Clustered seismicity in the Southwest Australia seismic zone, 2015-2016

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Abstract

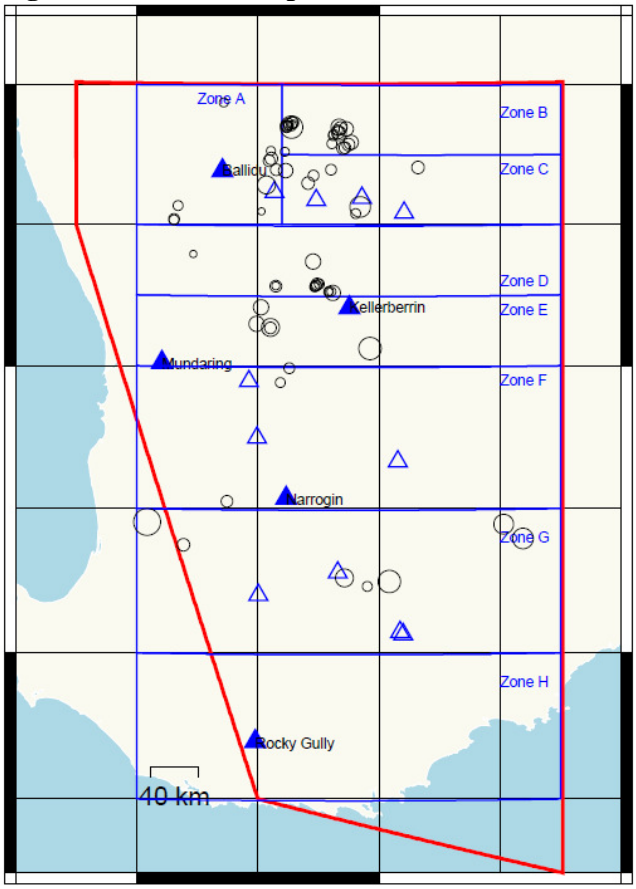
The seismicity of south-west Australia in 2015-16 is discussed in detail. The seismicity of the region in this period was possibly at the lowest level since relatively detailed monitoring of the region commenced in 1959. The seismicity in 2015-16 continued to display the highly clustered nature observed in two previous analyses of the area (2013-14, and 2014-15). Most of the 73 events located by GA during the period can be grouped into 17 cluster centres which were active during the year, and 10 of which were active in at least one of the two previous periods. The data suggest that close cluster centres commonly show approximately contemporaneous activity. They also suggest that non-clustered events may be a little more frequent in the west and south of the seismic zone. Some of the solutions provided by Geoscience Australia (GA) are revised using additional data provided by the "ACG/PSN" network in the region. The new solutions support earlier conclusions that the probable error in GA solutions is often of the order of 6 – 10 km. GA focal depths average about 10 km, but the new solutions, using more recording stations and a different earth model, suggests that the focal depths are generally less than 5 km.

1. INTRODUCTION

This report is the third in a series, each of which examines in detail the seismicity in the South West Australia seismic zone over a 12 month period, starting in June 2013, with a particular emphasis on the clustered nature of the seismicity. This zone, shown in Figure 1, is a close approximation of a zone first defined by Leonard (2008), and includes a smaller, ill-defined region generally known as "the southwest Seismic Zone" (SWSZ), first described by Everingham (1966), and named as such by Doyle (1971). The area referred to as SWSZ has grown with time, and some consider the terms are synonymous.

Three earlier reports (Dent 2013, 2014a & 2015) defined 36 cluster centres (Figure 1) to which the majority of events in the period June 2013-May 2015 could be assigned. This report continues the analysis, for the period June 2015- May 2016, and finds the majority of the 73 events located can be assigned to 17 cluster centres, seven of which are defined for the first time in this report.

Figure 1: Location map



Legend: Red box – SWA as defined by Leonard (2008) Blue boxes – SWA zone and subdivisions as used here. Circles – GA event locations, size reflects magnitude. Triangles — seismographs

Locations of all 36 cluster locations are tabulated in Dent (2016).

To assist analysis, the SWA zone was divided into 8 subzones (Dent, 2014) and this convention is retained for this report (Figure 1).

As mentioned in the earlier reports, a major problem in analysing the data is the lack of certainty in earthquake locations. This problem is gradually diminishing, as more data from a new seismograph network (The Public Seismic Network or PSN, Dent et al., 2010) becomes available. However, many more stations are required to achieve good locations over the whole area. In this report on 2015-16 clusters a new parameter is applied to cluster locations identified for the first time – a "confidence level" (see Table 1), reflecting a subjective assessment of the clusters existence and precision in spatial location

Table 1 – Description of Confidence levels used here

A	Relatively high confidence in the reality of the cluster and its spatial position (< 3 km)
B	Fair degree of confidence in the reality of the cluster. Uncertainty in position about ± 6 km
C	Fair degree of uncertainty in the reality of the cluster, and also its estimated position (about ± 15 km)

The ultimate aim of these reports is to investigate whether the number of cluster sites in the SWA zone is limited (i.e., < ~ 100), and if they are relatively long-lived (i.e. > ~ 10 years), and if the data can be correlated with the local geology. Cluster sites which may be identified in these reports may ultimately be found to represent sources of historical seismicity.

2. DESCRIPTION OF THE 2015-2016 SEISMICITY

2.1 An overview

The 12 months June 2015 – May 2016 was a very quiet period, with only 73 events located in the SWA zone, compared with 167 events in the same region in the previous 12 months (which was itself a relatively quiet year). There were two months in which only one event was recorded (October 2015, and February 2016). The largest events were ML 3.2 (near Harvey) and 3.1 (west of Beacon). The largest earthquake clusters in the region were northeast of Kalannie, and NW of Beacon, and there was some activity northeast of Kellerberrin, but the numbers of events in the clusters were low compared with the numbers observed in earlier years.

