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The Yorkrakine, W.A., seismic deployment, April-May 1996

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Abstract

An important earthquake swarm north of Kellerberrin, WA in 1996-1998 was monitored for a month with several portable recorders. Data obtained from the digital seismographs are reviewed, and some events have been relocated. A small sub-set of relatively accurate hypocentres has been obtained. The data suggest an epicentral zone about 4 km long, with a NE to NNE trend and the earthquakes are probably less than 4 km deep. The trend is consistent with trends deduced by other studies in the region, and suggests a regional trend in seismically active faults, at least in the northern parts of southwestern Australia, although it is not evident in regional geological maps. The study reinforces the need for dense, close monitoring of seismic events to reveal causative fault orientation.

1 Introduction

A number of earthquakes were felt in a region ~ 20 km north of Kellerberrin, (~150 km east of Perth) (Figure 1) on the morning of 11th March 1996. The initial event had a Richter Local Magnitude (Ml) of 3.1, and another 4 events of Ml ≥ 2.5 (including another Ml 3.1 event) occurred within the next 24 hrs.

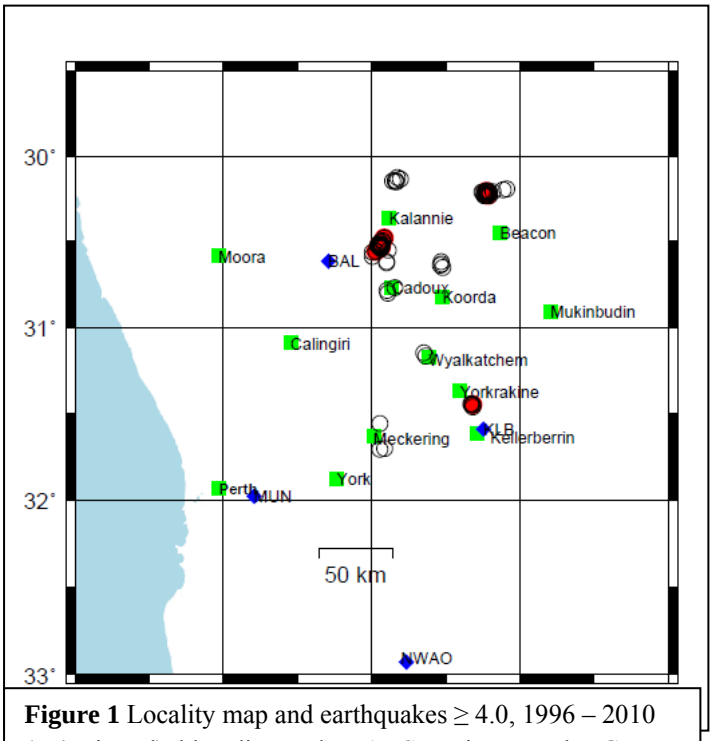

Figure 1 Locality map and earthquakes ≥ 4.0, 1996 – 2010 (≥ 4.5 in red). blue diamonds = ANSN seismographs. Green squares = towns.

At the time of this felt activity, the Mundaring Geophysical Observatory (MGO) – a division of BMR / AGSO (now Geoscience Australia), which operated from 1959 to April 2000, was responsible for ANSN seismograph operations and earthquake locations within WA.

These events were not particularly large in relation to the historical seismicity of the region (e.g. the Ml 6.7 Meckering event of October 1968), but when it became apparent after a couple of weeks that the activity was continuing, the MGO deployed three field seismographs in the area between 4th April and 23rd May, 1996. The purpose of a field station is to determine more accurate locations of the epicentres than would be achievable using the regional ANSN network alone.

Epicentres from the start of the swarm, on 10th March 1996 (UTC), up until and including the beginning of the temporary station deployment, on 4th April are plotted on Figure 2.

2 A brief description of the Yorkrakine swarm

Following the Ml 3.1 event on 10th March 1996, another 20 events (Ml ≥ 2.0) were recorded in the following two days. Activity then declined, without actually ceasing, until the end of March 1996, when activity increased again, and continued at a relatively high level until mid May 1996.

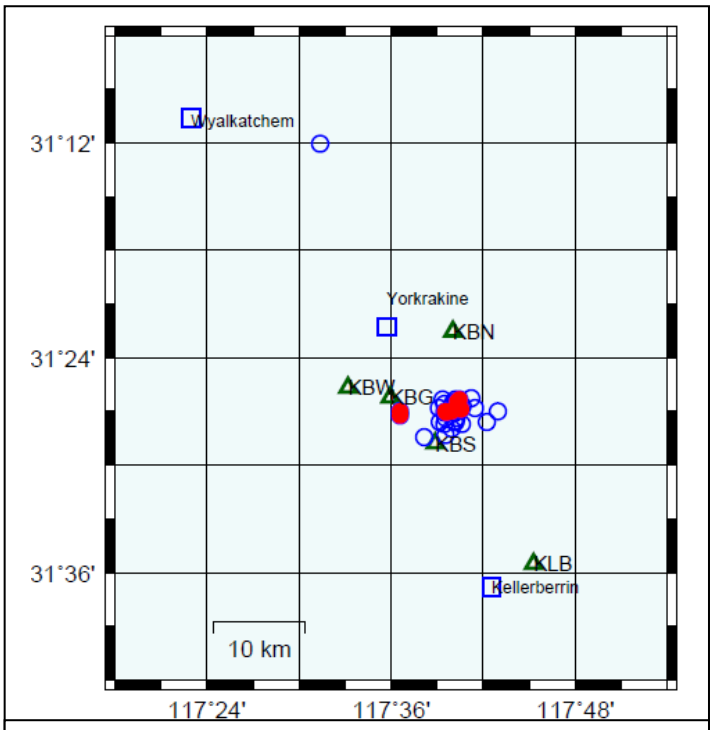

Figure 2 earthquakes Ml ≥ 2.0 10th Mar – 4th Apr 1996 (Ml ≥ 3.0 in red) Triangles = field seismographs.

Activity waxed and waned from then on, until another significant burst in activity in March and April 1997, and then another in late August – early September 1997. The largest events of the series occurred at this time, including an Ml 4.6 event on 31st August and an Ml 4.2 event on 3rd September. Activity then declined again until early June 1998, when 6 events of Ml ≥ 3.0 occurred between 7th and 12th June. There were 402 events of Magnitude Ml ≥ 2.0 in the area of

Figure 3A - March – May 1996

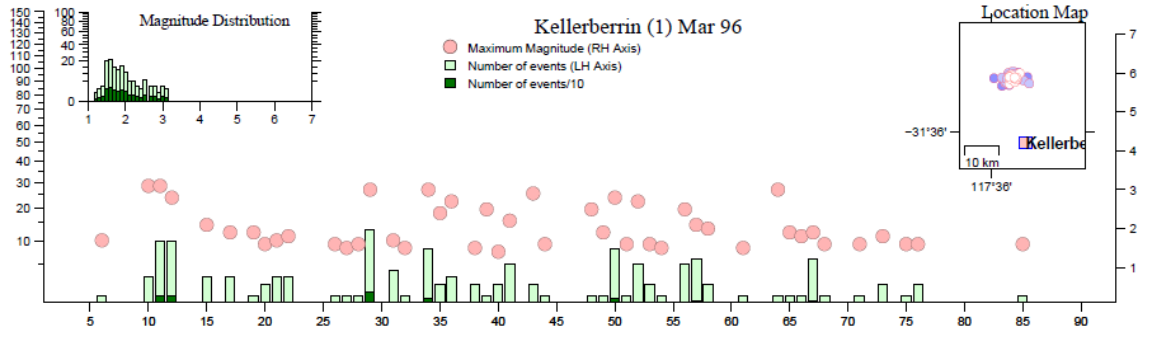

Figure 3B - August - October 1997

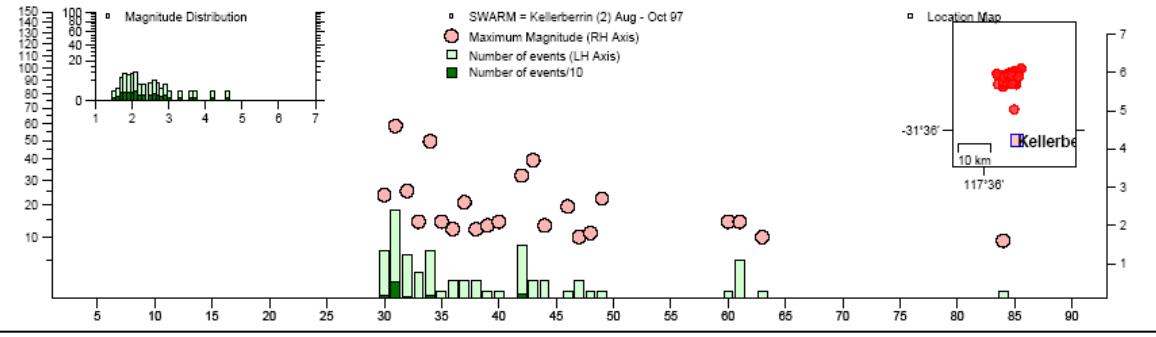

Figure 3. Two figures depicting phases of the Kellerberrin swarm (from Dent 2008A).

Figure 2 between 10th March 1996 and 18th June 1998. However, sporadic activity continued until at least December 1998.

The sequence was treated as part of a larger discussion of swarm activity in Australia by Dent (2008A), where graphs of various swarms were presented in order show the variations that exist in "swarm" behaviour. In that report the locality was described as "Kellerberrin", and it suggests that the swarm was the second most significant in the South West Seismic Zone (SWSZ) in the interval studied (1983 – 2007), with the Burakin swarm of 2000 – 2003 (Leonard, 2002, 2003) being the most significant. Because there has been other swarm-like activity in the general Kellerberrin area, the sequence will be from here on referred to as the "Yorkrakine" sequence, after a small locality ~ 10 km northwest of the epicentres (Figure 2).

Two plots of the "Kellerberrin" activity, each of 3 months duration, were presented in the 2008 report (i.e. March to May 1996 and August to October 1997) and these are reproduced in Figure 3. A lesser period of swarm activity occurred about 20 km east of Kellerberrin between May and June 1994, and was also graphed in that report.

