 G	3.4	Tennant Creek NT
1 23	0331 14.4	-20.164	134.031	5.0 G	4.1	Tennant Creek NT
1 25	1333 21.8	-38.306	148.572	24.0	3.2	E Bass Strait
1 26	2325 11.8	-37.547	139.987	4.0	3.5	Beachport SA
1 30	1957 39.1	-19.900	133.800	2.0 G	3.0	Tennant Creek NT
2 3	1300 58.8	-16.860	121.530	5.0 N	3.4	NW WA
2 4	0850 44.0	-27.702	136.000	5.0 G	3.2	Mt Dutton SA
2 7	0747 0.0	-38.400	153.200	0.0	3.5	Tasman Sea
2 8	0823 32.1	-27.859	137.537	5.0 G	4.6	Lake Eyre SA
2 11	1905 47.0	-19.900	133.800	2.0	3.5	Tennant Creek NT
2 14	1350 2.5	-25.760	137.640	5.0 N	3.6	Simpson Desert NT
2 18	0106 49.0	-19.900	133.800	2.0	3.0	Tennant Creek NT
2 18	0511 8.0	-19.900	133.800	2.0	3.1	Tennant Creek NT
2 18	1230 0.0	-38.500	154.000	0.0	3.5	Tasman Sea
2 18	2247 33.7	-18.250	118.230	5.0 N	4.5	Pt Hedland WA
2 19	1446 35.0	-19.900	133.800	2.0	3.1	Tennant Creek NT
2 19	2237 29.0	-19.900	133.800	2.0	3.7	Tennant Creek NT
2 20	1419 1.0	-16.540	128.510	5.0 N	3.1	Ord R WA
2 21	0452 15.9	-37.555	140.135	13.0	3.5	Beachport SA
3 3	0631 36.9	-25.859	138.177	8.0	3.0	Simpson Desert Qld
3 3	0631 39.0	-19.900	133.800	0.0	3.2	Tennant Creek NT
3 3	0914 9.0	-19.900	133.800	5.0	3.5	Tennant Creek NT
3 5	0655 10.3	-33.047	139.047	6.0	3.0	Terowie SA
3 6	0743 46.0	-19.900	133.800	0.0	3.1	Tennant Creek NT
3 8	0955 20.6	-37.499	140.748	14.0	3.1	Penola SA
3 10	1201 15.0	-19.900	133.800	5.0	4.2	Tennant Creek NT
3 11	2156 13.0	-19.900	133.800	5.0	3.2	Tennant Creek NT
3 13	1710 55.0	-19.900	133.800	5.0	3.0	Tennant Creek NT
3 16	1407 18.0	-19.900	133.800	5.0	4.3	Tennant Creek NT
3 17	0548 41.5	-33.410	117.820	5.0	3.2	Tennant Creek NT
3 17	0652 32.0	-19.900	133.800	5.0	4.1	Tennant Creek NT
3 20	2109 21.8	-18.460	124.240	5.0	3.4	NW WA
3 21	1337 22.0	-25.430	129.510	10.0	4.5	Mt Olga NT
3 24	1545 6.0	-19.900	133.800	5.0	3.3	Tennant Creek NT
3 25	0057 6.0	-19.900	133.800	5.0	3.2	Tennant Creek NT
3 25	1310 42.0	-19.900	133.800	0.0	3.2	Tennant Creek NT
3 26	1156 32.0	-19.900	133.800	0.0	3.3	Tennant Creek NT
3 30	1131 27.6	-24.020	113.390	5.0	3.5	Northwest Cape WA
3 30	1133 0.0	-34.250	150.830	5.0	3.0	Tasman Sea
3 31	1127 44.0	-19.900	133.800	5.0	3.7	Tennant Creek NT
4 1	1204 30.5	-36.650	149.821	12.0	3.4	Bega NSW
4 1	1250 25.1	-19.711	133.846	2.0 G	3.2	Tennant Creek NT
4 5	1002 9.9	-31.108	138.511	16.0	3.0	Northwest SA
4 5	2224 46.0	-28.864	136.523	17.0	3.1	Central north SA

Table 1 (cont.)

