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Is the Southwest Seismic Zone of Western Australia experiencing a "low-point" in its activity?

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Abstract

The southwest seismic zone (SWSZ) of Western Australia seems to have recently experienced a period of relatively low seismic activity. In order to define a "low" it is necessary to review the known seismic history of the SWSZ. Tables and graphs of seismic events are presented to indicate seismic trends, and from these identify highs and lows in seismic activity. Six quiet periods have been identified since 1960, of which the latest (June 2009 – Aug 2011) is the longest. Changing magnitude completeness levels in the catalogue makes it difficult to compare different time periods, particularly before 1960, where there are very few reliable data. Apparent "quiet" periods before the 1970s are suspect because of inadequate monitoring.

1 Introduction

The southwest of Western Australia has been described as the most active region in Australia (Leonard 2008). It has had many relatively large events over the years, the most notable being the magnitude Ms 6.8 event at Meckering in 1968. The region is commonly referred to as "The southwest seismic zone" or SWSZ, a term introduced by Doyle (1971), to describe a lineation in epicenters, first observed by Everingham (1965), who named it "The Yandanooka - Cape Riche Lineament".

While the dimensions of the SWSZ have not been, and may never be clearly defined, it is generally represented as a roughly oval region (-long axis trends to the NNW) approximately centred on the Meckering – Cadoux area.

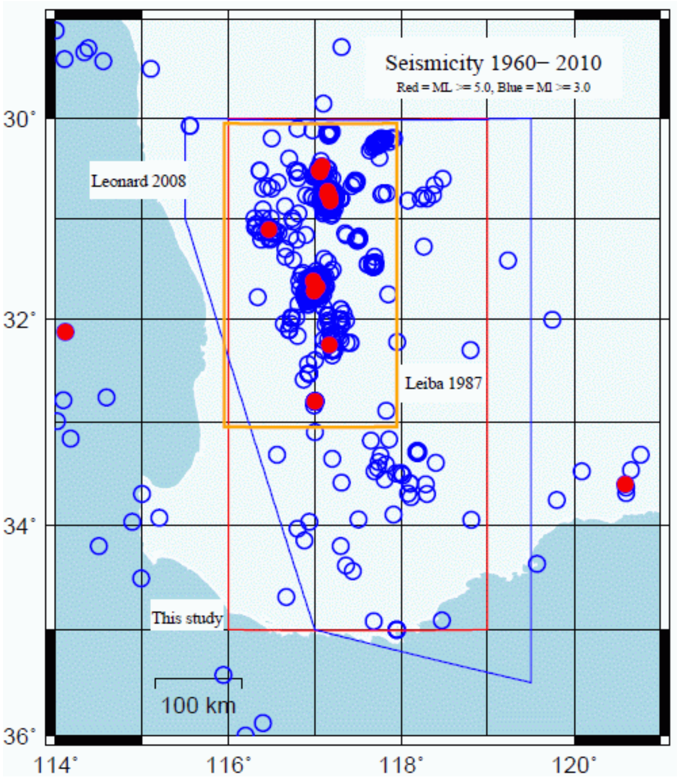

Figure 1 Earthquakes Ml ≥ 3 (Ml ≥ 5 in red), 1960 – 2011 and showing zone boundaries quoted.

Everingham & Tilbury (1972) identified an upsurge in seismic activity in the region after 1940. Michael-Leiba (1987) extended this study, and concluded that there had been a five-fold increase in activity between 1949 and 1983 (relative to 1923-1948).

For this study, an extra ~30 years of data are available. A rectangular region has been defined, for ease of searching the catalogue, the boundaries of which are 30-35S, 116-119E (Figure 1). This equates fairly closely to the trapezoid-shaped "South West Australia" zone or SWA, of Leonard (2008), and is slightly more than double the area of the region reviewed by Michael-Leiba (1987). Leonard's and Michael-Leiba's zone boundaries are also shown on Figure 1. The zone used here includes all the significant activity of the SWA zone as defined by Leonard, but excludes the off-shore activity sometimes noted in the general area off Cape Naturaliste and surrounding areas of the Indian Ocean. That activity occurs in a different tectonic environment (i.e. not in the Yilgarn cratonic block), and so is excluded from consideration in this report.

