AUSTRALIAN EARTHQUAKE CLUSTERS

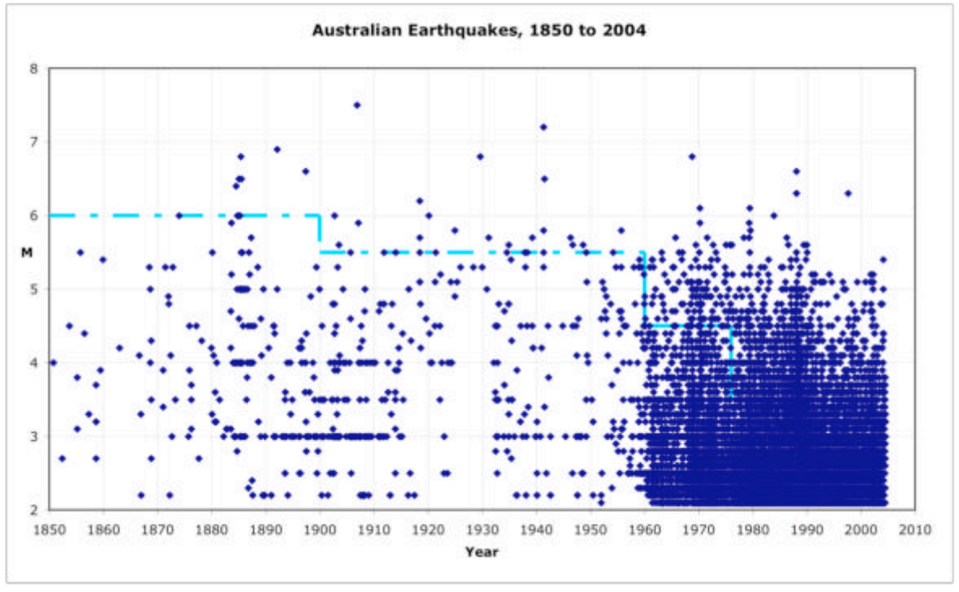
Gary Gibson, AEES 2004, Mt Gambier

Earthquakes cluster in time and space. Traditionally clusters have included foreshocks, the main shock, and aftershocks. Earthquake swarms are another form of cluster.
The earthquake cycle (opposite) is a development of this.

Fifteen large earthquakes in and surrounding Australia have been examined for clustering activity. Many of these were either offshore, occurred well before seismograph coverage was available, or both.

