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AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

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Australian Seismological Report, 1996

Kevin McCue, Peter Gregson & Cvetan Sinadinovski

17

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AUSTRALIAN SEISMOLOGICAL REPORT 1996

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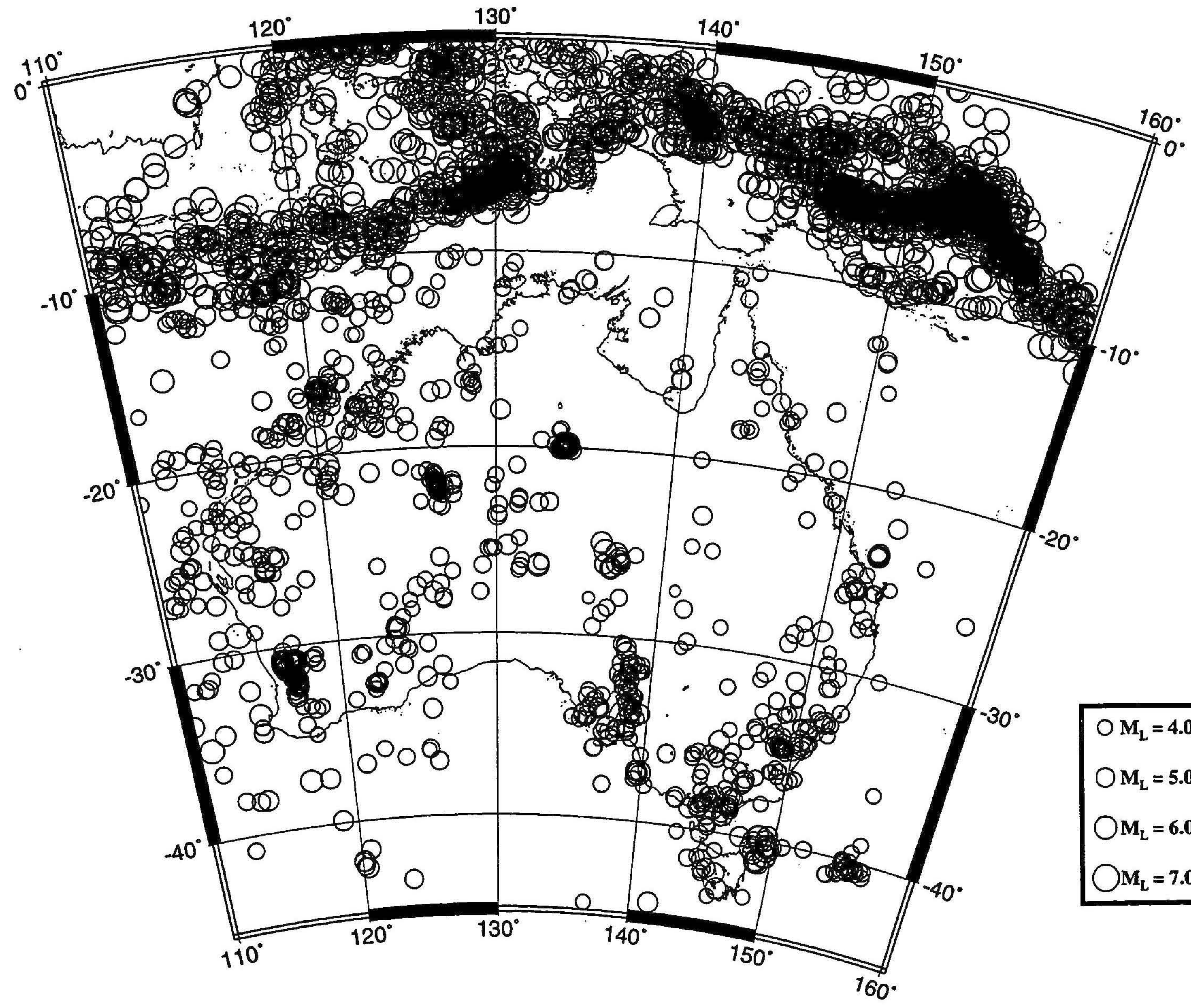

Epicentres of Australian earthquakes, 1788-1996, magnitude $M_L \geq 4.0$

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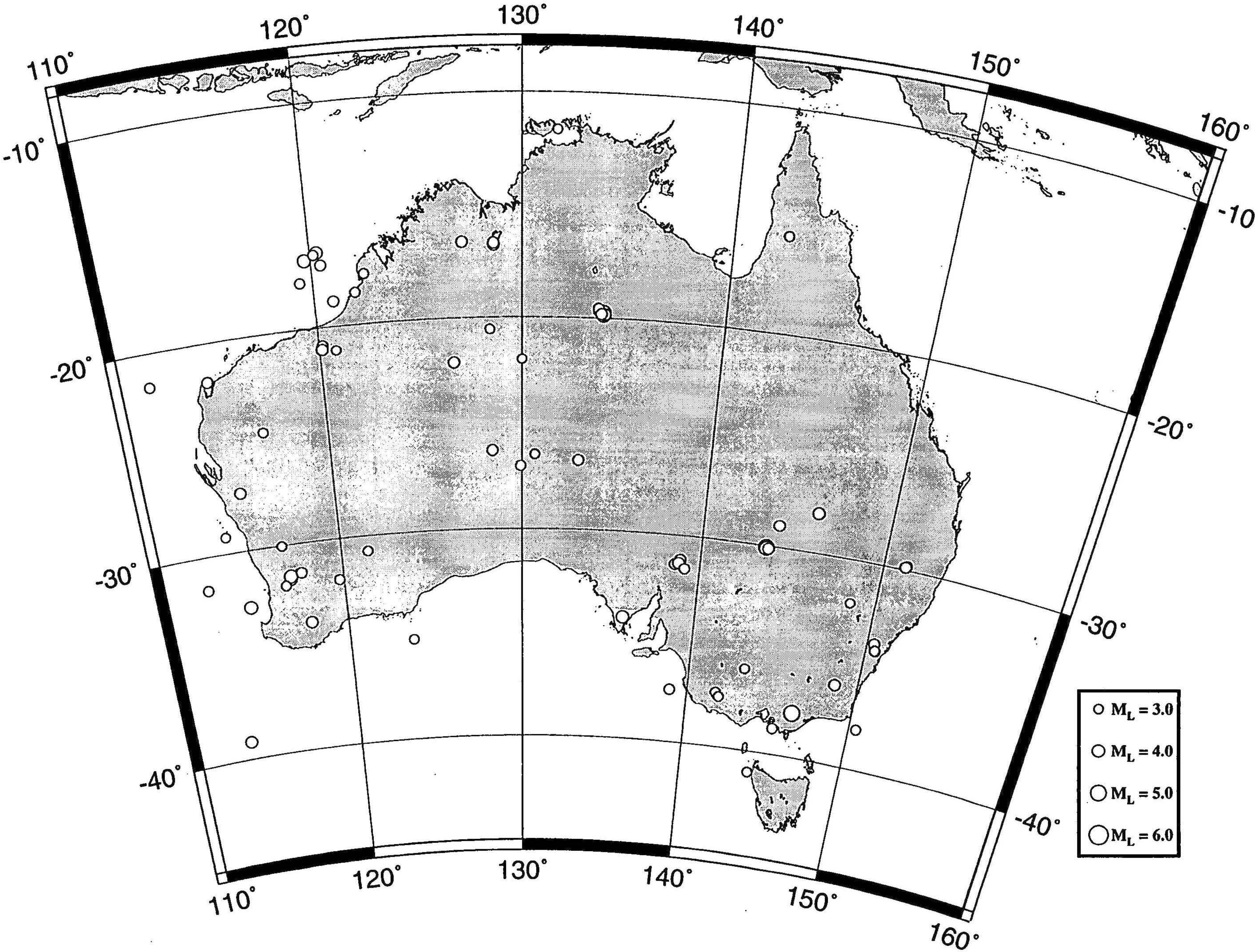


Epicentres of Australian earthquakes, 1996, magnitude $M_L \geq 3.0$

SUMMARY

The year was another marginally below average one with respect to the frequency and magnitude of earthquakes in Australia; there were two of magnitude 5 or more but no *large* earthquakes of magnitude 6 or more. It was an above average year for major earthquakes worldwide with one *great* earthquake of magnitude M 8.2 and 16 of magnitude M 7.0 or more.

The larger earthquakes in the Australian region in 1996 were in New South Wales and Victoria, the most populous States, yet no damage or casualties resulted during these two magnitude 5 events in remote country regions. The epicentre of the NSW earthquake was near a natural gas pipeline and the Victorian earthquake under a large concrete gravity dam but neither structure was damaged. Several of the 87 earthquakes of magnitude ML 3 or more reportedly caused damage but there were no deaths or injuries. The amazing aftershock sequence at Tennant Creek in the Northern Territory following the three mainshocks there on 22 January 1988 continued but in decline through 1996.

Intensity questionnaires were distributed and isoseismal maps compiled for eleven earthquakes that were felt widely enough in Australia; one a magnitude Ms 7.9 earthquake in the Flores Sea north of the Indonesian Island of Flores was felt in Darwin and the Top End on 17 June, there were two small earthquakes in June at Meckering WA (scene of the damaging Ms 6.8 earthquake on 14 October 1968) which warranted the distribution of questionnaires, the moderate magnitude ML 5 earthquakes at the Range NSW and Thomson Dam Victoria and three small earthquakes in Queensland. Small earthquakes at Gnowangerup WA and Picton NSW were felt strongly close to the epicentre; insurance claims were met following damage during the latter earthquake. Several earthquakes were felt by ANARE personnel at Macquarie Island during the year.

Worldwide the one great earthquake of magnitude 8 or more in 1996 was east of the island of Biak in Irian Jaya, but fewer than 500 earthquake-related mortalities resulted during the year compared with the average number of earthquake fatalities of about 10 000 per year since 1900.

During 1996, AGSO detected three underground nuclear explosion, one detonated by France at Mururoa in the Pacific and two by China at their Lop Nor test site. 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 about 200 earthquakes of magnitude 3 or more, and two of at least magnitude 5.0. Large earthquakes, those of magnitude 6 or more, occur somewhere in Australia every 5 years or so on average. None occurred in 1996 and the previous one was near Tennant Creek NT in 1988. These larger earthquakes are a threat to life and property and even the moderate sized ones can be a serious threat 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 1996 earthquakes and is the seventeenth 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 seven main sections: the **Australian region earthquakes** section contains a summary of the 1996 seismicity with a State by State breakdown and a brief description of the more important earthquakes; **Isoseismal maps** describing those that were widely felt; **Accelerograph data** which tabulates recordings from the accelerograph network; **Network operations** which gives details of the seismographs that operated in Australia during the year and calibration details; **Principal world earthquakes** which lists the largest and most damaging earthquakes that took place world-wide during 1996; and **Monitoring of nuclear explosions** which describes the operation of the Nuclear Monitoring Section and lists known underground nuclear explosions.

In this report we refer to the *magnitude* of an earthquake and *intensity* caused by an earthquake. These terms and others used in the report are defined in an appendix.

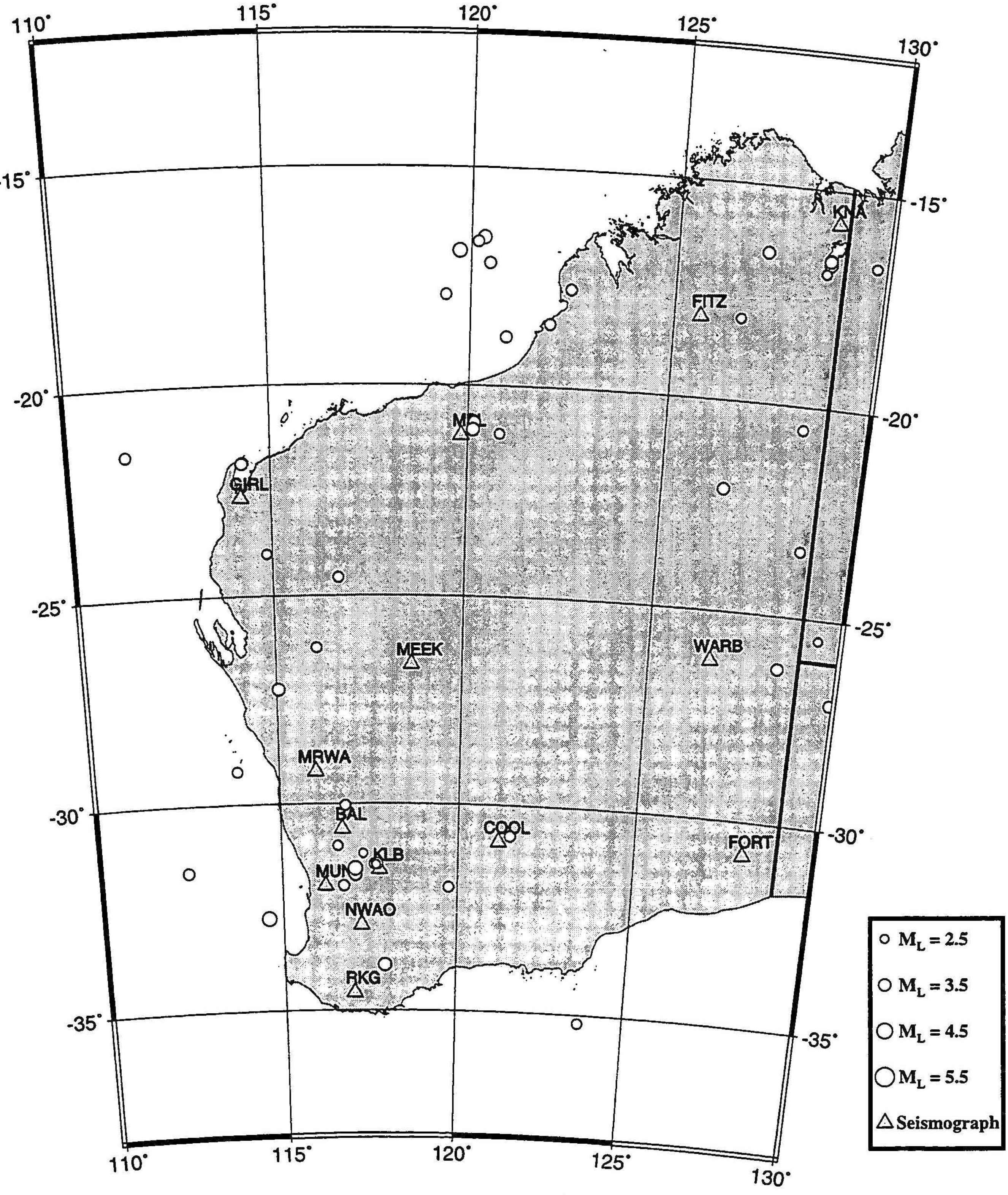
AUSTRALIAN REGION EARTHQUAKES, 1996

There were no injuries or serious damage caused by earthquakes in 1996 in Australia. Earthquakes of magnitude ML 3 or more recorded on AGSO's National Seismographic Network and State and regional networks are listed in Table 1, and those of magnitude ML 4 or more since 1788 are plotted from the AGSO earthquake database in Figure 2. The larger two earthquakes were each of magnitude 5.1, one in NSW the other in Victoria and both threatened lifelines and infrastructure as discussed later. The pattern of activity is similar to that of the previous year, a broad NW/SE swathe of activity across the continent with few earthquakes in Queensland.

Many of the earthquakes were felt locally, especially those in the more densely populated southeast of the continent and isoseismal maps have been prepared for eleven of them. Two earthquake swarms, like the classic sequence near Eugowra NSW in 1994 (Gibson and others, 1995), occurred in Western Australia. The largest event in these swarms had a magnitude of only 3.1 and 3.2.

Compared with a post-1980 yearly average of two earthquakes of magnitude 5.0 or more, 21 of magnitude 4.0 or more and more than 200 of magnitude 3.0 or more, there were 2, 8 (2) and 77 (10) respectively in 1996 - very similar to the respective numbers in 1995. The numbers in brackets are aftershocks at Tennant Creek, the annual totals are the sums of the two numbers. The year's seismicity was like that in 1995 about average in terms of energy release but there were far fewer small events than expected.

Kevin McCue



Earthquake epicentres in Western Australia 1996, magnitude $M_L \geq 2.5$

Western Australia (Figure 3)

In all 353 earthquakes were located in the region of Western Australia compared with 254 in 1995. This was higher than average resulting from two swarms near Kellerberrin and Talbot Brook, both in the southwest seismic zone. There were 41 earthquakes of magnitude ML 3.0 or greater during the year, four of which had magnitudes of ML 4.0 or more. Of the latter all were offshore, except for a magnitude ML 4.1 earthquake near Meckering on 21 June. Two of the offshore events were about 240 km north-west of Broome with magnitudes ML 4.0 and ML 4.1 in February and May respectively, and the other was 130 km south-west of Fremantle, magnitude ML 4.1 on 18 October. There were three events in December located near mine sites which were confirmed as not being mine blasts. These were near the Bellevue and Bounty mines.

The Southwest Seismic Zone was the most active area with 206 earthquakes compared with 142 earthquakes in 1995. The increase was due to two swarms near Kellerberrin and Talbot Brook. The largest, ML 4.1, occurred 5 km south-east of Meckering where 10 earthquakes were located in the vicinity. The Cadoux-Manmanning area continued to be active with 16 earthquakes. Other active areas were Wyalkatchem (11), 40 km south-west of Kojonup (7), Nyabing (5), Quairading (4), Kalannie (3), Wubin, Ballidu, Calingiri, Bonnie Rock, Darkan, Pingelly, 40 km south-west of Boyup Brook, Dumbleyung, and Gnowangerup (2 each). Single events were located at Beacon, Burakin, Bencubbin, Williams, Katanning and Ongerup. Two small earthquakes, ML 1.9 and 1.4 occurred near Wooroloo well west of the zone.

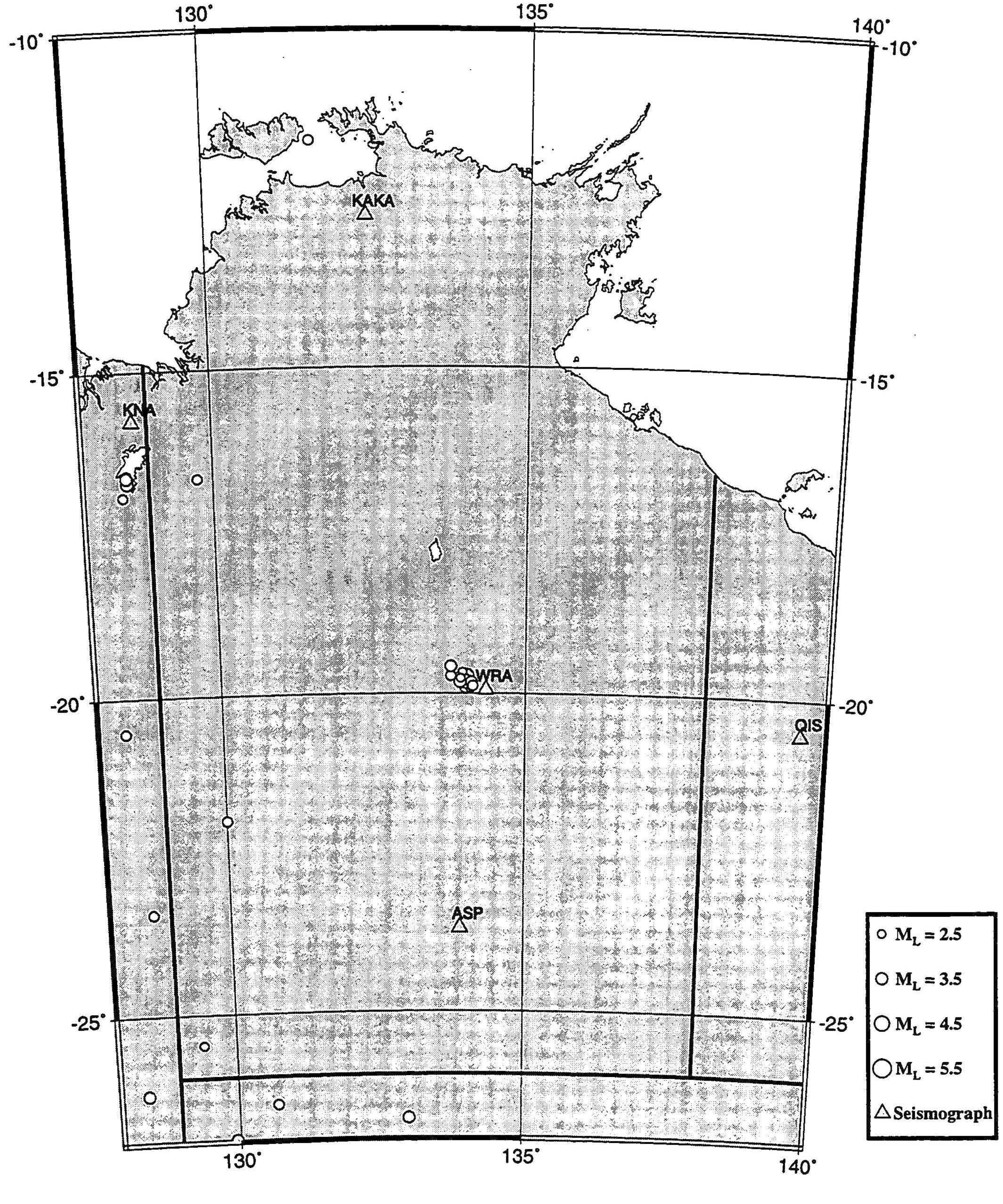
Twelve earthquakes occurred offshore, five above magnitude ML 3.0 towards the northern end of the north-west zone, two from Carnarvon, one from Geraldton, one 283 km from Exmouth and the most significant, ML 4.1, 30 km south-west off Fremantle. A magnitude ML 3.5 earthquake occurred 310 km west of Fremantle. There was one event (ML 3.8), 580 km south of Augusta and an ML 3.0 earthquake 190 km SE of Esperance.

Two earthquakes, both less than magnitude 2 were located in the south-east zone, six in the Carnarvon Basin, one 93 km north-east of Kalbarri had a magnitude ML 3.6. In the Tobin Lake region a magnitude ML 3.6 earthquake occurred 51 km east of Tobin Lake. Four other earthquakes ML 2.5 - 2.9 occurred east of the region. Of the 9 earthquakes located in the Halls Creek Mobile Belt, 4 of them were approximately 80 - 100 km south of Kununurra. Two of these had magnitudes ML 3.6.