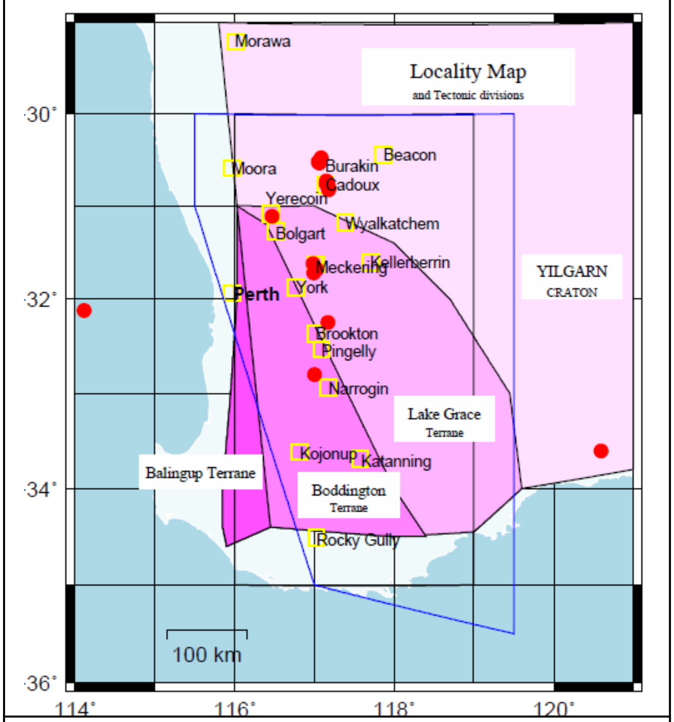

Figure 2 Locality map and tectonic divisions, and earthquakes Ml ≥ 5.0 from Figure 1.

Geological Setting

The area studied here lies within the Western Gneiss Terrane of the Yilgarn Craton, one of three major Precambrian shield regions in WA (the others being the Pilbara and Kimberley cratons). This division of the Yilgarn craton was proposed by Wilde et al. (1996) who also proposed three subdivisions of this terrane (the Balingup, Boddington and Lake Grace Terranes), the approximate boundaries of which are shown on Figure 2.

2 The Data

Seismic monitoring in Western Australia dramatically improved in late 1959, with the

