Seismotectonic Model for the Australian Plate – Beyond Borders

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Abstract

As part of the National Seismic Hazard Assessment (NSHA 18) Project, a novel approach in considering geologic and tectonic boundaries for a seismotectonic model for consideration is proposed in order to meet the aims of the project in revising the existing seismic hazard map (AS1170.4: 2007) for Australia. The contribution is two-fold towards the successful adoption of NSHA 18. Firstly, a new area based seismotectonic model, the DIM-AUS model that integrates seamlessly with other neighbouring seismotectonic models along complex plate boundaries. Area sources are categorised according to oceanic, cratonic, orogenic and inland basin structural and tectonic divisions, with the Tasman Line defining the geological units. And secondly, preparation of additional GMPEs using empirical data from South Australia based on two depth variations, including a shallow model (<10 km) and deep model (≥ 10km) will be prepared. A further development of DIM-AUS is to also consider faults as both segmented and non-segmented portions to account for epistemic uncertainty in future editions.

Keywords: seismotectonics, seismic hazard, PSHA, seismogenic sources, NSHA, Australia

1. INTRODUCTION:

The National Seismic Hazard Assessment Project (NSHA 18) is a collective approach in developing a new and improved version of the existing Australian Seismic Hazard Map (AS1170.4:2007). As part of this initiative, there are two contributions being made towards the common goals of NSHA 18. Firstly, an individual seismotectonic model used as an input into a Probabilistic Seismic Hazard Assessment (PSHA) to capture the extended continental shelf of the Australian Plate. And secondly, to develop a suitable Ground Motion Model (GMM) for South Australia, given the absence of a model derived using earthquakes recorded within this active region of Australia to date.

2. SEISMOTECTONIC MODEL:

2.1 Extent of DIM-AUS Seismotectonic Model:

A uniform area zone based seismotectonic model is proposed for use within the NSHA 18 project. Like other area based models (Brown & Gibson, 2004; Dimas et al, 2016), it is developed from grass-roots using information on seismicity, geology, tectonics, magnetics and gravity data where available. The unique features of the DIM-AUS seismotectonic model includes coverage to the continental shelf, including offshore basins whilst seamlessly joining to other SRC developed seismotectonic model of ASIA-1. It considers improved handling of integrating two separate region-based seismotectonic models along the boundary of the Australian Plate with the northern plates of Sunda, Timor Sea, Banda Sea, Maoke and Woordlark. Although the trench forms the boundary of the plates, allowing an outer rise parallel zone on the other side of the trench allows for better integration of seismicity along the subduction zone as a whole. In this manner, the DIM-AUS model's boundary is the outside of the ASIA-1 outer rise zones. Unlike the AUS6 seismotectonic model (Dimas et al, 2016), which is developed in isolation to respective plate motions, the DIM-AUS model captures plate boundaries more effectively whilst focusing on seismicity within the Australian Plate.

The DIM-AUS seismotectonic model was developed in an iterative process beginning from the plate boundary and working inwards, whilst capturing the offshore basins, continental shelf. The Tasman Line forms the boundary of the cratonic divisions, and segregates the inland basins and other major structural divisions within the Australian mainland. Throughout this process the area zones were split until the seismicity remained uniform. The final product is presented in Figure 1, showing the plate boundaries (as defined by Bird, 2002) north of Australia. This figure shows two levels of differentiation, with solid line boundaries forming the actual zone boundaries and the fill representing the regionalisation of all other similar zones. Firstly, the broad regional categories are used to differentiate geological units/periods (shown as a hatched variation underlay) and secondly with the individual 69 area zones labelled with a number that is sorted alphabetically in Table 1. Numerous variations of the Tasman Line exist, but the one adopted is taken from Shaw et al (1996) as it aligns better with magnetic and gravity data of the Australian continent (Geoscience Australia, 2009 & 2010).

2.2 Regional Categorisation of Model:

The division of regional categories (see Figure 1) incorporates cratons (west of the Tasman Line) and orogens (east of the Tasman Line), as well as inland basins and offshore basins. The cratons are split into four groups, Northern, Central, Gawler and Western; the orogens are split into two groups, the Lachlan-New England and Thompson with the Inland Basins forming the remaining regions west of the Tasman Line. The offshore basins include the outer extents of the continental shelf and beyond, where sufficient seismic data could be incorporated.

