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SEISMICITY, THE WORLD AND AUSTRALIA

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THE CAUSES OF EARTHQUAKES

The theory of plate tectonics regards the crust of the earth as comprising several plates, all moving relatively to each other. The plates can be several thousand kilometres across and are about 100 km thick. They rest on a plastic zone about 50 km thich which effectively decouples them from the more solid material at greater depth and enables them to move. Earthquakes are direct manifestations of the interactions taking place along the plate boundaries and also of strain release within the plates. Most earthquakes take place at the plate boundaries, and studies of their spatial distribution enable these boundaries to be delineated. Studies of the elastic radiation produced by the earthquakes provide information relating to the directions in which the plates are moving.

The relative motions between plates can be as high as 10 cm/yr; where this happens, large amounts of strain can be stored in the crust near the boundaries within a very short interval of time ($\sim$50 yr). It is in these regions that the very large earthquakes occur.

In general, new crustal material is formed at the mid-ocean ridges and consumed either in subduction zones at island arcs or in collision zones of mountain building. For example the mid-ocean ridge south of Australia generates new crustal material for the India/Australia plate, which moves north relative to the Antarctic Plate and is being consumed in the series of arc-like zones extending from the Himalayas to the New Hebrides.

At the plate boundaries the crust usually bends and then, when the stress exceeds the strength of the rocks, the crust breaks and "snaps" into

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a new position. In the breaking process, vibrations are generated at the fracture and propagated through the earth, and are recorded at seismograph stations.

EARTHQUAKE TYPES

There are basically three types of fracture, each corresponding to a different faulting mechanism in a different tectonic environment. These are:

(1) Strike-Slip faulting - (at fracture zones between spreading centres) e.g. the San Andreas fault.

(2) Normal faulting - at mid-ocean ridges and rift valleys.

(3) Thrust faulting at island arcs and zones of mountain building e.g. Alaskan earthquake of 1964, Solomon Sea earthquake of 1971 and the Great Assam earthquake of 1897 (this type produces the largest earthquakes).

These three types of earthquakes (which take place at plate margins) account for about 95% of the world's earthquakes. The other 5% or so take place within the plates. Examples of the intraplate type of earthquake can be found in several parts of the world, e.g.

U.S.A.	(i)	1811-12 New Madrid sequence which took place in the Mississippi Valley
	(ii)	1886 Charleston earthquake
India	(i)	1967 Konya earthquake in the supposedly inactive Deccan peninsula
Australia	(i)	1968 and 1970 Meckering and Calingiri earthquakes
	(ii)	1970 Canning Basin sequence - which is still continuing
	(iii)	1972 Simpson Desert earthquake
	(iv)	1973 Picton earthquake

This list includes some of the major recent Australian earthquakes. There have of course been several other large earthquakes such as those at Meeberrie in 1941 and Adelaide in 1954.

Continental earthquakes pose several problems because they do not appear to lie in any well defined pattern that extends over long distances and hence they are difficult to explain and to predict. They are infrequent and yet important because:

(i) They take place at shallow depth and therefore can cause much damage

(ii) They are indicators which give clues to the current tectonic environment of the surrounding region

Australian earthquakes fit these categories well.

MAGNITUDE, INTENSITY AND FREQUENCY DISTRIBUTION

In general there are two common ways to describe the severity of an earthquake.

Magnitude

The magnitude of an earthquake relates to the energy released, and is determined from the amplitude of the seismic waves recorded at seismograph stations at different parts of the Earth's surface. The best known scale for measuring magnitudes is the Richter Scale. The scale is logarithmic so that a magnitude of 6, for example, represents a disturbance with ground motion 10 times that of a magnitude 5 earthquake, and an energy release amounting to about 30 times that of a magnitude 5 earthquake.

Although the scale is open ended, no earthquake greater than 9 has yet been recorded. A shock of magnitude 2 is the smallest normally felt by humans; earthquakes with magnitudes of 6 or more can cause major damage if they are shallow and close to habitation.

