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EARTH STRUCTURE & EARTHQUAKES

ENV101 Earth Systems

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OUTLINE:

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The aim of this lecture is to introduce you to the earth's structure and the how effects and magnitude of earthquakes are measured, and their causes.

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DEFINITIONS

An ***earthquake*** is a sudden movement in the upper layers of the Earth caused by the release of accumulated strain or energy due either to the Earth's rotation and the varied character of the blocks that make up the crust, or to the lateral migration of the segments or plates that constitute the crust, or for all of these reasons. The release causes shock, pressure or seismic waves.

Focus is the point within the Earth where the seismic waves of the earth quake originate and the point on the surface directly above the focus is the ***epicentre***. Two types of seismic waves travel away from the epicentre. ***Pressure or P waves*** are compressional waves in which particles of matter vibrate parallel to the direction of propagation. They travel through surface rocks at speeds of 4-7 km/s. ***Shake or S waves*** travel slower at 2-5 km/s and particles vibrate perpendicular to direction of wave propagation. Both P and S waves readily pass through solid rock. P waves can also pass through fluids

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DEFINITIONS

but S waves cannot. Both P & S waves are recorded within 103° of arc of the focus, as shown in figure opposite. Only faint P waves and no S waves are recorded in the shadow zone from 103-143°. Between 143 & 180° of arc P waves are recorded but no S waves. This is explained by the Earth consisting of a mantle & a core. The faint P waves in the sector 143-180° suggest an inner core. As S waves cannot be transmitted by a fluid there is an S wave shadow beyond 103°. The P shadow between 103-143° of arc may be due to reflection and refraction at the mantle-core boundary. The Earth has 3 main zones, an outer thin crust, a middle mantle and an inner core. The crust and mantle are separated by the Mohorovicic discontinuity.

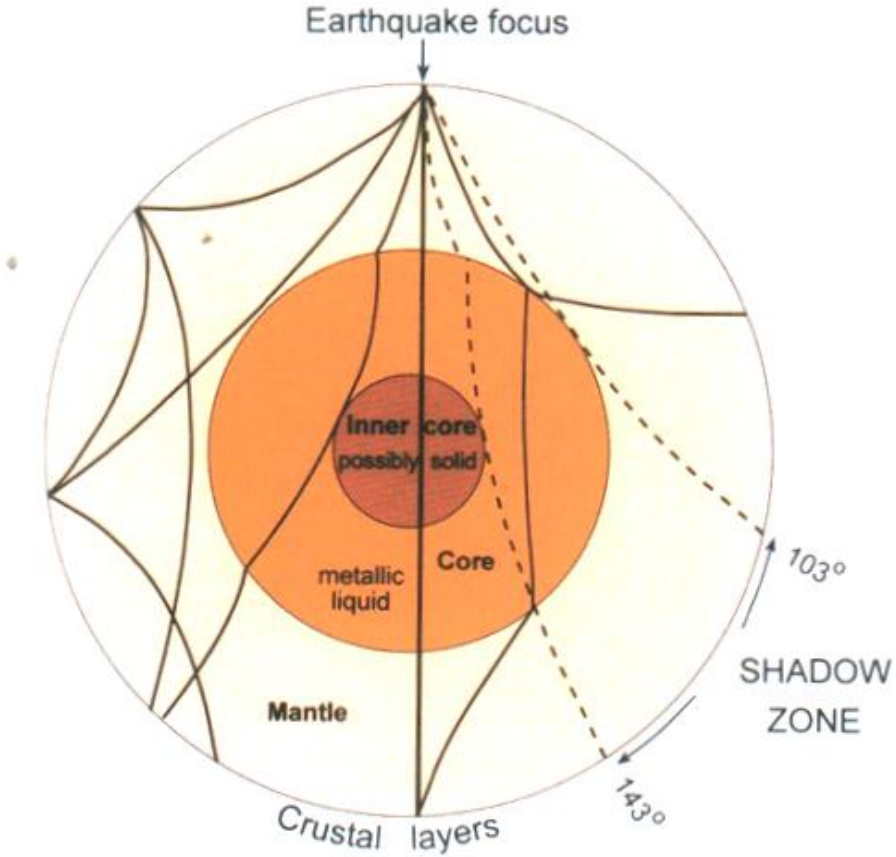

Fig. 2.4a: Cross-section through the Earth showing layered structure and travel paths of pressure waves. (After Hodgson 1964)

