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The Murrayville Earthquake M_L5.0 8th October 2021

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Abstract

This earthquake occurred in a low seismicity region on the border of South Australia and Victoria during Covid-19 restrictions. Aftershock monitoring was rapidly activated, with equipment deployed from each side of the border. The key problems were uncertainty of the epicentre, and limited access. In line with a previous event in the region, aftershocks died quite rapidly, but 170 aftershocks were detected, of which 38 were accurately located by all four aftershock recorders. Results showed that locations using permanent stations only, were about 10 km from those using the portables. Depths were 9 to 10 km, and there was no InSar anomaly. A first motion focal mechanism was not possible, although there is a slight indication of a plane dipping to the south-east, which intersected the border. A review of amplitudes shows that this earthquake is larger than first realised, with implications for displacement measurement and magnitude calculation procedures.

Keywords: Aftershock deployment, depth, magnitude

1 Region and past seismicity

The earthquake occurred in the Murray Mallee region of South Australia and Victoria. The southern Murray Basin sediments are mostly flat lying, with Quaternary unconsolidated surface sediments, sand hills, and limited topography, and no neotectonic faults are known near the site. There are wide areas of park covered in low level scrub; Ngarkat Conservation Park in South Australia, and Big Desert Wilderness Area in Victoria. There are no major geological features, and the seismicity is quite low. Previous significant events in the region are 1987, magnitude 4.9 (McCue et al., 1990), and 1905, magnitude 5.5 (Underwood, 1972). Seismicity is shown in Figure 1. The region is only lightly populated, and has had minimal monitoring and attention, being between two regional scale networks in past decades, so that the recorded seismicity is probably understated. Epicentres and depths in particular have significant uncertainties.

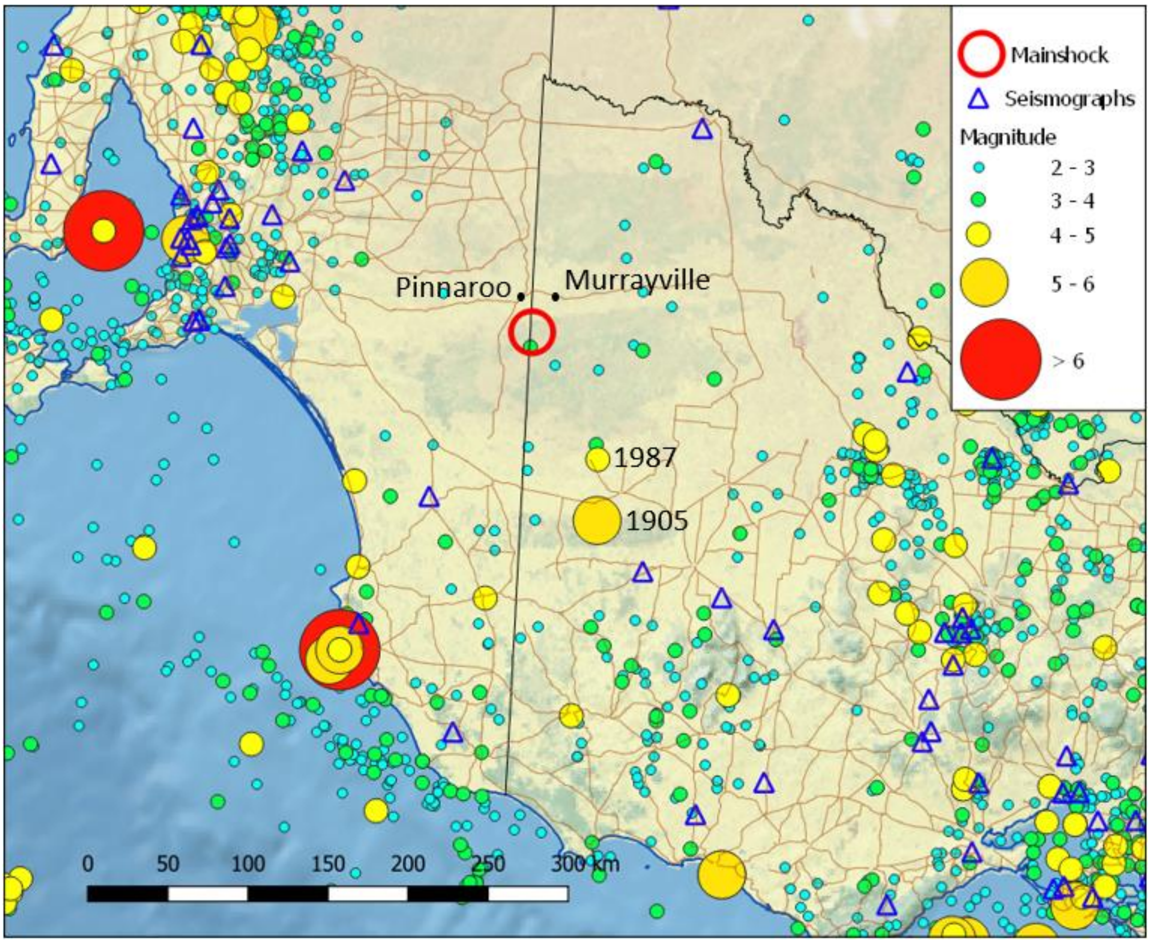

Figure 1. Past seismicity in the surrounding region, seismographs operating, and preferred mainshock location.