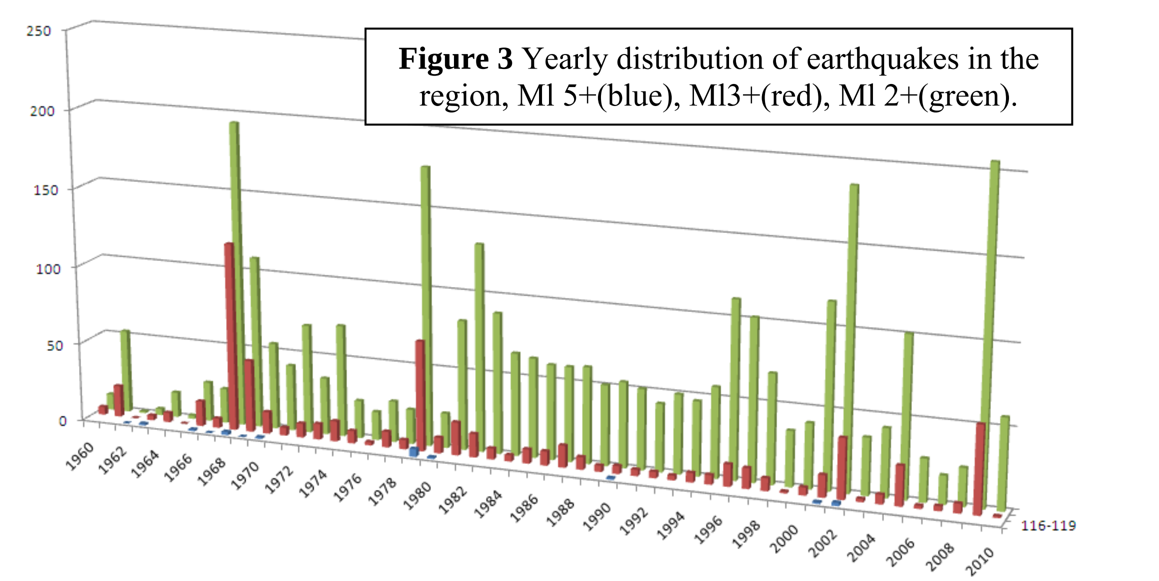

Figure 3 Yearly distribution of earthquakes in the region, Ml 5+(blue), Ml3+(red), Ml 2+(green).

establishment of the Mundaring Geophysical Observatory (MGO), and MUN seismic station. Because of this divide, this study has been divided into periods, before and after January 1960.

Earthquakes in the region of Ml ≥3.0 since January 1960 have been plotted on Figure 1. In order to graphically represent the variations in seismicity with time, three values have been extracted from the GA on-line catalogue for each year – namely the yearly earthquake totals in the magnitude ranges 2.0 - 2.9, 3.0 - 4.9 and 5.0 and above (Figure 3.)

From Figure 3, periods of relatively high and low seismic activity were identified, and are listed in Table 1 (A and B). The regions of highest activity are also indicated in Table 1(A).

Table 1A Periods of high activity identified from Figure 3

YEAR	active region	Size & date of max event	References
1961	Brookton	25 Jun 1961 Ml 4.4	
1968-9	Meckering	14 Oct 1968 Ml 6.9	Gordon & Lewis, 1980
1978	Cadoux	02 Jun 1979 Ml 6.2	Lewis et al., 1981
1996-8	Kellerberrin	31 Aug 1997 Ml 4.6	Dent, 2011
2001-3	Burakin	30 Mar 2002 Ml 5.2	Leonard, 2002
2005-6	Kalannie	22 Sep 2005 Ml 4.1	Dawson et al., 2008, Dent 2010
2009	Beacon	30 Jan 2009 Ml 4.1	Dent, 2009

Table 1 B Periods of low activity from Figure 3

Period	Prior activity	Ending Activity	# of Months	Comments
Sep 61- Dec 62	Ml 4.4, Aug 61	18 Jan 1963, Ml 5.4	16	Few seismographs, poor coverage
Dec 64 - Dec 65	2 ev 3+, Nov 64	Jan 1966, 8 ev Ml 3+	13	Few seismographs, poor coverage
Jul 98 - Jan 00	5 ev 3+, Jun 98	Feb 2000, 2 ev Ml 3+	19	One Ml 3.2 event in Jan 1999
Apr 03 –Sep 04	Ml 4.0, Mar 03	Oct 2004, 3 ev Ml 3+	18	Ml 3+ events in May 2003 and Sep 2004
Apr 06 - May 07	2 ev 3+, Mar 06	June 2007, Ml 3.8	14	No ML 3+ events
Jul 09 – Aug 11	Ml 4.2, June 09	Sep 2011, 2 ev Ml 3+	26	Ml 3+ events in Mar 2010 and Apr 2011

3 Examination of "low activity" periods.

The periods of apparent low activity were then examined in more detail, i.e. on a monthly time-scale. The GA database was examined for the time period encompassing the apparent "low" periods, and number of events of Ml ≥ 2.0 in each month was determined (Figure 4).

For the purposes of this study, a quiet period is defined as one of at least 12 months duration and are bounded by months which contained at least two Ml ≥ 3.0 events, or consecutive months with Ml ≥ 3.0 events, or a month with an Ml ≥ 3.5 event.