From: Twidale & Campbell (2005: p. 23)

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RICHTER SCALE

The seismic waves generated by earthquakes provide good estimates of their magnitude. This is an open ended numerical measure of the total energy released by an earthquake. It is a local magnitude scale (M_L scale) & was developed by Charles Richter in 1935 in collaboration with Beno Gutenberg for use in a specific study area in California. It is a base-10 logarithmic scale obtained by calculating the logarithm of the combined horizontal amplitude of the largest displacement from zero on a seismometer output. Richter arbitrarily chose a magnitude 0 event to be an earthquake that shows a maximum combined horizontal displacement of 1 µm on a seismogram recorded 100 km from the earthquake epicentre. So no negative magnitudes supposedly would be recorded but sensitive modern seismographs now routinely record earth quakes with negative magnitudes. No upper limit. Largest recorded earthquake was the Chilean earthquake of 22 May 1960 which had a Richter Scale of 9.5. The equation for Richter magnitude is

$$M_L = \log_{10} A(mm) + (\text{Distance Correction Factor})$$

where A is amplitude in mm measured directly from seismometer. Distance factor is found in Richter's (1958) book.

MODIFIED MERCALLI SCALE OF EARTHQUAKE INTENSITY

All terms used in the following definitions are outlined at the end of this section.

12 point scale

MMI - Not felt by people, except by a few under exceptionally favourably circumstances.

MMII - Felt by people at rest, on upper floors or favourably placed.

MMIII – Felt by people indoors; hanging objects may swing; vibrations may be similar to passing of a light truck; duration may be estimated; may not be recognised as an earth quake.

MMIV – Generally noticed by people indoors but not outside; light sleepers awakened; vibrations similar to passing of heavy traffic or to jolt of heavy object falling or striking a building. *Fittings*: Doors and windows rattle; glassware & crockery rattle; liquids in open vessels may be slightly disturbed; standing cars may rock. *Structures*: Walls and frames of buildings heard to creak; partitions and suspended ceilings heard to creak.

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MODIFIED MERCALLI SCALE OF EARTHQUAKE INTENSITY

MMV – Generally felt by people outside and by almost everyone indoors; most sleepers awakened; a few people alarmed. Fittings: small unstable objects displaced or upset; some glassware & crockery may be broken; hanging pictures knock against wall; open doors may swing; cupboard doors with magnetic catches may open; pendulum clocks stop, start or change rate. *Structures*: some windows Type I cracked; a few earthenware toilet fixtures cracked.

MMVI – Felt by all people; people and animals alarmed; many people run outside; difficult to walk steadily. *Fittings*: Objects fall from shelves; pictures fall from walls; some furniture moved on smooth floors; some unsecured fire places moved; glassware and crockery broken; very unstable furniture overturned; small school and church bells ring; appliances move on bench; filing cabinet drawers may open or shut. *Structures*: slight damage to buildings type I; some plaster falls; windows of type I broken; damage to a few weak domestic chimneys; some may fall. *Environment*: trees & bushes shake & rustle; landslides possible. ***Newcastle 28 December 1989 Earthquake***

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MODIFIED MERCALLI SCALE OF EARTHQUAKE INTENSITY

MMVII – People alarmed; difficult to stand; drivers notice & may stop cars. *Fittings*: large bells ring; furniture moves on smooth floors & may move on carpet; substantial damage to fragile contents of buildings. *Structures*: unreinforced stone & brick walls crack; buildings type 1 crack with minor masonry falls; a few instances of damage to buildings type II; unbraced building attachments fall; roofing tiles dislodged; many unreinforced chimneys damaged; water tanks type II may move & leak; some windows type II cracked; suspended ceilings damaged. *Environment*: water made turbid; small landslides; settlement; cracks; liquefaction

MMVIII – People are alarmed & may panic; car steering greatly affected. *Structures*: buildings type I heavily damaged; some collapse; buildings type II damaged, some with partial collapse; some type III buildings damaged; few instances of damage to type IV structures; monuments & pre-1976 elevated tanks & factory stacks twisted or collapsed; some pre-1965infill masonry panels damaged; few post-1980 brick veneers damaged; decayed timber piles of houses damaged; houses not secured to foundation may move; Environment: cracks on steep slopes & in wet ground; small to moderate landslides; small water & sand ejections.

