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Kevin McCue & Peter Gregson

Australian Geological Survey Organisation

Department of Primary Industries and Energy

AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

RECORD 1992/100

AUSTRALIAN SEISMOLOGICAL REPORT, 1989

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SUMMARY

An earthquake near Newcastle NSW at 10:27 a.m. local time on 28 December, caused the most costly natural disaster in Australia. Thirteen people died and another 160 were seriously injured at Newcastle when this moderate earthquake struck causing the collapse of several old 2 and 3 storey unreinforced masonry structures, or parts of structures in the downtown suburb of Hamilton. That it was a holiday period and late morning reduced the casualty total dramatically. The monetary loss has been variously estimated at between $1.2 billion and $4.0 billion.

Seismicity in the Australian region in 1989 was about average and the largest earthquake was that at Newcastle, which at magnitude ML 5.6, is the modal or most frequent annual maximum magnitude for mainland Australia. Another earthquake near Mt Olga, Northern Territory on 28 May had a similar size but their effects were dramatically different. Few people even felt the Mt Olga earthquake and only minor damage was reported by national park rangers at the tourist centre.

The earthquake at Newcastle highlighted the difference between earthquake hazard and earthquake risk: a magnitude 6+ earthquake in outback Australia represents a large hazard but a small risk, a moderate earthquake near a major city gives rise to a large risk, the integration of the hazard and vulnerability. In 1989 not a single Australian population centre of at least 50 000 residents was adequately monitored for earthquakes. In the past, seismographs were purposely sited as far from population centres as possible to minimise cultural noise which downgrades their sensitivity. In February 1990 four of the ten aftershock recorders installed in and around Newcastle in the last days of December 1989 were made into a permanent network at the request of then Australian Government Minister for Resources, Senator Peter Cook.

Six distant digital accelerographs were triggered by the Newcastle earthquake but no significant near-field accelerograms were recorded during 1989. Isoseismal maps were drawn for twelve of the year's earthquakes that were widely felt, including the Newcastle earthquake and its only aftershock the following day.

During 1989, 26 presumed underground nuclear explosions were detonated; 10 by the USA, 8 by France, 7 by the USSR, and 1 by the UK (at Nevada). This compares with 38 in 1988 and 47 in 1987.

INTRODUCTION

This report contains information on earthquakes of Richter magnitude 3 or greater that were reported in the Australian region during 1989. It is the tenth of an annual series compiled by the Australian Geological Survey Organisation (formerly the Bureau of Mineral Resources, Geology & Geophysics, BMR), using data from AGSO and various seismological agencies in Australia. Its purposes are to aid the study of seismic risk in Australia, and to provide information on Australian and world earthquakes for scientists and the general public.

The report has six main sections: **Australian region earthquakes**, which contains a summary of the 1989 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 1989; 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. 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

$$\mathrm{ML} = \log A - \log A_0$$

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.

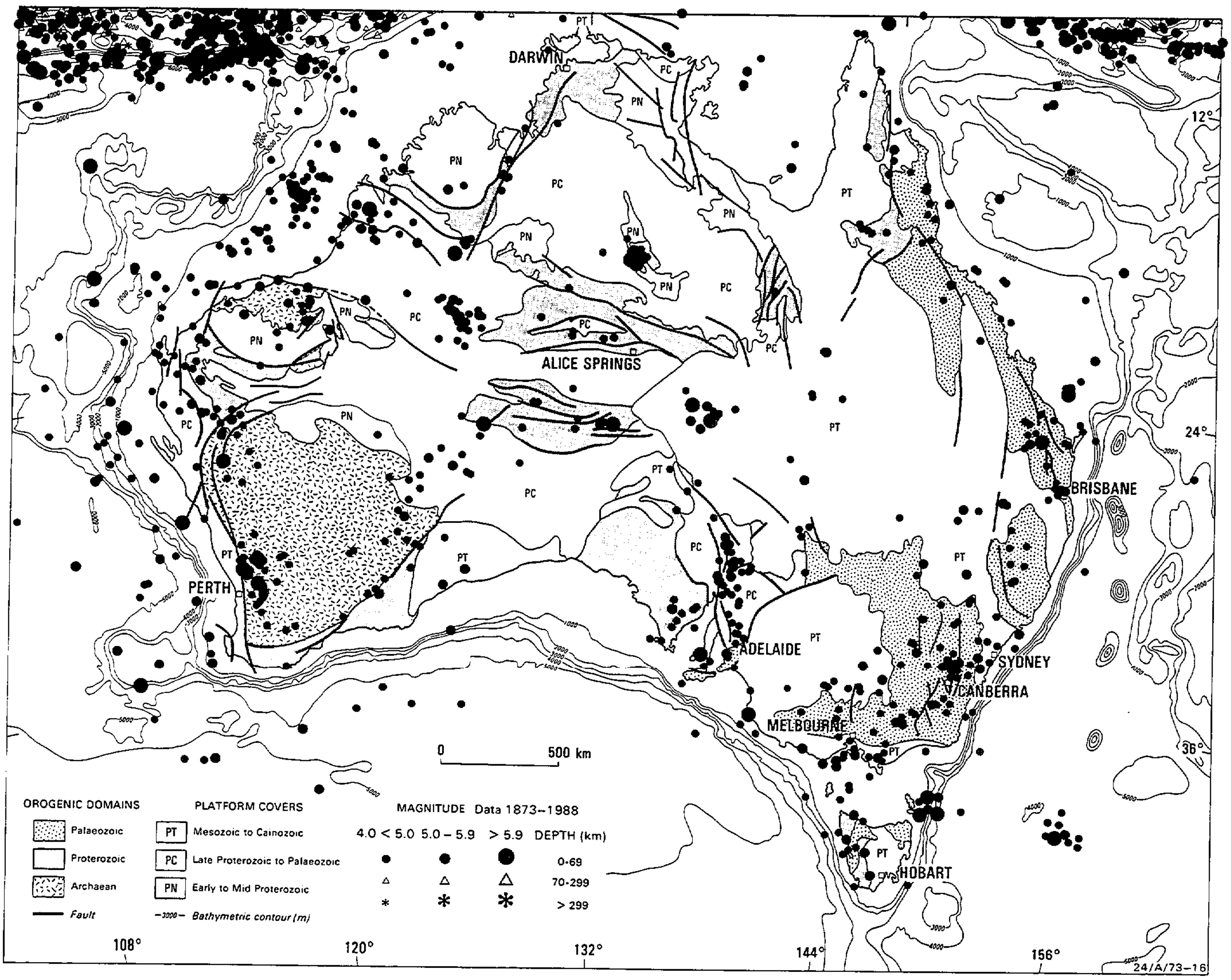


Figure 1 Epicentres of Australian earthquakes, 1873 - 1988, magnitude ML > 3.9

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

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

where τ 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

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

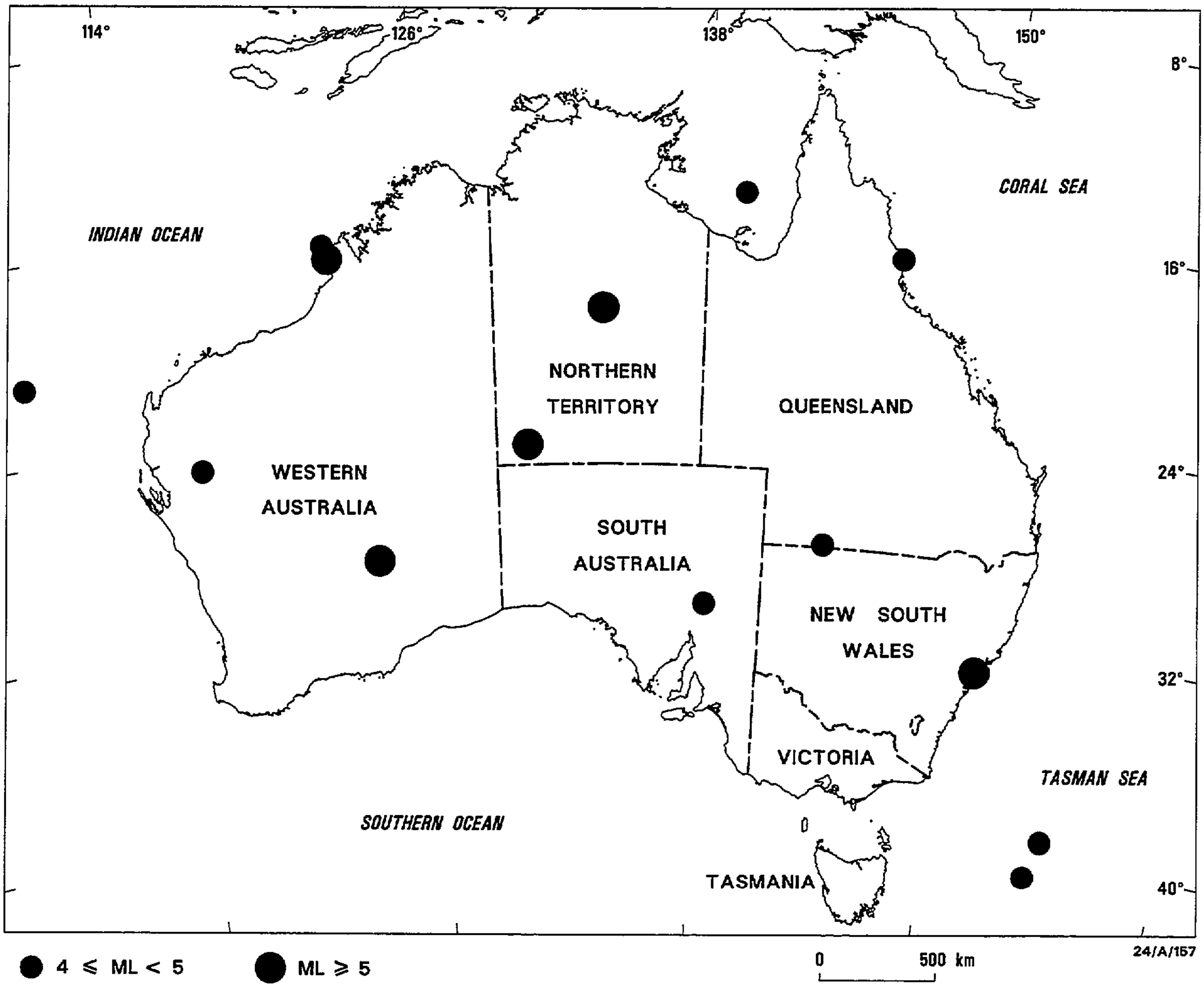


Figure 2 Epicentres of Australian earthquake, 1989, magnitude ML > 3.9

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, 1989

During 1989 the largest earthquake was that at Newcastle NSW with a magnitude of ML 5.6. There were 5 earthquakes of magnitude 5 or more, one of them an aftershock of the 22 January 1988 Tennant Creek mainshocks, and 31 of magnitude 4 or more, 15 of them Tennant Creek aftershocks. The average numbers of comparative sized earthquakes in Australia over the last 30 and 10 years respectively are 3.7 and 22, neglecting aftershocks. The protracted aftershock sequence at Tennant Creek aside, the year was an average one for seismic energy release in Australia.

If there is one 20th century earthquake that has etched itself into the Australian psyche it is that of 28 December 1989 at Newcastle, NSW. Thirteen people died in the rubble and another 160 were seriously injured, yet the results of those two or three seconds of strong shaking at 10:27 am (Eastern Summer Time) could have been far worse. Twelve hours later the Workers Club at Hamilton would have been overflowing with youths attending a rock-music concert featuring a popular Australian band. That morning the club was closed to the normal crowd of pensioners playing Bingo, in preparation for the evening's entertainment. The club collapsed for reasons still unknown and an unlucky 9 people lost their lives. Three others died under a hail of bricks as parapets, gables and outer skin walls collapsed onto awnings suspended over the outside footpaths, which in turn collapsed. The 13th victim died of a heart attack.

An earthquake of this size, magnitude ML 5.6, occurs on average about once every three years along the east coast of Australia where 75% of Australians live and work in a dozen sprawling cities, many of them in aging brick buildings. It was only a matter of time before such an earthquake would occur close to one of these population centres.

An earthquake code had been enshrined as an Australian Standard in 1979 (AS2121-1979) yet the only States to adopt the code by 1989 were South Australia and Western Australia where damaging earthquakes that had struck in 1954 and 1968 are still remembered. That NSW had not adopted the code was immaterial as Newcastle was in a zone designated 'zero' where the minimum requirement was to make no allowance for horizontal loads.

Prior earthquakes were not unknown in Newcastle (Hunter, 1991), but their infrequency coupled with on-going damage caused by coalmine subsidence seems to have removed their memory from the collective conscience of the local media and general population.

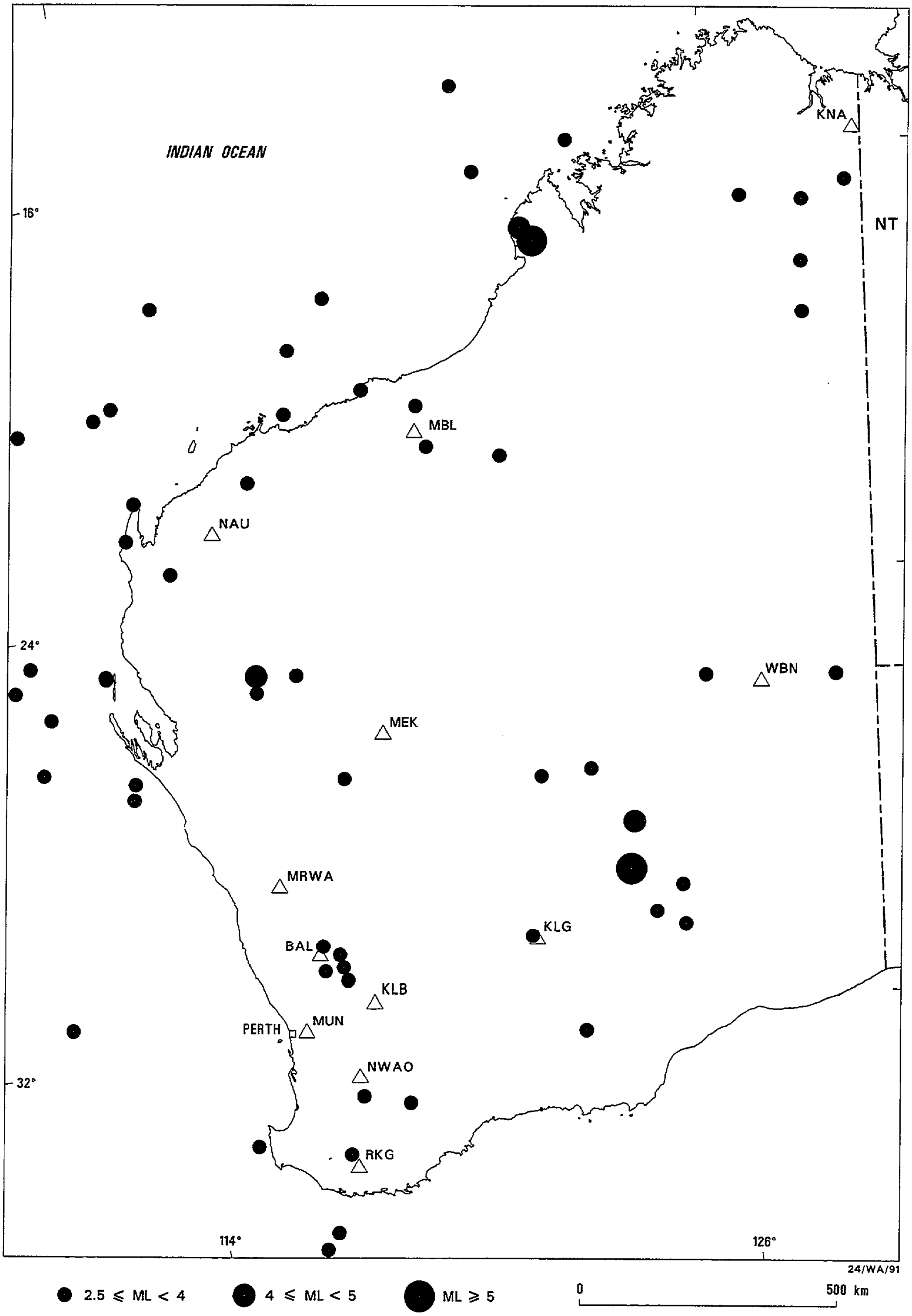


Figure 3 Epicentres of earthquakes in Western Australia, 1989, magnitude ML > 2.4

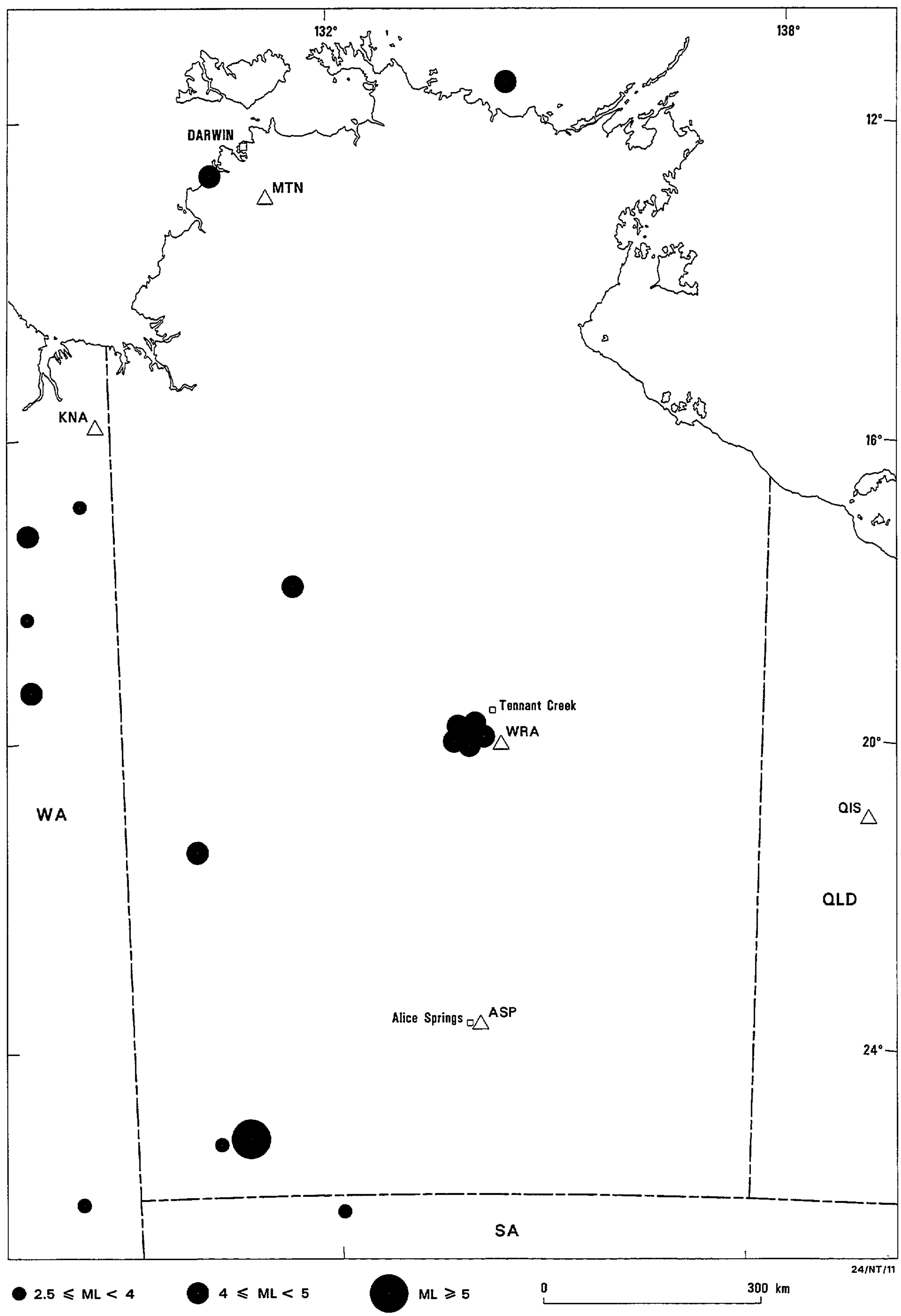


Figure 4 Epicentres of earthquakes in the Northern Territory, 1989, magnitude ML > 2.4