2 The event and portable deployment

The event occurred at 3:17am (SA time) on Saturday morning (8th at 1647 UT). The first author became aware of the event at 7am. It was quickly decided that the Seismological Association of Australia (SAA) would prepare three portable units and install them in a day trip. Melbourne University (Gary Gibson) also volunteered to install one spare unit, as most available aftershock kits were already deployed near Woods Point.

With limited time to review epicentres, and no recorders near the epicentre, it was difficult to locate the event and plan recorder locations. A key problem on the day was the declaration of a lockdown zone on the Victorian side of the border including the town of Murrayville. SAA received help from the Pinnaroo police and a local farmer, to install three recorders approximately along the border track. There were no obvious tracks or clear areas going east-wards into Big Desert Wilderness Area; only continuous mallee and low scrub. The first recorder was installed 12 hours after the main event. By this time more than 15 aftershocks had been recognised on the regional network. To the west, it was necessary to go into the park area from Nhill in the south to avoid the lockdown. This recorder was installed a day later. All sensors were in unconsolidated sediments, and were thus rather noisy. All were set to 200 sps or faster. Three were 3 component seismometers, and one vertical component only. The recorders were removed after 25 days. There were no failures.

3 Data processing

Four recorders are less than ideal for aftershock recording, however as processing progressed it became evident that the portables were placed in fortuitous positions, resulting in at least reasonable hypocentres. The epicentres were mostly within the network (maximum gap angle under 180 deg) and the nearest recorder was almost directly over the activity, giving excellent depth control. Two recorders were to the north and one to the east, giving reasonable horizontal control as well.

One of the recorders had timing issues and initially only eight events with suitable S-P times could be found. However on detailed examination it emerged that the errors were exactly whole seconds. Further detailed searching eventually uncovered 38 locatable events. The sequence of events is shown in figure 2. Magnitudes of small events from the portable stations should be considered as uncertain.

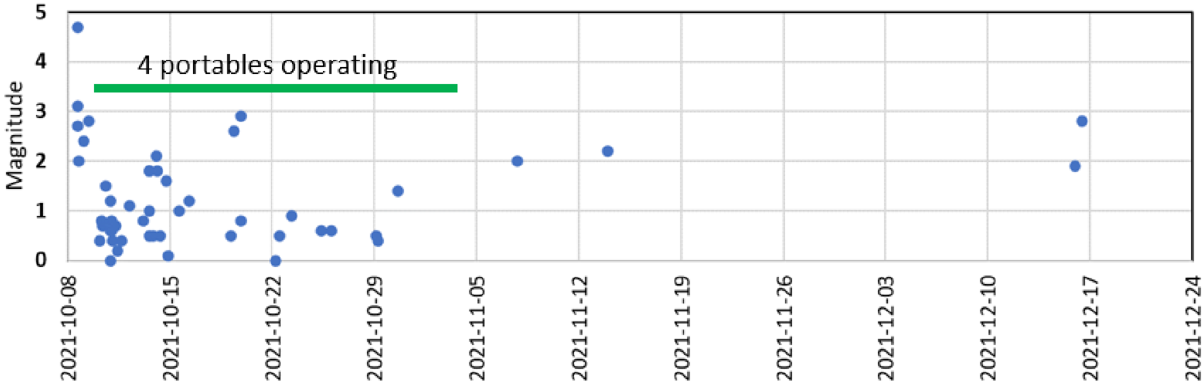

Figure 2. Murrayville sequence showing time when all portables were operating.

Event recordings on the 3 component stations usually showed SP conversions on the vertical channel before the S arrived on the horizontals (figure 3). This typically was recorded 0.3 to 0.5 seconds prior to the S arrival. This meant that the second arrival on the station with only a vertical sensor could not reliably be considered as an S phase. The conversion indicates a significant velocity change below the recorders.