4 10	0627 39.9	-29.300	138.130	9.0	3.0	Northwest SA
4 12	0800 10.5	-40.357	155.213	30.0	3.6	Tasman Sea
4 15	0620 21.8	-22.330	114.060	5.0 N	3.2	North central WA
4 15	1743 13.5	-34.774	149.181	0.0 G	3.1	Oolong NSW
4 20	0306 9.0	-19.900	133.800	0.0 G	3.1	Tennant Creek NT
4 21	2136 53.1	-26.140	127.300	10.0	3.1	Warburton WA
4 23	1020 57.0	-19.900	133.800	0.0 G	3.0	Tennant Creek NT
4 25	0316 41.3	-19.538	134.098	2.0 G	3.4	Tennant Creek NT
4 28	0634 9.5	-19.954	134.133	2.0 G	3.3	Tennant Creek NT
4 28	1301 40.5	-19.686	133.818	2.0 G	3.7	Tennant Creek NT
4 29	1125 16.0	-19.900	133.800	0.0 G	3.1	Tennant Creek NT
4 30	0424 30.8	-30.530	116.810	1.0 C	3.0	Ballidu WA
5 4	1206 7.0	-36.312	150.359	7.0	3.2	Montague Is NSW
5 6	1003 21.4	-33.894	139.267	17.0	3.4	Flinders R SA
5 6	1235 4.0	-19.900	133.800	2.0 G	3.6	Tennant Creek NT
5 8	1840 56.6	-30.780	117.100	2.0	4.5	Cadoux WA
5 9	0241 54.5	-27.450	105.970	5.0 N	4.1	Offshore WA
5 11	0222 40.9	-37.718	146.392	0.0 G	3.0	Thomson Dam Vic
5 13	0535 24.9	-17.260	146.150	0.0 G	4.2	Innisfail Qld
5 22	2144 46.0	-19.900	133.800	2.0 G	3.5	Tennant Creek NT
5 23	2139 10.0	-19.900	133.800	2.0 G	3.1	Tennant Creek NT
5 28	0336 35.8	-25.670	152.352	5.0 G	3.4	Tasman Sea
5 30	1943 47.1	-30.530	116.810	3.0	3.2	Cadoux WA
6 9	1342 13.1	-11.522	143.038	0.0 G	4.5	Cape York Qld
6 11	1508 2.4	-33.857	138.194	5.0 G	3.1	Clare SA
6 11	2028 42.9	-34.858	144.433	11.0	3.2	Deniliquin NSW
6 13	2023 54.2	-33.160	138.318	15.0	3.0	Laura SA
6 14	0527 0.0	-37.900	148.150	0.0	3.0	Gippsland Vic
6 25	1645 7.7	-19.688	133.842	5.0 N	3.0	Tennant Creek NT
6 26	2030 46.2	-18.700	126.800	5.0 N	3.3	Halls Ck WA
6 27	1423 49.6	-18.830	123.120	5.0 N	3.1	Broome WA
7 13	1818 25.4	-18.853	116.318	5.0	3.0	Dampier WA
7 17	0513 0.7	-30.769	121.477	5.0	3.2	Kalgoorlie WA
7 25	1017 54.1	-19.960	134.110	6.0	3.2	Tennant Creek NT
7 28	1339 40.7	-12.400	134.900	5.0	3.8	Arnham Land NT
8 3	1206 20.4	-26.254	146.238	0.0 G	3.1	S central Qld
8 6	1742 58.0	-19.900	133.800	2.0 C	3.0	Tennant Creek NT
8 7	0042 51.2	-19.757	134.181	5.0	3.6	Tennant Creek NT
8 9	1042 54.4	-19.733	133.812	5.0 G	3.7	Tennant Creek NT
8 11	0053 23.9	-19.729	133.885	5.0 G	3.7	Tennant Creek NT
8 11	1646 41.3	-19.898	134.398	4.0	3.0	Tennant Creek NT
8 11	1754 59.7	-23.092	130.147	38.0	4.5	W Alice Springs NT
8 13	0234 7.4	-19.897	133.867	5.0 G	3.1	Tennant Creek NT
8 16	0305 59.0	-38.109	149.786	0.0 G	3.7	Bass Strait Vic
8 17	1214 36.4	-17.780	122.610	0.0 N	4.2	Broome WA
8 20	0416 33.8	-19.918	134.056	0.0 G	3.2	Tennant Creek NT
8 20	1356 5.7	-31.175	138.633	5.0 N	3.4	Port Augusta SA
8 21	1049 15.3	-32.073	138.623	5.0 N	3.3	"
8 22	0205 36.4	-19.984	134.306	4.0	3.1	Tennant Creek NT
8 23	0740 54.5	-31.924	138.195	5.0 N	3.2	Port Augusta SA
8 24	2011 47.9	-19.800	134.094	5.0 N	3.2	Tennant Creek NT
8 26	0139 54.7	-31.923	138.530	5.0 N	3.3	Hawker SA
8 26	1547 4.3	-20.021	134.232	5.0 N	3.6	Tennant Creek NT
8 27	0612 5.9	-19.725	133.684	5.0 N	3.0	Tennant Creek NT

Table 1 (cont.)

8 27	0807 6.0	-19.846	134.901	5.0 N	3.2	Tennant Creek NT
8 28	1004 54.2	-22.860	112.750	0.0	3.6	Exmouth WA
8 28	2201 31.7	-19.610	133.696	5.0 N	3.1	Tennant Creek NT
9 3	0632 43.2	-40.446	149.543	10.0	3.5	West Tasman Sea
9 5	0412 5.7	-41.050	117.900	5.0 N	3.0	Albany WA
9 12	1020 3.9	-19.800	133.900	0.0	3.0	Tennant Creek NT
9 12	1205 39.5	-18.630	122.870	5.0 N	3.2	Broome WA
9 13	1456 58.4	-19.599	133.646	5.0 N	3.8	Tennant Creek NT
9 13	1749 36.0	-34.065	148.783	5.0 N	3.0	Blanket Flat NSW
9 13	1928 22.8	-32.847	148.289	0.0 G	3.3	Yarrabin NSW
9 14	1000 24.7	-19.800	133.900	0.0	3.3	Tennant Creek NT
9 15	1538 15.9	-29.890	108.910	5.0 N	3.7	WNW Perth WA
9 16	2057 34.2	-19.800	133.900	0.0	3.1	Tennant Creek NT
9 21	0408 3.4	-19.800	133.900	0.0	3.2	Tennant Creek NT
9 22	1321 32.7	-19.800	133.900	0.0	3.2	Tennant Creek NT
9 27	1241 51.8	-25.931	137.514	5.0 G	3.8	Simpson Desert NT
9 29	0914 13.4	-19.881	133.608	5.0 N	3.3	Tennant Creek NT
10 7	0004 17.1	-19.900	133.800	2.0 G	3.0	Tennant Creek NT
10 9	1816 15.5	-14.290	128.900	5.0 N	3.3	Kununurra WA
10 15	1949 27.2	-22.340	113.790	5.0 N	3.2	Learmonth WA
10 23	1313 29.2	-19.900	133.800	2.0 G	3.0	Tennant Creek NT
10 23	1430 44.5	-19.900	133.800	2.0 G	4.1	Tennant Creek NT
10 28	2140 51.0	-20.010	133.796	2.0 G	4.3	Tennant Creek NT
10 31	0600 10.6	-20.061	134.166	2.0 G	4.5	Tennant Creek NT
11 3	2308 38.0	-19.900	133.800	2.0 G	3.0	Tennant Creek NT
11 6	1049 39.4	-20.066	134.127	2.0 G	3.2	Tennant Creek NT
11 8	0003 9.0	-19.923	133.781	2.0 G	3.4	Tennant Creek NT
11 14	1856 45.0	-30.329	150.840	6.0	3.1	Armidale NSW
11 25	2146 51.4	-21.730	126.400	5.0 N	3.0	L Tobin WA
11 27	1721 11.9	-40.235	142.015	17.0	3.5	Bass Strait
11 27	2116 26.3	-20.046	133.599	0.0 G	**5.2**	Tennant Creek NT
12 1	2054 51.6	-26.527	131.809	12.0	3.3	Northwest SA
12 1	2235 16.3	-26.582	131.325	21.0	4.1	Northwest SA
12 3	1318 39.6	-31.420	139.323	5.0 G	4.2	Flinders Ranges SA
12 26	0010 40.2	-31.495	139.154	17.0	3.0	Flinders Ranges SA
12 28	0452 54.0	-19.900	133.800	2.0 G	3.1	Tennant Creek NT
12 28	1414 30.0	-19.900	133.800	2.0 G	3.5	Tennant Creek NT
12 29	1226 11.0	-19.900	133.800	2.0 G	3.0	Tennant Creek NT

