Pinpointing the Dumbleyung, West Australia, earthquake cluster of 2013-2014

V.F. Dent

University Associate, Department of Exploration Geophysics, Curtin University, Perth W.A.

Email vic_dent@yahoo.com

Abstract

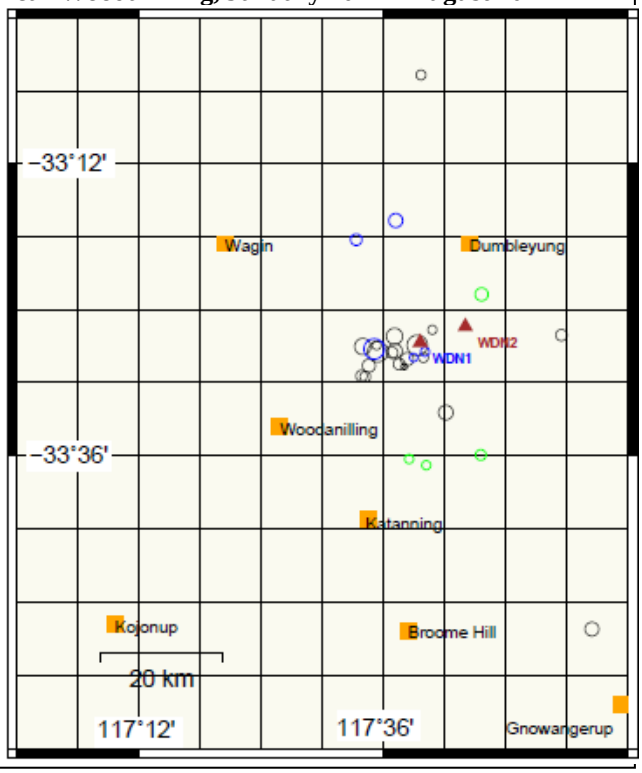
An earthquake cluster with ~20 events of magnitude (ML) > 1.7 occurred about 25 km NE of Woodanilling, WA, in the 8 months June 2013 – January 2014, and the published epicentres are over a region about 15 km wide. Two temporary seismographs recorded three events which were located by Geoscience Australia, as well as five smaller events, and the new data suggest that the true location for the cluster is a zone up to two km wide, about 1.5 km south of the principal temporary station. This cluster location, and possibly others may correlate with faults visible on an aeromagnetic map of the area

1) Introduction

Seismic clusters are common in a region east and southeast of Perth, WA, generally referred to (e.g. Gaull and Leiba, 1987) as the southwest seismic zone (SWSZ). Some of the recent clusters from this region include those at Yorkrakine 1994-1996 (Dent, 2011), Burakin 2001-2003 (Leonard, 2003), Beacon 2009 (Dent 2009), and Lake Mollerin (Dent 2012). Seismic activity at individual cluster locations can persist over several years at least, but cluster longevity has not been well studied. In general, cluster locations are not well constrained, and the above papers use data from temporary stations to provide improved location estimates.

A report by Dent (2013), using additional data provided by the new PSN network (Dent et al., 2010), showed that errors in published earthquake locations in this region can be relatively large (at times > 20 km), and suggested that the scattered earthquake locations within an earthquake cluster could be replaced by a single earthquake source.

Figure 1. Geoscience Australia locations of events near Woodanilling, January 2012 – August 2014



Circles = GA locations, diameter is proportional to magnitude: Green = 2012; Black = 2013; Blue = 2014.

In a study of Australian seismicity, Leonard (2008) examined a larger area, which included the SWSZ, which he termed the Southwest Australia (SWA) seismic zone. Dent (2014) subdivided this zone into 9 sub-zones, and identified twenty three recent cluster locations (designated A-W) within it.

One of these clusters (Location S, sub-zone G) occurred about 250 km southeast of Perth, and about 20 km northeast of Woodanilling, with events mostly between July and September 2013. There were about 20 events located by Geoscience Australia (GA), and the maximum magnitude was ML 2.9. The larger events were observed as loud "bangs" by the few local residents, and caused minor alarm but no damage. The GA locations suggest a diffuse zone, about 15 km wide, with a centre at approximately –33.45, 117.61 (Figure 1, Table 1).