The Geoscience Australia (GA) locations for the period were made using the Antelope location program (© Boulder Real Time Technologies), and the IASPEI-91 earth model.

62 of the 73 events have been relocated by the author, using the EQLOCL location program (© SRC, Melbourne) and the WA2 earth model. GA used the EQLOCL program for its earthquake locations until 2009, and also used the WA2 earth model until 2015. For relocations of 2015-16 events, the phase data set for each event has been extended by using data scaled from the PSN stations in the region. For the average event, this has increased the number of near stations used in a location by about 3.

2.2 A detailed examination of the seismicity by zone

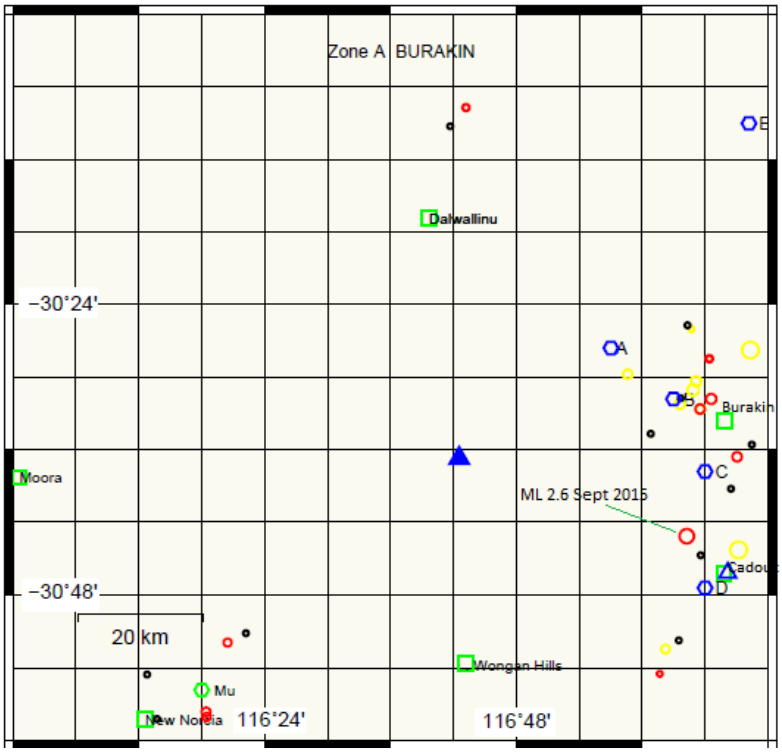
As noted above, the zonal convention used in the two earlier reports has been retained for this study.

Zone A: Burakin 11 events, largest ML 2.6

The largest event in the Burakin zone was an ML 2.6, event about 10 km NW of Cadoux (Figure 2), and appears to be isolated. A small event southwest of Cadoux (ML 1.6), is also isolated, but is close to the village of Manmanning, which has seen significant seismicity in the past (e.g. February to July 1982).

In the 2015-16 period there were 6 events located to the west of Burakin village, a roughly similar number to the previous reporting period. They were spread out over a range of about 20 km the largest being ML 2.3. They are also relatively evenly spread in time, although there were two events on successive days in September. There is one defined cluster point near Burakin (Location B), and these six events are tentatively assigned to this

Figure 2: Events in Zone A, "Burakin", 2015-2016



Legend Red circles – GA locations 2015-16; yellow circles GA locations 2014-15; small black circles – relocations of the 2015-16 GA locations.; Green hexagons – cluster centres first identified in 2015-16; Blue hexagons – identified cluster locations prior to 2015-16.; Blue triangles – seismograph locations; Green squares – population centres

Table 2 Cluster centres active in the SWA seismic zone in 2015-16

Zone	Cluster Location	Total events	Max ML	Name	Latit-ude	Longit-ude	Confid. Level	When active
Zone A	E of New Norcia	2	2.0	Mu	-30.96	116.31	C	19,20 Dec 2015
Zone A	Burakin	5	2.4	B				
Zone B	NE of Kalannie	13	2.9	Alpha				Mar & May 2016
Zone B	NW of Beacon	8	2.5	Nu	-30.31	117.68	B	Jun & Jul 2016
Zone B	West of Beacon	5	3.1	P				Apr & May 2016
Zone C	S of Bencubbin	2	2.8	Q				Nov 2015
Zone C	N of Koorda	2	2.2	F				Aug & Dec 2015
Zone C	NE of Koorda	1	2.0	K				Dec 2015
Zone D	SE of Wyalkatch	1	2.4	I				5 Dec 2015
Zone D	N of Cunderdin	2	2.1	M				17,18 Aug 2015
Zone D	NW of Kellerer	6	2.1	Omic	-31.44	117.47	B	Jun & Jul 2015
Zone D	N of Kellerber	4	2.5	Pi	-31.48	117.58	B	Jun & Jul 2015
Zone E	W of Bruce Rock	1	2.9	Rho	-31.84	117.84	C	
Zone E	S of Meckering	4	2.6	O				
Zone F	W of Quairading	2	2.1	V				Jul 2015
Zone G	Nyabing	3	2.9	Sigma	-33.5	117.92	C	Dec 2015
Zone G	Newdegate	2	2.8	Tau	-33.21	119.16	C	22 Jun 2015
	63 events out of 73							

point. However, the seismicity of this area is complex, as it was the site of three magnitude 5 events in 2001-2002 and many thousands of smaller events (Leonard 2003), and it warrants further in-depth investigation.

