

Balancing the Earthquake Budget in NSW

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Abstract

This new revised historical earthquake catalogue of NSW and the ACT lists more than 200 earthquakes in the last 200 years, 22 of them magnitude 5 or more to 1954 are discussed here, with two significant clusters; one around Newcastle, the other around Gunning. The two clusters are quite different in their behavior; at Newcastle there are few small earthquakes whilst around Gunning there are normal numbers of small and medium earthquakes. The M5⁺ events in the vicinity of Newcastle are solitary with an occasional small aftershock whilst at Gunning they are in swarms and have normal foreshock-mainshock-aftershock sequences. This behavioural difference coupled with a marked change in the principal stress direction suggests that the regions belong to different tectonic domains.

Magnitude 5 earthquakes in 1860 that caused minor damage in Yass, and in 1886 near Lithgow have been re-discovered. Federal Parliament in Canberra was shaken on several notable occasions and a possible 'largest' ACT earthquake found in 1940. Strong temporal clustering of earthquakes is noted in NSW in 1870, 1886 and the period 1933 to 1952, in the Gunning region. Earthquake swarms have 'magnitude' depending on the largest event of the swarm; 'small swarms' occurred near Macleay in 1870 and Young in 1902, 'medium swarms' near Gunning in 1933-1952, and a 'large swarm' struck NE Tasmania in 1883-1892, the larger events felt in southeastern NSW.

The largest known NSW earthquakes were those at Gunning in 1934 and Newcastle in 1989, both magnitude 5.6, but several others were almost as large. Combining different completeness intervals a recurrence relationship has been computed, the 'b' value 0.9. The once-per-year earthquake has a magnitude of 4.0. A magnitude 5⁺ earthquake has a return period of about 5 years, the last one was in 1997. A magnitude 6⁺ earthquake has, by extrapolation, an expected recurrence rate of about 70 years. A 'large' earthquake is surely overdue.

These new data and their interpretation are important for better hazard assessments by improving early earthquake details, by better definition of source zones and by extending the completeness intervals for any magnitude. They also serve to remind us that even relatively small earthquakes have the potential to cause structural damage to non-engineered structures as they have done in the past. This is a work in progress.

Keywords: earthquake, seismicity, cluster, New South Wales, Newcastle, Gunning

1 INTRODUCTION

The seismicity of New South Wales (including the ACT) has received considerable attention since the first earthquake was felt at Sydney Cove within six months of the founding of the new British colony there in January 1788 (see below). Factors for maintaining the interest included that the Rev. W.B. Clarke, recognised as the father of Australian Geology, took up residence in Sydney in 1839 (died 1878). He wrote the first paper about Australian earthquakes and compiled a list of Australian and New Zealand earthquakes, lost in a fire and unpublished but hopefully recreated here.

The first Observatory in NSW equipped with short period seismographs was established at St Ignatius College Riverview in 1909, and is still operating today. Directors of the Observatory, Pigot (the founding Jesuit observer), O'Connell, Burke-Gaffney and Drake (the last Jesuit observer) all contributed greatly to our understanding of NSW earthquakes and were regularly consulted by the media, newspapers in particular.

Others discussed earthquakes in the state of NSW including Griffith Taylor (in Jose and others, 1912) who included an interesting map of places where earthquakes were reported felt according to the Commonwealth Meteorologist. These would have included the large earthquakes originating in north-east Tasmania in the 1880-90s. Burke-Gaffney (1952) and Doyle, Everingham and Sutton (1968) dealt with the whole continent; Drake (1974) focussed on NSW; Doyle, Cleary and Gray (1968) and Gibson (2009) limited their scope to the Sydney Basin; while Hunter (1991), appropriately, studied the Hunter region.

Many other papers have been written about specific areas like the Snowy Mountains, Dalton-Gunning, or Newcastle (Hunter, 1991), or about specific earthquakes. Isoseismal maps for Australian earthquakes are compiled in three atlases by Everingham and others (1982), Rynn and others (1987) and McCue (1996). Included are maps of 15, 18 and 25 NSW earthquakes respectively. A number of additional maps have been compiled since the year 2000. It might be assumed there was not much more to add about early earthquakes in NSW.

However more information was elicited from previously unavailable newspapers with the recent publishing on-line of the scanned collection of Australian newspapers published to 1954, by the Australian National Library. This site, TROVE, allows users to correct the OCR copy of the scanned images which makes the collection even more valuable as this corrected text can be searched online by all.

So much additional information was found about Gunning region earthquakes for the three decades of the 1940s, '50s and '60s, prior to the establishment by the ANU of the local area seismographic network, that a separate report will be issued. The information is harder to extract due to a serious decline in the quality of newspapers in the 1950s.

It has been suggested for two centuries that earthquakes don't pose a threat to human life or structures in Australia, that somehow Australia's earthquakes aren't like, say, New Zealand earthquakes. Geologist Professor Edgeworth-David at Sydney University championed this view:

"There is no likelihood, however, of this mountain-building force in New South Wales becoming so accentuated in the near future as to cause earthquakes, such as would shatter buildings, and so endanger life." The Riverine Grazier (Hay) Friday 21 April 1905, page 4.

What can we do to dispel the Christchurch syndrome – 'it won't happen here'?

On the other side of the ledger, a Cooma newspaper in January 1924 found newsworthy, the fact that no earthquakes were felt there in 1923!

Figure 1 Map of places in NSW where earthquakes were felt since 1885 as compiled by the Commonwealth Meteorologist (from Jose and others, 1912).

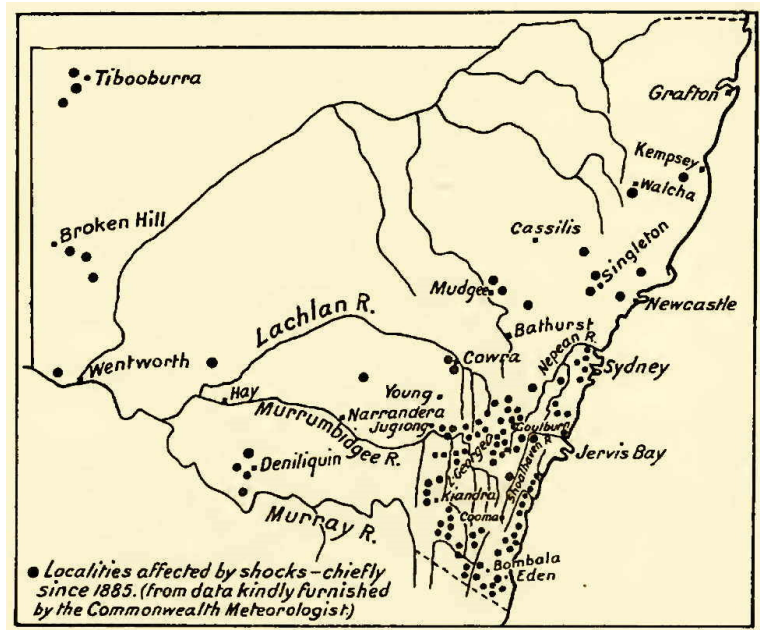


Figure 2 Seismicity of NSW, 1788 – 2009 (Payne, 2010); compare this pattern with the pattern of felt reports in Figure 1.

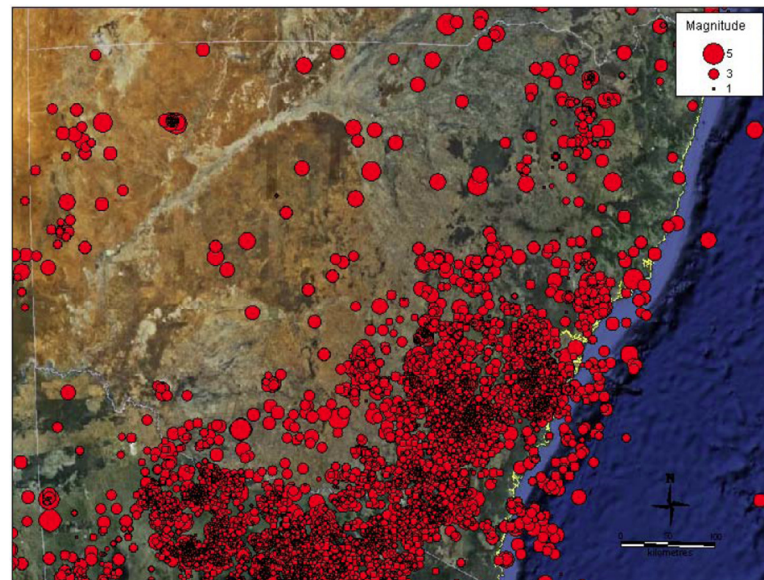


Figure 9: ES&S Earthquake Catalogue for New South Wales and surrounding region

2 ON TIME

The term Universal Coordinated Time (UTC) is used here even though it wasn't adopted until 1 January 1972, replacing Greenwich Mean Time that was introduced in Australia in February 1895. Before that, local mean time was based on noon being when the sun was directly overhead.

3 NOTES ON REPORTED EARTHQUAKES

The following notes on individual earthquakes of magnitude 5 or more, or otherwise important, are listed chronologically with comments on the magnitude and location or explanations as to decisions made in arriving at a solution. The full list of earthquakes, many smaller than 5, will be available on the AEES website.

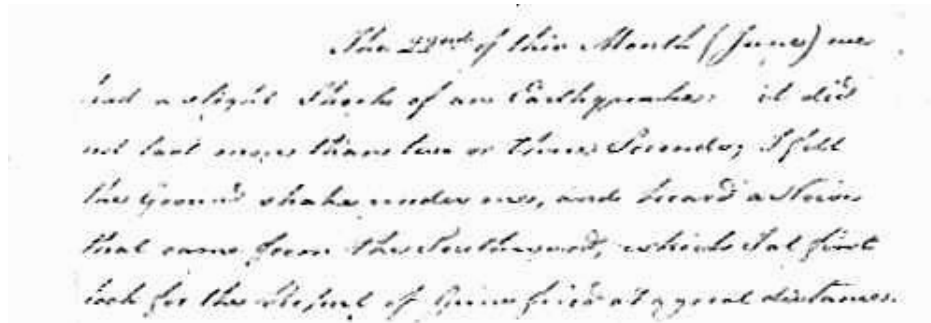
Until Europeans spread out from Sydney not much can be said about the first few earthquakes felt there, the magnitude and their location will never be ascertained but that did not last long. The earliest observation is included here for completeness.

1788 06 22 at 01:00 UTC, Sydney

Australian Town and Country Journal Saturday 19 October 1878, page 17.

THE FIRST EARTHQUAKE RECORDED IN NEW SOUTH WALES.

The following interesting extract is from Governor Phillip's " Voyage to New South Wales " :—



The 22nd of this Month (June) we had a slight shock of an Earthquake: it did not last more than ten or twelve seconds; I felt the ground shake under me, and heard a noise that came from the Eastward, which did not look for the report of gun fired at great distances.

1837 08 02 at 12:20 UTC, Newcastle

The following extract from the letter of the Rev. Wilton was taken from *The Sydney Herald* 10 August 1837, page 2. At the end he lists the previous known earthquakes in the colony. This was undoubtedly the largest, and the first of seven magnitude 5 or greater earthquakes in or near Newcastle to 2014. Earthquakes occurred in 1837 in Hobart, Adelaide and Port Phillip too.

EARTHQUAKE AT NEWCASTLE.

To the Editor of the Sydney Herald.

SIR.—The town of Newcastle, on the Hunter, upon the night of Wednesday the 2nd ultimo, at about twenty minutes past ten, was shaken by an earthquake, which occasioned a general consternation amongst the inhabitants. I was at the time sitting in my bedroom, when on a sudden I was alarmed by a cracking noise, which seemed to come from the eastern end of the parsonage, and the chair on which I was sitting was up-heaved; the walls of the house appeared to move; the timbers of the roof to strain like those of a ship at sea; and the windows were violently shaken. This continued for about the space of two or three seconds. One of my servants who had retired to rest, describes the sensation as if the bed was raised upwards; while another, whose bed was laid upon the floor in another room, thought the floor was being moved from underneath, and that the walls were about to fall. In the kitchen, several utensils of tin were thrown down from the wall, and the plates in the plate rack were struck against each other; while the man who was in that part of the house states that there was a noise on the shingles as if hailstones were falling upon them, and he ran out to see if such was the case, but there was not a cloud in the sky. In one instance, where a person was sitting at a table, the table seemed to move away, and then to return to its former position. One of the men employed at the signal-station, on the Telegraph-hill, was at the time in the act of stirring up the beacon-fire, situate nearly on the verge of the cliff over the sea, and he states, that the earth appeared to quiver beneath him, so that he hardly knew whether he was upon his feet or not; while the walls of the windmill on the opposite heights, above the church, are described by the night-watchman within them, as if about to tumble, to such a degree did they tremble. The shock in short was generally felt by those who had not gone to their night's rest, and many who were asleep at the time were awakened by it, and rose up to inquire the cause. The men who were at work in the coal mines, twenty-three fathoms below the surface, experienced nothing of the shock, while those of their companions who were above ground were greatly

terrified by it; and it would seem that it was felt with the greatest severity on the more elevated situations.

On reference to the " Chronology of the most remarkable occurrences from the first establishment of Australia down to 1829." in the Australian Almanack, we find notices of four shocks of earthquake in this Colony, and of one in Van Diemen's Land, viz —on the 22nd of June, 1788 ; 17th of January, 1801; 7th May, 1804; 24th September, 1806, and at Launceston on the 28th of November, 1823. These are, I believe, all the shocks upon record as having been felt in these Colonies; and whether they were greater than, or inferior to the one I have now endeavoured to describe, we have now no opportunity probably of ascertaining :

I remain, Sir,

Your obedient Servant,

C. PLEYDELL N. WILTON. Parsonage, Newcastle,

August 4, 1837.

The Sydney Monitor Monday 14 August 1837 page 2 mentions that this earthquake was felt (slight) in Sydney but that it did not awake the sleeping reporter.

1841 01 27 at 21:15 UTC, Newcastle

The Sydney Herald, Friday 19 February 1841, page 2.

To the Editor of the *Sydney Herald*.

Sir,—The Rev. W. B. Clarke, in your paper of the 9th instant, in his account of the shock of the Earthquake on the 28th of last month, as felt at Parramatta, mentions the state of the weather, and the many beautiful meteors which he had recently observed..... I have now before me the account of the shock of an Earthquake, which, with many other persons, I felt at Newcastle on the night of the 2nd of August, 1837, and of which I gave a description in the *Sydney Herald* the 10th of that month. From that it must appear that the shock came in a similar direction to that of the 28th of last month (which however was not felt at Newcastle) and it was preceded also by extraordinary atmospheric phenomena. The shock on the 28th was felt very strongly on the William and Patterson Rivers (as was also that of the 2nd of August, 1837) at Morpeth, East and West Maitland, and at Patrick's Plains. At West Maitland the labourers employed in erecting the Church thought that the building was coming down, as did also a man at work within the lately consecrated Church of St. James's, Morpeth, with respect to that building, out of which he ran upon feeling the strong vibrations accompanied by a rumbling noise. A resident upon the banks of the Hunter at Morpeth, likens the noise which he heard to that made by the paddle-wheels of a steam-boat in the first instance (so much so that he looked up to see if the steamer were coming) and then to that occasioned by the motion of a waggon laden with iron rods over a hard road. In each instance it would appear that the vibration seemed to come from about the north. From the information already obtained respecting this shock on the 28th instant, we perceive that it extended over a greater line of country and was attended by more violent effects than that to which I have alluded in 1837.

