Reconciling neotectonic and seismic recurrence rates in SW WA

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Introduction

The seismicity of the southwest corner of Western Australia has long been thought to be unusual. Everingham (1968) and Everingham and Tilbury (1972) undertook an analysis of the historical earthquake catalogue for south-western Australia, and concluded that the catalogue is complete above magnitude 4.5 since 1900, and probably since 1878. Michael-Leiba (1987) concluded that there was a sudden increase in seismicity around 1949. The geomorphology of the area (eg. the generally flat landscape) is not consistent with the seismicity rate for the last 40 years, which includes three scarp forming earthquakes, being typical of the seismicity over the Quaternary.

The new sources of data becoming available, such as DEMs and Optically Stimulated Luminescence (OSL) dating, (Clark 2005, Clark et al. 2004, Estrada et al. 2006) are enabling scientists to learn and suggest hypotheses about the nature of the seismicity of Australia, and possibly other areas of stable continental crust, which was not possible until now. This paper compares the number of expected M7.0-7.5 earthquakes estimated from seismic recurrence rates derived from several earthquake catalogues and the number of paleo fault-scarps which have been identified in the area - mostly from DEMs.

Data and method

The availability of high resolution digital elevation model (DEM) data has lead to the identification of over 50 features that are likely to be scarps of surface rupturing earthquakes (Clark 2006 & 2005). Few of these fault scarps have been fully studied but of the 20 which have been the subject of field work all are thought to be fault scarps. Using the fault length and displacement as proxies for magnitude and in some cases identifying multiple events, these scarps have been used to generate a neotectonic earthquake catalogue. The area used in this study is the subset of that covered by the WA Department of land Information (DLI) and Shuttle Radar Tomography Mission (SRTM) DEMs, which has an average rainfall of less than 400mm/yr. A wetter environment would result in more extensive tree coverage which makes identifying scarps more difficult and likely results in much higher erosion rates. This makes estimating magnitude completeness even more difficult and so the data from wetter areas has been excluded.

Estimating the magnitude completeness periods of neotectonic data is very difficult. The higher resolution DLI data is estimated to be complete above M7 for the last 100ka. The lower resolution SRTM is likely less comprehensive and M7.2 for the last 100ka is the completeness period estimated. All earthquakes above magnitude 7.0 are assumed to result in a significant fault scarp for the full length of the rupture area. Smaller earthquakes will not necessarily result in a scarp at all, let alone a full length scarp. Of those scarps formed by these smaller earthquakes their smaller size makes them more difficult to identify and they will have shorter periods of exposure. For these reasons, completeness periods for earthquake with magnitudes <M7 have not been included in this study.

Two sources of earthquake data are used in this study. The first is a catalogue of earthquakes in global stable continental crust (SCC) compiled by the Geological Survey of Canada (GSC) (Fenton et al. 2006, Adams 2005). This has been used to estimate global and Australian recurrence rates. The other is the recently compiled catalogue of Australian earthquakes (Leonard 2006), which has been used to estimate recurrence relations for all of Australia and the SW of WA (Figure 1). The software used is based on the program betaplot developed by the seismology group of the GSC. It uses the method of Weichart (1980), which includes multiple completeness periods, maximum magnitude (Mmax) and the option to fix β.

This software has been applied to the four catalogues discussed using an Mmax of 7.6 The choice of Mmax in SCC remains contentious. Johnston (1994) argues that M7.0 in areas of non-extended continental crust. Others (Somerville P. and Campbell K. Per. Com.) prefer values in the M7.2-7.5 range.

Results

Figures 2, 3, 4 and 5 show the recurrence results for the SWSZ, Australian Shield, Australian Continent and World Shield respectively. So as to be consistent with the output of the betaplot program, the neotectonic derived recurrence rates have been rescaled according to the area of each region and to a per annum basis. These results are given in Table 1. The neotectonic derived catalogue would appear to be complete for ≥M6.9. This is the magnitude where a curve with a slope of 1 (b = 1.0) is tangential to the data. A slope of 1 is chosen as the break point between the slope of the curves at small to medium magnitude (0.6-0.95) and the slope at higher magnitudes (>2). Below M6.8 the number of earthquakes rapidly decreases with 20-25% of the expected number of M6.7 earthquakes and 3% of M6.6 earthquakes being identified via neotectonic methods. This is likely a combination of the lower likelihood of the earthquakes causing a surface rupture and the smaller rupture more rapidly reducing in size to below the detection threshold. All earthquakes of ≥M7.0 appear to produce fault scarps. Scarps formed by earthquakes of ≥M7.3 appear over represented with M7.4-7.5 earthquakes being overrepresented by a factor of perhaps 4-6. This could be explained by the longer preservation age of these earthquakes.