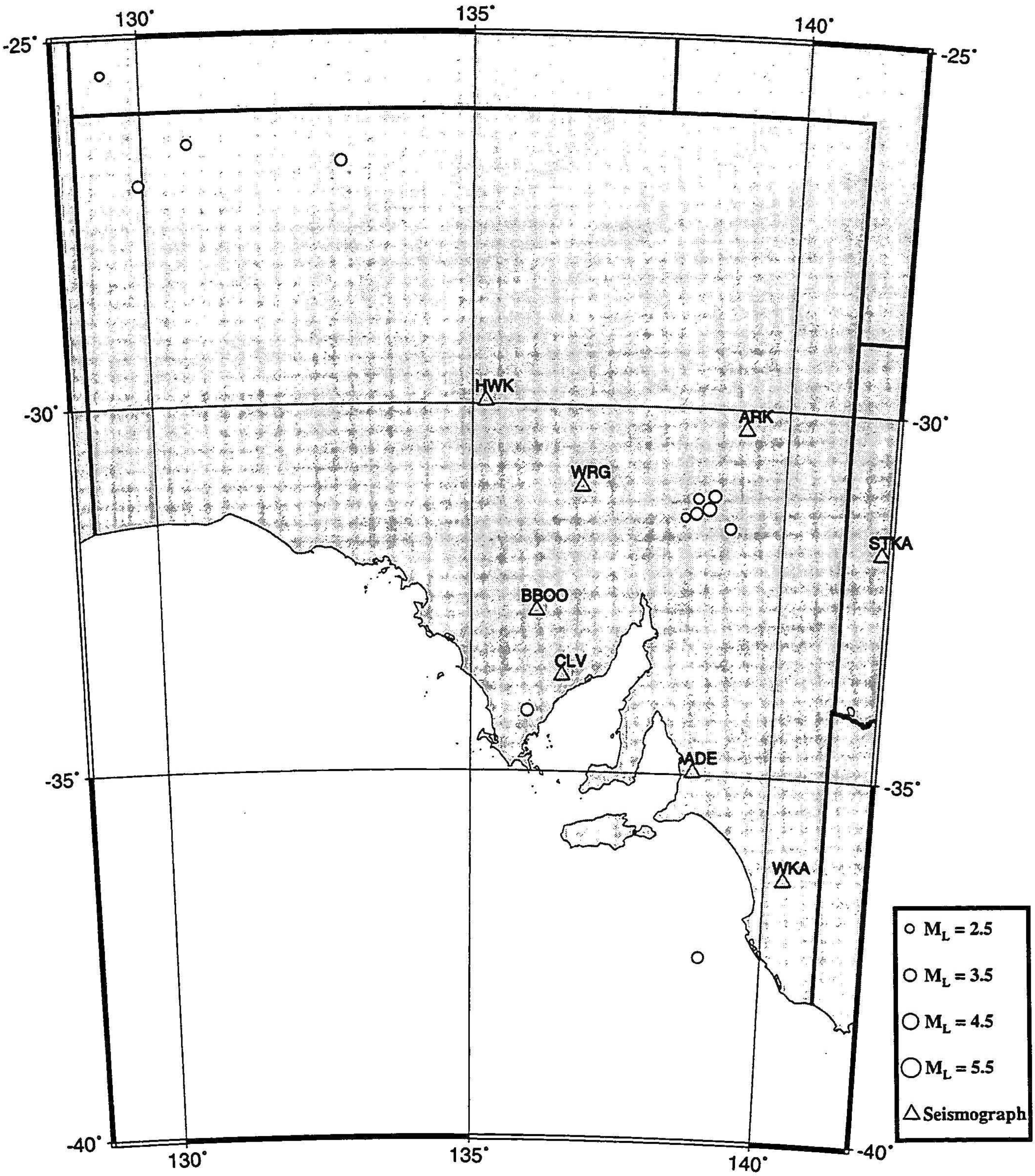
Kellerberrin (Yorkrakine) swarm, March 1996 On 8 March 1996, a small (ML 1.7) earthquake occurred near the town of Yorkrakine, about 20 km N of Kellerberrin. From 10 March to mid May, more than 670 small earthquakes, ranging in magnitude from 0.5 to 3.1 were recorded in the area. Although small, many of the events were close enough to be felt strongly by residents in nearby farm houses. The largest earthquake, magnitude 3.1, occurred on 11 March and was felt with intensity MM V. Although the earthquake sequence dwindled throughout June there were sporadic events including some with magnitude ML 3.0, occurring through till December 1996.

Talbot Brook swarm, April/May 1996 A short swarm of 25 earthquakes occurred near Talbot Brook, 12 km SW of York (about 90 km east of Perth) in September ranging in magnitude from ML 1.5 to ML 3.1. The largest earthquake, on 18 September, had a magnitude of ML 3.2. An earlier swarm occurred in the same location in November 1994 (McCue and Gregson, 1996).

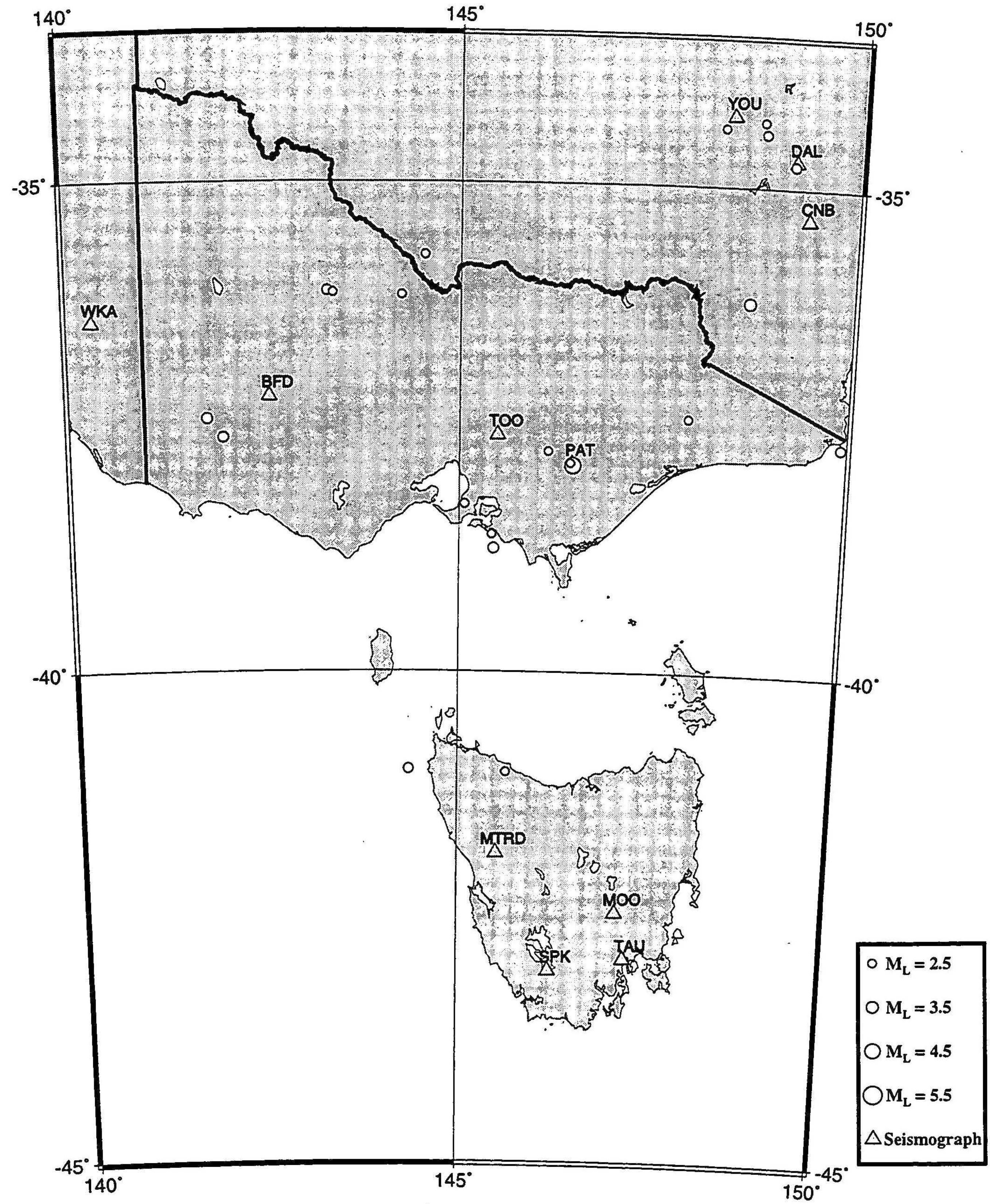
Peter Gregson and Edward Paull



Earthquake epicentres in Northern Territory 1996, magnitude $M_L \geq 2.5$



Earthquake epicentres in South Australia 1996, magnitude $M_L \geq 2.5$



Earthquake epicentres in Victoria and Tasmania 1996, magnitude $M_L \geq 2.5$

Northern Territory (Figure 4)

All but three of the ML3 or greater earthquakes were near Tennant Creek in the aftershock sequence that has continued there since January 1988. The largest of these aftershocks had a magnitude of 4.3. The other recorded events were; east of Melville Island and just north of Darwin on 1 August, and near the WA/NT border at a latitude between Alice Springs and Warramunga on 12 November.

Kevin McCue

South Australia (Figure 5)

The year 1996 was a particularly quiet year with only 169 earthquakes located in South Australia, down from the average of about 300 over the last decade. There is no obvious reason for this. Earthquakes generally occurred in the known active zones with, as always, a few located in unexpected places. The largest event was of magnitude 3.8 near Oraparinna in the Northern Flinders Ranges on 22 July. The strongest reported intensity was MM 5 from an Eyre Peninsula event of magnitude 3.5 on 9 June. No earthquakes were located near to Adelaide.

A small earthquake occurred at Marryat Creek where a large shallow earthquake on Sunday 30 March 1986 caused surface faulting with vertical reverse displacement of 0.6 m (Barlow & others, 1986).

David Love

Victoria & Tasmania (Figure 6)

In Victoria the largest earthquake was the magnitude ML 5.0 earthquake on 26 September under Thomson Dam about 125 km east of Melbourne where it was strongly felt (see discussion of felt reports under the Isoseismal Map section of this report). No structural damage was reported, and the Thomson Dam came through unscathed. In 1977 following completion of the dam, the SRC installed a seismograph network around and on the dam for the Victorian Rural Water Commission to monitor reservoir-induced seismicity, the instrumentation included an accelerograph on the dam abutment.

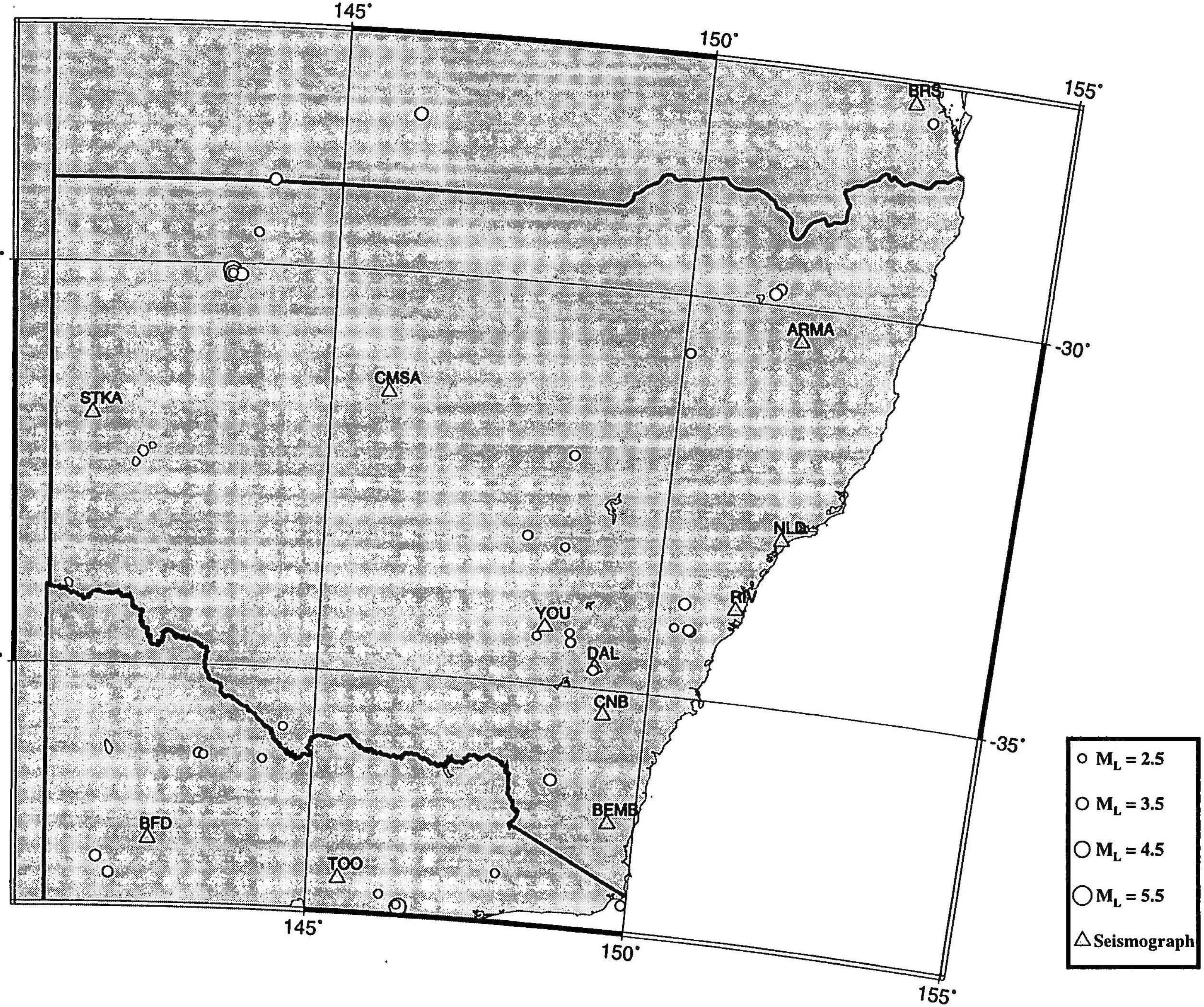
This was the largest earthquake in Victoria since the 1982 Wonnangatta event (Denham and others, 1985), 100 km to the northeast. It was widely felt, as far as the NSW border to the north and northeast and throughout Melbourne suburbs to the west. Attenuation appears to have been very rapid to the south which must be related to the earthquake mechanism as earlier earthquakes in the region do not show a similar effect.

The accelerogram enabled seismologists to accurately compute the focal depth at 10 ± 1 km. The mainshock occurred at 5:49 pm EST and was preceeded by a foreshock of magnitude ML 3.3 the previous day at 2:53 pm EST and another of magnitude ML 2 just a minute later (SRC Monthly Report, August 1996). Both of the foreshocks were felt at the dam. Numerous aftershocks were recorded, many of them felt, but none exceeded magnitude ML 3.

Three other small earthquakes ML ≥ 3 occurred in Western Victoria, one near the NSW/VIC border on the Tasman Coast and another south of Phillip Island.

No onshore Tasmanian earthquake exceeded magnitude ML 3, the only one to do so was off Temma on the Northwest coast on 25 November and it was not reported felt. Two small earthquakes occurred near the seafloor volcano out in the Tasman Sea at (40°S, 155°E).

Gary Gibson, Wayne Peck, Kevin McCue & Vagn Jensen



Earthquake epicentres in NSW and ACT 1996, magnitude $M_L \geq 2.5$

New South Wales and ACT (Figure 7)

The largest earthquake in NSW in 1996 was the ML 5.1 earthquake near *The Range* homestead 80 km north of White Cliffs in Western NSW on 13 August at 2:30 pm EST. A disused homestead on concrete footing suffered differential settlement so that the doors wouldn't shut but no other damage is known, this being one of the most isolated and least populated parts of the State of NSW about 200 km out the back of Bourke. The natural gas pipeline from the Cooper Basin SA to Sydney NSW passes within about 30 km of the epicentre and inspection confirmed that neither the pipeline nor the pumping stations were damaged.

Only a few sensitive Broken Hill residents felt the shaking there, 280 km from the epicentre. No foreshocks were recorded on the high gain STKA seismograph near Broken Hill but numerous aftershocks occurred and were recorded, the largest at magnitude ML 4.4 was 27 hours and 24 minutes after the mainshock.

Seismologists from AGSO and SRC installed a network of 5 portable seismographs in the area on 17/18 August and recorded 23 locatable aftershocks to the end of October which had focal depths in the range 6 to 8 km. The network was redistributed after the first epicentres were located and found to be west of and outside the network.

A reasonably well constrained focal mechanism of *The Range* mainshock is shown in Figure 19. The solid and dashed nodal plane sets indicate some measure of the uncertainty in the mechanism. Inspection of the near seismograms indicates that GOG in Victoria and a group of stations including CMSA, YOU, EUG and CNB in NSW are near nodal.

The latter group showed small dilatations precluding a thrust interpretation. All South Australian short period first motions were compressions but also important for the interpretation were the two Antarctic readings from MAW and CSY both of which were dilatations. Parameters are listed in Table 4, the principal stress direction is oriented NE/SW, and the least principal stress direction horizontal striking NNW.

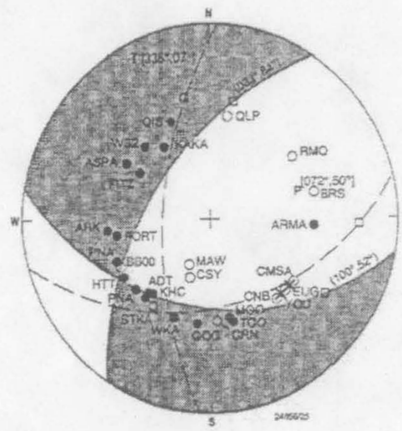


Figure 22 Focal Mechanism Solution

The aftershocks are orientated NNE (Gibson pers comm) which indicates that the near NS striking nodal plane with combined right lateral and dip slip is the likely fault plane. This is an unusual mechanism which shows that the principal stress direction is not everywhere near horizontal in the continent. There was a similar mechanism for an earthquake near Norseman WA on 28 July 1985 (McCue, 1989).

Small earthquakes were recorded northwest of Armidale and felt by Gilgai residents just after Christmas. There were others in the Snowy Mountains south of Canberra on 18 February and near Katoomba and Picton near Sydney. The pair of earthquakes near Picton on 10 December were strongly felt and reportedly caused minor damage at the Oaks near the epicentre (see the Isoseismal Map in this report).

No earthquakes were felt or recorded in the ACT during the year.

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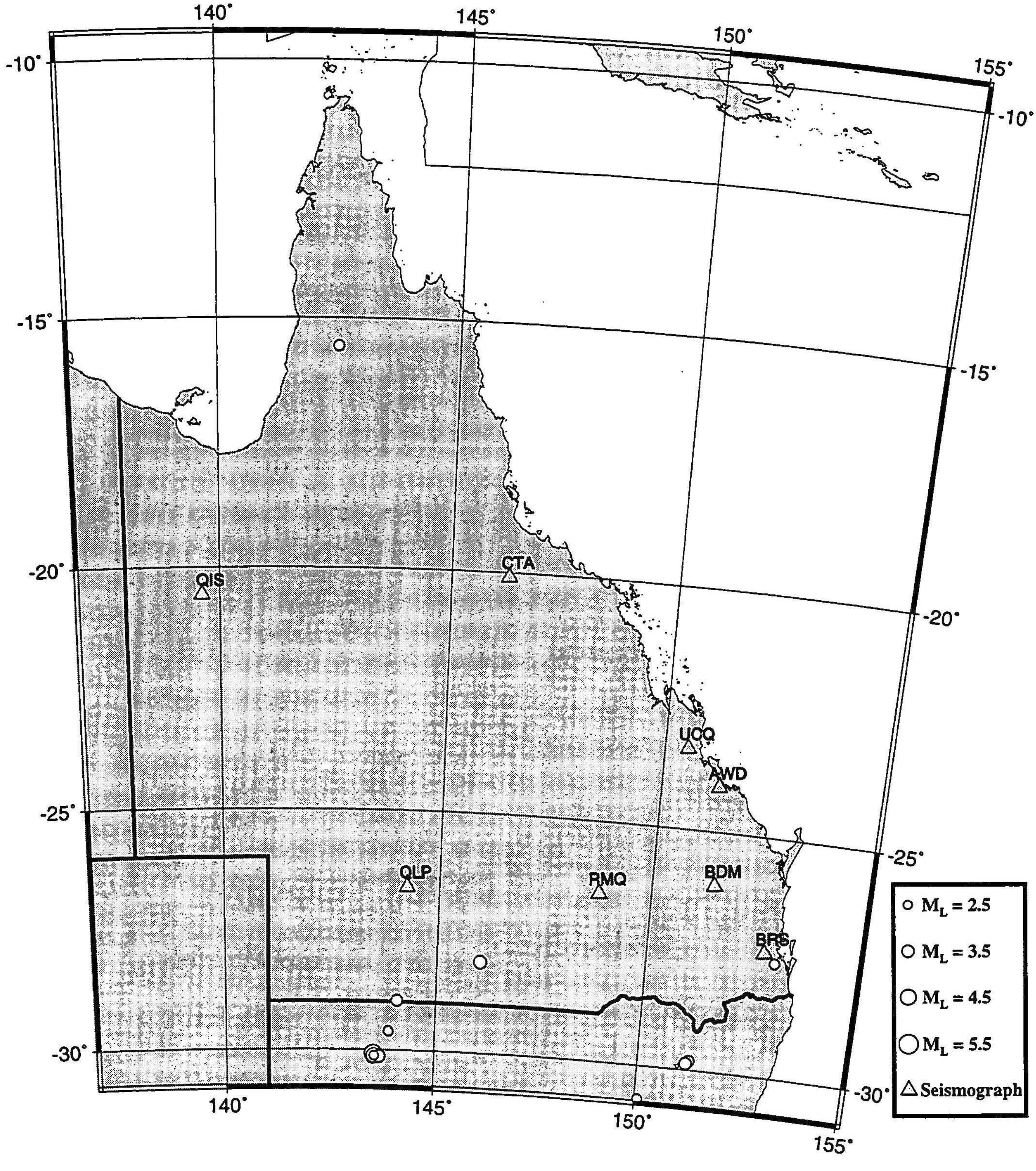


Earthquake epicentres in Queensland 1996, magnitude $M_L \geq 2.5$

Queensland (Figure 8)

There were only 3 earthquakes in Queensland of magnitude 3 or more in 1996 and one of those was on the Qld/NSW border near Hungerford on 4 June. The earthquake near Hungerford, magnitude ML 3.4, was not felt there or at Cunnamulla but was reported as sounding like a 'loud bang' at Boorara Station and 'two loud booms, one on top of the other' at Moombidary Station which is 60 km from Hungerford.

The largest earthquake, magnitude ML 3.8, occurred near Cunnamulla on 12 September and the third on the Cape York Peninsula on 13 June. Three earthquakes were reported felt at sufficient sites to enable isoseismal maps to be drawn.

