Improved Hypocentral estimates for two recent seismic events in south-western Western Australia, using temporary station data

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Abstract

Two significant seismic events occurred in the southern wheat-belt area of Western Australia in late 2007. The first was a magnitude 4.8 event in October 2007 with numerous felt foreshocks and aftershocks, and which caused significant local damage. The second, a month later, was an earthquake swarm, with perhaps 100 felt events per day at the peak of the activity, but with a maximum magnitude of only ML 2.3. Temporary seismographs were deployed at both locations, and the resultant data have been used to help reduce the uncertainties in locations for both of these events, as well as confirm the presence of many smaller events which have gone undetected by the existing regional seismic network. S-P intervals for events at both locations suggest focal depths of two km or less. Locations of aftershocks of the first event interestingly do not exactly correlate with a ground deformation feature identified by InSAR imagery. This may suggest a fault plane dipping to the southeast. The latter November swarm event was only about 10 km west of a similarly significant earthquake swarm which was reported in late 1990- early 1991. Improved locations for both of the 2007 events, as well as the 1991 swarm are all to the east of the original locations, which may suggest a systematic bias introduced by the location procedures or distribution of permanent seismographs.

Introduction

A magnitude 4.8 earthquake 30 km south of Katanning (**Figure 1**) on 10th October 2007 (9th Oct GMT) caused extensive local damage. The resident closest to the epicentre (Grant Taylor, "Newlands", ~3 km east of the computed epicentre) reported that many smaller events had been noted for at least 10 weeks prior to the main event, although Geoscience Australia (GA) had not detected any of these. The Modified Mercalli Intensity experienced at Newlands was probably at least MM VII, and the earthquake was felt as far away as Perth. An isoseismal map for the event is being prepared by GA.

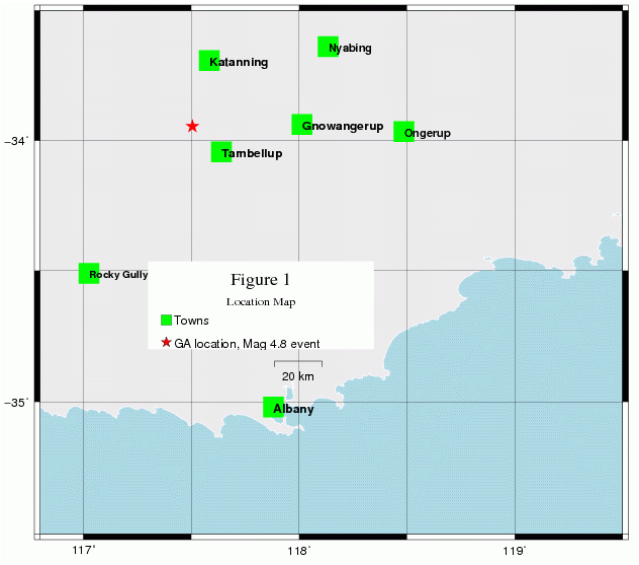


Figure 1 – *Map showing towns listed in text*

Satellite data have subsequently been used by Dawson *et al* (2008) to prepare an InSAR image (a recently developed differential radar interferometry technique) of the affected region. This image suggests a linear ground deformation, about 100 m long, with a strike of 45°, about 500 metres NW of Newlands (Dawson, *et al*., unpub. ms)

The GA location for the event used 12 stations from the Australian Seismograph Network, with the most remote being BBOO in South Australia. The closest stations had the most influence on the location, with the closest being RKGY (90 km to the SW). The next four closest were NWAO (116 km N), MUN (250 km NW), KLBR (260 km N) and BLDU (380 km N). Stations to the south and east of the earthquake would have allowed a better constrained solution.

A group of temporary stations was deployed in the area (**Figure 2**) by Geoscience Australia, three days after the main shock, and two stations were still operating in July 2008.