Table 2. Large or damaging Australian earthquakes, 1788 - 1990

Date UTC	Time	Lat °S	Long °E	ML	Ms	$AUS loss (1992$)	Location
1873 12 15	0400	26.25	127.5		6.0		SE WA
1884 07 13	0355	40.5	148.5		6.2		NE Tasmania
1885 01 05	1220	29.0	114.0		6.5		Geraldton WA
1885 05 12	2337	39.8	148.8		6.5		NE Tasmania
1892 01 26	1648	40.3	149.5		6.6		NE Tasmania
1897 05 10	0526	37.33	139.75		6.5		Kingston SA
1902 09 19	1035	35.0	137.4		6.0		Warooka SA
1903 04 06	2352	38.43	142.53	4.6			Warrnambool Vic
1903 07 14	1029	38.43	142.53	5.3			Warrnambool Vic
1906 11 19	0718	21.5	104.5		7.3		Offshore WA
1918 06 06	1814 24	23.5	152.5	6.2	5.7		Gladstone Qld
1920 02 08	0524 30	35.0	111.0		6.0		Offshore WA
1929 08 16	2128 23	16.99	120.66		6.6		Broome WA
1935 04 12	0132 24	26.0	151.1	6.1	5.4		Gayndah Qld
1941 04 29	0135 39	26.92	115.80	7.0	6.8		Meeberrie WA
1941 06 27	0755 49	25.95	137.34		6.5		Simpson Desert
1954 02 28	1809 52	34.93	138.69	5.4	4.9	100M	Adelaide SA
1961 05 21	2140 03	34.55	150.50	5.6		3M	Bowral NSW
1968 10 14	0258 50	31.62	116.98	6.9	6.8	29M	Meckering WA
1970 03 10	1715 11	31.11	116.47	5.1	5.1		Calingiri WA
1970 03 24	1035 17	22.05	126.61	6.7	5.9		L Mckay WA
1972 08 28	0218 56	24.95	136.26		6.2		Simpson Desert
1973 03 09	1909 15	34.17	150.32	5.6	5.3	2M	Picton NSW
1975 10 03	1151 01	22.21	126.58		6.2		L Mckay WA
1978 05 06	1952 19	19.55	126.56		6.2		L Mckay WA
1979 04 23	0545 10	16.66	120.27	6.6	5.7		Broome WA
1979 04 25	2213 57	16.94	120.48		6.1		Broome WA
1979 06 02	0947 59	30.83	117.17	6.2	6.1	9M	Cadoux WA
1983 11 25	1956 07	40.45	155.51	6.0	5.8		Tasman Sea
1985 02 13	0801 23	33.49	150.18	4.3		.09M	Lithgow NSW
1986 03 30	0853 48	26.33	132.52		5.8		Marryat Ck SA
1988 01 22	0035 57	19.79	133.93		6.3	1.2M	Tennant Ck NT
1988 01 22	0357 24	19.88	133.84		6.4		Tennant Ck NT
1988 01 22	1204 55	19.94	133.74		6.7		Tennant Ck NT
1989 12 27	2326 58	32.95	151.61	5.6	4.6	1 200M	Newcastle NSW

Table 3. Australian Seismographic Stations, 1990

Code#	Name	Lat° S	Long°E	Elev. (m)	Operator	Type*
Queensland						
AWD	Awoonga Dam	24.078	151.316	110	GSQ	1
BDM	Boondooma Dam	26.112	151.444	320	GSQ	1
BGR	Glenroy	20.549	147.105	160	GSQ	1
BLP+	Blunder Park	17.76	145.42	650	GSQ	
BRS	Mt Nebo Brisbane	27.392	152.775	525	QLD	5
BSL-	Bruslee	20.275	147.299	185	GSQ	1
CCQ+	Carron Creek	17.85	145.57	740	GSQ	
CVL	Colinsville	20.590	147.105	160	GSQ	1
CRC	Cracow	25.253	150.279	290	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	220	GSQ	1
GVA	Glen Eva	21.489	147.483	200	GSQ	1
HRD+	H Road	17.76	145.65	260	GSQ	
MCP	Mt Cooper	20.552	146.806	300	GSQ	1
MHP-	Mt Hope	21.396	146.802	200	GSQ	1
MNH+	Munroe Hill	17.97	145.80	40	GSQ	
MTMQ+	Mt Morgan	23.763	150.390	170	UCQ	8
QIS	Mount Isa	20.556	139.605	330	BMR	1
QLP	Quilpie	26.584	144.235	210	BMR	1
RMQ	Roma	26.489	148.755	360	BMR	1
RVH+	Ravenshoe	17.63	145.48	880	GSQ	
SCY+	Sunday Creek	17.88	145.34	690	GSQ	
UCQ+	UCQ Campus	23.323	150.517	35	UCQ	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
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 Dam	12.847	131.130	80	BMR	1
WRA	Warramunga	19.944	134.353	366	CAN	3
Western Australia						
BAL	Ballidu	30.607	116.707	300	MUN	1
COOL	Coolgardie	30.884	121.145	500	MUN	1
FORR	Forrest	30.799	128.067	530	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	Meekatharra	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
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

Table 3 (cont.)

