A PRELIMINARY SEISMICITY MODEL FOR SOUTHWEST WESTERN AUSTRALIA BASED ON NEOTECTONIC DATA

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1. INTRODUCTION

Seismic hazard assessment in Australia is based on the fundamental assumption that past earthquake activity is the key to what we might expect in the future. However, the instrumental record spans only 100-150 years and our historic record is not much more than 200 years. If this is compared with the 20-100 kyr return period for large earthquakes on Australian intraplate faults (e.g. Crone et al., 1997, 2003; Clark & McCue, 2003; Clark et al., 2005a,b) large earthquakes might be expected in unanticipated locations – i.e. for most regions of Australia the maximum magnitude earthquake has not yet been recorded. Paleoseismological investigations provide the only viable avenue to obtain constraints on the recurrence intervals of large and damaging earthquakes in intraplate Australia. However, analysis of the prehistoric record is compromised by difficulties related to finding direct evidence for large earthquakes (e.g. fault scarps), which may be subtle or difficult to recognise in the landscape.

In recent times, high resolution digital elevation models (DEMs) have emerged as an important tool for finding and characterising earthquake related geomorphology, and particularly fault scarps (e.g. Oguchi et al., 2003; Clark, 2005). Unlike airphoto interpretation, shaded-relief images derived from DEMs may be used to enhance lineaments by simulating topographic illumination from a variety of azimuths and elevations. The method lends itself well to reconnaissance for fault scarps over large or remote areas, and hence is useful in defining and mapping areas of probable elevated earthquake hazard. In addition, the location, spatial inter-relationships, geometry and recurrence information gleaned from the identified scarps has the potential to provide important constraint on seismicity models, which are arguably the future of seismic hazard assessment, at least at the national scale.

We present the results of a reconnaissance investigation of two DEM datasets covering a large portion of southwest and central Western Australia (**Fig. 1**). The primary dataset is a 10 m resolution DEM generated by the Western Australian Department of Land Information (DLI: http://www.landmonitor.wa.gov.au). The model has a vertical resolution of better than 2 m, and so may be used to identify single event scarps. The secondary dataset comprises selected tiles of the 3 arc-second (~80-90 m resolution) Shuttle Radar Topography Mission (SRTM) DEM (http://www2.jpl.nasa.gov/srtm/). The SRTM DEM has a vertical resolution of ~2-3 m and so is largely limited to 'seeing' multiple event scarps. It is employed here to test for continuation of trends beyond the limits of the DLI data. Additional fault scarps were catalogued as a result of discussions with state and federal field geologists and examination of lineaments marked on 1:250,000 scale geologic map sheets.