The GA locations for two small events east of New Norcia (19th & 20th December, ML 1.9 and 2.0) are almost identical, but the relocations are separated by about 7 km. Events in this area are hard to locate precisely because they are on the periphery of the seismic network. The two events, and a third small event in the same area have been assigned to a new cluster location, called location Mu (Table 2). This location is about 30 km northwest of the surface-rupturing Calingiri event (ML 5.7) in 1970 (Gordon & Lewis, 1980). It is given confidence level "C" because it is based on only a few events which are relatively poorly located. Note that similar small events in the area have occurred in most years.

Zone B: Beacon 27 events, largest ML 3.1

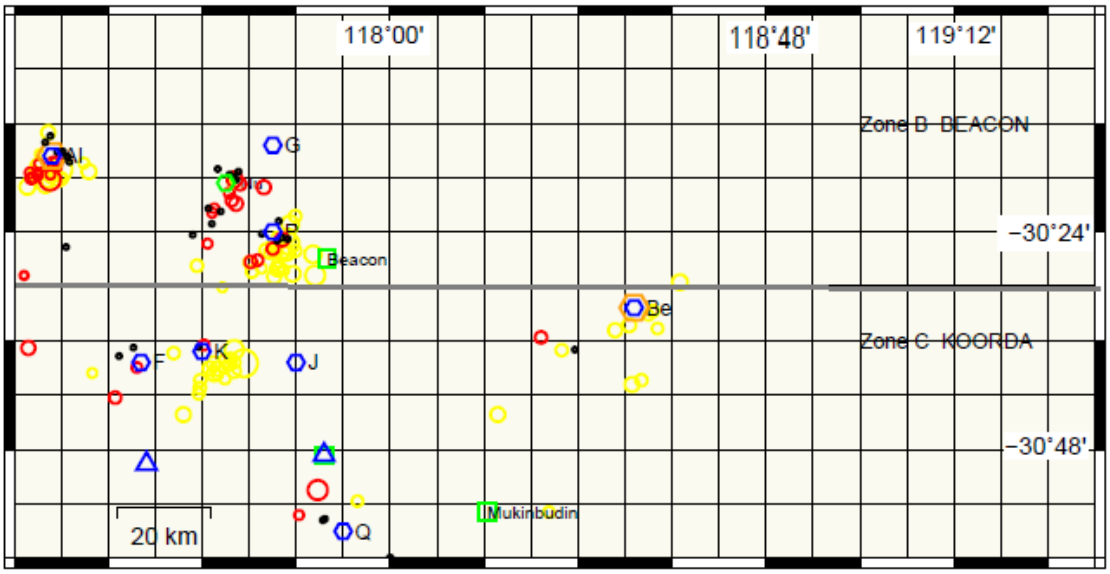
This zone (Figure 3) was the most active of the 8 zones in the previous reporting period (2014-15), and continued to be so in 2015-16 period. Figure 3 suggests three sources of activity, two of which have been previously defined.

1) Location Alpha, northeast of Kalannie – this activity would be a continuation of the cluster activity from the previous reporting period (2014-15).

2) It is proposed that a group of five events west of Beacon, including the second-largest event of the year, ML 3.1, in May 2016, have originated from location P, which was quite active during 2012-13.

3) The third region is about 30 km NW of Beacon – it is proposed that the activity here may represent a new source, about 10-12 km southwest of location G. It is called location Nu, and given a confidence level of "B". The linear nature of the plots of these events may be due to the poor seismic station distribution (Dent 2010).

Figure 3: Zones B and C (legend as for Figure 2)



One small event about 40 km NNE of Mukinbudin, (ML2.2, 1st Nov 2015) appears to be isolated.

Zone C: Koorda 7 events, largest ML 2.8

This zone was relatively quiet in 2015-16, with only 7 events, after registering 34 events in the previous year, (mainly from cluster location K, south of Lake Mollerin). One event in the 2015-16 year (December 2015) appears to come from this location. Two other events to the west of this event appear to come from Location J, which was quite active during 2012. Location J was very active in 2004, with several magnitude 4 events.

Two events south of Bencubbin (largest ML 2.8) have relocations very close to each other, and plot only about 5 km northwest of Location Q, and are here allocated to that location.

Zone D: Wyalkatchem 14 events, largest ML 2.4

This zone is of interest because events in it appear to define two new cluster centres northwest of Kellerberrin, here called Omicron and Pi. The separation of these is the same as the approximate uncertainties in event locations, but examination of the S-P times of events in the two groups suggests the two groupings are real, with little variation of event locations within the two groups. The groups have been each assigned confidence level B.

Omicron is about 30 km NW of Kellerberrin, and Pi is about 20 km NNW of Kellerberrin. Activity at these two centres was basically contemporaneous, in June and July 2015. Epicentres in the Omicron groups show a distinct NE trend, but this may be attributed to location biases introduced by the poor distribution of seismographs, as similar trends have been noticed in other cluster groups in the area (Dent 2010). Location Pi is about 6 km southwest of location H, which was a very active location between 1996 and 1998 (max mag ML 4.6, Dent, 2011). Relocations of some of the events in cluster Pi are close to location H, which casts some doubt on the validity of cluster group Pi.