Given most of remote Australia contains insufficient earthquakes to form reliable parameter estimates for the model, amalgamating like area zones from similar regional categories is adopted for statistical purposes. Where sufficient information exists, preference is given to individual area zone instead.

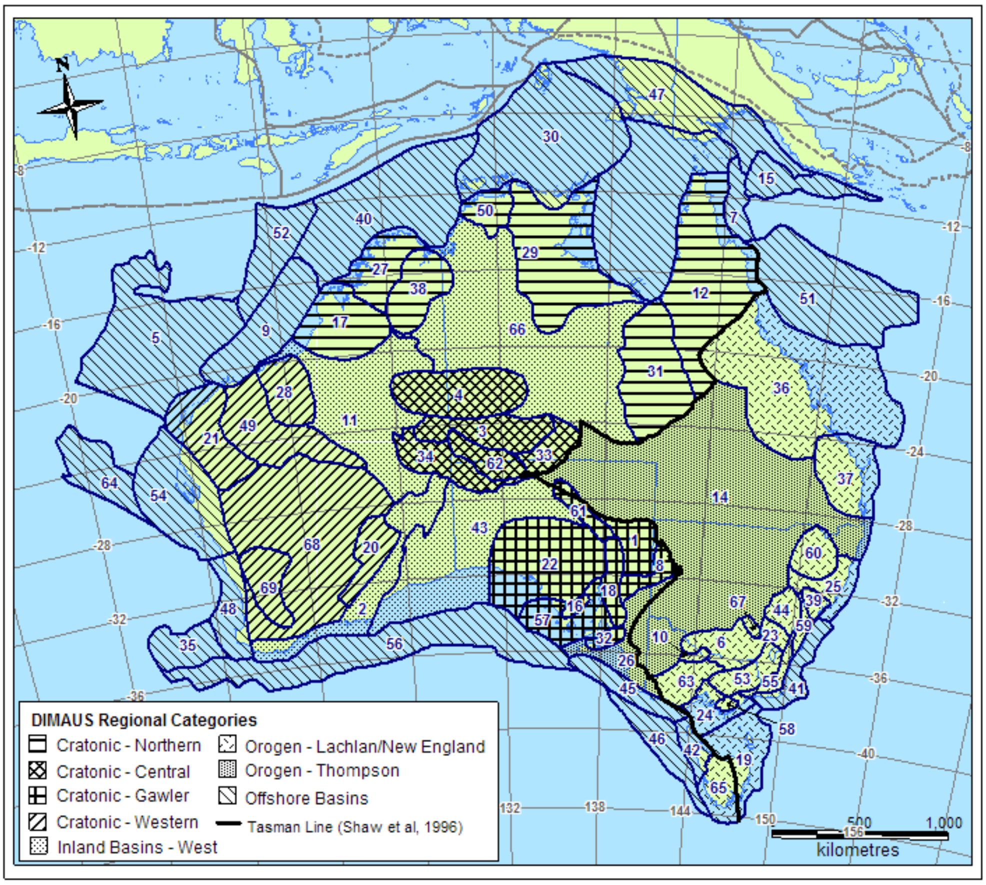

Figure 1: DIM-AUS seismotectonic source model (regional categories & Tasman Line defined)

The size of most area zones in this model are drawn to represent uniformity (with less variation in area size) than other models, such as AUS6 (Brown & Gibson, 2004; Dimas et al, 2016), where in south-eastern Australia most zones are at least one fifth or smaller than other more remote areas of Australia. The primary reason for this is to give preference to the total area within a category as being uniform where possible, whilst still capturing the seismicity within the zones. Incorporating lower magnitude events allows for area zones to be further sub-divided, an advantage of the AUS6 model (particularly in south-eastern Australia) but does not therefore produce a homogenous model throughout the whole of the Australian continent. Area zones in south-eastern Australia can utilise more recorded events with better accuracy over longer time periods. Careful revision over many iterations in the AUS6 model has led to small area zones bounded by seismicity, geology and neotectonic active faults. In contrast, the DIM-AUS model does not replicate these procedures of AUS6 but rather complement it in methodology by incorporating the extended offshore basins, particularly to the northern, western and southern edges of the Australian Plate.