NSW & ACT (cont)						
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
MEG	Meangora	35.101	150.037	712	CAN	1
RIV	Riverview	33.829	151.159	21	RIV	2
STK	Stephens Creek	31.882	141.592	213	BMR	7
WER	Werombi	33.950	150.580	226	CAN	1
YOU	Young	34.278	148.382	503	CAN	1
South Australia						
ADE/ADT	Adelaide	34.967	138.713	655	ADE	2
ARK+	Arkaroola	30.276	139.339	520	ADE	1
CLV	Cleve	33.691	136.495	238	ADE	1
GEX+	Naracoorte	37.0735	140.8251	80	ADE	1
HTT	Hallett	33.430	138.921	708	ADE	1
HWK‡	Hawksnest	29.958	135.203	180	ADE/BMR	1/8
KHC+	Kelly Hill Caves	35.9825	136.1111	100	ADE	1
MGR-	Mt Gambier	37.728	140.571	190	ADE	1
MGR2+	Mt Gambier	37.8011	140.6865	60	ADE	1
NBK	Nectar Brook	32.701	137.983	180	ADE	1
PDA+	Parndana	35.8059	137.2389	140	ADE	8
PNA	Partacoona	32.006	138.165	180	ADE	1
RPA	Roopena	32.725	137.403	95	ADE	1
SDN+	Sedan	34.5093	139.3374	125	ADE	8
THS+	The Heights HS	34.7416	138.7733	340	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
BUC	Bucrabanyule	36.238	143.498	210	PIT	1
CRN	Cairn Curran	36.991	143.972	230	PIT	8
DRO	Dromana	38.360	144.997	170	PIT	1
DTM/DTT	Dartmouth	36.529	147.469	436	PIT	8
FRT	Forrest	38.534	144.997	210	PIT	1
GOG	North Grampians	36.888	142.400	265	PIT	8
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
KOWA	Kowarra	35.791	144.521	85	PIT	1
MAL	Marshall Spur	37.749	146.292	1076	PIT	1
MEM	Merrimu	37.637	144.497	160	PIT	1
MCV+	McVeigh	37.691	145.899	630	PIT	1
MIC	Mount Erica	37.944	146.359	805	PIT	1
TOT	Thompson Dam	37.8423	146.4057	680	PIT	8
MLW	Molesworth	37.137	145.510	280	PIT	1
PAT	Plane Track	37.857	146.456	771	PIT	1

Table 3 (cont)						
Victoria (cont)						
PEG	Pegleg	36.985	144.091	340	PIT	1
POL+	Poley Tower	37.626	145.801	1200	PIT	1
PNH	Panton Hill	37.635	145.271	180	PIT	1
RUS	Rushworth	36.662	144.947	145	PIT	1
SIN	Swingler Track	37.739	146.292	980	PIT	8
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
TYR+	Tyers	38.1083	146.4354	280	PIT	1
UYB+	Upper Yarra	37.673	145.897	300	PIT	1
VPE+	Vantage Point	37.642	145.937	650	PIT	1
WSK	Woodstock	36.814	144.055	210	PIT	1
Tasmania						
MOO	Moorlands	42.442	147.190	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 Uni	42.910	147.321	132	TAU	2
TRR	Tarraleah	42.304	146.450	579	TAU	1
MCQ	Macquarie Is.	54.498	158.957	14	BMR	1/6
Antarctica						
CSY+	Casey	66.2894	110.5289	56	BMR	1
MAW	Mawson	67.607	62.872	15	BMR	5/7
MCQ	(see Tasmania)					

Refers to contributors listed on page iii.

* Type of seismograph
1. Short period (vertical and/or horizontal); 2. World Wide Standardised Seismographic Station (WWSSN); 3. Seismic array; 4. Seismological research observatory (SRO); 5. Long and short period; 6. Broad-band vertical ; 7. Broad-band triaxial; 8 Kelunji digital triaxial triggered.

+/- Opened/closed this year

Table 4. Focal parameters Meckering WA earthquake, 17 January 1990

Meckering WA		
	Azimuth (°)	dip (°)
P-axis	090	18
T-axis	228	65
B-axis	353	12
Double couples		
A	020	28
B	164	66