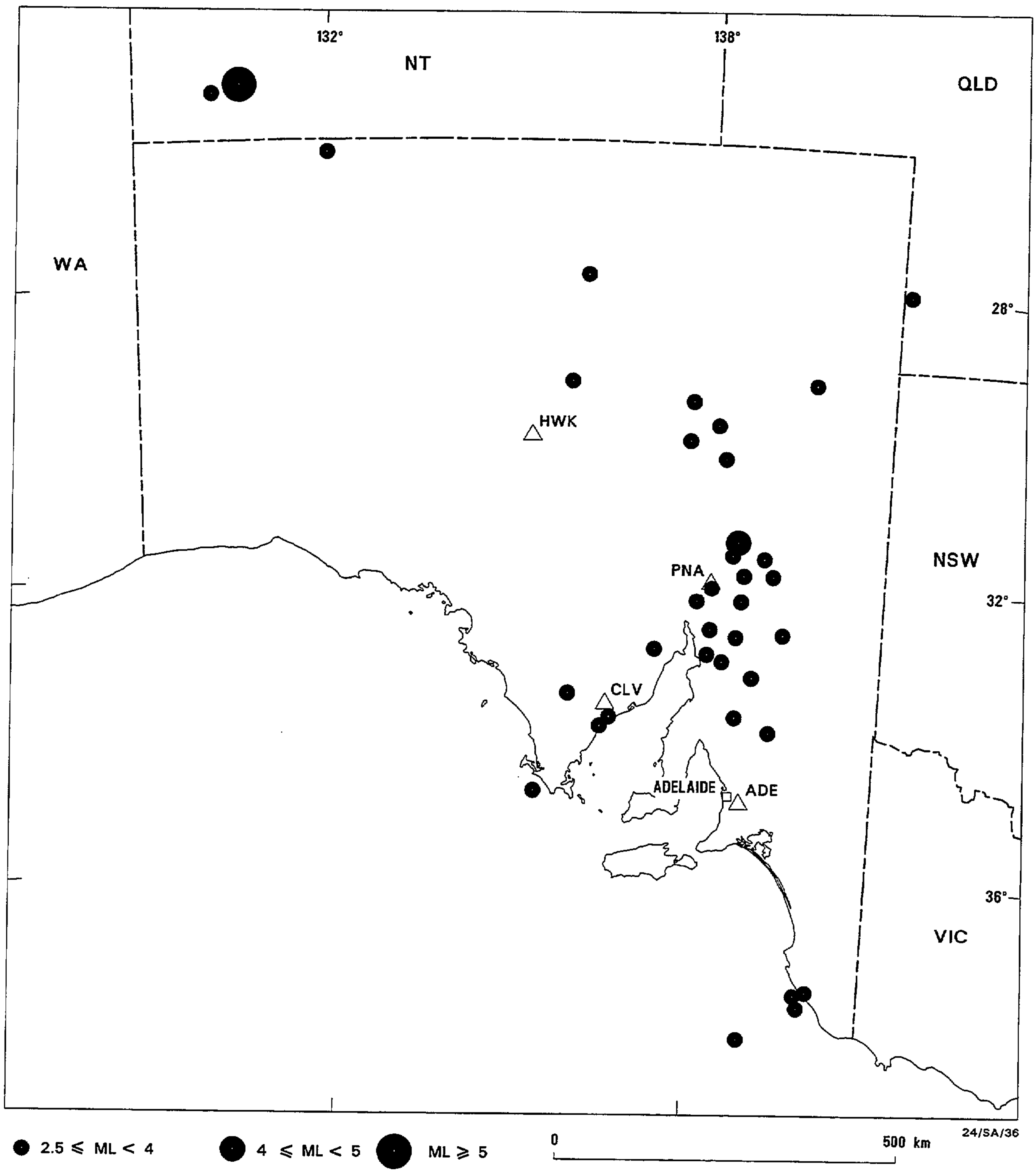


Figure 5 Epicentres of earthquakes in South Australia, 1989, magnitude ML > 2.4

Western Australia (Figure 3)

Five earthquakes of magnitude 4 or greater were located in the Western Australian region. Two of these occurred in an area 40-50 km northeast of Broome on 13 October and 9 December (ML 5.4 and 4.2), and another two were centred 160 km southeast of Laverton on 3 March, their magnitudes 4.8 and 5.4. The other occurred 60 km southeast of Erong Station on 7 January and its magnitude was ML 4.0.

Most of the activity occurred in or close to the known seismic zones. Notable exceptions were two earthquakes offshore from Dirk Hartog Island and another one 480 km west of Fremantle.

In the Southwest Seismic Zone, the level of activity was about the same as for 1988. Sixty-two earthquakes of magnitude 2 or more were located in the zone (Figure 9). There were no events of magnitude 4 or greater. The largest earthquake occurred on 10 November near Cadoux and its magnitude was ML 3.6. An extensive series of micro-earthquakes occurred near Wagin on 14 to 17 December, the largest being ML 2.6. Most of the seismic activity occurred at Cadoux (13), Wongan Hills (8), Wyalkatchem (7), Pingrup (5) and Meckering (4). Minor activity occurred near Brookton, Calingiri, Cranbrook, Nyabing and Narambeen.

Northern Territory (Figure 4)

The Tennant Creek aftershock sequence continued throughout 1989, as in 1988, in stark contrast with the solitary ML 5.4 earthquake which occurred near Mt Olga on 28 May. Seismologists from BMR, SADME and the ANU established seismographs near the Mt Olga epicentre but recorded not a single aftershock (Bowman & others, 1990). This is attributed to its greater-than-normal focal depth of 31 km. The largest Tennant Creek aftershock during the year occurred on 11 June and its magnitude was ML 5.0.

South Australia (Figure 5)

Isoseismal maps were drawn by seismologists at the Sutton Institute, SADME, for five small to moderate earthquakes in the State including one near Beachport in the South-East, which had a magnitude of ML 3.9. The highest intensity there was MM V and no damage was reported. The Mt Olga earthquake of 28 May was felt in the northwest of the State but most detected earthquakes, all of them small, were in the known seismic zones, along the Mt Lofty and Flinders Ranges and on Eyre Peninsula.

Victoria (Figure 6)

Most of the Victorian earthquakes were in the northeast of the State and another 2 were in Bass Strait, not far offshore. The largest was only magnitude ML 3.2 and no event was sufficiently widely felt to warrant distribution of intensity questionnaires.

New South Wales and ACT (Figure 7)

The devastation at Newcastle caused by the December earthquake shocked all Australians but provided many lessons, not just for local town planners, but engineers, insurers and politicians in intraplate regions world-wide. Small teams of investigators came from New Zealand, the UK, USA and Germany. Earthquakes of this size have occurred in NSW as recently as 1959, 1961 and 1973 so its occurrence should have come as no surprise. Fortunately for rescue workers there was only a single small aftershock 29 hours later which was not widely felt (Figure 22) but was well recorded on a network of temporary seismographs installed by a team of seismologists and technical officers from BMR and the Seismology Research Centre, PIT (McCue & others, 1990).

As a result of the earthquake: 1. a 4 station monitoring network for the Hunter region was provided and installed by BMR. Some financial assistance for the one of the seismographs installed at the Regional Museum, was provided by the Newcastle City

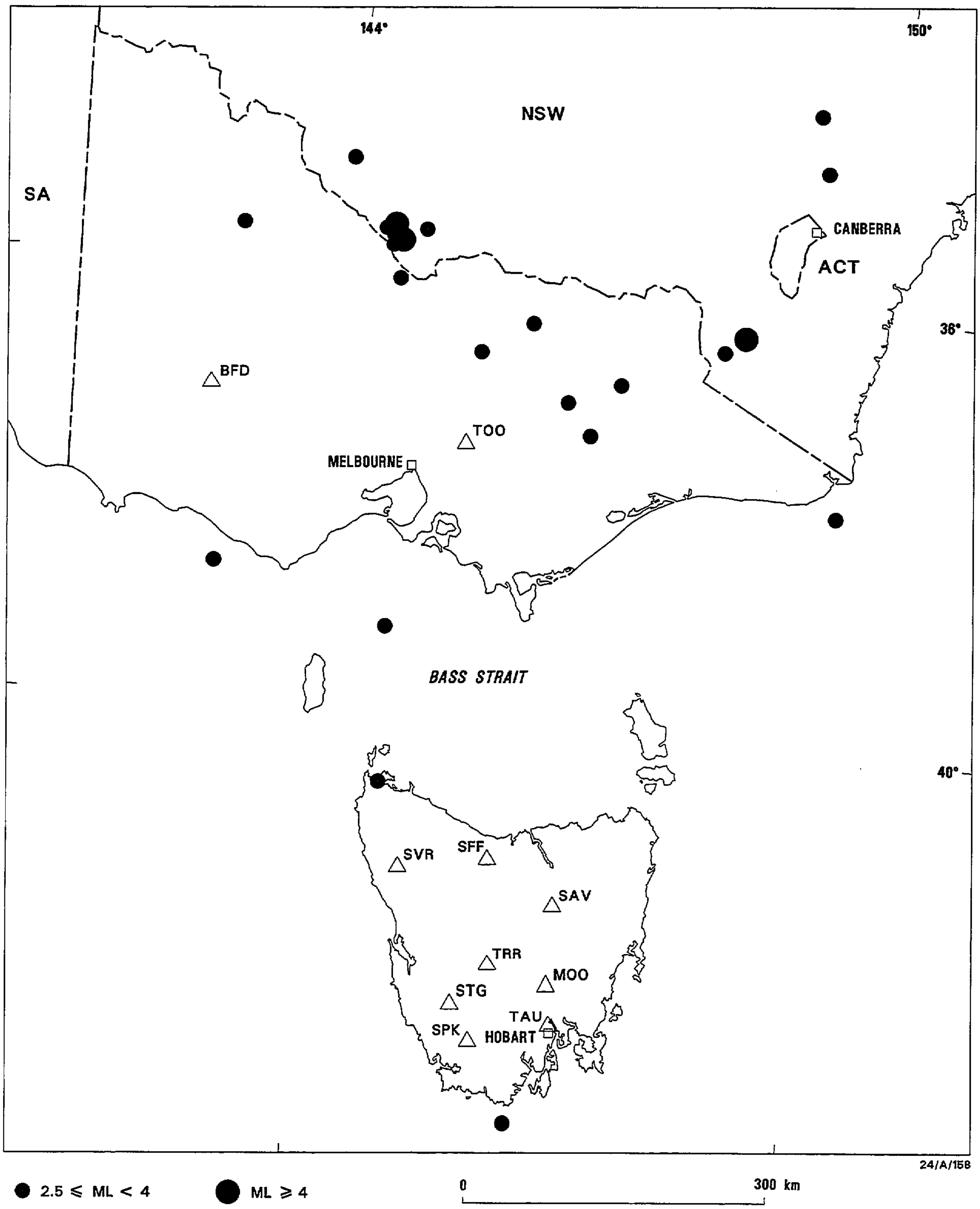


Figure 6 Epicentres of earthquakes in Victoria & Tasmania, 1989, magnitude ML > 2.4

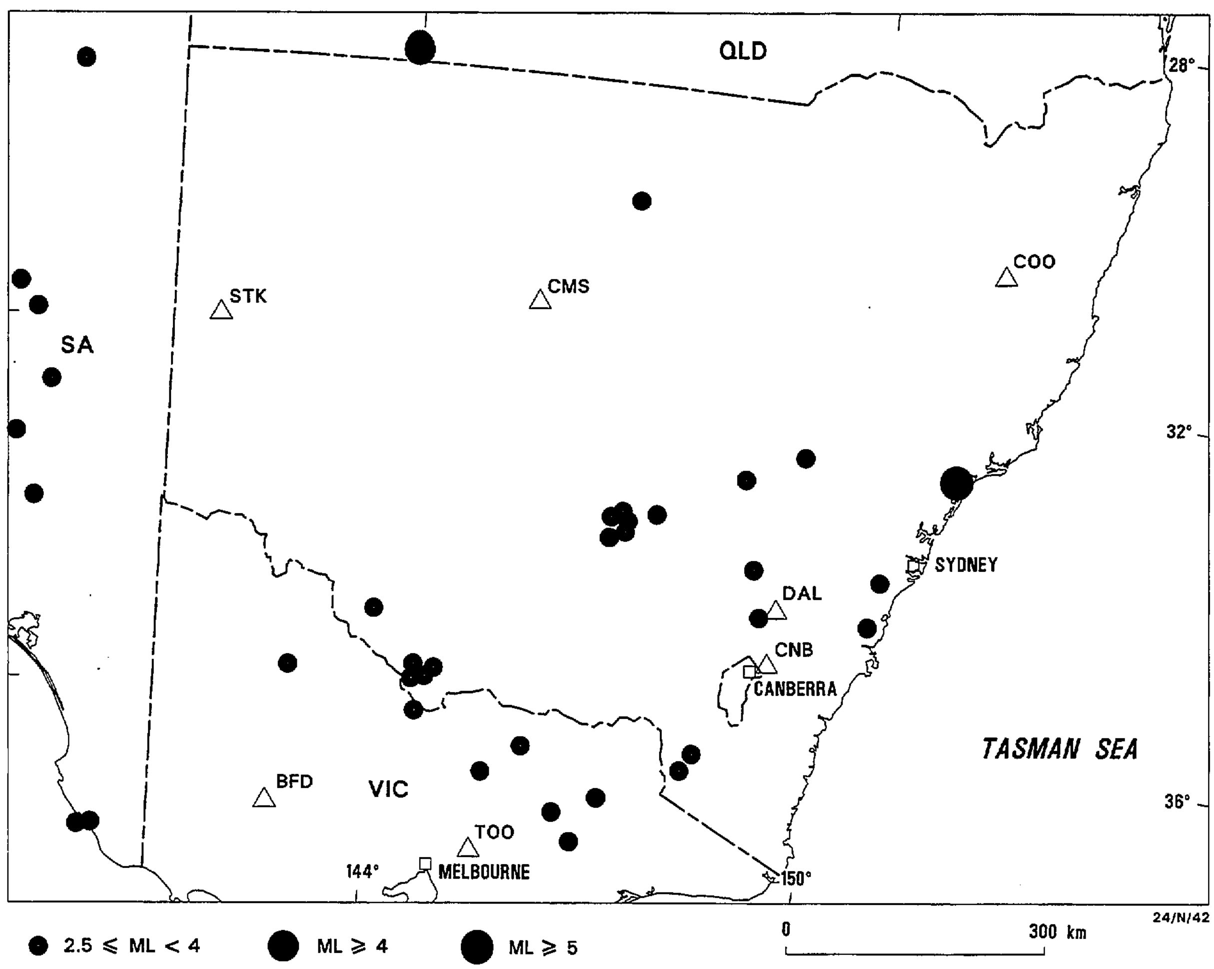


Figure 7 Epicentres of earthquakes in New South Wales, 1989, magnitude ML > 2.4

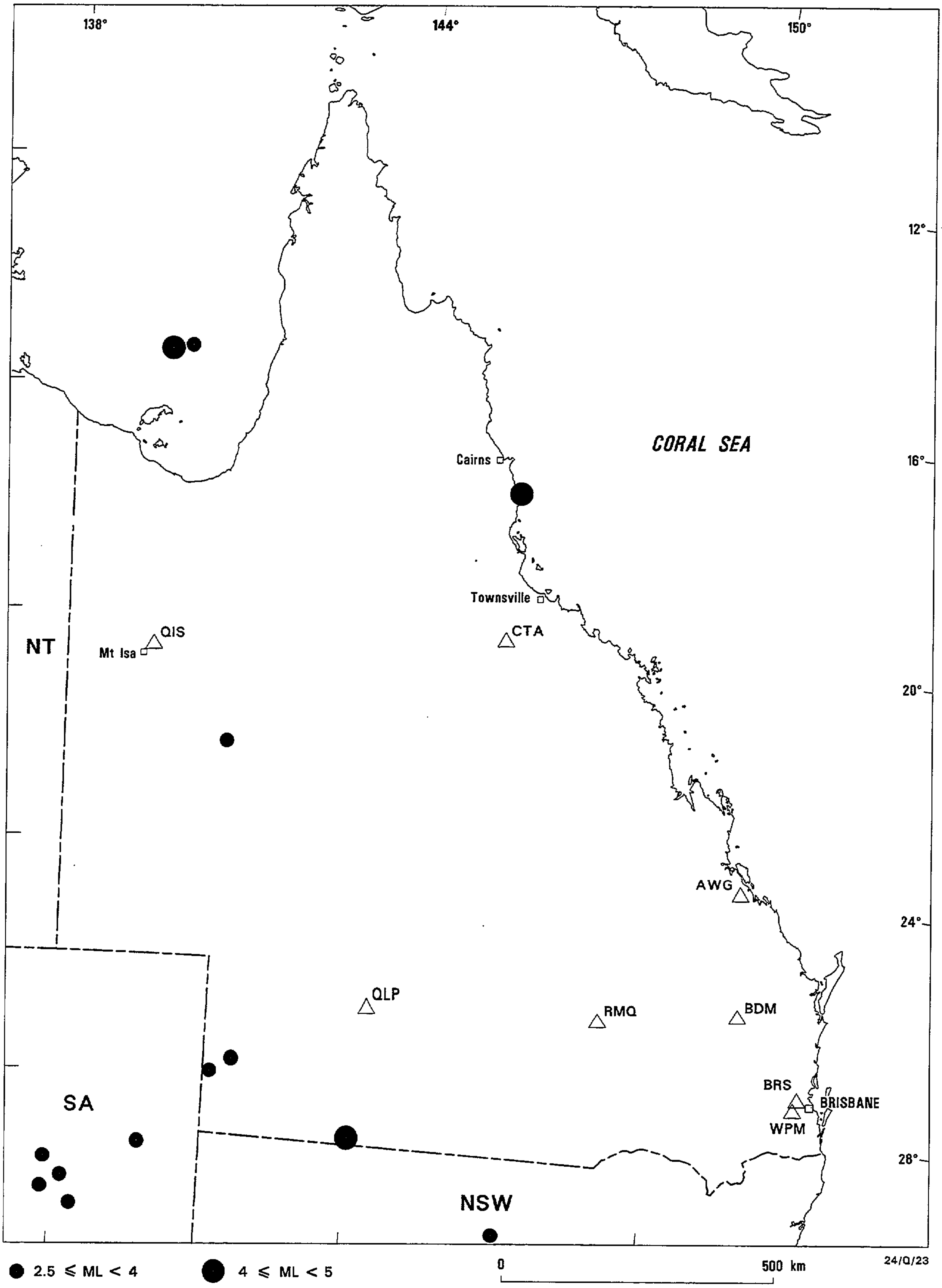


Figure 8 Epicentres of earthquakes in Queensland, 1989, magnitude ML > 2.4

Council, who also run the station, and Kiwanis International. The SRC provided logistical support during the installation; 2. BMR scientist, Dr Malcolm Somerville, and Professor Hiroshi Kagami from Hokkaido University, Japan (whose visit was funded by the Australian Academy of Sciences) conducted a microzonation study of the area of most damage in Newcastle. This study demonstrated that background seismic noise is strongly amplified in alluvial soils (thickness H) of the Hamilton region compared with nearby sites on rock, and the period (T) at which this amplification occurred was well predicted by the simple relationship T = 4H/s where s is the shear wave velocity; 3. A revision of the Earthquake Loading Code by Standards Australia was accelerated and plans made to harmonise this code with the equivalent New Zealand code.

Other earthquakes in NSW that merited media attention included the magnitude ML 3.9 earthquake near West Wyalong on 5 January where minor damage was reported, and the magnitude ML 3.7 earthquake near Jindabyne on 18 April.

Tasmania (Figure 6)

The low level of seismicity experienced in Tasmania in 1988 continued through 1989 with only 2 earthquakes exceeding magnitude 2.5, one off the south coast, the other on the northwest coast. The East Tasman Sea Seismic Zone, near a submarine seamount located at 40° S, 155° E, was active with two magnitude ML 4 earthquakes. These were not recorded in New Zealand so the locations are not well constrained.

Queensland (Figure 8)

There were 3 earthquakes in Queensland above magnitude ML 4, one of them in the Gulf of Carpentaria and another offshore, southeast of Cairns where it was felt.

The one onshore magnitude ML 4+ earthquake was on 23 May at 12:08 UTC in the southwest of the State. It was felt by bar patrons at Hungerford and duly reported to the ASC via an ABC news reporter. Unfortunately most of the seismograms telemetered into the ASC, Canberra were masked by the coda of the Ms 8.1 Macquarie Ridge earthquake and its occurrence could not be confirmed for a week, the time for seismograms from the nearest seismograph at Quilpie to travel by post to the ASC.