Intensity

The intensity as expressed by the Modified Mercalli Scale is a subjective measure which describes the severity of the earthquake experienced at a particular place. The MM scale ranges from I "Not felt except by a very few favourably situated" to XII "Damage total, lines of sight disturbed and objects thrown into the air".

High intensities are not necessarily caused by large magnitude earthquakes. Proximity to the focus of the shock is also critical. The potentially damaging earthquakes are those having magnitudes of 6 or greater and occurring at shallow depths (less than 50 km).

Frequency Distribution

The general frequency distribution of earthquakes over the observed range of magnitudes can be represented rather simply, for any given region, by:

$$\log N = A - BM \qquad (1)$$

where N is the number of shocks of magnitude M or greater per unit time and A and B are constants.

This formula can be applied universally except for large values of M. It is evident that since there is a physical upper limit to the strength of the crustal rocks, in terms of the maximum strain which they are competent to support without yielding, there must be some upper limit to earthquake magnitude.

On a Worldwide basis the upper limit is about 8.8, and for different regions the upper limit will be less than this value.

Unfortunately (from the prediction aspect) the larger earthquakes which are the most damaging, are also the most infrequent, so it is difficult to obtain an accurate estimate on upper limits when only a short period of data is available. In Australia, where there is only about 75 years of data, one could argue for a maximum earthquake of about 7.5 in the western and central regions and about 6.5 in the eastern regions. However, these arguments would be speculative rather than rigorous.

Ground Motion Predictions

Having determined the frequency of distribution of earthquakes the next step is to estimate the effect of the earthquakes on structures. The usual first order assumptions are that

$$Y = f\ (S,R,G) \qquad (2)$$

where Y is the maximum intensity, acceleration, velocity or displacement; S the source factor which depends on the size of the earthquake and its radiation pattern; R a propagation path factor which depends mainly on the distance of the earthquake from the site under consideration; and G a 'receiver' factor depending on the local site conditions.

Formula (2) can be simplified if the G factor is eliminated and if the S factor can be replaced by the magnitude of the earthquake, then we get

$$Y = f\ (M,R) \qquad (3)$$

where R is the distance from the hypocentre to the site.

Several attempts have been made to express (3) in analytical terms and the most common type of expression has been of the form

$$Y = a\ e^{bM}\ R^{-c} \qquad (4)$$

where a, b, and c are constants.

Unfortunately the source and receiver terms in (2) can each vary by an order of magnitude for a constant R, leading to extremely large scatters for the values of Y. It appears that the large uncertainties in the values of a, b, and c are simply facts of nature and although this type of approach does not give exact predictions it is the best currently available, so it has to be used.

AUSTRALIAN EARTHQUAKES

With these concepts in mind it is instructive to examine some recent large earthquakes on a worldwide and Australia-wide basis. Tables 1 and 2 list some of the largest earthquakes in these categories. It is noteworthy that although the largest Australian earthquakes, have caused significant damage they are, on the whole, about an order of magnitude smaller than the world's most damaging shocks.

In the last 73 years there have been 17 earthquakes of magnitude 6 or greater. The rate of occurrence of about 1 every 4 years compares with a world average of about 140 every year. The largest recorded magnitude was 7.4 for a shock off the west coast of Western Australia in 1906; the next largest was probably 6.8, for the Meckering earthquake.

There are no very active seismic zones crossing the Australian continent, but there are regions where minor but significant earthquake activity is experienced. In these regions earthquake risk factors are large enough to be considered in major civil engineering projects, and the spatial distribution provides information on the current tectonic activity within the continent. It is convenient to consider three earthquake provinces:

Eastern Region

The earthquakes of eastern Australia tend to be associated with the Tasman Geosyncline. They apparently result from regional stresses in the crust. The cause of the stress patterns is not known, but it appears to result from a predominant N-S compression at least in the Sydney-Canberra region. There are no significant lineations; rather, a diffuse distribution of shocks over a wide area, with a few localized "nests" of earthquakes where the activity rises above the regional level.

