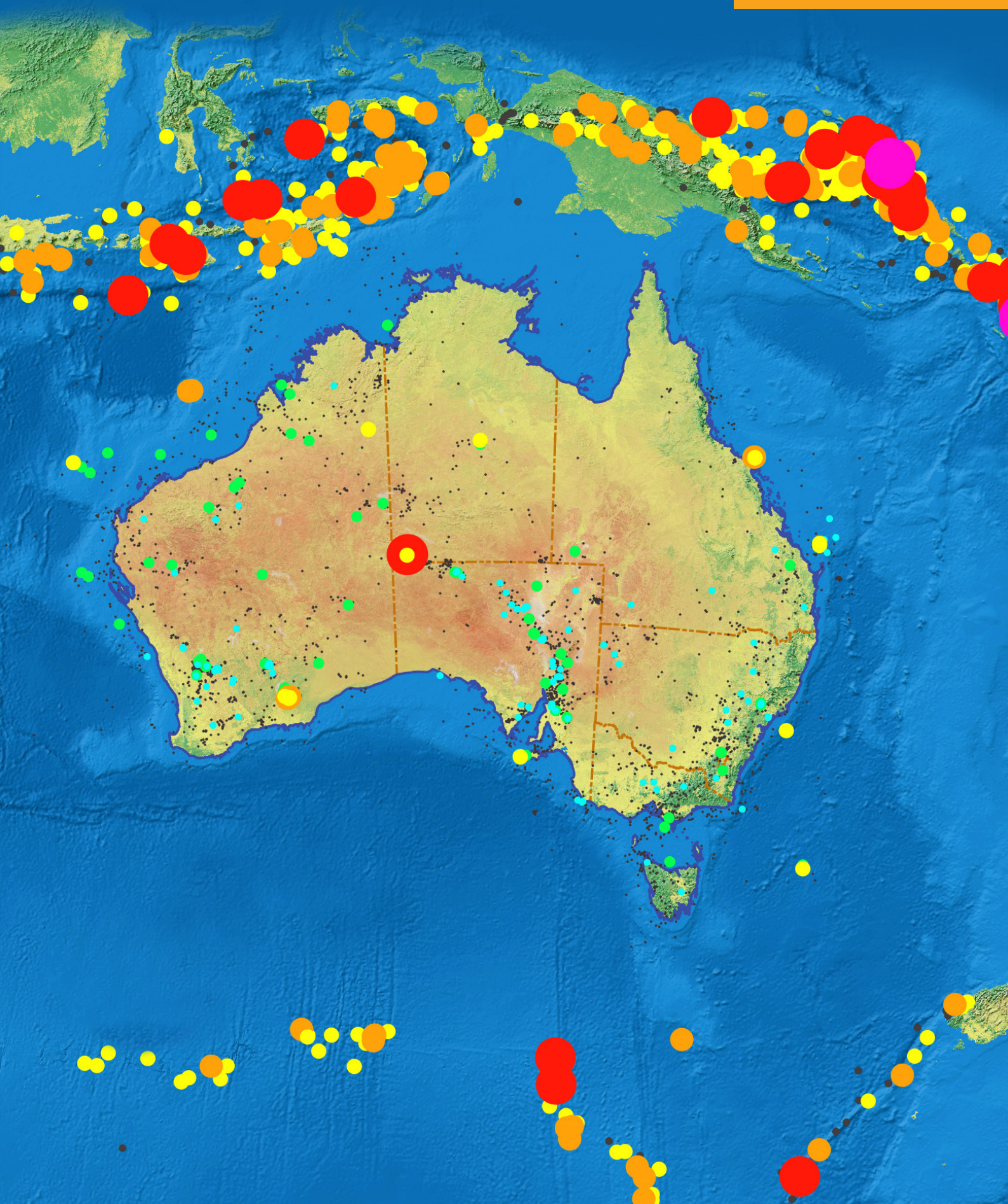


Australian Seismological Report

2016



Cover Legend

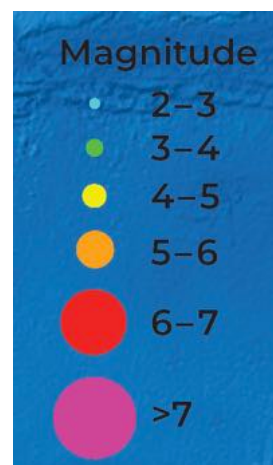
Coloured dots

Australian earthquakes for 2016, $ML \geq 2.5$ from Gary Gibson's GG cat
Surrounding areas for 2016, $M \geq 4.5$ from US Geological Survey

Small grey dots

Australian earthquakes for 2000-2015 $ML \geq 2.5$ from Gary Gibson's GG cat
Surrounding areas for 2000-2015 $M \geq 6.0$ from US Geological Survey

Background map from naturalearthdata.com

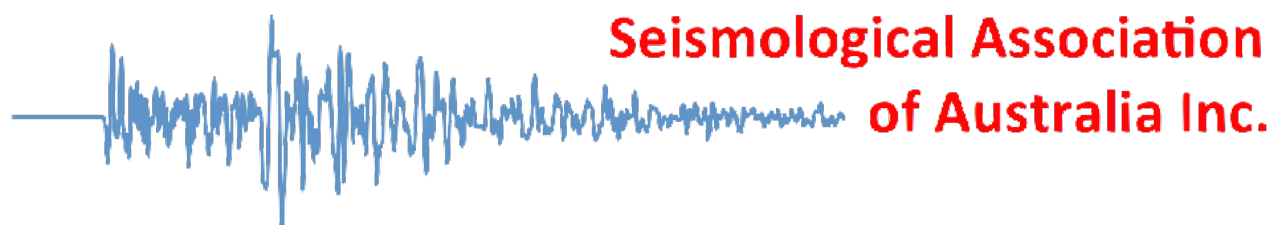


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In 2016 earthquakes were felt in several large population centres across Australia; Darwin (twice) and Alice Springs (NT), Townsville to Bowen (Qld), Moe to Melbourne (Vic), Sydney to Newcastle (NSW), Murray Bridge to Adelaide (SA), Canberra (ACT) and Kalgoorlie (WA). No damage was reported but a large earthquake near the NT/SA border ruptured the ground surface for 20km.

There was no damage to structures and there were no casualties from earthquakes.



Seismological Association of Australia inc.

Chairperson: Blair Lade

Secretary/Treasurer: Joe Grida

Chief Seismologist: David Love

Editors: Kevin McCue and David Love

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Seismological Association of Australia

Australian Seismological Report 2016

Contributors

Elodie Borleis¹, Vic Dent², Gary Gibson³, Abe Jones³, David Love⁴,
Geoff Luton⁵, Kevin McCue⁶, Michelle Salmon⁵, Malcolm Sambridge⁵,
Christian Sippl⁵, Andrea Thom⁷, Hrvoje Tkalčić⁵, Mike Turnbull⁶ and
Alison Wallace⁴

¹Seismology Research Centre, Melbourne, ²University of Western Australia and Curtin University,
³University of Melbourne, ⁴Geological Survey of South Australia, ⁵Australian National University,
⁶University of Central Queensland, ⁷Geoscience Australia

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1. Introduction

This report is the latest in a series of annual summaries of the seismicity of Australia, beginning in 1980 (Denham and Gregson, 1985) and the first published under the auspices of the Seismological Association of Australia.

The 11th Asian Seismological Commission General Assembly was held concurrently with the Australian Earthquake Engineering Society conference at the Melbourne Convention Exhibition Centre 24 to 27 November 2016. President and head of the ASC Organising Committee Gary Gibson opened the meeting. A meeting of Australian seismologists was held prior to the conference at the Exhibition Centre. Australian seismologist and President of AEES, Paul Somerville, opened the AEES Conference.

In 2016, earthquakes were felt in several large population centres across Australia; Darwin (twice) and Alice Springs (NT), Townsville to Bowen (Qld), Moe to Melbourne (Vic), Sydney to Newcastle (NSW), Murray Bridge to Adelaide (SA), Canberra (ACT) and Kalgoorlie (WA). A baby was injured in Mackay in the Bowen Qld. earthquake, no structural damage was reported but a large earthquake near the NT/SA border ruptured the ground surface on a 20km long previously unmapped fault.

The front cover map Figure 1 shows the 300 epicentres of magnitude 3 or more, the pattern of earthquakes as expected in the hazard map in the current Earthquake Loading Code.

2. Australian Earthquakes 2016, an Overview

The largest Australian earthquake in 2016 was a magnitude 6.3 earthquake on 9 September at 07:46 AEST, the epicentre 20km SW of the base on Macquarie Island, Tasmania on the Macquarie Ridge. The earthquake was felt strongly at the Antarctic Division base on the northern end of the island and at Bauer Bay about 5km south. A landslide cut the station water supply pipeline and goods were thrown off shelves but there was no other damage.

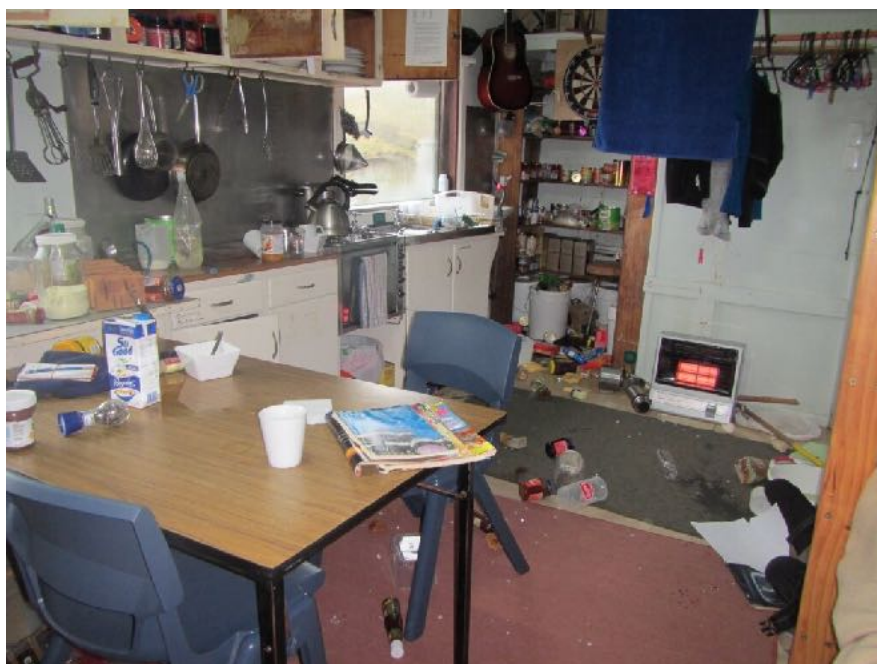
ABC New reported the following (Photo: Kimberley Kliska, Antarctic Division):

Australian Antarctic Division's Macquarie Island station leader Esther Rodewald said it was very noticeable.....good side-to-side shake, although I was in one of the earthquake-resistant buildings, so I may have felt it less than others much debate here as to how long it lasted – no more than 10 seconds is the best guess.

Photo Dislodged articles in an office on Macquarie Island

Ms Rodewald said after a check of station infrastructure and

buildings no major damage or injuries had been reported. A few things bounced off shelves, glass fell off one of the pictures in the mess, she said.



Ms Rodewald said 14 people were currently on station and one was in a field hut. A couple of people have reported feeling two further small tremors, she said.

Ms Roderwald's comments about aftershocks and about one of the earthquake resistant buildings is interesting - that some buildings are but not others.

Of more interest to intraplate seismologists were:

- a large M6.1 earthquake in the Petermann Ranges NT on 21 May that caused surface faulting visible with Insar and thousands of aftershocks. Seismologists from Geoscience Australia, Australian National University and Melbourne University investigated the surface deformation and installed a network of seismographs to monitor aftershocks.
- a strongly felt M5.8 earthquake offshore from Bowen Qld on 18 August at 2:30 pm. It was felt over a large area of east central Queensland but caused no damage. Many aftershocks were recorded. A baby in Mackay was reported to have incurred minor head injuries.

Some papers relevant to the seismicity of Australia in 2016 were published in the AEES2016 and AEES2017 conference proceedings available at www.aees.org.au.

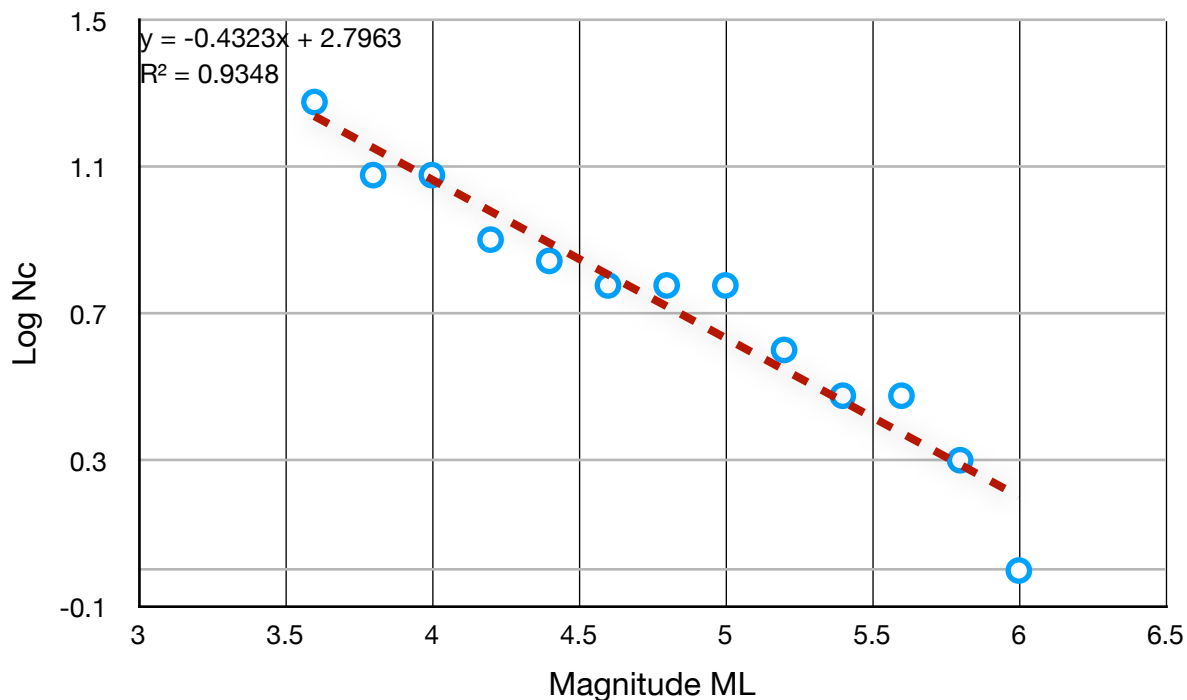


Figure 2 Recurrence relation for Australian earthquakes, 2016, the magnitude range $3.5 \leq ML \leq 6.2$. GA's target completeness ranges is earthquakes above ML 3.5

A plot of the recurrence relation $\log N_c = a - bM$ for the 2016 set of earthquakes downloaded from the GA on-line earthquake catalogue yields the attached Figure 2 for earthquakes in the magnitude range 3.5 to 6.1. Most, if not all, aftershocks have been deleted.

Note that the scale used is Richter magnitude ML, not moment or any other of the myriad of modern scales. The 'b' value of 0.43 is very low, there appear to be fewer small earthquakes, below about magnitude 4.5 than expected in an average year, but more larger earthquakes than expected, above magnitude 4.5.

Surely every earthquake above magnitude 3.5 should have been detectable and locatable in continental Australia in 2016.

The large Macquarie Ridge earthquake and another south of Tasmania (see cover Figure) have not been included in the analysis, one is on the Pacific-Australian Plate boundary, the other in Oceanic Crust and both are distant enough not to contribute to earthquake hazard in Australia though they should be considered for tsunami hazard.

Geoscience Australia (GA) located 669 Australian earthquakes in 2016, using data from the AU network which comprises 67 sites of the Australian National (broadband) Seismograph Network (ANSN) and 36 sites of the Urban Monitoring (short period & strong motion) network (UM) supplemented by stations operated and maintained by the Australian National University (WRA and Seismometers-in-Schools).

The most significant event of the year was the M6.1 earthquake in the Petermann Ranges, NT, with 42 aftershocks located in the first two days. As of November 2017, GA had located 86 earthquakes above magnitude ML 2.4, with seismic activity centred on the Petermann Ranges and Tennant Creek regions.

In Western Australia, 238 earthquakes were located in 2016. The most significant event was a M5.6 earthquake east of Norseman with extensive aftershock activity. Other significant earthquakes were a M5.1 earthquake SE of Hall's Creek in NE WA and a M5.3 offshore Broome, WA.

Queensland's seismicity remained elevated in 2016, with 75 earthquakes recorded by GA. The M5.8 earthquake offshore Bowen, Queensland's second largest earthquake on record. had 21 aftershocks on the same day, two of which were M4.0 and M4.1, respectively.

118 earthquakes were located in South Australia, the largest a widely felt M4.5 earthquake west of Kangaroo Island.

GA also located 123 earthquakes in NSW including a M4.0 offshore Gosford, 23 earthquakes in Victoria, five earthquakes in Tasmania and one earthquake in the ACT.

Magnitude

Worldwide, magnitude is measured on a bewildering number of scales. In Australia GA, SRC, UniMelb and SAA usually report Richter magnitude ML or occasionally Moment magnitude Mw, even mb as tabled below. ISC and USGS use all four scales, and many more.

ML: $M \leq 6.3$, distance $< 600\text{km}$

Ms: (shallow) $5.75 \leq M \leq 8$, distance between 20° and 130°

mb: (deep) $4.5 \leq M \leq 6.25$, distance between 6° and 110°

Mw: $6 \leq M$

All the scales purport to measure the relative size of earthquakes but usually do not give the same numerical magnitude for any event (McGregor and Ripper, 1976). Measured Richter magnitudes on Australian seismographs for a single event often range over one magnitude unit. The quoted magnitude is the mean value, the standard deviation is more than 0.2.

