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REASSESMENT OF EARTHQUAKE HAZARD IN AUSTRALIA

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SUMMARY

Earthquakes cluster in time and space, making it difficult to extrapolate to long-term hazard estimates from relatively short earthquake catalogues. Studies have shown that the next cluster often appears in a new location, where there has been little or no recent activity. Seismotectonic models based on instrumental and historical seismicity alone usually fail to anticipate where the next cluster of earthquakes will occur.

The map presented here is a preliminary earthquake hazard map showing the southeast of Australia. It was developed using a seismotectonic model that was defined primarily by consideration of regional geology and tectonics. Where there was sufficient earthquake data, the source zones were adjusted to reflect the earthquake distribution patterns. Over the next year the seismotectonic model will be extended to cover all of Australia.

INTRODUCTION

The creation of a seismotectonic model is a key step in earthquake hazard analysis. Although based on past seismicity, such models are usually applied in estimating future activity. Source zones define the spatial variations in the earthquake distribution. The seismicity in each source zone is usually described using an activity rate, the relative number of small to large earthquakes (b value), and a maximum magnitude.

Earthquakes tend to cluster in both time and space. New clusters often appear in new locations, where there has been little or no previous activity. Knowledge of where earthquake clusters have occurred in both historic and recent times, and relating this to large-scale regional geology, gives an indication of where activity is likely to occur in the future. This relationship to geology can reduce the uncertainty involved in defining source zones.

The widespread use of digital seismographs that can be operated in remote locations has recently improved the seismograph coverage in Australia. We now have earthquake data covering several additional years since the last hazard maps were produced. Improved coverage has lowered the catalogue completeness magnitude for many areas in the country, and reduced the uncertainty in estimates of both activity rates and the b value.

The seismotectonic model presented in this study is delineated by regional geology and tectonics, with historical and instrumental seismicity used to subdivide those large source zones areas with good coverage and to quantify source zones. The peak ground motion in eastern Australia for a 1 in 500 year exceedence interval is provided as an example of how this model performs.

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SEISMICITY IN AUSTRALIA

Australia is located entirely within a plate, which it shares with southern India, so all earthquakes occurring in Australia are intraplate. Despite Australia's low earthquake hazard compared to interplate areas, it is one of the most active intraplate regions in the world.

Australia can be divided into two main regions based on tectonics and seismic attenuation. Western and central Australia makes up a stable shield composed of Archaean basement. Some of the oldest rocks in the world can be found in Western Australia. Attenuation of seismic waves in western and central Australia is lower than in eastern Australian and is well below the world average. Attenuation in western and central Australia can be approximated by attenuation functions derived in eastern North America, particularly the shield areas of Canada.

Eastern Australia has a Palaeozoic basement and has higher attenuation than western and central Australia. The attenuation in eastern Australia can be approximated by attenuation functions derived in western North America, particularly California.

Earthquakes in Australia are shallow by world standards, so a high proportion of large Australian earthquakes has ruptured the surface. Almost all earthquake depths in eastern Australia range from very shallow (less than 1 km), to about 20 km. It is possible that western and central Australia experience deeper earthquakes.

Most of the earthquakes in Australia occur on reverse/thrust faults due to high horizontal compressive stresses, resulting in above average stress drop and a high proportion of seismic wave energy in high frequencies (Gibson 1997). The rate of earthquake activity, coupled with the shallow nature of Australian earthquakes, means that most Australians can expect to feel an earthquake every five to ten years (Gibson 1997).

Seismographs were first installed in Australia in 1888 (Doyle and Underwood 1965), but local earthquake seismograph coverage was not established until 1960, following the International Geophysical Year. Recently installed seismograph networks have improved the coverage of Australia, with the widespread use of digital seismographs located in remote regions and strong motion instruments in large urban areas. However, coverage is still far from uniform.

The Australian Geological Survey Organisation operates a national network in Australia that aims to locate earthquakes of magnitude ML 3.0 and above. However, it is possible that some events of magnitude ML 3.5 or larger in some remote areas are still not being located. Coverage in regional networks is now complete down to magnitude ML 2.0, or in some cases even smaller.

