KNOWING WHAT WE DON'T KNOW ABOUT AUSTRALIA'S EARTHQUAKES

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Abstract

Knowing little about the causes of Australia's earthquakes and being unable to forecast where the next large one will be shouldn't stop us planning to minimise the loss of life and cost of damage when it happens, and we should start now. Earthquake sequences akin to the Christchurch NZ sequence have already been observed in Australia on several occasions in the last 150 years.

Keywords: Seismic hazard assessment, earthquakes

Introduction

Earthquake hazard analyses (Cornell, 1968) require us to use as much information as we know about the earthquakes in a PSHA or equivalent and make educated judgments about what we don't know. The latter is the cause of high uncertainties in and poor security about hazard assessments and the longer the return period interval we are expected to investigate, the higher are the uncertainties.

What do we know about Australian earthquakes?

The Australian continent occupies the centre of the Australian Plate surrounded by oceanic crust, the nearest plate boundary about 500 km north of Darwin. All other Australian cities are more than 2000 km distant from a plate boundary where most of the World's earthquakes occur. Therefore we would conclude that, apart from Macquarie Island, an Australian sub-Antarctic island straddling the plate boundary south of New Zealand, the chance of a destructive earthquake striking Australia ought to be less than it is in any neighbouring country on the Australian Plate boundary, New Zealand, Vanuatu, Solomon Islands, PNG and Indonesia for example. Similarly the level of hazard in Australia ought to be similar to Eastern North America, India and Africa excluding the rift valley.

