

Historical earthquakes in Victoria

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Abstract Several hundred earthquakes felt in Australia have been documented in three volumes of the *Isoseismal Atlas of Australia* but sources have not yet been exhausted as we demonstrate with new information on 15 interesting earthquakes in Victoria. This new information has come about thanks to a courageous initiative of the Australian National Library, making scanned, searchable newspapers publicly available via the internet. The new data and their interpretation are important for better hazard assessments by improving early earthquake details or extending the earthquake database backwards, to better define source zones and to lower the magnitude threshold of completeness intervals.

This article focuses on 15 earthquakes reported in local and interstate newspapers including two poorly studied, moderate-sized earthquakes that shook Melbourne in 1922, one not in the national earthquake database, the other poorly located. More damage was caused by these moderate earthquakes than is generally acknowledged.

VICTORIAN SEISMICITY

No large (magnitude 6 or above) earthquakes have occurred in Victoria since European settlement in the early 1800s but geographers such as Hills (1963), Bowler and Harford (1966) and Twidale and Stehbens (1978) identified Recent fault scarps in the state left by large earthquakes in prehistoric times, some of which have subsequently been dated (McPherson and others, 2012).

The most destructive Victorian earthquakes to date were the two near Warrnambool in April and July 1903 (McCue, 1978 & 1996). By good fortune no lives were lost, as there was significant damage to unreinforced masonry buildings. Foundation failure (lateral spreading) and liquefaction led to the disturbance of tombstones in the local cemetery. The two earthquakes were obviously shallow and close to the city but relatively small at magnitudes 4.9 and 5.3. These events were a classic doublet with few if any foreshocks or aftershocks.

There is little doubt that the July earthquake was the larger of the two. Mr Baracchi's opinion (Warrnambool Portland Guardian, 20 July 1903) is: *that the earthquake originated a short distance south of the Merri River, two or three miles out to sea, at about 38deg. west of the Warrnambool town-hall, and about the same place as the earthquake on April 7. This present shock was more intense and deeper than the former one, and extended over a larger area The recent earthquake shock made a crack in the front wall of the Colonial Bank, a free stone building of two stories. The crack extends from the top of the front window of the public office to the roof, and though it is small outside, in the drawing-room, above the banking chamber, the wallpaper has been torn apart. At the residence of the railway station-master a chimney has been split.*

The Warrnambool area is distinctive for its lack of earthquakes in the intervening 108 years; there was just one. The Argus of 11 December 1922 stated that a slight earthquake rattled doors and windows in and around Warrnambool on Saturday 9th December at about 3:20 pm local time.

During this study we did learn of a possible foreshock to the April 1903 earthquake, the Argus newspaper of Wednesday 14 March 1900 page 8, reports: *On Monday morning between half-past 3 and 4 o'clock, a slight earthquake was felt in Warrnambool.*

The Warrnambool Standard says it caused the windows to rattle loudly and it was felt by a great number of residents and woke many others. A check showed that it was not an aftershock of the 1897 Beachport SA and that it wasn't felt elsewhere in Victoria so, the 1903 doublet is not an isolated occurrence in the region as previously thought.

Other known similar-sized earthquakes in Victoria to the larger of the 1903 Warrnambool doublet (magnitude 5.3) were at Mt Hotham in 1966 magnitude 5.5, Cape Otway 1960 and 1965

magnitude 5.3, and Gippsland in 1969 magnitude 5.3.

It should be noted that a remarkable belt of approximately 500 volcanoes of Quaternary age extends across central Victoria from east of Melbourne to southeastern South Australia. Some of these such as Tower Hill near Warrnambool, or Mt Eccles further west, may have erupted as recently as 25,000 years or 8,000 years ago respectively. These volcanoes and the independent large prehistoric earthquakes are symptomatic of currently active tectonism in the local crust. The Monaro Volcanics near Cooma NSW are an ancient analogue of Victoria's Newer Volcanics.

Victoria boasts the highest density of seismographs of any state or territory in Australia and Environmental Systems & Services locates about one hundred small earthquakes per year, excluding aftershocks (~200 aftershocks were recorded in 2009 - see Payne and others, 2010).