Table 5. Australian accelerographs, 1990

Location	*Lat °S*	*Long °E*	*Elev (m)*	*Foundation*	*Type*	*Owner*
ACT						
ASC-BMR	35.289	149.139	560	Soil	PIT	BMR
Parliament House	35.310	149.123	600	Sandstone	PIT	BMR
Corin Dam (2)	35.524	148.812	915	Granite	PIT	E&W
Lower Cotter Dam	35.308	148.908	535	Basalt	PIT	E&W
Telecom Tower (3)	35.275	149.096	810	Sandstone	PIT	TEL
New South Wales						
Oolong (OOL)	34.773	149.163	600	Weathered granite	SMA-1	BMR
Ferndale (FND)	34.745	149.166	580	Granite	PIT	BMR
Springfield (SPF)	34.765	149.151	580	Granite	PIT	BMR
Wilton (WIL)	34.800	149.221	660	Granite	PIT	BMR
Googong Dam (2)	35.431	148.878	610	Meta-sediments	PIT	E&W
Hume Weir	36.110	147.043	600	Dam wall	SMA-1	DWR
Hume Weir	36.110	147.043	600	Dam wall	SMA-1	DWR
Hume Weir	36.110	147.043	600	Dam wall	SMA-1	DWR
Hume Weir	36.110	147.043	329	Downstream bank	SMA-1	DWR
Hume Weir	36.110	147.043	600	Left hand abutment	SMA-1	DWR
Lucas Heights LHB	34.052	150.979	80	Hawksbury sandstone	PIT	ANSTO
LHR	34.05	150.98	80	Reactor Building	PIT	ANSTO
Newcastle (NPS)	32.933	145.781	20	Building Basement	PIT	BMR
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
Victoria						
Jeeralang 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 DDC	36.561	147.524	494	Dam crest	PIT	RWCV
	36.570	147.580	520	Hoist house	SMA-1	RWCV
Dartmouth Dam DDB	36.558	147.511	329	Ordivician meta-sediments	PIT	RWCV
	36.570	147.580	420	Downstream face	SMA-1	RWCV
	36.570	147.580	360	Access tunnel	SMA-1	RWCV
Animal Health Lab	38.15	144.39	10		SMA-1	CSIRO
	38.15	144.39	10		SMA-1	CSIRO
	38.15	144.39	10		SMA-1	CSIRO
Thomson Dam (TMT)	37.844	146.396	460	Outlet Tower	PIT	MMBW
Northern Territory						
Tennant Creek TCTY	19.642	134.183	370	Sediments	SSA-1	PIT

Table 5 (cont.)

Queensland						
Wivenhoe Dam	27.394	152.602	80	Crest	A700	BAWB
	27.395	152.603	28	Base	A700	BAWB
	27.347	152.631	78	Power Station	A700	QEC
	27.375	152.631	78	Power Station	A700	QEC
Splityard Ck. Dam	27.379	152.641	170	Dam Wall	A700	QEC
	27.375	152.641	65	Valve room	A700	QEC
Tully Millstream	17.76	145.42	65		PIT	QEC
	17.85	145.57	74		PIT	QEC
Western Australia						
Ballidu (BA-M)	30.607	116.707	300	Granite	MO2	BMR
Cadoux						
Avery C. (CA-C)	30.851	117.160	300	Alluvium	MO2	BMR
Emmott J. (CA-E)	30.895	117.123	320	Laterite	A700	BMR
Kalajzic C. (CA-K)	30.718	117.141	380	LateriteGranite	MO2	BMR
Kalajzic M. (CA-A)	30.746	117.151	320	Alluvium	A700	BMR
Robb A. (CA-R)	30.781	117.138	360	Alluvium	MO2	BMR
Shankland (CA-S)	30.810	117.132	400	W Granite	MO2	BMR
Canning Dam						
Lower gallery (CD--L)	32.154	116.126	142	Granite	A700	BMR
Upper gallery (CD-U)	32.154	116.126	202	Granite	A700	BMR
Dowerin (DO-W)	31.010	116.982	300	Granite	PIT	BMR
Goomalling (GO-O)	31.394	116.852	250	Granite	PIT	BMR
Kununurra						
Dam abutment KNA	16.113	128.737		Phyllite	A700	WAWA
Dam wall KNW	16.113	128.738		Rock fill, 3m clay core	A700	WAWA
Meckering MEK	31.694	116.982	200	Alluvium		BMR
Mundaring						
Weir MUW	31.958	116.164	140	Concrete wall 42m high	SMA1	WAWA
O'Connor museum MUC	31.957	116.162	106	Concrete floor	MO2	WAWA
North Dandalup NDD	32.52	116.01	205	Granite	A700	WAWA
Perth						
Telecom building PTB	31.953	115.850	10	Basement	SMA1	TEL
Telecom building PTM	31.953	115.850	40	Middle floor	SMA1	TEL
Telecom building PTT	31.953	115.850	70	Top floor	SMA1	TEL
Serpentine Dam						
Basement SEB	32.40	116.10		Granite	A700	WAWA
Wall SEW	32.40	116.10		Earthfill	A700	WAWA
Victoria Dam VID	32.04	116.06		Granite	A700	WAWA

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

Table 6. Australian accelerograms, 1990

Date	*Time UTC*	*Lat °S*	*Long °E*	*ML*	*Site*	**H/E km*	*Comp*	*T(S) s*	*Acc mms-2*
01 17	0638	31.72	116.99	5.5	DO-W	78/78	PZ	0.15	4.0
							PN	0.15	4.0
							PE	0.15	2.0
							SZ	0.075	23.0
							SN	0.075	21.0
							SE	0.075	93.0
					CA-E	90/90	PZ	0.104	26.0
							PN	0.129	30.0
							PE	0.153	49.0
							SZ	0.104	18.0
							SN	0.153	26.0
							SE	0.153	72.0
					MU-W	90/90	Z	0.08	98.0
							N	0.05	75.0
							E	0.08	278.0
					CA-S	100/100	LZ	0.046	31.0
							LN	0.052	35.0
							LE	0.058	51.0
					CD-U	100/100	PZ	0.25	15.0
							PN	(0.2)	12.0
							PE	(0.3)	18.0
							SZ	0.15	29.0
							SN	(0.7)	44.0
							SE	0.13	123.0
					CD-L	100/100	SZ		18.0
							SN	0.2	15.0
							SE	0.164	18.0
					CA-K	110/110	SZ	0.059	17.0
							SN	0.059	5.0
							SE	0.059	29.0
							LZ	0.147	24.0
							LN	0.059	16.0
							LE	0.147	40.0
02 23	1243	33.00	151.43	2.9	NPS	3.64 s	PZ	0.04	3.1
							PN	0.04	1.1
							PE	0.04	1.6
							SZ	0.1	1.9
							SN	0.1	4.9
							SE	0.1	4.9
05 08	1841	30.78	117.10	4.5	CA-S	4/6	PZ	0.035	155.0
							PN	0.030	91.0
							PE	0.030	86.0
							SZ	0.035	360.0
							SN		
							SE	0.035	910.0
							LZ	0.097	580.0

Table 6 (cont.)