Kevin McCue and Peter Gregson

ISOSEISMAL MAPS

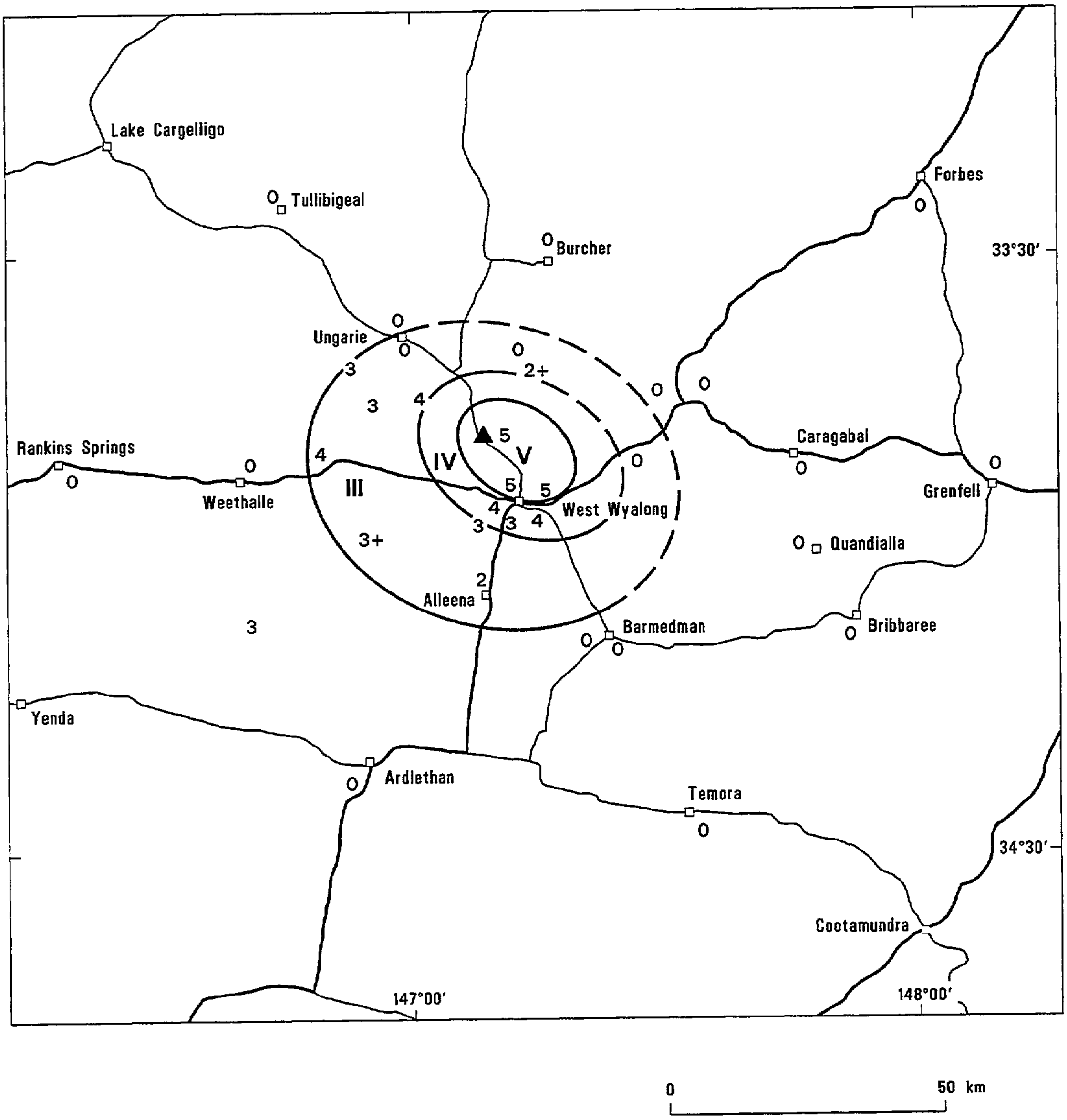
West Wyalong NSW, 5 January 1989 (Figure 9)

The magnitude ML 3.9 earthquake occurred on 5 January 1989 at 20:48 UTC (07:48 local time on 6 January) and was recorded by most seismographic stations of the Eastern Australian Network.

Questionnaires were distributed to residents within a 100 km radius of West Wyalong and additional observations were solicited by telephoning residents on selected properties surrounding the epicentre. Intensities ranging from MMIII to MMV were observed in West Wyalong while the nearby town of Wyalong experienced intensities of MMIV and MMV, although there were people in both towns who did not feel the earthquake. A few instances of minor damage were reported, mostly cracks in plaster and concrete. Many people stated that small objects had been shifted and others mentioned hearing loud earth noises.

The magnitude of ML 3.9 is the average from 10 stations, and phase arrival times from 23 seismographs were used to compute the earthquake epicentre. This was the largest earthquake in the vicinity of West Wyalong since 26 November 1982 when a magnitude ML 4.6 earthquake occurred there (Denham & others, 1984).

ISOSEISMAL MAP OF THE WEST WYALONG EARTHQUAKE, NEW SOUTH WALES, 5 JANUARY 1989



DATE: 5 January 1989
TIME: 20:48:27 UTC
MAGNITUDE: 3.9 ML
EPICENTRE: 33.82°S 147.12°E
DEPTH: 5 km

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

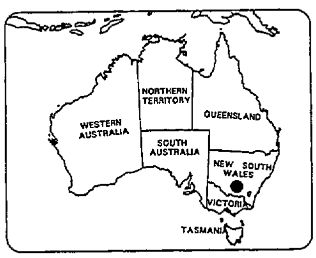
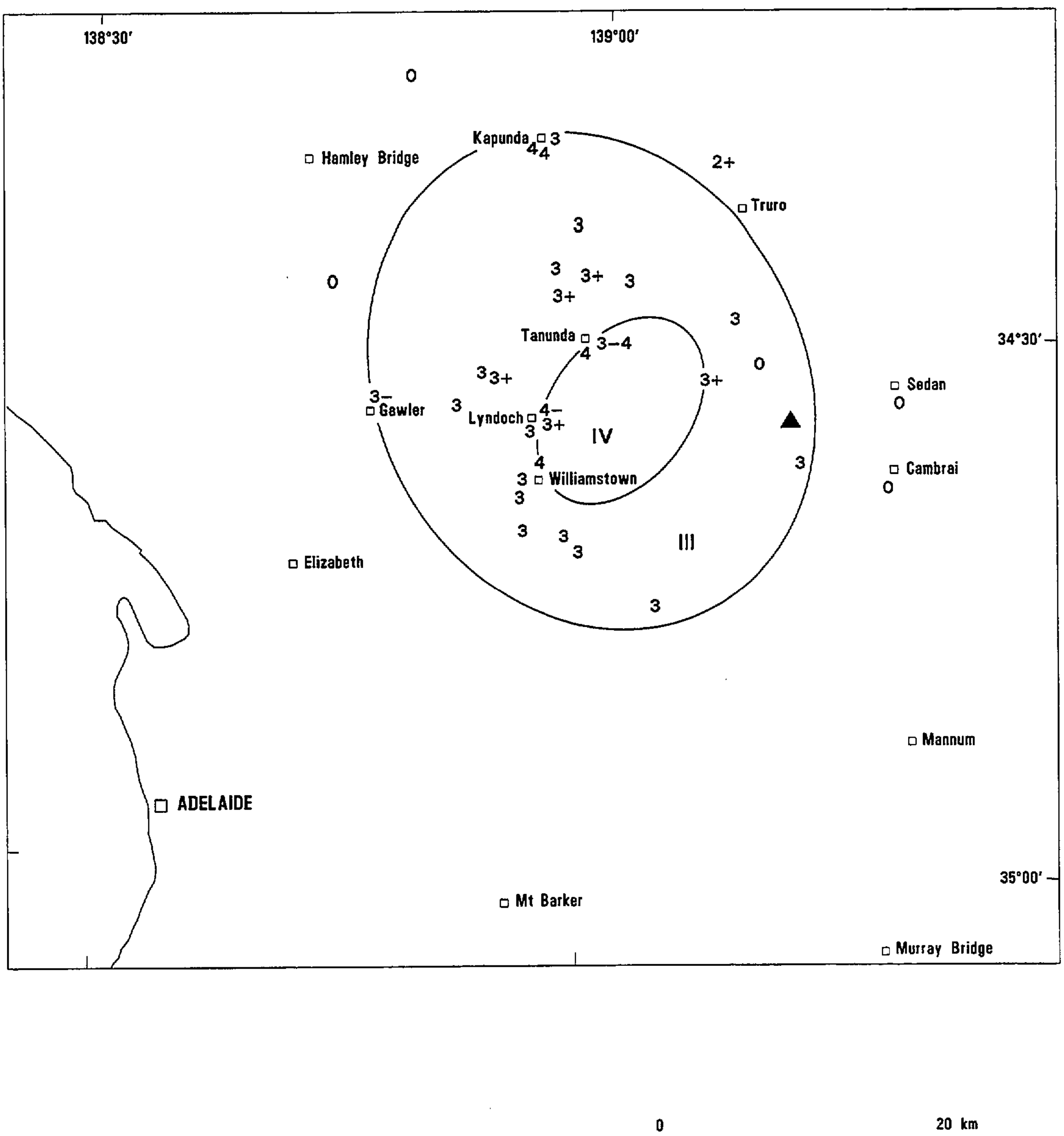


Figure 9

24/I55/31

ISOSEISMAL MAP OF THE TANUNDA EARTHQUAKE, SOUTH AUSTRALIA, 27 FEBRUARY 1989



DATE: 27 February 1989
TIME: 06:45 UTC
MAGNITUDE: 2.9 ML (I)
EPICENTRE: 34.60°S 139.21°E
DEPTH: 15 km

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

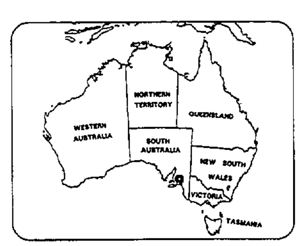
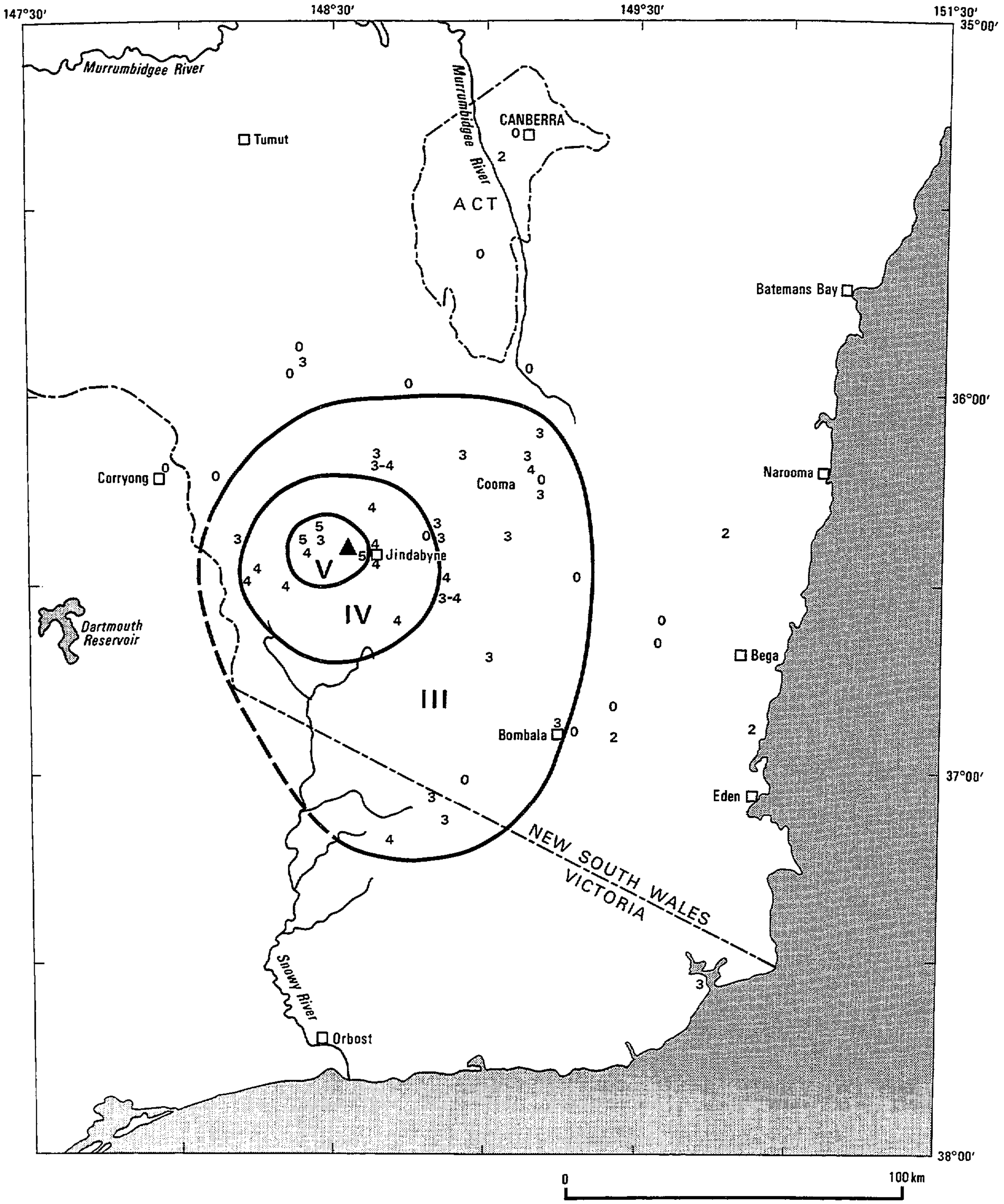


Figure 10

24/J54-9/1

ISOSEISMAL MAP OF THE JINDABYNE EARTHQUAKE, NEW SOUTH WALES, 18 APRIL 1989



DATE : 18 April 1989
TIME : 03:51:34 UT
MAGNITUDE : 3.7 (± 0.1) ML (BMR)
EPICENTRE : 36.40°S, 148.57°E
DEPTH : 14 (±7) km

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

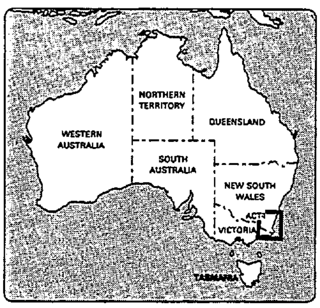
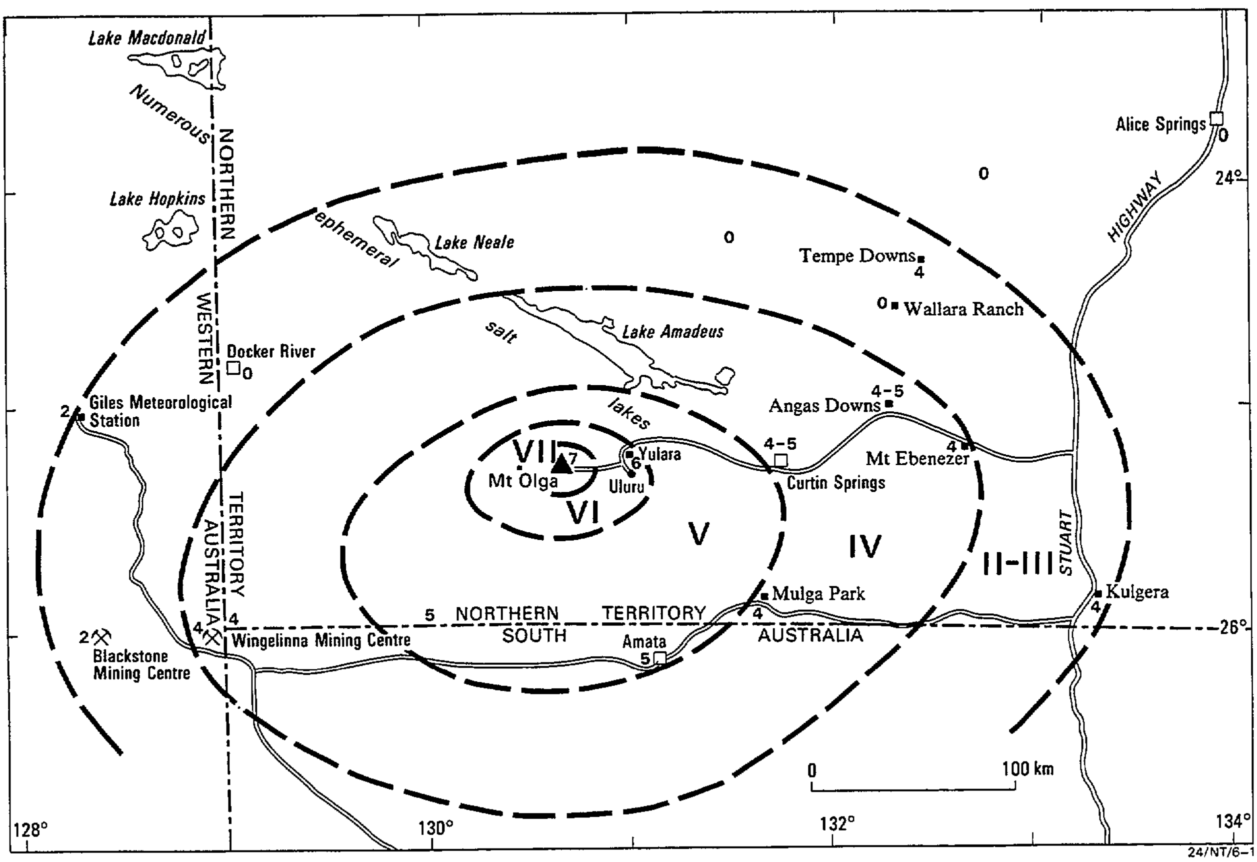


Figure 11

24 / J55 / 25

ISOSEISMAL MAP OF THE MT OLGA EARTHQUAKE, NORTHERN TERRITORY, 28 MAY 1989



DATE : 28 MAY 1989
TIME : 02.55:17.8UT
MAGNITUDE : 5.6 ML (BMR)
EPICENTRE : 25.275° S,130.667° E
DEPTH : 5km

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

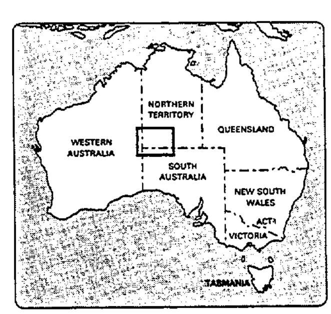
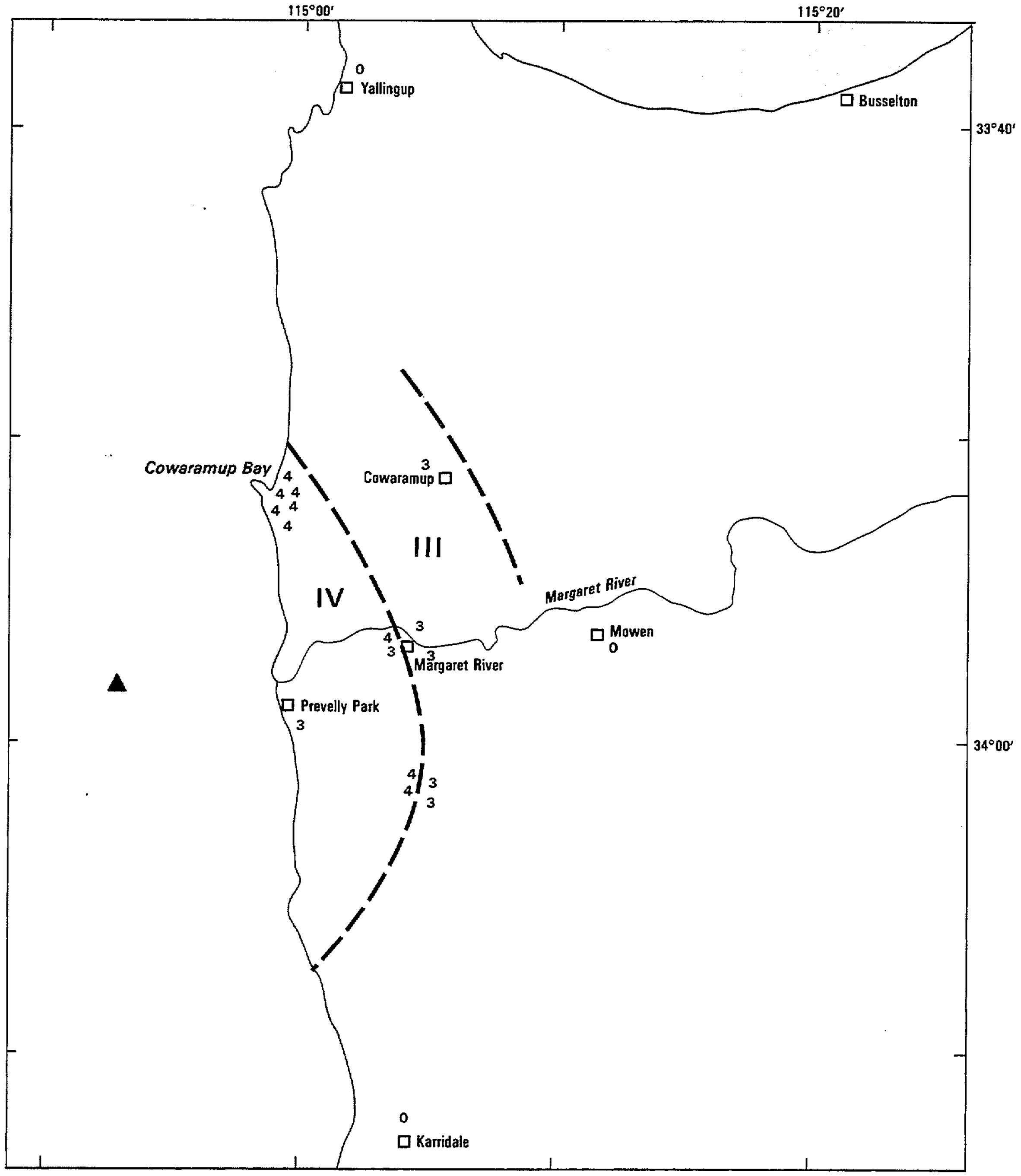
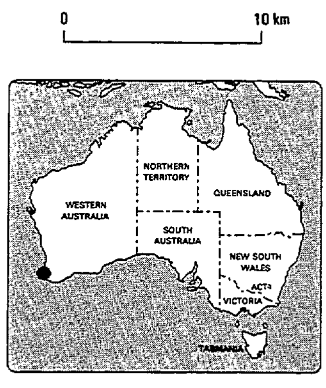


Figure 12

24/NT/6

ISOSEISMAL MAP OF THE MARGARET RIVER EARTHQUAKE, WESTERN AUSTRALIA, 20 JULY 1989





DATE :	*20 July 1989*
TIME :	*09:29:24.5 UT*
MAGNITUDE :	*3.2 ML (MUN)*
EPICENTRE :	*34.0°S 114.9°E*

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

Figure 13

24/I50/6

Tanunda SA, 27 February 1989 (Figure 10)

A small magnitude ML 2.9 earth tremor shook the Barossa Valley at 8:05 pm (local time). Minor effects such as rumbling and windows rattling were noticed by many people in this well populated area. The isoseismal map was produced from a phone survey by SADME seismologists.