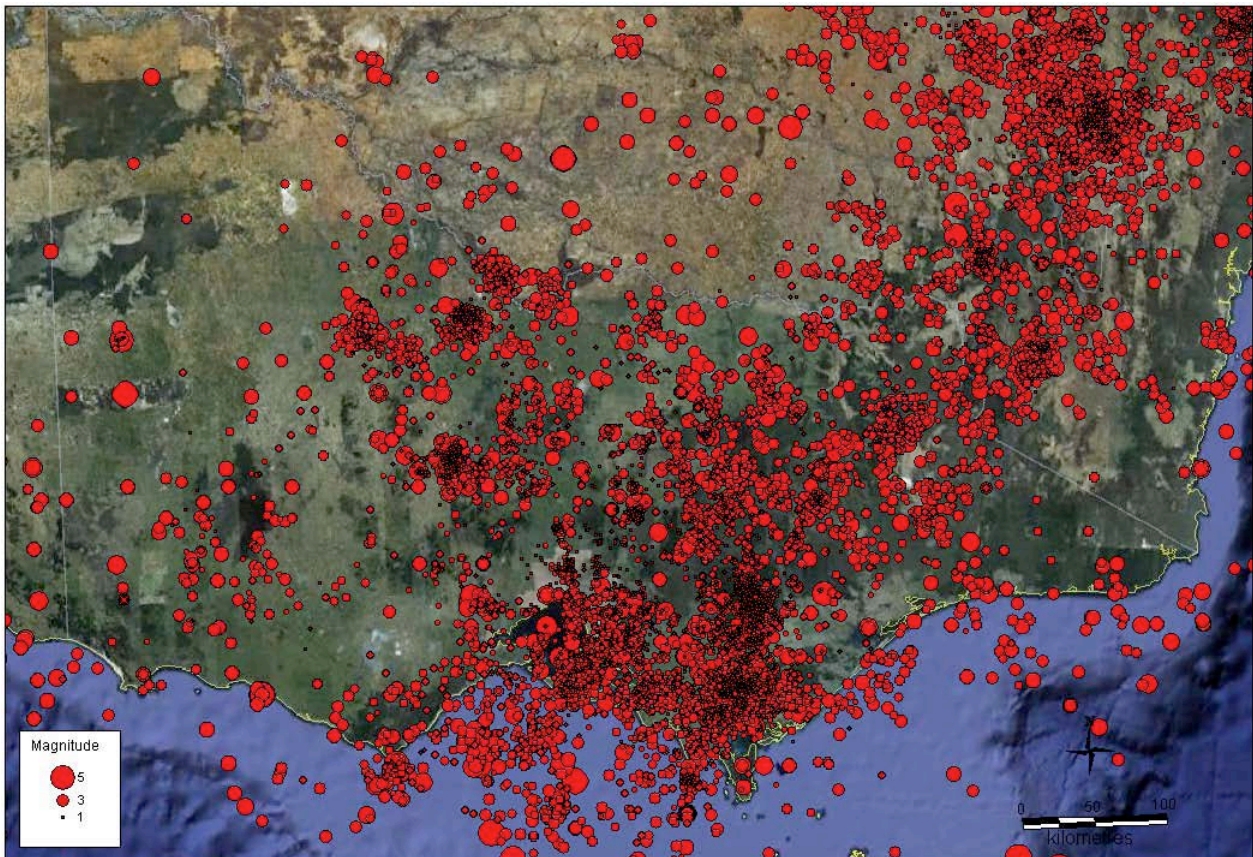


Figure 1 Seismicity of Victoria to 2009 (Payne and others, 2010).

Seismicity and seismic hazard in Victoria have been studied by Underwood (1972 & 1973), McCue (1978), Gibson and others (1981), Wilkie and others (1993, 1994), Gibson (1995), Brown and Gibson (1998) and Brown and Gibson (2004).

Damage, felt reports, isoseismal maps and hazard

Isoseismal maps for Australian earthquakes are compiled in three atlases by Everingham and others (1982), Rynn and others (1987) and McCue (1997). Included are maps of 10, 1 and 8 Victorian earthquakes respectively.

Brown and Gibson (2004) and the current hazard map of Victoria (in AS1170.4 - 2007) suggest that the state has moderate levels of seismicity and earthquake hazard, sufficient for earthquake loading, like wind loading, to be taken into account in normal structural design.

This paper was possible because of the recent publishing on-line by the Australian National Library of their scanned collection of early Australian newspapers. The site TROVE allows users to correct the OCR of the scanned images which makes the collection even more valuable as this corrected text can be searched on-line by all. Examples of the scanned newspapers are documented below.

Lighthouse reports

Victorian lighthouse keepers' logbooks containing meteorological and other observations such as earthquakes were used to draw up the isoseismal maps of the 1903 earthquakes at Warrnambool (McCue, 1978). These records are kept in Melbourne and researchers must visit Melbourne to view them which limits their usefulness.

Individual earthquakes

1838 No date, time or location

An article in the *South Australian* (Tuesday 1st June 1847) about the 1847 earthquake in Melbourne (listed below), states that *this is not the first instance of such an occurrence in this Province, a shock, heavier than the one now recorded, having been felt in 1838.*

1841 04 28 No time or location

The Sydney Monitor and Commercial Advertiser newspaper (Monday 10 May 1841 p2) selectively extracted stories from Port Phillip papers to 30th April including:

PORT PHILLIP

EARTHQUAKE.-Early in the morning of Wednesday last, a smart shock of an earthquake was felt in Melbourne and its neighbourhood, being the third similar irritation which has been experienced since the formation of the settlement. It is matter of congratulation, that these mysterious phenomena have hitherto been so slight as not to occasion the least danger or alarm to the inhabitants. Considering the evidently igneous formation of the province, it is singular that such convulsions do not more frequently occur.

The Adelaide newspaper *The Southern Australian* dated 22 June 1841 reports:

EARTHQUAKE.-The shock of an earthquake was generally felt in New Town and various parts of Melbourne, early yesterday morning. This is the second visitation of the same description which has been felt since the settlement of the province.

The first of these earlier events (two or three) was that in 1838. There may have been a subsequent one in 1841, the same source on Wednesday 23 June page 2 quoting from Port Phillip papers to 13th June 1841 says with no other details: *an earthquake caused a disagreeable sensation in the Church during Divine services.*

1847 April 28 at 06:00 UTC No location

All the papers agree in stating that a shock of an earthquake was experienced at Melbourne, of which we extract the following account: At half-past four o'clock, Melbourne was visited with one of those singular and at times dreadful phenomena. The shock was rather stiff and felt all over the town. In many of the streets some of the houses were severely shaken, and the inhabitants became very much alarmed, and ran into the streets. His Honor the resident Judge was presiding in the Supreme Court, in the cause of Boyd v. Wilson, when a noise like the rumbling of a carriage was heard, and the buildings appeared to rock. The proceedings were immediately suspended for a time, when the court was ultimately adjourned. The Flagstaff Hill was shaken to its centre, and also the other eminences in and about the town.

(Burnie Advocate Saturday 3rd May 1947, P4) ABOUT 4 p.m. on Wednesday, April 28, 1847, the 13,000 citizens of early Melbourne were conducting their ordinary daily business, attending to the wants of up-country pastoralists, loading and unloading the sailing vessels from "home" in the Yarra and at Sandridge, and engaging in the numerous other pursuits of a thriving colonial town.

SHORTLY after 4 p.m. the ground began to shake. People stopped in the street; those in buildings looked out of the windows, and then there was a mild panic. Someone shouted, "It's an earthquake," and those in the streets made for the buildings, while those inside started for the open air.