Russell Cuthbertson

NETWORK OPERATIONS 1996

The only change to the National Seismographic Network in the year was the joint installation of BBOO with PIRSA as discussed below. There were several changes in the State networks.

In South Australia Station WRG was closed on 5 August 1996 at 01:53 after running for 15 years. It was replaced in December 1995 by a joint AGSO/PIRSA station BBOO about 200km to the SSW on Eyre Peninsula, the data telemetered by satellite to AGSO Canberra. A new station was installed at Napperby (NAP) near the northeastern tip of Spencer Gulf.

In Victoria a new seismograph was installed at Cardinnia (CAD) by SRC for Melbourne Water but there were no further changes in NSW, NT, Qld, WA or Tasmania.

Calibration curves for the digital stations of the Australian National Seismograph Network are presented in the 1995 Annual Report (McCue and Gregson, 1997). Corresponding curves for many of the analogue stations were presented in the 1990 report as separate figures for Eastern and Western Australian networks.

Graeme Small, Peter Gregson, David Love, Kevin McCue and Russell Cuthbertson

ACCELEROGRAPH DATA and ATTENUATION

The Commonwealth/State initiative to install accelerographs in the cities, the Joint Urban Monitoring Project (JUMP) has again proven its worth providing another valuable dataset from the Thomson dam earthquake, and from several earthquakes felt in Darwin and Perth. The data are summarised in Table 4 and the locations of permanent accelerographs in 1996 are given in Table 5.

In Western Australia and the Northern Territory Eight earthquakes in the south west resulted in 11 recordings. The largest acceleration recorded was 140 mms^{-2} for a magnitude 4.1 Meckering earthquake on 21 June at a distance of 35 km where the MM intensity was IV (see isoseismal map). The same earthquake was recorded in Perth on one of the Joint Urban Monitoring Project instruments at a distance of 112 km where the peak acceleration was 12 mms^{-2}.

The Perth recording is relevant to the debate about the effects of deep sediments on ground motion amplitudes as the Cadoux and Perth acceleration amplitudes were similar at the same distance. Cadoux is on crystalline basement rock of the Yilgarn Block, Perth on deep sediments of the Perth Basin. The isoseismal maps of the two

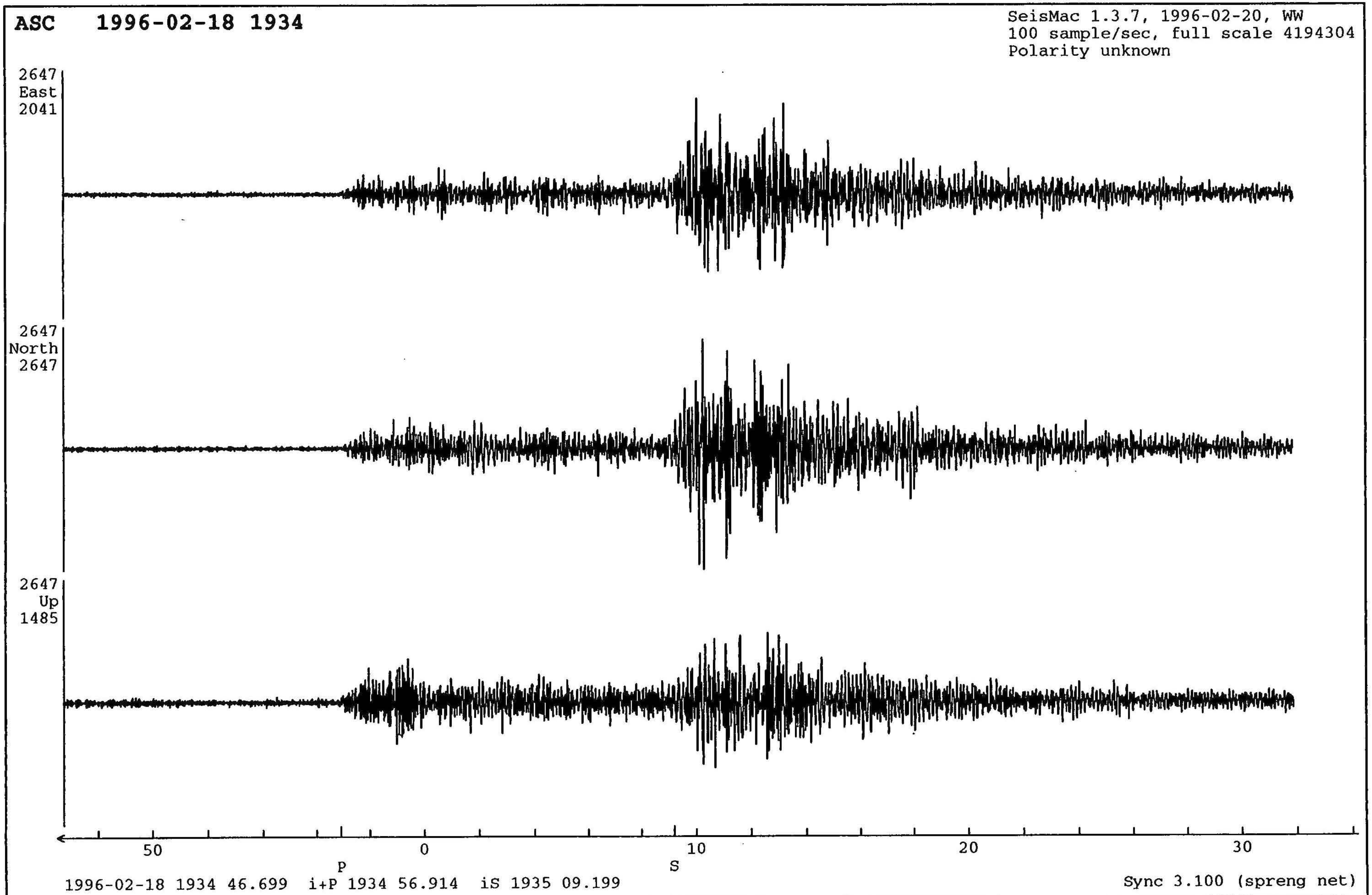


Figure 20 (i) Accelerogram of the Eucumbebe NSW earthquake on 18 February recorded in Canberra (AGSO Basement ASC)

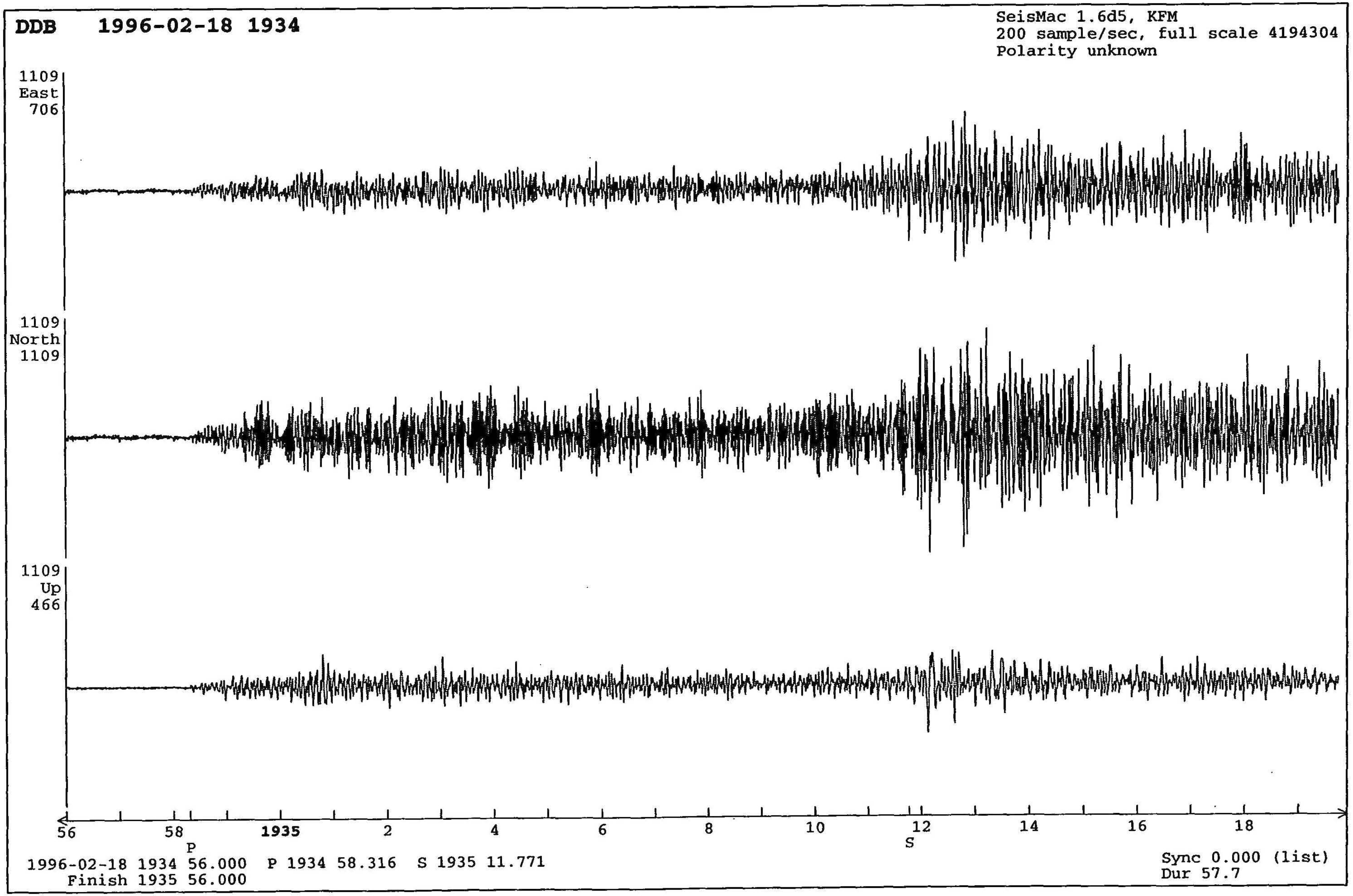


Figure 20 (ii) Accelerogram of the Eucumbebe NSW earthquake on 18 February recorded at Dartmouth (DDB from SRC)

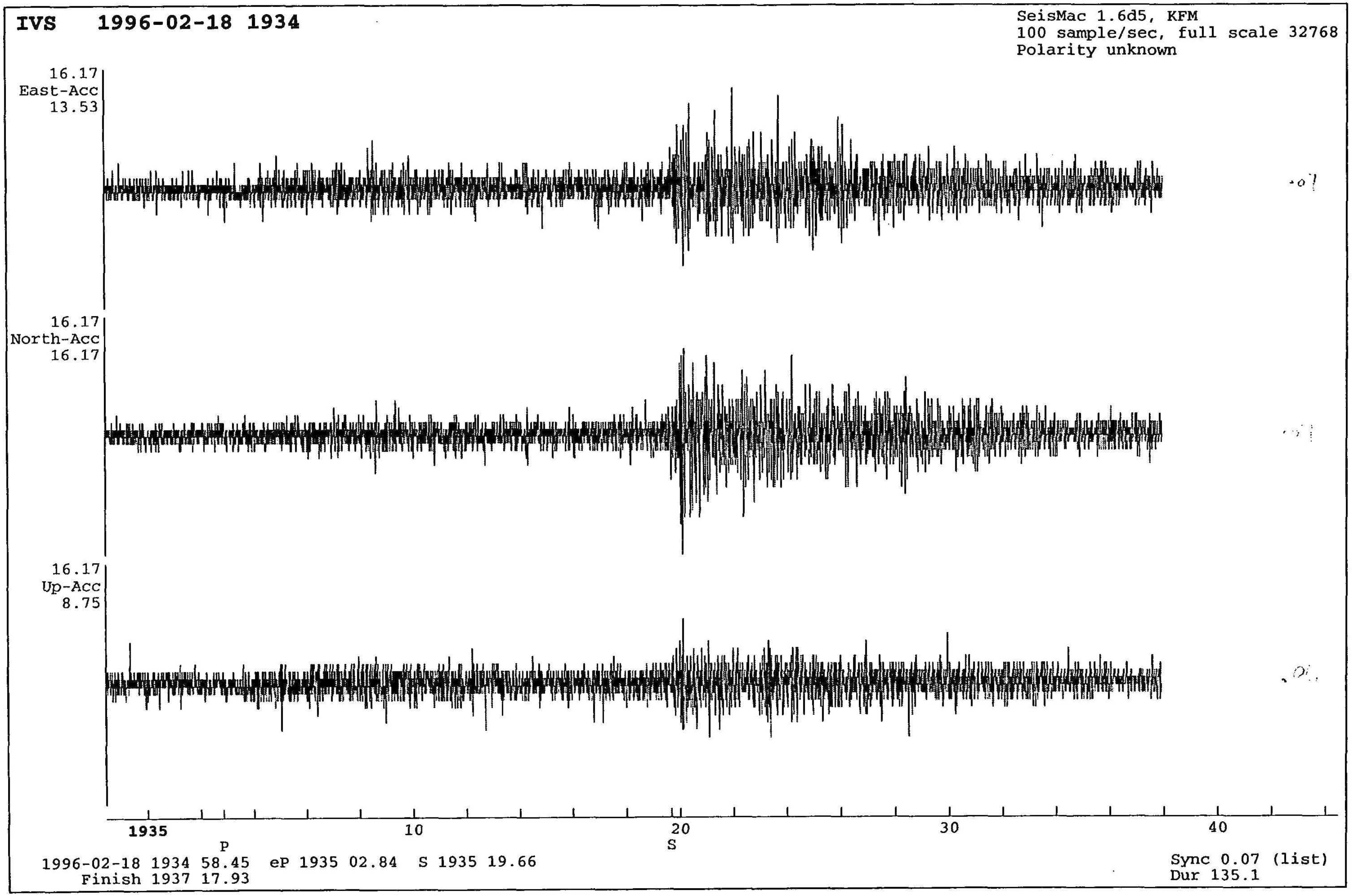


Figure 20 (iii) Accelerogram of the Eucumbebe NSW earthquake on 18 February recorded near Hume Dam (IVS from SRC)

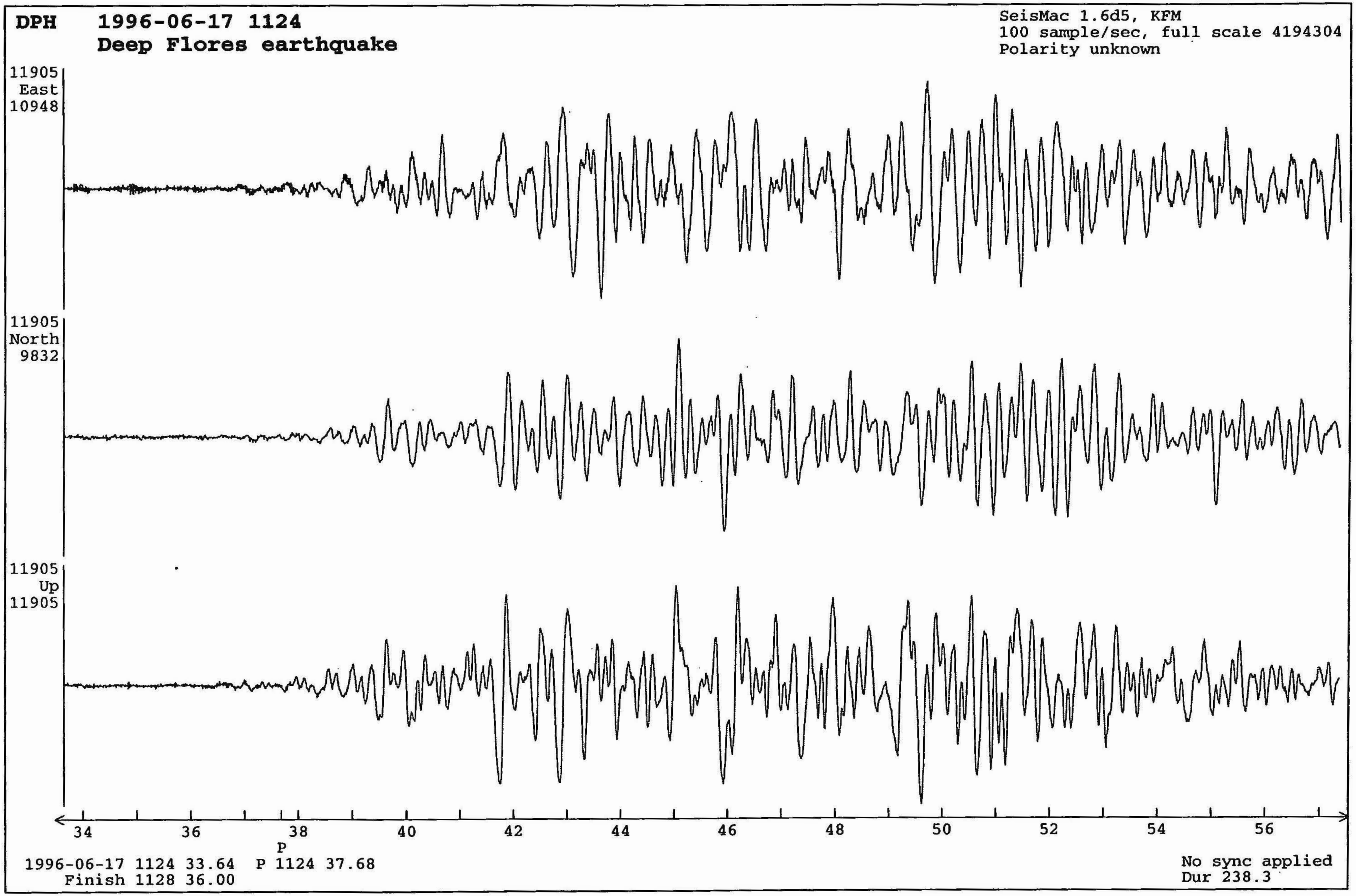


Figure 20 (iv) Accelerogram of a deep Flores Indonesia earthquake on 17 June recorded at Darwin (DPH on soft soils)

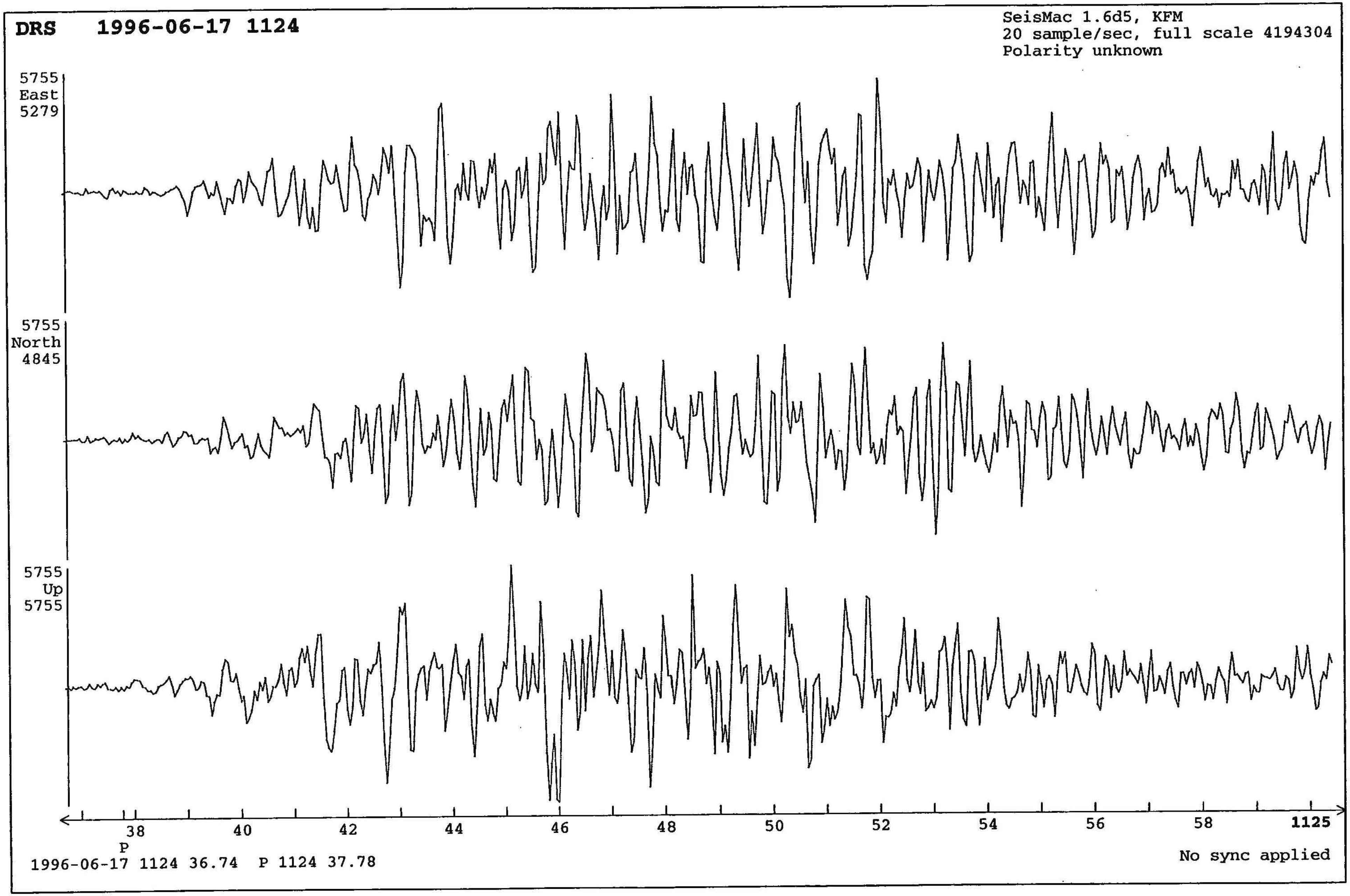


Figure 20 (v) Accelerogram of a deep Flores Indonesia earthquake on 17 June recorded at Darwin (DRS P wave on rock)

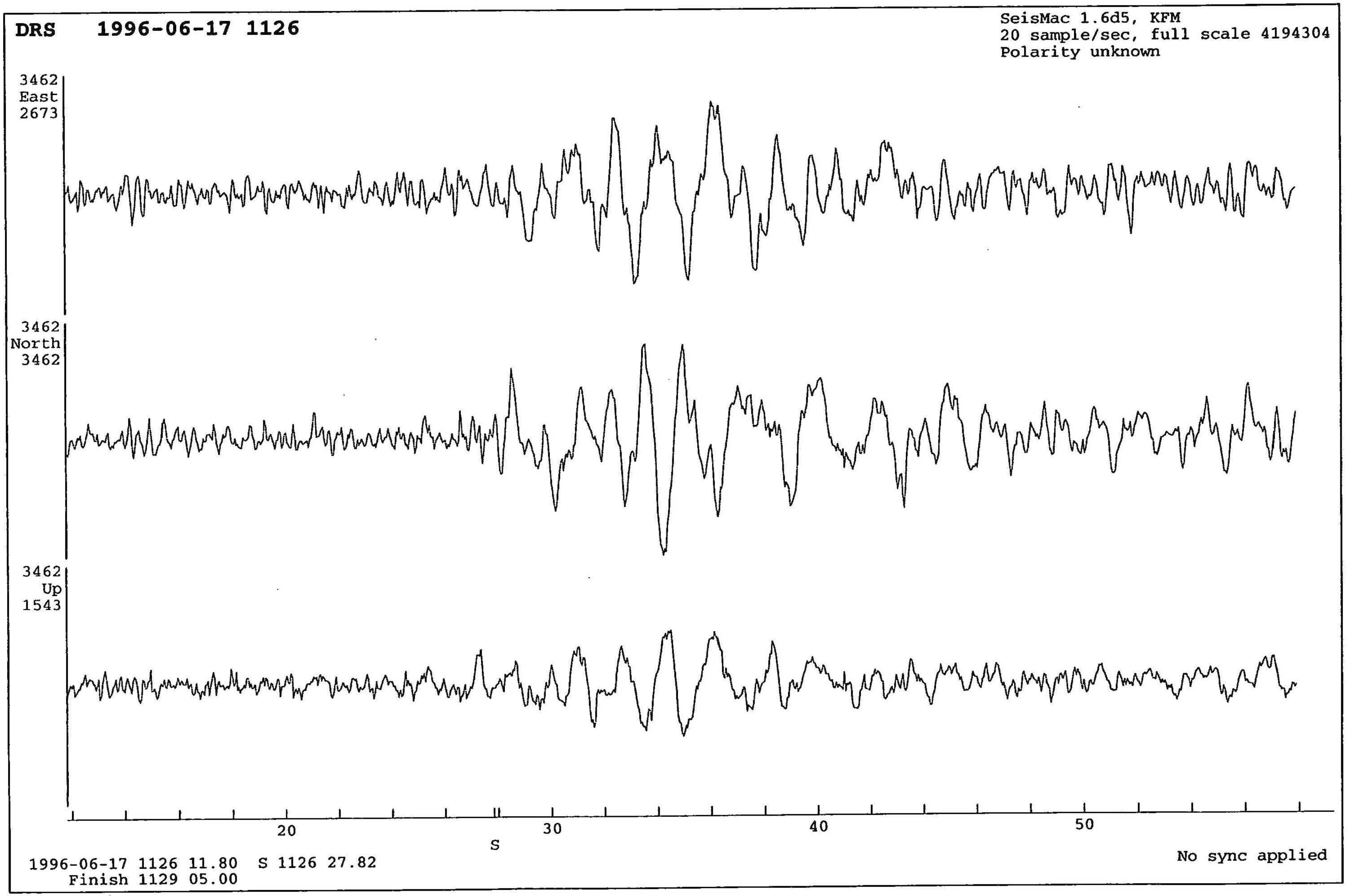


Figure 20 (vi) Accelerogram of a deep Flores Indonesia earthquake on 17 June recorded at Darwin (DRS S wave cont.)