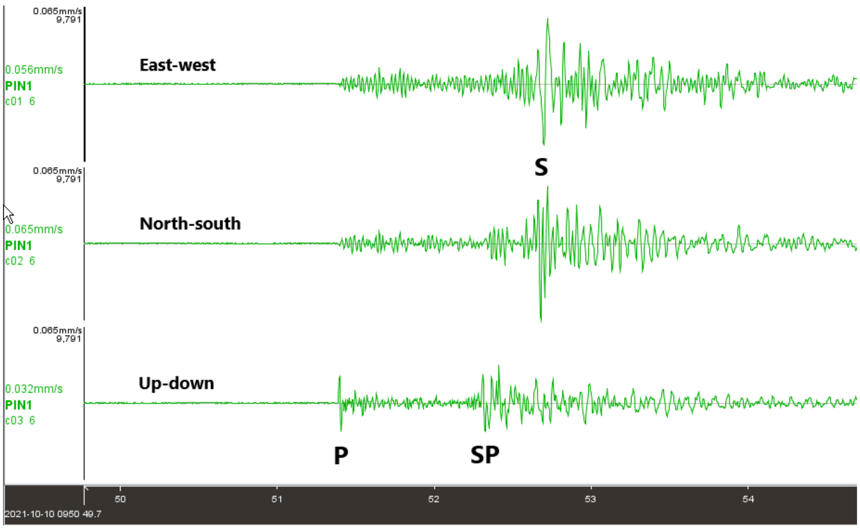

Figure 3. Typical seismogram showing strong SP conversion on vertical channel before S on horizontal.

For the 38 aftershocks located by all portables, standard deviation of residuals were under 0.1 sec, typically 0.08 however this should not be taken as indicating accurate results, given the small number of recorders. Both SA1A and VIC5A velocity models were tried. Very small systematic variations were produced depending on the location program and phase weighting.

The accurate aftershocks covered an area of about 4 sq km (Figure 4), a little less than the 9 sq km expected from a magnitude 5 event. The EqFocus program used indicated 1σ errors of around 0.9 km in east-west and north-south directions.

The difference in epicentre locations using the regional or portable instruments was about 10 km. This is shown in figure 4. Also shown are early mainshock estimates by GA, SAA and SRC. This event was closer to Pinnaroo. Perhaps it should be called The Border earthquake.

