Small Australian seismic events and their effects

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We review four small earthquakes in Australia and highlight various seismological aspects that are relevant when considering induced seismicity. The four events are in the magnitude range 2.5 to 4.1, a range that is likely to be of interest for those investigating geothermally induced events.

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Mt Barker (South Australia) event 16 April 2010 Magnitude 3.8

This earthquake occurred at 11:27pm on Friday night, about 25 km from the Adelaide CBD. It was widely felt, with a massive response to police and radio stations. There was no indication that the phone system failed, or that power outages occurred. The Primary Industries and Resources SA (PIRSA) earthquake network operated smoothly through the event, giving a very good location and magnitude estimate in less than 3 minutes. It took about 15 minutes to quickly review the event, and report it to the emergency services. The location was not entered on the PIRSA website until after the weekend. The first epicentre entry on the US Geological Survey website was about 100 km in error, but with a listed error estimate of 152 km. The first Geoscience Australia (GA) magnitude estimate was 3.2. While the internet remained operating, the GA and PIRSA websites were overloaded for a time. The PIRSA website received about 13,000 hits, a record. Hundreds of these emanated from overseas.

ABC radio Adelaide is normally run from Sydney late at night, but the Adelaide station was reopened in response to overwhelming public interest. Twitter and Facebook registered a huge amount of traffic. AdelaideNow website had about 1400 comments in short time; USGS Did You Feel It (DYFI) website plotted over 300 replies in less than one hour, and ES&S and GA had many replies to their website questionnaire. Management, particularly those associated with emergency response, expressed frustration at not knowing where to go for the best information at the eraly stages. In the following few weeks, a large number of insurance claims were lodged, with an estimate of 1,000 by one loss adjuster.

PIRSA circulated a questionnaire, but responses have not yet been analysed. Of the responses, only the USGS Did You Feel It system was available within a short time frame. As the earthquake was not in the US, the location information was limited to 6 ‘city’ locations, instead of postcode areas, rendering it of limited value.

There is a clear need for a DYFI system to be operated within Australia which can more effectively utilise location and intensity information, and disseminate it rapidly.

The depth of this earthquake was 25 km, with an uncertainty of about 2 km. This is quite deep for Australia. Normally depths of hypocentres are not available due to poor network coverage, however the new Adelaide network is producing accurate depths for a moderate number of events.

The magnitudes for stations of the Adelaide network ranged from 3.2 to 4.1, for stations of the GA network 3.5 to 4.2, and for stations of the ES&S network 3.4 to 4.0. These magnitudes were from peak amplitude measurements of seismographs, not moment magnitudes. Very little has been published on magnitudes in Australia in the last decade. Very few studies have been done to investigate corrections for individual sites on the basis of local geology, or to see how well magnitudes compare between networks.

The Eugowra (New South Wales) event 21 August 1994 Magnitude 4.1

This was the largest of a swarm of hundreds of events that occurred near the town of Eugowra, east of Orange, in country NSW. The swarm was very shallow, mostly less than 1 km deep. (Gibson *et al*, 1994)

The number of events, initially increasing in size resulted in public meetings being called. There was some concern, but generally not great. The main shock did stop the serious drinkers in the hotel for 5 minutes, but damage was limited to minor cracking and contents.

Portable instrumentation was installed close to the activity at an early stage in the swarm. From a beginning of one instrument, there was an increase eventually to 8 instruments, at moderately high sample rates of 200 to 400 sps. This resulted in probably the most accurately recorded sequence of events in Australian seismological history. It was possible to demonstrate the fault plane that accounted for most of the events in the sequence (figure 1). This, in conjunction with the local topography, gave a convincing geological story. It was also possible to roughly estimate the size of the main shock at about 1 km square from the accurate location of the shocks in the following 9 days (figure 2). Aftershocks in the following 9 months were spread out still further. No other earthquake under magnitude 5.5 has been monitored well enough to show the size, dip and strike of the faulted area. No fault mechanism was produced for any of the events, but the geological conclusion is that it was mainly thrust.