3 Swarm activity as precursory behaviour

Swarm-like activity has been proposed as possible precursory behaviour before a large earthquake (Leonard 2002), and the Kellerberrin activity (1996-1998) described here, as well as the Burakin region activity (2000-2003) seem to support this possibility. The largest Kellerberrin event (Ml 4.6) occurred in August 1997, some 18 months after activity initiation. The largest Burakin event (Ml 5.2) occurred in September 2001, a year after a minor swarm in the region (Leonard & Boldra, 2001, Leonard, 2002), in which the largest event was Ml 3.6. However, in other significant swarms in the southwest seismic zone this has not been the case, as for example in the Beacon sequence of January – May 2009 (Dent, 2009), where the largest event (Ml 4.6) occurred about 27 hours after the commencement of the swarm.

4 The temporary station deployment

Kelunji portable digital seismographs were deployed at four locations (Figure 2) during the six weeks of the survey. Station details are shown in Table 1. The station at KBW was moved to a better location (KBS), closer to the epicentral zone, about one week into the survey.

Table 1 field station details

Code	Location	Sample rate	opened	closed
KBN	31.3755 117.6673	200 s/s	04 Apr	28 May
KBG	31.4370 117.5991	200 s/s	04 Apr	28 May
KBW	31.4281 117.5535	200 s/s	04 Apr	11 Apr
KBS	31.4796 117.6482	200 s/s	11 Apr	28 May

Besides the temporary net, the continuously recording station KLB (Kellerberrin), which was ~ 20 km south-southeast of the activity, recorded most of the activity, although it only operated at 40 samples/sec (as against 200 samples/sec for the Kelunjis). Additional spatial coverage of stations and the extra precision of the field data are critical where higher spatial resolution of epicentres is required.

Due to the time elapsed since the activity, and the later closure of the MGO, the original data, including the Kelunji Journals showing station operational periods have not been located. The original digital field data also have not been located.

5 Review of survey data

Sixty eight events are found in the Geoscience Australia's online earthquake database (http://www.ga.gov.au/earthquakes/searchQuake.do) between 4th April and 23rd May 1996, and they have been listed in Appendix 1 and plotted on Figure 4. Field station recordings are available for 29 of these, as indicated in Appendix 1. Most of these are for one station only, but data from two or more stations have been used for solutions of seven events. Data from three stations were available in four instances (5th April @ 0617, 12th April @ 1905, 19th April @ 0233 and 21st April @ 0044). Many potential recordings were lost because the limited field

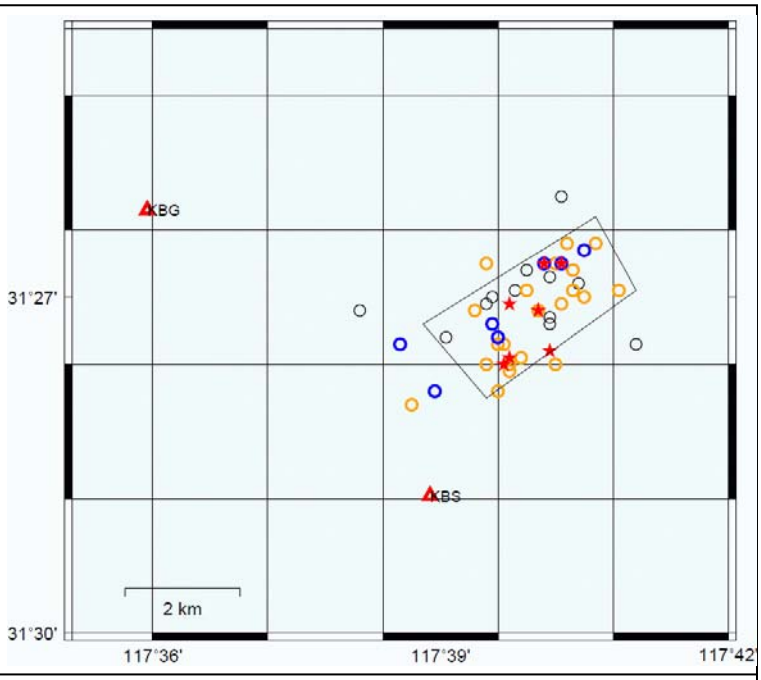

Figure 4 Earthquakes 4th April – 28th May 1996. Black = no field stns, orange = 1field stn, blue = 2 or more field stns. Red stars = revised locations for events with > 2 field station arrivals.

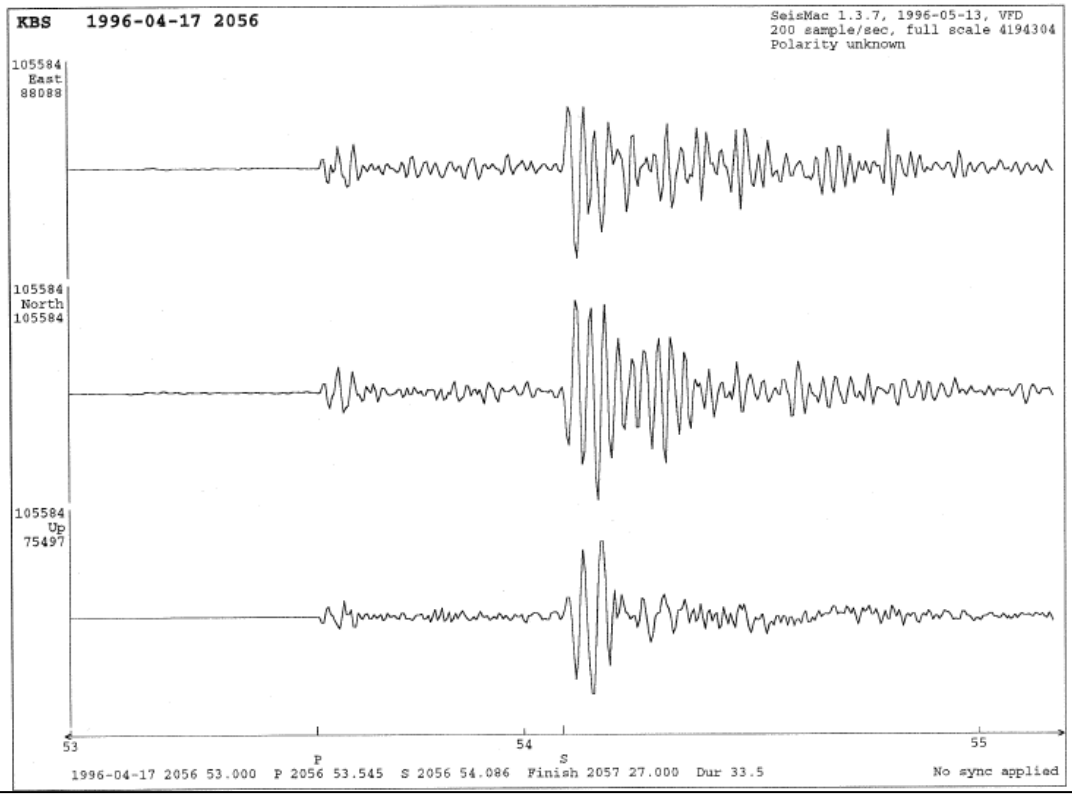

Figure 5 Example of a Yorkrakine event recorded on the KBS seismograph (S-P time of 0.54 sec.)

recorder memories were filled before a service visit could be made.

In addition, field recordings were obtained for nine events that were not located by the MGO and they have been noted in Appendix 1. It can be assumed that these events are of relatively low magnitude. A representative seismogram from the station KBS is shown on Figure 5. Note the clarity of the P and S phases, which suggests that it should be possible to calculate a precise hypocentral distance to the event, given an accurate velocity-depth model for the area.

6 A review and relocation of selected epicentres

As it is the closest station to the epicentres, KBS is the most useful in detecting small variations in the earthquake foci. The observed S-P times of events recorded at KBS , and distances to KBS are shown in Table 2. Given the high quality of the seismograms, these times are quite reliable.

In the procedure of locating an earthquake, extra weight should be given to portable station data because of their greater precision. This means that if for instance the observed KBS S-P time is say 0.420 secs, but the theoretical S-P time for the solution

Table 2 S-P times measured at KBS station

Date	UTC	Obs S-P	Calc. S-P*	Calc . dist (km)	comments
1996					
12 Apr	1900	0.37	0.37	2.6	
	1905	0.35	0.35	2.8	
16 Apr	1655	0.40			Not located
17 Apr	2056	0.54	0.56		
19 Apr	0221	0.42	0.36	3.0	Relocated to 2.9 k
	0228	0.42	0.32	1.3	Relocated to 3.3 k
	0229	0.43	0.45		
	0233	0.43	0.47	3.7	
21 Apr	0044	0.40	0.43	2.7	
25 Apr	1909	0.40	0.37	1.6	Relocated to 3.1 k
25 Apr	2009	0.41	0.44	3.4	
	2022	0.41			Not located
	2028	0.40			Not located
13 May	1557	0.44	0.44		
14 May	0601	0.41			Solution not found
23 May	2213	0.52	0.51		

* Calc. = theoretical value for the solution saved in GA database

Table 3 Summary of location data from Appendix 2

Date	UTC	Longitude East	Latitude South	Depth (km)	S.D. of resid[#]	# temp stations	comments
5/4/96	0000*	117.670	-31.445	2.8	0.042		Original solution, does not use KBG or KBW
	0000	117.671	-31.445	2.8	0.057	2	Relocation using KBW & KBG
5/4/96	0617*	117.694	-31.428	12			Original poor soln, still in GA data base
	0617	117.668	-31.445	3.2	0.032	3	New solution in DB, uses KBG, KGN, KBW
12/4/96	1900*	117.660	-31.457	5 N	0.349		"normal" depth. Original soln, does not use
	1900	117.653	-31.456	1.7	0.050		Relocation using KBS
12/4/96	1905*	117.643	-31.457	2			solution quoted in GA database not found
	1905	117.661	-31.460	1.6	0.031	3	New solution uses KBS, KBN & KBG
19/4/96	0221*	117.659	-31.454	0.9	0.078		Original solution, uses KBS
	0221	117.662	-31.457	2.1	0.041		Relocation – better S-P fit
19/4/96	0228*	117.645	-31.466	2.2	0.149		Original solution, uses KBS
	0228	117.666	-31.455	1.4	0.072		Relocation – better S-P fit
19/4/96	0233*	117.667	-31.452	1			Original, - but soln not found
	0233	117.669	-31.451	1.3	0.075	3	Relocation, uses KBS, KBG, KBN
21/4/96	0044*	117.662	-31.459	2.3	0.071	3	Uses KBS, KBG, KBN
25/4/96	1909*	117.650	-31.464	2.5	0.124	1	Uses KBS
	1909	117.669	-31.458	1.6	0.092	2	Relocation using KBS and KBG
25/4/96	2009	117.662	-31.451	1.7	0.076	3	Relocation – original solution not found
7/6/98	2242*	117.683	-31.464	5N	0.356		Outside the box (Ml 3.6)
	2242	117.675	-31.452	0.4	0.221		Relocation (inside the box)
		[#] = Standard Deviation of residuals					* = solution as found in GA catalogue

determined is 0.480 secs, the solution is not optimal. It may be possible to compute a solution in which the "residual" is reduced to 0.05 secs or less, by amending the weighting applied to the various phases used in the solution.