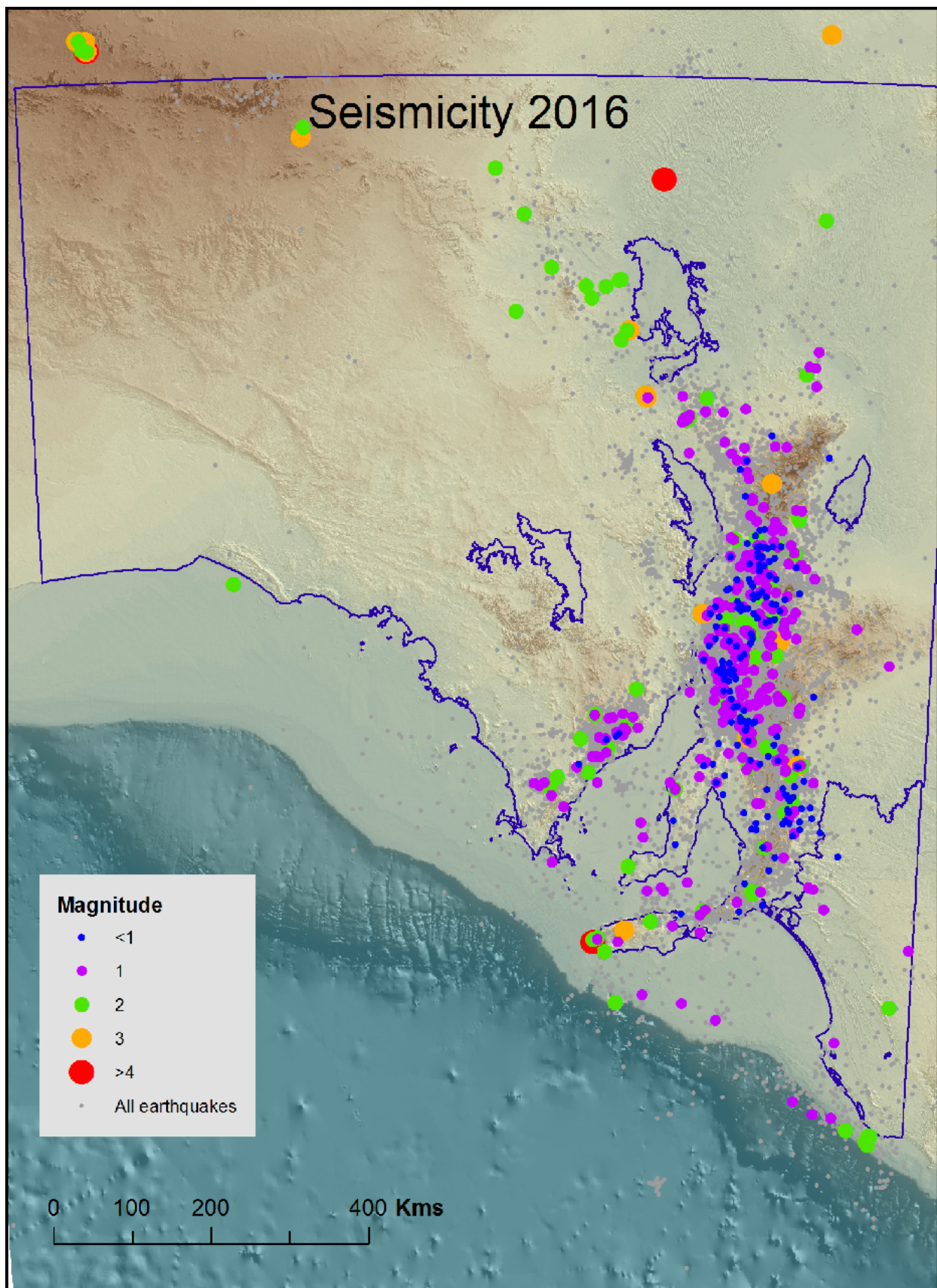


Figure 3 Earthquakes for 2016 located by Department of State Development SA. 2016 epicentres are shown in colour, and the complete catalogue of earthquakes (from 1840) shown in grey

3.1 South Australia

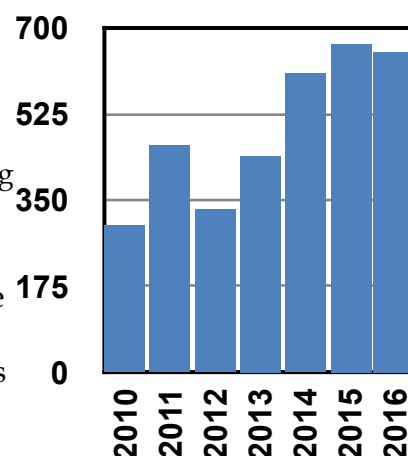
David Love and Alison Wallace, Geological Survey of South Australia

Seismicity

The most significant earthquake event of the year was the magnitude 6.1 event in the Petermann Ranges (NT), just north of the SA border. 31 events in the catalogue are in the area. Department staff assisted the aftershock survey, preparing four Geoscience Australia rapid deployment kits over the weekend, and preparing five other units to go with the Melbourne University team.

Seismicity (Figure 3) was mostly recorded in the usual regions, Flinders Ranges, Mount Lofty Ranges to Kangaroo Island, Eyre Peninsula, and near the continental slope. There were 650 events located in SA in 2016 (Figure 4). This is slightly less than last year.

Figure 4 Number of located earthquakes in South Australia during recent years



The largest event in the state was a magnitude 4.9 earthquake west of Kangaroo Island. This was widely felt and a preliminary felt map from Geoscience Australia of felt reports is shown in Figure 5. There was very limited aftershock activity. This is near the same area and a similar size to the event on 16 Dec 1986. The next largest event, magnitude 4.0 was north of Lake Eyre, where little seismicity has been recorded. There were a number of earthquakes just off shore to the west of Port Macdonnell. There was continuing activity from 2014 about 50 km SW of Marree, and notably more earthquakes than previous years in the band from Marree to Oodnadatta.

Three focal mechanism diagrams were produced (Figure 6). These were for:

- (a) The Mount Compass earthquake, magnitude 2.1, on 2016-01-11 1145 UT. This is a moderately well constrained focal mechanism, similar to the first event 2015-12-18 0307, but with a slightly different strike.
- (b) Another Mount Compass event magnitude 2.2 on 2016-02-06 This is different to the others and not quite as well constrained. The three events were in the depth range 19 to 22 km, and there were a few weak felt reports.
- (c) The Tea Tree Gully event magnitude 2.2 on 2016-03-05 1621, and 20 km deep. This is the best constrained of the three mechanisms. We received no felt reports for this event.

The largest events can be found on the GA on-line earthquake catalogue.

Magnitude measurements reverted to straight Richter during the year from a locally determined Richter scale with a modified distance term (Greenhalgh and Parham, 1986).

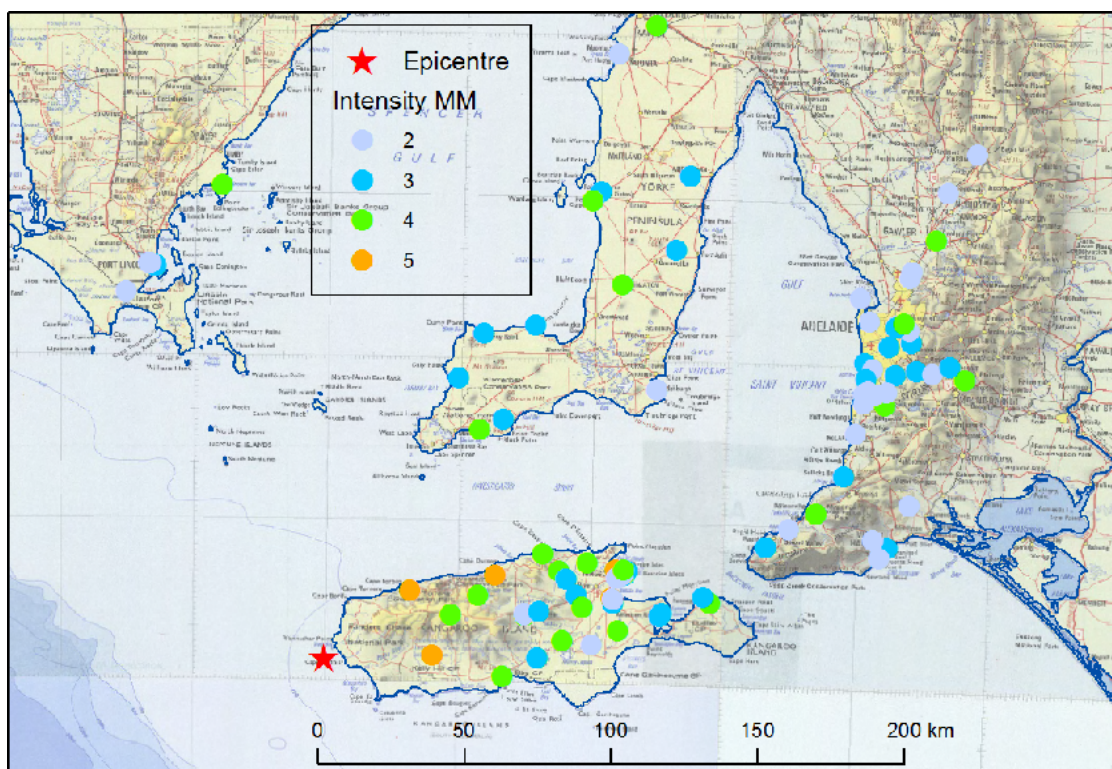


Figure 5. Felt reports from Geoscience Australia for the magnitude 4.9 Kangaroo Island earthquake of 19 June 2016

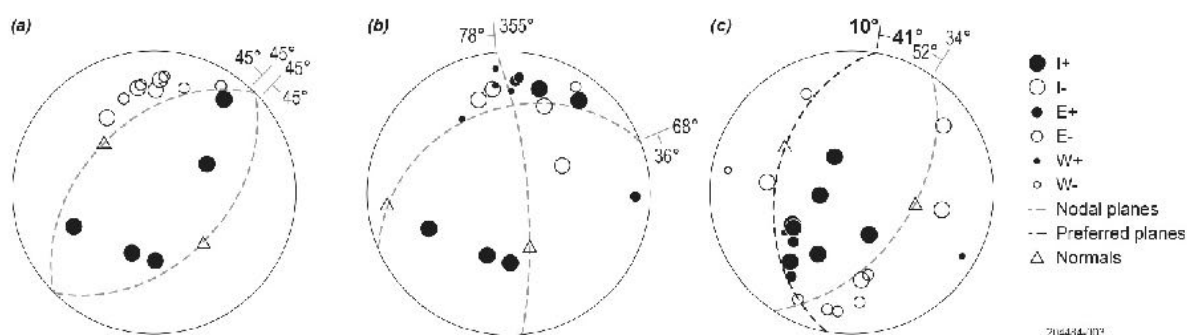


Figure 6 Focal mechanisms (upper hemisphere) for (a) Mt Compass 2016-01-11 1145 (b) Mt Compass 2016-02-06 0921 (c) Tea Tree Gully 2016-03-05 1621

Seismograph Network

The Geological Survey of South Australia announced its intention to discontinue earthquake monitoring; assisting Geoscience Australia to take over some of the seismograph sites.

ANU opened a new station at Murray Bridge High School, as part of the Seismometers in Schools program.

Following updates to both PSN and Eqserver software, we succeeded in sending triggered data from PSN sites GLDS and THS to our Eqserver site.

An STS-2 seismometer on loan from ANU was installed in the private vault near HMV1 station.

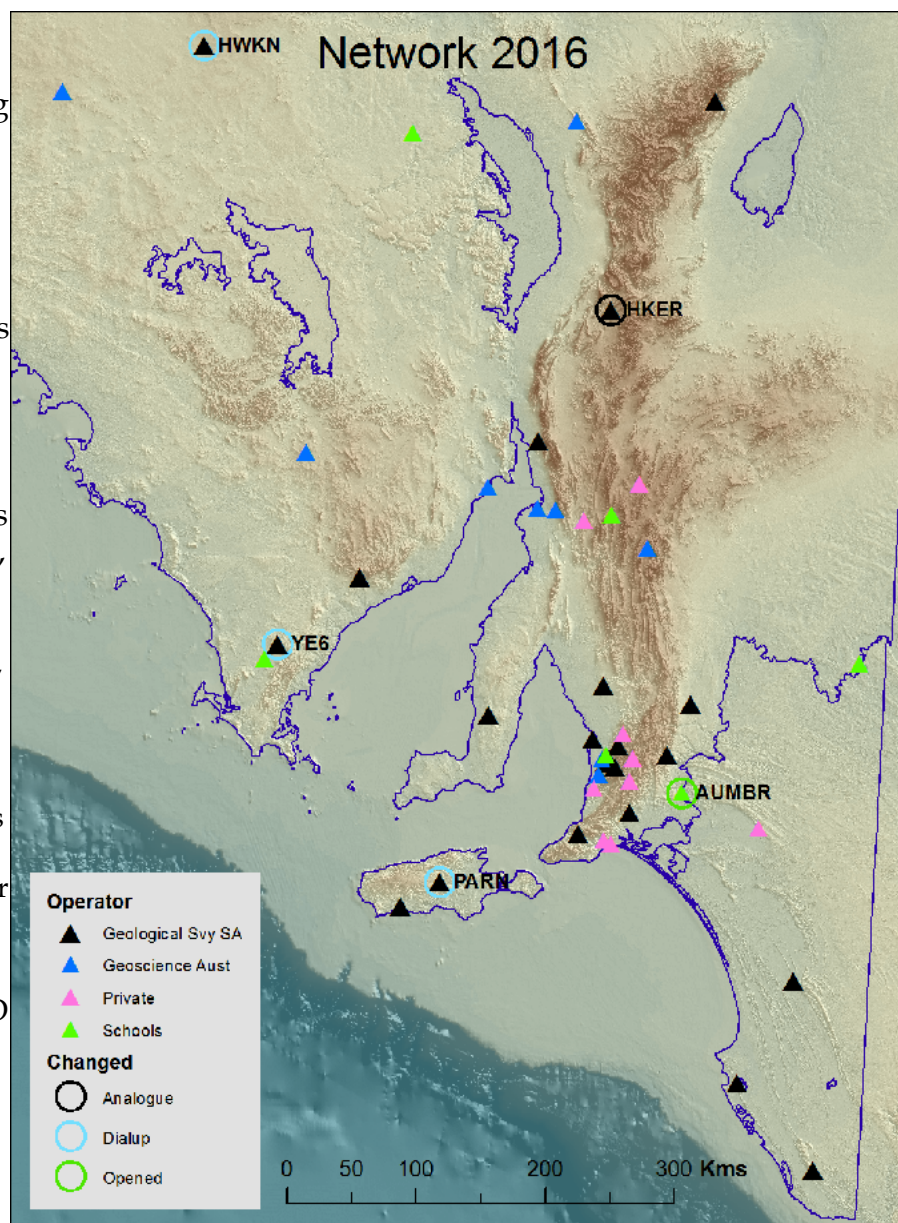
The Geological Survey operates 22 digital stations. This includes one remaining analogue station (with a low quality digital feed) at Hawker, and three old dial-up digital stations (HWK, YE6, PARN). Geoscience Australia operate 11 stations in the state, of which 6 are regional stations and 5 are urban monitoring (JUMP) stations. Six stations are in the Seismometers in Schools program managed by ANU, although only 5 are operational. There are 10 other private seismographs, mostly PSN type instruments.

Figure 7 South Australian seismographs in 2016. Circles show where changes or new stations have occurred, and for analogue and dial-up stations Other

- Bambang Setiawan (PhD candidate, Engineering, Adelaide University) carried out eight SPAC soundings around the Adelaide area.
- Early phase data from 1963 to 1977 was recovered from old printouts and manually entered into Eqlocl files.
- There were two meetings of the Adelaide seismological interest group.
- Three papers were published in the year (see References).

Procedures

Procedures changed during 2016. Due to the closure announcement, the normal final locations on Eqlocl software were delayed after January. This means that magnitudes (from Eqfocus) in the catalogue used the Richter formula instead of the Greenhalgh and Parham (1986) formula. These can be seen as the entries that do not have the other associated fields. Other procedures were unchanged. An attempt will be made to complete the Eqlocl solutions.



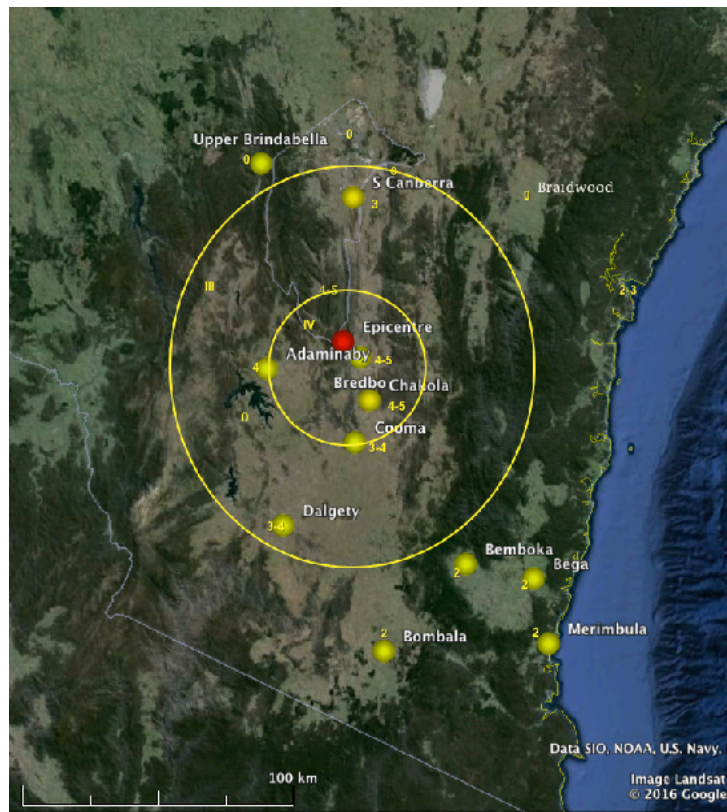
3.2 Australian Capital Territory

Kevin McCue and Elodie Borleis

One small earthquake was located by GA within the ACT in 2016 but at least two NSW earthquakes were felt in Canberra suburbs, the first in January, the second just 10 days later.

Bredbo NSW was the epicentral region of a small magnitude 3.6 earthquake on 31 January 2016 at 4:40 am AEST. It was felt over a wide area from Southern Canberra to Cooma and Bega. A short paper in the AEE2016 Conference by McCue discusses the earthquake and its unlikely association with the main geological feature in the area, the Murrumbidgee Fault.