Actually it was not an earthquake; it was an earth tremor, of which Melbourne has had many, and of which, one, and perhaps two, had already occurred in the town on the Yarra in the time between its settlement in 1834 and 1847. But this was the most severe up to that time, and possibly there has not been a more severe one since.

Naturally such an event could not be ignored by the papers of the day, and on the following Saturday, May 1, the Port Phillip "Gazette" devoted three-quarters of a column to the occurrence.

"On Wednesday, between 4 and 5 p.m.," the "Gazette" recorded, "Melbourne was visited by an earthquake, which fortunately did no injury to the town. The sensation to those inside was that of a heavy body falling on the upper part of their houses. The panic was considerable in the Supreme Court, where the case of Taylor and M'Pherson versus Sutherland was being tried, and it was at once adjourned.

"The shock was felt most heavily in Elizabeth street, but it was also quite apparent to persons living some miles out of Melbourne.

"This is the second or third time that earthquakes have been felt in this town, the last having occurred in April or May, 1841, at 4 a.m. "

16 September 1855 at 14:50 UTC unknown location

The next Victorian earthquake mentioned in the newspapers retrieved was discussed in a letter dated Monday 17th September 1855, to the Editor of the Argus by one Ludwig Becker. The earthquake occurred at 2:50 a.m. that morning and reportedly lasted between 1 and 2.5 minutes.

He reported that in the Union Hotel the shaking was sufficiently intense to awaken nearly all sleepers. Strong shaking *creakings, clatterings and grindings of objects on the surface of the earth* was observed at Collingwood, St Kilda and Windsor. This shaking was preceded by a subterranean noise (P wave?) with the *same pitch or tone as a heavy omnibus or artillery wagon passing rapidly.*

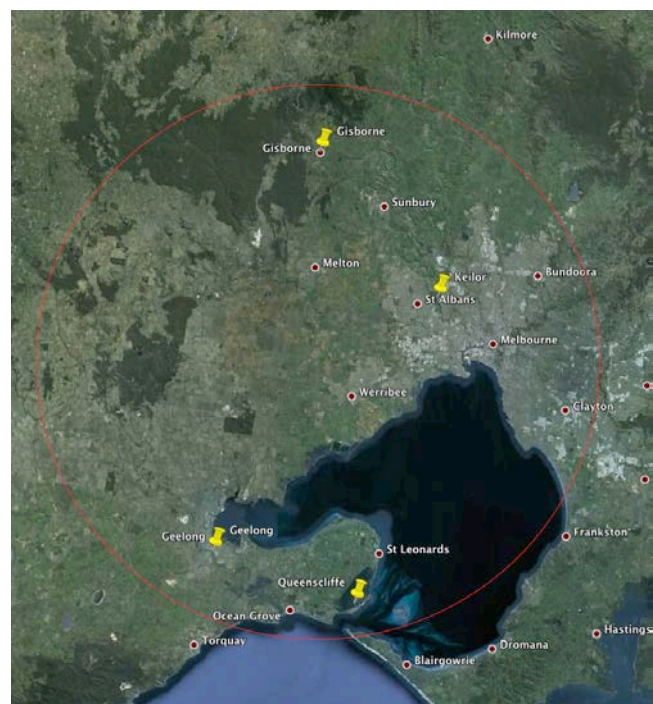
Interestingly, Becker notes that *all the earthquakes recently observed in Melbourne have been nearly to these points of the compass (horizontal north and south).* We may find out more about these earlier felt earthquakes when additional newspapers are scanned.

Further information is needed to get a magnitude and location for this earthquake but it must have been relatively close to Melbourne, judging by the descriptions of shaking and the lack of reports from Tasmania.

1867 August 09 19:30 UTC W of Melbourne

The Melbourne *Argus*, 12 August 1867 (from the *Empire* of Thursday August 15, 1867, p5) reported that an earthquake was experienced in Melbourne at 5:30a.m. on Saturday 10th August 1867 EST. It lasted about 6 seconds in Melbourne and shaking extended from Queenscliffe to Gisborne.

Figure 2 Felt area of the earthquake of 10 August 1867 west of Melbourne. The radius of perceptibility is at the very least 55km (ML 4.2).



According to the article, the shaking was stronger in Melbourne than earlier ones including that of September 1855, mentioned above, perhaps because it was closer.

At South Geelong, the ceiling of one house is reported to have fallen down. At Corio Bay, the shock was felt aboard the barque India, awakening the Captain who thought another boat had run into them. Windows rattled in Hawthorn and St Kilda whilst at Keilor everyone was awakened.

The felt area delineated in Figure 2 gives an approximate epicentre and magnitude, the earliest locatable earthquake in Victoria.

07 August 1872 at 19:10 UTC Maldon

Thursday A distinct shock of earthquake was felt here at 10 minutes past 5 this morning (The Argus, Friday 9th August 1872, P5).

22 July 1893 Bendigo

Bendigo was the supposed epicentre of an earthquake-like shock on Sunday morning according to the *Victorian Barrier Miner*. The story was headed *The Victorian Earthquake*, but subtitled *The effect on the mines. A fall of earth*. The newspaper reports that the area over which it was felt was nearly 2000 square miles (a circle of radius roughly 40 km corresponding to a magnitude of 3.9). The newspaper then highlights the damage underground in the Bendigo mines, particularly in the Confidence Mine.