The most consistently active area is the Dalton-Gunning zone about 50 km north of Canberra, and several damaging earthquakes have taken place there in the last 50 years. The Gayndah, Robertson, and Picton earthquakes of 1935, 1961, and 1973 probably caused the most damage of all the earthquakes in the eastern region.

Central Region

The central Australian seismic zone extends from Adelaide to the Simpson Desert. Most of the earthquakes arising in this region can be explained by postulating a regional stress field resulting from a predominantly N-S pressure axis. The Beachport, Warooka, and Adelaide earthquakes of 1897, 1902, and 1954 were in this zone and each caused considerable damage. The northern part of the zone - in the Simpson Desert - is uninhabited and no damage has been reported there; nevertheless it is comparatively active and in August 1972 an earthquake of magnitude 6¼ took place there. It generated a series of aftershocks extending ENE-WSW for about 120 km, and focal mechanism studies indicate a horizontal north-south pressure axis with a left-lateral strike-slip fault resulting from the earthquake.

Western Region

In Western Australia the stress patterns appear to produce several separate zones of seismic activity, each a few hundred kilometres long. Examples are in the Canning Basin, the SW corner of Western Australia, and east of Carnarvon. In addition to these zones there is considerable activity offshore which does not follow any well defined lineations and may correlate more with the bathymetry than with any other features.

Most of Australia's largest earthquakes have occurred in this State. The most important was the Meckering earthquake of October 1968 when a surface fault with a throw of up to 2 m extended over 35 km and the town of Meckering was wrecked.

So much for the tectonics of continental Australia. I should say that the effective earthquake coverage of Australia is very poor, and of the total of about 4000 Australian earthquakes for which we have a reliable epicentre over 98% occurred since 1960. Even now there could be several shocks per year greater than 4½ that are not located, particularly in Queensland, where the station coverage is very poor.

At present about 500 earthquakes per year are being located. This may seem very large but by world standards it is not, most of them are very large and we have only to examine the maps of World Seismicity and the lists of previous earthquake disasters to put the Australian position into perspective.

So much for the general picture. Detailed analyses of particular regions and discussions of how to use the data to assess the risk will be left to later papers.

