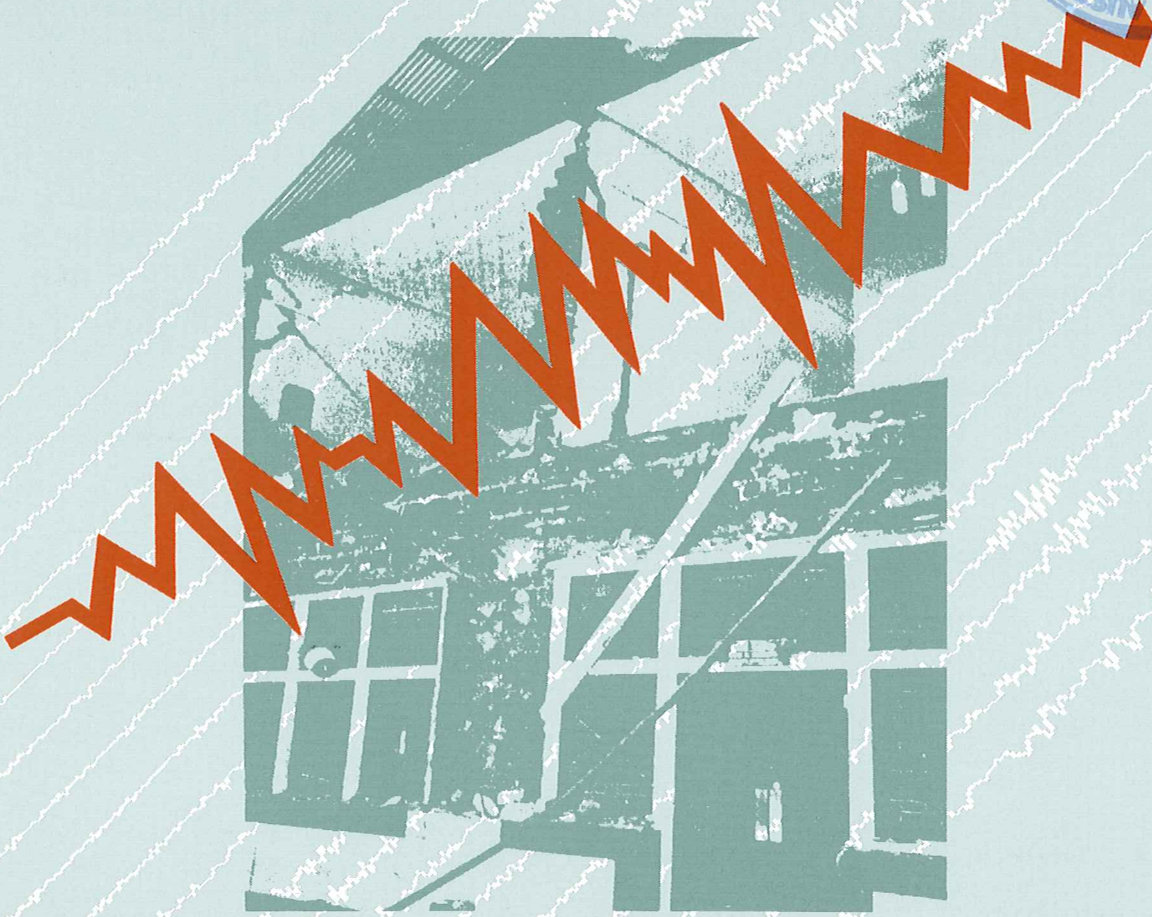
EARTHQUAKES 15

AGSO
AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

Australian Seismological Report, 1994

Kevin McCue and Peter Gregson



Record 1996/19

Geophysical Observatories and Mapping

Department of Primary Industries and Energy

AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

RECORD 1996/19

AUSTRALIAN SEISMOLOGICAL REPORT, 1994

Compiled by
Kevin McCue & Peter Gregson

AUSTRALIAN GOVERNMENT PUBLISHING SERVICE
CANBERRA

DEPARTMENT OF PRIMARY INDUSTRIES AND ENERGY

Minister for Primary Industries and Energy: Hon. J. Anderson, M.P.
Minister for Resources and Energy: Senator the Hon. W.R. Parer
Secretary: Paul Barratt

AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

Executive Director: Neil Williams

ISSN: 1039-0073
ISBN: 0 642 24957 1

Contributors

Contributors to this publication are listed below according to the information furnished or service performed:

Hypocentres and magnitudes

R. Cuthbertson, University of Queensland, Brisbane, Qld
V. Dent, AGSO, Mundaring Geophysical Observatory, Mundaring, WA
G. Gibson, Seismology Research Centre RMIT, Bundoora, Vic
P.J. Gregson, AGSO, Mundaring Geophysical Observatory, Mundaring, WA
International Seismological Centre (ISC), Newbury, UK
T. Jones, AGSO, Canberra, ACT
D. Love, Sutton Institute of Earthquake Physics, MESA, SA
K. McCue, AGSO, Canberra, ACT
M. Michael-Leiba, AGSO, Canberra, ACT
National Earthquake Information Service, US Geological Survey (USGS), Boulder, Colorado, USA
E.P. Paull, AGSO, Mundaring Geophysical Observatory, Mundaring, WA
J. Pongratz, University of Tasmania, Hobart, Tas
G. Small, AGSO, Canberra, ACT
V. Wesson, Seismology Research Centre RMIT, Bundoora, Vic

Intensities

R Cuthbertson, University of Queensland, Brisbane, Qld
G Gibson & A Pascale, Seismology Research Centre, RMIT, Melbourne, Vic
P Gregson, T Jones & E Paull, AGSO Mundaring & Canberra, WA & ACT
D Love & A McArdle, Sutton Institute of Earthquake Physics, MESA, SA

Network operations (by institution)

Australian Seismological Centre, Australian Geological Survey Organisation, Canberra, ACT (AGSO), and Mundaring, WA (MUN)
Central Queensland University, Rockhampton, Qld (CQU)
Research School of Earth Sciences, Australian National University, Canberra, ACT (CAN)
Seismology Research Centre, Royal Melbourne Institute of Technology, Bundoora, Vic (PIT)
St Ignatius College, Riverview, NSW (RIV)
Sutton Institute of Earthquake Physics, MESA, Adelaide, SA (ADE)
University of Queensland, Brisbane, Qld (UQ)
University of Tasmania, Hobart, Tas (TAU)

Strong-motion data

V Dent, & P Gregson AGSO, Mundaring Geophysical Observatory, Mundaring, WA
G. Gibson & V. Wesson, Royal Melbourne Institute of Technology, Bundoora, Vic
K. McCue & T Jones, AGSO, Canberra, ACT
D Love, Sutton Institute of Earthquake Physics, MESA, SA

Nuclear monitoring

K. Muirhead, S. Spiliopoulos, D Jepsen, M Leonard, C Sinadinovski, J Palmer, L Hodgson, W Penders, A Bullock, K Bevan

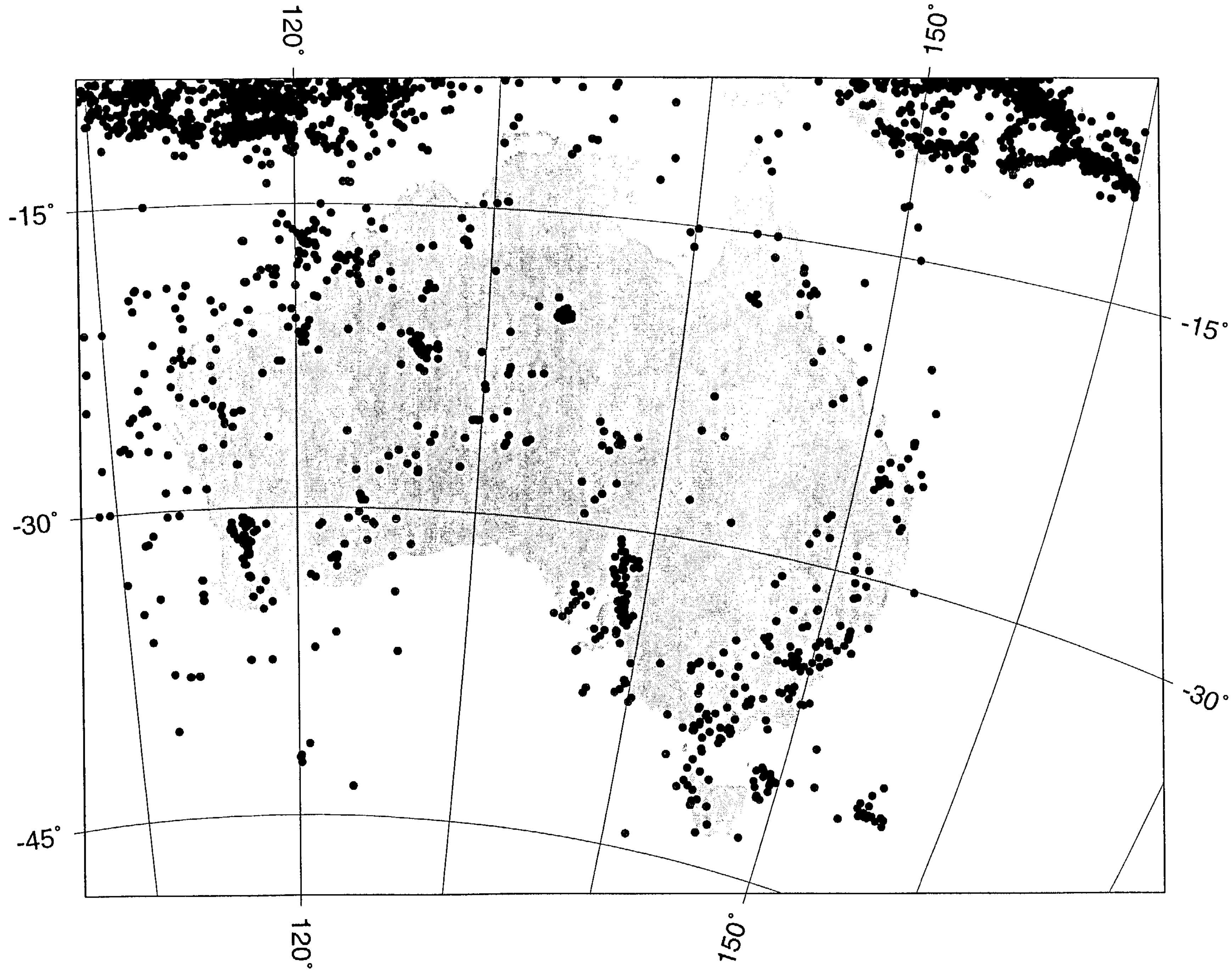


Figure 1. Epicentres of Australian earthquakes, 1873–1993, magnitude ML ≥ 4.0.

CONTENTS

Tables

Figures

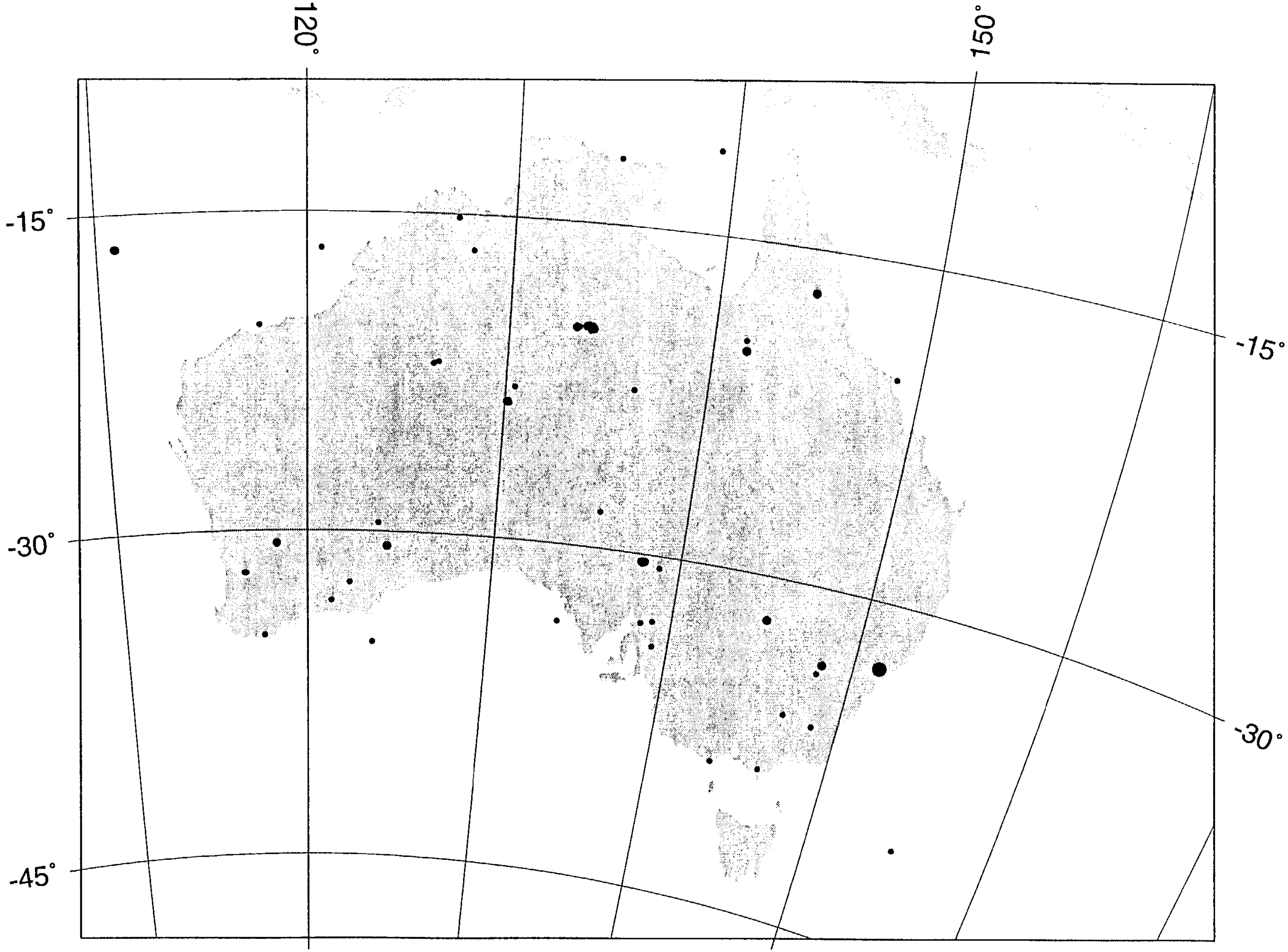


Figure 2 Epicentres of Australian earthquakes, 1994, magnitude ML ≥ 3.0. The small dots are magnitude 3.0 to 3.9, the medium dots magnitude 4.0 to 4.9, and the large dot magnitude 5 or greater.

SUMMARY

The largest and most damaging earthquake in Australia in 1994 was at Ellalong near Cessnock NSW on 6 August. This shallow magnitude ML 5.3 earthquake caused no deaths or serious injuries but badly damaged some buildings in Ellalong, Paxton and Wallaby Gully. Minor damage was widespread and claims totalling about $34M were lodged with insurance companies. After the shaking had ceased, patrons at the Ellalong Hotel reportedly resumed their socialising despite damage to the hotel and the loss of power - it is reported that they thought it must have been another Newcastle earthquake and expressed sympathy with their neighbours! Not all the population coped this way of course, many people were frightened or distressed.

The earthquake triggered recently installed digital accelerographs in the Sydney and Newcastle regions and a most useful dataset was obtained in the distance range 39 to 350 km. The focal depth was less than 5 km yet there were few if any aftershocks and none above magnitude 1.0.

Intensity questionnaires were distributed for thirteen earthquakes that were widely felt and isoseismal maps were compiled for the earthquakes at: Albury, Mount Mitchell, Ellalong and Eugowra NSW, Bonnie Rocks, Salmon Gums and Talbot Brook in WA, Whitsunday, Numil Downs and Chillagoe Qld, Frances and Eudunda SA, and Gungahlin in the ACT. Several earthquakes were felt by ANARE personnel at Macquarie Island during the year.

Earthquake swarms were a feature of the year's activity, not just the widely publicised Eugowra NSW swarm which brought the whole population to a public meeting in the town - such was their concern, but at Talbot Brook near York in WA and then Myrtle Springs in South Australia. No serious damage was reported, the swarms are enigmatic but provide a convenient natural laboratory for studying the earthquake process at close range.

At least 1100 people died in 1994, far fewer than the average number of earthquake fatalities of 10 000 per year since 1900. Worldwide there were two 'great' earthquakes and 11 'major' earthquakes. Unusual for its great depth was the magnitude Mw 8.2 earthquake under Bolivia which caused widespread landslides in South America but little structural damage. Ten tsunamis were reported, one on 17 September caused by the eruption of Tavurvur and Vulcan volcanoes in Rabaul Harbour, the other nine caused by earthquakes. A tsunami caused by the earthquake on 2 June south of Jawa Indonesia killed at least 250 Indonesians and propagated south to lash the North-Western Australian coastline where it caused a minor oil spill.

During 1994, two underground nuclear explosion were detonated by China at the Lop Nor test site on 10 June and 7 October. Other nuclear weapons States abided by a self-imposed moratorium on testing in recognition of the changed international political climate.

INTRODUCTION

Each year in Australia there are on average one earthquake of magnitude 5.3 or greater and about 200 of magnitude 3 or greater, excluding aftershocks. The larger ones are a threat to life and property as was so tragically demonstrated by the 1989 Newcastle earthquake. Analysis of the small ones will yield clues to the cause, location and style of future large ones. This report contains information on the 1994 earthquakes and is the fifteenth compiled by the Australian Geological Survey Organisation (and its predecessor BMR) since 1980. Its purposes are to aid the study of earthquake risk in Australia, and to provide information on Australian and world earthquakes for scientists, engineers and the general public.

The report has six main sections: **Australian region earthquakes** which contains a summary of the 1994 seismicity with a State by State breakdown and a brief description 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 1994; and **Monitoring of nuclear explosions** which describes the operation of the Nuclear Monitoring Section and lists known underground nuclear explosions. A new section on **tsunamis** has been added.

In this 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 as a magnitude 5 earthquake, but an energy release about 30 times greater.

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

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

Shocks as small as magnitude 1.0 are reported felt, whereas earthquakes of magnitude 5 or more may cause significant damage if they are shallow and close to buildings. *Great, major, large,* and *moderate* are terms used to describe earthquakes above magnitude 8, 7, 6 and 5 respectively whilst *small* and *micro-earthquake* are terms used for magnitudes below 5 and 3 respectively. The following magnitude scales are in common use.

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

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

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

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

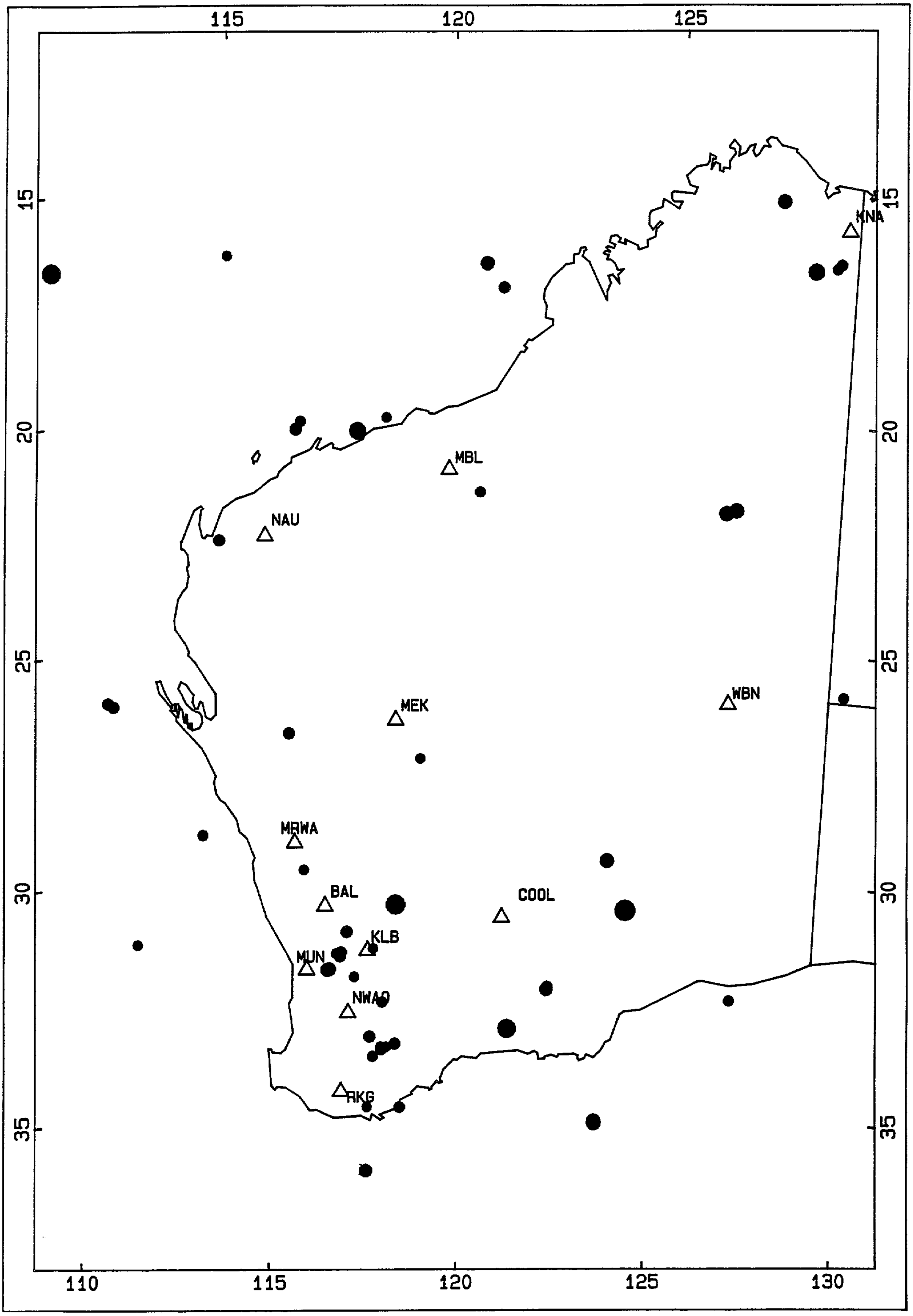


Figure 3 Epicentres of earthquakes in Western Australia 1994, magnitude ML ≥ 2.5.
In figures 3 to 8, the dots are epicentres (ML 2.5 to 5.3), the triangles are seismographs.

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

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

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

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

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

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

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

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

where t is the length of the earthquake coda in seconds (usually from the initial P onset), Δ is the distance from the epicentre, and a, b, and c are constants for a particular recording station. This is a most convnient way to measure magnitude and many other forms of this equation have been used. It is usually calibrated against Richter magnitude.

Seismic moment magnitude (Mw) Kanamori (1978) defined a world magnitude scale Mw from the seismic moment M_o

$$M_o = \mu A d$$

and

$$Mw = (\, log M_o) / 1.5 - 6.0$$

where μ is the rigidity of the bedrock, A the fault area displaced, and d the average slip on the fault. M_o is the amplitude of the force couple across the fault and is proportional to the amplitude of the far-field ground displacement at low frequencies.

Magnitude from isoseismals (M (Rp)) 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

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

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 approximately equivalent to ML below magnitude 6, and to Ms above magnitude 6. Greenhalgh & others (1989) modified the equation using a larger data

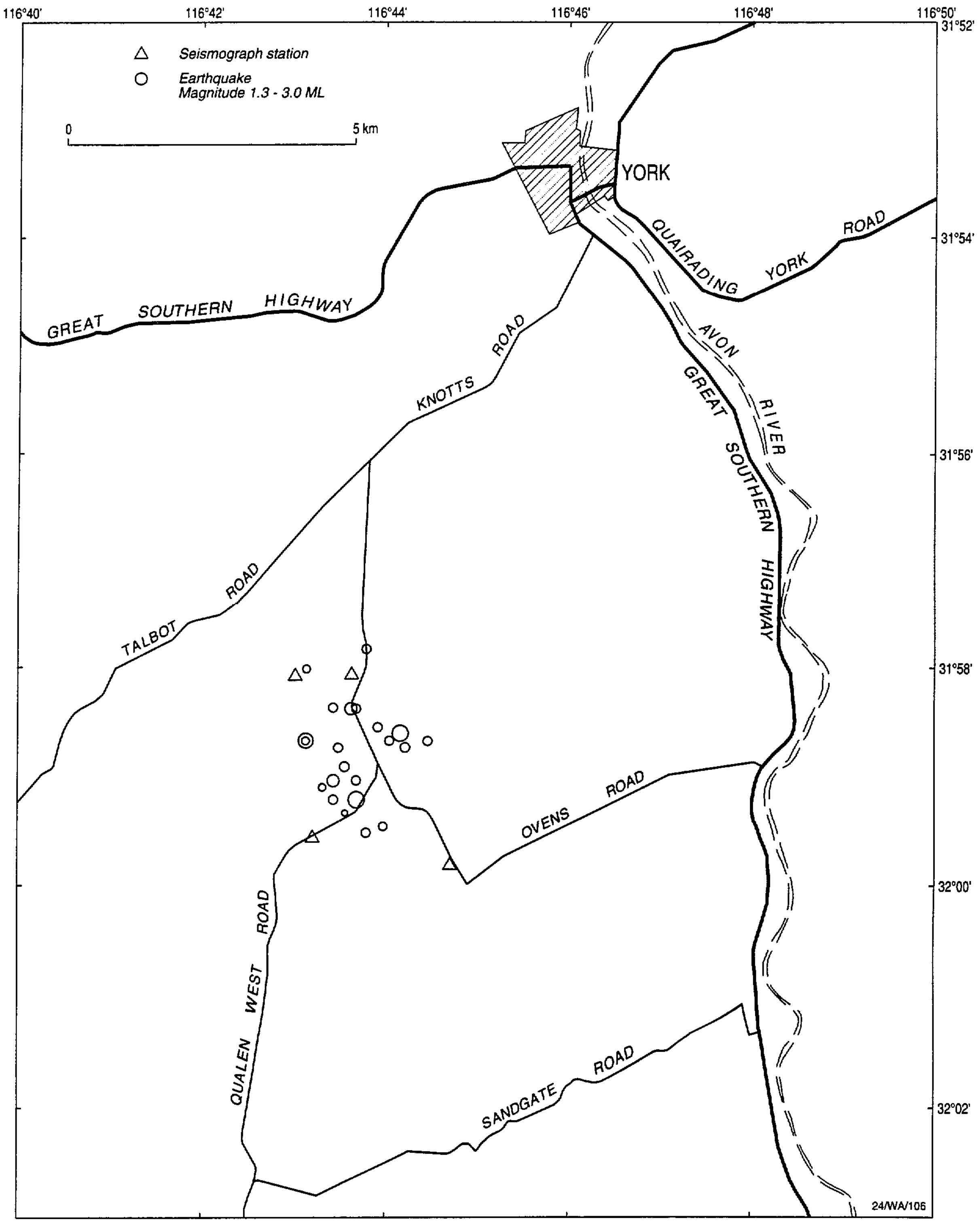


Figure 3a Epicentres of earthquakes in the swarm near York Western Australia in November 1994

set and extended the method to other intensities, but at the expense of simplicity in application. They derived the expression:

$$M(Rp) = 0.35\,(\pm 0.12)(\log Rp)^2 + 0.63\,(\pm 0.41)(\log Rp) + 1.87\,(\pm 0.36)$$

Additional information on magnitudes is available in McGregor & Ripper (1976), Båth (1981), and Denham (1982).

