# An earthquake cluster east of Wyalkatchem, Western Australia, in late 2017.

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## Abstract

An earthquake cluster occurred east of Wyalkatchem occurred between 2017 and February 2018. The maximum magnitude was ML 2.4. It was typical of the small earthquake clusters that occur relatively regularly in southwest Australia. The GA locations are spread over about 15 km, but relocations suggest that the events are much more tightly grouped. An epicentral zone about 2 km wide, and 2 km south of the largest event,is proposed. The largest event in the region was an ML 4.3 event in 1988, which was accompanied by many smaller events over a period of about 12 months. Other recent earthquake loci in the area suggest that Wyalkatchem could be at risk of future significant seismicity.

## Introduction

Wyalkatchem is a small town (population ~ 200) about 150 km northeast of Perth (Figure 1). A cluster of small earthquakes (largest ML 2.4) occurred east of Wyalkatchem between October 2017 and February 2018, with most events between 25 December 2017 and 16 January, 2018. The cluster had two main periods of activity. The activity commenced on the morning of Christmas Day, 2017, with an ML 1.7 event, and six more events in the following six hours, including the largest event of the sequence, (the 4th located event), at 0955 hrs (GMT). Four more events occurred on 31 Dec. and 01 Jan., and then another four events on 16 Jan., including the 2nd largest event (ML 2.2).

Figure 2 shows Geoscience Australia (GA) locations of events in the region from January 2017 to September 2018, suggesting locations are scattered over about 15 km.

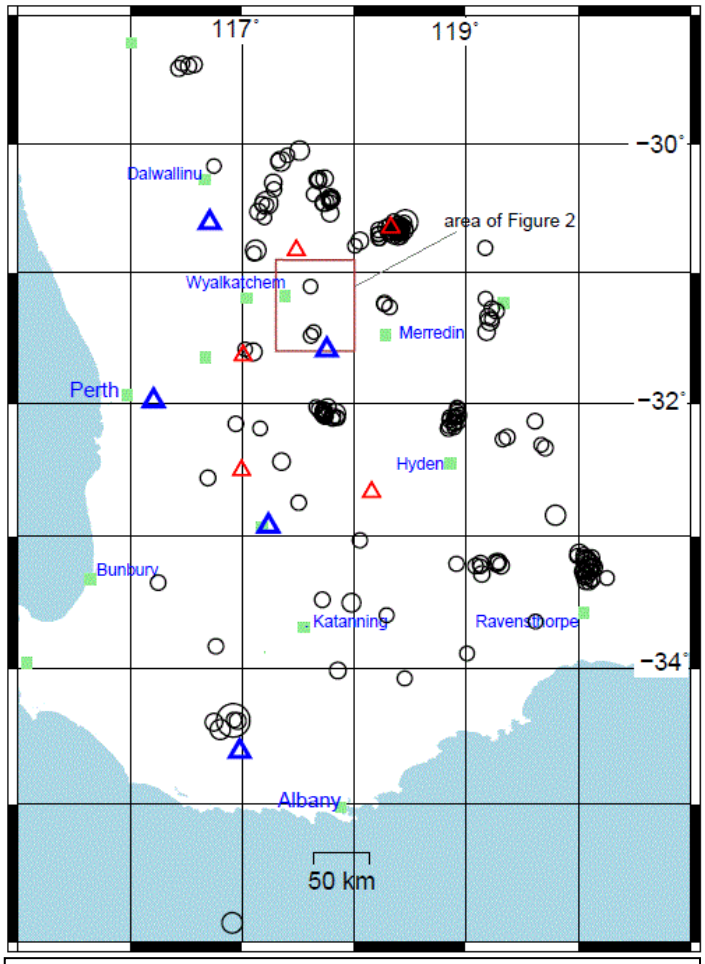


**Figure 1**. circles = earthquakes in southwest Australia, January 2017- September 2018, Magnitude > ML 2.3, size proportional to magnitude. Triangles = seismographs (blue = GA, red = PSN)

## Event relocations

GA located the events of Figure 2 using their local network of seismographs (Figure 1), and using the Antelope location program with the IASPEI91 velocity model (Kennett & Engdahl, 1991). All focal depths were held at 10 km. Most of the events have been relocated here (Table 1), using the EQLOCL location program (© SRC, Melbourne), and using the WA2 earth model (Dent, 1989). This was the procedure used by GA until 2009, and may be the better method, as the WA2 model may be more appropriate to the Achaean shield geology of the region. Additional data from local "PSN" stations (Dent et al., 2006) has been used in some relocations. The station at Koorda (KOO6), ~35 km to the northwest, was particularly useful. The stations used are listed in Table 2, and indicated on Figure 1.

