CENTRAL QUEENSLAND SEISMOLOGY RESEARCH GROUP

CQSRG Seismological Report 2016

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Introduction

This report details earthquakes detected and located by the Central Queensland Seismology Research Group (CQSRG) during the 2016 calendar year. Technical summaries of earthquakes that occurred or were felt in Central Queensland are provided. The date and time of earthquakes noted in this report are provided in Universal Coordinated Time (UTC).

CQSRG was established in 2002, under the auspices of the Faculty of Informatics and Communication of Central Queensland University (CQU), with Michael Turnbull (Lecturer, and later Adjunct Research Fellow) and Kevin McCue (Visiting Professor, and later Adjunct Professor) as the designated researchers. This affiliation with CQU continued until February 2013, when, due to a divergence in academic focus of CQU and CQSRG, the researchers allowed their Adjunct appointments to lapse. From February 2013 until December 2016, CQSRG operated independently of CQU, with the same two people conducting the research. In mid-2016 Dr Andrew Hammond, Senior Lecturer in Geology at CQUniversity, joined CQSRG as a research collaborator. Mike Turnbull's and Kevin McCue's adjunct academic appointments with CQUniversity were re-established in October 2016.

During the 2016 calendar year CQSRG operated one seismic monitoring station, designated FS03. Details of this station, including location and equipment, are provided in Appendix A. This report contains information relating to earthquakes detected by the FS03 seismic monitoring station.

CQSRG locates and quantifies earthquakes using the methods detailed in Appendices B, C and D.

FS03 Uptime 2016

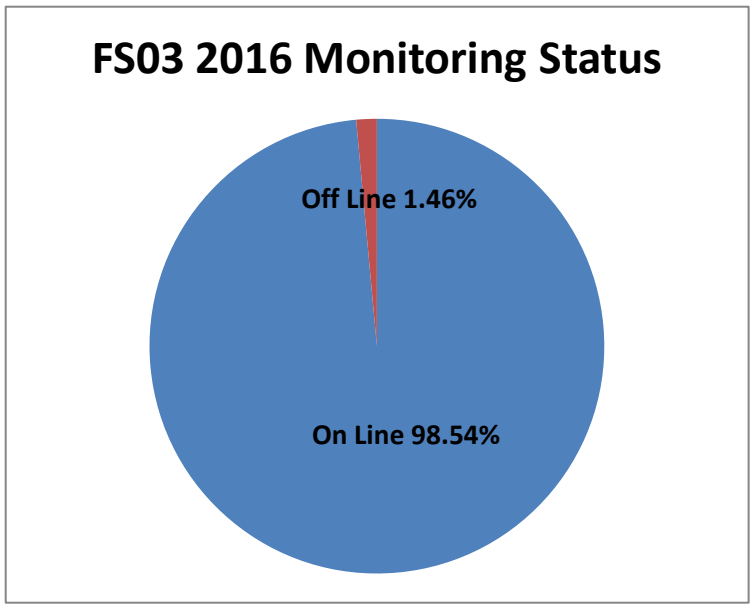

Figure 1: Percentage Uptime/Downtime of FS03 during 2016.

Throughout the 2016 calendar year the FS03 station was actively monitoring for seismic events over 98% of the time.

This high proportion of availability was due to automation of the data download process, and the provision of an RS232 serial data radio link to the station in April 2015.

Most of the down time was comprised of data download time.

The FS03 station itself had no downtime from power outages or any other equipment failures for the entire year.

Significant Earthquake Events Detected During 2016

Significant Event Sequences

Aftershock earthquakes associated with the February 2015 Mt Perry, and the July 2015 Rainbow Beach sequences continued throughout 2016.

On 18 August 2016 a significant M 5.8 earthquake occurred 63 km north east of Bowen, in the Whitsunday Passage waters north of Airlie Beach. This resulted in numerous aftershocks.

Continuing Mount Perry Earthquake Sequence

At 2015-02-15 15:57:08.74 UTC, a local magnitude 5.0 event occurred about 26 km NW of Mt Perry. CQSRG named it the **2015 Mt Perry Earthquake**.

Aftershock earthquakes occurred throughout 2015, and continued during 2016.

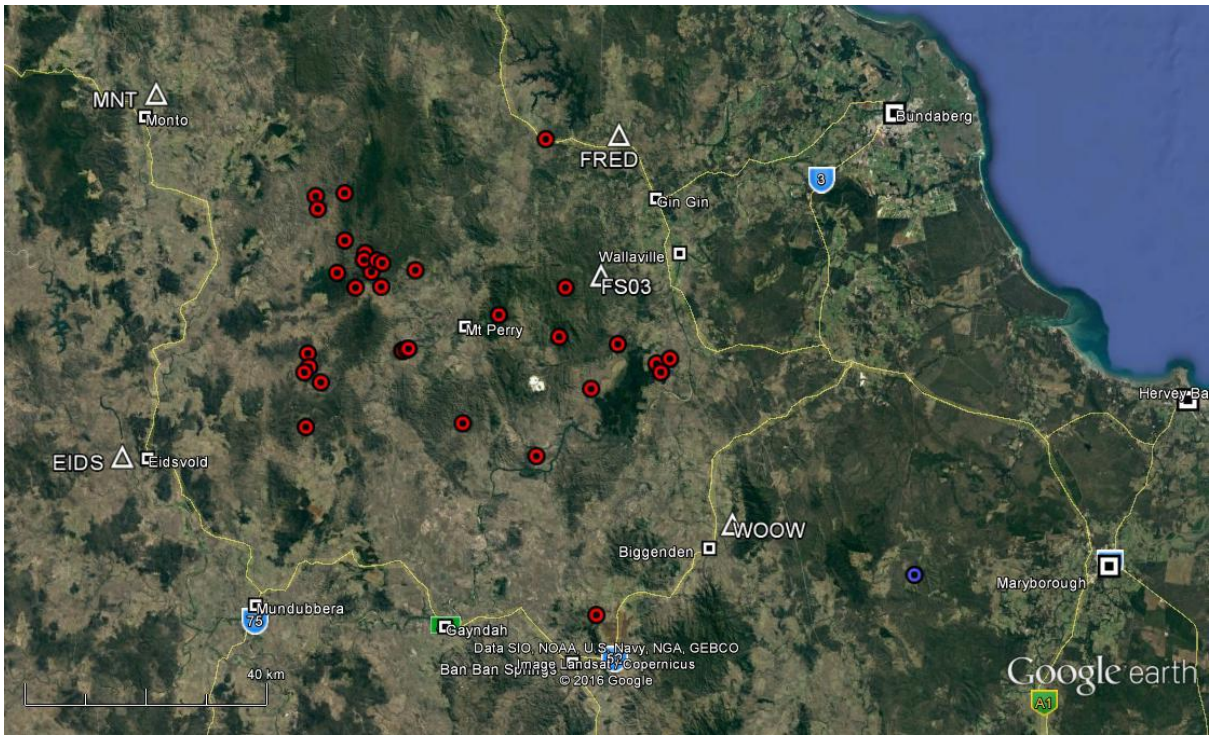

Figure 2: Mt Perry sequence aftershocks during 2016.

Table 1: Mt Perry sequence area background earthquake count 2004 to 2014.

Year	Count
2014	1
2013	4
2012	4
2011	6
2010	6
2009	0
2008	4
2007	13
2006	3
2005	2
2004	5
Average	4.4

As shown in Figure 2, 22 aftershocks events in the Mt Perry sequence were recorded during 2016, ranging in magnitude from M 3.0 to M 0.6. This compares to a background average of 4.4 events per year recorded during the 11 years prior to the main earthquake in 2015, as shown in Table 1.

Aftershock earthquakes continue to occur in the target area, but at a reducing rate, and gradual reduction in average magnitude, as shown in Figure 3.

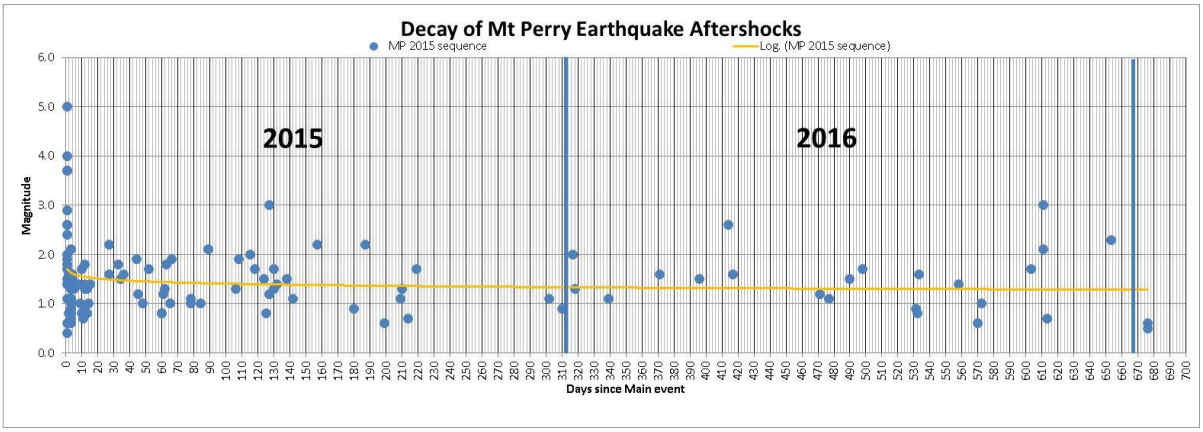

Figure 3: Logarithmic decay of the Mt Perry 2015 earthquake sequence.

Unlike the 2015 Rainbow Beach sequence, the 2015 Mt Perry sequence is ongoing, with no indication that it will halt in the near future.

Continuing Rainbow Beach Earthquake Sequence

At 2015-07-29 23:41:42.24 UTC a local magnitude 5.7 event occurred, out to sea, about 115 km NE of Rainbow Beach. CQSRG has named it the **2015 Rainbow Beach Earthquake**.

This event was followed two days later by an ML 5.2 event at 2015-08-01 03:38:44.06 UTC; and an ML 5.0 event at 2015-08-01 04:46:23.24 UTC. Although these two events could arguably be termed main events in their own right, CQSRG has chosen to classify them as aftershocks of the 2015 Rainbow Beach Earthquake.

The main ML 5.7 event was reported in the media as having been felt as far south as the New South Wales border, west to Gayndah, and north to Rockhampton. The following two greater than ML 5.0 events were also reported as having been felt down to Brisbane.

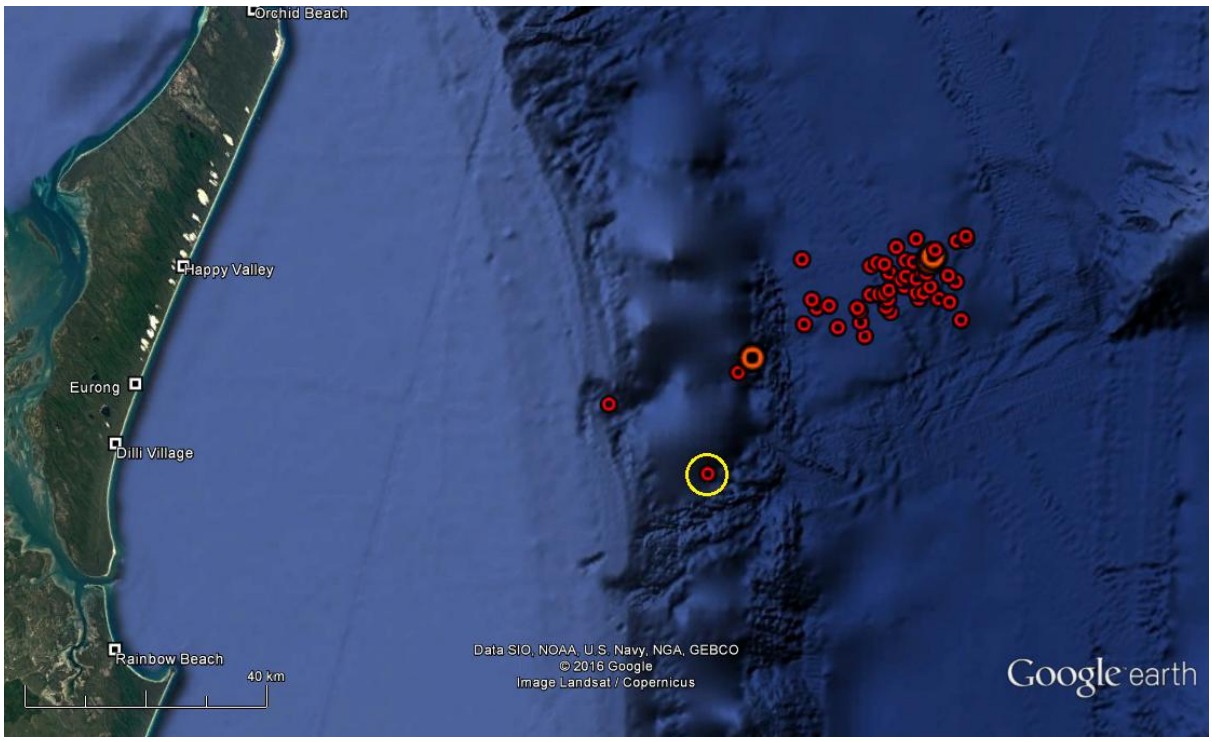

Figure 4: 2015 Rainbow Beach earthquake sequence as at the end of 2016.

Up to the end of 2015, 51 aftershocks had been recorded, including the two greater than ML 5.0 events. During 2016 only one aftershock was recorded, an M2.5 on 2017-08-11 at 17:41.