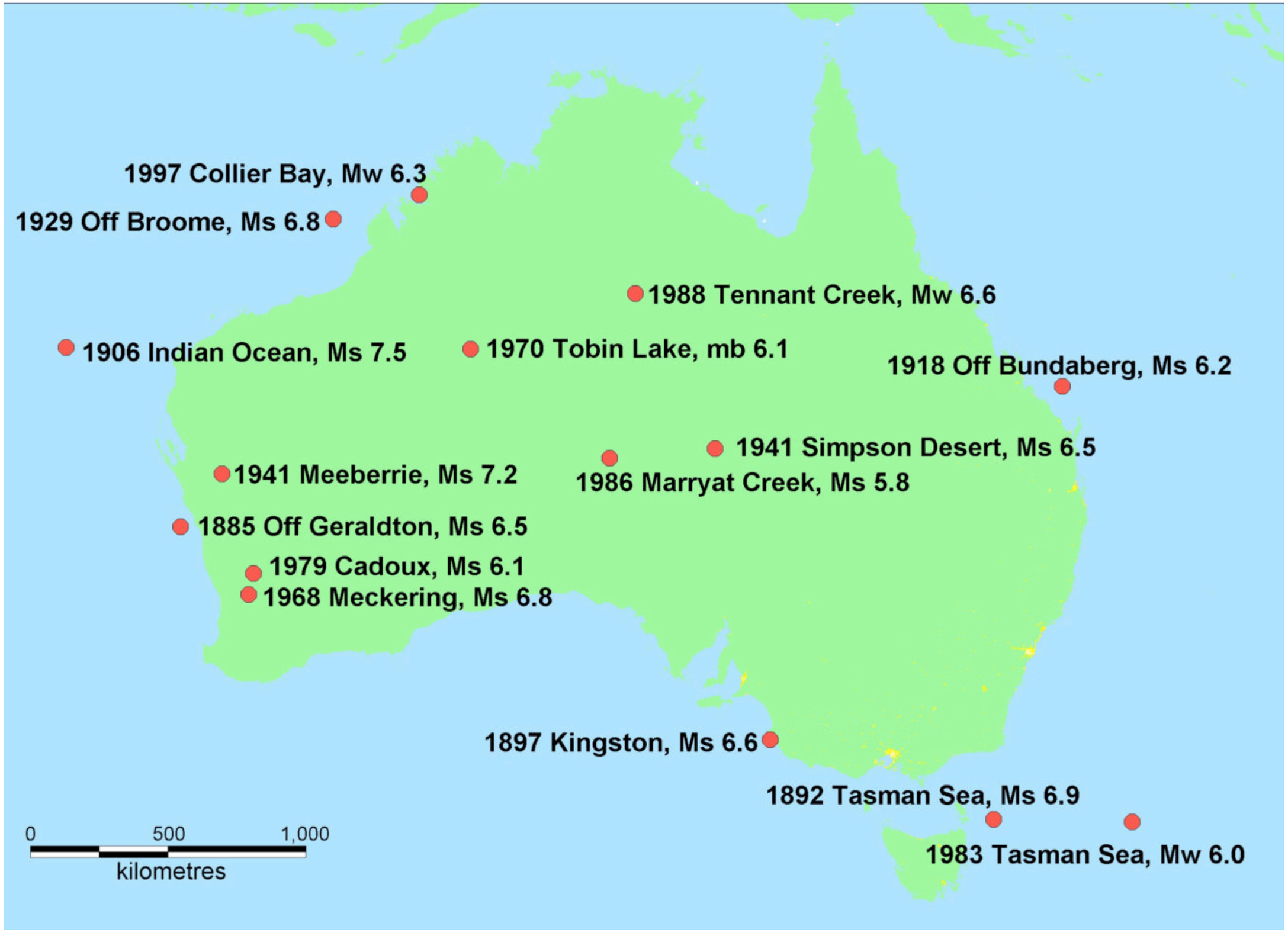
Of the remaining events, most showed every stage of the earthquake cycle, including precursory activity and adjustment activity.

The magnitude-time plot of known Australian earthquakes shown below has a light blue line. This approximates the magnitude for complete coverage for the area concerned – all events above the line should be included, some or most below the line are missing.