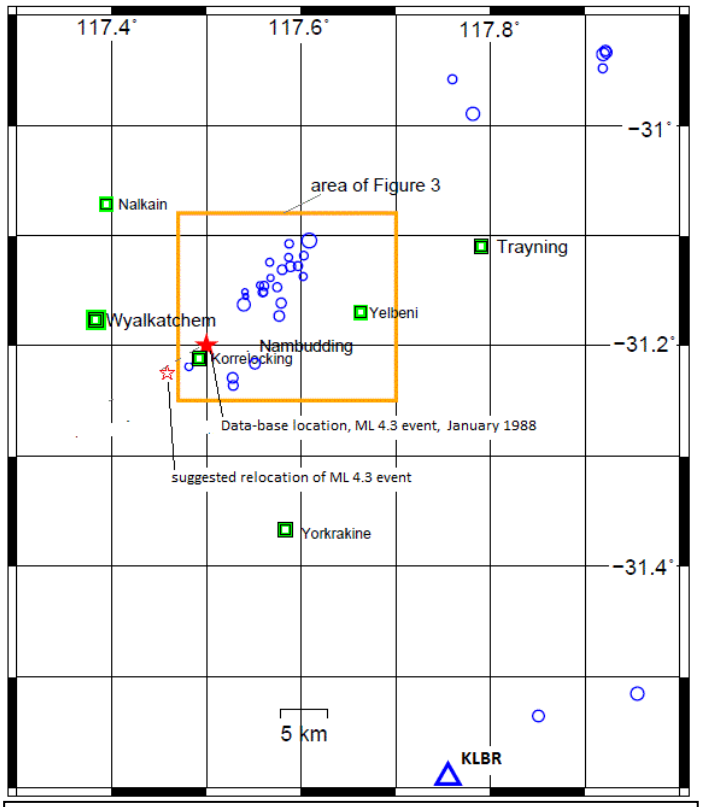


**Figure 2**. All earthquakes near Wyalkatchem, January 2016-Sept. 2018, size proportional to magnitude.

**Table 1**. Relocations of Yelbeni area earthquakes

| Date & Time | | Long | Lat | rms | Long. | Lat. | rms | dep | |
|---|---|---|---|---|---|---|---|---|---|
| (UTC) | ML | ( GA) | | secs | Relocation | | sec | km | |
| 2017-09-14 19:05 | 1.7 | 117.481 | 31.219 | 0.56 | 117.518 | -31.213 | .18 | 0.6 | remote |
| 2017-10-17 21.25 | 1.9 | 117.579 | 31.162 | 0.46 | 117.670 | -31.122 | .14 | 5.6 | |
| 2017-12-03 10.14 | 1.8 | 117.603 | 31.119 | 0.35 | 117.599 | -31.137 | .27 | 0.1 | |
| 2017-12-25 07:25:56 | 1.7 | 117.587 | 31.120 | 0.69 | 117.602 | -31.127 | .28 | 0.3 | |
| 2017-12-25 07:29:18 | 1.6 | 117.557 | 31.146 | 0.36 | 117.612 | -31.128 | .21 | 6.1 | |
| 2017-12-25 08:44:25 | 1.8 | 117.587 | 31.108 | 0.57 | 117.627 | -31.109 | .15 | 4.0 | |
| 2017-12-25 09.55.47 | 2.4 | 117.609 | 31.105 | 0.62 | 117.607 | -31.116 | .10 | 3.5 | main ev |
| 2017-12-25 10:02:30 | 1.5 | 117.541 | 31.156 | 0.61 | 117.610 | -31.125 | .19 | 6.4 | |
| 2017-12-25 10:57:37 | 1.6 | 117.541 | 31.152 | 0.49 | 117.609 | -31.119 | .11 | 4.1 | |
| 2017-12-25 13:31:41 | 1.7 | 117.567 | 31.125 | 0.64 | 117.597 | -31.126 | .17 | 5.1 | |
| 2017-12-31 00:43:51 | 2.0 | 117.528 | 31.230 | 0.18 | 117.596 | -31.121 | .06 | 3.9 | |
| 2017-12-31 17:54:48 | 2.0 | 117.551 | 31.217 | 0.41 | 117.601 | -31.13 | .25 | 2N | |