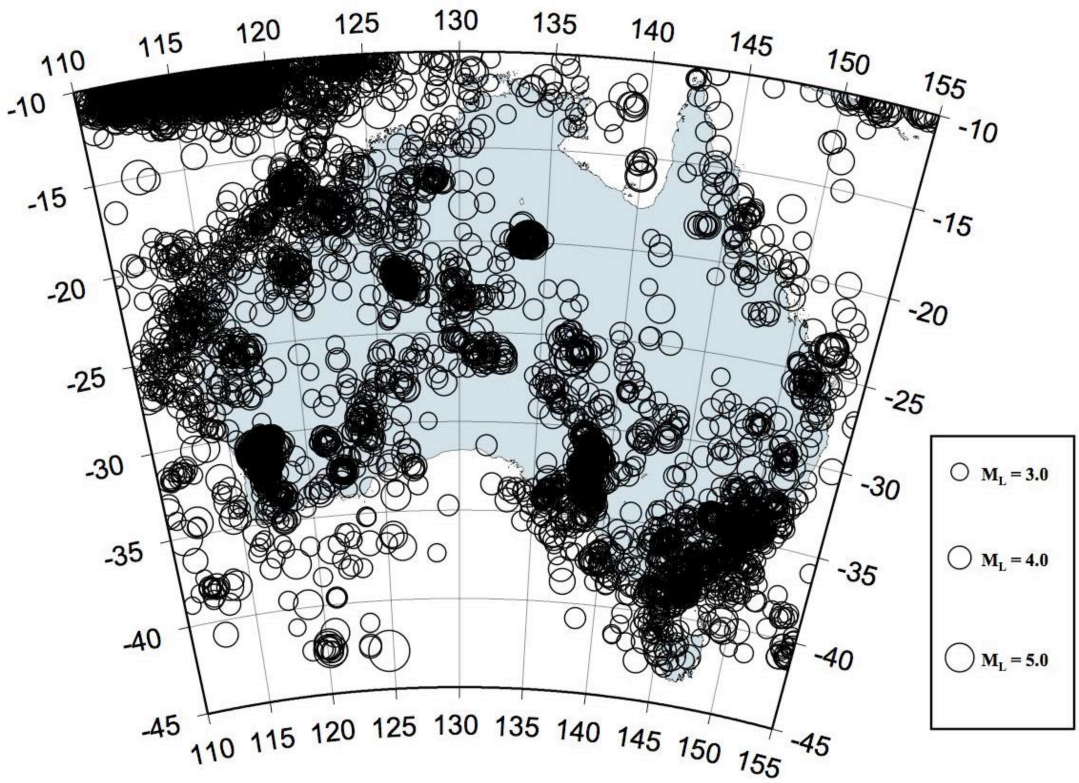

Figure 1 Seismicity of Australia and nearest plate boundary, 1900 – 2010, M≥4.0

The written history of Australia extends back to 1788 in Sydney and even less in the other capitals; Hobart (1803), Brisbane (1824), Perth (1929), Adelaide 1836), Melbourne (1837), Darwin (1869) and Canberra (1912). This history has been mined by many authors resulting in the publication of three isoseismal atlases (Everingham and others, 1982, Rynn and others, 1987 and McCue,1996). As a consequence, several hundred important earthquakes have been added to the Australian earthquake catalogue, including the largest known earthquake, offshore WA in 1906, its magnitude 7.2.

The completeness interval is tabulated from McCue (2004) below.

Table 1 Magnitude completeness intervals in continental Australia and Tasmania

Magnitude	≥6	≥5	≥4	≥3
Starting year	1901	1963	1975	1995

From this historical research, an extreme value distribution of large earthquakes for continental Australia results in the following figure.

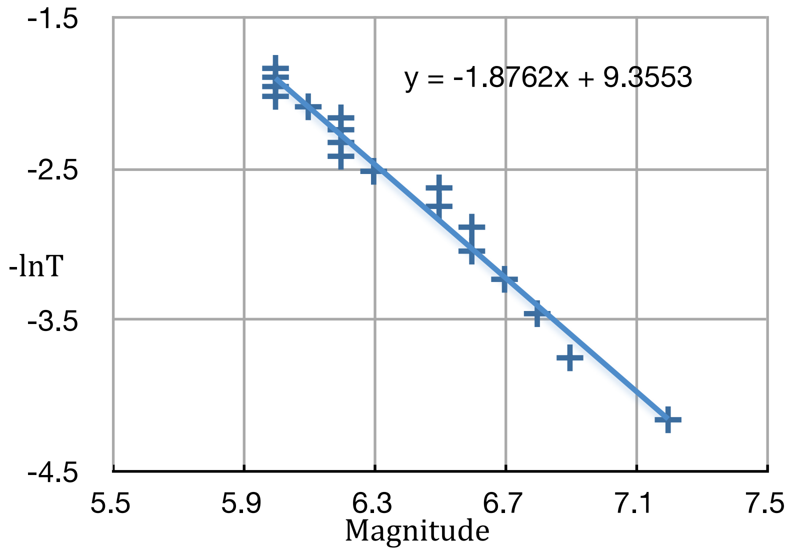

Figure 2 LnT, where T is return period in years, vs. magnitude Ms for Australia's continental earthquakes 1880 – 2010, M≥6.0 (aftershocks and multiple events removed).

According to the line-of-best-fit which has a 'b' value of 0.82 we get the following expected return period for the specified magnitude.

Table 3 Approximate return periods for listed magnitudes in continental Australia

magnitude	5.0	6.2	7.4
return period	1	10	100

Though few focal depths are well constrained, those that are, are mostly relatively shallow (notable exceptions are discussed by McCue and others, 1993), occurring in the upper 20km of the crust and they therefore give rise to strong shaking in the near-field. Earthquakes larger than about magnitude 5.8 are likely to rupture through to the surface. The two decades from 1968 are without precedent in Australia, 7 large earthquakes, all of which ruptured the crust.

Table 4 Large surface rupturing earthquakes post 1960

Place	Date	Magnitude	Rupture length km
Meckering WA	14 October 1968	6.8	35
Calingiri WA	1970	5.7	3
Cadoux WA	2 June 1979	6.2	15
Marryat Ck SA	30 March 1986	5.8	13
Tennant Ck NT	22 January 1988	6.3 6.5 and 6.7	35

Reconnaissance level paleoseismological studies have been made in Australia (Clark et al, 2003) but this work is underfunded and few of the identified possible fault scarps have been trenched and dated. The prehistoric large earthquakes are not associated with major mapped faults.