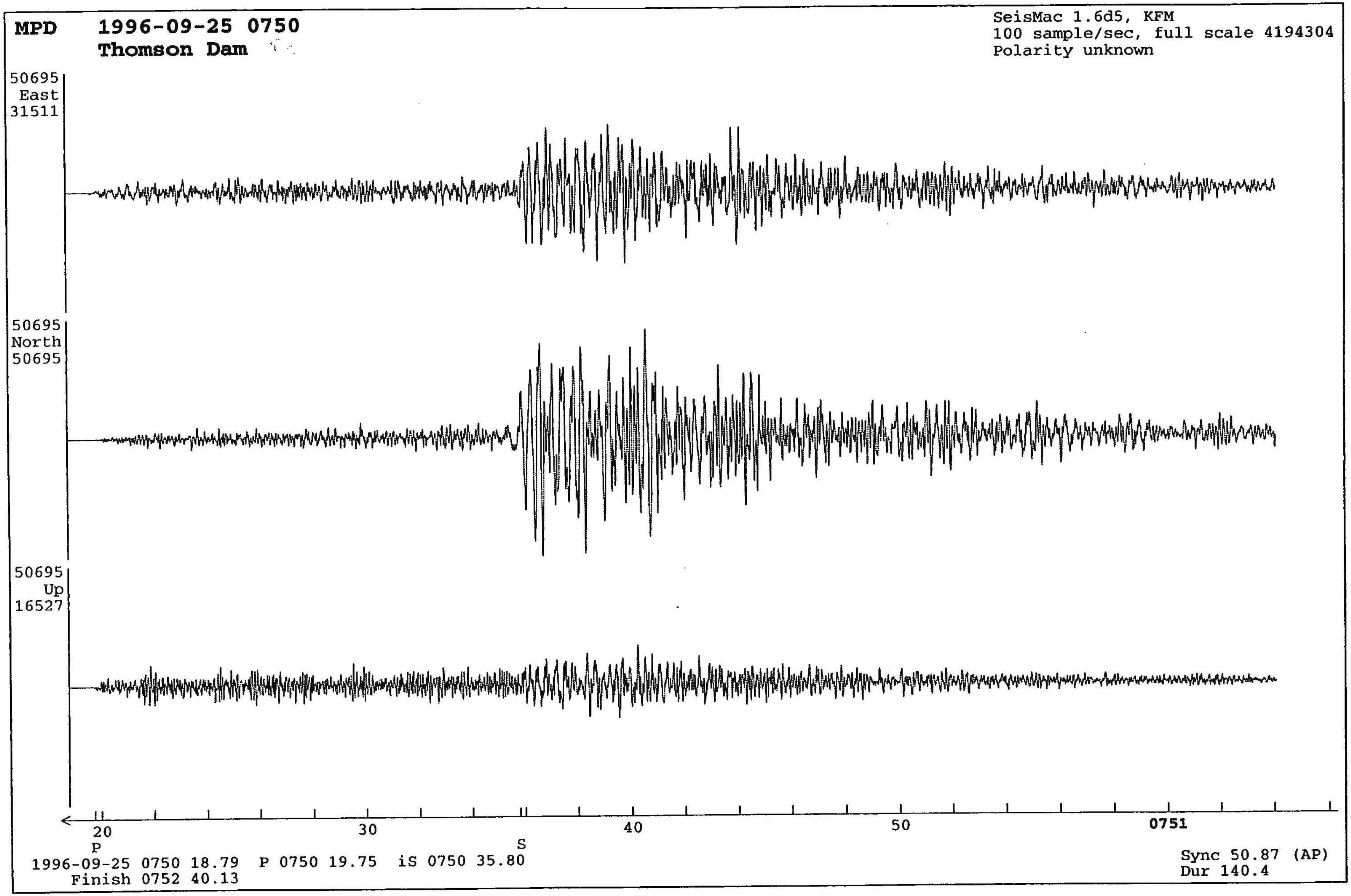


Figure 20 (vii) Accelerogram of the Thomson Dam Vic earthquake on 25 September recorded at Moonee Ponds Vic (MPD soil site)

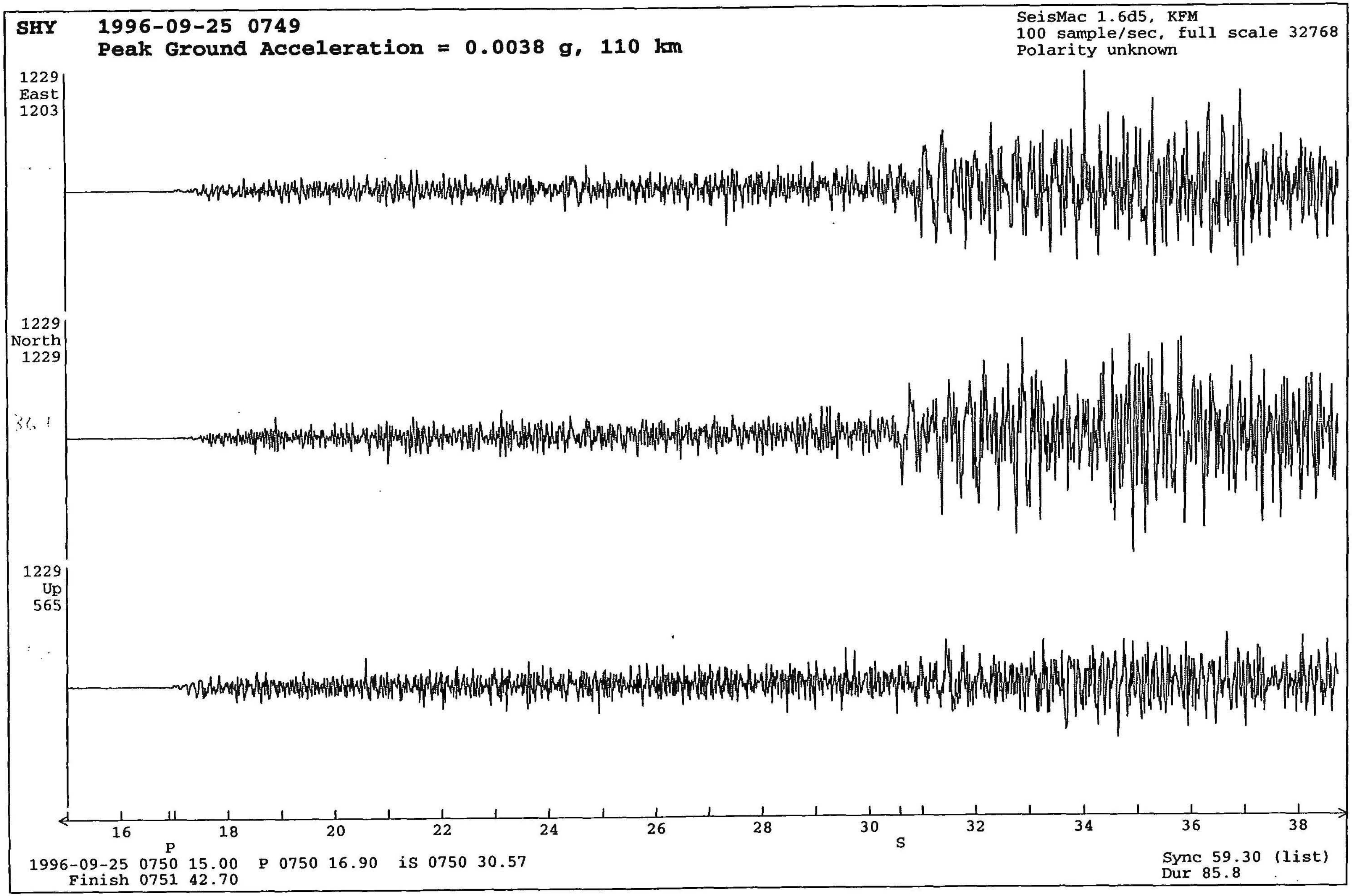


Figure 20 (viii) Accelerogram of the Thomson Dam Vic earthquake on 25 September recorded at Surrey Hills Vic (SHY rock site)

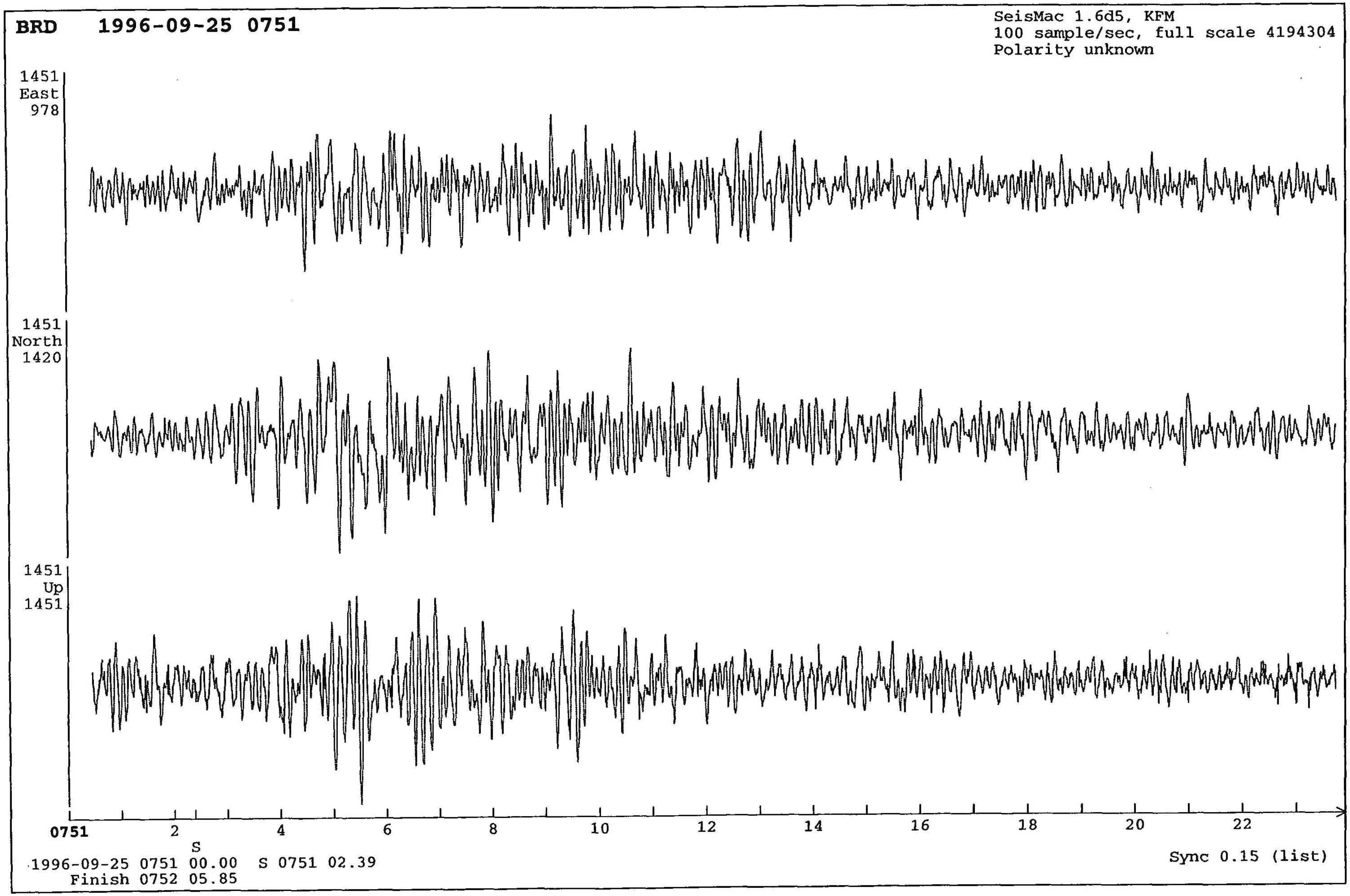


Figure 20 (ix) Accelerogram of the Thomson Dam Vic earthquake on 25 September recorded at Bradford Hills Vic (BRD)

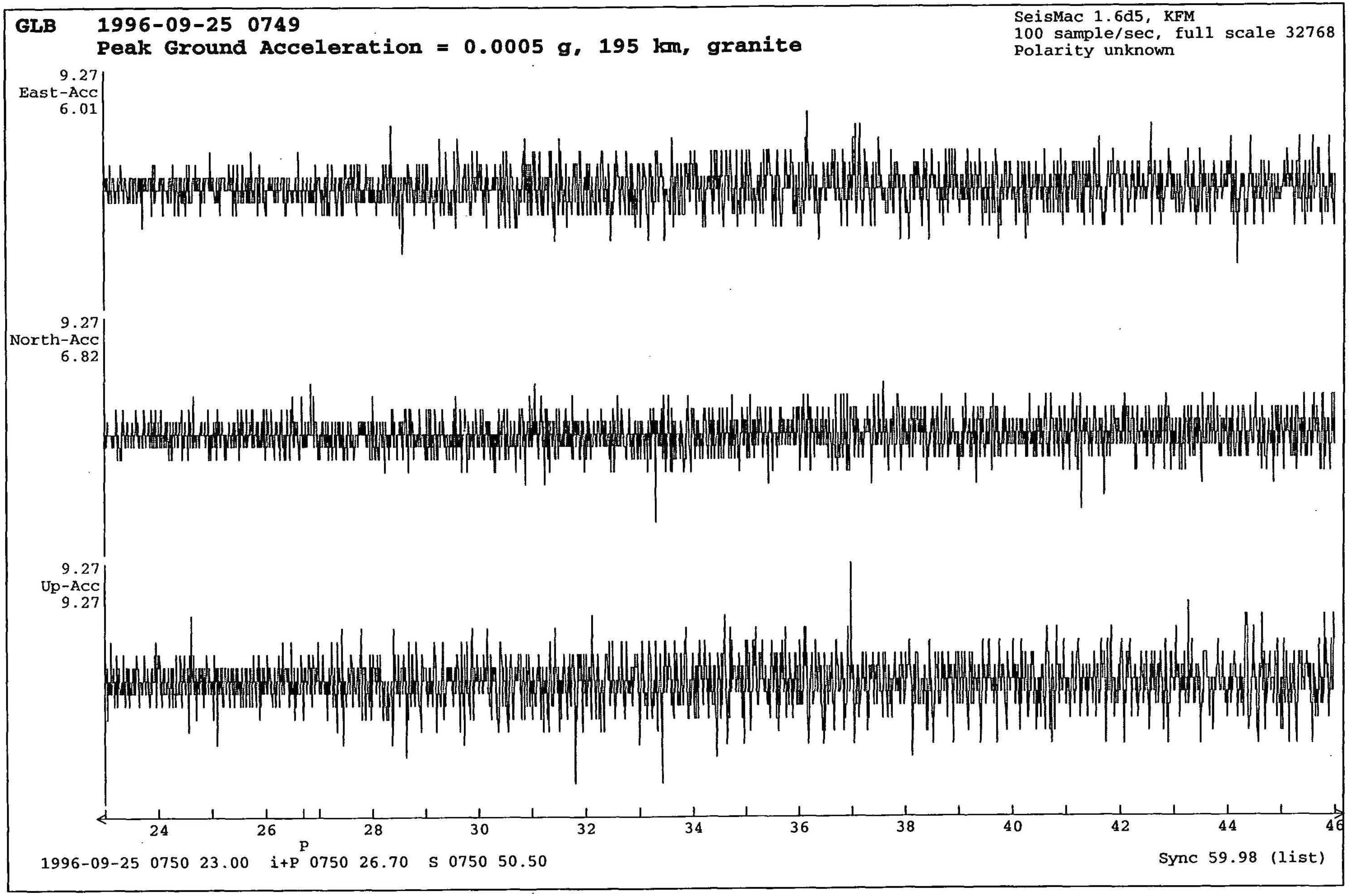


Figure 20 (x) Accelerogram of the Thomson Dam Vic earthquake on 25 September recorded at Geelong Vic (GLB - granite)

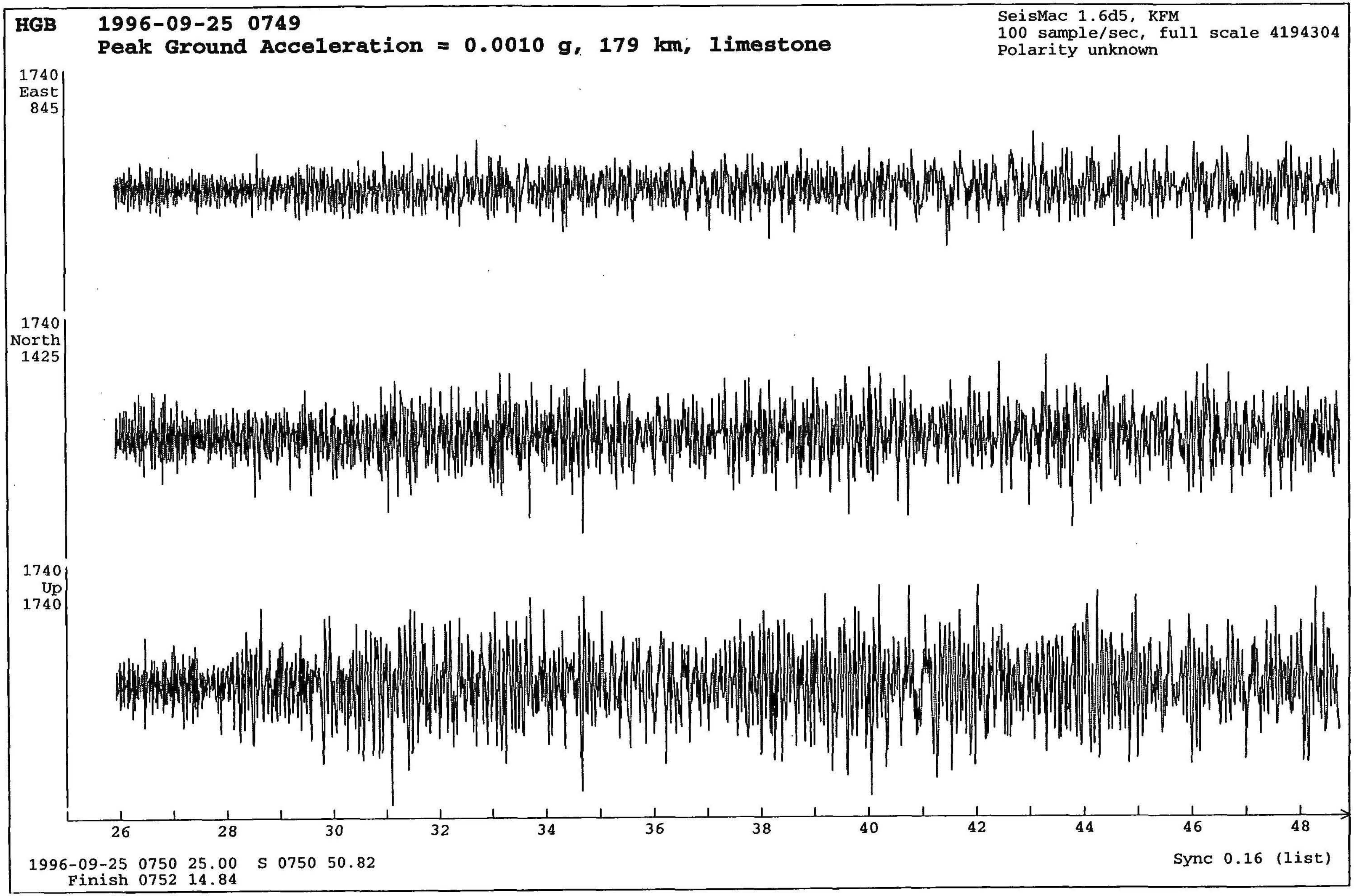


Figure 20 (xi) Accelerogram of the Thomson Dam Vic earthquake on 25 September recorded at Geelong Vic (HGB - limestone)

Meckering earthquakes of 1995 also show that there was no difference in intensity at sites of similar distance on Perth Basin sediments or on the Yilgarn Block.