Intensity

The intensity of an earthquake is a subjective estimate of its effects on people and buildings and should not be confused with magnitude which is a measure of the amplitude of seismic waves recorded on a seismogram. In this report we use the modified Mercalli (MM) scale (Eiby (1966) 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, 1994

Earthquakes of magnitude ML 3 or more recorded in 1994 on AGSO's National Seismographic Network stations are listed in Table 1, those of ML 4 or more are plotted from the earthquake database in Figure 2. The largest earthquake in Australia was the magnitude ML 5.3 event near Ellalong NSW situated about 50 km west-southwest of Newcastle. Details of the earthquake are described in later sections on the NSW seismicity, and under the intensity section. No buildings collapsed and damage was light in comparison with the 1989 earthquake near Newcastle though the insurance bill is reported to have topped $34M.

The focal depth was less than 5 km which may still put it under rather than in the sediments of the Sydney Basin, like the deeper 1989 earthquake only 20 km to the east. The focus is beneath a 700 m deep long-wall coalmine in which horizontal stresses as high as 38 Mpa have been measured. In the mine, ground-heave and wall and roof collapse are reportedly common, as might be expected with such high near-surface crustal stresses. A number of small magnitude 3 to 3.5 seismic events occurred in the area in the 12 months before the earthquake and these were attributed at the time to the mining activity. They are reported to have caused damage in and close to the mine. A re-asessment of these events is underway.

The temporary monitoring equipment was being removed from Ellalong when a swarm of small earthquakes was reported from Eugowra near Parkes NSW (Gibson & others, 1995). The swarm had started at least as early as 24 July with a magnitude ML 2.2 earthquake which was recorded at Canberra. The portable seismographs were relocated around Eugowra by SRC and AGSO seismologists to determine the geographical extent of the activity and to measure the ground motion. The swarm culminated in a magnitude ML 4.0 earthquake and then slowly waned but the episode caused great anxiety amongst town residents, some of whom took refuge elsewhere until the earthquakes stopped. Strong ground accelerations approaching 1 g were recorded near the epicentre. Further details are reported elsewhere in this report, under the NSW State section, the isoseismal map description and in Table 6 summarising parameters of the accelerograms.

Another swarm of earthquakes occurred during November and December in a localised shallow crustal volume 13 km from York WA, far enough for no damage to have resulted. AGSO's Mundaring group installed portable seismographs in the region for the duration of

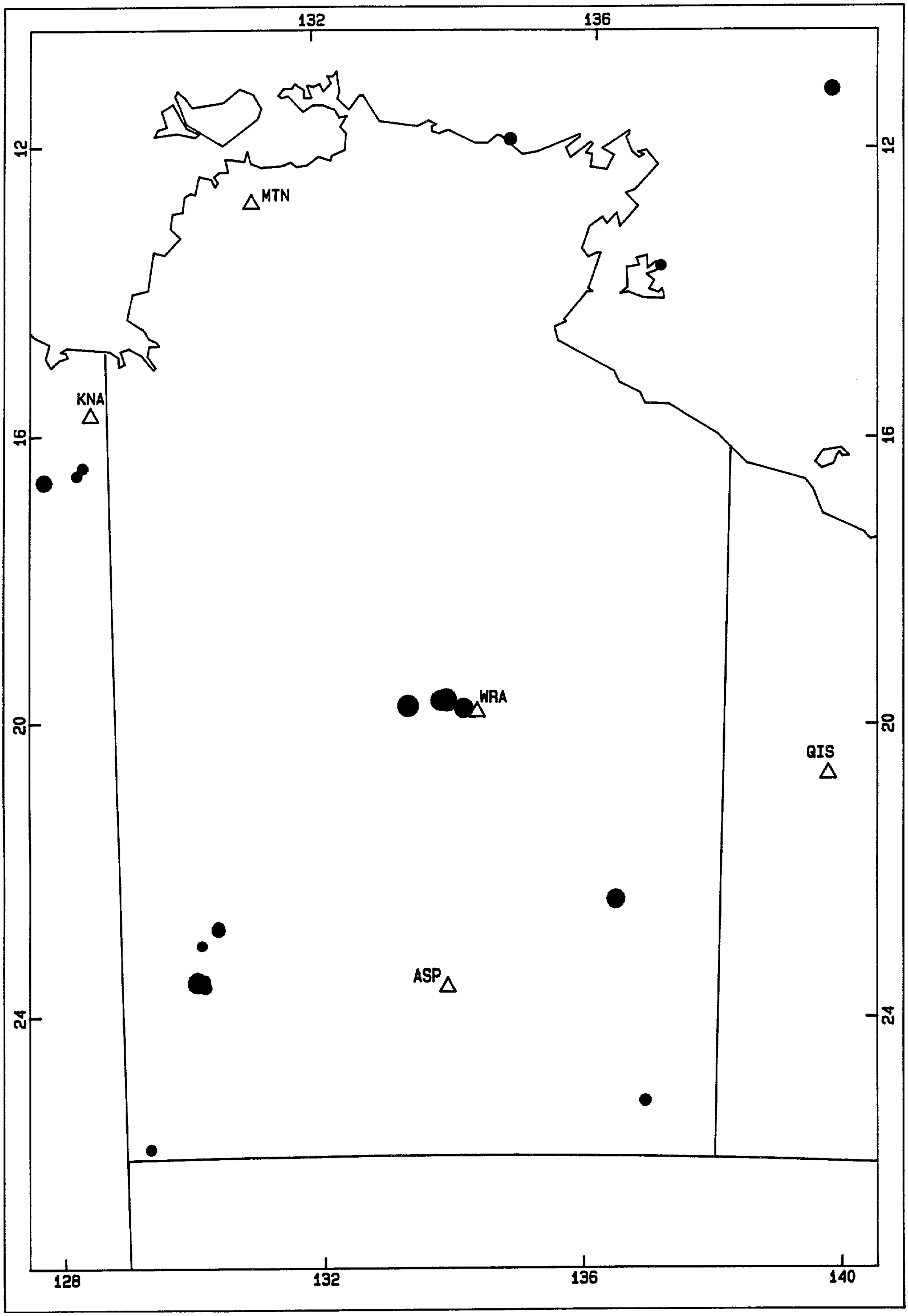


Figure 4 Epicentres of earthquakes in the Northern Territory 1994, magnitude ML ≥ 2.5.

the swarm and a report is included later. The sequence was not as energetic as that near Eugowra NSW.

A third swarm of earthquakes occurred near Myrtle Springs SA in November and December and again there was no damage. This swarm was the most energetic of the three with the larger two events exceeding magnitude 3.9, the largest had a magnitude of 4.2

The Tennant Creek NT aftershock sequence which began in 1988, continued throughout the year but none of the earthquakes were reported felt in the town of Tennant Creek.

Compared with a post-1980 yearly average of one earthquake of magnitude 5.3 or more, 21 of magnitude 4 or more and more than 200 of magnitude 3.0 or more, there were 1, 14 (5) and 67 (21) respectively in 1994. The numbers in brackets are afteshocks at Tennant Creek NT and are in addition to the independent total given first. The year's seismicity was somewhat below average.

Kevin McCue

Western Australia (Figure 3)

The level of seismic activity in Western Australia was slightly higher than for 1993. One hundred and ninety one events of magnitude ML 1.9 were located (as against 173 in 1993). The largest earthquake had a magnitude of ML 4.3 and was located 75 km ENE of Zanthus. There were in total four earthquakes of magnitude 4.0 or greater, two more than for 1992. Three isoseismal maps were prepared for earthquakes at Bonnie Rock (ML 4.1 on 26 April), Salmon Gums (ML 4.0 on 11 October), and Talbot Brook (ML 3.0 on 23 November).

The Southwest Seismic Zone was the most active area with 104 earthquakes compared with 76 in 1993. The largest (ML 4.1) was that near near Bonnie Rock. A swarm of more than 60 earthquakes ranging in magnitude from 0.6 to 3.0 occurred near York in a two week period in November (see below and the report in Gregson and others, 1995). Meckering continued to be active with 14 earthquakes. Sixteen earthquakes occurred in an area 12 km west of Wyalkatchem and 14 approximately 12 km south of Nyabing. Minor activity occurred throughout the zone.

Fifteen earthquakes were recorded offshore, ranging from Dampier in the northwest to Esperance in the south. Activity in the Lake Tobin area in the remote Gibson Desert region continued to decrease from the 1992 level with only 3 earthquake being recorded.

Six earthquakes occurred in the Halls Creek Mobile Belt mainly 80 to 90 km south of Kununurra. The largest (ML 3.6) was located near Turkey Creek.

<u>Swarm near York, November 1994</u> A significant swarm of microearthquakes occurred about 12 km south-southwest of York (about 90 km east of Perth) in November 1994 (Figure 3b). Residents in the area reported feeling 50 tremors per day or more at the peak of the activity and the tremors attracted considerable media attention in Perth. The largest event at magnitude ML 3.0 was felt at intensity MM V - VI in the epicentral area and caused some alarm in the immediate epicentral area. The maximum intensity at York was MM III.

Most of the felt events were so small that only 19 of them ranging in magnitude from ML 1.3 to ML 3.0 could be located in the two weeks of intense monitoring. The swarm commenced with two relatively small events on 16 and 17 November (ML 1.7 and 1.9), a period of no activity, and numerous microearthquakes between 22 and 25 November. Activity then tailed off rapidly. Occasional small felt events occurred for the next 6 months after 29 November, but the only event large enough to be located in this period was an ML 1.7 event on 13 December.

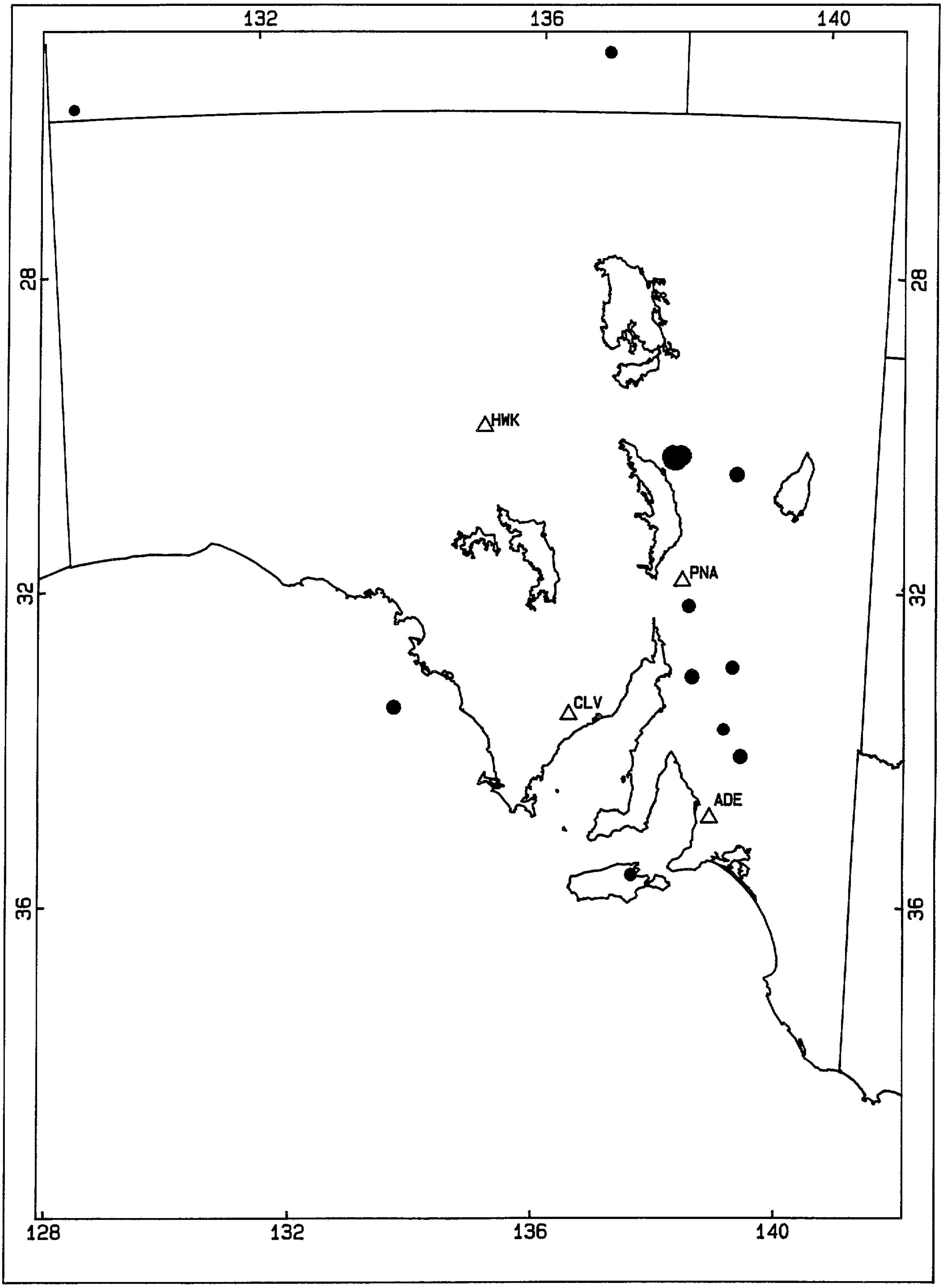


Figure 5 Epicentres of earthquakes in South Australia, 1994, magnitude ML ≥ 2.5.

Portable digital seismographs were deployed in the area within 6 hours of this event, and were operated until 1 December 1994. This assisted in improving the accuracy of the locations of many of the events, although only a handfull of events were recorded on more than one of the temporary recorders. The seismograph internal clock was calibrated using an Omega time signal receiver. The clock rates were too large to provide high resolution clock corrections, and the observed S-P intervals were the most useful feature in providing improved event location accuracy.

The best located events appeared to be less than 2 km deep, (on the basis of an S-P interval of 0.1 seconds) and to be confined within an epicentral zone of about 2 km diameter. Any linearity within this zone may be a function of the distribution of the seismographs. An accelerograph was set up in the area for a week towards the end of the activity. Three microearthquakes were recorded, the largest magnitude ML 1.3. The maximum acceleration of 140 mms^{-2} was recorded at a distance of 1 km from the ML 1.3 event.

A similar swarm occurred in the area in April - May 1966. The largest event in that swarm was ML 3.2 (on 1/5/1966).

Victor Dent

Northern Territory (Figure 4)

The largest earthquake in the aftershock sequence near Tennant Creek that has continued from January 1988 had a magnitude of 4.5; it occurred on 31 August. The epicentre was located about 50 km, or more than a fault length, west of the western end of the mapped fault scarp that ruptured in 1988 (Jones & others (1991).

Most of the remaining 23 aftershocks of magnitude 3 or more were scattered along the length of the 1988 surface rupture, some of them were nearer the Warramunga Array (WRA), a short distance off the eastern end.

Other isolated earthquakes occurred in Arnhem Land east of Darwin, and both east and west of Alice Springs. None of these were reported felt.

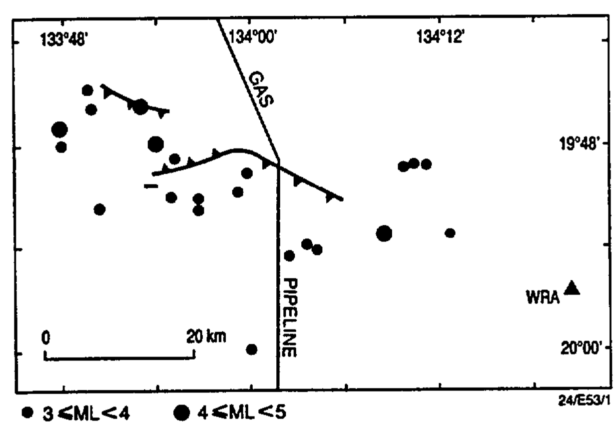


Figure 4a 1988 fault scarp and aftershocks

Kevin McCue

South Australia (Figure 5)

Apart from a swarm of events at Myrtle Springs Homestead west of Leigh Creek, activity was low this year. Only 287 events were located of which about 70 were in the swarm. There were 12 felt events and 19 events over magnitude 3. Two isoseismal maps were produced, one of them for a magnitude 3.2 earthquake at Eudunda in the Barossa Valley which was widely felt, and which triggered the two strong motion instruments in Adelaide where it was slightly felt.

During August amd September some activity began between Leigh Creek and Lake Torrens (slightly west of the northern Flinders Ranges). A magnitude 4.0 event on 30 November lead to a vigorous aftershock or swarm sequence during December. Three accelerographs intended for the joint (MESA/AGSO) urban monitoring program had been delivered, and these were despatched to the area. Events of magnitude 4.0, 3.8 and 3.5 were recorded at a distance of about 17 km. The events were not widely or strongly felt, but there were

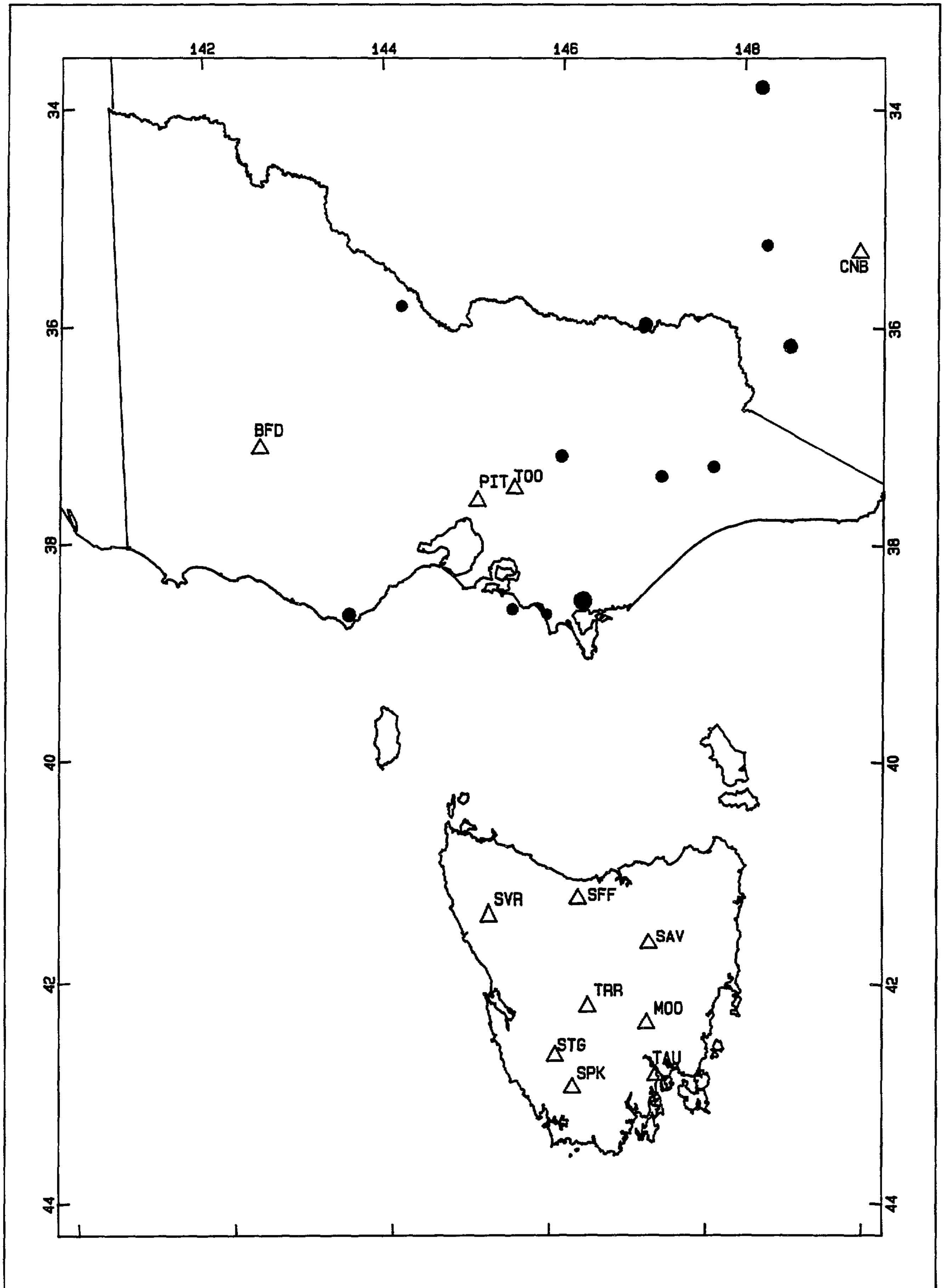


Figure 6 Earthquake epicentres in Victoria and Tasmania 1994, ML ≥ 2.5.

reports from Woomera (150 km away) for the two largest events (magnitude 4.0 and 3.6). This was the largest event in South Australia since 1990.

An isolated earthquake occurred off the coast south of Ceduna where there have been few if any earlier events.

David Love

Victoria & Tasmania (Figure 6)

A magnitude ML 3.7 earthquake occurred in the East Bass Strait Seismic Zone on 28 June, near a large guyot in the Tasman Sea but neither it nor any other Tasmanian earthquakes were felt.

The two largest earthquakes in Victoria in 1994 were at Boolarra South in the Strzelecki Ranges of South Gippsland on 1 February which had a magnitude of ML 3.8, and at Cape Otway on 14 May which had a magnitude of ML 3.0. The Boolarra South earthquake was reportedly heard and felt over a wide area including Foster, Morwell River and Toora and was the largest in Victoria since 1987. Many of the microearthquakes were felt locally (for details see the SRC monthly reports).

Gary Gibson, Wayne Peck & Kevin McCue

New South Wales and ACT (Figure 7)

NSW was the most active State with the damaging earthquake at Ellalong on 8 August and an extensive swarm at Eugowra from late July to the end of September. Seismologists from AGSO and the Seismology Research Centre at RMIT installed recorders in the epicentral regions to monitor aftershocks.

Whether the tiny events recorded near Ellalong after the mainshock were aftershocks or mine subsidence events is debatable. None of them was larger than magnitude 1.0. Activity did abate when mining ceased to enable clearing of rock that had collapsed onto the underground access roads after one of them. The mainshock did not give rise to similar collapses (Jones & others, 1995).

At Eugowra hundreds of events were felt in the town and many more were recorded on the seismographs. The swarm eventually abated without the damaging earthquake feared by many of the residents. The largest event in the swarm had a magnitude of ML 4.0 and caused minor damage to buildings in Eugowra where some brick walls were cracked (Gibson & others, 1994).

Earthquakes of magnitude 3 or more occurred near Belaraboon and Albury. The latter was widely felt but caused no appreciable damage though insurance companies reported receiving claims for minor damage in Albury. The Belaraboon earthquake had a magnitude of ML 4.2, the equal second largest in NSW in 1994 but it was not reported felt. Other small earthquakes near Sydney and Eucumbene dam were felt locally.

The Dalton-Gunning Seismic Zone was very quiet throughout the year with only 5 microearthquakes exceeding magnitude 1.9, the largest of them only magnitude ML 2.3. Their epicentres were close enough to Dalton that several were reported felt.

In the ACT, a very shallow magnitude 1.7 microearthquake on 6 September was felt in some of the northern suburbs of Canberra. Several similar sized events have been recorded in the Capital over recent years.

Kevin McCue, Trevor Jones and Marion Leiba

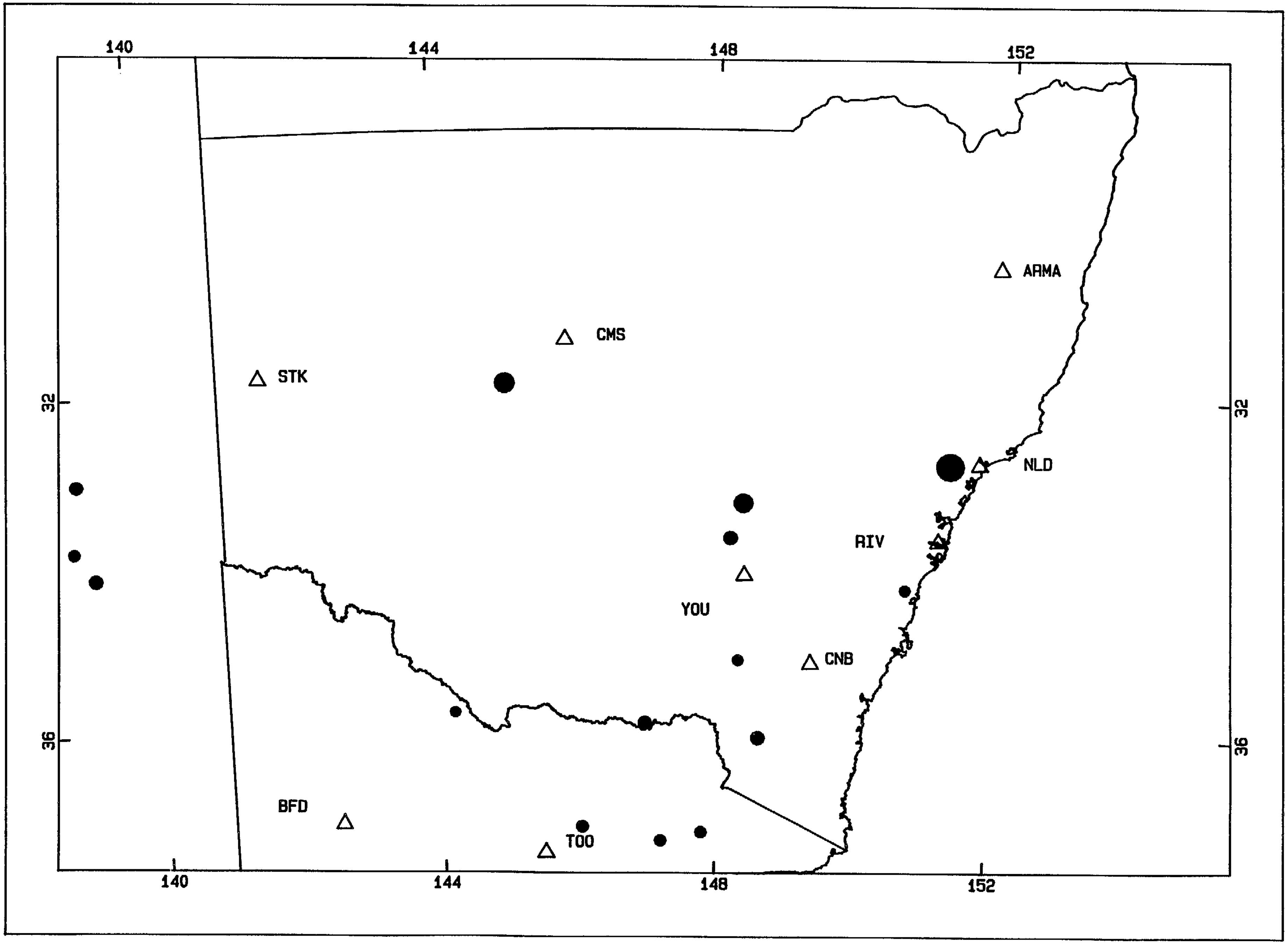


Figure 7 Epicentres of earthquakes in NSW and ACT 1994, magnitude ML ≥ 2.5.