I remain, Sir,

Your obedient servant,

C. PLEYDELL N. WILTON.

Parsonage, Newcastle,

February 13, 1841

P. S.—A report has just reached me that Mount Wingen has "tumbled in," and there are some who account for the late earthquake from this circumstance. The shock, if it reached that spot, may have caused such a change as reported in our Burning Mountain — but nothing more.

An isoseismal map was published (McCue, 1996), but with a typo in the time, showing strong shaking in the Newcastle area as reported also by Hunter (1991) in contradiction with Wilton's comment above. Several other points can now be added to the map but do not change the general shape.

1842 10 27 at 19:30 UTC, Newcastle

Two earthquakes were reported felt that morning at Newcastle, Patrick's Plains and Paterson, the first one was only slight. The larger one was felt widely; sharp at Port Macquarie, Maitland, Dunmore, Raymond-terrace Singleton and Kempsey, distinct at Windsor and Stroud, and slight at Parramatta. Hunter (1991) catalogued the earthquake and an isoseismal map was published (McCue, 1996) yielding a magnitude of 5.3. *The Sydney Morning Herald* Tuesday, November 1, 1842, page 2.

THE EARTHQUAKE.

AMONG our news from the interior will be found notices from Windsor, Newcastle, and Port Stephens, of the earthquake which occurred on Friday morning, and the course of which is thus traced for upwards of a hundred miles. We shall feel obliged by well-authenticated notices from other parts of the colony where it may have been felt, with reports of attendant phenomena, as we are anxious that full particulars of all such occurrences should be recorded in the Herald for future reference.

NEWCASTLE-EARTHQUAKE.

*On Friday morning last, the 28th instant, two shocks of earthquake were felt at Newcastle, by many of its inhabitants, who were awoken thereby out of their sleep, and who describe their beds as if tilted on one side, and on regaining their original position being violently shaken under them, while the walls of their chamber seemed to be falling down. Those persons who had risen from their beds when the second shock occurred, about half past five, state the earth as quivering beneath them, and themselves shaken, and as if lifted off the ground. Extraordinary atmospheric changes had taken place previous to this phenomenon ; particularly on the Monday preceding, during the whole of which day a thick haze prevailed, accompanied by a death-like stillness, the wind suddenly veering from W. to E. in the afternoon, the same stillness continuing. On Tuesday evening, there was incessant lightning to the E., while on Thursday there was thunder and rain from the S. W. **The present instance makes the fourth shock of earthquake felt on the Hunter since the commencement of the month of August, 1837.** I trust that this notice of these tremblements de terre which occurred at Newcastle yesterday morning, may be the means of inducing other individuals who may have experienced their effects in other localities, to make known their observations through the medium of*

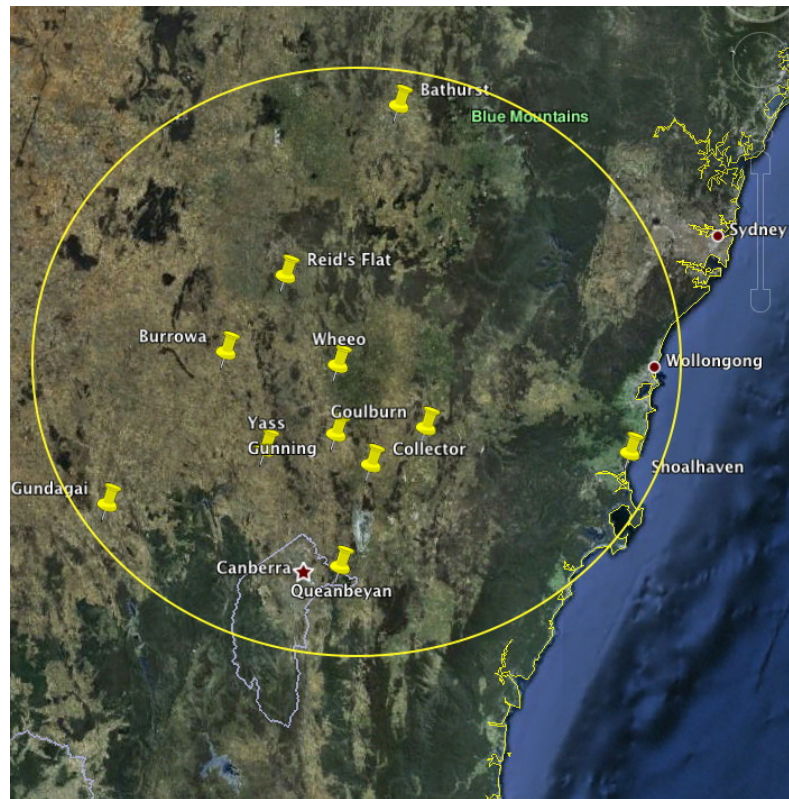
your journal.

1860 03 04 at 10:08 UTC, Yass

This earthquake is not in known catalogues.

The *Yass Courier* of Saturday March 10, 1860 reported the earthquake, the story was then picked up by *The Argus* on Monday 19th March.

Figure 3 Locations where the earthquake on 4th March 1860 (EST) was felt (yellow pins). The ellipse delineates the felt area and its radius of perceptibility is used to compute the magnitude.



Four aftershocks were felt at Yass where the strongest shaking was reported in the mainshock on Sunday evening indicating that the epicentre was nearby (34.8°S , 148.9°E). The effects were widely felt, from Bathurst in the north to Queanbeyan in the south, and from Shoalhaven in the east to Gundagai in the west. Other places reporting the earthquake included Gunning, Goulburn, Collector, Wheeo, Burrowa and Reid's Flat. Perhaps it was felt south of Queanbeyan but the 1860 Cooma newspaper is yet to be digitized.

Minor damage was caused in Yass, mortar falling from stonework on the Church of England and a timber roof support in another building was split.

The magnitude adopted here, ML5.0, is a minimum value, the maximum value, ML 5.5, is limited by the fact the earthquake doesn't appear to have been felt in Sydney.

1868 06 18 at 14:00 UTC, Maitland

An isoseismal map of this magnitude 5.3 earthquake was compiled by McCue (1996) with supportive information from Hunter (1991). Rev. W.B. Clarke felt this earthquake and wrote widely in the newspapers about it without, as far as we know, drawing an isoseismal map. The ready access to newspapers through TROVE has made much more information available e.g. sufficient for the metropolitan area of Sydney to be useful for microzonation. What better way to estimate potential ground motion amplification than using a real earthquake!

The felt area is similar to that of 1842 and both are assigned magnitudes of 5.3, the largest earthquakes at Newcastle before 1989.

1871 06 08 at 04:40 UTC, Tumut

The Manaro Mercury, and Cooma and Bombala Advertiser, Saturday 17 June 1871, page 3.

Dr Dirk Spennemann, Charles Sturt University, investigated a number of earthquakes in the Tumut, Albury, Adelong area, including this one and four of its aftershocks for which he compiled isoseismal maps, redrawn by GA to their standard format. The mainshock, magnitude about 5.3 based on the felt area, is interesting; it damaged the local public school, was felt strongly underground and was followed by aftershocks till at least September and ultimately another magnitude 5 earthquake on 3 January 1872. There are no reports in the Manaro paper of the mainshock being felt in Cooma or further to the southeast.

We have just experienced a very heavy shock of earthquake. Our townspeople all ran out of their houses, thinking they were coming down. I (the correspondent) was, with others, standing on the Camp Reef at the time, where the shock was so severe that it displaced an anvil from a log of wood. The men working in each ride of the deep shaft thought its sides would come-in on them. In Messrs. Henwood and Co.'s shaft, the deepest on this reef, Mr. W. Long was in the act of bailing water with a dipper, when the tools in the shaft began to dance, and the dipper to strike against the wall. In a short time, Long, thinking every thing had given way at top, made his ascent to grass. On gaining the open air, he found his mates as much surprised as he was, and those of the next claim, who had also come to earth, as greatly alarmed as he himself had been. In many of the houses in the township, plates, glasses, &c, were thrown down or shaken out of their places ; and at the Public School, I believe, the books were thrown from their shelves, the master at once dismissing the children for the day.

From the manner in which horses and cattle ran about during the time the shock lasted, I fancy they were as much astonished and alarmed as their owners.— June 8th. At the Adelong Crossing-Place, we understand the shock was more severe than at Gundagai.

A portion of the gable end of a strongly-built stone kitchen attached to the Home Hotel was cracked, and the rafters, with some planks on them, forming a kind of loft, were displaced. In the bar of this hotel, bottles and glasses on the shelves tumbled to the floor. It may be surmised that the inmates of the house were considerably alarmed. We believe the shock also did damage to Mr. Walsh's smithy. A new stone house, built by Mr. Neaves, has been so disturbed that its chimneys will probably have to be pulled down. The Public School building has been slightly canted to one side, and its chimney much injured. All the crockeryware in this educational establishment was, we believe, broken; and a large desk fairly danced on the floor, to the great alarm of the scholars, who thereupon rushed out of doors, somewhat fearful that the suddenly-animated piece of school furniture would follow them.

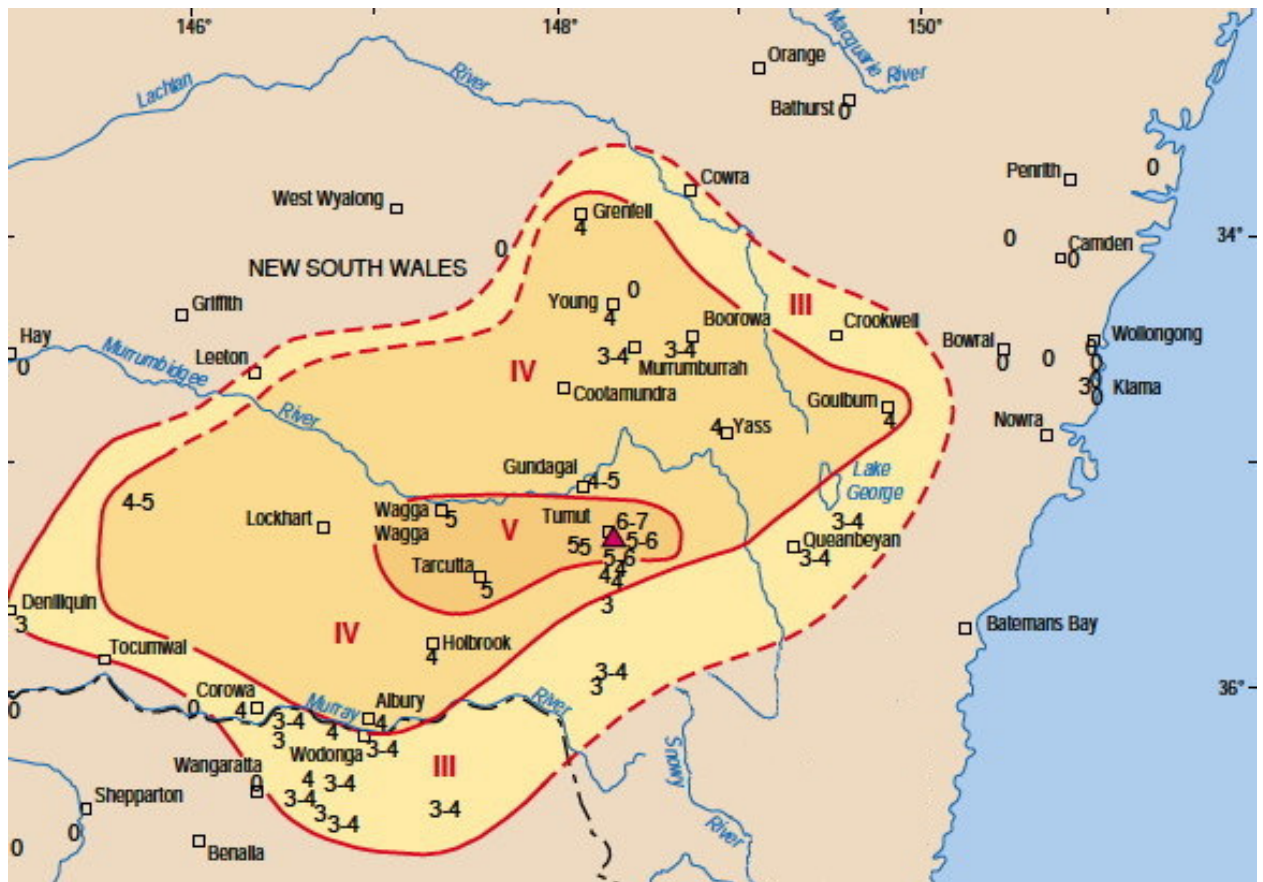


Figure 4 Isoseismal map of the magnitude ML 5.3 Adelong earthquake of June 8, 1871 (after Spennemann, 1998).

1875 06 03 at 10:00 UTC, Cobar

The following account of an earthquake in western NSW is perhaps exaggerated, but given the felt area, it was obviously quite a substantial event.

The Riverine Grazier, Wednesday 16 June 1875, page 2 reports:

The writer, travelling from Bourke to Hay via Cobar, on Thursday evening, 3rd inst., was at Corilla, 80 miles north of Cobar, about 8 o'clock p.m. Heard a long rumbling sound, beginning slow, gradually swelling, and then decreasing until lost in the distance. Though he had never heard or felt an earthquake, the impression made on his mind was that a shock had been felt, and, as he thought, in the direction of Cobar. Proceeding on his journey he found that, at Tindara, distance 40 miles from Cobar, a shock of earthquake had been felt causing great excitement; the people rushing out of their house expecting it to fall. At Cobar the excitement was intense, on the evening in question; the first sound heard was as though empty iron tanks were being beaten, followed in two or three minutes by a terrific shock as if an explosion had taken place immediately underneath. People rushed out of the houses with their hands over their heads, expecting the walls to fall; women were screaming in all directions, and some were frightened into hysterics. The men down in the Cobar mine rushed up, (and it is stated they got up in a fourth of the time the usually take). The commotion extended to the blacks, who cleared out of their camp, screaming and shaking. Their idea of the occurrence was, "that blackfellow jump up in some other country."

On Sunday morning, about 10 a.m., another shock was felt by myself and others, not so violent as the first, but still of considerable force, having split a chimney and caused a crack two inches wide. Proceeding on my journey I found as I got further south from Cobar, the shock was also felt, until near the Willandra; about 150 miles south, only a faint rumble was heard like a distant roll of thunder. Altogether between the evening of Thursday and Sunday morning over 20 distinct shocks were counted. The writer requested a resident to give his version which is annexed hereto.

Cobar, June 7th.— On Thursday night, the 3rd inst, about 8 o'clock, the whole of Cobar was thrown into great commotion by a frightful shock of an earthquake. The shock appeared to come from the north, and lasted about three minutes. [The foregoing writer thinks the direction of the shock was from west to east.] The nearest description I can give of it is, that some great explosion had taken place near at hand, the vibration being so great that every board in my house trembled to such an extent that those standing kept their feet going, as though they were on a treadmill. I have often heard of people's hair standing on end, but never witnessed it until the night in question. Children were awoke from their slumbers, their little hearts beating like the tick of a watch. Mothers' screaming and falling off into hysterics, miners rushed from their work below, fearing the whole mine was falling upon them. Parties out burning charcoal saw their kiln rise in front of them, the fright of which threw them off their equilibrium. Horses and cattle galloped about like mad. People knelt down and prayed, in fact many thought their last hour had come. I have felt two shocks before in Victoria, but nothing to equal the one felt here. Another heavy shock occurred about 3 o'clock on the morning of the 4th inst, causing the sleepers to roll from their beds; that is those that were in bed, many being too frightened to take their usual rest. We have had a succession of shocks up to Sunday, (6th inst) 10 a.m. At Tindara the shock was also great causing the water to over-flow from the bank, and throwing glasses and crockery from the shelves.