The MO2 accelerographs at Cadoux (CAS) and Meckering (MEK) were withdrawn from service by the end of 1996 as they were analogue, old and unreliable. Both the Teledyne A700 digital instruments at Cadoux (CAM) and Meckering (ME3) were also withdrawn as they were unreliable and maintenance was too time consuming leaving only two Kelunji accelerographs in operation.

In Darwin fourteen accelerograms were recorded from 12 earthquakes on the JUMP instruments. A major deep earthquake (Mw 7.9) under the Flores Sea on 17 June triggered both accelerographs in Darwin at a distance of 1030 km from the epicentre where the intensity was MMIV (see Peter Gregson's isoseismal map this report). Peak accelerations were 28 mms^{-2} and 14 mms^{-2} at DPH and DRS respectively (Figure 23).

In Eastern Australia The nearest accelerographs to the Range earthquake in outback NSW were in Port Augusta South Australia, too far for them to be triggered. During the Thomson Dam earthquake in Victoria all four of the joint Commonwealth/State Government accelerographs in Melbourne and Geelong triggered on the earthquake. Other accelerograms were obtained from instruments installed on or near some of the Victorian dams. The peak acceleration recorded near the epicentre was 0.11g compared with only 0.0001g in Melbourne at a distance of 130km. Acccelerograms of the earthquake recorded in Melbourne on JUMP instruments at Mooney Ponds MPD and Surrey Hills SHY and at Geelong are shown.

Accelerograms of a number of small earthquakes were also recorded including three records of the 18 February ML 3.5 earthquake near Eucumbene; about 100 km from the recording site in the basement of the AGSO building at Anzac Park East in Canberra (ASC), at a similar distance on Dartmouth dam (DDB) and at Inverness (IVS) in Victoria.

P Gregson, K McCue, G Gibson and V Dent

In South Australia No accelerograms were obtained during the year.

David Love

TSUNAMIS

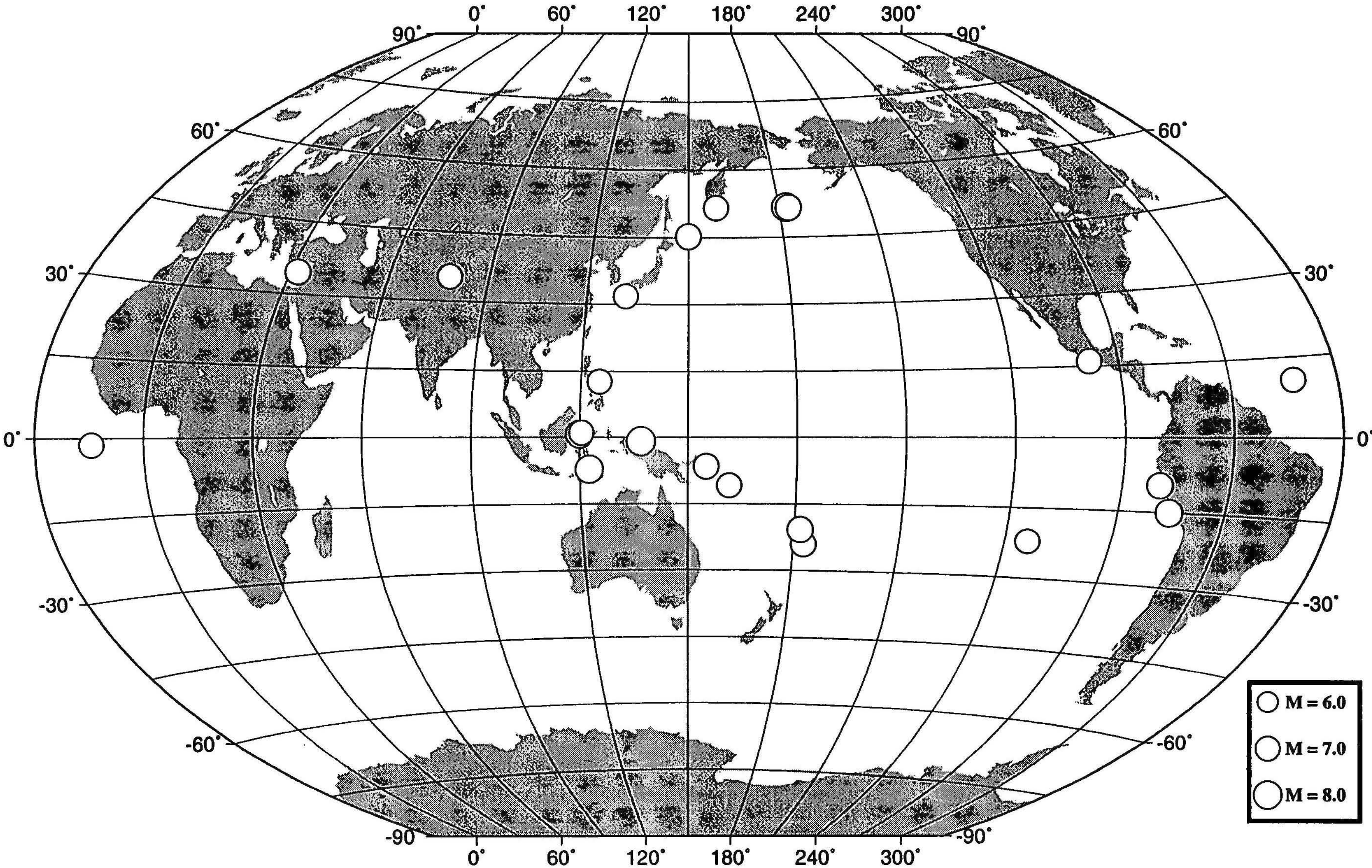
Several tsunamis occurred during the year. On 1 January a magnitude Ms 7.7 earthquake struck the Minahassa Peninsula, Sulawesi. A 1 m high tsunami caused damage in the coastal villages of Soni, Ankir and Dongko.

The great earthquake north of Irian Jaya on 17 February caused a 7 m tsunami in the village of Sarmi and 4 m in the town of Manokwari and the tsunami contributed much of the damage which was estimated at US$8.8M. The tsunami propagated north to Japan striking southern Honshu with a 1 m wave and northern Honshu a 30 cm high wave.

A tsunamigenic earthquake (Ms 6.7, Mw 7.4) on 21 February off Peru's west coast caused a 6 m tsunami in Chimbote where 10 people were killed and the harbour region was flooded.

An earthquake of magnitude Mw 7.1 struck the Andreanoff Islands on 10 June and the subsequent tsunami was recorded throughout the north Pacific but did no damage.

The Tsunami Newsletter of January 1997 reports 'A relatively small, Mw 5.7, earthquake on September 4, 1996, in the Izu Islands of Japan produced a small



Principal world earthquakes, 1996, magnitude 7.0 or greater

tsunami measured on nearby gauges. The mechanism of tsunami generation may have been magma injection beneath the sediments.'

The same source reports the occurrence of a small tsunami at Easter Island and Juan Fernandez by a magnitude Mw 6.7 earthquake along the East Pacific Rise on 5 September. This was both the largest earthquake on record and the only known tsunamigenic one along the East Pacific Rise. Three earthquakes near Kyushu Japan between 19 October and 2 December generated small tsunamis, the largest a 1.1 m wave (peak to trough) during the Mw 7.0 earthquake of 19 October. During this sequence in Japan, a Mw 7.7 earthquake occurred off the coast of Peru and generated a small tsunami. The earthquake caused a lot of housing damage and 14 people died, none of which is attributed to the tsunami.

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: Brisbane 12:07 pm, Melbourne 11:45 am, Hobart 11:45 am, Adelaide 11:10 am, Perth 9:39 am, 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).

AGSO converted from Omega to GPS recording of time signals to correct the station clocks following the announcement of the planned closure in 1997 of the Omega station near Sale in Victoria.

PRINCIPAL WORLD EARTHQUAKES, 1996

Table 7 lists earthquakes that occurred throughout the world in 1996 of magnitude 7.0 or greater, or that caused fatalities or substantial damage.

The largest earthquake was of magnitude Mw 8.2; it struck near Biak off the north coast of Irian Jaya on 17 February and caused considerable damage, most wreaked by the tsunami. According to the Smithsonian Institute 'there were 108 people reported dead, 58 missing and several hundred injured' (SEAN, 1996). Another 17 major magnitude 7 or greater earthquakes and 167 large magnitude 6 or greater earthquakes occurred worldwide. One of these major earthquakes on 17 June was of magnitude 7.9; it occurred at great depth below Flores where it was strongly felt. It was felt in Northern Australia as described under the Isoseismal Map section.

Fewer than 500 people died in earthquakes in 1996, compared with 7874 and 10 044 in 1995 and 1994 respectively, and the average for the century of about 10 000.

This information is from the 'Earthquake Data Reports' published by the United States Geological Survey and the SEAN Bulletin of the Smithsonian Institution (SEAN, 1996).

Peter Gregson, Yvonne Moiler and Kevin McCue

MONITORING OF NUCLEAR EXPLOSIONS

China and France again tested underground nuclear explosions in 1996, two at China's Lop Nor testing site and one at France's Pacific testing site under the Mururoa atoll (Table 8). All other Nuclear Weapons States abided by an agreed moritorium on testing. France exploded at least 123 nuclear bombs under Mururoa and eight under Fangataufa between 1975 and 1996.

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Table 1 Australian Earthquakes, 1996, magnitude 3 or more

SOURCE	DATE	ORIGIN TIME	LAT	LONG	MB	MS	ML	M_MAX	LOCATION
ASC	96/1/13	95813.2	-19.90	134.02			4	4	Tennant Ck NT
ASC	96/1/15	83821.7	-19.91	134.08			3	3	Tennant Ck NT
ASC	96/1/22	123401.3	-21.12	120.81			3	3	E Marble Bar WA
ASC	96/2/4	175527.3	-18.86	120.9			3.4	3.4	SW Broome WA
ASC	96/2/5	60738.3	-16.90	119.72			4.1	4.1	NW Broome WA
ASC	96/2/15	155029.5	-12.83	134.60			3	3	Arnhem Land NT
ASC	96/2/18	193438.6	-36.17	148.67			3.5	3.5	Eucumbene NSW
ASC	96/2/21	23838.5	-16.58	120.32			4	4	NW Broome WA
ASC	96/3/1	10003.1	-32.11	148.59			3	3	Dunedoo Vic
SRC	96/3/5	2721.2	-36.10	143.29			3	3	Glenloth Vic
ASC	96/3/5	44041.2	-19.80	134.00			3	3	Tennant Ck NT
ASC	96/3/10	180012.7	-20.54	128.42			3	3	Fitzroy C WA
ASC	96/3/10	185300.8	-31.45	117.66			3.1	3.1	Kellerberrin WA
ASC	96/3/11	3949.4	-29.21	113.86			3	3	Geraldton WA
ASC	96/3/11	62424.5	-31.45	117.61			3.1	3.1	Kellerberrin WA
ASC	96/3/11	232436.9	-16.53	127.16			3.5	3.5	W Kununurra WA
ASC	96/3/17	223934.1	-21.82	114.3			3.4	3.4	Exmouth WA
ASC	96/3/17	234736.8	-21.84	114.28			3.4	3.4	Exmouth WA
ASC	96/3/23	161013.9	-31.43	138.60			3.6	3.6	Parachilna SA
ASC	96/3/25	74558.6	-19.73	134.02			4.3	4.3	Tennant Ck NT
ASC	96/3/29	54141	-31.44	117.67			3	3	Kellerberrin WA
ASC	96/3/30	72455.6	-16.68	120.16			3.2	3.2	Broome WA
ASC	96/4/3	164313.9	-31.45	117.67			3	3	Kellerberrin WA
ASC	96/4/6	84623.5	-17.90	119.40			3.2	3.2	N Pt Hedland WA
ASC	96/4/19	42604.6	-19.83	134.01			3.5	3.5	Tennant Ck NT
ASC	96/4/21	234304.1	-40.15	155.25			3.2	3.2	Tasman Sea
ASC	96/4/22	95856.2	-22.08	126.59			3.6	3.6	E Lake Tobin WA
ASC	96/4/28	205215.8	-16.68	128.66			3.7	3.7	S Kununurra WA
ASC	96/5/2	4333.5	-31.44	117.66			3	3	Kellerberrin WA
ASC	96/5/10	124846.2	-20.86	120.16			3.4	3.4	Shay Gap WA
ASC	96/5/10	83832	-19.73	133.76			3	3	Tennant Ck NT
ASC	96/5/14	231405.2	-30.04	116.8			3	3	SW Kojonup WA
ASC	96/5/15	32637.3	-19.58	133.76			3.4	3.4	Tennant Ck NT

Table 1 Australian Earthquakes, 1996, magnitude 3 or more

ASC	96/5/21	202122.1	-18.53	121.97			3.2	3.2	SW Broome WA
MUN	96/6/1	71500.9	-30.74	121.47			3.1	3.1	Kalgoorlie WA QB
ASC	96/6/4	82722.3	-28.97	144.06			3.4	3.4	Hungerford Qld
ADE	96/6/9	14312.3	-34.17	135.93			3.5	3.5	Eyre Peninsula SA
ASC	96/6/13	155234.6	-15.55	142.49			3.1	3.1	Cape York Qld
MUN	96/6/18	133100.8	-31.71	117.06			3.7	3.7	Meckering WA
MUN	96/6/21	145659.3	-31.56	117.06			4.1	4.1	Meckering WA
ASC	96/7/8	220427.1	-19.83	134.1			3.5	3.5	Tennant Ck NT
MUN	96/7/9	92611	-26.99	129.94			3.2	3.2	Petermann R SA
MUN	96/7/15	125306.2	-21.58	111.42			3.2	3.2	Byro WA
ASC	96/7/17	213427.5	-19.82	133.91			3.6	3.6	Tennant Ck NT
MUN	96/7/22	631.4	-17.16	120.46			3.4	3.4	NW Broome WA
ADE	96/7/22	100925.1	-31.19	138.88			3.5	3.5	Oraparinna SA
ASC	96/7/23	42547.9	-31.37	138.81			3.8	3.8	Oraparinna SA
ASC	96/7/23	155401.3	-38.06	150.45			3.1	3.1	Tasman Sea
ASC	96/8/1	61854.3	-11.59	131.61			3	3	NE Darwin NT
ASC	96/8/13	43010.7	-30.08	143.52	4.9	4.2	5.1	5.1	White Cliffs NSW
ASC	96/8/13	54432.1	-30.10	143.55			3	3	White Cliffs NSW
ASC	96/8/14	31651.6	-30.15	143.50			3.6	3.6	White Cliffs NSW
ASC	96/8/14	92907.4	-30.12	143.54			4.4	4.4	White Cliffs NSW
ASC	96/8/14	103236.3	-30.14	143.65			3.7	3.7	White Cliffs NSW
MUN	96/8/18	114239.8	-35.21	123.67			3	3	SE Esperance WA
MUN	96/8/19	80018.4	-31.46	117.67			3	3	Kellerberrin WA
MUN	96/8/29	121436.5	-21.03	120.13			3.7	3.7	E Marble Bar WA
MUN	96/9/2	54616.1	-16.56	128.65			3	3	S Kununurra WA
ASC	96/9/4	121120	-26.44	130.69			3	3	SA/NT border
MUN	96/9/6	202449	-27.24	115.05			3.6	3.6	N Geraldton WA
SRC	96/9/7	110554.4	-37.40	141.74			3.2	3.2	Pigeon Ponds Vic
SRC	96/9/10	183549.1	-37.59	141.94			3.1	3.1	Cavendish Vic
ASC	96/9/12	145329.9	-28.10	146.03			3.8	3.8	Cunnamulla Qld
MUN	96/9/18	233554.5	-31.98	116.72			3.1	3.1	York WA
MESA	96/9/24	12702	-37.50	138.94			3.3	3.3	Otway Basin SA
SRC	96/9/25	45350.8	-37.86	146.44			3.3	3.3	Thomson Dam Vic
SRC	96/9/25	74956.96	-37.86	146.45			5.1	5.1	Thomson Dam Vic

Table 1 Australian Earthquakes, 1996, magnitude 3 or more

ASC	96/10/1	214222	-33.82	150.41			3.4	3.4	Katoomba NSW
MUN	96/10/18	52846.8	-32.76	114.59			4.1	4.1	SW Perth WA
MUN	96/10/18	212721.7	-42.50	119.88			3.2	3.2	Southern Ocean
MUN	96/10/23	182340	-16.60	128.65			3.6	3.6	Kununurra WA
MUN	96/10/26	85437.3	-33.90	117.91			3.7	3.7	Gnowangerup WA
ASC	96/11/12	50213.9	-21.96	130.01			3	3	NT/WA border
MUN	96/11/16	62138.3	-31.45	117.69			3.3	3.3	Kellerberrin WA
ASC	96/11/21	60629	-31.62	139.15			3.3	3.3	Martin's Well SA
ASC	96/11/25	203441.7	-41.00	144.34			3	3	Temma Tas
MUN	96/11/30	173839.6	-24.56	116.68			3.1	3.1	N Landor WA
MUN	96/12/1	45017.1	-26.70	132.99			3.4	3.4	Marryat Ck SA
MUN	96/12/2	182826.9	-39.17	113.25			3.8	3.8	Southern Ocean
MUN	96/12/3	75512.7	-32.00	119.75			3.1	3.1	N Bounty Mine WA
MUN	96/12/10	60212.3	-26.25	128.45			3.4	3.4	E Warburton WA
ASC	96/12/10	125426.1	-34.16	150.53			3.3	3.3	Picton NSW
ASC	96/12/10	125835.4	-34.14	150.50			3.2	3.2	Picton NSW
ASC	96/12/24	222808.9	-38.74	145.46			3.2	3.2	Wonthaggi Vic
ASC	96/12/27	162024.6	-29.81	151.25			3.2	3.2	Gilgai NSW
ASC	96/12/27	162821.8	-29.86	151.18			3.5	3.5	Gilgai NSW
MUN	96/12/29	92404.8	-31.61	112.39			3.2	3.2	W Fremantle WA
MUN	96/12/31	150420.6	-17.71	122.46			3.2	3.2	Broome WA

Table 2. **Large or Damaging Australian Earthquakes, 1788 - 1996**

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, 1996

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	180	QLD	8
BLO	Burdekin Lookout	20.625	147.121	234	QLD	1,8
BNB		25.6862	151.7872	150	QLD	8
BRS	Mt Nebo Brisbane	27.392	152.775	525	QLD	5
BWN		20.022	148.126	40	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
EDV	Eidsvold	25.438	151.292	220	QLD	8
GC1		27.9504	153.3607	60	QLD	8
GLD	Glenlyon Dam	28.969	151.480	48	QLD	1
MCP	Mt Cooper	20.552	146.806	300	QLD	1
MNT	Monto	24.855	151.141	250	QLD	8
MPR	Mount Perry	25.198	151.731	370	QLD	8
MRVQ	Maryvale Break	22.955	150.675	75	UCQ	1
MTMQ	Mt Morgan	23.763	150.390	170	CQU/AGSO	8
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
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
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
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
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
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

Table 3 (cont.)

NSW & ACT						
APN	Appin	34.171	150.823	277	SRC	8
ARMA	Armidale	30.4198	151.628	1130	AGSO	7
AVO	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
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
JBR	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	SRC	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
BBOO+	Buckleboo	32.811	136.057	285	ADE/AGSO	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
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

Table 3 (Cont.)

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, 1996

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
Dalton (DAL)	34.726	149.174	570	Weathered rock	SRC	AGSO
Fitzroy Falls (FTZ)	34.625	150.484	711	Sandstone	SRC	NSWWB
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
Manly MHL				Sandstone	SRC	AGSO/PW
Newcastle NLD	32.901	151.701	50	Sandstone	SRC	AGSO/PW
Newcastle NUMB				Sediments	SRC	AGSO/PW
Pipehead Depot (PHD)	33.847	150.969	90	Sandstone /shale	SRC	NSWWB
Riverview	33.829	151.159	21	Sandstone	SRC	AGSO/PW
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
Coronation Park	41.452	147.145	0			AGSO/TAU
Gladstone	40.97	148.02	0			AGSO/TAU
Gee's Lookout	41.4453	147.1236	0			AGSO/TAU

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
Moonee Ponds MPD	37.7684	144.9085	20	Tertiary sediment	SRC	AGSO/GSV
Plane Track PTA	37.357	146.357	771	Palaeozoic sediments	SRC	SRC
Surrey Hills SHY	37.826	145.1104	100	Palaeozoic sediments	SRC	AGSO/GSV
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	Building	SMA-1	ANAHL
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						
Darwin DPH (8 Mar 95)	12.432	130.899	20	Mesozoic Sandstone	AGSO	AGSO/DME
Darwin DRS (8 Mar 95)	12.467	130.842	10	Mesozoic Sandstone	AGSO	AGSO/DME
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

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

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

Table 6 Australian accelerograph data, 1996

Date UTC	*Time*	*Lat°S*	*Long°E*	*ML /mb*	*Site*	*H/E km s-p sec*	*Comp*	*T sec*	*Acc mms^{-2}*
1 10	2237	6.12	138.58	mB 5.8	DPH	764	SZ	0.19	4
							SN	0.21	6
							SE	0.26	6
1 16	647	30.73	117.08	2.0	CAA	7	SZ	0.04	12
							SN	0.04	64
							SE	0.04	30
1 21	701	30.73	117.12	2.6	CAA	4	SZ	0.04	33
							SN	0.04	123
							SE	0.04	60
1 23	29	6.55	129.41	mB 4.7	DPH	670	SZ	0.15	2
							SN	0.15	2
							SE	0.17	3
2 02	256	7.56	127.67	mB 4.6	DPH	644	SZ	0.13	3
							SN	0.14	3
							SE	0.13	4
2 03	2346	7.40	128.38	mB 5.0	DPH	621	SZ	0.17	3
							SN	0.20	3
							SE	0.18	5
2 17	1018	6.95	125.21	mB 5.9	DRS	890	SZ	0.22	2
							SN	0.23	3
							SE	0.29	2
2 18	19 34	-36.17	148.67	3.6	ASC	95	SE	0.1	4.8
							SN	0.1	6.2
							SV	0.1	3.5
					DDB	105	SE	0.1	1.7
							SN	0.1	2.6
							SV	0.07	1.1
					IVS	140	SE	0.07	4.0
							SN	0.07	4.8
							SV	0.06	2.6
2 24	1214	30.79	117.11	2.5	CAA	6	SZ	0.03	26
							SN	0.03	52
							SE	0.03	80
3 01	702	30.79	117.09	2.0	CAA	7	SZ	0.04	15
							SN	0.03	21
							SE	0.03	43
3 02	2233	30.75	117.18	1.6	CAA	3	SZ	0.04	46
							SN	0.04	90
							SE	0.03	30
3 05	2346	7.14	129.09	mB 4.6	DPH	617	SZ	0.22	2
							SN	0.22	2
							SE	0.22	4
3 11	624	31.45	117.62	2.8	CAA	90	SZ	0.05	0.7
							SN	0.05	1.1
							SE	0.05	1
3 15	1117	7.46	128.26	mB 4.8	DPH	625	SZ	0.21	2
							SN	0.21	3
							SE	0.21	5
3 29	1355	7.25	128.59	mB 4.6	DPH	630	SZ	0.20	2
							SN	0.21	2
							SE	0.21	3
4 02	1024	7.20	129.07	mB 4.9	DPH	610	SZ	0.15	2
							SN	0.14	3
							SE	0.14	4
4 05	1159	6.86	128.55	mB 5.1	DPH	670	SZ	0.15	3
							SN	0.16	4
							SE	0.16	4

6 17	11 22	-7.1	122.6	7.9	DPH	1100 590 km deep	E (P)	0.4	25
							N (P)	0.2	23
							V (P)	0.35	28
					DRS		E (P)	0.35	12
							N (P)	0.25	11
							V (P)	0.45	13
6 18	1331	31.71	117.06	3.7	GOO	40	PZ	0.03	5
							PN	0.03	6
							PE	0.03	5
							SZ	0.04	19
							SN	0.03	40
							SE	0.04	32
6 18	1331	31.71	117.06	3.7	CAA	108	PZ	0.13	6
							PN	0.09	4
							PE	0.07	3
							SZ	0.18	8
							SN	0.17	12
							SE	0.18	5
6 21	1456	31.56	117.06	4.1	GOO	35	PZ	0.03	10
							PN	0.05	18
							PE	0.03	10
							SZ	0.03	48
							SN	0.03	117
							SE	0.03	50
6 21	1456	31.56	117.06	4.1	CAA	103	PZ	0.11	6
							PN	0.11	4
							PE	0.13	3
							SZ	0.19	8
							SN	0.19	12
							SE	0.13	5
6 21	1456	31.56	117.06	4.1	TRI	112	SZ	0.23	4
							SN	0.24	11
							SE	0.29	9
8 22	535	7.12	123.28	mB 5.6	DPH	1040	SZ	0.16	3
							SN	0.20	2
							SE	0.26	2
8 22	535	7.12	123.28	mB 5.6	DRS	1040	SZ	0.26	1
							SN	0.26	2
							SE	0.26	2
9 25	07 50	-37.88	146.47	5.0	MPD	134	E	0.3	73
							N	0.3	118
							V	0.3	38
					SHY	110	E	0.3	359
							N	0.4	367
							V	0.6	169
					HGB	179	E	-	2
							N	-	3
							V	-	4
					GLB	195	E	-	2
							N	-	2
							V	-	3
					BRD	232	E		2.3
							N		3.3
							V		3.4

H/E is hypocetral/Epicentral depth in km or distance over focal depth km

Table 7. Principal world earthquakes, 1996

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

Date	Origin Time (UTC)	Region	Lat.	Long.	Magnitude	
01 Jan	08 05 11.9	Minahassa peninsula, Sulawesi	0.724 N	119.981 E	6.2mB, 7.7Ms	7.8Mw (HRV) 7.8Mw (GS)

Depth 33 km. Eight people killed, one person missing and over 200 houses and buildings damaged in the Tolitoli area. A local tsunami contributed to damage in the epicentral area. Felt (IV) at Palu and (III) at Gorontalo. Building damage estimated at approximately $US 1.2M.

