A new seismograph network in the southwest seismic zone of Western Australia

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Introduction

The southwest seismic zone (SWSZ) of Western Australia was first identified by Everingham (1966), who termed it at the time "The Yandanooka Cape Riche Lineament", and it is now a well-established feature of Australian seismicity. The SWSZ is probably the most active seismic region in Australia, followed by the Flinders ranges region of South Australia. Geoscience Australia (GA) operates a national seismograph network (ANSN) with 15 stations in WA, 6 of which are in the region of the SWSZ (Figure 1). The beginnings of a new seismograph network in the SWSZ were described by Dent, Heal & Harris (2006) and Dent (2007). The first station in the network was established in early 2006 at the UWA Geology Museum, and the second was a temporary station at the Gingin Gravity Observatory (open July-Dec 2006), about 90 km north of Perth. Since then, the network has grown to 8 stations in the SWSZ, and two outside it (Figure 1).

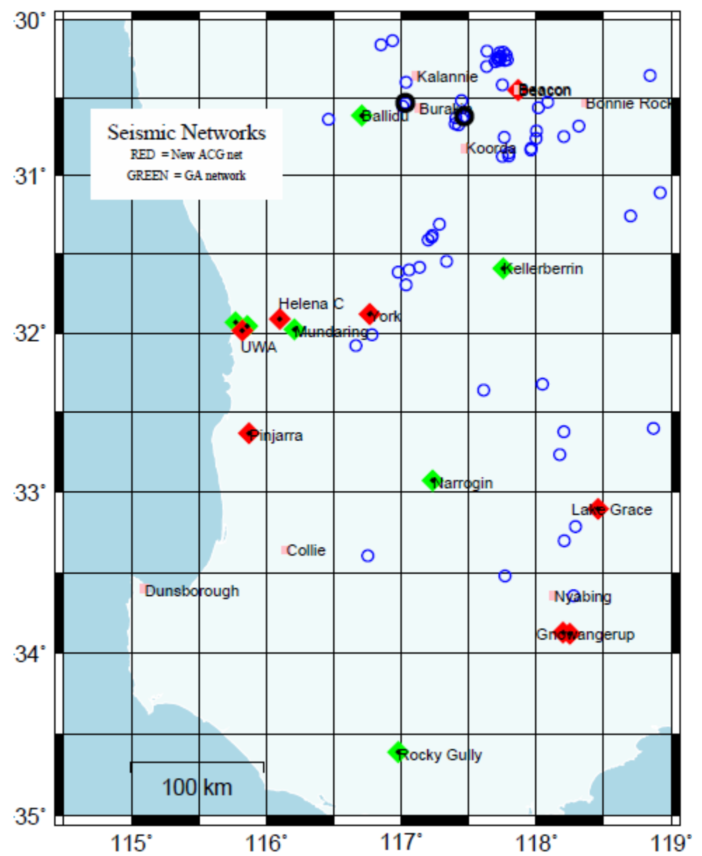

Figure 1 The ACG and GA networks in southwestern WA

The internet protocol that the network depends on was developed by the Australian Centre for Geomechanics (ACG), initially for monitoring mine seismicity, but separate "webpages" have been created to allow some regional coverage of natural earthquakes in Western Australia and NSW. The digitisers and amplifiers of the ACG network were purchased from Webtronics, Calif., and are thus similar to many "Public Seismograph Network" or PSN stations around the globe. However, the Australian network has been augmented by a sophisticated internet communications system developed by Paul Harris of the ACG.

In the ACG protocol, data from the stations (at 50 s/s) are posted to a central website every hour. When an event of interest is found by a user, they declare an "event", and the remote nodes are instructed to upload an interval of data at 200 s/s. Depending on the waveform, P and S waves can be accurately picked, and an approximate Richter magnitude (M_L) determined.

The data on the ACG webpages remain available indefinitely, unlike the Geoscience Australia data which are archived after approximately 2 months. The high sampling rate of the ACG networks also allows more accurate phase arrival picking than does GA data, which samples at 40 s/s.

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Access to the ACG website (www.regional-seismic.net) is password-protected, but access can be arranged for bona fide researchers. A second website (www.rsuw.daleh.id.au) gives photos and station details, and a log of events recorded, as well as current "drum-charts" from selected stations.