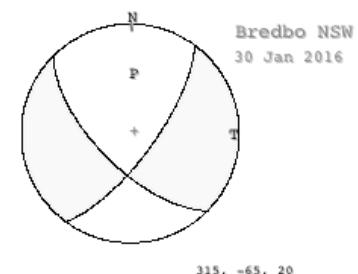
Figure 8 Iseismal map of the small earthquake on 31 January, its epicentre near Bredbo NSW. Shaking was felt in southern suburbs of Canberra



Another small earthquake, magnitude 3.2, to the west of Canberra near Wee Jasper NSW was felt in Canberra suburbs in Belconnen on 10 February at 4pm AEST.

A report from a Namadgi National Park ranger living in the southern part of the park had this to say about the Bredbo and Wee Jasper earthquakes: *Yes I did feel the earthquake. In fact it woke me up, which is a feat in itself given I am a heavy sleeper! Very loud rumble and lots of items rattling in the house, no damage however. Being no stranger to quakes having grown up at Crookwell I knew what was going on, but I must admit it was the strongest one I have felt for some years. I also felt the one about a week later in Wee Jasper, a low rumble and feint tremors at Gudgenby. I did submit a report to Geoscience Australia for both.*

Figure 9 Focal mechanism of the Bredbo NSW earthquake using public and private station first arrivals in the ACT and NSW. This shows an unusual strike-slip fault with a strong normal component. The Murrumbidgee Fault trends north-south in the region so is unlikely to be responsible for this earthquake



Seismograph Networks

The number of public seismographs in the ACT has grown significantly since the year 2000 when there were just four; CAN, CNB, KBH and RNDA. This is mainly a result of the Seismometers in Schools program administered by the ANU (pink dots in Figure 10). SRC operated six seismographs/accelerographs for Icon Water for dam monitoring in 2016, data from some

of these stations are available on request. Other seismographs are nearby in NSW, one of them a PSN station and others operated by GA (blue dots in Figure 10), SRC for Snowy Hydro or the Australian Seismological Centre at Aranda.

Figure 10 (right) Seismograph stations within ~200km of the centre of Canberra with publicly accessible data

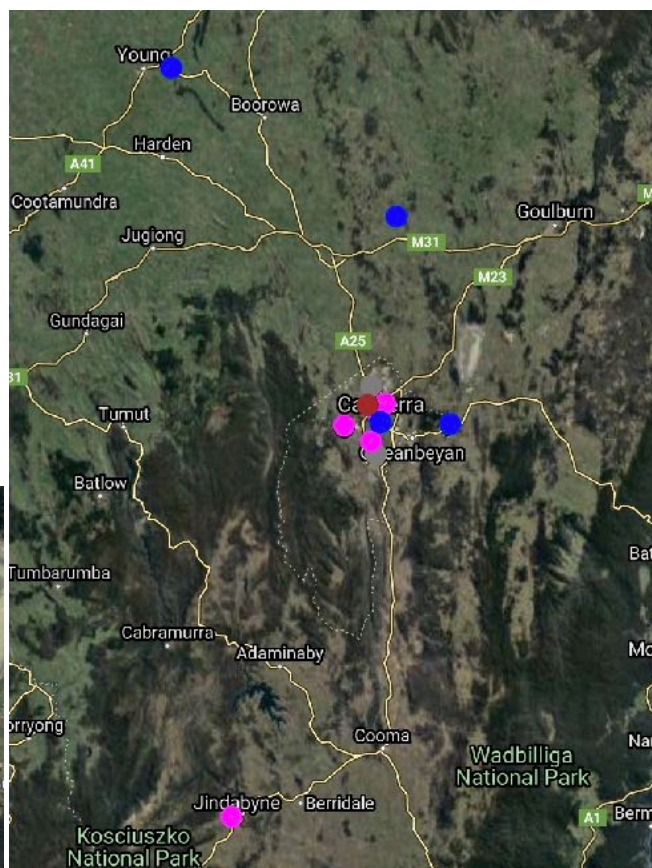
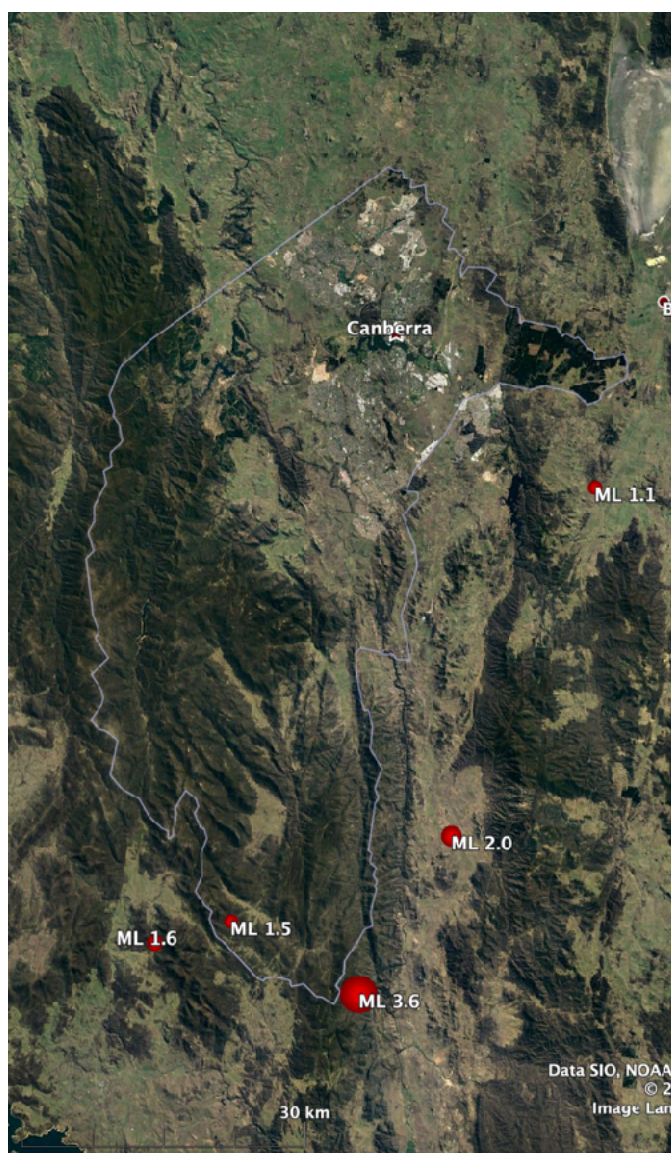


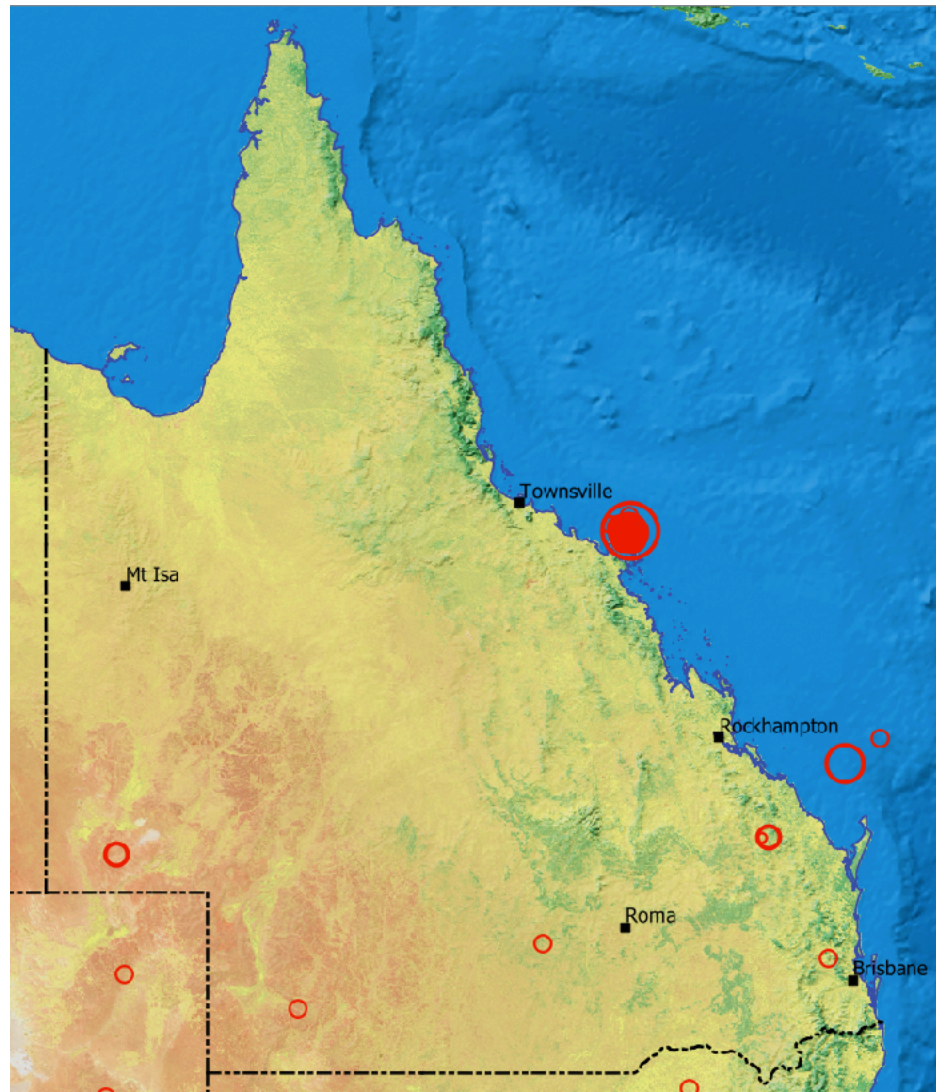
Figure 11 (left) Seismicity (magnitude $ML \geq 1.0$) in 2016 in the vicinity of the ACT (area enclosed in the white border line). The early morning earthquake in southern Namadgi National Park on 2 February, magnitude 1.5), was not reported felt. SRC have the location just over the border in NSW

3.3 Queensland

Kevin McCue, Mike Turnbull and Elodie Borleis

There were 53 earthquakes of magnitude 2.5 or more in Queensland, according to the GA on-line earthquake catalogue, epicentres plotted in Figure 12. Two hundred and sixty-seven events were located by the Seismology Research Centre throughout Queensland in 2016; twenty-three events were greater than or equal to magnitude 3.0, six were greater than or equal to magnitude 4.0 (all aftershocks of the Bowen earthquake). Only one event was greater than magnitude 5 the State's largest earthquake in 2016, off Bowen on 18 August at 04:30 UTC, magnitude Mw5.8. A strong aftershock sequence followed, many of the aftershocks felt locally. This was the second strong offshore earthquake in consecutive years (Borleis and Dimas, 2016).

Figure 12 Earthquakes of magnitude $M \geq 2.5$ in 2016 from the GA on-line catalogue



ABC News reported:

The second biggest earthquake ever recorded

off the east Australian coast has shaken areas of central and north Queensland but there have been no reports of serious damage, however minor cracking has occurred at some properties. There were evacuations in Townsville CBD buildings and at Cairns and Mackay air traffic control towers.

Shaking was reported all the way from the Sunshine Coast up to north of Townsville.

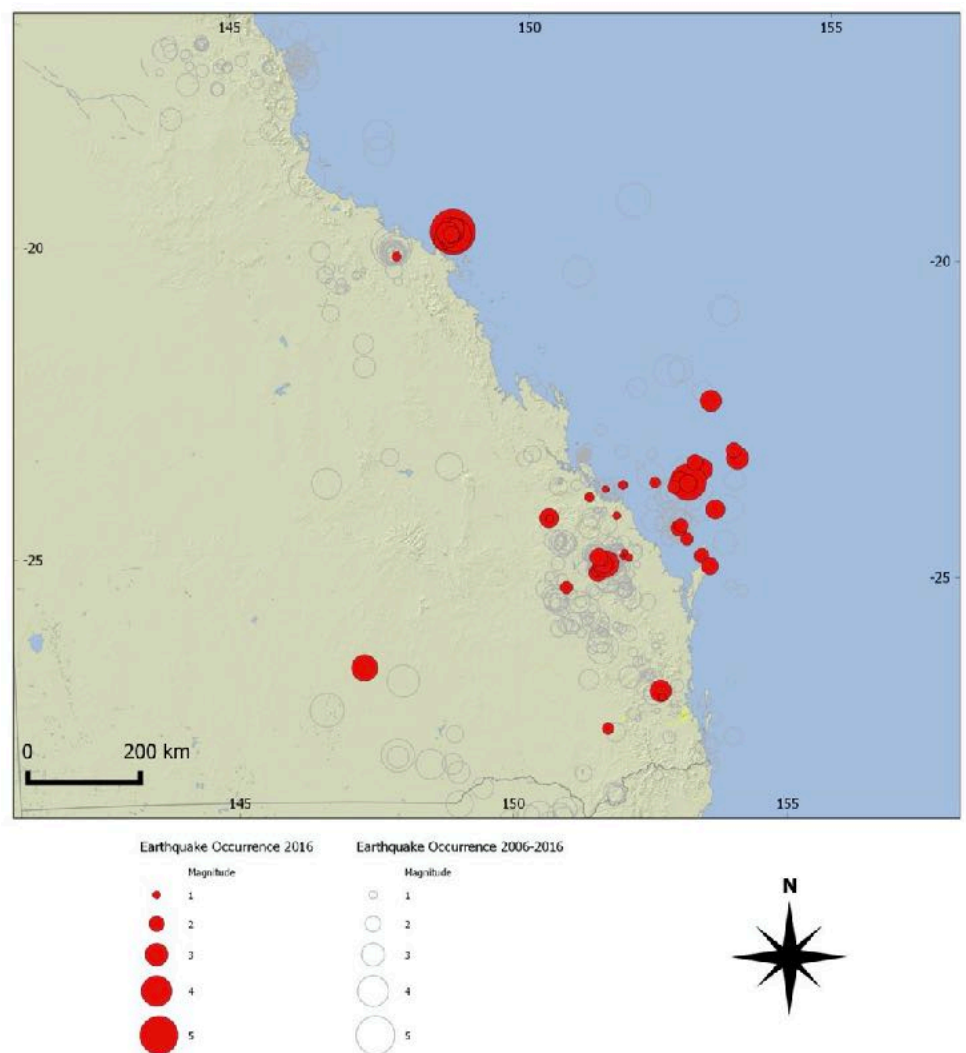
Townsville resident John Towing said he was watching ABC News 24 when his chair started to shake. "I thought, there's no train around, no plane around then I got up and had a look and I thought, geez, the whole bloody place is shaking," he said. "I sat down again and it was like the bloody chair was vibrating. When you looked around at everything on the wall you could see it all shaking."

Mr Towning said one of his neighbours fled her house because she believed it was not safe. "I'd say it lasted a good six or seven seconds," he said. "It was more funny than scary. You don't normally get those things here. You watch the clock shaking across the wall a bit, everything on top of the fridge is shaking. ABC journalist Brigid Glanville was holidaying with her family on Hamilton Island in the Whitsundays and also felt the quake. "It certainly shook everyone up. I went into the general store and a few things came off the shelves and everyone is talking about it," she said.

The Guardian recorded an interview with Greg Williamson, the mayor of Mackay, by the Daily Mercury newspaper and captured the sound of a shaking floor when the quake struck, prompting Williamson to ask: "Is that an actual earthquake?"

Figure 13 Earthquakes of magnitude $M \geq 1$ in 2016 (from SRC)

The tremors reportedly lasted 40 seconds in Mackay, with fainter and shorter echoes felt as far south as the Sunshine Coast and west of Charters Towers. The Mackay hospital and health service said a baby with a *minor head injury* in Bowen was the sole known casualty from the quake.



Office workers in one Townsville building described a quake that some felt and others did not notice, which did not dissuade council workers from evacuating their building nearby. In Cairns, a building housing Torres and Cape hospital and health service workers was reportedly evacuated after it started shaking.

Seismograph Network

The Seismology Research Centre network now comprises 18 seismographs and accelerographs located along the eastern seaboard of Queensland. GA's network comprises 7 ANSN stations (the same as in NSW) and 12 Jump stations that cover the whole state. There are 7 AUSIS schools in Queensland, all coastal.

Central Queensland

This report details earthquakes detected and located by the Central Queensland Seismology Research Group (CQSRG) at its station FS03 during 2016.

Aftershocks 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 north of Airlie Beach. This resulted in numerous aftershocks.

Mount Perry Earthquake Sequence Continuing

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. Aftershocks occurred throughout 2015, and continued during 2016.

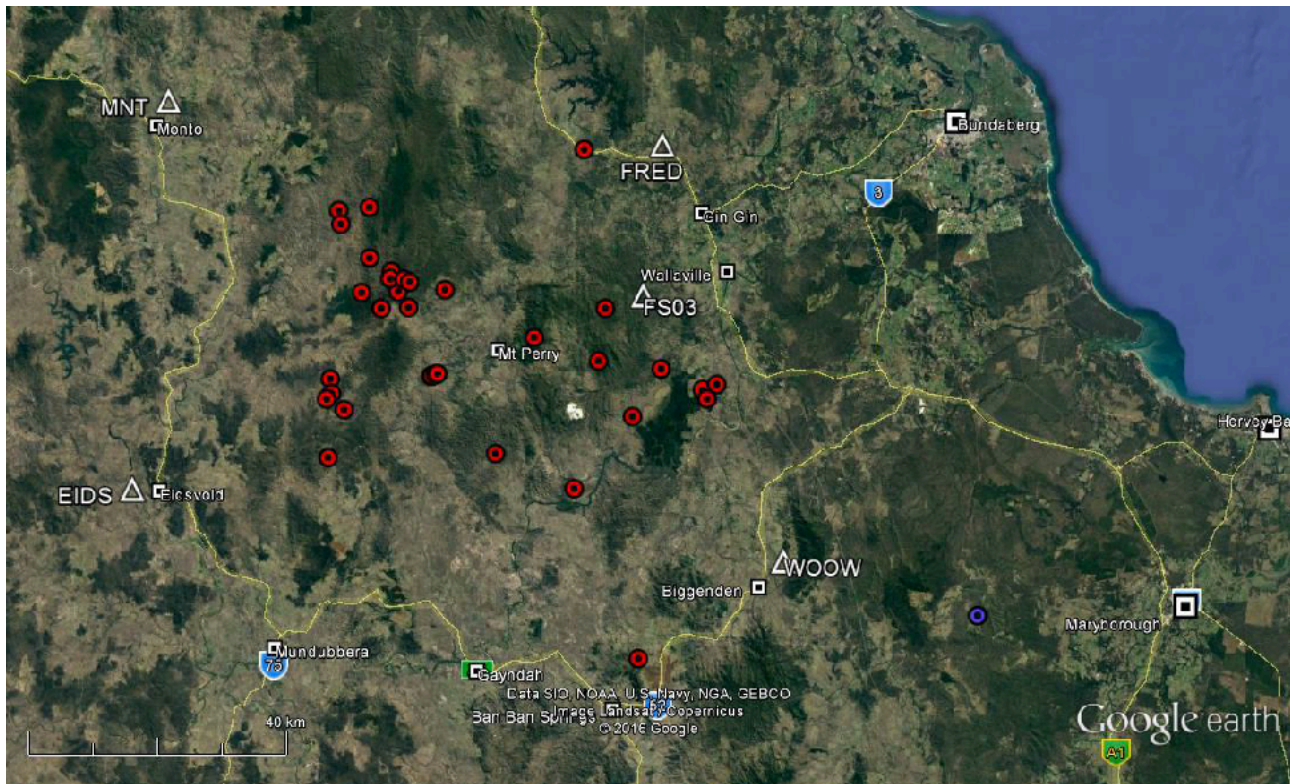


Figure 14 Mt Perry sequence aftershocks during 2016

As shown in Figure 14 above, 22 aftershocks in the Mt Perry sequence were recorded during 2016, ranging in magnitude from M 0.6 to M 3.0. This compares to a background average of 4.4 events per year recorded during the 11 years prior to the main earthquake in 2015. Aftershocks continue to occur in the target area, but at a reducing rate, and gradual reduction in average magnitude, as shown in Figure 15. The aftershocks are scattered over a wide area, incompatible with any thought they can be attributed to a single fault or even a set of conjugate faults.