Table 1 Locations/Relocations of larger events in the Woodanilling cluster

Date	UTC	Geoscience Australia location data					Relocation (includes PSN data)			
		ML	Long.	Lat.	Dep km	* #stations/ #phase/ SD	Long.	Lat.	Dep Km	* #stations/ #phase/ SD
4/08/2012	13:22:56	2.3	117.761	-33.379	3	6/9/0.49	117.722	-33.459	2N	5/7/0 .307
11/02/2013	20:02:48	1.9	117.680	-33.428	2	6/10/0.79				
26/032013	18:45:35	2.1	117.57	-33.492	12	5/9/ 0.80				
1/04/2013	12:12:44	1.6	117.634	-33.478	1	4/8/0.13				
3/07/2013	01:58:21	2.3	117.639	-33.648	0	6/12/0.52				
3/07/2013	07:03:33	2.2	117.625	-33.475	0	5/9/0.55				
5/07/2013	01:53:33	**2.9**	117.591	-33.458	5	8/15/1.0	117.676	-33.451	1.2	6/7/0.249
5/07/2013	03:19:21	2.6	117.618	-33.437	2	5/10/0.92	117.664	-33.462	1.1	5/7/0 .079
9/07/2013	05:55:53	2.3	117.576	-33.477	0	3/6/1.23				
15/07/2013	08:40:24	1.9	117.589	-33.449	6	4/7/0.31				
20/07/2013	15:24:40	2.5	117.702	-33.541	5	7/12/1.52	117.725	-33.452	2.9	7/10/0 .212
4/08/2013	14:52:20	2.2	117.891	-33.435	2	4/6/1.04	117.701	-33.462	1C	4/5/0 .143
21/082013	11:02:57	**2.9**	117.655	-33.449	0	9/17/0.85	117.719	-33.450	5N	6/6/0 .071
15/092013	13:19:45	2.0	117.665	-33.466	0	4/8/0.43				
22/092013	19:28:58	2.5	117.619	-33.457	5	6/12/0.58				
22/09/2013	22:26:23	2.2	117.564	-33.491	5	4/8/1.16				
1/10/2013	07:12:00	2.6	117.566	-33.451	6	9/12/0.70				
2/10/2013	11:23:00	2.2	117.614	-33.459	2	6/11/0.92				
31/01/2014	03:03:25	**2.9**	117.585	-33.454	6	10/17/8.15	117.672	-33.451	2.3	5/8/0 .110
31/01/2014	03:47:07	1.8	117.649	-33.466	5	4/8/0.57	117.688	-33.443	1.8	4/8/0 .094
31/01/2014	04:17:16	1.9	117.668	-33.458	0	8/4/0.49	117.674	-33.447	0.9	5/9/0 .315

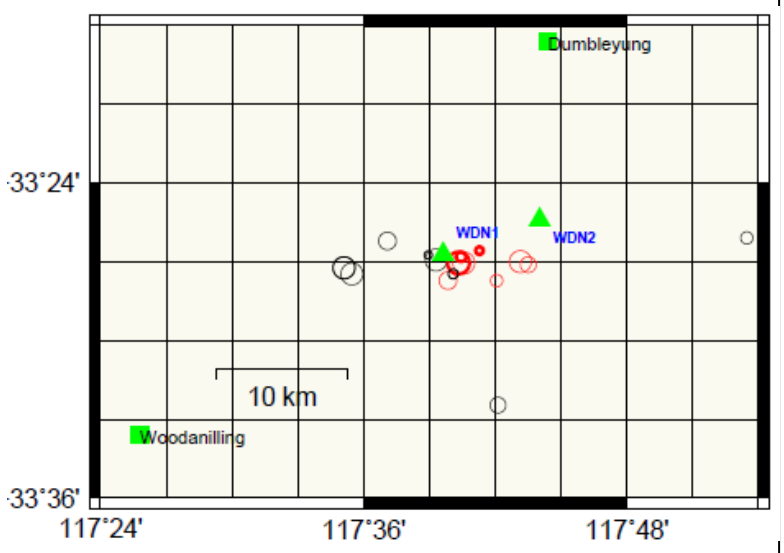
*This column shows Number of stations used, number of phases used, and Standard Deviation of residuals

The closest GA station to the cluster was about 70 km to the northwest at Narrogin (NWAO). In late 2013, two temporary seismic stations were installed near the estimated epicentre to try and further refine the locations of the events occurring there. This report presents conclusions based on these new data.

2) The temporary seismograph network near the Woodanilling cluster

Two new stations (WDN1 and WDN2, Figure 2) were installed to better monitor the cluster activity, although, by the time they were installed, the peak of seismic activity had passed. WDN1, near the estimated epicentre, was installed on 29th October 2013 and is still operating. WDN2 was located about 8 km northeast of WDN1 operated from 10th November 2013 until 21st December 2013. The new stations were the elementary "PSN" kit recorders, as described in Dent et al., (2006). These are basically a

Figure 2 Relocations of Geoscience Australia solutions



Legend: Black circles- GA locations. Red circles- relocations. Bolded circles – events in 2014

geophone with an analogue to digital converter, attached to a PC. While basic in operation, they sample much faster than the GA recorders (200 s/s vs 40 s/s), and have (generally) GPS timing.

Events recorded

WDN1 recorded a brief period of increased activity on 31st January 2014, as well as several smaller events in November and December 2013 (which were also recorded on WDN2). Events which have been identified since the installation of WDN1 are listed in Table 2. Other small events may be present in the data from WDN1, but because of their very low magnitudes, they are often concealed in periods of noise, and have not yet been identified.

Table 2 Events recorded on Temporary recorders

Date	UTC	S-P WDN1	S-P WDN2	ML approx	Comment
15/11/2013	0611	0.23	0.93	1.6	
15/11/2013	0630	0.24	0.90	0.9	
15/11/2013	0733	0.29	--	0.7	
15/11/2013	0745	0.25	0.88	.80	
03/12/2013	1745	0.23	0.86	0.3	
03/12/2013	2052	0.24	0.92	0.9	
31/01/2014	0303	0.29	--	2.9	GA located
31/01/2014	0347	0.30	--	1.8	GA located
31/01/2014	0417	0.30	--	1.9	GA located
17/03/2014	1744	0.25	--	1.2	
14/04/2014	0851	0.26	--	1.7	
16/04/2014	1945	0.27	--	1.1	
20/04/2014	1626	0.36		1.0	

3) Conventional locations of Woodanilling events

A “conventional” earthquake location is here defined as a location made by entering phase data into a computer program and allowing the computer to find the best-fit location from these data.

The GA locations of events near Woodanilling (Table 1) used P wave phase data only, scaled from stations in the Australian National Seismograph Network (ANSN). These data were used as input into the Antelope earthquake location program (a product of Boulder Real Time Technologies, BRTT). The computed focal depths were mostly between 0 and 5 km, although one event in March, earlier than most of the cluster events, was given a depth of 12 km.