Sensors are normally 3 component Mark Products L-15B geophones (4.5 Hz). These have proved robust and reliable, and are quite sensitive to regional seismicity. The station Gnowangerup "B" has a Willmore Mark II seismometer, but does not show an improved detection capability to the geophone.

The ACG network described here is based in schools in the state education system, but other sites are also used (University of WA, and a farm northeast of Gnowangerup). The system is very low-cost, with a typical installation costing $500-$600. The schools are asked to provide internet services and a host computer. Running costs are negligible, except for the need for the occasional service visit, which generally depends on the computer knowledge of the local operator. It has not been necessary to visit the Beacon seismograph since its installation in March 2009.

The ACG network in the SWSZ

The ACG network in the SWSZ has been designed to complement the national network operated by GA, i.e., fill in the "gaps" in seismic coverage. Of the GA stations, Mundaring (MUN), which was established in 1959, was the longest running modern seismograph in Western Australia, although it was out of service between March 2008 and November 2010 due to vandalism. The Short Period (SP) seismometer at Narrogin (NWAO) has not been operational since early 2009.To some extent, two broadband "Joint Urban Monitoring Project" or JUMP stations in the Perth metropolitan area (CARL Carlisle and MTKN Mt Kenneth) have provided alternate data for Mundaring. The ACG stations at Beacon (March 2009) and Lake Grace (Sept 2010) help to monitor events in the far north, and southeast of the zone, in areas not currently well monitored by the GA network.

York (Aug 2007) was the second permanent station in the network, and is close to Meckering, and the periodically active swarm location southwest of York (Dent 2008b). Gnowangerup was added in Feb 2008 to monitor the recent swarm there, and Beacon (Mar 2009) for the swarm NW of that town. Helena College (Feb 2010) is relatively close to the GA Mundaring station. Three other stations were added in 2010, Pinjarra, GnowangerupB and Lake Grace, making a total of 8 stations in the network. It is hoped to add stations at Mukinbudin and in the Margaret River area in the future.

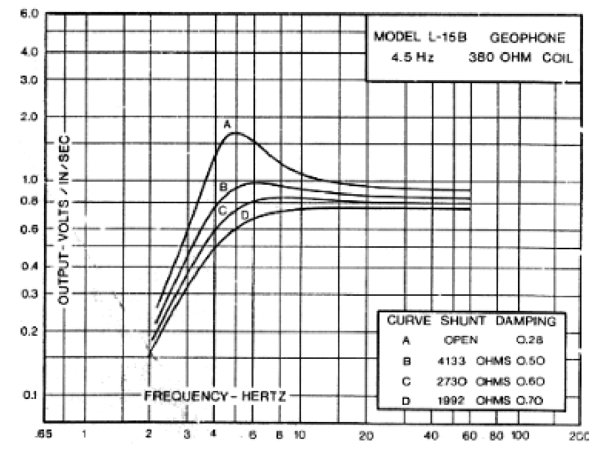

Figure 2 Response curves of L-15B geophone

Magnitude Calculations

Magnitudes can be calculated on the ACG website after a distance is determined by selecting P and S wave onsets, and "swiping" the maximum amplitude, but more work needs to be done to calibrate these values. The formula used incorporates the L-15B geophone response values shown in Figure 2, and assumes that the amplifiers are in the "low gain" setting. However, usually the "High Gain" setting has been chosen for this network because relatively low background noise levels permit it. The Richter Magnitude (M_L) therefore calculated is 0.6 of a unit too high.

Recent seismicity in the southwest seismic zone

Earthquakes with magnitudes $M_L \geq 2.0$ for the 18 month period May 2009 – Oct 2010 are plotted in Figure 1. After a period of very high activity northwest of Beacon in early 2009 (Dent 2009), this period has had relatively little seismicity, with only two events of ML ≥ 3.0– one north of Koorda (M_L 4.2) and the other west of Burakin (M_L 3.0). Both of these events occurred in recent significant swarm locations (Dent, this volume). Note an apparent northeast trend in epicentres between York and the Bonnie Rock area (about 60 km east of Beacon), which was also noted by Dent (2008a) in a review of Australian earthquake swarms, 1982- 2007.