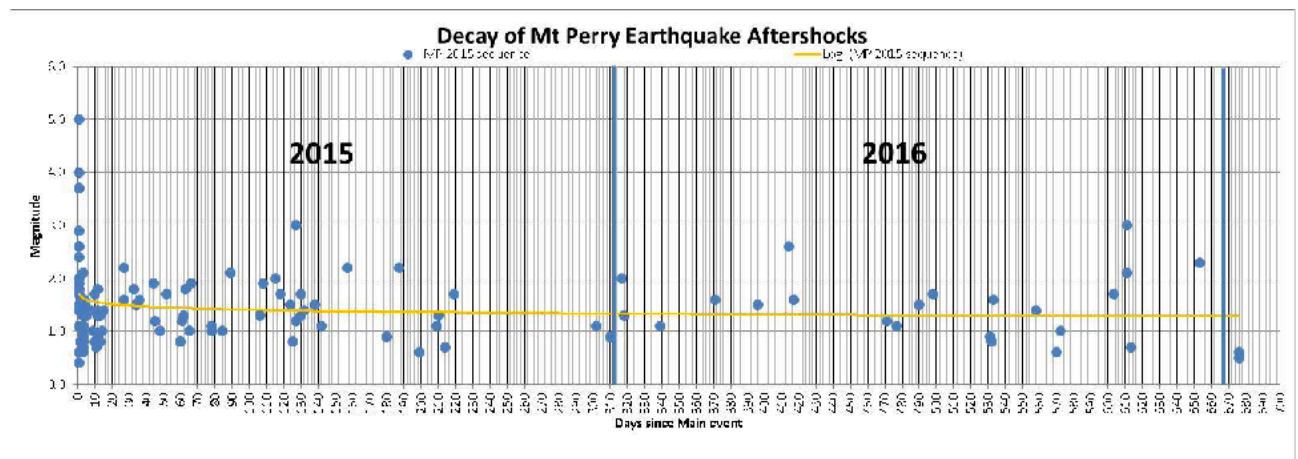


Figure 15 Logarithmic decay of the Mt Perry 2015/16 earthquake sequence

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

Bowen Earthquake Sequence

On 2016-08-18 at 04:30 UTC a magnitude M 5.8 earthquake occurred 63 km northeast of Bowen in the Whitsunday Passage. This was followed over the next three weeks by 77 aftershocks ranging from magnitude 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. A map of the earthquake locations is presented in Figure 16.

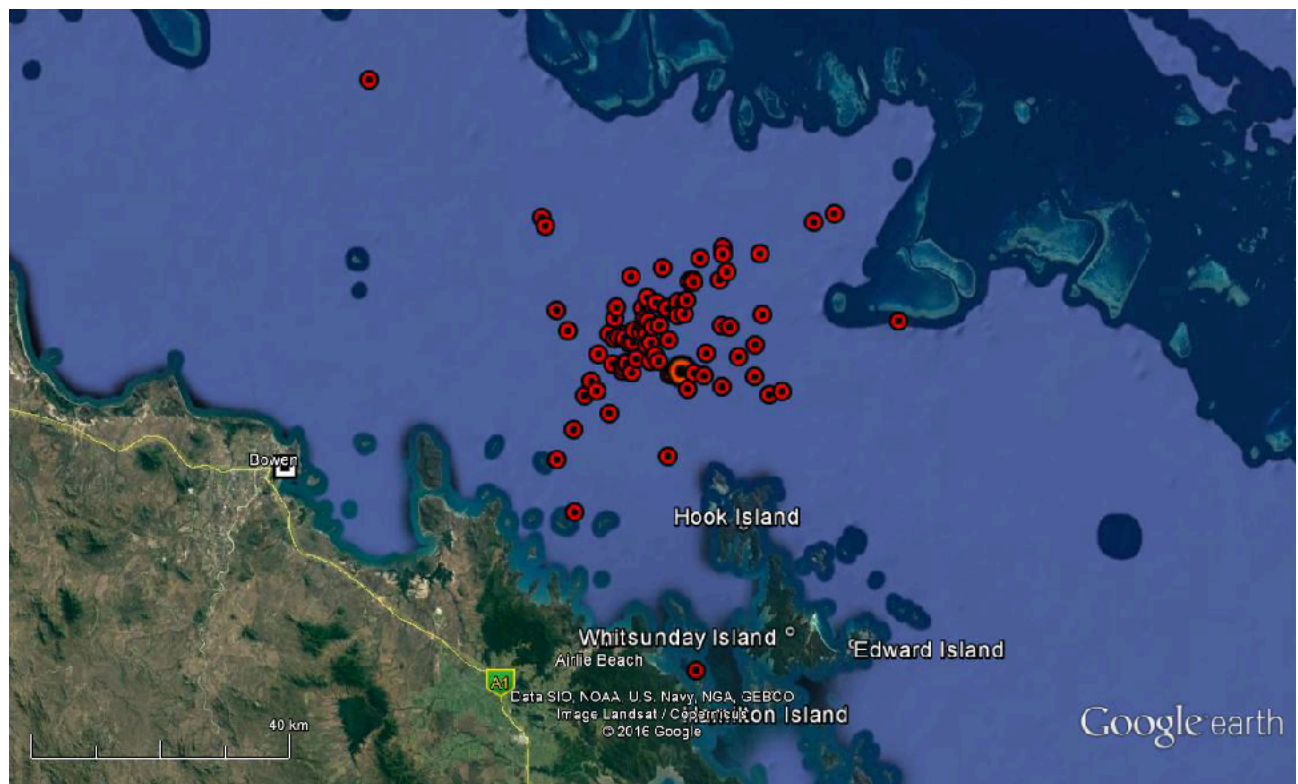


Figure 16 The 2016 Bowen earthquake sequence

The Seismological Importance of the Bowen 2016 Event

The Bowen 2016 main event is arguably the second largest earthquake to have been recorded on the east coast of mainland Australia since European arrival. 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 magnitude 3.5 or greater.

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 a magnitude M 3.2 earthquake occurred 92 km south west of Thargomindah. Several other earthquakes with magnitudes above M 3 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 have only been recorded since about 2011, may be an indication that that region is becoming seismically active. It can further be reasonably inferred that relatively more, perhaps 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 Method of Magnitude Quantification from EIDS Records

Many attempts have been made to develop consistent local magnitude scales in Australia based on the Richter magnitude equation

$$M = \log_{10} A - \log_{10} A_0$$

Where:

A is the maximum amplitude of the seismic record of the earthquake on a Wood-Anderson seismograph, 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.

I have developed a formula to estimate magnitudes from measurements of signal amplitude and computed epicentral distance at station EIDS as follows:

$$M_{EIDS} = \log_{10} A - (-0.064(S-P) + 2.63)$$

Where:

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

A is the maximum amplitude of the EIDS seismogram signal; S is the arrival time of the S wave and P the arrival time of the P wave, in seconds, a measure of epicentral distance.

Twenty Queensland local earthquakes were used, their amplitude and S-P time measured from the EIDS seismograms

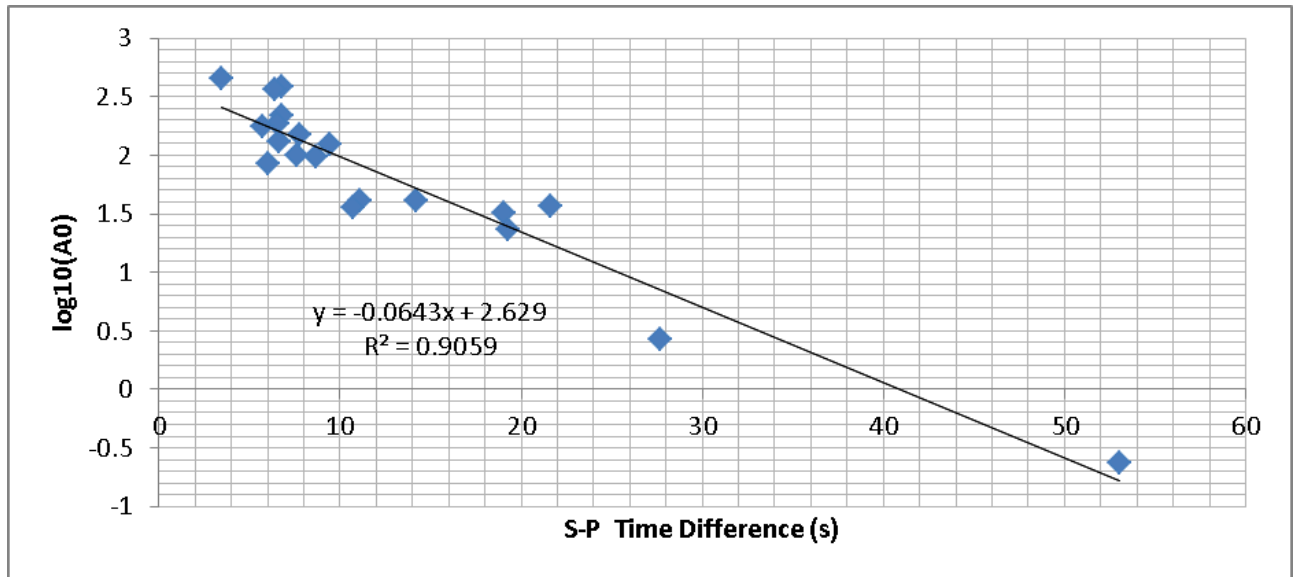


Figure 17 The line of best fit, calculated using linear regression of the parameter A_0 against distance as measured by (S-P) time in seconds, along with the slope, intercept, and correlation coefficient (R^2). The R^2 value of 0.91 supports the assumed linear relationship although there is a large gap in events in the distance range 250 to 400km

3.4 Western Australia

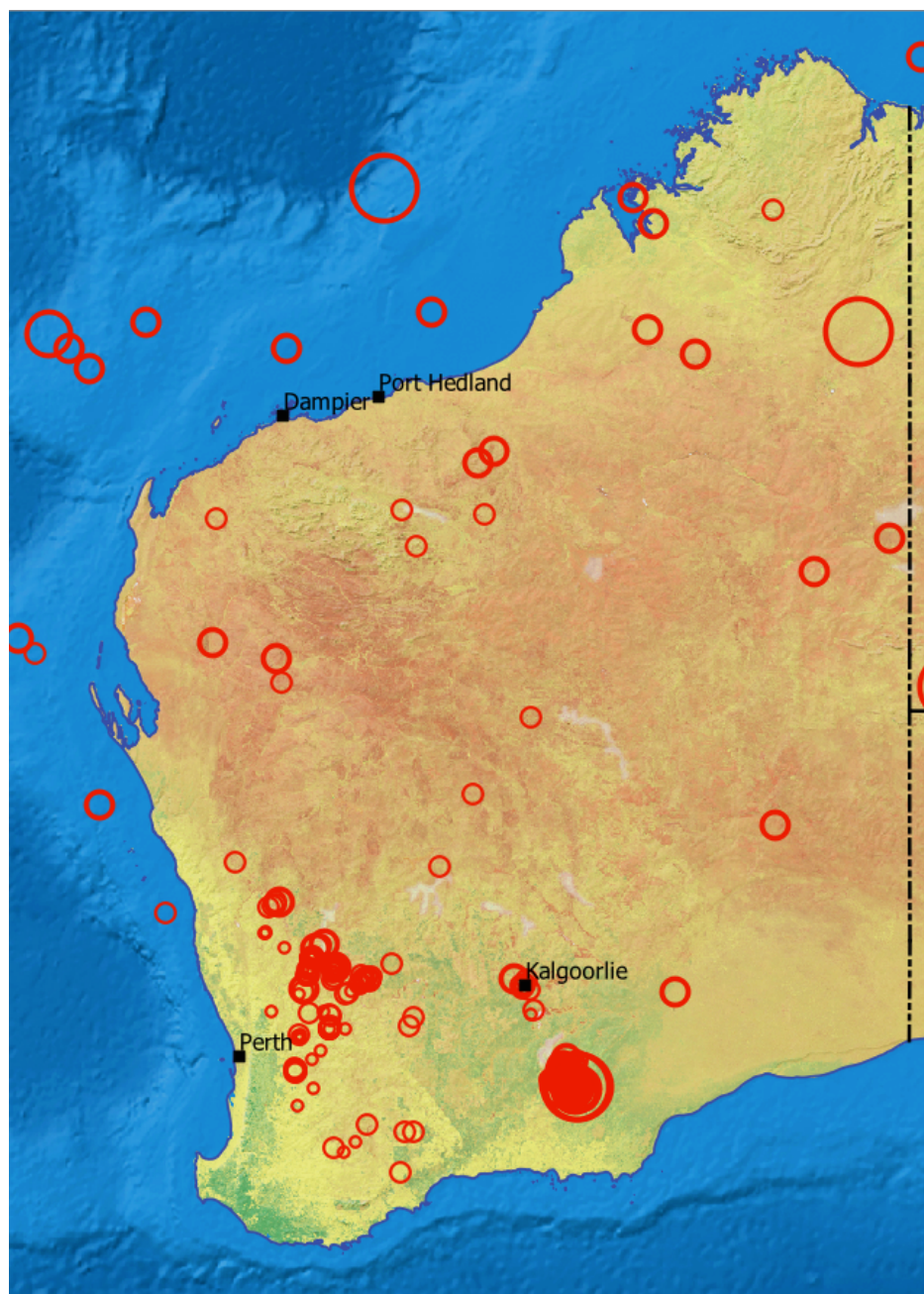
Vic Dent, Elodie Borleis and Kevin McCue

There were 136 earthquakes of magnitude 2.5 or more, 5 of them magnitude 5 or more in WA in 2016 - three SE of Norseman (see media report below) in the period May-July (Dent & Love, 2018), one near Halls Creek in November magnitude ML 5.1 and another off the NW shelf in May, magnitude ML 5.3.

Figure 18 WA seismicity 2016, ML ≥ 2.5

In the active wheatbelt region of southwest Australia, there were about 120 earthquakes located by GA during 2016, a relatively small number. Of those, there were only 4 events of ML 3.0 or more. Two were north of Kalannie (both ML 3.3), one was near Manmanning, south of Cadoux (ML 3.4), and one was west of Beacon (ML 3.1). The Beacon event was the largest in a cluster of ~12 events. This location has shown periods of repeated activity since 2012, when 5 ML 3+ events were located there (largest ML 3.5).

Lesser groups of clustered earthquakes were numerous, and have been described in two publications (Dent, 2016, Dent 2017). One cluster of ~12 events, mostly in Nov 2016 (largest ML 2.6), south of Bonnie Rock, appears to be precursory activity to an ML 4.3 event in January 2017 (Dent & Collins, 2017). The locations of the clusters are plotted as circles on Figure 19. The locations of the Kalannie, Beacon and Bonnie Rock clusters are coloured black.



GA located events using the five main stations shown on the accompanying Figure. The PSN network continued through 2016 although data from some stations were intermittent. Seismographs at Cadoux, Kulin, Quairading, Koorda, Bencubbin, Gnowangerup, Kojonup, Pingelly and Meckering (see accompanying Figure) contributed significant data, assisting in the relocation of nearly 80 events during the year. These epicentres have been sent, and are being sent to the ISC on a regular basis. The station at Gnowangerup (Karingal) was closed in January, but Gnowangerup "C" operated until Dec 2016, when it was closed, and moved to Gnowangerup township. The station north of Kojonup was closed in April 2016.