Figure 3 is a map of the 2015 Rainbow Beach Earthquake sequence, as located by CQSRG. The orange marker at the south west end of the sequence is the main event. The two orange markers at the north east end are the other two greater than ML 5.0 events. The event circled in yellow is the 2016 aftershock.

Figure 4 is a graphic depiction of the aftershocks of the 2015 Rainbow Beach Earthquake up to the end of 2016. The red markers show the magnitudes of the individual events as a function of time in days after the main event. This aftershock sequence is referred to within CQSRG as the **RB 2015 sequence**.

It was noted in 2015 that the average magnitude of aftershock events in the RB 2015 sequence was increasing, which was unusual. The single aftershock in 2016 provided clarification that, in fact, the average magnitude of the aftershocks was not increasing – at least, not significantly. Reference to Figure 4 shows that the average magnitude of the aftershock sequence has leveled out at about M 3. Figure 4 also shows that the time between aftershock events has blown out to an order of about 200 days. If no further events are recorded in this area it may be considered that the sequence has halted.

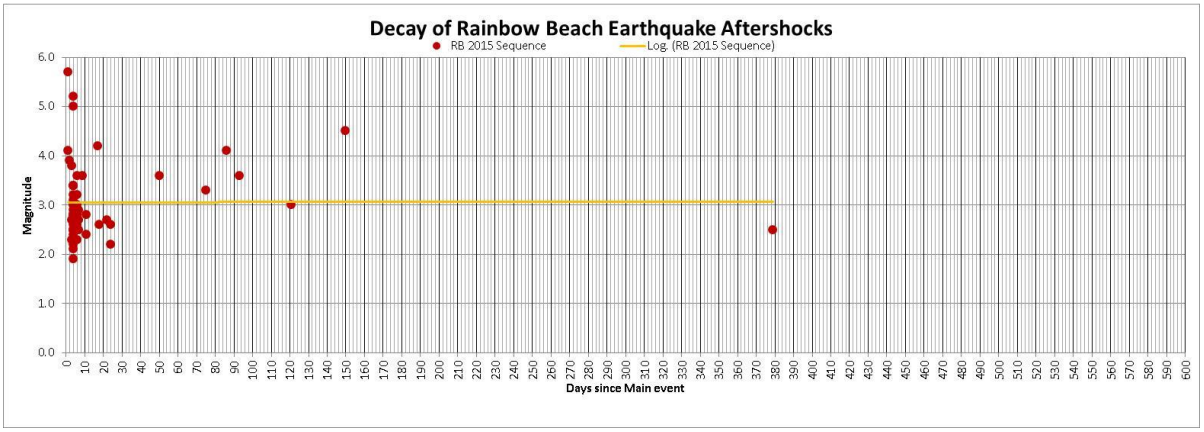

Figure 5: Logarithmic decay of the Rainbow Beach 2015 earthquake sequence.

The RB 2015 sequence is a typical example of an area in Australia where significant earthquake events and aftershock sequences have occurred despite there having been no record of earthquakes in that area in previous history. In 1918 there was a magnitude 6.0 earthquake, reported to have occurred in the vicinity of Lady Elliot Island. The dubious location of that 1918 event was made from seismograms recorded as far away as Egypt and Java. The nearest recording was made in Sydney. It may well be that the 1918 event occurred in the same area as the 2015 events; however, that may never be known for sure.

Bowen Earthquake Sequence

On 2016-08-18 at 04:30 UTC an M 5.8 earthquake occurred 63 km north east of Bowen in the Whitsunday Passage. This was followed over the next three weeks by 77 aftershocks ranging from M 1.6 to M 4.2; however there were many more aftershocks of magnitudes below M 1.6 that have been identified by CQSRG in the Bowen Joint Urban Monitoring Program (JUMP) site (BW1H) seismic records but have not been located. This sequence of events is known within CQSRG as the **2015 Bowen Earthquake** and Aftershock Sequence (BW 2016). A map of the earthquake locations is presented in Figure 5.

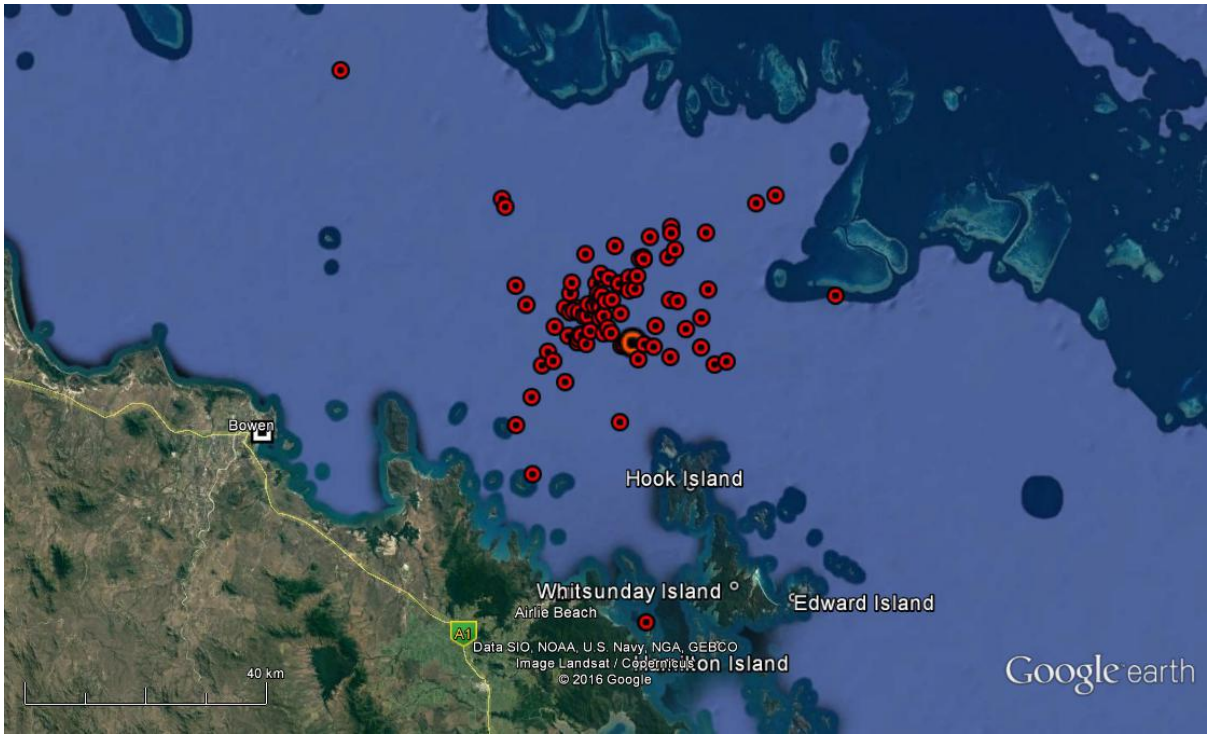

Figure 6: The 2016 Bowen earthquake sequence.

The region of the BW 2016 sequence lies outside the primary area of CQSRG research, which only extends to just north of Rockhampton. Figure 7 shows the decay of the 2015 Bowen sequence over the first 150 days.

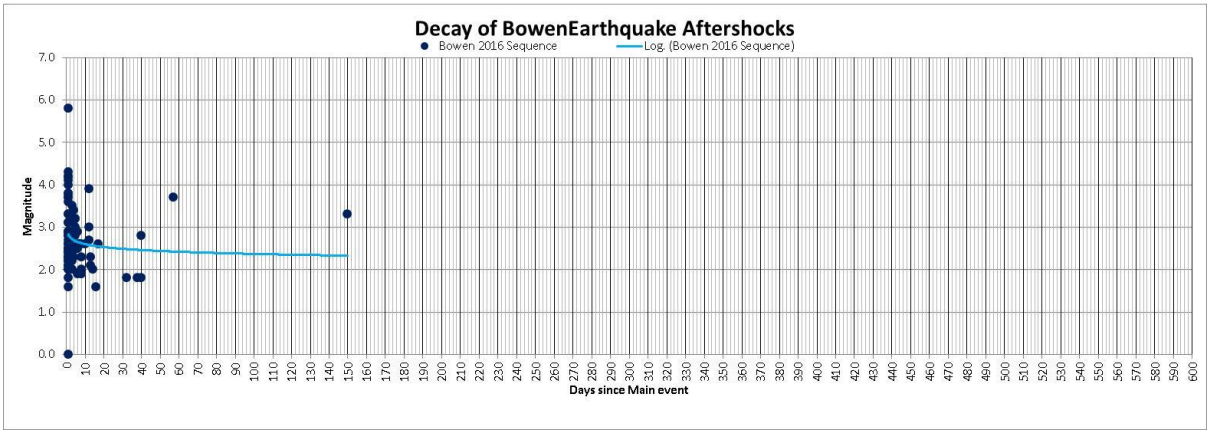

Figure 7: Decay of the 2016 Bowen earthquake sequence.

The Seismological Importance of the BW 2016 Event

The BW 2016 main event is arguably the second largest earthquake to have been recorded on the east coast of mainland Australia since the European arrivals. Consequently, in an Australian historical context, it is a very significant event.

The seismological history in Queensland from the late 1800s to the present time indicates that there are three principal seismogenic areas – the Mt Perry area, the Rainbow Beach to Lady Elliot Island area, and the Whitsunday Passage area. Although numerous other minor earthquakes have been recorded that sit outside the immediate core of these three areas, the historical record shows that these three areas have produced by far the largest number of earthquakes of greater than M 3.5 magnitude.

Further Observations of Significant Queensland Earthquakes

On 2016-09-22 at 09:21 UTC an M 3.1 earthquake occurred 70 km south of Morven in south western Queensland. On 2017-01-22 at 15:34 UTC an M 3.2 earthquake occurred 92 km south west of Thargomindah. Several other earthquakes with magnitudes above M 3.0 have been recorded in the region from Thargomindah in the west to St George in the east.

The fact that these events of magnitudes greater than M 3.0 are occurring, and only have been recorded in relatively recent times (since about 2011) may be an indication that that region is becoming seismically active. It can further be reasonably inferred that relatively more, perhaps that many more, earthquakes of lesser magnitudes are occurring in that region but are not being noted in the State's earthquake catalogues.

Given the existence of an expansive Coal Gasification industry in the eastern extent of the identified region, and the documented expectation that that industry will migrate to the western extent over the next 10 to 50 years, there is a need to do more detailed earthquake monitoring in western Queensland. The only Queensland based seismic monitoring stations in the south western region are at Roma and Quilpie. There are no monitoring stations between Roma and Toowoomba, and the JUMP station at Toowoomba does not provide any data that is of sufficient quality to be usable in earthquake locations.

CQSRG Earthquake catalogue 2016

During 2016, 137 earthquake events were detected and catalogued by CQSRG. Details of these events are provided in Table 1. The online full version of the CQSRG catalogue can be accessed at http://www.cqsrg.org.

It should be noted that the 2016-05-20 18:14 M 6.1 event in the Northern Territory was included in the CQSRG catalogue despite the event not being located in Queensland. This event was well recorded on the CQSRG FS03 station due to its high magnitude.

It should also be noted that, although the main M 5.8 Bowen event and many of the listed aftershocks were well recorded on the CQSRG FS03 station, numerous other aftershocks that are listed in the CQSRG catalogue were not principally detected on the CQSRG network. Most of those aftershock events were identified by manual inspection of the daily records obtained off the BW1H Joint Urban Monitoring Program (JUMP) station at Bowen. Careful inspection of the daily records was conducted for only three weeks following the main event. This identified 79 aftershocks in the range from M 1.6 to M 4.8. However, aftershocks in the range M 2.8 to M 3.9 are still being detected on FS03 seven months after the original event.

It is also noted that the depth has been constrained to the local norm where the EQLOCL algorithm could not calculate a depth, due to lack of vertical resolution. Due to FS03 being off line at the time, magnitudes of the Mt Perry earthquake and aftershocks occurring on 2015-02-15 and 16 were determined using EIDS records, according to the method described in Appendix D.

Table 2: Earthquake Events Detected by CQSRG during 2016.

Date (UTC)	Time (UTC)	Longitude	Latitude	Depth	Depth Status	Magnitude	Event Type	Place	Comment
2016-12-30	00:20:40.07	150.852	-25.501	10.0 km	Constrained to local norm	1.7 ML	Earthquake Mainshock	Eidsvold	31 km SW Eidsvold. Reviewed 2016-12-30.
2016-12-26	12:28:33.36	153.271	-25.213	10.0 km	Constrained to local norm	2.5 ML	Earthquake Mainshock	Fraser Island	55 km E Hervey Bay, East coast of Fraser Island. 2 km S of Cathedrals Caraval Park with 500 residents and not felt. Reviewed 2016-12-27.
2016-12-13	15:33:28.49	152.678	-24.336	10.0 km	Constrained to local norm	2.1 ML	Earthquake Mainshock	Lady Elliot Island	24 km SW Lady Elliot Island Reviewed 2016-12-13.
2016-12-13	08:55:21.13	151.403	-24.985	10.0 km	Unconstrained	2.3 ML	Earthquake Aftershock	Mt Perry	Aftershock of 2015-02-15 15:57 event. 33 km NW Mt Perry. Reviewed 2016-12-13.