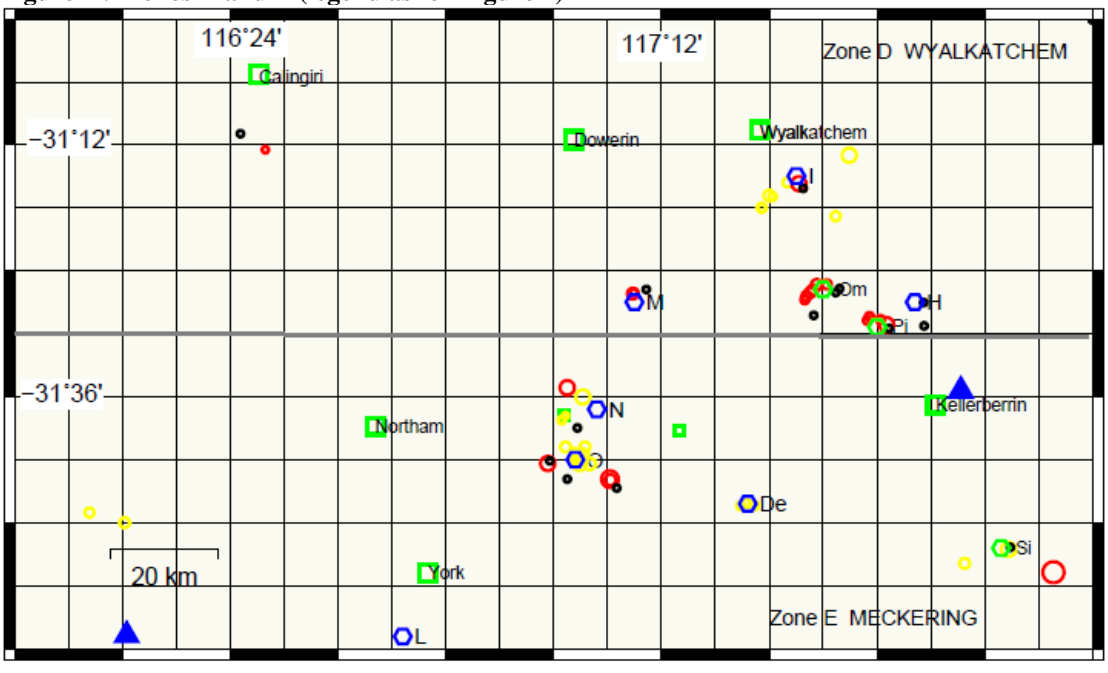
Activity returned to location Pi in June 2016, just after the current reporting period.

Two events on 17th&18th August (Max ML 2.1) about 20 km north of Cunderdin, plot very close to cluster location M, and are here assigned to that location.

An event about 20 km SE of Wyalkatchem (ML 2.4, 5th December), is very close to activity noted in 2011 (Location I) and this event is allocated to this location in **Table 2**.

A solitary event (ML 1.6) is noted about 10 km south of Calingiri.

Figure 4: Zones D and E (legend as for Figure 2)



Zone E: Meckering (31.5ºS - 32.0ºS) 5 events, largest ML 2.9

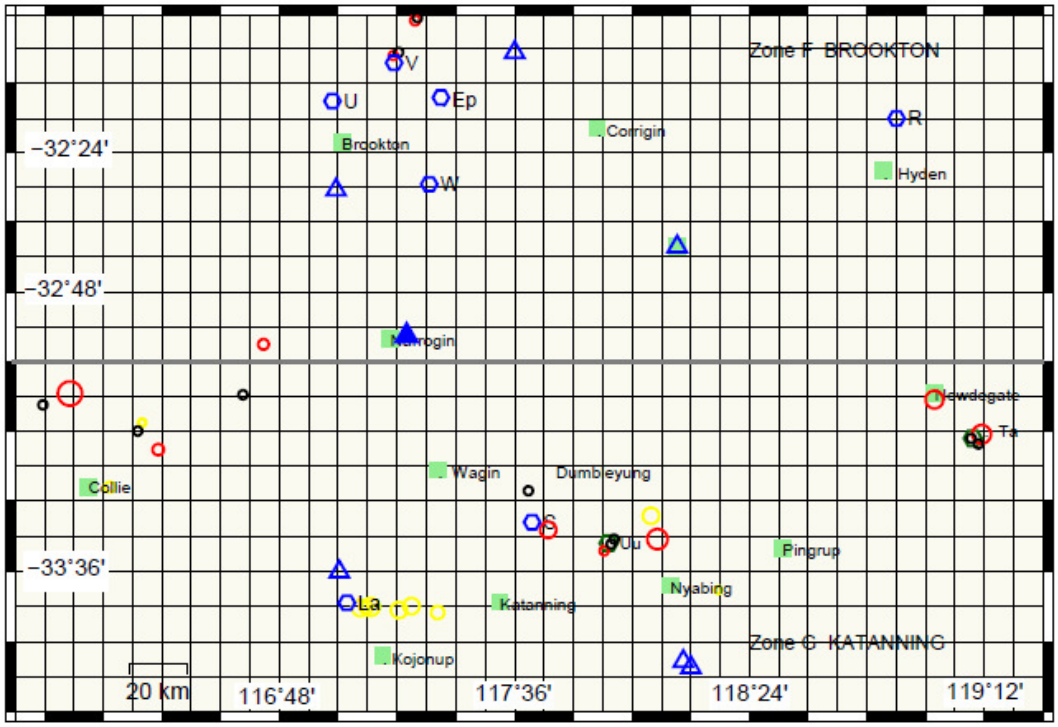
Four of the five events in this zone are near Meckering. The fifth, and largest, ML 2.9, is a single event about 15 km west of Bruce Rock.

Two of the four Meckering events (October and November 2015) were located by GA at about 15 km SE of Meckering, and relocation basically support this location. The ML 2.4 event, just north of Meckering has been relocated, with the aid of a PSN station at Meckering, installed a month earlier, and what is considered a very accurate location has been achieved. The new location is about 10 km SSE of the GA location at a depth of 5.7 km.