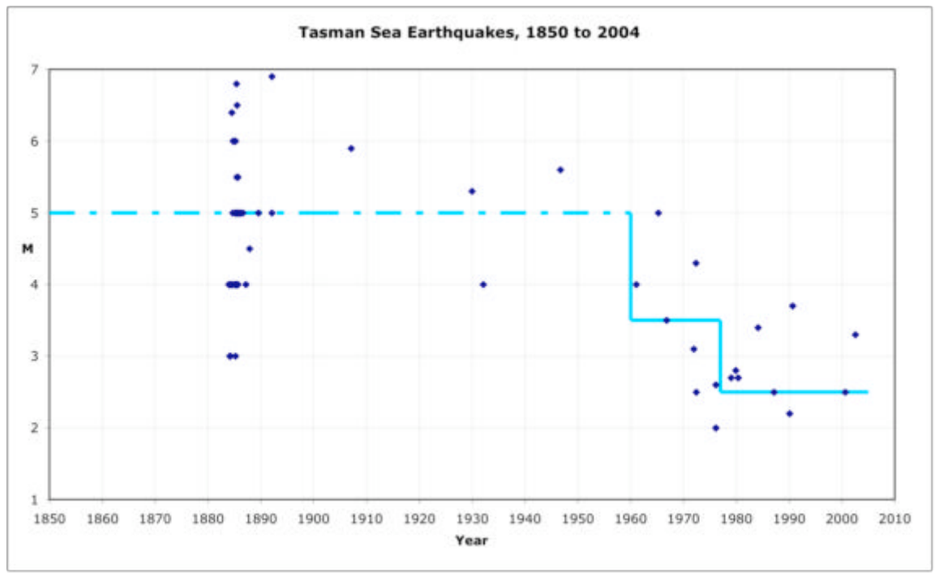


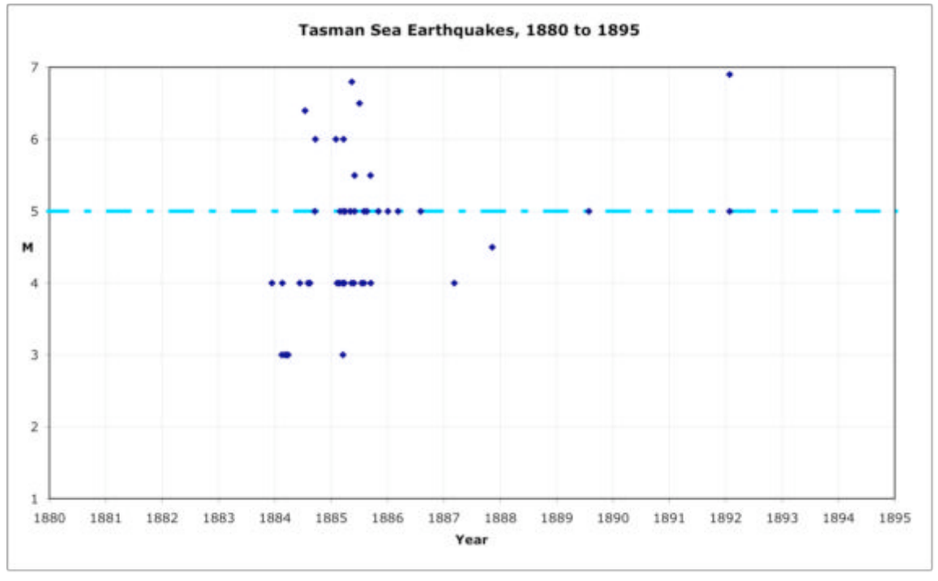
The Earthquake Cycle

Stage	*Description*
Quiesence	Long period without much activity, possibly lasting thousands or hundreds of thousands of years in stable regions like Australia. Strain energy and stress gradually building up.
Precursory	Occur weeks to years before the mainshock. Rather than being simply the result of high stress, they may indicate initiation of the rupture process.
Foreshocks	If they occur, these are minutes to hours before the main shock, probably acting as a trigger. They probably result in irreversible changes in the stress field that lead to the main shock.
Mainshock	The largest event in the sequence, or the first if two or more have the same maximum magnitude.
Aftershocks	Most, but not all, large earthquakes are followed by many events in the following days to weeks. They occur at a rapidly diminishing rate, reducing by half every few days. They are probably closely associated with additional movement about the main rupture.
Adjustment Events	Slowly decaying activity in following years to tens of years, decaying by half every ten years or so. The proportion of small to large events (b value) may drop with time. These are probably the result of stress changes throughout the surrounding region.
Quiesence	Another long period without much activity


1997 Collier Bay, Mw 6.3
1929 Off Broome, Ms 6.8
1988 Tennant Creek, Mw 6.6
1906 Indian Ocean, Ms 7.5
1970 Tobin Lake, mb 6.1
1918 Off Bundaberg, Ms 6.2
1941 Simpson Desert, Ms 6.5
1941 Meeberrie, Ms 7.2
1986 Marryat Creek, Ms 5.8
1885 Off Geraldton, Ms 6.5
1979 Cadoux, Ms 6.1
1968 Meckering, Ms 6.8
1897 Kingston, Ms 6.6
1892 Tasman Sea, Ms 6.9
1983 Tasman Sea, Mw 6.0
0
500
1,000
kilometres