Jindabyne NSW, 18 April 1989 (Figure 11)

Operators of the 'Blue Cow' ski resort rushed to the end of the SKITUBE fearing that the train had crashed through the end barrier; such was the jolt and noise in the resort office that accompanied the earthquake. Reports were phoned in from as far as Mallacoota on the Victorian coast and a southern suburb of Canberra but no damage was reported in the epicentral region. Snowy Mountains Authority engineers in the Geehi tunnel reported feeling the earthquake as did a road construction gang at Bunyan, south of Cooma. SMA engineers inspected the skitube tunnel but found no evidence of faulting or spalling.

Seismic energy seems to have been preferentially propagated to the southeast although there are few reporting points to the northwest and none in the mountains to the southwest.

The epicentre is on the Crackenback fault, a 45 km long, ENE trending fault linking the Jindabyne and Berridale Thrust fault and Long Plain-Indi fault. Previous earthquakes in the same region include the 1885 and 1959 Berridale earthquakes (Everingham & others, 1982; Rynn & others, 1987).

Mt Olga NT, 28 May 1989 (Figure 12)

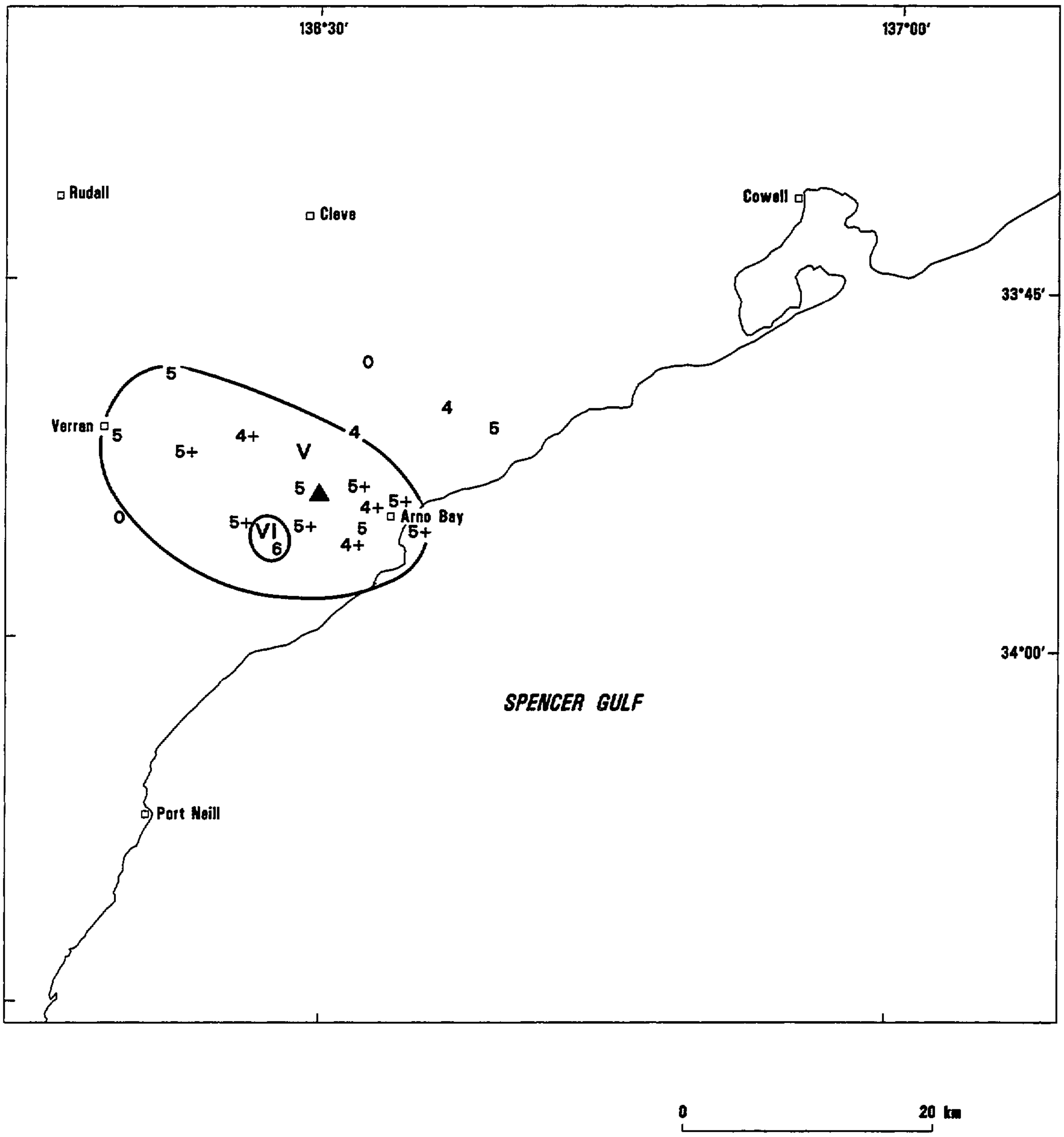
Questionnaires were distributed in the Mt Olga region, Central Australia following the earthquake on 28 May. From the responses, letters and interviews an isoseismal map was drawn which indicates that the earthquake was felt over a sparsely populated elliptical shaped area of approximately 156 000 km^2. The following newspaper extract is from *The Northern Territory Times* on 29 May 1989 (page 2)

> Startled guests and staff watched a 'ripple effect' on glass walls and saw waves in a hotel pool during a 20-second earthquake at Uluru National Park's Yulara resort yesterday.
> The quake struck Uluru and surrounding areas about 12:25 pm, with an epicentre about 60 km north-west of the resort township. The park superintendent, Mr Terry Piper, said it was believed to be one of the strongest known quakes in the area, and the first tremor of any kind for many years. He said people on Uluru (Ayers Rock) had said they felt the tremor. A number of people at the base of the rock said they had been taken aback by 'a thunder-like roll, followed by a loud crack'.
> At the resort, which contains two hotels and a number of flats, maisonettes and a large resident living quarters, staff and guests ran to the safety of a concourse area in the centre of the township..... A preliminary search by engineers and staff failed to reveal any new structural damage to any of the buildings. The resort's Sheraton Hotel recently closed almost 100 of its rooms following damage caused by the area's heaviest recorded rains.

Later reports indicated that minor cracks occurred in brick walls of the modern hotel and tourist complex at Yulara, the closest modern structure to the computed epicentre.

Despite an intensive search, no fault scarp was found and no aftershocks were recorded on portable seismographs deployed by BMR, SADME and ANU seismologists in the epicentral region a few days after the earthquake. This is attributed to the abnormally large focal depth of 31 km, constrained by world-wide observations of depth phases, pP and sP.

ISOSEISMAL MAP OF THE ARNO BAY EARTHQUAKE, SOUTH AUSTRALIA, 13 AUGUST 1989



DATE: 13 August 1989
TIME: 19:17:43.3 UTC
MAGNITUDE: 3.1 ML
EPICENTRE: 33.85°S 136.45°E
DEPTH: 12.1 km

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

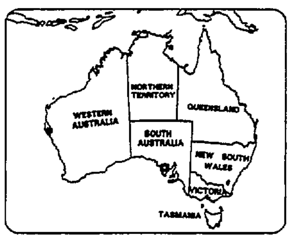
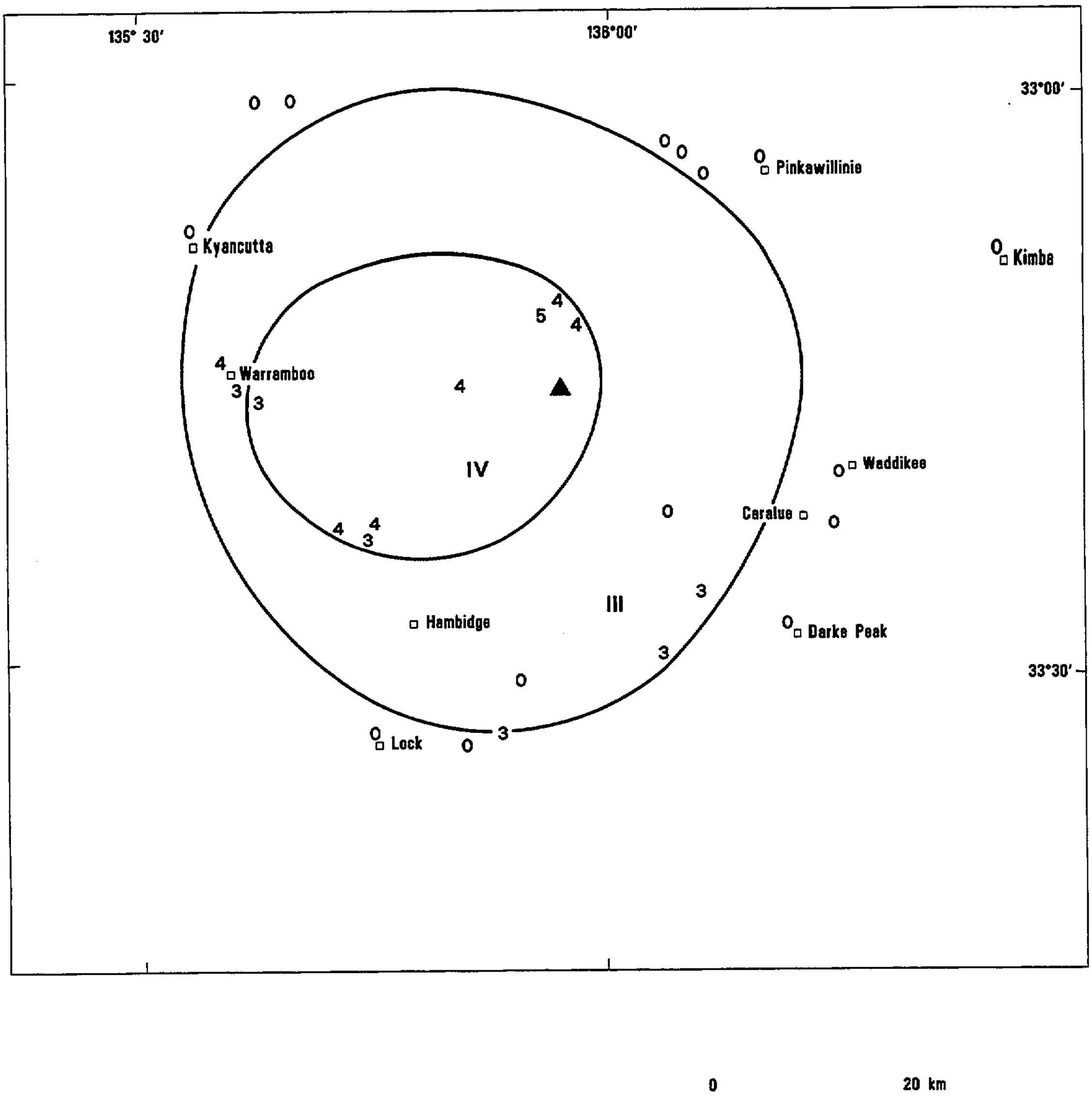


Figure 14

24/I53-8/1

ISOSEISMAL MAP OF THE HAMBIDGE EARTHQUAKE, SOUTH AUSTRALIA, 7 SEPTEMBER 1989



DATE: 7 September 1989
TIME: 08:08:29.7 UTC
MAGNITUDE: 2.9 ML
EPICENTRE: 33.55°S 135.92°E
DEPTH: 21.1 km

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

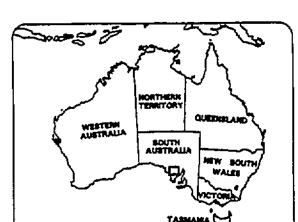
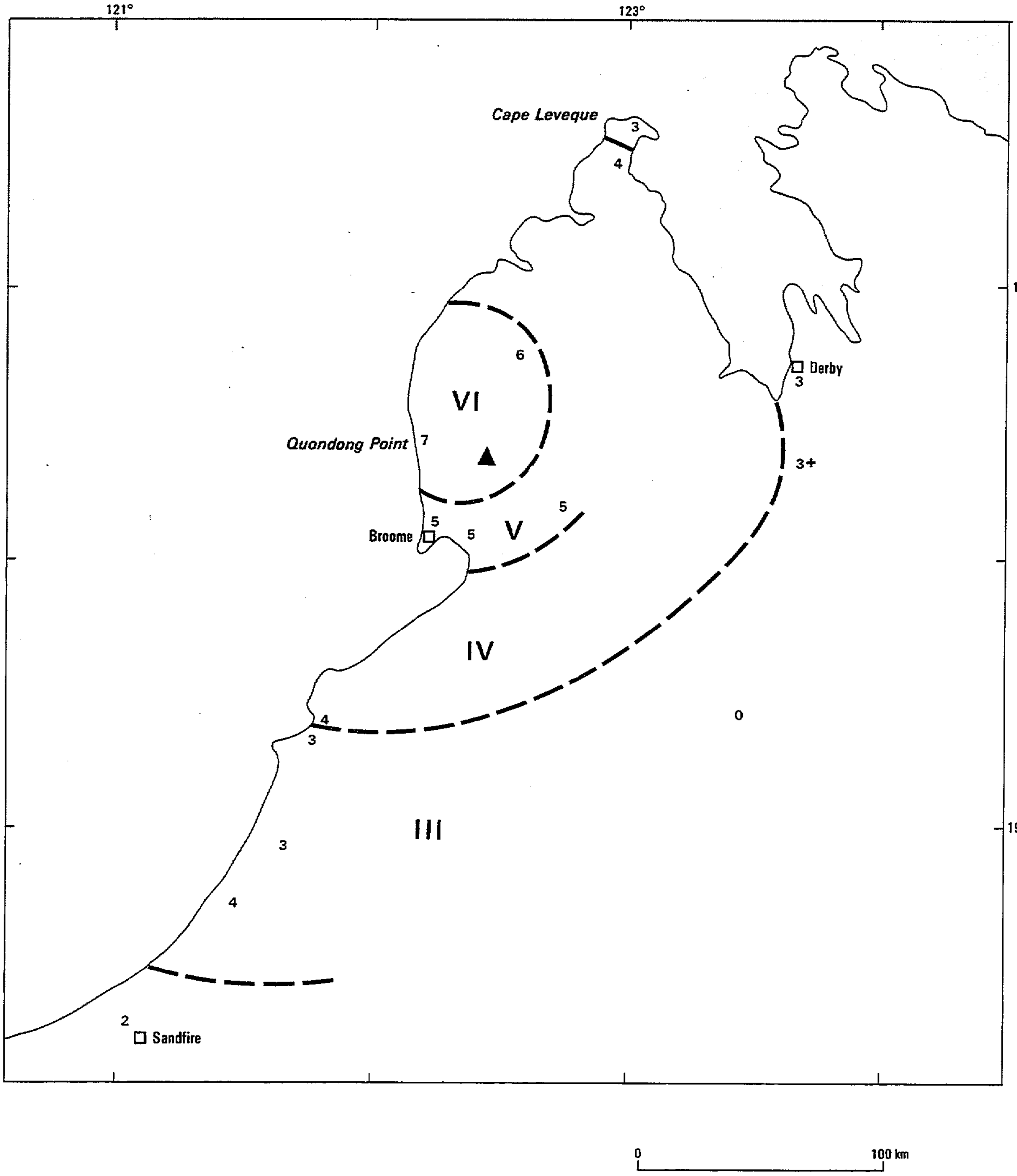


Figure 15

24/I53-7/1

ISOSEISMAL MAP OF THE BROOME EARTHQUAKE, WESTERN AUSTRALIA, 13 OCTOBER 1989



DATE :	*13 October 1989*
TIME :	*09:59:14.6 UT*
MAGNITUDE :	*5.4 ML (MUN)*
EPICENTRE :	*17.6°S 122.4°E*
DEPTH :	*Crustal*
▲	*Epicentre*
IV	*Zone Intensity Designation*
4	*Earthquake Felt (MM)*
0	*Earthquake Not Felt*

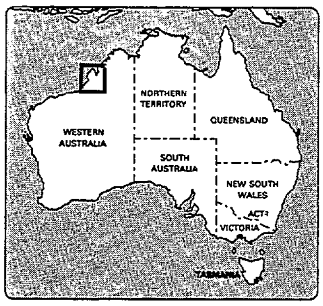


Figure 16

24/E51/1

Margaret River WA, 20 July 1989 (Figure 13)

This earthquake was located offshore about 10 km west of Prevelly Park. The maximum intensity was MM IV at the seaside resort of Cowaramup Bay and at the towns of Margaret River and Witchcliffe. There were no reports that it was felt beyond 25 km from the epicentre.

Four small tremors occurred within the 10 hours before the main shock and there were ten afterwards, all in the magnitude range 2.0 - 2.4. At least five of them were felt in the Cowaramup Bay area.

Other earthquakes in the area in recent times were as follows:

1978, 9 June	12 km E of Mowen	ML 3.0
1986, 15 January	4 km SW of Augusta	ML 3.8

Arno Bay SA, 13 August 1989 (Figure 14)

At 4:47 am on Monday 14 August (local time), Arno Bay residents were woken by a small close magnitude ML 3.1 earthquake. Because of the early hour, intensities below IV could not be gauged, but a number of people near the epicentre described moderate intensities. There were 22 replies from 31 questionnaires distributed and some noted minor damage, mainly slight plaster cracks. In one case a planter pole overbalanced and crashed through a window.

This was the largest of many events that occurred in 1989 on Eyre Peninsula. Most of them were slightly east of Arno Bay, and five were felt on one day in April.

Hambidge SA, 7 September 1989 (Figure 15)

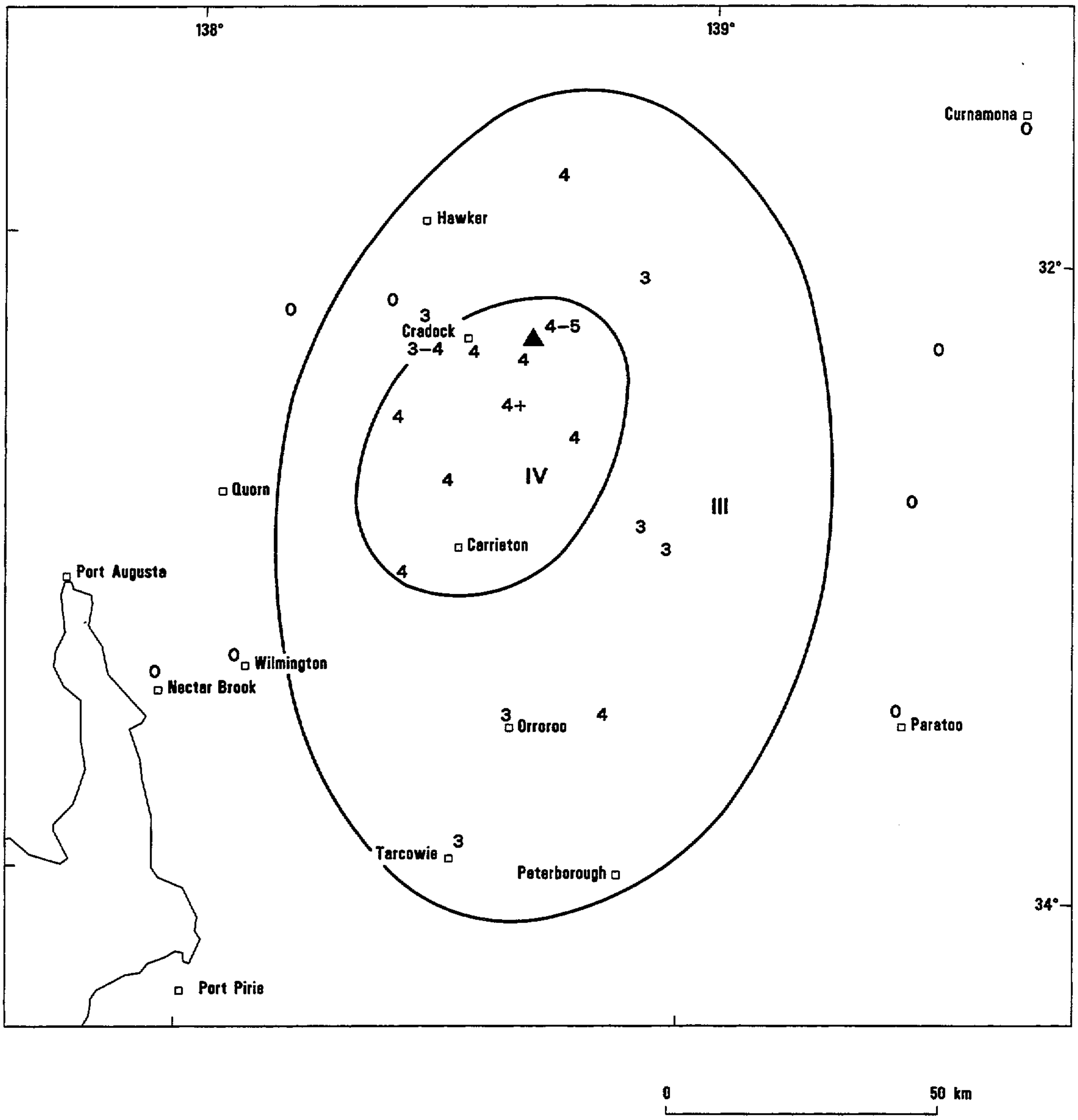
On this Thursday at 5:38 pm (local time) a small ML 2.9 earthquake shook the central Eyre Peninsula. The effects were fairly minor, being limited to loud noises, and rattling dishes. The area is sparsely and unevenly populated with Hambidge Conservation Park in the middle. SADME staff distributed 26 questionnaires and the map was produced from 20 replies and a number of phone calls.