The *South Australian Register* Thursday 17 June 1875, page 7 briefly mentions the earthquake in its "River District Notes":

Brewarrina.— The river is rising at the rate of 1 foot in twenty-four hours. A shock of earthquake was experienced here yesterday It is mentioned that a shock of earthquake was experienced in Bourke on the 3rd.

This region of western NSW was not densely populated but the felt area is very large. With an epicentre near Cobar where the intensity was high, the felt distance north and south of about 150km indicates a magnitude in excess of 5. Nyngan about 120km to the east wasn't surveyed until 1882.

1880 07 31 at 07:00 UTC, Coonamble

The *Evening News*, Saturday 6 February 1892, page 3S lists earthquake reports collated by Mr. H. C. Russell (Government Astronomer) starting with:

1880 — In the Coonamble report of July 31 it appears that at 5 p.m. a peculiar noise was heard for 250 miles along the Castlereagh River, and for a range of 50 miles wide. It was like the discharge of rifle and cannon, or as if a large iron tank was bumping on the ground. Mr. Steuglin heard it, and said the blackfellow with him got off his horse and went down on the ground in terror, saying, " Devil devil coming " and even the horses shook with fear. It was heard by many

persons all over the area specified, and seems to have been confined to these limits.

This is a very eccentric area representing an earthquake of at least magnitude 5.4 (I assume it was an earthquake). The location is very uncertain, the Castlereagh River flows downstream through or near the towns of Coonabarabran, Binnaway, Mendooran, Gilgandra and Coonamble, but is taken here to be near Coonamble. This stretch of the river around Coonamble is remarkably straight and oriented SSE, or more nearly NS, and looks to be strongly fault controlled.

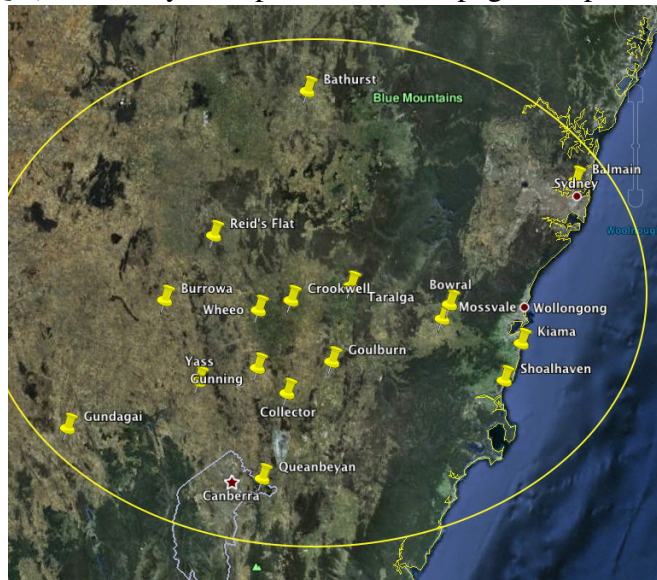
1883 08 29 at 14:00 UTC, Crookwell

The Sydney Morning Herald of Friday 31 August 1883 (page 5) reported that an earthquake had been felt in Goulburn, Kiama and Taralga about midnight on Wednesday 29 August 1883. The *South Australian Advertiser* says the shock was also felt at Collector, Bowral and Crookwell.

Morning Bulletin (Rockhampton, Qld), Saturday 1 September 1883, page 3 reports:

Shocks of earthquake are reported to have been felt at Burrowa, Mossvale, and Balmain, and at Bundaroo, near Mossvale, a loud report like the discharge of a cannon was followed by a rumbling noise, which lasted for several seconds. The iron roofs on the house rattled briskly, and houses were shaken.

Figure 5 The ellipse encompasses places where shaking was reported felt (yellow pins) during the 29 August 1883 Crookwell quake.



THE *Goulburn Herald* says:—A strong shock of earthquake was felt in Goulburn and surrounding districts on Wednesday night about 12 o'clock. It was accompanied by a rumbling noise, and was sufficiently powerful to cause windows and doors to shake, and articles of crockery and glass-ware to rattle. In the upper floor of a three-story house the vibration was strong enough to overturn a jug which was standing on the floor. Many persons were awakened by the shock, and some not a little alarmed. The duration of the shock was estimated by persons who were up at from 10 to 30 seconds, the former period being probably nearest the mark. The direction of the wave has been stated variously according to the locality and the observer, some saying from north to south, others from west to east, and others from south-west to north-east. It was felt very strongly towards the Shoalhaven, and at Reevesdale, near Bungonia, was powerful enough to shake over a small pile of firewood stacked against the house. It was slight at Bowral, and strong in the direction of Crookwell and Taralga.

This felt area corresponds to an earthquake of magnitude ~ 5.2, with an epicentre between Crookwell and Goulburn at (34.5°S, 149.7°E).

Coincidentally, this earthquake occurred within 24 hours of the earlier magnitude 5.9 Gayndah earthquake in Queensland, and a month after a large earthquake off NE

Tasmania, to say nothing of disastrous earthquakes in New Zealand and Italy in August 1883. Krakatoa volcano erupted in the same month.

1886 04 25 21:02 UTC, Lithgow vicinity

This earthquake was widely reported, for example *The Sydney Morning Herald* of Tuesday 27 April 1886, page 7 and Thursday 29 April page 12 reported:

SHOCK OF EARTHQUAKE.

LITHGOW, MONDAY.

A severe shock of earthquake was felt here this morning at two minutes past 7, lasting several seconds. The direction of the wave was from east to west.

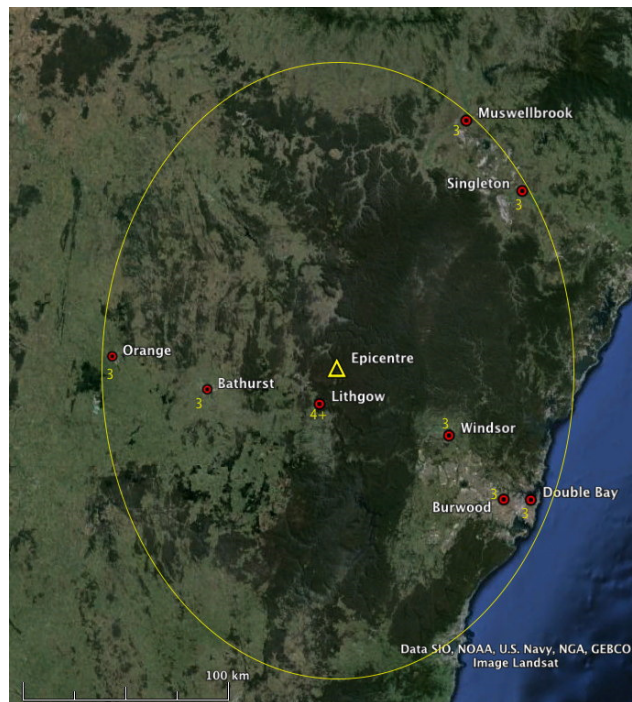
Figure 6 Isoseismal map of the April 1886 earthquake near Lithgow, the ellipse enclosing intensities interpreted as MM3 or more.

SINGLETON, MONDAY.

A slight shock of earthquake was felt here at 7 o'clock this morning, lasting about 15 seconds. The vibration appeared to travel from south-east to north.

A few residents of Bathurst also felt the earthquake at about 7 a.m. and it is quite probable that it was felt at Mulgoa.

The Maitland Mercury and Hunter River General Advertiser, Saturday 1 May 1886, page 16S



The Recent Earthquake.— Concerning the earthquake reported in the *Herald* of Tuesday, the Government Astronomer, Mr. H. C. Russell, writes — "In addition to the places mentioned in your columns at which the earthquake was felt on Monday morning, I have a letter from J. H. Cox, Esq., of Negoa, near Muswellbrook, stating that the earth tremor was felt there at 7 a.m., and lasted four or five seconds, during which the house was felt to shake.

At Burwood, also, the shock was sufficient to rattle the crockeryware. I did not feel the shock, nor was it sufficient at the Observatory to record itself upon any of the instruments." Writing from Windsor on Tuesday, Mr. John Tebbutt says:-- " The earthquake shock referred to in your issue of to-day was distinctly felt here at half a minute past 7 o'clock on Monday morning. It lasted about three seconds. It shook everything in my bedroom, and likewise the window sashes and shutters. It was impossible to determine satisfactorily the direction of the shock, but it appeared to me to be vertical."

The SMH of Friday 30 April 1886, page 8 mentioned that several people in Orange also felt the earthquake. Obviously the epicentre must be nearer Lithgow than any other place

reporting the earthquake, the uncertainty is high. All the same the felt area is large corresponding to a magnitude of ML5.

1886 11 29 at 16:57 UTC, Gunning

An isoseismal map was published for this earthquake (Rynn and others, 1987) that they rated at magnitude 5.5 from the felt area, and their location was near Yass where minor damage was reported though they counsel that the location was very poorly determined. The information presented here would change the shape of the inner isoseismal and shift the epicentre nearer Gunning and Dalton. At Dalton the earthquake was rated a severe shock but no details (*Goulburn Evening Penny Post* Saturday 4 December 1886, page 6) whilst at Gunning it was the most severe ever experienced, and much alarmed many of the residents whose houses seemed to rock to and fro (*Goulburn Herald* Thursday 2 December 1886, page 2). It was not felt in Sydney.

An interesting postscript appeared in the *Goulburn Penny Post* on Thursday 9 December page 4:

The Recent Earthquake. we (Echo) are informed by Mr. C. H. Russell, the Government Astronomer, that the record at Lake George shows no sign of the earthquake, although the observer felt it; and the Newcastle tide sheet is also without mark of the earthquake. It would seem, therefore, that the vibration must have been so momentary that it did not set the water in motion.

The *Goulburn Evening Penny Post* Tuesday 30 November 1886, page 2 commented in a light-hearted manner on the effect of the earthquake at the Goulburn Hospital. The shaking was sufficiently pronounced that Mrs. Guille, the matron of the hospital, got up and did a ward round to check on the patients. The newspaper summarized the effects of the earthquake in a previous paragraph:

EARTHQUAKE SHOCKS. Two distinct shocks of earthquake were experienced in Goulburn this morning at about 3 o'clock. They were accompanied by a loud rumbling sound, and were so severe that the majority of persons were awakened. Houses shook, beds oscillated, crockery and windows rattled, and dogs barked excitedly. Different accounts are given as to the duration of the shocks; but each appears to have lasted several seconds, and there was only a slight intermission between the two. The rumbling sound died away gradually at the close. The shocks were experienced at Bathurst, Yass, Bungendore, Michelago, and Gunning, and doubtless through the whole colony. Opinions vary as to the direction of the current; but the majority believe that it travelled from west to east. They were undoubtedly the most severe shocks ever experienced in Goulburn—at all events, within the memory of most of the inhabitants; and no little excitement has been caused, the occurrence being the principal topic of conversation to-day. A correspondent writes as follows:— " About 3 a.m. this morning two very severe shocks of earthquake running north and south were experienced, the first shock lasting about seven seconds and the last about ten seconds, about five seconds elapsing between the two shocks, the last being accompanied with a heaving sensation and a rumbling like distant artillery. The shocks were severe enough to cause all the glassware and crockery in the room to rattle and the bedsteads to heave to and fro in the direction of the shocks, the vibration lasting fully three minutes after the shocks. The sky was clear at the time, excepting a bank of dark clouds running north and south, the stars having a particularly bright appearance.

Yours obdtly., Fred. H. Wedd, Salford House, Sloane-street."

Gunning, Tuesday. A severe earthquake shock occurred this morning at 2.55, lasting fully a minute. It appeared to travel west to east, followed by a slight shock.

Burrowa, Tuesday. A severe shock of earthquake was felt here this morning at about 3 o'clock. It lasted several seconds, and shook houses very much, frightening several of the inhabitants. Several things in different houses were shaken from the shelves and other places. No serious damage was done. About half-an-hour afterwards another light shock was felt. The first shock was the heaviest ever felt in Burrowa.

1888 07 05 at 20:15 UTC, Gurrundah

When Burke-Gaffney (1952) tabulated this earthquake he assigned it to the Bowral region but McCue (1996) thought that the isoseismal map showed it to have struck the Dalton-Gunning region, neither was convincing. Reports such as that from Camden and Picton – slight, and Bowral – awakened a number of people, indicate that it wasn't near Bowral, but the Yass report – distinct and rattled windows and doors was not too dissimilar. By contrast, at Crookwell, it was called the worst shock ever felt there, and the Goulburn experience was similar. There is no mention of it being felt in Gundagai, though the effects of the earthquake elsewhere were reported.

The centre of the felt area is between Crookwell, Goulburn and Gunning, east of Gurrundah so that is where we will locate it for now.

1912 01 17 at 20:09 UTC, Bega

The Border Morning Mail and Riverina Times Friday 19 January 1912, Page 3.

EARTHQUAKE AT PAMBULA.

AN ALARMING SHOCK. PAMBULA, Thursday.

The residents of this town were greatly alarmed this morning by a severe earthquake which lasted for half a minute. Houses rocked and furniture and crockery rattled in a manner that gave people a great shock. (Pambula, in the electorate of Bega, is situated on the River Pambula, 275 miles south from Sydney, four miles from Merimbula, and 12 miles from Eden, Twofold Bay. It has a charming climate, and is the centre of a dairy and mixed farming and mining district. The population of the town is 43 and of the district 1440.)

An isoseismal map was drawn up by McCue (1996) from which a magnitude of 4.9 ± 0.3 was determined. On the map, the intensity at Pambula was rated MMIV. The earthquake was not included in Drake's list (1974) of post-1909 earthquakes.

1925 12 18 at 10:47:10 UTC, Newcastle

This magnitude 5.3 earthquake (McCue in Rynn and others, 1987; Drake, 1974 measured it at ML5.2 from the RIV recording) was felt from Wollongong in the south to Taree in the north.

PANIC IN PICTURE THEATRE.

A few minutes before 9 o'clock this evening Newcastle and its environs were shaken by two severe earth tremors, which were felt in all parts of the district. Thousands of citizens rushed out of doors to ascertain what had happened.

At Betts' Union Picture Theatre, in Hunter-street West, the tremor caused a panic amongst a large section of the audience. The manager (Mr Fenton) states that when the first tremor was experienced, numbers of the audience shifted uneasily in their seats, and when, almost immediately, the building was again shaken to its foundations, there was a wild stampede for the exits. For a few minutes hopeless pandemonium reigned, and had it not been for the efforts of the theatre attendants, many people would undoubtedly have been severely injured. As it was, many women fainted and had to be carried into the foyer, where restoratives were applied.

At the Strand Picture Theatre, in Hunter-street, Newcastle, the tremor also caused considerable alarm amongst the audience, although those who left the building, did so in a calm and orderly manner.

Coincidentally, the welcoming function for the first bulk oil tanker to visit Newcastle, the Vacuum Oil Company's tanker Pulpit Point, was being held at the Great Northern Hotel that evening and the earthquake caused consternation there. (*The Muswellbrook Chronicle* Wednesday 23 December 1925, page 3.)