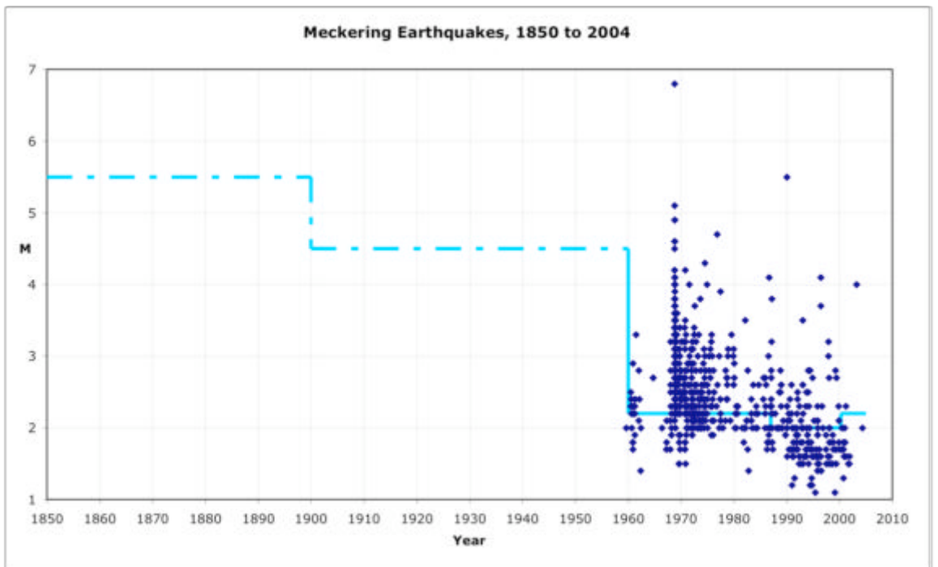
Tasman Sea, 1892, Ms 6.9

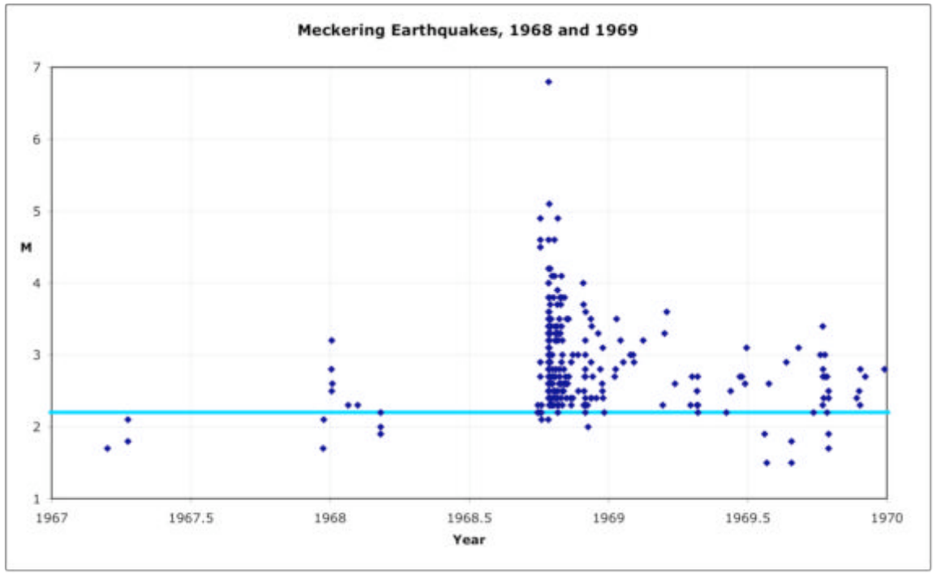




Precursory events occur over the eight years before the mainshock. Few aftershocks occur, followed by adjustment events over the next hundred years.