Queensland (Figure 8)

1994 saw activity scattered throughout the State with earthquakes at Julia Creek in the north-west, at Innisfail and Chillagoe in the north, and at St George, Goondiwindi and Inverell in the south. There were seven earthquakes of magnitude 3.0 or more. A small magnitude ML 3.0 earthquake in the WhitSunday Islands shook holiday makers at the Hayman Island tourist resort and another occurred in the Gulf of Carpentaria.

Russell Cuthbertson

NETWORK OPERATIONS 1994

Major changes took place in the National Seismographic Network in 1994 following in-house development of a satellite telemetry system designed by Ken Muirhead. In all, eleven of these systems were installed, six in Eastern Australia (at Young, Stephens Creek and Armidale NSW, Mount Isa and Charters Towers Qld, and Toolangi Vic), and another five in Western Australia (at Woolibar, Forrest, Fitzroy Crossing, Meekatharra and Warburton). Only the Fitzroy Crossing station is a new site which closes a large hole in AGSO's national detection capability. At most sites, triaxial broad-band seismometers were installed in bore-holes or vaults prepared in previous years.

Following a request fom the Incorporated Research Institutions for Seismology (IRIS), plans were initiated at AGSO to install IRIS stations at Casey and Macquarie Island Antarctica, and Marble Bar WA. Construction of the Casey vault commenced in the 1994 Summer under the Antarctic Division's guidance and with their approval of the Environmental Impact Statement. The Macquarie Island borehole will be drilled by the successful New Zealand tenderer in the 1995 Summer season. Existing IRIS (or IDA) stations are at Charters Towers Qld, Narrogin WA, Hobart Tas, and Tennant Creek NT.

In Western Australia, satellite links were installed at Forrest, Meekatharra and Warburton. The latter was upgraded from a single component vertical seismometer to a three component broad band Guralp seismometer. The station at Coolgardie was relocated to Woolibar and upgraded to a three component broadband Guralp seismometer. A new station was installed at Fitzroy Crossing after Aboriginal land rights issues were resolved. A three component broad band Guralp seismometer was lowered 20m to the bottom of a borehole drilled the previous year in a limestone ridge north of the town.

The removal of the Tully-Millstream network in north-east Queensland has downgraded the locating capability in this area but the instruments were installed late in 1994 in a dense network in south-east Queensland.

Graeme Small, Peter Gregson, Kevin McCue and Russell Cuthbertson

Urban Monitoring

During the second year of a three year program to upgrade earthquake monitoring of Australian cities where human vulnerability to earthquakes is highest, two accelerographs were installed in each of the following cities: Sydney, Melbourne, Adelaide Perth, Newcastle, Rockhampton and Launceston. Sites were chosen to monitor the response of differing soil foundations. In Perth the sites were at Trinity College which is built on alluvium and fill, and at Kings Park which is on limestone.

This is a joint program between Commonwealth, State, Territory and Local Governments which has already been rewarded with the recording of local earthquakes in Sydney, Newcastle, and Adelaide.

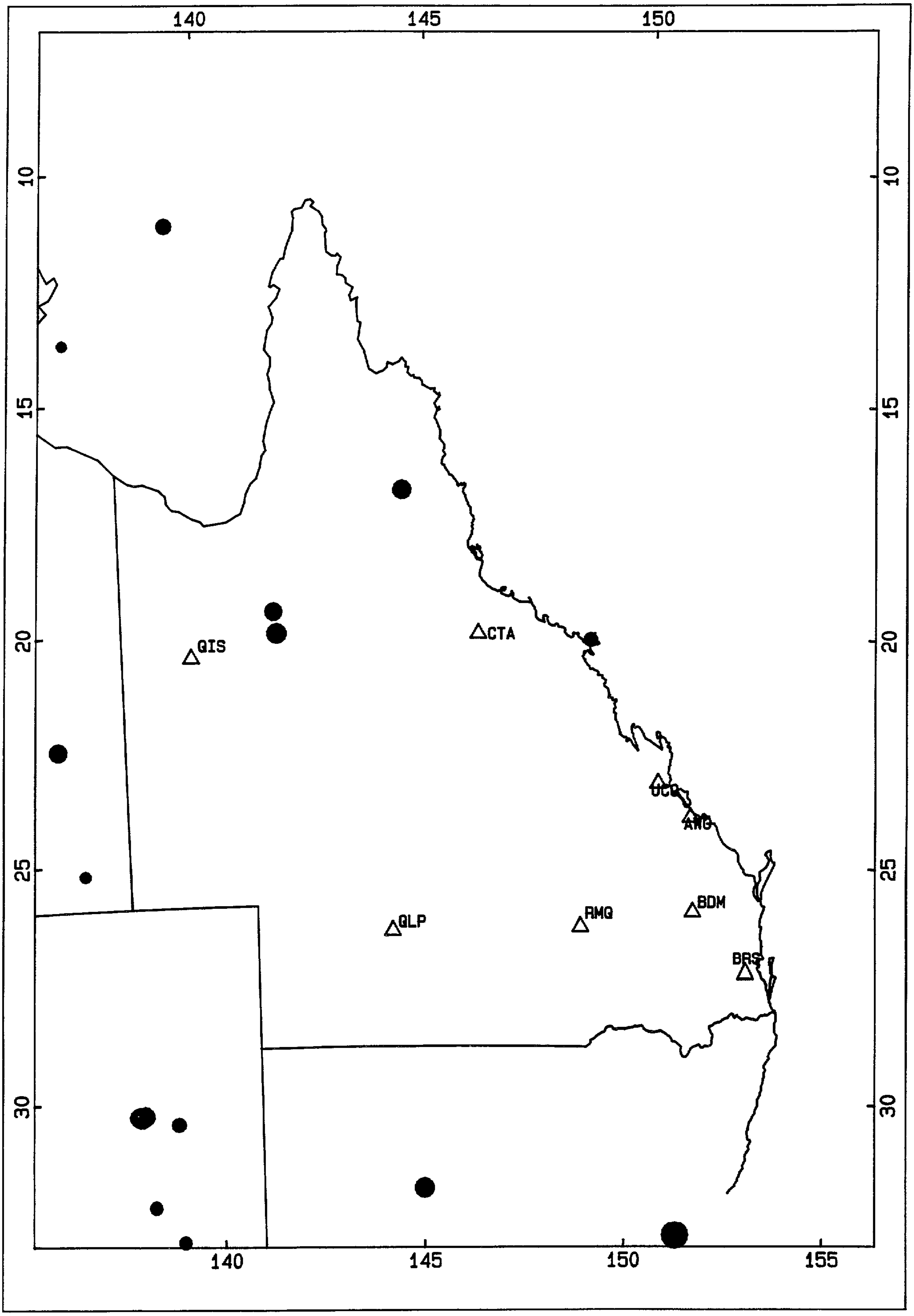


Figure 8 Epicentres of earthquakes in Queensland 1994, magnitude ML ≥ 2.5.

All sites have been equipped with triaxial accelerometers, GPS clocks and digital Kelungi recorders which can be interrogated by telephone.

Trevor Jones, Victor Dent and Peter Gregson

MICROZONATION OF LAUNCESTON

During the period 1884-1994, the city of Launceston in northern Tasmania has been damaged by five earthquakes with epicentres up to 200 km away in the west Tasman Sea off northeastern Tasmania. As this damage was thought to be due to amplified site response, the Launceston City Council requested AGSO to prepare a zoning map of Launceston with zones related to the requirements of Australian Standard AS 1170.4-1993. To accomplish this, AGSO carried out a microtremor survey of Launceston. Recordings were made at 53 sites on sediment and three on dolerite. Launceston has a complex geology involving at least two deep NNW-SSE trending valleys filled with variably consolidated sediments.

Ratios of the spectra of the horizontal and vertical components of microtremors suggest amplified responses of Tertiary and Quaternary sediments at 46 of the 53 sediment sites at periods ranging from 0.1 more than 1 second. The three dolerite sites showed no site resonance. Sediments in the deep valleys showed amplification at periods around 0.7 to greater than 1 second, which would be expected to most affect medium and high rise buildings. Ceilings of two churches in this zone have been damaged by earthquakes. Natural periods of 0.1-0.5 seconds were measured on Quaternary and Tertiary sediments overlying shallow dolerite basement in the eastern part of the Launceston Central Business District. The buildings which would be most affected by site resonance in this area would be low or medium rise buildings. There have been several reported cases of damage to these sorts of structures in this area in earthquakes.

Based on the microtremor measurements, the soils map and gravity results, AGSO staff have prepared a 1:10 000 scale zoning map of Launceston. This shows the site factor in AS 1170.4-1993 to be used for low, medium or high rise buildings in various parts of the city. The zones are consistent with the microtremor measurements and with most reports of damage in earthquakes.The zoning maps should provide a reasonable regional indication of site response in another earthquake off northeastern Tasmania, or in the Western Tasmanian Zone.

AGSO has been involved in other microtremor/microzonation surveys of Australian cities: Perth WA, Newcastle NSW, and Rockhampton Qld, whilst MESA has undertaken a comprehensive zonation of Adelaide using both microtremors and drilling.

M.Michael-Leiba

ACCELEROGRAPH DATA & ATTENUATION

This the second year of the Commonwealth Government's Urban Monitoring project coordinated by AGSO and with State Government participation, produced excellent early results. The project was funded to install two accelerographs in those urban area with more than 50 000 people. Earthquakes were recorded on each pair of recorders in Newcastle and Sydney during the Ellalong earthquake, and in Adelaide during the Eudunda earthquake.

<u>In Western Australia</u> Accelerograms were recorded from 21 events, approximately two thirds of the number recorded in 1993. Thirteen of these were in the Cadoux area, all of which were relatively minor, the largest being only ML 2.1.

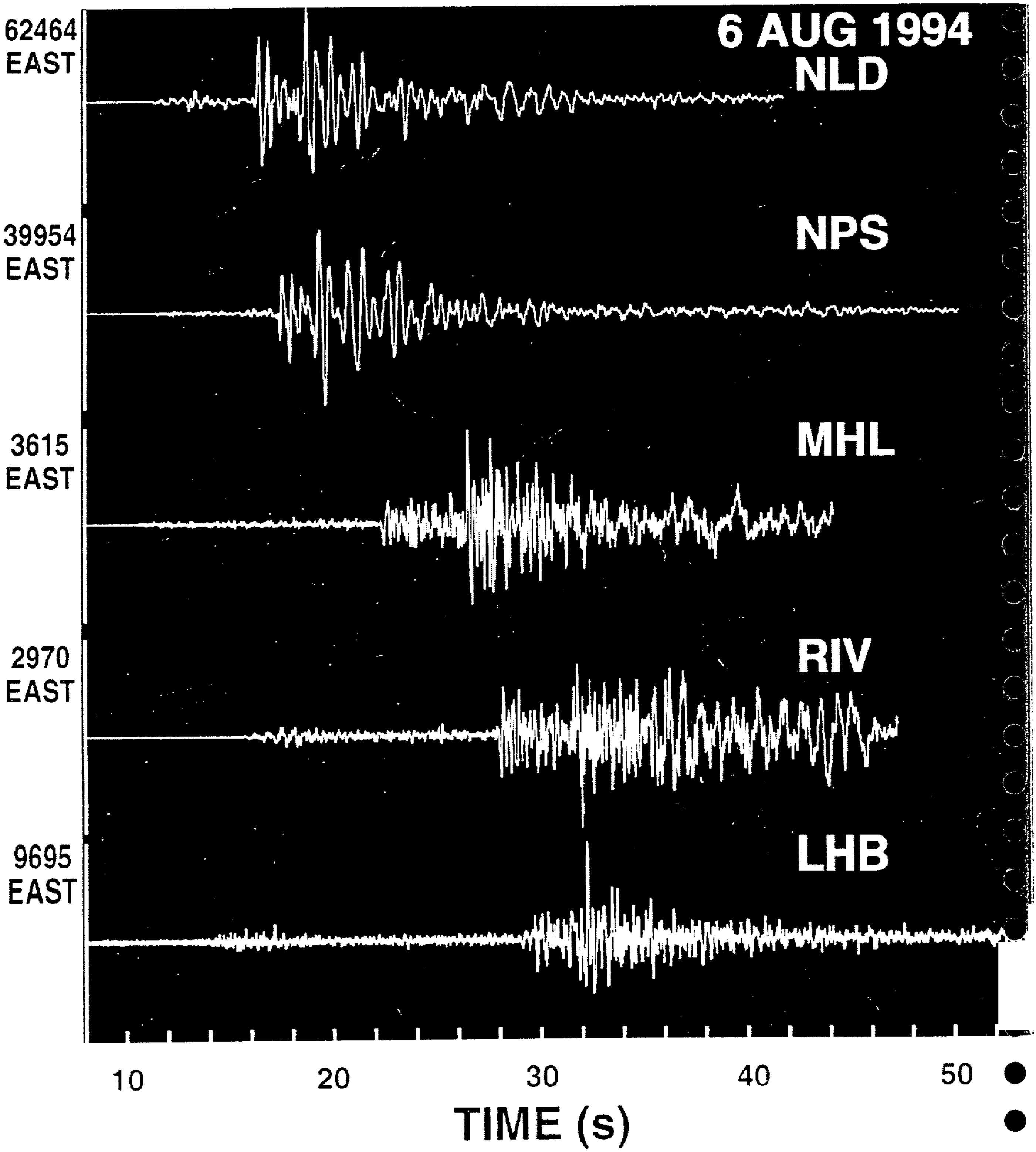


Figure 22 Sample accelerograms of the Ellalong NSW earthquake.

AGSO

95/960

The magnitude ML 4.1 Bonnie Rock earthquake of 26 April was recorded at Cadoux (station CAA, 128 km distant) and Goomalling (station GOO, 178 km distant). Unfortunately only the P wave was well recorded, as the instruments were transferring the P wave data to memory and temporarily not recording, when the S wave arrived.

Three small aftershocks (ML 1.3, 1.2 and 1.2) of the York swarm in November and December were recorded on an instrument temporarily placed in the area.
The highest acceleration recorded (154 mm/s^2) was from a minor Cadoux event (ML 1.4 on 17 May), the instrument was right on top of the event at 2 km depth.

Vic Dent and Peter Gregson

In Eastern Australia The most important dataset yet obtained in Australia was the recording of the Ellalong earthquake on accelerographs installed under the Urban Monitoring program in Newcastle, Sydney and Canberra, on stations installed by the Water Board in and south of Sydney and those at Lucas Heights. Accelerograms of the ground motion, from North Lambton at 9 km to Lucas Heights at 105 km epicentral distance, are shown in Figure 22.

Another useful record was that at Lucas Heights at the same free-field site where the P-wave of the Newcastle earthquake was recorded. Its companion accelerograph on the Reactor Building was also triggered.

By scaling the peak acceleration (a, fraction of g) and computed velocity (v, ms^{-1}) from each horizontal component and the ratio of vertical to horizontal acceleration, a good measure of attenuation on 'rock' in the Sydney Basin has been made. The following equations were obtained by least squares (McCue & others, 1995):

$$a = 5.12\,R^{-1.76}$$

$$v = 14.4\,R^{-2.08}$$

The power of the distance term R (km) is close to 2 for velocity which is the value expected for elastic geometric spreading. Scatter is large about the mean value.

Other interesting accelerograms were recorded at Eugowra (Gibson & others, 1995) including one with a pulse which reached almost 1g vertically and 0.5 g horizontally. The accelerographs were about 1 km from the focus of these small very shallow earthquakes.

In South Australia A magnitude 3.2 earthquake at Eudunda in the Barossa Valley was widely felt and triggered the two strong motion instruments in Adelaide where it was slightly felt. Although the maximum accelerations measured were only 0.00019 g on rock and 0.00055 g on soil, it gives confidence that the instruments will achieve their intended purpose.

A magnitude 4.0 event on 30 November between Leigh Creek and Lake Torrens led to a vigorous aftershock or swarm sequence during December. Three instruments intended for the joint urban monitoring program were despatched to the area. Events of magnitude 4.0, 3.8 and 3.5 were recorded at a distance of about 17 km where the maximum acceleration varied from 0.04 g to 0.016g (Figure 23).

K McCue, T Jones & D Love

TSUNAMI

During the year, AGSO commissioned the Narural Hazards Research Centre at Macquarie University to compile a listing of tsunamis that have impacted on the Southwest Pacific and particularly Australia (Allport & Blong, 1995). A tsunami database was then established by AGSO (Lenz & others, in prep.) and populated with the NHRC data supplemented with

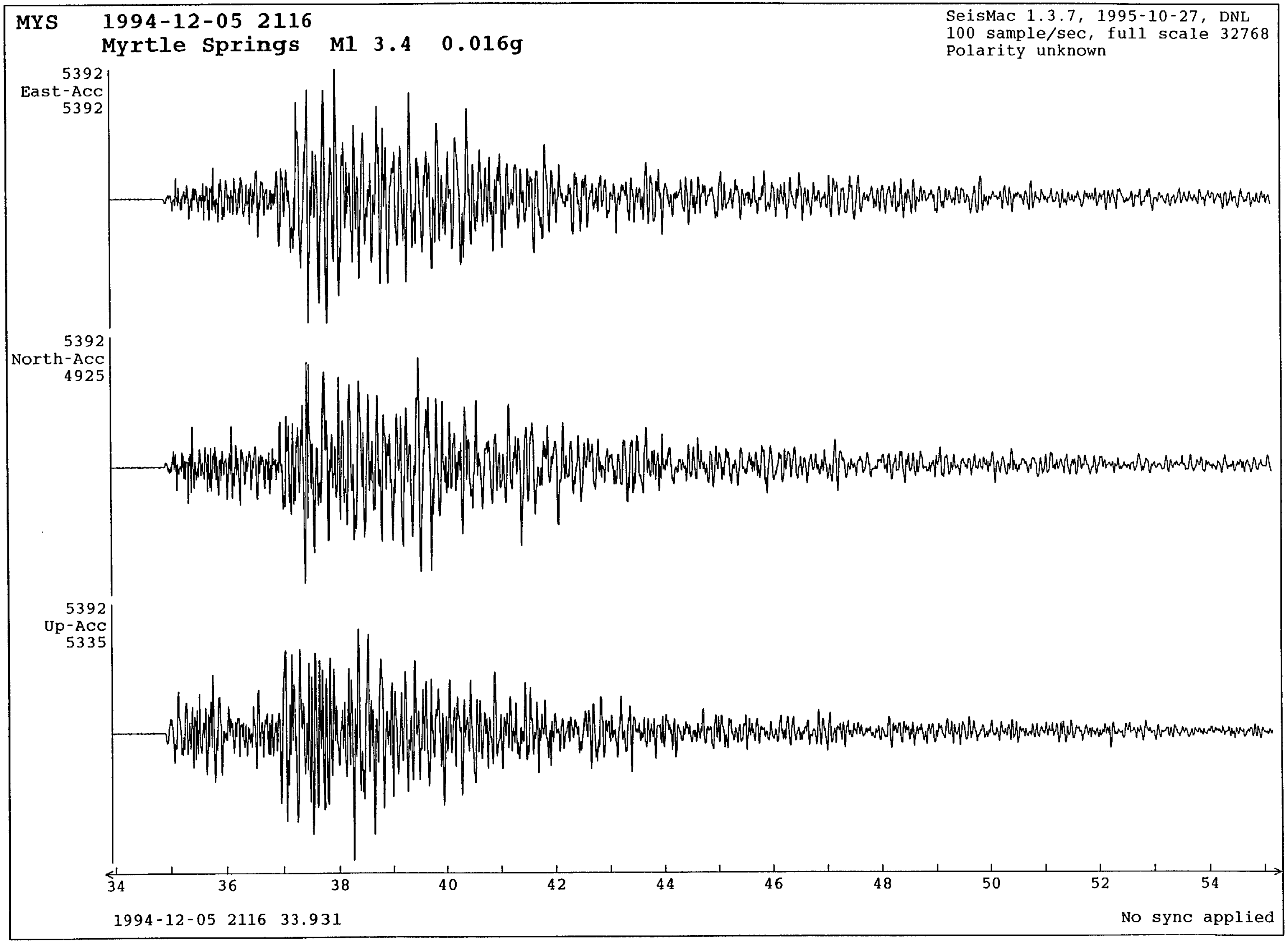


Figure 23 Accelerogram of one of the Myrtle Springs SA earthquakes.

other observations from McCue and Palfreyman. Below are reports from the database of the tsunami caused by the major Indonesian earthquake of 2 June (Table 7).

• ITIC Newsletter XXVI(1) (1994) states that "Initial accounts fromIndonesia's Meteorological and Geophysical Agency (MGA) reported that a tsunami hit coastal areas in Banyuwangi district and killed 204 people; some 22 people were reported as missing. The report also said that 1226 homes in the disaster area were destroyed. In a report dated June 17, the DHA-Geneva indicated 222 people were killed, 17 missing and 440 wounded by the tsunami. Total monetary losseswere estimated at US$2.2 million..According to Mr. Soetardjo, an MGA survey team reported the tsunami swept inland about 300 metres in some areas. Numerous small boats were sunk or destroyed." Runup is given at 6.1-9.5 m.

• ITIC Newsletter XXVI(1) (1994) indicates that this area was a "damaged area swept by tsunami of June 3, 1994.", and that "the survey team encountered heavy erosion along the coast caused by the tsunami." Preliminary tsunami runup (in metres, with no tidal correction) is given at 1.03-4.45 m.

Comments: Foley, G. (1994) states that "the most significant impact made on the shoreline occured near the Northwest Cape. The tsunami inundated the beach and car park at Baudin where the shore is exposed by a gap in the Ningaloo reef. A surge estimated at around 3 to 4 m carried hundreds of fish, as well as crayfish, rocks, and coral inland for a distance of two to three hundred metres. The area was deserted at the time, however the tsunami was heard by residents of nearby caravan parks who described the noise as like the 'roar of a train'. There were reports of similar inundation at parts of the coast further to the south, again where gaps in the reef exposed the shoreline to the surge".

• Foley, G. (1994) states that "The Western Austrlian Department of Transport maintains a network of stilling well/float actuated digital loggers..[and] clear evidence [of the passage of the tsunami] was revealed at Carnarvon".

"A pair of tankers transferring petroleum from one to another off the coast of Onslow experienced dificulty in maintaining their separation due to the tsunami, causing the connecting pipeline to rupture and resulting in the spillage of some oil. It was estimated that the amplitude of the wave was around 0.8 m during the incident".

"A Liquid Natural Gas ship near King Bay experienced a sudden oscillation at around 0615 WST, recording a loading of up to 50 tonnes on the mooring ropes".

K McCue & S Lenz

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

A focal mechanism solution for the Ellalong earthquake was obtained using the first motion directions at Australian National Network and urban monitoring stations (Jones & others, 1994). The results (Figure 25 opposite) are tabulated in Table 4 below. This solution, of a thrust mechanism with nodal planes dipping at about 45° and principal stress direction oriented NE/SW, is very similar to that of the deeper 1989 Newcastle earthquake (McCue & others, 1990).