The Bombala Times of Friday 25 December 1925 page 1 printed an interesting quote after the earthquake: Rev. Father Pigot, of Riverview College, who is the recognised authority in Australia on earthquakes, declared that there was nothing to be alarmed about, and that a similar shock would not occur for another 20 or 25 years.

History shows that the wait was just short of 7 years, when a similar sized earthquake struck near Gunning. Newcastle had to wait another 64 years.

1933 01 11 at 20:12 UTC, Dalton-Gunning

An earthquake on Thursday 12th January 1933 seems to have heralded the start of a 50 year period of unusually high seismic activity in the Dalton/Gunning region of NSW, apparently dormant since the storm of 1886 to 1888. The earthquake was felt in Sydney suburbs and therefore warranted further investigation. Riverview Observatory had been in operation since 1909 and recorded the earthquake but there were no other seismographs in the state outside Sydney at that time. The epicentre is based on the place reporting the highest intensity, compatible with the distance from Riverview. It was also recorded at Melbourne Observatory.

According to the *Central Queensland Herald* of 19 January 1933: *The tremor left a trail of broken rock and an earth fissure across paddocks. Rocks, some of them weighing 20 tons, were split and shattered.*

Drake (1974) listed the earthquake as the first of magnitude 4 or more in Gunning since 1909 when the Riverview Observatory opened, its magnitude ML4.8. It is worth repeating part of a contemporary newspaper article about the earthquake, noting the damage: *The Sydney Morning Herald* (NSW: 1842 - 1954), Friday 13 January 1933, page 9, with a comment about damage caused by a previous tremor (1886 or 1888?).

Damage at Gunning.

A severe shock of earthquake was experienced over a wide area between Yass and Goulburn early yesterday morning. Considerable damage was done at Gunning, which appears to have received the full force of the tremor.

The shock was felt distinctly at Coogee, Bondi, and other seaside suburbs, and was recorded on seismographs at Sydney and Riverview observatories.

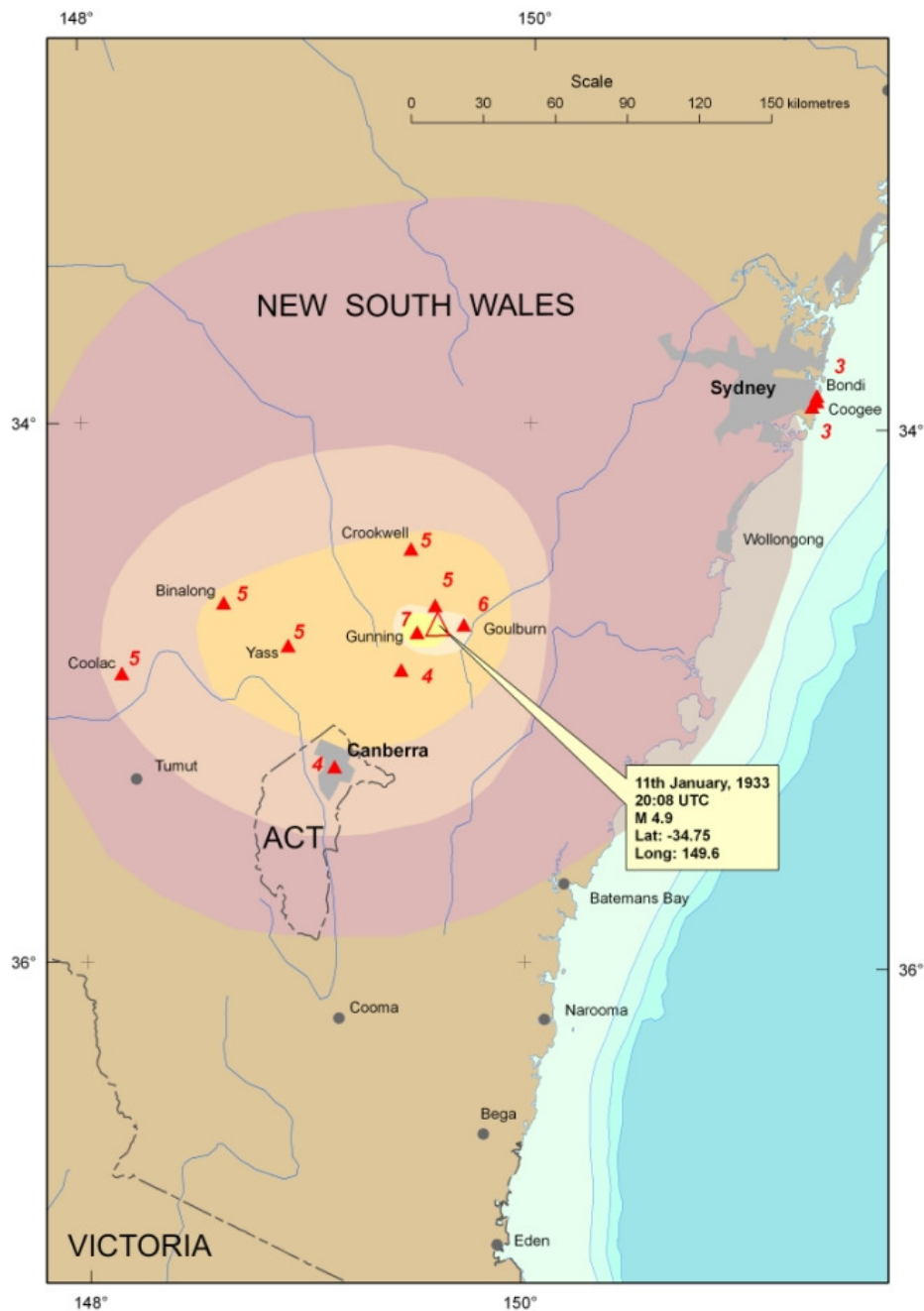


Figure 7 Iseismal map of the 11 January 1933 Gunning earthquake.

At Gunning the concrete dwelling of E. Hallam was badly damaged chimneys being broken walls cracked, and a verandah broken away from the house. The concrete walls of a neighbouring house, occupied by T Johnson developed cracks that would admit a hand. Olivet, the residence of Mr G E Ardill, MLA, had its walls cracked. In nearly every room plaster was scattered about. The walls of the Public school, which had been cracked by a previous tremor, and which had

been recently repaired were again opened up. The wails and ceilings of many other buildings were damaged and articles were shaken off shelves. At one house a 1000-gallon tank full of water was shifted almost off its stand.

After the first shock which occurred at 6.8a.m. tremors of varying intensity continued at short intervals until 6.50a.m. when another severe shock was experienced. Between 6.8a.m., and 7.10a.m., 12 distinct tremors occurred and these were followed by others at 8.40 a.m., 9.40 a.m., and 10.15 a.m.

A resident on the outskirts of the town stated that nothing could be seen distinctly in the town. Everything seemed to be in a haze caused by the shaking of the earth and the buildings.

In Canberra pronounced shaking was reported by residents of Red Hill, Forrest and Gungahleen (now Gungahlin). Dr. W.G. Woolnough, Geological Adviser to the Commonwealth Government, made a request for felt reports via the *Canberra Times* newspaper but received only six responses. Unfortunately these do not seem to have been left for posterity. Newspapers reported it was felt in Crookwell (people thrown from beds) and Coolac (many sleepers awakened).

More than 21 aftershocks were felt in the first thirty hours and 100 aftershocks had been reported felt up to 20 February 1933.

This and many other examples show that old un-reinforced masonry buildings behave poorly in earthquakes. The 1954 Adelaide and 2010/12 Christchurch earthquakes have shown that such buildings are very vulnerable to strong shaking but they may be successfully strengthened by retrofitting with steel (or fibre) bands.

1934 01 30 at 20:30, Gunning swarm and foreshocks

The Braidwood Dispatch and Mining Journal Friday 2 February 1934 page 2.

Gunning was awake practically all Tuesday night owing to the continuous tremors there. Altogether there were some 50 or 60 recorded, the most marked one being that which occurred shortly before 8.30 on Wednesday morning. This shock was felt in Goulburn and Crookwell. At Braidwood and throughout the district a distinct tremor was felt at 6.30 a.m., while at 10.30 or 11 o'clock the previous night a minor shake was experienced. The 6.30 shock, was preceded by a particularly terrific noise like an explosion. 'It gave one the impression that the bottom had fallen out of everything,' said one Gunning resident. Plaster was cracked in many homes, the walls in particular suffering. Crockery was knocked from the dressers and smashed, while floor and window frames were thrown out of alignment. Considerable damage was done at the residence of Mr. A. J. Sumner, on the Dalton road, about two miles from Gunning. The building of concrete and brick suffered badly, practically every wall being cracked from the ceiling to the floor. A room recently added to the main building, which was only completed last week, was torn away from the main building. The walls were cracked, and the door frames were knocked out of position. The dining-room chimney was cut in two vertically, and the kitchen fireplace was cracked in two places. Mr. Sumner said that during the worst tremors the house seemed to rock backwards and forwards, and the noise was nerve racking. At the residence of Mr. Lawliss, a neighbor, plaster fell in the rooms, and portion of the chimney fell, one of the bricks falling through the roof and landing on the breakfast-room

table. The shocks in Gunning are still continuing at frequent intervals, and two or three severe shakes occurred between 1 and 2 o'clock. An underground tank at the residence of Mrs. J. Clancy burst, and 1000 gallons of water escaped. An earth tremor which set beds creaking and crockery rattling was felt in Goulburn at about 6.30 a.m. Residents in different parts of the city reported feeling the tremor with varying degrees of intensity. At Crookwell three shocks were experienced. The first was at about 11 o'clock on Tuesday night, the next at about 2 a.m., and the third, which was most marked, at about 6.30 a.m. This one lasted about a minute.

The magnitude was at least 4.3 to have been so widely felt and cause damage to URM. This swarm is embedded in a remarkable sequence of earthquakes that commenced in 1930 and culminated in a damaging M5.6 earthquake in November 1934.

1934 11 18 at 21:58:41 UTC, Dalton-Gunning – damage to water supply at Goulburn

This and the 1989 Newcastle earthquake are the two largest NSW earthquakes that have occurred since 1788, their magnitude 5.6. The TROVE project has unearthed new information such as the following from *The Sydney Morning Herald* Friday 23 November 1934, page 10:

GOULBURN, Thursday.

The earthquake yesterday afternoon was responsible for the holding up of portion of the Goulburn water supply. A large iron buoy in the settling tank at the waterworks was lifted up, automatically closing the valve regulating the low-level supply. The water was cut off for about two hours. The hold-up was not as serious as it might have been, as most of the Goulburn residents, owing to the hardness of the water through the supply, have rain tanks. Cracks have appeared in the mixing trough and filter tank at the pumping station, and it is estimated that it will cost £15 to repair the damage.

1935 06 18 10:20 UTC Gunning aftershock

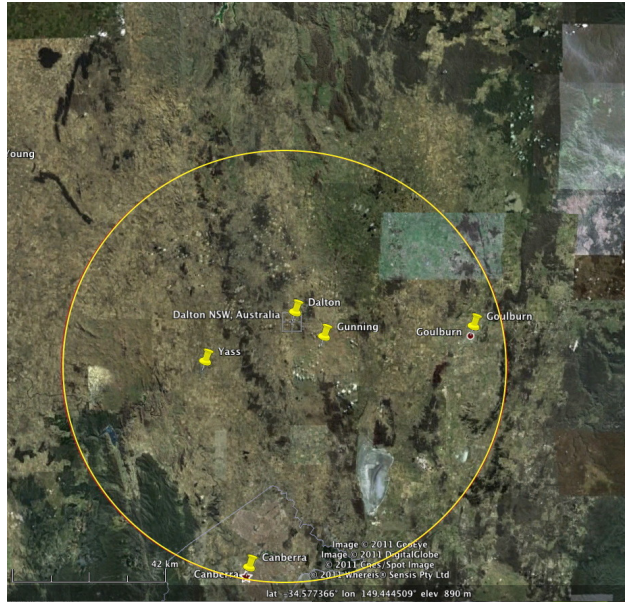
Sydney Morning Herald Thursday 20 June 1935
SEARCH FOR "SAFE-BLOWERS."

Earth tremors, which apparently did no damage, but which set windows and crockery rattling in many homes, were reported on Tuesday night and yesterday morning in southern parts of New South Wales..... The first tremor was reported at. 8.20 o'clock on Tuesday night, and was felt distinctly in Goulburn, Yass, and other towns on the southern tablelands. At Gunning the shock was accompanied by a low rumbling sound, but it was so slight that residents took little notice of it. There was a less pronounced tremor at Yass at 9 p.m.

Figure 8 Felt area of the June 18, 1935 earthquake near Gunning, most probably an aftershock of the magnitude 5.6 mainshock on 18 November 1934 (McCue and others, 1989).

The seismograph at Riverview Observatory recorded the first tremor, but the indication on the instrument was so slight that it was barely perceptible.

The magnitude from the felt area corresponds to about ML 4.3. People reported 15 aftershocks between 6am and 11am. Many more aftershocks in this sequence could probably be documented, such as the event mentioned at 9pm the same night.



1935 07 09 14:05 UTC Gunning aftershock

The Canberra Times of Thursday 11 July page 11 reported that this earthquake was more severe than any other that occurred last November! Crockery was broken and walls cracked in Gunning. The earthquake was felt in Bondi and Coogee, as well as Kiama, Goulburn, Queanbeyan and Yass, almost the same area as the 1933 earthquake warranting a magnitude of at least 4.8 though it is not in Drake's (1974) list. This seems to have been the largest aftershock in the sequence following the magnitude 5.6 mainshock on 18th November 1934.

1938 03 24 at 20:03 UTC, Riverina

The *Daily Advertiser* Saturday 26 March 1938, page 6 reports:

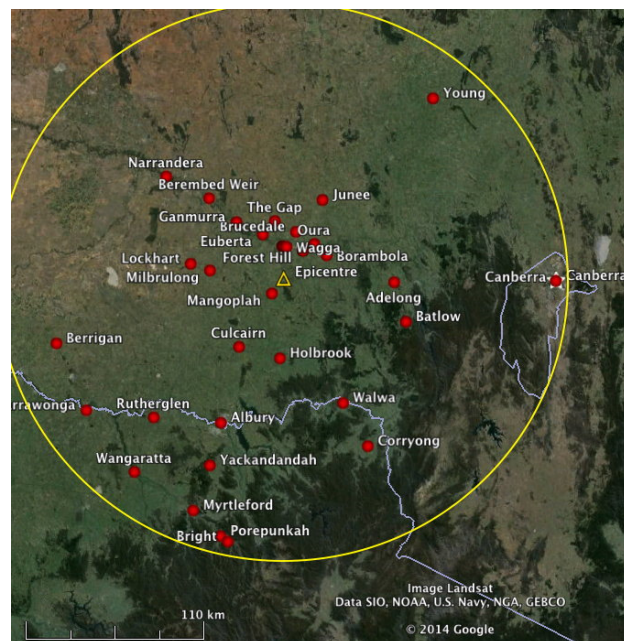
Earth Tremor

FELT IN RIVERINA EFFECT IN WAGGA NO DAMAGE TO PROPERTY

Awakened from their slumber shortly after 6 o'clock yesterday morning, residents of Riverina were alarmed to find themselves in the throes of a severe earth tremor which lasted more than a minute. No damage to property or loss of life resulted, but the effect was startling and by no means pleasant. Houses were shaken, windows rattled, crockery was dislodged from shelves, timbers creaked, beds were moved, and water in tanks and cisterns was ejected. The tremor was remarkable in that it was confined solely to Southern Riverina and a portion of the North East of Victoria. Reports of the tremor show that it was felt from the plains at Lockhart and Milbrulong, south-west of Wagga, right to Batlow, more than 100 miles east of Wagga among the hills, south to Albury on the border and Wangaratta in the north-east of Victoria. Reports as to the exact nature of the tremor vary but all are substantiated, showing that it had different effects. In portions of Wagga it was like a heavy deluge of water pouring on the roofs of houses. At other places it was like a heavy vehicle passing over a paved road. In country districts it resembled a shower of rain, but this was ironical in view of the urgent necessity for rain, and elsewhere it was said to appear like the noise of an empty water tank being carted over a road.