05 08	1841	30.78	117.10	4.5	CA-A	6/6	PZ	0.103	137.0
							PN	0.074	61.0
							PE	0.074	65.0
							SZ	0.035	607.0
							SN	0.025	2458.0
							SE	0.056	2036.0
05 08	1841	30.78	117.10	4.5	CA-K	8/8	PZ	0.050	154.0
							PN	0.050	108.0
							PE	0.050	114.0
							SZ	0.065	632.0
							SN	0.053	457.0
							SE	0.059	685.0
					CA-E	15/15	PZ	0.039	47.0
							PN	0.10	16.0
							PE	0.10	14.0
							SZ	0.125	128.0
							SN	0.147	140.0
							SE	0.145	309.0
					DOW	28/28	PZ	0.05	18.0
							PN	0.03	33.0
							SZ	0.04	61.0
							SN	0.035	65.0
					GO-O	68/68	PZ	0.043	8.0
							PN	0.043	8.0
							PE	0.043	18.0
							SZ	0.043	40.0
							SN	0.043	33.0
							LE	0.043	74.0
5 11	0222	37.759	146.37	3.0	JNA	66/66	SZ	0.085	0.73
							SN	0.08	0.75
							SE	0.095	0.73
5 19	1709	37.761	146.37	3.0	PTA	13.6/13	SZ	0.135	9.3
							SN	0.115	19.0
							SE	0.15	16.2
					TMT	10/9.4	SZ	0.09	35.9
							SN	0.06	26.28
							SE	0.06	21.74

* Hypocentral/epicentral distance (km) or (S-P) time (seconds)

Table 7. Principal world earthquakes, 1990

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

Date	Origin Time (UTC)	Region	Lat.	Long.	Magnitude
28 Feb	23 43 36.6	Southern California	34.140 N	117.700 W	5.5 mb, 5.5 Ms 5.2 ML (PAS) 6.2 ML (BRK)
Depth 5 km. Thirty people received minor injuries and damage was estimated to be at least 12.7 million dollars. Some damage (VII) at Claremont, Covina, La Verne, Montclair, Mount Baldy, Ontario, Pomona, San Dimas, Upland and Walnut. Slight damage (VI) at Arcadia, Azusa, Chino, Colton, Compton, Glendora, Lincoln Heights, Lytle Creek, Pico Rivera and West Covina. Felt from Santa Barbara to Ensenada, Mexico and northeast as far as Las Vegas, Nevada.					
03 Mar	12 16 27.9	South of Fiji Islands	22.122 S	175.163 E	6.3 mb, 7.4 Ms 7.4 Ms (BRK) 7.1 Ms (PAS)
Depth 33 km.					
04 Mar	19 46 19.6	Pakistan	28.925 N	66.331 E	5.8 mb, 6.1 Ms
Depth 10 km. At least 11 people killed, about 40 injured and many homes and buildings damaged in the Kalat area. Also felt at Quetta and Mastung. Complex event.					
05 Mar	16 38 12.5	Vanuatu Islands	18.318 S	168.063 E	5.6 mb, 7.0 Ms 7.0 Ms (BRK) 6.8 Ms (PAS)
Depth 21 km. Felt (V) at Port Vila.					
25 Mar	13 22 55.6	Costa Rica	9.919 N	84.808 W	6.2 mb, 7.0 Ms 6.8 Ms (BRK)
Depth 22 km. Ten people slightly injured. Damage (VIII) in the Puntarenas area and about 60 buildings severely damaged (VII) in the San Jose area. Several landslides blocked roads in the area for a short time. Felt throughout Costa Rica and southwestern Nicaragua. Felt (IV) at Almirante and Puerto Armuelles and III and David, Panama.					
18 Apr	13 39 19.0	Minahassa Peninsula	1.186 N	122.857 E	6.2 mb, 7.4 Ms 7.3 Ms (BRK)
Depth 26 km. At least 3 people killed and 25 people injured. More than 1,140 houses damaged in the Bolaang-Gorontalo area. Felt strongly throughout the Minahassa Peninsula. Also felt in central Sulawesi. Two events about 4.5 seconds apart.					
26 Apr	09 37 15.0	Qinghai Province, China	35.986 N	100.245 E	6.5 mb, 6.9 Ms 6.7 Ms (BRK) 6.4 Ms (PAS)
Depth 8 km. At least 126 people killed, many injured, extensive damage and landslides in the Gonghe-Xinghai area. Also felt in Gansu Province.					

Table 7 (Cont.)

Date	Origin Time (UTC)	Region	Lat.	Long.	Magnitude
05 May	07 21 29.5	Southern Italy	40.775 N	15.766 E	5.3 mb, 5.4 Ms 5.6 MD (TTG) 5.5 MD (TRI) 5.4 MD (STR) 5.3 ML (LJU) 5.2 ML (THE)

Depth 10 km. Two people died from heart attacks, 16 injured and damage (VII) in the Potenza area. Felt strongly in many parts of southern Italy. Also felt along the coast of Montenegro, Yugoslavia.

20 May	02 22 01.6	Sudan	5.121 N	32.145 E	6.7 mb, 7.1 Ms 7.4 Ms (BRK) 7.2 Ms (PAS)

Depth 15 km. Some buildings damaged in the Juba area. Also some damage in the Moyo area, Uganda. Felt in the Nakuru area, Kenya and in Uganda. Believed to be the largest earthquake ever recorded in Sudan.

24 May	20 00 08.1	Sudan	5.358 N	31.848 E	6.5 mb, 7.0 Ms 7.0 Ms (BRK) 6.9 Ms (PAS)

Depth 16 km. Some buildings damaged in the Juba area. Felt in the Kapenguria area and at Nakuru, Kenya. Also felt in Uganda.