4) Relocated and new Woodanilling events

4.1 Relocations June 2013 – October 2013

Nine of the 21 GA locations in Table 1 were relocated (Dent 2013, 2014) and these relocations are also shown in Table 1 and plotted on Figure 2. These relocations used a combination of ANSN and PSN data, and used the EQLOCL (Seismology Research Centre, www.src.com.au/) earthquake location program. The earth models used by GA and Dent were essentially the same. The relocations are suggested to be better than the GA solutions because more near-field phase data (ie. distances of < 100 km) was used, and the standard deviation (SD) of phase residuals is less than for the GA solutions. The focal depths range from 0 to 5 km, although some of the relocated depths were constrained to 2 km, because the computed solution was negative (ie. above ground level). The differences in the location pairs ranged between 1 km (for event at 0417 on 31/01/14) and 19 km (for event at 1452 on 4/8/2014), with an average difference of 8 km.

The new locations were generally east of the original GA locations, and on this basis, a cluster location at 33.45°S, 117.70°E was assigned by Dent (2013).

4.2 New locations using temporary station data

The period when both WDN1 and WDN2 were operating (ie. between 10th November and 21st Dec, 2013) unfortunately had no events large enough to be located by the ANSN. However, six relatively small events (magnitudes estimated to be < ML 1.7, Table 2) were detected in November and December 2013. Also, three "large" events on 31st Jan 2014, located by GA, were recorded by WDN1.

4.2.1 Relocations of events on 31st Jan 2014

WDN1 recorded the three GA-located events on 31st Jan 2014 and the P and S wave data were added to the data already used by GA, and new solutions were computed using the EQLOCL program. These solutions indicated that the station (WDN1) was within 3 km of the epicentres of the events. The focal depths computed ranged between 0.9 and 2.3 km. The relocations are listed in Table 1, and the actual computer outputs from the program are shown in Appendix 1.

The relocations are relatively closely spaced, and if the true location were taken to be at the average location, it would be at 33.447°S, 117.678°E (solution 1, Table 3). The relocation of the first and largest event (ML 2.9) is significantly different from the GA location (about 10 km east of it), but the relocations of the two smaller events (ML 1.8, 1.9) are relatively close to the original GA locations (i.e. < 3 km).

The relocations of the events listed above, as well as the original locations, are plotted on Figure 2.

Table 3 Possible locations of the Woodanilling cluster

Soln #	Description	Latitude	Longitude
1	Average of relocations of events 31/01/2014	-33.447	117.678
2	S-P location of events 15/11/2013 at 1.5 km depth	-33.455	117.657
3	S-P location of events 15/11/2013 at 1.0 km depth	-33.462	117.662
4	S-P location of events 15/11/2013 at 0 km depth	-33.464	117.664

4.3 Earthquake locations/relocations using non-standard methods

4.3.1 Locations using S-P times

While the small events recorded between November and December 2013 cannot be readily located using the EQLOCL program, the S-P times recorded by WDN1 and WDN2, as shown in **Table 2**, can be used in a graphical method to obtain quite accurate hypocentral estimates. A sample waveform, from which the P and S phases are identified, is shown in Figure 3.

Factors constraining use of S-P times for locations

Before discussing locations using S-P times, a number of caveats need to be noted. These caveats also apply to phase data as used in "conventional" computer locations.

1) Sharp phase on-sets are required if an accurate estimate of hypocentral distance is to be obtained. The sharpness of a phase onset can be influenced by the orientation of a sensor in

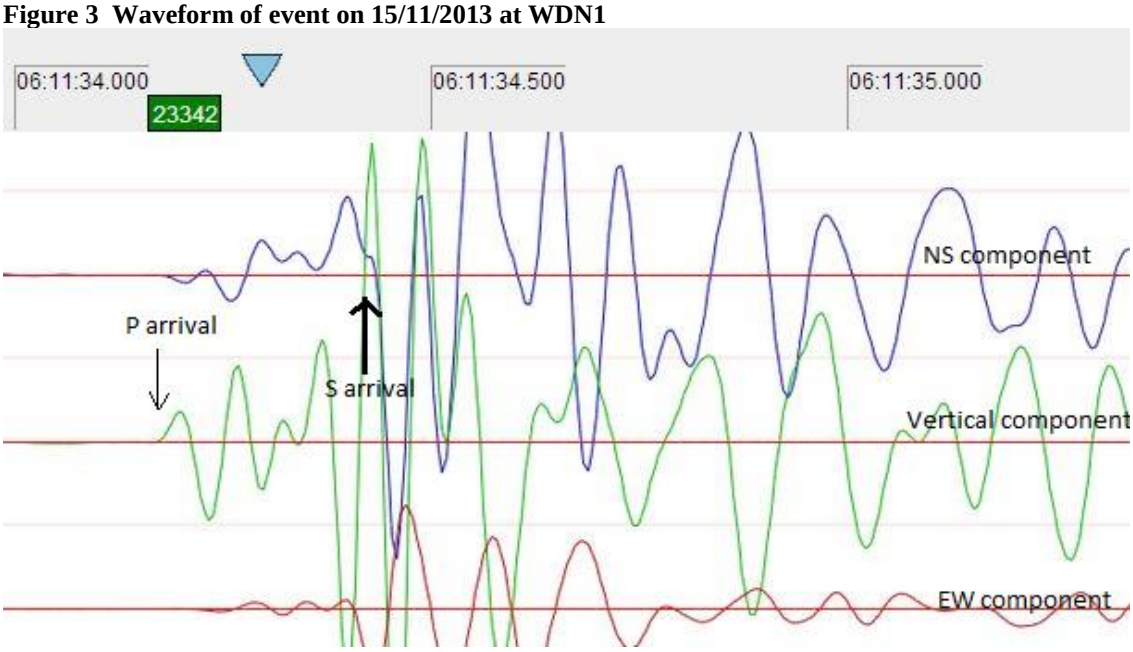
relation to the wave motion. Often horizontal sensors will record an S phase onset more clearly than the vertical component, and vice versa for the P phase.