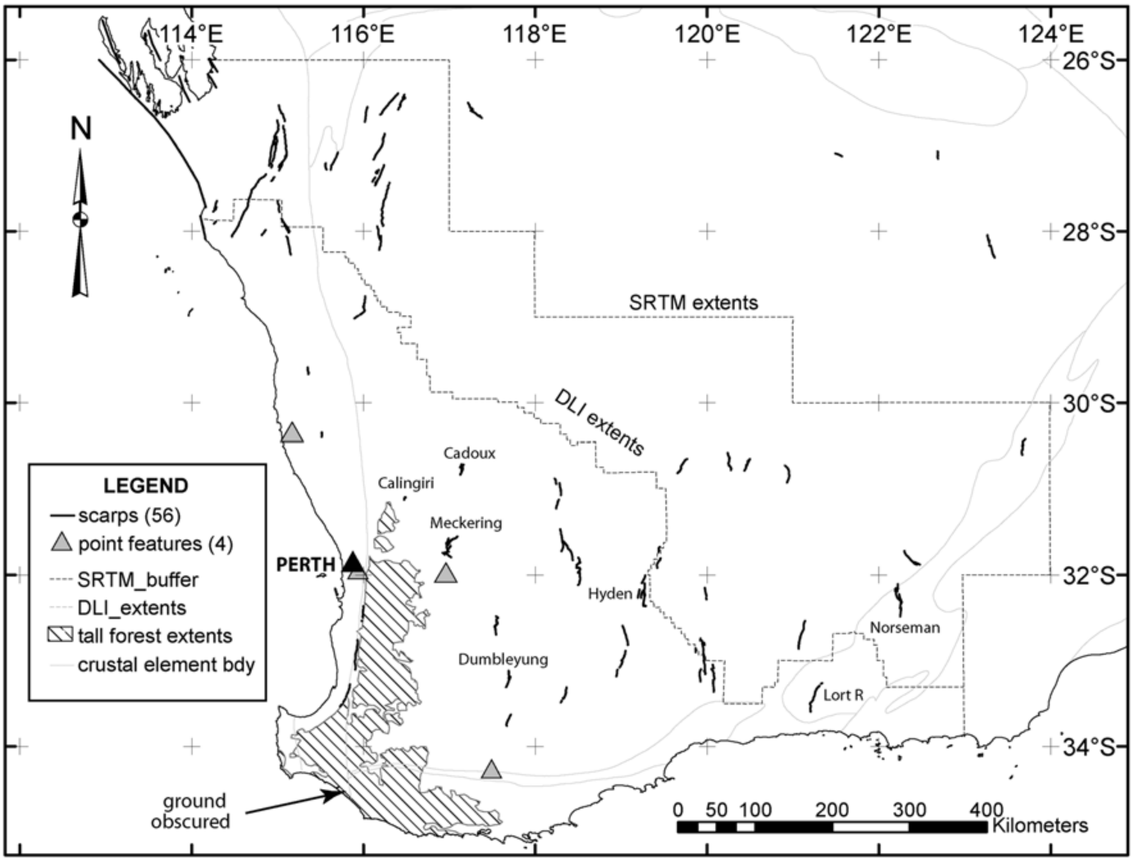

Figure 1. The study area showing extents of the DEMs and Quaternary scarps.

2. RESULTS: EARTHQUAKE FOOTPRINTS IN THE LANDSCAPE

A total of thirty-three new scarps of probable Quaternary age were identified using the two DEMs (**Fig. 1**), bringing the total number of Quaternary earthquake-related features identified in the study area to sixty. Sixteen occur in the area covered by the DLI DEM, and seventeen in the adjacent area covered by the SRTM DEM. Seven of the new features observed on the DLI DEM were sufficiently prominent to also be 'discoverable' on the SRTM DEM. Four further features were identified following discussions with field geologists, but were not sufficiently elevated to be discernable on the DEMs.

The northerly trending features range in length from ~15 km to over 45 km, and from ~1.5 m to 20 m in height. Their distribution is remarkably uniform, and most scarps where a displacement sense could be determined from the DEM data suggest reverse displacement on the underlying fault. In the few instances where high-resolution aeromagnetic data is coincident with a scarp's location (e.g. Hyden, Clark et al. (2005b); Meckering, Dentith et al. (2005); Cadoux, Geoscience Australia, unpublished data; Lort River, M. Dentith unpublished data), the ruptures are seen to exploit pre-existing crustal weaknesses. Nineteen of the features have been verified by ground-truthing, and range in apparent age from perhaps less than a thousand years to many tens of thousands of years.

A comparison of scarp distribution and the distribution of earthquake epicentres (Geoscience Australia online earthquake database, 2005) shows that while some scarps are associated with contemporary seismicity (e.g. Norseman), most are not (**Fig. 2**). This predominance of scarps not associated with contemporary seismicity suggests that earthquake activity is episodic/migratory and that significant periods of quiescence might separate large events. Palaeoseismic studies suggest this interval might range from 20 - 100 kyr or more (Crone et al. 1997, 2003; Clark et al., 2005a,b).