Station details and Performance

Station coordinates and operational periods are listed in Table 1.

Because many of the stations are in schools, there is extra background noise, at least during school term. However, some schools have surprisingly low background noise (e.g. Beacon Primary). A descriptor of background noise levels is included in Table 1.

Table 1 Details of ACG stations in the SWSZ

Station	situation	Lat S	Long E	Perform	opened	Comments
UWA museum	museum	31.958	115.820	reliable	Apr 2006	Noisy
York	District High	31.8933	116.7603	intermittent	Aug 2007	U/S for long periods
Beacon	Primary	30.4511	117.8687	reliable	Mar 2009	quiet
Helena College	Senior High	31.9076	116.0909	reliable	Oct 2009	quiet
Pinjarra	Senior High	30.198	117.807	reliable	Feb 2010	noisy
Gnowangerup	farmhouse	33.8728	118.1999	reliable	Feb 2008	quiet
GnowangerupB	farmhouse	33.8796	118.2491	reliable	Feb 2010	~ 5 km E of GNOW
Lake Grace	District High	33.1036	118.4591	reliable	Sept 2010	noisy

Network successes

The new network has so far helped define centres of significant seismic activity near Beacon (Dent, 2009), and Gnowangerup, (Dent 2008b) as well as identify several events of $M_L > 2.0$ not located by GA.

The Beacon swarm, January 2009 onwards

This swarm commenced in late January 2009, and three temporary seismographs were installed in the region within the next few days. However, the closest recorder only operated for a matter of weeks. A PSN station (BEAC) was set up at the local Primary School in March 2009, and from then on was the closest station to the swarm centre (i.e. about 26 km SE of the swarm) and allowed a new set of improved hypocentral locations to be determined (Dent, 2009).

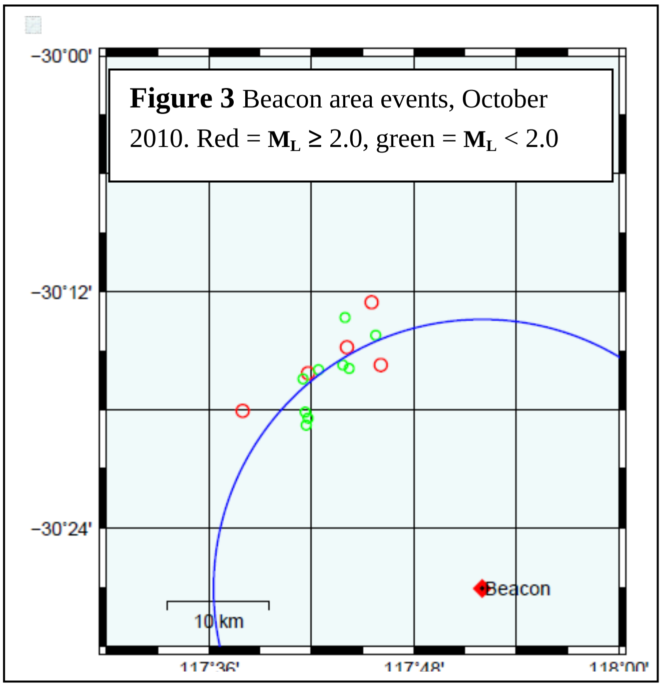

Figure 3 Beacon area events, October 2010. Red = $\mathbf{M_L} \geq 2.0$, green = $\mathbf{M_L} < 2.0$