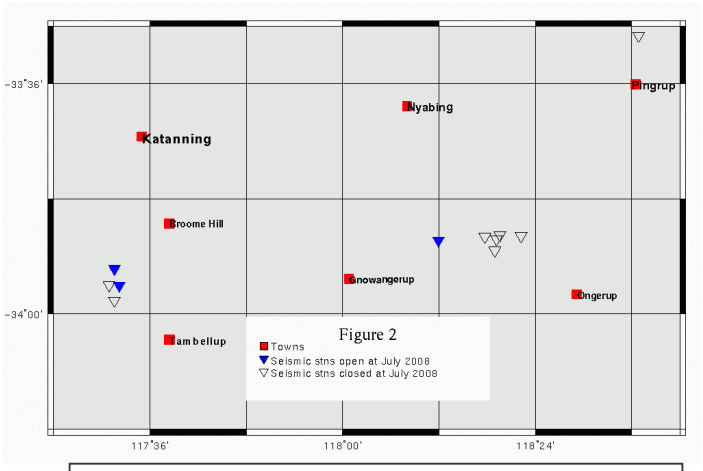


Figure 2 *Temporary Stations in Katanning area.*

In mid November 2007, a report was received on the University of Western Australia website (Appendix 1) that a local farmer was experiencing hundreds of small felt tremors at "Karingal" **(Figure 3),** located about 20 km NE of Gnowangerup and ~ 60 km east of the Katanning earthquake. Although this sequence began only one month after the Katanning event, it is probably unrelated to the Katanning event. Of the hundreds of events felt, only three events (ML 1.9, 2.3 and 1.8, see Table 1) were large enough to be located using the regional seismograph network. Because of the limited distribution of seismographs in the region, events below magnitude ~ ML 1.8 will not generally be located by GA routine analysis procedures. A review of the detection capabilities of Australian seismographic networks over time is currently in progress (Dent & Leonard in prep).

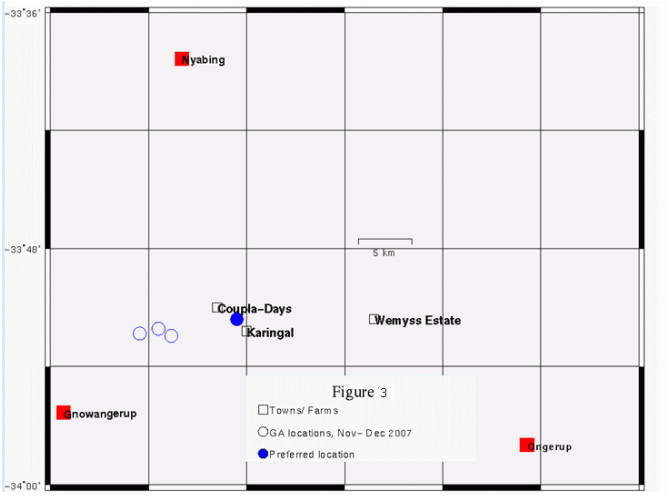


Figure 3 *GA located events near Karingal Nov/Dec 2007, and preferred location*

A seismograph was installed by the author at Karingal in late Jan 2008, using the low cost instrumentation and data communications as described by Dent *et al*., (2006).

The Karingal sequence has similarities to the Ongerup swarm of 1991 (Wemyss Estate, **Figure 3**), as reported by Dent (in Gregson & McCue, 1994) and is only about 10 km to the west of that swarm. The two sequences are similar in that the maximum event magnitude was in the mid ML 2 range, and that hundreds of smaller events were reported felt in the ensuing months. The Ongerup swarm was particularly well instrumented with portable digital recorders ("closed stations", Figure 2), although little has been since done with the data, principally because of the poor timing methods in use in 1991. The Ongerup swarm is briefly reviewed later in this paper.

Previous seismicity

The far south of Western Australia had a particularly poor distribution of seismographs until the establishment of the Rocky Gully station (RKG) in July 1983. Before that installation, the only seismograph in the region was at Narrogin (NWAO, established 1976), about 200 km north of RKG. This means that the earthquake catalogue in that region will be substantially incomplete prior to 1983.