Date	Origin Time (UTC)	Region	Lat.	Long.	Magnitude	
03 Feb	11 14 19.8	Yunnan, China	27.299 N	100.341 E	6.3mB, 6.5Ms	6.5Ms (GS) 6.6Ms (HRV)

Depth 10 km. At least 251 people killed, 4,027 seriously injured. Approximately 1,000,000 left homeless and at least 329,000 houses destroyed in northwestern Yunnan Province, mainly in the Lijiang-Zhongdian area. Disruption of communication lines, problems with water supply and harsh weather conditions continued to worsen the conditions for survivors. Maximum intensity IX at Lijiang. Rockslides occurred in the Lijiang area. Two events about 1.5 seconds apart. Depth from broadband displacement seismograms, based on second event.

Date	Origin Time (UTC)	Region	Lat.	Long.	Magnitude	
07 Feb	21 36 45.1	Kuril islands	45.321 N	149.909 E	6.3mB, 7.0Ms	7.1Ms (GS) 7.2Mw (HRV)

Depth 33 km. Some minor damage (V) on Iturup. Felt (IV) on Kunashir.

Date	Origin Time (UTC)	Region	Lat.	Long.	Magnitude	
17 Feb	05 59 29.7	Irian Jaya Region,	0.950 S	137.027 E	6.5mB, 8.1Ms	7.9Mw (GS)

Depth 33 km. At least 108 people killed, 423 injured, 58 missing, 5,043 houses destroyed or damaged in the epicentral area. Extensive damage on Biak and Supiori from the tsunami, which reached heights of 7 meters in many areas. Also damage along the north coast of Irian Jaya from Manokwari to Sarmi. Estimated losses amounted to $US 8.8 M.

Date	Origin Time (UTC)	Region	Lat.	Long.	Magnitude	
21 Feb	12 51 04.3	Off coast of N Peru	9.620 S	79.568 W	5.8mB, 6.6Ms	7.3MwGS 7.5Mw HRV

Depth 33 km. Four people killed, three missing and two injured from a local tsunami. The tsunami also destroyed about 150 huts along the coast near Chimbote. Felt (IV) at Chimbote and Huarmey; (III) at Casma; (II) at Huacho and Huaraz.

Table 7 (Cont'd)

Date	Origin Time (UTC)	Region	Lat.	Long.	Magnitude	
25 Feb	03 08 18.8	Oaxaca, Mexico	16.204 N	97.963 W	5.9mB, 6.9Ms	7.1Mw (GS) 7.0Ms (HRV)

Depth 33 km. Felt along the coast of Guerrero and Oaxaca States. Also felt at Mexico City.

Date	Origin Time (UTC)	Region	Lat.	Long.	Magnitude	
28 Mar	23 03 49.8	Ecuador	1.036 S	78.737 W	5.8mB, 5.2Ms	5.9Mw (GS) 5.9Mw (HRV) 5.1Ms (BRK)

Depth 33 km. At least 19 people killed, 58 injured, several thousand homeless and considerable damage and destruction to homes, bridges and water pipes in Cotopaxi, Pastata and Tungurahua Provinces. Landslides blocked several roads in the epicentral area. Minor damage (VI) at Ambato, Latacunga and San Miguel de Salcedo. Felt (IV) at Quito; (III) at Ibarra; (II) at Cuenca and Guayaquil. Felt in many parts of Ecuador.

Date	Origin Time (UTC)	Region	Lat.	Long.	Magnitude	
16 Apr	00 30 54.6	South of Fiji Islands	24.061 S	177.036 W	6.4mB, 6.8Ms	7.1Mw (GS) 7.1Mw (HRV)

Depth 110 km. No damage or casualties reported.

Date	Origin Time (UTC)	Region	Lat.	Long.	Magnitude	
29 Apr	14 40 41.0	Solomon Islands	6.518 S	154.999 E	6.3mB, 7.5Ms	7.1Mw (GS) 7.2Mw (HRV)

Depth 44 km. One person killed and several houses collapsed in Western Bougainville. Felt throughout the island of Bougainville. Two events about 6.5 seconds apart. Depth of broadband displacement seismograms, based on first event.

Date	Origin Time (UTC)	Region	Lat.	Long.	Magnitude	
03 May	03 32 47.1	Western Nei Mongol China	40.774 N	109.661 E	5.5mB	5.9Mw (GS) 6.0Mw (HRV)

Depth 26 km. At least 18 people killed, 300 injured and extensive damage in the Baotou area. Felt at Beijing, Hohhot, Taiyuan, Xian and Yinchuan.

Table 7 (Cont'd)

Date	Origin Time (UTC)	Region	Lat.	Long.	Magnitude	
10 Jun	04 03 35.4	Aleutian Islands	51.564 N	177.632 W	6.6mB, 7.6Ms	7.9Mw (GS) 7.9Mw (HRV) 7.4Ms (BRK)

Depth 33 km. Felt (VI) on Adak and Atka. Tsunami generated with wave heights (peak-to-trough) recorded at the following selected tide stations: 102 cm on Adak; 15 cm on Shemya; 12.5 cm at Kodiak and 10.2 cm at Sand Point, Alaska; 46 cm on Midway; 55 cm at Kahului, 38 cm at Hilo; 33 cm at Nawiliwili and 10 cm at Honolulu, Hawaii; 30 cm at Crescent City, California; 10 cm at Port Angeles, Washington. Complex event observed on broadband displacement seismograms.

10 Jun	15 24 56.0	Aleutian Islands	51.478 N	176.847 W	5.9mB, 7.1Ms	7.1Mw (GS) 7.2Mw (HRV) 6.9Ms (BRK)

Depth 26 km. Felt strongly on Adak. Two events about 5.5 seconds apart. Depth from broadband displacement seismograms, based on second event.

11 Jun	18 22 55.7	Samar, Philippine Islands	12.614 N	125.154 E	6.0mB, 7.0Ms 6.9Mw (GS)	7.1Mw (HRV) 7.2Ms (BRK)

Depth 33 km. Felt (V RF) at Catarman; (IV RF) at Bulusan, Luzon and Palo, Leyte; (III RF) at Legaspi, Luzon; (I RF) at Quezon, Luzon.

17 Jun	11 22 18.5	Flores Sea, Indonesia	7.137 S	122.589 E	6.6mB 7.5Ms	7.9Mw (HRV) 7.8Mw (GS)

Depth 587 km. Some damage at Kupang, Indonesia. Felt at Larantuka and Maumere, Indonesia. Also felt at Putatan, Malaysia. Complex event observed on broadband displacement seismograms.

22 Jul	14 19 35.7	Minahassa Peninsula Sulawesi	1.000 N	120.450 E	6.0mB, 6.9Ms 6.9Mw (GS)	7.0Mw (HRV)

Depth 33 km. Some damage (VIII) in the Tolitoli area. Felt (V) in the Palu area.

Table 7 (Cont'd)

Date	Origin Time (UTC)	Region	Lat.	Long.	Magnitude	
02 Aug	12 55 29.3	Solomon Islands	10.769 S	161.445 E	6.2mB, 7.1Ms	6.9Mw (GS) 6.9Mw (HRV)

Depth 33 km.

05 Sep	08 14 14.4	Easter Island Region	22.118 S	113.436 W	6.2mB, 7.0Ms	6.7Mw GS, 6.9 Mw (HRV) 7.0Ms (BRK)

Depth 10 km.

09 Oct	13 10	Cyprus	34.5 N	32.1 E		6.8 Ms

This earthquake was strongly felt on Cyprus and elsewhere in the region including Turkey, Syria, Lebanon, Israel and Egypt. Both Cyprus and Egypt reported one fatality and several additional injuries were reported in Cyprus.

13 Oct	23 26	Solomon Islands	7.03 N	155.52 E		Ms 7.0

This earthquake was strongly felt on Treasury and Shortland islands, which are S of Bougainville along the New Britain-New Hebrides trench system. This trench system marks the subduction of oceanic crust beneath the Solomon Islands. The epicenter was ~140 km SE of Nonda volcano on Vella Lavella Island and ~180 km SE of Simbo volcano on Solomon Island.

12 Nov	16 59 44.0	Near coast of Peru	14.993 S	75.675 W	6.5mB, 7.3Ms	7.7Mw (GS) 7.7Mw (HRV)

Depth 33 km. At least 14 people killed, 560 injured and 12,000 homeless from Chincha Alta to Acari. Over 4,000 houses damaged or destroyed (VIII) at Nazca. Felt (VII) in the Marcoona area; (VI) at Ica and Palpa; (IV) at Arequipa and Camana; (III) at Lima and Tacna; (II) at Huancayo and Pucallpa. Felt by people in high-rise buildings at Guayaquil, Ecuador and La Paz, Bolivia. This thrust earthquake is associated with the subduction of the Nazca Ridge (a major feature of the Nazca plate) beneath the South American plate. It originated near the southern end of a seismic gap between the large Peruvian earthquakes of August 24 1942 and October 3 1974, with the aftershock sequence progressing southward into the zone of the 1942 event. This is a complex earthquake, with at least two larger events occurring about 20 and 33 seconds after the onset.

Table 8 Nuclear explosions detected*, 1996

Date	Time UTC	mb	Ms	Yield kton	Lat	Long	Site	Source
960127	212957.6	5.3			22.259S	138.810W	Mur	PDE
960608	025557.9	5.9	4.3		41.657N	88.690E	LopN	PDE
960729	014857.8	4.9			41.824N	88.420E	LopN	PDE

Site:
LopN: Lop Nor China
Mur: French Polynesia

Source:
¤ PDE Preliminary Determination of Epicentres; QED Quick Epicentre Determination

* from: AGSO Nuclear Explosions Database

Table 9. Yield versus magnitude for underground nuclear explosions

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

APPENDIX 1

ISOSEISMAL MAPS

Eleven earthquakes during 1996 were sufficiently widely felt in Australia that questionnaires were distributed and the returned forms collated to draw up isoseismal maps; four in Western Australia, three in Queensland, two in New South Wales, one in Victoria and one in Indonesia.

The format of these maps is the same as those printed in the three volumes of the AGSO (BMR) Isoseismal Atlas (Everingham and others, 1982; Rynn and others, 1987; McCue, 1995).

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.

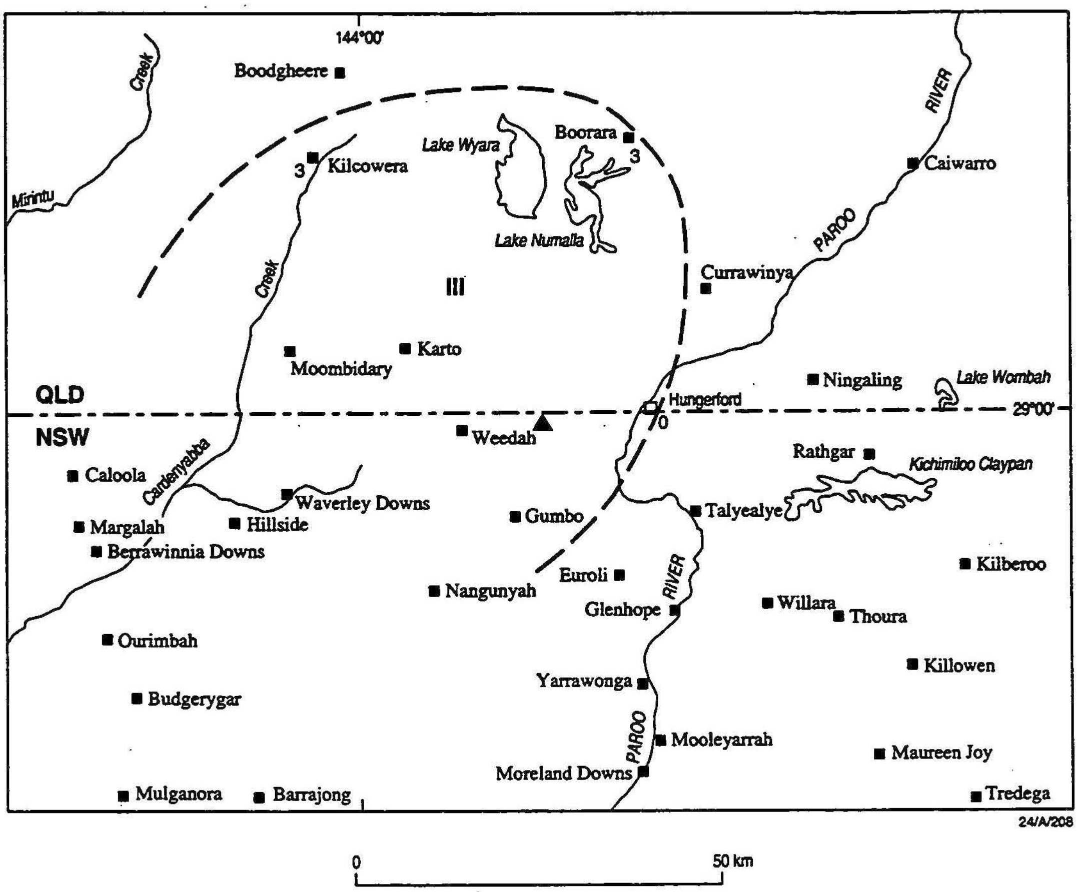
The `domestic water tanks' listed under MM VII are of the cylindrical corrugated-iron type common in New Zealand rural areas. If these are only partly full, movement of the water may burst soldered and riveted seams. Hot-water cylinders constrained only by supply and delivery pipes may move sufficiently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

Isoseismal map of the Hungerford Qld earthquake 4 June 1996

The majority of the population in the epicentral area was concentrated in the township (normal population 11) for an agricultural field demonstration. The large number of vacant outlying station homesteads resulted in a limited number of felt reports. The computed epicentre is also of limited accuracy as the closest seismograph was more than 170 km away.

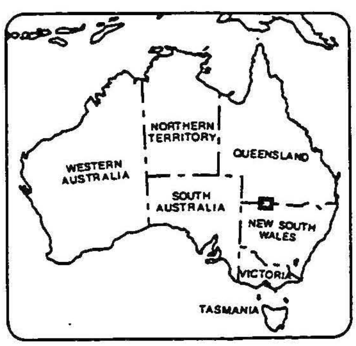
Russell Cuthbertson

ISOSEISMAL MAP OF THE HUNGERFORD, QLD, EARTHQUAKE
4 JUNE 1996



DATE: 4 June 1996
TIME: 08:27:00 UTC
MAGNITUDE: ML 3.4
EPICENTRE: 29.04°S 144.26°E

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



Isoseismal map of the Flores Sea earthquake 17 June 1996

An earthquake occurred on 17 June in the Flores Sea (7.14° S and 122.59° E) at 1122 UT (2052 CST). The USGS reported the magnitude as mB 6.6 and Mw 7.8, with a depth of 587 km.

Some damage was reported at Kupang Timor and the earthquake was felt at Laratuka and Maumere, Indonesia and Putatan in Malayasia. It was also felt in Australia with a maximum assigned intensity of MM V at Darwin. The radius of the MM IV isoseismal in Australia is approximately 1050 km. In northern Australia, the greatest distance the earthquake was felt was 1500 km from the epicentre. The earthquake was also felt in tall buildings, one each in Perth and Adelaide, 2800 km and 3450 km from the epicentre respectively.

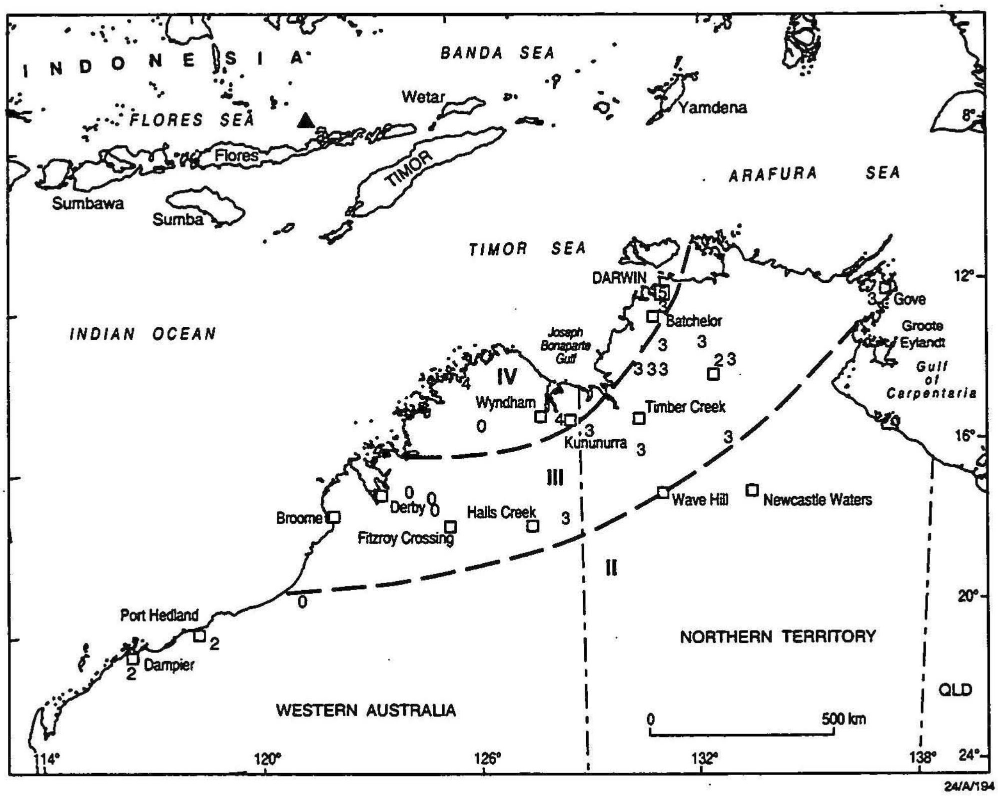
A seiche with amplitude 30 centimetre was evident on the tide gauge at Cape Lambert (near Karratha, WA).

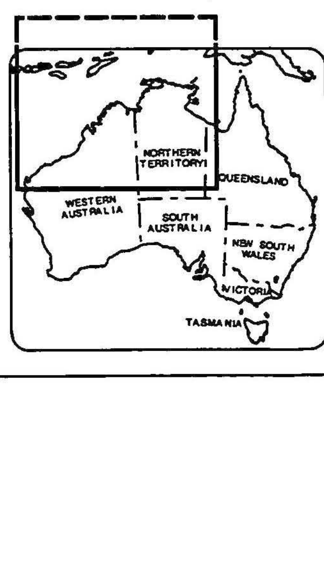
Strong motion was recorded in Darwin with peak ground accelerations at -

Location	*Acceleration*	*Distance km*
Parliament House	25 mms^{-2}	1100
Dept of Mines, Rock Store	12 mms^{-2}	1100

Peter Gregson

ISOSEISMAL MAP OF THE FLORES SEA EARTHQUAKE, 17 JUNE 1996





DATE: 17 JUNE 1996
TIME: 11:22:18.5 UTC
MAGNITUDE: 7.9 Mw
EPICENTRE: 7.14°S, 122.59°E
DEPTH: 587 km

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

Isoseismal map of the Meckering WA earthquake 18 June 1996

Meckering, 110 km east of Perth was strongly shaken by an earthquake of magnitude ML 3.7 on 18 June at 13:31 UTC (9.31 p.m. WST). Effects commensurate with an intensity of MM V were reported from the townsite where many people were frightened and small plaster cracks occured. Windows and crockery rattling up to 35 km from the epicentre. The earthquake was felt (intensities MM III) in the outer eastern suburbs of Perth up to 100 km from the epicentre, and 120 km to the north-west. The outer Perth suburbs east of the Darling Fault are built on granite of the pre-Cambrian shield. There were very few reports of the earthquake being felt west of the fault.