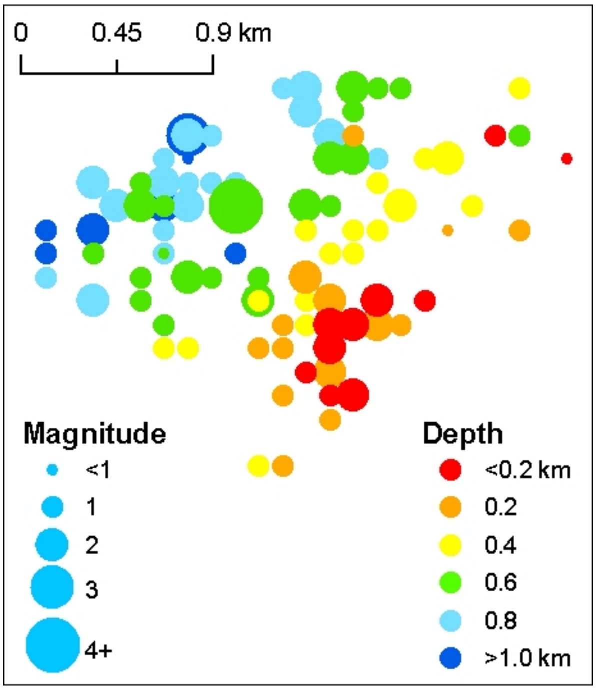

Figure 1: Hypocentres of the Eugowra earthquake swarm showing a shallow fault rupture clearly dipping to the north-west.

One accelerograph recorded a peak value of 0.97g. This is the largest acceleration recorded to date from an earthquake in Australia. The frequency of this peak was above 50 Hz. Unfortunately the sampling rate on the instrument was insufficient to calculate a velocity. The damage was very minor, demonstrating that acceleration is definitely not a good parameter to use when considering a management plan for induced events. Velocity is a much better predictor of damage, although it does not solve all problems. Detailed intensity information was not processed for this event, as a large effort was put into monitoring.

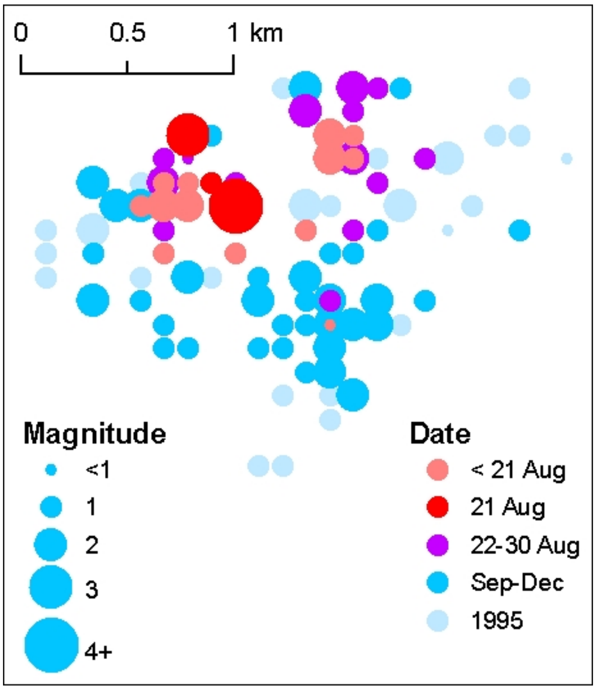

Figure 2: Hypocentres of the Eugowra earthquake swarm. The 22-30 August hypocentres outline an area of approximately 1 square km, which was probably the rupture surface of the largest event, magnitude 4.1.