The tremor appeared to move, from west to east and was of about two minutes' duration. Its approach was like the rolling of distant thunder, and the actual tremor lasted about eight seconds.

Figure 9 Felt area of the 1938 Riverina NSW earthquake. No damage was done which is surprising given the estimated magnitude is about 5.2.



Considerable excitement was caused at Euberta, The Gap, Mangoplah, Brucedale, Lockhart, Milbrulong, Forest Hill, Oura, Ganmurra, Moorong, Young, and other district centres. Mr. A. A. Beck, of The Gap, said that the tremor caused the house to shiver like an aspen leaf, and when it was at its height fears were held that considerable damage would be done. Mr. P. Reid, of Ganmurra, declared that the noise was formidable, the crockery in the house rattled, and the house was badly shaken. In one household in the Borambola district the tremor caused much alarm. The occupants were about to rush out of the building, taking with them as much furniture as they could manage when the tremor gradually lessened in intensity and passed away. At the Wagga telephone exchange, the subscribers' shutters dropped, but no damage was occasioned any of the mechanism at the post office.

.... At The Gap, Mr. Glen Hancock was awakened by the rumbling, simultaneously to his friend, Mr. W. Robinson. A delay in printing operations was caused by the tremor at the office of 'The Dally Advertiser' when the paper web on the rotary printing machine was broken. The tremor

was noticeably felt at the Wagga Base Hospital, both in the building proper and in the nurses' quarters. Most patients were awake at this time, but those who had been sleeping were soon aroused from their slumber by the tremor. The vibration lasted for two minutes, but no damage was done to property, and no one suffered any ill effects. No ill effects were felt at Lewisham Hospital, where the sisters and patients just realised that a tremor had occurred.

BATLOW, Friday. Batlow residents were awakened about 6 o'clock this morning by the earth tremor which shook houses, rattling crockery, etc. People jumped out of their beds to see what was the matter. This is the second occasion on which an earth tremor has been felt at Batlow, the first one being only very slight in November, 1934.

1940 09 21 at 14:55 UTC, Canberra

Federal election day with the Pacific War looming, it is perhaps not surprising that this earthquake didn't rate much of a mention in national or local newspapers. The shaking was strong in Canberra where houses shook violently and woke residents there and in Queanbeyan and Tumut. It was also felt in Gundagai.

The Goulburn Evening Post Tuesday 24 and 25 September 1940, Pages 1 and 2 respectively.

BUILDINGS ROCKED Heavy Earth Tremors Goulburn was shaken early on Sunday morning by an earth tremor lasting a quarter of a minute. Although most householders had retired for the night, people living in various parts of the city experienced the tremor, which was of sufficient violence to send a vibration through buildings. Superintendent A. J. Wingate, who was on duty at the ambulance station, said that the quake started at 12.56 a.m. and continued for from 15 to 20 seconds. The whole building was shaken but no damage resulted. Mr. Wingate said that for a moment he thought that the rumbling noise was made by a train passing through the nearby railway yards, but he soon realised that he had been mistaken.

A Montague Street resident said that the wardrobe in her bedroom was severely shaken, while in a house at South Goulburn crockery in the kitchen cabinet rattled in uncanny fashion. At a Bourke Street home a fireplace grate was rocked by the vibration. Employees of the Evening Post who were working on late election returns also experienced the tremor, which caused the front doors of the building to rattle so loudly that it was thought that a caller was knocking. So far there are no reports of damage to buildings, some of which have been badly cracked by similar occurrences in the past.

FELT AT GUNDAROO

A report from the Post's Gundaroo correspondent states that the tremor was experienced there shortly before 1 am. It lasted several seconds and set up a loud rumbling that resembled thunder. Buildings were shaken and many people were awakened from their sleep.

Tremor Widespread. The earth tremor experienced in Goulburn shortly before 1 a.m. on Sunday was felt over an extremely wide area of the Southern Tablelands. Centres which felt the shock also included Canberra, Queanbeyan and Braidwood.

More reports need to be found to tie down this elusive earthquake, magnitude 4.7 based on the felt area here, with an epicentre possibly to the west of Canberra in the ACT which would make it the largest known earthquake in the ACT. The timebase is admittedly very short.

138	"	21	eNE iNE F	14 55 53 55 56 14 56.6	<1							A few very small waves superposed on microseisms. Felt at Queanbeyan, N.S.W. Houses shaken, people awakened. Very little damage. Distance about 160 miles.
(Concluded on next sheet)												

Figure 10 Extract from RIV Bulletin 9/1940 by D.J.K. O'Connell SJ, Director RIV (provided by Hugh Granville, Geoscience Australia). No reports of damage have been unearthed.

1943 02 22 at 14:45, 20:00, 20:30, 21:00 and 21:45 UTC, Gunning

Goulburn Evening Post Wednesday 24 February 1943, Page 1.

EARTH TREMORS AT GUNNING Gunning was visited again yesterday Tuesday by a few earth tremors. The first occurred about a quarter to one a.m. and was fairly heavy, accompanied by a distant rumbling. Somewhere about 6 a.m. another tremor came not so severe as the first. Then at 6.30 a.m. a sharp and fairly heavy one occurred and was followed by two more, one at 7 a.m. and another at 7.45. It is some time now since we have had a visit of these earth settlements writes our correspondent, and it was thought that we were done with them.

The newspaper print is almost indecipherable so these times might not be correct.

The Canberra Times Wednesday 24 February 1943, Page 3.

EARTH TREMORS AT CANBERRA

A slight earth tremor was experienced in Canberra yesterday morning.

The tremor, which occurred at about 6.35 a.m. and lasted for about six seconds was felt by a number of residents. Rooms shook with a light but steady vibration followed by a faint underground ticking.

Inquiries at Mt. Stromlo Observatory revealed that recordings of such phenomena are not kept there.

Similar tremors have occurred intermittently in the A.C.T. over a period of years and are believed to originate around the Lake George District.

The lack of a seismograph at the Observatory on Mt Stromlo was not remedied for another 20 years, and the fixation of geologists that because the largest fault in the region was along the western edge of Lake George therefore it must be the source of the earthquakes, hasn't changed much.

1945 02 27 at 05:10 UTC, Canberra

The Canberra Times Wednesday 28 February 1945, Page 2.

Earth Tremor Felt in Canberra

An earth tremor was experienced in Canberra about 3.10 yesterday afternoon, but was of brief duration. It resembled a distant detonation, a low rumbling sound being followed by a tremor lasting about 12 seconds.

The occurrence was noticed by householders in some parts of the city and was also experienced in the Commonwealth offices. One of those who noticed the tremor in the Commonwealth offices was Mrs. Fisher who formerly resided at Rabaul, where her husband (Dr. Fisher) was attached to the observatory where seismic disturbances were recorded frequently. "I knew I was not mistaken that it was an earth tremor," said Mrs. Fisher when she rang "The Canberra Times" later to enquire if any other reports of the tremor had been received. "It almost made me feel homesick," she added.

Earth tremors have been experienced at Canberra on several occasions during the last 20 years and are believed, to originate from subterranean settlement which is taking place in the Gunning-Gundaroo district along the northern end of the Lake George fault.

There are no reports that this earthquake was felt locally elsewhere, like Queanbeyan, Sutton, Gundaroo, Murrumbateman, Gunning or Royalla, so we suppose it was an ACT event to the southwest of the city, magnitude about 3.

1946 05 10 at 16:00 UTC, Gunning

Goulburn Evening Post Thursday 16 May 1946, Page 1

GUNNING SHAKEN by Earth Tremor Gunning: Residents were awakened at two a.m. on Saturday last, when the town experienced a recurrence of the earth tremors so prevalent a few years ago. The first shock was sharp and sudden, lasting about three seconds. This was followed by three tremors of lesser intensity, but accompanied by a sustained rumbling noise. No damage to property has been reported.

This was obviously a small but close earthquake.

1946 08 10 at 15:45 UTC, Goulburn and Gunning

Goulburn Evening Post Monday 12 August 1946, Page 7.

EARTH TREMOR At Goulburn and Gunning A sharp earth tremor was felt at Goulburn and Gunning between 1.30 am. and 2 a.m. yesterday. At Gunning the tremor was preceded by a deep rumbling sound. This was followed by a loud report and a distinct tremor, which shook houses and rattled iron roofs. A minor tremor occurred a few minutes later, followed by more deep rumbling. The tremor travelled in a south-easterly direction. During the past fortnight there have been several minor tremors at Gunning.

With an epicentre between Goulburn and Gunning but closer to Gunning the magnitude would have to be at least 3.4.

1947 05 05 at 04:43, Gunning

FOUR HEAVY TREMORS. CANBERRA ALSO SHAKEN.

SYDNEY, May 5.—Earth tremors were felt at several towns in New South Wales this afternoon. At Canberra there were also two shocks. The worst quake was at Gunning, between Goulburn and Yass, where buildings were shaken, and people became alarmed. There were four tremors described as "heavy" within 15

minutes. Three shocks were recorded at Riverview Observatory, where an official said that the first of the three shocks was the heaviest recorded in Gunning district since 1934.

Two of these earthquakes had to be around magnitude 4 to have been felt in Canberra, indeed the largest was measured at 4.5 by Drake (1974).

1948 02 02 at 07:26 UTC, Sydney suburbs

Newcastle Morning Herald and Miners' Advocate Tuesday 3 February 1948, Page 1.

Earth Tremor in Sydney Suburbs

SYDNEY, Monday.—An earth tremor felt in several suburbs at 5.26 p.m. today shook houses and rattled windows. Father O'Connell, of Riverview Observatory, said there was a distinct recording on the seismograph. The Weather Bureau was flooded with telephone calls from people inquiring about the tremor. The shake was felt at Arncliffe, Bexley and Eastwood. One man at Arncliffe said his house shook alarmingly, but the shake was not sufficient to cause damage. Police at Kogarah said they did not feel the tremor, but heard what sounded like a dull explosion in the distance. Mrs. F. Day, of Halley-avenue, Bexley, said: "I heard what I thought to be an explosion. It shook the house, and, thinking it was an explosion, I ran outside. People were running from their homes asking each other what had happened." Mr. R. A. Burt, of Victoria-street, Arncliffe, said there was an explosion like a big gun going off, and his house shook slightly.

Other papers carried the following interesting paragraph:

An assistant at Riverview Observatory said tonight the tremor was a type which occurred occasionally in Sydney, but was nothing to worry about. These tremors were caused by a small re-adjustment in Sydney's underlying rock formation.

Earthquakes under Sydney suburbs are fairly rare and this one, felt over a radius of 16km (reported as 10 miles) was smaller than magnitude 3.0.

1949 03 10-16, Gunning

Joklik (1951) wrote up the field survey conducted by BMR soon after the mainshock on 10 March 1949 at 8:31am EST, and included an isoseismal map for the source area. He commented that the attenuation was very rapid. Very usefully he tabulated the RIV amplitudes measured by Burke-Gaffney for the mainshock and main aftershocks, for both the 1934 and 1949 earthquakes. This enables the magnitudes of those aftershocks to be computed and confirms the difference in size of the two mainshocks as 0.1 (5.6 and 5.5).

1949 07 17 at 14:59 UTC, North of Newcastle

Newcastle Morning Herald and Miners' Advocate Tuesday 19 July 1949, page 2.

Earth Tremor at Bulahdelah An earth tremor lasting about a minute shook Bulahdelah about 1 am. yesterday. Houses trembled, but no damage was done. Sergeant Casey, of Bulahdelah, said he was awakened by the violent shaking of the police station. He thought it had been caused by an explosion. When he went into the street he found that the occupants of houses in the

vicinity had also been awakened. An alum mine is the only one operating in the Bulahdelah area. The tremor was felt at Stroud, 30 miles west of Bulahdelah, and at Coolongolook, 16 miles north.

Many Tea Gardens residents got up and had a look around when their sleep was disturbed shortly after 1 a.m. on Monday morning. It was like a dull explosion and houses and crockery shook almost immediately. The Riverview Observatory recorded a shock at 12.59 a.m., whereas locals timed it at 1.9 a.m.

It woke a few people at Bulahdelah. A magnitude of 3.5 is consistent with the felt reports and its detection at RIV (Thanks to Cynthia Hunter, 1991 for finding this event).

1951 07 09 at 04:45 UTC, Newcastle

The *Newcastle Morning Herald and Miners' Advocate* Tuesday 10 July 1951, page 1.

Earth Tremors Shake Homes In Newcastle District.

Earth tremors shook houses over a wide area in the Newcastle district between 2.45 and 3 p.m. yesterday.

In the absence of official information, Mr. Mark Howarth, of Grange Mount Observatory, Mayfield, said the tremors might have been caused by the collapse of a cliff or shelf under the sea. About 20 years ago a similar phenomenon occurred at sea between Norah Head and Redhead.

Mr. Howarth was working in his garden when he heard a sound he had believed to be thunder. He did not take much notice of it till his wife, who was in the house, said the building had trembled. Men at the lighthouse at Norah Head, which is within sight of Bird Island, said planes were dropping practice rockets or bombs on the island between 1.30 and 2 p.m. yesterday. They heard explosions and saw earth thrown up, but the ground did not tremble nor the lighthouse shake.

The tremors were felt in Newcastle and suburbs. They were pronounced in the Lake Macquarie area and at West Wallsend. A number of shocks were felt about 2.45. They were followed about five minutes later by a single tremor. Mr. A. Connor, of Speers Point, said his house shook and windows rattled. Believing it was an explosion, he went into the street, where a lot of people had assembled. Mr. Joe Walters, of Fourth-street, Boolaroo, said he felt six or seven tremors in his house. People in the area congregated in the street. Some believed there had been an explosion in a mine or that blasting was taking place nearby.

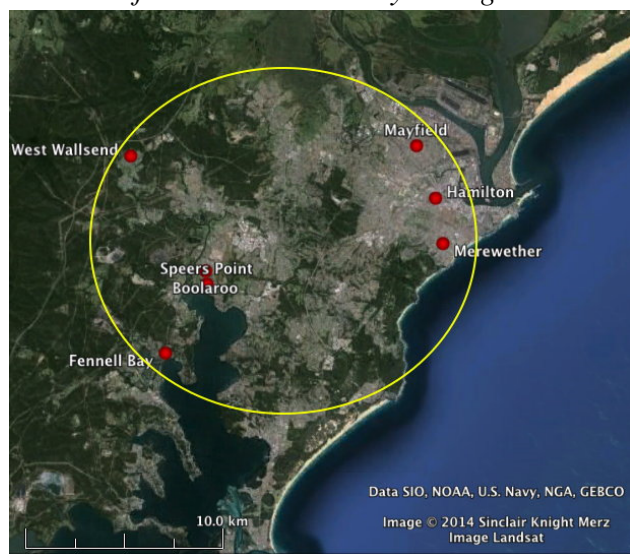


Figure 11 This plot of the felt reports is intriguing, the centre is near the epicentre of the 1989 Newcastle earthquake and

aftershock. The timing rules out the bombing exercise as the cause as does the location of Bird Island, nearly 40 km south-southwest of the city. Hunter (1991) discussed this event, plotted the felt reports and concluded it was an earthquake.