Since 1983, some notable swarms have been recorded from NE of Gnowangerup, Nyabing, Pingrup and Dumbleyung, as well as Ongerup. These are noted in a report on recent Australian earthquake swarms (Dent 2008). In addition, an ML 3.7 event occurred about 20 km WNW of Gnowangerup in October 1996, and an isoseismal map for the event was prepared (McCue *et al*, 1999). The event appeared to be isolated, and no aftershocks were located.

Table 1

GA located events -33.5 - 34.5 and 117.0 – 118.5, Jan 2007- June 2008

Date	Origin Time	Magn	Long	Lat	Dep	REMARKS
09-10-07	23 58 40.58	**ML 4.8**	117.505	-33.946	0 G	
10-10-07	05 30 57	ML 1.9	117.496	-33.950	0 G	
14-10-07	06 29	ML 0.9	-	-	-	FELT, S-P 0.11at BH-C
14-10-07	06 40 21.57	**ML 2.0**	117.485	-33.956	0 G	GA located aftershock
14-10-07	06 40 21.24		117.5294	-33.9570	0.3	revised location
14-10-07	18 02 26	**ML 2.0**	117.501	-33.957	0 G	GA located aftershock
14-10-07	18 02		117.5294	-33.9570	0.3	Revised location
16-10-07	05 27					FELT, S-P 0.55 at BH-N
16-10-07	16 01					FELT, S-P 0.24 at BH-W
19-11-07	06 46 23	ML2.1	118.123	-33.874	0	Near Karingal
20-11-07	14 11 28	ML 2.3	118.11	-33.868	0	Near Karingal
03-12-07	16 31 18	ML 1.8	118.091	-33.872	0	Near Karingal
08-04-08	23 50 53	ML 1.5	118.284	-33.674	0	North of Karingal

Field seismic data from the Katanning event

A network of temporary stations in the epicentral area was set up on Oct 13th, about 72 hrs after the Mag 4.8 event. Three sets of digital instruments were used, two of which (BH-C and BH-N) are still operating (Aug 2008). The third set was used to record for relatively short periods at two other locations (BH-S and BH-W – see **Figure 4**). The seismograph at BH-C was located at Newlands, where the maximum Modified Mercalli intensities had been reported, and was a Kelunji ECHO, operating in continuous mode) BH-N (a Kelunji "D" series, operating in triggered mode) was sited at "Holmhurst", about 4 km north of BH-C.

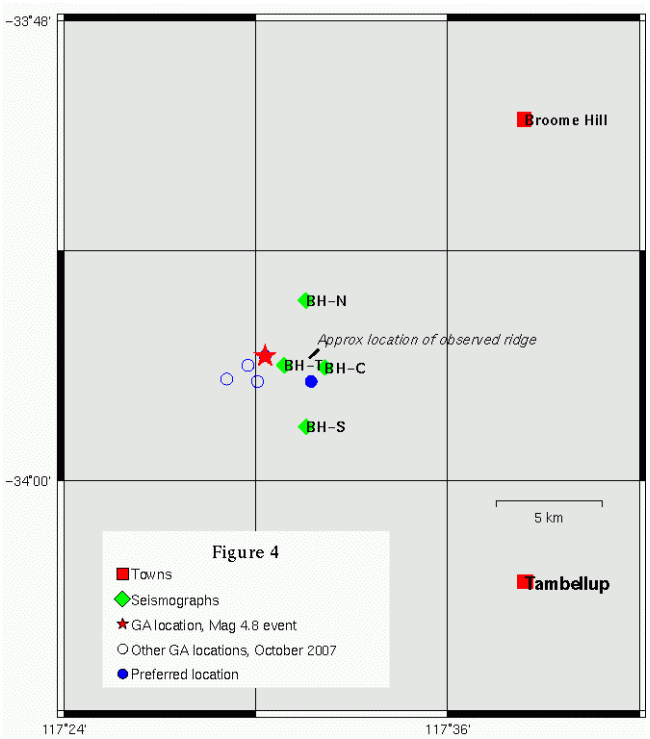


Figure 4 *Seismic stations and earthquake locations near Broome Hill*

Following the installation of BH-C, the farmer at "Newlands" started noting times of felt events, and instrumental data were collected for many of these, although the note-taking persisted only for a few days.