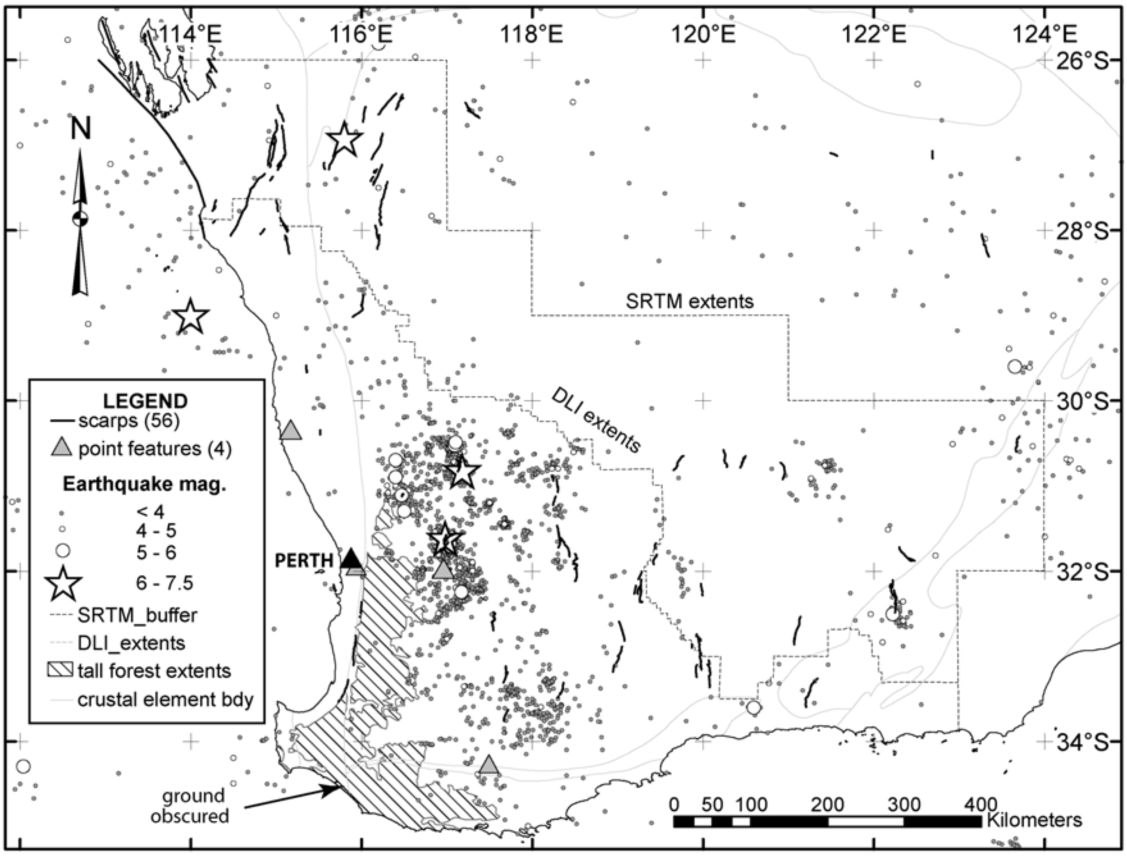

Figure 2. Comparison of Quaternary scarps and the historic catalogue of seismicity.

3. BUILDING BLOCKS FOR A SEISMICITY MODEL COVERING SOUTHWEST WESTERN AUSTRALIA

The above observations form the building blocks with which a seismicity model for the southwest of Western Australia may be constructed. The key points (see also Clark, 2005) may be summarised as: 1) scarps are northerly oriented, 2) reverse mechanisms predominate, 3) scarps are uniformly distributed (ie. strain is distributed at a craton scale), 4) ruptures exploit pre-existing upper crustal weaknesses, 5) scarps range in age from modern to many tens of thousands of years old , with few scarps being associated with modern seismicity (ie. the locus of stress relief is migratory), and 6) seismicity is episodic at a single fault scale and within an area.

The uniform distribution of northerly trending scarps suggests that strain is uniformly distributed over the Yilgarn Craton at geologic timescales, and that the easterly-trending compressive contemporary stress field is likely to have pertained for many tens of thousands of years. These observations, when combined with the above evidence, is consistent with a seismicity model whereby the ductile part of the lithosphere deforms uniformly in response to an imposed easterly-trending contractional strain, and the upper (seismogenic) layer accommodates this large-scale flow by localised, transient and recurrent brittle deformation along lines of pre-existing crustal weakness (see also Braun et al., AJES submitted).

4. IMPLICATIONS FOR SEISMIC HAZARD ASSESSMENT

The proposed seismicity model implies uniform hazard across the southwest of Western Australia, but at a timescale much greater than useful for most seismic hazard assessment applications. The use of the model for hazard assessment will come with an understanding of how large-scale uniform deformation manifests in a given area in a fifty to several thousand year timeframe. While this understanding can only be achieved through the collection and analysis of a significant body of palaeoseismological data, some indications are present in the extant data.

For example, the most recent of the pre-historic surface ruptures, near Dumbleyung (Clark, 2005), may be significantly younger than a thousand years and the region proximal to the scarp is not associated with historic seismicity. The implication is that the locus of seismic activity is migratory on a timescale perhaps not much greater than the span of historic recordings. We might therefore expect that the current locus of activity, in the Meckering-Calingiri-Cadoux-Burakin area, will lapse into quiescence in the decades to come. This expectancy re-enforces the need to be wary when scribing regions of high hazard around the epicentres of large historic earthquakes, as is the current practice (Standards Australia, 1993). Assessment of the probability of several temporally close large events in an area might benefit from consideration of stress transfer, geodetic or palaeoseismological arguments in addition to potentially one-off historic precedents.

Of paramount importance is establishing a pattern in the stress relief within an active region (ie. what constitutes a period of activity for a region), and between active regions (if one exists). Does the large scale lithospheric flow driving seismicity typically result in a series of closely spaced (in time and location) ruptures (thus relieving an area of stress) as seems to have been the case in the Meckering-Calingiri-Cadoux-Burakin area, or in single one-off ruptures, or a combination of both? Is there a standard period over which a region is relieved of stress, before seismicity migrates elsewhere? The data are too spare to answer these questions at present. However, palaeoseismic evidence from the Hyden area (Clark et al., 2005b) is consistent with a period of activity constituting a series of closely spaced ruptures, similar to that seen in the Meckering area.