The data in Table 2 suggest that the computed solutions fit the field data fairly well in most instances, but for two solutions however (19th April @ 0221 and 0228), the KBS data show relatively poor fit suggesting the solutions are not optimal. These two events have been relocated by the author using EQLOCL (as was used for the original solutions), with final solutions chosen such that the residuals for the KBS S-P times are at a minimum. For the first event (19th April @ 0221), the change to the epicentre was insignificant, but the depth was increased from 0.9 to 2.1 km. For the second event (19th April @ 0228), a 2 km shift to the northeast resulted, which moved the epicentre closer to the main grouping of events.

The original EQLOCL solutions and the relocations proposed for the events above are shown in Appendix 2, and the data in Appendix 2 are summarised in Table 3. This table lists the standard deviations (S.D.) of the arrival time residuals for the P and S waves (i.e. observed arrival time – computed arrival time). The object of the earthquake location procedure is to make this value as small as possible given the available data. Note that the S.D.s for relocations presented here are usually significantly less than the S.D.s for the original locations.

7 Focal depths

The focal depths of the earthquakes listed in Appendix 1 are generally between 1 and 3 km. Where a depth has been indicated as 5 km, it generally means that the computer location could not find an acceptable depth and the value has been assigned by the operator. It must be noted however, that where focal depths have been computed without the aid of a relatively dense and close network of seismographs (i.e. denser than the Yorkrakine net), the resulting depths are generally unreliable (as stated, for example, by Gibson et al., 1994).

Depths shown in Table 3 are generally between 0.5 km and 2.5 km, and this is probably a good indication of the focal depth range of the data set, but because depth is the hardest parameter to constrain in a hypocentral solution, too much reliance should not be given on individual values. Where an earthquake has been located using two or more field stations, it is probable that it is has a more reliable depth. The depth range found here is consistent with the range of accurate depths found for Burakin region earthquakes by Allen et al. (2006).

8 The best-located events

The five events indicated in Table 3 as having been recorded on three field recorders are potentially the best constrained solutions in the data set. These events have been relocated, and are shown as red stars on Figure 4, along with the two relocated events (above) of 19th April 1996.

The GA database location for the 12th April event (1905 UTC) puts it outside the box (117.643E, 31.457S), well to the west of the main group of epicentres, but the EQLOCL output pertaining to that location has not been found. A non-preferred solution found in the archives utilises data from

3 field stations, and puts it at 117.668E, 31.463S (which is just inside the box) at a depth of 0.9 km. This may well be a better solution than the one indicated in the GA catalogue as "preferred".

The original EQLOCL solution for the event on the 25th April also has not been found, and it is unclear if field data were used for the solution. The author has relocated the event, including the field station data, and the new location is at 117.662 E, 31.451 S, with a focal depth of 1.7 km, which places it in the centre of the box shown on Figure 4.

Again, the original EQLOCL locations of the above earthquakes, where available, and the relocations, are shown in Appendix 2.

9 Events after survey closed

As noted earlier, the seismic activity at Yorkrakine continued for some 2 years after the field instruments were withdrawn. Over 300 more events were located during this time, and events of Ml ≥ 3.0 (May 1996 – June 1998) are plotted on Figure 6. This plot shows considerable scatter, with a possible north-south trend. However, if only the larger events are considered (i.e. Ml ≥ 3.5) all but one are within the enclosed area shown in Figure 4, and are also concentrated at its eastern end. Because of the extra data available, the larger events can be assumed to be better located than the smaller ones. The scatter of the smaller events may be attributed to greater location inaccuracies.

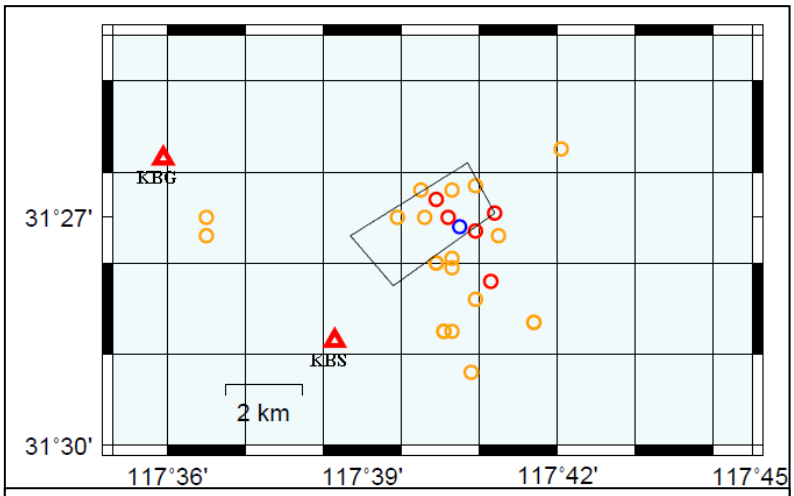

Figure 6. Events May 1996 – June 1998. Orange = Ml 3.0 – 3.4 Red = Ml 3.5 – 4.6 blue = relocated Ml 3.6 event (7th June1998). Box is as shown on Figure 4.

The solution for the exception noted above (Ml 3.6 on 7th June 1998) has been re-examined. The EQLOCL solution for this event indicates that the depth had been constrained to 5 km, and many distant arrivals, (not particularly useful for the solution), had been included. The event also has been relocated and allowed unconstrained depth. The new solution (Appendix 2) puts the event inside the source zone, at a depth of 0.9 km.

10 Discussion

The more accurately determined epicentres appear to lie within the northeasterly trending box shown on Figure 4. The box is about 4 km long and 2 km wide. Most of the epicentres recorded during the survey fall within the box, and the best located events (red stars) show a NNE trend within that box. The errors in locations which do not have the benefit of near station data are such that it is reasonable to propose that most, if not all, of the events in the sequence, i.e. over 400

events between 1996 and 1998, actually occurred within this box. The dimensions of this suggested source zone are consistent with the probable rupture area for a magnitude 4.6 earthquake. Gibson (pers. comm.) has indicated that the rupture area for a similar magnitude event in a region where a high stress drop is expected is approximately 5 km^2.

The focal depths have been found to be shallow – probably less than 3 km, in agreement with other results in the region. Computed depths are to some extent earth-model dependent, in this case the "WA2" model (Dent, 1989), but the extent of this dependency is yet to be determined. The nearness of the station KBS to the epicentres, and the very short S-P times observed at KBS indicate that the events must be very shallow.

The WA2 model was used by the MGO during the 1990s, and was also used by GA when locating WA events from 2000 to 2010. This is a relatively simple model with only two supra-Moho layers, and was constructed over 20 years ago by inversion of available earthquake and blast phase data (including some data from this survey). It does not contain a near-surface low-velocity layer, which is generally accepted as being present (P. Somerville, pers. comm.). Initial tests suggest that including such a layer could cause computed focal depths to increase by about 0.5 km.

11 A comparison with other studies

The NE-SW trend in epicentres noted above is consistent with results from two other recent seismic episodes in southwest WA. Dawson et al. (2008) used satellite interferometry to investigate the nature of the faults on which the Kalannie sequence of Sept 2005 (~ 150 km NNW of Kellerberrin) and the Ml 4.9 Katanning earthquake (9th Oct 2007, ~ 300 km south of Kellerberrin) of 2007 occurred. They were able to detect measurable surface deformation from both earthquakes. They concluded the Kalannie earthquakes occurred on a fault with a strike of 53° and that the Katanning fault had a strike of 231° (i.e. 51°), although neither of these trends were observable from the epicentral plots alone. The Kalannie sequence was not monitored using field equipment and a review of epicentres in the swarm (Dent, 2010) shows a dense "ball" of events in which no trend can be discerned. The Katanning event had only two notable aftershocks, and a field station deployment there soon after the event (Dent, 2008B) did

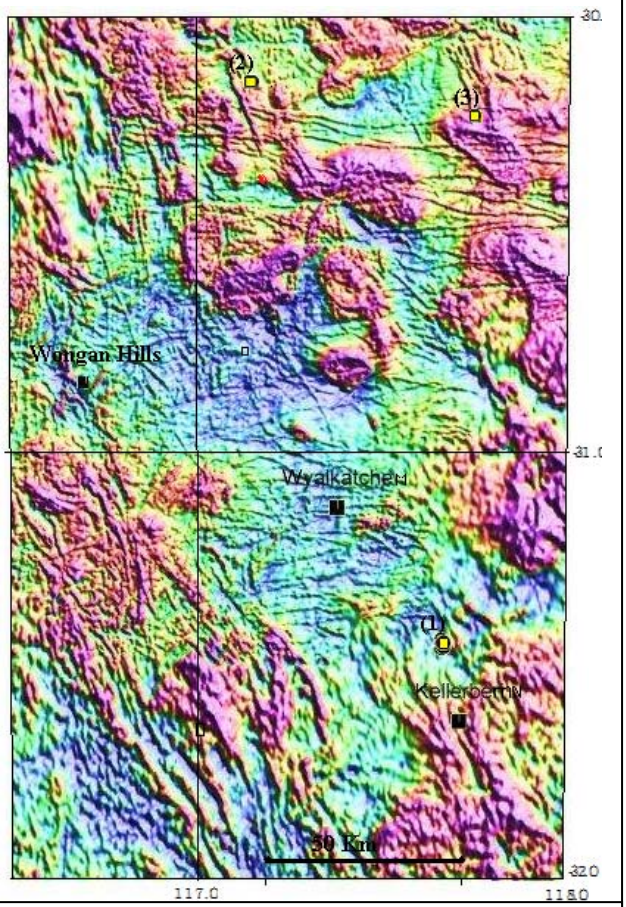

Figure 7. Regional aeromagnetic map, showing epicentral zones of Yorkrakine (1), Kalannie (2) and Beacon (3) swarms (yellow squares).

not reveal any apparent trend in the smaller events recorded. However, larger well-located events from the Burakin sequence of 2000-2003 suggest a lineation to the NNE (Dent, 2010). Using aero-magnetic data in the Meckering region, and relatively old epicentral data (i.e. 1968-1970), Dentith & Featherstone (2003) and Dentith et al. (2009) suggested a conjugate NE and SE trending fault system in the Meckering region.