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MODIFIED MERCALLI SCALE OF EARTHQUAKE INTENSITY

MMIX – *Structures*: many type I buildings destroyed; type II buildings heavily damaged, some collapse; type III buildings damaged; type IV structures damaged in some cases; damage or permanent distortion to some type V structures; houses not secured to foundations shifted off; brick veneers fall & expose frames. *Environment*: conspicuous ground cracking; general landsliding on steep slopes; liquefaction effects intensified & widespread with large lateral spreading.

MMX – *Structures*: most type I buildings destroyed; many type II buildings destroyed; type III buildings heavily damaged; some collapse; type IV structures damaged, some with partial collapse; type V structures moderately damaged but few partial collapses; few instances of damage to structures type VI; some well built timber buildings moderately damaged; railway lines slightly bent; concrete & asphalt roads badly cracked or thrown into waves. Environment: widespread landsliding; landslide dams & severe liquefaction

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MODIFIED MERCALLI SCALE OF EARTHQUAKE INTENSITY

MMXI – *Structures*: most type II buildings destroyed; many buildings type III destroyed; type IV structures heavily damaged, some collapses; structures type V damaged, some with partial collapse; structures type VI suffer minor damage, a few moderately damaged

MMXII – *Structures*: most buildings type III destroyed; many structures type IV destroyed; structures type V heavily damaged; structures type VI moderately damaged

CONSTRUCTION TYPES – used in above definitions

Buildings Type I – low standard of workmanship; poor mortar; constructed of weak materials; weak reinforced concrete or composite materials not well tied together

Buildings Type II – ordinary workmanship; no extreme weakness but neither designed nor reinforced to resist lateral forces

Buildings Type III – reinforced masonry or concrete buildings; not formally designed to resist earthquake forces

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MODIFIED MERCALLI SCALE OF EARTHQUAKE INTENSITY

Structures Type IV – buildings & bridges designed & built to resist earthquakes to normal use standards, ie no special collapse or damage limiting measures taken

Structures Type V – buildings and bridges designed and built to resist earthquakes to normal use standards, ie code requirements

Structures Type VI – structures dating from about 1980with well defined foundation behaviour designed for minimal damage

WINDOWS – *Type I:* large display windows, especially shop windows

Type II: ordinary sash or easement windows

WATER TANKS – *Type I*: external stand-mounted corrugated iron water tanks

Type II: domestic hot water cylinders unrestrained, except by supply & delivery pipes

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PLATE TECTONICS

There is a close correspondence between earthquake occurrence & the boundaries of crustal plates. There are six major (Antarctica, Americas, Pacific, India to Australia, Africa, Eurasia) and many minor plates that move relative to one another. Tectonics mean the study of structural features of the crust and their origin, Four major types of plate boundaries:

1. **Diverging boundary** where two plates are moving apart (mid-ocean ridge),
2. **Converging boundary** where one plate of heavier material sinks below lighter material at **subduction zones**. They account for majority of ear.thquakes and volcanoes.
3. **Collision boundary** where neither plate is consumed.