Broome WA, 13 October 1989 (Figure 16)

An earthquake of magnitude ML 5.4 was felt over a wide area between Broome and Cape Leveque at 09:59 UTC (5:59 pm local time) on 13 October. The computed epicentre was 42 km northeast of Broome. The maximum intensity was assessed at MM VII at Quandong Point, 27 km west of the epicentre. The effects are colourfully described by David Mayhew in a letter with the returned questionnaire:

> Fortunately Broome was 40 km south of the epicentre, but guess where I was? you have guessed it, 50 km north of Broome sitting on the very edge of the epicentre; at Kadilikan (Pt Quandong).
>
> I was the only camp here at the time and was lying down waiting for the news to come on and they had just announced the time at 17.59 hours, when the wooshing, rattling and banging commenced; seemed to come in from the north-east; next instant the sand surface was jiggling like a jelly and I was being jolted up and down. The durin (wild plum tree) which measures 8 feet in circumference was gyrating from side to side at crazy angles and also being projected upwards at the same time by the convulsions of the ground surface. I was fully convinced the ground would crack apart and take the lot including me: it was frightening, I can assure you.
>
> From the first indications to the last rattle was about 15/20 seconds but that is not too reliable as the thoughts whizzing through my mind during the tremor were not given to documenting time but astonishment turning to

ISOSEISMAL MAP OF THE CRADOCK EARTHQUAKE, SOUTH AUSTRALIA 15 OCTOBER 1989



DATE: 15 October 1989
TIME: 11:35:07.1 UTC
MAGNITUDE: 3.1 ML
EPICENTRE: 32.27°S 138.67°E
DEPTH: 15.0 km

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

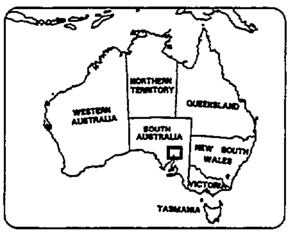
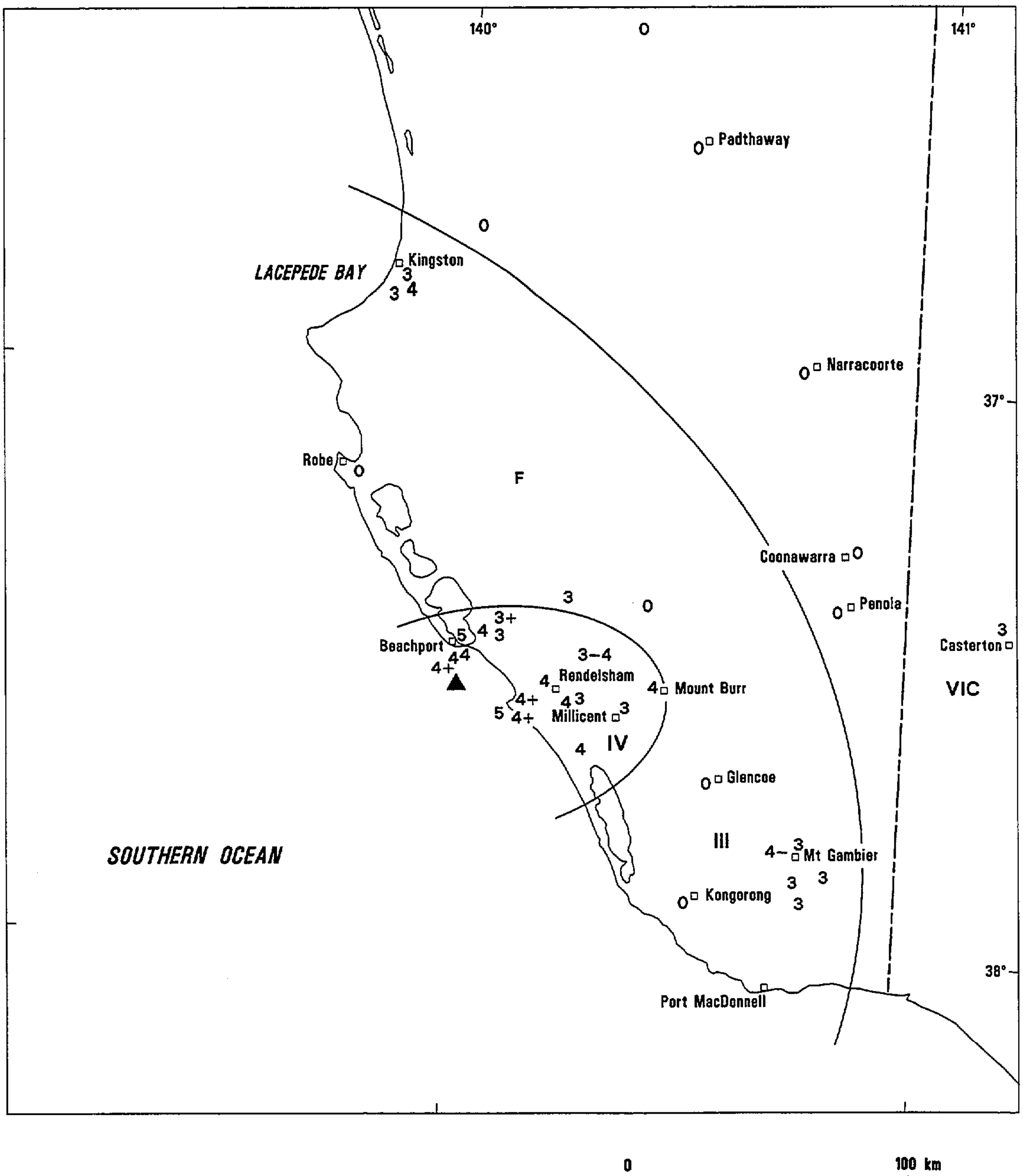


Figure 17

24/154–1/1

ISOSEISMAL MAP OF THE BEACHPORT EARTHQUAKE, SOUTH AUSTRALIA, 8 NOVEMBER 1989



DATE: 8 November 1989
TIME: 05:06:30.7 UTC
MAGNITUDE: 3.9 ML
EPICENTRE: 37.55°S 140.06°E
DEPTH: 13.3 km

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

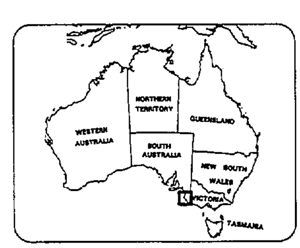
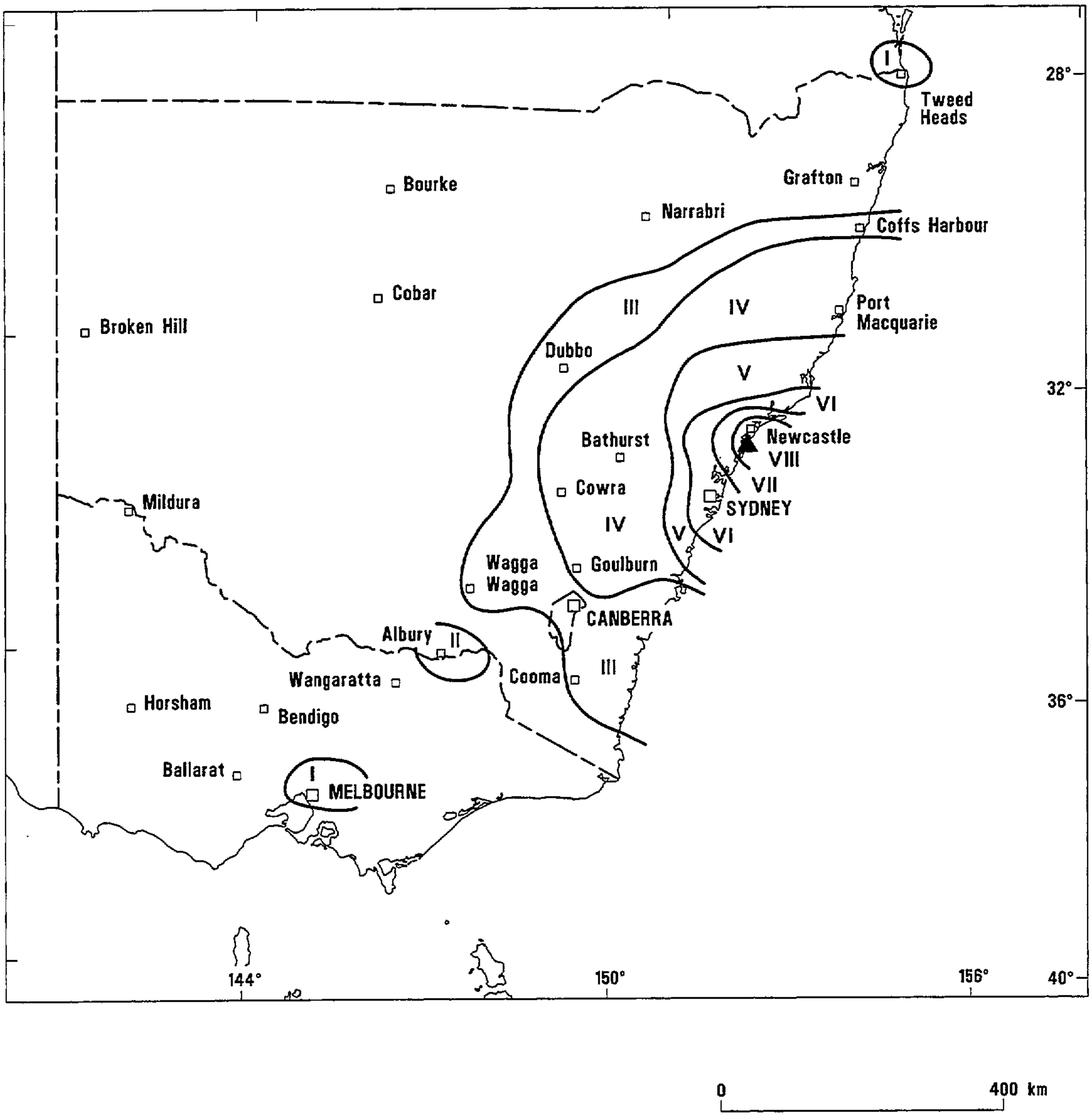


Figure 18

24/J54-6/1

ISOSEISMAL MAP OF NEWCASTLE EARTHQUAKE, NEW SOUTH WALES
27 DECEMBER 1989



DATE:	27 DECEMBER 1989
TIME:	23:26:58 UTC
MAGNITUDE:	5.6 ML,5.3 M
EPICENTRE:	32.95°S, 151.61°E

▲ *Epicentre*

IV *Zone intensity designation*

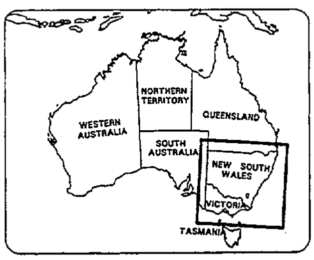


Figure 19a

4/A/156

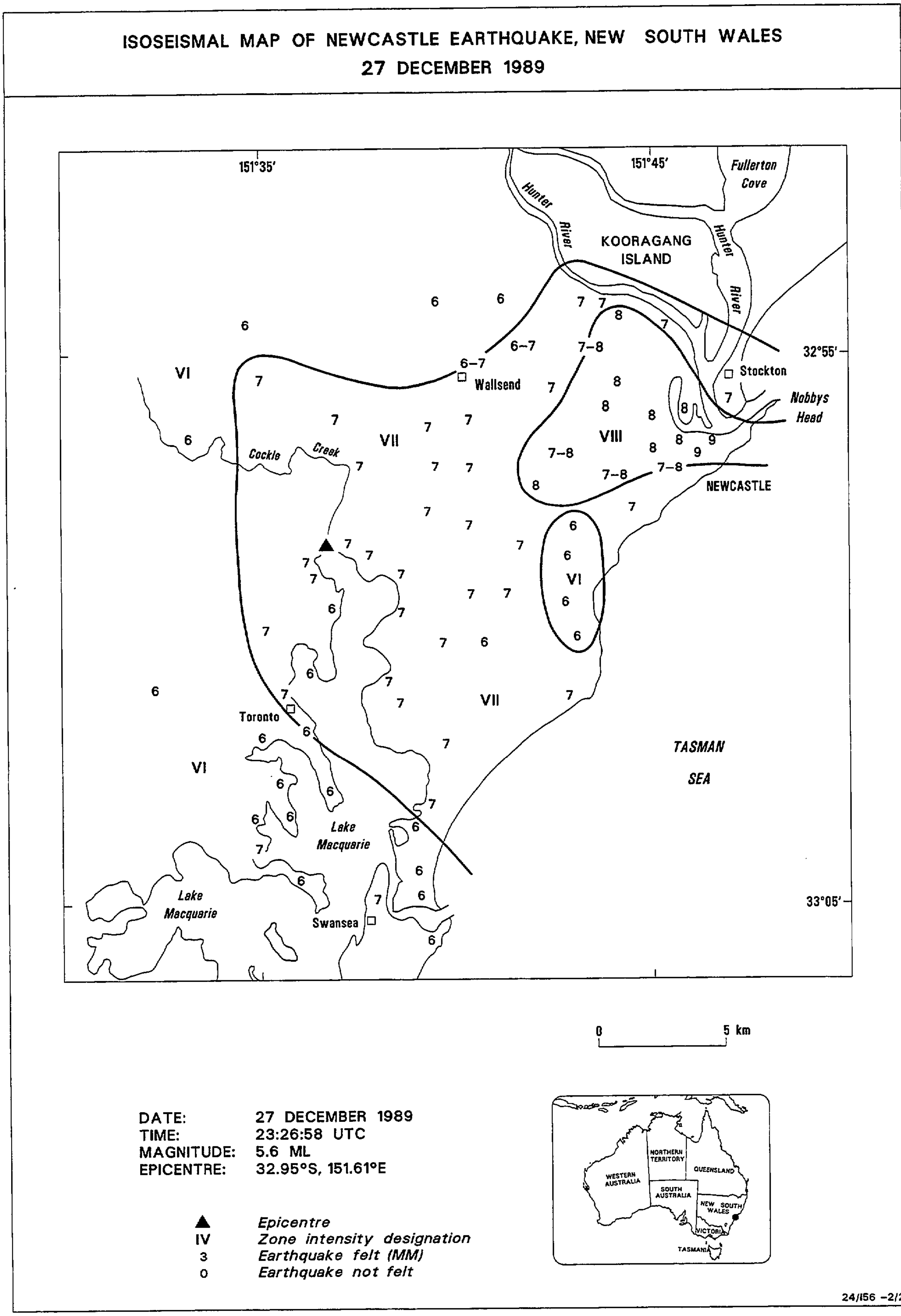
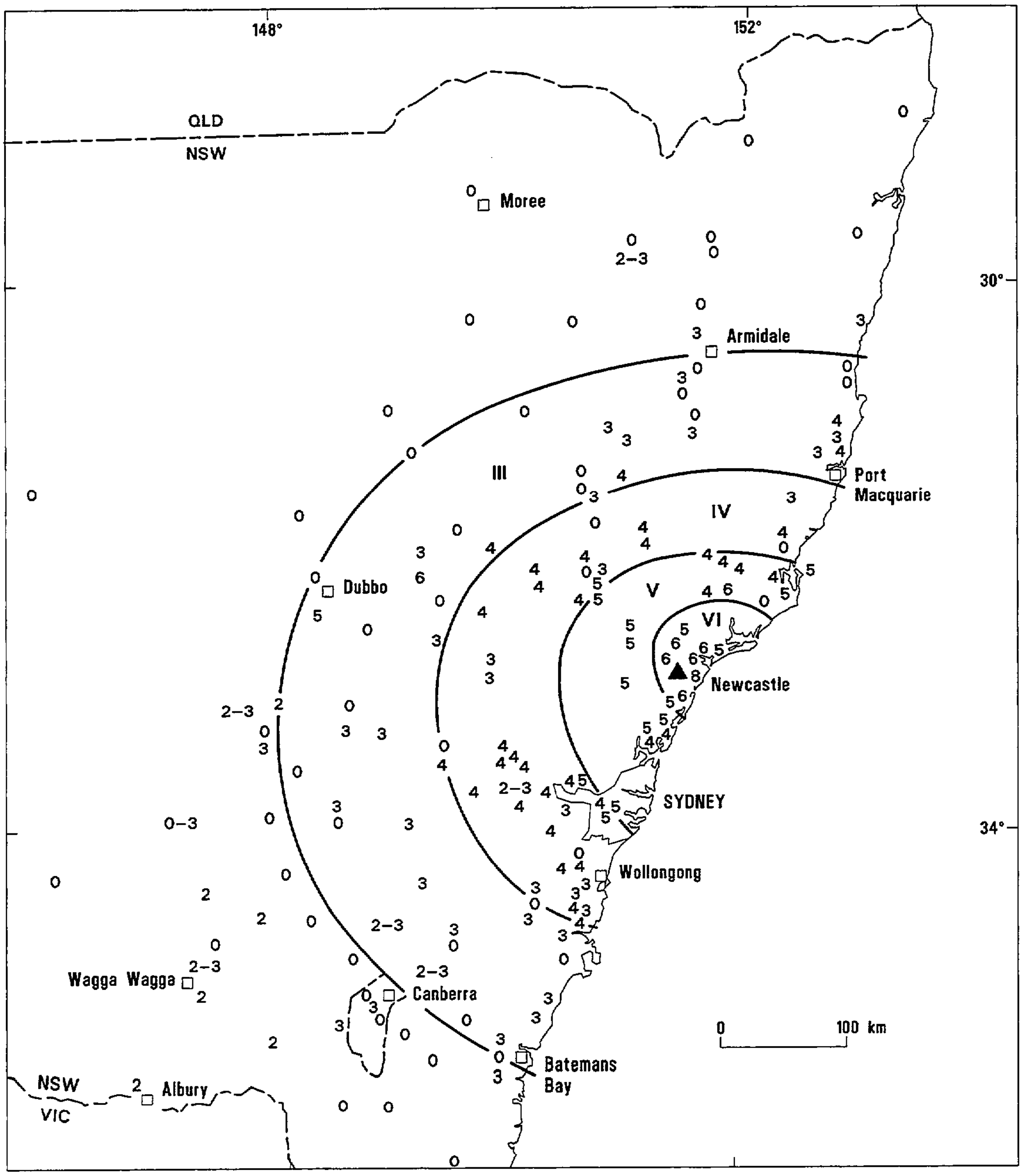


Figure 19b Detail of Figure 19a, Newcastle region intensities

ISOSEISMAL MAP OF NEWCASTLE, NEW SOUTH WALES
27 DECEMBER 1989



DATE: 27 DECEMBER 1989
TIME: 23:26:58 ±1.5s UTC
MAGNITUDE: 5.6 ML
EPICENTRE: 32.95°S 151.61°E
DEPTH: 11.5 ±1.0 km

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

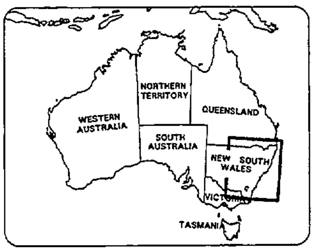


Figure 19c

24/156/14–1

a sort of bewilderment as the tremor intensified; was it a nuclear attack? no bright light yet! must be an earthquake! will the ground open up?

When the shaking and cracking sounds subsided I rose from the swag and looked out to sea and inland across the scrub but nothing stirred.

Broome was the closest town and experienced intensities of MM V. The earthquake was felt (MM II) as far as Sandfire, 280 km from the epicentre with the radius of the MM IV isoseismal being 130 km.

Cradock SA, 15 October 1989 (Figure 17)

At 9:05 pm (local time) on Sunday 15 October, a small ML 3.1 earthquake occurred in the Flinders Ranges. It was noticed from Tarcowie to Warcowie (130 km), but did little more than rattle bottles, ornaments and leave pictures askew. The area is not well populated, but 34 questionnaires were distributed, and a reasonable map was drawn by SADME seismologists from 24 replies.

Beachport SA, 8 November 1989 (Figure 18)

On Wednesday 8 November at 3:36 pm local time, coastal towns in the South-East were shaken by an ML 3.9 earthquake. At Beachport and Southend near the epicentre, some small objects were upset and light kitchen furniture appeared to jump. One group of people reported a sensation of being on a wave.