People working in offices in Telford-street, City, were startled when windows shook and a noise like an explosion seemed to strike the premises. Householders at Hamilton, Merewether West, Mayfield and Merewether proper noticed that the windows in their properties rattled. A sound like thunder accompanied the rattles. A group of tennis players at a Merewether court put the noise and tremors down to thunder—there were heavy cloudbanks in the south and rain had been falling. Tremors were felt at Argenton and Fennell's Bay. At West Wallsend a miner who heard the noise said it sounded much like a shot echo followed by vibration. Two members of Lake Macquarie Ambulance, Messrs. Ken Avery and George Barnier, who were in an ambulance car at Warner's Bay, said they felt the concussion just as the car had stopped at a house.

1952 05 19 at 11:10 UTC, Western NSW

This earthquake was very widely felt according to the *Barrier Miner* Tuesday 20 May 1952, page 4.

Broken Hill last night was affected by an earth tremor centred mainly south of the city. Most of the several thousand square miles of the West Darling district felt the shock. Reports today disclosed that most parts of the city were affected. The tremor lasted up to about ten seconds. It was felt about 9a.m.

Many residents said that glass in windows and glassware in the house rattled. They said the tremor was accompanied by a low rumble. It resembled the noise of a 20-ton truck passing on the roadway. It is believed the tremor was more severe in the southern portion of the city. No reports of damage or actual earth movement were received. The tremor did not interrupt work on the mines. Many people slept through the tremor and were told about the happenings this morning.

Figure 12 Felt area of the Western NSW earthquake of 19 May 1952. The epicentre (compatible with the felt reports) is very approximate.

Outback stations disclosed that the shocks were more severe there. They were felt at Menindee, Wilcannia and to a lesser degree in the Cockburn area.

Station hands were awakened by the rumble and shaking of their quarters. Station property south of the city seemed to get full force of the tremor.

A report from Pine Point station showed that when the tremor occurred, the walls and roof shook, and a bed rocked sideways. Other stations also reported similar experiences. Although party telephone lines in the outback were kept busy last night, the Broken Hill exchange did not experience any noticeable increase in phone calls. There was no undue panic as the result of the tremor.

Broken Hill experienced a more severe shaking about 50 years ago when windows, furniture and crockery rattled. A local resident said today he recalled a tremor about 8 o'clock at night in May 1903 (Author - good memory: 1 May 1903 at 6:20pm local time). He remembered men going underground to check workings.

1952 09 07/08, Gunning, old cracks reopened

The little town of Gunning (pop. 700), half-way between Goulburn and Yass, may be a mild earthquake centre. The director of the Riverview Observatory, Father N. Bourke-Gaffney, said yesterday that the town appears to lie on a "fault" in the earth's crust.

It is in such areas that earth tremors are most likely. The "fault" would explain why Gunning feels tremors so often. The latest occurred yesterday and on Sunday. There were 15 altogether. "We recorded our first tremor on Sunday at 3.42 p.m.," said Father Bourke-Gaffney. "It is likely that the shocks to-day were only 'after shocks'."

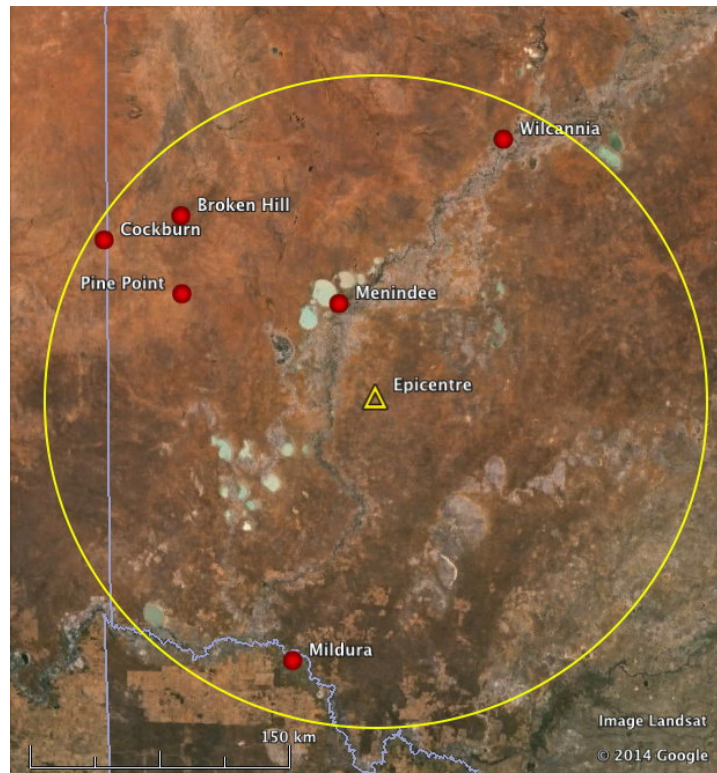
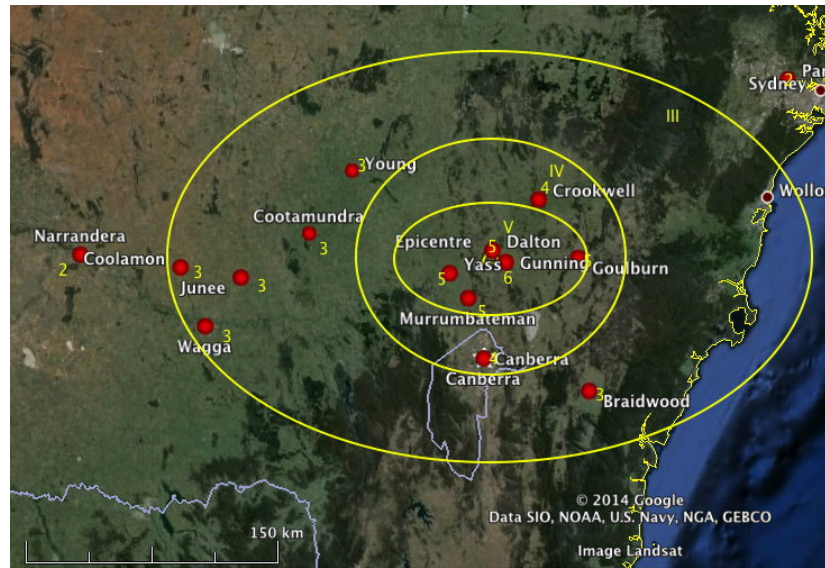


Figure 13 Isoseismal Map of the Gunning earthquake of 19 November 1952 at 01:59 UTC. The felt area indicates a magnitude of 5.2, higher than Drake's (1974) estimate of 4.9, but it was felt as far as Parramatta (200km away MM2) and Narrandera. This map may change as more newspapers are scanned by ANL.



Older residents say the tremors are commonplace. Mr. Bill Lyell, a grazier, of Byalla Street, who is a lifelong resident, can, like many other people, point to cracked walls in nearly every room. "Yesterday's tremors opened cracks we had sealed and shook the roof back a couple of inches," he said. "We are used to these things now. We try to fix up the cracks, but each year they open up again."

Tremors May Last Centuries CANBERRA, Sunday.—The earth tremors which continue to shake Gunning may recur intermittently for thousands of years. The Chief Geologist of the Bureau of Mineral Resources (Dr. N. H. Fisher) said this to night. Ultimately they would result probably in a change in the terrain, which may take the form even of a new range of hills. Dr. Fisher said there was nothing to indicate any likelihood of a major earthquake at Gunning. Severe earthquakes usually occurred suddenly. The Gunning tremors were known to be reasonably deep and were probably associated with movements of a fault in the earth's surface, which were associated with the formation of Lake George, near Goulburn. A severe tremor last night shook Gunning, Yass, Dalton and Crookwell. It rumbled like thunder beneath Parliament House, Canberra, 40 miles away. It dislodged plaster from walls and ceilings but did no other damage. Sergeant V. D. Daley, of Gunning police, said the earth shook at half-hourly intervals to-day, with the most distinct tremor at 3 p.m. Sergeant Daley said he was in the station woodshed when the big shake occurred. "It sounded like thunder in a big tank and I felt the floor move under me," he said.

There was an earlier earthquake at Gunning on 18 August, no details in the *Goulburn Evening Post* of Thursday 1 January 1953, page 2.

1954 05 28, daytime, Newcastle

Newcastle Morning Herald and Miners' Advocate Saturday 29 May 1954, page 3:

The cause of earth tremors which rattled windows and shook wall fixtures in many Newcastle homes yesterday remains a mystery. The R.A.A.F. at Williamtown did some bombing, strafing and rocket firing at Morna Point yesterday (author: 33km NE Newcastle city), but the blast from those

operations is not likely to have reached Newcastle. Suggestions that the tremors were caused by subterranean upheavals were not supported last night by a report that Sydney observatory had no record of any earth tremor near Newcastle during the day. Riverview Observatory also had no record of an earth tremor.

From many similar experiences, the author is confident in attributing this incident to the nearby RAAF exercise.

1954 06 09 at 16:26 UTC, Crookwell

Crookwell seems to have borne the brunt of the shaking at 2:26 a.m., where the 3000 residents are reported to have spent a sleepless night (*Argus*, Friday June 11, 1954 page 3). At Gunning the shaking was also rated severe. The *Canberra Times* mentions that it was slightly felt in Canberra, (author - not one I remember). It has been assigned magnitude 4.5 subject to more information. It was recorded at Riverview but not mentioned by Drake (1974).

For copyright reasons, ANL cannot digitise newspapers later than 1954 (apart from *The Canberra Times*) so there is a gap between then and about 1959 when an ANU seismograph network became operational. Two earthquakes in that period were noted in *The Canberra Times* and are included below for interest.

1956 08 15 at 16:47 UTC, Orange

The Canberra Times Friday 17 August 1956, page 3:

SYDNEY, Thursday. — Severe earth tremors to-day shook Newcastle and Orange districts, rattling doors and windows.

At Orange, where the tremor occurred at 2.47 a.m., residents ran outside their homes in night attire to see what had happened. Police thought the "crack" of the tremor was the noise of a safe being blown. They patrolled the main streets in an attempt to find the cause of the tremor. Mrs. Noel Wheatley, of Kite Street, Orange, said she was drinking coffee with her husband and friends when she heard a loud rumbling noise. "It came close, and then the windows and doors rattled," she said. Other residents said the tremor made a noise like an express train. In a grocery shop in Price Street goods were thrown to the floor.

Police said no damage had been reported. It was the third tremor Orange has had in five years.

1956 08 16 at 01:00 UTC, Newcastle

The Canberra Times Friday 17 August 1956, page 3:

The first tremor in Newcastle was reported from the police station and later from Merewether and Mayfield. Police said they felt the tremor soon after 11 a.m. It shook the building and caused lights to sway. It was followed shortly after by another distinct tremor, similar to the first.

Mr. M. Howarth, of the Grange Mount Observatory, said the tremors could have been caused by the collapse of a marine shelf some miles from the coast. This has happened before. The last time I can recall that tremors were felt in Newcastle was about 28 years ago," he said.

4 DISCUSSION

There are some big unknowns in modeling earthquake recurrence in Australia:

- Why do large intraplate earthquakes occur in Australia? Is an upper bound of 7.5 realistic and what controls the upper bound?
- Is the pattern of earthquakes $M \geq 3$ during the short period of seismograph coverage of the continent stationary? If so why?
- Will the pattern of future earthquakes reflect the pattern of past earthquakes?
- Earthquakes under the northern Sydney Basin are virtually singular events, quite different from those under the southern Sydney Basin and Dalton-Gunning regions that have extensive aftershock and some foreshock sequences. From focal mechanism studies, the principal stress direction in the Newcastle region is almost orthogonal to that in the Dalton-Gunning region – why?
- Why did none of the 20 observed large ($M > 5.9$) earthquakes of the last 100 years occur on a known fault? Should a knowledge of the whereabouts of large faults influence earthquake hazard estimates?
- Where might the next large earthquake occur?
- When will a large earthquake strike a major Australian city (~10 of them); or a critical facility such as the Lucas Heights nuclear reactor; the Geelong Animal Health Laboratory; or one of the many (~500 according to ANCOLD) ‘large’ dams.
- Why are there active volcanoes in continental Australia, far from the plate boundaries and plumes?

This study aimed to recreate Clarke’s lost list, the earthquake history of NSW since European settlement, and assign the events a magnitude, to help answer the first four of these questions. Additions and improvements in the epicentres will be made as more newspapers and other historical documents are scanned and made publicly available by the ANL. For example, the 1933 Gunning NSW earthquake should have been felt at Wollongong, Picton, Bowral and Crookwell, unless its location reported here is incorrect.

The study shows that we can be reasonably confident that a large ($M \geq 6.0$) earthquake has not occurred in NSW in the last 150 years, since ~1865, about double the inferred return period. There have been 19 earthquakes of magnitude 5 or more in that time; about one per 7 years on average, the last one in 1997 (The Range in Western NSW), 17 years ago, more than twice the average return period. Six of the earthquakes were of magnitude 5.5 or more, the largest the 1989 Newcastle and 1934 Dalton-Gunning earthquakes of magnitude 5.6.

Table 1 Approximate completeness and recurrence intervals in NSW

Magnitude	Complete since	Return period (yr)
3	1972	0.12
4	1910	1
5	1865	7
5.5	1865	25

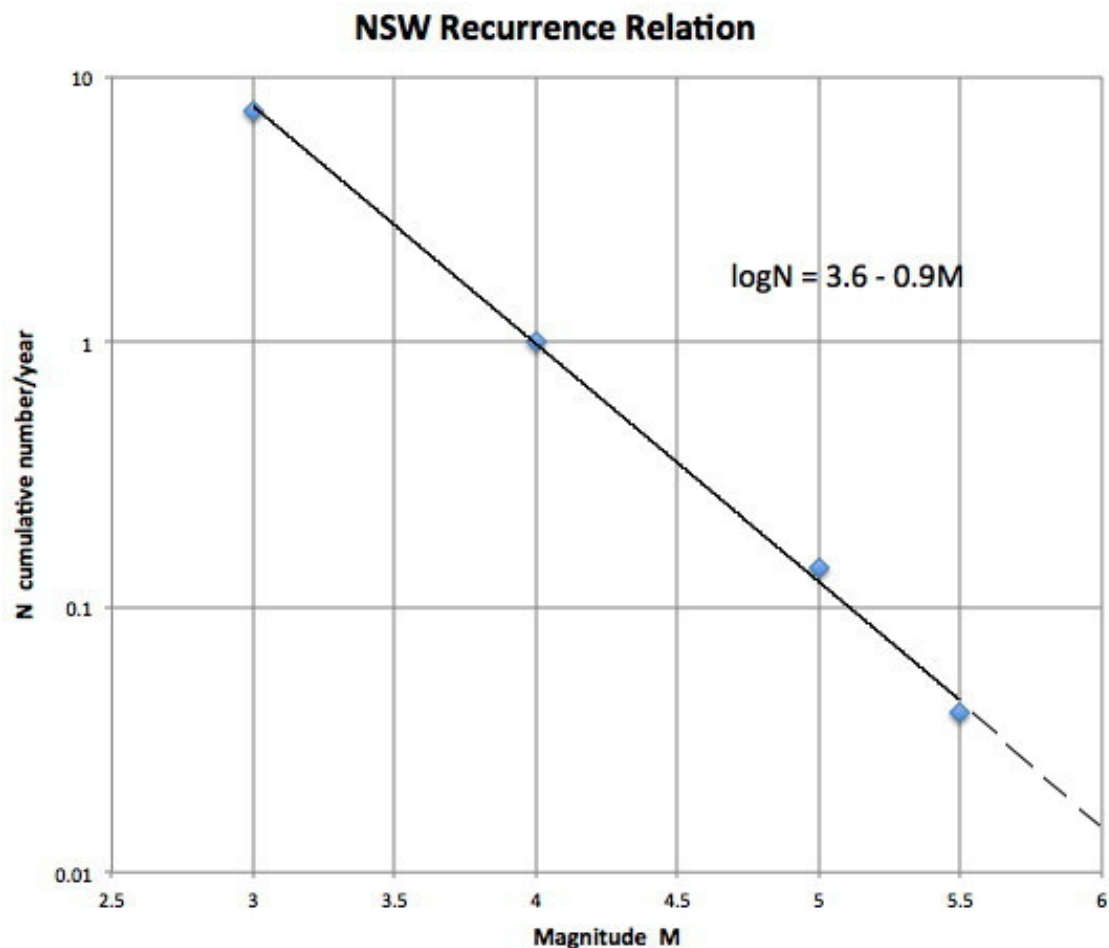


Figure 14 Recurrence relation using data from Table 1. The slope or ‘b’ value is 0.9. The magnitude uncertainty is about ± 0.2 . The inferred return period for a large earthquake, $M \geq 6$, is about 70 years.

