Comparing the Activity of Earthquake Zones in South-eastern Australia

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ABSTRACT: Cumulative seismic moment release over the whole period of recorded history shows that the earthquake hazard rating of four active zones in South-eastern Australia are, in order high to low: NE Tasmania, Dalton-Gunning, Gippsland and lastly Newcastle. This is in stark contrast with the latest PSHA of Australia showing that limiting the sample to the short instrumental period may be quite misleading.

1 INTRODUCTION

Estimating earthquake hazard in active tectonic areas is difficult enough; to do so in intraplate areas with a low frequency of earthquakes and short instrumental record in relation to the return period of earthquakes of interest, is more of an art than a science. The numerical result of an analysis will depend almost entirely on the assumptions made. It seems self-evident that the longer the recorded history of earthquakes, the more comfortable we can be with the evaluation.

The question: *why bother evaluating historical- and archeo-seismology ?* was answered by Ambraseys (2005): *As we cannot know what will happen in the future, to estimate likely earthquake hazards we have to find out what happened in the past and extrapolate from there.*

Four 'active' areas of Southeastern Australia are compared using recently published (for earthquake details see McCue 2014 and 2015) historical records dating back 150-200 years as a basis for comparison with earthquake hazard results also recently published (Burbidge, 2012) but based on just the last ~50 years of instrumental data – a three to fourfold extension of the earthquake database.

Some paleoseismological results allow us to estimate a maximum magnitude based on the length and throw of recent faults, assuming that even larger earthquakes would be evident in the lansdcape. Larger earthquake-capable faults have been mapped but, though striking, are ancient features that are deemed to be inactive either adversly oriented in the current stress field or healed.

Moment release rates were used as the metric, recurrence relations make no sense sometimes as seismologists usually remove those earthquakes that are most important for engineering purposes, the infrequent larger ones, because they inconveniently don't fall on the line expected or are deeemed statistically insignificant. As will be shown here, the 'a' and 'b' values are decidely time dependent.

2 CHOSEN SOURCE AREAS

The four active areas chosen, are from north to south; Newcastle NSW, Dalton-Gunning NSW, Gippsland Victoria and northeastern Tasmania. Each area was circular with a radius of 150km, about the fault length for the maximum credible earthquake in continental intraplate Australia.

The tectonic settings of all four areas are identical, solidly intraplate and more than 1500km from the nearest plate boundary, all in crust of Phanerozoic age (0-545Ma) that has not undergone significant deformation such as mountain building, basin formation or extensive shearing in the last few tens of millions of years and all near the eastern edge of the Australian continent. The principal stress direction is near horizontal and, for all but Newcastle, strikes in a northwest-southeast direction, the least stress direction in all four zones is vertical. Near Newcastle the principal stress direction strikes northeast-southwest but in either case the expected earthquake focal mechanisms are shallow thrusts.

Earthquake monitoring of the whole area started about the end of the 19^{th} century but was not comprehensive until the mid 1960s with the installation of high-gain short-period seismographs. After 1788, Europeans spread rapidly and soon established railheads, towns and then local newspapers which routinely published stories about interesting natural phenomena including earthquakes in the new colony.

These reports of earthquakes from the newspapers were studied to derive their date, time, location and magnitude. The magnitudes M are based on the felt area (or Radius of Perceptibility, R km), the bigger the felt area the larger the earthquake and the relationship is quite sensitive, being logarithmic so the uncertainty in magnitude is better than 0.5, perhaps as small as 0.2.

$$M = 1.01\ln R + 0.13 \quad \text{……………………(1)}$$

This was derived from earthquakes across the continent so estimates of magnitudes in eastern australia based on this equation are likely to be underestimates; there are rarely 'not felt' reports helping to define the felt area so the observed felt area is a minimum. Earthquakes of a given magnitude may be more widely felt in western Australia than in eastern Australia but that is not clear.

3 CHOSEN SOURCE AREAS

The areas chosen for comparison are centred on points as per the following table which also lists the commencement of reporting of earthquakes.

Table 1 Centres of source zones with radius 150km.

