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Earthquakes in the Canberra Region

Marion Leiba

SPATIAL INFORMATION FOR THE NATION

Earthquakes in the Canberra Region

Compiled December 2007

by

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Cover: Lake George escarpment. (Photos by Jim Mason)

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INTRODUCTION

This booklet is an update of Earthquakes in the Canberra Region published by the Australian Geological Survey Organisation (AGSO, now Geoscience Australia) and the ACT Emergency Services Bureau in 1996. As 10 years have passed since the previous booklet was published, it was considered appropriate to produce an updated version which includes the more recent earthquake activity in the ACT and surrounding region**.**

REGIONAL SETTING

The map of Australian earthquake epicentres (Figure 1) shows earthquakes from 1841-2001 with magnitudes of 3.0 or more on the Richter scale. Events of magnitude 4.0 or more are capable of causing damage to buildings. Canberra lies within a broad NE-SW trending belt of epicentres. The largest events recorded in this zone were of Richter magnitude ML 5.6, the same size as the December 1989 Newcastle earthquake. Small earthquakes occur under Canberra's suburbs but the nearest active seismic zone is 60 km north of Canberra in the Dalton – Gunning area, NSW.

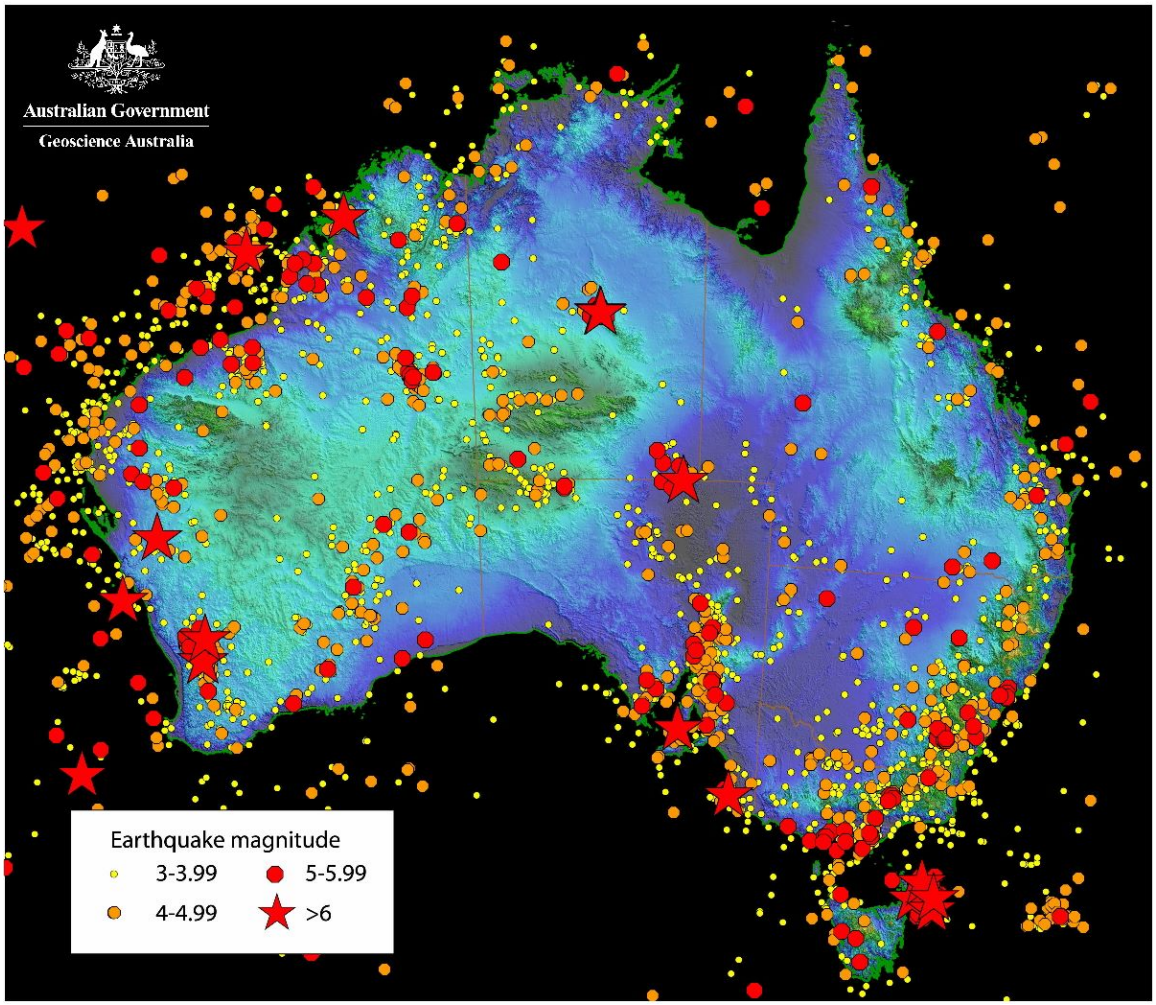

Figure 1. Epicentres of earthquakes with magnitudes of 3.0 or more on the Richter scale, 1841- 2001.

GEOLOGY OF THE CANBERRA REGION

The rocks of the Canberra region are mainly metamorphosed Middle to Late Ordovician sedimentary and Silurian igneous and sedimentary rocks, ranging in age from about 408-468 million years. They have been subjected to several periods of reverse faulting, that is, the lower older rocks were thrust up and over the younger ones, on north-south faults, some of which may be as old as the Late Silurian.

Folding and faulting occurred in the mid Devonian (around 380 million years ago) and again in the post mid-Devonian to Carboniferous (about 350 million years ago). As mentioned above, the earlier faults trended north-south, whereas later faults trended NE and NW. Both sets were caused by east-west compression. Rejuvenation of the north-south faults commenced during uplift in the Miocene, approximately 20 million years ago, and this initiated escarpments such as that at Lake George. Minor earthquake activity has continued in the region. The geology of the Canberra region is summarised in the publication by Abell (1992).

The major faults in the region are shown in Figure 2. The one best known to most Canberrans is the Lake George Fault. Its scarp has eroded back approximately 0.5 km from its original position near the western edge of the lake, but it is still a spectacular topographic feature (Figure 14).

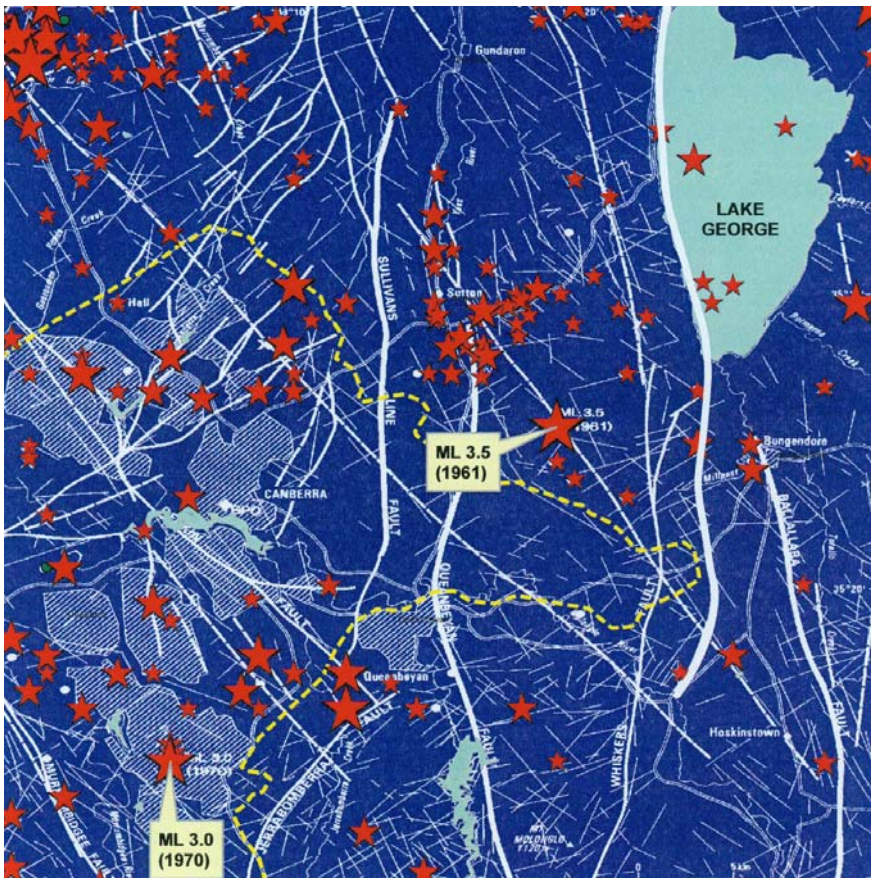

Figure 2. Faults, lineaments and earthquake epicentres in the Canberra region.

LOCAL CANBERRA EARTHQUAKES

Canberra is occasionally shaken by earthquakes in the surrounding region, particularly in the Dalton-Gunning zone (see later), but Canberra also has its own earthquakes (Leiba, 1993, 1994). Earthquakes which have been recorded within a radius of 20 km of the Canberra GPO are shown in Figure 3. The more recent of these that have occurred between 1996 and November 2007 within this area are listed in Table 1.