2.3 Assumptions of DIM-AUS Seismotectonic Model:

The A and b-value parameters of the DIM-AUS model are still being processed at present, but are expected to be incorporated in the final model. A brief discussion of the assumptions of the DIM-AUS model to be submitted early 2017 are outlined here. All zones will assume an identical depth range and maximum magnitudes, being 2 to

20 kilometres and M7.5 respectively. Completeness periods will be estimated once the complete earthquake catalogue is made available (G Gibson 2016, pers. comm., 29 July). This will be prepared for each area zone preferably, or by using the combined events for a given regional category. Regions with well-established seismic networks, such as in South Australia and south-eastern Australia will tend to have lower completeness periods relating to the data quality captured over a longer period of time. The activity rate and b-value of each area zone will be determined using the exponential Gutenberg-Richter (G-R) (1944; 1956) ratio of small to large earthquakes. This will include both least squares and maximum likelihood methods for comparative purposes in the final compilation of the parameters. The fault mechanism of all area zones is assumed to be reverse as the Australian continent is under compressive stress and hence most active neotectonic faults are mapped and assumed to be reverse fault sources.

2.4 Fault Sources and Uncertainties:

A fault source model, as documented in the Australian Neotectonic Feature Database (ANFD, Clark et al, 2011; 2012) will be modelled in addition to the area zones in the final version of the DIM-AUS model. A basic interpretation of assumed slip rates will be made, assigning a slip rate of 0, 2, 5, 10, 20 or 30 m/Myr to each identified fault segment. The selection of the most appropriate slip rate (in absence of quantified existing data and research) will be made in considering all faults within a localised area and identifying firstly the main or prominent faults/features. These will be assigned higher slip rates to those subsequent smaller faults/features within the same localised area, with these being assigned smaller slip rates. Assuming b-values for each fault will be based on the determined value of the area zone that the fault lies mostly within.

The earthquake magnitude recurrence (EMR) model to be incorporated for the DIM-AUS model will be to incorporate both the exponential G-R approach (for smaller to moderate sized faults, up to Mmax of 6.0+) and the characteristic approach for all other large faults (with Mmax 6.0-7.5). This approach is based on years of experience in preparing zone EMRs of the AUS6 model with notable blind faults following a similar patter to the G-R exponential scatter (Gibson & Dimas, 2014). The fault model will be in addition to the defined area zone model. This is assumed due to the limited time-span of earthquakes recorded throughout Australia over only the last fifty years. We therefore assume that not all earthquakes have been observed, particularly when considering the episodic nature of fault movements in low-seismicity regions such as Australia (Crone et al, 1997; Clark & Leonard, 2015).

Uncertainty of these parameters will be included once the first iteration of earthquake magnitude recurrence data is prepared for all area zones. A logic-tree approach incorporating the mean, plus and minus one and two standard deviations will therefore be incorporated in the final model. Total annualised moment release for the combined DIM-AUS model will be estimated using the Kostrov summation method to verify the total seismicity is not greater than t6he Kostrov method.

3. GMM FOR AUSTRALIAN DATA:

GMMs (more commonly referred to as Ground Motion Prediction Equations) developed for Australia have favoured use of stochastic datasets given the lack of extensive earthquake records for preparation of a truly empirical based approach. The few recorded events used as empirical data, typically form the basis of Australian

GMMs, with additional stochastic datasets then required to develop a sufficient magnitude-distance range for a GMM to be peer accepted. At present, three Australian recent GMMS exist on this basis. The Liang et al (2008) model incorporates limited events with magnitudes less than ML4.5 in south-western Western Australia. The Somerville et al (2009) cratonic and non-cratonic GMMs for Australia are based on earthquake scaling relations of a small set of moderate sized events in both regions to generate sufficient simulated datasets. The Allen (2012) model developed for south-eastern Australia is based on 75 events recorded with magnitudes M_w 2.8-5.4 recorded during 1989 to 2011, as well as supplementary simulated datasets.

Table 1: Parameters of DIM-AUS seismotectonic model (work to date, ongoing)