The observed pattern of epicentres is not representative of a uniform distribution at a high level of confidence (Sinadinovski and McCue, 2010), therefore a model that identifies the cause (McCue and others, 1998) as Coulomb failure should be prominently represented in the source zone models in future earthquake hazard mapping of the continent, as opposed to past-earthquake models or geoilogically-based models.

What do we know that we do *not* know about Australian earthquakes?

It is quite generally accepted by seismologists that earthquakes occur on faults whether existing or new. In intraplate areas like Australia and Eastern North America there are very few identified active faults – those which earthquakes are known to have ruptured in a defined time interval before the present. The USGS commented after a recent earthquake near Washington DC: *At well-studied plate boundaries like the San Andreas fault system in California, scientists may be able to determine the specific fault that is responsible for an earthquake. In contrast, east of the Rocky Mountains this is rarely the case.*

There are few if any well defined active faults in Australia, the largest mapped fault, the Darling Fault east of Perth does not appear to be active but is very near an active seismic zone known to have generated the large Meckering, Calingiri and Cadoux earthquakes in the 11 years 1968 – 1979 (see listing). Why the earthquakes occurred within the Precambrian Yilgarn block rather than on the nearby Darling Fault on its boundary has not yet been satisfactorily explained.

The main boundary faults to the Flinders Rangers don't seem to be active whilst many small well-located earthquakes occur beneath the ranges. Perhaps the period of recording is too short but hazard analyses based on presumptions of active faults and slip rates are just that – presumptions.

In general, analysts assign a focal depth to Australian earthquakes because their focal depth cannot be accurately computed. Generally the uncertainty is at least half the thickness of the crust, except for earthquakes that occur within a local area network around a dam for example or aftershocks within a temporary network, or those which are large enough to have generated identifiable depth phases at 2000 km or more distance.

We have no idea where or when the next large earthquake will occur in Australia though it has a 50% chance of occurring in WA, more than a 30% chance of happening in central Australia (SA or NT) and almost 20% chance of happening in eastern Australia, based on the last 100 years of data. The younger more highly folded geological rocks of eastern Australia are less seismically active than the ancient flat shield area of central and western Australia. How is that so?

When a large earthquake does occur we cannot predict the ground motion near to the source because we have no measurements of near-field ground shaking during a large Australian earthquake, and there are so few instruments installed here that we are unlikely to record such shaking in future earthquakes. Somerville and others (2009) have derived GPE's for eastern and Western Australia but their only calibration was a magnitude 4.5 earthquake in Victoria during the moderate ML5.0, Mw4.5 Thomson Dam earthquake in 1996. Christchurch has yielded a significant number of near-field records from three large shallow intraplate earthquakes with similar mechanisms to typical Australian events. Now that such instruments are becoming very cheap, seismologists and engineers should insist that they be installed in Australian cities and on buildings in cities to learn as much as possible about the ground shaking in future earthquakes and the response of typical Australian buildings and foundations.

Many engineers in New Zealand were greatly puzzled by the high ground accelerations recorded at Christchurch in 2010 and 2011, some even suggesting that there was something wrong with the accelerographs because the ground shaking was about 1g. In Australia there have been a few recordings of high ground accelerations from small earthquakes as shown in the following table

Table 5 Some measurements of pga in Australia

Location	*Date*	*Magnitude/Distance*	*pga*
Dalton NSW	08 Sep 1984	4.3 at 5km	0.3g
Tennant Ck NT	29 Apr 1988	5.0 at 9 km	0.5g
Eugowra NSW	24 Aug 1994	4.0 at 1km	1g

The latter two readings were vertical ground motions, the horizontal shaking only slightly less. Significant vertical strong ground motion is usually ignored by engineers. If you get close enough to the source, a fracture of strong rock, then there