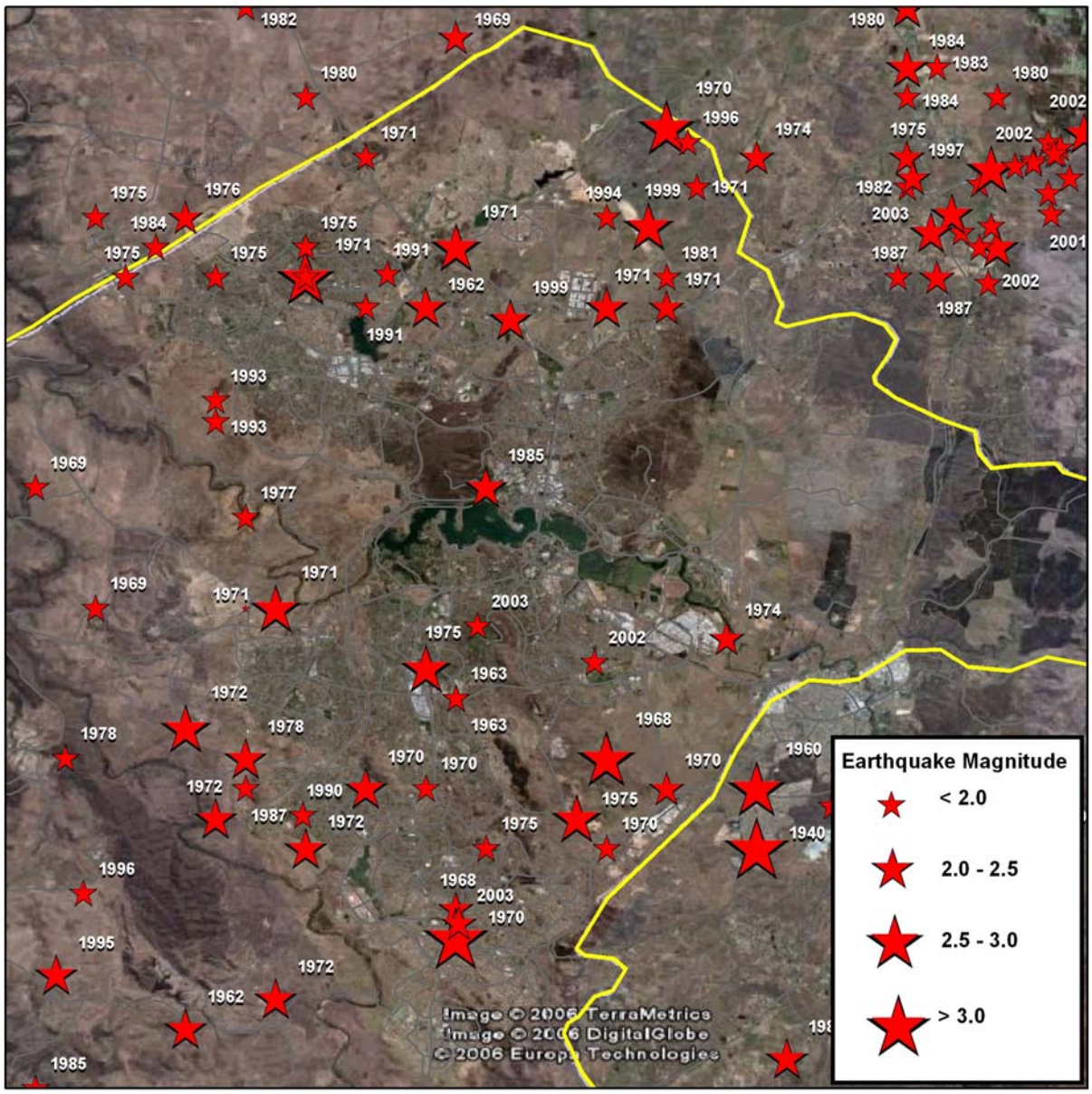

Figure 3. Earthquakes within 20 km of the Canberra GPO recorded up to November 2007.

Table 1. Earthquakes within a square with sides 20 km from the Canberra GPO, for the period 1996 – November 2007.

DATE	TIME(UTC)	LAT	LON	DEPTH	MAG	COMMENTS
19960410	234524.2	-35.165	149.177	0.0	1.7	7 km W of Sutton NSW. Heard.
19960620	201615.8	-35.171	149.292	4.0	1.0	Sutton NSW.
19960625	152218.0	-35.415	148.976	5.0	1.2	Tidbinbilla ACT. Heard.
19971021	160634.8	-35.177	149.252	4.0	2.0	Sutton NSW
19990618	64034.9	-35.224	149.118	0.0	2.4	Kaleen/ Gungahlin ACT. Felt.
19990621	135935.9	-35.193	149.164	7.0	2.5	Mitchell/Gungahlin ACT. Felt.
20010919	150120.1	-35.189	149.298	NULL	1.8	Sutton NSW
20011227	152327.3	-35.155	149.341	5.0	1.9	Sutton NSW. Felt.
20020114	102853.02	-35.165	149.322	0.0	1.6	Sutton NSW. Felt.
20020116	133952.6	-35.182	149.329	0.0	1.5	Sutton NSW. Felt.
20020120	94253.72	-35.169	149.299	0.0	1.8	Sutton NSW. Felt.
20020123	24412.1	-35.162	149.309	0.0	2.3	Sutton NSW.
20020123	90047.3	-35.174	149.278	0.0	2.5	Sutton NSW. Felt.
20020129	14720.5	-35.193	149.278	1.6	1.5	Sutton NSW. Felt.
20020129	133946.7	-35.177	149.304	0.0	1.4	Sutton NSW.
20020129	160154.5	-35.172	149.292	0.0	1.7	Sutton NSW.
20020131	165506.5	-35.179	149.274	0.9	1.3	Sutton NSW.
20020201	193500.8	-35.169	149.3	0.0	1.4	Sutton, NSW.
20020202	70705.76	-35.189	149.265	1.3	2.2	Sutton, NSW. Felt.
20020313	210008.6	-35.212	149.277	2.7	1.2	Sutton NSW.
20020418	5155.55	-35.167	149.301	0.0	1.7	Sutton NSW. Felt.
20020810	151947.28	-35.195	149.268	2.9	1.3	Sutton NSW.
20020813	45106.06	-35.2	149.274	1.7	1.4	Sutton NSW. Felt
20021202	20804.19	-35.386	149.225	3.9	1.8	Sutton NSW.
20021202	63017.18	-35.182	149.297	0.5	1.9	Sutton NSW.
20021203	12149.82	-35.338	149.146	4.4	1.5	Sutton NSW.
20030612	62857.32	-35.425	149.101	5.5	2.0	Tuggeranong ACT. Felt.
20030705	34824.58	-35.195	149.258	0.0	2.4	Sutton NSW. Felt.
20030705	112016.75	-35.173	149.286	2.4	1.4	Sutton NSW.
20031003	222509.58	-35.299	149.085	2.3	1.4	Yarralumla ACT. Felt.
20060120	22001.7	-35.396	149.278	10.8	1.4	SE of Queanbeyan NSW.

The data have been obtained largely by cooperation between Geoscience Australia and the Research School of Earth Sciences at the Australian National University (ANU). Three seismographs in the ACT and a number of others, run by either ANU or Geoscience Australia, in neighbouring parts of NSW were used to determine the locations of Canberra region earthquakes as small as magnitude 1.0 or occasionally lower. ANU installed the first ACT seismograph, at Mt Stromlo, in 1958. Others in the Canberra region followed in 1959. Geoscience Australia's at East Kowen Forest and Kambah were installed in 1979 and December 1985 respectively. The ANU network of seismographs in southeastern

NSW, which was useful for more accurately determining the epicentres of very small earthquakes in the Canberra region, was closed around the year 2000. The epicentres of larger earthquakes, with magnitudes of 2.5 or above, can be located using more distant seismographs run by Geoscience Australia or other organisations (Figure 4a), so are not as dependant on a sensitive local network of seismographs..

At present (December 2007) there are three seismographs in the ACT with readily accessible data for determining the locations of Canberra earthquakes. The Canberra seismograph (CNB) at East Kowen Forest near Bungendore is a digital instrument. Its data is displayed and analysed readily and accurately using a computer. Since 2001, the Kambah seismograph (KBH) has been privately owned by Marion Leiba. It is an old analogue seismograph (1970s technology), recording data in ink on paper wrapped around a rotating drum (Figure 4b). Measurements are made using a ruler and hand lens. A third ACT seismograph run by the Australian National University at Mt Stromlo that is part of a worldwide network (Geonet) of digital seismograph stations, and the data from this are available on line to Geoscience Australia on line in late 2006.

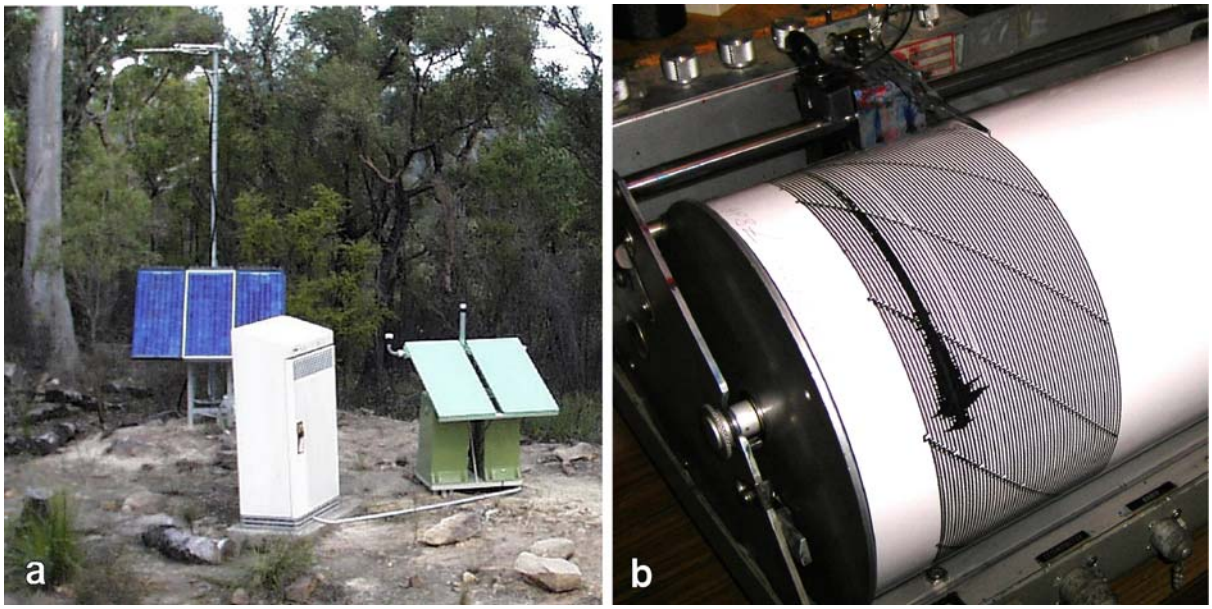

Figure 4. (a) A telemetred digital station of the Australian National Sesimograph Network operated by Geoscience Australia at Mangrove Creek. (b) Analogue seismograph in Kambah, ACT operated by Marion Leiba recording the Magnitude 3.3 Oolong earthquake that occurred at 11.30 pm on 13 August 2006.

Geoscience Australia's digital seismographs at Young, Mangrove Creek Dam (near Gosford), and near Bemboka are used, along with the ACT seismographs, for determining the locations of Canberra region earthquakes with magnitudes as small as 1.4, or occasionally lower.

Largest earthquakes within 20 km of Canberra GPO

The two largest earthquakes within 20 km of the GPO, since the installation of the ANU recorder, occurred on 9 February 1961 and 25 April 1970 (local dates) and had Richter magnitudes ML 3.5 and 3.0 respectively. Both were reported in the press.

The Canberra Times of 9 February 1961 noted that "a slight earth tremor shook Canberra early this morning, waking many residents. At the height of the tremor crockery on shelves rattled, pictures shifted on walls and windows were shaken". It occurred at 4.56 am local time. "Residents described it as 'like a long clap of thunder'. It could be heard approaching the city and later moving away". Its epicentre was south of Sutton and 18 km ENE of the Canberra GPO; no damage was reported.

The earthquake at 8.54 pm local time on 25 April 1970 was mentioned in the Canberra Times of 27 April. It stated that "an earth tremor over a wide area of the ACT on Saturday night caused houses to sway slightly and shook crockery and ornaments. A low rumbling accompanied the tremor" which was reported to be felt at Belconnen, Garran, Narrabundah, Naas and Williamsdale. The epicentre was at Tuggeranong.

Frequency of occurrence of earthquakes within 20 km of Canberra GPO

Seventy-two earthquakes occurred within 20 km of the GPO in the 36 years prior to the end of 1995, and during this period yearly numbers varied between zero and nine with a mean number of 2.0. During the period January 1996 to November 2007, 30 earthquakes with Richter magnitudes 1.0-2.5 occurred within this same area, giving a mean number of 2.5 earthquakes per year. Yearly numbers varied between 0 in 1998, 2000, 2004 and 2005 and a maximum of 18 in 2002 when a swarm of earthquakes occurred at Sutton. The epicentres of these earthquakes (except the June 1996 Tidbinbilla ACT event which is outside the Canberra map sheet) are shown in Figure 3 .