Date (UTC)	Time (UTC)	Longitude	Latitude	Depth	Depth Status	Magnitude	Event Type	Place	Comment
2016-10-28	20:39:24.31	151.483	-25.07	10.0 km	Constrained to local norm	0.7 ML	Earthquake Aftershock	Mt Perry	Aftershock of 2015-02-15 15:57 event. 20 km NW Mt Perry. Reviewed 2016-10-29.
2016-10-26	16:55:28.11	151.493	-25.098	10.0 km	Constrained to local norm	2.1 ML	Earthquake Aftershock	Mt Perry	Aftershock of 2015-02-15 15:57 event. 18 km NW Mt Perry. Reviewed 2016-10-27.
2016-10-26	16:18:09.10	151.467	-25.121	10.0 km	Constrained to local norm	3.0 ML	Earthquake Aftershock	Mt Perry	Aftershock of 2015-02-15 15:57 event. 19 km NW Mt Perry. Reviewed 2016-10-27.
2016-10-18	01:54:33.63	151.55	-25.213	10.0 km	Constrained to local norm	1.7 ML	Earthquake Aftershock	Mt Perry	Aftershock of 2015-02-15 15:57 event. 10 km sW Mt Perry. Reviewed 2016-09-19.
2016-10-13	13:12:41.99	148.96	-19.735	10.0 km	Constrained to local norm	3.9 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 81 km NE Bowen. Reviewed 2016-10-14.
2016-10-10	00:35:53.55	151.761	-25.372	10.0 km	Constrained to local norm	1.4 ML	Earthquake Mainshock	Mt Perry	24 km SE Mt Perry. Reviewed 2016-10-10.
2016-10-05	10:31:57.91	151.851	-25.273	10.0 km	Constrained to local norm	0.9 ML	Earthquake Mainshock	Mt Perry	23 km SE Mt Perry. Reviewed 2016-10-10.
2016-09-26	21:54:41.74	148.898	-19.919	10.0 km	Constrained to local norm	3.3 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 69 km NE Bowen. Reviewed 2016-09-27.
2016-09-26	12:15:25.49	148.789	-19.843	10.0 km	Constrained to local norm	3.7 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 60 km NE Bowen. Reviewed 2016-09-27.
2016-09-24	17:29:14.61	153.096	-23.843	10.0 km	Constrained to local norm	2.4 ML	Earthquake Mainshock	Lady Elliot Island	49 km NE Lady Elliot Island. Reviewed 2016-09-25.
2016-09-24	10:26:02.12	148.751	-19.893	10.0 km	Constrained to local norm	2.8 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 55 km NE Bowen. Reviewed 2016-09-28.
2016-09-24	08:21:31.45	151.675	-27.759	10.0 km	Constrained to local norm	2.2 ML	Earthquake Mainshock	Pittsworth	6 km SE Pittsworth. Reviewed 2016-09-28.
2016-09-22	09:26:14.54	147.277	-27.044	10.0 km	Constrained to local norm	3.1 ML	Earthquake Mainshock	Morven	72 km S Morven. Reviewed 2016-09-23.
2016-09-20	13:34:28.38	153.892	-23.284	10.0 km	Constrained to local norm	3.6 ML	Earthquake Mainshock	Lady Elliot Island	150 km NE Lady Elliot Island. Reviewed 2016-09-20.

Date (UTC)	Time (UTC)	Longitude	Latitude	Depth	Depth Status	Magnitude	Event Type	Place	Comment
2016-09-18	14:29:00.77	148.987	-19.928	10.0 km	Constrained to local norm	1.8 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 78 km NE Bowen. Reviewed 2016-09-20.
2016-09-17	13:48:43.81	151.481	-25.08	10.0 km	Constrained to local norm	1.0 ML	Earthquake Aftershock	Mt Perry	Aftershock of 2015-02-15 15:57 event. 20 km NW Mt Perry. Reviewed 2016-09-18.
2016-09-15	19:39:07.63	151.641	-25.323	10.0 km	Constrained to local norm	0.6 ML	Earthquake Aftershock	Mt Perry	Aftershock of 2015-02-15 15:57 event. 16 km S Mt Perry. Reviewed 2016-09-17.
2016-09-03	20:14:59.53	148.638	-19.676	10.0 km	Constrained to local norm	2.6 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 55 km NE Bowen. Reviewed 2016-09-06.
2016-09-03	00:37:37.75	151.502	-25.081	10.0 km	Constrained to local norm	1.4 ML	Earthquake Aftershock	Mt Perry	Aftershock of 2015-02-15 15:57 event. 18 km NW Mt Perry. Reviewed 2016-09-03.
2016-09-02	18:22:15 .94	148.751	-19.842	10.0 km	Constrained to local norm	1.6 ML	Earthquake Mainshock	Bowen	Aftershock of 2016-08-18 04:30 event. 56 km NE Bowen. Reviewed 2016-09-05.
2016-08-31	16:25:19.46	148.755	-19.882	10.0 km	Constrained to local norm	2.0 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 55 km NE Bowen. Reviewed 2016-09-03.
2016-08-30	16:16:54.37	148.737	-19.883	10.0 km	Constrained to local norm	2.1 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 53 km NE Bowen. Reviewed 2016-08-31.
2016-08-30	05:20:54.12	148.871	-19.739	10.0 km	Constrained to local norm	2.3 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 72 km NE Bowen. Reviewed 2016-08-31.
2016-08-29	23:38:22.28	148.821	-19.852	10.0 km	Constrained to local norm	3.9 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 63 km NE Bowen. Reviewed 2016-08-31.
2016-08-29	21:27:48.15	148.9	-19.834	10.0 km	Constrained to local norm	3.0 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 71 km NE Bowen. Reviewed 2016-08-31.
2016-08-29	07:30:46.94	148.859	-19.769	10.0 km	Constrained to local norm	2.7 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 71 km NE Bowen. Reviewed 2016-09-03.
2016-08-27	03:53:35.76	148.91	-19.759	10.0 km	Constrained to local norm	2.6 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 75 km NE Bowen. Reviewed 2016-08-31.
2016-08-25	23:10:23.08	151.858	-25.608	10.0 km	Constrained to local norm	1.1 ML	Earthquake Mainshock	Ban Ban Springs	9 km NW Ban Ban Springs. Reviewed 2016-09-03.

Date (UTC)	Time (UTC)	Longitude	Latitude	Depth	Depth Status	Magnitude	Event Type	Place	Comment
2016-08-25	16:44:46.33	148.753	-19.888	10.0 km	Constrained to local norm	1.9 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 55 km NE Bowen. Reviewed 2016-08-31.
2016-08-25	09:10:51.02	148.788	-19.858	10.0 km	Constrained to local norm	2.3 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 59 km NE Bowen. Reviewed 2016-08-31.
2016-08-25	04:51:51.70	148.784	-19.806	10.0 km	Constrained to local norm	2.8 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 61 km NE Bowen. Reviewed 2016-08-29.
2016-08-25	04:50:09.88	148.77	-19.837	10.0 km	Constrained to local norm	2.0 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 58 km NE Bowen. Reviewed 2016-08-29.
2016-08-24	22:40:14.46	148.82	-19.81	10.0 km	Constrained to local norm	2.6 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 64 km NE Bowen. Reviewed 2016-08-29.
2016-08-24	18:21:48.83	148.82	-19.807	10.0 km	Constrained to local norm	2.6 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 64 km NE Bowen. Reviewed 2016-08-29.
2016-08-23	11:20:03.10	149.163	-19.834	10.0 km	Constrained to local norm	2.5 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 98 km NE Bowen. Reviewed 2016-08-29.
2016-08-23	11:16:43.31	148.8	-19.873	10.0 km	Constrained to local norm	1.9 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 60 km NE Bowen. Reviewed 2016-08-29.
2016-08-23	07:36:08.79	148.857	-19.899	10.0 km	Constrained to local norm	2.9 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 65 km NE Bowen. Reviewed 2016-08-29.
2016-08-22	22:47:16.42	148.949	-19.862	10.0 km	Constrained to local norm	3.2 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 75 km NE Bowen. Reviewed 2016-08-29.
2016-08-22	19:05:05.62	148.86	-19.772	10.0 km	Constrained to local norm	2.8 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 70 km NE Bowen. Reviewed 2016-08-29.
2016-08-22	15:03:36.46	149.072	-19.682	10.0 km	Constrained to local norm	3.0 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 94 km NE Bowen. Reviewed 2016-08-29.
2016-08-22	08:34:07 .25	148.924	-19.878	10.0 km	Constrained to local norm	3.2 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 73 km NE Bowen. Reviewed 2016-08-29.
2016-08-22	07:55:47.79	148.747	-19.846	10.0 km	Constrained to local norm	2.9 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 56 km NE Bowen. Reviewed 2016-08-25.

Date (UTC)	Time (UTC)	Longitude	Latitude	Depth	Depth Status	Magnitude	Event Type	Place	Comment
2016-08-21	16:18:12.52	148.872	-19.903	10.0 km	Constrained to local norm	2.9 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 66 km NE Bowen. Reviewed 2016-08-25.
2016-08-21	12:47:24.98	148.785	-19.832	10.0 km	Constrained to local norm	3.4 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 60 km NE Bowen. Reviewed 2016-08-25.
2016-08-21	12:36:51.69	149.041	-19.693	10.0 km	Constrained to local norm	3.2 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 90 km NE Bowen. Reviewed 2016-08-26.
2016-08-21	05:21:29.63	148.733	-19.841	10.0 km	Constrained to local norm	2.3 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 55 km NE Bowen. Reviewed 2016-08-25.
2016-08-20	20:14:20.23	148.768	-19.854	10.0 km	Constrained to local norm	2.0 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 57 km NE Bowen. Reviewed 2016-08-25.
2016-08-20	20:11:00.20	148.712	-19.92	10.0 km	Constrained to local norm	2.4 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 50 km NE Bowen. Reviewed 2016-08-25.
2016-08-20	20:08:30.51	148.674	-20.088	10.0 km	Constrained to local norm	2.5 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 45 km E Bowen. Reviewed 2016-08-25.
2016-08-20	16:46:40.24	148.786	-19.821	10.0 km	Constrained to local norm	3.5 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 60 km NE Bowen. Reviewed 2016-08-25.
2016-08-20	07:10:37.63	148.854	-19.771	10.0 km	Constrained to local norm	2.8 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 69 km NE Bowen. Reviewed 2016-08-25.
2016-08-20	01:17:27.52	148.672	-19.835	10.0 km	Constrained to local norm	2.4 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 49 km NE Bowen. Reviewed 2016-08-25.
2016-08-20	00:53:37.42	148.73	-19.952	10.0 km	Constrained to local norm	2.2 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 51 km E Bowen. Reviewed 2016-08-25.
2016-08-19	23:56:43.87	148.805	-19.881	10.0 km	Constrained to local norm	2.6 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 60 km NE Bowen. Reviewed 2016-08-25.
2016-08-19	22:41:36.78	148.845	-19.816	10.0 km	Constrained to local norm	2.9 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 66 km NE Bowen. Reviewed 2016-08-24.
2016-08-19	20:40:30.64	148.772	-19.877	10.0 km	Constrained to local norm	2.7 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 57 km NE Bowen. Reviewed 2016-08-23.

Date (UTC)	Time (UTC)	Longitude	Latitude	Depth	Depth Status	Magnitude	Event Type	Place	Comment
2016-08-19	17:03:32.17	148.804	-19.799	10.0 km	Constrained to local norm	2.2 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 63 km NE Bowen. Reviewed 2016-08-23.
2016-08-19	11:15:41.48	148.847	-19.921	10.0 km	Constrained to local norm	2.5 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 64 km NE Bowen. Reviewed 2016-08-23.
2016-08-18	21:38:57.18	148.815	-19.751	10.0 km	Constrained to local norm	3.3 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 66 km NE Bowen. Reviewed 2016-08-22.
2016-08-18	18:27:37.42	148.808	-19.831	10.0 km	Constrained to local norm	4.3 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 62 km NE Bowen. Reviewed 2016-08-22.
2016-08-18	17:17:43.19	148.745	-19.804	10.0 km	Constrained to local norm	2.8 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 57 km NE Bowen. Reviewed 2016-08-22.
2016-08-18	16:23:58.15	148.788	-19.838	10.0 km	Constrained to local norm	2.9 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 60 km NE Bowen. Reviewed 2016-08-23.
2016-08-18	15:52:00.47	148.876	-19.872	10.0 km	Constrained to local norm	2.5 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 68 km NE Bowen. Reviewed 2016-08-22.
2016-08-18	15:47:33.76	148.798	-19.833	10.0 km	Constrained to local norm	2.3 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 61 km NE Bowen. Reviewed 2016-08-22.
2016-08-18	15:44:24.67	148.656	-19.806	10.0 km	Constrained to local norm	0.0 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 49 km NE Bowen. Reviewed 2016-08-22.
2016-08-18	15:05:29.70	148.849	-19.797	10.0 km	Constrained to local norm	2.9 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 67 km NE Bowen. Reviewed 2016-08-22.
2016-08-18	14:04:31.20	148.825	-19.899	10.0 km	Constrained to local norm	4.0 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 62 km NE Bowen. Reviewed 2016-08-22.
2016-08-18	14:03:10.36	148.643	-19.688	10.0 km	Constrained to local norm	3.6 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 55 km NE Bowen. Reviewed 2016-08-22.
2016-08-18	13:57:20.29	148.899	-19.77	10.0 km	Constrained to local norm	2.5 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 73 km NE Bowen. Reviewed 2016-08-22.
2016-08-18	10:06:45.07	148.792	-19.824	10.0 km	Constrained to local norm	2.8 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 61 km NE Bowen. Reviewed 2016-08-23.