Fortunately, the field instruments were in place in time to collect instrumental data for two of only three aftershocks located by Geoscience Australia (on 14th Oct). However, a large number of smaller aftershocks were recorded by the

field stations. Parameters for the magnitude 4.8 event and the larger instrumentally recorded aftershocks are listed in Table 1.

The instrumental data acquired has been used to compute more accurate hypocentres for the two significant aftershocks on 14th Oct (Table 1). These accurately located aftershocks probably reflect the true location of the main (ML 4.8) event. If so, then the true location is about three km ESE of the original location, and about 0.7 km south of the feature identified by InSAR imagery.

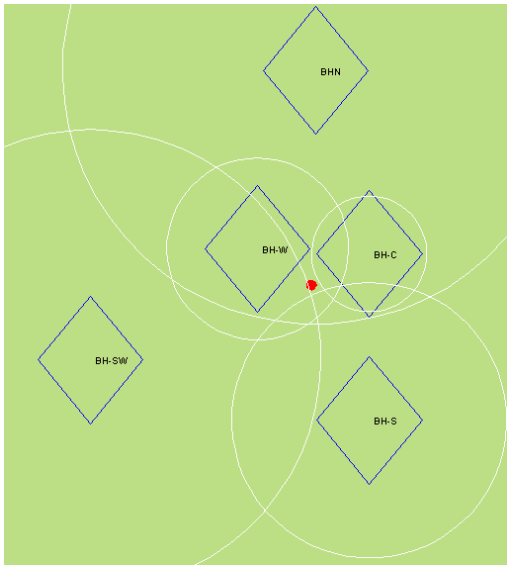


Figure 5 – *distances from stations determined by EQFOCUS using averaged S-P intervals*

The program used to relocate the epicentres was EQFOCUS (developed by ES&S, Melbourne), and the earth velocity model used was GIP2A, which was designed to suit the slow P wave velocities (4.0 km/s) in the sedimentary strata of Gippsland, Victoria. This was used because if the standard earth model for the region (WA2) is used to locate the events, the locations tend to rise above 0 km. The graphical output for the EQFOCUS solution is shown in **Figure 5**.

Because of the very short epicentral distances here, the influence of weathering means that the average seismic velocities are lower than what would apply regionally. The GIP2A model resulted in a focal depth of 0.3 km.

"Ground Truthing" of InSAR image.

Figure 6 – *figures standing on apparent ridge-line discovered in paddock at "Newlands"- looking to the SW.*

Without being aware of the InSAR image, the farmer at "Newlands" reported noticing a new "bump" in his wheat field after harvesting. This was investigated by the author in January 2008, and although the deformation was not obvious (**Figure 6**) the orientation of the apparent ridge was found to coincide (+/- 10m) with the position of maximum inferred deformation on the InSAR image.

The 45° strike observed for the ridge and InSAR image is consistent with other structural trends observed in the SWSZ (Dentith and Featherstone, 2003, Dent, this vol.)

It might be expected that the locations of the aftershocks would correlate more closely with the above ridge. The discrepancy may be attributable to several possible causes. The centre of activity may have migrated since the main shock occurred, the sample of aftershock studied may not be large enough to

reflect true aftershock distribution, or the aftershock locations may be deeper than the EQFOCUS solutions suggest, and the events may be occurring on a fault-plane dipping to the southeast.

Data from Gnowangerup (November 2007 – September 2008)

Geoscience Australia located only three events near Karingal, ~ 20 km NE of Gnowangerup, between Nov 2007 and Aug 2008, (Figure 3 & Table 1) although the farmer there reported feeling "hundreds" of events from 15 Nov 2007 (Appendix 1). The GA locations were ~ 15 km west of Karingal, but farmers near that location were not aware of the tremors.