Figure 1 shows all known earthquakes in Australia above magnitude ML 4.0 to December 1997. It also shows the spatial clustering of Australian earthquakes. Each earthquake cluster usually occurs in a new location, and often in areas that have had little or no recent activity.

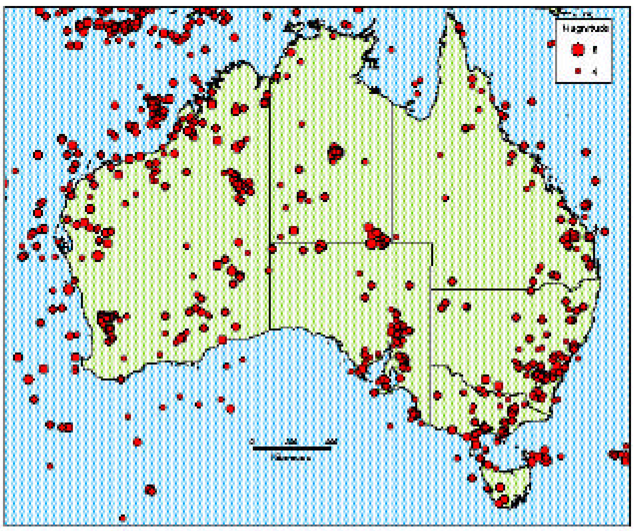

Figure 1: Australian Earthquakes greater than ML 4.0 to December 1997.

AUSTRALIAN EARTHQUAKE HAZARD

Probabilistic Earthquake Hazard

Probabilistic earthquake hazard assessment is based on a seismotectonic model. The model is made up of multiple source zones. Each source zone represents an area of specified seismicity, usually to be taken as uniform.

The source zones in the seismotectonic model presented here have been primarily defined using regional geology and tectonics. In areas that have good seismograph coverage, some source zones have either been sub-divided or adjusted to match the earthquake distribution.

Several parameters are needed to define each zone, including activity rate (Ao), the relative number of small to large earthquakes (b value), maximum magnitude (Mmax) and an appropriate attenuation function. For ground motion recurrence computations it is often necessary to define a minimum magnitude (Mmin), depending on the purpose of the study.

Earthquake Activity and b values

To determine activity levels, the earthquake catalogue is first declustered, removing foreshocks, aftershocks and swarm events. The activity level is usually represented as the number of events exceeding magnitude ML 0.0 per area of 100x100 km per year. Australian b values tend to be below world average, ranging from 0.75 to 1.00. A low b value can be an indication of an incomplete catalogue, or an indication of high stress. A maximum likelihood method (Aki 1965) was used to determine the activity and b value for each source zone, and their uncertainties.

Maximum and Minimum Magnitudes

When dealing with an earthquake catalogue that is far shorter than the average return period of large earthquakes, the activity over a large area must be considered when assigning a maximum credible earthquake. For this study, the area considered was taken as all of Australia. Smaller maximum magnitudes may be considered appropriate for some sources, such as small faults.

The maximum magnitude assigned was MW 7.5, based on previous large earthquakes that have occurred in Australia up to magnitude MW 7.2. Most seismologists in Australia agree that an even larger earthquake may be possible, although extremely rare, (Gaull & others 1990, Gibson 1997). The assigned maximum magnitude will usually make little difference to hazard estimates for short return periods of less than 1,000 years.

Australian earthquakes are mainly on reverse faults, so tend to release a high proportion of seismic wave energy in high frequency motion, producing high peak ground acceleration, but short duration of strong ground motion. A well engineered structure is not likely experience damage from the high frequency, short duration strong ground motion often experienced in shallow earthquakes up to magnitude ML 4.0 or even ML 5.0. For ground motion recurrence calculations in this study, the minimum magnitude used was ML 4.0.

Attenuation

Seismicity in Australia, as elsewhere, is complicated by variations in structure, geology and attenuation. An example is the lower attenuation in central and western Australia.

Sadigh & others (1997) defined an attenuation function based on Californian strong motion data, and this has been used in this study for eastern Australia. In central and western Australia the attenuation function used will be that defined by Toro & others (1997), based on central and eastern North American strong motion data.