SADME distributed 63 questionnaires and the isoseismal map was produced from the 52 replies. A peak intensity of MM V was assigned. Two small aftershocks in the following three hours were felt by a few people at Southend.

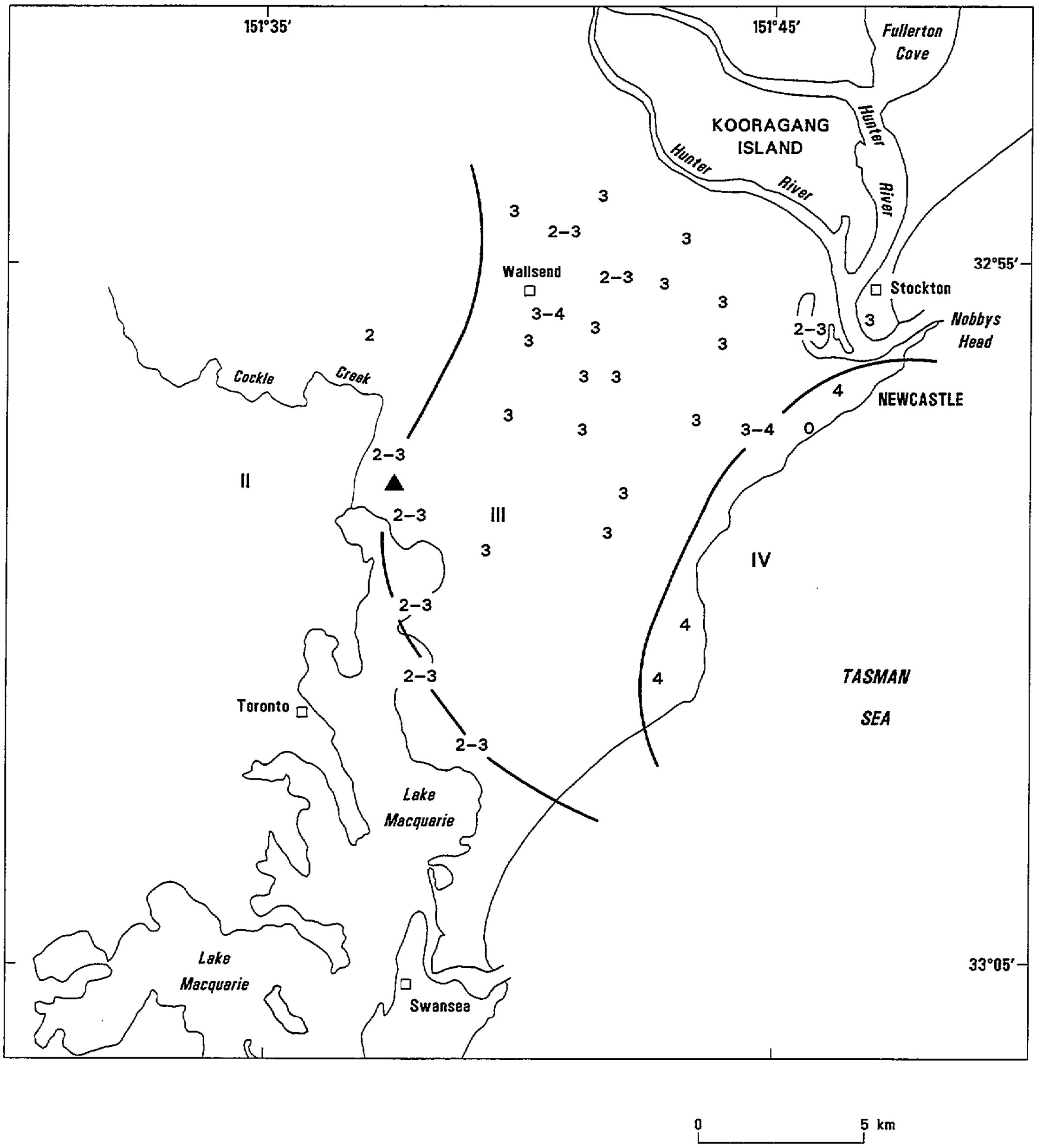
Newcastle NSW, 27 December 1989 (Figure 19 a,b,c)

Questionnaires designed to assess the intensity of the ground motion were distributed by Jerry Vahala and the returned forms were used to compile the *official* AGSO isoseismal map (Figure 19c, opposite). Other `fill-in' data were obtained by on-site observation and radio and telephone interviews. The maximum intensity is assessed at MMVIII (McCue & others, 1990; Melchers, 1990). Some modern structures in the epicentral region and downtown Newcastle suffered considerable damage including the Pasminco zinc refinery, the then unopened John Hunter hospital, Newcastle Technical College and Junction Motel. Special reasons can always be found for such failures, many other structures were undamaged, but the ground motion was undeniably strong. Other authors who briefly visited the area rated the intensity as a low MM VII (Tiedemann, 1990; Pappin & others, 1991). Rynn (1991) assigned it intensity IX and drew the isoseismal maps in Figures 19 a,b. MMIX is too high given the poor materials and workmanship, and MM VII too low given the extent of Masonry C damaged. Rynn's detailed map of the city area is similar to that prepared by the Institution of Engineers, Australia except for the intensities of IX, and shows a high correlation between the areas of alluvial fill and the intensity VIII contour. This region is 15 km from the epicentre at Booleroo, 11 km above the focus, where the intensity was VI.

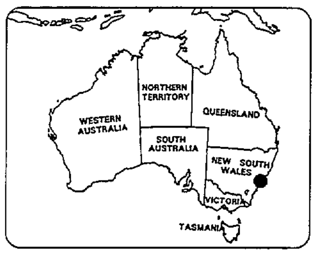
The difference of two intensity units between the epicentral region and the city amounts to at least a fourfold magnification of peak ground velocity which is attributed to the alluvial fill underlying a large area of inner Newcastle. Such effects are commonly observed in areas where earthquakes are more frequent. The October 1989 Santa Cruz or Loma Prieta earthquake was a classic example; intensities in San Francisco, 100 km from the epicentre, were rated similar to those in the epicentral region and the cause was attributed to ground motion amplification in the bay muds.

The Newcastle earthquake was felt at intensity IV-V in Sydney (VI according to Rynn which is too high) and clearly in Canberra, especially in tall buildings (one janitor rang to ask if another earthquake was likely in which case he would evacuate the building). The radius of perceptibility was about 310 km. The shape of the contours is similar to those of other Hunter Valley earthquakes in 1868 and 1925 but the 1989 earthquake was felt over a wider area and is obviously the largest of the three.

ISOSEISMAL MAP OF NEWCASTLE EARTHQUAKE, NEW SOUTH WALES
29 DECEMBER 1989



DATE: 29 DECEMBER 1989
TIME: 09:08:11 UTC
MAGNITUDE: 2.1 ML
EPICENTRE: 32.96°S, 151.63°E
DEPTH: 13 km



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

Figure 20

24/156 -2/1

In the meizoseismal region, the rapid attenuation of intensity would normally indicate that the focus was very shallow but in this case the focal depth is well constrained at 11.5 (±2 km) by P wave reflections from the underside of the Earth's surface recorded on Alice Springs and Tennant Creek seismographic array stations in Australia, and on the Eskdalmuir seismographic array in Scotland.

Newcastle NSW aftershock, 28 December 1989 (Figure 20)

As one of the team of seismologists who had just completed installing the temporary network around Newcastle, McCue was sitting on the steps of the cellar housing the Merewether seismograph, a portable MEQ-800 recorder, giving a media briefing on the days activities when the phone rang and a concerned police officer at the Newcastle CBD headquarters informed him that an earthquake had been felt there, and at Hamilton. On rotating the recorder drum he was able to confirm that an aftershock had indeed occurred but none of the ten or so people in the room had felt it. Later reports indicated that it had been felt at Adamstown too.

Rynn (1991) compiled this isoseismal map which is not at all constrained by 'not-felt' reports nor a single report, felt or otherwise, west of the epicentre. This lack of coverage prevents any comparisons between the felt areas of the mainshock and aftershock and severely limits conclusions on the correlation between the felt area and the aftershock location which is well constrained by seismographic data.

K McCue, D Love, P Gregson & J Rynn

NETWORK OPERATIONS 1989

The permanent network underwent minor changes during the year (Table 3). In WA the seismograph at Kalgoorlie (KLGA) was closed in 1989 following relocation of the seismograph site to Coolgardie (COOL) in 1988. BMR installed a new analogue seismograph at Quilpie, Qld (QLP) to fill a large gap in the monitoring capability in Eastern Australia. The GSQ closed seismographs at Colinsville and Thallon Rd and opened a new seismograph at Cricket Rd. Four new seismographs were opened in Victoria, a digital triaxial station in Western Victoria north of BMR's Belfield site and other recorders at Cairn Curran, Dartmouth and Swingler.

A temporary network of 10 analogue and digital triaxial seismographs was established by BMR and PIT seismologists and technical officers in the Newcastle area on 29 December to monitor aftershocks of the Newcastle earthquake. Four of these were left around Newcastle as a permanent network, at the request of the then Minister for Resources and Energy, Senator Peter Cook.

Kevin McCue and Peter Gregson

ACCELEROGRAPH DATA

There were no accelerographs close to any of the magnitude 5^+ earthquakes of 1989.

<u>In Western Australia</u> Accelerograph coverage in the south-west seismic zone improved significantly during 1989 with the installation of Kelunji accelerographs at Goomalling (GOO) in December 1988, and at Dowerin (DOW) in September 1989 (Table 5).

Thirty accelerograms were recorded by the network in the South-west Seismic Zone during 1989, from 24 different earthquakes, 22 of which were in the Cadoux area. The other two were in the Meckering region. Only five of the events were of magnitude 2.0 or greater. The largest event recorded was ML 3.6, in the Cadoux area, on 10 Nov 1989, and this event was recorded on 5 accelerographs, up to a distance of

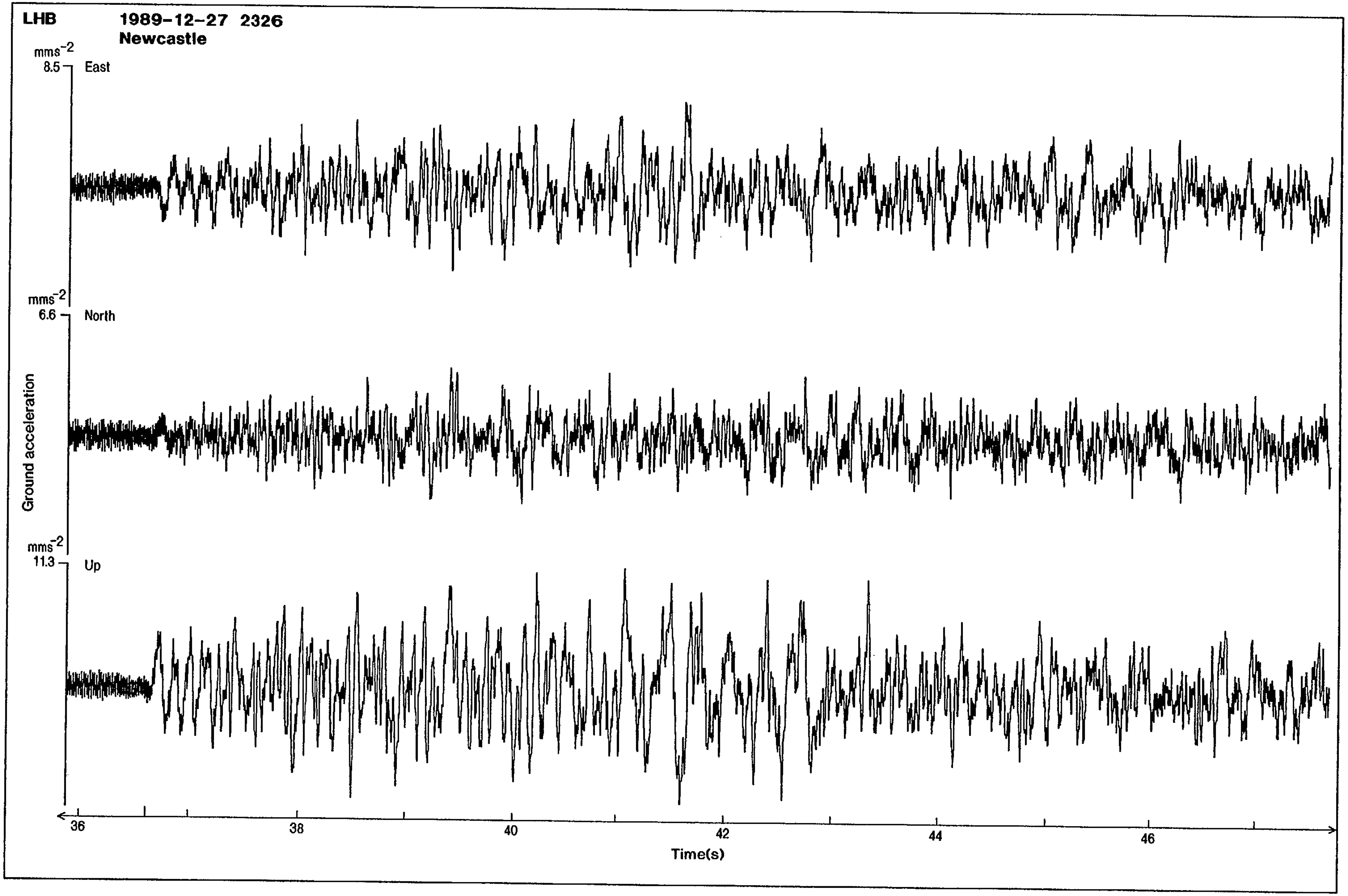


Figure 21 Accelerogram of the Newcastle earthquake, 27 December 1989 recorded at Lucas Heights near Sydney.

77 km (at Goomalling, GOO). Eight of the 22 events recorded in the Cadoux region were foreshocks or aftershocks of this event.

Only the more significant triggerings are shown in Table 6.

In Eastern Australia Accelerograms of mostly academic interest were recorded at 100, 300 (2), 550 and 750 (2) km from the epicentre of the Newcastle NSW earthquake. The nearest recording, at Lucas Heights south of Sydney (Figure 21) captured only the P wave, and of the two near Dalton NSW, one triggered on the surface waves missing both P and S, while the other triggered on the S phase but suffered a fault in the analogue to digital board rendering the record unusable. The accelerograph on the Dartmouth Dam embankment in Victoria triggered on the S wave and that at PTA, Melbourne on surface waves.

The first 40 s of the great Macquarie Ridge earthquake, magnitude Ms 8.1, were recorded on accelerographs installed by the Seismology Research Centre in Melbourne, at an epicentral distance of nearly 2000 km. An analogue SMA-1 recorder on Macquarie Island also triggered but seems to have missed most of the strong ground shaking, only the final 20s of coda were recorded.

Several other accelerograms were recorded during small earthquakes in the Dalton Gunning region of NSW and Thompson Dam, Victoria.

K McCue & V Dent

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 MECHANISMS

When the BMR's hydro-fracture equipment was decommissioned in 1989, the direct measurement of in-situ crustal stress by BMR ceased. Focal mechanism studies became the only way to continue the stress monitoring, leaving the choice of location and timing of the study to nature. The project lasted long enough to demonstrate that the carefully conducted shallow stress measurements gave comparable principal stress directions to those from the study of focal mechanisms (Chopra, in BMR 1988; Figure 70). Unfortunately the magnitude of the stresses cannot be determined from focal mechanism studies.

The two earthquakes analysed in 1989 were the Mt Olga NT and Newcastle NSW earthquakes, for which impulsive P-wave first motions were reported at regional and teleseismic distances. The results are summarised in Figure 23 and Table 4.

K M^c^Cue

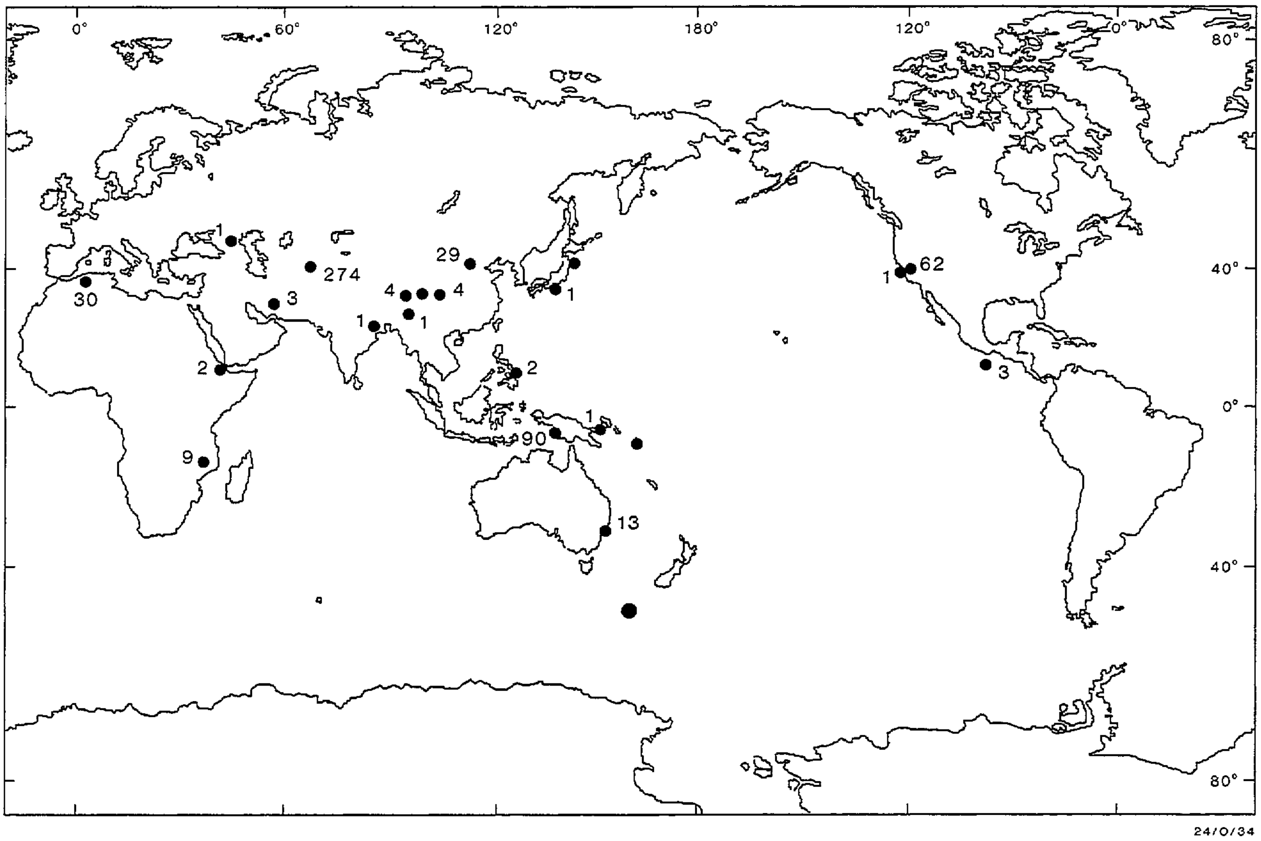


Figure 22 Epicentres of the principal world earthquakes during 1989, showing the numbers of casualties. Details and a brief description of each of the earthquakes are listed in Table 7.

PRINCIPAL WORLD EARTHQUAKES, 1989

Table 7 lists earthquakes that occurred throughout the world in 1989 of magnitude 7.0 or greater, or that caused fatalities or substantial damage. Figure 22 shows the locations of these earthquakes and the number of casualties. World-wide deaths during 1989 were more than 530 compared with 26 550 and 1086 in 1988 and 1987 respectively. The most disastrous earthquake was on 22 January when 274 people were killed, many injured and extensive damage reported in the Gissar area of Tajik SSR. Mudslides were responsible for most of the casualties which buried two villages.

The largest earthquake, Ms 8.1, occurred on 23 May on the Macquarie Ridge, 150 km north of Macquarie Island where it was strongly felt. A small tsunami was recorded on tide gauges up the southeast coast of Australia. An Ms 7.1 earthquake occurred near Santa Cruz, Central California on 18 October, resulting in 62 deaths and $5.6 billion damage. Much of the damage was 100 km away in the Marina district of San Francisco which is founded on reclaimed land. One 17 m leaf of the San Francisco - Oakland Bay Bridge collapsed and long sections of the double decker Oakland Freeway simply pancaked as the supports collapsed. This is attributed to strong amplification of ground motion in the underlying bay mud layers.

Thirteen people died and 160 were seriously injured at Newcastle, Australia and about $1.2 billion damage was incurred in a moderate ML 5.6 intraplate earthquake on 28 December UTC (details p29).

P Gregson and K McCue

MONITORING OF NUCLEAR EXPLOSIONS

Underground nuclear explosions presumed to have been detonated during 1989 are listed in Table 8. Except for four small Nevada tests which are in the core-shadow zone, all listed events were recorded by Australian seismic stations. Eleven nuclear explosions were conducted at the US test site in Nevada, and the USSR performed all seven tests at their East Kazakhstan test site. One of the larger French nuclear tests was conducted at Fangataufa, and the remaining seven 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).