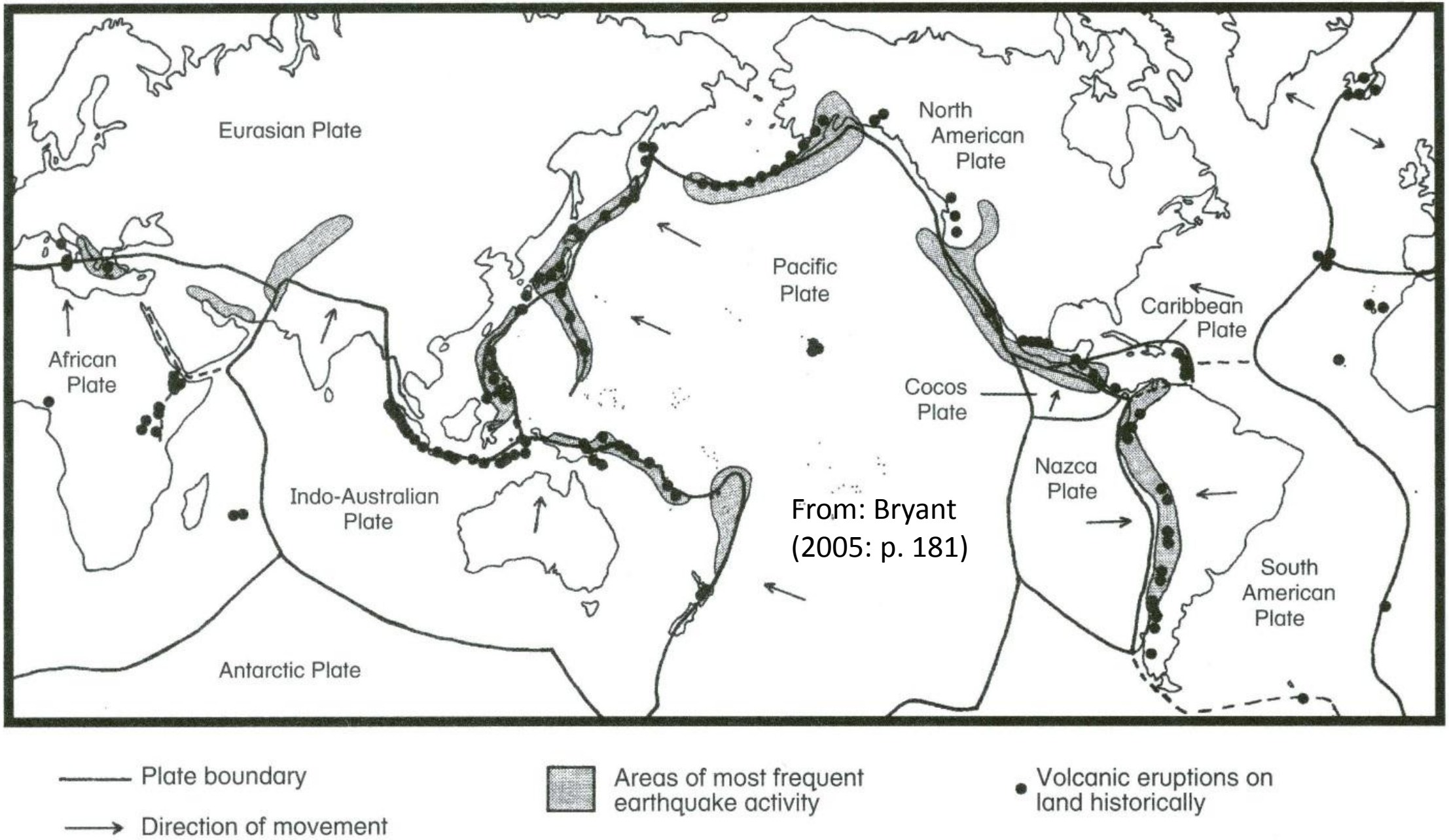

Fig. 9.1 Distribution of plate boundaries, intense earthquakes and historical land-based volcanic eruptions (based on Press & Siever, 1986; Bolt, 1993).

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PLATE TECTONICS

4. **Conservative boundary** where relative plate motion is parallel to the boundary.

But there are also **Intra-plate earthquakes** which result from crustal stresses away from plate boundaries.

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EARTHQUAKE OF 26 DECEMBER 2004 NEAR SUMATRA

Earthquake (9.3 on Richter scale) occurred at 0758 h. Focus located about 30 km below sea level with epicentre about 100 km west of northeast Sumatra. Vertical displacement of 10-20 m of sea floor along 1200 km of fault zone. Earth wobbled on its axis by as much as 25 mm. Occurred in Sunda subduction zone where Indo-Australian plate sliding beneath Eurasian plate. Previous major earthquakes in 1833 & 1861. Only 450 km long section of subduction ruptured in 2004.