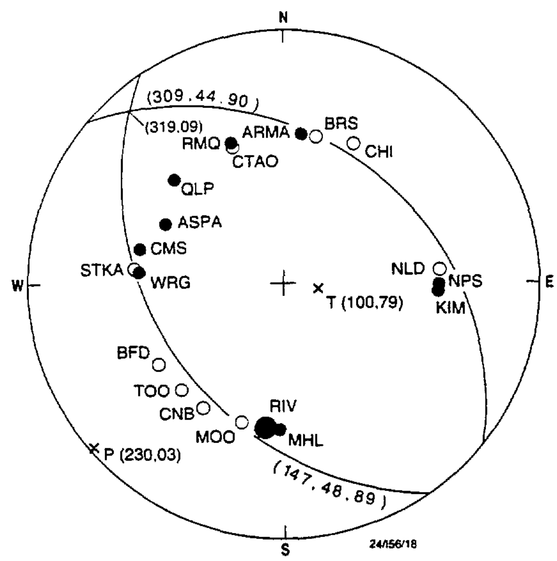


Figure 25

Table 4. Focal Mechanism of the Ellalong earthquake, 6 August 1994

	Strike	*Dip*	*Slip*	*Azimuth*	*Plunge*
Nodal Plane	309°	44°	90°		
Nodal Plane	147°	48°	89°		
P-axis				230°	03°
T-axis				100°	79°
N-axis				319°	09°

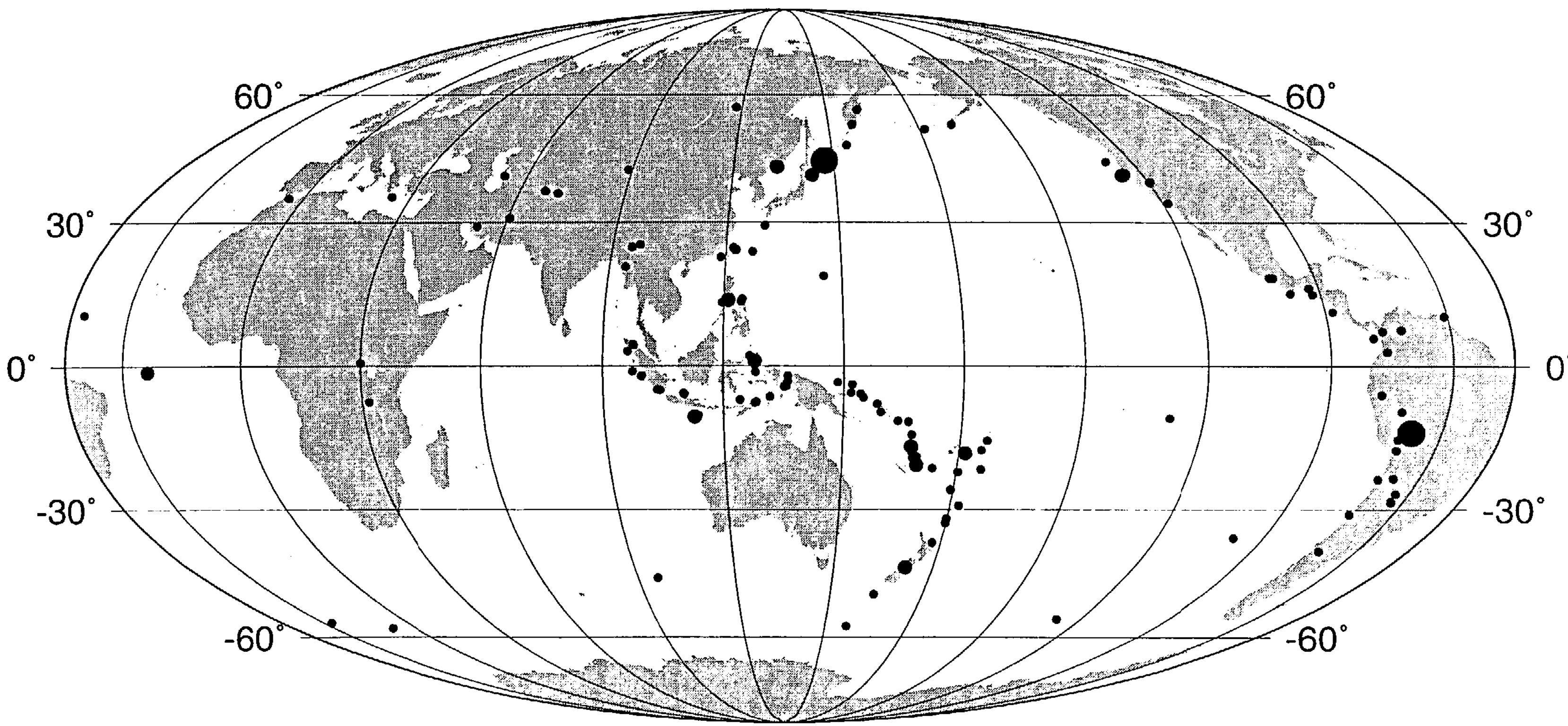
PRINCIPAL WORLD EARTHQUAKES, 1994

Table 7 lists worldwide earthquakes in 1994 that were of magnitude 7.0 or greater, or that caused fatalities or substantial damage. There were two *great* earthquakes; in Bolivia on 9 June with magnitude Mw 8.2 and in the Kurile Islands on 4 October with magnitude Mw 8.3. The Bolivian earthquake was at the most unexpected depth of 650 km. It caused numerous landslides but only minor damage in the epicentral region, and was felt at remarkable distances in North America. The source area was very small, only 50 x 40 km^2 compared with dimensions of more than 300 x 40 km^2 for a shallow earthquake of similar size. Interestingly another deep earthquake of magnitude Mw 7.5 had occurred under Fiji at more than 560 km deep earlier in the year on 9 March.

Ten of the thirteen earthquakes of magnitude Ms 7 or more occurred around the Pacific rim. The other three in the Asian region of Indonesia The largest at magnitude Ms 8.1 occurred on 4 October in the Kuril Islands. The most destructive was in Columbia on 6 June, with at least 295 people killed, 500 missing and 13 000 homeless. Severe damage occurred to houses, highways and bridges as a result of the earthquake and following landslides. World-wide, more than 1101 people died in earthquakes in 1994, compared to at least 10 044 and 2880 in 1993 and 1992 respectively, and the average mortality rate for the century of 10 000 per year.

This information is from the monthly 'Earthquake Data Reports' published by the United States Geological Survey and the SEAN Bulletin of the Smithsonian Institution (SEAN, 1992).

Peter Gregson, Kevin McCue and Yvonne Moiler



GMT **Figure 24** Principal world earthquakes, magnitude 6 or greater. Data extracted from the AGSO/ISC earthquake database. Small dots are magnitude 6.0 to 6.9, medium dots magnitude 7.0 to 7.9, and large dots magnitude 8.0 or larger.

MONITORING OF NUCLEAR EXPLOSIONS

China detonated the only underground nuclear explosions in 1994 at its test site at Lop Nor. The explosions at 06:26 on 10 June and 03:26 on 7 October (UTC) had corrected body-wave magnitudes of mb 5.3 and 6.1 corresponding to a yield in the range 10 to 40 and 40 to 150 ktons respectively. All other Nuclear Weapons States abided by an agreed moritorium on testing.

CONSULTANCIES

As a result of the Richards review, AGSO has been set a goal to attract 30% of its operating costs through consultancies. To help achieve this goal, the Earthquake Hazard Project hired Dr Malcolm Somerville, an engineering seismologist/geophysicist with extensive experience in earthquake hazard analysis to bid for and undertake a range of consultancy projects.

These included:

- Recommendations for a design earthquake for ANSTO's Lucas Heights Reactor Site
- Hazard analyses for gas pipelines in the WA Goldfields and in South-Eastern Australia
- Recommendation for instrumentation of dams in NSW and ongoing analysis of data
- Review of hazard calculations for Australia by a major international risk insurance firm.

REFERENCES

Anderson, J.A. & Wood, H.O., 1925 — Description and theory of the torsion seismometer. *Bulletin of the Seismological Society of America*, **15**, 1-72.

Båth, M., 1981 — Earthquake magnitude - recent research and current trends. *Earth Science Reviews*, **17**, 315 - 398.

Bisztricsany, E., 1958 — A new method for the determination of the magnitude of earthquakes. *Geofizikai Kozlemenyek*, **7**, 69-96.

Denham, D., 1982 — Proceedings of the workshop on Australian earthquake magnitude scales. BMR, Canberra, 21 May 1982. *Bureau of Mineral Resources, Australia, Record* 1982/29.

Eiby, G., 1966 — The Modified Mercalli Scale of earthquake intensity and its use in New Zealand. *New Zealand Journal of Geology and Geophysics*, **9**, 122-129.

Everingham, I.B., Denham, D., & Greenhalgh, S. A., 1987 — Surface-wave magnitudes of some early Australian earthquakes. *BMR Journal of Australian Geology & Geophysics*, **10**, 253-259.

Everingham, I.B., McEwin, A.J., & Denham, D., 1982 — Atlas of isoseismal maps of Australian earthquakes. *Bureau of Mineral Resources, Australia, Bulletin* **214**.

Foley, G. 1994 The tsunami event along the northwest Australian coast on 3 June 1994 Report of the National Tsunami Workshop, Brisbane, 25 August 1994, Bureau of Meteorology.

Gibson, G., Wesson, V., & Corke, T., 1995 — The Eugowra NSW earthquake swarm, 1994. in Proceedings of the Australian Earthquake Engineering Seminar, Canberra 14-15 November 1994.

Gregson & others, 1995 —

Greenhalgh, S., Denham, D., McDougall, R., & Rynn, J.M.W., 1989 — Magnitude-intensity relations for Australian earthquakes. *Bulletin of the Seismological Society of America*, **78**, (1), 374-379.

Gutenberg, B., 1945 — Amplitudes of P, PP and SS, and magnitudes of shallow earthquakes. *Bulletin of the Seismological Society of America*, **35**, 57-69.

Jones, T. D., Gibson G., McCue, K. F., Denham, D., Gregson, P. J., and Bowman, J. R., 1991. Three large intraplate earthquakes near Tennant Creek, Northern Territory, Australia, on 22 January 1988, *BMR J. Australian Geology & Geophysics,* **12**(4), 339-343.

Jones, T.D., Wesson, V., McCue, K., & Gibson, G., 1995 — The Ellalong NSW earthquake, 6 August 1994. in Proceedings of the Australian Earthquake Engineering Seminar, Canberra 14-15 November 1994.

Kanamori, H., 1978 — Quantification of earthquakes. *Nature*, **271**, 411-414.

Luck, J. McK., 1991 — Report to National Time Committee of National Standards Commission, Australia on 21st General Assembly of the International Astronomical Union. Buenos Aires, 21 July - 2 August 1991.

Marshall, P.D., & Basham, P.W., 1973 — Rayleigh wave magnitude scale Ms. *Pure and Applied Geophysics*, **103**, 406-414.

McCue, K.F., 1980 — Magnitude of some early earthquakes in Southeastern Australia. *Search*, **11**(3), 78-80.

McCue, K.F., Kennett, B., Gaull, B., Michael-Leiba, M. ,Weekes, J. & Krayshek C., 1989 — A century of earthquakes in the Dalton-Gunning region of New South Wales. BMR Journal of Australian Geology & Geophysics, 11, 1, pp 1-9.

McCue, K.F., Wesson, V, & Gibson, G., 1990 — The Newcastle New South Wales earthquake of 28 December 1989. *BMR Journal of Australian Geology & Geophysics,* **11**, 559-567.

McCue, K., Dent, V., Jones, T., Gregson, P., & Gibson, G., 1995— Attenuation of strong shaking in Australia. in Proceedings of the Australian Earthquake Engineering Seminar, Canberra 14-15 November 1994.

McGregor, P.M., & Ripper, I.D., 1976 — Notes on earthquake magnitude scales. *Bureau of Mineral Resources, Australia, Record* 1976/76.

NBS 1972 — NBS frequency and time broadcast services. Ed P. P. Viezbicke, Special publication 236, US Department of Commerce, Boulder, Colorado.

Richter, C.F., 1958 — Elementary Seismology. *Freeman & Company, San Francisco.*

Rynn, J.M.W., Denham, D., Greenhalgh, G., Jones, T., Gregson, P., McCue, K.F., & Smith, R.S., 1987 — Atlas of isoseismal maps of Australian earthquakes, part 2. *Bureau of Mineral Resources, Australia, Bulletin* **222.**

SEAN 1994 — *Scientific Event Network Bulletin, Smithsonian Institution, Washington, USA.*

Somerville, M.R., Kagami, H., & McCue, K., 1993 — Seismic amplification determined from mocrotremor monitoring at alluvial sites in Newcastle. Bulletin of the New Zealand National Society for Earthquake Engineering, June 1993.

Willmore, P., 1979 — Manual of seismological observatory practice. *World Data Centre for Solid Earth Geophysics, US Department of Commerce, Boulder, Co, USA,* Report **SE-20**.

ISOSEISMAL MAPS

Thirteen earthquakes during 1994 were sufficiently widely felt or in strategic or unusual locations that questionnaires were distributed and the returned forms collated to draw up isoseismal maps; four of them in New South Wales, three each in Western Australia and Queensland, two in South Australia and one in the ACT.

The format of these maps is the same as those printed in the three volumes of the AGSO (BMR) Isoseismal Atlas.

APPENDIX 1 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.

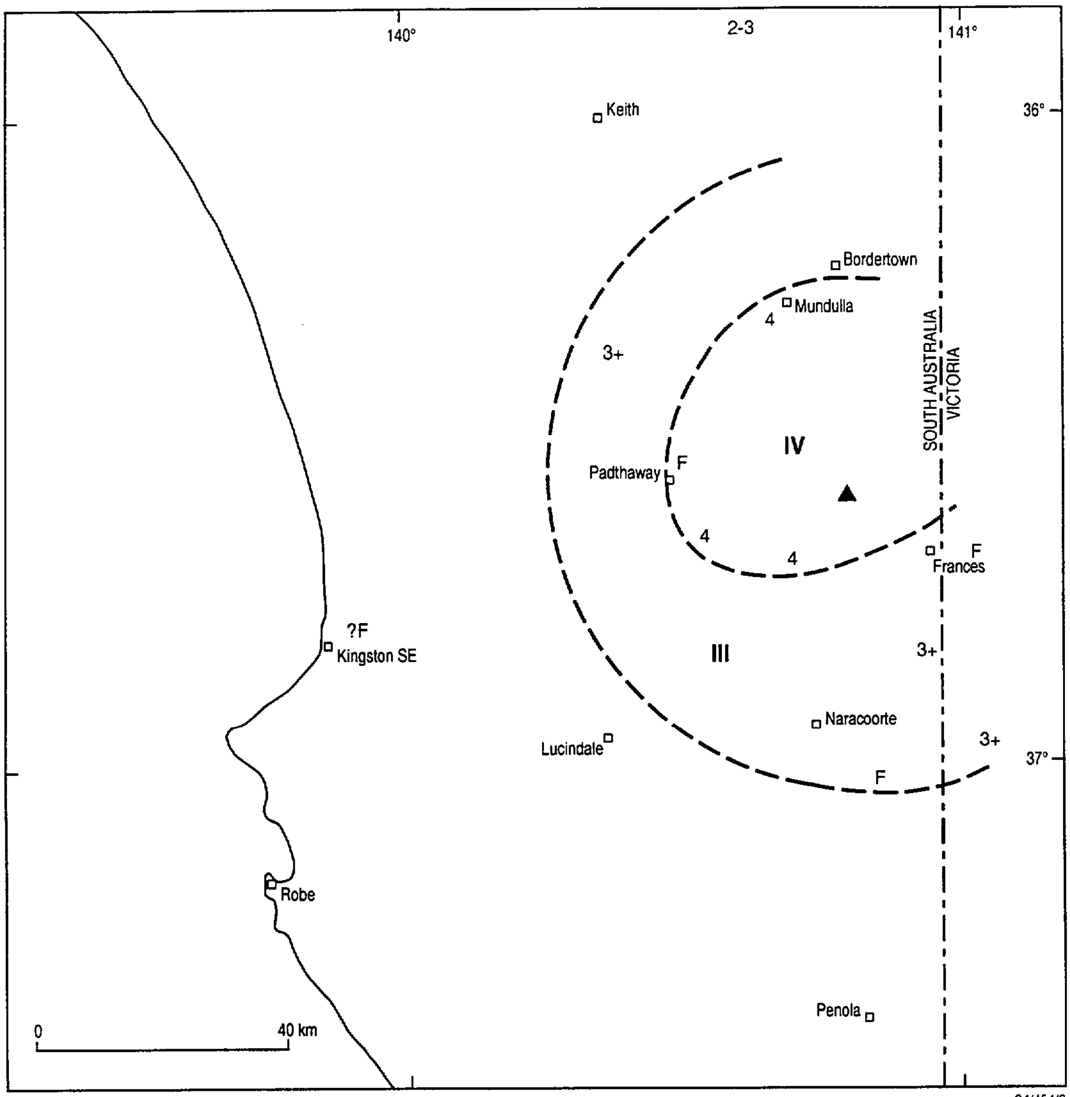
The `domestic water tanks' listed under MM VII are of the cylindrical corrugated-iron type common in New Zealand rural areas. If these are only partly full, movement of the water may burst soldered and riveted seams. Hot-water cylinders constrained only by supply and delivery pipes may move sufficiently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

Isoseismal map of the Frances earthquake South Australia 20 April 1994

A microearthquake of magnitude ML 2.5 occurred in the South East of the State, north of Naracoorte at 10:32 pm local time. It was felt by a number of people near the epicentre, with reports of a loud explosion and rattling of doors and windows. Of particular interest were the reports that came in from more distant places, describing faint distant thunder (at a time when many farmers were waiting for rain). The isoseismal map was constructed from reports by people who rang SADME. (The report from Kingston was via a radio station).

David Love

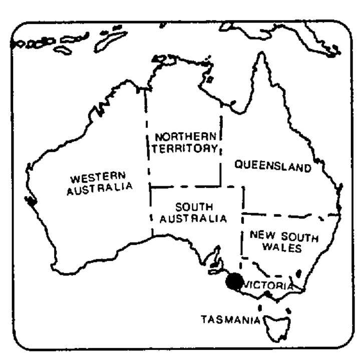
ISOSEISMAL MAP OF THE FRANCES EARTHQUAKE, SOUTH AUSTRALIA
20 APRIL 1994



24/J54/3

DATE: 20 APRIL 1994
TIME: 13:02 UTC
MAGNITUDE: ML 2.4
EPICENTRE: 36.59°S, 140.79°E
DEPTH: 8 km

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



Isoseismal map of the Bonnie Rock earthquake Western Australia 26 April 1994

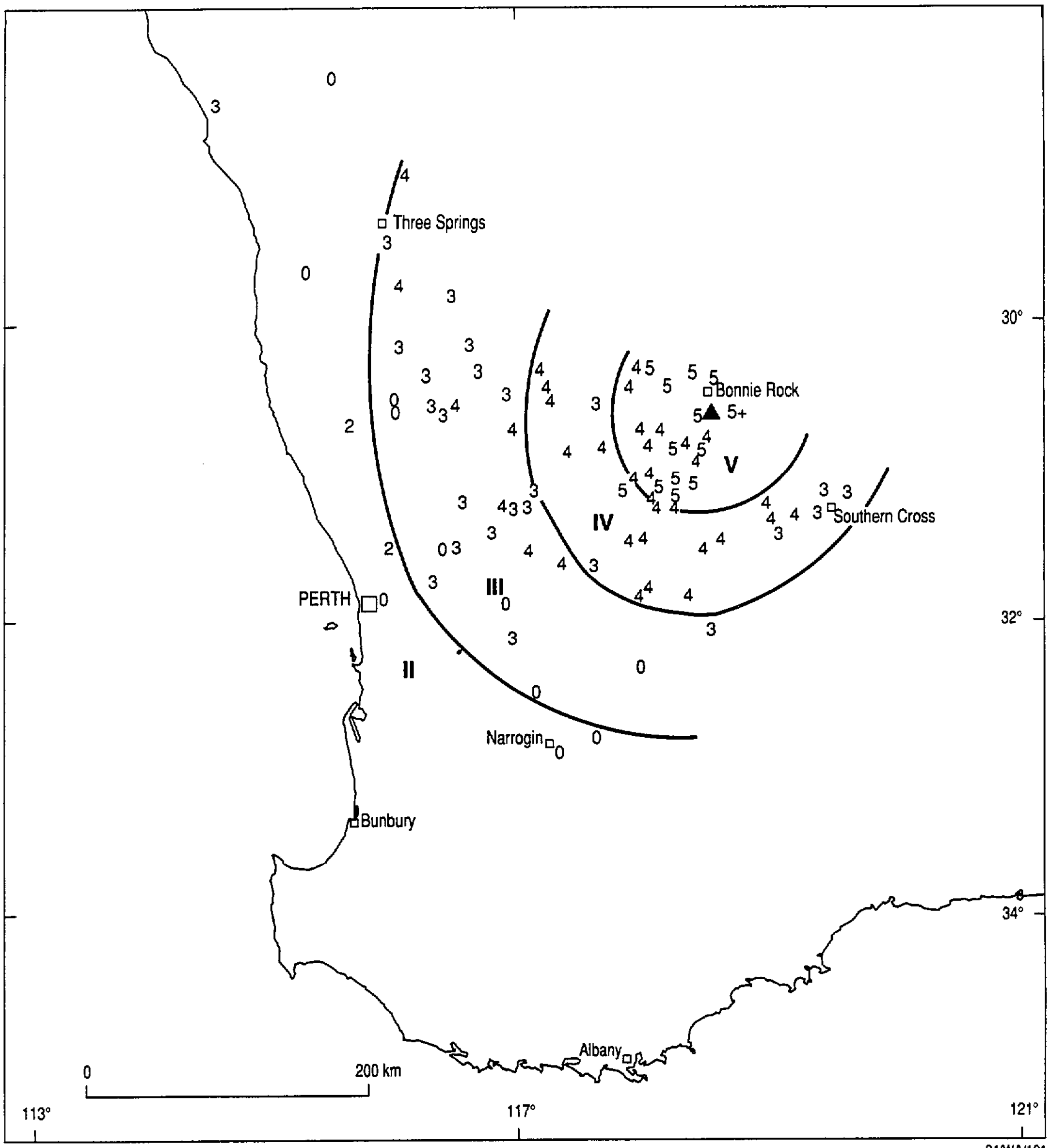
A magnitude ML 4.1 earthquake occurred at 11:49 p.m. (15:49 UT) on 26 April. The epicentre was 13 km southeast of Bonnie Rock and 346 km northeast of Perth.

Many nearby residents were woken up by the loud rumbling but no damage was reported. There were a few reports that the shaking was felt at Kalgoorlie and Geraldton, 450km from the epicentre. The radii of the V and IV isoseismals were 75km and 150km respectively. The ground motion was recorded on an accelerograph at Goomalling, 180km from the epicentre.

Previous activity in the region occurred in June 1968, 1973/74 and 1993, the largest a magnitude ML 4.0 earthquake on 21 June 1968.

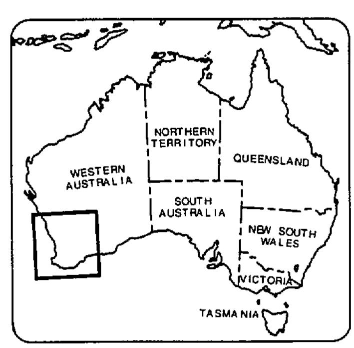
Peter Gregson

ISOSEISMAL MAP OF THE BONNIE ROCK EARTHQUAKE, WESTERN AUSTRALIA
26 APRIL 1994



DATE: 26 APRIL 1994
TIME: 15:49:39.5 UTC
MAGNITUDE: 4.1 ML (MUN)
EPICENTRE: 30.60°S 118.48°E

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

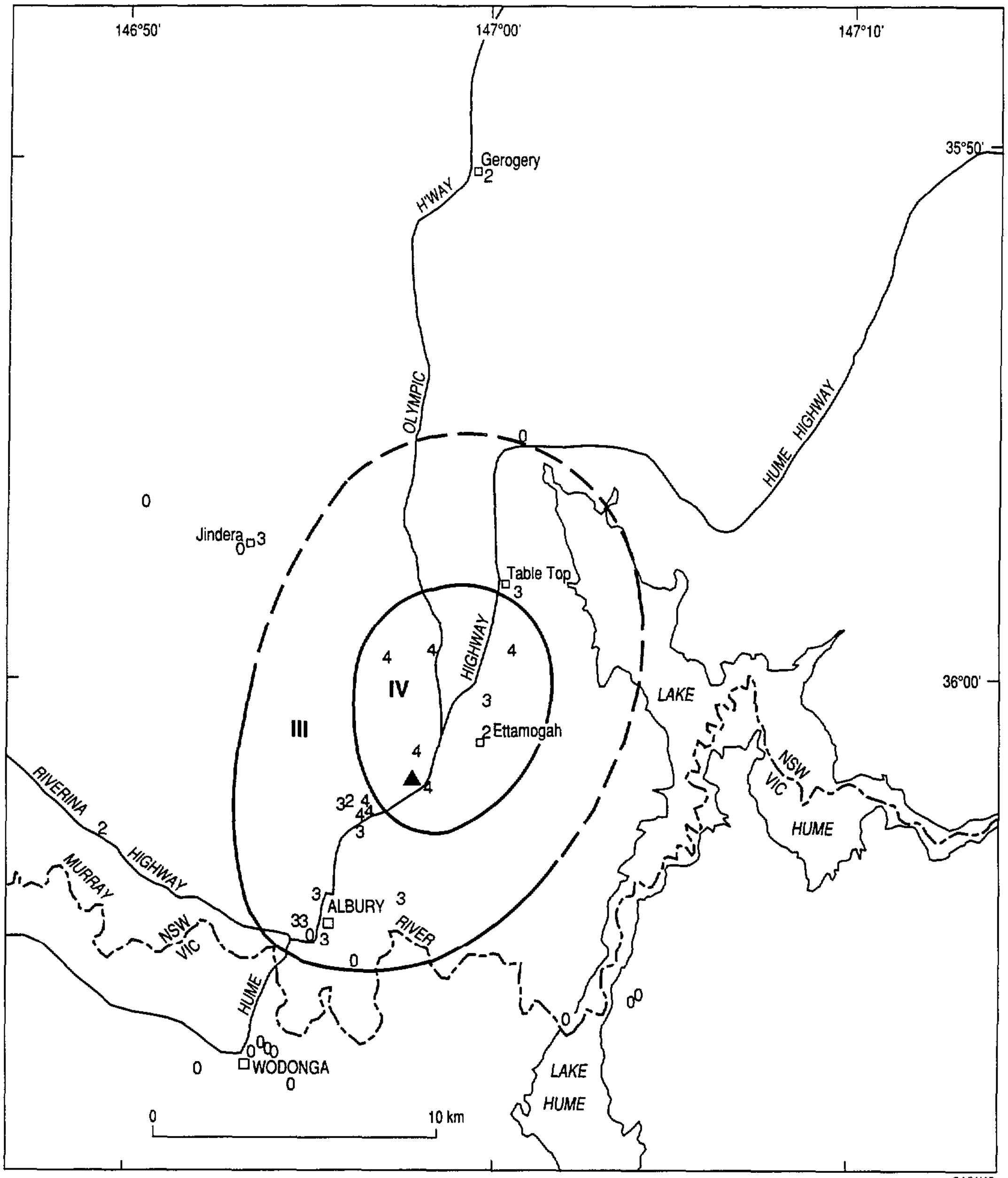


Isoseismal map of the Albury earthquake New South Wales 21 May 1994

The earthquake was felt at Ettamogah and by residents of the northern suburbs of Albury, especially Lavington. Most reports describe a sound like a large explosion, or two loud bangs within a second or two (extract from the Seismology Research Centre May 1994 Preliminary Earthquake Location bulletin).