2) Sometimes a P phase arrival can have a very much smaller amplitude than the S phase, and be quite emergent. As the gain of the trace is increased, it may be observed that the P arrival becomes earlier than first estimated.

3) Sometimes what appear to be several secondary phases appear to be present, and there may be some uncertainty in identifying the phase.

4) The validity of the relationship between S-P time and distance is limited by the validity of the assumed P and S wave velocities.

Figure 3 Waveform of event on 15/11/2013 at WDN1



For the above reasons, the S-P time vs distance values must be regarded with some caution. In particular, no recent surveys have been conducted in SWA which can verify the P and S wave velocities used in the WA2 earth model used here (Dent, 1989). Therefore future analysis of the data presented here may result in some adjustment to the computed epicentres.

Locations of events on 15th November and 3rd December 2013

Four events were recorded by WDN1 and WDN2 on 15 November 2013, and another two on 3 December 2013. These events had very similar S-P times and wave-forms at both stations (**Table 2).** For this reason, a location using the average S-P times at these stations is considered to be reasonably accurate. The values to be used are 0.24 secs for WDN1 and 0.9 secs. for WDN2.

Graphs representing the relationship between S-P time and distance in SWA were presented in Dent (2011). Data

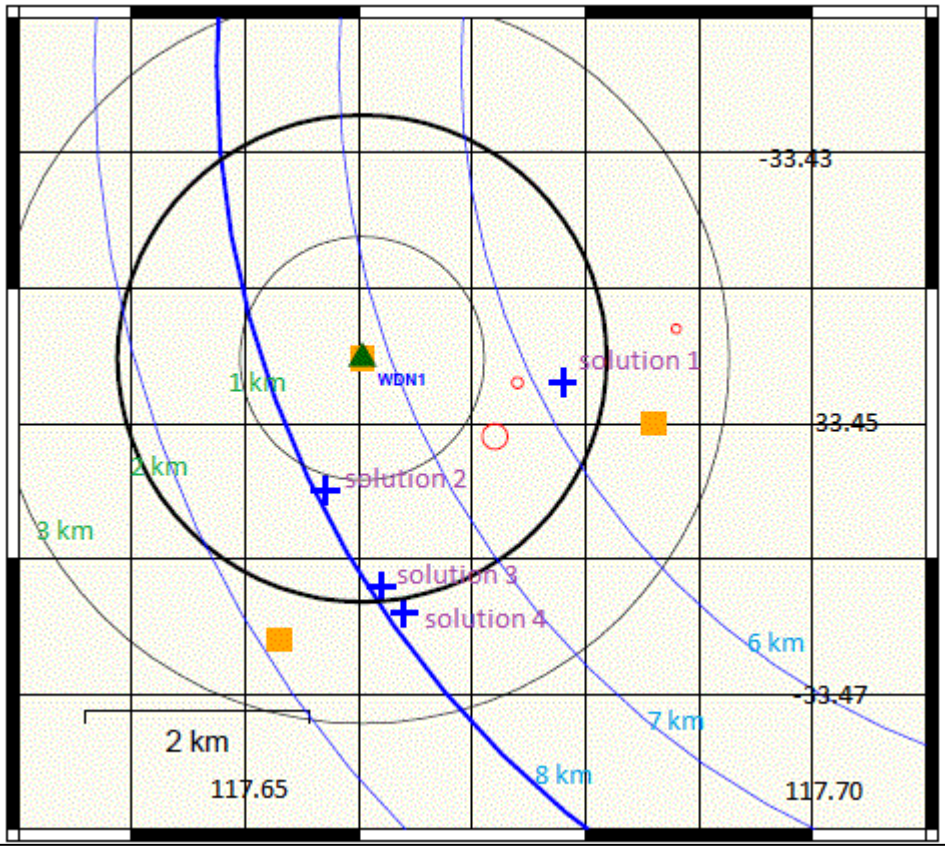
Table 4 S-P time vs epicentral dist.

S-P secs	Depth 0 km	Depth 1.0 km	Depth 1.5 km
0.2	1.76	1.45	0.93
0.3	2.65	2.45	2.2
0.4	3.53	3.4	3.2
0.5	4.4	4.3	4.15
0.6	5.3	5.2	5.1
0.7	6.2	6.1	6.0
0.8	7.06	7.0	6.9
0.9	7.94	7.9	7.8
1.0	8.8	8.76	8.7

from these graphs have been summarised in Table 4 to present a table of S-P time vs. distance. New data have been added, showing epicentral distances for a focal depth of 1.0 km, and also 1.5 km. From Table 4, it can be seen that, for a focal depth of 1.5 km, an S-P of 0.24 seconds (WDN1) equates to an epicentral distance of 1.04 km and 0.9 seconds (WDN2) equates to a distance of 7.8 km. The intersection of arcs with these radii from WDN1 and WDN2 suggest an epicentre at -33.455 117.657 (**Figure 4,** and solution 2 in **Table 3**). The uncertainties in these distances are estimated to be about +/- 0.5 km., and the uncertainty in the location is about +/- 1 km (0.01^{o}). The solution for a focal depth of 1 km is shown as solution 3 in Table 3.