| 2017-12-31 18:38:03 | 2.0 | 117.577 | 31.173 | 0.50 | 117.613 | -31.116 | .12 | 2.3 | |
| 2018-01-01 06:41:37 | 1.9 | 117.528 | 31.236 | 0.14 | 117.590 | -31.124 | .10 | 1.4 | |
| 2018-01-16 13:49:21 | 2.2 | 117.539 | 31.163 | 0.54 | 117.624 | -31.116 | .12 | 4.3 | |
| 2018-01-16 14:57:40 | 1.8 | 117.559 | 31.152 | 0.53 | 117.622 | -31.118 | .11 | 1.4 | poor |
| 2018-01-16 19:58:04 | 1.9 | 117.580 | 31.131 | 0.51 | 117.613 | -31.124 | .14 | 6.2 | |
| 2018-01-16 20:26:06 | 1.9 | 117.589 | 31.129 | 0.63 | 117.618 | -31.116 | .23 | 5.6 | |
| 2018-01-16 20:30:08 | 1.8 | 117.560 | 31.152 | 0.81 | 117.629 | -31.105 | .17 | 7.9 | |
| 2018-02-10 23:30 | 1.6 | 117.568 | 31.139 | 0.51 | 117.624 | -31.120 | .07 | 2.6 | |

## Results

Although some relocations remain poor, the relocations of events northwest of Yelbeni (Figure 3) in general compress the "cloud" of epicentres to a much smaller region, about 2 km south of GA's location of the ML 2.4 event. Considering the remaining uncertainties in locations, the results are consistent with the events occurring at a "common" location, suggested to be at 31.12°S, 117.61°E (to the nearest 0.01 degree). The relocations also suggest a focal depth in the vicinity of 5 km, although the uncertainty around this figure is high, as focal depths are hard to determine accurately if there are no seismographs within ~ 10 km of the epicentres.