Date (UTC)	Time (UTC)	Longitude	Latitude	Depth	Depth Status	Magnitude	Event Type	Place	Comment
2016-08-18	10:03:05.81	148.65	-20.014	10.0 km	Constrained to local norm	0.0 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 42 km E Bowen. Reviewed 2016-08-23.
2016-08-18	09:30:52.30	148.768	-19.762	10.0 km	Constrained to local norm	3.7 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 61 km NE Bowen. Reviewed 2016-08-22.
2016-08-18	09:29:39.23	148.793	-19.881	10.0 km	Constrained to local norm	0.0 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 60 km NE Bowen. Reviewed 2016-08-22.
2016-08-18	09:23:32.52	148.905	-19.734	10.0 km	Constrained to local norm	2.9 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 76 km NE Bowen. Reviewed 2016-08-22.
2016-08-18	09:19:56.78	148.755	-19.848	10.0 km	Constrained to local norm	0.0 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 59 km NE Bowen. Reviewed 2016-08-22.
2016-08-18	08:56:49.98	148.78	-19.839	10.0 km	Constrained to local norm	3.7 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 59 km NE Bowen. Reviewed 2016-08-22.
2016-08-18	07:37:26.91	148.791	-19.792	10.0 km	Constrained to local norm	2.4 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 62 km NE Bowen. Reviewed 2016-08-21.
2016-08-18	07:35:02.50	148.74	-19.848	10.0 km	Constrained to local norm	2.6 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 55 km NE Bowen. Reviewed 2016-08-21.
2016-08-18	07:33:21.85	148.905	-19.725	10.0 km	Constrained to local norm	0.0 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 76 km NE Bowen. Reviewed 2016-08-21.
2016-08-18	07:31:57.07	148.758	-19.883	10.0 km	Constrained to local norm	0.0 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 55 km NE Bowen. Reviewed 2016-08-21.
2016-08-18	05:57:36.05	148.836	-19.799	10.0 km	Constrained to local norm	2.6 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 66 km NE Bowen. Reviewed 2016-08-19.
2016-08-18	05:53:58.97	148.947	-19.906	10.0 km	Constrained to local norm	2.7 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 74 km NE Bowen. Reviewed 2016-08-19.
2016-08-18	05:37:47.62	148.765	-19.896	10.0 km	Constrained to local norm	4.2 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 56 km NE Bowen. Reviewed 2016-08-18.
2016-08-18	05:37:45.19	148.961	-19.82	10.0 km	Constrained to local norm	4.1 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 77 km NE Bowen. Reviewed 2016-08-18.

Date (UTC)	Time (UTC)	Longitude	Latitude	Depth	Depth Status	Magnitude	Event Type	Place	Comment
2016-08-18	05:36:28.65	148.742	-19.82	10.0 km	Constrained to local norm	3.4 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 56 km NE Bowen. Reviewed 2016-08-18.
2016-08-18	05:30:37.11	148.791	-19.825	10.0 km	Constrained to local norm	4.3 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 61 km NE Bowen. Reviewed 2016-08-18.
2016-08-18	05:23:53.50	148.912	-19.836	10.0 km	Unconstrained	3.8 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 72 km NE Bowen. Reviewed 2016-11-05.
2016-08-18	05:09:29.75	148.763	-19.855	20.0 km	Unconstrained	3.1 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 57 km NE Bowen. Reviewed 2016-11-05.
2016-08-18	05:06:14.28	148.388	-19.476	10.0 km	Constrained to local norm	2.1 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 61 km N Bowen. Reviewed 2016-11-05.
2016-08-18	05:03:30.25	148.848	-20.314	10.0 km	Constrained to local norm	2.0 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 71 km SE Bowen. Reviewed 2016-11-05.
2016-08-18	04:58:19.21	148.676	-19.973	10.0 km	Constrained to local norm	2.2 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 45 km NE Bowen. Reviewed 2016-11-05.
2016-08-18	04:56:43.28	148.704	-19.906	5.0 km	Unconstrained	2.4 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 50 km NE Bowen. Reviewed 2016-11-05.
2016-08-18	04:55:56.11	148.968	-19.932	10.0 km	Constrained to local norm	2.2 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 77 km NE Bowen. Reviewed 2016-11-05.
2016-08-18	04:46:45.53	148.694	-19.926	10.0 km	Constrained to local norm	2.4 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 48 km NE Bowen. Reviewed 2016-11-05.
2016-08-18	04:45:52.55	148.8	-19.75	10.0 km	Constrained to local norm	2.3 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 65 km E Bowen. Reviewed 2016-11-04.
2016-08-18	04:41:37.18	148.794	-19.855	7.0 km	Unconstrained	2.5 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 60 km E Bowen. Reviewed 2016-11-08.
2016-08-18	04:38:50.22	148.821	-19.9	10.0 km	Unconstrained	3.8 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 62 km NE Bowen. Reviewed 2016-11-04.
2016-08-18	04:36:53.03	148.741	-19.897	10.0 km	Constrained to local norm	3.1 ML	Earthquake Aftershock	Bowen	Aftershock of 2016-08-18 04:30 event. 52 km NE Bowen. Reviewed 2016-11-04.

Date (UTC)	Time (UTC)	Longitude	Latitude	Depth	Depth Status	Magnitude	Event Type	Place	Comment
2016-08-18	04:30:08.42	148.84	-19.895	20.0 km	Unconstrained	5.8 ML	Earthquake Mainshock	Bowen	63 km NE Bowen. Reviewed 2016-11-04.
2016-08-13	15:31:13.08	152.933	-23.714	15.19 km	Unconstrained	4.4 ML	Earthquake Mainshock	Lady Elliot Island	50 km NNE Lady Elliot Island. Reviewed 2016-08-14.
2016-08-11	17:41:15.29	154.057	-25.634	10.0 km	Constrained to local norm	2.5 ML	Earthquake Aftershock	Rainbow Beach	Aftershock of 2015-07-29. 101 km ENE Rainbow Beach. Reviewed 2016-08-12.
2016-08-09	11:59:20.69	151.39	-25.238	10.0 km	Constrained to local norm	1.6 ML	Earthquake Aftershock	Mt Perry	Aftershock of 2015-02-15 15:57 event. 27 km WSW Mt Perry. Reviewed 2016-08-10.
2016-08-08	07:54:30.53	151.565	-25.096	10.0 km	Constrained to local norm	0.8 ML	Earthquake Aftershock	Mt Perry	Aftershock of 2015-02-15 15:57 event. 12 km NW Mt Perry. Reviewed 2016-08-08.
2016-08-07	15:17:59.02	151.45	-25.051	10.0 km	Constrained to local norm	0.9 ML	Earthquake Aftershock	Mt Perry	Aftershock of 2015-02-15 15:57 event. 24 km NW Mt Perry. Reviewed 2016-08-08.
2016-07-05	23:52:30.97	151.511	-25.085	10.0 km	Constrained to local norm	1.7 ML	Earthquake Aftershock	Mt Perry	Aftershock of 2015-02-15 15:57 event. 17 km NW Mt Perry. Reviewed 2016-07-06.
2016-06-27	15:19:05.20	151.543	-25.215	10.0 km	Constrained to local norm	1.5 ML	Earthquake Aftershock	Mt Perry	Aftershock of 2015-02-15 15:57 event. 11 km WSW Mt Perry. Reviewed 2016-06-28
2016-06-19	17:54:32.42	152.898	-24.754	10.0 km	Constrained to local norm	1.9 ML	Earthquake Mainshock	Bundaberg	57 km ENE Bundaberg. Reviewed 2016-06-20.
2016-06-17	19:57:15.77	152.598	-27.133	10.0 km	Constrained to local norm	3.0 ML	Earthquake Mainshock	Mt Mee	18 km WSW Mt Mee. Reviewed 2016-06-19.
2016-06-14	18:28:37.47	151.701	-25.163	10.0 km	Constrained to local norm	1.1 ML	Earthquake Aftershock	Mt Perry	Aftershock of 2015-02-15 15:57 event. 6 km ENE Mt Perry. Reviewed 2016-06-15.
2016-06-08	11:12:09.20	151.546	-25.215	10.0 km	Constrained to local norm	1.2 ML	Earthquake Aftershock	Mt Perry	Aftershock of 2015-02-15 15:57 event. 11 km SW Mt Perry. Felt at -25.162 151.621 10 km from located epicentre. Reviewed 2016-06-09.
2016-06-08	05:37:35	151.799	-25.196	10.0 km	Constrained to local norm	0.3 ML	Earthquake Mainshock	Mt Perry	16 km East of Mt Perry. Reviewed 2016-06-08.

Date (UTC)	Time (UTC)	Longitude	Latitude	Depth	Depth Status	Magnitude	Event Type	Place	Comment
2016-06-07	00:02:18.98	152.645	-33.506	10.0 km	Constrained to local norm	3.8 ML	Earthquake Mainshock	Gosford	121 km East of Gosford, NSW. Reviewed 2016-06-07.
2016-05-20	18:14:05.16	129.77	-25.61	120.0 km	Unconstrained	6.1 ML	Earthquake Mainshock	Uluru	131 km WSW Uluru. Reviewed 2016-05-20.
2016-05-17	03:44:52.34	153.58	-24.005	10.0 km	Constrained to local norm	2.6 ML	Earthquake Mainshock	Lady Elliot Island	89 km E Lady Elliot Island. Reviewed 2016-05-17.
2016-05-14	12:33:15.98	151.409	-25.261	10.0 km	Constrained to local norm	1.8 ML	Earthquake Mainshock	Mt Perry	25 km SW Mt Perry. Reviewed 2016-05-15.
2016-05-07	13:43:55.00	153.599	-22.842	10.0 km	Constrained to local norm	3.2 ML	Earthquake Mainshock	Swains Reef	263 km NE Gladstone Reviewed 2016-05-09.
2016-04-15	17:14:53.52	151.437	-25.099	10.0 km	Constrained to local norm	1.6 ML	Earthquake Aftershock	Mt Perry	Aftershock of 2015-02-15 15:57 event. 23 km NW Mt Perry. Reviewed 2016-04-16.
2016-04-12	20:43:52.98	151.382	-25.246	10.0 km	Constrained to local norm	2.6 ML	Earthquake Aftershock	Mt Perry	Aftershock of 2015-02-15 15:57 event. 28 km WSW Mt Perry. Reviewed 2016-04-13.
2016-04-09	05:43:21.77	151.98	-25.229	10.0 km	Constrained to local norm	1.0 ML	Earthquake Mainshock	Wallaville	17 km SSW Wallaville. Reviewed 2016-04-09.
2016-04-07	11:36 22.55	151.895	-25.207	10.0 km	Unconstrained	0.6 ML	Earthquake Mainshock	Wallaville	18 km SSW Wallaville. Reviewed 2016-04-08.
2016-03-26	06:13:45.40	151.553	-25.212	10.0 km	Unconstrained	1.5 ML	Earthquake Aftershock	Mt Perry	Aftershock of 2015-02-15 15:57 event. 10 km SW Mt Perry. Reviewed 2016-03-26.
2016-02-28	23:30:33.08	151.388	-25.218	10.0 km	Unconstrained	1.6 ML	Earthquake Aftershock	Mt Perry	Aftershock of 2015-02-15 15:57 event. 26 km WSW Mt Perry. Reviewed 2016-02-29.
2016-02-10	17:59:15.21	151.779	-24.903	10.0 km	Constrained to local norm	0.9 ML	Earthquake Mainshock	Gin Gin	21 km NW Gin Gin. Reviewed 2016-02-12.
2016-02-08	21:51:30	151.81	-25.123	10.0 km	Constrained to local norm	0.8 ML	Earthquake Mainshock	Doughboy	21 km SW Gin Gin. Reviewed 2016-02-09.
2016-02-07	10:09:59.68	151.958	-25.236	10.0 km	Unconstrained	0.9 ML	Earthquake Aftershock	Childers	Aftershock of 2016-02-04 04:53. 32 km W Childers. Reviewed 2016-02-08.

Date (UTC)	Time (UTC)	Longitude	Latitude	Depth	Depth Status	Magnitude	Event Type	Place	Comment
2016-02-04	04:53:33.65	151.965	-25.249	10.0 km	Unconstrained	1.4 ML	Earthquake Mainshock	Childers	31 km W Childers. Reviewed 2016-02-04.
2016-01-30	21:46	151.384	-25.327	10.0 km	Constrained to local norm	0.8 ML	Earthquake Mainshock	Eidsvold	27 km ENE Eidsvold. Reviewed 2016-01-31.
2016-01-27	17:39:03.72	151.406	-25.004	10.0 km	Constrained to local norm	1.1 ML	Earthquake Aftershock	Mt Perry	Aftershock of 2015-02-15 15:57 event. 31 km NW Mt Perry. Reviewed 2016-01-28.
2016-01-25	12:03:01.92	152.897	-24.745	10.0 km	Constrained to local norm	1.6 ML	Earthquake Mainshock	Bundaberg	57 km ENE Bundaberg. 61 km N Hervey Bay. Reviewed 2016-01-25.
2016-01-22	19:01:45.15	153.072	-24.945	10.0 km	Constrained to local norm	1.9 ML	Earthquake Mainshock	Hervey Bay	45 km NNE Hervey Bay. Reviewed 2016-01-25.
2016-01-06	07:43:42.99	151.509	-25.12	10.0 km	Constrained to local norm	1.3 ML	Earthquake Aftershock	Mt Perry	Aftershock of 2015-02-15 15:57 event. 15 km NW Mt Perry. Reviewed 2016-01-06.
2016-01-05	13:34:03.31	151.45	-24.981	10.0 km	Constrained to local norm	2.0 ML	Earthquake Aftershock	Mt Perry	Aftershock of 2015-02-15 15:57 event. 30 km NW Mt Perry. Reviewed 2016-01-06.