Source	Central Latitude	Central Longitude	Commencement
Newcastle	-32.9	151.8	1801
Dalton-Gunning	-35.0	149.0	1850
Gippsland	-38.0	147.5	1865
NE Tasmania	-41.0	148.0	1844

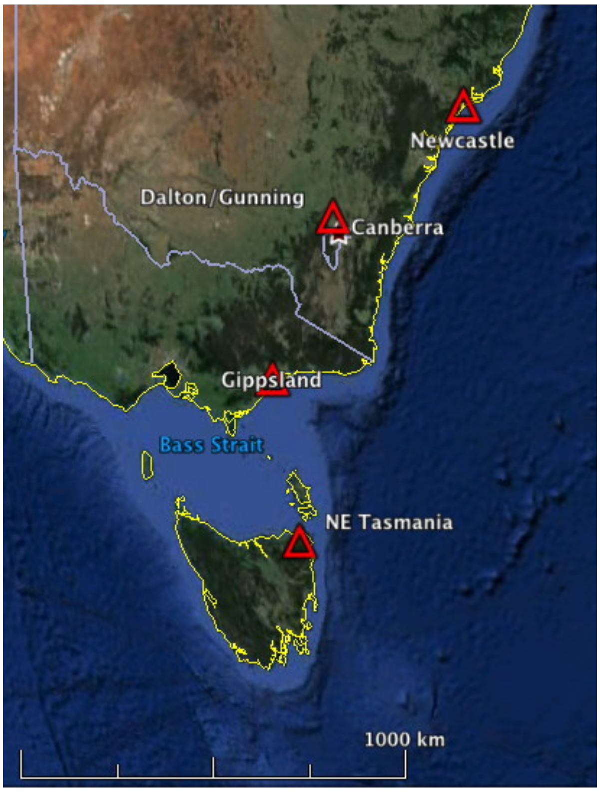

Figure 1 Source Zone Map. Non-intersecting circles with a radius of 150km and centred on the plotted red triangle define the hazard centres.

4 THE DATA

4.1 Newcastle NSW

This area was settled by europeans soon after they first arrived in Australia and its seismicity was the subject of a special study by Cynthia Hunter (1990) whose book was going to press at the time of Australia's most destructive earthquake, near Newcastle in December 1989. Previous moderate earthquakes ($M \geq 5$) near the city in 1837, 1841, 1842, 1868 and 1925 caused damage and were widely reported at the time. Their magnitudes were assessed from their isoseismal maps using equation (1) above (McCue 1980 and 1996). Many others were tabulated by Hunter and a few additional ones discovered by McCue (2014) after scanned searchable copies of early Australian newspapers became available on–line via TROVE a creation of the Australian National Library.

The earthquakes here are usually solitary events, followed by few or no aftershocks. None were reported felt after any of the larger pre-1989 earthquake and only a single aftershock followed the 1989 earthquake and was felt and recorded on the local area network installed ~12 hours after the mainshock. As a result of extensive coal mining in the area there are many coal mine blasts and caving-wall collapses up to the high magnitude 3s which are sometimes difficult to distinguish from earthquakes.

The focal depths extend to mid-crustal depths, the 1989 mainshock and aftershock were 12km to 14km deep. By contrast the 1994 Ellalong earthquake near the Basin edge was only 5km deep but all occurred in Lachlan Foldbelt rocks under the Sydney Basin.

Swarms of earthquakes have been observed but these may well be mining related.

4.2 **Dalton-Gunning NSW**

The area is larger than the name implies including Boorowa (current spelling), Yass, Goulburn, Bowral and Cooma, all in the Lachlan Foldbelt. The earthquake history of this area (McCue and others, 1989) was updated recently (McCue, 2014) and includes two Newcastle sized earthquakes in 1934 and 1949, and others near Bowral in 1961 and 1973 which all caused structural damage and ground deformation but no casualties. Two slightly smaller earthquakes struck in 1886 and 1888.

The behaviour of earthquakes near Gunning and Picton/Bowral is strikingly different to those at Newcastle. Most earthquakes are followed by extensive aftershock sequences, many aftershocks were reported felt in pre-instrumental times but many more are recorded these days even for earthquakes as small as 3. Swarms too are known. Mostly the earthquake foci are just a few kilometres deep in the granite batholith of the Dalton/Gunning region, their S-P times on aftershock recorders in the epicentral area less than 0.5s but those near Bowral with well determined focal depths seem to be mid-crustal, a similar range to Newcastle.