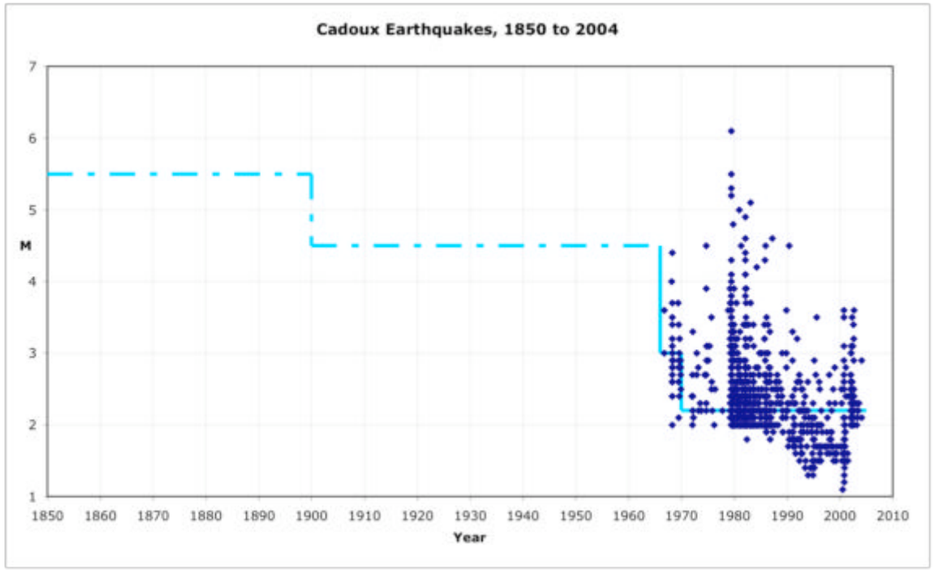
Meckering, 1968, Ms 6.8

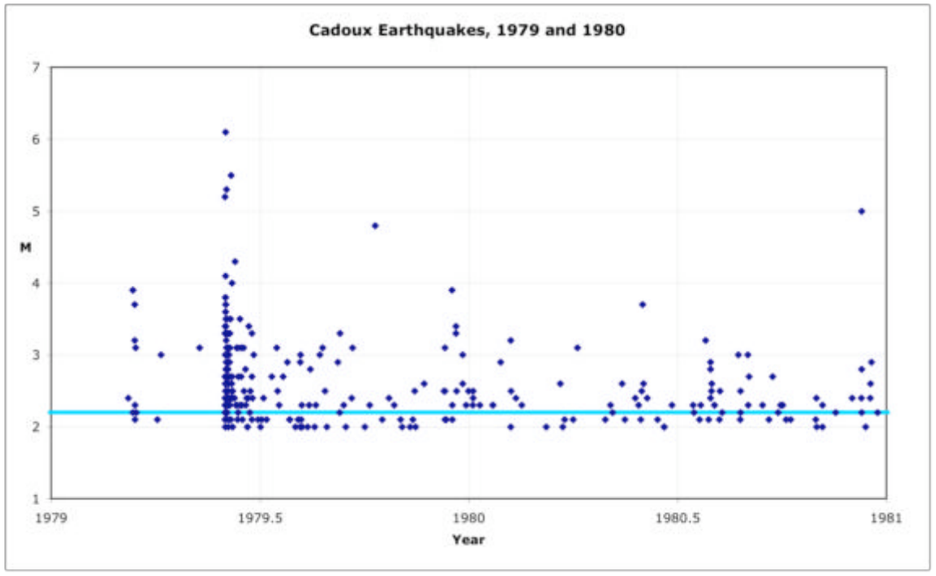




Some possible precursory events occur over the ten years before the foreshocks and mainshock. Intense aftershocks decay over the next few weeks, then the long slow decay of the adjustment events.