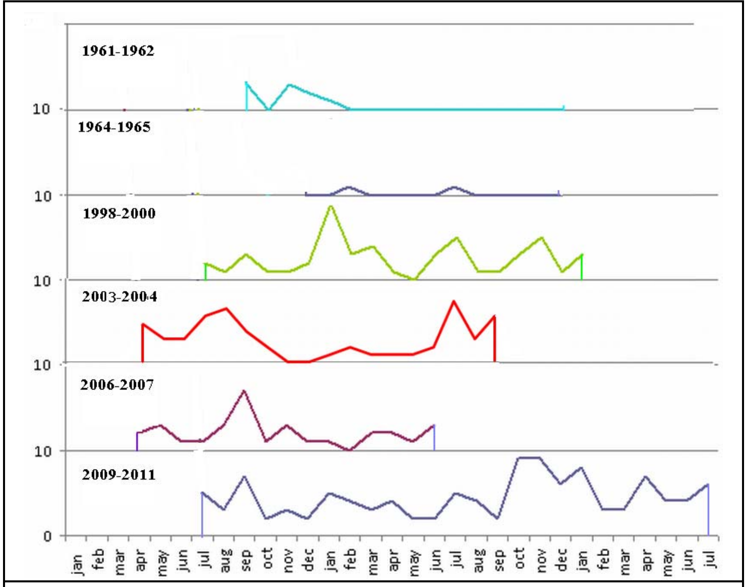

Figure 4 Number of events per month of Ml ≥ 2.0 in low activity periods.

Assumptions

There are two important assumptions that have been made when using the GA catalogue to compare the seismicity of different times.

1-- That the changing formulae used to compute magnitudes over the decades have produced consistent results.
Note that in the 1960s/70s, magnitudes were based on the MUN station alone, and may be less reliable than in later years when there were more stations providing magnitude data. Note also that the Richter local Magnitude scale (abbreviated to Ml), is the scale used in this report.

2 -- That no events of Ml ≥ 3.0 in the study area since 1960 have gone un-detected. (It is to be expected that some Ml 2.0 – 2.9 events may have been missed, and particularly so in the 1970s and earlier – but these are not critical to the investigation).

Item 1 is the subject of on-going investigation by Geoscience Australia, but it is assumed that variations in magnitude determination methods over the years will not affect the conclusions of this report.

Figure 5

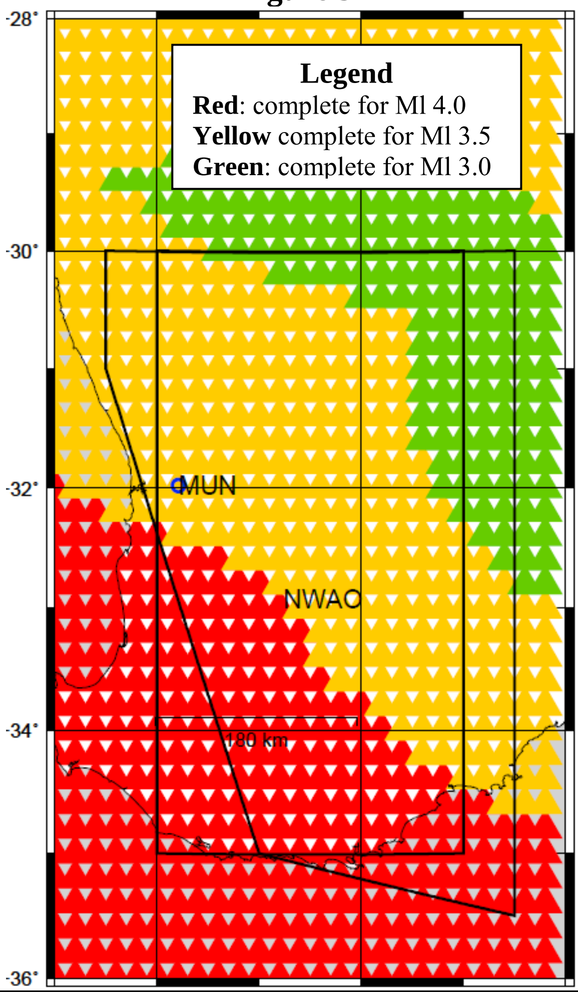

Figure 5. Portion of Magnitude-completeness map for 1980 for WA – from Dent (2009).