If the focal depth was the maximum possible for an S-P of 0.24 sec, the event would be about 2 km deep, and directly under WDN1.

Figure 4 Possible locations of the Woodanilling events using distances from S-P times. Black arcs are distances in 1 km intervals from WDN1; blue arcs from WDN2



Legend: Blue crosses – locations from Table 3. Red circles – relocations of events on 31/1/2015. Yellow squares – farm residences. Green triangle – location of WDN1

Discussion

There are insufficient data to provide a solution constrained in latitude, longitude and depth. Assuming that a 1.5 km focal depth estimate is reasonable, a "composite" epicentre for events on 15th November 2013 and 3rd December 2013 at -33.455, 117.657, +/- 1 km, is suggested.

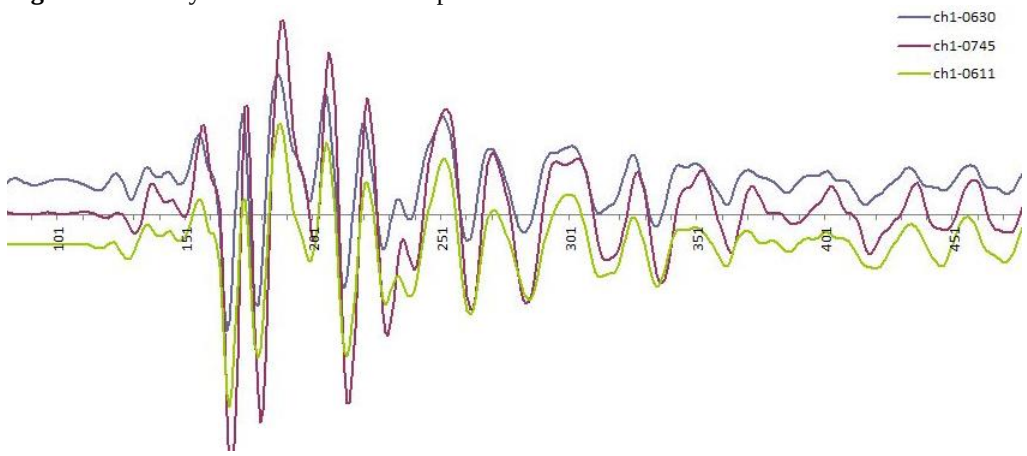
This location is only about 2 km southwest of the average location of events on 31 Jan 2014. It is suggested that this location, based on S-P readings for five relatively small events represents the actual best-location estimate for the entire Woodanilling cluster.

4.3.2 Location estimates using wave-form similarities

Subtle differences in wave forms have been used to estimate small differences in locations for closely-spaced events in clusters, and the techniques described by Robinson et al., (2011) may have future application to clusters like the Woodanilling cluster described here.

The waveforms at WDN1 for the three small events on 15th November are all virtually identical, as can be seen when the traces for the north-south component (channel 1) for the events are overlaid (**Figure 5**). Further analysis has not been attempted here, but the above observation suggests that the events are very close to each other, probably less than 0.5 km apart, and that the focal mechanisms of the events are the same. The waveforms are also similar to those for events on 3rd December 2013, and 31st January 2014.

Figure 5 Overlay of traces for NS components for 3 minor events on 15th November 2013



5) The relationship between clusters and local geology and geophysics

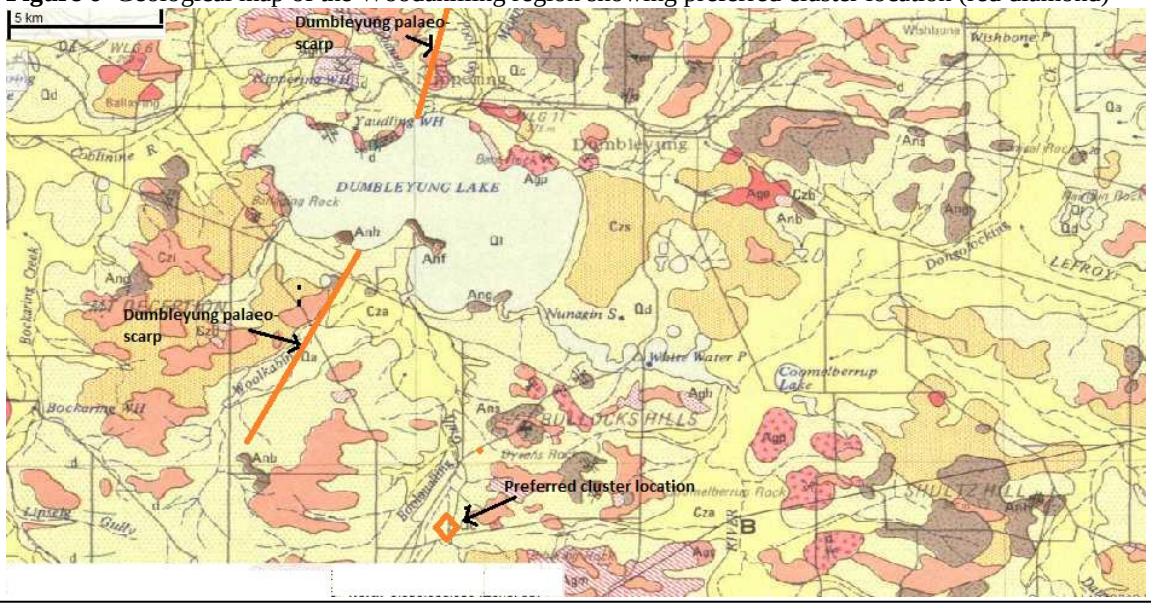
In an earlier work on SWA clusters, Dent (2011) plotted several cluster locations (at Kalannie, Beacon and Yorkrakine) on a regional magnetic anomaly map, and concluded that there was no obvious correlation between the cluster locations and any features on the anomaly map.