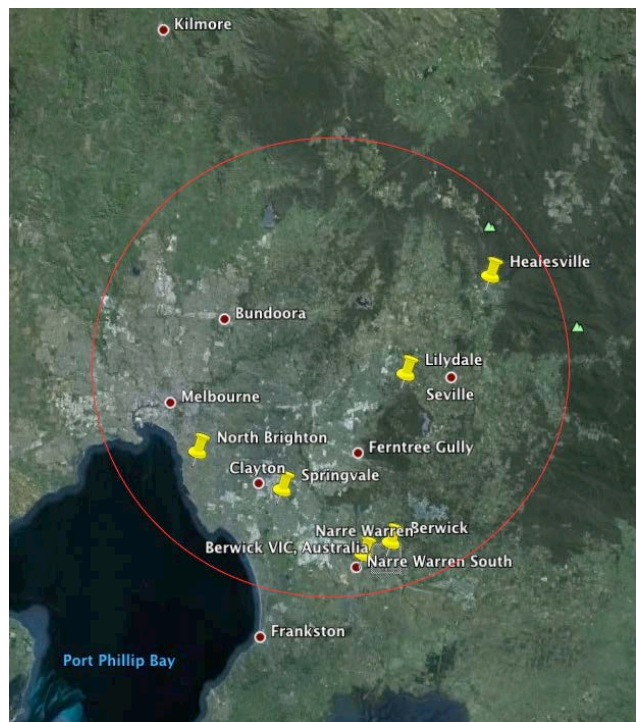
We infer this was a mine-induced seismic event.

09 July 1904 at 09:27 UTC W of Lilydale

North Brighton was the only place to report minor damage following the earthquake at 7:27 pm on Saturday 9th July 1904. According to the Observatory, it lasted about 20 seconds.

Figure 3 Felt area of the earthquake of 9 July 1904 east of Melbourne (above). The radius of perceptibility is at the very least 36 km.

The earthquake was felt widely throughout the eastern portion of the metropolitan area and at Lilydale, Narre Warren and Springvale according to the *Argus*, Monday 11 July 1904. Clocks were stopped at Berwick. *The Healesville and Yarra Glen Guardian* of 16 July 1904 mention that Healesville and Lilydale were thrown into a state of consternation.



22 September 1904 at 12:00 UTC Korumburra

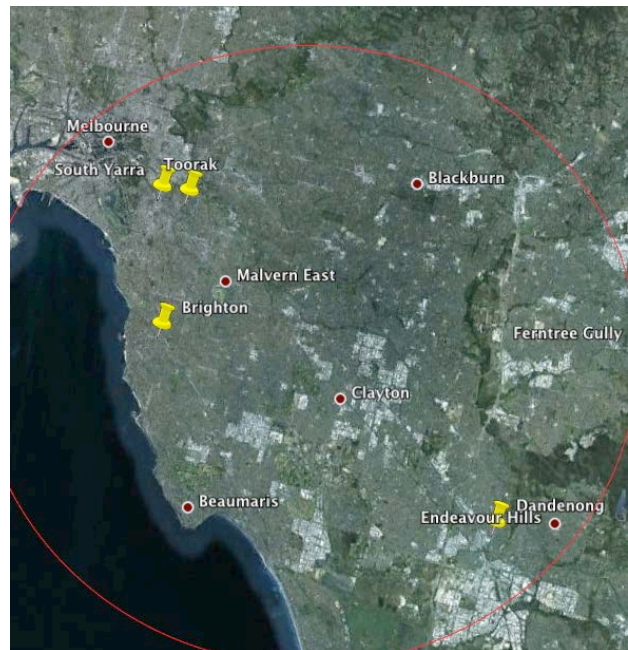
Korumburra was the likely epicentre of a small earthquake felt by town residents just before 10pm on Thursday night (*The Argus*, Saturday 24 September 1904, P16).

This earthquake heralded later shakes for the residents of Korumburra. On 20 June 1969 the whole of Gippsland was strongly shaken by a magnitude ML 5.3 earthquake. Again on several occasions in 2011, earthquakes shook Korumburra, one of them felt by thousands of delegates attending the IUGG meeting in Melbourne in early July.

06 January 1911 at 17:55 UTC SE Melbourne

SMH 7 January 2011, P14: Melbourne, Friday. A slight earthquake shock was experienced in Melbourne at 5 minutes to 4 o'clock this morning and alarmed a great many people in the southern suburbs. In some cases nervous folk were awakened by the disturbance which lasted only a few seconds. They rushed out of doors in their night clothes but by a great majority the shock was not noticed. Along the bay front from Port Melbourne to Brighton the effect seems to have been most pronounced. The shocks were said to have been accompanied by a muffled rumbling noise resembling a distant explosion.

Figure 4 Felt area of the small earthquake near Melbourne on 7th January 1911 at 3:55a.m. EST. The distance from Melbourne to Dandenong is ~30 km.



The Argus, Saturday 7 January 1911, P19 noted that there was a distinct vibration of buildings and rattling of windows in East Melbourne, South Yarra and Toorak. A following article in the same paper noted that a distinct earthquake was felt at Dandenong at 5 minutes past 4 a.m., (clocks then were not set using GPS!).

This information is consistent with an earthquake of about magnitude 3.5 located some 10km southeast of the city of Melbourne.

28 February 1922 at 15:00 UTC Ocean Grove

The year 1922 was quite an active one, felt earthquakes are headlined in newspaper articles right across southern Australia. One of these earthquakes early on 1st March (EST) shook the city of Melbourne frightening many of the residents. Interest in this event seems to have been

Figure 5 Extract from *The Argus*, 2 March 1922.