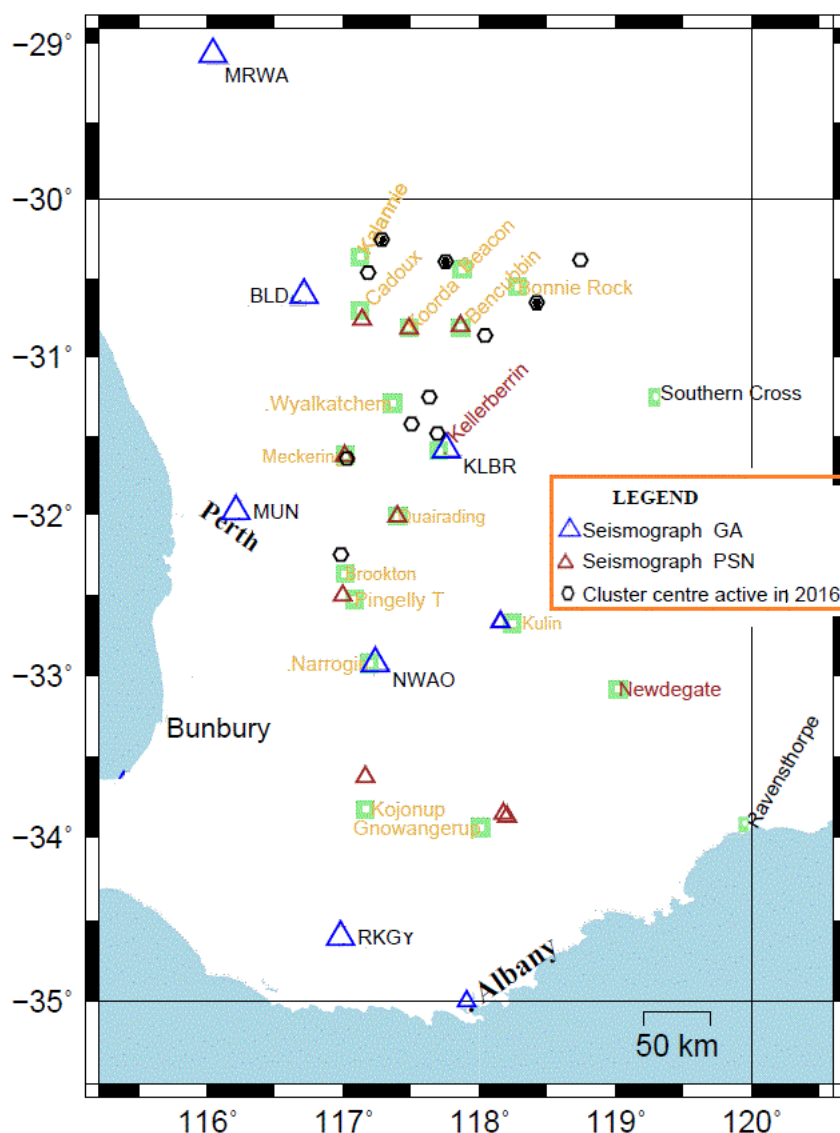
Figure 19 Seismic activity in southwest WA in 2016

Norseman earthquake widely felt. *The Guardian* newspaper of 29 May 2016 reports:

Three earthquakes hit near Norseman, including a magnitude 5.2 tremor reportedly felt as far away as Perth and Esperance. The first was a 4.9 magnitude quake about 6km under the surface hitting about 11.30pm local time, then the 5.2 was about an hour later and the last was a 3.2 magnitude tremor about 1.44am on Sunday.

Brodie Woods, who works at Norseman BP, said he woke up to the first tremor on Saturday night, thinking someone was trying to break into his house. "The window in my bedroom was rattling like crazy," he said. Woods said he ran outside to see who was trying to get in – joining most of his neighbours who thought the same thing until they realised it was a quake. He then thought it was a nearby mine blasting, but then there was another.

Claye Poletti, the owner of the Bottlemart Express Norseman Hotel, said the 5.2 felt "pretty severe". It kept on shaking, shaking and shaking," Poletti said. He said the 1934-built character pub didn't sustain any damage but the quake rattled the two-storey landmark. "It rocked the old building. It shook pretty well." Poletti said dogs could be heard barking madly,



but Shadow, his Staffordshire terrier, wasn't too worried. "He's pretty tough – he probably thought it was a heavy train like everyone else did."

Halls Creek earthquake 6 November 2016

The Kimberley Echo, Friday, 11 November 2016 by Peter de Kruijff.

Outstation rocked by earthquake

An outstation 90km south of Halls Creek was rattled on Sunday by the fourth-biggest earthquake recorded in Australia this year. The "explosive" 5.1 magnitude event was recorded on Sunday just before 6pm, with reports it could be felt as far away as Kununurra.

Geoscience Australia noted the earthquake's epicentre was near Ruby Plains Station's outstation of Sturt Creek. Pastoralist Jenny Wortley from Ruby Plains, located between Halls Creek and Sturt Creek, said most of the staff heard an explosion.

It sounded like someone blew something up, she said. It certainly rattled the buildings a fair bit.

Mrs Wortley said the people at Sturt Creek were outside at the time of the quake and could feel the ground physically shake.

Halls Creek Bureau of Meteorology technical observer Dave Murray said the earthquake had made a noise like a freight train.

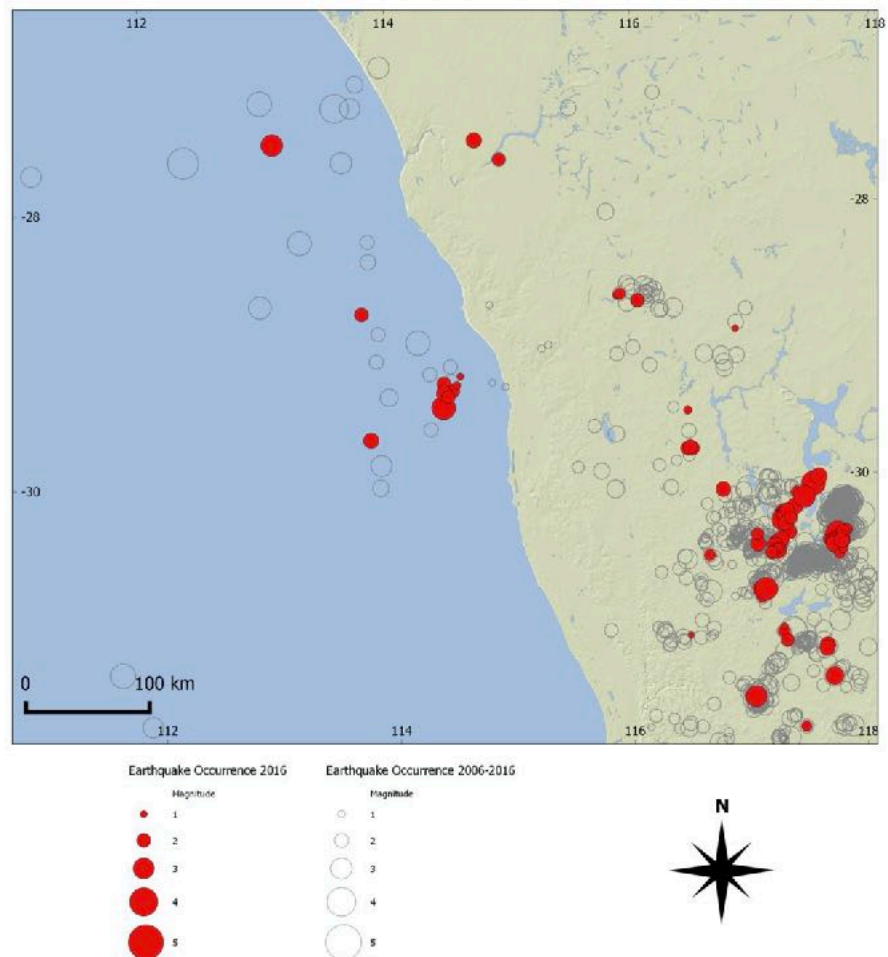
It lasted a good 10 seconds, he said. It just sounded like a freight train coming from one end of the house to the other ... with the little rattles and rolls. I know a couple of people out walking and they didn't even feel a thing.

Halls Creek Pharmacy owner Gus Dizwani said he was at his workplace when Sunday's quake struck and ducked under his desk when he realised what it was. It was massive, I thought it was a truck at the beginning, he said.

Mr Dizwani said a few items fell off the shelves at the pharmacy but there was no damage.

Seismograph Networks

Figure 20 The Seismology Research Centre has a small network of 3 seismographs in WA around 300km north of Perth. Stations are continuously telemetered and regional earthquakes are located



3.5 Northern Territory

Kevin McCue

Eighty five earthquakes of magnitude 2.5 or more were retrieved from the Geoscience Australia catalogue for 2016, all but 5 of them the foreshock, mainshock and aftershocks of the M6.1 Petermann Ranges earthquake of 20 May 2016 at 18:14 UTC. A single M3.5 foreshock heralded the sequence on 19 May at 12:48UTC. Of interest are two small earthquakes that had occurred there in 2001 and 2003.

Figure 21 Earthquakes of magnitude 2.5 or more located by Geoscience Australia

Melbourne University, Australian National University and Geoscience Australia teams were soon on site to monitor aftershocks and investigate the extent of surface faulting. Others used remote sensing to investigate the mechanism (Gold et al, 2017; Polcari et al, 2018; Hejrani and Tkalčić 2019; Attanayake et al, 2020).

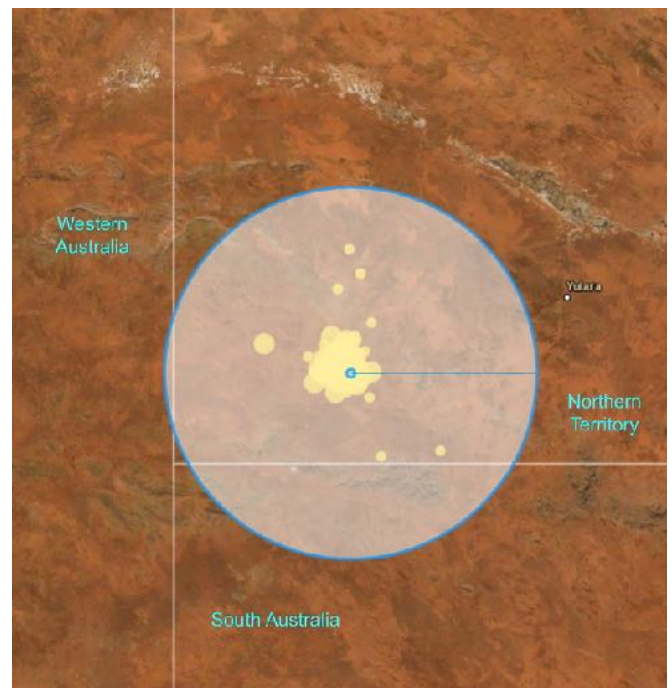
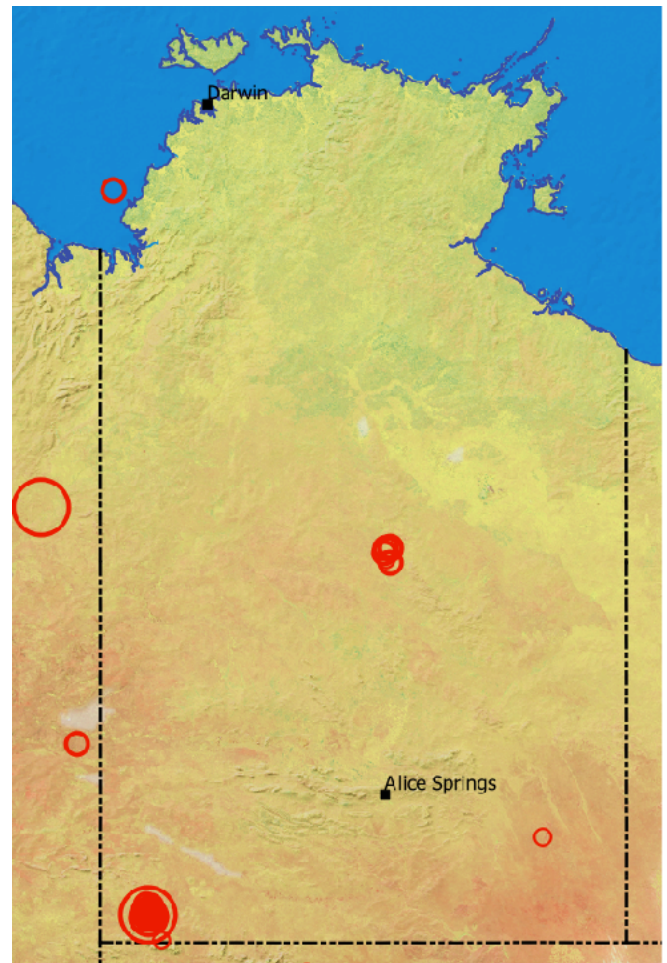
This was continental Australia's largest earthquake in 2016 and it spawned thousands of aftershocks. A 20km long thrust fault scarp was discovered and mapped. Research is on-going.

Figure 22 Petermann Ranges earthquake and aftershocks. Data from GA

Four small aftershocks occurred near Tennant Creek, site of a large earthquake sequence in 1987/88 that is continuing more than 30 years later, above the previous background seismicity rate.

One small earthquake was detected offshore near the WA border, southwest of Darwin.

Residents of Darwin were shaken by two large earthquakes on the Australian/Eurasian Plate boundary through Indonesia, some 600km north of the city.



An earthquake of magnitude 6.2 struck the Tanimbar Island region in Indonesia on Wednesday 26 February, the European Mediterranean Seismological Centre (EMSC) said. The focus was at a depth of 49km (EMSC). The Bureau of Meteorology said there was no tsunami threat to Australia following the earthquake, which was felt in Darwin.

The second earthquake, as reported in *The Guardian* of Wednesday 21 December :

A magnitude 6.7 earthquake near Indonesia has shaken people in the Northern Territory, but authorities say there is no tsunami threat to Australia. Geoscience Australia confirmed tremors from the quake near the Banda Sea off Indonesia were felt in Darwin on Wednesday morning.

The quake occurred around 9am local Indonesian time with an epicentre 180km deep, and there were no immediate reports of damage. Indonesia's disaster agency said residents in the south-west of the Moluccas island chain also felt the quake.

The epicentre was 630km north-west of Darwin, but Bureau of Meteorology senior forecaster Chris Kent, who is based in the city, said the quake lasted several minutes.

Local Andy Chandler was on a ladder in her kitchen in Coconut Grove doing some pre-Christmas cleaning when she felt the tremor. "Pots and pans started rattling and the whole house and everything started shaking," she told ABC local radio.

Fellow Darwinian Bev Luke said she watched the Christmas decorations "do a dance" in her home, while Celeste Green said she felt the earth move under her feet. "My whole building just shook for about five seconds, so much that my pictures fell off the wall," Green said.

Australia's Northern Territory News said the quake was widely felt across Darwin and surrounding areas.

Angela Pattison said Howard Springs was "rocking and rolling" with the tremor. "The fish tank was a-sloshing and the cabinets were a-rattling and my chair was doing the four-legged jive!" she said. Other Territorians felt it as far away as the Tiwi Islands, Yirrkala in Eastern Arnhem Land and in Katherine.

Seismograph Network

GA jointly operates an array at Tennant Ck with the ANU and UKAEC and an array at Alice Springs with Detachment 421 in the US Air Force. In addition they have seismographs at Manton Dam and east of Darwin and 2 JUMP recorders in Darwin.

Warramunga seismic array In operation since 1965, the array was set up jointly by Australia and the UK for long-distance detection of nuclear explosions. In 1999 it was upgraded for service as a primary station in the International Monitoring System of the Comprehensive Nuclear-Test-Ban Treaty. The array now comprises 24 seismometers, with a corner cluster of 4 sites (C1-C4) supplementing the original 20-element array with roughly linear 'blue' (B1-B10) and 'red' (R1-R10) arms. The sensors are in shallow boreholes in granite.

Alice Springs seismic array Commander travels 'Down Under' to observe seismic work
By Susan A. Romano, AFTAC Public Affairs / Published January 20, 2016

PATRICK AIR FORCE BASE, Fla. -- The commander of the Air Force Technical Applications Center and her command chief master sergeant visited the center's most far-reaching detachment located in Australia's Northern Territory Dec. 14-18.

Col. Jennifer P. Sovada and Chief Master Sgt. Neil Jones made the 10,200-mile journey to get an up-close view of the seismic work being conducted by AFTAC personnel at Detachment 421 in Alice Springs, a small outpost in the center of the Australian outback. The duo also wanted to see the steps the detachment has taken to improve the living conditions for the assigned Airmen.

AFTAC, the Department of Defense's sole nuclear treaty monitoring center, has nine detachments, six operating locations and more than 60 unmanned equipment locations worldwide and on every continent that monitor and record natural and man-made seismic disturbances in support of AFTAC's long range nuclear detection mission.

Det 421 is an integral part of the U.S. Atomic Energy Detection System and has a seismic array that includes 22 detectors buried 30 meters deep, covering an area of approximately 80 kilometers. The assigned Airmen operate and maintain the seismic equipment to ensure it delivers accurate geologic data to analysts here at the center.

<https://www.acc.af.mil/News/Article-Display/Article/660244/commander-travels-down-under-to-observe-seismic-work/>

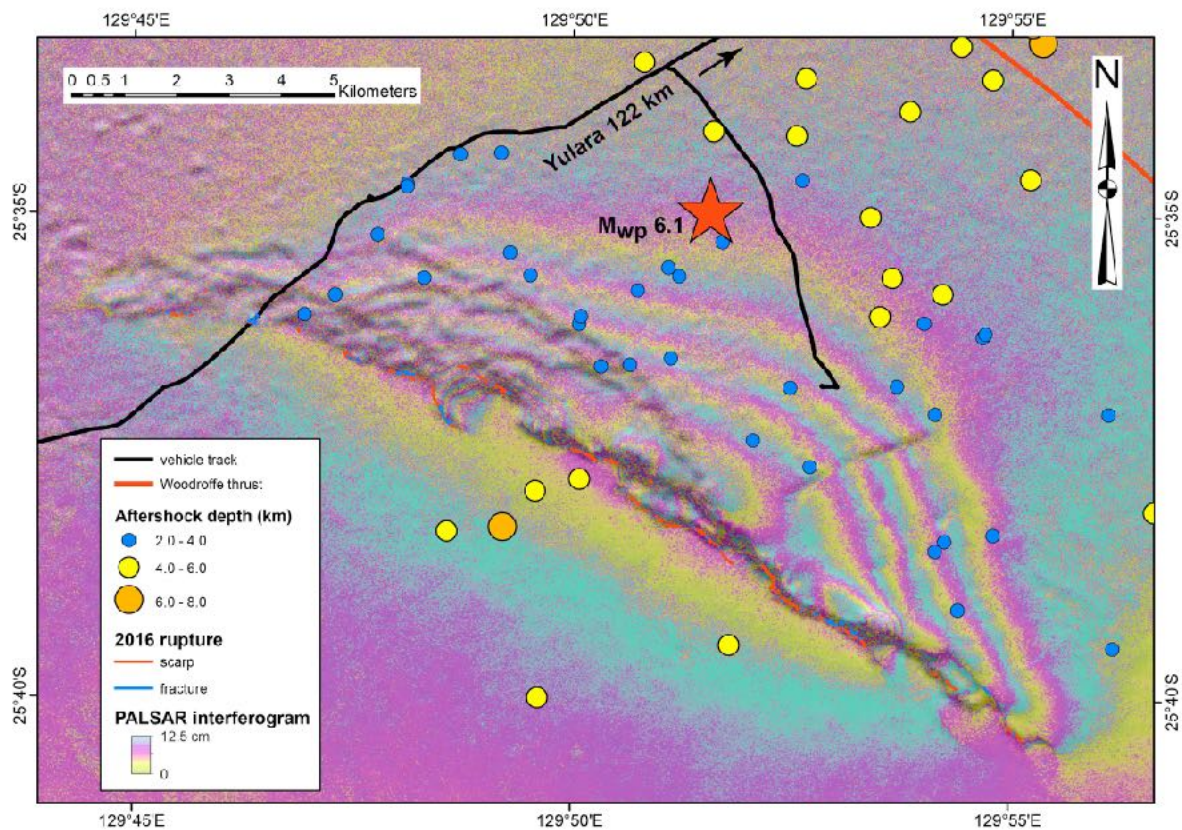


Figure 23 (From Dan Clark). Surface deformation relating to the 2016 Mw 6.1 Petermann Ranges earthquake. Base image is the PALSAR phase interferogram draped over the unwrapped interferogram. Each colour fringe represents 12.5 cm of line of site deformation. Discrete scarp segments and fractures based upon field mapping are overlain. Aftershock locations define a ~ 30 degree NE dipping rupture plane (from Attanayake et al 2020). A conjugate ENE fracture can be seen offsetting fringes about 1km south of the end of the access track but it was difficult to see on the ground.