In all the recurrence analyses an Mmax of 7.6 has been used. Several of the fault scarps identified on the DEMs in SW WA consistent with M7.4-7.5 earthquakes. The long period of time (100ka or more) for which it is likely that the neotectonic catalogue is complete for earthquakes >M7 makes it likely that there have been several earthquakes close to Mmax. The Australian instrumental catalogue is complete for M7 earthquakes for around 100yrs. As the study area covers approximately 1/20 of the continent, the likelihood of the neotectonic catalogue having a Mmax earthquake is about 50 times that of the instrumental catalogue. Assuming global shield (N.A., S.A., Africa & Australia) catalogues are also complete for >M7 for 100 years, the Neotectonics catalogue is about 11 times more likely to have recorded an Mmax earthquake (Table 2). The lower rate of Global Shield seismicity compared to Australia suggests that this factor of 11 is possibly an underestimate. The three M7.5 and three M7.4 earthquakes suggest that an Mmax of 7.5 or 7.6 is reasonable. In the regressions M7.6 is used so that the recurrence curve included M7.5.

For the SWSZ the neotectonic derived recurrence rate is an order of magnitude below the seismic recurrence rate (Table 2). This is suggestive that the activity in the SWSZ over the last 50 years is higher than its long term (>10ka) rate. For the Australian shield the neotectonic recurrence rate is about twice the contemporary seismic recurrence rate. Given the uncertainties involved in these estimates this is a close correlation, and supports the hypothesis that seismicity in Australia is not stationary and varies spatially and temporally. In which case, the contemporary activity in the SWSZ is just one of several recent episodes of heightened seismicity, along with notable examples such as Tennant Creek and Simpson Desert. This is consistent with a model of episodic seismicity in Australia as suggested by several authors in recent times (Leonard 2006, Clark 2005, Crone et al. 2003, Crone et al. 1997).

For the whole of Australia the neotectonic and contemporary recurrence rates are approximately the same (Table 2). As the seismic includes data from the Flinders Ranges and SE Australia which are thought to have different tectonic environments to shield areas it is difficult to draw conclusions about this correlation. For the world shield earthquakes the situation reverses with the neotectonic rate being higher than the seismic rate and for the world excluding Australia the neotectonic data over estimates the number of large earthquakes by an order of magnitude. Fenton et al. (2006) model the world shield data with an Mmax of 7.0 which has a slightly better fit to the data than when using Mmax of 7.6. Whether an Mmax of ≥M7.4 to all regions of SCC is statistically consistent with contemporary seismicity is a question for the future.

Conclusions

When combined with the Australian and global earthquake databases a catalogue derived from the recently identified neotectonic fault scarps has the potential to provide significant insights into the seismicity of Australia and possibly the seismicity of other areas of stable continental crust. At present only about _ of the features of have had field investigation. All those inferred scarps that were checked in the field were verified to be actual earthquake scarps. This suggests the method of identifying scarps from DEMs is valid.

This study suggests that:

Under the right geological and climatological conditions fault scarps can be preserved for 100ka or more for scarps from ≥M7.3 earthquakes.
Mmax in stable continental crust is perhaps more like M7.5 than M7.0-7.2.
The recurrence rate for the neotectonic catalogue and historical earthquakes in the SCC of Australia are similar.
The contemporary level of seismicty in SW WA is an order of magnitude higher than that needed to generate the scarps.
Approximately 20% of M6.8 and 100% 7.0 earthquakes are expected to form scarps.