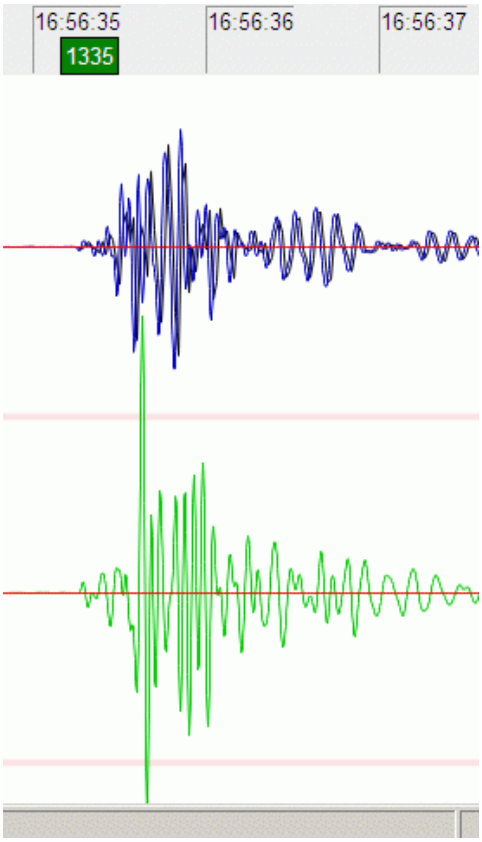


Figure 7 – *typical Gnowangerup event, 19 May 2008. Top trace = vertical component, lower trace = single horizontal component.*

In late January 2008 a low cost PSN (Public Seismic Network) recorder was installed at Karingal. Felt events were rare by this time. This installation was as described by Dent (2007) and has GPS timing, and records continuously at 200 samples per second. The compressed data are fed at hourly intervals, via the internet, to the Perth node of the Australian Centre for Geomechanics (ACG). The data can then be viewed via the internet, arrival times determined, and approximate magnitudes computed.

In the eight months following the installation of the seismograph, 22 probable local events have been recorded (Table 2). This is complicated by the fact that they are single station recordings, and distance and magnitude estimates rely on the identification of an S phase, which is not always clear. Many recordings are confirmed as being local events however because they correlate with felt reports from Mr Laurie. The S-P interval for most of the events recorded is about 0.25 secs suggesting a maximum epicentral distance of 2.5 km from the seismograph (assuming a focal depth of < 0.5 km). A typical recording is shown in **Figure 7**.

Since the GA locations of the November 2007 events were about 10 km due west of Karingal, a common location 2.5 km due west of Karingal has been used in Table 2 as the most likely location for the aftershocks. This is supported by the fact that the only other farmer in the area to notice the events was located at "Coupla-Days", ~5 km NW of Karingal.

Unfortunately, no earthquakes from the Gnowangerup swarm have been large enough to locate by the regional seismic network since the installation of the field recorder in Jan 2008. Consequently it has not been possible to compare locations from the regional and local networks for the same event.

Besides being close to the 1991 Ongerup swarm, the Karingal sequence is also relatively close to a swarm of six events, with magnitudes between 2.0 and 2.5, which occurred in Jan/Feb 1983. These events were located at -33.81, 118.1 i.e., about 10 km NW of the November 2007 swarm. This distance is less than the uncertainty in locations of the earthquakes.

DATE	GMT	S-P at Karingal	approx magn	Remarks
2007				
19 Nov	0646	--	**ML 2.1**	**GA loc**
20 Nov	1411	--	**ML 2.3**	**GA loc**
05 Dec	1631	--	**ML 1.8**	**GA loc**
2008				
12 Feb	2148	0.11	ML 0.2	
15 Feb	12 35	0.19	ML -0.13	FELT
20 Feb	2237	0.14	ML -0.27	
08 Apr	2350	3.8	ML 1.5	GA loc
12 Apr	1850	0.28	ML 0.6	
13 Apr	08 38	0.18	ML -0.14	
21 Apr	1639	1.0	ML 0.6	
23 Apr	0530	0.29	ML 1.1	
23 Apr	0533	0.3	ML 0.1	FELT
27 Apr	0507	0.16	ML 1.3	FELT
06 May	22 38	unclear		FELT
19 May	0852	0.29	ML 0.1	
19 May	0856	0.29	ML 1.2	
19 May	1251	0.19	ML 1.6	
25 May	1140	0.32	ML 0.4	
27 Jun	2332	unclear		
28 Jul	1729	0.15	ML 0.8	
03 Aug	0410	unclear		FELT
26 Aug	0807	0.22	ML -0.1	FELT
26 Aug	0812	0.18	ML -0.2	FELT
07 Oct	1735	0.22	ML 0.7	FELT
07 Oct	1835	3.6		FELT