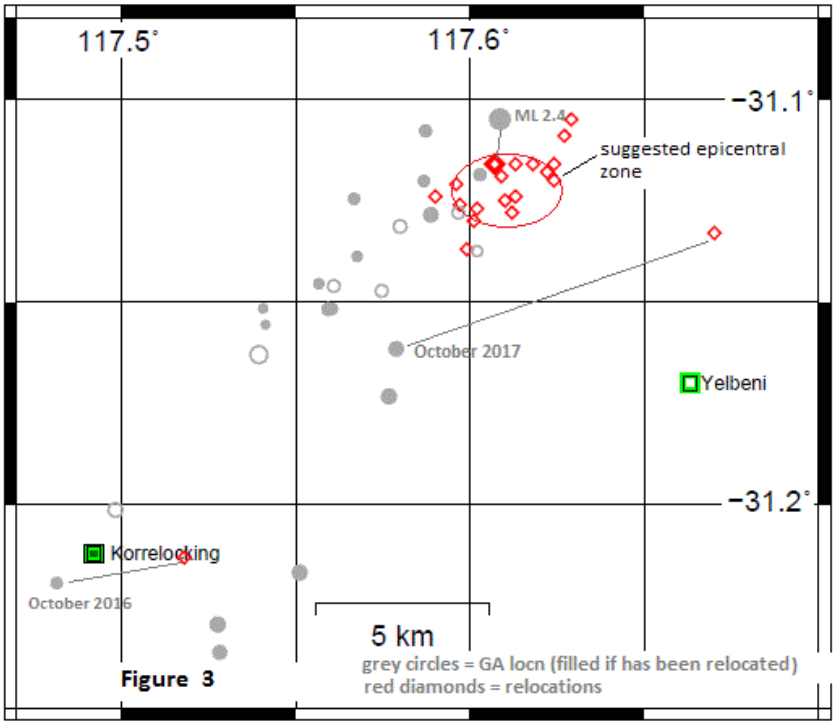


**Figure 3**: relocations of Yelbeni events. green square = village

**Table 2**. Public Seismic Network stations used in relocating Wyalkatchem area events

| Station | CODE | Lat. °S | Long. °E | | Opened |
|---|---|---|---|---|---|
| Koorda | KOO6 | 30.8264 | 117.4818 | | February 2013 |
| Pingelly | PING | 32.5605 | 116.9929 | | January 2013 |
| Bonnie Rock | BR4 | 30.6481 | 118.3267 | | January 2017 |
| Kulin | KULI | 32.6706 | 118.1540 | | February 2013 |
| Meckering | MECK | 31.632 | 117.008 | | November 2015 |
| Wyalkatchem | WYAL | 31.236 | 117.561 | | January 1988 (temp GA stn) |

## Earthquake focal depths

As mentioned above, GA has assigned focal depths of 10 km to the events of Table 1, primarily because the errors in focal depth determinations are such that quoting a "free depth" solution may be misconstrued as being more precise than in the actual case. For the EQLOCL solutions in Table 1, using the WA2 model, the "free depths" have been given. The full EQLOCL solution for the main (ML 2.4) event of 25 Dec. 2017, with a depth of 3.4 km. is shown in the appendix. Most of the EQLOCL solutions in Table 1 have depths of < 5 km. However, it has been found that using a model with generally slower seismic velocities (in this case, the VIC5A model, intended to model the crust in the state of Victoria), results in generally greater focal depths (of the order of 9 km), with only a small increase in the root mean square (RMS) of the residuals. The EQLOCL solution for the ML 2.4 event is also shown in the appendix

## Historical seismicity

A magnitude ML 4.3 event occurred east of Wyalkatchem on 6 January 1988, and its GA location is indicated on Figure 2. That location was 31.2$^{o}$S, 117.5$^{o}$E, or about 15 km southwest of the suggested centre for the December 2017 activity. It was the largest event in a group of at least 40 earthquakes which had commenced as early as February 1987.A field instrument was deployed southeast of Korrelocking (Figure 2) after the event (Dent, 1990), but it was not digital, and the events it recorded could not be well-located. They suggested an S-P time for the series of about 1.4 secs. from the station.

Some archived GA phase data for the event has been located, and a location made for the event using EQLOCL and the VIC5A model (Appendix A). The location it suggests is about 5km west of the database location (Figure 2). The S-P time in the solution shown in the appendix is "deferred" as it was not actually measured for the ML 4.3 event, but inferred from some of the aftershocks recorded by the survey. The earth models which have been used in the various earthquake locations are shown in Appendix B.

The series died away significantly shortly after the ML 4.3 event in January 1988, with only six possible events between March 1988 and April 1989.

## Other recent seismicity

A group of three events SE of Wyalkatchem, in October 2016 (largest ML 2.4), and another group of three events about 15 km west of Wyalkatchem in January 2017 (largest ML 2.4), were noted in Dent (2017). Recorded earthquake clusters in the Wyalkatchem region may be defining a north-east trending lineation, and future seismicity needs to be monitored to see if this trend continues. These events suggest the high probability of further significant seismicity in the Wyalkatchem region.

## Conclusions

A seismic cluster occurred east of Wyalkatchem in December 2018 and continued into January 2018. It was typical of cluster activity in the regions. Relocations shrink the epicentral zone from being about 15 km wide, to a suggested zone about 2 km wide. A further reduction might be expected if the locations could be made with greater precision. A possible northeasterly trend to seismicity in the region is noted.

## Acknowledgements

Thankyou to GA for access to their archived seismic data.

## References

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

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Dent, V.F., Heal, D. and Harris, P., 2006. A new network of low cost recorders in WA. *Proceedings of the Australian Earthquake Engineering Society Conference, 2006*, Canberra.