Thus the probability is that all four Meckering events are within 10 km of location O, and they are tentatively assigned to this location. However, the distribution of events in the Meckering area needs further closer attention. It might be expected that Meckering events would show a north-south trend following the 1968 surface rupture, but such a connection is not obvious.

The Bruce Rock area has been the location of some significant earthquake clusters in earlier years (eg March – May, 2001), but the events in these clusters were also poorly located, which makes it difficult to draw any connections between the earlier events and the event in this period. The relocation of the ML 2.9 September 2015 event places it at the location of an event a year earlier, and so this location has been called a new cluster location, location "Rho", but given a confidence level of C because it is based on so few events.

Figure 5: Zones F and G (legend as for Figure 2)



Zone F: Brookton (32ºS – 33ºS) 3 events, largest ML 2.1

That there were only 3 small (and probably poorly located) events in this zone indicates a very low level of activity – in the previous year there were 27 events in this zone. All three of

the events occurred in July 2015 and two of these were about 15 km west of Quairading. One plots on location V, and it is possible that the other also originated from this location, and so they have been both assigned to this location.

The third event (ML 2.1) was about 50 km west of Narrogin in the southwest of the zone, and is solitary. Events in this area are uncommon.

Zone G: Katanning (33ºS – 34ºS) 7 events, largest ML 3.2

There are 7 events in this zone, and the two events in the west of the region, (which includes the largest of the year in SWA, ML 3.2, about 15 km east of Harvey), appear to be solitary. Considering the solitary event near Williams, in the west of zone F, this may suggest a pattern for events in this region. Relocation of the Harvey event moves it about 5 km, and brings it closer to the Harvey reservoir, raising the possibility that the earthquake is related to water-loading. Note that the new location (Figure 5) is actually about 1 km outside of the western boundary of the SWA zone as used here.

Another small event, about 25 km NE of Collie, is also apparently solitary. Note that both the GA location for this event, and its relocation, have relatively large uncertainties.

In the far east of the zone, two events near Newdegate on 22nd June 2015 (ML 2.7 and 2.8) probably define a new cluster centre, but locations in this region are difficult, as they lie outside of the network of seismographs. The GA locations are about 20 km apart. The relocation of the ML 2.8 event agrees closely with the GA location, and the new cluster location (location Sigma) has been assigned to that point, with a confidence level C.

There are also three events southeast of Dumbleyung which are believed to be clustered, but the locations are poor. Relocations of the first two events (ML 2.9 and ML 1.9) are close to GA's location of the ML 1.9 event, and the new cluster location has been assigned to that point, which is about 15 km west of Nyabing (Location Tau). Again, the confidence level is C. Significant cluster activity has been noted near Nyabing in previous years (e.g. April 1995).

Zone H: Cranbrook (34ºS – 35ºS)

As with the previous (2014-15) reporting period, there are no GA located events in this zone for this period. The fact that GA's seismic station in the south of the SWA region (RKGY) was only intermittently operating during the year (H. Glanville, pers. comm., 2016) may suggest that some normally locatable seismicity could have been missed.

3. DISCUSSION

The number of cluster centres active (17) in the 2015-16 period is slightly higher than in either of the two preceding periods, but some of these centres represent very minor activity. The total number of events in the period is quite low because none of the cluster centres had high levels of activity.

The object of this exercise is to see how many events can be allocated to distinct cluster groups, and to determine if the cluster groups exhibit recurring activity over long periods of time. A visual examination of event locations, in conjunction with noting their occurrence in time, allows an initial categorization of events as clustered or isolated. Relocation of an event may cause an events categorization to change.

In the initial report defining cluster centres (Dent, 2012), an effort was made to find historical clusters where the cluster centre was well defined, usually because of the placement of temporary instruments. In retrospect, only the cluster centres labelled A to H from that report can be assigned a confidence level A.

In these following reports, where the seismicity of whole years is being considered, many of the cluster groups are less well defined, because only permanent seismic sites are available. Some of the suggested cluster sites are considered to be poorly constrained because of lack of events, or poor locations for reasons such as being outside the boundaries of the seismic network. A confidence classification (A, B or C) has been added to **Table 2**.

Sixty three of the 73 events in the 12 month period have been assigned to a cluster centre (**see** Table 2**).** Most of these centres have less than 5 events in this 12 month period, but some have been more active in past years. The most active centre in 2015-2016 was Location Alpha (north east of Kalannie) in Zone B and this activity represents a continuation of stronger activity from the cluster centre in the previous 12 months. Two lesser centres (Omicron, Pi) northwest of Kellerberrin, do not appear to be represented in the earlier reports.

Some of the cluster centres (eg, near Meckering and Burakin) are rather vague, i.e. clustering in time is not always pronounced, nor is clustering in space, though this could be attributed to poor locations. These areas need to be more closely examined in the future.

Some of the larger events during the year appear to be isolated – i.e., the Harvey event (ML 3.2), the Cadoux event (ML 2.6), and perhaps the Bruce Rock event (ML 2.9), although the Cadoux and Bruce Rock events are close to known cluster centres. An examination of the seismic record suggests isolated events are more dominant in the western and southern regions of the SWA zone.

Cluster centre B, west of Burakin has been active every year since activity at the location was noted in 2000 (Leonard 2002), although in this reporting year, as mentioned earlier in this report, there were only five small events and their connection to location B is to some degree tenuous. This may be because the area is on the periphery of the seismic network, and locating events here accurately, particularly small events, is difficult.

Identification of clusters is still limited by poor locations for many earthquakes. Because of poor locations, it can be difficult to discriminate between close centres. It is fairly obvious that events northwest of Kellerberrin belong to two clusters, but in the case of events northwest of Beacon, this is less obvious.