2016 Statistical Summary

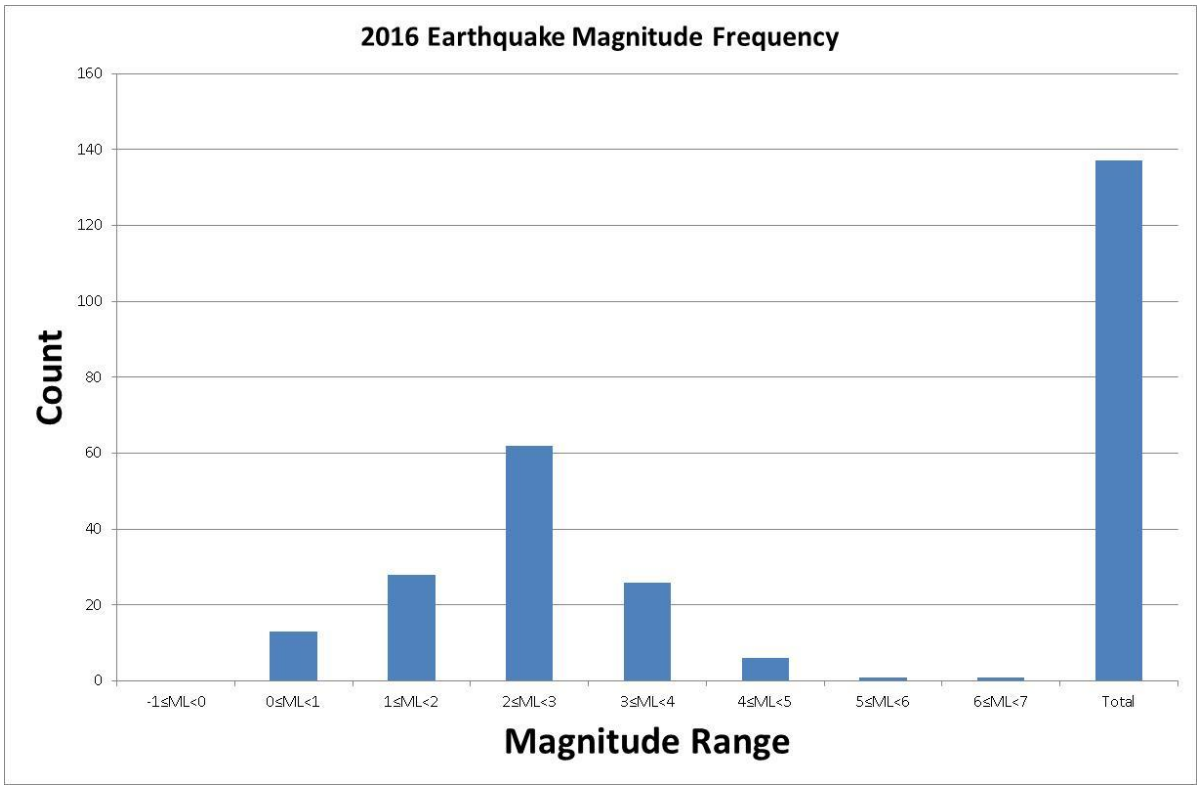

Figure 8: Earthquake magnitude Frequency 2016.

Figure 8 provides a graphical representation of the frequency of magnitude spread.

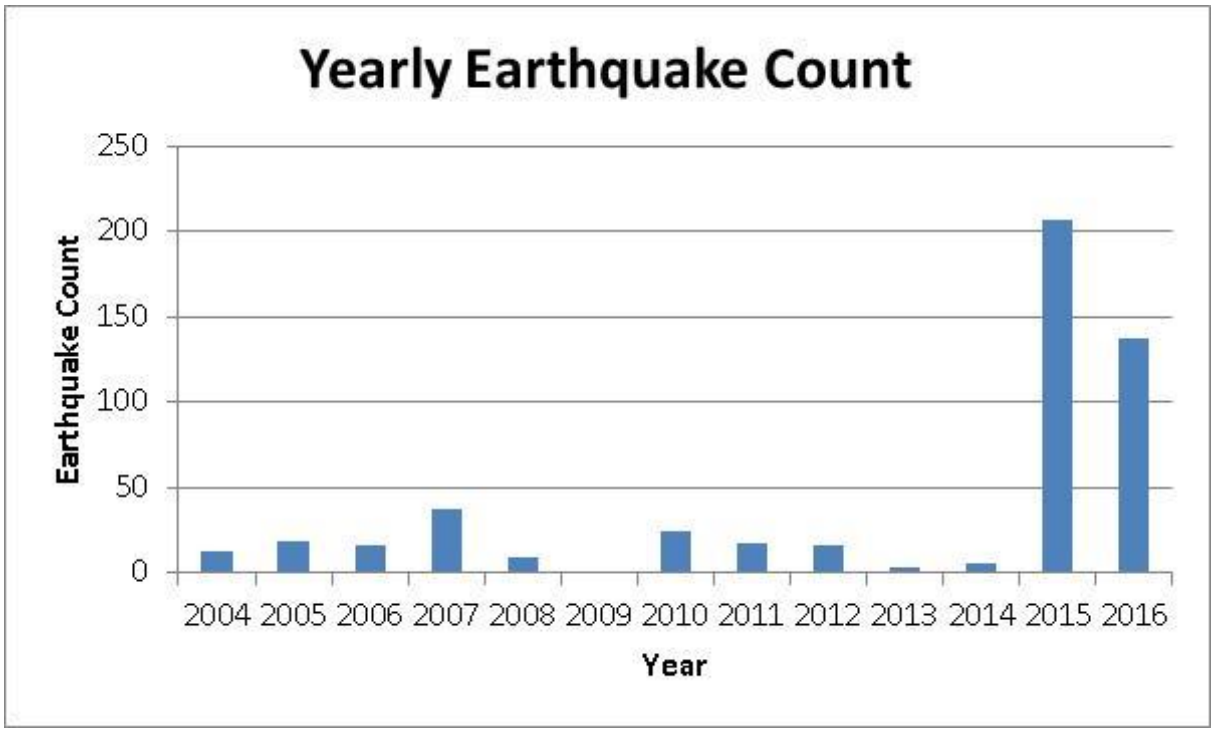

Figure 9: Yearly count of earthquakes detected by CQSRG.

2016 exhibited a significantly greater number of earthquake events than all previous years with the exception of 2015. The M 5.8 Bowen event is probably the second largest earthquake to have been recorded on the East coast of Mainland Australia in modern times.

Figure 9 puts into context the extraordinary number of earthquakes detected during 2015 and 2016 when compared to the numbers detected in previous years.

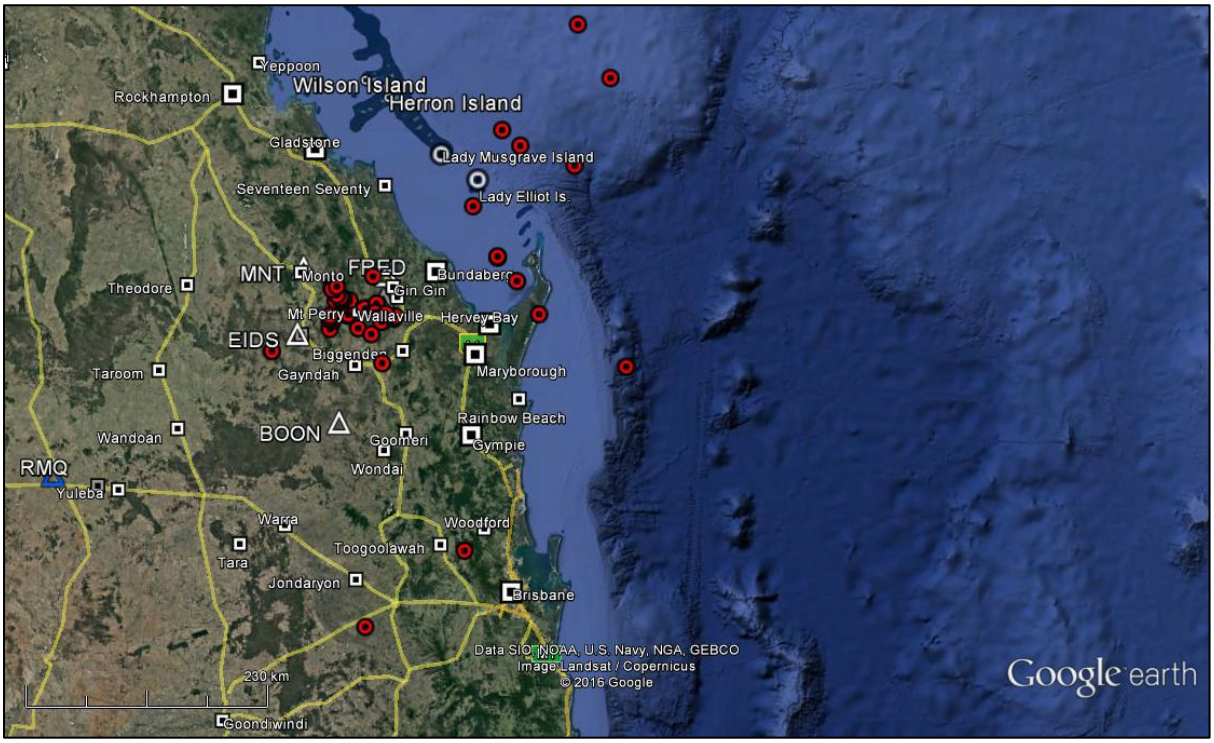

Figure 10: Broad view of earthquakes located by CQSRG in Southern coastal Queensland.

Figure 10 is a broad-view map of the earthquakes location in the southern coastal part of Queensland by CQSRG in 2016. This does not include any of the 2016 Bowen earthquakes, nor the M 6.1 Northern Territory event.

Figure 11 is a broad-view map of the 2016 Bowen earthquake sequence, as located by CQSRG.

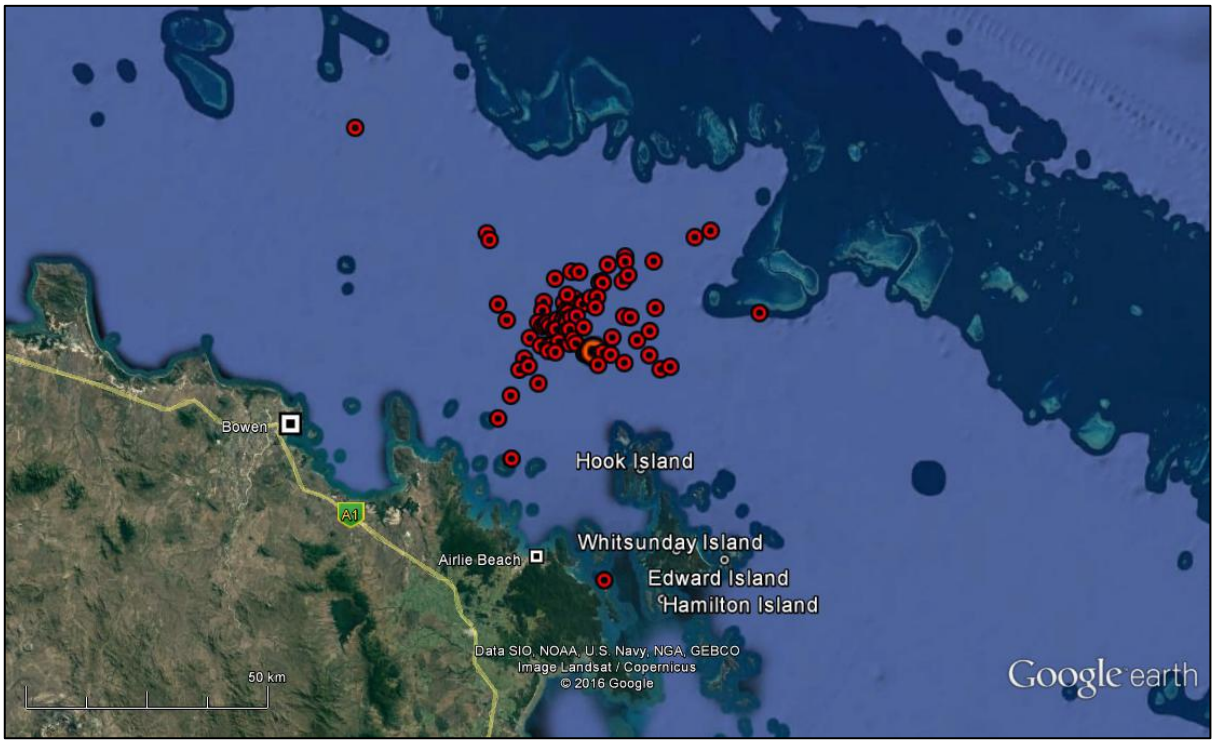

Figure 11: The 2016 Bowen earthquake sequence locations.

Public Seismic Network (PSN)

Since 2011-08-05 CQSRG has hosted a PSN seismograph station, known to the Australian PSN community as the Gin Gin or the Horse Camp station. Vic Dent and Mike Turnbull originally installed the station with a rudimentary setup consisting of a 3D geophone attached to a PSN A/D board, in a vacant brick shed on Mike Turnbull's property at Horse Camp, 16 km SW of Gin Gin. Mike provided a desktop computer onto which the PSN software was installed. Since then the station has been regularly uploading GIF pictures of the daily seismogram traces to the Regional Seismic Users web site at http://www.rsuw.daleh.id.au/, operated by Dale Hardy. The station also uploads continuous data to the Regional Seismic Network (RSN), operated by the Australian Centre for Geomechanics (AGC) (Information at http://www.acg.uwa.edu.au/).