Seismotectonic Zones

The reduction in the catalogue completeness magnitude, and a better understanding of the nature of Australian seismicity has improved the resolution that is possible in seismotectonic models. Until patterns emerge in the seismicity, the clustering of earthquakes in time and space still cannot be easily modelled.

In 1976 McEwin, Underwood and Denham developed seismotectonic zones based on instrumental seismicity. The earthquake database available at the time was only for the period 1960 to 1972. The model, and consequently the earthquake hazard maps produced, were significantly affected by the limited seismograph distribution at the time and by the few large earthquakes that had occurred during this period.

Standards Association of Australia (1978) produced the second generation of seismotectonic model and earthquake hazard maps. The model was produced using earthquake data up to 1976, including some consideration of historical (pre 1960) earthquakes. The model did not include some areas of activity in Queensland and central Australia (Gibson 1997). However, uncertainties were considered and represented by creating simplified rectangular source zones in areas with poorly located earthquakes.

In 1990 Gaull, Michael-Leiba and Rynn produced a seismotectonic model using zones that were based on three main factors. The source zones were polygons (to satisfy the computer program), were mainly defined by patterns in seismicity, and some consideration was given to geology and tectonics. Background zones for eastern, western and central Australia were created to include the possibility of earthquakes occurring in areas outside the defined source zones that had little or no previous known seismicity.

Even using a catalogue that spanned from 1859 to 1987, the model was still primarily based on instrumental earthquake locations. This was highlighted when the Tennant Creek MW 6.8 earthquake sequence occurred in an area that had not previously been considered seismically active.

The most recent Australian seismotectonic model to be developed was in 1992 by Standards Australia. The resulting earthquake hazard maps were incorporated in the Earthquake loading code (AS1170.4 1993). While the model was based on the Gaull, Michael-Leiba and Rynn (1990) source zones, greater consideration was given to regional geology and tectonics during smoothing of the earthquake hazard map contours.