4.3 **Gippsland**

Earthquakes in Gippsland have recently been felt throughout Melbourne and southeast Victoria (Hoult and others, 2014) as the following media release reports: *A magnitude ML5.4 (mb5.2) earthquake struck Gippsland near Moe at 8.55 pm on 19 June 2012, at a shallow depth of 10 km. It was the strongest recorded in Victoria in at least three decades with some sources suggesting it was the strongest in over a century. It was felt across much of Victoria and parts of New South Wales, with strong shaking reported across Melbourne. Some minor building damage was reported in the Latrobe Valley close to the epicentre, and in the eastern suburbs of Melbourne. Around 30 requests for help were made to the SES, mainly due to cracked walls and ceilings and a number of local businesses lost some stock. Approximately 60 aftershocks were recorded the following day, but most of these were not felt.*

A magnitude 4.5 aftershock occurred in the same area at 7.11 pm on 20 July 2012 at a similar depth. This tremor was felt across south Gippsland, as well as Melbourne and the Mornington Peninsula. This aftershock is the strongest of more than 200 that have occurred since the initial quake.

This area has a very different historical record of felt earthquakes than that in the last 50 years.

4.4 **Northeast Tasmania**

The most intense sequence of earthquakes known so far in Australia struck north-eastern Tasmania, part of the Lachlan Foldbelt beginning in 1883 and extending to about 1892. There were at least six magnitude 6+ earthquakes and thousands of felt aftershocks (Carey and others, 1960; McCue, 2015). A separate late M5+ earthquake occurred there in 1946. A list of these earthquakes was compiled by students of Professor Sam Carey under his direction and the watchful guidance of Lesley Read (now Hodgson).

5 **ANALYSIS**

A spreadsheet was created to prepare a chart showing the cumulative moment release ΣM_0 vs. time for each of the source zones using the widely used equations:

$Mw = 2/3\log_{10}M_0 - 6.07$ or $M_0 = 10^{(1.5Mw)} . 10^{9.2}$ and ML = Mw

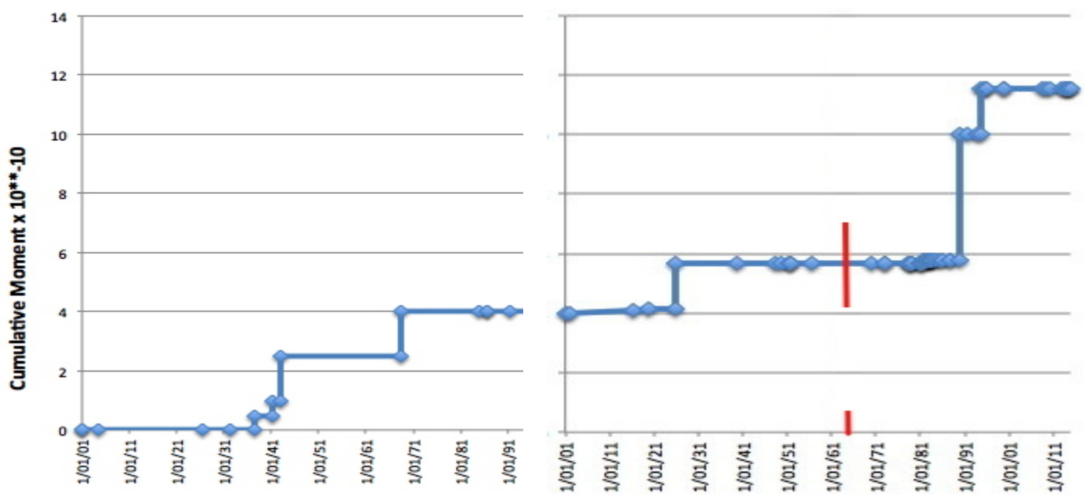

Figure 2 Cumulative Seismic Moment release within 150km Newcastle NSW, 1801-2015.