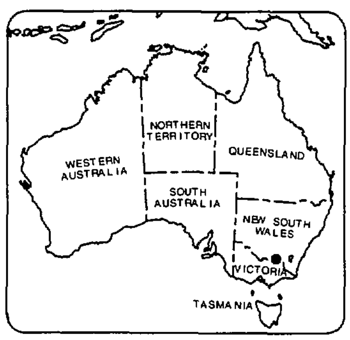
Gary Gibson and Adam Pascale

ISOSEISMAL MAP OF THE ALBURY EARTHQUAKE, NEW SOUTH WALES
21 MAY 1994



DATE: 21 MAY 1994
TIME: 08:59:18 UTC
MAGNITUDE: 3.0 ML
EPICENTRE: 36.034°S 146.962°E
DEPTH: 3 (± 5) km

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



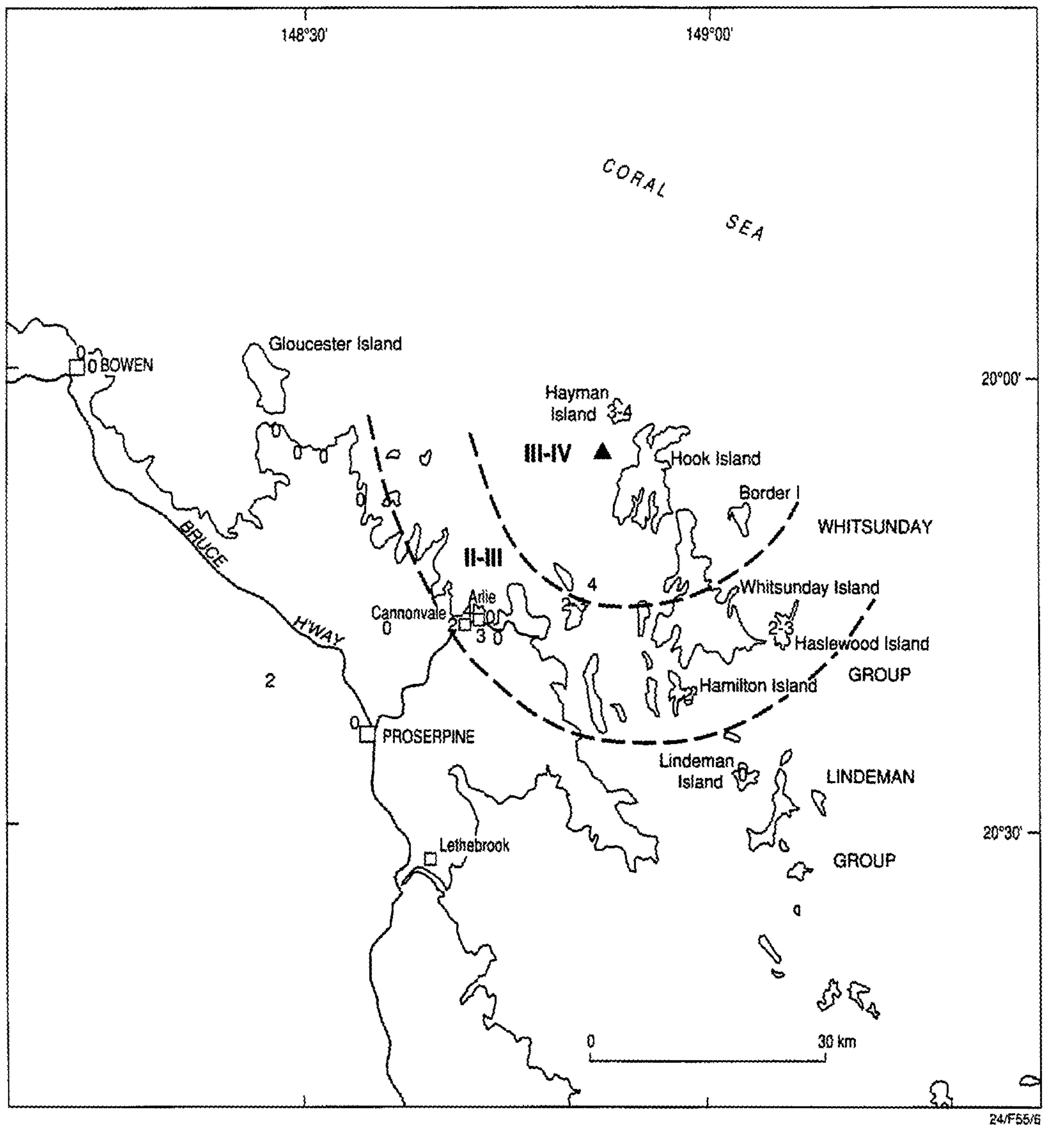
Isoseismal map of the Whitsundays earthquake Queensland
17 June 1994

This earthquake was felt in an area restricted to the Airlie Beach - Shute Harbout area on the coast, and the island resorts of the Whitsundays.

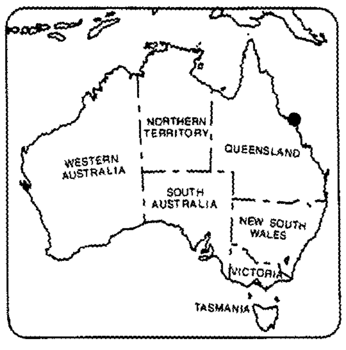
Russell Cuthbertson

ISOSEISMAL MAP OF THE WHITSUNDAYS EARTHQUAKE, QUEENSLAND

17 JUNE 1994



DATE: 17 JUNE 1994
TIME: 11:52:33.7 UTC
MAGNITUDE: 3.4 ML
EPICENTRE: 20.21°S, 148.87°E
DATE: 4 km



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

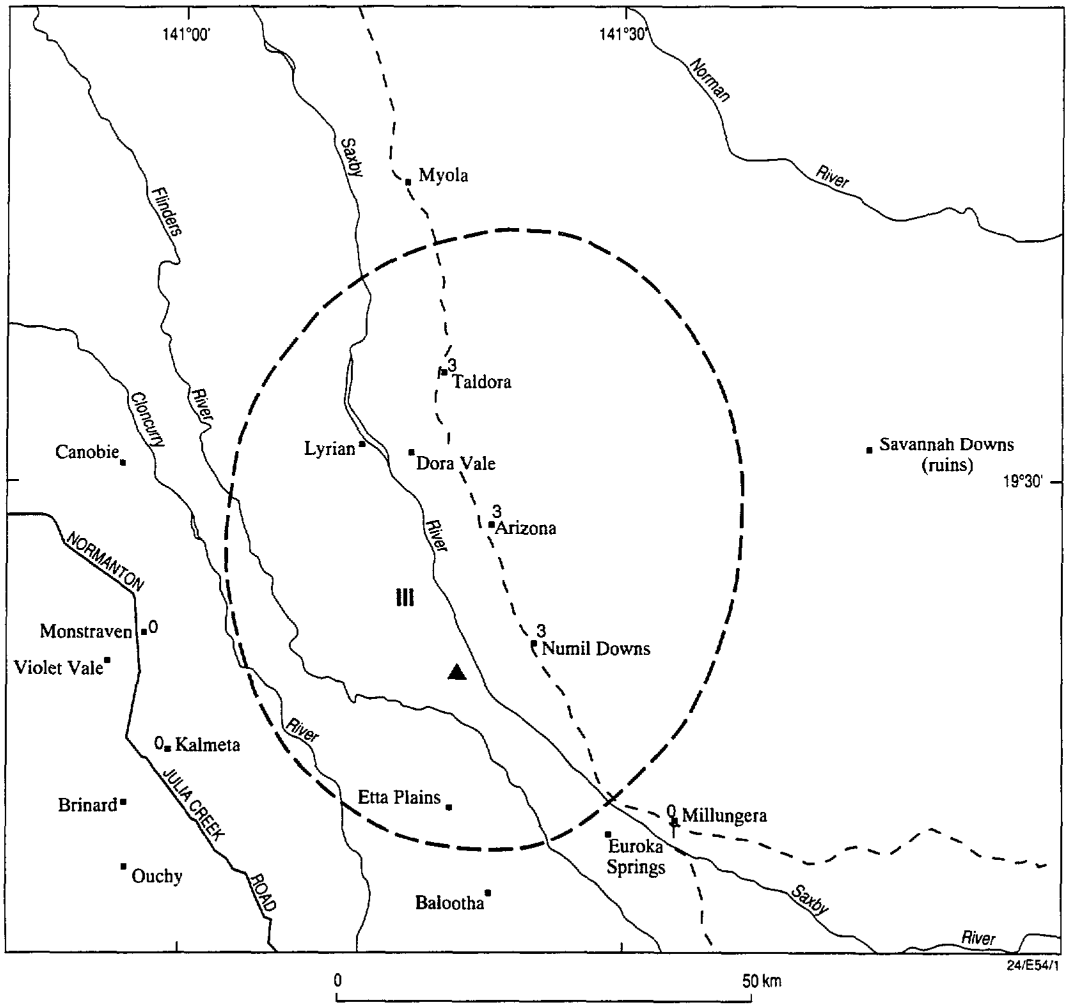
Isoseismal map of the Numil Downs earthquakes Queensland 4&5 July 1994

Two earthquakes 34 hours apart were felt by residents of three stations north of Julia Creek in north-west Queensland. Both events had similar felt effects and so they are plotted on the one map. The epicentral details are extremely uncertain as this part of Queensland is not adequately monitored for small tremors.

Russell Cuthbertson

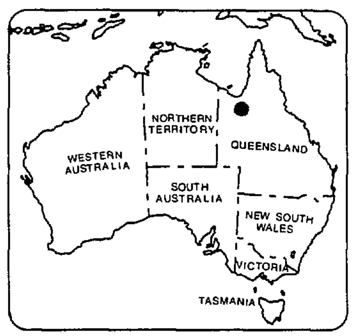
ISOSEISMAL MAP OF THE NUMIL DOWNS EARTHQUAKES, QUEENSLAND

4 & 5 JULY 1994



DATE: 4 & 5 JULY 1994
TIME: 09:10:14, 19:07:24 UTC
MAGNITUDE: 3.8,4.2
EPICENTRE: 19.7°S,141.3°E
DEPTH: 10 km

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



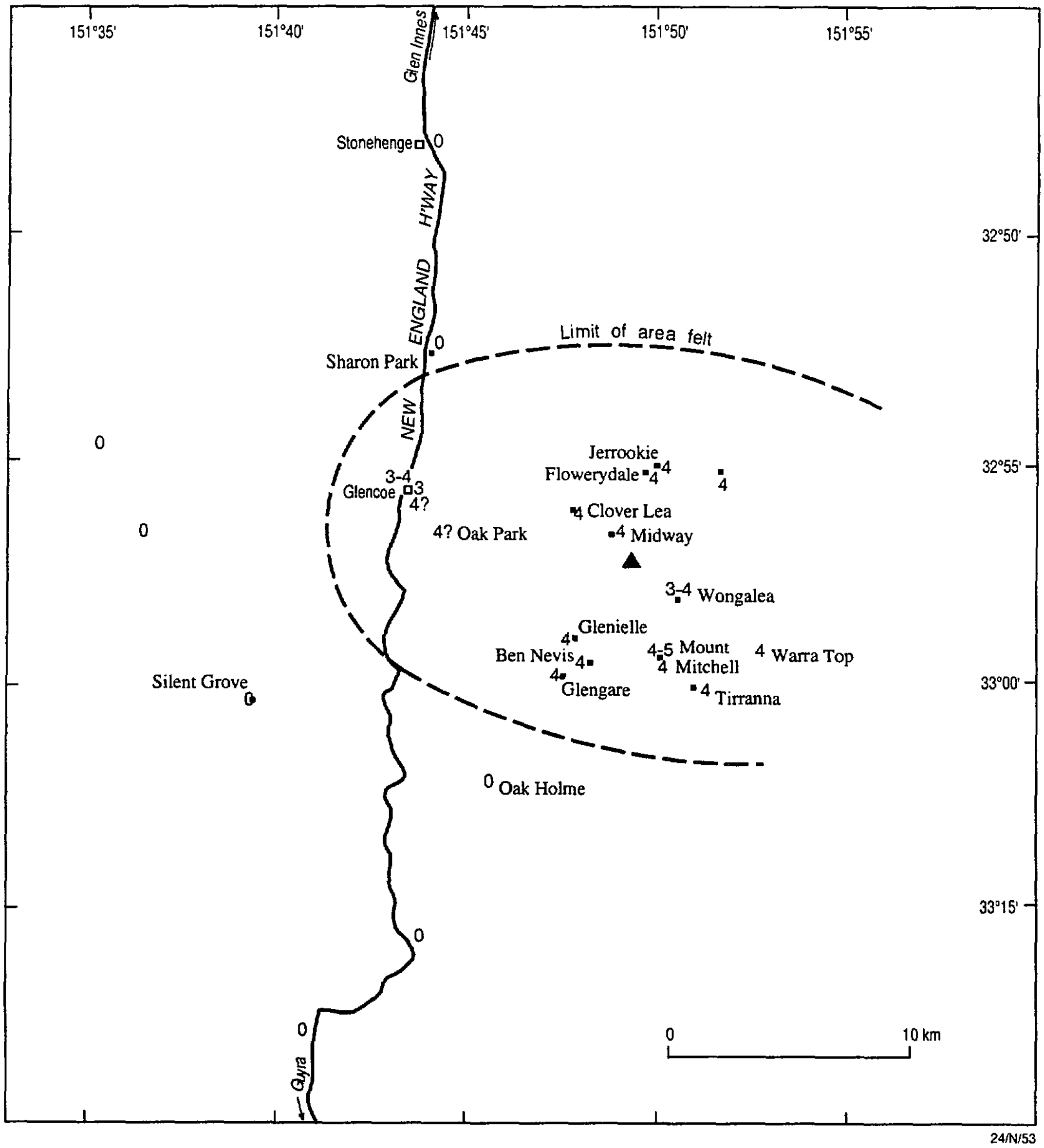
Isoseismal map of the Mount Mitchell earthquake New South Wales 17 July 1994

A small earthquake (ML 2.7) occurred at 9:35 pm AEST (11:35 UTC) on Sunday, 17 July 1994 in the New England region of NSW. The earthquake was felt over an average radius of about nine kilometres and the maximum intensity was MMIV-Vat the Mount Mitchell station. It was felt at Glencoe and at homesteads up to about 16 km to the east and southeast of the town.

The Australian Seismological Centre received several telephone calls regarding the earthquake and canvassed other stations in the area by telephone and questionnaire. A total of twenty five reports were received of which eight were 'not felt'.
A computed epicentre was obtained for the event using seismographs at Armidale, Brisbane and in the Wivenhoe network. However, the computed epicentre was located outside of the felt area and we have placed the epicentre in the approximate centre of the felt area.

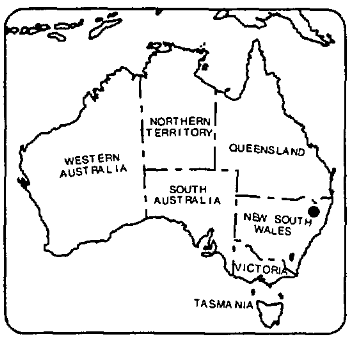
Trevor Jones, Andrew Murphy and Wendy Welsh

ISOSEISMAL MAP OF THE MOUNT MITCHELL EARTHQUAKE, NSW
17 JULY 1994



DATE: 17 JULY 1994
TIME: 11:35:36 UTC
MAGNITUDE: 2.3
EPICENTRE: 29.958°S, 151.823°E
DEPTH: CRUSTAL

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



Isoseismal map of the Ellalong earthquake New South Wales 6 August 1994

At five minutes past nine pm, many residents of Ellalong, Cessnock and Newcastle were shocked to feel their houses shaking again, so soon after the 1989 Newcastle earthquake. This time there was little structural failure, no structural collapse and damage was again mostly in lowrise buildings. The earthquake caused $32M insured damage, the third largest earthquake damage claim in Australian history.

The epicentre was only thirty kilometres west of the 1989 epicentre, but the focal depth was less than 5 km compared with the 1989 earthquake which was 12 km below the surface. These two factors had a strong influence on the damage.

Shaking was felt over a wide area of east-central NSW, from Taree to Wollongong and as far west as Mudgee. Many people in Sydney did not feel the earthquake including patrons of a restaurant at Cronulla, yet football fans at the nearby Caltex Ground were reported to have evacuated the rocking stadium and the Rugby League game was temporarily halted until the all clear was given. As in Newcastle in 1989 (Somerville & others, 1993) the foundations played a big part in the intensity of ground motion in Sydney, the restaurant was built on competent sandstone, the stadium on filled ground; an old garbage tip overlying dune sands. The isoseismal map shows a large difference in felt area, and in the area of damage enclosed by the MM VII isoseismal to that of the 1989 earthquake.

Trevor Jones and Kevin McCue

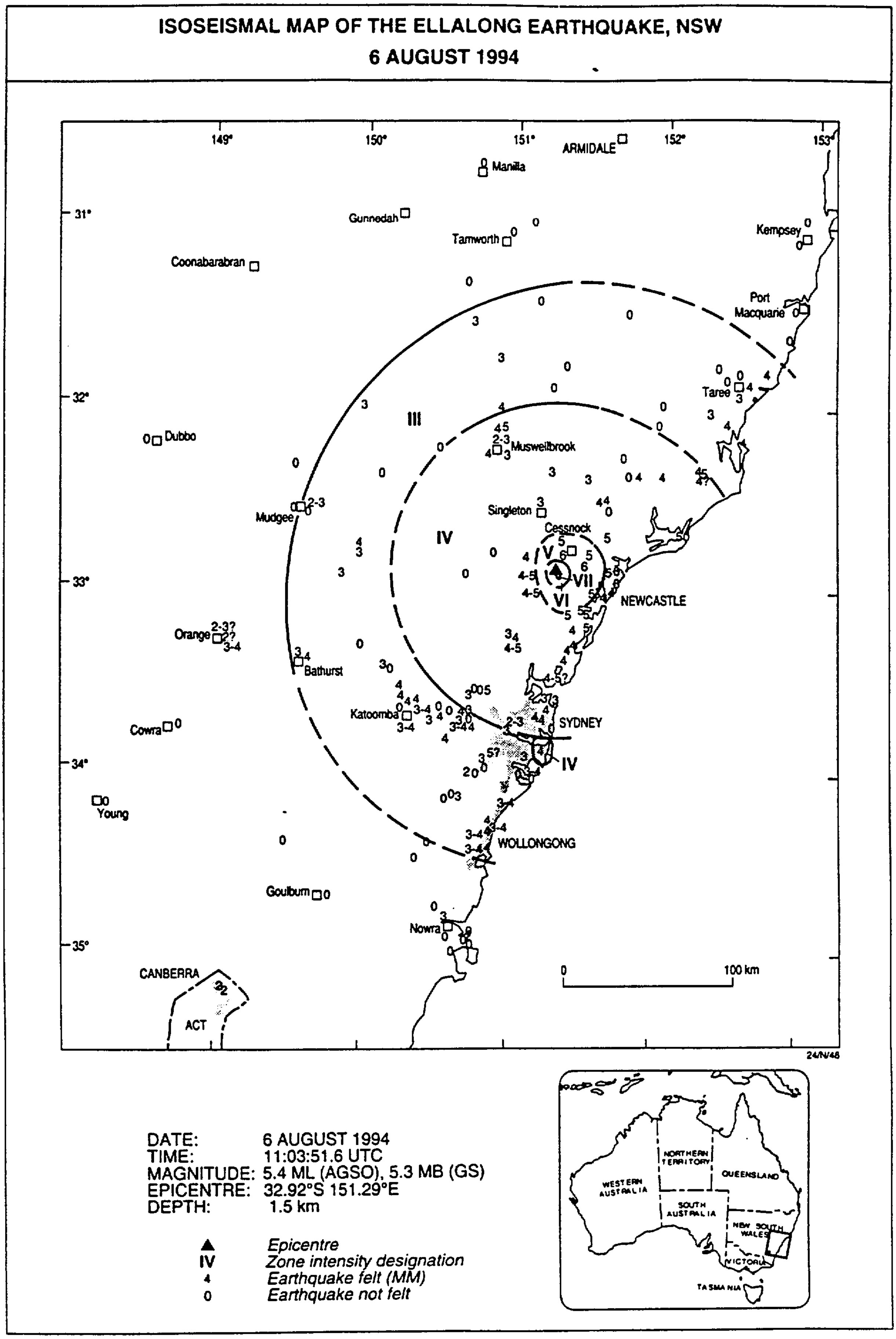


Figure 2 Isoseismal map of the Ellalong earthquake, 6 August 1994.

Isoseismal map of the Ellalong earthquake New South Wales
Epicentre Details
6 August 1994

At five minutes past nine pm, many residents of Ellalong, Cessnock and Newcastle were shocked to feel their houses shaking again, so soon after the 1989 Newcastle earthquake. This time there was little structural failure, no structural collapse and damage was again mostly in lowrise buildings. The earthquake caused $32M insured damage, the third largest earthquake damage claim in Australian history.

The epicentre was only thirty kilometres west of the 1989 epicentre, but the focal depth was less than 5 km compared with the 1989 earthquake which was 12 km below the surface. These two factors had a strong influence on the damage.

Shaking was felt over a wide area of east-central NSW, from Taree to Wollongong and as far west as Mudgee. Many people in Sydney did not feel the earthquake including patrons of a restaurant at Cronulla, yet football fans at the nearby Caltex Ground were reported to have evacuated the rocking stadium and the Rugby League game was temporarily halted until the all clear was given. As in Newcastle in 1989 (Somerville & others, 1993) the foundations played a big part in the intensity of ground motion in Sydney, the restaurant was built on competent sandstone, the stadium on filled ground; an old garbage tip overlying dune sands. The isoseismal map shows a large difference in felt area, and in the area of damage enclosed by the MM VII isoseismal to that of the 1989 earthquake.

Trevor Jones and Kevin McCue

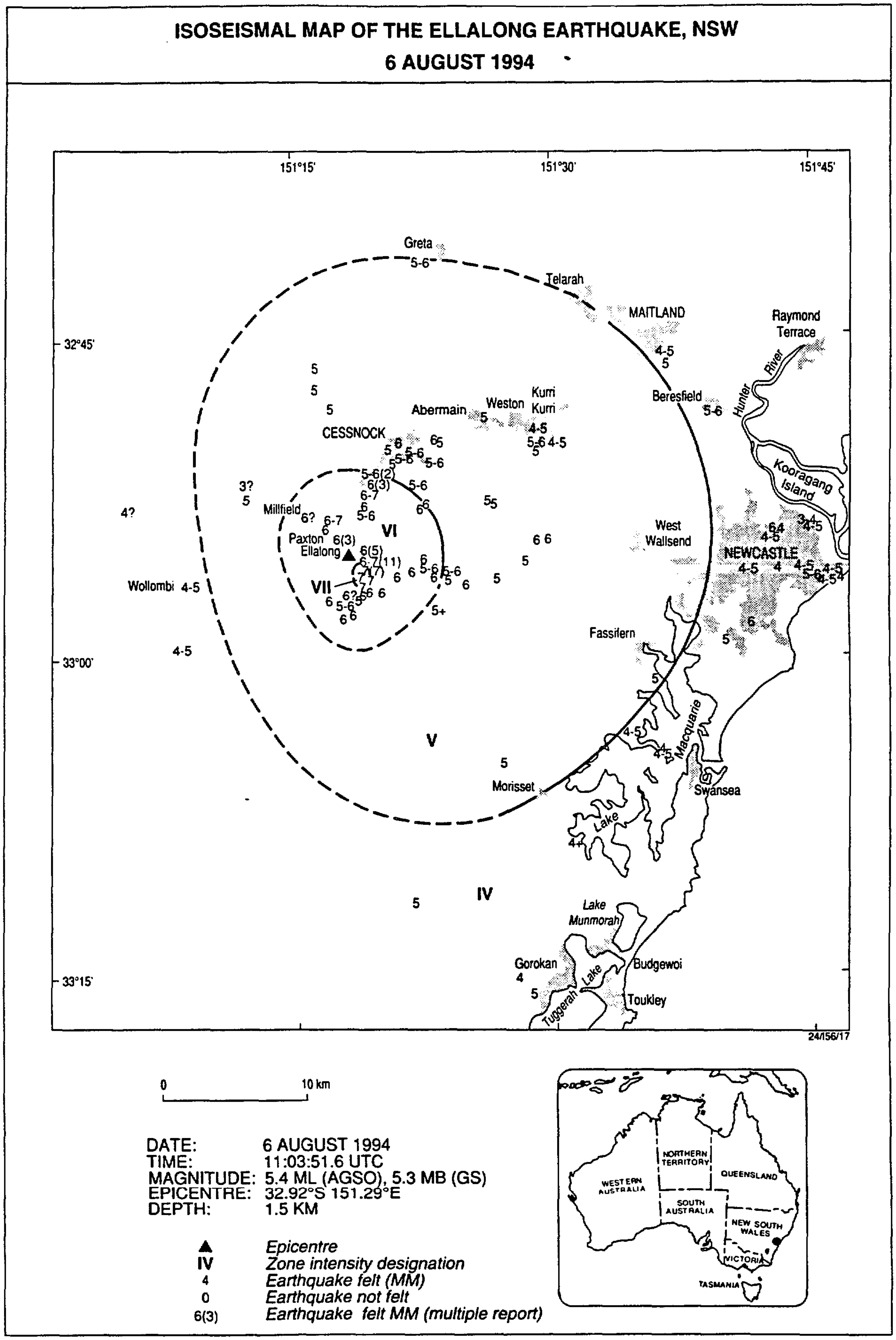


Figure 1 Isoseismal map for the epicentral area of the Ellalong earthquake, 6 August 1994.