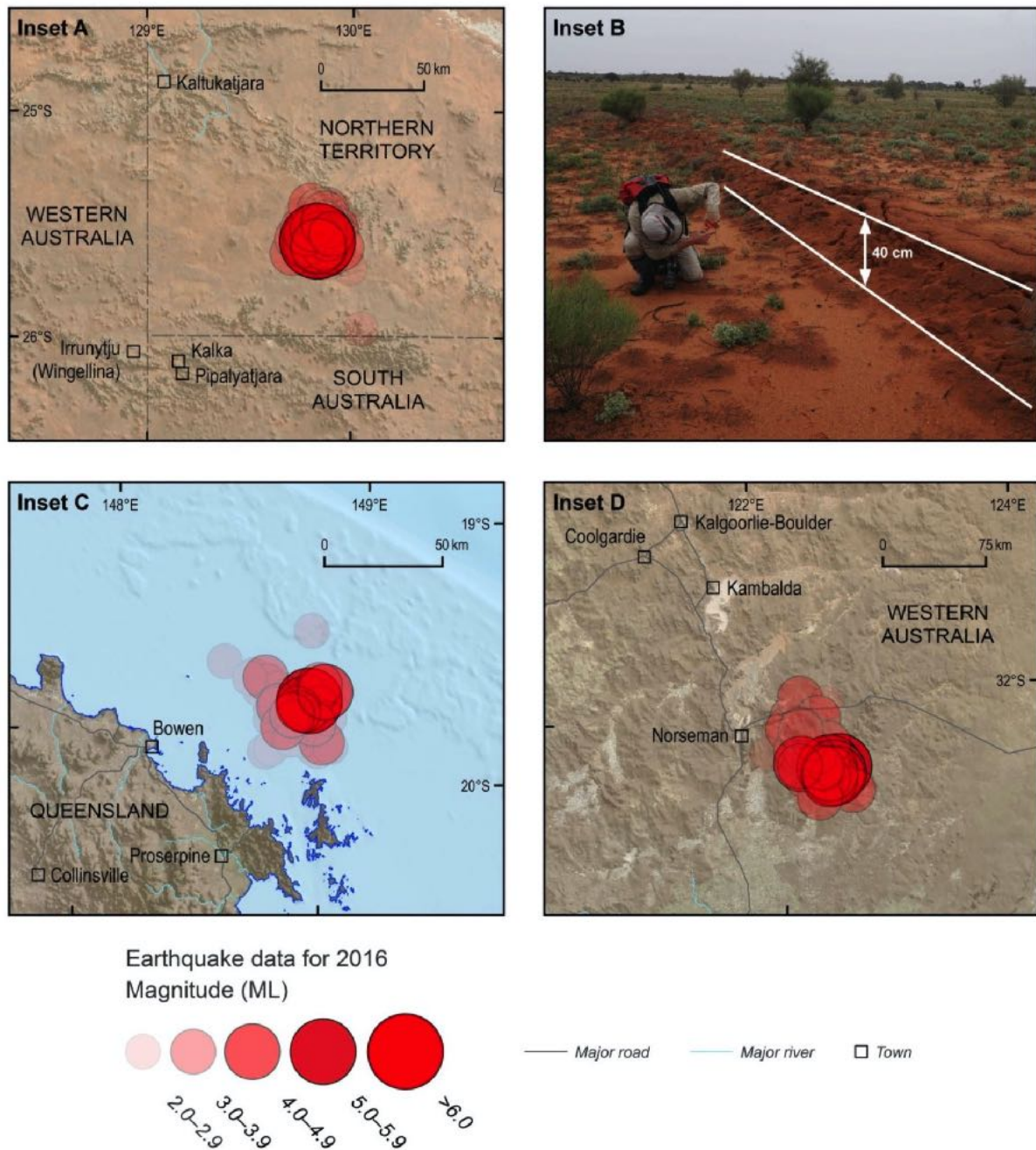


Figure 24 (Inset A, B) Petermann Ranges WA earthquake sequence. (Inset C) Bowen Qld earthquake sequence. (Inset D) Norseman WA earthquake sequence. From Thom (2017)

Ten earthquakes have ruptured the surface during earthquakes in Australia since the Meckering WA earthquake of 14 October 1968; in WA, SA and NT. This is more than in any other intraplate region worldwide. All of them have resulted from shallow thrust mechanism earthquakes, the upper crust at least is obviously under compression as a result of plate boundary processes.

3.6 Tasmania

Elodie Borleis and Kevin McCue

Only three small earthquakes, between magnitude 2.5 and 3.0, occurred in Tasmania in 2016. The most significant event was a magnitude MLv 3.0 earthquake recorded on 05 June offshore north of Devonport. Forty-nine events were located by the Seismology Research Centre throughout Tasmania in 2016; eight were greater than or equal to magnitude 2.0, the largest magnitude 3.0.

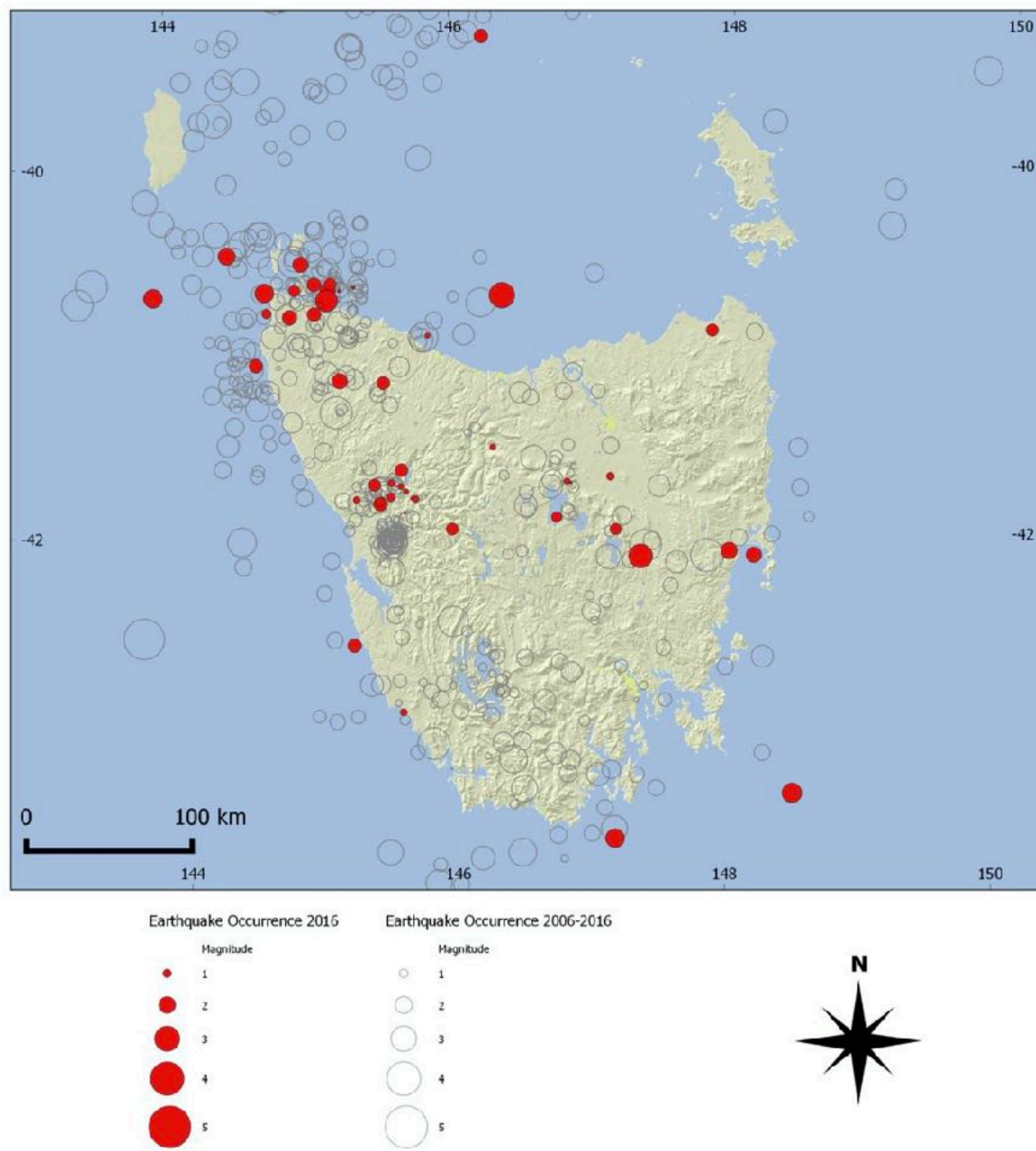


Figure 25 shows the epicentres located in Tasmania by SRC in 2016

There are no media reports that any of the three small earthquakes were felt, such a contrast with the history of the last two decades of the 19th century when thousands of earthquakes were felt, 4 of them above magnitude 6 or larger.

Such is the variability of the seismicity in intraplate Australia.

Recent fault scarps onshore in Tasmania attest to even greater variability over time.

Seismograph Network

The Tasmanian seismic monitoring network operated by the Seismology Research Centre for Hydro Tasmania now comprises 8 seismographs and accelerographs throughout Tasmania and on King and Flinders Islands. A new station was installed near Curries River Dam (CURRY) in northern Tasmania at the end of 2016. All sites are continuously telemetered.

GA has just one ANSN site at the University of Tasmania plus two JUMP sites.

There are 3 AUSIS stations provided by ANU in Tasmanian schools.

Melbourne University operates two seismographs on islands in Bass Strait, Deal and Hogan Islands, and SRC has other very useful seismographs on King and Flinders Islands.

3.7 New South Wales

Elodie Borleis, Abe Jones and Kevin McCue

The largest earthquake in the state in 2016, GA assigned a magnitude ML 4.0 (4.2 according to SRC) earthquake offshore Gosford north of Sydney where it was felt but did no damage. According to the Sydney Morning Herald of 7 June: *A small earthquake has been detected off the NSW Central Coast, with residents reporting feeling the ground shake from Sydney to Newcastle. Those people reported about 10 seconds worth of shaking, and a few reports of shaking trees and buildings shaking, and picture frames askew.*

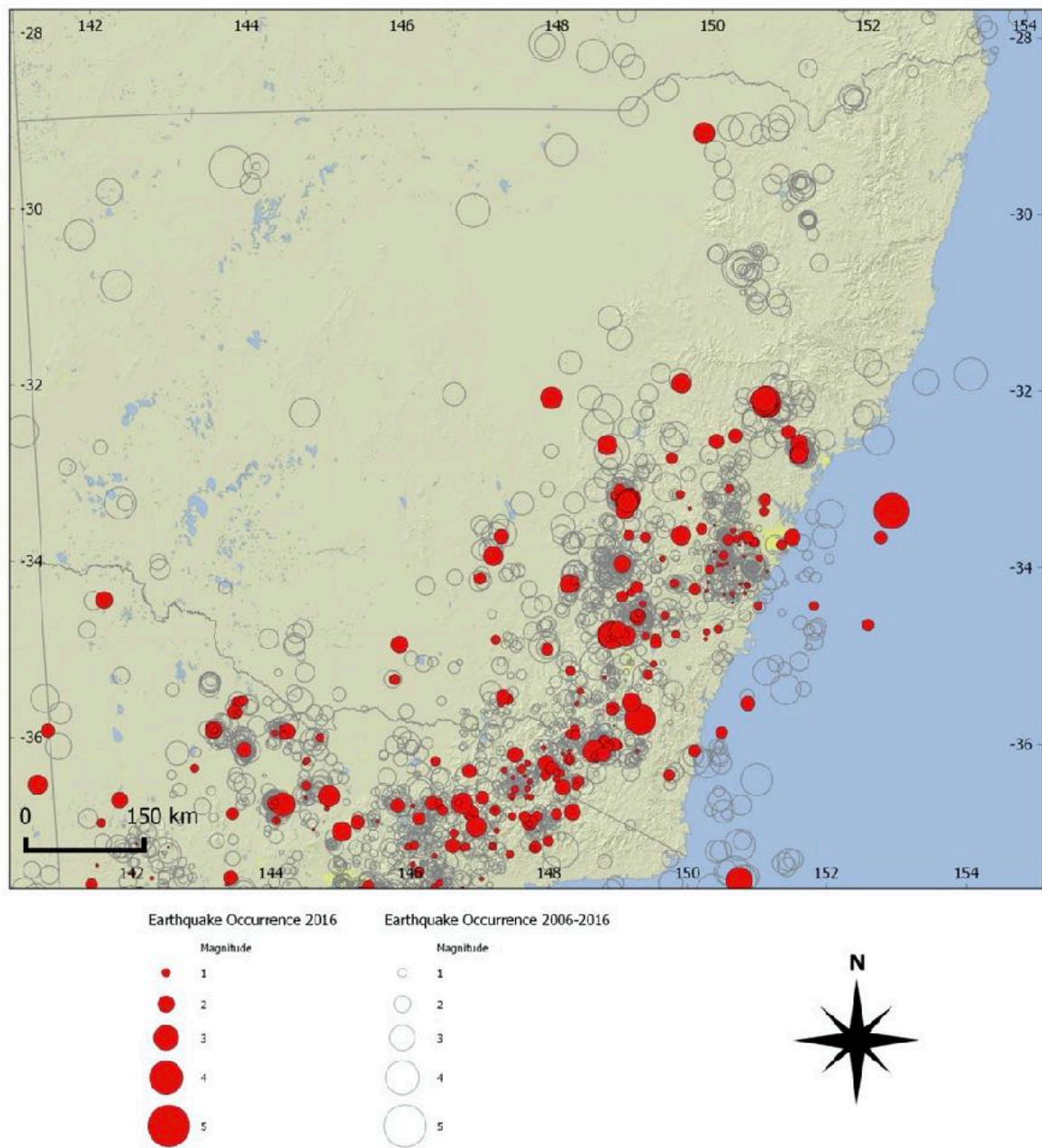


Figure 26 Earthquake epicentres SRC located in NSW in 2016 in red, historical events in grey

SRC located 24 earthquakes in NSW of magnitude 2.5 or more, 9 of them magnitude 3 or more. Of the 24, 11 were in the Muswellbrook area and occurred outside the permitted blasting time in this coal mining area. Whether they are mining related is a moot point. SRC seismologists believe that the events occurring in Cadia are related to mining activity in that area.

Most of the epicentres occurred in a broad zone in the southeast of the state, a similar pattern to where they have occurred in the last 200 years.

The single isoseismal map drawn up for a NSW earthquake is shown under the ACT section of this report. There should have been enough felt reports for the Gosford earthquake to have compiled a map.

Seismograph Networks

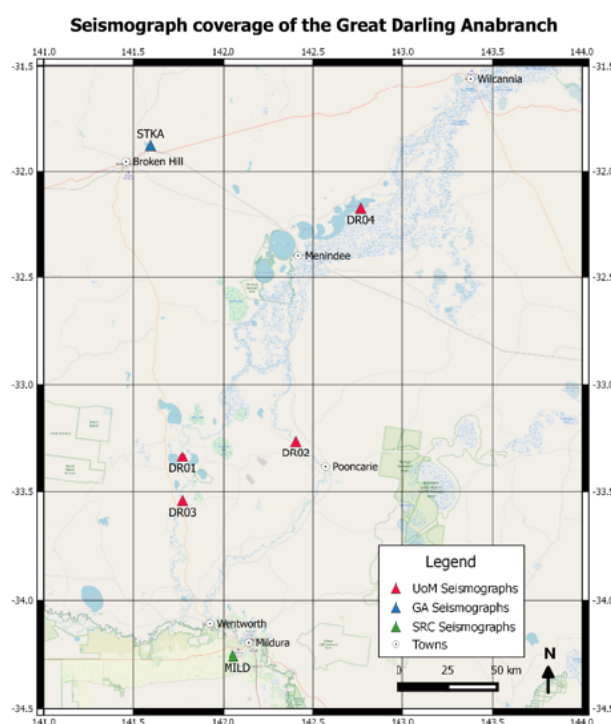
The New South Wales network operated by the Seismology Research Centre now comprises 37 seismographs and accelerographs located primarily south and west of Sydney, and around the ACT and Snowy Mountains. The GA network in NSW includes 7 ANSN stations and 5 JUMP stations distributed broadly across the state and the ACT and Norfolk Island (see Glanville and others, 2016). Seven AUSIS stations are operational in NSW schools, operated by ANU.

PSN seismographs were operational at a number of sites in NSW and maintained by Vic Dent. Michael Andre Phillips runs a comprehensive Observatory at Coonabarabran dedicated to the Rev. Father Edward Pigot who established the observatory, astronomical, magnetic and seismological, at Riverview College in Sydney in 1908. The RIV seismograph there commenced recording in March 1909.