The agreement of the trend of Yorkrakine events with the results described above suggests that a fault orientation of about 025° - 045° may represent a regional trend. More detailed studies, using dense seismograph deployments around future earthquake sequences, are needed to confirm this.

12 Relation to regional geology

The epicentral zone is within the Yilgarn Archaean craton, a region of relatively low relief. The most detailed geological map publically available (the 1:250,000 Kellerberrin sheet) does not show any faults in the vicinity of the epicentral zone. Aeromagnetic data downloaded from GA show more detail of the local structure than the geological map, and many linear features in the region can be seen on Figure 7. These are interpreted as mainly mafic dykes (M. Dentith, pers. comm.), and seem to have dominantly an EW to ENE trend. The epicentral zone is indicated (labeled "1"), as well as source locations for earthquake swarms north of Kalannie (2) and north of Beacon (3). The magnetic highs (red tones) are interpreted as granitoid intrusive masses. There is no obvious relationship between these source zones and the mafic dykes or granitoid intrusions.

13 Conclusions

The range in the KBS S-P values indicates that the earthquakes are not originating from a point source. The plot of the best available locations suggests a small source zone, with a northeast trend. Larger, presumably well-located events which occurred after the survey support this conclusion. Smaller events are much more scattered, but this can be attributed to poorer locations.

Current aeromagnetic data and regional geological maps do not support to the suggested northeast trend, or link the earthquakes to mapped faults.

The best-constrained focal depths in the sequence range between 1.3 km and 3.2 km. Future improvements to the local earth model may increase calculated focal depths marginally.

Poor locations (as in routine solutions from ANSN stations, made without the benefit of near stations recording with a high sampling rate) can obscure a trend.

"Preferred" solutions as listed in the database can still be improved on by modifying the weighting applied to the data – analysts tend to include insignificant phase arrivals from relatively distant stations in the solutions.

It is reasonable to suggest that ALL the events of the Yorkakine sequence (i.e. between March 1996 and December 1998) originated from within the box indicated on Figure 4, and the scatter found in GA Earthquake database locations is due to the difficulty in locating them accurately.

It is difficult to interpret catalogue data because of the lack of "metadata" about the events – i.e. solution reliability, what stations were used, etc.

14 Acknowledgements

The author acknowledges Geoscience Australia for access to their seismic archives. Thanks to Professor Michael Dentith for assisting with Figure 7, and making general comments. Thanks also to David Love, Clive Collins, John Glover, Virginia Ward and Brian Gaull for revisions to the manuscript.

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APPENDIX 1

Epicentres from the Geoscience Australia Earthquake Database

(plus unlocated events observed on field recorders. Also events of Ml ≥ 2.5 are bolded)

DATE	UTC	Ml	Longit	Latitude	Depth	Temp Stns (KBS/KBN/KBG/KBG)	Comments
4/04/1996	02:33	1.5	117.670	-31.460	3		
4/04/1996	14:04	2.4	117.674	-31.448	2		
4/04/1996	23:16					KBG	recorded at KBG but not located
5/04/1996	00:00	2.2	117.670	-31.445	3	KBG,KBW	
5/04/1996	01:11					KBG	recorded at KBG but not located
5/04/1996	02:19	1.5	117.670	-31.460	3		
5/04/1996	**06:17**	**2.7**	**117.668**	**-31.445**	**3**	KBG,KBN,KBW	
5/04/1996	06:17	2.7	117.694	-31.428	12		"Poorly determined"**(duplicate!)**
6/04/1996	10:22					KBN	recorded at KBN but not located
7/04/1996	06:44					KBN	recorded at KBN but not located
7/04/1996	18:07	1.5	117.670	-31.460	3		
7/04/1996	20:05	1.5	117.660	-31.464	1	KBN	
8/04/1996	**01:17**	**2.5**	**117.660**	**-31.456**	**2**	**KBN**	
9/04/1996	12:42	1.4	117.669	-31.453	2		
9/04/1996	19:42	1.3	117.663	-31.449	1		
10/04/1996	06:04	1.7	117.670	-31.460	3		
10/04/1996	06:18	2.0	117.661	-31.457	2	KBN	
10/04/1996	13:55	2.0	117.658	-31.460	1	KBN	
10/04/1996	16:32	1.8	117.662	-31.461	1	KBN	
10/04/1996	18:05	2.2	117.664	-31.459	3	KBN	
12/04/1996	19:00	2.4	117.660	-31.457	5	KBS	
12/04/1996	**19:05**	**2.9**	**117.643**	**-31.457**	**2**	KBS,KBN,KBG	
13/04/1996	15:56	1.6	117.669	-31.454	2		
16/04/1996	16:55					KBS	recorded at KBS but not located
17/04/1996	**20:56**	**2.5**	**117.681**	**-31.449**	**1**	**KBS**	
18/04/1996	18:36	1.9	117.670	-31.460	3		
19/04/1996	02:21	2.0	117.659	-31.454	1	KBS,KBN	
19/04/1996	02:28	2.2	117.645	-31.466	2	KBS	
19/04/1996	02:29	2.0	117.665	-31.449	1	KBS	
19/04/1996	**02:33**	**2.8**	**117.667**	**-31.452**	**1**	KBS, KBG, KBN	
19/04/1996	02:35	1.6	117.670	-31.460	3		
19/04/1996	02:31					KBG	recorded at KBG but not located
19/04/1996	14:45	1.6	117.670	-31.460	3		
19/04/1996	14:47	1.5	117.670	-31.460	3		
19/04/1996	14:48	1.7	117.670	-31.460	3		
20/04/1996	13:34	1.6	117.670	-31.460	3		
21/04/1996	**00:44**	**2.7**	**117.662**	**-31.460**	**3**	KBS,KBG,KBN	
21/04/1996	01:48	1.8	117.675	-31.450	1	KBG	
21/04/1996	**01:53**	**2.5**	**117.671**	**-31.445**	**3**	KBG	
21/04/1996	02:04	2.0	117.671	-31.451	2	KBG	
21/04/1996	18:35	1.7	117.673	-31.449	3	KBG	
22/04/1996	06:55	1.6	117.723	-31.468	5		
22/04/1996	17:16	1.6	117.681	-31.449	1		
23/04/1996	04:27	1.5	117.665	-31.446	2		
25/04/1996	19:09	1.9	117.649	-31.464	2	KBG,KBS	
25/04/1996	19:32	1.3	117.684	-31.457	4		
25/04/1996	**20:09**	**2.5**	**117.675**	**-31.443**	**3**	KBS,KBN,KBG	
25/04/1996	20:22					KBS	recorded at KBS but not located
25/04/1996	20:28					KBS	recorded at KBS but not located
25/04/1996	20:44	2.1	117.636	-31.452	1		
25/04/1996	22:12	1.5	117.656	-31.452	1	KBN	
26/04/1996	01:19	1.9	117.669	-31.447	1		
26/04/1996	01:28	1.8	117.673	-31.446	1		
26/04/1996	01:35	2.1	117.651	-31.456	2		
26/04/1996	01:47	1.8	117.659	-31.450	1		
26/04/1996	01:54	1.5	117.658	-31.451	4		
26/04/1996	02:05					KBG	recorded at KBG but not located
26/04/1996	03:53	1.5	117.671	-31.435	1		
27/04/1996	06:42	2.0	117.672	-31.442	1	KBG	
27/04/1996	07:06	1.5	117.677	-31.442	2	KBG	
30/04/1996	08:07	1.5	117.658	-31.445	1	KBG	
2/05/1996	**00:43**	**3.0**	**117.665**	**-31.444**	**4**		
3/05/1996	13:30	1.9	117.660	-31.450	3		

4/05/1996 01:43	1.8	117.660	-31.450	3	
5/05/1996 02:48	1.2	117.660	-31.469	3	
5/05/1996 05:14	1.4	117.676	-31.464	3	
5/05/1996 14:03	1.9	117.668	-31.453	1	
5/05/1996 15:09	1.4	117.692	-31.440	5	
5/05/1996 15:19	1.6	117.681	-31.457	1	
5/05/1996 20:31	1.5	117.660	-31.450	3	
6/05/1996 18:35	1.6	117.681	-31.452	2	
9/05/1996 02:20	1.6	117.660	-31.450	3	
11/05/1996 8:54	1.7	117.660	-31.450	3	
11/05/1996 20:57	1.8	117.660	-31.450	3	
13/05/1996 15:57	1.6	117.660	-31.455	2	KBS
14/05/1996 6:01	1.5	117.660	-31.450	3	KBS
14/05/1996 6:27	1.6	117.660	-31.450	3	
23/05/1996 22:13	1.6	117.675	-31.451	1	KBS

APPENDIX 2

EQLOCL text outputs for events referred to in paper

Event 5th April at 0000 UTC - MGO location (16 May 1996)

```
Date           1996-04-05
Origin Time    0000 15.00   +   1.32
Zone                50
Easting            563.62   +  14.45              Longitude     117.670
Northing          6520.91   +  12.44              Latitude      -31.445
Depth                2.81   +  38.90

Arrival times    =  6           S.D. = 0.042        Seismographs =  3
Nearest recorder =   18.4 km    Gap  = 197.1 deg    Accuracy = B
Effects Code     =              Imax =  0           Fault =

   4 km NE ( 27 deg) of  KBS
WESTERN AUSTRALIA
 181 km  E ( 72 deg) of PERTH
  21 km  N (347 deg) of Kellerberrin
MN

No magnitudes known                              Assign ML  2.2
```

DATA USED

Code	Wave	AT	+	WT	CT	DT	Dist	Azim	Ad	Ae
KLB	i P	18.00	0.10	1.44	18.04	-0.04	18.4	152	9.6	9.6
KLB	i S	20.20	0.10	1.29	20.16	0.04	18.4	152	9.6	9.6
BAL	e P	36.30	0.10	0.86	36.26	0.04	130.6	315	-30.8	30.8
BAL	i S	51.10	0.10	1.11	51.10	0.00	130.6	315	1.4	1.4
MUN	e P	39.00	0.50	0.62	39.05	-0.05	150.6	246	-30.8	30.8
MUN	i S	56.60	0.50	0.79	56.59	0.01	150.6	246	1.2	1.2
				6 times used, S = 0.042						
Deferred Data										
MRWA	e P	46.30	0.50	0.58	56.97	-10.67	294.6	326	-42.2	42.2
MRWA	i S	94.20	0.50	0.75	88.23	5.97	294.6	326	-40.3	40.3