These earthquakes include foreshocks and aftershocks, which either precede or follow larger earthquakes, and which may be considered as part of the one event (the 'main shock') . When foreshocks and aftershocks are excluded, there were 47 main shocks in the 36 years to the end of 1995 - a mean of 1.3 per year, with yearly numbers ranging from zero to six. Between 1 January 1996 and 30 November 2007, there were 15 main shocks, a mean of 1.3 per year with yearly numbers varying between zero and five.

In summary, the ***mean level of earthquake activity*** in Canberra has changed little in the past 10 years from that in the previous 36 years. Looking at the data for the past 40-50 years, o*n average*, one can expect 1-2 main shocks per year within 20 km of the Canberra GPO, or 2-3 earthquakes per year if foreshocks and aftershocks are included.

Actual (not average) yearly numbers of earthquakes are highly variable - anything in the range 0-18, or 0-6 if foreshocks and aftershocks are excluded, is likely.

Heard or felt earthquakes, 1982 - 1995

Most of the Canberra events are very shallow, at depths of 0-15 km beneath the Earth's surface. Consequently, seven of these little earthquakes were reported heard or felt, and are described below.

A magnitude ML 2.4 earthquake, the largest in metropolitan Canberra during this period, occurred at 7.51 am Eastern Australian Summer Time on 29 November 1985. The epicentre, shown in Figure 5, was in the Turner-Black Mountain area, where the earthquake was felt strongly. The numbers on the map are intensities on the Modified Mercalli (MM) Scale (Appendix 1).

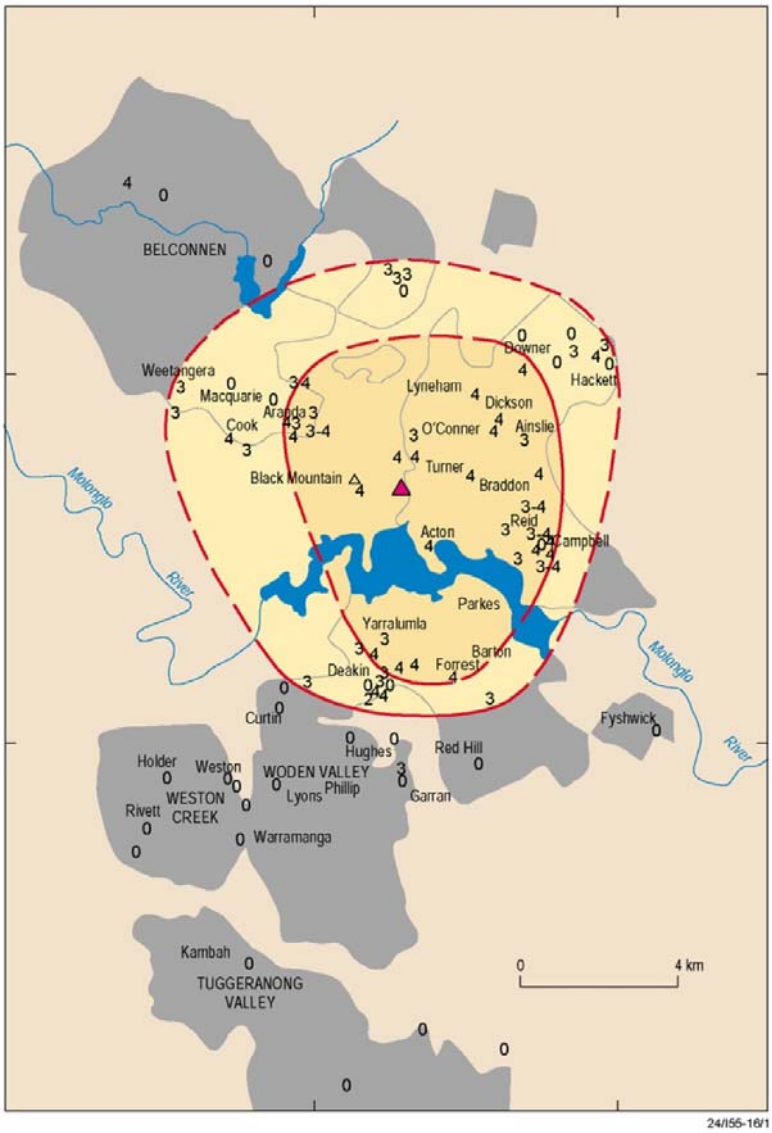

Figure 5. Isoseismal map of the Canberra earthquake, magnitude ML 2.4, of 29 November 1985 (local date). The red triangle is the epicentre. Reported MM intensity values and isoseismal contours are shown; intensity values of 0 indicate the earthquake was not felt.

At 2.07 am Eastern Australian Summer Time on 3 December 1990 a very small earthquake occurred under the western part of Kambah. It was well recorded (Figure 6) on the Kambah seismograph, KBH, 3 km from the epicentre. An appeal made through the local media, who were quite excited by this small earthquake (Michael-Leiba, 1990), resulted in felt reports that are plotted on the isoseismal map (Figure 7) in MM intensity units.

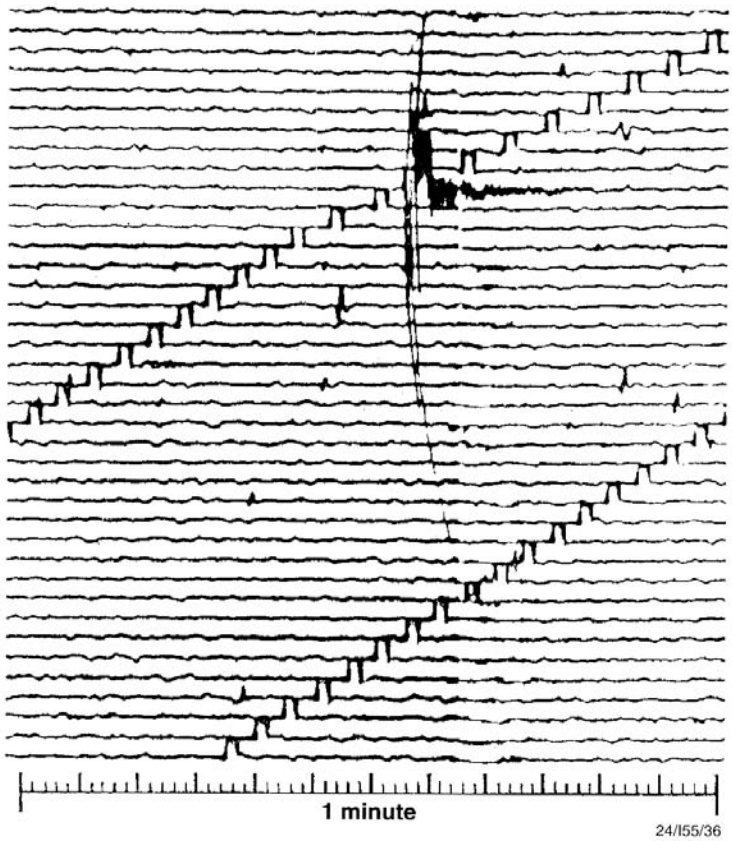

Figure 6. Seismogram of the Kambah earthquake of 3 December 1990 (local date). The Kambah seismograph that recorded this was 3 km from the epicentre.

The three observers nearest to the earthquake described it as an explosion which shook the house, or an enormous bang. The other three Kambah observers were about 3 km from the epicentre. One awoke suddenly, another experienced a deep huge boom which went right through her body, and the third was disturbed by his dog howling (a very unusual occurrence for this geriatric Pekingese) half to one minute before he felt a shudder. The magnitude of this earthquake is only MD 1.2. MD is the duration magnitude, an approximation for the Richter magnitude ML derived from the maximum amplitude of the oscillations on the seismogram.

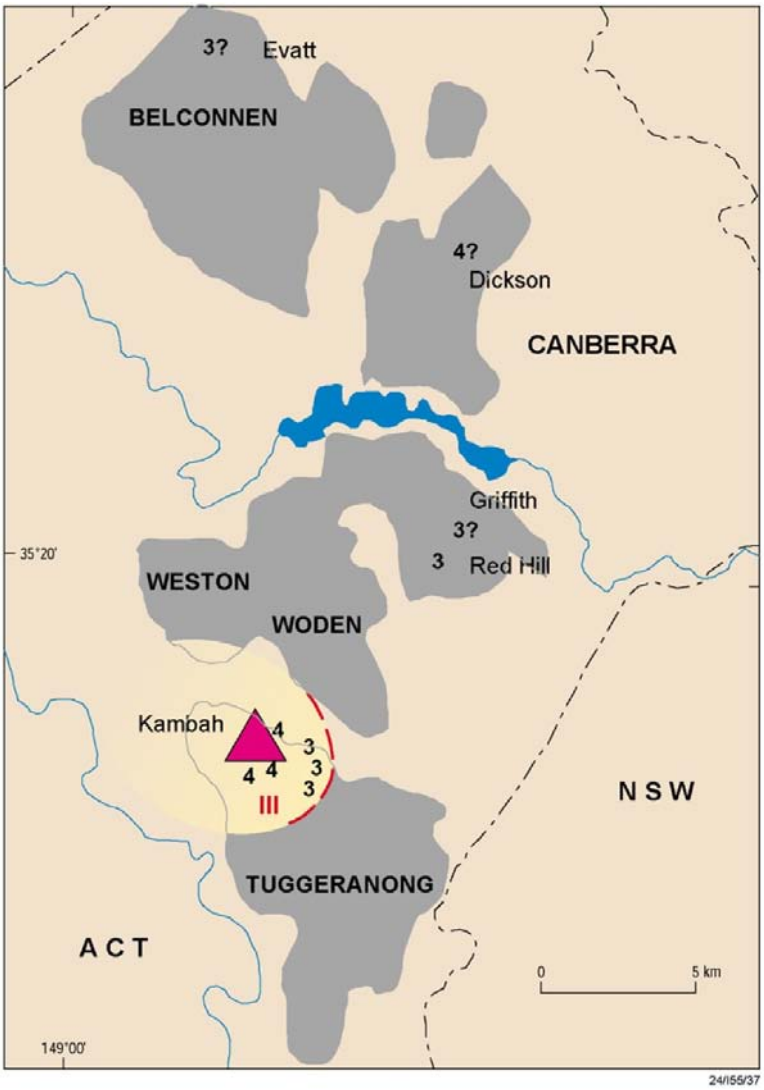

Figure 7. Isoseismal map of the magnitude MD 1.2 Kambah earthquake of 3 December 1990 (local date). The red triangle is the epicentre. Reported MM intensity values and isoseismal contours are shown.

An earthquake in Evatt woke people at 1.29 am local time on 21 July 1991. It was described as sounding like an "explosion" and the "whole house shook". The magnitude of this microearthquake was MD 1.3. On the isoseismal map (Figure 8, compiled by Marion Leiba), the epicentre is shown as a triangle and the numbers are MM intensities.