University of Melbourne Darling River Anabranch Network, NSW

Installed in 2015 to investigate if there was any local seismicity in the region, this 3-station array was expanded in July 2016 to include a fourth station (DR04) about 125km to the north-east. All four stations use Guralp CMG-6T seismometers shallowly buried in unconsolidated sediments, with data recorded by Kelunji EchoPro Seismographs at 200 sps with a finite impulse response (FIR) filter. The remote location and lack of mobile coverage has so far prevented these sites from telemetering data; instead the instruments are serviced every 10-12 months during which the full continuous datasets are recovered. Following manual recovery, these datasets are uploaded to the UoM server. Due to the remote location of these instruments, station noise levels are very low, allowing continuous (compressed) data for a full 12-month period to be saved to 64Gb USBs without exceeding the capacity of these drives.

Figure 27 The UoM seismic network in rural NSW, between Mildura and Broken Hill



3.8 Victoria

Elodie Borleis, Abe Jones and Kevin McCue

Three hundred and seventy-six events were located in Victoria by the Seismology Research Centre in 2016. Twenty-two events were greater than or equal to magnitude 2.0, three of them at least magnitude 3.0. The most significant event for Victoria in 2016 was a magnitude MLv 3.3 earthquake recorded on 04 April near Tarwin. Many earthquakes were recorded in the ongoing sequence of seismic events near Korumburra during 2016. The largest event of the sequence was a magnitude MLv 2.1 aftershock on 5 August.

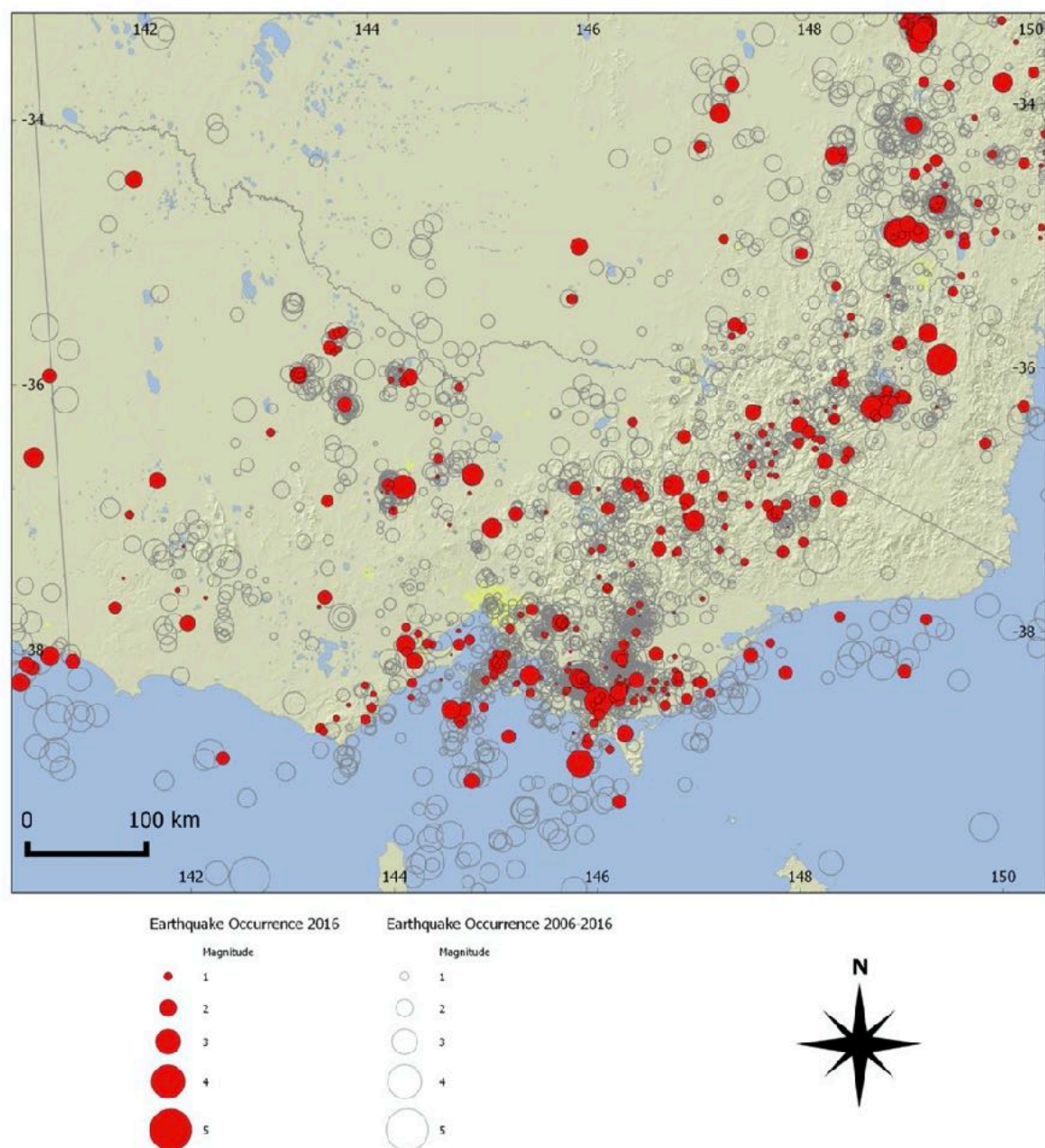


Figure 28 SRC epicentres of magnitude 1.0 or greater earthquakes in Victoria in 2016

The State's three larger events, ML2.9, ML3.0 and ML3.3 were reported felt. Their epicentres were near Leongatha and Tarwin in Gippsland (04 April), South of Bendigo at Bradford Hills (01 May), and offshore Cape Liptrap (12 June).

The ABC News of 5 April reported:

A magnitude 3.2 earthquake has struck near Leongatha in Victoria's south-east early this morning, waking some residents at about 5:40am. Susan McAlpine said the quake was "moderately noisy" and shook household items. The earthquake was reportedly felt as far as the beach-side suburb of Brighton in Melbourne's east and Foster near Wilsons Promontory.

Emergency services said they had not received any reports of damage or injuries.

Local resident Ruth said she felt the earthquake but thought it was a truck on the highway nearby. "I was out checking cows that are calving and I thought a truck had hit a big pot hole," she said. "I heard this rattle, rattle, rattle and then it suddenly flashed through my mind, that might have been an earth tremor."

Seismograph Networks

The Victorian seismic monitoring network operated by the Seismology Research Centre now comprises 26 seismographs and accelerographs throughout Victoria. GA maintains 2 ANSN seismographs and 4 JUMP stations in Victoria.

There are 5 AUSIS school sites in Victoria including one at Hawkesdale near Warrnambool, where wide-spread damage was caused by 2 moderate earthquakes in April and July 1903.

The University of Melbourne (UoM) operated 3 discrete subnetworks in 2016 in Victoria and NSW, along with a temporary aftershock network installed following the Mw 6.1 Petermann Ranges NT earthquake in May. Recorded data can be accessed through the UoM server at <http://meiproc.earthsci.unimelb.edu.au/eqserver/>.

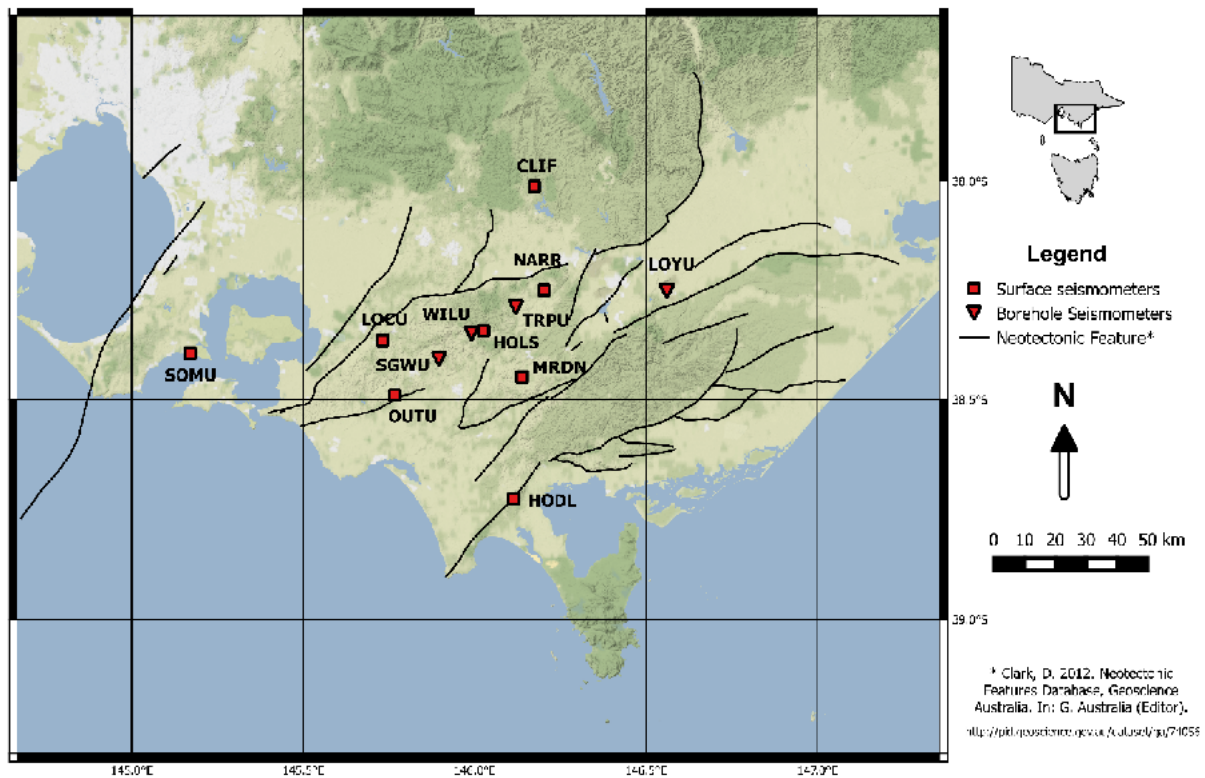
Gippsland Network, Vic

The largest of the three UoM sub-networks is located in Gippsland, in South-East Victoria. This network, now 12 stations, was first installed in 2012, with additions and modifications to the network continuing over the last 4 years. This network currently consists primarily of Guralp CMG-6T seismometers and CMG-5T accelerometers installed with Kelunji EchoPro recorders, and also includes a single Guralp CMG-3ESPC seismometer, three IESE S10g geophones operating with REFTEK 130s digitisers, and an additional RefTEk 130s digitiser at the LOYU station, where there are two OYO Geospace HS-1 transducers installed at depths of 1350m (4.5Hz sensor) and 2m (2.0Hz sensor) respectively.

Castlemaine Network, Vic

This four-instrument subnetwork is maintained by Gary Gibson and is comprised of Guralp CMG-6T seismometers, Guralp CMG-5T accelerometers and Kelunji EchoPro seismographs. These stations typically record at 100, 200 or 250 sps.

UoM Gippsland Seismic Monitoring Network - 2016



UoM Victorian Seismometer Stations - 2016

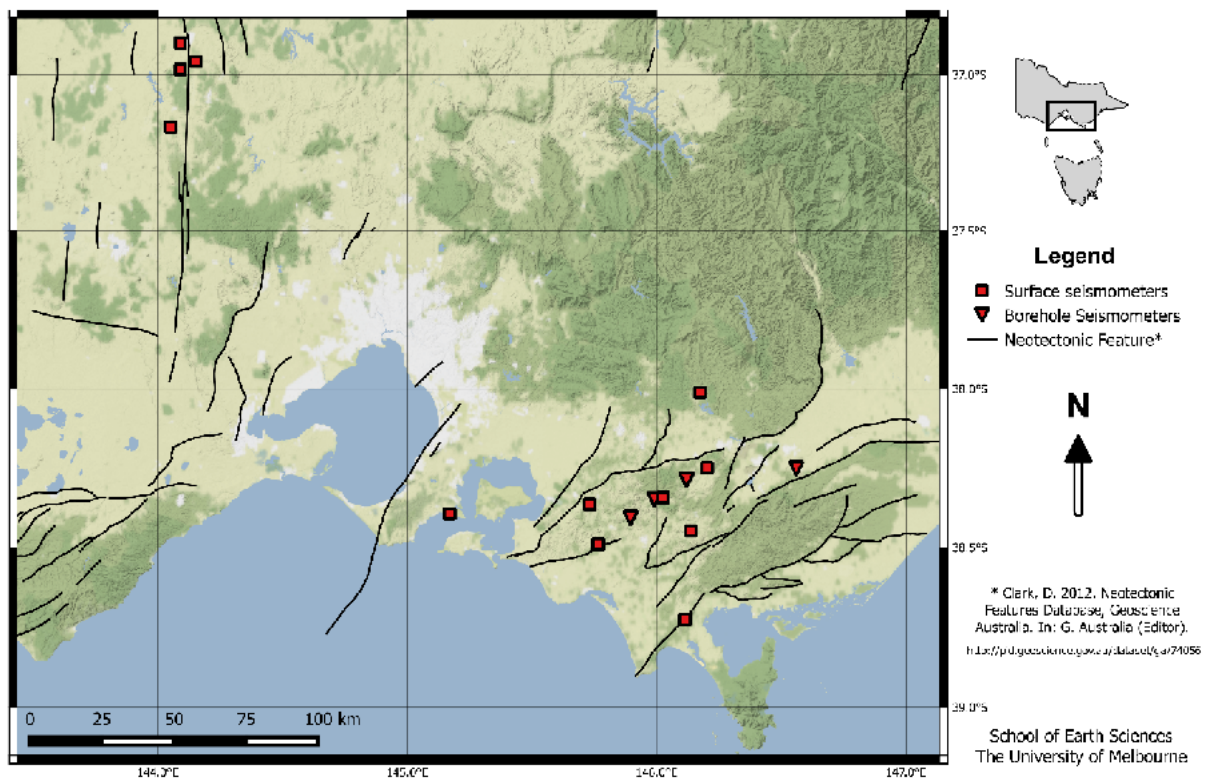


Figure 29 Top Gippsland, bottom all UoM stations operating in Victoria. The Castlemaine network can be seen at top left in the lower map. Black lines are known mapped faults

4. Iseismatic Map and Strong Motion Data

Despite there being one magnitude 6.1 and 5 other earthquakes above magnitude 5 in the year there was only one isoseismal map compiled for a small earthquake near Canberra on 31 January and a plot of felt reports for an earthquake off Kangaroo Island, SA on 19 June. There don't appear to have been any useful or interesting accelerograms recorded.

A traditional isoseismal map was drawn up for a small earthquake near Canberra, its proximity to the capital city where it was felt and location near a major mapped fault were reason enough to investigate the earthquake. This is reported under Sect. 3.2 on ACT earthquakes. According to local newspapers thousands of people reported feeling the Bowen Qld earthquake and two large earthquakes north of Darwin NT were widely felt yet no isoseismal maps have been published for them. These same earthquakes ought to have triggered the Bowen JUMP sites and Darwin accelerographs but nothing published so far.

5. Rapid Earthquake Response Deployments

5.1 The Petermann Ranges NT

The earthquake, magnitude 6.1, on 26 May attracted researchers from GA, ANU and Melbourne University, Dan Clark with a new piece of kit, a drone, that proved very for investigating the surface fault scarp. Aftershock kits were deployed and thousands of aftershocks were recorded, the larger ones located accurately in 3-D. The deployed instruments included Lennartz and Guralp CMG-6T seismometers and a Kelunji Gecko PRISM (Portable Rugged Interferometry Seismometer). Instruments were installed in 8 unique locations. Four of these were temporary deployments which were removed once UoM staff members returned to Melbourne, whilst the remaining four instruments remained in place until early 2017. The scarp was accurately mapped in quite some detail.

5.2 Bowen (Whitsunday Passage) Qld

GA seismologists also set up 4 seismographs after the M5.8 Bowen Qld earthquake on 18 August and recorded many aftershocks, those located can be downloaded from the GA website www.ga.gov.au. Mike Turnbull has created a web page at <https://cqsrg.org/bowen/> to display the 2016 ML 5.8 earthquake sequence, still going in 2020.

6. Australian Seismometers in Schools Network (AuSIS)

Michelle Salmon and Malcolm Sambridge

The AuSIS program now has 44 permanent seismometers installed in schools and two test stations in Canberra. There have been two new installations since 2015 into Murray Bridge High School, Murray Bridge, SA and into Parklands High School in Burnie, TAS.

For recent updates on the project see our facebook page www.facebook.com/ausisnetwork, our website ausis.edu.au or email ausis@anu.edu.au

7. Temporary Arrays, Australian National University

Michelle Salmon, Geoff Luton, Christian Sippl, and Hrvoje Tkalčić

Two temporary seismic arrays were operating over 2016. The AQT Qld seismic array and the Mulga NT array which was a small aftershock deployment around the May 20th Petermann Ranges earthquake.

Figure 30 AQT Array map

AQT Southwest Queensland. The array was installed in three stages from December 2015 and will be operational till August/September 2017. Instruments are Lennartz LE-3Dlite (SP shown in red) and 120s Trillium Compacts (BB1 shown in magenta) coupled with ANU LPR200 recorders and Guralp 3ESP sensors coupled with Earthdata recorders (BB2 shown in blue). Sample rates are 100 sps.