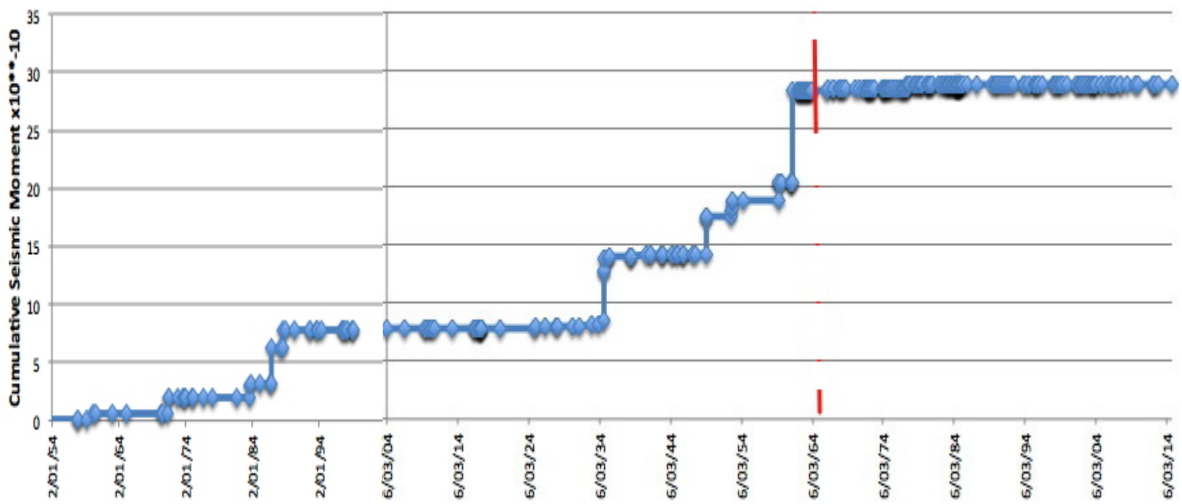

Figure 3 Cumulative Seismic Moment release within 150km Dalton-Gunning NSW, 1850-2015

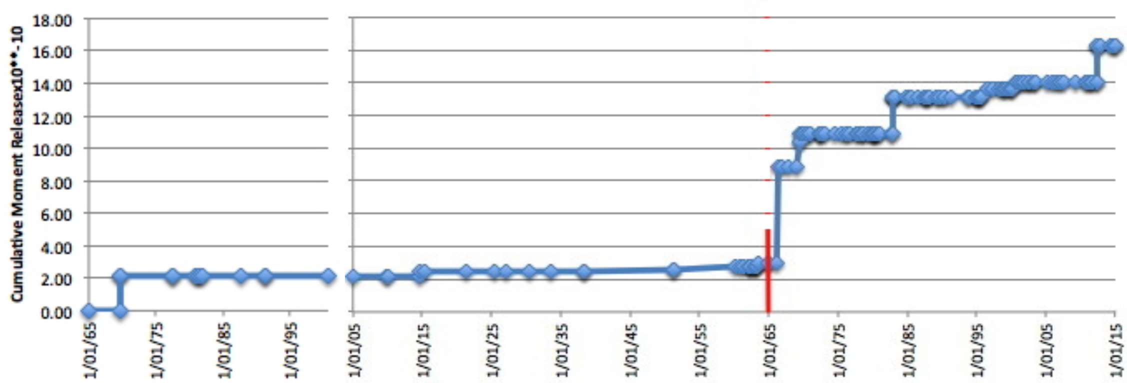

Figure 4 Cumulative Seismic Moment release within 150km Central Gippsland, 1865-2015

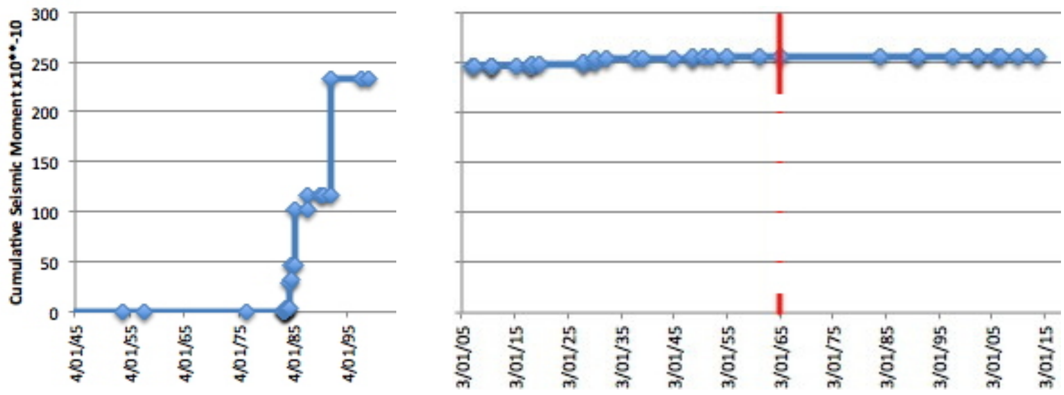

Figure 5 Cumulative Seismic Moment release within 150km Northeast Tasmania, 1844-2015

We assume there are no missing earthquakes above about magnitude 4 in our sample except for Northeast Tasmania where the limit may be M5 or more depending how far they occurred offshore.