Item 2 is more significant. Strictly speaking, seismicity of different periods should only be compared by using catalogues that are known to be complete above the magnitude threshold values selected. Some attempts have been made to produce "Magnitude Completeness" or Mc maps for Australia – e.g. Sagar & Leonard (2007) and Dent (2009), and an expanded portion of Figure 5(c) from Dent (2009) is reproduced in Figure 5. This gives the computed Mc levels in SWA for 1980. It suggests that the southwest portion SWA is only complete for magnitudes of Ml ≥ 4.0. Also that the central portion is complete for Ml ≥ 3.5 and the northeast is complete for Ml ≥ 3.0. This assumes that an earthquake needs to be recorded on Mundaring (MUN), Narrogin (NWAO) and Meekatharra (MEK) (the three closest stations in operation in 1980) in order to be located. Obviously however, the MGO would have been able to detect and roughly locate smaller earthquakes, using two or fewer stations, had they occurred. This is not taken into account in the algorithm used to compute the map shown and much work still needs to be done to compute accurate Mc maps for Australia. For convenience it is assumed here that the catalogue is complete for Ml ≥ 3.0 events in SWA since 1960. For reference, seismic stations in the region, and their installation dates, are given in Table 2.

However, the criteria applied mean that we cannot compare current activity with pre-1960 activity, as the limited seismic coverage at the time (only PER was operating) means that some relatively large events within the SWA zone were probably missed.

Table 2 Seismographs in SWA*

Code	Name	Date installed
PER	Perth	1906
WAT	Watheroo	Apr 1958-Jan 59
MUN	Mundaring	Aug 1959
NWA	Narrogin	Feb 1976
KLB	Kellerberrin	Sep 1981
BAL	Ballidu	Sep 1982
RKG	Rocky Gully	July 1983
* original codes shown – minor location changes have often occurred since then.		

4 A Discussion of the "low" periods, 1960 -2011

Low (1) Sep 1961-Dec 1962**.** There are nine earthquakes in the GA catalogue for this period, the largest of which was Ml 2.9 (November 1961). Reference to the MGO annual report for 1962 shows that Benioff recorder was replaced with the "World Wide Standard Seismograph" system in May-June, which resulted in an apparent decrease in sensitivity. A substitute system was installed on 25th Sep 1962. It is therefore probable that events, including potentially large ones, were not detected. Therefore, this "low" period should be treated with caution.

The period ended with the Ml 5.4 "Nourning Spring" event, near the town of Beverley, on 18th Jan, 1963. This event had many aftershocks which were apparently not detected by the Mundaring seismograph.

Low (2) Dec 1964 – Dec 1965. There are only two earthquakes of Ml 2.0 or above in the GA catalogue for this period (in February and July of 1965), which seems anomalously low. Mcgregor (1967) reported that 1965 was the least active year for the "Yandanooka Cape Riche zone" since recording began in August 1959. The report lists seven events for 1965, with a maximum magnitude of 2.2. Locations are not given – rather distances and bearings, as locations at the time were estimated using S-P times at the MUN station, together with the relative amplitudes of the signals on the horizontal components of the seismograph. This illustrates the relative imprecision of earthquake locations at the time.

The period ended with a swarm of events northwest of the town of Narrogin in January 1965. A magnitude 5.0 event on 23rd Feb 1966 shown in the catalogue as part of this swarm is actually an error, as the original MGO location places the event off the west coast of WA.

Low (3) July 1998 – Jan 2000 The only Ml 3+ event in this 18 month quiet period was an Ml 3.2 event southwest of Kojonup on 22 Jan 1999. The event was the largest of a sequence of earthquakes at this location.