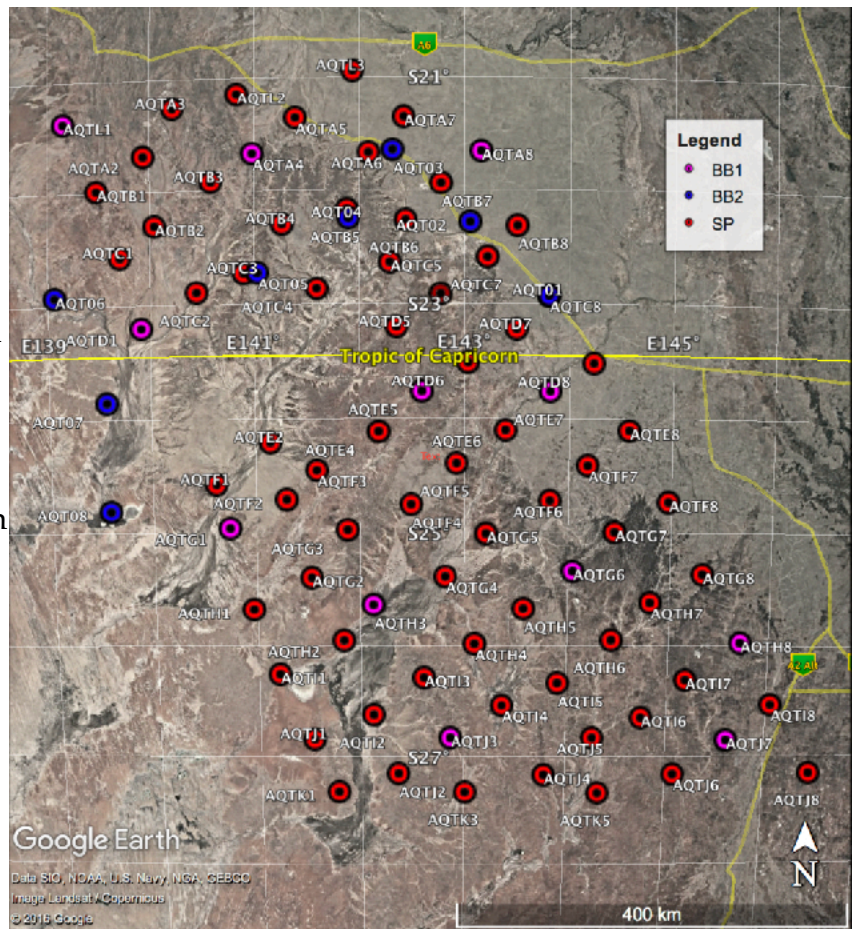


Figure 31 Mulga Array NT (below)

The array was deployed at the beginning of June and was operational for just over 3 months to mid-September. Instruments used were Lennartz LE-3Dlite coupled with ANU LPR200 recorders.



8. World Seismicity in 2016

Kevin McCue

This was an average year with no great earthquake of magnitude 8 or more. About 1300 people were killed compared with an average since the year 2000 of more than 40,000 fatalities though the number is very variable. According to the ISC, there were 16 major earthquakes of magnitude 7 or more including three earthquakes of magnitude 7.8, the first on 2 March 2016, a shallow earthquake southwest of Sumatra, the second another shallow event on 16 April 2016 near the coast of Ecuador and the last in the South Island of New Zealand on 14 November 2016.

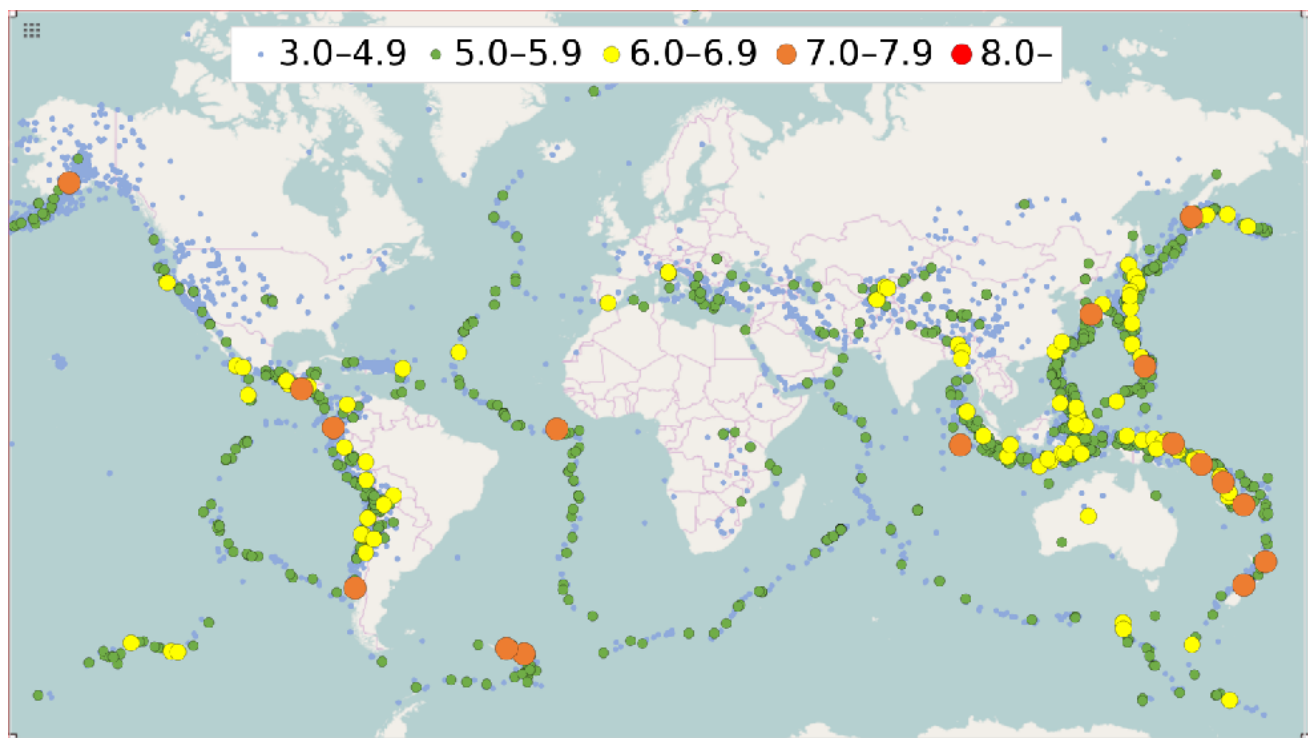


Figure 32 Seismicity of the World for 2016, map above and table below, from the USGS. There were no great earthquakes, magnitude 8 or more

Table 2 World earthquake numbers by magnitude (USGS)

Magnitude	Year 2016
8.0-9.9	0
7.0-7.9	16
6.0-6.9	127
5.0-5.9	1,507
4.0-4.9	12,771
Total	14,421

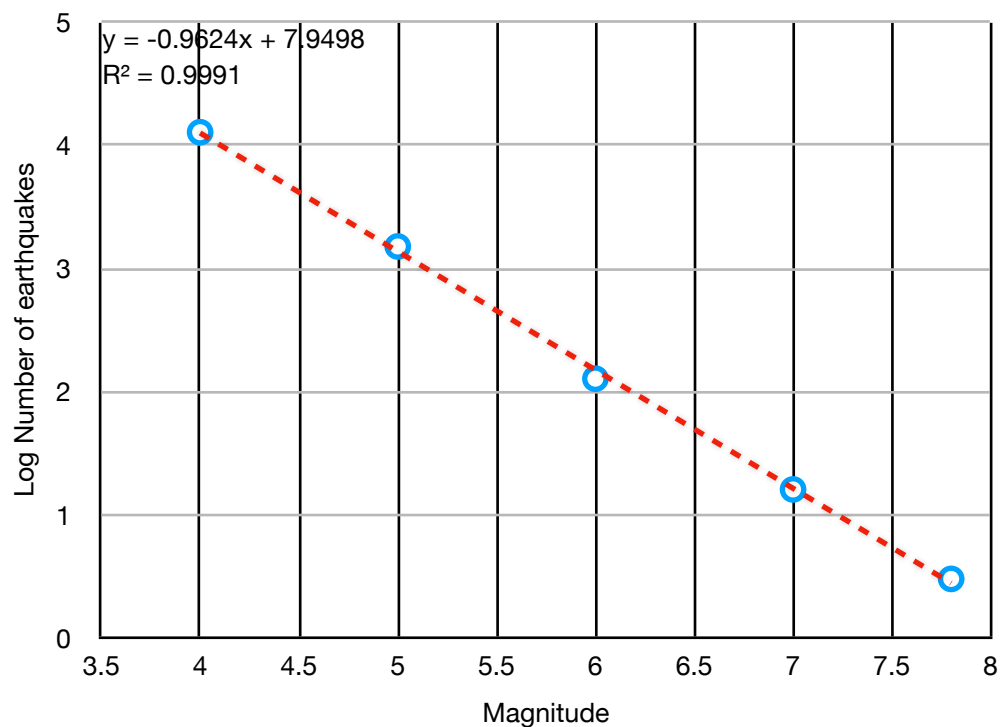


Figure 33 Cumulative number (converted from the incremental numbers from USGS in the table above) of earthquakes in the magnitude range 4.0 to 7.8, in the World, in 2016

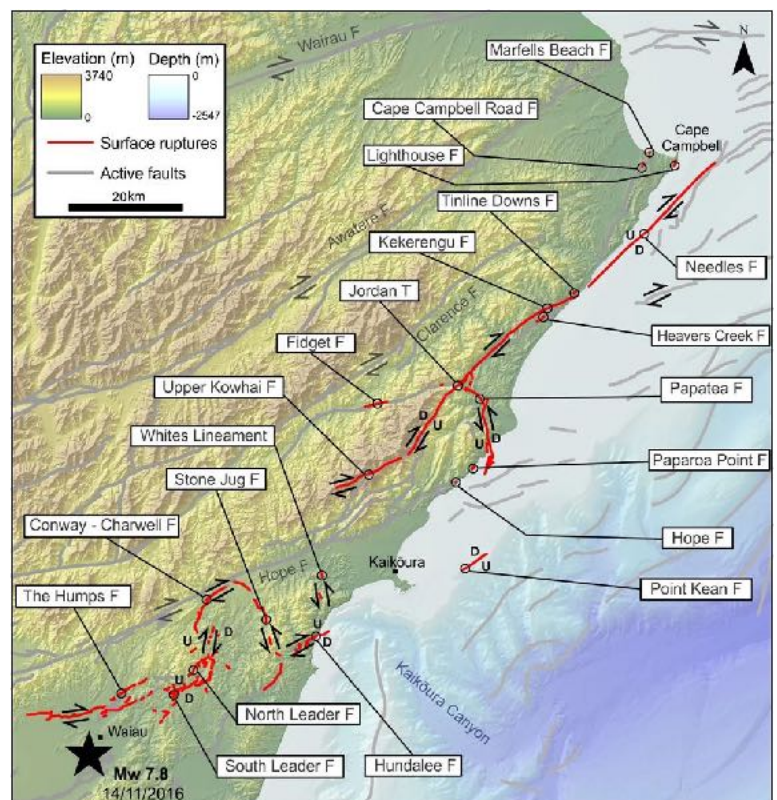
The USGS and ISC publish different magnitudes for the same earthquakes, the reasons are complex but both can't be right.

The 'b' value, in this case 0.96, is close to 1.0 which is the expected value. There are usually 10 times as many magnitude 7 earthquakes as magnitude 8 earthquakes, ten times as many magnitude 6 earthquakes as magnitude 7 earthquakes etc. in any year. The world's greatest known earthquake occurred in Chile in 1960, its magnitude 9.6.

Figure 34 Faulting on the South Island of New Zealand in the 14 November 2016 Kaikoura earthquake. (Map from geonet.org.au).

Three of the World's largest earthquakes in 2016 occurred in the Southwest Pacific region.

The Kaikoura NZ earthquake in the South Island in November has



fundamentally changed our thinking about earthquakes. It ruptured multiple distinct faults on the east coast, from south of Kaikoura right up to and into Cook Strait off Cape Campbell (Figure 34). Surprisingly it did not involve movement on the plate boundary along the parallel Alpine Fault along the west coast where the next major earthquake was expected. Two people were killed and there was extensive surface faulting, landslides and isolated cases of damage, as far as Wellington.

A magnitude 7.8 earthquake struck the Solomon Islands on December 8, the focus 70 km west-southwest of Kirakira and 130 km from Honiara at a focal depth of 40 km. The shaking was assessed at intensity MM VIII. Large aftershocks continued to terrify the inhabitants.

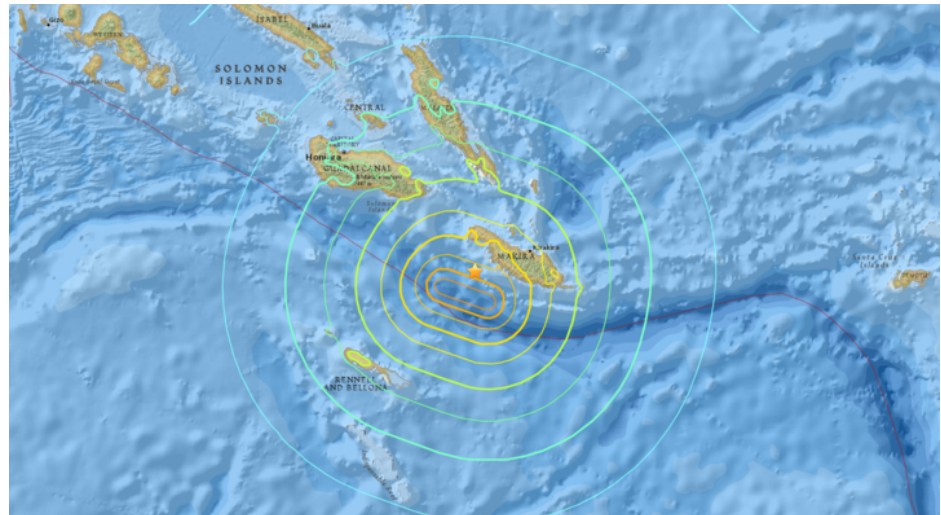
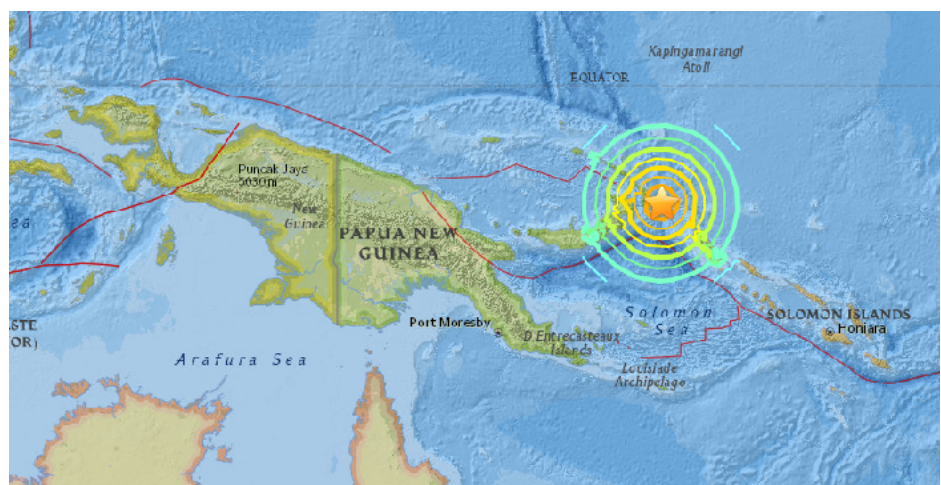


Figure 35 Solomon Islands earthquake 08 December 2016

Tsunami waves up to 5 cm were measured in New Caledonia and Vanuatu. Some 200 houses in the southern part of Malaita were damaged and buildings collapsed in Makira. Eleven schools and a medical clinic were damaged. More than 9,700 people were affected by the quake. An eleven-year-old girl reportedly died when a building in Guadalcanal she was in collapsed.

The year's largest earthquake (USGS Mw 7.9) struck off the southeast coast of New Ireland Papua New Guinea.

Figure 36 Location of the World's largest earthquake of 17 December 2016, 10:51UTC, at the triple junction between Bougainville, New Ireland and New Britain



This was a shallow thrust earthquake which generated a small tsunami locally. This area of New Ireland and northwest Bougainville are sparsely populated without significant engineered structures, earthquakes (gurias) are common so there was little if any damage.

Table 1 Australian earthquakes, magnitude 4 or more in 2016, from GA

Date/Time UTC	Latitude	Longitude	Depth*	Mag	Place
07/06/2016 00:02:19	-33.50	152.50	0	4.0	Offshore E of Gosford, NSW. (felt).
16/07/2016 11:44:49	-32.50	122.44	0	4.0	SE of Norseman, WA. (Reported felt).
18/08/2016 05:30:34	-19.73	148.92	0	4.0	Offshore NE of Bowen, QLD.
28/04/2016 16:52:44	-19.77	133.89	10	4.0	Tennant Creek, NT.
18/08/2016 18:27:36	-19.78	148.84	0	4.1	Offshore NE of Bowen, QLD. (felt).
21/05/2016 08:46:18	-25.60	129.84	0	4.1	Petermann Ranges, NT.
05/09/2016 16:23:37	-32.42	122.22	0	4.2	SE of Norseman, WA. (felt).
14/07/2016 10:08:55	-32.54	122.43	0	4.2	E of Norseman, WA. (Reported felt).
31/07/2016 13:45:49	-19.12	112.12	10	4.2	Offshore NW Australia, Indian Ocean.
08/06/2016 02:01:09	-32.51	122.49	0	4.3	SE of Norseman, WA. (felt).
13/08/2016 15:31:13	-23.82	152.87	10	4.4	Offshore NE of Bundaberg, QLD. (felt).
19/06/2016 01:54:09	-35.92	136.45	10	4.5	West of Kangaroo Island, SA. (felt).
28/05/2016 15:30:26	-32.50	122.47	0	5.0	SE of Norseman, WA. (felt).
06/11/2016 09:54:31	-19.11	127.99	10	5.1	SE of Hall's Creek, WA. (felt).
28/05/2016 16:38:44	-32.46	122.44	0	5.1	SE of Norseman, WA. (felt).
03/06/2016 13:40:15	-49.24	148.53	36	5.3	South of Tasmania.
10/05/2016 09:44:35	-16.40	118.69	0	5.3	Offshore NW Australia, Indian Ocean.
08/07/2016 09:40:50	-32.46	122.51	0	5.6	E of Norseman, WA. (Reported felt).
14/01/2016 12:15:29	-53.13	159.75	0	5.6	Macquarie Island Region.
18/08/2016 04:30:07	-19.77	148.86	0	5.8	NE Bowen, QLD. (goods shaken off shelves).
20/05/2016 18:14:02	-25.58	129.83	0	6.1	Petermann Ranges, NT. (felt, faulting).
08/09/2016 21:46:20	-54.52	158.61	0	6.3	Macquarie Island Region (goods shaken off shelves).

* Depth, if 0 or 10, constrained by analyst

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11. Web pages of interest

- Real-time seismograms from south-east Australia
<http://meiproc.earthsci.unimelb.edu.au/eqserver/>
- Map of recent earthquakes in SA
<https://earthquakes.mappage.net.au/q.php>
- Seismographs in Schools project
<http://ausis.edu.au/>
- Map of recent events in Australia
<http://www.ga.gov.au/earthquakes/>
- Edward Pigot Seismic Observatory
<http://www.map.id.au/seismic/>

Contributing Organisations