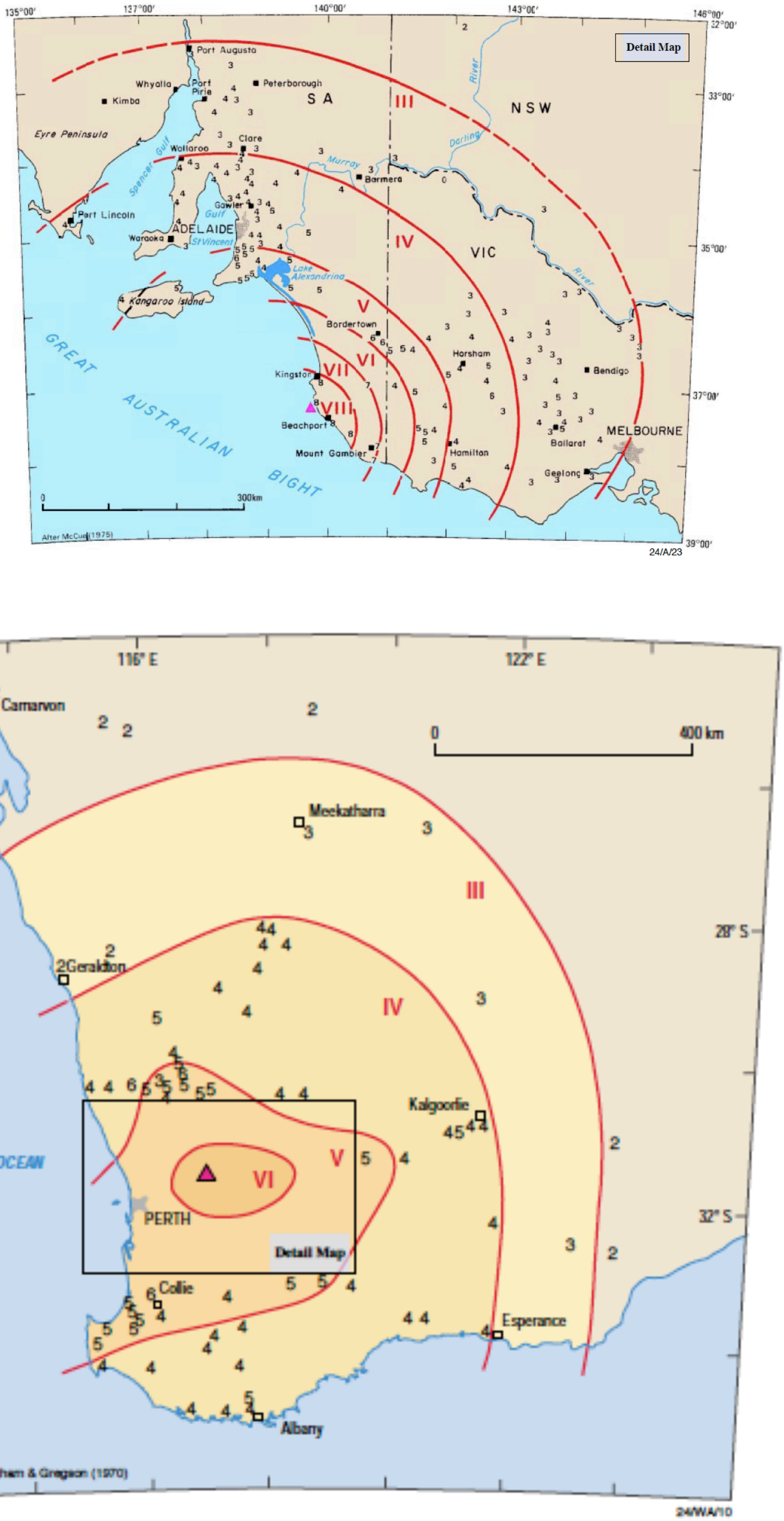

Figure 3 Isoseismal maps, at similar scales, for the 10 May 1897 Kingston-Beachport (top) and 14 Oct 1968 Meckering WA earthquakes (bottom from Everingham and Gregson, 1970). In the top map, intensity attenuation is obviously influenced by the gross geology whereas in the lower map it is not (see text).