This will not impact the results or conclusions given how much more active this zone is than the other three. In the analysis for ease of treating the large numbers involved, the computed seismic moments have been divided by 10^{10}.

The plots show dramatically different behaviour over the last ~200 years of written records and the last 50 years of modern seismological recording (marked by the vertical red bar at 1965). They also show how inappropriate a recurrence relation would be for just these small areas.

It was not sensible to try to include them on one plot because of the different observation periods and cumulative moment release dominated by the Northeast Tasmania sequence. The plots were thought to be instructive as they stand but the numerical values have been tabulated (Table 2) to make the point more obvious. What the Tasmanian and Gippsland sequences demonstrates is that we have not yet lived and sampled long enough to capture their earthquake cycle, all we have is a 200yr snapshot.

Table 2 Moment release rate for the four zones both for the whole period of observation and for the post-1965 period.

Source zone	Whole period (x10^{10}/yr)	1965 – 2014 (50 years) (x10^{10}/yr)
Newcastle NSW	.05	.12
Gippsland Vic	.10	.26
Dalton-Gunning NSW	.17	.01
Northeast Tasmania	1.49	.001

6 DISCUSSION

Considering the four plots and table 2, the following points can be made:

- The long term cumulative moment release rates of the four zones are quite different, Northeast Tasmania has experienced nearly 10 times the moment release of the next highest zone at Dalton-Gunnning with a factor of two to next placed Gippsland and lastly Newcastle. On this basis the potentially most destructive series of earthquakes in eastern Australia's recorded history occurred in the area that has recently been rated the lowest by Burbidge and others, 2012.
- The moment release rate in the Newcastle and Dalton-Gunning regions shows 50yr-long periods of earthquake inactivity separated by active periods but it would not be unreasonable to estimate an acceptable average rate of occurrence over the observation period.

- The moment release rate in Gippsland and Tasmania could not be considered average over the period of observation; Gippsland was apparently inactive for 100 years before 1965 after which the rate increased, conversely NE Tasmania has been quiescent over the last 100 years. This demonstrates the time dependent nature of recurrence relatonships.
- Basing a hazard analysis on just the last 50 years (Burbidge, 2012) is quite misleading, reversing the order of observed long-term cumulative moment release rates.
- Northeast Tasmania gives us a preview of what we might expect anywhere along the Southeast coast of Australia, from Tasmania to Brisbane. Earthquakes may well exceed magnitude 6.5 and there may be several above magnitude 6 following the first one.
- Dalton/Gunning and northeast Tasmania are quiescent at the moment and conversely the Newcastle and Gippsland regions are quite active, but for how long?

The computed moment release is quite sensitive to magnitude so changing the magnitudes by 0.2 can cause noticeable changes in the actual numbers (increasing the magnitude of the Newcastle earthquake from 5.6 to 5.8 for example) but not enough in the cases discussed to change the outcome. Choosing a different radius, 100 or 200km, could also affect the results significantly. If the radius is too small seismologists can only define a small-earthquake model, all damaging earthquakes will be excised from the recurrence relation and extrapolation made over several orders of magnitude to larger earthquakes. Engineers and planners are more interested in a large-earthquake model. All four areas should be combined into a single large Southeast Australian zone for a traditional hazard analysis.

One possible explanation of the different aftershock behaviour of the three areas south of Newcastle compared with Newcastle could be the rotation of the principal stress direction from perpendicular to the coastline (principal lineament direction) to parallel to that direction in the case of Newcastle alone of the zones investigated here.

If one followed Ambraseys' (2005) advice, history would dictate that the hazard rating would be in the order high to low: NE Tasmania, Dalton-Gunning, Gippsland and lastly Newcastle. This is in contrast with the results of the latest PSHA of Australia (Burbidge, 2012) and does not necessarily accord with our expectations because we have not yet lived long enough. We don't have the benefit of a glass bowl prediction, hazard analyses can only be based on the best information available and I submit that the last 150^{+} year history is a better basis than the last 50 years. A revision of earthquake hazard should be initiated based on the published longer record and using bigger source areas. Still the record is not long enough to think that Australian seismologists and the public won't continue to be unpleasantly surprised in the future.

The best way forward is to put more resources into completing and ground-truthing the Geoscience Australia paleo-seismology study (Clarke and others, 2012) so that all scarps are mapped and dated expanding the large-earthquake model out to the thousands of years required for a more stable earthquake model than the last 50 years or even 200 years provide.

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