It will take time to determine, but a desired outcome is to know the final density of cluster centres in the region and if patterns in cluster distribution exist. For example, linear patterns could suggest lines of weakness, or blind faults. On the other hand it could emerge that whole regions are equally susceptible to clustered earthquake activity. Such observations should offer insights into the origins of the seismicity, and influence the manner in which earthquake hazard and risk maps for the region are determined.

Earthquake focal depths and earth velocity models

The average depth of the GA event solutions is approximately 10 km, with the deepest events at 17 km depth (Appendix 1). The velocity model used was IASPEI 91, for which the top layer (0 – 20 km) velocity is 5.80 km/sec. The average RMS of residuals is quite high (~0.9 s).

The relocations presented here (Appendix 2) use the WA2 earth model (Dent, 1989), which was the model used by GA until May 2014. This model has higher P wave velocities (6.13 km/sec from 0 - 19 km). The average focal depth for events is about 2 km, but this is largely because about half of the solutions have been constrained to 2 km depth. This was necessary because the unconstrained solutions were slightly negative. However, the average RMS of residuals for the solutions was much lower than the GA solutions (i.e. < 0.2 secs.). It is obvious that the velocity model used has a large effect on focal depths, but all aftershock surveys in the region, using data from relatively close stations (e.g. Leonard, 2002, Dent 2011, 2012), suggest focal depths of less than 5 km. This is a field which requires further in-depth investigation.

4. ACKNOWLEDGEMENTS

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Appendix 1 Geoscience Australia's locations of events in South west Australia

(includes RMS of residuals, and # of stations used)

Longit-ude	**Latit-**ude	**ML**	**Date**	**Time**	**Depth** (km)	**RMS** (secs.)	**#Stns**	**order**	**Remarks**
117.092	-30.544	2.1	01/06/2015	17:25:05	8	1.34	7	1	Near Burakin
117.626	-30.357	1.9	04/06/2015	11:00:12	10	0.66	4	2	NW of Beacon
117.621	-30.365	1.9	06/06/2015	16:24:05	10	0.63	4	3	NW of Beacon
117.611	-30.422	1.9	07/06/2015	13:06:57	8	1.63	4	4	NW of Beacon
117.669	-30.303	2.5	08/06/2015	07:26:00	14	0.76	6	5	NW of Beacon
117.657	-30.328	2.0	08/06/2015	09:20:24	14	0.95	5	6	Near Beacon
116.465	-31.208	1.6	11/06/2015	17:34:04	4	0.51	5	7	S of Calingiri
117.606	-31.478	1.8	12/06/2015	19:08:09	0	0.58	4	8	Kellerberrin
117.731	-30.318	2.3	13/06/2015	04:48:39	8	1.89	7	9	Near Beacon
117.681	-30.312	2.2	19/06/2015	02:32:23	11	1.59	6	10	NW of Beacon
119.03	-33.109	2.7	22/06/2015	12:13:26	12	1.13	4	11	Newdegate
119.19	-33.209	2.8	22/06/2015	12:58:47	0	1.77	6	12	SE of Newdegate
117.466	-31.446	1.8	25/06/2015	10:20:20	4	0.94	5	13	NW of Kellerberrin
117.481	-31.431	2.0	25/06/2015	11:27:17	5	0.39	4	14	NW of Kellerberri
117.488	-31.423	2.1	25/06/2015	21:25:22	10	0.72	5	15	NW of Kellerberrin
117.469	-31.44	1.9	25/06/2015	22:17:11	5	0.45	4	16	NW of Kellerberrin
117.476	-31.435	2.0	26/06/2015	00:56:15	6	0.49	4	17	NW of Kellerberrin
116.989	-31.706	2.4	26/06/2015	19:30:09	14	0.75	6	18	Near Meckering
117.586	-31.473	1.8	04/07/2015	08:51:01	6	0.43	4	19	NW of Kellerberrin
117.582	-31.479	1.8	04/07/2015	09:56:46	4	0.56	4	20	NW of Kellerberrin
117.261	-32.017	2.0	10/07/2015	11:53:15	12	0.55	4	21	W of Quairading
117.507	-31.422	1.9	11/07/2015	16:45:13	12	0.47	4	22	NW of Kellerberrin
116.745	-32.951	2.1	16/07/2015	18:27:15	6	1.75	6	23	NW of Williams
117.252	-30.275	1.9	17/07/2015	15:01:48	15	2.53	5	24	NE of Kalanning
117.663	-30.342	2.2	19/07/2015	08:32:45	12	0.53	6	25	NW of Beacon
117.672	-30.348	2.3	19/07/2015	09:20:06	15	0.67	7	26	NW of Beacon
117.187	-32.119	1.9	24/07/2015	09:58:08	6	0.52	4	27	Quairading
117.11	-30.53	2.2	25/07/2015	03:30:36	13	0.78	6	28	Near Burakin
117.703	-30.455	2.2	28/07/2015	11:41:29	13	0.78	6	29	W of Beacon
117.415	-30.705	2.2	08/08/2015	10:20:17	12	1.44	6	30	NW of Koorda
117.77	-30.414	2.3	11/08/2015	16:14:53	13	0.81	6	31	Near Beacon
117.149	-31.435	1.7	17/08/2015	23:40:07	8	0.49	4	32	Meckering
117.147	-31.437	2.1	18/08/2015	07:19:58	9	0.61	7	33	NE of Meckering
116.341	-30.865	1.9	19/08/2015	06:00:46	8	0.5	5	34	W of Wongan Hills
116.086	-33.092	3.2	02/09/2015	16:40:22	10	2.65	10	35	Near Harvey
117.151	-30.61	2.1	03/09/2015	05:52:54	12	1.57	5	36	Near Burakin
117.23	-30.614	2.3	04/09/2015	16:42:20	11	2.09	6	37	Burakin
117.071	-30.719	2.6	11/09/2015	08:02:33	17	1.8	6	38	NW of Cadoux
117.927	-31.878	2.9	28/09/2015	00:12:24	10	1	8	39	Near Bruce Rock
117.104	-31.731	2.6	04/10/2015	09:30:34	1	2.47	8	40	Near Meckering
118.321	-30.594	2.2	01/11/2015	12:22:31	10	0.77	6	41	NE of Mukinbudin
117.846	-30.875	2.8	01/11/2015	23:33:22	12	2.01	8	42	Bencubbin
117.105	-31.732	2.1	07/11/2015	12:53:58	0	0.71	5	43	SE of Meckering