Acacia Ridge (Queensland) event 18 July 1996 Magnitude 2.7

This earthquake shows that even small events, which often may not be felt in other countries, are still noticed in Australia. This earthquake occurred at 3:40pm in the suburbs of Brisbane, only 13km from the central business district. It initially produced only a small number of reports, however press reports and a phone survey collected over 150 intensity reports (Lynam and Cutherbertson 1997). The general radius of perceptibility of the main felt area was about 14 km with another felt area to the south-west and an isolated report as far as 70km away. Intensities assigned were low, with no reports reaching intensity 5 (figure 3).

The higher intensities were concentrated around the epicentre, and in a separate area to the south-west. The intervening area had lower intensities and even *not felt* replies. Variations in the intensities showed some correlation with surficial geology; lower intensities were associated with areas of Mesozoic sandstones and coal measures and Cainozoic sandstones and basalts, while higher intensities occurred on the Palaeozoic basement rocks. This observation, somewhat contrary to what is usually observed, is thought to be due to the high frequency nature of this relatively small magnitude event. Attenuation of the high frequency energy in the Mesozoic and Cainozoic rocks may have been more significant than the amplifying effects normally associated with surface sediments and lower frequencies of larger events. Many smaller events are noticed more by the noise, emanating from very high frequencies, than the vibration.

While there were nine seismographs within 90 km, the distribution of these meant that there is an uncertainty of several kilometres in the epicentre (particularly in a NE-SW direction) and the depth is unknown. This is common for most events in Australia. This lack of hypocentral depths means that there are limited data available to compare intensities with hypocentral distances at the close distances that are of interest to the geothermal industry.

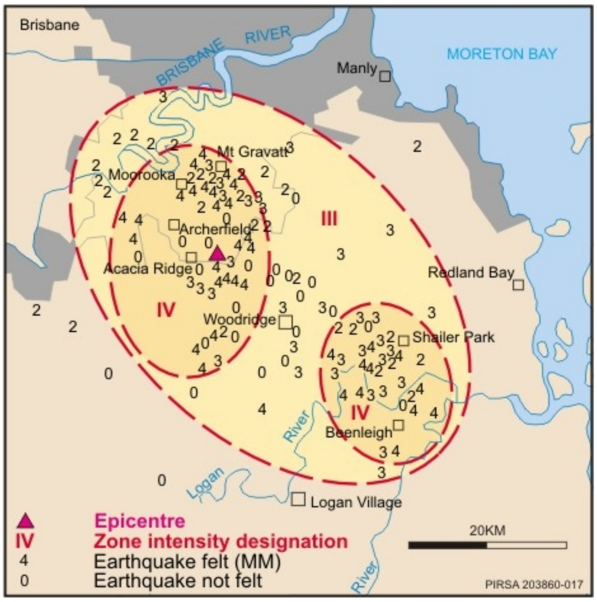

Figure 3: Isoseismal map of the Acacia Ridge earthquake. Source: Geoscience Australia

Caulfield (Melbourne) event 22 October 2006 Magnitude 2.5

An even smaller event was widely felt in Melbourne at 10:36pm while most people were quietly at home.

Information for this isoseismal map (figure 4) was collected by the intensity form on the ES&S website. As a result, in contrast to the Acacia Ridge earthquake, it has only one *not felt* reply. There are only two MM5 intensity reports listed, again showing the expected low intensities.

Despite the very low magnitude of the event, and the low intensities reported to the ES&S website, there were many insurance claims made, primarily for cracked plaster, cracked and lifted tiles and other cosmetic damage.

The good seismograph distribution meant that the epicentre and depth were known to within about 2 km. This is fairly unusual for Australia. It has the benefit that any measured velocities and estimated intensities can be included in more specific attenuation analyses for small earthquakes at close range. Peak amplitudes for the four closest seismographs were in the 10 to 25 Hz range. Individual station magnitudes varied from 2.0 to 3.4.