Love (2013) observed that there is generally very little obvious correlation between seismicity in Australia and mapped geologic or topographic features. The preferred location for the Woodanilling cluster (solution 1 in Table 3) has been plotted as a red diamond on a 1:250,000 regional geological map (Figure 6), and a magnetic anomaly map (Figure 7), both produced via the "Geoview" on-line mapping facility of the Geological Survey of Western Australia.

There is no obvious correlation between the cluster location and any feature on the GSWA geological map. However, this map does not show a palaeo-scarp, approximately 25 km long, and up to 3 m. high, which was investigated by teams from GA and the University of Western Australia (Estrada et al., 2006). The southern portion of the fault scarp has been added to Figure 6. The southern tip of the mapped fault is about 7 km northwest of the preferred earthquake cluster location. A connection between the two features is only a mild possibility.

However, on the geomagnetic map (Figure 7), the preferred location is only about 1 km to the west of a north-east trending linear feature, (one of many such features on the map). Similar features in a detailed anomaly map in the Meckering area (Dentith et al., 2009) have been

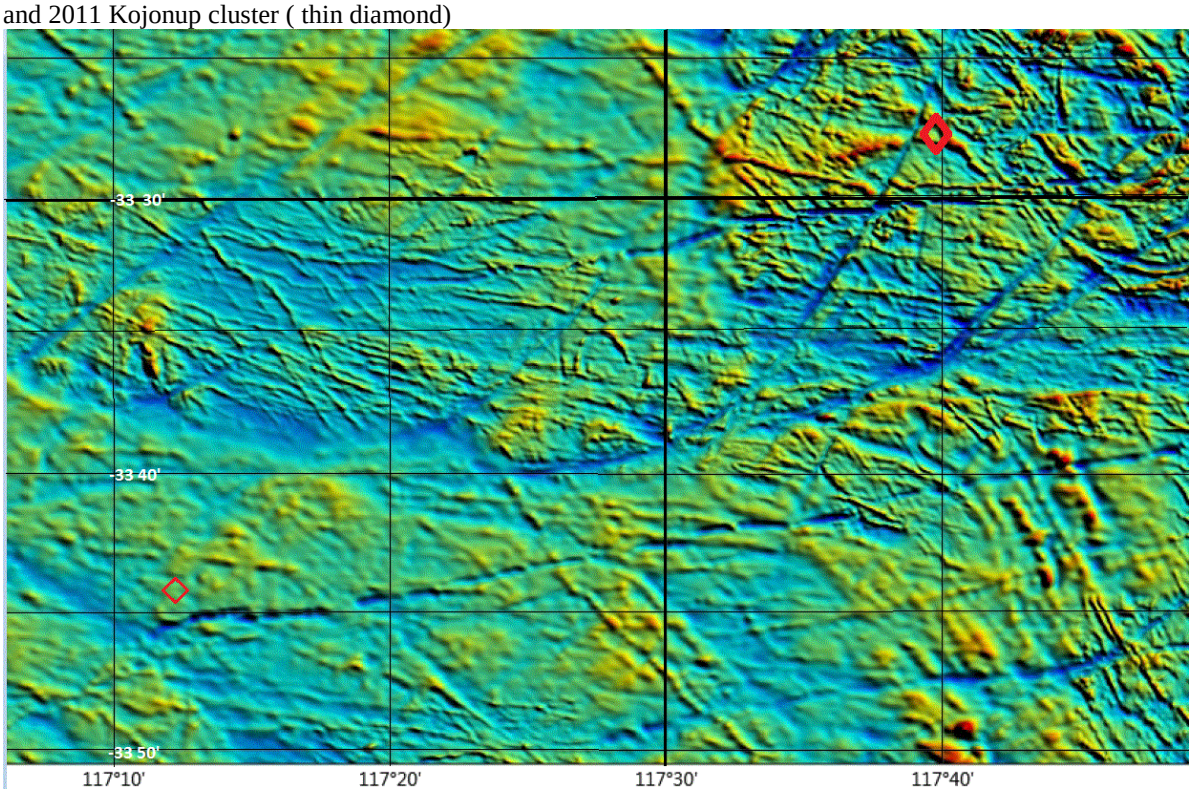
Figure 6 Geological map of the Woodanilling region showing preferred cluster location (red diamond)



interpreted as mafic dykes which have either intruded along faults, or are the sites of subsequent faulting. This therefore may be the causative fault of the Woodanilling cluster.

In order to see if this is a random correlation, the approximate location of a similar earthquake cluster, about 50 km to the southwest of this cluster, in September-October 2011 has been also been plotted on Figure 7 (thin diamond). This cluster is also close to a possible east-northeast trending fault. These observations suggest that there may be a connection between earthquake clusters and mappable faults, but more work needs to be done.

Figure 7 Geomagnetic map of the Woodanilling region showing preferred cluster location (bold red diamond) and 2011 Kojonup cluster (thin diamond)



6) Conclusions

Contrary to the impression given by published earthquake locations, the events in this earthquake cluster are probably relatively tightly clustered. The GA locations for events in the cluster range over a region ~20 km wide, but the best relocations are within a region about 3 km wide. Re-examination of the original phase data, and the computer locations which have used these data, may reduce these ranges to some degree, but precise locations will not be obtained given the relatively poor quality of the input data. Though uncertainties in the data do not allow the exact degree of tightness to be identified, it is suggested that all events may lie within a volume of about 2 km diameter. The similarity of the waveforms for events recorded on 31st January 2014 suggests that the actual separations between these hypocentres are likely to be in the range of 1 km or less.