116.387	-33.253	2.2	01/12/2015	07:46:12	0	0.86	5	44	NW of Darkan
117.806	-30.921	1.9	01/12/2015	18:52:22	10	0.88	4	45	SW of Bencubbin
117.461	-30.65	2.0	01/12/2015	20:17:40	8	0.59	4	46	N of Koorda
117.455	-31.262	2.4	05/12/2015	06:01:42	13	1.02	6	47	Nr Wyalkatchem
118.086	-33.508	2.9	06/12/2015	22:12:07	10	1.6	9	48	SE of Dumblyung
117.604	-30.608	2.0	07/12/2015	19:40:48	5	0.69	5	49	NE of Koorda
116.308	-30.967	1.9	19/12/2015	17:07:22	7	0.65	4	50	NW of Calingiri
116.307	-30.96	2.0	20/12/2015	10:20:55	7	0.55	5	51	NW of Calingiri
117.617	-31.486	2.4	16/01/2016	03:17:56	4	1.48	4	52	NW of Kellerberrin
117.025	-31.586	2.4	31/01/2016	18:28:43	0	0.79	8	53	Meckering
117.905	-33.542	1.9	23/02/2016	16:53:23	12	0.78	4	54	SE of Dumbleyung
117.241	-30.3	2.0	02/03/2016	01:06:57	17	0.51	6	55	Kalannie
117.714	-33.482	2.6	02/03/2016	04:36:28	15	2.38	9	56	Dumbleyung
117.107	-30.475	1.8	06/03/2016	22:48:15	7	0.55	4	57	Burakin
117.236	-30.301	2.1	16/03/2016	19:33:29	17	0.51	5	58	Kalannie
116.72	-30.128	1.8	18/03/2016	13:02:23	9	0.84	4	59	N of Dalwallinu
117.29	-30.271	2.1	23/03/2016	20:25:02	14	1.2	5	60	NE of Kalannie
117.292	-30.281	1.7	27/03/2016	02:39:42	10	0.66	4	61	Kalannie
117.25	-30.296	1.9	28/03/2016	05:59:41	17	0.53	4	62	Kalannie
117.277	-30.294	1.9	30/03/2016	02:21:21	10	0.71	5	63	Kalannie
117.276	-30.304	2.9	30/03/2016	13:34:36	17	1.54	9	64	NE of Kalannie Felt.
117.221	-30.48	1.8	30/03/2016	18:01:49	8	0.8	4	65	Burakin
117.75	-30.431	2.2	30/04/2016	23:44:27	6	1.8	6	66	NW of Beacon
117.233	-30.291	2.0	02/05/2016	11:16:13	17	0.6	4	67	NE of Kalannie
117.25	-30.291	1.8	02/05/2016	12:45:02	17	0.61	4	68	NE of Kalannie
117.028	-30.908	1.6	02/05/2016	18:31:01	6	0.61	5	69	SW of Cadoux
117.282	-30.272	2.1	02/05/2016	19:59:05	14	1.2	6	70	NE of Kalannie
117.755	-30.454	2.2	13/05/2016	14:37:48	12	1.33	6	71	Near Beacon
117.278	-30.289	2.4	23/05/2016	01:16:54	15	0.55	6	72	NE of Kalannie
117.737	-30.455	3.1	23/05/2016	15:00:42	10	4.19	6	73	W of Beacon

Appendix 2 - relocations of events in Southwest Australia, 2015-2016

Longit	Latit	date	time	depth	#stn	RMS	Region	remarks
117.014	-30.578	01/06/2015	17:25:05	2N	4	0.164	Near Burakin	
117.613	-30.357	04/06/2015	11:00:12	0.9	5	0.063	Beacon	
117.62	-30.385	06/06/2015	16:24:05	2N	5	0.226	Beacon	
117.58	-30.405	07/06/2015	13:06:57	2N	4	0.065	Beacon	
117.673	-30.304	08/06/2015	07:26:00.6	2N	7	0.157	NW of Beacon	
117.639	-30.362	08/06/2015	09:20:24	2N	6	0.189	Beacon	
116.419	-31.182	11/06/2015	17:34:04	1.6	4	0.039	S of Calingiri	
117.686	-31.451	12/06/2015	19:08:09	2N	6	0.223	Kellerberrin	
117.633	-30.284	13/06/2015	04:48:39	0.9	5	0.199	Beacon	
117.677	-30.289	19/06/2015	02:32:23	0.5	4	0.099	Beacon	
119.154	-33.220	22/06/2015	12:13:26	0.9	6	0.200	Newdegate	
119.179	-33.236	22/06/2015	12:58:47	0.8	7	0.312	SE of Newdegate	use DAL1A mdl
		25/06/2015	10:20:20		not relocated		Kellerberrin	
		25/06/2015	11:27:17		not relocated		Kellerberrin	
117.482	-31.471	25/06/2015	21:25:22	1C	4	0.123	Kellerberrin	
		25/06/2015	22:17:11	2N	not relocated		Kellerberrin	
117.53	-31.429	26/06/2015	00:56:15	2.5	5	0.089	Kellerberrin	
116.993	-31.702	26/06/2015	19:30:09	1.8	7	0.015	Near Meckering	
117.622	-31.492	04/07/2015	08:51:01	2N	4	0.043	Kellerberrin	
		04/07/2015	09:56:46		not relocated		Kellerberrin	
117.27	-32.009	10/07/2015	11:53:15	2N	3	0.056	W of Quairading	poor location
117.523	-31.435	11/07/2015	16:45:13	6.9	4	0.048	Kellerberrin	
116.675	-33.095	16/07/2015	18:27:15	1C	6	0.099	NW of Williams	
117.277	-30.223	17/07/2015	15:01:48	1.8	6	0.471	Kalannie	