Isoseismal map of the Eudunda earthquake South Australia 10 August 1994

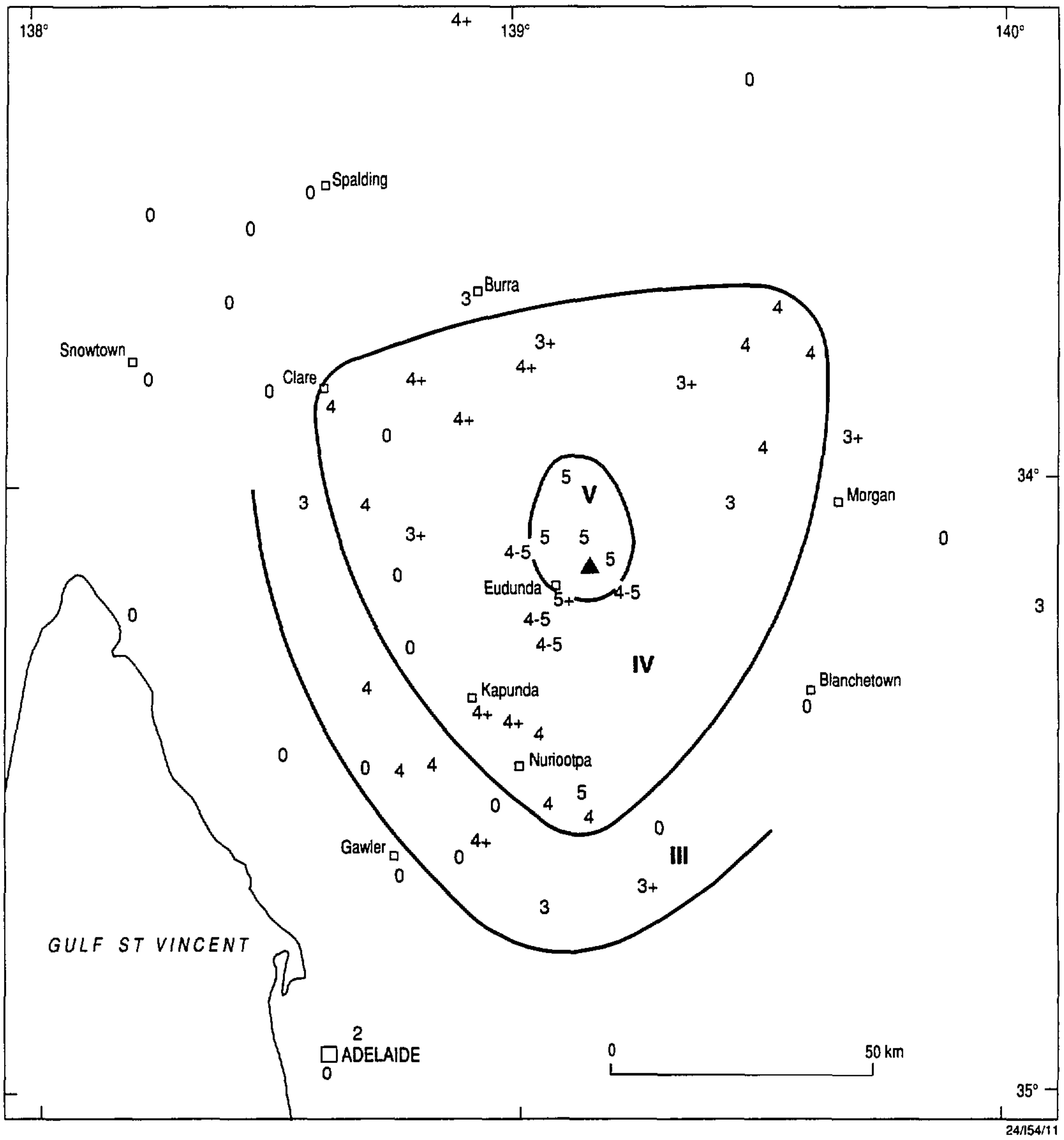
Residents of the town of Eudunda were rudely woken by a small earthquake on 11 August at 6:07 am CST (10 August at 20:37 UTC) . In early news bulletins there were a few reports of people noticing the event as far away as Adelaide and in the Mt Lofty Ranges east of Adelaide. There were no immediate reports of damage in the epicentral area. The earthquake was given wide publicity coming so soon after the Ellalong NSW event.

It triggered the 2 strong motion instruments which were installed in Adelaide the previous November. A search for past activity came up with previous significant events on 17 August 1991 at Truro and 17 August 1992 near Clare.

A questionnaire was distributed and an isoseismal map produced from the returns. There were a few replies noting minor cracking in houses near the epicentre. The number of intensity 4 reports at a considerable distance rom the epicentre is probably due to the quiet hour of the morning when people were just or nearly awake.

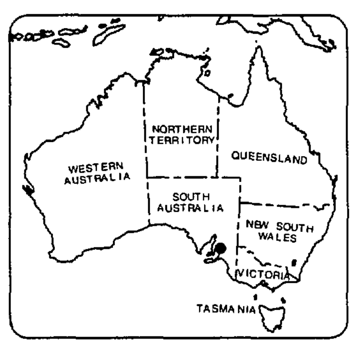
David Love

ISOSEISMAL MAP OF THE EUDUNDA EARTHQUAKE, SOUTH AUSTRALIA
10 AUGUST 1994



DATE: 10 AUGUST 1994
TIME: 20:37:00.4 UTC
MAGNITUDE: 3.2 ML (ADE)
EPICENTRE: 139.15°E 34.16°S
DEPTH: 18 km

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

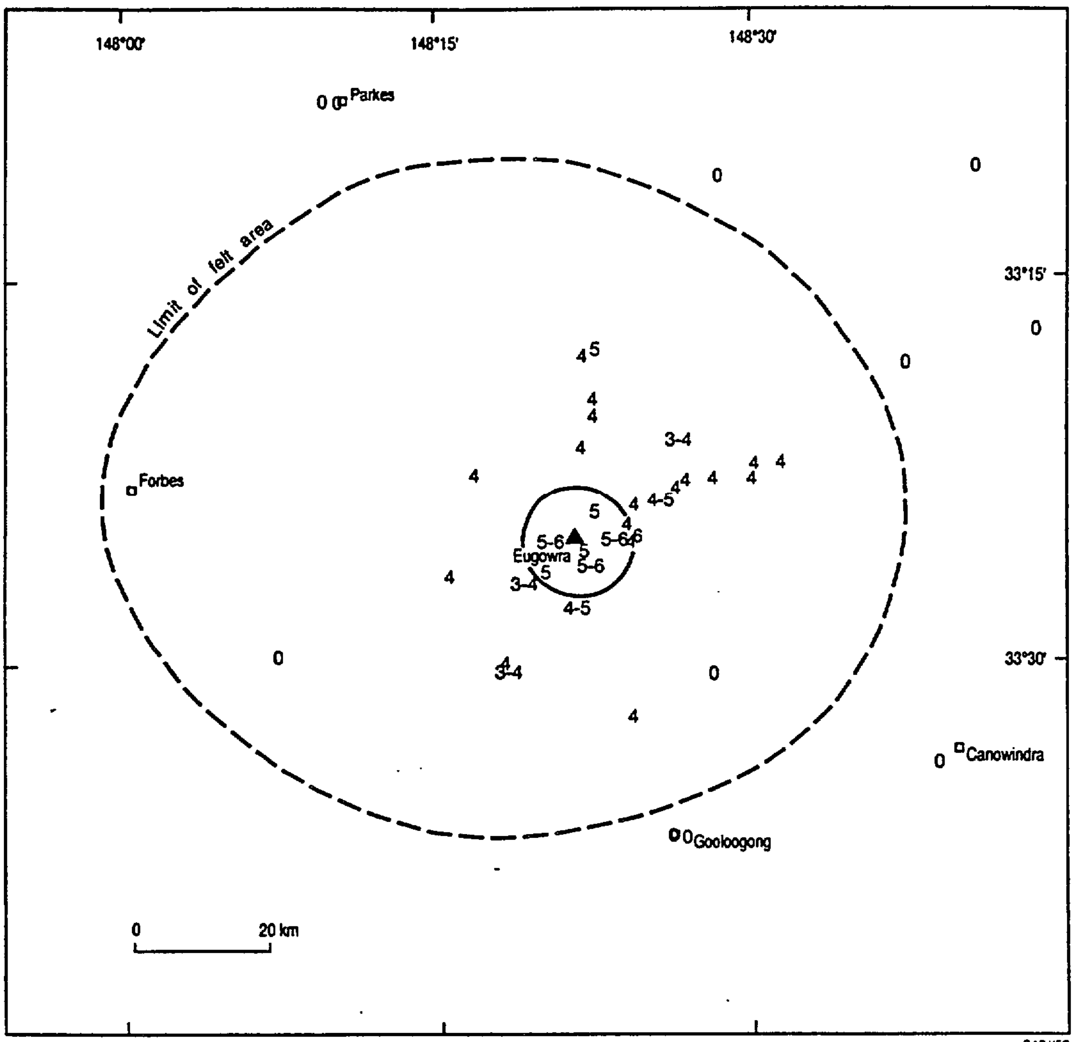


Isoseismal map of the Eugowra earthquake New South Wales 21 August 1994

The largest earthquake of the swarm caused a lot of fear and excitement amongst Eugowra residents, sufficient that some left town. A public meeting was held to discuss the threat and it was attended by most of the remaining residents.

Trevor Jones

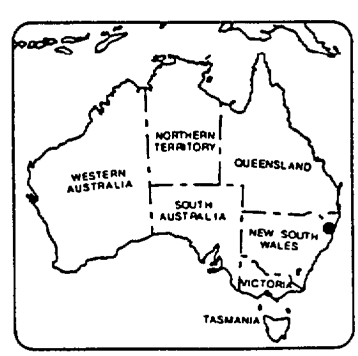
ISOSEISMAL MAP OF THE EUGOWRA EARTHQUAKE, NSW
21 AUGUST 1994



24/N/52

DATE: 21 AUGUST 1994
TIME: 05:53 UTC
MAGNITUDE: 4.0 ML (AGSO)
EPICENTRE: 33.421°S, 148.364°E
DEPTH: 0 KM

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



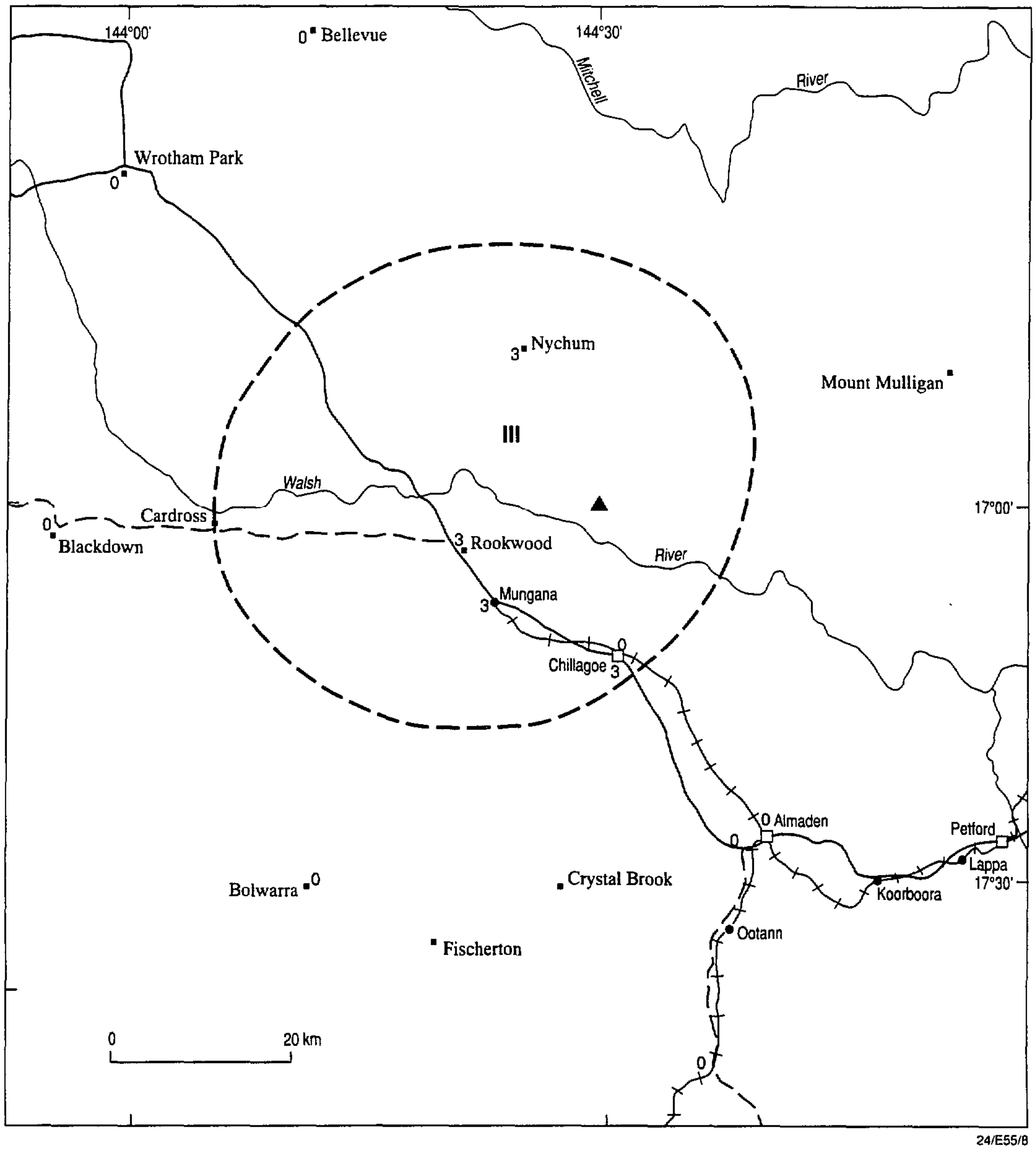
Isoseismal map of the Chillagoe earthquake Queensland 4 September 1994

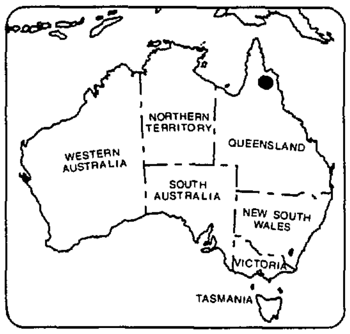
A magnitude 4.0 earthquake near Chillagoe in northern Queensland caused considerable in the Red Dome open-cut mine; they thought there had been an explosives accident. The sparse popuylation precludes a more definitive isoseismal map.

Russell Cuthbertson

ISOSEISMAL MAP OF THE CHILLAGOE EARTHQUAKE, QUEENSLAND

4 SEPTEMBER 1994





DATE: 4 SEPTEMBER 1994
TIME: 01:08:02.1 UTC
MAGNITUDE: 4.0 ML
EPICENTRE: 16.99°S,144.50°E
DEPTH: 8 km

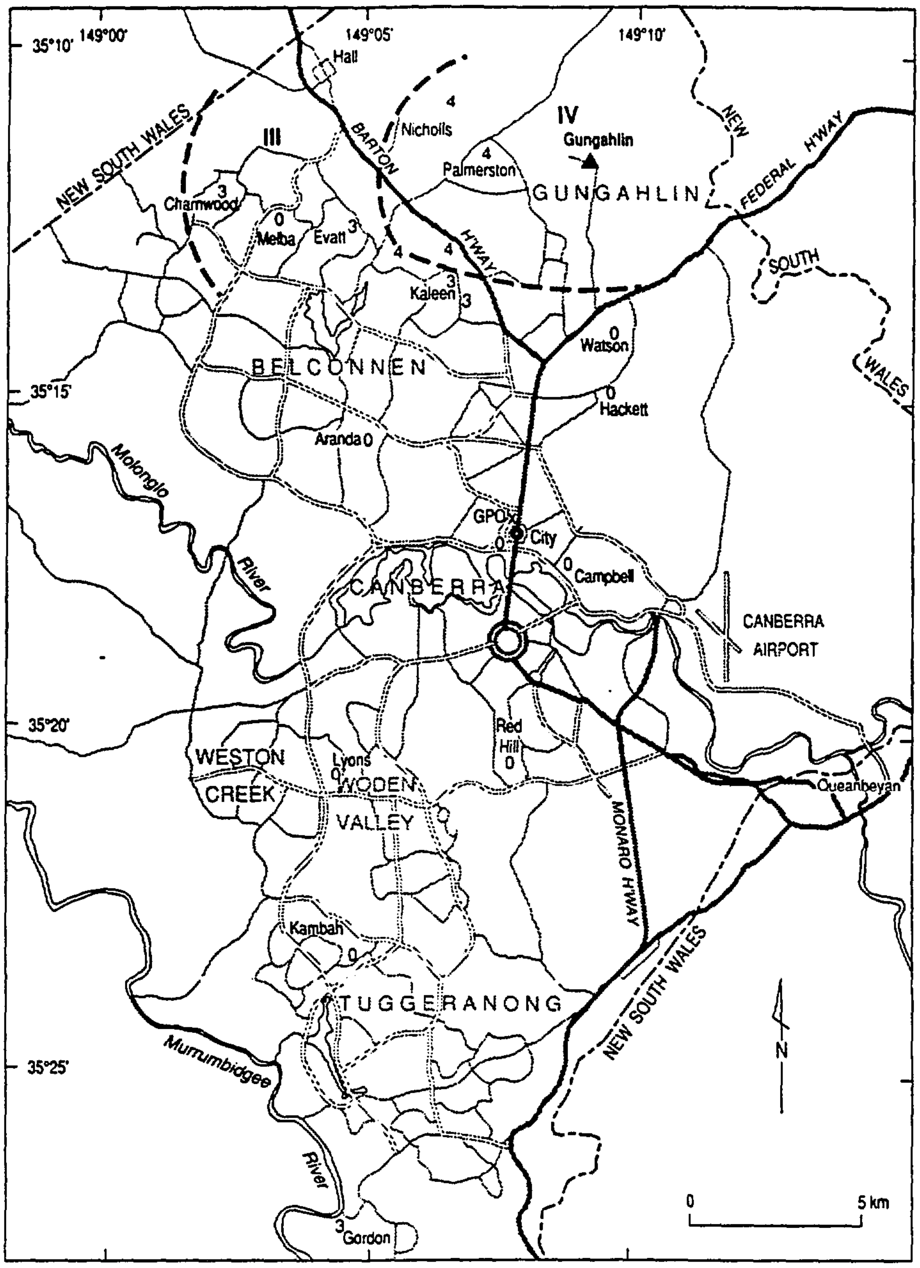
▲ *Epicentre*
III *Zone intensity designation*
3 *Earthquake felt (MM)*
0 *Earthquake not felt*

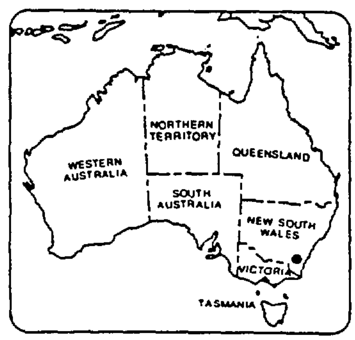
Isoseismal map of the Gungahlin earthquake ACT 6 September 1994

On 6 September 1994 at 11.44 pm local time a magnitude MD 1.6 earthquake occurred at Gungahlin, 10 km NNE of the Canberra GPO. The epicentre was located to an accuracy of 3 km in the east-west direction and 2 km in the north-south direction according to the computer solution, but the focal depth could lie between 0 and 11 km. The position of the epicentre is consistent with the isoseismals which were drawn on the basis of telephone felt reports and, due to lack of data, were not constrained to the east of the epicentre. Near the epicentre the microearthquake sounded like an explosion. It was reported felt to the west over a radius of about 12 km. There was an isolated felt report from Gordon, 31 km SSW of the epicentre.

Marion Michael-Leiba and Trevor Jones

ISOSEISMAL MAP OF THE GUNGAHLIN EARTHQUAKE, ACT
6 SEPTEMBER 1994





DATE: 6 SEPTEMBER 1994
TIME: 13:44:51.1 UTC
MAGNITUDE: 1.0 ML, 1.6 MD (AGSO)
EPICENTRE: 35.19°S 149.15°E
DEPTH: 1 km

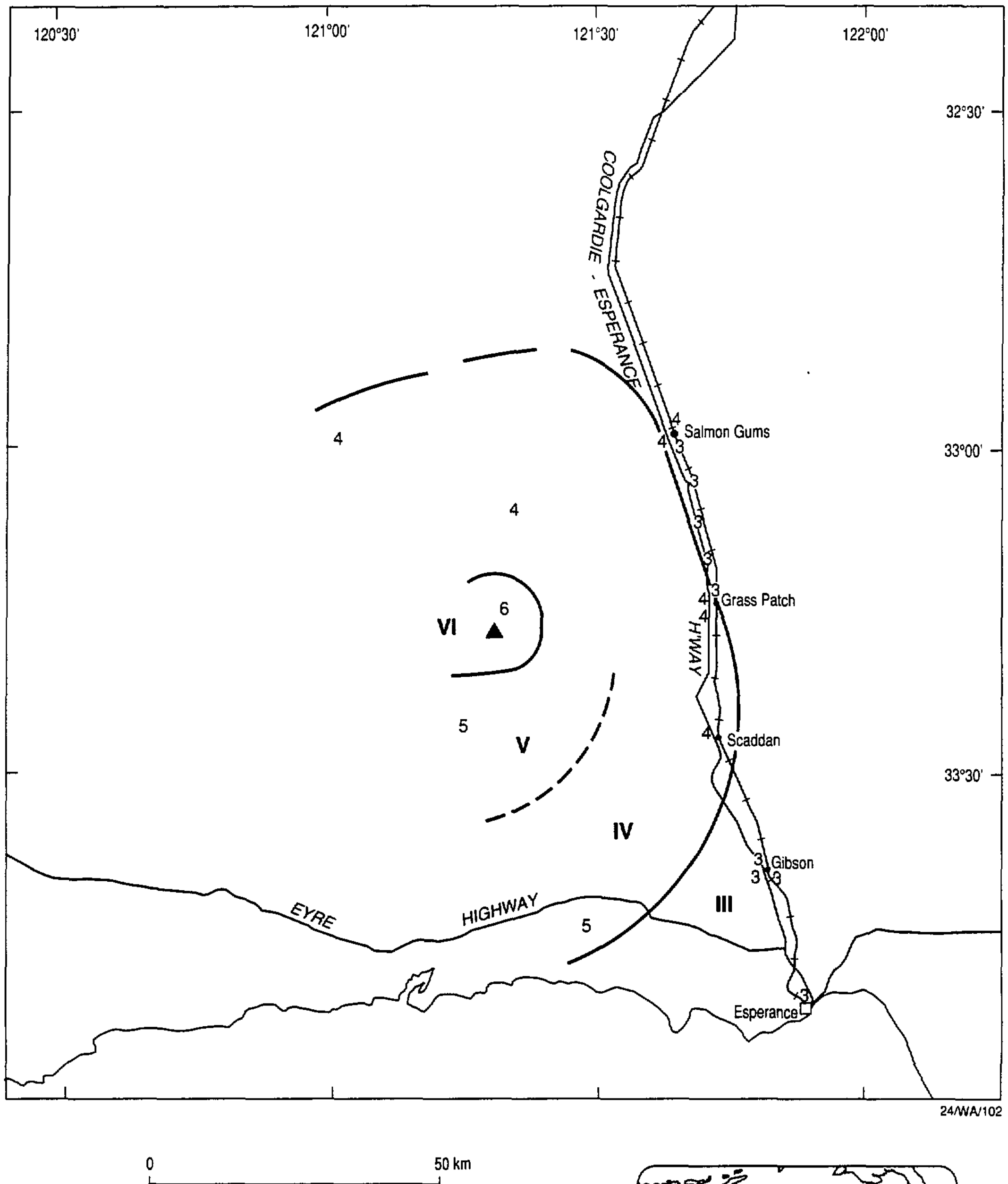
▲ *Epicentre*
IV *Zone intensity designation*
4 *Earthquake felt (MM)*
0 *Earthquake not felt*

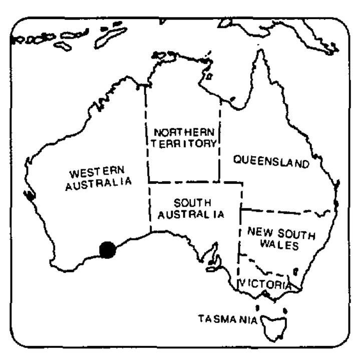
Isoseismal map of the Salmon Gums earthquake Western Australia 11 October 1994

A strong tremor on 11 October at 6.34 p.m. (WST) was felt in the Esperance region up to 80 km from the epicentre. Apart from Esperance, the region is sparsely populated, therefore the tremor was not felt by many. The epicentre was located about 50km SW of Salmon Gums and the magnitude was ML 3.9. The maximum intensity experienced near the epicentre was MM VI. Small objects were shifted and plaster cracked on walls. The radius of the MM IV isoseismal was 40-50km.