No.	Zone Name	Regional Category	Area (km²)	No.	Zone Name	Regional Category	Area (km²)
1	Adelaide Foldbelt	Cratonic - Gawler	72,062	36	NE Qld Basins	Orogen - New England	635,505
2	Albany-Fraser	Inland Basin - West	200,180	37	New England	Orogen - New England	146,292
3	Amadeus Basin	Cratonic - Central	123,934	38	New Ord River	Cratonic - Northern	117,563
4	Arunta Block	Cratonic - Central	192,964	39	Newcastle	Orogen - Lachlan	17,890
5	Barrow-Dampier Basin	Offshore Basin	483,638	40	Northwest Basin	Offshore Basin	422,978
6	Benambra Terrane	Orogen - Lachlan	80,850	41	NSW Offshore Coast	Offshore Basin	69,078
7	Bligh Basin	Offshore Basin	48,782	42	NW Tasmania	Offshore Basin	38,700
8	Broken Hill	Cratonic - Gawler	41,588	43	Officer-Eucla Basin	Inland Basin - West	443,852
9	Broome Basin	Offshore Basin	204,636	44	Orange	Orogen - Lachlan	37,993
10	Bunnaloo	Orogen - Lachlan	8,871	45	Otway Shelf	Offshore Basin	72,321
11	Canning Basin	Inland Basin - West	402,522	46	Otway-Sorell Basin	Offshore Basin	90,609
12	Cape York	Cratonic - Northern	396,429	47	Papuan Basin	Offshore Basin	302,791
13	Carpentaria Basin	Offshore Basin	459,522	48	Perth Basin	Offshore Basin	102,887
14	Eastern Inland Basins	Orogen - Thompson	1,371,442	49	Pilbara	Cratonic - Western	200,962
15	Eastern-Papuan Plateau	Offshore Basin	87,302	50	Pine Creek	Cratonic - Northern	57,159
16	Eyre Peninsula	Cratonic - Gawler	11,037	51	Queensland Plateau	Offshore Basin	382,180
17	Fitzroy Crossing	Cratonic - Northern	167,299	52	Scott Plateau	Offshore Basin	141,363
18	Flinders Ranges	Cratonic - Gawler	50,631	53	SE Highlands	Orogen - Lachlan	59,603
19	Flinders-East Tassie	Orogen - Lachlan	114,425	54	Shark Bay	Offshore Basin	264,394
20	Fraser	Cratonic - Western	77,772	55	Southern NSW Coastline	Orogen - Lachlan	26,359
21	Gascoyne	Cratonic - Western	168,268	56	Southern Ocean	Offshore Basin	423,494
22	Gawler Craton	Cratonic - Gawler	296,436	57	Spencer Gulf	Cratonic - Gawler	110,328
23	Goulburn	Orogen - Lachlan	18,848	58	Strzelecki Ranges	Orogen - Lachlan	7,483
24	Greater Melbourne	Orogen - Lachlan	58,641	59	Sydney Basin	Orogen - Lachlan	17,862
25	Gunnedah Basin	Orogen - Lachlan	68,533	60	Tamworth	Orogen - Lachlan	63,503
26	Kanmantoo Province	Orogen - Thompson	95,319	61	Torrens	Cratonic - Gawler	38,298
27	Kimberley Basin	Cratonic - Northern	118,370	62	Uluru	Cratonic - Central	63,532
28	Marble Bar	Cratonic - Western	100,441	63	Victorian Goldfields	Orogen - Lachlan	61,711
29	McArthur	Cratonic - Northern	353,165	64	Wallaby Plateau	Offshore Basin	123,459
30	Money Shoal-Arafura Basin	Offshore Basin	480,887	65	West Tassie	Orogen - Lachlan	63,980
31	Mt Isa	Cratonic - Northern	242,079	66	Wiso-Georgina Basin	Inland Basin - West	805,492
32	Mt Lofty Ranges	Cratonic - Gawler	17,359	67	Wyalong	Orogen - Lachlan	7,860
33	Musgrave East	Cratonic - Central	61,658	68	Yilgarn Craton	Cratonic - Western	626,872
34	Musgrave West	Cratonic - Central	104,982	69	Yilgarn SW	Cratonic - Western	88,369
35	Naturaliste Plateau	Offshore Basin	86,360				

South Australia is one of the most seismically active pockets in Australia, due to ongoing activity within the Flinders and Mt Lofty Ranges where prominent and evident active neotectonic faults are clearly visible in the topography. A long-term and reliable seismic network operating continuously in this region has allowed data capture of recent well located events suited to development of a GMM. At least 32 events are identified for consideration in the model (see Figure 2), with magnitudes ranging from M 3.1-4.9 and 899^{+} recordings between March 2012 and June 2016. Given a spread of data across the magnitude axis, two GMMs representing shallow events (<10 km) and deep events (≥10 km) is proposed. As existing Australian GMMs have not incorporated any empirical data from South Australian datasets to date, it is worth preparing a suitable GMM using this dataset alone. The purpose of this is to identify any subtle differences crossing over the Tasman Line, from Palaeozoic eastern Australia geology/tectonic regions to the western Australian cratonic regions. The Flinders and Mt Lofty Ranges within the Gawler Craton is believed to be this transition from the Archaean west to the more recent rifted east and may hold clues on travel paths between these distinct geological units.