Event 5th April at 0000 UTC - relocation (uses KBG and KBW)

```
Date           1996-04-05
Origin Time    0000 15.03   +   0.49
Zone                50
Easting            563.74   +   4.74              Longitude     117.671
Northing          6520.84   +   4.70              Latitude      -31.445
Depth                2.80   +   9.38
```

Arrival times = 11 S.D. = 0.057 Seismographs = 5
Nearest recorder = 6.9 km Gap = 197.4 deg Accuracy = B
Effects Code = Imax = 0 Fault =

4 km NE (29 deg) of KBS
WESTERN AUSTRALIA
181 km E (73 deg) of PERTH
21 km N (347 deg) of Kellerberrin

No magnitudes known Assign ML 2.2

DATA USED

Code	Wave	AT	+	WT	CT	DT	Dist	Azim	Ad	Ae
KBG	S-P	0.83	0.05	1.76	0.85	-0.03	6.9	277	0.0	0.0
KBG	i P	16.24	0.05	1.76	16.26	-0.02	6.9	277	24.3	24.3
KBG	i S	17.06	0.05	1.59	17.11	-0.05	6.9	277	24.3	24.3
KBW	S-P	1.41	0.10	1.49	1.33	0.08	11.3	279	0.0	0.0
KBW	P	16.99	0.01	2.36	16.94	0.05	11.3	279	15.4	15.4
KLB	i P	18.00	0.50	1.04	18.05	-0.05	18.3	152	9.6	9.6
KLB	i S	20.20	0.50	0.94	20.16	0.04	18.3	152	9.6	9.6
BAL	e P	36.30	0.10	0.86	36.31	-0.01	130.8	315	-30.8	30.8
BAL	i S	51.10	0.50	0.80	51.16	-0.06	130.8	315	1.4	1.4
MUN	e P	39.00	1.00	0.54	39.09	-0.09	150.6	246	-30.8	30.8
MUN	i S	56.60	0.50	0.79	56.65	-0.05	150.6	246	1.2	1.2
				11 times used, S = 0.057						
Deferred Data										
KBW	i S	18.40	0.01	2.12	18.26	0.14	11.3	279	15.4	15.4
MRWA	e P	46.30	0.50	0.58	57.02	-10.72	294.7	326	-42.2	42.2
MRWA	i S	94.20	0.50	0.75	88.29	5.91	294.7	326	-40.3	40.3

Event 5th April at 0617 – MGO Location - Uses KBG, KBN, KBW

Date 1996-04-05
Origin Time 0617 20.92 + 0.28
Zone 50
Easting 563.45 + 2.22 Longitude 117.668
Northing 6520.92 + 1.65 Latitude -31.445
Depth 3.17 + 4.25

Arrival times = 13 S.D. = 0.032 Seismographs = 7
Nearest recorder = 6.6 km Gap = 152.2 deg Accuracy = A
Effects Code = Imax = 0 Fault =

4 km NE (25 deg) of KBS
WESTERN AUSTRALIA
181 km E (72 deg) of PERTH
21 km N (346 deg) of Kellerberrin

DATA USED

Code	Wave	AT	+	WT	CT	DT	Dist	Azim	Ad	Ae
KBG	S-P	0.80	0.10	1.54	0.84	-0.04	6.6	277	0.0	0.0
KBG	i P	22.10	0.10	1.54	22.13	-0.03	6.6	277	27.8	27.8
KBN	S-P	0.97	0.10	1.53	0.95	0.02	7.7	359	0.0	0.0
KBN	i P	22.30	0.10	1.53	22.29	0.01	7.7	359	24.4	24.4
KBW	S-P	1.36	0.10	1.49	1.31	0.05	11.0	279	0.0	0.0
KBW	i P	22.80	0.10	1.49	22.80	0.00	11.0	279	17.5	17.5
KLB	i-P	24.00	0.10	1.44	23.99	0.01	18.5	151	10.6	10.6
KLB	i S	26.10	0.50	0.94	26.12	-0.02	18.5	151	10.6	10.6
BAL	i	42.10	0.10	1.23	42.14	-0.04	130.5	315	-30.8	30.8
BAL	i S	57.00	0.50	0.80	56.99	0.01	130.5	315	1.5	1.5
MUN	e P	44.90	0.50	0.62	44.92	-0.02	150.4	246	-30.8	30.8
MUN	i S	62.50	0.20	0.95	62.48	0.02	150.4	246	1.3	1.3
NWAO	i P	47.60	0.10	1.20	47.56	0.04	169.3	193	-30.8	30.8
				13 times used, S = 0.032						
Deferred Data										
KBS	S-P	5.00	0.10	1.57	0.63	4.37	4.3	205	0.0	0.0
NWAO	i S	67.80	0.10	1.08	67.60	0.20	169.3	193	-23.9	23.9
MRWA	e P	63.00	1.00	0.51	62.84	0.16	294.5	326	-42.2	42.2
MRWA	i S	95.00	0.30	0.83	94.07	0.93	294.5	326	-40.3	40.3
MRWA	S2	100.00	0.50	0.41	99.21	0.79	294.5	326	-23.9	23.9

Event 12th April at 1859 – MGO Location (13 Apr 1996) -"Normal" depth

```
Date           1996-04-12
Origin Time    1859 59.99   +-   0.85
Zone                 50
Easting           562.66    +-   6.75              Longitude     117.660
Northing         6519.50    +-   5.96              Latitude      -31.457
Depth               5.00    +-  13.66  N

Arrival times    =  8           S.D. = 0.349        Seismographs =  4
Nearest recorder =   17.7 km    Gap  = 191.6 deg    Accuracy = B
Effects Code     =              Imax =  0           Fault =

   2 km NE ( 35 deg) of  KBS
WESTERN AUSTRALIA
 180 km  E ( 73 deg) of PERTH
  20 km  N (343 deg) of Kellerberrin

No magnitudes known                              Assign ML  2.4

DATA USED
Code  Wave       AT    +-    WT      CT     DT     Dist  Azim    Ad    Ae
KLB  i P       63.10  0.10  1.44   63.00   0.10    17.7   147   16.7  16.7
KLB  i S       65.10  0.10  1.30   65.09   0.01    17.7   147   16.7  16.7
BAL  i P       81.40  0.10  1.23   81.12   0.28   131.0   315  -30.8  30.8
BAL  i S       96.00  0.10  1.11   96.21  -0.21   131.0   315    2.3   2.3
MUN  i P       83.90  0.10  1.22   83.66   0.24   149.1   246  -30.8  30.8
MUN  i S      101.20  0.10  1.10  101.21  -0.01   149.1   246    2.0   2.0
NWAO i P       85.50  0.10  1.20   86.27  -0.77   167.7   193  -30.8  30.8
NWAO i S      106.40  0.10  1.08  106.07   0.33   167.7   193  -23.9  23.9
                        8 times used, S = 0.349
Deferred Data
MRWA e S      139.00  0.10  0.72  132.98   6.02   295.2   326  -40.3  40.3
```

******

Event 12th April at 1859 – relocation (15 May 1996) using KBS

```
Date           1996-04-12
Origin Time    1900  0.06   +-   0.20
Zone                 50
Easting           562.00    +-   1.75              Longitude     117.653
Northing         6519.72    +-   1.17              Latitude      -31.456
Depth               1.70    +-   3.55

Arrival times    =  9           S.D. = 0.050        Seismographs =  5
Nearest recorder =    2.6 km    Gap  = 190.0 deg    Accuracy = A
Effects Code     =              Imax =  0           Fault =

   2 km  N ( 20 deg) of  KBS
WESTERN AUSTRALIA
 179 km  E ( 73 deg) of PERTH
  20 km  N (342 deg) of Kellerberrin


No magnitudes known                              Assign ML  2.4

DATA USED
Code  Wave       AT    +-    WT      CT     DT     Dist  Azim    Ad    Ae
KBS    S-P      0.36  0.03  2.05    0.37  -0.01     2.6   200    0.0   0.0
KBS    P        0.64  0.10  1.61    0.59   0.05     2.6   200   38.2  38.2
KLB  i P        3.10  0.10  1.44    3.05   0.05    18.2   146    6.3   6.3
KLB  i S        5.10  0.10  1.30    5.13  -0.03    18.2   146    6.3   6.3
BAL  i P       21.40  0.10  1.23   21.34   0.06   130.4   316    0.9   0.9
BAL  i S       36.00  0.10  1.11   36.08  -0.08   130.4   316    0.9   0.9
MUN  i P       23.90  0.10  1.22   23.93  -0.03   148.6   246  -30.8  30.8
MUN  i S       41.20  0.10  1.10   41.12   0.08   148.6   246    0.8   0.8
NWAO i S       46.40  0.10  1.08   46.42  -0.02   167.8   193    0.7   0.7
                        9 times used, S = 0.050
Deferred Data
NWAO i P       25.50  0.10  1.20   26.62  -1.12   167.8   193  -30.8  30.8
MRWA e S2      79.00  0.10  0.40   78.57   0.43   294.7   326  -23.9  23.9
```

Event 12th April at 1905 – MGO Location (2 June 1996) (not the "preferred" soln)

```
Date           1996-04-12
Origin Time    1905 56.63   +-   0.38
Zone                 50
Easting           563.43    +-   4.03              Longitude     117.668
Northing         6518.91    +-   2.43              Latitude      -31.463
Depth               0.92    +-   8.56

Arrival times    =  7           S.D. = 0.018        Seismographs =  4
Nearest recorder =    2.8 km    Gap  = 194.2 deg    Accuracy = A
Effects Code     =              Imax =  0           Fault =

   2 km NE ( 48 deg) of  KBS
 181 km  E ( 73 deg) of PERTH
  19 km  N (345 deg) of KELLERBERRIN


No magnitudes known                              Assign ML  2.9

DATA USED
Code  Wave       AT    +-    WT      CT     DT     Dist  Azim    Ad    Ae
KBS    S-P      0.34  0.03  2.05    0.35  -0.01     2.8   228    0.0   0.0
KBS    P       57.15  0.10  1.61   57.14   0.01     2.8   228   23.2  23.2
KBG    S-P      0.80  0.05  1.77    0.77   0.03     6.7   284    0.0   0.0
KBG    P       57.72  0.10  1.54   57.75  -0.03     6.7   284   10.2  10.2
KBN    S-P      1.10  0.05  1.73    1.10  -0.00     9.7   359    0.0   0.0
KBN    P       58.23  0.10  1.50   58.22   0.01     9.7   359    7.2   7.2
NWAO i P       83.20  0.10  1.20   83.19   0.01   167.4   193  -30.8  30.8
                        7 times used, S = 0.018
Deferred Data
KLB  i P       59.90  0.10  1.45   59.37   0.53    16.8   148    4.2   4.2
KLB  i S       61.90  0.10  1.30   61.28   0.62    16.8   148    4.2   4.2
BAL  i P       78.00  0.10  1.23   78.16  -0.16   132.0   315    0.5   0.5
BAL  i S       92.70  0.10  1.11   93.08  -0.38   132.0   315    0.5   0.5
NWAO i S      103.00  0.10  1.08  102.86   0.14   167.4   193    0.4   0.4
MRWA i P       98.50  0.10  1.14   99.01  -0.51   296.1   326  -42.2  42.2
MRWA   SMS    136.00  0.10  0.57  136.31  -0.31   296.1   326  -25.5  25.5
```