Also of importance for hazard studies is the realisation that each scarp considered as part of this study represents at least one earthquake event of magnitude larger than 6.0, and in some cases exceeding magnitude 7.0 (cf Wells & Coppersmith, 1994). Furthermore, there is good evidence from palaeoseismological studies (e.g. Clark & McCue, 2003; Clark et al., 2005a,b), and from the height of many of the scarps (e.g. all the scarps visible to the SRTM dataset, Clark, 2005), that suggests recurrence of large events on individual faults is common. The scarp distribution map (**Fig. 1**) therefore provides an indication of earthquake prone regions within southwest Western Australia.

5. CONCLUSIONS

Examination of two regionally extensive DEMs has resulted in the delineation of 33 new northerly-trending linear fault scarps of probable Quaternary age in central west and southwest Western Australia, bringing the total number of Quaternary tectonic features to 60 for this area. The geometric, recurrence and spatial attributes of these features makes it possible to propose a model describing the causative seismicity. The model contends that uniform contractional strain in the ductile lithosphere manifests as localised, transient and recurrent brittle deformation in zones of pre-existing crustal weakness in the upper lithosphere.

Event timing and recurrence information for large earthquakes associated with individual scarps and groups of scarps in a region is necessary to provide some certainty in seismic hazard assessments for short return periods. However, the data presented identify 'earthquake prone' regions that could be employed as a basis for further investigation, and are suitable for immediate application to hazard assessments for longer return periods (e.g. the one in several tens of thousands of years event that might be designed for in the case of dams).

REFERENCES

Braun J., Gesto F., Burbidge D., Cummins P., Sandiford M., Gleadow A., and Kohn B. (2004) Constraints on the current rate of deformation and surface uplift of the Australian continent from a new seismic database. Australian Journal of Earth Science, in review.

Clark D.J. and McCue K. (2003) Australian palaeoseismology: towards a better basis for seismic hazard estimation. Annales of Geophysics, Vol 46, pp 1087-1105.

Clark D.J., Cupper M., Sandiford M., and Kiernan K. (2005a) Style and timing of late Quaternary faulting on the Lake Edgar Fault, southwest Tasmania, Australia: implications for hazard assessment in intracratonic areas. Geological Society of America Special Publication, in review.

Clark D.J., Dentith M., Wyrwoll K.-H. and Yanchou L. (2005b) The Hyden Fault scarp, Western Australia: palaeoseismic evidence for repeated Quaternary displacement in an intracratonic setting. Australian Journal of Earth Sciences, in review.

Clark, D.J. (2005) Identification of Quaternary faults in southwest and central western Western Australia using DEM-based hill shading. Geoscience Australia Record 2005, 60p.

Crone, A.J., Machette, M.N. and Bowman, J.R. (1997) Episodic nature of earthquake activity in stable continental regions revealed by palaeoseismicity studies of Australian and North American Quaternary faults. Australian Journal of Earth Sciences, Vol 44, pp 203-214.

Crone, A.J., de Martini, P.M., Machette, M.N., Okumura, K. & Prescott, J.R. (2003) Paleoseismicity of aseismic Quaternary faults in Australia: implications for fault behaviour in stable continental regions. Bulletin of the Seismological Society of America, Vol 93, pp 1913-1934.

Dentith, M.C., Clark, D.J., Featherstone, W.E., and Mathison C.I. (2005) A new geological model for the 1968 Ms 6.8 Meckering Earthquake earthquake, Western Australia: pre-Cambrian Geological Controls on Modern Seismicity. Australian Journal of Earth Sciences, in review.

Gaull, B.A., Michael-Leiba, M.O., and Rynn, J.M.W. (1990) Probabilistic earthquake risk maps of Australia. Australian Journal of Earth Sciences, Vol 37, pp 169-187.

Geoscience Australia online earthquake database (2005). August 2005. http://www.ga.gov.au/oracle/quake/quake_online.jsp.

Oguchi T., Aoki T., and Matsuta N. (2003) Identification of an active fault in the Japanese Alps from DEM-based hill shading: Computers and Geosciences, Vol 29, pp 885-891.

Standards Australia (1993) Minimum design loads on structures Part 4: Earthquake loads Australian Standard AS 1170.4-1993.

Wells D.L. and Coppersmith K.J. (1994) New Empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement. Bulletin of the Seismological Society of America, Vol 84, pp 974-1002.