Low(4) Apr 2003 – Sep 2004. There are 54 events above Ml 1.9 during this period, the majoriy of which are low magnitude events representing the ending phase of the 2000-2003 Burakin swarm (Leonard, 2002).

Low(5) Apr 2006 – May 2007. This period appears to have lower average activity than the following 2009-11 period, and contains no Ml 3+ events, but is of shorter duration.

Low(5) July 2009 – August 2011**.** There were only two events of Ml 3.0 or above during this period, both from near Burakin. The first of these was Ml 3.0 on 29 Mar 2010, and the second was Ml 3.4 on 26 Apr 2011. The period ended with two Ml 3+ events (Ml 3.4 and 3.0) in September 2011.

Conclusions for the recent era (1960 – 2011)

Figures 3 and 4 suggest that, since about 1998, the SWSZ seems to be experiencing more frequent periods of low seismicity, of which the latest (2009- 2011) is the longest. Two periods in the 1960s had no Ml 3+ events, and fewer located events overall, but this is inconclusive because MUN was the only seismograph in the region, and it was not particularly sensitive by modern standards. It is highly likely that many events up to Ml 3.0, and some possibly larger, passed undetected by the Mundaring seismograph. Also, there were significant periods when there was no monitoring because the only seismograph in the region was unserviceable.

5 The period before 1960

The seismicity of the region prior to 1960 was discussed by Everingham (1968), and Everingham & Tilbury (1972). Everingham & Tilbury described the difficulties in evaluating the seismicity of the region as follows…

"Data for the period 1900-1922

All but a few years of the Perth Observatory seismograms for the years 1904-1922 when the Milne seismograph was in operation, could not be located. However, this type of recording, extremely crude by modern standards, would have been of little use for the study of the relatively small magnitude earthquakes which occurred during that period. Also, the population was sparse, newspaper descriptions and filed reports from the public pertaining to tremors were sketchy and consequently it was not possible to improve the data tabulated by Everingham (1968a – Table 5)."

They produced a list of seismic events in the region (1923-1959), based on a review of seismograms from the Milne-Shaw seismograph at the Perth Observatory (PER). The list they constructed forms the basis of GA's online catalogue for the region in that period, and the events they identified are shown in Table 3. The first event they identified was on 18 Dec 1940, with an estimated magnitude of Ml 4.2. However, there was a general lack of activity in the region before 1949 and they state that "The Perth seismograms prove that earthquakes with magnitudes (Ml) of 4.5 or greater could not have occurred in the zone during the period 1923-1939, and the observed effects suggest that none occurred during 1900-1922."

The period from 1949 to 1958 is dominated by activity in the Gabalong – Yerecoin area (~ 150 km north of Perth), where several events estimated to have magnitudes over 5.0 (the largest Ml 5.8), as well as many smaller events, occurred between 1955 and 1958. Another significant event in the period was near Bolgart (~ 100 km NE of Perth) in 1952 (Ml 5.1)

On the basis of the above activity, they concluded that *"Tremors in the area" (i.e. SWSZ) "have been noted relatively frequently since 1878, but they have become more frequent since 1940".*

The felt reports listed by Everingham (1968) for the period 1906 – 1955 are basically extracted from the records of the Perth Astronomical Observatory, and these have also been discussed in a history of the Perth Astronomical Observatory (Utting, 1993).

Using Everingham's 1968 list, Michael-Leiba (1987) also reviewed the seismicity of the region, and identified eight new "events" for the period 1911 – 1937 (one of the entries being a "swarm" event over a 3 month period in 1937). These have been included in Table 3. Michael-Leiba assigned magnitudes of "ML 4.0 +" to each of these, on the basis that the felt reports indicate Modified Mercalli intensities of MM 4 or greater. As Michael-Leiba notes, there is an element of risk in applying this assumption. She concluded that there was an approximate five-fold increase in the mean yearly number of Ml 4.5+ main shocks during the period 1949 to 1983, compared to 1923-1948. Almost all of these events are in the northern half of the SWA zone, suggesting that a division of the zone into two sectors may be warranted.