D Jepson

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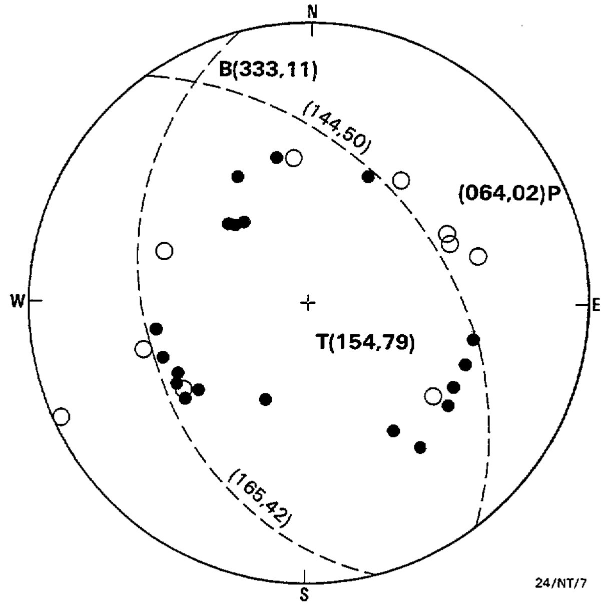

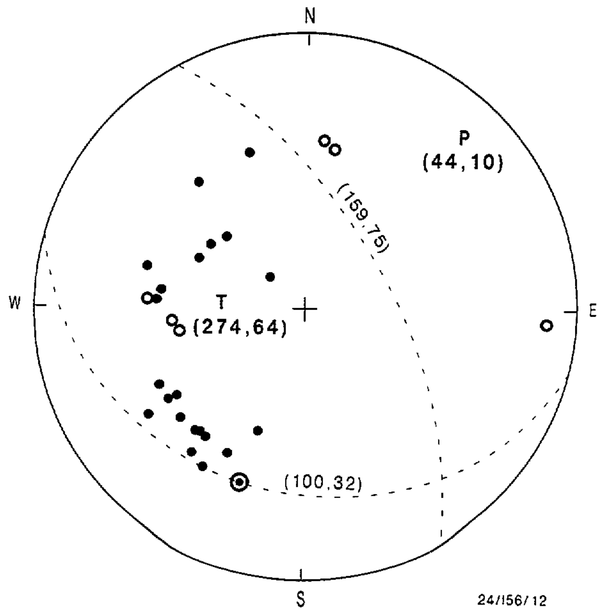

Figure 23 Focal mechanisms of the Mt Olga NT (upper figure) and Newcastle, NSW (lower figure) earthquakes. The solid dots are compressions on short-period seismograms; the open circles dilatations, and the crosses are emergent arrivals. P and T are the major and least principal stress axes respectively and the intermediate stress axis is at the intersection of the nodal planes.

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Table 1. Australian earthquakes, 1989, ML ≥ 3.0

Date	Time (UTC)	Latitude °S	Longitude °E	Depth km	ML/Ms	Comments
1 2	0347 58.0	19.900	134.000	0	3.0	Tennant Ck NT
1 2	0809 5.2	15.325	139.727	8	4.0	G Carpentaria
1 2	1933 32.7	27.840	107.570	5	3.5	Indian Ocean
1 3	2120 17.0	19.900	134.000	0	3.6	Tennant Ck NT
1 5	0857 15.0	15.900	123.320	5	3.2	NW WA
1 5	2048 27.1	33.824	147.124	0	3.9	Wyalong NSW
1 7	1141 43.9	25.390	116.080	5	4.0	Erong S WA
1 9	2229 1.0	19.900	134.000	0	3.4	Tennant Ck NT
1 11	0551 24.4	33.299	138.905	5	3.0	Flinders R SA
1 12	0511 11.0	19.900	134.000	0	3.0	Tennant Ck NT
1 13	0716 36.0	19.900	134.000	0	3.2	Tennant Ck NT
1 13	1638 37.8	30.910	117.160	5	3.0	Calingiri WA
1 14	0719 5.0	19.900	134.000	0	3.4	Tennant Ck NT
1 20	1741 37.2	35.651	144.471	2	3.2	Bunnaloo NSW
1 20	2005 25.6	35.665	144.749	2	3.2	"
1 24	0952 27.0	19.900	134.000	0	3.0	Tennant Ck NT
1 24	1658 39.0	19.900	134.000	0	3.5	"
2 8	0455 0.0	19.900	133.800	2	4.4	"
2 9	0619 48.0	19.900	133.800	2	3.3	"
2 9	1714 40.1	37.966	147.519	2	3.2	Bairnsdale Vic
2 12	1059 25.0	19.900	134.000	0	3.2	Tennant Ck NT
2 14	2031 54.0	19.800	133.800	2	3.1	"
2 17	1151 21.5	19.340	117.550	5	3.3	Indian Ocean
2 17	1416 34.0	14.810	121.130	5	3.9	"
2 18	1947 9.0	19.900	133.800	2	3.0	Tennant Ck NT
2 19	0218 35.0	19.900	133.800	2	3.0	"
2 24	1216 51.0	20.030	113.940	5	3.4	Indian Ocean
3 3	0051 6.7	21.690	121.570	5	3.0	NW WA
3 3	0351 51.0	19.900	133.800	0	3.2	Tennant Ck NT
3 3	0922 7.0	29.590	123.640	5	4.8	Laverton WA
3 3	1326 41.7	29.600	123.650	5	**5.4**	"
3 3	1409 10.3	29.600	123.650	5	3.5	"
3 3	1449 45.0	29.600	123.650	5	3.2	"
3 3	1542 58.0	19.900	133.800	0	3.2	Tennant Ck NT
3 4	1125 59.9	35.709	142.753	0	3.1	Kerang Vic
3 6	0656 59.0	19.900	133.800	0	3.4	Tennant Ck NT
3 19	2246 19.0	19.900	133.800	0	3.5	"
3 21	1800 24.6	23.240	114.580	10	3.5	North West WA
3 22	1616 39.0	19.900	133.800	0	3.4	Tennant Ck NT
3 24	1655 33.0	19.900	133.800	0	3.1	"
3 24	2156 16.0	19.900	133.800	0	3.6	"
3 27	1034 9.0	19.900	133.800	0	3.1	"
3 27	1225 53.4	25.580	111.730	5	3.2	Indian Ocean
3 27	1339 31.0	19.900	133.800	0	3.7	Tennant Ck NT
3 30	1246 31.0	19.900	133.800	0	4.1	"
3 31	0400 5.6	30.950	116.810	3	3.0	New Norcia WA
4 1	0517 40.7	19.340	127.720	5	3.7	Margaret R WA
4 8	0418 38.4	32.785	138.647	0	3.0	Flinders R SA
4 9	2150 13.8	19.900	133.800	2	3.4	Tennant Ck NT
4 10	0737 34.2	17.120	126.620	5	3.5	Kimberley WA

Table 1. (cont)

4 14	1823 32.9	19.900	133.800	2	3.6	Tennant Ck NT
4 17	1556 20.8	16.370	121.410	5	3.0	Indian Ocean
4 18	0351 34.6	36.348	148.508	23	3.7	JindabyneNSW
4 19	2208 58.1	19.900	133.800	2	3.2	Tennant Ck NT
4 20	0352 42.7	19.900	133.800	2	3.1	"
4 22	1453 47.7	19.900	133.800	2	3.2	"
4 23	1412 51.8	19.900	133.800	2	3.3	"
4 30	0152 22.4	19.900	133.800	2	3.2	"
4 30	0819 51.2	19.900	133.800	2	3.0	"
5 3	0606 18.8	31.655	139.006	10	3.5	Flinders R SA
5 3	0922 6.0	19.900	134.000	0	3.5	Tennant Ck NT
5 5	0617 0.9	17.929	131.445	21	3.5	Mt Reid WA
5 9	1027 38.0	19.900	134.000	0	4.4	Tennant Ck NT
5 9	1138 38.1	43.812	146.806	11	3.0	Southern Tas
5 13	0217 2.2	30.362	147.000	15	3.0	Brewarrina NSW
5 15	2151 52.0	19.900	134.000	0	3.7	Tennant Ck NT
5 16	0417 7.0	19.900	134.000	0	3.1	"
5 20	0759 44.0	19.900	134.000	0	3.0	"
5 22	0211 46.0	19.900	134.000	0	3.1	"
5 22	2040 47.0	19.900	134.000	0	3.1	"
5 23	1208 56.3	28.843	143.978	5	4.0	Hungerford Qld
5 23	1303 42.5	19.747	133.918	5	4.2	Tennant Ck NT
5 24	1938 35.8	35.718	144.459	8	3.0	Booleroo NSW
5 25	0343 40.4	19.923	134.153	3	3.1	Tennant Ck NT
5 28	0255 20.6	25.25	130.65	31	**5.6**/5.3	Mt Olga NT
5 28	1649 21.0	19.900	134.000	0	3.2	Tennant Ck NT
5 31	0009 3.0	38.821	142.692	0	3.0	South coast Vic
6 1	0326 29.0	19.900	134.000	0	3.1	Tennant Ck NT
6 5	0509 33.0	19.900	134.000	0	3.3	"
6 7	1338 16.0	19.900	134.000	0	3.1	"
6 11	1452 39.2	19.858	133.939	4	**5.0**	"
6 12	0650 7.0	19.900	134.000	0	3.8	"
6 12	0959 58.0	19.900	134.000	0	3.0	"
6 13	1621 13.0	19.900	134.000	0	3.0	"
6 26	0004 25.0	19.900	134.000	0	3.5	"
6 26	1118 15.8	31.478	138.584	0	4.4	Flinders R SA
6 26	1757 11.1	31.220	111.140	5	3.5	Indian Ocean
6 26	1813 51.9	19.910	133.860	5	3.7	Tennant Ck NT
6 27	0412 12.0	19.900	134.000	0	3.1	"
6 28	0901 34.1	21.730	109.970	5	3.2	Indian Ocean
6 30	1254 53.0	19.900	134.000	0	3.4	Tennant Ck NT
7 2	2324 39.2	19.900	133.800	2	3.3	"
7 4	1244 7.0	20.326	113.671	5	3.3	Indian Ocean
7 4	1535 53.4	19.900	133.800	2	3.2	Tennant Ck NT
7 7	0541 49.9	19.900	133.800	2	3.1	"
7 9	0043 54.0	19.900	133.800	2	3.3	"
7 13	2216 42.1	19.900	133.800	2	4.2	"
7 14	2033 52.6	35.800	144.440	0	3.1	Booleroo NSW
7 15	0306 5.0	35.770	144.520	0	3.2	"
7 16	0844 53.2	19.900	133.800	2	3.2	Tennant Ck NT
7 19	0323 45.2	19.900	133.800	2	3.3	"
7 19	1143 17.9	19.900	133.800	2	3.1	"

Table 1. (cont)

7 20	0929 24.5	33.992	114.881	5	3.2	Margaret R WA
7 23	2041 18.0	12.563	130.472	5	3.7	
7 24	0014 11.2	19.900	133.800	0	3.2	Tennant Ck NT
7 26	2012 48.7	19.900	133.800	0	3.2	"
7 26	2349 12.3	29.213	139.735	5	3.5	NE SA
7 27	0607 48.7	26.090	125.470	5	3.0	Warburton R WA
7 27	2044 22.5	19.900	133.800	0	3.7	Tennant Ck NT
7 31	1621 12.0	40.750	144.830	14	3.7	NW Tasmania
8 2	0435 6.0	19.900	134.000	0	3.4	Tennant Ck NT
8 7	0424 6.0	19.900	134.000	0	3.3	"
8 7	1044 58.0	19.900	134.000	0	3.1	"
8 8	0654 23.4	27.630	141.521	10	3.3	West Qld
8 8	0654 28.2	27.923	141.152	7	3.0	"
8 10	0904 49.0	19.900	134.000	0	3.1	Tennant Ck NT
8 10	1545 28.8	29.952	124.696	5	3.1	SE WA
8 13	1917 43.3	34.015	136.391	5	3.1	Arno Bay SA
8 15	2126 0.0	37.400	146.900	0	3.0	Mt Buller Vic
8 16	2016 22.0	19.900	134.000	0	3.2	Tennant Ck NT
8 18	0324 32.9	32.960	137.258	0	3.1	"
8 23	2208 4.0	19.900	134.000	0	4.5	Tennant Ck NT
8 25	1509 16.8	36.130	144.551	17	3.0	Shepparton Vic
8 27	0149 37.0	19.900	134.000	0	4.2	Tennant Ck NT
8 28	0414 41.0	19.900	134.000	0	4.2	"
8 31	0233 43.0	19.900	134.000	0	3.4	"
9 1	0122 21.9	19.900	134.000	0	3.0	"
9 6	0722 42.8	19.900	134.000	0	3.3	"
9 7	0808 26.6	33.617	135.871	7	3.0	Hambidge SA
9 9	1127 10.9	19.900	134.000	0	3.6	Tennant Ck NT
9 11	2217 14.9	19.900	134.000	0	3.8	"
9 12	1007 2.5	25.620	116.080	5	3.0	Mt Gascoyne WA
9 13	2027 30.2	24.850	110.430	5	3.4	Indian Ocean
9 13	2152 0.0	21.517	129.969	5	3.5	L Mackay WA
9 14	0830 35.5	19.788	133.931	5	3.8	Tennant Ck NT
9 14	1950 26.0	39.000	156.000	0	4.0	Tasman Sea
9 15	0615 32.6	40.543	155.592	5	4.1	"
9 15	2226 7.3	19.900	134.000	0	3.3	Tennant Ck NT
9 17	1602 52.3	19.900	134.000	0	3.1	"
9 20	0241 31.9	19.900	134.000	0	3.0	"
9 20	2044 14.6	19.900	134.000	0	3.0	"
9 21	0709 38.3	33.736	147.627	15	3.0	Wyalong NSW
9 30	1633 40.8	19.900	134.000	0	3.3	Tennant Ck NT
10 1	2109 4.7	19.554	133.905	5	3.8	"
10 2	1607 4.6	24.420	111.170	5	3.1	Indian Ocean
10 3	0607 4.9	19.900	133.800	2	3.1	Tennant Ck NT
10 4	0110 42.2	15.248	140.111	10	3.8	G Carpentaria
10 7	0045 34.9	36.741	145.538	0	3.0	Shepparton Vic
10 7	0416 20.0	19.900	133.800	2	3.5	Tennant Ck NT
10 7	0417 16.8	19.900	133.800	2	4.0	"
10 7	1139 10.8	19.900	133.800	2	3.9	"
10 7	1538 51.7	19.900	133.800	2	3.5	"
10 8	1223 9.6	19.900	133.800	2	3.9	"

Table 1. (cont)

10 11	0704 54.8	11.355	134.473	5	3.9	Arafura Sea
10 12	0403 29.5	27.690	122.920	5	3.5	Central WA
10 13	0959 14.6	17.640	122.430	5	**5.4**	Broome WA
10 13	1032 35.6	17.720	122.460	10	3.3	"
10 14	0146 40.8	33.932	147.239	0	3.1	Wyalong NSW
10 15	1135 7.1	32.272	138.668	7	3.1	Cradock SA
10 16	0534 29.9	19.900	133.800	2	3.1	Tennant Ck NT
10 19	1202 2.7	19.854	133.774	2	4.1	"
10 19	1507 28.4	19.900	133.800	2	3.3	"
10 21	0136 15.8	19.900	133.800	2	3.0	"
10 23	0132 11.0	19.900	133.800	2	3.1	"
10 23	0938 19.6	19.900	133.800	2	4.0	"
10 23	1159 4.0	19.900	133.800	2	4.1	"
10 23	1433 24.4	19.900	133.800	2	4.0	"
10 23	1911 25.1	19.900	133.800	2	3.9	"
10 25	1350 57.2	19.900	133.800	2	3.0	"
10 25	1855 5.0	17.670	122.400	5	3.3	Broome WA
10 27	1924 8.6	19.900	133.800	2	3.6	Tennant Ck NT
10 29	1924 34.6	19.900	133.800	2	3.5	"
10 31	0137 12.6	19.900	133.800	2	3.5	"
10 31	0157 26.1	19.900	133.800	2	3.8	"
11 4	0057 41.1	17.240	127.800	5	3.4	Durack R WA
11 5	1749 39.0	19.900	134.000	0	3.0	Tennant Ck NT
11 6	1252 7.0	19.900	134.000	0	3.2	"
11 7	0624 48.0	19.900	134.000	0	3.1	"
11 8	0506 30.7	37.547	140.056	13	3.9	Beachport SA
11 8	1504 50.0	19.900	134.000	0	3.1	Tennant Ck NT
11 9	0114 33.0	19.900	134.000	0	3.1	"
11 10	1658 8.8	30.750	117.130	2	3.6	Cadoux WA
11 11	0128 47.0	19.900	134.000	0	4.1	Tennant Ck NT
11 14	0830 58.9	34.750	149.176	5	3.2	Taralga NSW
11 15	1831 0.0	30.720	117.150	3	3.0	Cadoux WA
11 16	1043 24.7	17.386	146.296	5	4.0	Cairns Qld
11 17	1338 2.6	39.269	144.807	26	3.2	C Otway Vic
11 23	1822 30.0	19.900	134.000	0	3.6	Tennant Ck NT
11 26	1620 3.0	19.900	134.000	0	3.8	"
12 5	2249 37.6	20.260	118.870	5	3.6	Pt Hedland WA
12 6	2348 49.0	19.900	134.000	5	3.1	Tennant Ck NT
12 8	1652 45.0	19.900	134.000	5	4.9	"
12 9	2105 30.1	17.510	122.300	5	4.2	Dampier L WA
12 10	0057 41.1	17.460	122.380	5	3.4	Dampier L WA
12 10	0620 0.0	19.900	134.000	5	3.0	Tennant Ck NT
12 16	0028 56.1	34.700	150.670	23	3.2	Wollongong NSW
12 21	1354 0.0	19.900	134.000	5	3.1	Tennant Ck NT
12 21	1905 54.4	17.500	122.270	5	4.0	Dampier L WA
12 22	0312 28.6	35.880	116.400	5	3.2	Southcoast WA
12 23	2346 44.0	19.900	134.000	5	3.3	Tennant Ck NT
12 27	2326 57.0	32.946	151.607	11	**5.6**/4.6	NewcastleNSW
12 30	1157 54.6	21.120	109.050	5	4.1	Indian Ocean
12 31	1835 41.1	34.070	147.030	6	3.0	Wyalong NSW

Table 2. Large or damaging Australian earthquakes, 1873 - 1989

Source #	Date UTC	Time	Lat °S	Long °E	Depth km *	ML	Ms
ET	1873 12 15	0400	26.25	127.5	0 G		6.0
MML	1884 07 13	0355	40.5	148.5	0 G		6.2
ET	1885 01 05	1220	29.0	114.0	0 G		6.5
MML(b)	1885 05 12	2337	39.8	148.8	0 G		6.5
MML	1892 01 26	1648	40.3	149.5	0 G		6.6
ADE	1897 05 10	0526	37.33	139.75	0 G		6.5
ADE	1902 09 19	1035	35.0	137.4	14		6.0
G&E	1906 11 19	0718	22	109	5		7.8
UQ	1918 06 06	1814 24.0	23.5	152.5	15	6.2	5.7
EDG	1920 02 08	0524 30	35.0	111.0	0 G		6.0
BMR	1929 08 16	2128 23.4	16.99	120.66	3N		6.6
EDG	1935 04 12	0132 24	26.0	151.1	0 G	6.1	5.4
BMR	1941 04 29	0135 39.4	26.92	115.80	0 G	7.0	6.8
BMR	1941 06 27	0755 49.0	25.95	137.34	0 G		6.5
ADE	1954 02 28	1809 52	34.93	138.69	4 G	5.4	4.9
BMR(f)	1968 10 14	0258 50.6	31.62	116.98	5	6.9	6.8
BMR	1970 03 10	1715 11	31.11	116.47	1	5.1	5.1
BMR	1970 03 24	1035 17.6	22.05	126.61	0 G	6.7	5.9
BMR	1972 08 28	0218 56.2	24.95	136.26	10		6.2
MUN(f)	1975 10 03	1151 1.8	22.21	126.58	0		6.2
BMR	1978 05 06	1952 19.6	19.55	126.56	17		6.2
BMR	1979 04 23	0545 10.8	16.66	120.27	10	6.6	5.7
BMR(a)	1979 04 25	2213 57.4	16.94	120.48	1		6.1
BMR(f)	1979 06 02	0947 59.3	30.83	117.17	5	6.2	6.1
CGS	1983 11 25	1956 7.8	40.45	155.51	19	6.0	5.8
BMR(f)	1986 03 30	0853 48	26.33	132.52	5		5.8
BMR(f)	1988 01 22	0035 57.4	19.79	133.93	5		6.3
BMR(b)	1988 01 22	0357 24.3	19.88	133.84	5		6.4
BMR(b)	1988 01 22	1204 55.8	19.94	133.74	5		6.7
BMR	1989 12 27	2326 58	32.95	151.61	13	5.6	4.6

* G,N indicate depth restrained, or set at normal depth, by the geophysicist
\# ET - Everingham & Tilbury (1972), G&E - Gregson & Everingham (1991)
EDG - Everingham & others (1987), MML - Michael-Leiba (1989)
a,b,f - aftershock, related event, surface faulting observed

Table 3. Australian Seismographic Stations, 1989

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
BRS	Mt Nebo Brisbane	27.392	152.775	525	QLD	5
BSL	Bruslee	20.275	147.299	185	GSQ	1
CVL	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	220	GSQ	1
GVA	Glen Eva	21.489	147.483	200	GSQ	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
QLP	Quilpie	26.584	144.235	210	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
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	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
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

Table 3 (cont.)