Kennett B. L. N & Engdahl, 1991. Travel times for global earthquake location and phase identification. *Geophys. J. Int. 105 (1991).*

# Appendix A. EQLOCL solutions for 25/12/2017 (ML 2.4) and 06/01/1988 (ML 4.3) events

## (a) Solution for Dec 2017 (ML 2.4) event using WA2 model

```
Date           2017-12-25
Origin Time    0955 48.10   +   0.25
Zone                 50
Easting           557.86    +   2.85              Longitude     117.607
Northing         6557.33    +   1.53              Latitude      -31.116
Depth               3.47    +   4.05

Arrival times    =  9          S.D. = 0.095        Seismographs =  6
Nearest recorder =   34.3 km   Gap  = 112.1 deg    Accuracy = A
Effects Code     = U           Imax =  0           Fault =

  29 km  N (348 deg) of  KBN
WESTERN AUSTRALIA
 191 km NE ( 61 deg) of PERTH
  34 km  S (159 deg) of Koorda
MAGNITUDES
Assign ML  2.4
```

DATA USED

| Code | Wave | AT | + | WT | CT | DT | Dist | Azim | Ad | Ae |
|---|---|---|---|---|---|---|---|---|---|---|
| KOO6 | P | 53.69 | 0.05 | 1.58 | 53.72 | -0.03 | 34.3 | 339 | 6.3 | 6.3 |
| KOO6 | S | 57.54 | 0.50 | 0.90 | 57.62 | -0.08 | 34.3 | 339 | 6.3 | 6.3 |
| KLBR | P | 56.93 | 0.01 | 2.10 | 57.01 | -0.08 | 54.5 | 165 | 4.0 | 4.0 |
| KLBR | S | 63.23 | 0.01 | 1.89 | 63.19 | 0.04 | 54.5 | 165 | 4.0 | 4.0 |
| BR4 | P | 62.24 | 0.05 | 1.47 | 62.17 | 0.07 | 86.2 | 53 | 2.5 | 2.5 |
| BLDU | P | 64.75 | 0.01 | 1.99 | 64.82 | -0.07 | 102.4 | 302 | 2.1 | 2.1 |
| MUN | P | 74.05 | 0.01 | 1.91 | 73.91 | 0.14 | 163.5 | 233 | -30.8 | 30.8 |
| NWAO | P | 79.08 | 0.01 | 1.88 | 79.01 | 0.06 | 203.7 | 189 | -42.2 | 42.2 |
| NWAO | S | 101.95 | 0.01 | 1.69 | 102.09 | -0.14 | 203.7 | 189 | -40.3 | 40.3 |
| | | | | 9 times used, S = 0.095 | | | | | | |
| Deferred Data | | | | | | | | | | |
| MECK | P | 61.70 | 0.10 | 1.29 | 61.27 | 0.43 | 80.7 | 224 | 2.6 | 2.6 |
| MECK | S | 71.20 | 1.00 | 0.73 | 70.41 | 0.79 | 80.7 | 224 | 2.6 | 2.6 |
| BR4 | S | 73.00 | 1.00 | 0.72 | 71.93 | 1.07 | 86.2 | 53 | 2.5 | 2.5 |
| BLDU | S | 76.93 | 0.01 | 1.79 | 76.41 | 0.52 | 102.4 | 302 | 2.1 | 2.1 |
| MUN | S | 92.51 | 0.01 | 1.72 | 93.29 | -0.78 | 163.5 | 233 | 1.3 | 1.3 |
| KULI | PG | 77.04 | 0.04 | 1.44 | 77.45 | -0.41 | 179.9 | 163 | 1.2 | 1.2 |
| KULI | P | 77.04 | 0.05 | 1.38 | 76.14 | 0.90 | 179.9 | 163 | -42.2 | 42.2 |
| KULI | SG | 98.20 | 1.00 | 0.68 | 97.80 | 0.40 | 179.9 | 163 | 1.2 | 1.2 |
| MORW | P | 90.10 | 0.01 | 1.83 | 87.35 | 2.75 | 272.6 | 326 | -42.2 | 42.2 |
| MORW | S | 116.74 | 0.01 | 1.64 | 116.60 | 0.14 | 272.6 | 326 | -40.3 | 40.3 |
| RKGY | S | 144.97 | 0.01 | 1.59 | 141.67 | 3.30 | 391.7 | 188 | -40.3 | 40.3 |
| MEEK | P | 116.28 | 0.01 | 1.72 | 115.58 | 0.70 | 505.9 | 11 | -42.2 | 42.2 |
| MEEK | S | 160.58 | 0.01 | 1.55 | 165.74 | -5.16 | 505.9 | 11 | -40.3 | 40.3 |
| FORT | P | 175.42 | 0.01 | 1.60 | 175.70 | -0.28 | 1003.4 | 90 | -42.2 | 42.2 |
| FORT | S | 267.96 | 0.01 | 1.44 | 270.42 | -2.46 | 1003.4 | 90 | -40.3 | 40.3 |