Peter Gregson

ISOSEISMAL MAP OF THE SALMON GUMS EARTHQUAKE, WESTERN AUSTRALIA
11 OCTOBER 1994





DATE: 11 OCTOBER 1994
TIME: 10:34:34.7 UTC
MAGNITUDE: 3.9 ML (MUN)
EPICENTRE: 33.29°S 121.31°E

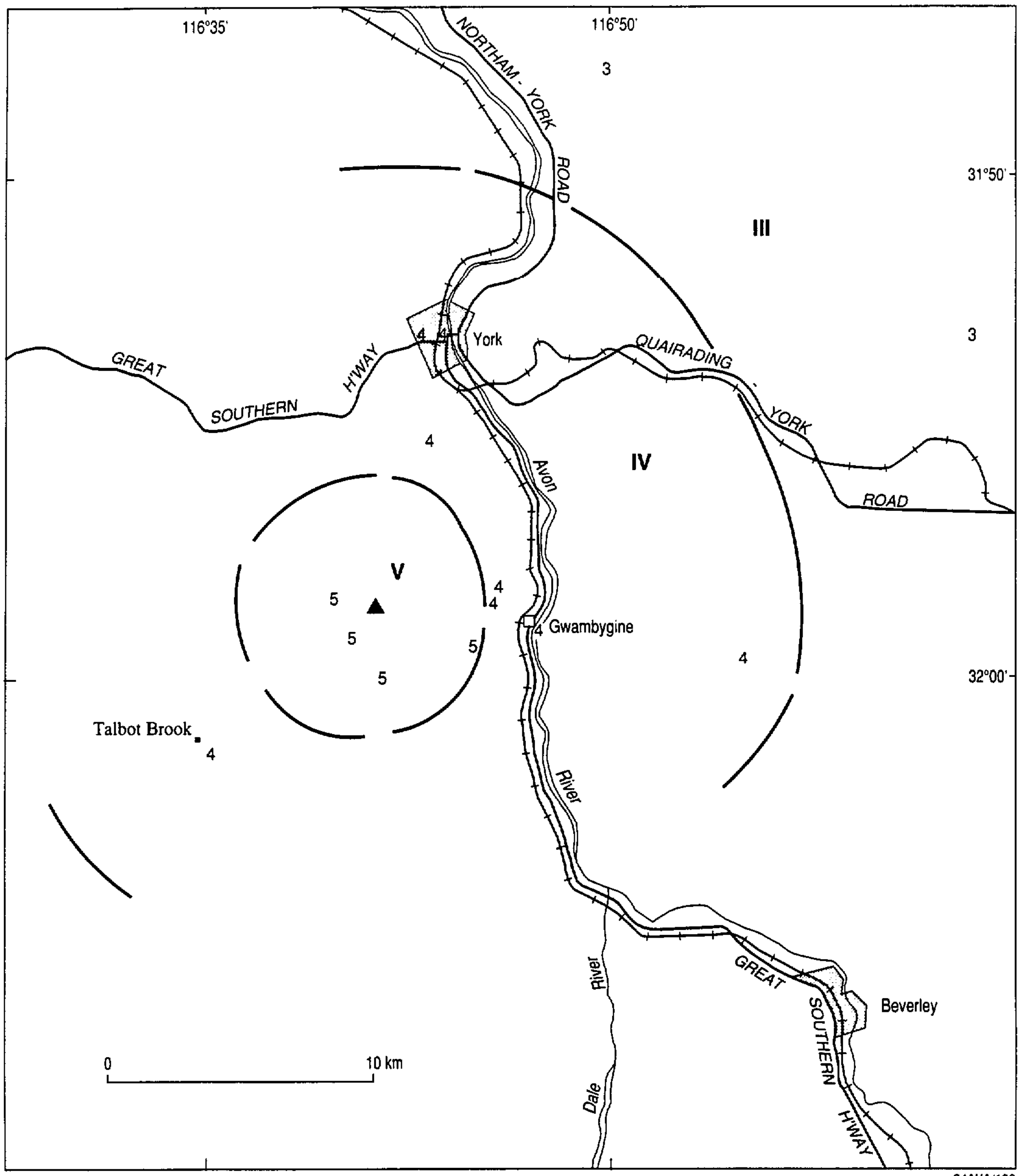
▲	*Epicentre*
IV	*Zone intensity designation*
4	*Earthquake felt (MM)*
0	*Earthquake not felt*

Isoseismal map of the Talbot Brook earthquake Western Australia 23 November 1994

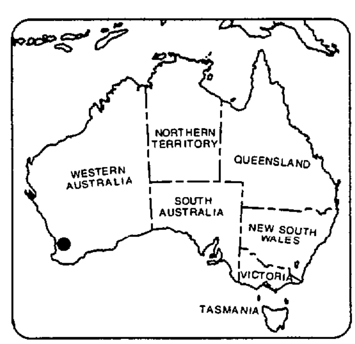
At 4.53 a.m. (WST) on 24 November, a magnitude ML 3 earthquake woke many residents in the York-Talbot Brook area. The epicentre was 12km SSW of York, 10km NE of Talbot Brook. No damage was reported but small objects moved and one observer reported that he thought the roof was going to "lift off". The radii of the V and VI isoseismals were 5 and 15km respectively and the tremor was felt at least up to 25 kilometres away.

Peter Gregson

ISOSEISMAL MAP OF THE TALBOT BROOK EARTHQUAKE, WESTERN AUSTRALIA
23 NOVEMBER 1994



24/WA/103



DATE: 23 NOVEMBER 1994
TIME: 20:53:29.9 UTC
MAGNITUDE: 3.0 ML (MUN)
EPICENTRE: 31.98°S 116.74°E

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

Table 1 Australian epicentres, 1994, ML ≥3

Date		Time UTC		Lat °S	Long °E	Depth km	ML	Place
1	7	1213	21.2	32.425	122.297	5	3.0	Norseman WA
2	1	0553	7.4	38.602	146.305	11	3.8	Boolara South Vic
2	8	0408	30.4	19.853	133.945	7	3.8	Tennant Creek NT
2	8	1531	5.5	19.761	133.885	5	4.3	Tennant Creek NT
2	11	0725	27.3	19.746	133.827	5	3.3	Tennant Creek NT
2	11	2313	02	16.610	110.890	5	4.0	NW Exmouth WA
2	20	1432	41.5	29.610	123.760	5	3.2	Laverton WA
2	23	1913	40.7	19.862	133.840	5	3.6	Tennant Creek NT
2	27	0445	38.1	19.904	134.071	5	3.6	Tennant Creek NT
2	28	0758	10.1	15.170	127.270	5	3.2	NW Kununurra WA
3	20	2049	42.0	19.800	133.800	5	3.0	Tennant Creek NT
3	23	1150	37.0	20.292	117.714	5	3.7	Port Hedland WA
3	23	1158	46.5	34.113	105.662	5	3.0	WSW Pert WA
4	7	2057	26.4	11.978	134.799	33	3.0	E Darwin NT
4	17	1258	17.4	33.035	138.973	8	3.0	Doughboy Hill SA
4	19	1125	6.9	21.917	126.548	5	3.4	L Tobin WA
4	19	1526	57.7	19.798	133.899	5	4.1	Tennant Creek NT
4	26	1549	39.5	30.605	118.481	5	4.1	Bonnie Rock WA
5	8	0417	14.9	19.901	134.064	5	3.0	Tennant Creek NT
5	14	1433	35.1	38.738	143.549	0	3.0	C Otway Vic
5	21	0859	17.9	35.972	146.947	0	3.0	Albury NSW
5	25	1825	50.6	16.687	120.686	5	3.1	Broome WA
5	28	0150	43.5	19.851	133.916	5	3.2	Tennant Creek NT
6	16	1918	51.9	19.847	133.987	4	3.3	Tennant Creek NT
6	17	1152	33.9	20.200	148.860	5	3.2	Hayman Is Qld
6	19	0224	42.5	33.168	138.363	11	3.2	Laura SA
6	23	0340	8.1	19.863	133.946	5	3.9	Tennant Creek NT
6	23	1355	27.4	34.920	117.680	5	3.0	Albany WA
6	26	0736	3.0	33.605	133.815	13	3.2	Coastal SA
6	28	1826	53.0	40.344	154.817	10	3.7	East Bass Strait
7	4	0910	17.1	19.580	141.530	5	3.8	Julia Ck Qld
7	5	1907	22.3	20.055	141.589	5	4.2	Julia Ck Qld
7	7	1351	12.3	19.889	134.142	1	4.1	Tennant Creek NT
7	8	1840	33.7	30.557	138.922	13	3.3	Nepabunna SA
7	9	1430	55.7	31.993	144.990	10	4.2	Belaraboon NSW
7	22	0049	23.5	19.783	133.799	5	4.2	Tennant Creek NT
8	6	1103	51.6	32.924	151.288	2	**5.3**	Ellalong NSW
8	10	2037	0.4	34.161	139.150	18	3.2	Eudunda SA
8	19	0219	36.0	33.422	148.361	1	3.0	Eugowra NSW
8	19	1809	51.1	33.422	148.361	1	3.2	Eugowra NSW
8	19	2352	10.0	33.422	148.361	1	3.3	Eugowra NSW
8	21	0215	7.2	33.422	148.361	1	3.0	Eugowra NSW
8	21	0553	51.1	33.421	148.364	1	4.0	Eugowra NSW
8	22	0331	49.0	21.990	126.320	5	3.4	Tobin Lake WA
8	31	2048	30.2	19.859	133.321	5	4.5	Tennant Creek NT
9	1	0625	30.2	22.873	130.459	5	3.1	L McKay NT
9	4	0108	2.1	16.987	144.502	0	4.0	Chillagoe Qld
9	4	1301	28.5	30.690	124.250	5	4.3	Zanthus WA
9	4	2144	5.0	30.300	137.962	0	3.0	Lyndhurst SA
9	12	0449	54.5	19.845	133.452	13	3.2	Tennant Creek NT
9	12	1203	1.2	22.512	136.427	5	3.9	Lucy Ck NT
9	18	0408	51.1	33.836	148.184	0	3.1	Grenfell NSW
9	23	1406	51.5	19.729	134.096	5	3.6	Tennant Creek NT
9	27	0758	34.0	36.202	148.619	13	3.1	Snowy Mtns NSW
10	9	1501	26.7	16.652	128.070	5	3.6	Warmun WA
10	11	1448	47.5	19.819	134.173	0	3.9	Tennant Creek NT
10	11	1034	34.7	33.294	121.307	3	3.9	Salmon Gums WA

Table 1 (cont)

Date	*Time UTC*	*Lat °S*	*Long °E*	*Depth km*	*ML*	*Place*
10 17	1741 14.4	20.000	134.000	3	3.4	Tennant Creek NT
10 19	2007 43.9	35.208	123.602	5	3.3	SE Esperance WA
10 20	1010 48.8	19.813	133.921	3	3.0	Tennant Creek NT
11 2	0902 27.7	19.887	134.213	0	3.1	Tennant Creek NT
11 4	2200 8.4	28.316	135.440	12	3.0	E Lake Eyre SA
11 11	2000 41.5	19.822	134.165	2	3.3	Tennant Creek NT
11 23	2053 29.8	31.977	116.786	5	3.0	York WA
11 24	2003 21.9	31.987	116.728	5	3.0	York WA
11 30	1953 19.5	30.349	138.087	0	4.2	Myrtle Springs SA
11 30	2023 55.6	30.432	138.042	0	3.4	Myrtle Springs SA
12 2	1942 36.4	23.587	130.133	0	4.2	Lake MacKay NT
12 3	0855 10.3	19.764	133.831	0	3.0	Tennant Ck NT
12 5	1946 53.7	30.415	138.040	4	3.0	Myrtle Springs SA
12 5	1957 14.9	30.371	138.000	0	3.1	Myrtle Springs SA
12 5	2029 40.2	30.414	138.005	0	3.3	Myrtle Springs SA
12 5	2049 38.5	30.357	137.952	4	4.0	Myrtle Springs SA
12 5	2102 39.0	30.412	138.013	5	3.8	Myrtle Springs SA
12 5	2116 34.4	30.397	137.949	5	3.5	Myrtle Springs SA
12 7	0532 43.5	30.445	137.988	5	3.0	Myrtle Springs SA
12 9	1553 14.6	30.427	137.944	4	3.2	Myrtle Springs SA
12 12	0203 5.5	30.395	137.964	0	3.1	Myrtle Springs SA
12 22	1024 15.8	19.910	134.041	2	3.8	Tennant Ck NT
12 24	0818 37.7	11.208	139.311	5	3.5	C York Qld
12 24	1628 0.4	19.828	133.997	15	3.6	Tennant Ck NT
12 27	1910 14.2	23.649	130.248	5	3.0	NT/WA Border area

Table 2. Large or damaging Australian earthquakes, 1788 - 1995

Date UTC	*Time*	*Lat °S*	*Long °E*	*ML*	*Ms*	*$AUS loss (1994$)*	*Location*
1873 12 15	0400	26.25	127.5		6.0		SE WA
1884 07 13	0355	40.5	148.5		6.2		NE Tasmania
1885 01 05	1220	29.0	114.0		6.5		Geraldton WA
1885 05 12	2337	39.8	148.8		6.5		NE Tasmania
1892 01 26	1648	40.3	149.5		6.6		NE Tasmania
1897 05 10	0526	37.33	139.75		6.5		Kingston SA
1902 09 19	1035	35.0	137.4		6.0		Warooka SA
1903 04 06	2352	38.43	142.53	4.6			Warrnambool Vic
1903 07 14	1029	38.43	142.53	5.3			Warrnambool Vic
1906 11 19	0718	21.5	104.5		7.3		Offshore WA
1918 06 06	1814 24	23.5	152.5	6.0	5.7		Gladstone Qld
1920 02 08	0524 30	35.0	111.0		6.0		Offshore WA
1929 08 16	2128 23	16.99	120.66		6.6		Broome WA
1935 04 12	0132 24	26.0	151.1	5.2	5.4		Gayndah Qld
1941 04 29	0135 39	26.92	115.80	7.0	6.8		Meeberrie WA
1941 06 27	0755 49	25.95	137.34		6.5		Simpson Desert
1946 09 14	1948 49	40.07	149.30	6.0	5.4		West Tasman Sea
1954 02 28	1809 52	34.93	138.69	5.4	4.9	107M	Adelaide SA
1961 05 21	2140 03	34.55	150.50	5.6		3M	Bowral NSW
1968 10 14	0258 50	31.62	116.98	6.9	6.8	31M	Meckering WA
1970 03 10	1715 11	31.11	116.47	5.1	5.1		Calingiri WA
1970 03 24	1035 17	22.05	126.61	6.7	5.9		L Mckay WA
1972 08 28	0218 56	24.95	136.26		6.2		Simpson Desert
1973 03 09	1909 15	34.17	150.32	5.6	5.3	2M	Picton NSW
1975 10 03	1151 01	22.21	126.58		6.2		L Mckay WA
1978 05 06	1952 19	19.55	126.56		6.2		L Mckay WA
1979 04 23	0545 10	16.66	120.27	6.6	5.7		Broome WA
1979 04 25	2213 57	16.94	120.48		6.1		Broome WA
1979 06 02	0947 59	30.83	117.17	6.2	6.1	10M	Cadoux WA
1983 11 25	1956 07	40.45	155.51	6.0	5.8		Tasman Sea
1985 02 13	0801 23	33.49	150.18	4.3		.09M	Lithgow NSW
1986 03 30	0853 48	26.33	132.52		5.8		Marryat Ck SA
1988 01 22	0035 57	19.79	133.93		6.3	1.3M	Tennant Ck NT
1988 01 22	0357 24	19.88	133.84		6.4		Tennant Ck NT
1988 01 22	1204 55	19.94	133.74		6.7		Tennant Ck NT
1989 12 27	2326 58	32.95	151.61	5.6	4.6	1 270M	Newcastle NSW
1994 08 06	1103 52	32.92	151.29	5.3		34M	Ellalong NSW

Table 3. Australian Seismographic Stations, 1994

Code#	*Name*	*Lat °S*	*Long °E*	*Elev.m*	*Operator*	*Type**
Queensland						
AWD	Awoonga Dam	24.078	151.316	110	QLD	1
BDM	Boondooma Dam	26.112	151.444	320	QLD	1
BGD	Biggenden	25.530	152.094		QLD	1
BLO	Burdekin Lookout	20.625	147.121	234	QLD	1,8
BLP-	Blunder Park	17.76	145.42	650	QLD	8
BRS	Mt Nebo Brisbane	27.392	152.775	525	QLD	5
CCQ	Carron Creek	17.85	145.57	740	QLD	8
CRC	Cracow	25.253	150.279	290	QLD	1
CTAO+	Charters Towers	20.088	146.255	357	QLD/AGSO	2/7
DLB	Dalbeg	20.151	147.264	70	QLD	1
DNG	Doongara	20.555	146.475	280	QLD	1
DPT-	Dingo Pocket	17.913	145.823	100	QLD	1
DRG	Durong	26.286	151.292		QLD	1
EDV	Eidsvold	25.438	151.292		QLD	1
GCM2-	German Ck Mine	22.98	148.55	136	CQU	1
GLD	Glenlyon Dam	28.969	151.480	48	QLD	1
HRD-	H Road	17.76	145.65	260	QLD	8
MCP	Mt Cooper	20.552	146.806	300	QLD	1
MNH-	Munroe Hill	17.97	145.80	40	QLD	1
MNT	Monto	24.855	151.141		QLD	1
MPR	Mount Perry	25.198	151.731		QLD	1
MRVQ	Maryvale Break	22.955	150.675	75	UCQ	1
MTMQ	Mt Morgan	23.763	150.390	170	CQU/AGSO	8
NWL-	Newlands	21.221	147.868	290	QLD	1
PFD	Peter Faust Dam	20.386	148.375	12	QLD	1
QIS+	Mount Isa	20.556	139.605	330	AGSO	7
QLP	Quilpie	26.584	144.235	210	AGSO	1
RMQ	Roma	26.489	148.755	360	AGSO	1
RVH-	Ravenshoe	17.63	145.48	880	QLD	1
SCY-	Sunday Creek	17.88	145.34	690	QLD	8
UCQ2	CQU Campus	23.329	150.524	27	CQU	1
UKA	Ukalunda	20.899	147.127	200	QLD	1
WBA	Buaraba	27.353	152.308	100	QLD	1
WCR-	Cricket Road	27.520	152.455	100	QLD	1
WMB	Mt Brisbane	27.115	152.550	160	QLD	1
WPM	Pine Mountain	27.536	152.735	35	QLD	1
WRC	Reedy Creek	27.187	152.663	190	QLD	1
WTG	Toogoolawah	27.146	152.333	130	QLD	1
WTR-	Thallon Rd	27.5286	152.4645		QLD	1
WWH	Wivenhoe Hill	27.370	152.587	190	QLD	1
Northern Territory						
ASPA	Alice Springs	23.667	133.901	600	AGSO	3
MTN	Manton Dam	12.847	131.130	80	AGSO	1
WRA	Warramunga	19.944	134.353	366	CAN	3
Western Australia						
ARG	Argyle Diamond	16.7092	128.427	230	SRC	8
BAL	Ballidu	30.607	116.707	300	MUN	1
COOL-	Coolgardie	30.884	121.145	500	MUN	1
FITX+	Fitzroy Crossing	18.109	125.642	110	MUN	1
FITZ	Fitzroy Crossing	18.102	125.639	110	MUN	7
FORT+	Forrest	30.779	128.059	165	MUN	7
KLB	Kellerberrin	31.578	117.760	300	MUN	1
KNA	Kununurra	15.750	128.767	150	PWD/MUN	1
MBL	Marble Bar	21.160	119.833	200	MUN	1
MEEK+	Meekatharra	26.638	118.615	530	MUN	1
MGO	Mundaring Office	31.9033	116.165	250	MUN	1

Table 3 (cont.)

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
RKG	Rocky Gully	34.570	117.010	300	MUN	1
WARB+	Warburton	26.184	126.643	460	MUN	7
WOOL+	Woolibar	31.073	121.678	325	MUN	7
NSW & ACT						
APN	Appin	34.171	150.823	277	SRC	8
ARMA+	Armidale	30.4198	151.628	1130	AGSO	7
AVD	Avon	34.376	150.615	532	SRC	8
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
CAV	Cavalon	29.6495	151.6227	96	SRC	8
CBR	Cabramurra	35.943	148.393	1537	CAN	1
CMS	Cobar	31.487	145.828	225	AGSO	1
CNB	Canberra (AGSO)	35.314	149.362	855	AGSO	1
COP	Copeland Dam	29.9194	150.9336	62	SRC	8
CPX	Mt Cotopaxi	34.476	150.625	622	SRC	8
DAL	Dalton	34.726	149.174	570	AGSO	1
DON	Donald's Castle Ck	34.359	150.713	401	SRC	8
DRA+	Dora Dora	35.965	147.375	230	SRC	8
IVY	Inveralochy	34.972	149.718	770	CAN	1
JNL	Jenolan	33.826	150.017	829	CAN	1
KBH	Kambah	35.390	149.080	600	AGSO	1
FTZ	Fitzroy Falls	34.620	150.484	711	SRC	8
GRV	Greaves Creek	33.662	150.309	980	SRC	8
JBD	Jenolan	33.762	150.049	1235	SRC	8
LBX	Letterbox	34.272	150.874	400	SRC	8
MEG	Meangora	35.101	150.037	712	CAN	1
NAT	Nattai	34.206	150.427	632	SRC	8
NLD	North Lambton	32.901	151.701	50	NCC	8
NPSD	Newcastle Police	32.931	151.786	20	ASC	8
PHD	Pipehead Depot	33.847	150.969	90	SRC	8
PIN	Pindari Dam	29.3977	151.2407	53	SRC	8
QFS	Quorrobolong	32.933	151.396	14	ASC	8
RIV	Riverview	33.829	151.159	21	RIV	2
STKA	Stephens Creek	31.8769	141.5952	213	AGSO	7
WER	Werombi	33.950	150.580	226	CAN	1
YOU	Young	34.278	148.382	503	AGSO	1
South Australia						
ADE/ADT	Adelaide	34.967	138.714	655	ADE	2/1
ARK	Arkaroola	30.276	139.339	520	ADE	1
CLV	Cleve	33.691	136.495	238	ADE	1
GEX	Naracoorte	37.074	140.825	80	ADE	8
HTT	Hallett	33.430	138.921	708	ADE	1
HWK	Hawksnest	29.958	135.203	180	ADE/AGSO	8
KHC	Kelly Hill Caves	35.983	136.911	100	ADE	1
MGR2	Mt Gambier	37.801	140.686	60	ADE	1
NBK	Nectar Brook	32.701	137.983	180	ADE	1
PDA	Parndana	35.806	137.239	140	ADE	8
PNA	Partacoona	32.006	138.165	180	ADE	1
RPA	Roopena	32.725	137.403	95	ADE	1
SDN	Sedan	34.509	139.337	125	ADE	8
THS	The Heights HS	34.742	138.773	340	ADE	1
WKA	Willalooka	36.417	140.321	40	ADE	1
WRG	Woomera	31.105	136.763	168	ADE/AGSO	1

Table 3 (Cont.)

Victoria						
ABE	Aberfeldy	37.719	146.389	549	SRC	1
BEL	Bell's Track	37.761	146.389	545	SRC	1
BFD	Bellfield	37.177	142.545	235	AGSO	1
BUC	Bucrabanyule	36.238	143.498	210	SRC	1
CRN	Cairn Curran	36.9906	143.9722	230	SRC	8
DRO	Dromana	38.360	144.997	170	SRC	1
DTM/DTT	Dartmouth	36.5293	147.4686	436	SRC	8
FRT	Forrest	38.534	144.997	210	SRC	1
FSK	Fish Creek	38.753	145.994	45	SRC	8
GOG	North Grampians	36.888	142.400	265	SRC	8
GVL	Greenvale	37.6186	144.9006	188	SRC	1
HOP	Mount Hope	35.995	144.207	300	SRC	1
IVS+	Inverness	36.134	147.068	330	SRC	8
JEN	Jeeralang Junction	38.351	146.420	330	SRC	1
KOWA	Kowarra	35.791	144.521	85	SRC	1
MAL	Marshall Spur	37.749	146.292	1076	SRC	1
MEM	Merrimu	37.637	144.497	160	SRC	1
MCV	McVeigh	37.691	145.899	630	SRC	1
MIC	Mount Erica	37.944	146.359	805	SRC	1
TOT	Thompson Dam	37.843	146.406	680	SRC	8
MLW	Molesworth	37.137	145.510	280	SRC	1
PAT	Plane Track	37.857	146.456	771	SRC	1
PEG	Pegleg	36.985	144.091	340	SRC	1
POL	Poley Tower	37.626	145.801	1200	SRC	1
PNH	Panton Hill	37.6346	145.2709	180	SRC	1
RUS	Rushworth	36.662	144.947	145	SRC	1
SIN	Swingler Track	37.739	146.292	980	SRC	8
TMD	Thomson Dam	37.810	146.349	941	SRC	1
TOM	Thomson	37.810	146.348	941	SRC	1
TOO	Toolangi	37.572	145.490	604	AGSO	7
TOS	Thomson PABX	37.8243	146.4057	68	SRC	8
TYR	Tyers	38.108	146.435	280	SRC	1
UYB	Upper Yarra	37.673	145.897	300	SRC	1
VPE	Vantage Point	37.642	145.937	650	SRC	1
WSK	Woodstock	36.814	144.055	210	SRC	1
Tasmania						
MOO	Moorlands	42.442	147.190	325	TAU	1
MTRD	Mount Read	41.846	145.544	1090	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
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	AGSO	1/6
Antarctica						
CSY	Casey	66.289	110.529	56	AGSO	1
MAW	Mawson	67.607	62.872	15	AGSO	5/7
MCQ	(see Tasmania)					

Refers to contributors listed on page iii.
* Type of seismograph
1. Short period (vertical and/or horizontal) 2. World Wide Standardised Seismographic Station (WWSSN) 3. Seismic array 4. Seismological Research Observatory (SRO) 5. Long and short period 6. Broad-band vertical 7. Broad-band triaxial 8 Kelunji digital triaxial triggered

Notes +/- Opened/closed this year
This list does not include stations or temporary networks installed during the year

Table 5. Australian accelerographs, 1994

Location	*Lat °S*	*Long °E*	*Elev (m)*	*Foundation*	*Type*	*Owner*
ACT						
ASC-AGSO	35.289	149.139	560	Alluvium	SRC	AGSO
Parliament House	35.310	149.123	600	Sandstone	SRC	AGSO
Corin Dam (2)	35.524	148.812	915	Granite	SRC	ACTEW
Lower Cotter Dam	35.308	148.908	535	Basalt	SRC	ACTEW
Telecom Tower (3)	35.275	149.096	810	Sandstone	SRC	TEL
New South Wales						
Avon (AVD)	34.376	150.615	532	Sandstone	SRC	NSWWB
Cataract bedrock CTB	34.265	150.811	322	Sandstone	SRC	NSWWB
Cataract Dam (CTD)	34.267	150.802	294	Concrete dam	SRC	NSWWB
Oolong (OOL)	34.773	149.163	600	Weathered granite	SMA-1	AGSO
Ferndale (FND)	34.745	149.166	580	Granite	SRC	AGSO
Fitzroy Falls (FTZ)	34.625	150.484	711	Sandstone	SRC	NSWWB
Springfield (SPF)	34.765	149.151	580	Granite	SRC	AGSO
Wilton (WIL)	34.800	149.221	660	Granite	SRC	AGSO
Googong Dam (2)	35.425	149.264	620	Meta-sediments	SRC	ACTEW
Hume Weir (3)	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
Jenolan (JBD)	33.672	150.049	1235	Palaeozoic dacite	SRC	NSWWB
Lucas Heights LHB	34.052	150.979	80	Sandstone	SRC	ANSTO
Lucas Heights LHR	34.05	150.98	80	Reactor Building	SRC	ANSTO
Newcastle Police Stn NPSD	32.931	151.786	20	Building basement	SRC	AGSO
Pipehead Depot (PHD)	33.847	150.969	90	Sandstone /shale	SRC	NSWWB
Water Board Office	33.876	151.207	90	Multi-storey bldg	SRC	NSWWB
Warragamba dam abutment WDA	33.883	150.593	180	Sandstone	SRC	NSWWB
Warragamba dam base WDB	33.885	150.594	30	Concrete dam	SRC	NSWWB
Warragamba Dam Centre (WDC)	33.885	150.594	60	Concrete dam	SRC	NSWWB
Warragamba Dam Top WDT	33.885	150.594	100	Concrete dam	SRC	NSWWB
Warragamba bedrock WGB	33.866	150.575	254	Concrete dam	SRC	NSWWB
Yerranderie (YER)	34.142	150.232	554	Sandstone	SRC	NSWWB
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 HosSRCal	34.83	138.70	50	Marl & clay	MO2	PWDSA
Admin. Centre	34.925	138.608	50	Alluvium	MO2	PWDSA
Govt House GHS	-34.921	138.599	40	Stiff clay	SRC	AGSO
Tucker's TUK	-34.968	138.659	320	Rock	SRC	AGSO
Tasmania						
Gordon Dam	42.71	145.97	350	Quartzite	MO2	HEC

Table 5 (cont.)