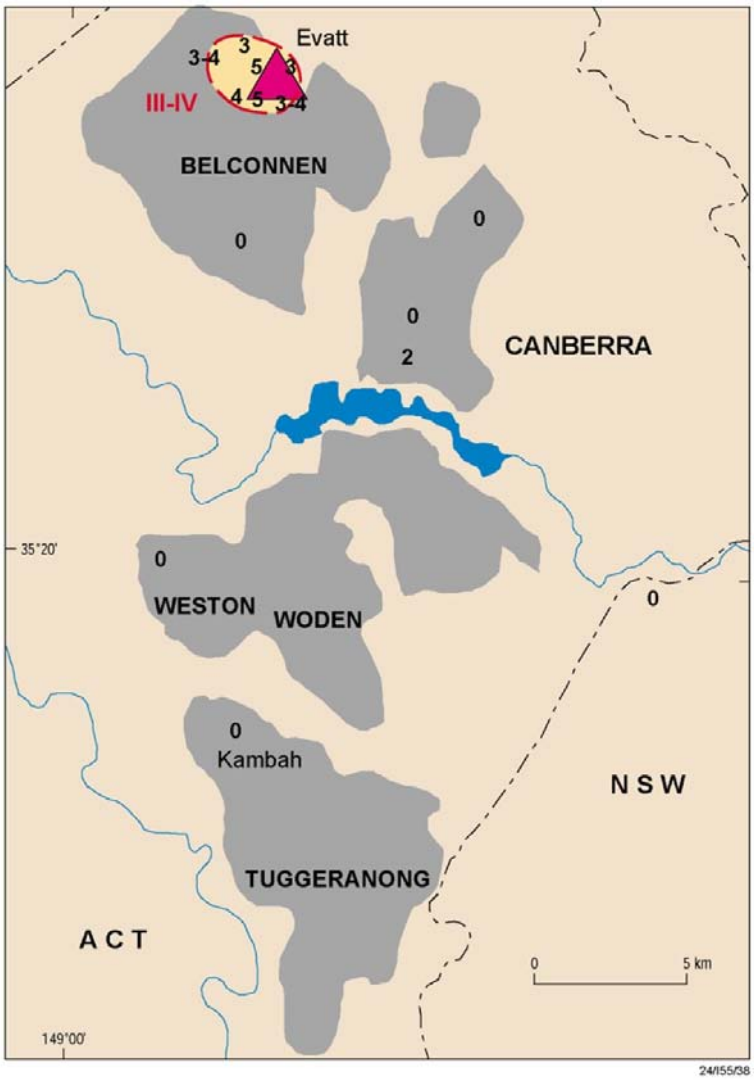

Figure 8. Isoseismal map of the magnitude MD 1.3 Evatt earthquake of 21 July 1991 (local date). The red triangle is the epicentre. Reported MM intensity values and isoseismal contours are shown; intensity values of 0 indicate the earthquake was not felt.

At 7.34 pm local time on 10 August 1991, a small earthquake occurred under a horse racing stud at Burbong, 20 km ESE of the Canberra GPO. Having a magnitude of only MD 1.0, it was heard by the owners of the stud, but not felt. They thought it was blasting.

Two events occurred under the suburb of Hawker, 10 km WNW of the GPO, on 28 July 1993.at 9.53 and 10.00 pm Eastern Australian Standard Time. The magnitudes of these events were MD 1.3 and 1.4. The first earthquake was heard as a muffled explosion at Hawker. People near the epicentre ran outside to investigate because they thought it might have been the work of a letterbox bomber who had been active there recently. The second shook houses and rattled things, convincing residents that both events were indeed earthquakes and not the work of vandals! It was felt in the suburbs of Hawker, Scullin and Higgins but the intensity with which it was experienced varied from not felt to one report of things being shaken off shelves. These two earthquakes were clearly related, the first being a foreshock to the second.

On 6 September 1994 at 11.44 pm local time a magnitude MD 1.6 earthquake occurred at Gungahlin, 10 km NNE of the Canberra GPO. The isoseismal map (compiled by Marion Leiba and Trevor Jones) is shown in Figure 9. Near the epicentre it sounded like an explosion. It was reported felt to the west over a radius of about 12 km. There was an isolated felt report from Gordon, 31 km SSW of the epicentre.

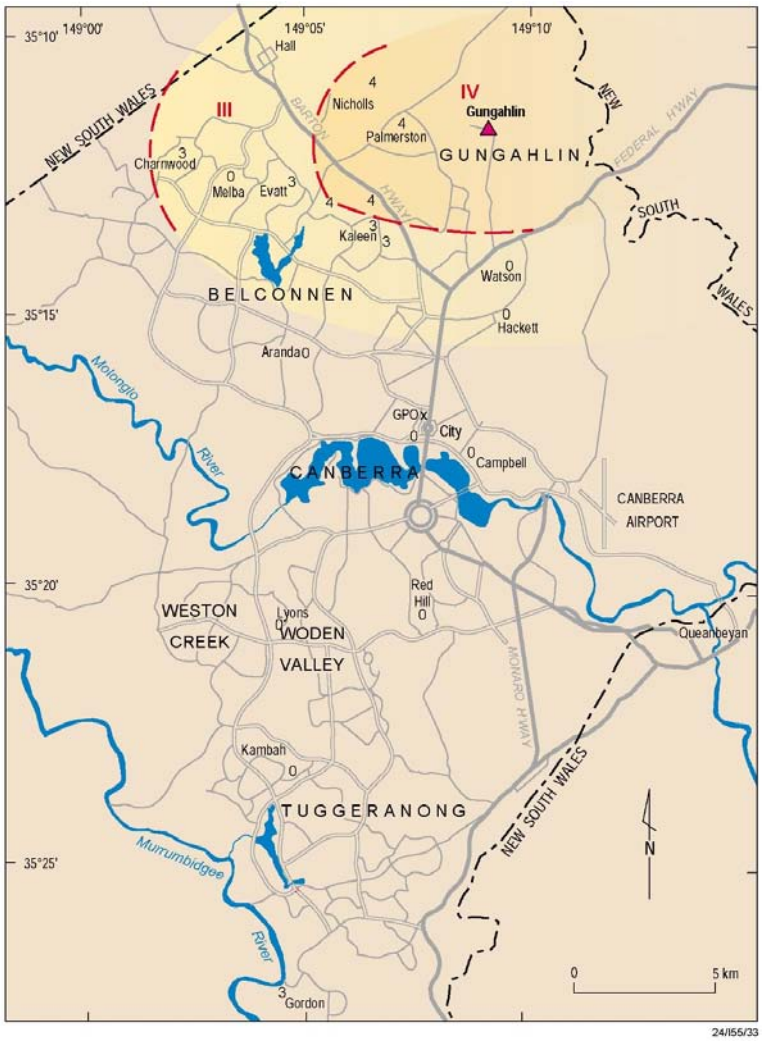

Figure 9. Isoseismal map of the magnitude MD 1.6 Gungahlin earthquake of 6 September 1994. The red triangle is the epicentre. Reported MM intensity values and isoseismal contours are shown; intensity values of 0 indicate the earthquake was not felt.

In 1995, two Canberra region earthquakes were felt in the ACT.

The first was in the Brindabella Range, 40 km west of the Canberra GPO. It happened at 3.20 am local time on 3 January 1995 and was the largest event in nine years within 45 km of the GPO. Its magnitude was ML 2.5. It was reported felt in Kambah and Curtin and heard in Watson, Lyons and Deakin.

The second was at 7.10 pm local time on 10 October 1995 and its epicentre was near Birrigai Camp and Tidbinbilla Nature Reserve, 23 km SSW of the Canberra GPO. Its magnitude was MD 2.0, making it the largest earthquake within 25 km of the GPO since the Black Mountain earthquake in November 1985. At Birrigai Camp, it was heard as a loud explosion, felt very strongly and made things rattle inside. Outside, it was felt by a

teacher and children camping. The Canberra Times of 12 October 1995 said that "David Dwyer, one of the three rangers living in a 100-year-old house on the Tidbinbilla Nature Reserve, said the earthquake sounded like a person running along the ceiling."

Heard or felt earthquakes, January 1996 – November 2007

This section excludes earthquakes in the Sutton and Dalton-Gunning areas because they are discussed later.

In 1996, three earthquakes were heard or felt in the ACT. The first was a magnitude ML 3.6 earthquake at 6.34 am daylight saving time on 19 February 1996 with an epicentre about 10 km east of Eucumbene. It was reported heard and felt in Canberra, about 100 km NE of the epicentre. Felt reports came from the following suburbs of Canberra:

Theodore: *Felt by people dozing. The bedroom and windows shook and it opened the front door.*
Chifley: *Windows rattled.*
Caldwell: *Woke person sleeping lightly. She felt it. It sounded like a soft explosion and windows shook.*
Red Hill: *It felt like a heavy truck passing and the windows rattled.*
Duffy: *People heard two distinct rumbles that sounded like a garage door being taken up and then down. Then the house shook and they felt it.*
Conder: *House creaked.*

At 1.22 am on 26 June 1996 a magnitude MD 1.2 earthquake occurred 20 km SW of the Canberra GPO. Its epicentre was near the Tidbinbilla Nature Reserve and it was heard 7 km SW of the epicentre as a deep rumbling sound like a passing aircraft but lasting only a short time.

At 5.23 am local time on 15 February 1998, a magnitude ML 4.2 earthquake occurred in the Brindabella Mountains, near Brindabella Homestead. The report and isoseismal map (Figure 10) were compiled by Kevin McCue, who stated that the "few residents of homesteads in the Brindabella Mountains were reportedly shaken out of their beds; at Argalong Station a window was broken and minor non-structural cracking of the walls of an outhouse was reported. The noise of things shaking woke many Canberra and Tumut residents and at Burrinjuck Dam the shaking woke most people. It was felt as far away as Harden-Murrumburrah to the northwest and Cooma to the south. A bushwalker and his family camped at the summit of Mt Gingera were surprised by the intensity of shaking," frightening the children.

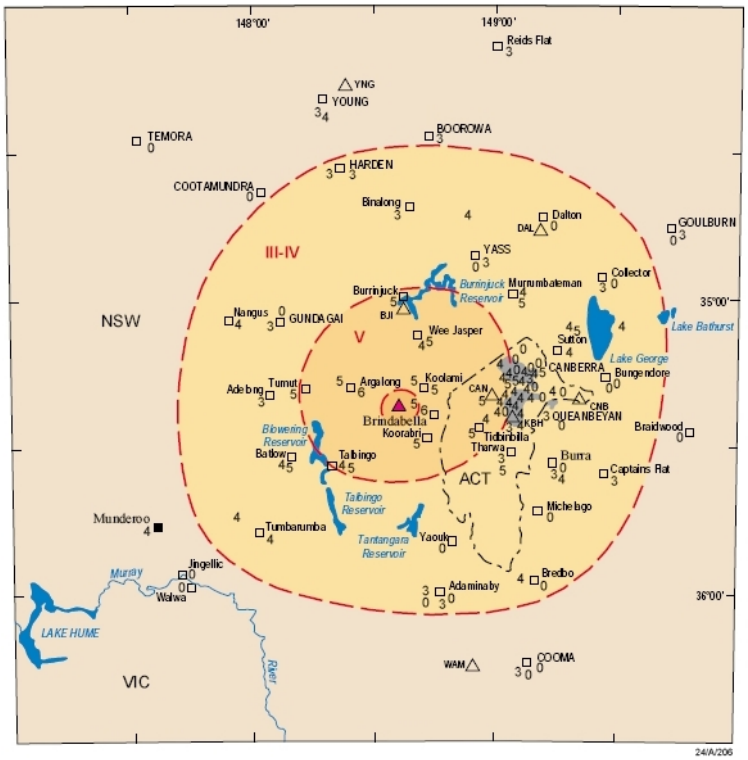

Figure 10. Isoseismal map of the magnitude ML 4.2 Brindabella NSW earthquake of 15 February 1998 (local date). Open triangles are seismographs, the red triangle is the epicentre. Reported MM intensity values and isoseismal contours are shown; intensity values of 0 indicate the earthquake was not felt.