**(b) solution for Dec. 2017 (ML 2.4) event using VIC5A model**

```
Date           2017-12-25
Origin Time    0955 47.56   +   0.39
Zone                 50
Easting            556.15   +   4.17              Longitude     117.589
Northing          6556.22   +   2.31              Latitude      -31.126
Depth                6.73   +  11.06

Arrival times    = 11           S.D. = 0.172        Seismographs =  6
Nearest recorder =   34.8 km    Gap  = 109.8 deg    Accuracy = A
Effects Code     = U            Imax =  0           Fault =

  28 km  N (344 deg) of  KBN
WESTERN AUSTRALIA
 189 km NE ( 62 deg) of PERTH
  34 km  S (162 deg) of Koorda

MAGNITUDES

Mean              0.0     0.0     0.0     0.0                     Assign
ML  2.4

DATA USED
Code  Wave       AT    +    WT      CT     DT     Dist  Azim    Ad    Ae
KOO6    P      53.69  0.05  1.58   53.70  -0.01    34.8   342    0.0  38.8
KOO6    S      57.54  0.50  0.90   57.92  -0.38    34.8   342    0.1  29.4
KLBR    P      56.93  0.01  2.10   56.80   0.13    53.9   163    0.0  38.8
KLBR    S      63.23  0.01  1.89   63.27  -0.04    53.9   163    0.0  29.4
BR4     P      62.24  0.05  1.46   62.37  -0.13    88.2    53    0.0  38.8
BR4     S      73.00  1.00  0.72   72.88   0.12    88.2    53    0.0  29.4
BLDU    P      64.75  0.01  1.99   64.54   0.21   101.6   304    0.0  38.8
MUN     P      74.05  0.01  1.92   74.24  -0.19   161.5   233    0.0  38.8
KULI    P      77.04  0.05  1.38   76.87   0.17   179.3   162  -37.9  52.0
KULI    PG     77.04  0.04  1.44   77.14  -0.10   179.3   162    0.0  38.8
KULI    SG     98.20  1.00  0.68   98.36  -0.16   179.3   162    0.0  29.4
                      11 times used, S = 0.172
Deferred Data
MECK    P      61.70  0.10  1.28   60.81   0.89    78.7   224    0.0  38.8
MECK    S      71.20  1.00  0.73   70.19   1.01    78.7   224    0.0  29.4
BLDU    S      76.93  0.01  1.79   76.62   0.31   101.6   304    0.0  29.4
MUN     S      92.51  0.01  1.72   93.37  -0.86   161.5   233    0.0  29.4
NWAO    P      79.08  0.01  1.88   79.80  -0.72   202.3   189  -37.9  52.0
NWAO    S     101.95  0.01  1.69  103.44  -1.49   202.3   189  -36.7  45.7
MORW    P      90.10  0.01  1.83   88.80   1.30   272.6   326  -37.9  52.0
MORW    S     116.74  0.01  1.64  119.20  -2.46   272.6   326  -36.7  45.7
RKGY    S     144.97  0.01  1.59  145.59  -0.62   390.3   188  -36.7  45.7
MEEK    P     116.28  0.01  1.72  118.88  -2.60   507.3    11  -37.9  52.0
MEEK    S     160.58  0.01  1.55  171.87 -11.29   507.3    11  -36.7  45.7
FORT    P     175.42  0.01  1.60  181.02  -5.60  1000.5    90  -41.1  53.0
FORT    S     267.96  0.01  1.44  283.90 -15.94  1000.5    90  -37.1  45.7
```