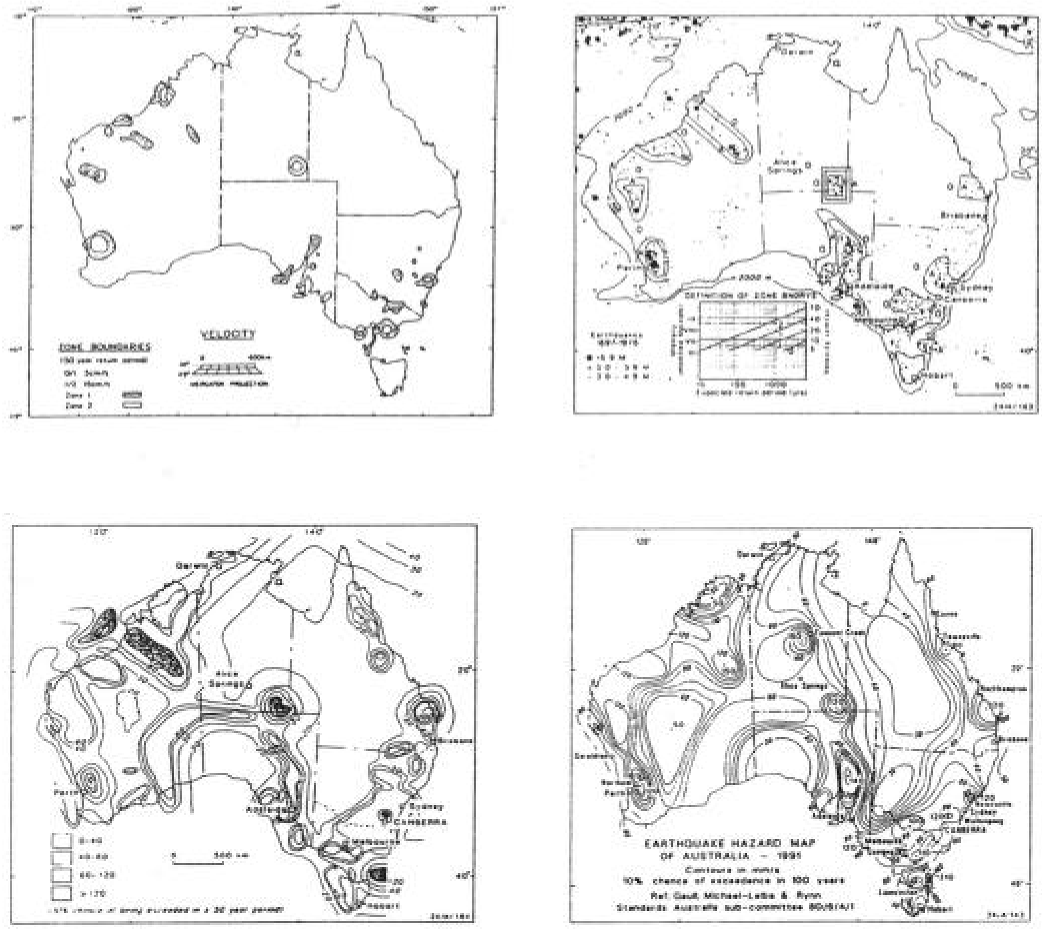

Figure 2: Earthquake Hazard Maps for Australia. McEwin, Underwood & Denham 1976 (top left), AS2121-1979 (top right), Gaull, Michael-Leiba & Rynn 1990 (bottom left), and AS1170.4-1993 (bottom right).

Figure 2 show the earthquake hazard maps produced in each generation, and shows that each improved on the previous map. The 1979 model considered uncertainties, and the 1990 and 1993 models used the Cornell-McGuire approach coupled with partial consideration of regional geology and tectonics.

For this study, the source zones are primarily based on regional geology and tectonics. In areas with good seismograph coverage, historical and instrumental seismicity is sometimes later used to subdivide larger source zones. The use of regional geology and tectonics increases the earthquake activity information available from tens or hundreds of years when using an earthquake catalogue, to thousands or even millions of years. This means that a model created using regional geology and tectonics will be less affected by clustering of earthquakes in time and space.

The model shows a good correlation between the earthquake distribution and the tectonics. This gives us confidence that this method will provide an improved long-term description of Australian seismicity and earthquake hazard.

Delineation of Source Zones

Figure 3 shows the gross geological features of southeast Australia as given by Palfreyman, 1984, used as a basis for the seismotectonic model. The Great Dividing Range is a prominent feature in eastern Australia, and is reflected in the seismotectonic model. Earthquake activity is higher within the ranges than the surrounding lowlands, and is lowest in the sedimentary basins. This is to be expected in a region where reverse faulting predominates.

Large areas in central Australia have very few located earthquakes, either due to a low level of activity or poor seismograph coverage, or both. In these areas the problems associated with lack of data are a little less significant because of the larger areas (refer to figure 3). For example the Murray Basin in northwest Victoria covers almost 320,000 km2, and is much larger than zones defined in the more complex Eastern Highlands. Although activity is low, there are enough earthquakes in these large zones to estimate preliminary activity rates and b values.

Figure 3: Tectonic structures in southeast Australia (Extract from Palfreyman 1984*)*

Quantification of Source Zones

Although regional geology and tectonics define the boundaries of the source zones, the level of seismicity and the b value is defined by seismicity data.

The Sydney Basin is located in New South Wales and extends from Wollongong to the south of Sydney to just south of Newcastle. It is in a region that has good seismograph coverage by Australian standards both in time and space, with the catalogue completeness magnitude of ML 3.0 since 1960 and ML 2.0 since 1992.

The distribution of earthquakes within the Basin (Figure 4) is heterogeneous, with greater activity in the west, within the uplifted portion under the Blue Mountains. Using the earthquake distribution as a guide, the basin was divided into three smaller zones. West Sydney Basin is the most active and encompasses the Blue Mountains.

East Sydney Basin has a moderate rate of activity. The Northern Sydney Basin has a relatively low activity rate dating back to 1788, contrasting with both East and West Sydney Basin and the area immediately north, about Newcastle. When individual active faults can be delineated, these can be added as the source zones.