On 19 August 1998 at 9.12 pm local time, a magnitude ML 3.0 earthquake occurred in the Orroral Valley, Namadgi National Park, ACT, approximately 43 km SSW of the Canberra GPO and 19 km SSW of Tharwa. Its epicentre was just west of the 1:100,000 Canberra map sheet area (Figure 2). The report and isoseismal map (Figure 11) for this earthquake were compiled by Y Li and Andrew McEwin.

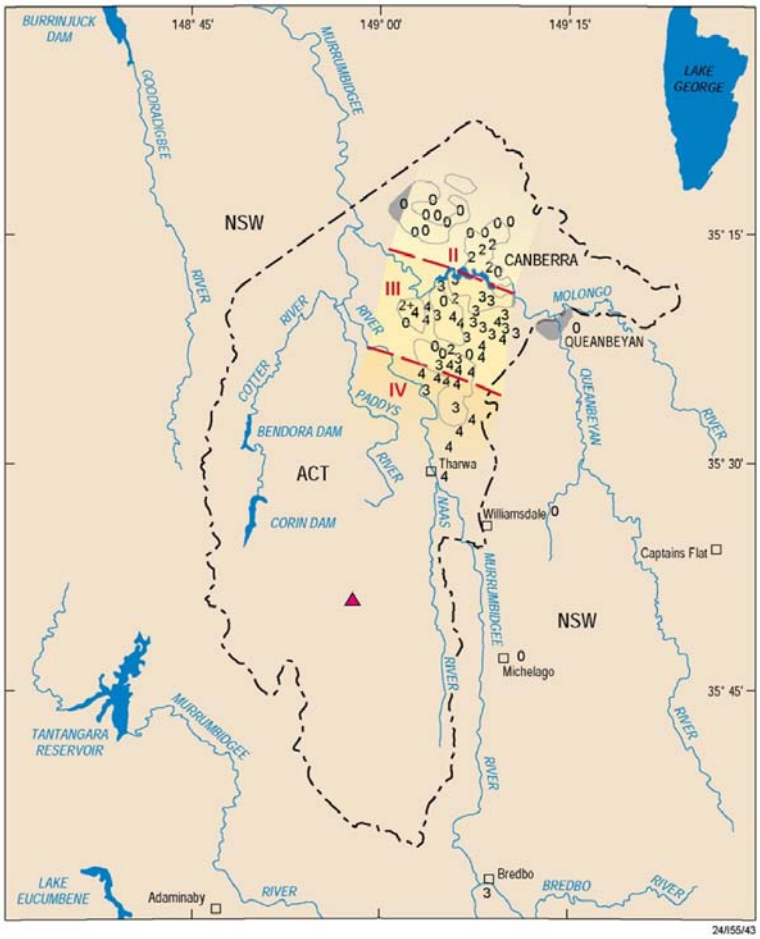

Figure 11. Isoseismal map of the magnitude ML 3.0 Orroral Valley earthquake of 19 August 1998. The red triangle is the epicentre. Reported MM intensity values and isoseismal contours are shown; intensity values of 0 indicate the earthquake was not felt.

Despite its remote location, the earthquake was felt weakly by a few people in the innermost North Canberra suburbs and strongly, although briefly, by some in the southern suburbs, where alarmed Garran residents apparently ran out into the street. Li and McEwin summarised a selection of the approximately 100 reports as follows:

Kambah: *Felt by all in the house, windows rattled, strong vibrations felt within the house. Also heard loud, rumbling sound.*
Curtin: *Felt by all five of us and sounded like a low rumble as if a very large truck was going past.*
Gordon: *We heard it coming then it shook the house but the windows didn't rattle, the furniture, book shelf did.*
Wanniassa: *Huge 20 sec shudder – the ground vibrated and made a thundering noise, wasn't aware of the windows rattling but my daughter's bed shook.*
Tharwa: *Heard then felt big rumble, everything rattled, foundations shook.*

On 31 December 1998, a magnitude ML 3.2 earthquake occurred at 5.11 pm local time between Bredbo and Michelago, just east of the ACT border. Although it was felt most strongly east of the ACT from Burra to Bredbo, there were a number of felt reports from the southern part of Canberra and from Cooma. The report and isoseismal map (Figure 12) were compiled by Kevin McCue.

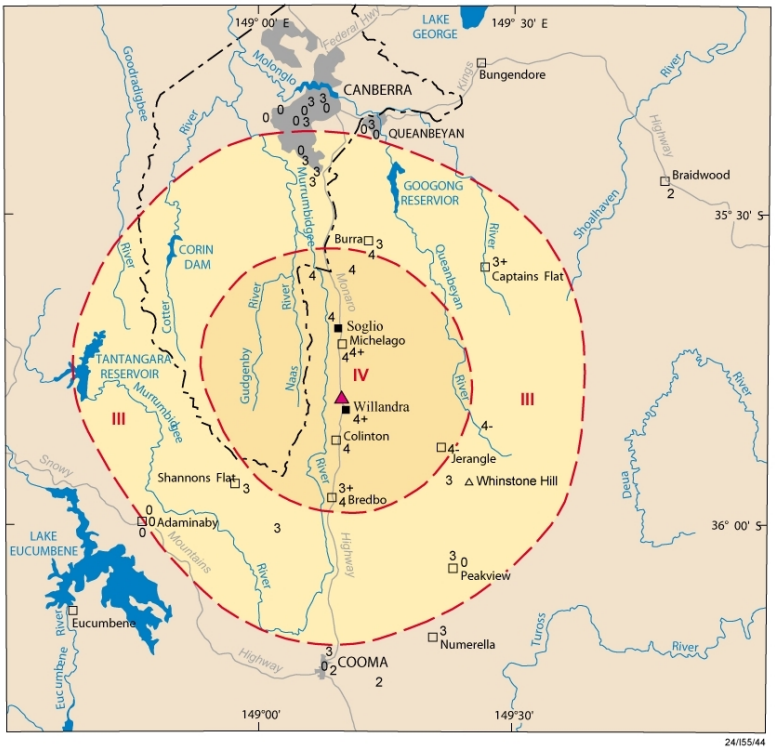

Figure 12. Isoseismal map of the magnitude Ml 3.2 Michelago NSW earthquake of 31 December 1998.

In 1999, two earthquakes, only three days apart were felt in Canberra.

The first, at 4.40 pm local time on 18 June 1999, with an epicentre in northwestern Kaleen near the boundary with Gungahlin, was felt in Giralang. Its magnitude was ML 2.4.

The second, a magnitude ML 2.5 event at 11.59 pm on 21 June 1999, with an epicentre northeast of Mitchell, was felt in Gungahlin, Belconnen, and North Canberra, as well as in Sutton and Queanbeyan (Figure 13). The isoseismal map and report on the earthquake were compiled by Andrew McEwin, Y Li, and Kevin McCue. They quote the following email report from a Gungahlin resident:

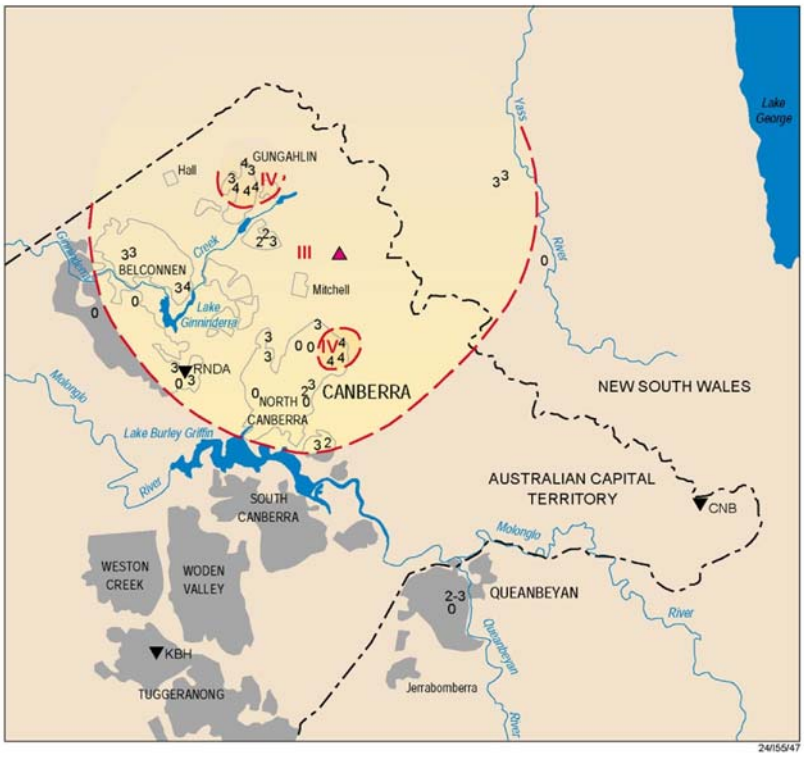

Figure 13. Isoseismal map of the magnitude ML 2.5 Gungahlin earthquake of 21 June 1999 The red triangle is the epicentre. Reported MM intensity values and isoseismal contours are shown; intensity values of 0 indicate the earthquake was not felt.

I was in bed in that state of relaxed bliss that precedes the onset of sleep, when a loud somewhat muffled noise caused me to sit bolt upright. The house shook momentarily and the glass in the windows of my bedroom rattled in its frame. My first thought was that my house was a road-rage target or that a ham-fisted burglar was breaking into my house. The possibility of an earthquake also passed through my mind. I looked at my watch: spot on the witching hour; 'It must be a paranormal phenomenon", I thought. I got up and checked the front door of the house and the door to the garage. Nothing amiss was apparent. 'Bloody earthquake', I thought and returned to bed.

McEwin, Li and McCue also note that "in Aranda, one person lying in bed reading thought that a large possom was jumping on the deck but resolved that it must have been an earthquake because possoms aren't that big. A neighbouring sleeping seismologist was not awakened."

At 11.20 am local time on 23 October 2000, a magnitude ML 2.9 earthquake occurred near Bendoora Dam, about 20 km west of Kambah. It was felt at several localities, including Bonython, Evatt and Theodore.

The next Canberra earthquake to be felt, happened at 4.28 pm on 12 June 2003. It had a Richter magnitude of 2.0. The epicentre was in Tuggeranong and it was reported felt in Kambah, Gordon, Calwell, Isabella Plains, Monash and Conder. It was heard at Derrington Crescent, Bonython, as a very loud explosion followed by a smaller bang. It is probable that the epicentre was in or near Bonython. The smaller bang may have been a

little aftershock immediately following the main shock. In Conder, it was heard as a quick boom and the "walls vibrated and thudded".