is no physical limit to the pga. In mines pgas of many g are recorded. It is interesting that the maximum recorded pga has increased with time mirroring what happened in the US from 1930 on. Measurements of pga in excess of 2g have been made in the US with many thousands of accelerographs now deployed. The value of pga is no indicator of damage potential and its use for this purpose should be abandoned by engineers (Ambraseys, 1973).

Table 6 Large Continental Australian Earthquakes, 1870 - 2011

Date UTC	*Time*	*Lat °S*	*Long °E*	*ML*	*Ms*	*Location*
1873 12 15	0400	26.25	127.5		6.0	SE WA
1884 07 13	0355	40.5	148.5		6.2	NE Tasmania
1885 01 05	1220	29.0	114.0		6.5	Geraldton WA
1885 05 12	2337	39.8	148.8		6.5	NE Tasmania
1892 01 26	1648	40.3	149.5		6.6	NE Tasmania
1897 05 10	0526	37.33	139.75		6.5	Kingston SA
1902 09 19	1035	35.0	137.4		6.0	Warooka SA
1906 11 19	0718	21.5	104.5		7.2	Offshore WA
1910 01 13	0015	44.5	155.2		6.0	Tasman Sea
1918 06 06	1814 24	23.5	152.5	6.0	5.7	Gladstone Qld
1920 02 08	0524 30	35.0	111.0		6.0	Offshore WA
1929 08 16	2128 23	16.99	120.66		6.6	Broome WA
19371220	2235 02	25.4	136.5		6.0	Simpson Desert
1941 04 29	0135 39	26.92	115.80		6.9	Meeberrie WA
1941 06 27	0755 49	25.95	137.34		6.5	Simpson Desert
1946 09 14	1948 49	40.07	149.30	6.0	5.4	NE Tasmania
1968 10 14	0258 50	31.62	116.98		6.8	Meckering WA
1970 03 24	1035 17	22.05	126.61	6.7	5.9	L Mckay WA
1972 08 28	0218 56	24.95	136.26		6.2	Simpson Desert
1975 10 03	1151 01	22.21	126.58		6.2	L Mckay WA
1978 05 06	1952 19	19.55	126.56		6.2	L Mckay WA
1979 04 23	0545 10	16.66	120.27	6.6	5.7	Broome WA
1979 04 25	2213 57	16.94	120.48		6.1	Broome WA
1979 06 02	0947 59	30.83	117.17	6.2	6.1	Cadoux WA
1983 11 25	1956 07	40.45	155.51	6.0	5.8	Tasman Sea
1986 03 30	0853 48	26.33	132.52		5.8	Marryat Ck SA
1988 01 22	0035 57	19.79	133.93		6.3	Tennant Ck NT
1988 01 22	0357 24	19.88	133.84		6.4	Tennant Ck NT
1988 01 22	1204 55	19.94	133.74		6.7	Tennant Ck NT
1997 08 10	092035.2	16.10	124.38		6.3	Collier Bay WA

Ground motion in the near field of a large earthquake will be strongly influenced by the length and orientation of faulting and by the azimuth of a site with respect to the direction of faulting. These parameters cannot be known in advance.

At large distances, the geology can influence attenuation in a gross sense, but not always, as shown in the two isoseismal maps above. In the 1897 Kingston-Beachport earthquake, the intensity drops off quickly along the Otway Basin towards Melbourne, at double the rate it decreases across the Gawler Craton to the northwest through Adelaide. Perversely, in the Meckering 1968 earthquake, the Perth Basin to the west of the Darling Fault which parallels the coast onshore does not appear to amplify the ground motion relative to the Yilgarn Craton to the east of the fault, in the vicinity of Perth. There is no sudden change of intensity across the fault.