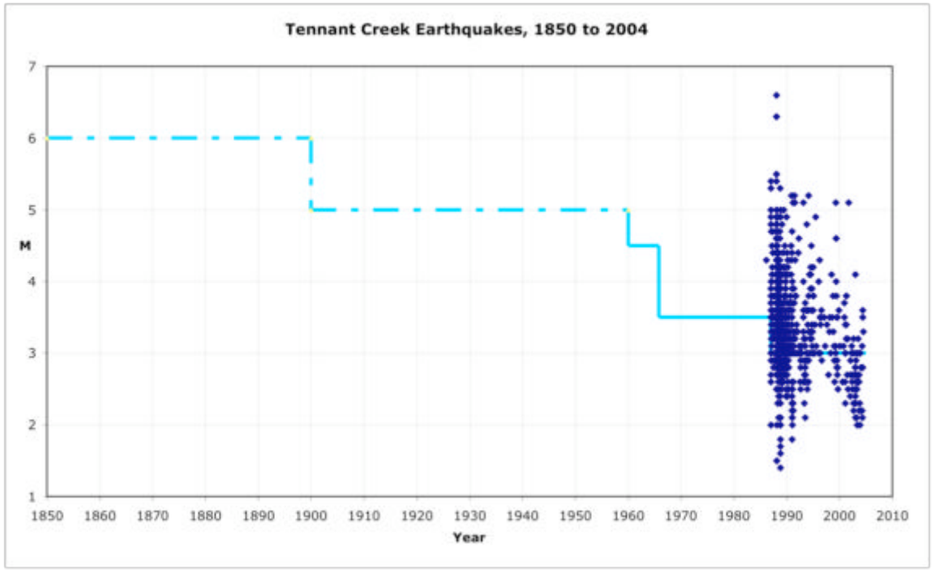
Cadoux, 1979, Ms 6.1

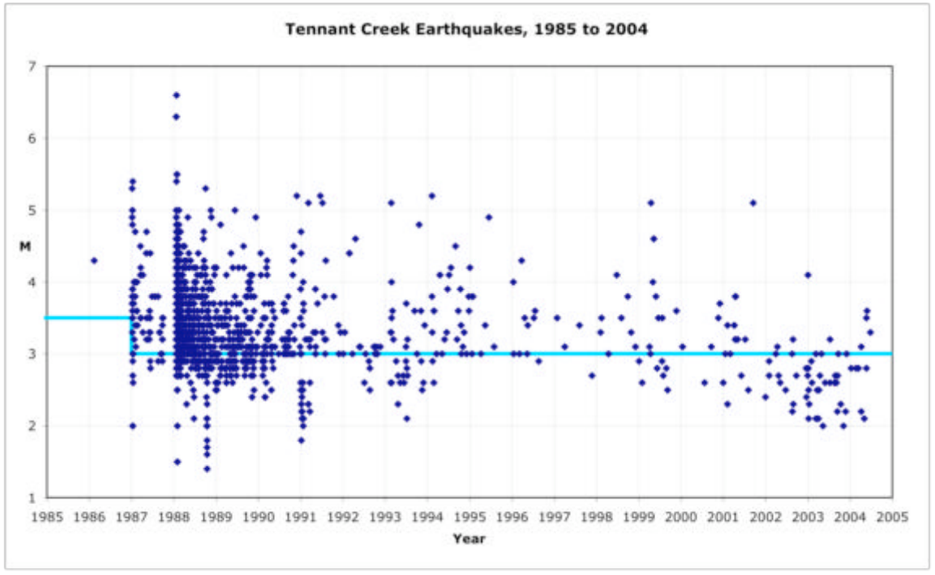




Precursory events occur over ten years before the foreshocks and mainshock. Aftershocks decay over a few weeks, followed by the long slow decay of adjustment events.

Tennant Creek, 1988, Mw 6.6





Precursory events occur over the two years before the foreshocks and mainshock. Intense aftershocks decay over the next few months, followed by the long slow decay of the adjustment events.