In 2013 the geophone was replaced with a Sprengnether S6000 seismometer, and the PSN A/D board was housed in a respectable electronics housing, along with custom made adaptor electronics to accommodate the sensor and GPS interface.

Since the PSN station is located only 300 m from FS03, data from the PSN station is not used in locating events detected by CQSRG.

Appendix A – Details of FS03

Station FS03 is registered with the International Registry of Seismograph Stations maintained jointly by International Seismological Centre & World Data Centre for Seismology.

Go to: http://www.isc.ac.uk/cgi-bin/stations?stnsearch=STN&sta_list=FS03&stn_ctr_lat=&stn_ctr_lon=&stn_radius=&max_stn_dist_units=deg&stn_bot_lat=&stn_top_lat=&stn_left_lon=&stn_right_lon=&stn_srn=&stn_grn=.

LOCATION

Latitude -25.1068, Longitude 151.8667, Height above sea level 180 m. Approximately 16 km SW Gin Gin, Queensland, Australia.

SITE AND SAMPLING

Sampling of ground velocity at 100 sample/sec, full scale 4194304 counts (for about a month after the Mt Perry earthquake the sample rate was increased to 200 sample/second)

Ch	Type	Serial	Name	Direction	Gain	Filters
1	L43D	#1482	East	90 deg true	0.00	DC 50.0
2	L43D	#1482	North	0 deg true	0.00	DC 50.0
3	L43D	#1482	Up	Positive up	0.00	DC 50.0

DATA LOGGER

Kelunji Classic #153, GURIA V4.16A Operating System.

TIME SYNC

Sync every day at 1400 UCT, using GPS. Wait for up to 80 seconds
Wait up to 120 seconds for a position
Auto-correct clock after sync

TRIGGER SETTINGS

STA/LTA Channel 3, filter 1.00 to 7.50 Hz
Time const 0.20, 2.0, 20.0, 200.0 seconds
Ratios Fast 3.50, slow 1.75, squelch 5, 15 days
Length 100 to 200 secs, 80.00 sec pre-trigger, 1.10 cutoff.

Appendix B – CQSRG Method of Earthquake Location

In general, CQSRG only catalogues earthquake events that are detected by its seismic monitoring station(s). However, in the event of significant local events that, for reasons of station downtime, are not recorded by CQSRG stations, locations are conducted by obtaining data from other agencies.

The general process for earthquake event location at CQSRG is as follows.

1. Identify local earthquake events from visual inspection of FS03 seismograms.

2. Download extra seismograms from other agencies; typically, University of Queensland, Geoscience Australia, and the Australian National University (ANU) Australian Seismometers in Schools (AuSIS) project.

3. Send email requests to other agencies; typically, the Seismology Research Centre (SRC), and the South East Queensland Water Company (SeqWater).

4. Collect all available seismogram records and pick P and S phase arrival times using EqWave (SRC sourced software).

5. Enter the picked P and S times into EQLOCL (SRC sourced software).

6. Use the location calculated by EQLOCL.

In the not so rare cases where the only record available is that from FS03, an attempt is made to locate the event using first motion polarity and near field trigonometry. This can only be done when the first motions are sufficiently impulsive to give an unambiguous indication of the arrival azimuth.

In cases where only two records are available (invariably FS03 and EIDS), and the S-P derived radial distance circles meet, but do not over extend, the touch point is used as a seed to the EQLOCL algorithm.

In cases where only two records are available (invariably FS03 and EIDS), and the S-P derived radial distance circles over extend, but the first motions are sufficiently impulsive to derive an unambiguous azimuth, the radial touch point indicated by the azimuth direction is used as a seed to the EQLOCL algorithm.

In cases where only two records are available (invariably FS03 and EIDS), and the S-P derived radial distance circles over extend, but the first motions are insufficiently impulsive to derive an unambiguous azimuth, the locations of both the radial touch points are used as seeds to the EQLOCL algorithm, and the resulting ambiguous locations are noted in the catalogue entry comments.

In cases where the only information that can be gleaned is the radial distance from FS03, that distance may be noted in the catalogue listing comments.

Appendic C – CQSRG Method of Magnitude Quantification from FS03 Records

Calibration of FS03 Seismometer for Earthquake Magnitude Determination.

Mike Turnbull, 7 November, 2012.

Introduction

FS03 is the designation of a seismic monitoring station operated by the Central Queensland Seismology Research Group (CQSRG). It is located about 16 km south-west of Gin Gin.

When the FS03 station was first installed it had a Sprengnether S6000 seismometer attached to a data logger manufactured by the Seismology Research Centre (SRC). The characteristics of this sensor and the amplification factors of the data logger section of the seismograph were used as input to the SRC software used to locate and quantify earthquakes recorded on the seismograph. When the S6000 sensor failed it was replaced with a Mark Products L43D seismometer sensor. By comparison of the calibration waveform amplitudes of the S6000 against the L43D, a correction factor of 1.7 was calculated and used to adjust the amplitude value input to the SRC software to determine earthquake magnitudes using the new sensor – and this provided a temporary solution.

In order for the SRC software to be able to calculate an earthquake magnitude, it first must be able to calculate the earthquake's epicentral location. This can only be done if seismographic records from at least three different stations are available. In situations where only one or two records are available the software cannot locate the epicentre. Consequently, in cases where an earthquake cannot be located, determination of its magnitude using EQLOCL has always been problematic.

This appendix describes a method of extracting parametric information from past earthquake magnitudes, located with the SRC software using FS03 seismograms, that can be used in a suitable mathematical formula to determine the magnitude of other earthquakes recorded on the FS03 seismograph, using information from the single station data. This allows the magnitude determination to be done independent of the SRC software.

Background Information

The Richter local earthquake magnitude (M) is calculated using the formula given in Eq. 1.

$$M = log_{10}A - log_{10}A_0 \qquad \text{(Eq. 1)}$$

Where:

A is the maximum amplitude of the seismic record of the earthquake, and

A_0 is the maximum amplitude that would be produced on the same sensor by an earthquake of magnitude zero, occurring at the same location as the earthquake under consideration.

The value of $\log_{10}A_0$ is dependent only on the epicentral distance of the earthquake from the sensor, and the response characteristics of the sensor itself. It is assumed that the relationship is as given in Eq. 2 **(NOTE: This assumed relationship has yet to be confirmed as being valid)**.

$$log_{10}A_0 = a\delta + b \qquad \text{(Eq. 2)}$$

Where:

δ is the epicentral distance, and

a and b are parameters yet to be determined, characteristic of the sensor.

Method

It is clear that Eq.2 is linear. Therefore the sensor parameters a and b can be determined from the slope and intercept, respectively, of the graph of $\log_{10}A_0$ plotted against δ, providing that sufficient data is available

The epicentral distance δ can be expressed in any value that provides a valid determination of the distance from the sensor to the epicentre. This could be (for example):

- the difference in arrival times of the P and S waves (in seconds for example); or,
- the surface distance from sensor to epicentre (in km for example); or,
- the Earth centric angle of arc from sensor to epicentre (in degrees for example).

The values for $\log_{10}A_0$ can be calculated from past earthquake events, the magnitudes of which have been determined with the SRC software using FS03 seismograms.

Transformation of Eq.1 gives Eq. 3.

$$log_{10}A_0 = log_{10}A - M \qquad \text{(Eq.3)}$$

Table 2 presents the calculations of $\log_{10}A_0$ based on nine past events that were quantified with the SRC software, showing the S-P time differences used to measure epicentral distances.

Table 3: Determination of $\log_{10}A_0$ from past events recorded on the FS03 seismograph.

Earthquake Date	Measured P arrival in relative seconds	Measured S arrival in relative seconds	S-P time (s)	Measured Amplitude A	Magnitude estimated using ES&S algorithm M	Calculated $\log_{10}(A_0)$
2012-09-19 06:14	11.54	14.97	3.43	1900	1.6	1.6787536
2012-05-20 17:58	42.23	45.79	3.56	1103	1.5	1.5425755
2012-09-22 23:59	38.31	41.91	3.6	243	1.0	1.3856063
2012-04-10 01:51	37.54	42.57	5.03	473.2	1.4	1.2750447
2012-09-25 03:06	10.56	22.7	12.14	456	1.9	0.7589648
2012-08-19 22:37	29.38	41.82	12.44	215	1.5	0.8324385
2012-09-03 15:04	10.86	26.84	15.98	1828	2.8	0.4619762
2012-09-23 16:29	36.21	53.77	17.56	3620	3.2	0.3587086
2012-01-05 14:05	9.96	56.18	46.22	1352	4.3	-1.1690233

Figure 8 shows the graph of $\log_{10}A_0$ plotted against the associated S-P time difference (extracted from Table 2).

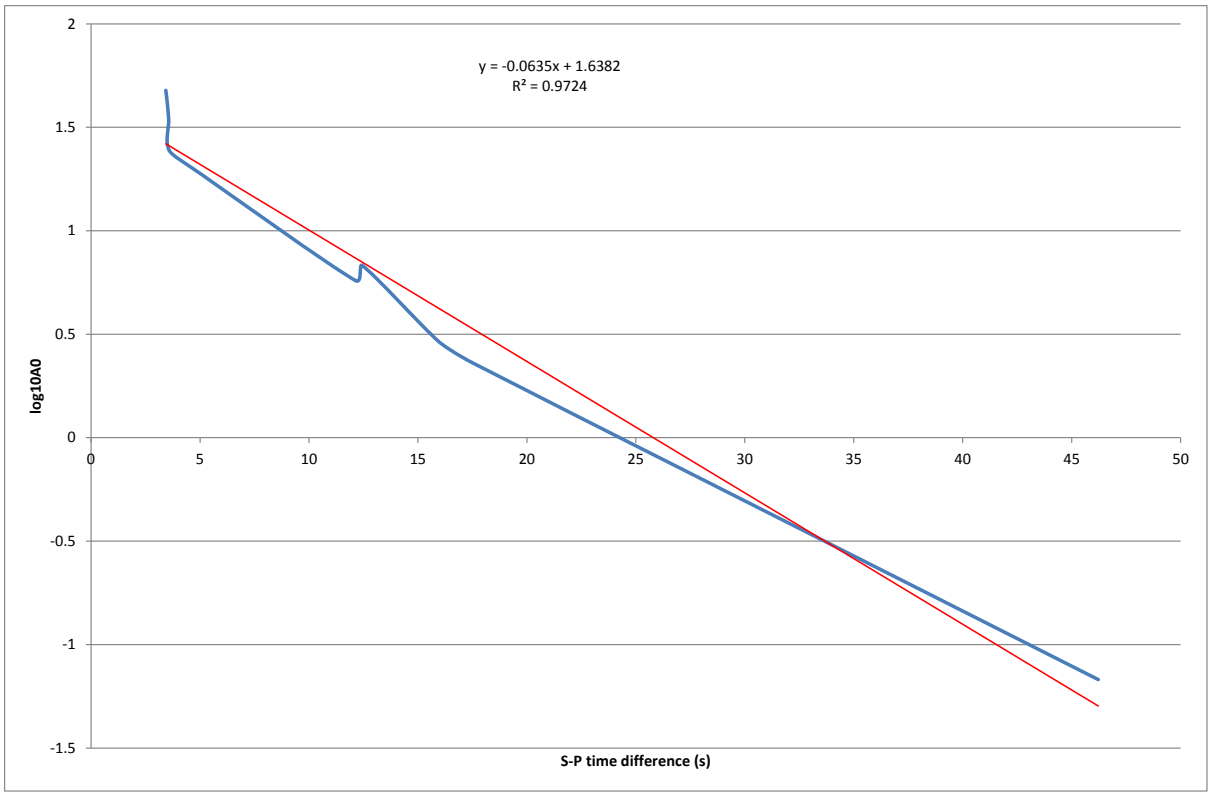

Figure 12: $\log_{10}A_0$ Vs S-P

Figure 8 also displays the line of best fit, calculated using linear regression of the plotting data, along with the slope, intercept, and correlation coefficient (R^2). **The R^2 value of 0.97 confirms that the assumed linear relationship is valid.**

By substituting the slope and intercept values into Eq.1 and Eq.2 we arrive at the formula for FS03 magnitudes given in Eq.4.

$$M_{FS03} = log_{10}A - (-0.064(S - P) + 1.64) \quad \text{(Eq.4)}$$

Where:

M_{FS03} is the Richter magnitude determined from an FS03 seismogram record;

A is the maximum amplitude of the unfiltered FS03 seismogram record;

S is the arrival time of the S wave in seconds, and;

P is the arrival time of the P wave in seconds.

Important Note Concerning Accuracy and Precision

Table 2, Figure 8, and Equation 4, show a shortened calculation using only 9 historical events, to demonstrate the method. A consequence of using so few input values is that the resulting error ranges will suffer. Consequently, in order to reduce the standard errors in magnitude calculations

based on this method, and extend the accuracy to at least one decimal point, many more input data are required.

The calculations used to determine the actual $\log_{10}A_0$ values for FS03, used in quantifying earthquake magnitudes, used 34 historical events. This resulted in parameter **a** and **b** values for Equation 2, as shown in Table 3.

Table 4: Equation 2, a and b Parameter values and Standard Errors.

	a	b
Estimation	-0.088	1.81
Standard Error	±0.004	±0.05
Correlation	0.94	

This implies that magnitudes determined using this method will be accurate to at least one decimal place. The a and b values shown in Table 3 are those used at CQSRG to calculate local magnitudes of events recorded by station FS03.

Example Usage

Figure 9 shows the seismogram of an earthquake that was recorded on station FS03 on 26 October 2012.