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Magnitude	Century	SWSZ	Australian Shield	Australian continent	World Shield
6.5	0.10900	0.059690	0.90833	2.38762	10.17333
6.6	0.10800	0.059143	0.90000	2.36571	10.08000
6.7	0.10700	0.058595	0.89167	2.34381	9.98667
6.8	0.10100	0.055310	0.84167	2.21238	9.42667
6.9	0.08600	0.047095	0.71667	1.88381	8.02667
7.0	0.06400	0.035048	0.53333	1.40190	5.97333
7.1	0.03900	0.021357	0.32500	0.85429	3.64000
7.2	0.01900	0.010405	0.15833	0.41619	1.77333
7.3	0.01300	0.007119	0.10833	0.28476	1.21333
7.4	0.01000	0.005476	0.08333	0.21905	0.93333
7.5	0.00600	0.003286	0.05000	0.13143	0.56000

Table 1 Recurrence rates per century for the Neotectonics catalogue. The recurrence rates have been scaled for area.

Region	SW WA	SWSZ	Australian Shield	Australian continent	World Shield	World ex Aust.
Area 1000 km^2	420	230	3500	9,400	39,200	35700
Mmax likelihood	1	1/2000	1/120	1/45	1/11	1/12
M7 Seis.	-	0.41	1.26	1.72	1.83	0.68
M7 Neot.	0.064	0.035	0.53	1.40	6.0	6.0
Seis. / Neot.	-	12	2.4	1.2	0.3	0.11

Table 2 Summary of recurrence rates and for earthquakes in various regions.

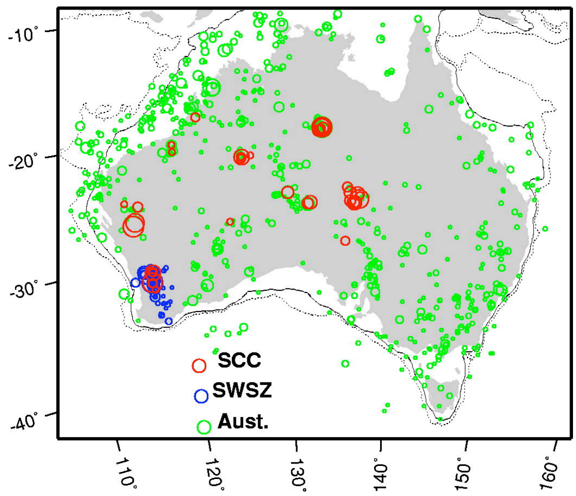

Figure 1 The three catalogues of Australian earthquakes used in this study. The green and blue data are from the GA catalogue and the red data are from the GSC Stable Continental Crust (SCC) database. The two isobaths are at 500m & 2500m.

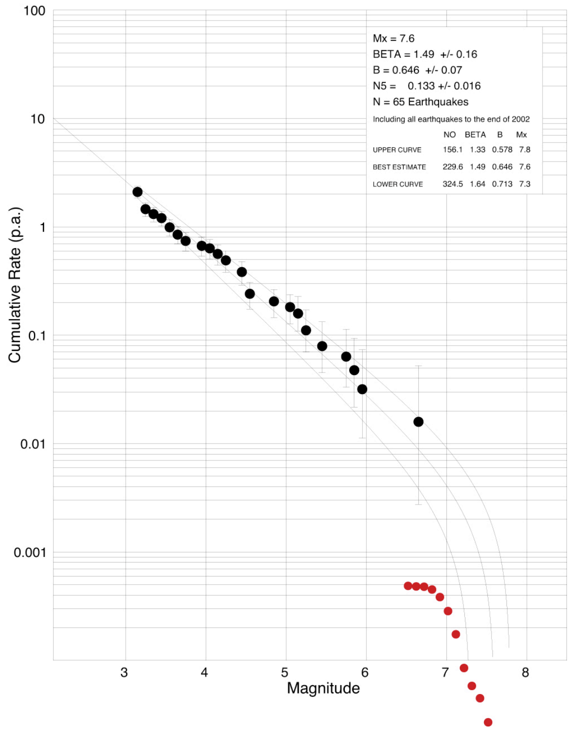

Figure 1 The cumulative recurrence rate of earthquakes in the SWSZ (black) from the GA catalogue and the SW WA neotectonics catalogue (red). The neotectonic catalogue has been scaled for time and area to match the earthquake catalogue.