Table 2 Beacon events, October 2010

Date	UTC	Lat S	Long E	M_L	Depth	BEAC S-P	M_L (Beac)	Comments
04 Oct 2010	2211	30.269	117.697	2.1	0C	2.89	2.0	
04 Oct 2010	2327	30.247	117.735	2.0	0C	2.91	1.9	
04 Oct 2010	2330	30.307	117.697	1.9	0C	2.87	1.3	
05Oct 2010	0142	30.222	117.733	1.8	0C	2.92	1.3	
05 Oct 2010	0540	30.266	117.707	1.8	0C	2.83	1.1	
05 Oct 2010	**0715**	**30.262**	**117.768**	**2.6**	**0C**	**2.93**	**2.5**	
05 Oct 2010	0724	30.301	117.633	2.4	0C	2.91	2.1	
05 Oct 2010	0728	30.313	117.695	2.0	0C	2.93	1.5	
05 Oct 2010	1005	30.265	117.737	1.9	0C	3.5	1.5	Double event?
05 Oct 2010	1153	30.302	117.694	1.9	0C	2.8	1.0	
16 Oct 2010	1515	30.237	117.763	1.8	5	2.76	1.5	
17 Oct 2010	**1053**	**30.209**	**117.759**	**2.9**	**0C**	**2.90**	**2.9**	
17 Oct 2010	1210	30.237	117.763	1.6	0C	2.83	1.5	
24 Oct 2010	0910	30.262	117.731	1.8	0C	2.89	1.3	

Occasional minor events at the swarm location have continued into 2010, and a minor burst of activity occurred on Oct 4th & 5th, 2010 (Table 2 and Figure 3). The circles shown on Figure 3 and subsequent figures indicate the epicentral distances computed from the S-P times. Figure 4 shows three events recorded on the Beacon seismograph between 0715 hours and 0730 hrs (UTC) on 5th Oct 2010. The fast sampling enables accurate picking of the S-P times, as shown on Table 2 and Figure 5. The S-P

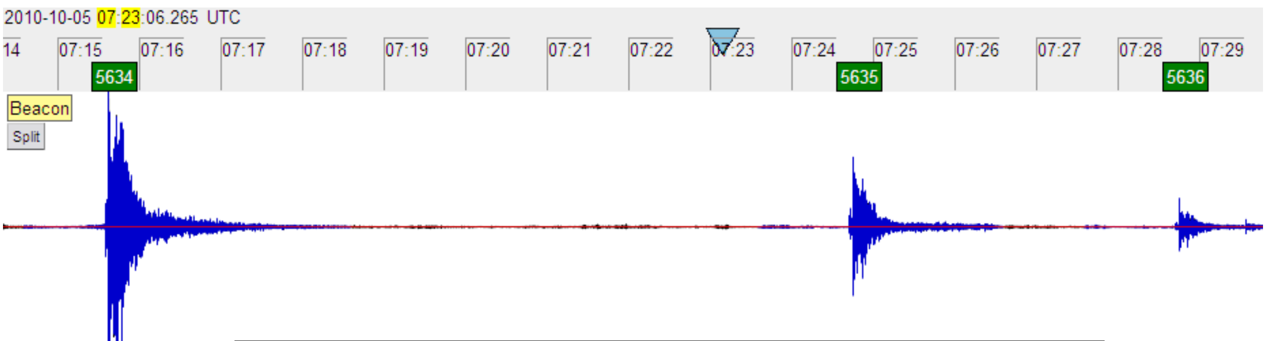

Figure 4 Three Beacon events on 5th Oct 2010, M_L's 2.6, 2.4 & 2.0

times are all very close to 2.9 seconds (other than the event at 1005 hrs on Oct 5th, which may be a double event), which equates to an epicentral distance of 27 km (Figure 3). It also indicates that the events are much more tightly grouped than the GA solutions suggest and that the centre of activity has not migrated since the major activity of early 2009, which was centred on 30.22S, 117.75E (Dent 2009).

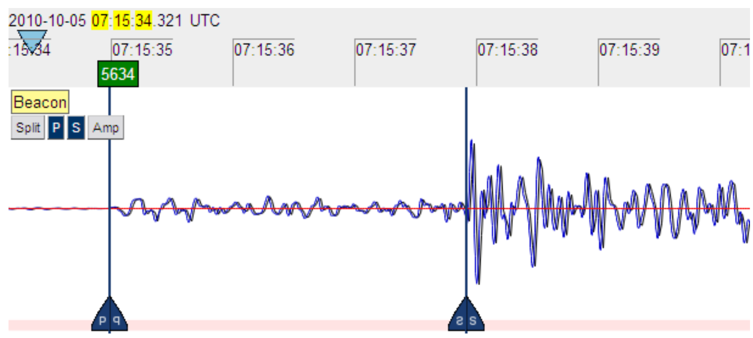

Figure 5 Beacon event 5th Oct showing S-P of 2.93 secs.