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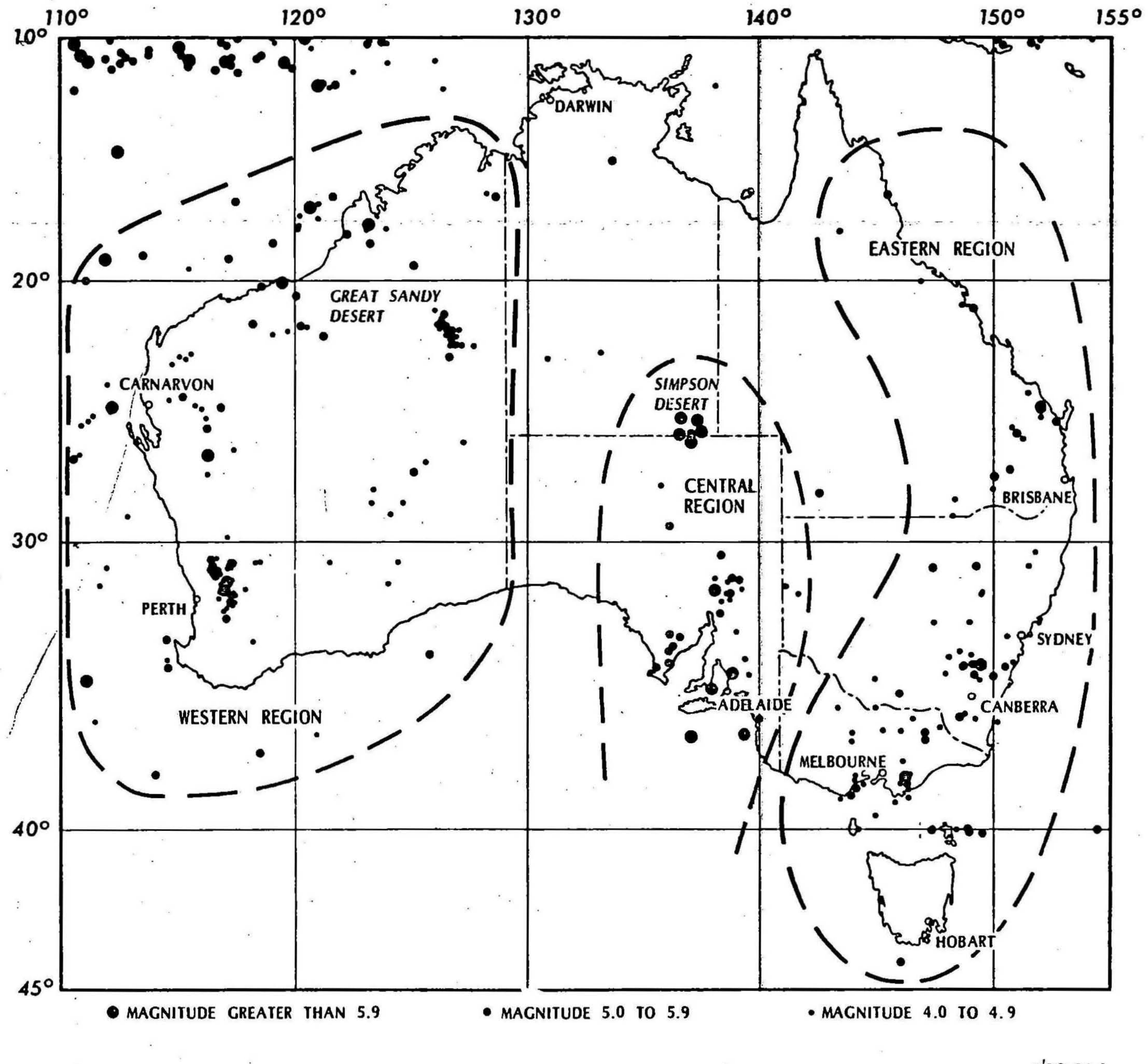
Table 1 Some major earthquakes - Worldwide

Date	Place	M	Dead	Damage $ x10^6	Houses destroyed
1905	Kangra (India)	8.6	20 000		
1906	San Francisco (US)	8.3	700	800	
1908	Messina (Italy)	7.5	75 000		
1920	Kansu (China)	8.6	180 000		
1923	Tokyo (Japan)	8.3	143 000		
1935	Quetta (Pakistan)	7.6	60 000		
1960	Agadir (Morocco)	5.7	12 000		100% at Kasbah
1960	Chile	8.4	1 000	600	
1962	Iran	7.5	12 000		21 000
1964	Skopje (Yugoslavia)	5.4	1 000		37%
1964	Alaska (US)	8.4	125	311	
1964	Niigata (Japan)	7.5	25	800	
1968	Iran	6.3	11 588		
1968	Tokachi-Oki (Japan)	7.9	47	131	
1970	Peru	7.8	50 000	250	
1971	San Fernando (US)	6.6	65	700	
1972	Managua (Nic.)	6.2	10 000		city of 400 000 abandoned

Table 2 Some large Australian earthquakes

Date	Place	M	Damage
1941	Meeberrie, W.A.	6.5	?
1954	Adelaide, S.A.	6.5	£ 4 million
1961	Robertson, N.S.W.	5.5	?
1968	Meckering, W.A.	6.8	$ 2.2 million
1970	Canning Basin, W.A.	6.7	nil
1973	Picton, N.S.W.	5.5	$ ½ million



Locations of Australian earthquakes.