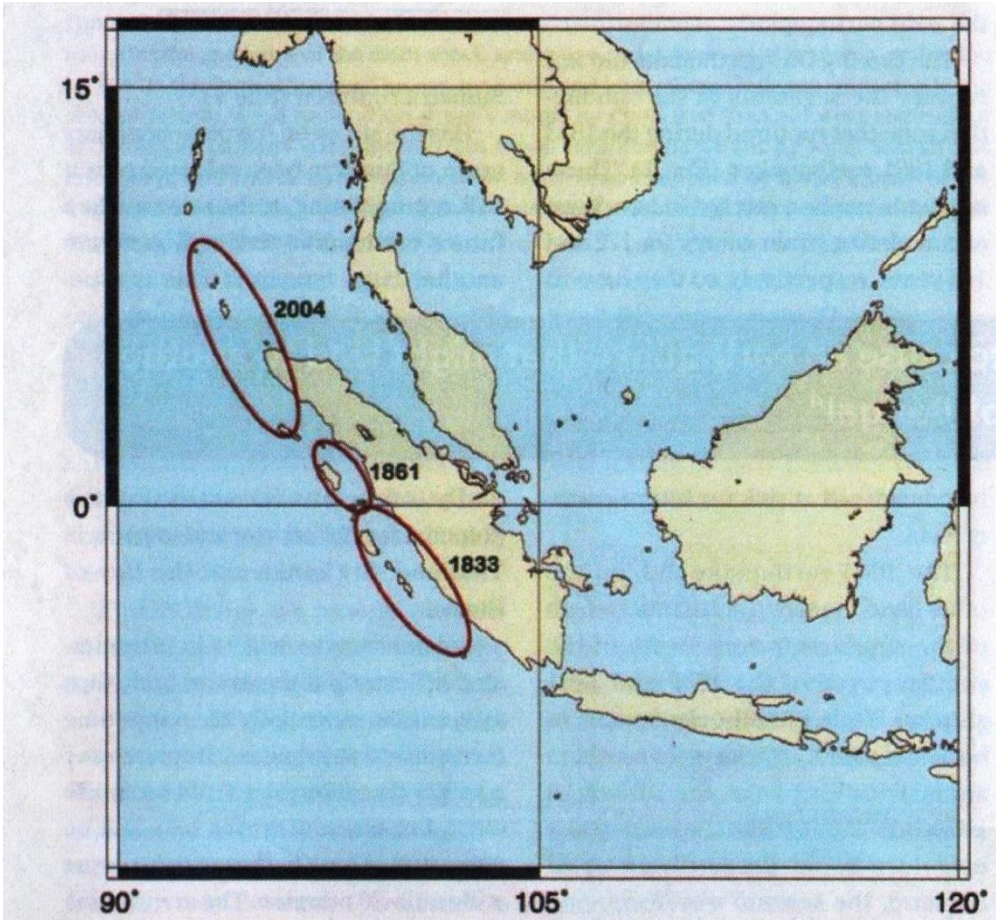

Figure 1. Great earthquakes in the Sumatran subduction zone. Note that other large earthquakes occurred in the Andaman and Nicobar Islands in 1881 and 1941.

From: Cummins (2005: p. 17)

Seismic waves only generated efficiently when entire fault slips as a unit within a few minutes. Seismic activity extended from Andaman Islands through Nicobar Islands to northern Sumatra. Probable stress relief along the plate boundary for the entire extent of the aftershock area. Question of whether there was partial or complete stress relief.