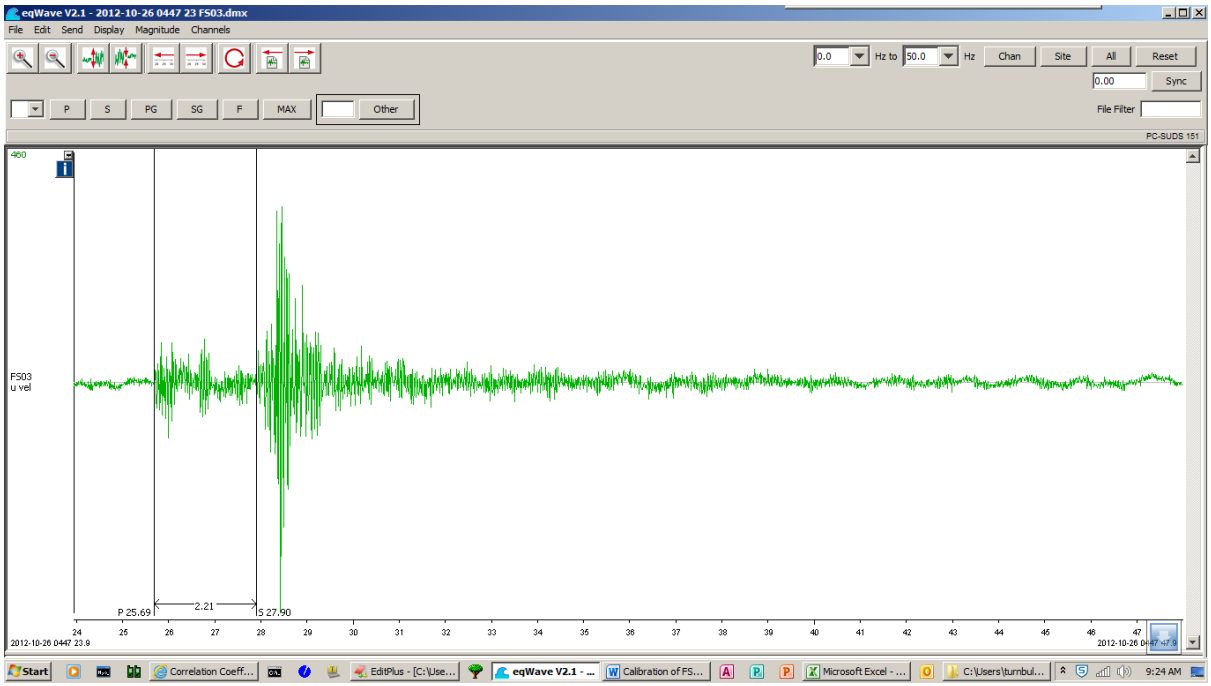

Figure 13: FS03 record of an earthquake.

From Figure 9 we can obtain the maximum amplitude (A = 460), the P wave arrival time (P = 25.69 s) and the S wave arrival time (S = 27.90 s); from which the time difference (S – P = 2.21 s) can be determined.

Inserting these values into Eq.4 we calculate a Richter magnitude of 1.2 (rounded to one decimal place).

Table 4 shows the results of some other similar calculations, for different earthquakes.

Table 5: Calculations of FS03 Richter magnitudes for some earthquakes.

Earthquake Date	Measured P arrival in relative seconds	Measured S arrival in relative seconds	S-P time (s)	Measured Amplitude A	Calculated M_{FS03} Magnitude
2012-09-28 16:38	10.56	22.7	12.14	304	1.6
2012-10-03 17:29	25.09	27.69	2.6	259	0.9
2012-10-18 14:48	23.43	25.91	2.48	911	1.5
2012-10-26 04:47	25.69	27.9	2.21	460	1.2

Student Resources

Figures 10, 11, 12 and 13 are images of earthquake seismograms recorded by FS03. They are included here for the reader to use as practice on the CQSRG magnitude determination method. They can also be used as a resource for High School science teachers who may want to use the formulae presented here as real-world examples of applied mathematics.

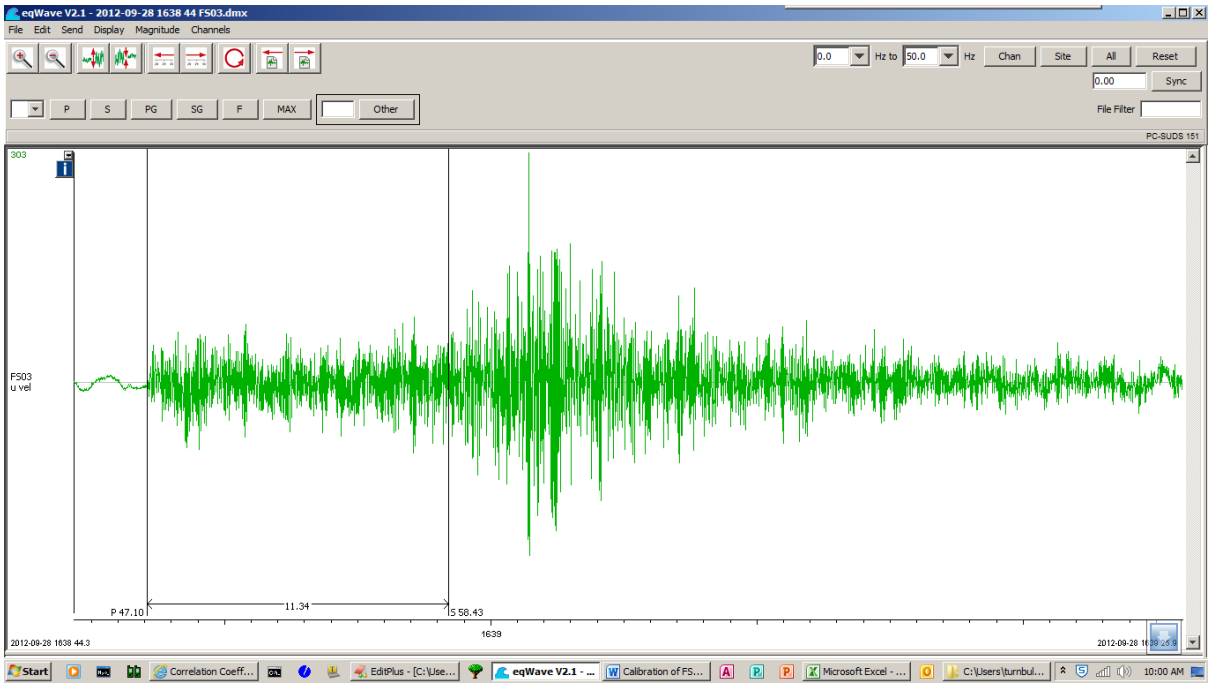

Figure 14: Earthquake recorded on FS03 on 28 September 2012

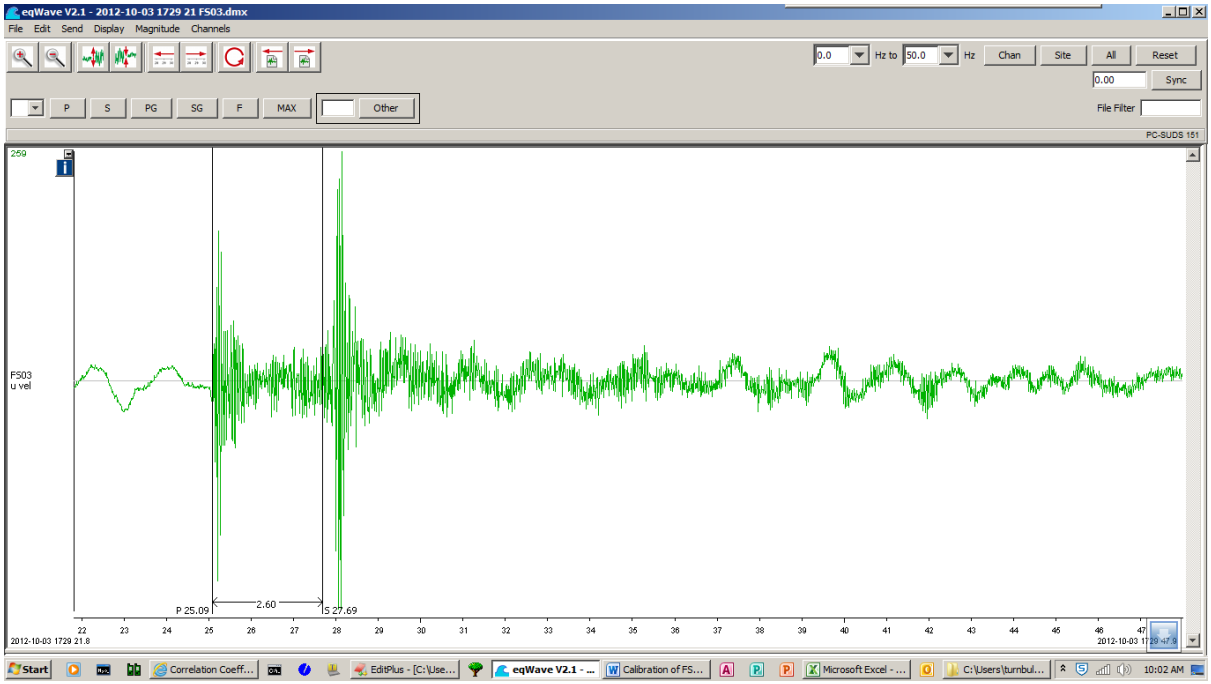

Figure 15: Earthquake recorded on FS03 on 3 October 2012

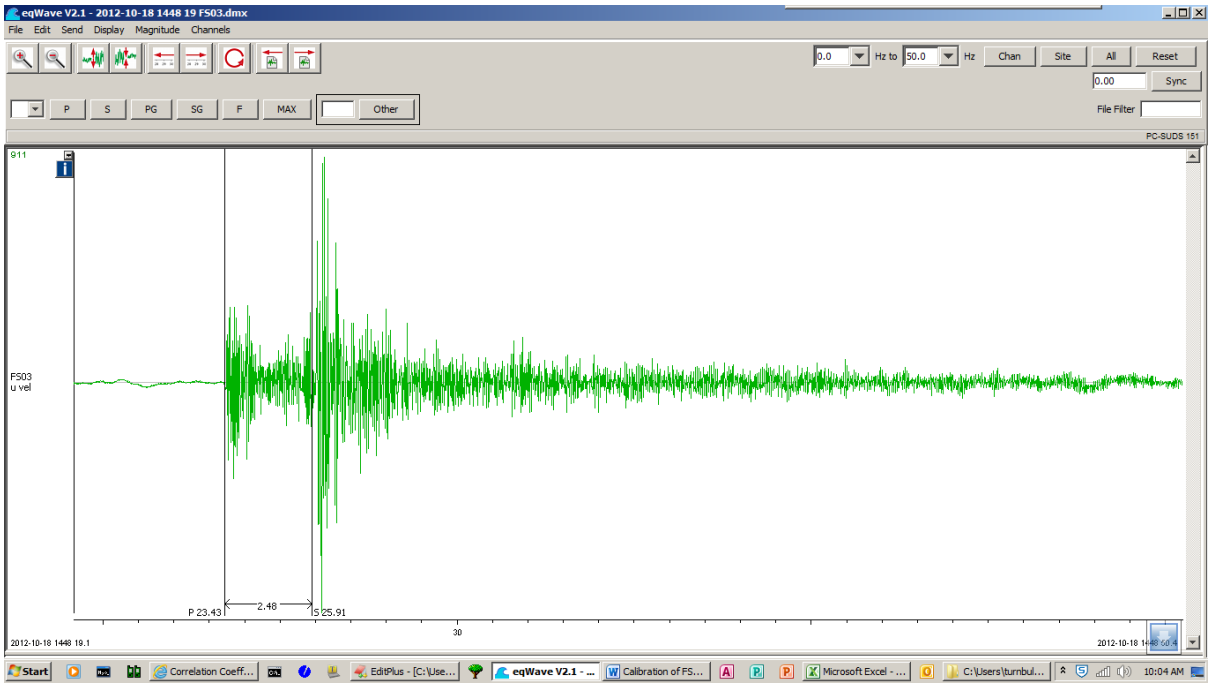

Figure 16: Earthquake recorded on FS03 on 18 October 2012

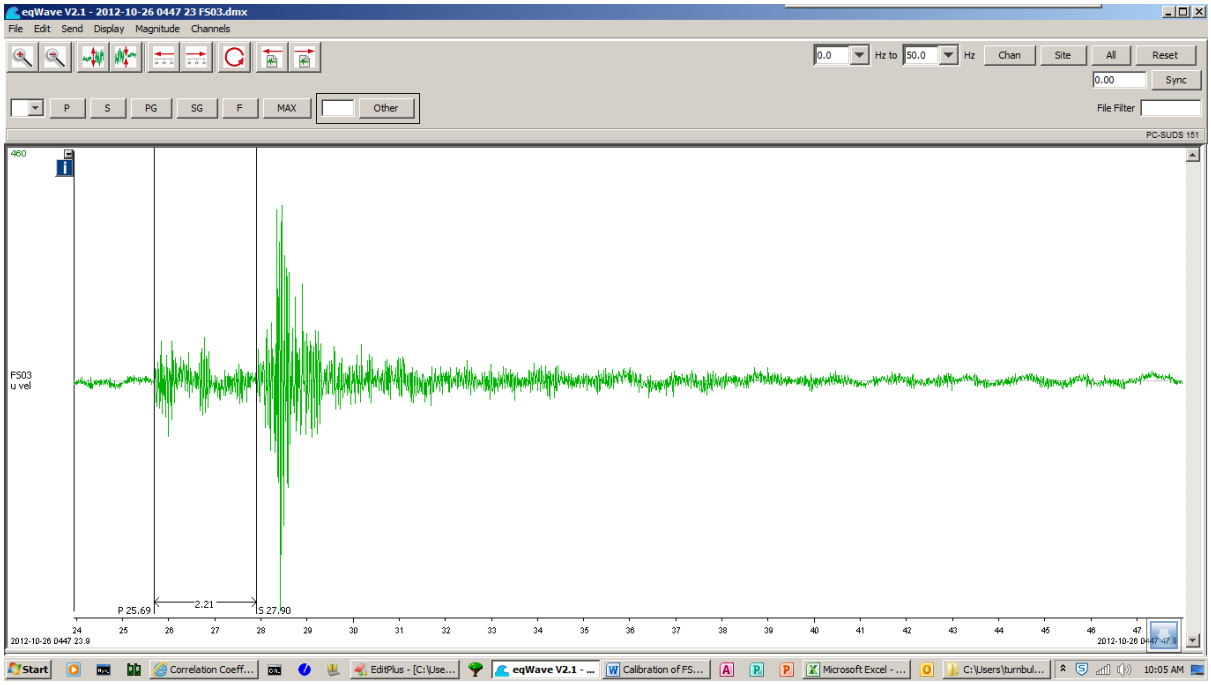

Figure 17: Earthquake recorded on FS03 on 26 October 2012

Appendix D - CQSRG Method of Magnitude Quantification from EIDS Records

Relative Calibration of EIDS Seismometer for Earthquake Magnitude Determination Based on FS03 Past events.