Event 12th April at 1905 – relocation (3 May 1996)

```
Date           1996-04-12
Origin Time    1905 56.64   +   0.27
Zone                 50
Easting           562.78    +   2.90              Longitude     117.661
Northing         6519.18    +   1.90              Latitude      -31.460
Depth               1.58    +   3.82

Arrival times    =  8           S.D. = 0.031        Seismographs =  5
Nearest recorder =    2.4 km    Gap  = 190.0 deg    Accuracy = A
Effects Code     =              Imax =  0           Fault =

   2 km NE ( 29 deg) of  KBS
WESTERN AUSTRALIA
 180 km  E ( 73 deg) of PERTH
  20 km  N (343 deg) of Kellerberrin

No magnitudes known                              Assign ML  2.9

DATA USED
Code  Wave       AT    +    WT      CT     DT     Dist  Azim    Ad    Ae
KBS    S-P      0.34  0.03  2.07    0.35  -0.01     2.4   209    0.0   0.0
KBS    P       57.15  0.10  1.62   57.14   0.01     2.4   209   37.4  37.4
KBG    S-P      0.80  0.05  1.77    0.76   0.04     6.4   293    0.0   0.0
KBG    P       57.72  0.10  1.54   57.73  -0.01     6.4   293   16.3  16.3
KBN    S-P      1.10  0.05  1.73    1.09   0.01     9.4     3    0.0   0.0
KBN    P       58.23  0.10  1.51   58.21   0.02     9.4     3   11.3  11.3
```

```
BAL  i P       78.00  0.10  1.23   78.06  -0.06   131.3   315    0.8   0.8
NWAO i P       83.20  0.10  1.20   83.16   0.04   167.5   193  -30.8  30.8
                        8 times used, S = 0.031
Deferred Data
KLB  i P       59.90  0.50  1.05   59.49   0.41    17.3   147    6.2   6.2
KLB  i S       61.90  0.10  1.30   61.46   0.44    17.3   147    6.2   6.2
BAL  i S       92.70  0.50  0.80   92.92  -0.22   131.3   315    0.8   0.8
NWAO i S      103.00  0.10  1.08  102.90   0.10   167.5   193    0.6   0.6
MRWA i P       98.50  0.10  1.14   98.87  -0.37   295.5   326  -42.2  42.2
MRWA   SMS    136.00  0.10  0.57  136.10  -0.10   295.5   326  -25.5  25.5
```

******

Event 19th April at 0221 – MGO solution (13 May 1996)(has big KBS residual)

```
Date          1996-04-19
Origin Time   0221 48.68   +-   0.39
Zone                50
Easting           562.61   +-   3.68              Longitude     117.659
Northing         6519.87   +-   2.80              Latitude      -31.454
Depth               0.93   +-   9.77

Arrival times    =  7           S.D. = 0.078        Seismographs =  4
Nearest recorder =    3.0 km    Gap  = 192.1 deg    Accuracy = A
Effects Code     =              Imax =  0           Fault =

   2 km NE ( 30 deg) of  KBS
WESTERN AUSTRALIA
 180 km  E ( 73 deg) of PERTH
  20 km  N (343 deg) of Kellerberrin

No magnitudes known                              Assign ML  2.0

DATA USED
Code  Wave       AT    +-    WT      CT     DT     Dist  Azim    Ad    Ae
KBS    S-P      0.42  0.05  1.84    0.36   0.06     3.0   210    0.0   0.0
KBS    P       49.19  0.10  1.61   49.20  -0.01     3.0   210   22.7  22.7
KLB  i P       51.70  0.10  1.44   51.62   0.08    18.0   147    3.9   3.9
KLB  i S       53.60  0.10  1.30   53.67  -0.07    18.0   147    3.9   3.9
BAL  i P       70.10  0.10  1.23   70.00   0.10   130.7   315    0.5   0.5
BAL  e S       84.60  0.10  0.78   84.78  -0.18   130.7   315    0.5   0.5
MUN  i P       72.70  0.10  1.22   72.70   0.00   149.2   246  -30.8  30.8
                        7 times used, S = 0.078
```

******

Event 19th April at 0221 – relocation (smaller KBS residual)

```
Date          1996-04-19
Origin Time   0221 48.75   +-   5.59
Zone                50
Easting           562.90   +-  30.65              Longitude     117.662
Northing         6519.56   +-  46.52              Latitude      -31.457
Depth               2.14   +-  73.60

Arrival times    =  5           S.D. = 0.041        Seismographs =  4
Nearest recorder =    2.9 km    Gap  = 192.4 deg    Accuracy = A
Effects Code     =              Imax =  0           Fault =

   2 km NE ( 39 deg) of  KBS
WESTERN AUSTRALIA
 180 km  E ( 73 deg) of PERTH
  20 km  N (344 deg) of Kellerberrin

No magnitudes known                              Assign ML  2.0

DATA USED
Code  Wave       AT    +-    WT      CT     DT     Dist  Azim    Ad    Ae
KBS    S-P      0.42  0.05  1.85    0.43  -0.01     2.9   218    0.0   0.0
KLB  i P       51.70  0.10  1.44   51.64   0.06    17.6   148    7.9   7.9
```

```
KLB  i S       53.60  0.10  1.30   53.65  -0.05    17.6   148    7.9   7.9
BAL  i P       70.10  0.10  1.23   70.13  -0.03   131.1   315  -30.8  30.8
MUN  i P       72.70  0.10  1.22   72.68   0.02   149.4   246  -30.8  30.8
                         5 times used, S = 0.041
Deferred Data
KBS    P       49.19  0.10  1.61   49.36  -0.17     2.9   218   40.5  40.5
BAL  e S       84.60  0.10  0.78   84.97  -0.37   131.1   315    1.1   1.1
```

******

Event 19th April at 0228 – MGO solution (13 May 1996)(big KBS residual)

```
Date           1996-04-19
Origin Time    0228 33.81   +-   0.46
Zone                 50
Easting           561.26   +-   5.88              Longitude     117.645
Northing         6518.58   +-   7.15              Latitude      -31.466
Depth               2.23   +-   4.21

Arrival times    =  8           S.D. = 0.149        Seismographs =  4
Nearest recorder =    1.3 km    Gap  = 185.4 deg    Accuracy = A
Effects Code     =              Imax =  0           Fault =

   1 km  N (  7 deg) of  KBS
WESTERN AUSTRALIA
 178 km  E ( 73 deg) of PERTH
  20 km  N (339 deg) of Kellerberrin

No magnitudes known                              Assign ML  2.2

DATA USED
Code  Wave       AT    +-    WT      CT     DT     Dist  Azim    Ad    Ae
KBS    S-P      0.42  0.05  1.90    0.32   0.10     1.3   187    0.0   0.0
KBS    P       34.29  0.10  1.66   34.27   0.02     1.3   187   63.7  63.7
KLB  i-P       36.80  0.10  1.44   36.73   0.07    17.7   142    8.1   8.1
KLB  i S       38.60  0.20  1.13   38.76  -0.16    17.7   142    8.1   8.1
BAL  i P       55.20  0.10  1.23   55.13   0.07   130.7   316  -30.8  30.8
BAL  i S       69.80  0.20  0.96   69.92  -0.12   130.7   316    1.1   1.1
MUN  e P       57.90  0.20  0.74   57.48   0.42   147.5   246  -30.8  30.8
MUN  e S       74.30  0.10  0.77   74.56  -0.26   147.5   246    1.0   1.0
                         8 times used, S = 0.149
```

******

Event 19th April at 0228 – relocation (better KBS residual)

```
Date           1996-04-19
Origin Time    0228 33.83   +-   4.38
Zone                 50
Easting           563.28   +-  38.76              Longitude     117.666
Northing         6519.79   +-  32.42              Latitude      -31.455
Depth               1.35   +- 107.17

Arrival times    =  5           S.D. = 0.072        Seismographs =  4
Nearest recorder =    3.3 km    Gap  = 194.1 deg    Accuracy = A
Effects Code     =              Imax =  0           Fault =

   3 km NE ( 41 deg) of  KBS
WESTERN AUSTRALIA
 181 km  E ( 73 deg) of PERTH
  20 km  N (345 deg) of Kellerberrin


No magnitudes known                              Assign ML  2.2

DATA USED
Code  Wave       AT    +-    WT      CT     DT     Dist  Azim    Ad    Ae
KBS    S-P      0.42  0.05  1.84    0.42   0.00     3.3   221    0.0   0.0
KLB  i-P       36.80  0.10  1.44   36.71   0.09    17.6   149    5.4   5.4
KLB  i S       38.60  0.20  1.13   38.71  -0.11    17.6   149    5.4   5.4
BAL  i P       55.20  0.10  1.23   55.23  -0.03   131.2   315    0.7   0.7
MUN  e P       57.90  0.20  0.74   57.89   0.01   149.8   246  -30.8  30.8
```

5 times used, S = 0.072

Deferred Data

KBS		P	34.29	0.10	1.60	34.43	-0.14	3.3	221	26.6	26.6
BAL	i	S	69.80	0.20	0.96	70.08	-0.28	131.2	315	0.7	0.7
MUN	e	S	74.30	0.10	0.77	75.21	-0.91	149.8	246	0.6	0.6

******

Event 19th April at 0233 – relocation (using 3 field stations)

Date 1996-04-19
Origin Time 0233 3.44 + 0.16
Zone 50
Easting 563.57 + 1.28 Longitude 117.669
Northing 6520.16 + 0.77 Latitude -31.451
Depth 1.31 + 2.69

Arrival times = 14 S.D. = 0.075 Seismographs = 8
Nearest recorder = 3.7 km Gap = 152.3 deg Accuracy = A
Effects Code = Imax = 0 Fault =