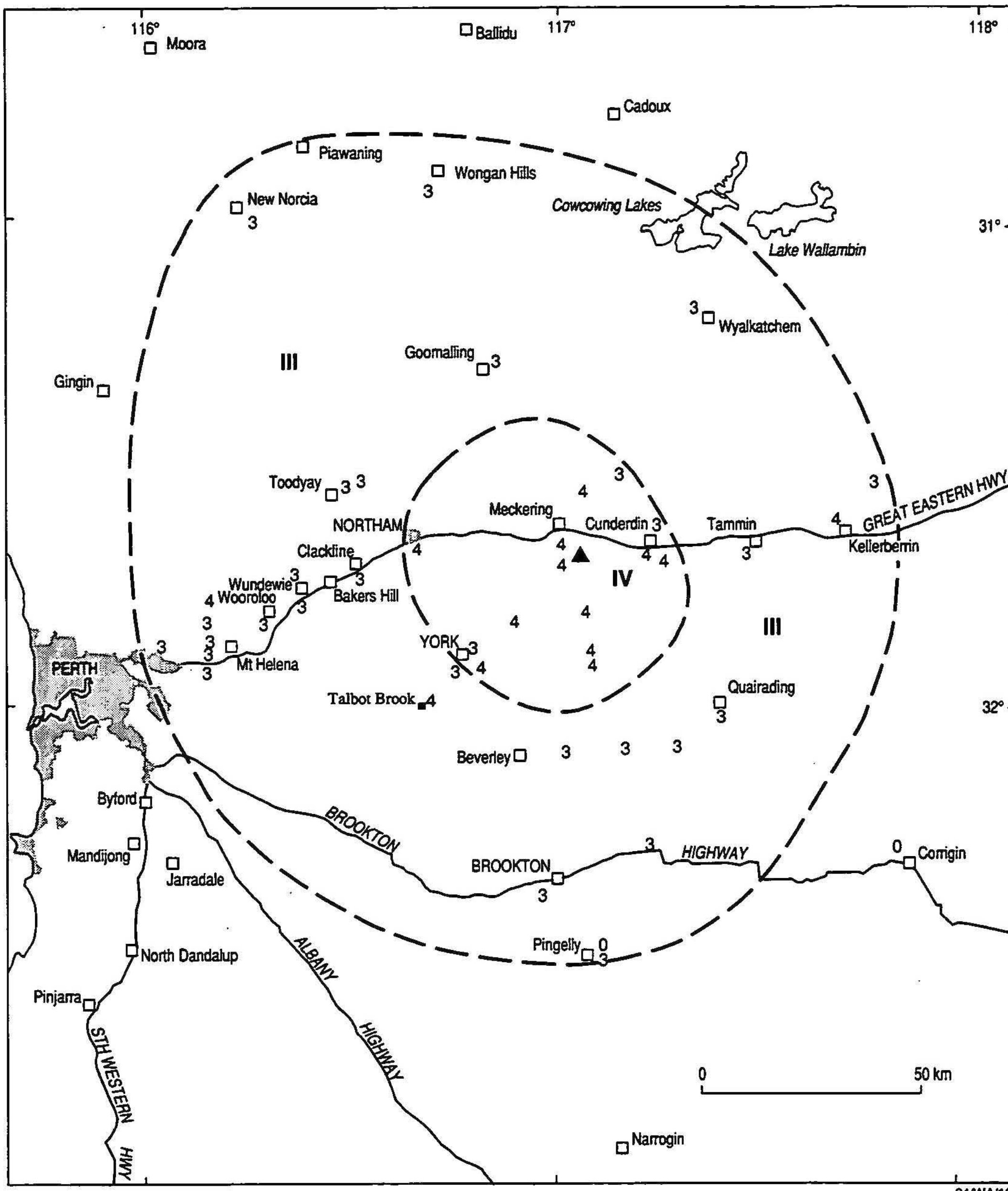
Strong motion was recorded at two locations with peak ground accelerations at -

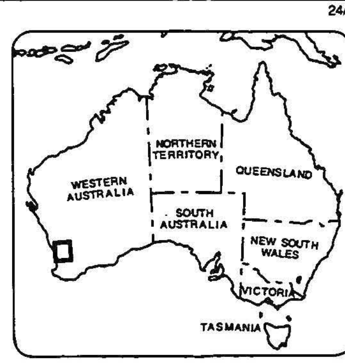
Location	*Acceleration*	*Distance km*
Goomalling GOO	40 mms^{-2}	40
Cadoux CAA	4 mms^{-2}	100

Peter Gregson

ISOSEISMAL MAP OF THE MECKERING EARTHQUAKE, WESTERN AUSTRALIA

18 JUNE 1996





DATE: 18 JUNE 1996
TIME: 13:13:00.8 UTC
MAGNITUDE: 3.7 ML (MUN)
EPICENTRE: 31.71°S, 117.06°E
DEPTH: 5 km

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

Isoseismal map of the Meckering WA earthquake 21 June 1996

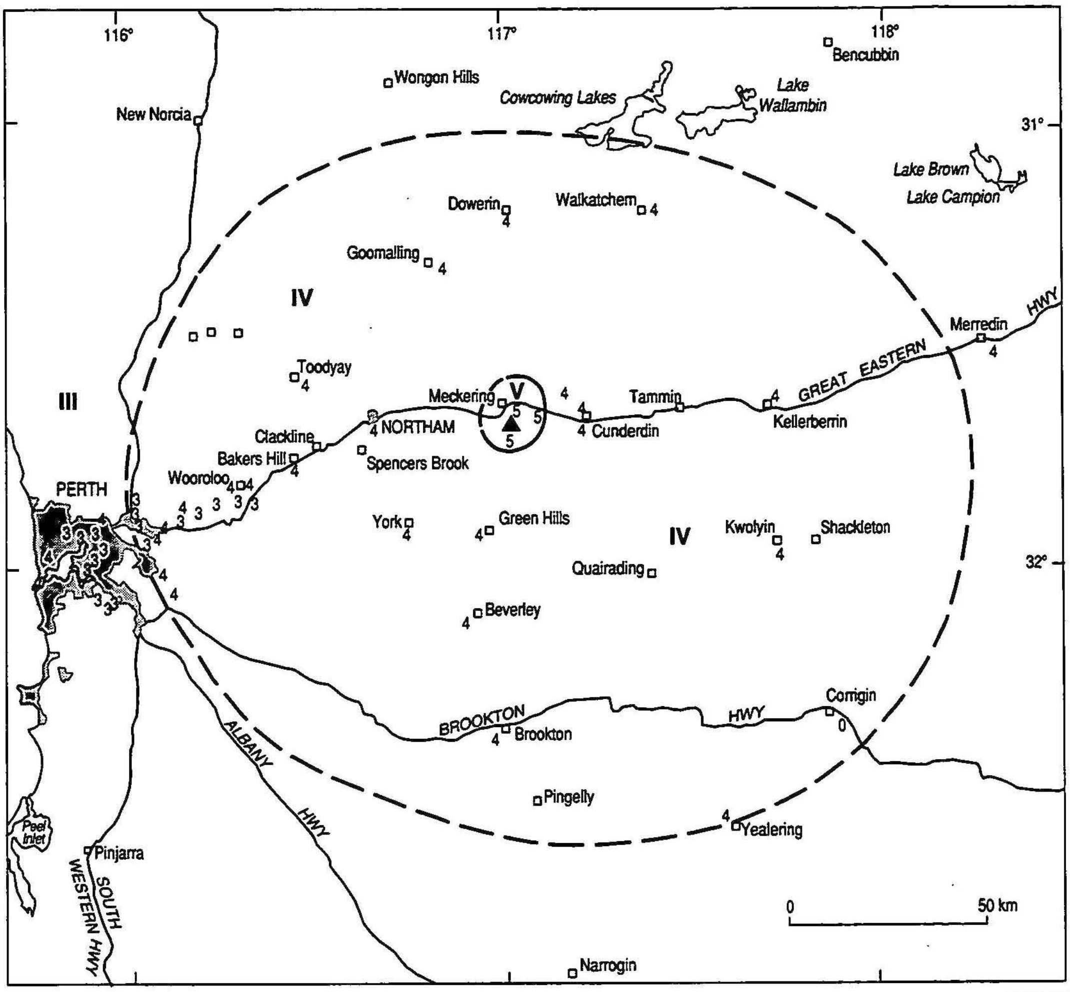
Three days after an earlier shaking, Meckering was again rocked by an earthquake. The magnitude of this event was ML 4.1 and it occurred at 14:56 UTC (10:56 p.m. WST) on 21 June. It was located 5 km south east of the Meckering townsite, about 5 km closer than the earlier event. Intensities of MM V were assigned with some people awakened, and there were reports of small objects overturning within 10 km of the epicentre. The average radius of the MM IV isoseismal was 105 km with an elongation of up to 20% in an easterly direction. Generally intensities experienced in Perth and inner suburbs were assigned MM III although there were pockets which warranted MM IV. It is difficult to determine the maximum distance at which the earthquake could have been felt because of the lateness of the hour.

Strong motion was recorded at three locations with peak ground accelerations at -

Location	*Acceleration*	*Distance*
Goomalling GOO	140 mms^{-2}	40
Cadoux CAA	12 mms^{-2}	100
Perth	11 mms^{-2}	111

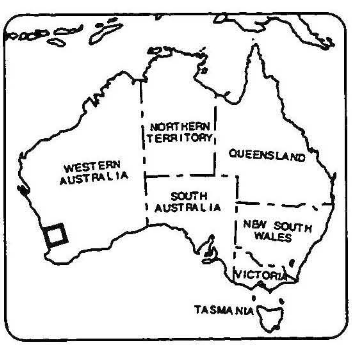
Peter Gregson

ISOSEISMAL MAP OF THE MECKERING EARTHQUAKE, WESTERN AUSTRALIA
21 JUNE 1996



DATE: 21 JUNE 1996
TIME: 14:56:59.3 UTC
MAGNITUDE: 4.1 ML (MUN)
EPICENTRE: 31.56°S, 117.06°E
DEPTH: 6 km

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



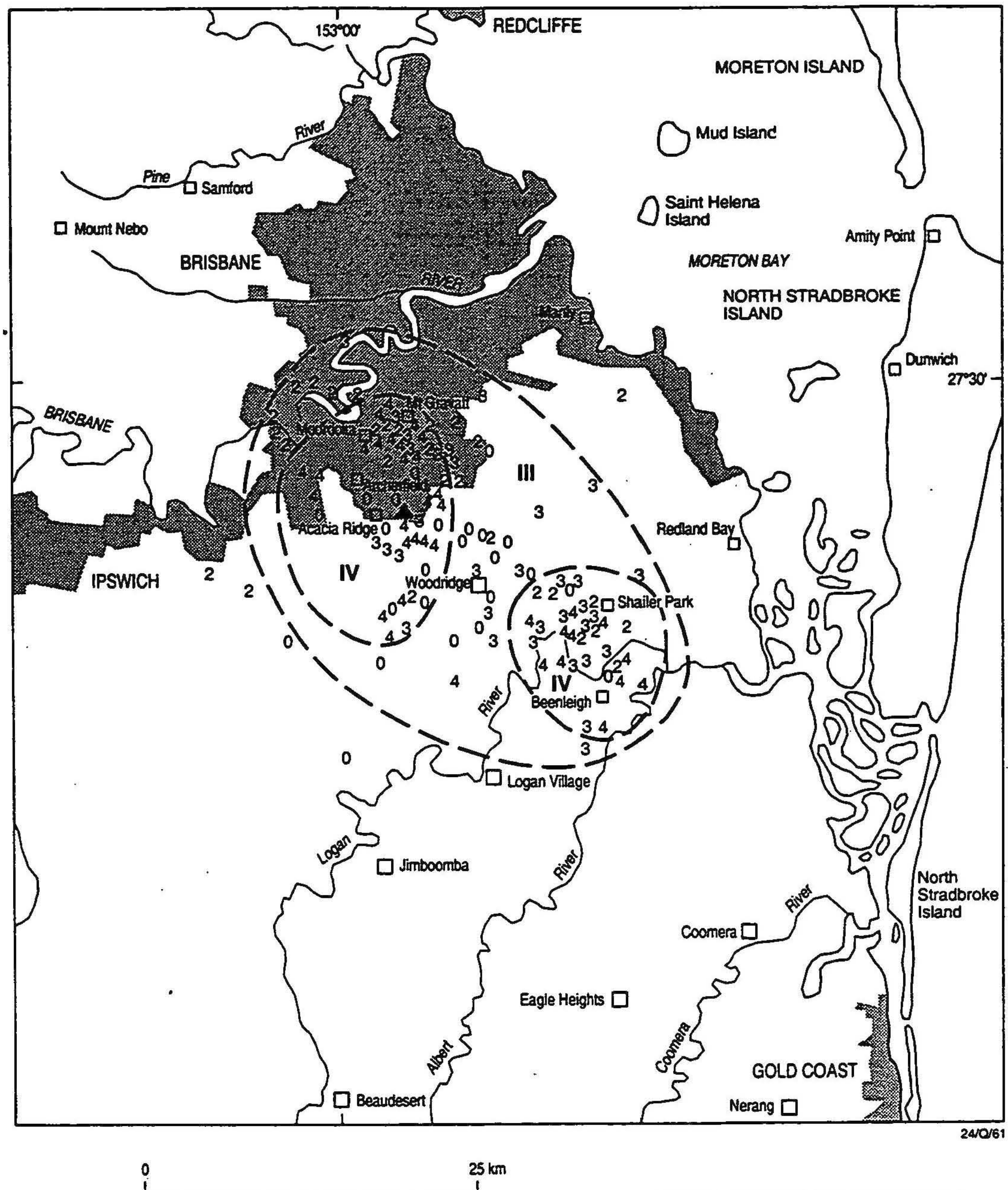
Isoseismal map of the Acacia Ridge Qld earthquake 18 July 1996

The tremor occurred at 3:40 pm local time in the suburbs of Brisbane, only 13km from the Central Business District. There was initially only a small number of reports of the event being felt, due to people either being at work or out collecting children from schools. Subsequent press reports and a phone survey collected over 150 intensity reports. Although there were reliable report of the event being felt as far away as 70km the general radius of perceptibility was only 14km.

The higher intensities were concentrated around the epicentre and in a separate area to the south-west. The intervening area had lower intensities and even *not felt* replies. Variations in the intensities showed some correlation with surficial geology; lower intensities were associated with areas of Mesozoic sandstones and coal measures and Cainozoic sandstones and basalts, while higher intensities occurred on the Palaeozoic basement rocks. This observation, which is somewhat contrary to what is usually observed, is thought to be due to the high frequency nature of this relatively small magnitude event. Attenuation of the high frequency energy was evidently more significant than the amplifying effects normally associated with surface sediments.

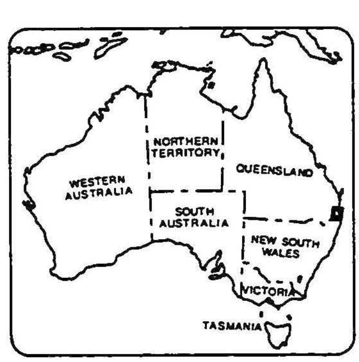
Russell Cuthbertson

ISOSEISMAL MAP OF THE ACACIA RIDGE EARTHQUAKE, QLD
18 JULY 1996



DATE: 18 July 1996
TIME: 15:40:16 UTC
MAGNITUDE: 2.7 ML
EPICENTRE: 27.04°S 153.04°E

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



Isoseismal map of The Range NSW earthquake 13 August 1996

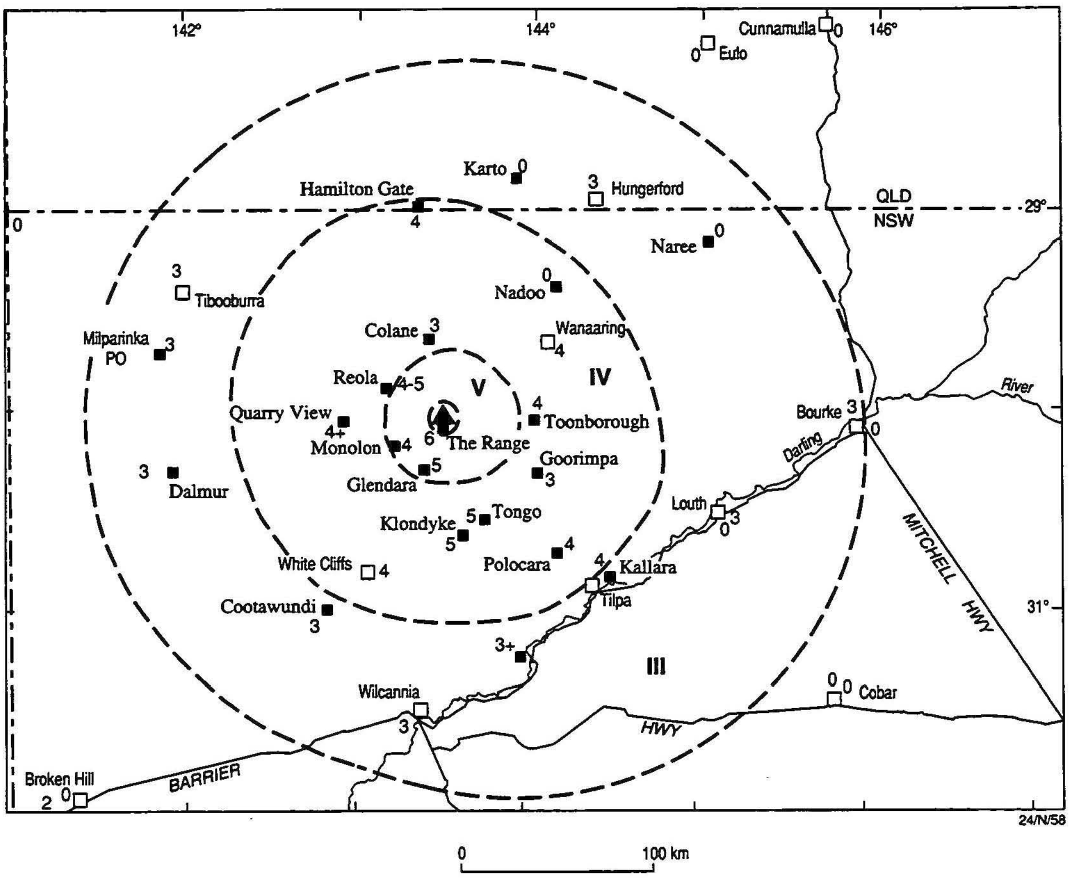
This earthquake shook the most sparsely populated part of New South Wales. Questionnaires provided by AGSO were distributed by the Bourke NSW SES and additional intensities were solicited by AGSO, UQ and RMIT seismologists by phone and on location to draw up the map opposite. In the epicentral area a disused homestead on concrete footings suffered differential settlement in the earthquake so that the doors would no longer shut but no other damage is known. The earthquake was clearly felt as far as Wilcannia and Bourke up to 200 km from the epicentre and at Hungerford over the Queensland border but it was not felt in South Australia. One resident at Bourke was so frightened that she fled the house, perhaps an understandable reaction in a place where earthquakes are so rare.

Another Bourke respondant did mention they remembered a previous earthquake in late October or early November 1935/36 but we have no record of this earlier event. Only a sensitive few Broken Hill residents felt the shaking there.

The natural gas pipeline from the Cooper Basin in South Australia to Sydney passes within about 30 km of the epicentre and an inspection by Eastern Gas Pipeline staff confirmed that neither the pipeline nor pumping stations were damaged. If nothing else it highlighted the vulnerability of long pipelines.

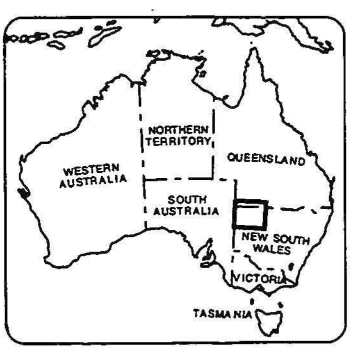
Kevin McCue, Adam Pascale, Russell Cuthbertson, Malcolm Somerville, and Tony Corke

ISOSEISMAL MAP OF "THE RANGE" EARTHQUAKE, NEW SOUTH WALES
13 AUGUST 1996



DATE: 13 AUGUST 1996
TIME: 04:30:11.3 UTC
MAGNITUDE: ML 5.1, mb 4.9
EPICENTRE: 30.08 $\pm$ (0.06)°S, 143.53 $\pm$ (0.06)°E

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



Isoseismal map of the Thomson Dam Vic earthquake 25 September 1996

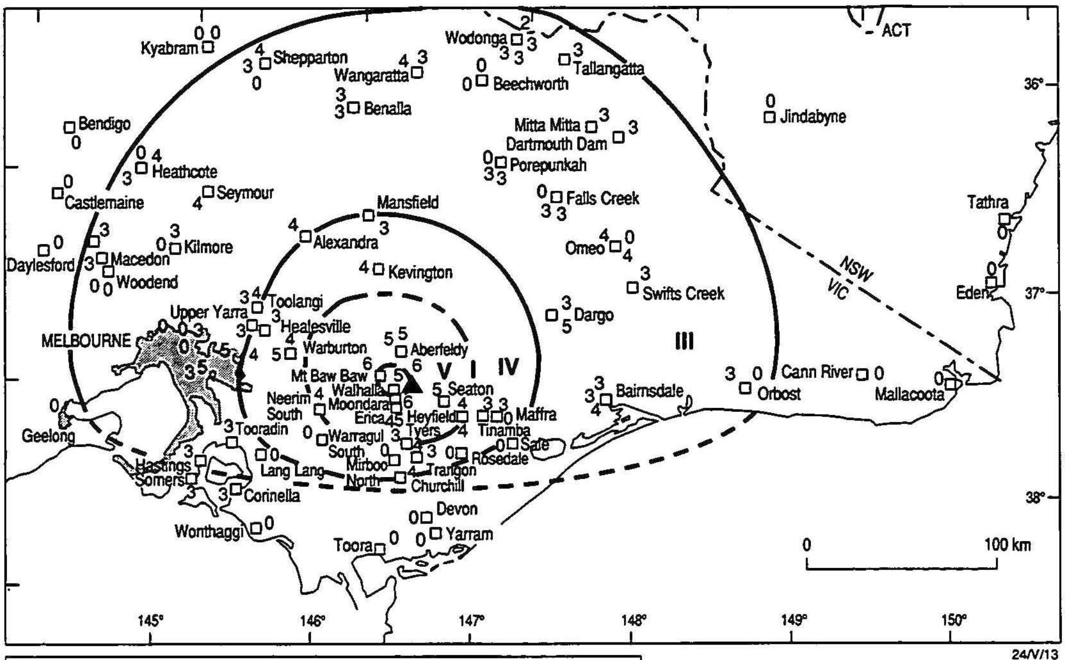
This was the largest earthquake in Victoria since the 1982 Wonnangatta event (Denham and others, 1985) 100 km to the northeast and the second largest in Australia in 1996. Questionnaires were distributed statewide by AGSO and in the metropolitan and epicentral areas by SRC, and an isoseismal map was jointly compiled. Telephone queries were subsequently made to gain more information.