Mike Turnbull, 17 Feb, 2015.

Introduction

FS03 is the designation of a seismic monitoring station operated by the Central Queensland Seismology Research Group (CQSRG). It is located about 24 km south-west of Gin Gin.

EIDS is the Geoscience Australia station located near Eidsvold. The characteristics of the EIDS sensor and associated equipment are unknown (to the author); however, it would be useful to be able to estimate event magnitudes using records from EIDS.

This paper describes a method of extracting parametric information from past earthquakes recorded by both FS03 and EIDS, and quantified using the FS03 seismograms or some other reliable method, that can be used in a suitable mathematical formula to determine the magnitude of earthquakes recorded on the EIDS seismograph.

Background Information

The Richter local earthquake magnitude (M) is calculated using the formula given in Eq. 1.

$$M = log_{10}A - log_{10}A_0 \qquad \text{(Eq. 1)}$$

Where:

A is the maximum amplitude of the seismic record of the earthquake on a given sensor, and

A_0 is the maximum amplitude that would be produced on the same sensor by an earthquake of magnitude zero, occurring at the same location as the earthquake under consideration.

The value of $\log_{10}A_0$ is dependent only on the epicentral distance of the earthquake from the sensor, and the response characteristics of the sensor itself. It is assumed that the relationship is linear as given in Eq. 2 **(NOTE: This assumed relationship has yet to be confirmed as being reasonable)**.

$$log_{10}A_0 = a\delta + b \qquad \text{(Eq. 2)}$$

Where:

δ is the epicentral distance from the sensor under consideration, and

a and b are parameters yet to be determined, characteristic of the sensor under consideration.

Method

Eq.2 is linear, therefore the sensor parameters a and b can be determined from the slope and intercept, respectively, of the graph of $\log_{10}A_0$ plotted against δ, using linear regression, providing that sufficient data is available for the sensor being considered.

The epicentral distance δ can be expressed in any value that provides a valid determination of the distance from the sensor to the epicentre. This could be (for example):

- the difference in arrival times of the P and S waves (in seconds for example); or,
- the surface distance from sensor to epicentre (in km for example); or,
- the Earth centric angle of arc from sensor to epicentre (in degrees for example).

The values for $\log_{10}A_0$, for the sensor under consideration, can be calculated from the amplitudes and S-P times of records of past earthquake events, the magnitudes of which events have been determined by some other reliable method – in this case, from magnitudes determined from FS03 records, or as published by Geoscience Australia.

Transformation of Eq.1 gives Eq. 3.

$$log_{10}A_0 = log_{10}A - M \qquad \text{(Eq.3)}$$

Table 5 presents the calculations of $\log_{10}A_0$ values for EIDS based on past events that were quantified with FS03 seismograms, showing the S-P time differences used to measure epicentral distances from the EIDS sensor. The EIDS seismograms were all similarly conditioned using a 2 Hz to 10 Hz band-pass filter.

Table 6: Determination of log10A0 from past events recorded on the EIDS seismograph.

Earthquake Date	Measured EIDS P arrival	Measured EIDS S arrival	EIDS S-P	Measured EIDS Amplitude A	Magnitude Estimated using FS03 M	Calculated EIDS $\log_{10}(A_0)$
14/06/2014 14:19	17.82	25.48	7.66	99198	3	1.996503
26/06/2014 11:02	17.63	45.34	27.71	678	2.4	0.43123
22/08/2014 08:34	37.56	43.62	6.06	6649	1.9	1.922756
22/08/2014 08:35	27.14	33.69	6.55	92100	2.7	2.26426
22/08/2014 08:38	21.63	28.42	6.79	137217	2.8	2.337408
03/01/2013 19:11	55.16	65.87	10.71	1422	1.6	1.5529
07/01/2013 18:41	60.16	71.28	11.12	822	1.3	1.614872
14/02/2013 23:03	15.7	34.76	19.06	3992	2.1	1.501191
05/01/2012 14:05	75.3	128.37	53.07	4691	4.3	-0.62873
10/04/2012 01:51	43.44	52.12	8.68	2440	1.4	1.98739
20/05/2012 17:58	50.12	59.56	9.44	3879	1.5	2.08872
19/08/2012 22:37	16.48	19.93	3.45	14340	1.5	2.656549
03/09/2012 15:03	15.13	34.44	19.31	14467	2.8	1.360378
19/09/2012 06:14	17.89	25.65	7.76	5905	1.6	2.17122
22/09/2012 23:59	40.45	46.17	5.72	1761	1	2.245759
23/09/2012 16:29	32.05	46.23	14.18	65547	3.2	1.616553
25/09/2012 03:05	22.88	44.51	21.63	2944	1.9	1.568938
03/12/2012 07:41	44.89	51.7	2447	9544	1.4	2.57973
04/12/2012 20:17	55.01	61.41	6.4	570212	3.2	2.556036
12/12/2012 10:36	53.69	60.33	6.64	20513	2.2	2.112029

Figure 14 shows the graph of $\log_{10}A_0$ plotted against the associated S-P time difference (extracted from Table 5).

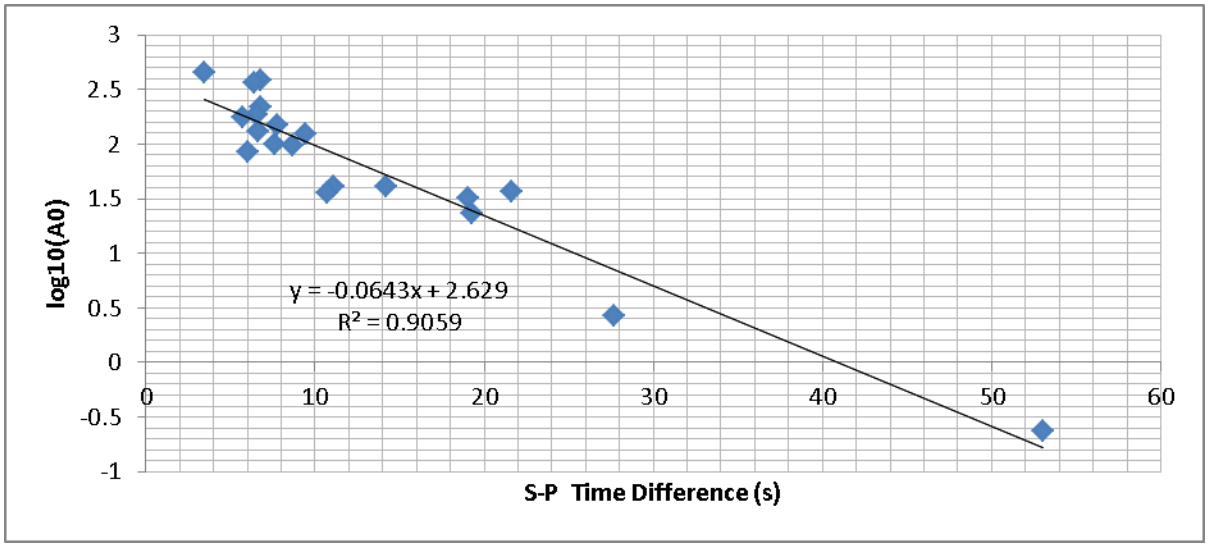

Figure 18: log10A0 Vs S-P

Figure 1 also displays the line of best fit, calculated using linear regression of the plotting data, along with the slope, intercept, and correlation coefficient (R^2). **The R^2 value of 0.91 confirms that the assumed linear relationship is reasonably valid.**

By substituting the slope and intercept values into Eq.1 and Eq.2 we arrive at the formula for EIDS magnitudes given in Eq.4.

$$M_{EIDS} = log_{10}A - (-0.064(S - P) + 2.63) \quad \text{(Eq.4)}$$

Where:

M_{EIDS} is the Richter magnitude determined from an EIDS seismogram record;

A is the maximum amplitude of the EIDS seismogram record;

S is the arrival time of the S wave in seconds, and;

P is the arrival time of the P wave in seconds.

Example Usage

Figure 15 shows the seismogram of an earthquake that was recorded on station EIDS on 15 February 2015.

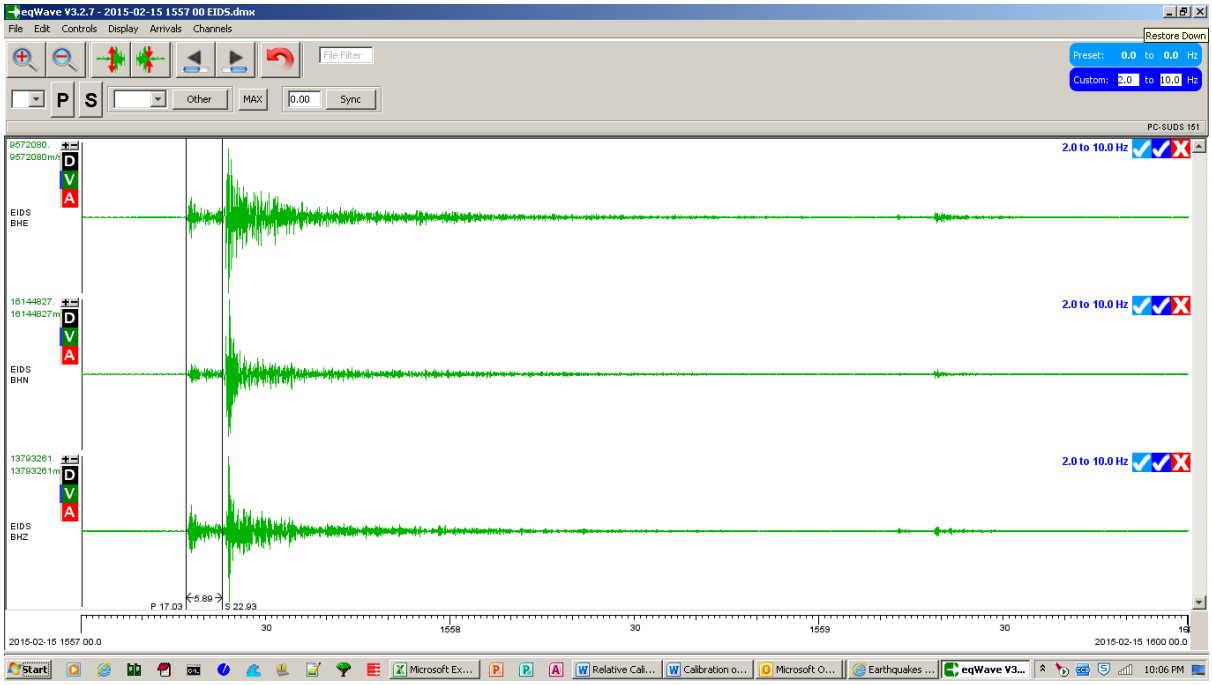

Figure 19: EIDS record of an earthquake.

From Figure 15 we can obtain the maximum amplitude (A = 13793261), the P wave arrival time (P = 17.03 s) and the S wave arrival time (S = 22.93 s); from which the time difference (S – P = 22.93 s) can be determined.

Inserting these values into Eq.4 we calculate a Richter magnitude of 4.9 (rounded to one decimal place).

Table 6 shows the results of some other similar calculations, for different earthquakes, along with the GA published magnitudes for the same events.

Table 7: Calculations of EIDS Richter magnitudes for some earthquakes.

Earthquake Date	Measured P arrival	Measured S arrival	S-P	EIDS Amplitude A	Calculated M_{EIDS} Magnitude	GA Published Magnitude
15/02/2015 15:57	17.03	22.93	5.9	13793261	4.9	5.1
15/02/2015 15:58	12.58	18.56	5.98	869195	3.7	
15/02/2015 16:40	43.7	49.25	5.55	278525	3.2	3.2
15/02/2015 17:37	13.18	19.15	5.97	907859	3.7	3.4
15/02/2015 18:06	14.56	20.54	5.98	125151	2.9	2.5
16/02/2015 05:56	58.18	64.14	5.96	1703875	4.0	4.0