With the present data, a dip or orientation of a fault plane cannot be estimated, nor can a focal mechanism be determined. Further definition of hypocentral parameters would require data from perhaps another half dozen close stations, and it is hoped that some future swarms in southwest Australia may be monitored to that degree of precision.

The most accurately located events using EQLOCL, and the S-P times from smaller events, are consistent with epicentres originating from within a zone of maximum width about 2 km, and about 2 km south of WDN1. That is, at 33.46^{o}S, 117.66^{o}E approximately. The location uncertainty is estimated to be about +/- 2 km (0.02^{o}). The depths of the events are estimated to be between 1 and 3 km. The errors attached to the other events in the cluster, located by GA without the benefit of close station data, are such that it is probable that they too originated from this relatively tight zone.

The best estimate for the location of the cluster places the cluster very close to a probable fault, visible on an aeromagnetic map of the area. The connection between clusters and such features is provisionally supported by a less-well defined cluster southwest of Woodanilling, and more research into this possibility is required.

7 Acknowledgements

The author wishes to thank local land owners, Phillip and Helle Crossley, and Keith Ladyman, for their enthusiastic support, Clive Collins and Mike Dentith for very constructive comments on the manuscript, and Dale Hardy for help with the figures.

8 References

Dentith, M., Clark, D., and Featherstone, W., (2009). Aeromagnetic mapping of Precambrian structures that controlled the 1968 Meckering earthquake (M_S 6.8): Implications for intraplate seismicity in Western Australia. *Tectonophysics*, 475 (2009) 544- 553.

Dent V. F., (1989). Computer generated crustal models for the southwest seismic zone, Western Australia. *Bur. Min. Res. Aust*. Rept. 1989/43.

Dent, V. F., Heal, D, and Harris, P., (2006). A new network of low cost recorders in Western Australia. *Proc. AEES 2006 Conference*, Canberra.

.

Dent, V. F., (2009). The Beacon, WA, earthquake swarm of 2009. *Proc. AEES 2009 Conference*, Newcastle.

Dent, V. F., Harris, P, and Hardy, D., (2010). A new seismograph network in the southwest seismic zone of Western Australia. *Proc. AEES 2010, Conference*, Perth.

Dent, V.F. (2011) – The Yorkrakine, W.A. seismic deployment, April – May 1996. *Proc. AEES 2010 Conference*, Barossa Valley.

Dent, V. F., (2014). Earthquake clusters in southwest Australia in 2013-14. *Proc. AEES 2014 Conference*, Lorne, Vic.

Estrada, B., Clark, D., Wyrwol, K. & Dentith, M. (2006). Palaeoseismic investigations of a recently identified Quaternary fault in Western Australia: the Dumbleyung fault. *Proc. AEES 2006 Conference*, Canberra.

Gaull, B.A., and M. Michael-Leiba. (1987). Probabilistic earthquake risk maps of southwest Western Australia, *BMR Journal of Australian Geology and Geophysics*, 10, 145-151, 1987.

Leonard, M., (2002). The Burakin WA Earthquake sequence Sep 2000 – Jan 2002 Proc AEES Adelaide 2002.

Leonard, M., (2003) Respite leaves Burakin quaking in anticipation. Ausgeo News 70, June 2003.

Leonard, M. (2008). One Hundred Years of Earthquake Recording in Australia. *Bull. Seismol. Soc. Am*. 98, 1458–1470.

Love, D. N. L., (2013). Do earthquakes occur on fault-lines? *Proc. AEES 2013 Conference*, Hobart.

Robinson, D., Sambridge, M. and Snieder, R, (2011). A probabilistic approach for estimating the separation between a pair of earthquakes directly from their coda waves *J. Geophys. Res*., 116, B04309, doi:10. 1029/2010JB007745.

Appendix 1 - EQLOCL relocations of GA located events on 31-01-14

```
Date            2014-01-31
Origin Time     0303 24.62   +   0.49
Zone                   50
Easting            562.41   +   7.20        Longitude     117.672
Northing          6298.55   +   5.35        Latitude      -33.451
Depth                2.28   +   4.25

Arrival times    =  8       S.D. = 0.110        Seismographs =  5
Nearest recorder =    1.2 km    Gap  = 166.1 deg    Accuracy = A
Effects Code     =              Imax =  0           Fault =

   1 km SE (119 deg) of  WOOD
WESTERN AUSTRALIA
  15 km  S (201 deg) of Dumbleyung

No magnitudes known                              Assign ML  2.9

DATA USED
Code  Wave       AT    +    WT      CT     DT     Dist  Azim    Ad    Ae
WOOD   P       25.11  0.03  2.12   25.09   0.02     1.2   300   64.4  64.4
WOOD   S       25.40  0.01  2.38   25.41  -0.01     1.2   300   64.4  64.4
GNOW   P       35.71  0.03  1.66   35.69   0.02    67.8   133    2.2   2.2
GNOW   S       43.31  0.30  0.94   43.36  -0.05    67.8   133    2.2   2.2
NWAO   P       36.41  0.10  1.30   36.21   0.20    71.0   324    2.1   2.1
NWAO   S       44.40  0.50  0.85   44.25   0.15    71.0   324    2.1   2.1
KULI   P       40.54  0.03  1.61   40.52   0.02    97.5    27    1.5   1.5
PING   P       44.37  0.03  1.58   44.59  -0.22   122.4   328    1.2   1.2
                        8 times used, S = 0.110
Deferred Data
WOOD   S-P      0.30  5.00  0.75    0.32  -0.02     1.2   300    0.0   0.0
RKGY   P       48.42  0.10  1.22   47.74   0.68   143.6   206  -30.8  30.8
RKGY   S       66.44  0.50  0.80   64.29   2.15   143.6   206    1.0   1.0
KLBR   P       57.43  0.20  1.03   55.98   1.45   206.2     2  -42.2  42.2
MUN    P       57.43  0.10  1.18   56.81   0.62   213.2   319  -42.2  42.2
MUN    S       82.46  1.00  0.67   80.81   1.65   213.2   319  -40.3  40.3
```