More data will improve all of the events studied in this paper (summarised in Table 2 below) and perhaps this information will come to light in the future, there is always scope for improvement as Underwood (1972) pointed out 40 years ago. Many of the earthquakes mentioned in the Appendix have not yet been investigated. Additional historical events will be found and further study of some of the events mentioned in new newspaper extracts will enable their magnitudes to be estimated so that they can be added to databases, pushing the completeness interval to a lower magnitude and an earlier starting date.

It is suggested from time to time that some of the earthquakes reported felt in NSW were caused by mining, reservoir filling or other non-tectonic causes. Indeed human activities are increasingly leading to earthquakes, whether pumping fluids underground for waste

disposal or geothermal reservoir production, filling large reservoirs or mining. Historically, mining has shown a capacity to induce earthquakes, the coalmines of NSW and Queensland as well as the hard rock mines in NSW, SA and WA and more recently fracking operations in coal rich areas. All such operations should be monitored closely with local networks of seismographs, and it is essential that the data be made publicly available even if it has to be undertaken by governments to achieve this. A national publicly-accessible database of induced seismic events should be created both to prevent such man-made events corrupting earthquake databases and for more robust study of the phenomena.

Table 2 NSW earthquakes. Most of the listed magnitudes were derived from the felt area.

Date	Time (UTC)	Lat°S	Long°E	Mag	Location and comments
1788 06 22	01:00			-	Sydney
1800 01 17	-			-	Parramatta (?)
1801 02 12	13:00	33.8	150.7	4.0	Penrith
1804 05 07	11:30	33.7	150.9	3.3	Parramatta
1806 09 24	-			-	Richmond (Hill), 12km N Penrith
1826 04 21	10:00	33.9	150.9	3.3	Parramatta
1837 08 02	12:20	32.7	151.6	5.0	Newcastle
1841 01 27	21:15	32.8	151.6	5.0	Newcastle
1842 03 02	22:45	33.4	149.6	3.8	Bathurst
1842 10 27	19:30	32.6	151.6	5.3	Newcastle
1850 09 23	17:20	34.9	148.8	3.0	Good Hope (near Yass)
1850 11 30	02:30	34.0	149.7	3.0	Abercrombie River (N Crookwell)
1858 06 24	09:00	35.9	144.3	4.0	Murray River near Echuca
1859 03 05	00:30	35.53	149.63	3.6	Braidwood
1860 03 04	10:08	34.8	148.9	5.0	Yass
1860 08 16	16:30	35.6	149.8	3.5	Araluen
1862 04 23	17:45	33.0	149.6	4.0	WNW Sofala
1862 12 19	19:00	34.6	148.8	3.3	Yass/Boorawa
1865 02 13	-	34.5	148.8	3.0	Boorawa (evening)
1865 10 09	-	30.5	151.7	3.0	Armidale
1866 11 27	11:45	36.7	149.8	3.0	Bega
1868 06 18	14:00	32.8	151.6	5.3	Maitland/Newcastle
1870 03 26	09:45	29.3	151.0	3.5	Wallangra
1870 04 05	-	30.5	152.9	3.0	Lower Macleay
1870 04 10	11:20	30.5	152.9	3.5	Lower Macleay
1870 04 18	08:00	30.5	152.9	3.5	Lower Macleay, the 3 rd and largest, to 22 nd
1870 04 21	19:55	30.5	152.9	3.0	Lower Macleay
1870 05 28	12:00	34.5	149.5	3.5	Crookwell
1870 06 18	01:30	30.5	152.9	3.5	Lower Macleay, 1st of many to 23 rd
1870 06 18	03:20	30.5	152.9	3.5	Lower MacLeay
1870 06 18	06:00	30.5	152.9	3.0	Lower Macleay
1870 06 23	08:10	30.5	152.9	3.8	Lower Macleay
1870 06 27	15:50	30.5	152.9	3.0	Lower Macleay
1870 07 08	02:00	34.1	149.2	3.0	Markdale
1870 08 03	20:30	30.5	152.9	3.5	Lower Macleay (largest of 3 shocks)
1870 08 06	20:00	36.1	150.0	3.5	Eurobodalla
1870 08 24	16:55	30.5	152.9	4.0	Lower Macleay, largest earthquake of swarm
1870 08 06	20:00	36.1	152.9	3.5	Eurobodalla
1870 08 27	15:50	30.5	152.9	3.5	Lower Macleay
1870 10 ??	-	30.5	152.9	3	Lower Macleay
1871 05 01	20:55	35.3	149.7	3.5	Braidwood
1871 06 08	04:40	35.4	148.1	5.3	Tumut/Adelong
1871 07 13	16:00	35.2	148.0	3.0	Tumut/Adelong
1872 01 03	13:10	35.6	148.2	5.1	Tumut
1872 10 18	09:50	33.7	150.0	5.3	Jenolan Caves
1872 11 16	18:50	35.35	149.25	3.5	Queanbeyan
1873 05 19	08:20	33.7	150.0	4.5	Near Lithgow/Portland
1873 07 22	06:55	34.7	150.0	3.0	Marulan (Morowollen)
1873 09 23	16:45	34.75	149.7	3.0	Goulburn
1874 01 22	12:00	35.3	148.2	3.0	Tumut
1874 12 14	01:00	34.75	149.7	3.0	Goulburn
1875 01 25	00	36.2	149.1	3.0	Cooma
1875 06 03	10:00	31.7	145.6	5.2	Cobar

1875 07 11	06:00	36.9	149.8	3.8	Bega and Eden
1875 07 16	01:12	36.9	149.8	4.0	Southern Monaro, Bega and Eden
1875 08 05	-	36.0	146.9	3.0	Felt Albury
1875 09 25	12:00	34.4	150.7	4.0	NE Bowral
1876 01 21	04:30	33.2	145.9	3.2	Bathurst/Hillend
1876 02 08	07:15	33.5	150.1	3.0	Lithgow
1876 08 03	01:20	34.8	149.1	3.5	Yass and Gunning
1877 02 27	08:00	33.6	149.1	3.2	Carcoar
1877 11 28	02:30	37.1	148.9	4.0	Bombala
1878 02 03	02:00	36.25	148.75	3.5	Berridale
1880 07 31	07:00	31.0	148.4	5.4	Coonamble region
1880 11 26	03:15	31.0	151.65	3.5	Walcha
1881 05 10	07:00	30.9	153.0	3.0	Macleay District
1881 09 23	00	28.9	152.0	3.5	Tenterfield
1881 09 30	11:30	35.3	148.15	3.0	Adelong and Tumut
1883 08 29	14:00	34.5	149.7	5.2	Crookwell
1883 09 20	11:50	35.45	149.45	4.0	Bungendore/Braidwood/Queanbeyan
1885 01 18	01:57	33.89	151.24	2.0	Sydney Eastern Suburbs
1885 01 21	01:00	36.3	149.1	4.7	Berridale
1886 02 08	02:00	31.5	146.0	3.5	Near Cobar
1886 04 14	00:00	33.6	149.1	3.5	Carcoar and district
1886 04 25	21:02	33.34	150.24	5.0	Near Lithgow
1886 08 02	10:50	36.5	149.8	4.0	Bombala
1886 08 29	20:15	34.3	148.3	3.5	Young, goods off shelves
1886 09 06	18:30	32.9	151.7	3.0	Newcastle
1886 09 12	-	36.5	149.8	3.0	Bombala
1886 09 12	09:30	32.7	151.5	3.0	West Maitland
1886 11 29	16:57	34.7	149.1	5.5	Gunning
1887 07 28	07:23	31.4	146.9	4.0	Nyngan
1888 02 06	12:30	34.75	149.7	3.0	Goulburn
1888 07 05	20:15	34.65	149.5	5.3	East of Gurrundah
1888 10 26	13:00	34.7	146.5	3.0	Narandera
1888 12 27	22:45	35.3	148.0	3.0	Adelong
1889 10 04	03:40	31.0	152.9	3.0	Smithtown, Macleay River
1890 04 25	16:10	34.0	149.3	3.0	Tuena
1891 03 14	15:00	30.9	153.0	3.5	Kempsey Macleay district
1891 06 14	22:40	32.7	151.6	3.0	Morpeth, many small events
1892 08 22	09:30	35.1	148.1	3.0	Gundagai
1892 08 27	20:30	36.25	149.1	3.0	Cooma
1893 07 31	16:00	34.7	149.7	3.0	Goulburn two shocks
1893 09 25	08:45	35.2	148.5	4.2	Tumut
1894 05 27	11:30	36.25	149.1	3.5	Cooma
1896 03 12	12:45	30.8	148.7	3.5	Cowra, double shock like explosion
1896 10 26	02:00	31.25	149.3	3.0	Coonabarabran
1897 05 05	18:55	35.35	149.25	3.5	Queanbeyan
1897 08 16	19:30	36.25	149.1	3.5	Cooma
1897 10 20	12:22	34.6	149.7	3.5	Goulburn
1898 02 21	14:40	34.3	148.3	3.0	Young
1898 02 24	11:40	34.3	148.3	3.5	Young
1898 11 13	15:00	35.4	149.3	3.0	Queanbeyan
1898 11 16	-	36.3	149.1	3.0	Series at Cooma
1899 03 15	10:30	34.65	149.65	3.0	Goulburn
1900 07 21	02:00	35.3	149.7	3.5	Braidwood
1900 08 07	23:05	34.0	149.7	4.0	Oberon, Crookwell etc
1900 10 06	05:00	36.25	149.1	3.0	Cooma
1900 10 06	13:30	36.25	149.1	3.0	Cooma
1901 03 07	10:00	36.2	149.1	3.5	Cooma, 5 events

1902 02 27	18:00	32.65	151.4	3.8	Greta
1902 02 28	12:30	34.07	150.65	4.3	Camden minor damage, not felt Observatory
1902 05 27	02:00	33.5	150.1	3.0	Lithgow, people fled houses
1902 07 07	21:00	34.25	148.25	3.0	Young
1902 07 07	22:00	34.35	148.35	3.0	Young
1902 07 08	07:23	34.3	148.3	3.3	Young 3 events, largest at 5:23pm local time
1902 08 13	10:20	34.3	148.3	3.0	Young
1902 08 25	18:10	34.3	148.3	3.0	Young
1902 09 13	18:15	34.3	148.3	3.5	Young, possibly the largest of the swarm
1902 10 15	11:14	36.1	149.0	3.2	Cooma and Adaminaby
1902 10 18	15:10	34.3	148.3	3.2	Young
1902 10 18	20:25	34.3	148.3	3.0	Young
1902 10 25	18:10	34.3	148.3	3.0	Young
1903 02 26	12:30	33.5	150.1	3.0	South Bowenfels, Lithgow
1903 03 26	07:00	29.9	150.6	3.0	Bingara
1903 04 30	08:20	31.75	141.2	4.3	Western NSW near Broken Hill
1903 06 02	12:00	31.8	141.2	3.0	Silverton, Broken Hill
1903 06 11	07:57	32.3	148.9	3.0	Cooma and Berridale
1903 07 16	11:00	31.8	141.2	3.0	Broken Hill
1904 03 06	11:55	34.7	149.55	3.0	Goulburn, start of swarm
1905 10 20	05:00	28.3	153.5	3.5	Tweed River
1906 05 15	17:00	33.0	151.6	–	Newcastle – a damaging ‘creep’*
1906 08 24	02:20	33.65	149.15	3.5	Carcoar
1907 01 30	08:30	33.5	150.1	3.2	Lithgow
1907 02 01	07:55	36.9	149.2	2.5	Bombala
1907 04 05	02:00	32.5	149.5	2.5	Cullenbone
1909 07 28	11:10	35.0	148.1	3.0	Gundagai
1909 07 28	11:40	35.0	148.1	3.0	Gundagai
1910 01 17	00:45	34.3	148.3	3.0	Young NSW
1910 01 20	13:30	30.0	146.8	3.5	Brewarrina, unusual location
1910 02 25	17:00	30.5	151.7	3.5	Armidale
1910 05 ?	-	34.1	150.3	4.0	Burraborang Valley
1910 06 01	01:59	36.0	148.8	4.5	Yaouk
1910 07 02	13:15	30.9	153.0	3.5	Macleay District
1910 08 16	12:35	36	148.8	3	Cooma
1910 10 29	11:20	34.7	149.6	3.0	Goulburn
1912 01 17	29:09	36.5	150.0	4.9	Bega Cooma
1913 06 16	20:30	34.7	149.6	3.0	Goulburn
1915 11 08	08:30	31.4	141.6	4.2	Euriowie
1916 06 10	17:51	32.25	152.5	4.6	Seal Rocks
1916 06 11	09:50	34.64	148.0	3.0	Cootamundra
1916 06 13	11:30	34.7	149.55	3.0	Goulburn
1916 09 17	12:30	34.7	149.5	3.0	Goulburn
1916 12 31	15:02	33.8	149.0	4.5	Near Cowra (damage), Carcoar
1917 03 23	21:15	36.25	148.6	3.0	North of Jindabyne
1917 03 23	21:30	36.2	148.55	3.0	Jindabyne
1917 03 23	21:50	36.3	148.7	3.5	Jindabyne
1917 03 23	22:10	36.2	148.65	3.5	Jindabyne
1917 04 02	19:55	35.9	147.3	4.7	Holbrook
1917 06 09	15:00	35.3	148.2	3.0	Tumut, two earthquakes
1917 06 09	16:00	35.25	148.2	3.0	Tumut
1917 06 11	17:00	35.3	148.15	3.2	Tumut, three distinct shocks
1917 06 11	17:02	35.3	148.25	3.0	Tumut
1917 06 11	17:05	35.35	148.15	3.0	Tumut
1920 03 23	-	34.7	149.5	3.0	Goulburn night time
1924 11 04	-	33.4	148.8	3.0	Cargo, near Canowindra - morning
1925 01 07	10:23	34.4	150.7	4.3	Port Kembla