On 4 October 2003 at 8.25 am local time, a magnitude ML 1.4 earthquake in Yarralumla was felt by many residents in the inner southern suburbs of Canberra. In Yarralumla and Deakin it gave the impression of a small explosion and windows rattled. In Garran it was experienced as a sharp, single shake accompanied by quite a loud noise like a blast. However, at one locality in Norman Street, Deakin, the earthquake was experienced more spectacularly. The resident reported a "massive" explosion during which the whole house shook, windows rattled violently, the front door opened, and the TV, small tables and ornaments all moved. Even the dogs stopped barking for a minute.

Earthquakes in the Sutton area, January 1996 – November 2007

Small earthquakes in the vicinity of Sutton are not uncommon, and because of increased activity (an "earthquake swarm") during this period, Sutton earthquakes are discussed separately in this section. However, for the first part of the decade, activity was not high.

In 1996, two earthquakes occurred in the Sutton area.

On 11 April 1996 at 9.45 am local time, a magnitude 1.7 earthquake, 7 km west of Sutton and about 14 km NNE of the Canberra GPO, was heard near the epicentre as a loud explosion. It was also heard at Deakin.

The second earthquake happened at 6.16 am local time on 21 June 1996 and had a magnitude of 1.0. Its epicentre was 4 km east of Sutton and 20 km northeast of the Canberra GPO. It probably was too small and too early in the morning for residents to have felt it, and no reports were received.

Geoscience Australia's earthquake database has records of only one other Sutton earthquake before the start of the swarm activity. It was a magnitude ML 2.0 event at 2.06 am local time on 22 October 1997. It was not reported felt, presumbly because people were asleep.

The Sutton earthquake swarm started in September 2001 and continued until December 2002. The earthquake database has records of 21 earthquakes with magnitudes in the range ML 1.2 - 2.5 in the vicinity of Sutton, NSW, during this period. Ten of these were reported heard/felt, the first being at 2.23 am local time on 28 December 2001, when a resident of Bywong, in Harriot Road off Macs Reef Road, heard a loud bang like an explosion and her house rattled. She said that this magnitude ML 1.9 earthquake woke her neighbour.

The highest level of seismic activity in the Sutton area during 2001-2002 was in January – February 2002 when 12 earthquakes were recorded by Geoscience Australia's seismographs. Seven of those in the earthquake database, including one as small as magnitude ML 1.2, were reported heard/felt in Bywong. In addition, five not in the database were reported heard/felt by a family in Newington Road, off Macs Reef Road, Bywong - two on January 17th, one on the 23rd, one on the 25th and one on the 29th. The

most likely explanation is that these earthquakes were too small to record on enough seismographs to be able to determine their location, but that they were so close to Bywong, and at such a shallow depth, that people near the epicentre could detect them. It is however possible that some of these events may not have been earthquakes.

The largest earthquake of the swarm near Sutton was a magnitude ML 2.5 at 8.00 pm local time on 23 January 2002. The observer in Newington Road, Bywong, reported that his family inside the house heard a deep, loud crack with an echo and felt the house shudder. He made the following comment:

The three at home at this time felt that this earth tremor was the biggest we have had over the last few weeks. I was outside and felt the vibration thru my feet, plus a loud bang sound. My wife and son were a bit shaken/scared by this one.

In his emailed felt report, he noted down times for three events during a three-minute period. One was clearly the magnitude 2.5 earthquake, another was a magnitude 1.2 aftershock, and the other was one of the events not in the database – probably a very small aftershock.

After December 2002, there are no records of earthquakes in the Sutton area until 5 July 2003. On that day, the earthquake database has records of three earthquakes, two of which, with magnitudes ML 2.4 and 1.6, were reported heard/felt. One observer noted a loud noise, slight rumble similar to blasting close by, and mentioned that there have been several today rattling. However, his emailed report was submitted before the magnitude ML 1.4 event at 9.20 pm local time. He commented:

Have heard / felt? small quakes all day. Two loudest were after 6.00 pm. Similar to those of about fifteen months ago.

The other observer, in Newington Road, Bywong, also submitted his report before the 9.20 pm event, so we do not know whether this earthquake was felt. He noted a vibrating floor and a loud, thunder-type sound. He and his family felt the magnitude ML 2.4 event at 1.48 pm local time, another one within a minute, and the magnitude ML 1.6 at 7.24 pm. He remarked:

There were a series of tremors around Feb 2002, which subsided (a recording device was placed on our property for about a month). There have now been three today, all quite loud.

The Geoscience Australia database has no records of earthquakes in the Sutton area from August 2003 –May 2007.

EARTHQUAKES ON THE LAKE GEORGE FAULT

Table 2 and Figure 2 show that only small earthquakes have occurred on or near the Lake George Fault in recent years. Very few of them were reported felt, probably due to their size and the low population density in the neighbourhood of the fault.

Table 2. Earthquakes on or near the Lake George Fault, January 1960 – November 2007

DATE	TIME(UTC)	LAT	LON	DEPTH	MAG	COMMENTS
19620206	182929.6	-34.96	149.39	6.0	2.0	
19670124	232556.1	-34.94	149.42	3.0	3.6	4 km SSW of Collector. Felt and caused minor damage 20 km SSW of epicentre
19790313	41839.8	-35.01	149.37	16.0	1.6	
19820313	160659.0	-34.97	149.36	6.0	1.5	
19830101	215133.0	-35.01	149.36	0.0	1.5	
19830123	133726.2	-34.98	149.36	7.0	1.6	
19870614	33559.0	-34.99	149.37	NULL	1.5	
19870614	181959.0	-34.99	149.4	NULL	0.7	
19920110	131126.3	-35.17	149.408	15.0	1.0	Southern Lake George – on fault?
19920110	133121.5	-35.158	149.403	14.0	1.3	Southern Lake George – on fault?
19930618	3906.6	-35.072	149.379	4.0	2.0	Lake George - felt
19951217	144845.1	-35.178	149.371	1.0	0.7	Lake George Range
19970531	184428.4	-35.012	149.366	0.0	1.2	Western side of Lake George – on fault?
19980618	133510.6	-35.16	149.42	0.0	1.5	Lake George Fault

The largest was north of the map in Figure 2. Its epicentre was 2 km east of the fault and 4 km SSW of Collector. A Richter magnitude of 3.6 was calculated from measurements on the seismogram from Riverview College Observatory in Sydney. It occurred at 9.25 am E.A.S.T. on 25 January 1967. This earthquake was not mentioned in the Canberra Times, Evening Post (Goulburn), Queanbeyan Age or Yass Tribune so, in early March 1996, telephone interviews were conducted with residents of the Gearys Gap area who were there at the time of the earthquake. A lady living about 20 km SSW of the epicentre heard and felt it. She said that it was the second strongest she had experienced since moving to the district in the early 1930s. She was inside at the time. The shaking was very strong and there was a roaring sound like a truck dumping gravel. The earthquake produced cracks in plaster in the section near the ground of external stone and plaster chimneys of their old house. Another resident said that a crack in their brick lounge room wall which incorporates a chimney may also have been caused by this earthquake. He lives about 23 km SW of the epicentre. A lady on a property about 20 km SW of the epicentre thought she had felt the earthquake but that it was not very severe.

In 1993 a small earthquake, magnitude 2.0, had its epicentre near the western margin of Lake George and 32 km NE of the Canberra GPO. It occurred at 10.39 am E.A.S.T. on 18 June and was heard and felt by residents near the epicentre. Closest to the epicentre, it was described by a resident as 'an almighty bang as though something hit the house'. She

actually heard a series of three bangs in quick succession with the first being the loudest. Two to 3 km south of the epicentre, it was experienced as "a bit of a rumble" which shook the house. Nine to 10 km SSW of the epicentre, a woman playing the piano felt it momentarily and said it sounded like a loud truck and wall beams creaked. Thirteen to 14 km ESE of the epicentre, the earthquake was reported felt like a big explosion. There was a loud noise and a shake with only the fly screens rattling a bit.

It is important to note that uncertainties in earthquake locations in the Canberra region can be as large as 5 km or more. This makes it difficult to ascertain if an earthquake is associated with a particular fault. Consequently, it is uncertain whether the Lake George Fault is still active, but it appears likely.

Figure 14. Lake George. The escarpment, at the left of the picture, has weathered back from its original position on the Lake George Fault which is to the right of the highway. This has occurred by erosion and landslides, like this one in June 2005 (inset) which caused a semi trailer to jack knife.

MURRUMBATEMAN EARTHQUAKES

The cluster of earthquake epicentres at the northwest corner of Figure 2 is just south of the township of Murrumbateman, 35 km NNW of the Canberra GPO.

Fourteen earthquakes, with Richter magnitudes ranging from 1.2-2.4 have occurred within a square with sides 10 km from the township during the period 1981-1995. Of these events, nine were main shocks (an average of 0.6 per year), and five of these were in the area of Figure 2.

A magnitude MD 2.1 earthquake, with an epicentre 3 km west of the northwest corner of Figure 2, and 33 km NNW of the Canberra GPO, was felt at Hall and Flynn in the ACT at 9.27 am E.A.S.T. on 9 August 1987.

In 1993, two small earthquakes were felt at Murrumbateman. Their epicentres were 31 and 32 km NNW of the Canberra GPO and they happened at 5.16 pm on 29 May and 7.34 pm E.A.S.T. on 1 June. They are probably related. Their magnitudes were ML 1.2 and 1.6 respectively. The first of these earthquakes was felt inside and in the open by residents near the epicentre. It made windows and saucepan lids rattle and sounded as though something had hit the house or landed on the roof. The second was felt by residents of the township and sounded like a loud explosion.

Table 3. Earthquakes within a square with sides 10 km from Murrumbateman, January 1996 – November 2007

DATE	TIME-(UTC)	LAT	LON	DEPTH	MAG	COMMENTS
19970215	211915.2	-34.968	149.103	3.0	1.2	27km S Dalton NSW
20000425	32405.1	-35.052	149.007	8.0	2.5	Murrumbateman NSW. Felt
20000723	3624.4	-34.97	148.97	0.0	1.5	Murrumbateman NSW
20010109	214554.7	-35.059	149.01	3.0	2.5	Murrumbateman area NSW. Felt
20010324	120701.9	-34.984	149.085	2.0	1.8	Murrumbateman NSW
20010324	133856.7	-34.99	149.04	7.0	2.8	Murrumbateman NSW. Felt
20030114	134315.3	-35.019	149.012	1.3	3.1	Murrumbateman NSW. Felt

Earthquakes in the vicinity of Murrumbateman during the period January 1996 – November 2007 are listed in Table 3. A total of seven events occurred during this period, six of which were main shocks. This gives an average of 0.5 main shocks per year, similar to the period 1981-1995, suggesting that the average level of earthquake activity has remained almost the same. Three of these events were in the area of Figure 2.

Four of the earthquakes in Table 3 were felt.

The magnitude 2.5 event at 1.24 pm local time on 25 April 2000 was felt by all residents of a Murrumbateman property, 1 km from the Boral quarry, and all thought it was an explosion. Our informant noted that things in the kitchen sink lifted then fell, but nothing fell off the shelves.