MILD EARTHQUAKE SHOCK.
FELT OVER WIDE AREA.
DOORS RATTLE AND BEDS ROCK.
 Many residents of Melbourne and of a number of outlying country and seaside places were rudely awakened at about 1 o'clock yesterday morning by unusual disturbances in their homes. Beds rocked, doors banged, and windows rattled. To some the unexpected happenings caused alarm; but the level-headed jumped to the conclusion which was subsequently proved to be correct—that an earth tremor had occurred. Official reports received yester-

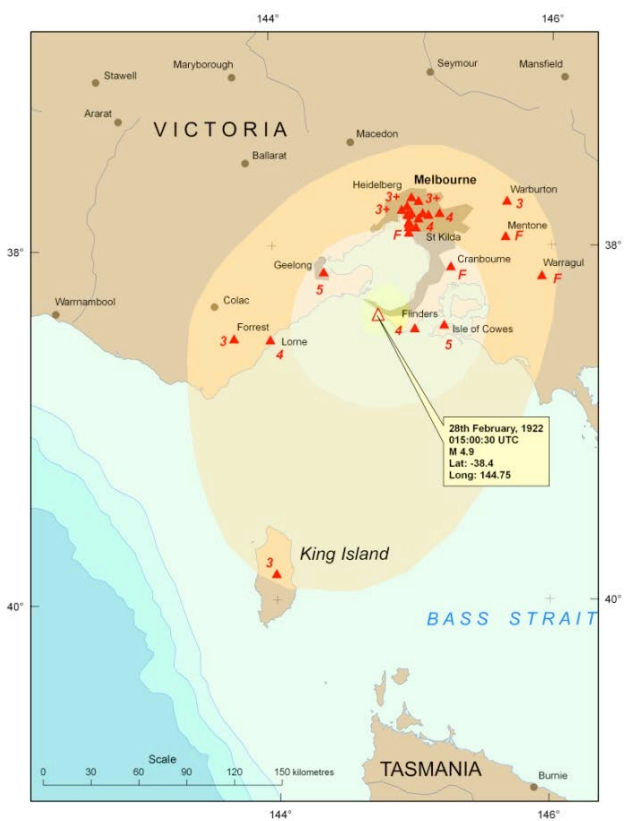


Figure 6 Isoseismal Map Ocean Grove earthquake, 28 February 1922.

eclipsed by a magnitude Ms 5.2 earthquake in Bass Strait (Everingham and others, 1987) five weeks later on 10th April which also shook the city, but more strongly. In neither case was damage substantiated.

Surprisingly no isoseismal map had ever been prepared for either earthquake; the March earthquake is not in the Geoscience Australia database though it is in Underwood's (1972) extensive listing of Victorian earthquakes. The epicentre of the April event in Table 1 below (e.g. Underwood, 1972; Everingham and others, 1987) is quite uncertain – which one to choose for hazard studies?

The Victorian earthquake at 1am on the 1st March 1922 local time was felt throughout Melbourne and widely reported from southern Victoria, despite the early hour. Most reports were that the tremor was short and sharp, mainly the vibration of furniture and rattling of doors and windows. At Cowes some picture frames propped against a wall fell down, breaking the glass – the only reported damage. It was recounted during the April earthquake that this March event had also been felt on King Island (as mentioned by Underwood, 1972) the only point south of the interpreted epicentre off Cape Otway.

The Argus says it wasn't 'recorded' at the Mt Pleasant Observatory at Ballarat, an astronomical, not a seismological, observatory and the logbook of the day makes no mention that it was felt. The later earthquake on 10th April was however noted by the astronomer John Brittain in the logbook: *9pm Earth tremor.*



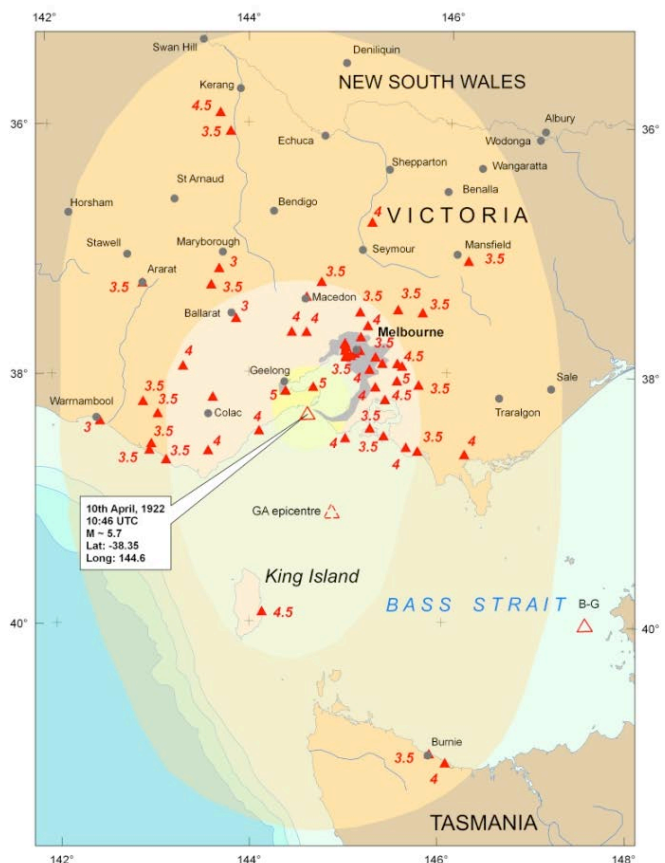
This earthquake was recorded at Melbourne Observatory, the P wave at 15:00:42, the duration about one minute, the maximum amplitude only 0.3mm. The epicentre was interpreted by staff (correctly!) to have been within 100 miles of the observatory.

10 April 1922 at 10:46 UTC Ocean Grove

It was hard to ignore the 10th April earthquake, so many reports were extracted by TROVE in a search of 1922 newspapers and many of them were at odds with an epicentre in eastern Bass Strait (Everingham and others, 1987). Ground shaking was felt at Burnie on the northwest coast of Tasmania, strongly on King Island, and as far west as Warrnambool and north to Ivanhoe in Victoria.

There were more reports of damage than in the earlier earthquake, both of which were felt throughout Melbourne; a chimney reportedly collapsed in Glen Iris and several places reported that crockery had vibrated off shelves and broken: in Pakenham, Portarlington, Cranbourne and East Malvern.

Figure 6 Isoseismal Map Ocean Grove earthquake, 10 April 1922



The isoseismal map shown here supports an epicentre off Ocean Grove in Victoria, not far from the earlier earthquake discussed above.