117.658	-30.294	19/07/2015 08:32:45	2N	4	0.119	Beacon	
117.668	-30.3	19/07/2015 09:20:06	2N	7	0.149	Beacon	
117.205	-32.109	24/07/2015 09:58:08	7.3	5	0.138	Quairading	
117.061	-30.529	25/07/2015 03:30:36	2N	5	0.092	Near Burakin	
117.764	-30.38	28/07/2015 11:41:29	1.9	3	0.223	Beacon	
117.423	-30.629	08/08/2015 10:20:17	2N	5	0.323	NW of Koorda	
117.727	-30.404	11/08/2015 16:14:53	5.9	5	0.175	Near Beacon	
		17/08/2015 23:40:07		not relocated		Meckering	
117.172	-31.43	18/08/2015 07:19:58	2N	4	0.042	NE of M eckering	
116.37	-30.852	19/08/2015 06:00:47	0.2	5	0.126	W of Wongan	
115.995	-33.124	02/09/2015 16:40:22	2N	7	0.101	Near Harvey	
117.174	-30.593	03/09/2015 05:52:54	3.6	6	0.314	Near Burakin	
117.141	-30.654	04/09/2015 16:42:20	2.5	6	0.105	East of Burakin	
117.093	-30.745	11/09/2015 08:02:33	2N	5	0.231	Near Cadoux	
117.847	-31.839	28/09/2015 00:12:24	2N	8	0.211	W of Bruce Rock	
117.054	-31.749	04/10/2015 09:30:3 6.2	2N	6	0.136	S of Meckering	
118.393	-30.617	01/11/2015 12:22:31	2N	5	0.048	NE of Mukinbudin	
117.861	-30.928	01/11/2015 23:33:22	3.5	6	0.047	Bencubbin	
117.117	-31.745	07/11/2015 12:53:58	2N	3	0.015	SE of M eckering	poor location
116.317	-33.2	01/12/2015 07:46:12	2N	4	0.491	NW of Darkan	poor location
117.857	-30.93	01/12/2015 18:52:22	2N	4	0.031	SW Bencubbin	
117.453	-30.613	01/12/2015 20:17:40	2N	6	0.103	N of Koorda	
117.463	-31.269	05/12/2015 06:01:42	1.2	5	0.069	Nr Wyalkatchem	
117.94	-33.508	06/12/2015 22:12:07	2N	6	0.161	SE Dumbyung	
117.592	-30.612	07/12/2015 19:40:48	1.4	5	0.004	NE of Koorda	good location
116.229	-30.97	19/12/2015 17:07:22	4.3	5	0.074	NW Calingiri	
116.213	-30.909	20/12/2015 10:20:55	2N	4	0.226	NW Calingiri	
117.687	-31.488	16/01/2016 03:17:56	2N	5	0.074	NW Kellerberrin	
117.044	-31.65	31/01/2016 18:28:43	5.6	6	0.057	Meckering	good location
117.929	-33.522	23/02/2016 16:53:23	2N	5	0.114	SE of Dumbyung	
		02/03/2016 01:06:57	5C	not relocated		Kalannie	
117.647	-33.37	02/03/2016 04:36:28	2N	5	0.289	Dumbleyung	
117.072	-30.429	06/03/2016 22:48:15	0.5	5	0.166	Burakin	
117.31	-30.428	16/03/2016 19:33:29		6	0.193	Kalannie	
116.695	-30.154	18/03/2016 13:02:24.3	2N	4	0.132	N of Dalwallinu	
		23/03/2016 20:25:02		not relocated		Kalannie	
		27/03/2016 02:39:42		not relocated		Kalannie	
		28/03/2016 05:59:41		not relocated		Kalannie	
		30/03/2016 02:21:21		not relocated		Kalannie	
117.303	-30.252	30/03/2016 13:34:36	2.9	5	0.158	NE of Kalannie	
		30/03/2016 18.01.49		not relocated		East Burakin	
117.759	-30.416	30/04/2016 23:44:27	0.2	5	0.116	Beacon	
117.291	-30.252	02/05/2016 11:16:13	2N	5	0.266	Kalannie	
117.266	-30.235	02/05/2016 12:45:02	4.1	5	0.107	NE of Kalannie	
117.058	-30.862	02/05/2016 18:31:01	2.7	6	0.055	SW of Cadoux	
117.313	-30.261	02/05/2016 19:59:05	3.2	6	0.091	Kalannie	
117.782	-30.413	13/05/2016 14:37:48	2.6	6	0.173	Beacon	
117.317	-30.271	23/05/2016 01.16.00	2N	5	0.116	Kalannie	
117.77	-30.411	23/05/2016 14:59:00	0.9	7	0.066	Beacon	