Ground Motion Recurrence

Using the seismotectonic model shown in figure 4, maps of earthquake hazard can be created. The earthquake hazard can be represented using various ground motion variables (peak or spectral; displacement, velocity, or acceleration), and selected return periods. The catalogue must be declustered before earthquake magnitude recurrence estimates are computed.

As an example, figure 5 is a map showing the peak ground acceleration in southeast Australia with a 1 in 500 year exceedence interval. This was created with the computer program EZ-Frisk (Risk Eng. 1997) using the Cornell-McGuire probabilistic approach. Consideration of earthquake greater than magnitude 4 leads to greater variation in PGA recurrence than for earlier studies.

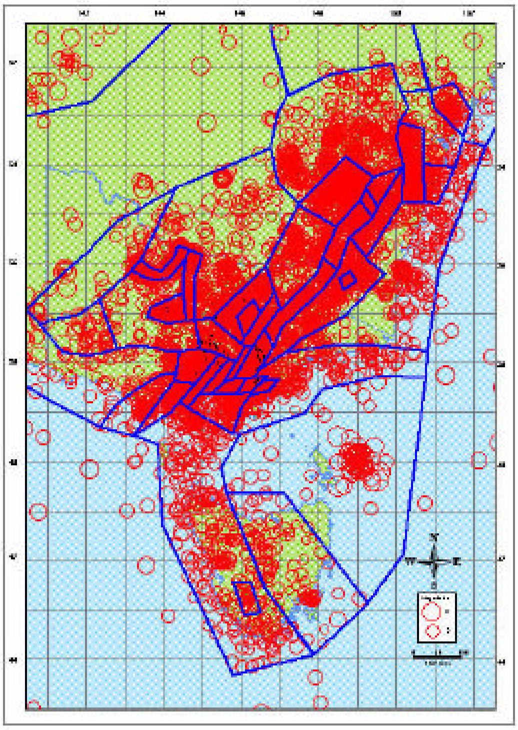

Figure 4: Preliminary Seismotectonic Model for southeast Australia, 1999. Earthquakes are shown before declustering.

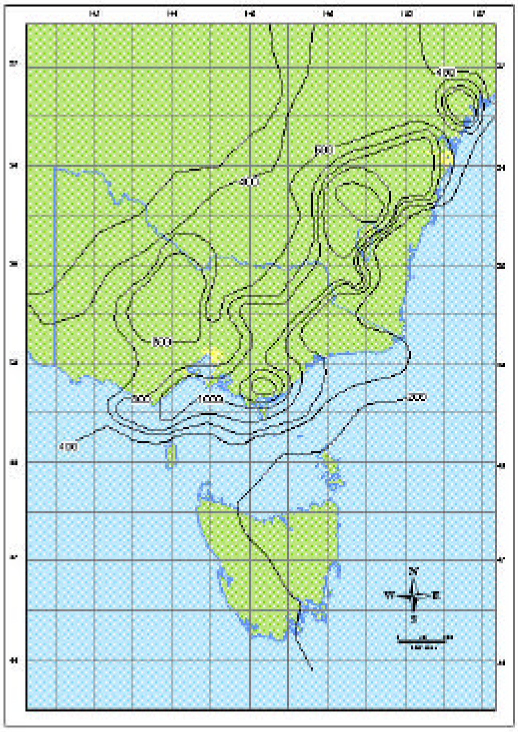

Figure 5: 500 year PGA recurrence for southeast Australia (using M 4 to 7.5 earthquakes), 1999. (contours show acceleration in mm/s2)

CONCLUSIONS

An attempt was made to create a model that was based on geological information as well as historical and instrumental seismicity. The model created used regional geology and tectonics to create source zones. In areas with good seismograph coverage these source zones were subdivided to better reflect any heterogeneous nature of seismicity within tectonic structures. Source zones were quanitied using seismicity data.

A map of peak ground acceleration in eastern Australia for a 1 in 500 year exceedence interval was produced. The map generally agrees with those previously published, but has been based on a higher resolution seismotectonic model.

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