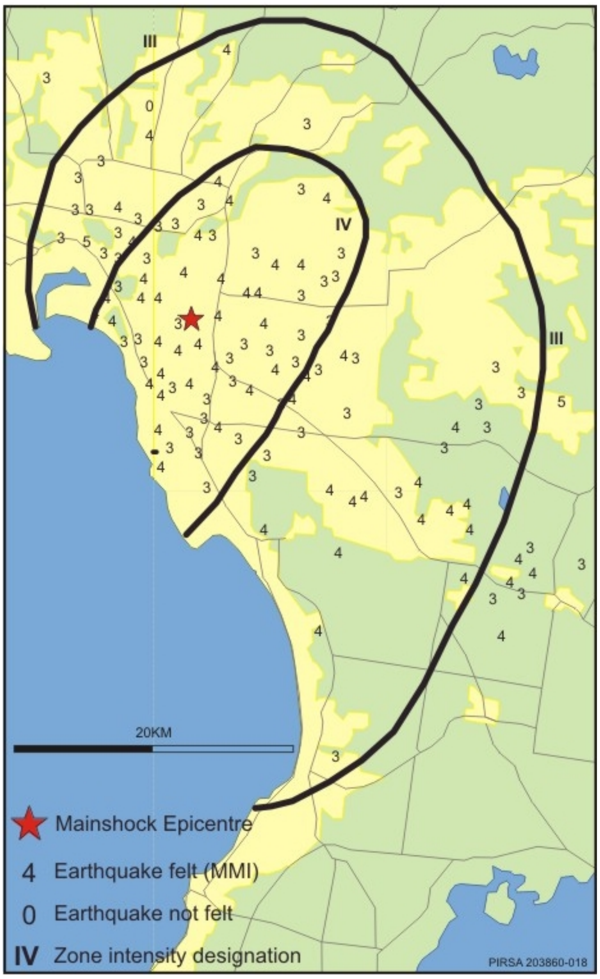

Figure 4: Isoseismal map of the Caulfield earthquake

Conclusions

Quite small events are felt, heard and newsworthy in Australia, even though the real damage consequences are minor or non-existent. While there is a considerable amount of information of interest and value available to the geothermal industry, some extra effort could improve the data collection and interpretation to more suitably address the needs of the industry.

Information that is accurate, and quickly available saves the difficulty and complaints that come later, from the inability of management and the public to find the information when desired.

Given the large public response, even for small events, there is clearly a need for a good community consultation program which addresses perceived risk as well as the risk of damage.

A 'Did You Feel It' intensity collection system, run in Australia would significantly improve the collection of intensity data, particularly over the important populated areas, and make it rapidly available in easily understood form. This will lead to improved attenuation formulae. The project should be easy and inexpensive. Improved intensity data will give a much clearer indication of the level of induced seismicity that may be tolerated, and the level of public response to vibrations.

There are currently New Generation Attenuation (NGA) formulae in use in earthquake hazard assessment. (Power *et al*, 2008) The development of modified NGA formulae to cover the magnitude range 3 to 5 would also provide valuable tools for use in induced seismicity risk assessments. The current NGA formulae are designed for higher magnitudes and lower frequencies, and not suitable to be extrapolated beyond these ranges. There is a vast amount of recorded information for smaller earthquakes. Unfortunately these are nearly all from overseas events. Events from stable continental areas, especially Australia would be needed, particularly for better handling of high frequencies.

More detailed monitoring, particularly active and populated areas would lead to improved source information, and more local data for modified NGA formulae. Unfortunately this is a more expensive exercise, and most populated areas are not monitored to this extent. More portable deployments of larger scale to measure swarms or aftershocks at close range, and with higher sample rates, would provide valuable information on velocities, accelerations, rupture sizes and focal mechanisms of use to the industry. This is not done as often now as it was in the past.

The collection of intensity data in the same localities as velocity data will further improve the estimation of effects and damage in populated areas.

There is a need to compare magnitude data across Australia, review magnitude formulae currently in use, begin usage of moment magnitudes, and investigate seismograph site magnitude corrections. This is not difficult, but has not been happening over the last decade, with limited interaction between seismological observatories.

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