Table 3 Earthquakes in south-western Australia, 1900 – 1959

DATE	TIME UTC	MAG	AREA	SOURCE	COMMENTS
10-Apr-07	~0800 UT	5.0+?	unknown	Everingham, 1968	
19-Aug-11	unknown	4.0+?	York	M-Leiba 1987	
30-May-13	~2010 UT	5.0+?	unknown	Everingham, 1968	
30-May-13	~2130 UT	5.0+?	unknown	Everingham, 1968	
02-Jun-16	unknown	4.0+?	York	M-Leiba 1987	
01-Dec-16	unknown	4.0+?	Meckering	M-Leiba 1987	
03-Jun-17	unknown	4.0+?	York	M-Leiba 1987	
15-Mar-32	unknown	4.0-4.4?	Muresk	M-Leiba 1987	
02-Nov-32	unknown	4.0-4.4?	Northam	M-Leiba 1987	
18-Aug-36	unknown	4.0-4.4?	NE of Katanning	M-Leiba 1987	
Mar-May 1937	unknown	4.0-4.4?	NE of Katanning	M-Leiba 1987	swarm?
18-Dec-40	2145	4.2	Beverley	IBE/Tilb	not in GA cat
19-Apr-46	2113	5.7	West of Yallingup	in GA cat	dubious Magnitude
17-Sep-46	1512	4.5	Pingelly	in GA cat	
02-May-49	1000	5.1	Yerecoin	in GA cat	
07-May-49	1709	4.1	Yerecoin	in GA cat	
11-Mar-52	0609	5.1	Bolgart	in GA cat	
27-Nov-54	0836	unknown	York	IBE/Tilb	not in GA cat
29-Apr-55	0914	4.7	Yerecoin	in GA cat	
29-Apr-55	1949	4.4	Yerecoin	in GA cat	
29-Aug-55	0609	5.3	Gabalong	in GA cat	
30-Aug-55	1352	5.8	Gabalong	in GA cat	
30-Aug-55	1407	4.7	Gabalong	in GA cat	
30-Aug-55	1656	4.6	Gabalong	in GA cat	
24-Feb-56	0627	4.5	Yerecoin	in GA cat	
05-Apr-56	2313	4.5	Yerecoin	in GA cat	
20-Mar-58	0303	4.8	Beverley	in GA cat	
3-Oct-59	1207	5.0	offshore	in GA cat	offshore

Everingham's 1968 table also lists three events felt in Perth, in 1907 (two events) and 1913, although the 1913 events are not noted as confirmed by readings on the PER seismograph. These are potentially Magnitude 5+ events within the Southwest Australia zone, which was very thinly populated at the time. These events have also been added to Table 3.

Reference to Figure 3 suggests only moderate seismic activity in the SWSZ for the ~ 20 years following the Cadoux activity of 1979-1980. Relatively high activity returned in 2001 with the major earthquake swarm at Beacon, followed by swarms at Kalannie (2005) and Beacon (2009). All of this activity was in the northern sector of the SWA zone. However, as Figure 3 indicates, activity following the Beacon swarm has been very low.

6 Conclusions

Six periods of relative quiet since 1960, meeting specified criteria, have been identified, of which the most recent is the longest. The first two, in the early 1960s are questionable, partly because of instrumentation problems, and partly because of the lack of seismographs in the region then.

The period before 1960 is harder to assess because of very poor monitoring. There was undoubtedly a very active period in the mid to late 1950s, and earlier periods appear to have been relatively quiet, although seismic monitoring was poor. It is difficult to compare those periods accurately with more recent times, when vastly superior data are available.

There have been more frequent periods of relatively low seismicity since about 1998, and this may represent a return to more "normal" levels of seismicity, i.e. pre-1950s levels, for the southwest seismic zone. However it could also be interpreted that the pre-1950s levels were abnormally low.

7 Acknowledgements

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