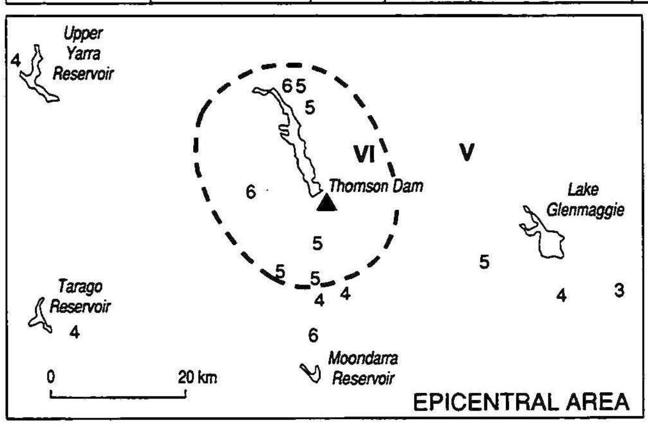
The intensity in the epicentral region was MMVI where it is reported to have sounded like a large explosion and buildings shook strongly though there was no structural damage to the dam or other structures. In Melbourne suburbs the intensity varied from MMV to not felt, some people felt shaking strongly enough to be frightened, others felt nothing. People reported feeling the earthquake at Shepparton and Wodonga, 200 km to the north and Orbost a similar distance to the east but it was not felt at Geelong to the west. To the south there were no reports further than 60 km from the epicentre.

The map is strikingly asymmetric, radiated energy was strongly attenuated to the south and east which we attribute more to the mechanism of the earthquake than the geology based on the more symetric shape of isoseisms of earlier earthquakes.

Adam Pascale, Gary Gibson and Kevin McCue

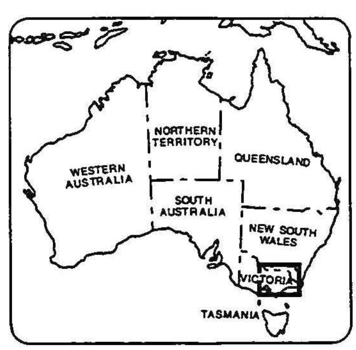
ISOSEISMAL MAP OF THE THOMPSON DAM EARTHQUAKE, VICTORIA
25 SEPTEMBER 1996





DATE:	25 SEPTEMBER 1996
TIME:	07:49:57 UTC
MAGNITUDE:	5.0 ML
EPICENTRE:	37.88°S,146.46°E
DEPTH:	10.5 km

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



Isoseismal map of the offshore WA earthquake 18 October 1996

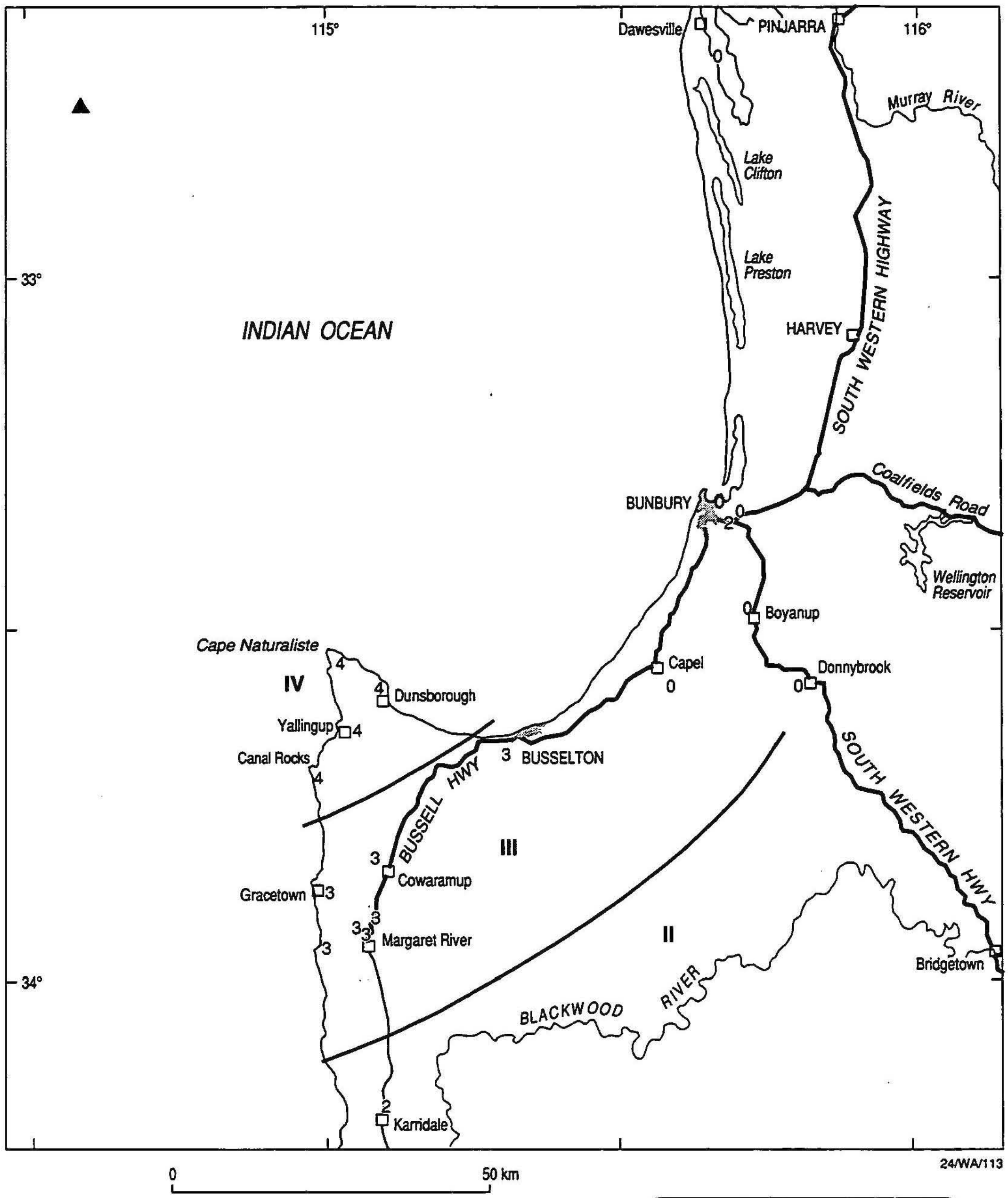
The south-western corner of Western Australia was shaken by an earthquake at 1.28 p.m. on 18 October 1996. The magnitude ML 4.1 earthquake was located offshore about 130 km south-west of Fremantle and 95 km north-northwest of Cape Naturaliste.

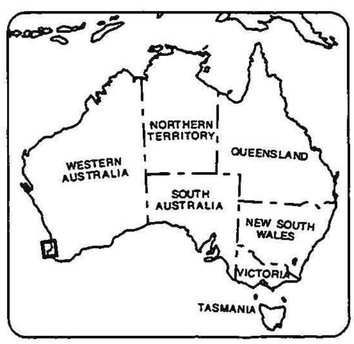
The maximum intensity experienced was MM IV and was generally confined to a small area of about 35 km^2 in the Cape Naturaliste area. The radius of the MM IV was 115 km. The earthquake was felt with intensity MM II at Karridale, 165 km from the epicentre in a southerly direction. There was also one report from the north-east at Gidgegannup, 180 km from the epicentre.

There were numerous reports from the MM Zone III from Gracetown and Margaret River areas on the Precambrian Shield, west of the Dunsbrough fault. It is interesting to note that apart from Bunbury (MM II) there were no reports of the earthquake having been felt in the Perth Basin between Bunbury and Perth. A magnitude 5.2 earthquake in 1980 located about 70 km to the north-west of this earthquake resulted in similar effects. Intensities of MM III were generally experienced in the Basin in the Perth area with MM IV on the Pre-cambrian shield east of the Darling Fault, further away from the epicentre.

Peter Gregson

ISOSEISMAL MAP OF THE OFFSHORE EARTHQUAKE, WESTERN AUSTRALIA
18 OCTOBER 1996





DATE: 18 OCTOBER 1996
TIME: 05:28:46.8 UTC
MAGNITUDE: 4.1 ML (AGSO)
EPICENTRE: 32.76°S, 114.59°E

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

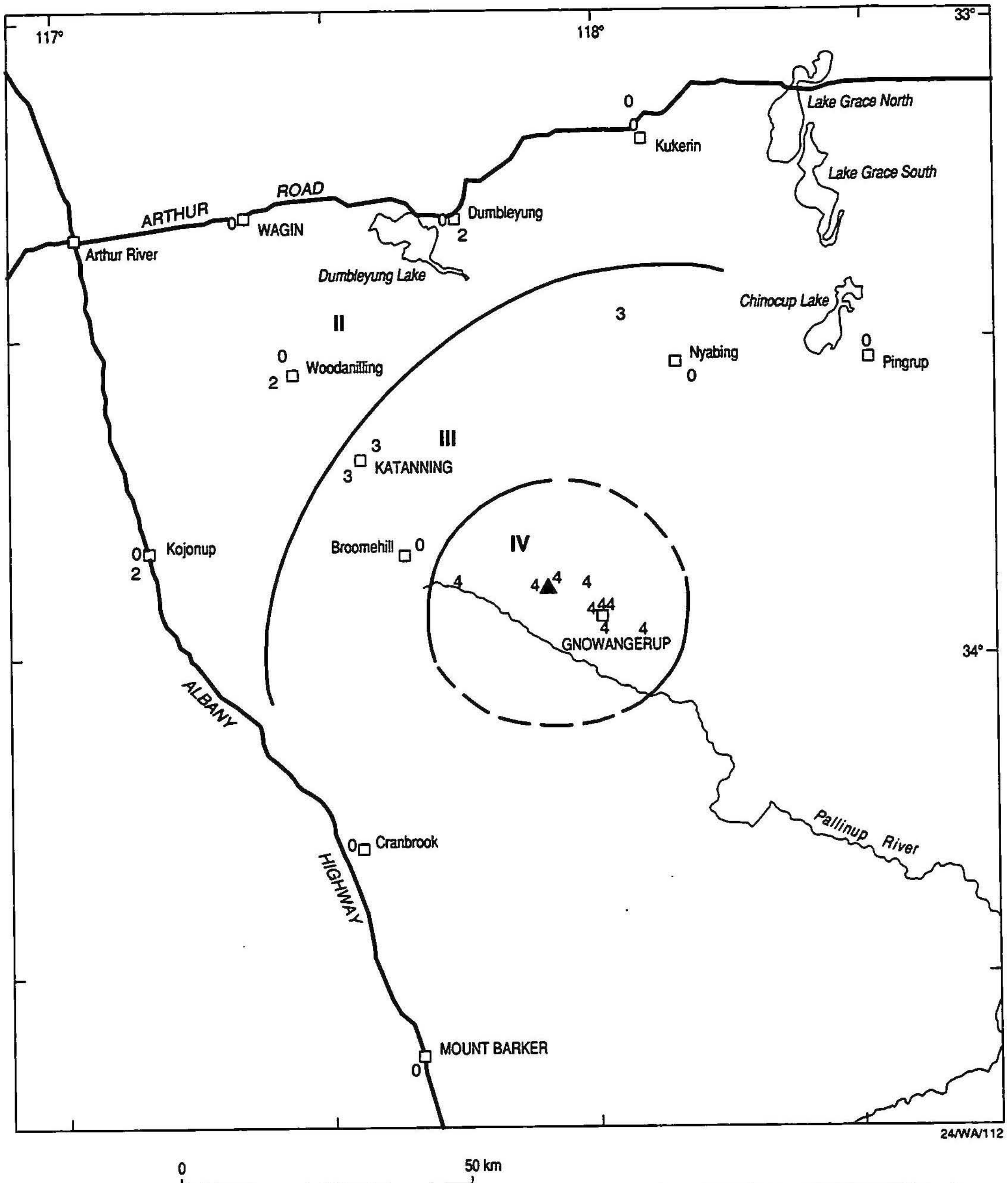
Isoseismal map of the Gnowangerup WA earthquake 26 October 1996

A large portion of the population of the small town of Gnowangerup, 300 km south-east of Perth WA experienced intensity MM IV shaking from a magnitude ML 3.7 earthquake which occurred at 4.54 p.m.(WST) on 26 October. The epicentre was located 9 km west of the townsite. Windows rattled and the noise was very loud.

The radius of the MM IV isoseismal was 12 km and the earthquake was felt 30 km south-west of Kojonup, 85 km from the epicentre.

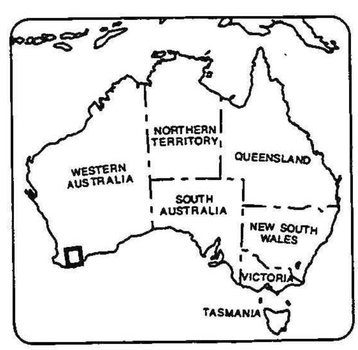
Peter Gregson

ISOSEISMAL MAP OF THE GNOWANGERUP EARTHQUAKE, WESTERN AUSTRALIA
26 OCTOBER 1996



DATE: 26 OCTOBER 1996
TIME: 08:54:37.3 UTC
MAGNITUDE: 3.7 ML (AGSO)
EPICENTRE: 33.9°S, 117.91°E

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



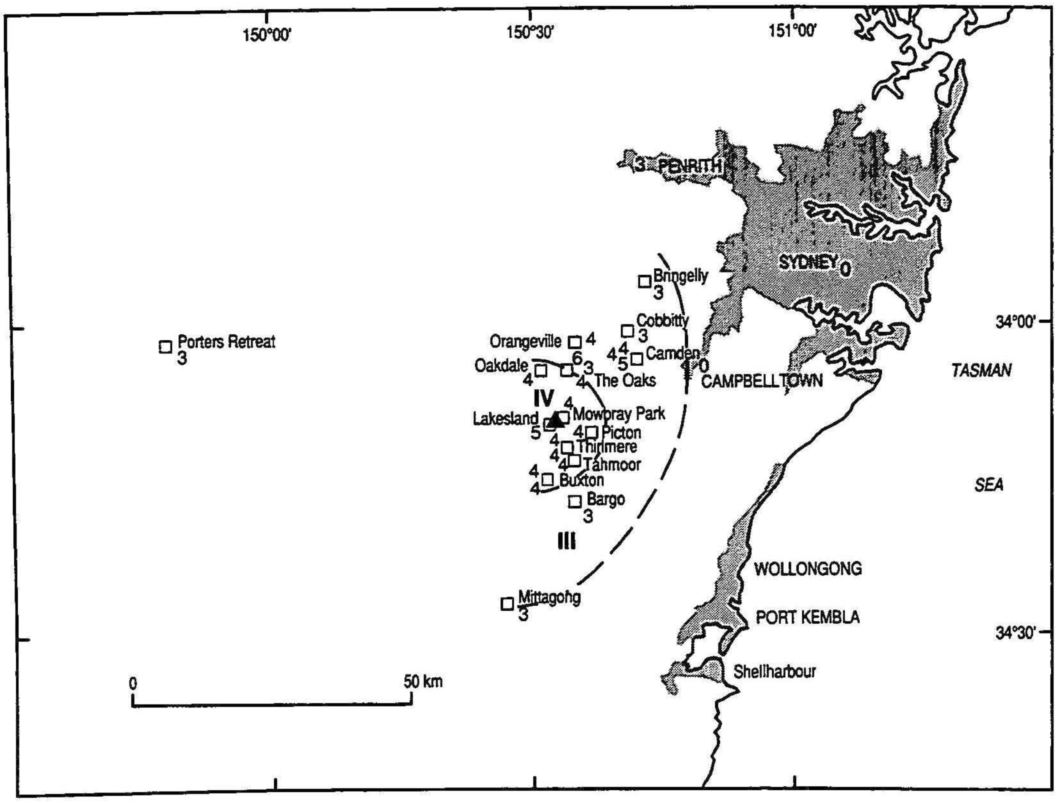
Isoseismal Map of the Picton NSW earthquake 10 December 1996

Two small earthquakes just four minutes apart and a few minutes before midnight ESST woke many people in the Picton area, callers likened the experience to a truck striking the house. Minor damage was reported at The Oaks, and at Cobbity and Oakdale about 50 km SW of Sydney.

Surprisingly the earthquake was felt at Porters retreat about 65 km west of the epicentre whereas no one reported it from Campbelltown less than 30 km to the northeast. It was not reported felt in Sydney or Wollongong but people rang from Penrith at a similar distance to enquire about the shaking they felt.

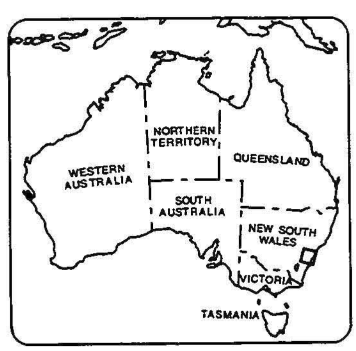
Kevin McCue and Lesley Hodgson

ISOSEISMAL MAP OF THE PICTON EARTHQUAKE, NSW
10 DECEMBER 1996



DATE: 10 December 1996
TIME: 12:54:26 UTC
MAGNITUDE: ML 3.3
EPICENTRE: 34.16° S 150.53° E
DEPTH: 5km (+/- 5km)

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



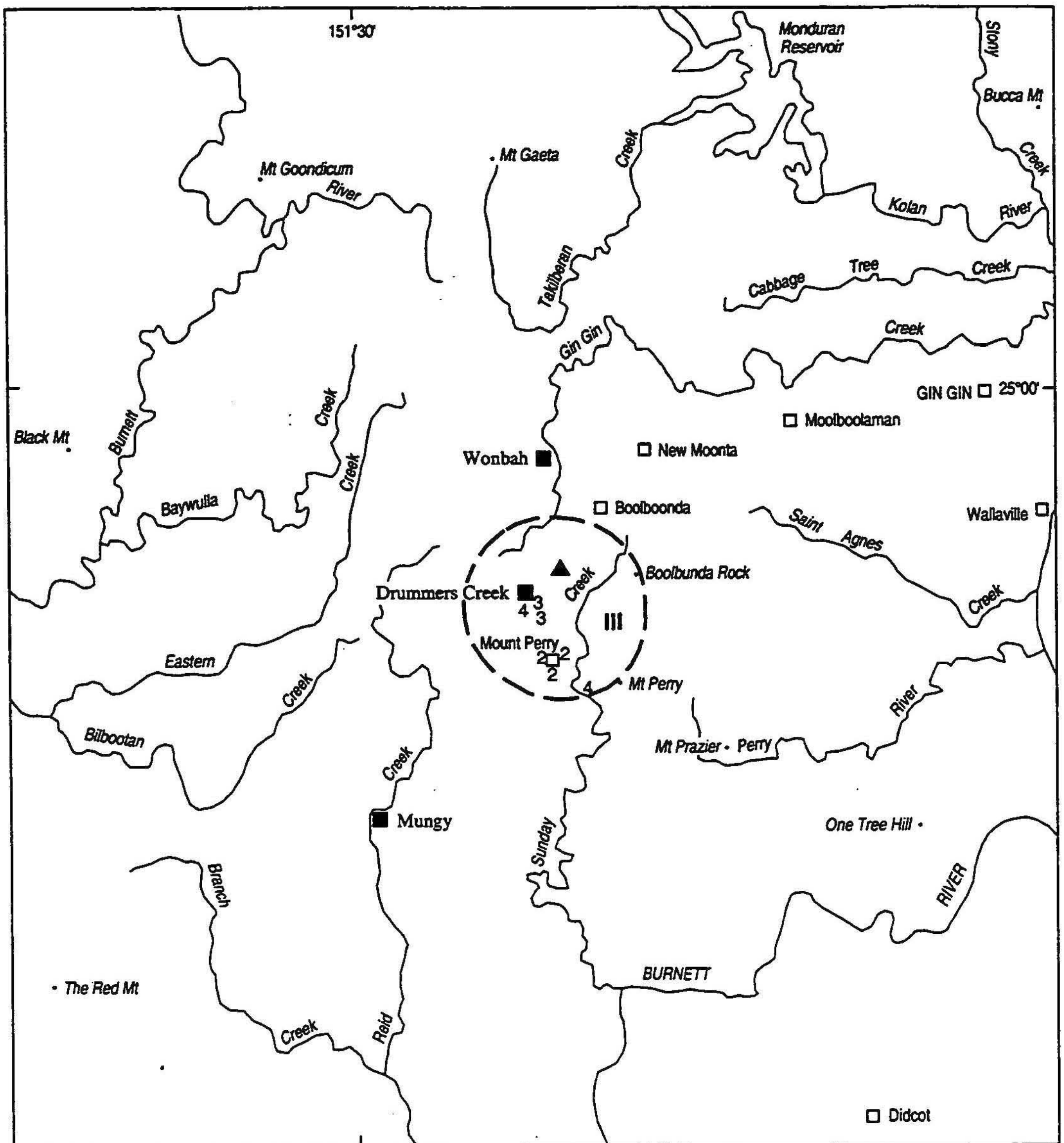
24/N/60

Isoseismal map of the Mt Perry Qld earthquake
26 December 1996

The Mt Perry tremor, at 1:20 pm on Boxing Day, produced a limited number of felt reports. An acceleration of 0.001g was produced on the nearby digital seismograph / accelerograph at Mt Perry, at an epicentral distance of 11 km.

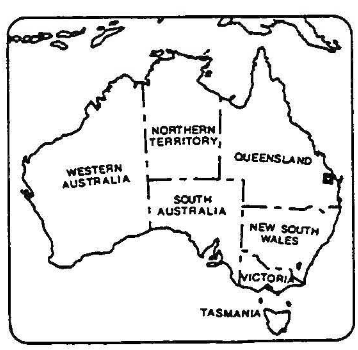
Russell Cuthbertson

ISOSEISMAL MAP OF THE MT PERRY EARTHQUAKE, QLD
26 DECEMBER 1996



DATE: 26 December 1996
TIME: 13:20:00 UTC
MAGNITUDE: 2.6 ML
EPICENTRE: 25.11°S 151.65°E

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



Appendix 2

GLOSSARY

In this report we refer to the *magnitude* of an earthquake and *intensity* caused by an earthquake, the terms are very different.

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.**Surface-wave magnitude (Ms)** The surface-wave magnitude was originally defined for shallow earthquakes in the distance range Δ=20–160°, and in the period range T = 17–23s. 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 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), Denham (1982), Everingham & others (1987), and Ambraseys and Free (1997).

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