Large Australian Earthquakes

Year	Place Name	Longitude range	Latitude range	Number of events in cluster	Precursory events (days before)	Foreshock (days before)	Mmax	Aftershock (number)	Adjustment event (number)	Adjustment duration (days after)
1883	Tasman Sea	148.0 .. 151.0	-41.0 .. -39.0	68 + *	-2966	Ocean	6.9	Ocean	Many	36013
1885	Off Geraldton	112.0 .. 116.0	-31.0 .. -27.0	(2)	Ocean	Ocean	6.5	Ocean	Maybe 1	122 ?
1897	Kingston	138.0 .. 140.5	-39.0 .. -37.0	101	-28 ?	?	6.6	Few	Some	38967 +
1918	Off Bundaberg	151.5 .. 153.5	-24.5 .. -22.5	6	Ocean	Ocean	6.2	Few	Ocean	1369 ?
1929	Off Broome	119.7 .. 121.7	-18.0 .. -16.0	107	Ocean	Ocean	6.8	Ocean	Few	26534 ?
1941	Simpson Desert	135.0 .. 140.0	-27.0 .. -23.0	69	-1337	Remote	6.5	Remote	Many	23102 +
1941	Meeberrie	115.1 .. 117.1	-27.8 .. -25.8	7	Remote	Remote	7.2	Remote	Few ?	7426 ?
1968	Meckering	116.7 .. 117.2	-31.9 .. -31.3	756	-880 ?	-14	6.8	Many	Many	13160 +
1970	Tobin Lake	125.0 .. 128.0	-23.0 .. -21.0	255	Remote ?	Remote ?	6.1	Many	Many	8284
1979	Cadoux	116.9 .. 117.4	-30.9 .. -30.5	1058	-4118	-0.5	6.1	Many	Many	8114
1986	Marryat Creek	131.8 .. 133.2	-27.0 .. -26.0	20	-959 ?	No	5.7	Few	None	
1988	Tennant Creek	133.0 .. 135.0	-21.0 .. -19.0	2452	-710	-0.5	6.7	Many	Many	6110 +
1997	Collier Bay	123.0 .. 126.0	-17.0 .. -15.0	6	No ?	No ?	6.3	Few	None	

Did the earthquake have precursory, foreshock, aftershock or adjustment events?
For Ocean or Remote events, it may be difficult to say

Yes Maybe Maybe Not No

? Uncertain + Continuing

* Over 2000 Tasman Sea events were reported felt on Flinders Island and in NE Tasmania

Discussion and Summary

1. Earthquakes cluster in time and space.
   A cluster is sequence of dependent events.
   The cluster is usually named after the largest event in the cluster, which is regarded as an independent event.

2. Traditionally, clusters included foreshocks, mainshock and aftershocks, plus swarms.
   It now appears necessary to include precursory events, foreshocks, mainshock, aftershocks, and adjustment events, some or all of which may occur between quiescent periods.

3. Australian earthquakes are strongly clustered.
   A large proportion of Australian earthquakes are dependent events, although this proportion varies significantly from place to place.
   For example, the proportion is high in southwest Western Australia.

4. Clusters including events larger than about magnitude 6.0 more often than not include precursory events in the months or years before the mainshock, and a slowly decaying sequence of adjustment events in the months to tens of years after the aftershock sequence.

5. Clusters in which the largest event is smaller than magnitude 6.0 may form swarms that begin days to months before the largest event, then take somewhat longer than this to decay.

6. Two practical reasons to study clusters:

   a. Earthquake recurrence estimates for hazard studies usually assume independent events.
   If dependent events are included, these are by definition smaller than the mainshock, so the relative number of small to large events is increased, the b value is higher, and the computed ground motion (hazard) is too low.
   The effects are particularly severe in studies for sites in areas of low seismicity.

   b. Since most large Australian earthquakes are preceded by precursory events that occur in the months to years before the mainshock, recognition of these may allow for alerts, forecasts, or even predictions.
   The challenge is to distinguish precursory events from swarms that are not followed by a large event. For example, a small shallow swarm will probably not be followed by a large event.
   High resolution seismograph monitoring of new earthquake sequences should help to identify precursory events.