30 May	02 34 05.8	Northern Peru	6.016 S	77.229 W	6.1 mb, 6.5 Ms 6.6 Ms (BRK) 5.9 Ms (PAS)

Depth 24 km. Three events about 1.5 and 4.8 seconds apart respectively. At least 135 people killed, more than 800 injured and severe damage (VI) in the Moyobamba-Rioja area. Felt (V) at Chachapoyas; (IV) at Cajamarcaj; (III) at Chiclayo and Chimbote. Also felt (IV) at Guayaquil, Ecuador.

30 May	10 40 06.1	Romania	45.841 N	26.668 E	6.7 mb 7.1 mb (PAS)

Depth 89 km. Nine people killed, more than 700 injured and severe damage in the Bucharest-Braila-Brasov area. Four people killed, some injured and many buildings damaged in Moldavia, USSR. One person died of a heart attack and extensive damage in northern Bulgaria. Felt (VI) at Silistra and (V) at Sofia, Bulgaria. Felt (VI) at Kishinev; (IV) at Kiev, Lvov, Moscow, Rostov, Sochi and Uzhgorod; (III) at Stavrapol and Leningrad, USSR. Also felt in Hungary, Greece, Poland, Turkey and Yugoslavia.

09 Jun	01 14 34.5	Northern Peru	6.062 S	77.136 W	5.5 mb, 4.9 Ms

Depth 26 km. One person killed and at least 14 houses destroyed, (VI) in the Rioja-Moyobamba area. Felt (ii) at Iquitos.

14 Jun	07 40 56.2	Panay, Philippine Islands	11.760 N	121.899 E	6.0 mb, 7.1 Ms 6.8 Ms (BRK)

Depth 18 km. At least four people killed, 15 injured in the Culasi area. Considerable damage in other parts of Panay. Felt (VI RF) at Iloilo; (V RF) at Bacolod, Negros and on Cebu; (III RF) on Camiguin; (II RF) at Sorsogon and (I RF) at Manila, Luzon.

Table 7 (Cont.)

Date	Origin Time (UTC)	Region	Lat.	Long.	Magnitude
14 Jun	12 47 28.8	Kazakh-Xinjiang Border Region	47.869 N	85.076 E	6.1 mb, 6.8 Ms 6.5 mb (PAS) 6.6 Ms (BRK) 6.4 Ms (PAS)
Depth 58 km. One person killed, 3,000 houses destroyed and 20,000 people left homeless in the Ust-Kamennogorsk-Zaysan area, USSR. Damage in Jeminay and Habahe Counties, China. Felt (V) at Novosibirsk, Semipalatinsk and Ust-Kamenogorsk and (III) at Andizhan and Frunze, USSR. Also felt at Urumqi, China.					
20 Jun	21 00 09.9	Western Iran	36.957 N	49.409 E	6.4 mb, 7.7 Ms 7.7 Ms (BRK) 7.4 Ms (PAS)
Depth 19 km. Estimated 40,000 to 50,000 people killed, more than 60,000 injured, 400,000 or more homeless and extensive damage and landslides in the Rasht-Qazvin-Zanjan area, Iran. Nearly all buildings were destroyed in the Rudbar-Manjil area. Substantial damage occurred as far away as Khalkhal and Now Shahr and slight damage occurred at Tehran. Felt in most of northwestern Iran, including Arak, Bakhtaran and Tabriz. Slight damage also occurred in southern Azerbaijan, USSR. Felt (VII) at Astra and Lenkoran; (VI) at Dzhibrail, Lerik, Mossony and Yardyshny; (III) at Baku, USSR. Complex event.					
21 Jun	09 02 14.6	Western Iran	36.636 N	49.799 E	5.8 mb, 5.3 Ms
Depth 15 km. At least 20 people killed and additional damage in the Lowshan-Manjil area.					
13 Jul	14 20 43.4	Hindu Kush Region	36.415 N	70.789 E	5.6 mb
Depth 217 km. At least 43 mountain climbers were killed on Pik Lenina, USSR by an avalanche which was triggered by the earthquake. Felt (IV) at Dushanbe, Garm, Gezan, Gissar, Khorog, Kulyab, Langar, Leninabad, Namangan and Pyandzh; (III) at Andizhan, Fergana and Ura-Tyube; (II) at Tashkent, USSR.					
16 Jul	07 26 34.6	Luzon, Philippine Islands	15.679 N	121.172 E	6.5 mb, 7.8 Ms 7.6 Ms (BRK) 7.3 Ms (PAS)
Depth 25 km. At least 1,621 people killed, more than 3,000 people injured and severe damage, landslides, liquefaction, subsidence, and sandblows in the Baguio-Cabanatuan-Dagupan area. Damage also occurred in Bataan Province and at Manila. Large fissures were observed in the epicentral area. Surface faulting occurred along the Philippine and Digdig faults. Felt (VII RF) in the Manila area (VI RF) at Santa, (V RF) at Cubi Point and (IV RF) at Callao Caves.					
11 Aug	02 59 54.9	Ecuador	0.071 S	78.528 W	5.0 mb
Depth 5 km. At least four people killed, 10 injured, considerable damage and landslides in the Pomasqui area. Felt strongly at Quito.					
26 Sep	23 08 24.1	Republic of South Africa	28.050 S	26.693 E	5.6 mb, 4.7 Ms
Depth 5 km. Two people killed and 5 injured in a mine in the Welkom area. Slight damage at Welkom.					
25 Oct	04 53 46.5	Hindu Kush Region	35.190 N	70.740 E	6.1 mb, 4.8 Ms
Depth 6 km. Eleven people killed, more than 100 injured and damage in the Chitral-Mardan-Malakand area, Pakistan. Felt throughout northern and central Pakistan. Also felt in northwestern India. Felt (III) at Fergana, Kulyab and Dushanbe, USSR.					