3 km NE (32 deg) of KBS
WESTERN AUSTRALIA
181 km E (73 deg) of PERTH
20 km N (346 deg) of Kellerberrin

No magnitudes known Assign ML 2.8

DATA USED

Code	Wave	AT	+	WT	CT	DT	Dist	Azim	Ad	Ae
KBS	S-P	0.43	0.03	2.02	0.46	-0.03	3.7	212	0.0	0.0
KBS	P	4.08	0.10	1.59	4.09	-0.01	3.7	212	23.5	23.5
KBG	S-P	0.85	0.05	1.77	0.80	0.05	6.8	283	0.0	0.0
KBN	S-P	1.00	0.10	1.52	0.97	0.03	8.4	358	0.0	0.0
KLB	e P	6.50	0.10	1.01	6.35	0.15	17.8	151	5.2	5.2
KLB	i S	8.40	0.10	1.30	8.37	0.03	17.8	151	5.2	5.2
BAL	i	24.80	0.10	1.23	24.83	-0.03	131.2	315	0.7	0.7
BAL	i S	39.60	0.10	1.11	39.67	-0.07	131.2	315	0.7	0.7
MUN	i-P	27.50	0.10	1.22	27.56	-0.06	150.2	246	-30.8	30.8
MUN	i S	45.10	0.10	1.09	44.94	0.16	150.2	246	0.6	0.6
NWAO	e P	30.10	0.10	0.84	30.14	-0.04	168.6	193	-30.8	30.8
NWAO	i S	49.90	0.20	0.94	50.01	-0.11	168.6	193	0.5	0.5
MRWA	e S	77.20	0.20	0.63	77.07	0.13	295.2	326	-40.3	40.3
MRWA	SMS	82.80	0.10	0.57	82.83	-0.03	295.2	326	-25.5	25.5

14 times used, S = 0.075

Deferred Data

KBG	P	4.54	0.10	1.54	4.58	-0.04	6.8	283	13.2	13.2
KBN	P	4.96	0.10	1.52	4.83	0.13	8.4	358	10.8	10.8
MRWA	e P	45.00	0.30	0.64	45.65	-0.65	295.2	326	-42.2	42.2
MRWA	e PMP	48.20	0.20	0.42	48.23	-0.03	295.2	326	-31.9	31.9
MEEK	P	77.50	2.00	0.59	75.43	2.07	541.3	9	-42.2	42.2
MEEK	e S	128.00	1.00	0.43	128.92	-0.92	541.3	9	-40.3	40.3
MEEK	e SG	152.00	1.00	0.43	152.95	-0.95	541.3	9	0.2	0.2
WARB	e P	138.20	0.30	0.57	137.66	0.54	1055.9	58	-42.2	42.2
WARB	e S	237.00	1.00	0.40	237.26	-0.26	1055.9	58	-40.3	40.3

Event 21st April at 0044 – MGO location (2 June 1996) (using 3 field stations)

Date 1996-04-21
Origin Time 0044 17.65 + 0.17
Zone 50
Easting 562.88 + 1.26 Longitude 117.662
Northing 6519.28 + 0.86 Latitude -31.459
Depth 2.32 + 1.93

Arrival times = 13 S.D. = 0.071 Seismographs = 8
Nearest recorder = 2.7 km Gap = 137.7 deg Accuracy = A
Effects Code = Imax = 0 Fault =

2 km NE (35 deg) of KBS
180 km E (73 deg) of PERTH

```
  20 km  N (344 deg) of KELLERBERRIN
  Record      Dur    Sync    Unc    Resp   Seismometer      Recorder        Pol
MAGNITUDES
Code      R       ML      MD      MB      MS      MW      MN

No magnitudes known                             Assign ML  2.7

DATA USED
Code  Wave       AT    +    WT      CT     DT     Dist  Azim    Ad    Ae
KBS    S-P      0.40  0.02  2.23    0.43  -0.03     2.7   214    0.0   0.0
KBG    S-P      0.79  0.05  1.78    0.75   0.04     6.1   282    0.0   0.0
KBN    S-P      1.06  0.05  1.73    1.09  -0.03     9.3     3    0.0   0.0
KBN    P       19.23  0.10  1.51   19.23  -0.00     9.3     3   15.7  15.7
KLB  i-P       20.60  0.10  1.44   20.52   0.08    17.4   147    8.6   8.6
KLB  e S       22.40  0.10  0.91   22.51  -0.11    17.4   147    8.6   8.6
BAL  e P       39.00  0.10  0.86   39.05  -0.05   131.3   315  -30.8  30.8
BAL  e S       53.90  0.10  0.78   53.93  -0.03   131.3   315    1.1   1.1
MUN  e P       41.40  0.10  0.85   41.56  -0.16   149.2   246  -30.8  30.8
MUN  e S       59.00  0.10  0.77   58.89   0.11   149.2   246    1.0   1.0
MRWA e S       91.30  0.20  0.63   91.18   0.12   295.5   326  -40.3  40.3
MRWA   SMS     96.90  0.20  0.50   97.02  -0.12   295.5   326  -25.5  25.5
MEEK e SG     167.60  0.30  0.55  167.51   0.09   542.5    10    0.3   0.3
                      13 times used, S = 0.071
Deferred Data
KBS    P       18.25  0.10  1.62   18.27  -0.02     2.7   214   43.6  43.6
KBG    P       18.77  0.10  1.55   18.74   0.03     6.1   282   23.2  23.2
MRWA e P       59.00  0.30  0.64   59.80  -0.80   295.5   326  -42.2  42.2
MEEK e P       91.90  1.00  0.48   89.69   2.21   542.5    10  -42.2  42.2
MEEK e S      142.60  0.30  0.55  143.22  -0.62   542.5    10  -40.3  40.3
```

Event 25th April at 1909 – MGO location (using KBS)

```
Date           1996-04-25
Origin Time    1909 18.82   +-   0.38
Zone                 50
Easting            561.80   +-   2.52              Longitude     117.650
Northing          6518.72   +-   3.57              Latitude      -31.464
Depth                2.55   +-   3.97

Arrival times    = 10           S.D. = 0.124        Seismographs =  6
Nearest recorder =    1.6 km    Gap  = 176.6 deg    Accuracy = B
Effects Code     =              Imax =  0           Fault =

   1 km NE ( 27 deg) of  KBS
WESTERN AUSTRALIA
 179 km  E ( 73 deg) of PERTH
  20 km  N (340 deg) of Kellerberrin

No magnitudes known                             Assign ML  1.9

DATA USED
Code  Wave       AT    +-    WT      CT     DT     Dist  Azim    Ad    Ae
KBS    S-P      0.39  0.02  2.27    0.37   0.02     1.6   207    0.0   0.0
KLB  i-P       21.80  0.10  1.44   21.72   0.08    17.5   143    9.3   9.3
KLB  e S       23.50  0.10  0.91   23.73  -0.23    17.5   143    9.3   9.3
BAL  e P       40.10  0.10  0.86   40.15  -0.05   131.0   316  -30.8  30.8
BAL  e S       55.00  0.20  0.68   55.01  -0.01   131.0   316    1.2   1.2
MUN  e P       42.40  0.10  0.85   42.54  -0.14   148.0   246  -30.8  30.8
MUN  e S       59.70  0.10  0.77   59.72  -0.02   148.0   246    1.1   1.1
NWAO e P       45.50  0.30  0.68   45.17   0.33   166.8   193  -30.8  30.8
NWAO e S       64.90  0.50  0.55   64.90   0.00   166.8   193    1.0   1.0
MRWA e P       61.00  0.50  0.58   60.93   0.07   295.4   327  -42.2  42.2
                      10 times used, S = 0.124
Deferred Data
KBS    P       19.43  0.10  1.65   19.35   0.08     1.6   207   61.4  61.4
MRWA e S       93.10  0.30  0.58   92.29   0.81   295.4   327  -40.3  40.3
MRWA e S2      98.00  0.30  0.32   97.42   0.58   295.4   327  -23.9  23.9
```

Event 25th April at 1909 – relocation (using KBS and KBG)

```
Date           1996-04-25
Origin Time    1909 18.86   +-   0.66
Zone                 50
Easting            563.60   +-   6.81              Longitude     117.669
Northing          6519.45   +-   7.53              Latitude      -31.458
Depth                1.61   +-  13.79

Arrival times    =  8           S.D. = 0.092        Seismographs =  6
Nearest recorder =    3.1 km    Gap  = 183.3 deg    Accuracy = B
Effects Code     =              Imax =  0           Fault =

   3 km NE ( 39 deg) of  KBS
WESTERN AUSTRALIA
 181 km  E ( 73 deg) of PERTH
  20 km  N (346 deg) of Kellerberrin

No magnitudes known                              Assign ML  1.9

DATA USED
Code  Wave       AT    +-    WT      CT     DT     Dist  Azim    Ad    Ae
KBS    S-P      0.39  0.02  2.21    0.42  -0.03     3.1   219    0.0   0.0
KBS    P       19.43  0.10  1.60   19.46  -0.03     3.1   219   31.3  31.3
KBG    S-P      0.90  0.02  2.12    0.83   0.07     7.1   289    0.0   0.0
KLB  i-P       21.80  0.10  1.45   21.68   0.12    17.1   150    6.4   6.4
KLB  e S       23.50  0.10  0.91   23.63  -0.13    17.1   150    6.4   6.4
BAL  e S       55.00  1.00  0.49   55.24  -0.24   131.7   315    0.8   0.8
NWAO e P       45.50  0.30  0.68   45.45   0.05   167.9   193  -30.8  30.8
MRWA e P       61.00  0.50  0.58   61.12  -0.12   295.8   326  -42.2  42.2
                        8 times used, S = 0.092
Deferred Data
BAL  e P       40.10  0.50  0.62   40.35  -0.25   131.7   315    0.8   0.8
MUN  e P       42.40  0.10  0.85   42.93  -0.53   150.0   246  -30.8  30.8
MUN  e S       59.70  0.10  0.77   60.29  -0.59   150.0   246    0.7   0.7
NWAO e S       64.90  0.50  0.55   65.25  -0.35   167.9   193    0.6   0.6
MRWA e S       93.10  0.30  0.58   92.57   0.53   295.8   326  -40.3  40.3
MRWA e S2      98.00  0.30  0.32   97.66   0.34   295.8   326  -23.9  23.9
```