Table 1 Earthquake details reported by different sources

Date	Time UTC	Lat °S	Long °E	Mag	Approx Location	Source
28 02 1922	15:00	39	145		NE King Is Tas	Melbourne Observatory
	15:00:30	38.4	144.75	4.9	Off Lorne Vic	This paper
10 04 1922	10:45	39.3	144.3		N King Is Tas	Melbourne Observatory
	10:47:39	40	147.5	4.8 ML	Flinders Is Tas	B-G
		40	147.5	5.2 Ms	Flinders Is Tas	EDG
		38.35	144.60	5.7 ML	Off Lorne Vic	This paper

The year was not finished with earthquakes, a slight but very distinct earthquake was experienced along the Tallangatta Valley on Friday 17th November at 8:30pm local time (*The Argus*, Monday 20 November 1922, P7). There was also a very local earthquake near Warrnambool on 9th December mentioned in the introduction above.

17 April 1931 at 03:51 UTC Benalla

Benalla Victoria seems to have been close to the epicentre of this earthquake that was reported felt from Rutherglen in the north to Mansfield in the south.

The Argus (18 April 1931) reports that a chimney collapsed in Mr McLean's house in Benalla.

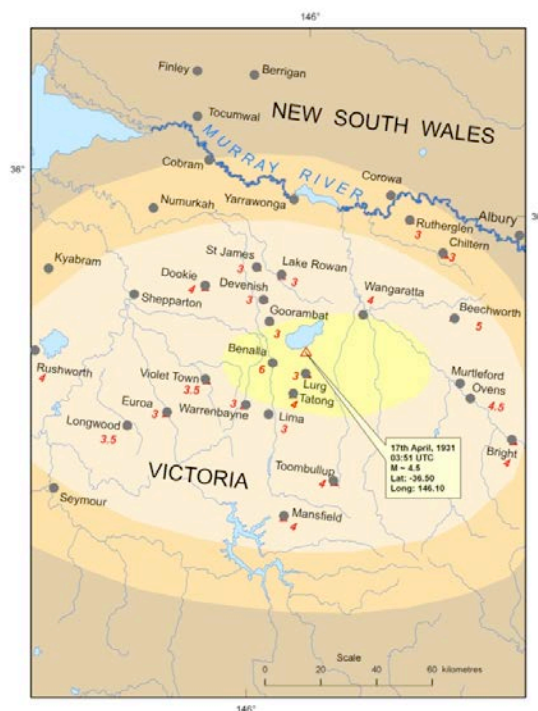
The North Eastern Ensign (Benalla, VIC.) Friday 24 April 1931 Page 3:

EARTH TREMOR AT BENALLA CONSTERNATION AMONG RESIDENTS. SHORTLY before 2 o'clock on Friday last Benalla suffered from a severe earth tremor which caused much consternation among the residents. The tremor was accompanied by a rumbling like thunder, and business people rushed from their shops while residents left their homes to ascertain the cause. The earth shook, and in many instances some weird experiences were felt.

The Governor, Lord Somers, was being entertained by local returned soldiers at the Benalla Hotel at the time and those in the dining room felt the tremor. Members of the staff of the State Electricity Commission who were busy at their work got a rude awakening when the desks began to move and Mr. Bob Rennle was hurled to the floor. They apparently thought that they would be safer downstairs, and lost no time in gaining the ground floor.

Several cracks were noticed in the building, particularly on the ground floor. A large crack was also noticed in the wall of one of the rooms at the High School, and several openings were also observed at the Convent. A rack of furs at the shop of T. J. Davis and Co. were hurled to the ground and goods in other shops in the town left the racks.

Figure 7 Isoseismal Map, Benalla earthquake, 17 April 1931.



Mr T. Murrhy of the State Electricity Commission was effecting repairs at the top of an electric light pole when he felt the shocks and quickly returned to the ground. The feeling was uncanny, and his experience was an unenviable one. In the private houses crockery rattled on the shelves, furniture shook and generally everything moved. A stack of motor tyres at the store of the State Electricity Commission in Bridge Street was knocked down.

The shock was felt around Warrenbayne, Lima, Lurg, St. James, Devenish, Lake Rowan, Goorambat and other parts. It was severely felt at Tatong and Toombullup where the tremor was preceded by a heavy rumbling noise that resounded through the gullies. Residents were terrified at the experience which 'they' declare they do not hope to feel again. An old prospector who was sitting on a box on the bed of a creek was terrified when the box swayed backwards, and forwards and he narrowly missed being hurled into the creek. Mr Ern Dickson who is also prospecting in that locality had an unenviable experience. He was down a 17 foot shaft, when the earth began to sway and he declared he never got out of anything quicker in his life. A table at the home of Mr Sims moved about six inches and the crockery in the kitchen of all the houses clinked on the shelves.

The Melbourne Observatory seismograph recorded a small earthquake disturbance from a comparatively near source on Friday. The first signs on the record occurred at 1h. 51m. 7s. p.m. This corresponds closely with the time of the tremor in the Benalla district.

2 September 1932 at 18:22 UTC Mornington

Holmes (1933) was acting government astronomer at the time of this earthquake and he must have been thrilled receiving hundreds of phone calls from excited residents of southern Victoria reporting an earthquake. A good physicist, he sent out a questionnaire via *The Argus* newspaper and more than 200 people sent responses from which he compiled an isoseismal map. Unfortunately Holmes did not plot his assigned intensities nor did he bother to include the MM3 isoseismal contour and the questionnaire responses have not been unearthed, so I decided to redo a map just from the 46 newspaper reports I found, partly to check our method.

The two maps are published below. The epicentres agree very well. The magnitude computed from the radius of perceptibility is ML 5.1 which is rather larger than the 4.6 quoted in Everingham and others, 1982. The larger magnitude may be warranted considering the earthquake was recorded on the Sydney Observatory seismograph (and on the Riverview station as expected). The value of ML 5.1 is commensurate with Ms 4.6 from Riverview (Everingham and others, 1982).