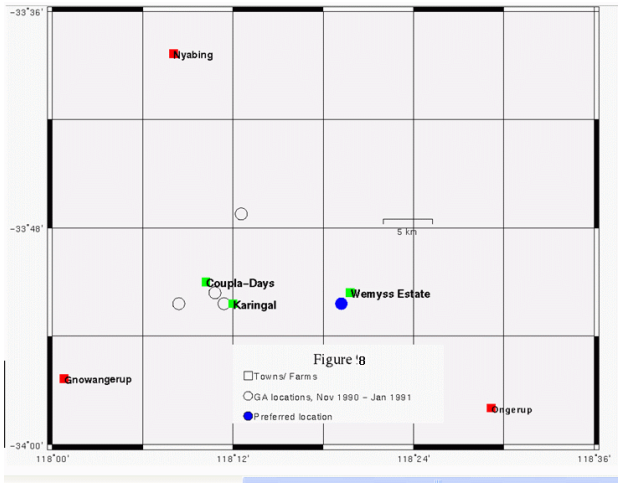
Table 2 – *Events instrumentally recorded at Karingal, Nov 2007 – Oct 2008*

It is interesting that although the magnitude determinations are only approximate, most of the events felt at Karingal after Jan 1998 have magnitudes significantly less than ML 1.0. Although described as "felt", the description provided by Mr. Laurie suggests "heard" might be a more accurate description. This is similar to the events experienced at Newlands, some of which were also observed by the author.

Data from Ongerup (Feb – April, 1991)

A sequence of small events, very similar to the swarm at Gnowangerup described above, was reported from the Wemyss Estate, about 20 km NE of Ongerup (**Figure 8**), beginning in November 1990. Up to 20 felt events per night were reported, and 30 small events were located, with a maximum magnitude ML 1.0 (Dent, 1994). This swarm was only about 10 km due east of the Gnowangerup swarm, which may account for their similar characteristics

As with the 2007 Gnowangerup events, GA located a few small events in the area in late 1990, which probably correlate with the start of the swarm (Table 3 and Figure 8), and the GA location puts them almost under Karingal, rather than under the location of the felt reports (about 10 km further east). Again, however, this is reasonable considering the low magnitude of the events and the poor seismographic network. The consistent size and direction of the error for both Karingal and Ongerup locations suggests a systematic bias, rather than just random error. This might indicate inadequacies in the earth velocity model used in the region. GA uses the model WA2 (Dent, 1990) for earthquake locations in Western Australia.



Up to four Kelunji recorders were deployed by the author in the area at various locations, and for differing time intervals between 5th Feb & 16th April 1991. At the time, GPS timing was not an option and large clock errors were recorded. Consequently only the S-P intervals are useful for locating the events. However, multiple arrivals on some stations makes phase identification uncertain (**Figure 9**).