Victoria						
Hume Dam HUM+	36.111	147.029	190	Dam wall	SRC	DWR
Inverness IVS+	36.1337	147.0618	330	Granite	SRC	DWR
Jeeralang JNA	38.351	146.419	330	Mesozoic sediments	SRC	SRC
Moone Ponds MPD+	37.7684	144.9085	20	Tertiary sediment	SRC	
Plane Track PTA	37.357	146.357	771	Palaeozoic sediments	SRC	SRC
Surrey Hills SHY+	37.826	145.1104	100	Palaeozoic sediments	SRC	
Bradford Hills BRD	36.892	144.099	284	Granite	SRC	SRC
Phillip Institute SRC	37.683	145.061	116	Eocene sediments	SRC	SRC
Dartmouth Dam DDC	36.561	147.524	494	Dam crest	SRC	RWCV
	36.570	147.580	520	Hoist house	SMA-1	RWCV
Dartmouth Dam DDB	36.558	147.511	329	Ordivician meta-sediments	SRC	RWCV
	36.570	147.580	420	Downstream face	SMA-1	RWCV
	36.570	147.580	360	Access tunnel	SMA-1	RWCV
Animal Health Lab(3)	38.15	144.39	10		SMA-1	CSIRO
Thomson Dam (TMT)	37.844	146.396	460	Outlet Tower	SRC	MMBW
Thomson Abutment TMA	37.8440	146.3972	180	Abutment	SRC	MW
Northern Territory						
Tennant Creek TCTY	19.642	134.183	370	Sediments	SSA-1	SRC
Queensland						
Wivenhoe Dam	27.394	152.602	80	Crest	A700	BAWB
	27.395	152.603	28	Base	A700	BAWB
	27.347	152.631	78	Power Station	A700	QEC
	27.375	152.631	78	Power Station	A700	QEC
Splityard Ck. Dam	27.379	152.641	170	Dam Wall	A700	QEC
	27.375	152.641	65	Valve room	A700	QEC
Tully Millstream	17.76	145.42	65		SRC	QEC
	17.85	145.57	74		SRC	QEC
Western Australia						
Beverley (BEM)	32.159	117.200	240	Alluvium	A700	AGSO
Cadoux (CAA)	30.746	117.151	320	Laterite/ Granite	A700	AGSO
Cadoux (CAS)	30.810	117.132	400	Weathered granite	MO2	AGSO
Canning Dam						
Lower gallery (CDL)	32.154	116.126	142	Granite	A700	WAWA
Upper gallery (CDU)	32.154	116.126	202	Granite	A700	WAWA
Goomalling (GOO)	31.394	116.852	250	Granite	SRC	AGSO
Kununurra						
Dam abutment KNA	16.113	128.737		Phyllite	A700	WAWA
Dam wall KNW	16.113	128.738		Rock fill, 3m clay core	A700	WAWA
Meckering MEK	31.694	116.982	200	Alluvium/granite	MO2	AGSO
Meckering ME3	31.714	117.054	200	Alluvium/granite	A700	AGSO
Mundaring LAK	31.86	116.34	310	Alluvium/granite	SRC	AGSO
Mundaring Weir						
Weir MUW	31.958	116.164	140	Concrete wall 42m high	SMA1	WAWA
Mukinbudin MBC	30.728	118.253	350	Alluvium/granite	MO2	AGSO

Table 5 (cont.)

Mukinbudin MBS	30.740	118.256	360	Laterite	SRC	AGSO
Museum MUC	31.957	116.162	106	Concrete floor	MO2	WAWA
Perth TRI	31.959	115.878	5	Clay-alluvium	SRC	AGSO
Perth Kings Park KPK	31.960	115.842	60	Limestone	SRC	AGSO
Quairading QUW	31.987	117.270	300	Weathered granite	MO2	AGSO
North Dandalup NDD	32.52	116.01	205	Granite	A700	WAWA
Serpentine Dam						
Basement SEB	32.40	116.10		Granite	A700	WAWA
Victoria Dam VID	32.04	116.06		Granite	A700	WAWA
Wall SEW	32.40	116.10		Earthfill	A700	WAWA
York (Temporary)	31.968	116.717	380	Granite	SRC	MUN

ANSTO Australian Nuclear Science & Technology Organisation; BAWB Brisbane and Area Water Board; AGSO Australian Geological Survey Organisation, Canberra/Mundaring; EWSSA Engineering & Water Supply Department, South Australia; ACTEW ACT Electricity and Water Authority; HEC HydroElectric Commission, Tasmania; MMBW Melbourne & Metropolitan Board of Works; SRC Seismology Research Centre, RMIT; PWDSA Public Works Department, South Australia; PWDWA Public Works Department, Western Australia; QEC Queensland Electricity Commission; TEL Telecom (ACT & Perth); RWCV Rural Water Commission, Victoria; DWR Department of Water Resources, NSW; WAWA Water Authority of Western Australia; MW Melbourne Water.

Table 6 **Australian strong motion data, 1994**

Date UTC	*Time*	*Lat°S*	*Long°E*	*ML*	*Site*	*H/E km*	*Comp*	*T Sec*	*Acc mms^{-2}*
01 17	2155	31.62	117.09	2.8	GOO	34/34	SZ	0.040	8
							SN	0.035	12
							SE	0.040	18
04 26	1549	30.60	118.48	4.1	CAA	128/128	PZ	0.050	6
							PN	0.080	4
							PE	0.050	5
							SZ	0.070	8
S Values may not be maximum							SN	0.050	19
							SE	0.040	12
					GOO	178/178	PZ	0.040	3
							PN	0.040	3
							PE	0.050	5
S Values are not maximum							SZ	0.050	6
							SN	0.040	8
							SE	0.040	12
04 30	0326	30.7	117.1	<1.0	CAA	2/.2	SZ	0.020	22
							SN	0.025	94
							SE	0.020	78
04 30	1628	30.7	117.1	<1.0	CAA	2/.2	SZ	0.025	15
							SN	0.030	52
							SE	0.020	64
04 30	1638	30.7	117.1	<1.0	CAA	2/.2	SZ	0.030	4
							SN	0.035	13
							SE	0.025	14
05 07	1346	31.18	117.24	2.3	GOO	44/44	SZ	0.030	2
							SN	0.030	3
							SE	0.040	3
05 12	2059	30.7	117.1	<1.0	CAA	2/.2	SZ	0.030	5
							SN	0.045	16
							SE	0.030	13
05 17	1315	30.7	117.1	<1.0	CAA	2/.2	SZ	0.040	4
							SN	0.030	16
							SE	0.020	16
05 17	1337	30.7	117.1	1.4	CAA	2/.2	SZ	0.040	34
							SN	0.035	154
							SE	0.020	107

Table 6 (Cont.)

Date UTC	*Time*	*Lat°S*	*Long°E*	*ML*	*Site*	*H/E km*	*Comp*	*T Sec*	*Acc* mms^{-2}
05 18	0249	30.7	117.1	<1.0	CAA	2/.2	SZ	0.040	4
							SN	0.040	16
							SE	0.025	14
05 18	0317	30.7	117.1	<1.0	CAA	2/.2	SZ	0.040	4
							SN	0.025	23
							SE	0.020	20
06 08	0613	31.71	117.06	2.8	MEK	7/7	SZ	0.02	97
							SN	0.02	110
							SE	0.02	106
					GOO	40/40	PZ	0.035	3
							PN	0.030	3
							PE	0.030	3
							SZ	0.040	9
							SN	0.040	19
							SE	0.040	24
08 06	1103	32.92	151.29	5.3	NLD	39/39	SZ	0.58	80
							SN	0.55	150
							SE	0.55	80
					NPS	47/47	SZ	0.68	50
							SN	0.55	100
							SE	0.55	100
					MHL	95/95	SZ	0.32	4
							SN	0.18	5
							SE	0.27	9
					RIV	101/101	SZ	0.27	3
							SN	0.24	6
							SE	0.78	7
					LHB	129/192	SZ	0.26	10
							SN	0.30	10
							SE	0.27	20
08 10	2037	4.16	139.15	3.2	TUK	95/95	SZ		1.7
							SN		1.5
							SE		1.8
					GHS	95/95	SZ		4.4
							SN		5.4
							SE		5.4

Table 6 (Cont.)

Date UTC	Time	Lat°S	Long°E	ML	Site	H/E km	C omp	T Sec	Acc mms^{-2}
08 24	0553	33.42	148.36	4.0	EUCH	1/1	SZ	0.02	9500
							SN	0.03	3960
							SE	0.05	3100
					EUKM	5/5	SZ	0.04	1060
							SN	0.03	620
							SE	0.04	880
09 04	2301	30.74	117.13	1.9	CAA	2/2	SZ	0.050	29
							SN	0.050	49
							SE	0.040	51
09 17	1535	30.84	117.08	2.1	CAA	12/11.5	SZ	0.02	4
							SN	0.02	8
							SE	0.02	12
10 11	0947	30.80	117.09	1.6	CAA	9/8.5	SZ	0.04	16
							SN	0.02	59
							SE	0.02	33
10 14	1458	30.8	117.1	<1.0	CAA	3/3	SZ	0.025	2
							SN	0.025	7
							SE	0.025	3
10 16	2024	30.77	117.14	1.5	CAA	3/2.8	SZ	0.025	41
							SN	0.025	141
							SE	0.025	114
11 26	1416	31.81	116.92	2.7	GOO	47/47	SZ	0.030	8
							SN	0.030	9
							SE	0.030	11
12 01	1347	31.98	116.72	1.2	YK4	1.0/0.8	SZ	0.020	21
							SN	0.020	36
							SE	0.020	40
12 01	2105	31.98	116.72	1.2	YK4	1.0/0.8	SZ	0.020	29
							SN	0.020	23
							SE	0.020	19
12 01	2130	31.98	116.72	1.3	YK4	1.0/0.8	SZ	0.020	85
							SN	0.020	137
							SE	0.020	134
12 15	2049	30.36	137.95	4.0	MYS	17/-	SZ	0.01	356
							SN	0.01	389
							SE	0.01	371

Table 6 (Cont.)

Date UTC	*Time*	*Lat°S*	*Long°E*	*ML*	*Site*	*H/E km*	*C omp*	*T Sec*	*Acc* mms^{-2}
12 15	2102	30.41	138.01	3.8	MYS	18/-	SZ	0.01	388
							SN	0.01	323
							SE	0.01	412
12 15	2116	30.40	137.95	3.5	MYS	18/-	SZ	0.01	160
							SN	0.01	147
							SE	0.01	160

Note: YK4, EUCH & EUKM, MYS were temporary stations operated by AGSO at York WA (YK4), by the SRC at Eugowra NSW and by MESA at Myrtle Springs SA.

Table 7. **Principal world earthquakes, 1994**

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

Date	*Origin Time (UTC)*	*Region*	*Lat.*	*Long.*	*Magnitude*
17 Jan	12 30 55.3	Southern California	34.213 N	118.537 W	6.4mB, 6.8Ms 6.7Mw (GS) 6.7Mw (HRV) 6.7Mw (PAS) 6.7ML (BRK)

Depth 18 km. Sixty people were killed; more than 7000 injured; 20,000 homeless and more than 40,000 buildings damaged in Los Angeles, Ventura, Orange and San Bernardino Counties. Severe damage occurred in the San Fernando Valley: maximum intensities of (IX) were observed in and near Northridge and Sherman Oaks. Lesser, but still significant damage occurred at Fillmore, Glendale, Santa Clarita, Santa Monica, Simi Valley and in western and central Los Angeles. Damage was also sustained to Anaheim Stadium. Collapsed overpasses closed sections of the Santa Monica Freeway, the Antelope Valley Freeway, the Simi Valley Freeway and the Golden State Freeway. Fires caused additional damage in the San Fernando Valley and at Malibu and Venice. Preliminary estimates of damage are between 13 and 20 billion U. S. dollars. Felt throughout much of southern California and as far away as Turlock, California; Las Vegas, Nevada; Richfield, Utah and Ensenada, Mexico. The maximum recorded acceleration exceeded 1.0 g at several sites in the area with the largest value of 1.8g recorded at Tarzana, about 7 km south of the epicentre. A maximum uplift of about 15 cm occurred in the Santa Susana Mountains and many rockslides occurred in mountain areas, blocking some roads. Some ground cracks were observed at Granada Hills and in Potrero Canyon. Some liquefaction occurred at Simi Valley and in some other parts of the Los Angeles Basin.

21 Jan	02 24 29.9	Halmahera, Indonesia	1.015 N	127.733 E	6.2mB, 7.2Ms 7.0Mw (GS) 7.0Mw (HRV) 7.3Ms (BRK)

Depth 20 km. Seven people killed, 40 injured and 550 houses damaged in the Kau area. Felt strongly at Ternate.

05 Feb	23 34 09.9	Uganda	0.593 N	30.037 E	5.8mB, 6.0Ms 6.2Mw (GS) 6.2Mw (HRV)

Depth 14 km. At least two people killed; several injured and most buildings damaged in Fort Portal area. Two people killed and one injured by a landslide at Kasese. Felt at Kampala and eastern Zaire.

12 Feb	17 58 23.9	Vanuatu Islands	20.553 S	169.361 E	6.4mB, 7.1Ms 7.0Mw (GS) 7.0Mw (HRV) 7.2Ms (BRK)

Depth 28 km. Felt at Port Vila.

15 Feb	17 07 43.8	Southern Sumatera, Indonesia	4.967 S	104.302 E	5.9mB, 7.0Ms 6.6Mw (GS) 6.9Mw (HRV) 6.8Ms (BRK)

Table 7 (Cont.)

Date	*Origin Time (UTC)*	*Region*	*Lat.*	*Long.*	*Magnitude*

Depth 23 km. At least 207 people killed; more than 2000 injured; 75,000 homeless and extensive damage from landslides, mudlsides and fires in Lampung Province. Much of the damage and loss of life occurred in the Liwa area. At least 6000 homes, shops and government buildings damaged or destroyed from landslides in the Liwa area. Damage estimated to be about 169 million U S. dollars. Felt throughout much of southern Sumatra and parts of Western Jawa. Felt at Jakarta and in Singapore.

23 Feb	08 02 04.7	Northern Iran	30.853 N	60.596 E	6.1mB, 6.1Ms 6.0Mw (GS) 6.1 Mw (HRV)

Depth 6 km. Six people killed and many injured in the Sistan region.

01 Mar	03 49 00.8	Southern Iran	29.096 N	52.617 E	5.8mB, 6.0Ms 6.0Mw (GS) 6.1Mw (HRV)

Depth 13 km. At least two people killed; 50 injured and damage in the Firuzabad area. Landslides blocked roads in the mountainous region of Fars Province. Felt at Mamasani and Fasa.

02 Mar	03 38 03.8	Haiti Region	19.803 N	72.799 W	5.2mB, 5.0Ms 5.4Mw (HRV) 5.1Ms (BRK)

Depth 59 km. Four people killed and damage to houses in the St Luis du Nord area. Felt (V) and Kajabon, Mao and Villa Vasquez; (IV) at Santiago; (III) at Santo Domingo, Dominican Republic. Felt in eastern Cuba as far west as Santiago de Cuba and Holguin.

09 Mar	23 28 07	Fiji	18.03 S	178.41 E	7.5 Mw (GS)

Depth 563 km.

02 Jun	18 17 34.0	South of Jawa, Indonesia	10.477 S	112.835 E	5.7mB, 7.2Ms 7.8Mw (GS) 7.8Mw (HRV) 6.8Ms (BRK)

Depth 18 km. At least 250 people killed; 27 missing; 423 injured and many left homeless. About 1,500 houses damaged and 278 boats sunk or damaged. Most of the casualties and damage were caused by a tsunami along the southeast coast of Jawa. The quake was felt strongly across Bali, central and eastern Jawa, Lombok and Sumbawa Islands. Minor tsunami damage on the NW coast of Australia.

05 Jun	01 09 30.1	Taiwan	24.511 N	121.905 E	6.1mB, 6.6Ms 6.4Mw (GS) 6.4Mw (HRV) 6.1Ms (BRK)

Depth 11 km. One person killed at Chi-lung and two people injured in the I-lan-Tai-pei area. Two thirds of the houses were damaged in the Nan-ao area. Surface cracks were also observed in the area. Landslides blocked a highway between Su-ao and Hua-lien. Felt (V JMA) at Nan-ao; (IV JMA) at Hua-lien, Su-ao and Tai-pei; (III JMA) at Chia-i and Hsin-chu; (II JMA) at Tai-chung and Tai-nan. Also felt on Iriomote-jima, Ishigaki-shima and Yonaguni-jima, Japan.

Table 7 (Cont.)

Date	*Origin Time (UTC)*	*Region*	*Lat.*	*Long.*	*Magnitude*
06 Jun	20 47 40.5	Colombia	2.917 N	76.057 W	6.4mB, 6.6Ms 6.7Mw (GS) 6.8Mw (HRV) 6.3Ms (BRK)

Depth 12 km. At least 295 people killed; 500 missing; 13000 homeless and severe damage to houses, highways and bridges by the earthquake and ensuing landslides in Cauca, Huila, Tolima and Valle Departments. At least 200 homes were destroyed, including 25 at Toribio and 15 at Piendamo. Moderate structural damage occurred at Bogota and Cali. An avalanche from the Huila Volcano blocked the Paez River causing severe flooding at Belalcazar and Neiva. Felt in much of west-central Colombia from Tunja to Pasto.

09 Jun	00 33 16.2	Northern Bolivia	13.841 S	67.553 W	7.0mB 8.2Mw (GS) 8.2Mw (HRV) 7.4mB (BRK)

Depth 631 km. Five people killed in Peru; 3 killed in Arequipa Province. Numerous injuries and landslides occurred in southern Peru. Some minor structural damage at Brasilia; Campo Grande; Porto Velho and Manaus Brazil; Arica Chile and Tacna Peru. Felt in many parts of South America including most of Argentina, Bolivia and Brazil; felt lightly in Uruguay. Felt in the Dominican Republic; Puerto Rico; at many locations in North America including Los Angeles; Renton; Omaha; Sioux City; Minneapolis; La Crosse; Chicago; Parkersburg; Norwich; Boston and Toronto Canada. This is the first earthquake from this part of South America believed to have been felt in North America and is also believed to be the largest ever recorded in this general area.

18 Jun	03 25 15.8	South Island, New Zealand	42.963 S	171.658 E	6.2mB, 7.1Ms 6.7Mw (GS) 6.8Mw (HRV) 7.1Ms (BRK) 6.5ML (WEL)

Depth 14 km. Some structural damage (VI) at Christchurch. Landslides blocked highway 73 between Arthur's Pass and Christchurch. Felt throughout South Island and the southern part of North Island.

20 Jun	09 09 02.9	Southern Iran	28.968 N	52.614 E	5.9mB, 5.7Ms 5.8Mw (GS) 5.9Mw (HRV) 5.9Ms (BRK) 5.8MD (RYD)

Depth 9 km. At least three people killed and 100 injured in the Firuzabad-Shiraz area. Twelve villages destroyed and 50 others severely damaged in the Firuzabad-Shiraz area. Landslides blocked a road in the Zagros Mountains. Felt at Jahrom.

04 Jul	21 36 41.9	Off Coast of Oaxaca, Mexico	14.888 N	97.322 W	6.1mB, 6.1Ms 6.0Mw (GS) 6.5Mw (HRV)

Depth 15 km. Two people were killed in the city of Oaxaca by a stone wall that fell during the earthquake and several people were injured. Felt in the states of Guerrero, Oaxaca, Puebla and Veracruz. Also felt at Mexico City.

Table 7 (Cont.)

Date	*Origin Time (UTC)*	*Region*	*Lat.*	*Long.*	*Magnitude*
13 Jul	02 35 56.0	Vanuatu Islands	16.620 S	167.518 E	6.4mB, 7.3Ms 7.1Mw (GS) 7.2Mw (HRV) 7.3Ms (BRK)

Depth 33 km. Felt (VI) at Port-Vila and (V) on Malakula. Also felt on Ambrym, Aoba, Efate, Epi, Erromango, Espiritu Santo, Maewo and Pentecost.

21 Jul	18 36 31.7	Near southeast coast of Russia	42.340 N	132.865 E	6.5mB 7.3Mw (GS) 7.3Mw (HRV) 6.6mB (BRK)

Depth 471 km. Felt (III JMA) at Onahama and Tokyo; (II JMA) at Aomori, Sapporo and Yokohama; (I JMA) at Tottori, Japan.

18 Aug	01 13 06.1	Northern Algeria	35.562 N	00.107 W	5.5mB, 5.9Ms 5.8Mw (HRV)

Depth 9 km. At least 159 people were killed, 289 injured. 8000 to 10,000 left homeless and thousands of houses destroyed in Mascara Province.

01 Sep	15 15 53.2	Off coast of Northern California	40.406 N	125.648 W	6.6mB, 7.0Ms 7.1Mw (GS) 7.0Mw(HRV)

Depth 10 km. Felt (V) at Rio Dell and (IV) at Miranda. Felt throughout much of northern California as far south as Fresno. Also felt in parts of southern Oregon. Tsunami generated with maximum wave heights of 14 cm (peak-to-trough) at Crescent City.

16 Sep	06 20 18.3	Taiwan Region	22.546 N	118.743 E	6.5mB, 6.7Ms 6.8Mw (GS) 6.7Mw (HRV)

Depth 12 km. One person was killed and at least 400 were injured in Guangdong and Fujian Provinces, China. Structural damage occurred in Guangdong and Fujian Provinces, China. Some houses damaged and ground cracks (IV JMA) observed on Peng-Hu, Taiwan. Felt (III JMA) at Chia-i, Kao-hsiung and Tai-nan; (II JMA) at Heng-chun, Hua-lien, Tai-chung and Tai-pei, Taiwan. Felt (V) at Hong Kong, United Kingdom. Also felt at Nanjing and Wuhan, China.

04 Oct	13 22 58.3	Kuril Islands	43.706 N	147.328 E	7.4mB, 8.1Ms 8.2Mw (GS) 8.3Mw (HRV)

Depth 33 km. At least 10 people killed or missing and extensive damage on Iturup. Extensive damage and possibly some deaths and injuries on Kunashir, Shikotan and other islands in the Kuril chain from the earthquake and tsunami. One person died from a heart attack, at least 340 people injured and extensive damage occurred along the east coast of Hokkaido, Japan. Felt strongly in northern Honshu and also felt in the Tokyo area, Japan. Tsunami wave heights from selected tide stations (peak-to-trough) were as follows; 346 cm at Hanasaki, 164 cm at Kushiro, 162 cm at

Chichijima; 144 cm at Miyako; 130 cm at Hachinohe, 92 cm at Ofunato; 62 cm at Onahama; 46 cm at Omae-zaki; 42 cm at Choshi and 26 cm at Abashiri, Japan; 300 cm at Yuzhno-kurilsk, Kunashir Island; 15 cm at Shemya, Alaska; 17 cm at Wake Island; 50 cm at Midway Island and 48 cm at Hilo, Hawaii.

08 Oct	21 44 09.1	Halmahera, Indonesia	1.222 S	127.992 E	6.3mB, 6.8Ms 6.9Mw (GS) 6.8Mw (HRV) 6.8Ms (BRK)

Depth 31 km. One person killed, twelve seriously injured and 40 slightly injured. At least 113 houses severely damaged, 364 slightly damaged and some other buildings damaged on Obi. Also some damage to bridges and piers on Obi. Felt strongly on Ambon.

09 Oct	07 55 38.0	Kuril Islands	43.899 N	147.905 E	6.5mB, 7.0Ms 7.1Mw (GS) 7.3Mw (HRV) 6.7Ms (BRK)

Depth 23 km. Felt (VI) on Iturup. Felt (IV JMA) in the Kushiro area, Hokkaido, Japan. Tsunami wave heights (peak-to-trough) from tide stations were 18 cm at Hanasaki and 6 cm at Kushiro, Japan.

14 Nov	19 15 30.7	Mindoro, Philippine Islands	13.532 N	121.087 E	6.1mB, 7.1Ms 7.0Mw (GS) 7.1Mw (HRV) 7.1Ms (BRK)

Depth 33 km. At least 78 people killed and 225 injured on Luzon and Mindoro. A local tsunami contributed to extensive damage (VII RF) in the Calapan and Puerto Galera areas. More than 797 houses destroyed and 3,288 damaged on Mindoro. Seven houses destroyed at Batangas, Luzon. Liquefaction, sand boils and surface faulting occurred in the epicentral area. Felt (IV RF) at Batangas, Guinayangan, Manila and Tagaytay City; (III RF) at Quezon City, Luzon. Also felt (II RF) at Masbate.

28 Dec	12 19 23.6	Off east coast of Honshu, Japan	40.451 N	143.491 E	6.4mB, 7.5Ms 7.7Mw (GS) 7.7Mw (HRV) 7.2Ms (BRK)

Depth 33 km. Two people were killed and more than 200 injured and damage (VI JMA) in the Hachinohe area. Felt (V JMA) at Aomori, Morioka and Mutsu; (IV JMA) at Miyako and Ofunato; (III JMA) at Sendai. Also felt (IV JMA) at Hakodate, Obihiro, Tomakomai and Urakawa; (III JMA) at Sapporo, Hokkaido. Felt as far away as Tokyo. Local tsunami generated with maximum wave heights (peak to trough) recorded at the following selected tide stations: 110 cm at Miyako; 88 cm at Hachinohe; 54 cm at Ofunato; 10 cm at Choshi Honshu; 48 cm at Urakawa; 36 cm at Hakodate and Kushiro Hokkaido.

Table 8 Nuclear explosions detected, 1994

Date	*Time*	*magnitude*		*Yield*	*Lat*	*Long*	*Site**	*Source*	*Comments*
m d	*UTC*	*mb*	*Ms*	*kt*					
06 10	0625 56	5.3		10-40	41.7° N	88.8° E	LopN	ASAR	China
10 07	0325 57	6.1		40-150	41.7° N	88.8° E	LopN	ASAR	China

Site:
LopN: Lop Nor China

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