Event 2

```
Date            2014-01-31
Origin Time     0347  5.77   +   0.44
Zone                   50
Easting            563.94   +   3.69        Longitude     117.688
Northing          6299.38   +   4.15        Latitude      -33.443
Depth                1.80   +   6.35

Arrival times    =  8       S.D. = 0.094        Seismographs =  4
Nearest recorder =    2.6 km    Gap  = 167.5 deg    Accuracy = A
Effects Code     =              Imax =  0           Fault =

   2 km  E ( 85 deg) of  WOOD
WESTERN AUSTRALIA

  14 km  S (196 deg) of Dumbleyung
No magnitudes known                              Assign ML  1.8

DATA USED
Code  Wave       AT    +    WT      CT     DT     Dist  Azim    Ad    Ae
WOOD   P        6.34  0.01  2.57    6.32   0.02     2.6   265   38.8  38.8
```

WOOD	S	6.63	0.10	1.46	6.70	-0.07	2.6	265	38.8	38.8
GNOW	P	16.74	0.03	1.66	16.75	-0.02	67.3	135	1.8	1.8
GNOW	S	24.43	0.30	0.94	24.37	0.06	67.3	135	1.8	1.8
PING	P	25.63	0.30	0.99	25.75	-0.12	122.5	327	1.0	1.0
PING	S	39.80	0.30	0.89	39.61	0.19	122.5	327	1.0	1.0
RKGY	P	29.04	0.10	1.22	29.14	-0.10	145.0	206	-30.8	30.8
RKGY	S	46.06	0.50	0.80	45.84	0.22	145.0	206	0.8	0.8

8 times used, S = 0.094

Deferred Data

NWAO	P	17.03	0.10	1.30	17.40	-0.37	71.2	323	1.7	1.7
NWAO	S	26.04	0.50	0.85	25.46	0.58	71.2	323	1.7	1.7
KLBR	P	38.05	0.10	1.18	37.08	0.97	205.3	1	-42.2	42.2
KLBR	S	61.10	1.00	0.67	60.42	0.68	205.3	1	-40.3	40.3
MUN	P	39.05	0.10	1.18	38.06	0.99	213.5	319	-42.2	42.2
MUN	S	63.10	1.00	0.67	62.13	0.97	213.5	319	-40.3	40.3

Event 3

```
Date            2014-01-31
Origin Time     0417 16.58   +   0.86
Zone                   50
Easting            562.68   +   8.13        Longitude     117.674
Northing          6298.98   +   5.63        Latitude      -33.447
Depth                0.90   +  16.77

Arrival times    =  9       S.D. = 0.315        Seismographs =  5
Nearest recorder =    1.4 km    Gap  = 143.4 deg    Accuracy = B
Effects Code     =              Imax =  0           Fault =

   1 km  E ( 97 deg) of  WOOD
WESTERN AUSTRALIA
  15 km  S (200 deg) of Dumbleyung

No magnitudes known                              Assign ML  1.9
```

DATA USED

Code	Wave	AT	+	WT	CT	DT	Dist	Azim	Ad	Ae
WOOD	P	16.84	0.02	2.30	16.88	-0.04	1.4	277	41.6	41.6
WOOD	S	17.14	0.10	1.50	17.08	0.06	1.4	277	41.6	41.6
GNOW	P	27.49	0.30	1.05	27.66	-0.18	67.9	134	1.0	1.0
GNOW	S	35.49	0.30	0.94	35.34	0.14	67.9	134	1.0	1.0
NWAO	P	28.84	0.10	1.30	28.14	0.70	70.8	324	0.9	0.9
KULI	P	32.49	0.05	1.45	32.40	0.08	97.0	27	0.7	0.7
KULI	S	43.30	0.30	0.91	43.37	-0.07	97.0	27	0.7	0.7
PING	P	36.09	0.03	1.58	36.51	-0.42	122.1	328	0.6	0.6
PING	S	50.20	0.50	0.81	50.33	-0.13	122.1	328	0.6	0.6

9 times used, S = 0.315

Deferred Data

NWAO	S	36.85	0.50	0.85	36.15	0.70	70.8	324	0.9	0.9
RKGY	P	40.86	0.10	1.22	39.89	0.97	144.1	206	-30.8	30.8
RKGY	S	56.87	0.50	0.80	56.39	0.48	144.1	206	0.5	0.5
KLBR	P	48.86	0.10	1.18	48.04	0.82	205.8	2	-42.2	42.2
KLBR	S	71.90	0.50	0.77	71.48	0.42	205.8	2	-40.3	40.3
MUN	P	49.86	0.10	1.18	48.91	0.95	213.0	319	-42.2	42.2
MUN	S	74.90	1.00	0.67	72.99	1.91	213.0	319	-40.3	40.3