Above is a table of large earthquakes known to have occurred in Australia since 1880**.** When a large earthquake does occur we can only guess at how the subsequent seismicity will develop. The 1968 Meckering earthquake was a textbook event with 4 foreshocks, the mainshock and thousands of aftershocks in the following 30 years, the largest aftershock, one magnitude unit smaller than the mainshock, occurred the next day. Other sequences were very different.

Take the sequence off NE Tasmania that according to newspaper reports started in April 1883 (Ripper, 1963). The first large earthquake occurred in July 1884 followed by larger earthquakes in 1885 and 1892 (Michael-Leiba, 1989) when the sequence of 2000 felt earthquakes appeared to end.

However earthquakes continued to be felt and in December 1929 an earthquake damaged the hospital in Launceston, fortunately no one was killed or injured (see attached scan from the Mercury Newspaper, 30 December 1929).

In 1946, there was yet another large damaging earthquake and then nothing of significance to the present day. Fortunately the epicentral region of the sequence appears to have been offshore and not under an urban area.


Launceston Damage.

LAUNCESTON, Monday.—The earthquake shock on Saturday morning last was particularly severe in the locality of the Launceston Public Hospital. At that institution 12 feet of bricks tumbled off the top of the chimney over the laboratory, knocking holes in the roof. A coping slab weighing about 3 cwt. fell off the chimney over the operating theatre, making a hole about 2 feet square in the slate roof over the anaesthetic room. Some of the coping fell about 40 feet into the yard, but luckily struck no one. Plaster also came down in one of the rooms in the nurses' home.

Figure 4 Extract from The Mercury Newspaper 30 December 1929

Another notable earthquake sequence commenced in January 1987 southwest of Tennant Ck, NT and appeared to have petered out when a series of large earthquakes occurred there in on 22 January 1988. In all there were three large earthquakes in 12 hours each one bigger than the one before, and each one ruptured the ground surface causing gas-pipeline damage and building damage in the town of Tennant Ck. The sequence is still popping away, more than 20 years later. Again we were lucky that the epicentral region was so remote from a major urban area.

A third multiple-shock sequence occurred in the remote Simpson Desert between 1937 and 1972 but surface faulting has not been found there, quickly concealed perhaps by the shifting desert dunes.

Christchurch New Zealand wasn't so lucky, three large earthquakes in ten months, the latter two about the size of Australia's one in 10 year earthquake, virtually bullseye hits on the city. It was surprising that no aftershock in the magnitude 6 range occurred after the major M7.1 September 2010 Christchurch earthquake until February 2011. There was still room for surprise as the location was about 40 km east of the eastern end of the September rupture and very close to the city where several building collapsed and 181 people were tragically killed. The subsequent June event caused further damage, 3 building collapsed but fortunately no further deaths.

Discussion

We don't know a lot about Australia's large intraplate earthquakes or their likely impact on buildings, old and new. Swarms, aftershock sequences and multiple large earthquake sequences are features of intraplate seismicity that await our undersatnding. The bullseyes around large earthquakes in past hazard maps reflect the history that these sites are quite likely to suffer subsequent large earthquakes, at least during the next 50 years. Engineers, planners and US&R personnel need to be aware of these features, and that few buildings in Australia have been carefully designed and built to resist earthquakes.

Australian engineers and seismologists should start installing an extensive network of cheap accelerographs in buildings in cities and in the free field in the high hazard areas identified in hazard maps.

Christchurch should be a wake-up call to building code developers in Australia as it has been in New Zealand. Cross Tasman links should be strengthened and discussions held to plan for the next version of the loading code, free of political interference and outside influence from user groups.

Acknowledgments

The referees' (RC and PS) comments were very useful but one (PS) too late to accommodate in full. This paper was a contribution to the discussion on whether we had learned enough in the last 5 years to change the Australian Earthquake Hazard map in the current Loading Code, looking back.

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