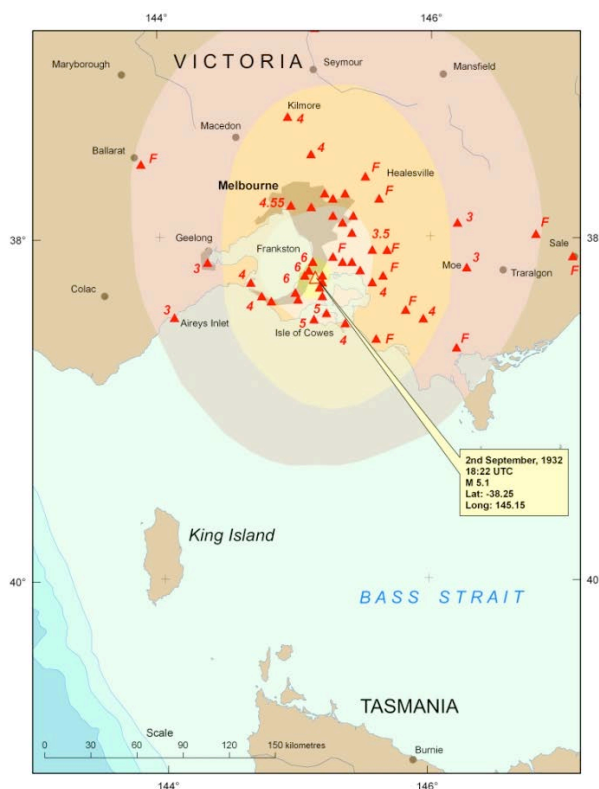


Figure 8 Comparison of isoseismal maps of the Mornington earthquake of 2 September 1932 by McCue (this report) from Newspaper reports alone, left, and the original by Holmes (1933), right, from newspaper reports and questionnaires. Holmes did not plot individual point assessments or an isoseismal delineating intensity 3, the felt area. The epicentres are virtually identical, as much as the intensities allow.

Many reports claim there was little or no damage but then, like the *Frankston & Somerville Standard* of Saturday 10 September 1932 they itemise the damage.

EARTHQUAKE. Mt. Eliza was severely shaken by the earthquake last Saturday. Little serious damage was done. At Mt. Eliza store several bottles, tins and other goods were thrown from the shelves. At the public hall a large crack has appeared in the north wall, but as this is only a temporary wall the damage will not cause the committee serious concern. At the Church of St. James the Less the tremor cracked one of the arches. The damage is so serious that repairs will have to be effected.

A public appeal was mounted for funds to carry out the repairs on the church, one of the oldest in the State and this work was completed in December the same year.

The same paper reported that the earthquake was felt elsewhere:

SOMERVILLE - THE EARTH TREMOR. Although no serious damage was done at Somerville by the earth tremor which disturbed a large number of people of southern Victoria on Saturday morning last, a number of minor damage was reported. Walls of several brick buildings were cracked, plaster fell from walls and ceilings, pictures and mirrors fell from the walls and bottles and other articles were thrown from shelves. In one case a washhouse chimney was shattered. It is interesting to note that in quite a number of cases the first impression was that a large motor car or truck had crashed into the house, and in several cases it was thought that horses were either in the house or rubbing against or kicking at the walls. One man on springing out of bed grabbed a gun and cartridges in preparation for a supposed burglar. In comparing impressions most people admitted being more or less alarmed and even terrified. Young children were the least affected, some of them sleeping soundly throughout the disturbance.

at Tyabb:

Many residents felt the severe earth tremor at 4.20 a.m. last Saturday. Old-time residents state that 40 years ago a similar tremor occurred. (Ed. this might refer to the 1892 earthquake off NE Tasmania).

1932 September 19 15:00 UTC Benalla

During this search for earthquakes in Victoria in 1932 I came across many reports of a series of earthquake near Benalla in September. *The Argus* of Wednesday 21 September 1932 reports:

EARTH TREMORS AT BENALLA. SLIGHT DAMAGE TO BUILDINGS,

BENALLA Tuesday. Benalla residents were startled shortly after 1 o'clock this morning by an earth tremor which shook the town. Most residents had retired and when the shock was felt many left their homes. Those living in Bridge street rushed into the street in their nightclothes to ascertain the cause of the disturbance. In some of the buildings crockery was displaced and articles fell from mantelpieces. The shock resembled a sharp gun report, and numbers of residents thought that a safe was being blown open. Two railway detectives were on duty, believing that a robbery was being perpetrated at the Broken River butter factory, hurried to the factory.

The principal buildings affected were the State Savings Bank and Noonan's Commercial Hotel, where large pieces of plaster were broken from the walls. At the Bank of Australasia the blinds in the banking chamber fell.

A second tremor was felt at about 3 o'clock, but it was much milder. It was felt also at Tatong, Devenish and Thoona. This is the second tremor which has occurred in Benalla in the last 18 months (see April 1931 earthquake above).

1932 September 21 05:30 UTC Benalla

The Argus of Thursday 22 September followed up with:

BENALLA SHAKEN AGAIN. RESIDENTS TERRIFIED. MUCH DAMAGE TO BUILDINGS.

BENALLA Wednesday - Residents of Benalla were terrified this afternoon by another earth tremor following a slight tremor which was felt this morning at half-past 3 o'clock. This was followed by a rumbling which lasted about five minutes.

At half past 3 o'clock this afternoon the second tremor came with terrific force, and it resulted in much damage to buildings while many persons were thrown with great force from their seats. Probably the worst damage was done at the offices of Mr. R. P. Lewers, solicitor. He was seated at his table and narrowly escaped being struck by falling plaster. Large bundles of files which were stacked away on racks were scattered about the room. A large crack occurred in the walls at the Bank of Australasia where some damage was done by the tremor on Monday morning. Pictures were scattered over the floor, and much plaster was broken from the walls. Large cracks were observed at the fire brigade station. Most damage occurred at the residential quarters where part of the wall shifted for at least two inches.