Event 25th April at 2009 – relocation using 3 field stations)(MGO soln not found)

```
Date           1996-04-25
Origin Time    2009 52.26   +   0.28
Zone                 50
Easting            562.87   +   1.59              Longitude     117.662
Northing          6520.23   +   1.06              Latitude      -31.451
Depth                1.67   +   3.33

Arrival times    = 10           S.D. = 0.076        Seismographs =  7
Nearest recorder =    3.4 km    Gap  = 145.6 deg    Accuracy = A
Effects Code     =              Imax =  0           Fault =

   3 km  N ( 21 deg) of  KBS
WESTERN AUSTRALIA
 180 km  E ( 73 deg) of PERTH
  21 km  N (344 deg) of Kellerberrin

No magnitudes known                              Assign ML  2.5

DATA USED
Code  Wave       AT    +     WT      CT     DT     Dist  Azim    Ad    Ae
KBS    S-P      0.41  0.02  2.20    0.45  -0.04     3.4   201    0.0   0.0
KBG    S-P      0.75  0.01  2.45    0.73   0.02     6.1   284    0.0   0.0
KBN    S-P      1.00  0.01  2.40    0.97   0.03     8.4     3    0.0   0.0
KLB  e P       55.30  0.10  1.01   55.25   0.05    18.2   149    6.2   6.2
KLB  e S       57.20  0.10  0.91   57.32  -0.12    18.2   149    6.2   6.2
BAL  e P       73.60  0.10  0.86   73.57   0.03   130.6   315    0.9   0.9
BAL  e S       88.30  0.10  0.78   88.35  -0.05   130.6   315    0.9   0.9
MUN  e P       76.10  0.10  0.85   76.28  -0.18   149.6   246  -30.8  30.8
```

NWAO e P	79.00	0.20	0.73	78.92	0.08	168.5	193	-30.8	30.8
NWAO e S	99.10	0.30	0.61	98.81	0.29	168.5	193	0.7	0.7
10 times used, S = 0.076									
Deferred Data									
KBS P	53.06	0.10	1.60	52.91	0.15	3.4	201	29.9	29.9
KBN P	53.99	0.01	3.03	53.67	0.32	8.4	3	13.3	13.3
MUN e S	94.00	0.20	0.67	93.59	0.41	149.6	246	0.7	0.7
MRWA e P	94.10	0.20	0.70	94.38	-0.28	294.7	326	-42.2	42.2
MRWA e S	126.00	0.30	0.58	125.74	0.26	294.7	326	-40.3	40.3

Event 7th June 1998 at 2009 – MGO location (12 June 1998) - "Normal" depth

Date 1998-06-07
Origin Time 2242 56.20 +- 0.38
Zone 50
Easting 564.87 +- 2.48 Longitude 117.683
Northing 6518.75 +- 2.41 Latitude -31.464
Depth 5.00 +- 5.21 N

Arrival times = 17 S.D. = 0.356 Seismographs = 9
Nearest recorder = 15.9 km Gap = 91.7 deg Accuracy = A
Effects Code = Imax = 0 Fault =

15 km NW (332 deg) of KLB
WESTERN AUSTRALIA
182 km E (73 deg) of PERTH
19 km N (349 deg) of Kellerberrin

No magnitudes known Assign ML 3.6

DATA USED

Code	Wave	AT	+-	WT	CT	DT	Dist	Azim	Ad	Ae
KLB	i-P	58.90	0.10	1.45	58.94	-0.04	15.9	152	18.4	18.4
BAL	i+P	77.40	0.10	1.23	77.62	-0.22	133.1	315	-30.8	30.8
MUN	e P	80.00	0.10	0.85	80.11	-0.11	150.9	247	-30.8	30.8
MUN	e S	97.90	0.10	0.77	97.91	-0.01	150.9	247	2.0	2.0
NWAO	e P	82.60	0.10	0.84	82.45	0.15	167.6	194	-30.8	30.8
NWAO	e S	102.20	0.20	0.66	102.24	-0.04	167.6	194	-23.9	23.9
MRWA	e P	98.10	0.10	0.80	98.24	-0.14	297.0	326	-42.2	42.2
MRWA	e PMP	101.20	0.10	0.48	100.94	0.26	297.0	326	-31.8	31.8
MRWA	e S	130.10	0.10	0.72	129.57	0.53	297.0	326	-40.3	40.3
RKG	e PMP	109.00	0.30	0.38	108.29	0.71	350.0	190	-31.5	31.5
RKG	e SMS	149.50	0.50	0.29	148.87	0.63	350.0	190	-24.9	24.9
WOOL	e P	109.20	0.50	0.57	108.65	0.55	383.1	84	-42.2	42.2
WOOL	e PG	117.80	0.30	0.63	118.71	-0.91	383.1	84	0.8	0.8
WOOL	e S	147.90	0.30	0.56	147.70	0.20	383.1	84	-40.3	40.3
FORT	e P	182.50	0.50	0.51	182.80	-0.30	996.5	88	-42.2	42.2
FORT	e S	277.30	0.50	0.46	276.80	0.50	996.5	88	-40.3	40.3
WARB	e P	190.50	0.50	0.51	189.97	0.53	1055.5	58	-42.2	42.2
17 times used, S = 0.356										
Deferred Data										
RKG	e P	106.50	0.30	0.63	104.64	1.86	350.0	190	-42.2	42.2
RKG	e PG	110.60	0.20	0.69	113.30	-2.70	350.0	190	0.9	0.9
RKG	e S	142.00	1.00	0.45	140.72	1.28	350.0	190	-40.3	40.3
RKG	e S2	146.00	0.50	0.29	148.31	-2.31	350.0	190	-23.9	23.9
WOOL	e SG	159.00	0.50	0.51	162.05	-3.05	383.1	84	0.8	0.8
MEEK	e P	129.20	0.30	0.61	127.93	1.27	542.4	9	-42.2	42.2
MEEK	e S	180.40	0.50	0.49	181.27	-0.87	542.4	9	-40.3	40.3
MEEK	e SG	204.50	0.50	0.49	206.05	-1.55	542.4	9	0.6	0.6
FORT	e SG	329.60	0.50	0.46	331.47	-1.87	996.5	88	0.3	0.3
GIRL	w P	189.00	1.00	0.45	187.48	1.52	1035.2	339	-42.2	42.2
WARB	e S	291.10	0.50	0.46	289.29	1.81	1055.5	58	-40.3	40.3
WARB	e SG	344.90	1.00	0.40	347.79	-2.89	1055.5	58	0.3	0.3
FITZ	e S	421.40	0.50	0.46	422.53	-1.13	1688.8	30	-40.3	40.3

Event 7th June 1998 at 2009 – Relocation

Date	1998-06-07				
Origin Time	2242 55.96	+-	0.51		
Zone	50				
Easting	564.14	+-	5.72	Longitude	117.675
Northing	6520.06	+-	3.08	Latitude	-31.452
Depth	0.35	+-	9.10		

Arrival times	= 9	S.D.	= 0.221	Seismographs	= 6
Nearest recorder	= 17.4 km	Gap	= 186.0 deg	Accuracy	= A
Effects Code	=	Imax	= 0	Fault	=

4 km NE (48 deg) of KBS
WESTERN AUSTRALIA
182 km E (73 deg) of PERTH
20 km N (348 deg) of Kellerberrin

No magnitudes known Assign ML 3.6

DATA USED

Code	Wave	AT	+-	WT	CT	DT	Dist	Azim	Ad	Ae
KLB	i-P	58.90	0.10	1.44	58.80	0.10	17.4	152	2.1	2.1
BAL	i+P	77.40	0.10	1.23	77.43	-0.03	131.6	315	0.3	0.3
MUN	e P	80.00	0.10	0.85	80.23	-0.23	150.7	246	-30.8	30.8
MUN	e S	97.90	0.10	0.77	97.59	0.31	150.7	246	0.2	0.2
NWAO	e P	82.60	0.10	0.84	82.75	-0.15	168.6	194	-30.8	30.8
NWAO	e S	102.20	0.20	0.66	102.54	-0.34	168.6	194	0.2	0.2
MRWA	e P	98.10	0.10	0.80	98.32	-0.22	295.5	326	-42.2	42.2
MRWA	e S	130.10	0.10	0.72	129.84	0.26	295.5	326	-40.3	40.3
RKG	e S	142.00	1.00	0.45	141.55	0.45	351.1	189	-40.3	40.3
			9 times used, S = 0.221							
Deferred Data										
MRWA	e PMP	101.20	0.10	0.48	100.89	0.31	295.5	326	-31.9	31.9
RKG	e P	106.50	0.30	0.63	105.05	1.45	351.1	189	-42.2	42.2
RKG	e PMP	109.00	0.30	0.38	108.61	0.39	351.1	189	-31.5	31.5
RKG	e PG	110.60	0.20	0.69	113.24	-2.64	351.1	189	0.1	0.1
RKG	e S2	146.00	0.50	0.29	148.88	-2.88	351.1	189	-23.9	23.9
RKG	e SMS	149.50	0.50	0.29	149.45	0.05	351.1	189	-25.0	25.0
WOOL	e P	109.20	0.50	0.57	108.99	0.21	383.8	84	-42.2	42.2
WOOL	e PG	117.80	0.30	0.63	118.56	-0.76	383.8	84	0.1	0.1
WOOL	e S	147.90	0.30	0.56	148.42	-0.52	383.8	84	-40.3	40.3
WOOL	e SG	159.00	0.50	0.51	161.97	-2.97	383.8	84	0.1	0.1
MEEK	e P	129.20	0.30	0.61	128.06	1.14	541.2	9	-42.2	42.2
MEEK	e S	180.40	0.50	0.49	181.61	-1.21	541.2	9	-40.3	40.3
MEEK	e SG	204.50	0.50	0.49	205.47	-0.97	541.2	9	0.1	0.1
FORT	e P	182.50	0.50	0.51	183.15	-0.65	997.2	88	-42.2	42.2
FORT	e S	277.30	0.50	0.46	277.53	-0.23	997.2	88	-40.3	40.3
FORT	e SG	329.60	0.50	0.46	331.42	-1.82	997.2	88	0.0	0.0
GIRL	w P	189.00	1.00	0.45	187.57	1.43	1033.8	340	-42.2	42.2
WARB	e P	190.50	0.50	0.51	190.23	0.27	1055.5	58	-42.2	42.2
WARB	e S	291.10	0.50	0.46	289.86	1.24	1055.5	58	-40.3	40.3
WARB	e SG	344.90	1.00	0.40	347.53	-2.63	1055.5	58	0.0	0.0
FITZ	e S	421.40	0.50	0.46	422.95	-1.55	1688.1	30	-40.3	40.3