Figure 8 *Locations of events northwest of Ongerup, 1990 -1991*

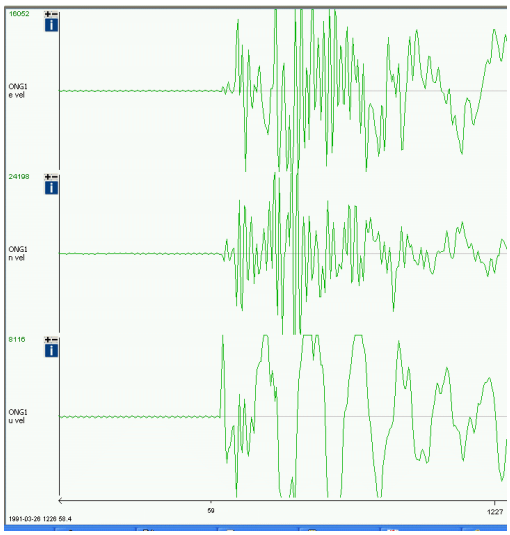


Figure 9 *Seismogram from Ongerup recorded in 1990, showing three probable phases within 0.2 secs of onset of event.*

Date	Origin Time	Mag	Long	Lat
22-11-90	08 19 52	**1.9**	118.14	-33.87
22-11-90	15 28 20	2.3	118.18	-33.86
22-11-90	15 29 53	**2.0**	118.19	-33.87
04-01-91	02 17 16	1.5	118.209	-33.787

Table 3 – *GA located events near the 1990-1991 Ongerup swarm, and preferred location*

Table 3 gives a list of some of the larger instrumentally recorded events in the Ongerup swarm. Some good quality digital wave form recordings were made during this survey and could provide an important resource for future research into micro-earthquakes in the region.

Discussion

While the Katanning sequence, from the main event onwards, behaves like a typical aftershock sequence, the foreshocks may have exhibited more swarm-like behaviour. In contrast, the Gnowangerup and 1991 Ongerup sequences are more typical of swarms, although in both cases, the only events large enough to be located by conventional procedures occurred at the very beginning of the sequences, which gives them main shock/ aftershock characteristics.

Further analysis of instrumental data collected at Katanning, and at Ongerup in 1991, could reveal more detail about the focal zones of these earthquakes, but an improved local earth model would be desirable before this is done. For the Gnowangerup events, the fact that the events are only recorded by one station means that little further processing can be done.

Logistic and budgetary considerations mean that today only the most significant aftershock or swarm events are visited with field instruments. Cheaper alternatives, like that being used at Gnowangerup are needed if useful data about our seismological environment are not to be missed.

Conclusions

Data from temporary field stations have helped reduce the uncertainties of the hypocentres for two recent seismic events in southern WA. They also confirm very shallow focal depths for the events. They may suggest that the fault plane for the Katanning event dips to the south east. They have also added confirmed events to a swarm north-east of Gnowangerup and helped establish its similarity to a nearby swarm in 1990-91.

Acknowledgments

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Appendix 1 – Initial report to UWA website from Ian Laurie (Karingal), 17/11/2007

"Significant tremors since Thu 15/11/07.Between 7-8pm Sat 17/11/07 15-20 tremors felt during the hour. Bangs booms & shudders. Still feeling shudders 3-4 times per hour as at 1.20 pm Sun 18/11/07.Earthquakes aside, this is the most activity we have felt in 30 years."

Report received 20 Nov 2007

First noticed on Thu. 15/11/07. Have had tremors here for all the time we have farmed here since 1968. But these tremors are definitely out of the ordinary. Probably between 10-20 per hour. Have counted 5 in 2 minutes. Since Thu. in excess of 600.

7-8pm WDST Sat 17/11/07 there was a run of 15-20 bigger tremors in the hour which shuddered buildings. Other times receive only 2-5 similar shudders per hour.

--- Intensity ---

Shudders .
Felt inside Buildings. Sharp shock felt through floors , walls and roof. With bang at same instant.
2-5 of these per hour. Up to 15-20 in an hour .Have had 2 in 2 minutes Had 3 while writing this email up to this point.

Bangs.
Felt inside and outside. Moderate noise inside , noticeable noise outside. Sharp noise like gunshot.
10 or more per hour.

Booms.
Felt mostly outside but also inside. More like booming noise. 5 or more per hour.

Other.
Have had mild shakes on occasions but these are not like a quake which is more like waves. During the Broomehill quake, the fridge was bouncing on the floor. During Meckering quake fridge bounced into room.

After 6 days these tremors are starting to get on my nerves.