The same person also reported that she and her neighbours felt the magnitude 2.5 earthquake of 10 January 2001 at 8.45 am local time. This sounded and felt like an explosion, and she felt the “air” pick up and drop the house on one corner. Her pet cats stood with their hair on end. Her property was at the epicentre of the earthquake, but it was also reported felt by one person in Spence, ACT. He was sitting at a desk when he felt/heard a rumble then a shake with the vibration of the floor.

One person in Murrumbateman reported feeling the magnitude 2.8 event at 12.38 am local time on 25 March 2001, but no details are available. It seems that most people were asleep then.

By contrast, the magnitude 3.1 earthquake of 15 January 2003 at 12.43 am local time was felt by many people in the Murrumbateman area, and woke a number of them. It was experienced as an explosion which shook several houses. One person, who was woken up, felt as though a car ran into his house, while another reported that a tap handle fell off. A seismologically-minded resident described hearing a "loud explosive bang as p wave came straight up, like many events at Dalton Gunning. Heard s wave faintly rumbling away to the south". The explosion-like bang woke them, and her husband went outside to look around.

The largest known earthquake within 10 km of Murrumbateman had an intensity-based Richter magnitude of 4.0. It happened on 7 March 1924 at 9.45 am local time and its epicentre was 8 km northwest of the township. According to Cotton (1925), "At the town of Murrumbateman the shock was exceptionally severe; articles were thrown down from shelves, and the plaster fell in several houses, being thrown right across the room from the north west wall to the south east in one case. The ground was observed to heave and wave, and fences and trees rocked perceptibly. A 1000-gallon water tank swayed in an alarming manner." Its isoseismal map (Everingham and others, 1982) indicates that the earthquake was felt in the northwesternmost part of the ACT.

DALTON-GUNNING EARTHQUAKES AND THEIR EFFECT ON CANBERRA

The Dalton-Gunning Zone, only 60 km north of Canberra, has been assessed as one of the highest hazard earthquake areas in eastern Australia (Gaull and others, 1990). Three earthquakes with Richter magnitudes of 5.5 or greater are known to have occurred, during the last 130 years, in November 1886, November 1934 and March 1949 (McCue and others, 1989). All three were felt strongly in the Canberra area.

The 1886 event caused damage in Yass and was felt in Queanbeyan with a Modified Mercalli (MM) intensity of IV-V. The magnitude of 5.5 was deduced from the radius over which the shock was felt as there were no seismographs to record it (Everingham and others, 1982).

In the 1934 earthquake, practically every brick and stone building in Gunning was damaged and the event was felt over much of SE New South Wales. In Canberra, trees vibrated violently, a road appeared to be undulating, and the water in the swimming pool at Manuka was shaken, as was the telephone in the pool office. It wobbled so much that it began ringing. The magnitude of the earthquake was ML 5.6 (McCue and others, 1989), the same as that of the December 1989 Newcastle event.

The magnitude ML 5.5 1949 earthquake was felt from Sydney and Katoomba in the north to Jindabyne, Cooma and Narooma in the south (Everingham and others, 1982). According to The Sun newspaper (Sydney) of 11 March 1949, the worst damage was in the Dalton area where ``buildings swayed crazily, walls cracked, chimneys toppled, water

tanks burst, and more than 100 bottles of liquor in an hotel were smashed. In Canberra, minor cracks were reported in the walls of some houses, and doors burst open. A number of cracks have appeared in walls of the Government administrative block near Parliament House. A lift stopped working".

A recent smaller event causing minor damage at Oolong (6 km south of Dalton) was the Oolong earthquake of 9 August 1984. It was felt over a radius of about 70 km and with an intensity of MM III in Canberra, and it occurred at a depth of 5 km (McCue and others, 1989). Although its magnitude (ML 4.0) was much lower than the 1886, 1934 and 1949 events, it cracked walls in Oolong and in Dalton where it knocked the cross crooked on St Matthews Anglican Church (Figure 15). The epicentral intensity was relatively high because the earthquake was very shallow.

Figure 15. St Matthews Anglican Church, Dalton in 1988. The cross was knocked crooked by the magnitude ML 4.0 Oolong earthquake of 9 August 1984.

For four years from June 1993, AGSO (now Geoscience Australia) published a monthly bulletin of events recorded within 15 km of the seismograph on the Klein's property at Dalton. During the 29 months, June 1993 - December 1995 (excluding May and June 1994 when the Dalton seismograph was not operating), these bulletins reported a total of 185 events with Richter magnitudes ranging from -0.1 to 2.7. This is an average of six per month. If foreshocks and aftershocks are excluded, the monthly average decreases to three. During this period 24 little earthquakes with Richter magnitudes 0.6 to 2.7 were reported felt, and an additional nine were heard only, but several may have gone unreported as heard or felt earthquakes in this area are so frequent that they are not considered newsworthy!

On average one earthquake a month was reported heard or felt in the Dalton area during the period June 1993 – December 1995. These events had magnitudes as low as ML 0.6. This is because, like the 1984 event, the majority of earthquakes in the Dalton-Oolong area are very shallow, with focal depths of 5 km or less. Small very shallow events may be felt strongly and larger ones have an enhanced damage potential because of proximity to the surface. By contrast, large earthquakes associated with seismically and volcanically active island arcs such as Indonesia, Papua New Guinea and Solomon Islands can be up to several hundred kilometres deep yet still be felt but cause no damage at the epicentre (the point on the surface of the earth above the earthquake) because the earthquake is effectively many tens or even hundreds of kilometres below the point of impact.

The project involving detailed monitoring of very small (magnitude 1.0 or less) earthquakes by Geoscience Australia ceased in 1996, but determining the locations of events large enough to be recorded by three or more seismographs continues. All earthquakes with magnitudes of 2.5 or more on the Richter scale are recorded in the Geoscience Australia database and these are listed in Table 4.

Table 4. Dalton-Gunning earthquakes with magnitudes of ML 2.5 and greater, January 1996 – November 2007

DATE	TIME (UTC)	LAT	LON	DEPTH	MAG	COMMENTS
19960813	123334.6	-34.766	149.158	0.0	2.9	Oolong N.S.W.
19970529	174024.4	-34.775	149.147	0.0	2.5	Oolong N.S.W.
19990927	92938.0	-34.754	149.149	1.0	2.7	Dalton NSW. Felt
20031125	173524.8	-34.726	149.283	1.0	2.6	Gunning NSW. Felt.
20031126	43953.93	-34.773	149.247	0.0	3.0	Gunning NSW. Felt.
20060302	61747.36	-34.799	149.176	3.0	3.4	S of Oolong NSW.
20060421	81150.34	-34.811	149.144	5.2	3.1	S of Dalton NSW.
20060813	133004.31	-34.802	149.146	3.2	3.3	S of Oolong NSW

Only eight events have happened in 11.9 years and, if foreshocks and aftershocks within one month of each other or of a main shock are excluded, the number drops to seven. Table 5 examines how the average level of main shock activity has varied since 1960.

Table 5. Variation in the average level of earthquake activity, considering only main shocks, in the Dalton-Gunning area, January 1960 – November 2007

Time period	No. of years	No. of main shocks	Average no. per year
1960-1965	6	8	1.3
1966-1975	10	9	0.9
1976-1985	10	16	1.6
1986-1995	10	11	1.1
1996-Nov 2007	11.9	7	0.6

It is clear that the average activity during the period 1996 to November 2007 is the lowest in more than 45 years, but three earthquakes with magnitude ML greater than 3.0 happened in the first eight months of 2006. This may be a random fluctuation or may indicate an increase in seismic activity.

The seismograms recorded from the magnitude ML 3.3 Oolong earthquake of 13 August 2006 are shown in Figure 16. These were recorded by Geoscience Australia's digital seismographs at Canberra, Young, Riverview (at Lane Cove, Sydney) and Mangrove Creek The recording on the Kambah seismograph is shown in Figure 4b. This earthquake was felt widely and the felt reports are summarised below.

Dalton: *A loud noise. Windows and small objects rattled. People felt it and were awakened. Dogs were frightened. There was a report of slight plaster cracking.*

Gunning: *Felt by all in community and woke people. Dogs barked. Loud double-barrelled bang and a stone house jerked. One person said it was the loudest bang in 30 years, windows rattled, doors banged, and there were a couple of new small cracks (in windows?).*

Goulburn: *Felt by several people, shelves rattled, ornaments toppled.*

Yass: *Awakened and felt by all in house. Very low-frequency rumble that lasted 30-45 seconds.*

Murrumbateman: *Felt by very few. Rumble lasted about 15 seconds. Slight rattle.*

Ngunnawal ACT: *Felt by one person in house. Sound similar to thunder. Windows rattled slightly. Small copper bucket full of baby bath items vibrated.*

Kambah ACT: *Child woken some time after 11 pm – an unusual occurrence. Windows rattled.*

Cowra: *Windows rattled some time during the period 11.30 pm – 12.30 am.*

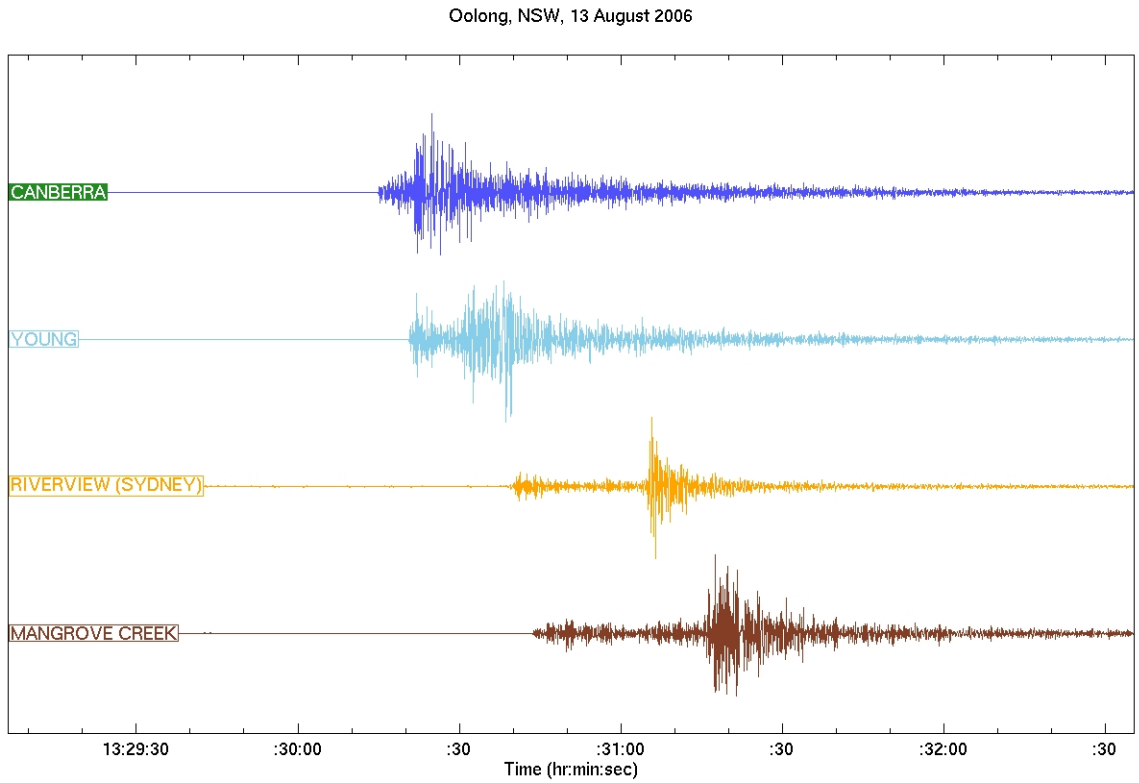

Figure 16. Seismograms of the magnitude ML 3.3 Oolong earthquake of 13 August 2006, recorded by Geoscience Australia's digital seismographs at Canberra, Young, Riverview (Sydney) and Mangrove Creek.