**(c) solution for Jan. 1988 (ML 4.3) event using VIC5A model**

```
Date           1988-01-06
Origin Time    0342  7.59   +   0.97
Zone                 50
Easting           543.14   +  15.33            Longitude     117.453
Northing         6546.92   +   5.76            Latitude      -31.211
Depth               4.78   +  30.71

Arrival times    =  7          S.D. = 0.266       Seismographs =  5
Nearest recorder =   51.3 km   Gap  = 163.4 deg   Accuracy = B
Effects Code     =             Imax =  0          Fault =

  10 km  W (285 deg) of  WYAL
WESTERN AUSTRALIA
 173 km NE ( 62 deg) of PERTH
  40 km  E ( 92 deg) of Dowerin

No magnitudes known                              Assign ML  4.3

DATA USED
Code  Wave       AT    +    WT      CT     DT     Dist  Azim    Ad    Ae
KLB  i-P       16.40  0.10  1.33   16.48  -0.08    51.3   145    5.6   5.6
WA4  i P       19.70  0.20  1.13   19.85  -0.15    70.9   342    4.1   4.1
BAL  i       24.60  0.10  1.26   24.23   0.37    97.8   313  -23.0  23.0
BAL  i S       36.00  0.30  0.91   36.39  -0.39    97.8   313  -23.0  23.0
MUN  i-P       32.00  0.10  1.22   31.80   0.20   145.5   233  -23.0  23.0
MUN    S       49.20  0.40  0.83   49.49  -0.29   145.5   233  -23.0  23.0
NWAO   P       38.40  0.30  0.96   38.43  -0.03   191.3   186  -37.9  37.9
                      7 times used, S = 0.266
Deferred Data
WYAL   S-P      1.40  0.50  1.10    1.49  -0.09    10.7   105    0.0   0.0
KLB  e S       21.90  0.50  0.61   22.98  -1.08    51.3   145    5.6   5.6
MRWA i      45.10  0.10  0.81   47.96  -2.86   261.6   327  -44.1  44.1
MRWA   PMP     48.00  0.30  0.56   48.58  -0.58   261.6   327  -39.6  39.6
MRWA   SMS     78.00  1.00  0.36   78.61  -0.61   261.6   327  -39.5  39.5
RKG  i-P       61.10  0.10  1.12   61.95  -0.85   374.7   186  -44.1  44.1
RKG    P1      66.00  0.50  0.57   68.17  -2.17   374.7   186  -23.0  23.0
RKG  e SN     100.00  2.00  0.26  101.75  -1.75   374.7   186  -44.1  44.1
RKG  e SG     114.00  1.00  0.44  119.44  -5.44   374.7   186    0.8   0.8
```

# Appendix B. Earth models used in EQLOCL solutions

**(a) IASPEI earth model (used by Geoscience Aust.)**

| Depth | Pv (km/s.) | Sv (km/s.) |
|---|---|---|
| | 5.8 | 3.36 |
| 20 | | |
| | 6.5 | 3.75 |
| 35 | | |
| | 8.04 | 4.47 |

**(b) WA2 earth model (used by MGO/GA)**

| Depth | Pv (km/s.) | Sv (km/s.) |
|---|---|---|
| | 6.13 | 3.62 |
| 10 | | |
| | 7.14 | 3.96 |
| 36.5 | | |
| | 8.27 | 4.75 |

**(c) VIC5A earth model (used by the SRC)**

| Depth | Pv (km/s.) | Sv (km/s.) |
|---|---|---|
| | 4.81 | 3.11 |
| 2.15 | | |
| | 6.00 | 3.52 |
| 6.72 | | |
| | 6.17 | 3.57 |
| 18.76 | | |
| | 6.32 | 3.66 |
| 35.18 | | |
| | 7.81 | 4.46 |