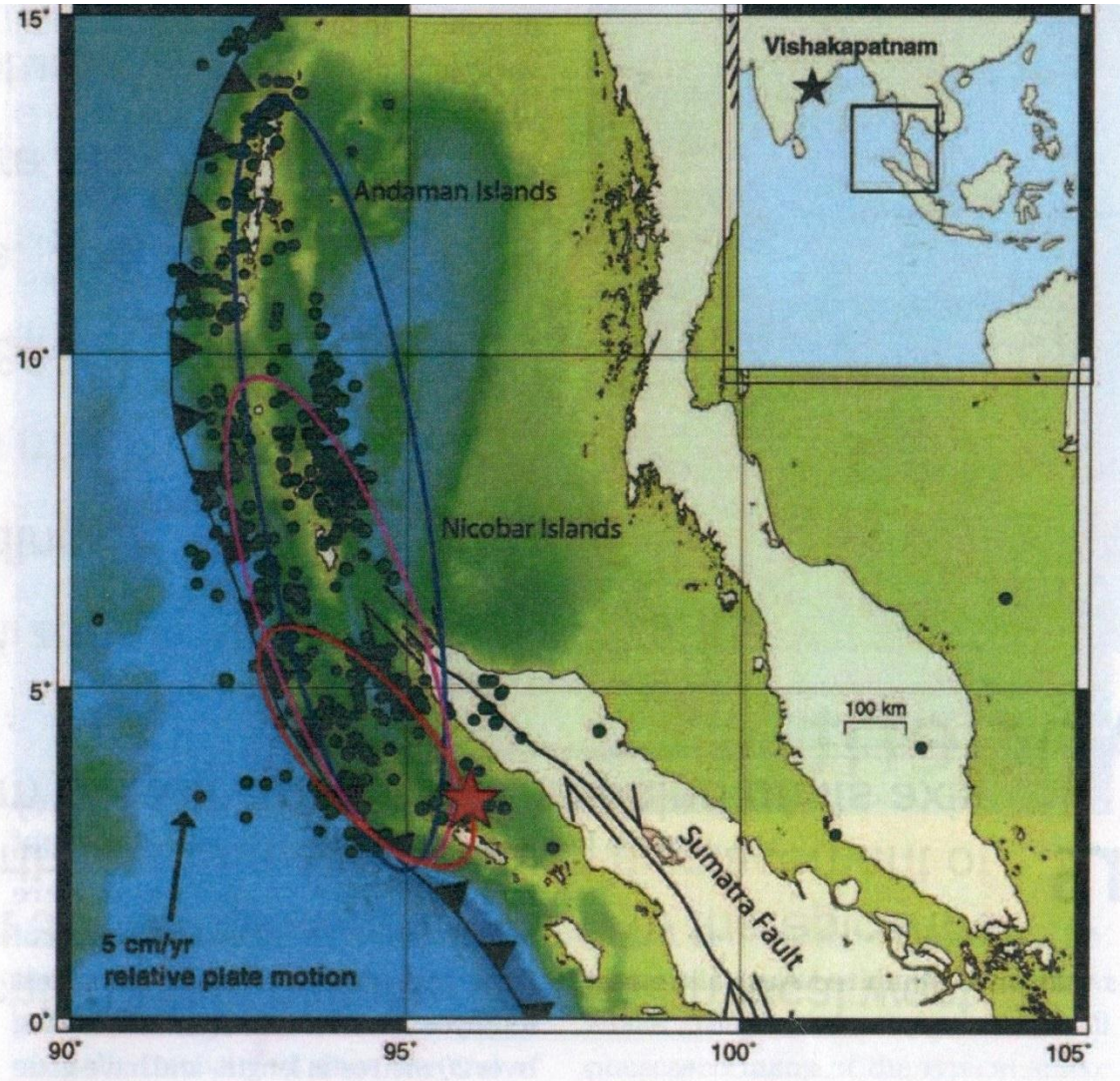

Figure 4. The 26 December 2004 Sumatra–Andaman Islands earthquake. The red star indicates the epicentre of the main shock, and green circles those of aftershocks, estimated by the US Geological Survey. The red, magenta and blue ellipses indicate respectively the area of seismic wave generation (from a model by Chen Ji of the California Institute of Technology), tsunami generation (from travel time computations by Kenji Satake and Eric Geist), and crustal deformation (from information supplied by Roger Bilham of the Cooperative Institute for Research in Environmental Sciences). The position of the tide gauge at Vishakapatnam is indicated.

From: Cummins (2005: p. 19)

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1989 NEWCASTLE EARTHQUAKE

Lasted no more than 10 s at 1027 h on 28 December 1989. It was an intraplate earthquake where the focus was 11.5 km below the surface & epicentre was about 15 km southwest of Newcastle. Thrust aligned northwest to southeast parallel to known faults. 5.6 on Richter Scale & category VII on MMS. 9 people died in Newcastle Workers Club when two floors collapsed. 13 people killed, 1st in Australia. 167 injured. A$1000 million of damages. Return period of about 1500 years.At least 4 other earthquakes of magnitude 5 or greater in nearby Hunter region since 1804. Ellalong earthquake of 6 August 1994 at 11.03 h & was 5.4 on Richter Scale and MMS VII.

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OTHER AUSTRALIAN EARTHQUAKES

Meckering (WA) earthquake at 1059 h on 14 October 1968. 6.9 on Richter Scale. Associated with faulting scarps and fissures. MMS MMIX. Some scarps were up to 3 m high. 20 people injured and much building damage.

Tennant Creek earthquakes of 22 January 1988 – 6.3, 6.4 and 6.7 on Richter Scale

Fig. 2.7b: Fault or dirt scarps developed during the Meckering earthquake. (WA Newspapers)

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CONCLUSIONS

Twidale & Campbell (2005: p. 28) “The lesson to be learned from these occurrences is that no place on Earth is stable. It is just that some areas are more unstable than others”.

Bryant (2005: p. 184) “…while earthquakes are most likely to occur along plate boundaries, the largest earthquakes in terms of death toll and destruction have not been associated with plate margins”.

He went on to say that:”…..no continent or region can be considered aseismic. Even those that are perceived as being aseismic have a remarkably high incidence of earth quakes above 6 on the Richter Scale” (Bryant 2005: p. 184).

The earthquake risk in Australia is very real and needs to be addressed in emergency plans and building codes (My view!!!)