The Gnowangerup swarm, November 2007 onwards

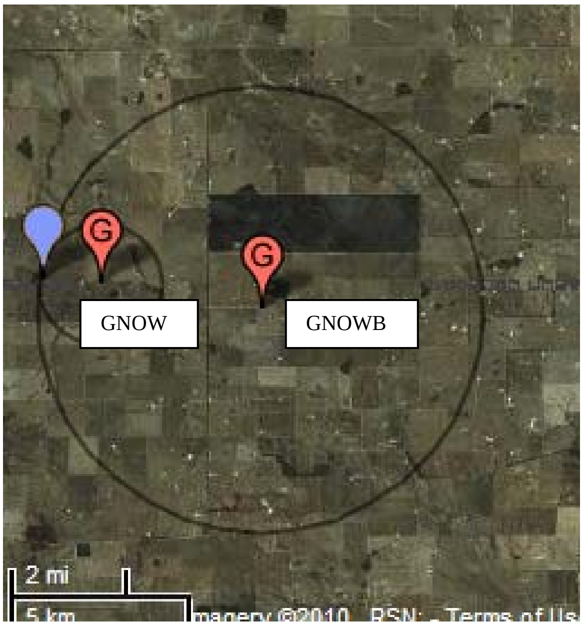

Figure 6 Location of Gnowangerup swarm events

A swarm of hundreds, if not thousands of small felt events occurred northeast of Gnowangerup in November – December 2007 (Dent 2008b), but only three events were locatable by GA, the largest being M_L 2.3 (Table 3), and these locations were relatively poorly constrained. The station at Gnowangerup (GNOW) was installed in March 2008 and subsequently recorded a number of small events, not detected by GA. The S-P times indicated they were about 2 km from the recorder, but the direction was uncertain. However, the station GNOWB, co-recorded two events in May 2010, and another in Sept 2010, and the combined S-P time data (Figure 6) indicated that the probable epicenter was about 2km west of GNOW. This is about 6 km east of the GA locations, and suggests the GA locations are in error by this amount.

Table 3 Located events of Gnowangerup swarm

Date	UTC	Lat S	Long E	M_L	Depth	Auth	Comments
19 Nov 2007	0646	33.874	118.123	2.1	0C	GA	GA location
20 Nov 2007	1411	33.868	118.110	2.3	0C	GA	GA location
03 Dec 2007	0631	33.872	118.091	1.8	3C	GA	GA location
29 May 2010	2152	33.872	118.182	~1.2		ACG	
30 May 2010	1041	33.871	118.179	~0.7		ACG	
28 Sep 2010	2209	33.870	118.181	~0.1		ACG	
15 Nov 2010	2329	33.869	118.173	~1.6		ACG	

Events southwest of York

Figure 7 Locations of York events

Three small events were located by GA near York in mid-February, 2010 (Table 4). Unfortunately, the York recorder was operating intermittently and only recorded the last and smallest of these events (1211 UTC on 24 Feb 2010, M_L 1.3). The GA location for the event (red marker), and of the largest of the two earlier events (green marker) are shown on Figure 7, along with the epicentral distance as suggested by the S-P time on the York recorder. Also shown is the average location of swarm events from November 1994 (blue marker). It can be seen that the

February 2010 events are more probably located at the location of the 1994 swarm than the location given in the GA "Quakes" data base.

Some of the smaller events in 1994, and later in 1996, were accurately located with the aid of close temporary seismographs (Dent, 1998). Two of these good locations are included in Table 4.

This area has been the source of some major earthquakes swarms in the 1950's and 60's, if not earlier (Everingham 1968, Everingham & Tilbury, 1972), and is often referred to as the "Talbot Brook" area.