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	Jelolan	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	7
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
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	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
MIC	Mount Erica	37.944	146.359	805	PIT	1
MLW	Molesworth	37.137	145.510	280	PIT	1
PAT	Plane Track	37.857	146.456	771	PIT	1
PEG	Pegleg	36.985	144.091	340	PIT	1
PNH	Panton Hill	37.635	145.271	180	PIT	1
RUS	Rushworth	36.662	144.947	145	PIT	1
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
WSK	Woodstock	36.814	144.055	210	PIT	1

Table 3 (cont.)						
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 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						
MAW	Mawson	67.607	62.872	15	BMR	5/7

* 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 triaxial triggered digital recorder

Table 4. Focal parameters, Mt Olga NT, and Newcastle NSW, earthquakes

Mt Olga NT: 28 May 1989		
	Azimuth	dip
P-axis	064	02
T-axis	154	79
B-axis	333	11
Double couples	A	B
Strike	144	165
Dip	50	42

Newcastle NSW: 27 December 1989		
	Azimuth	dip
P-axis	044	10
T-axis	274	64
B-axis	140	12
Double couples	A	B
Strike	159	100
Dip	75	32

Table 5. Australian accelerographs, 1989

Location	Lat° S	Long° E	Elev.(m)	Foundation	Type	Owner
ACT						
ASC	35.289	149.139	560	Deep soil	PIT	BMR
Parliament House	35.310	149.123	600	Sandstone	PIT	BMR
Corin Dam	35.524	148.812	915	Granite	PIT	E&W
Cotter Dam	35.308	148.908	535	Basalt	PIT	E&W
Telecom Tower	35.275	149.096	810	Sandstone	PIT	TEL
NEW SOUTH WALES						
Oolong (OOL)	34.773	149.163	600	Firm soil/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	35.431	148.878	610	Metasediments	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 (LHR)	34.052	150.979	80	Hawksbury sandstone	PIT	ANSTO
	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
WESTERN AUSTRALIA						
Cadoux						
Kalajzic C. (CA-K)	30.810	117.132	300	Sandplain	MO2	BMR
Shankland (CA-S)	30.810	117.132	300	Sandplain	MO2	BMR
Avery (CA-C)	30.851	117.160	300	Tertiary sands/granite	MO2	BMR
Kalajzic M. (CA-A)	30.746	117.151	320	Laterite	A700	BMR
Robb (CA-R)	30.781	117.138	300	Alluvium/granite	MO2	BMR
Goomalling (GOO)	31.394	116.852	250	Granite	PIT	BMR
Mundaring Weir	31.967	116.169	250	Concrete wall	SMA-1	PWDWA
Perth						
Telecom	31.953	115.850	10	Basement	SMA-1	TEL
Exchange	31.953	115.850	40	Middle floor	SMA-1	TEL
Building	31.953	115.850	70	Top floor	SMA-1	TEL
VICTORIA						
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

Table 5 (cont.)

Location	Lat° S	Long° E	Elev.(m)	Foundation	Type	Owner
Dartmouth Dam (DDB)	36.558	147.511	329	Ordivician metasediments	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	Top of Outlet Tower	PIT	MMBW
NORTHERN TERRITORY						
Tennant Creek (temporary station)						
TCTY	19.642	134.183	370	Sediments	SSA-1	PIT
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 Chamber	A700	QEC
Tully Millstream	17.76	145.42	65		PIT	QEC
	17.85	145.57	74		PIT	QEC

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	Phillip Institute of Technology
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

Table 6 Australian accelerograms, 1989

Date m d	Time (UTC)	Lat °S	Long °E	ML/ Ms	Code	H-E/ km or (S-P) s	CO	T(s)	ACC mms^{-2}
1 9	0903	38.488	146.61	1.9	JNA	23/22.7	SZ	0.12	1.6
							SN	0.1	1.8
							SE	0.1	1.7
2 9	1714	38.175	146.68	3.0	PTA	114/113	SZ	0.1	2.3
							SN	0.13	3.5
							SE	0.12	3.1
					TMT	118/117	SZ	0.09	4.17
							SN	0.06	1.7
							SE	0.05	0.93
3 13	2003	37.831	146.43	1.0	PTA	4.6/3.5	SZ	0.09	4.18
							SN	0.087	6.78
							SE	0.095	3.94
4 30	2352	38.404	146.31	2.7	JNA	14/11.4	SZ	0.21	5.16
							SN	0.065	3.96
							SE	0.18	5.98
					PTA	62.6/62	SZ	0.05	1.6
							SN	0.12	2.04
							SE	0.15	3.31
					TMT	63.6/63	SZ	0.09	2.7
							SN	0.05	2.13
							SE	0.04	2.09
5 12	1707	37.774	146.35	2.1	PTA	13.3/13	SZ	0.08	2.15
							SN	0.105	3.8
							SE	0.075	3.76
					TMT	8.9/8.8	SZ	0.06	15.0
							SN	0.05	11.1
							SE	0.06	19.5
5 21	0534	37.854	146.38	0.4	TMT	1.9/1.9	SZ	0.04	5.87
							SN	0.04	6.93
							SE	0.04	5.53
5 23	1059	52.614	160.19	8.2	JNA	1910	SZ	2.4	0.6
							SN	2.1	0.8
							SE	2.24	0.65

Table 6 (cont.)

5 23	1059	52.614	160.19	8.2	PTA	1956	SZ	2.1	1.27
							SN	2.27	1.0
							SE	2.1	0.7
5 27	1756	37.852	146.37	0.5	TMT	2.3/2	SZ	0.08	3.7
							SN	0.03	3.46
							SE	0.05	4.17
5 29	1225	37.811	146.36	1.0	TMT	7.9/4.7	SZ	0.08	4.3
							SN	0.06	3.98
							SE	0.05	3.25
6 7	2356	37.808	146.40	1.3	PTA	8/7.5	SZ	0.08	2.93
							SN	0.085	6.18
							SE	0.08	5.53
					TMT	4.9/3.9	SZ	0.07	7.25
							SN	0.04	17.5
							SE	0.04	19.5
6 21	1324	37.809	146.41	1.2	PTA	9.2/6.4	SZ	0.06	2.2
							SN	0.06	2.1
							SE	0.07	2.2
7 7	1227	37.817	146.42	1.7	PTA	9.4/5.6	SZ	0.06	5.06
							SN	0.06	5.17
							SE	0.06	5.27
					TMT	8.4/3.6	SZ	0.04	15.0
							SN	0.03	9.98
							SE	0.03	10.3
7 8	0714	37.817	146.42	1.0	PTA	8.3/5.7	SZ	0.04	1.2
							SN	0.035	3.2
							SE	0.025	0.97
1109	2117	30.75	117.15	2.8	CA-A	1/1	PZ	0.035	300
							PN		64
							PE	0.087	43
							SZ	0.048	51
							SN	0.055	203
							SE	0.048	155
					CA-K	3/3	LZ	0.029	34
							LN	0.029	16
							LE	0.029	32

Table 6 (Cont.)

11 10	1658	30.75	117.14	3.6	CA-A	2.5/2	PZ	0.065	44.1
						0.32s	N	0.020	27.4
							E	0.020	20.6
							SZ	0.048	32.3
							N	0.030	68.6
							E	0.032	45.1
11 10	1658	30.75	117.14	3.6	CA-K	3.5/3	PZ	0.034	6.5
							N	0.034	8.6
							E	0.029	4.6
							SZ	0.046	58.0
							N	0.046	51.0
							E	0.034	54.0
					CA-S	9/8.5	LZ	0.037	2.0
							N	0.037	3.0
							E	0.037	3.0
					DO-W	33/33	PZ	0.040	0.2
							N	0.040	0.2
							E	0.040	0.2
							SZ	0.040	0.2
							N	0.040	0.6
							E	0.040	0.9
					GO-O	77/77	PZ	0.040	0.1
							N	0.040	0.2
							E	0.040	0.3
							Z	0.045	0.2
							N	0.045	0.8
							E	0.045	0.9
11 11	0931	37.804	146.36	0.7	TMT	6.3/5.6	SZ	0.08	4.97
							SN	0.05	3.66
							SE	0.05	4.63
11 14	0830	34.75	149.18	3.2	WIL	0.75s	SZ		107.6
							SN		128.7
							SE		106.5

Table 6 (Cont.)

11 15	1831	30.75	117.13	3.0	CA-A	3/2	PZ	0.024	365
							PN	0.015	120
							PE	0.015	150
					CA-K	4/3	PZ	0.030	31
							N	0.030	21
							E	0.030	11
							SZ	0.042	100
							N	0.038	81
							E	0.030	74
					CA-R	5/4	PZ	0.035	17
							N	0.035	6.0
							E	0.035	12
							SZ	0.059	72
							N	0.059	110
							E	0.059	68
12 27	2330	32.909	151.49	5.6	LHB	100	PZ	0.1	11.3
							PN	0.1	6.6
							PE	0.1	8.4
					FND	300	LZ	0.4	15.9
							LN	0.4	13.3
							LE	0.4	11.4
					SPF	300	SZ	0.2	40
							SN	0.2	40
							SE	0.2	40
					DDC	550	Z	0.4	14.3
							N	0.4	30.6
							E	0.4	19.5
					PTA	715.6	SZ	0.34	1.16
							SN	0.38	1.7
							SE	0.34	3.46
					JNA	759.6	SZ	0.56	1.3
							SN	0.6	1.7
							SE	0.9	2.6

Date/Time Universal Co-ordinated Time (UTC); *ML* Richter magnitude
H-E Hypocentral / Epicentral distance (km) or (S-P) time (s)
CO Component; *T(s)* Ground Period (s)
ACC Peak ground acceleration (mm/s^2)

TABLE 7. PRINCIPAL WORLD EARTHQUAKES, 1989

(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 Meterological Agency, TRI Trieste, NEIS US Geological Survey)*

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude
22 Jan	23 02 07.1	Tajik, SSR	38.465 N	68.694 E	5.3 mb

Depth 33 km. Two hundred seventy-four people killed, many injured, extensive damage (VII) and mudslides in the Gissar area. Nearly all the casualties were caused by mudslides which buried Sharora and two nearby villages. Felt (VI) at Gulkhani and Sarkishti: (V) at Dushanbe and Tursunzade: (IV) at Denau and Nurek.

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude
19 Feb	12 27 09.9	Near S Coast of Honshu, Japan	35.964 N	139.788 E	5.5 mb

Depth 60 km. One person killed and one injured. Felt (IV JMA) at Tokyo, Utsunomiya and Mito; (III JMA) at Kumagaya, Chashi, Yokohoma and Tateyama; (II JMA) at Shirakawa, Maebashi and Kawaguchi-ko; (I JMA) at Ofunato.

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude
10 Mar	14 14 10.2	New Britain Region	4.345 S	152.797 E	5.6 mb, 5.4 ML

Depth 53 km. One person killed by a landslide in the Rabaul area. Felt (V) at Rabaul.

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude
10 Mar	21 49 45.8	Malawi	13.702 S	34.420 E	6.2 mb, 6.1 Ms 6.6 Ms(BRK)

Depth 30 km. At least two people killed, 100 injured and damage in the Salima area. Six people killed and damage in the Dedza area and one person killed and damage in the Mohinji area. About 50,000 left homeless in Malawi. Felt strongly in much of central Malawi. Felt in Niassa and Tete Provinces, Mozambique. Also felt in Zambia. Depth from broadband displacement seismograms.

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude
15 Apr	20 34 08.9	Sichuan Province, China	29.987 N	99.195 E	6.2 mb, 6.2 Ms

Depth 13 km. Four people killed, 5 injured and considerable damage in the Batang area. Seven people killed, at least 37 injured and additional damage in the area due to a number of aftershocks. Depth from broadband displacement seismograms.

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude
25 Apr	14 29 00.5	Near Coast of Guerrero, Mexico.	16.773 N	99.328 W	6.2 mb, 6.8 Ms 7.1 Ms(BRK) 6.5 Ms(PAS)

Depth 19 km. Mo=1.4*10**19 Nm(PPT). Three people killed, a few injured and some damage at Mexico City. Minor damage reported in the Acapulco area. Felt strongly in much of southern Mexico and as far away as Guadalajara. Depth from broadband displacement seismograms.

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

TABLE 7 (cont.)

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude
07 May	00 38 18.5	Burma-China Border Region	23.553 N	99.526 E	5.3 mb, 5.6 Ms

Depth 33 km. At least one person killed, 91 injured and 5,300 houses destroyed in the Gengma area, China. Felt strongly in Lancang and Menglian Counties Direct economic losses of more than 54 million dollars were sustained.

23 May	10 54 46.3	Macquarie Islands Region	52.341 S	160.568 E	6.4 mb, 8.2 Ms 8.0 Ms(BRK) 7.8 Ms(PAS)

Depth 10 km. Mo=2.5*10**21 Nm(PPT). Felt (V) on Cambell Island. Also felt on Macquarie Island. Small tsunami reported along the southeastern coast of Tasmania and in Jervis Bay and Sydney Harbour, Australia. Complex event, observed on braodband displacement seismograms.

12 Jun	00 04 09.7	Bangladesh	21.861 N	89.763 E	6.1 mb, 5.1 Ms

Depth 6 km. One person killed, at least 100 injured and minor damage in the Banaripara area. Felt throughout eastern Bangladesh from Chittagong to Rangpur. Also felt in Meghalaya, India.

01 Aug	00 18 06.7	West Irian	4.500 S	138.938 E	5.9 mb, 5.8 Ms 5.7 Ms(BRK)

Depth 33 km. At least 90 people killed and 15 injured by landslides which buried two villages in the Kurima District. Landslides also blocked the Baliem River.

03 Aug	07 42 41.0	Eastern Caucasus	43.587 N	43.358 E	5.0 mb, 4.9 Ms

Depth 17 km. One person killed and damage in the Groznyy area, USSR.

08 Aug	08 13 27.5	Central California	37.130 N	121.952 W	4.9 mb, 4.5 Ms 5.3 ML(BRK)

Depth 15 km. Mo=2.6*10**16 Nm(BRK). One person killed, some minor injuries and damage (VI) in the Las Gatos, Campbell and Saratoga areas. Also slight damage (VI) at Ben Lamond, Brookdale, Cupertins and Santa Cruz. Felt (V) throughout much of the San Francisco Bay area. Felt from San Luis Obispo to Sanoma and east as far as Tracy.

20 Aug	11 16 56.1	Ethiopia	11.752 N	41.937 E	5.8 mb, 6.3 Ms

Depth 10 km. Two people killed, two injured and damage in the Yaboki, Djibouti area. Damage and landslides in eastern Ethiopia

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude
22 Sep	02 25 53.5	Sichuan Province, China	31.545 N	102.464 E	6.0 mb, 6.1 Ms

Depth 33 km. At least 54 people injured, about 4, 270 houses destroyed, more than 300 animals killed and damage caused to bridges, highways and a phosphorms mine in the Xiaojin area.

18 Oct	00 04 15.2	Central California	37.036 N	121.883 W	6.6 mb, 7.1 Ms 7.0 ML(BRK)

Depth 19 km. Mo=4.0*10**19 Nm(PPT). At least 62 people killed, about 3200 injured and an estimated 5.6 billion dollars damage in the San Francisco Bay area and in the Santa Cruz-Hollister area. Numerous landslides occurred in the epicentral area and liquefaction occurred in some parts of Oakland and San Francisco. Felt from Eureka to Los Angeles and east as far as Fallon, Nevada. Also felt in high-rise buildings in San Diego. A small Tsunami with maximum wave height (peak-to-trough) of 49 cm was recorded at Monterey.

18 Oct	14 57 22.3	Northeastern China	39.900 N	113.841 E	5.2 mb, 5.4 Ms

Depth 10 km. At least 29 people killed, 34 injured and about 27,500 houses damaged in the Datong-Yangyuan area. Also felt at Beijing.

27 Oct	21 04 52.4	Solomon Islands	10.998 S	162.382 E	6.1 mb, 7.1 Ms 7.1 Ms(BRK)

Depth 29 km. Mo=3.0*10**19 NM(PPT). Felt at Honiara and on San Cristobal. Minor landslide and ground fissure reported on Santa Catalina.

29 Oct	19 09 13.4	Algeria	36.785 N	2.449 E	5.8 mb, 5.9 Ms

Depth 10 km. At least 30 people killed, 245 injured and damage in the Cherchell- Tifaza area. Felt in Algiers. Also felt (IV) in the Balearic Islands, Spain.

01 Nov	18 25 35.9	Near East Coast of Honshu, Japan	39.798 N	142.835 E	6.3 mb, 7.3 Ms

Depth 38 km. Mo=1.3*10**20 Nm(PPT). Felt (IV JMA) at Aomori and Moriaka; (III JMA) at Misawa; (I JMA) at Yamagata. Also felt (I JMA) in parts of Hokkaido. Tsunami generated with wave heights 56 cm at Miyako, 34 cm at Ayukawa, 24 cm at Hachinahe and 28 cm at Ofunato.

20 Nov	03 21 07.9	Sichuan Province, China	29.876 N	106.825 E	5.1 mb

Depth 33 km. Four people killed, 161 injured and at least 1,000 homes destroyed in Jiangbei County.

TABLE 7 (cont.)

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude
20 Nov	04 19 06.4	Southern Iran	29.811 N	57.691 E	5.6 mb, 5.5 Ms

Depth 33 km. At least 3 people were killed, 45 injured and damage in the Shahdad area.

15 Dec	18 43 46.0	Mindanao, Philippine Islands	8.393 N	126.778 E	6.1 mb, 7.4 Ms 7.4 Ms(BRK)

Depth 33 km. Mo=4.0*10**20 Nm(PPT). Two people killed and many injured on Mindanao. Damage (VII RF) in the Bislig area. Slight damage (VI RF) at Davao. Felt (VI RF) at Catabato and (I RF) at Dipalog. Also felt (IV RF) on Camiguin, (III RF) on Cebu and (I RF) in southeastern Luzon.

27 Dec	23 26 56.7	Near S.E. Coast of Australia	32.948 S	151.635 E	5.5 mb 5.5 ML(CNB)

Depth 10 km. Thirteen people killed, 120 injured and severe damage in the Newcastle area. Felt strongly at Sydney and also felt at Canberra, Orange and Kempsey. This is the first time an earthquake is known to have caused fatalities in Australia.

Table 8. Underground Nuclear Explosions, 1989

Date	Time UTC	Latitude	Longitude	MB	Ms	Site*	Ref¤	Comments
Jan 22	035706.5	49.915N	78.857E	6.0	4.5	EKaz	PDE	
Feb 10	200600.0	37.077N	116.001W	5.2		NTS	PDE	"texarkana"
Feb 12	041506.7	49.895N	78.758E	5.9	4.4	EKaz	PDE	
Feb 17	040106.8	49.877N	78.126E	5.0		EKaz	PDE	
Feb 24	161500.0	37.128N	116.122W	4.4§		NTS	PDE	"kawich"<20 kt
Mar 09	140500.0	37.143N	116.067W	4.9		NTS	PDE	"ingot"
May 11	164458.1	21.881S	138.978W	5.6		Mur	PDE	
May 15	131000.0	37.073N	116.080W	4.4		NTS	PDE	"palisade" <20 kt
May 20	175900.0			4.1		Mur	ASAR	<10kt
May 26	180700.0			§		NTS	PDE	"tulia"<20kt
Jun 03	172958.4	21.835S	138.996W	5.3		Mur	PDE	
Jun 10	172958.2	22.252S	138.734W	5.5		Fan	PDE	
Jun 22	211500.8	37.183N	116.412W	5.3		NTS	PDE	"contact"
Jun 27	153000.0	37.275N	116.354W	4.9		NTS	PDE	"amarillo"
Jul 08	034657.6	49.888N	78.802E	5.6	4.1	EKaz	PDE	
Sep 02	041657.3	50.039N	79.019E	5.0		EKaz	PDE	
Sep 14	150000.1	37.236N	116.163W	4.2§		NTS	PDE	"diskoelm"
Oct 04	112957.6	49.746N	78.013E	4.6		EKaz	PDE	
Oct 19	094957.2	49.937N	78.972E	6.0	4.5	EKaz	PDE	
Oct 24	162958.1	21.908S	138.977W	5.4		Mur	PDE	
Oct 31	153000.0	37.263N	116.491W	5.7		NTS	PDE	"hornitos"
Oct 31	165658.5	21.826S	138.910W	5.2		Mur	PDE	
Nov 15	202000.1	37.107N	116.013W	§		NTS	PDE	"muleshoe"
Nov 20	172858.3	21.851S	138.964W	5.3		Mur	PDE	
Nov 27	165958.0	22.276S	138.836W	5.6	4.0	Mur	PDE	
Dec 08	150000.0	37.231N	116.409W	5.5	4.2	NTS	PDE	"barnwell"

* NTS Nevada Test Site, USA; Mur/Fan Mururoa/Fangataufa, French Polynesia
Ekaz East Kazakhstan, USSR; ASAR Alice Springs Array, Australia.
¤ PDE Preliminary Determination of epicentres, USA.
§ 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.