Data collection has begun in July 2016, but given the amount of data processing required, as well as a testing phase for development of a South Australian GMM, it is unlikely to be ready in time for complete integration into the NSHA 18 project at this point in time. Nonetheless, the project will continue to be developed and will no doubt become included in future seismic hazard projects at local and national scales, once peer-reviewed.

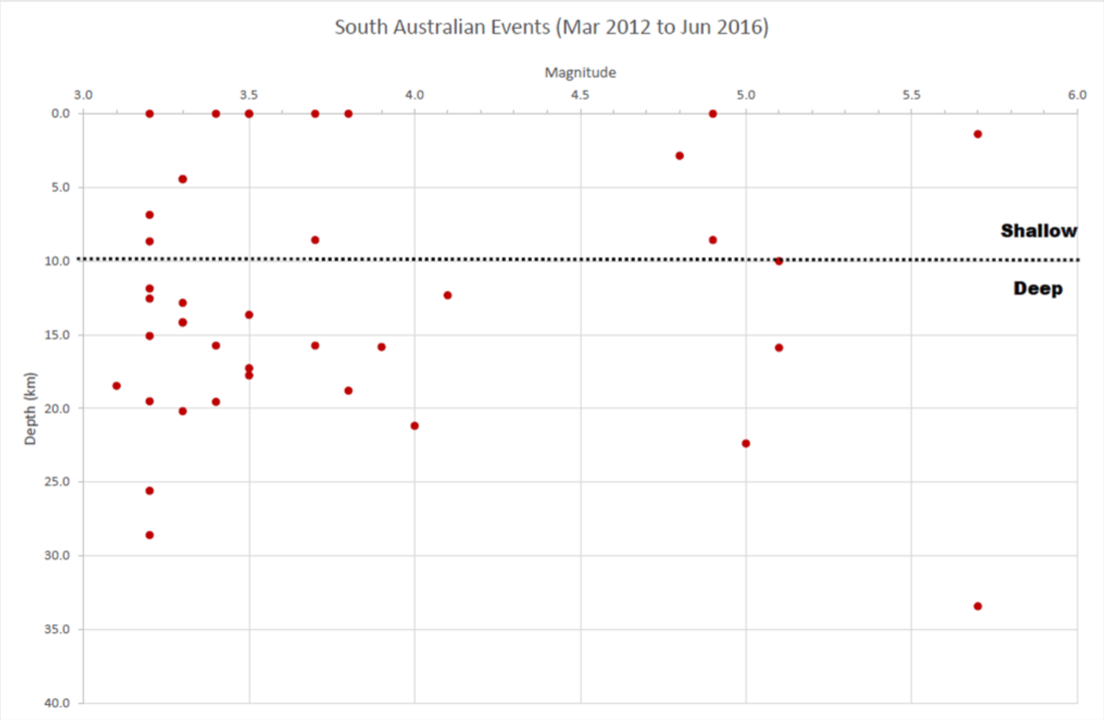

Figure 2: Depth variation of South Australian data (Shallow <10 km; Deep ≥10 km)

4. CONCLUSION:

A seismotectonic source model based on area zones is outlined for inclusion in the NSHA 18 project towards production of the revised Australian seismic hazard map. The DIM-AUS model is developed using seismicity, geology, tectonics, magnetics and gravity data to define 69 uniform seismicity zones. The model extends beyond political borders, by seamlessly integrating with other seismotectonic models to the north along the trench or boundary of the plates. The improvements are part of revisions to the ASIA-1 model with the outer rise zones (that run parallel to the trench) being realigned to fit and form the boundary of this and the DIM-AUS model to the south. In this way, the model also captures the extended offshore basins off the continental shelf of Australia (particularly to the north, west and south), accounting for seismicity in these regions separately to the complex subduction zone boundaries.

Ongoing work into preparing suitable GMM models for both shallow (<10 km) and deep (≥10 km) events for recent well recorded South Australian earthquakes is also being undertaken for purposes of the NSHA 18 (although may not be available for 2018 release). With a vast amount of data processing and preparation, it is however unlikely this model will have the complete opportunity for peer-review at appropriate levels for complete adoption to NSHA 18. Nonetheless, the continual improvements made in this field will improve the choice of GMMs for selection in PSHA studies and thus for national or local site studies in future.

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