In the Dalton-Gunning zone, the average time interval between large, potentially damaging magnitude ML 6.0 earthquakes is of the order of 120 years (McCue and others, 1989). Events of this magnitude occurring in the part of the zone closest to Canberra would be expected to produce intensities in the city ranging from MMIV to MMVII, depending on the foundation conditions. Thus, these earthquakes may cause some damage in Canberra.

CANBERRA EARTHQUAKE HAZARD

Let us assume that the frequency of occurrence of earthquakes is the same for Canberra as for the rest of eastern New South Wales and northern Victoria (excluding the Dalton-Gunning Zone). Then we can calculate the average time interval which would be expected between earthquakes within 20 km of the GPO with magnitudes equalling or exceeding a given value. A magnitude ML 3.0 or greater would occur on average once every 15 years, magnitude ML 4.0 once every 170 years, and magnitude ML 5.5 once every 6000 years. A Richter magnitude 5.6 or greater event, the size of the December 1989 Newcastle earthquake, would be expected to occur on average once every 8000 years. Remember that earthquakes are *not* evenly spaced in time, and these time intervals are only very approximate average values. For example, the return period for a magnitude ML 5.5 or greater event, given as 6000 years above, could actually be anything from 3000 to 9000 years. The uncertainty comes from the best estimate of 6000 years being based on a very small amount of data, as earthquakes of this size are rare in southeastern Australia. For magnitude ML 4.0 or greater earthquakes, the return period could range from 150 to

210 years, with 170 years being the best estimate, as mentioned above. However, the return periods give a rough idea of the expected frequency of earthquakes within 20 km of the GPO.

For building design, disaster planning and insurance purposes, it is useful to have an assessment of the probability of experiencing a certain intensity of ground shaking from earthquakes in a given period of time. This was done for the whole of Australia by Gaull and others (1990). They produced maps showing contours of the ground motion which has a 10% probability of being exceeded in a 50 year period. For Canberra, they assessed this Modified Mercalli intensity to be MM VI-VII. As mentioned previously, shallow earthquakes are usually felt more strongly than deeper ones. Gaull and others (1990) adopted an average depth for eastern Australian earthquakes of 10 km. However, in Canberra and the Dalton region, earthquakes are commonly at a depth of 5 km or less. If this depth is used, the intensity with a 10% chance of being equalled or exceeded in 50 years may be as high as MMVII for the Canberra GPO and other localities in the northern part of the ACT.

An earthquake action guide, outlining what to do before, during and after an earthquake, is given in Appendix 2.

EARTHQUAKE FREQUENCY IN THE CANBERRA 1:100 000 MAP SHEET

The Canberra 1:100 000 map sheet (Figure 2) has a much bigger area than the circle of radius 20 km centred on the Canberra GPO discussed in the previous section. Consequently, earthquakes would be expected to be more frequent in the region covered by Figure 2 and the average expected time intervals between them will be less. A magnitude ML 3.0 or greater would occur on average once every 7 years and a potentially damaging ML 4.0 or greater once every 85 years. An event the size of the December 1989 Newcastle earthquake (ML 5.6) or greater would be expected to happen on average once every 4000 years. Again it must be remembered that earthquakes are *not* evenly spaced in time, and that these calculated average intervals between events are only very approximate estimates. For example, the best estimate for the average time interval between magnitude ML 5.5 or greater earthquakes is 3000 years, but it could be anything from 1000 to 5000 years. The return period for a magnitude ML 4.0 or greater earthquake could lie between 75 and 105 years, with the best estimate being 85 years, as mentioned above.

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APPENDIX 1: MODIFIED MERCALLI (MM) SCALE OF EARTHQUAKE INTENSITY (after Eiby, 1966)

MM I Not felt by humans, except in especially favourable circumstances, but birds and animals may be disturbed. Reported mainly from the upper floors of buildings more than ten storeys high. Dizziness or nausea may be experienced. Branches of trees, chandeliers, doors, and other suspended systems of long natural period may be seen to move slowly. Water in ponds, lakes, reservoirs, etc., may be set into seiche oscillation.

MM II Felt by a few persons at rest indoors, especially by those on upper floors or otherwise favourably placed. The long-period effects listed under MMI may be more noticeable.

MM III Felt indoors, but not identified as an earthquake by everyone. Vibrations may be likened to the passing of light traffic. It may be possible to estimate the duration, but not the direction. Hanging objects may swing slightly. Standing motorcars may rock slightly.

MM IV Generally noticed indoors, but not outside. Very light sleepers may be awakened. Vibration may be likened to the passing of heavy traffic, or to the jolt of a heavy object falling or striking the building. Walls and frame of building are heard to creak. Doors and windows rattle. Glassware and crockery rattle. Liquids in open vessels may be slightly disturbed. Standing motorcars may rock, and the shock can be felt by their occupants.

MM V Generally felt outside, and by almost everyone indoors. Most sleepers awakened. A few people frightened. Direction of motion can be estimated. Small unstable objects are displaced or upset. Some glassware and crockery may be broken. Some windows crack. A few earthenware toilet fixtures crack. Hanging pictures move. Doors and shutters swing. Pendulum clocks stop, start, or change rate.

MM VI Felt by all. People and animals alarmed. Many run outside. Difficulty experienced in walking steadily. Slight damage to masonry D. Some plaster cracks or falls. Isolated cases of chimney damage. Windows and crockery broken. Objects fall from shelves, and pictures from walls. Heavy furniture moves. Unstable furniture overturns. Small school bells ring. Trees and bushes shake, or are heard to rustle. Material may be dislodged from existing slips, talus slopes, or slides.

MM VII General alarm. Difficulty experienced in standing. Noticed by drivers of motorcars. Trees and bushes strongly shaken. Large bells ring. Masonry D cracked and damaged. A few instances of damage to Masonry C. Loose brickwork and tiles dislodged. Unbraced parapets and architectural ornaments may fall. Stone walls crack. Weak chimneys break, usually at the roof-line. Domestic water tanks burst. Concrete irrigation ditches damaged. Waves seen on ponds and lakes. Water made turbid by stirred-up mud. Small slips, and caving-in of sand and gravel banks.

MM VIII Alarm may approach panic. Steering of motor cars affected. Masonry C damaged, with partial collapse. Masonry B damaged in some cases. Masonry A undamaged. Chimneys, factory stacks, monuments, towers, and elevated tanks twisted or brought down. Panel walls thrown out of frame structures. Some brick veneers damaged.

Decayed wooden piles break. Frame houses not secured to the foundation may move. Cracks appear on steep slopes and in wet ground. Landslips in roadside cuttings and unsupported excavations. Some tree branches may be broken off.

MM IX General panic. Masonry D destroyed. Masonry C heavily damaged, sometimes collapsing completely. Masonry B seriously damaged. Frame structures racked and distorted. Damage to foundations general. Frame houses not secured to the foundations shift off. Brick veneers fall and expose frames. Cracking of the ground conspicuous. Minor damage to paths and roadways. Sand and mud ejected in alluviated areas, with the formation of earthquake fountains and sand craters. Underground pipes broken. Serious damage to reservoirs.

MM X Most masonry structures destroyed, together with their foundations. Some well-built wooden buildings and bridges seriously damaged. Dams, dykes, and embankments seriously damaged. Railway lines slightly bent. Cement and asphalt roads and pavements badly cracked or thrown into waves. Large landslides on river banks and steep coasts. Sand and mud on beaches and flat land moved horizontally. Large and spectacular sand and mud fountains. Water from rivers, lakes, and canals thrown up on the banks.

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

MM XII Damage virtually total. Practically all works of construction destroyed or greatly damaged. Large rock masses displaced. Lines of slight and level distorted. Visible wave-motion of the ground surface reported. Objects thrown upwards into the air.

Categories of non-wooden construction

Masonry A Structures designed to resist lateral forces of about 0.1g, 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.

APPENDIX 2: EARTHQUAKE ACTION GUIDE

This information is provided by courtesy of the Disaster Awareness Program, Emergency Management Australia.

If your area has an earthquake history or potential, this advice could help save you injury and distress.

Know your local earthquake risk.
Ask your State/Territory Emergency Service (S/TES), council and insurance company for this information:
• Whether tremors or earthquakes have ever occurred in your area and what damage resulted.
• Ask your S/TES for a free pamphlet and/or poster which show Australia's earthquake risk zones.
• Study that information and ask your council about ways to make your house safer in an earthquake.
• Check that your insurance covers earthquake damage.

Emergency kit and check list
During and after an earthquake you will need:
• A portable radio and torch with fresh batteries.
• Candles, matches and containers of fresh water.
• A first aid kit and basic first aid knowledge.
• Plan together where your family will meet if separated.
• Know your safe areas during an earthquake *(see below)*.
• Your emergency contact numbers. For **life threatening situations** (police, fire, ambulance) **000**. For other emergency numbers, see your phone book.

Watch for possible warning signs
• **Erratic animal behaviour** - Scared, confused pets running about, or bird calls not usually heard at night.
• **Ground water levels** - Watch for sudden water level changes in wells or artesian bores.

During the earthquake
• If **indoors**, stay there (clear of falling debris outside). Keep clear of windows, chimneys and overhead fittings. Shelter under and hold a door frame, table, bench etc.
• In **high rise buildings**, stay clear of windows and outer walls. Get under a desk near a pillar or internal wall.
• Do **not** use elevators.
• In **crowded areas or stores**, do not rush for doors. Move clear of overhead fittings and shelves.
• If **outside**, keep well clear of buildings, overhead structures, walls, bridges, power lines, trees, etc.
• In a **city street**, shelter from falling debris under strong archways or doorways of buildings. Don't go under awnings or parapets as they may collapse.
• If in a **vehicle**, stop in an open area until shaking stops. Beware of 'downed' power lines and road damage, including overpasses and bridges. Listen to your car radio for warnings before moving.

After the earthquake

Watch for hazards and tend injuries as follows:

• Turn off electricity, gas, water. Do **not** light matches until you have checked for gas or fuel leaks.

• Check for injuries. Apply first aid. Do **not** move the seriously injured unless in immediate danger.

• Check for broken water, sewerage or electrical mains.

• Do **not** use the telephone immediately (to avoid congestion) unless there is a serious injury or fire etc.

• Check for cracks/damage, in roof, walls, chimneys etc.

• Evacuate if badly damaged. Be prepared for aftershocks.

• Do **not** waste food and water as supplies may be interrupted. Collect emergency water from heaters, ice cubes, toilet tanks and canned foods.

• Listen to local radio and heed warnings and advice on damage and service disruptions.

• Avoid driving unless for emergency (keep streets free).

• Do not go sight-seeing or enter damaged buildings.

• Stay calm and help others if possible.

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