1925 01 15	11:30	35.1	148.1	3.5	Gundagai
1925 03 15	08:00	35.2	149.4	4.3	Bungendore
1925 12 18	10:47:10	33.0	151.6	5.3	Newcastle
1926 07 05	06:15	34.74	149.72	3.6	Goulburn, broken crockery, cracked wall
1927 12 31	09:22	30.5	151.6	3.9	Armidale
1928 02 03	07:30	32.6	148.9	3.7	Wellington, first ever
1928 02 13	08:45	36.0	149.1	3.0	Bredbo
1928 05 06	12:10	34.6	149.7	3.5	North of Goulburn
1928 08 27	01:55	31.0	143.0	4.5	White Cliffs
1930 05 22	03:10	35.1	150.1	4.4	West of Milton
1931 05 12	21:55	36.25	149.1	3.5	Cooma
1933 01 11	20:12	34.75	149.5	4.8	Gunning, possible start of a 50 year cycle
1933 06 07*	06:00	32.0	141.5	-	South Broken Hill 'bump'
1934 01 30	20:30	34.8	149.2	4.3	Gunning earthquake swarm 50-60 events
1934 07 02	14:30	33.2	149.2	4.0	Orange Bathurst region swarm
1934 11 10f	23:47:40	34.8	149.2	4.9	Gunning
1934 11 18	21:58:41	34.8	149.2	5.6	Gunning - damage to Goulburn water supply
1934 11 19a	07:10:16	34.8	149.2	4.3	Gunning
1934 11 21a	06:32:07	34.8	149.2	5.2	Gunning
1935 05 ??	-	30.3	151.5	4.2	Guyra, Armidale, Bundarra, Tenterden, Inverell
1935 06 18a	10:20	34.75	149.5	4.3	Gunning, aftershock of the 1934 earthquake
1935 06 01	21:00	34.6	148.4	3.5	Harden
1935 07 09	14:05	34.75	149.5	4.8	Aftershock of the 1934 earthquake
1936 06 13	03:05	33.3	149.0	3.6	Mount Canobalas
1937 06 17	14:45	32.6	147.5	3.5	Tullamore
1938 03 24	20:03	35.3	147.3	5.2	Riverina
1938 05 12	18:00	32.2	148.2	3.5	Narromine
1938 06 04	17:05	35.3	148.2	3.2	Tumut, three small events
1938 06 27	22:55	30.2	151.7	4.3	Guyra
1938 09 02	21:45	33.9	148.1	3.0	Grenfell
1938 09 23	04:00	33.8	148.7	3.2	Cowra
1939 11 20	05:30	33.0	151.75	3.0	Newcastle, off Redhead
1940 09 21	14:55	35.3	149.0	4.7	Canberra region
1941 04 28	09:35	34.7	149.8	3.5	Goulburn
1941 06 12	16:56	34.75	149.8	3.8	Goulburn, not Gunning, 4 events
1942 11 07	16:00	35.0	149.4	3.0	Gundaroo and Goulburn
1943 02 22	14:45	34.8	149.2	3.5	Gunning
1943 02 22	20:35	34.8	149.2	4.0	Gunning
1944 05 03	21:00	34.7	149.8	3.2	North Goulburn
1944 06 14	09:30	34.75	149.8	3.2	Goulburn
1945 01 15	18:00	36.7	149.9	3.0	Bega and Tathra
1945 01 21	-	34.8	149.2	2.5	Small swarm at Gunning
1945 02 27	05:10	35.4	148.8	3.0	Canberra
1945 10 08	13:00	34.75	149.8	2.5	Goulburn
1945 10 15	-	32.03	148.0	2.5	Trangie small swarm
1946 01 06	03:10	34.1	148.5	2.5	Murringo district
1946 01 10	11:00	34.05	148.45	3.0	Murringo district
1946 01 13	18:10	34.15	148.55	3.2	Murringo district
1946 05 10	16:00	32.0	149.2	3.2	Gunning
1946 08 10	15:45	32.0	149.2	3.4	Gunning
1947 05 05	04:43:48	34.75	149.2	4.5	Gunning, 4 events, worst since 1934
1947 09 25	10:57	34.0	148.6	4.6	Cowra, also felt Goulburn and Bathurst
1948 02 02	07:26	34.9	151.1	2.5	Sydney suburbs
1949 03 10	22:31:36	34.8	149.2	5.5	Gunning
1949 03 11a	05:33:54	34.8	149.2	4.8	Gunning
1949 03 16a	15:25:24	34.8	149.2	4.2	Gunning
1949 07 17	14:59	32.4	152.2		Bulahdelah, north of Newcastle

1951 07 09	04:45	32.95	151.65	3.0	Newcastle
1952 05 19	11:10	32.9	142.6	5.3	Western NSW, felt in 3 states
1952 09 07	05 41:46	34.8	149.2	5.0	Gunning
1952 11 18	18:03:42a	34.8	149.2	4.7	Gunning
1952 11 19	01:59	34.8	149.25	5.0	Gunning, damage in town, recorded RIV
1952 11 22	07:57:56a	34.8	149.2	4.8	Gunning
1953 02 11	00:30	29.8	141.9	3.5	Milparinka and Mt Browne
1954 06 09	16:26	34.6	149.7	4.6	Crookwell
1956 08 15	16:47	33.3	149.1	3.5	Orange
1956 08 16	01:00	32.95	151.75	3.0	Newcastle

a = aftershock, f = foreshock, * = a mining 'creep' or 'bump', not an earthquake

5 ACKNOWLEDGMENTS

The isoseismal map of the 1933 Gunning earthquake was kindly drawn by cartographer Gayle Young. Frank Joklik BMR geologist, whom I never met, very thoroughly investigated the 1949 and 1952 Gunning earthquakes, it was a pleasure to read his reports. Dirk Spennemann made an exhaustive search of newspapers to evaluate the earthquake swarm around Tumut and Adelong in the 1870s. I am grateful for the many others who investigated the history of NSW earthquakes including, Thomas Noel Burke-Gaffney SJ, David Denham, Lawrence Drake SJ, Hugh Doyle, and the very first Australian seismologist Rev William Branwhite Clarke. Many details were corrected by a fastidious reviewer for which I am thankful.

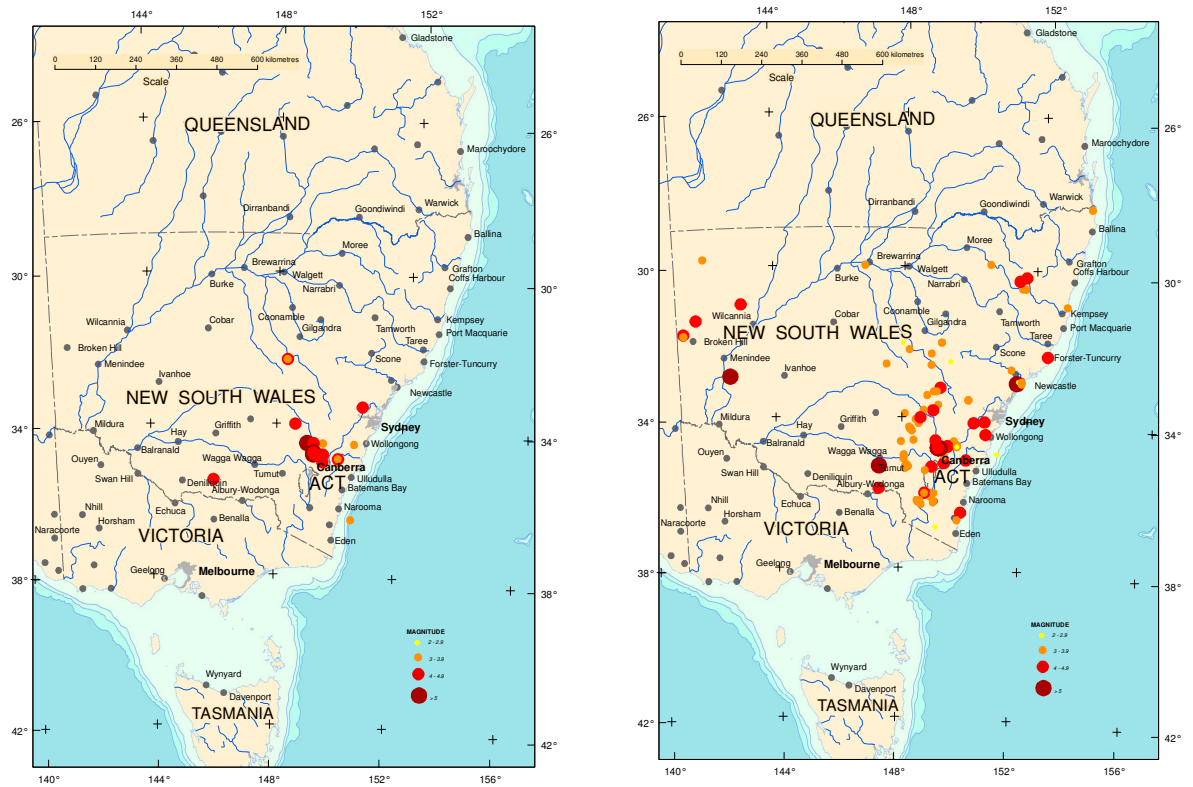
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Figure 15 Pre-1901 earthquake epicentres (left) Geoscience Australia, (right) this report.



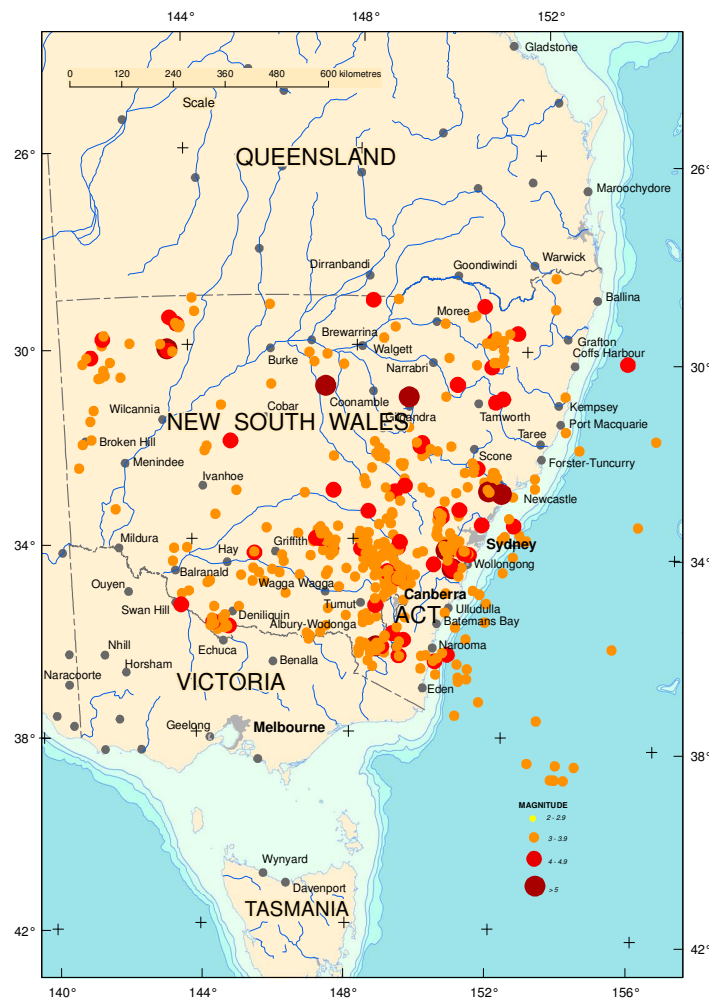


Figure 16 1901-1954 earthquake epicentres (left) Geoscience Australia, (right) this report.

Figure 17 Earthquake epicentres, Geoscience Australia 1955 – 2014.

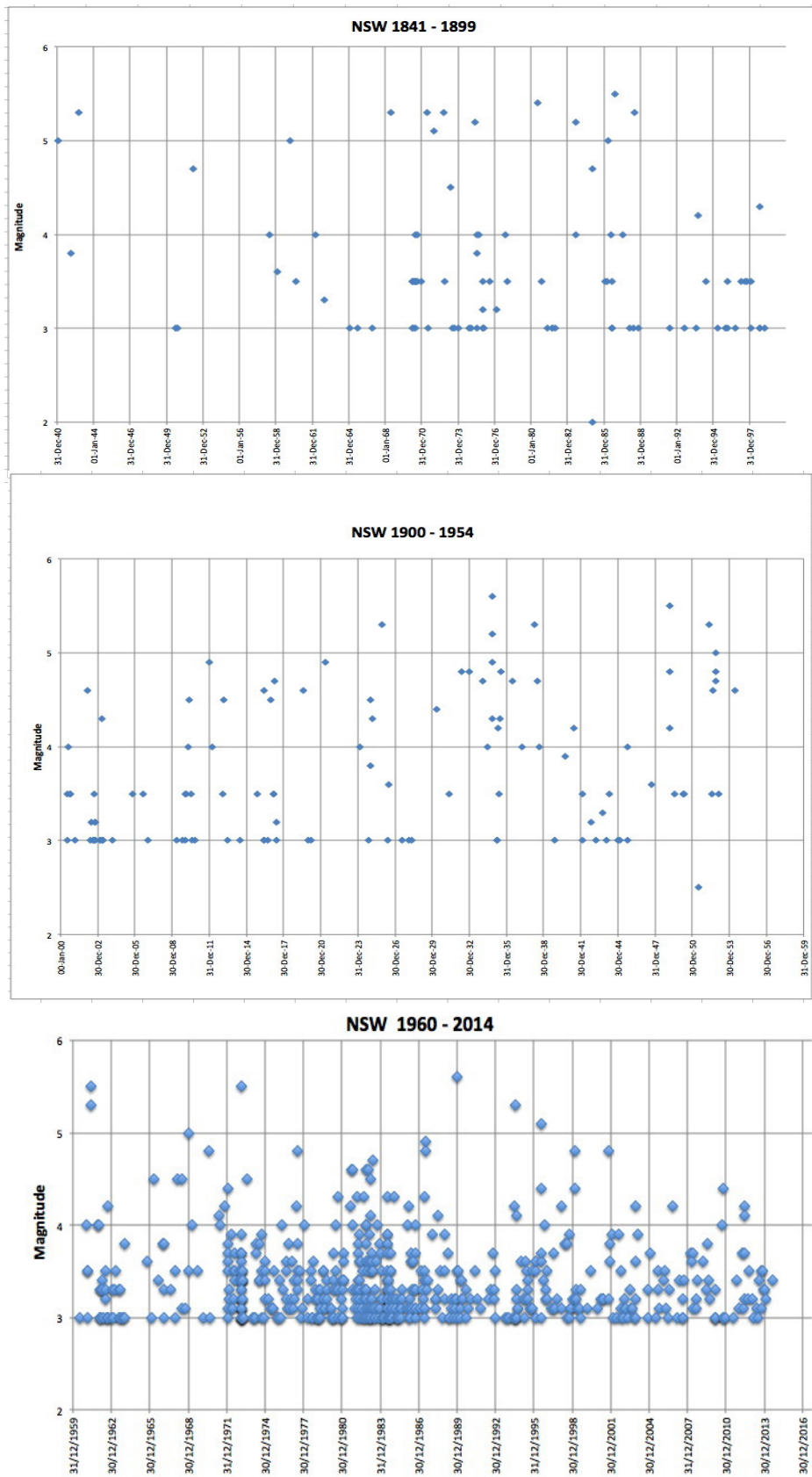


Figure 18 Timeline of known NSW earthquakes and their magnitudes