Table 7 (Cont.)

Date	Origin Time (UTC)	Region	Lat.	Long.	Magnitude
06 Nov	18 45 54.1	Southern Iran	28.234 N	55.455 E	6.2 mb, 6.8 Ms 6.7 Ms (BRK)

Depth 25 km. At least 22 people killed, 100 injured, 21,000 homeless and 18 villages severely damaged in the Darab area.

06 Nov	20 14 30.9	Komandorsky Islands Region	53.468 N	169.929 E	6.4 mb, 7.0 Ms 6.8 Ms (BRK)

Depth 32 km. Felt (IV) on Attu and Shemya.

01 Dec	18 09 28.8	Kirghiz SSR	40.797 N	73.622 E	5.0 mb, 4.6 Ms

Depth 32 km. Approximately 3000 people homeless and more than 940 buildings damaged (VI) in the Uzgen area. Felt (V) at Dzhalal-Abad and (IV) at Osh. Also felt at Frunze.

13 Dec	00 24 24.3	Sicily	37.198 N	15.502 E	5.4 mb

Depth 10 km. At least 19 people killed, about 200 injured, 2,500 homeless and severe damage (VII) in the Carlentini area. Damage also occurred at Augusta, Lentini and Noto and slight damage occurred as far away as Cefalu. Felt as far west as Trapani.

13 Dec	03 01 49.0	Taiwan	24.032 N	121.669 E	5.9 mb, 6.2 Ms

Depth 14 km. At least 2 people killed and 3 people injured. Damage (IV JMA) at Hualien. Also felt (IV JMA) at Taipei. (III JMA) at Chiai, Hsinchu and Ilan. (II JMA) at Chilung and Taitung and (I JMA) at Kaohsiung.

21 Dec	06 57 44.0	Greece	40.984 N	22.338 E	5.8 mb, 5.9 Ms

Depth 18 km. One person killed, at least 60 injured and damage in the Edhessa-Kilkis area. Several people injured slightly and some buildings damaged (VIII) in the Gevgelija-Strumica area, Yugoslavia. Felt in Macedonia and southern Serbia, Yugoslavia. Also felt in Albania and at Mikhailovgrad, Plovdiv and (IV) at Sofia, Bulgaria. Felt (III) at Bucharest, Romania.

22 Dec	17 27 54.8	Costa Rica	9.908 N	84.299 W	5.3 mb, 5.6 Ms

Depth 13 km. One person killed at Alajuela, one person died of a heart attack and about 350 people injured in central Costa Rica. Damage (VIII) at Santiago de Puriscal, (VII) at Alajuela and (VI) at Heredia and San Jose. Felt throughout Costa Rica and in western Panama.

30 Dec	19 14 19.7	New Britain Region	5.090 S	150.984 E	6.7 mb, 7.0 Ms

Depth 188 km. Some damage in the Hoskins area. Felt at Port Moresby and many parts of Papua New Guinea.

Table 8. Underground Nuclear Explosions, 1990

Date	*Origin T (UTC)*	*Latitude*	*Longitude*	*mB*	*Ms*	*Site*	*Source*	*Comments*
Mar 10	160000.0	37.113N	116.055W	5.1		NTS	PDE	metropolis
May 26	075958.3	41.654N	88.736E	5.4	3.9	LopN	PDE	
Jun 02	172958.7	21.819S	138.940W	5.3		Mur	PDE	
Jun 07	173000.0	21.000S	138.000W	4.3		Mur	WRA	<10kt
Jun 13	160000.0	37.262N	116.420W	5.7		NTS	PDE	bullion
Jun 21	181500.0	36.993N	116.004W	4.0		NTS	PDE	austin
Jun 26	175958.2	22.192S	138.841W	5.5	4.2	Fan	PDE	
Jul 04	175958.4	21.866S	139.046W	5.1		Mur	PDE	
Jul 25	150000.0	37.207N	116.214W	4.8		NTS	PDE	mineral quarry
Aug 16	045957.7	41.586N	88.799E	6.2	4.4	LopN	PDE	
Sep 20	161500.0					NTS	USAEC	sundown
Oct1 2	173000.0	37.248N	116.494W	5.6	4.2	NTS	PDE	tenabo
Oct 24	145758.1	73.364N	54.827E	5.6	4.0	NovZ	PDE	
Nov 14	181158.3	22.147S	138.852W	5.6	5.6	Fan	PDE	
Nov 14	191700.7	37.227N	116.371W	5.4		NTS	PDE	houston
Nov 21	165958.0	21.906S	138.960W	5.4		Mur	PDE	

* NTS Nevada Test Site, USA; Mur/Fan Mururoa/Fangataufa, French Polynesia; Ekaz East Kazakhstan, USSR; LopN Lop Nor China; NovZ Novaya Zemlya, Russia;

¤ PDE Preliminary Determination of epicentres, USA; USAEC United States Atomic Energy Commission; ASAR Alice Springs Array, Australia; WRA Warramunga Array, Australia.

§ not recorded in Australia.

Table 9. Yield versus magnitude for underground nuclear explosions

Magnitude mb		*Yield ktons*
Test site		
Nevada	Other	
0.0 - 4.5	0.0 - 4.8	< 10
4.6 - 4.8	4.9 - 5.1	5 - 20
4.9 - 5.0	5.2 - 5.4	10 - 40
5.1 - 5.3	5.5 - 5.7	20 - 80
5.4 - 5.6	5.8 - 6.0	40 - 150
> 5.6	> 6.0	>80

APPENDIX Modified Mercalli (MM) Scale of Earthquake Intensity (after Eiby, 1966)

MMI 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.

MMII 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.

MMIII 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.

MMIV 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.

MMV 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. 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.

MMVI 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.

MMVII 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.

MMVIII 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.

MMIX 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.

MMX 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.

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

MMXII 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.

Notes

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.

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

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.