	Table 4 – locations of events southwest of York						
Date	**UTC**	**Lat**	**Long**	**Depth**	**M_L**	**Auth**	**Comments**
23 Nov 1994	2053	31.97	116.736	5C	3.0	GA	
24 Nov 1994	2003	31.98	116.728	5C	3.0	GA	
29 Nov 1994	1431	31.97	116.719	1C	2.6	VFD	Recorded on YK2 & YK3
18 Sep 1996	2335	31.97	116.724	1C	3.1	GA	
01 Oct 1996	1711	31.97	116.735	0C	2.0	VFD	Recorded on YK2 ,YK3 & YK5
2010 events							
19 Feb 2010	1424	32.01	116.784	0C	2.0	GA	
19 Feb 2010	1831	32.08	116.665	0C	2.1	GA	
24 Feb 2010	1211	31.90	116.805	10C	1.3	GA	

Earthquakes near Pingrup

The new Lake Grace seismograph is well positioned to assist in the location of events in the Pingrup area, and the station recorded several small events there on 16th Sept, 2010, which were below the detection threshold of the GA network (Table 5). The seismographs near Gnowangerup have helped to define the epicentral region of the largest of the events (Figure 8). This figure suggests that the events may be originating from the same location (33.57S, 118.34E) as a significant earthquake swarm in July 1989 (Dent 2008)

Table 5 **Notable Lake Grace & Pingrup events**

Date	UTC	Latitude	Longitude	M_L	Depth	Auth	Comments
23 Jul 1989	0120	33.567	118.334	2.2	1	GA	1989 swarm event
26 Jul 1989	0914	33.568	118.340	2.7	1	GA	1989 swarm event
26 Jul 1989	0922	33.573	118.337	2.7	1	GA	1989 swarm event
26 Jul 1989	0940	33.580	118.347	2.8	1	GA	1989 swarm event
13 Aug 1989	1254	33.585	118.343	2.9	1	GA	1989 swarm event
08 Apr 2008	2350	33.674	118.284	1.5	0	GA	
14 Nov 2009	2124	33.213	118.219	2.3	16	GA	~ 22 km SW of Lake grace
12 May 2010	1109	33.646	118.278	2.6	4	GA	
16 Sep 2010	1843	33.580	118.340	0.8		ACG	Recorded at Lake Grace
16 Sep 2010	1847			0.7		ACG	Not locatable
19 Sep 2010	0151			1.1		ACG	Not locatable
26 Sep 2010	2042			0.6		ACG	Not locatable
30 Oct 2010	0728	33.634	118.210	1.5	4	GA	~ 20 k SE of Nyabing
30 Oct 2010	2335	33.303	118.208	2.8	2	GA	~ 30 k SW of Lake Grace

Educational aspect

While most schools seem keen to host their seismographs, and the teachers are curious about their new toy, more teacher education is needed for follow-on into the class-room situation.

Summary

For a budget-priced network, this has been surprisingly useful. Given the low cost of stations, it is anticipated that new stations may be added in the eventuality of future significant earthquake swarms in the region. The ACG plans to add further functionality to website seismic processing, e.g. automatic event detection, soon.

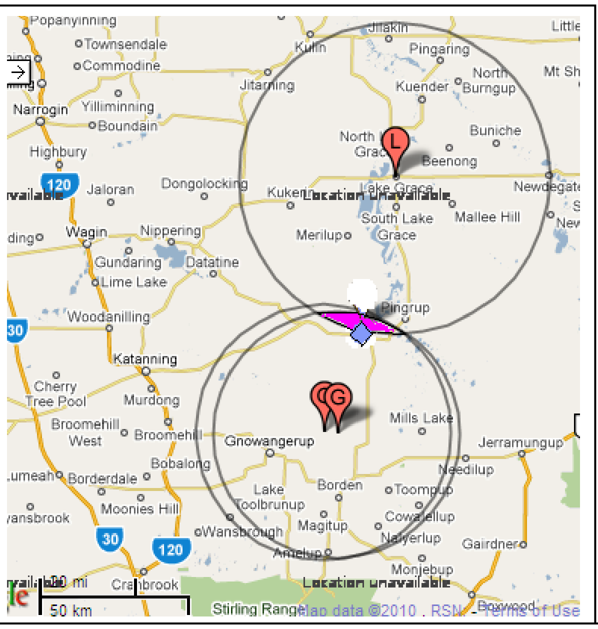

Figure 8 Pink zone – probable location area of event 16-9-2010 @ 1843hrs GMT. Blue diamond – location of Pingrup earthquake swarm, July 1989

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