Plaster was broken in many places at the post-office and a large crack was noticed at the Lands office, which adjoins the offices of the Country Roads Board. A chimney fell at the residence of Mr. W Say, and a valuable chandelier was broken. Mr. J. Burns who was in a cafe at the time of the tremor fainted and was removed outside. Three of the main clocks in the town stopped at the moment of the tremor. They were the clocks outside the post-office, at the goods shed and at the railway station. The National Bank chambers were strewn with broken plaster. In private homes large cracks were noticed in the walls and a considerable amount of crockery was broken. At some homes many valuable ornaments fell and were broken to pieces.

The tremor came with more force than the one felt early on Monday morning. Occupants of shops in Bridge, Carrier and Nunn streets left the buildings hurriedly and rushed into the streets in an excited state.

These September 1932 events are probably part of a nested mainshock/aftershock sequence within the 1931 earthquake sequence and not an independent set of events. There were insufficient reports from other towns to compile an isoseismal map so the magnitude is estimated at $ML\ 4.0 \pm 0.3$; it did damage so it was bigger than $ML\ 3.5$, on the other hand it was not widely felt like the April 1931 earthquake so was less than $ML\ 4.5$.

Discussion

This study has focused only on earthquakes discovered by a search of early scanned newspapers, there are many more in Underwood's (1972) list to be more carefully analysed at some future time when the relevant newspapers have been digitised. The relocation of the 1922 Bass Strait events should improve a re-assessment of earthquake risk in the Melbourne region, especially to the southwest of the city where there are special structures like the Animal Health Laboratory and oil and gas storage facilities; this ought to be done as new information comes to hand, or at least at 5 yearly intervals. Improvements in the epicentres of historical earthquakes may be made when more local newspapers are scanned by the Australian National Library, or other sources such as diaries are made available to improve the isoseismal maps. There is always scope for improvement as Underwood (1972) pointed out 40 years ago.

Small earthquakes near the cities are as important as larger rural earthquakes to improve risk assessments to those cities, especially if the events can be associated with mapped faults.

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 hard rock mines of Victoria are no exception as the event near Bendigo in 1893 shows clearly. More recently fracking operations in coal rich areas will no doubt provide many more examples. Such operations should be monitored closely with dense networks of seismographs, and the data made publicly available.

Appendix 1 List of earthquakes discussed in this paper. The small earthquakes for which isoseismal maps were not produced have been assigned a magnitude of ML 3.5 being a reasonable balance between being felt only locally, but strongly enough to be noted in a newspaper, without causing damage.

Date UTC	Time UTC	Latitude °S	Longitude °E	Approx. Mag.	Comments
1867 08 10*	19:10	37.8	144.6	4.2	One ceiling is reported to have collapsed at South Geelong
1872 08 07 *	18:50	37.0	144.05	3.5	Maldon, small close local event
1900 03 11	15:45	38.38	142.48	3.5	Warrnambool small close local
1904 07 09	09:27	37.8	145.3	3.8	Clocks were stopped at Berwick
1904 09 22	11:58	38.43	145.83	3.5	Korumburra
1911 01 06	17:55	37.9	145.1	3.5	Near Clayton
1922 02 28	15:00	38.40	144.75	4.9	SE of Ocean Grove
1922 04 10	10:46	38.35	144.60	5.7	South of Ocean Grove
1922 11 17	10:30	36.2	147.2	3.5	Tallangatta Valley (Hume Reservoir)
1922 12 09	05:20	38.38	142.48	3.5	Warrnambool
1931 04 17	03:51	36.5	146.1	4.5	Benalla
1932 09 19	15:00	36.5	146.1	4.0	Benalla
1932 09 21	17:00	36.5	146.1	3.5	Benalla
1932 09 02	18:22:32	38.25	145.15	5.1	Mornington
1932 09 21	05:30	36.5	146.1	4.0	Benalla, the largest of five earthquakes mentioned.

* Prior to the introduction of Eastern Standard Time when time was based on actual longitude. In Melbourne, at longitude 145°, this would have been 9h 40m ahead of Greenwich (not 10 hours).

Acknowledgments The TROVE resource developed by the Australian National Library is a treasure indeed for researchers who used to make long trips to the cities to dig out old newspapers but can now do it all from their office. Rob Underwood searched Victorian newspapers and used the old Melbourne Observatory logbook to publish a comprehensive list of early earthquakes, the places where they were felt, and the intensity, but not the magnitude. Cartographer Gayle Young drew the maps from rough sketches provided by the author.

The manager of Bendigo Observatory, Judith Bailey, searched out the daily logbook of two of the Benalla earthquakes at the request of the author. My late father Bill and brother David helped search out data for the 1903 Warrnambool earthquakes. There are too many others who provided information and help for this study to mention, except for the irrepressible Gary Gibson who was always ready to discuss and debate the physics of earthquakes in Victoria. Sonja Lenz reviewed the manuscript but is not responsible for the seismological conclusions.

Appendix 2 Earthquake Poetry

"BASS STRAIT QUAKE."

by A. EVELYN LYNCH. Bonbeach. Published in the *Frankston & Somerville Standard* Saturday 24 September 1932, page 5 following the Mornington earthquake.

*There's a dawn I shall remember,
August had just said "How do to September".
Suddenly a loud rumbling like heavy thunder,
Startled Peninsula folk from their slumber.
Houses were quaking on their foundations,
And quivering beds gave queasy sensations.
Astronomers are seeking the cause of commotion,
Deeming the tremor began in the ocean.
Maybe Earth developed a pain in her "tummy,"
Her quivering and groaning made us all feel rummy.
If attacked there again and not stand the strain,
She may pop with a terrific explosion.
Then we'll be drying our tears in a new strathasphere,
Or fleeing from sharks in the ocean.*

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