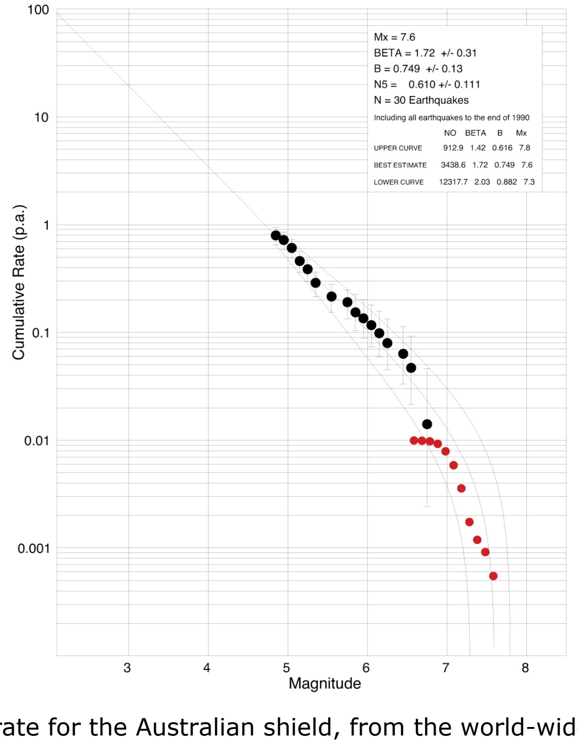

Figure 2 The recurrence rate for the Australian shield, from the world-wide CSS catalogue, and the scaled neotectonic catalogue.

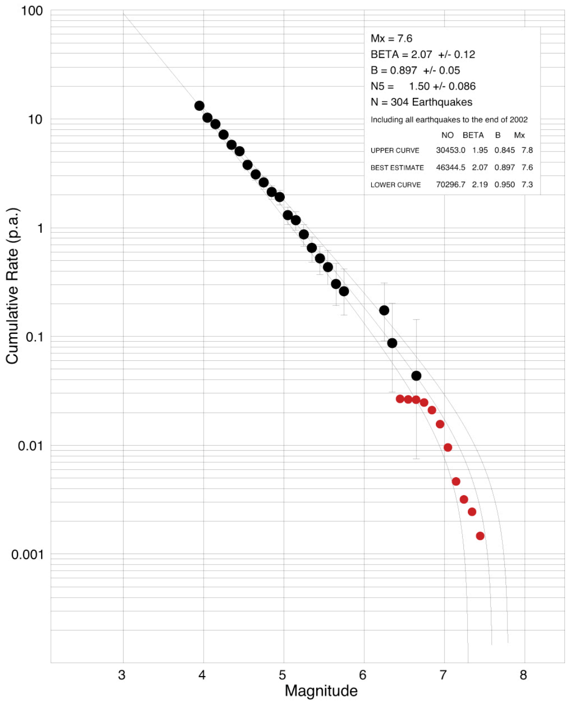

Figure 3 The recurrence rate for the Australian continent and the scaled neotectonic catalogue.

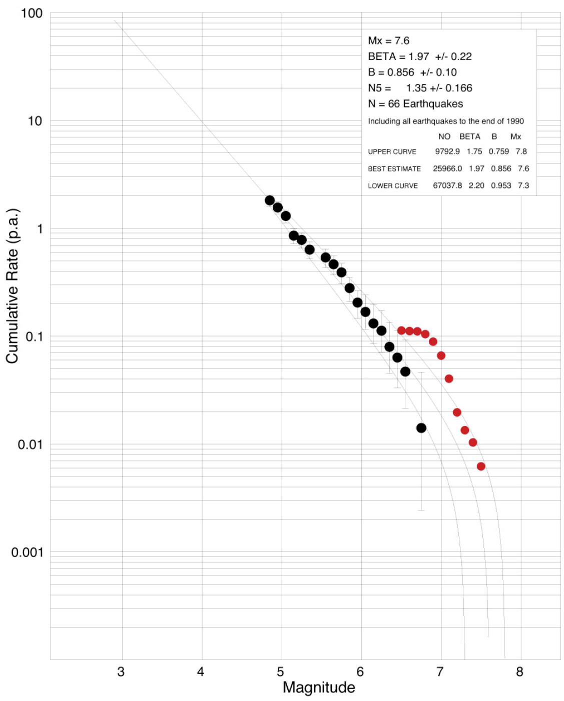

Figure 4 The recurrence rate for the world-wide SCC catalogue and the scaled neotectonic catalogue.