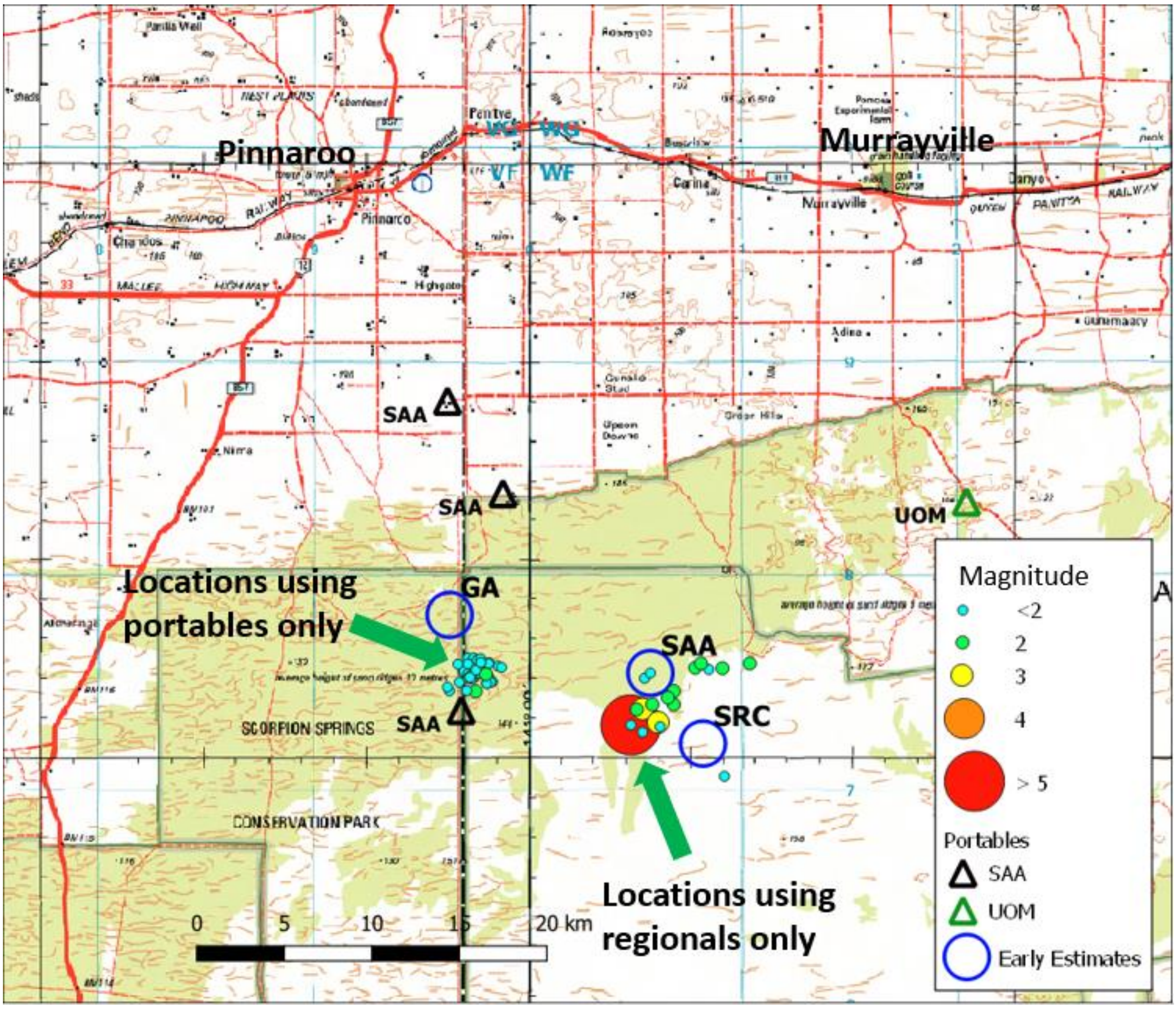

Figure 4 showing epicentres calculated using portables only or regional stations only, early estimates of mainshock position, and positions of portables installed.

As the nearest permanent seismograph was 120 km away, a depth for the mainshock could not be estimated from the location calculation. The best located aftershocks were 9 to 10 km deep. As one SAA station was effectively over the events, these depths can be considered as quite good, limited more by velocity model uncertainty than by station distribution. EqFocus gave 1 σ values of about 0.9km. If we assume that a magnitude 5 rupture is about 3 X 3 km, the mainshock depth is likely to be quite close to the aftershock depths.

4 Focal Mechanism

First motions were picked for 57 records. An attempted focal mechanism is shown in figure 5. It is obvious that the data are too poorly distributed to estimate nodal planes, with nearly all points being on the circle of critically refracted points. The uncertainty of the velocity model also affects this. The first motions of the aftershocks on the portables were variable, so it is not valid to produce a combined focal mechanism. Numerous recordings were in disagreement with others at the same azimuth, so that even a direction of principal stress is not possible.

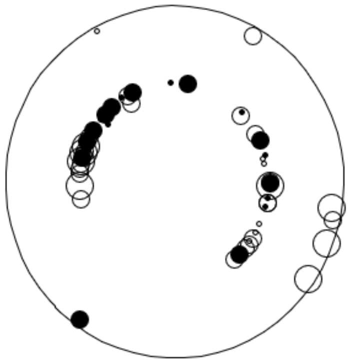

Figure 5. First motions. Nodal planes and direction of compression cannot be determined.

An approximate plane is indicated from aftershock hypocentres, but it is unstable. This is shown as a cross-section in figure 6, going from north-west to south-east through the accurately located aftershocks near the border. Proposing any causative fault is considered speculative. Given the accurate location and depth, waveform modelling may be possible, to shed more light on the rupture plane. A proposed deep seismic line in the region next year may provide some control for the velocity model.

McCue et al (1990) includes a focal mechanism for the 1987 event, with a limited spread of data points on the sphere. Leonard et al (2002) includes an alternative solution.

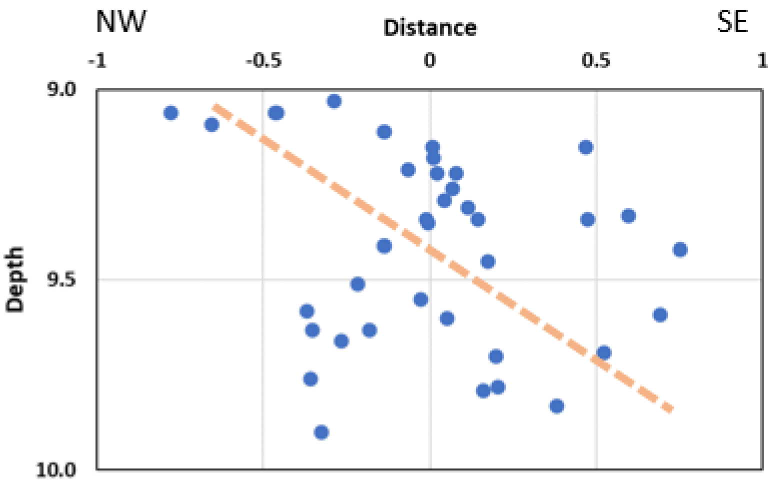

Figure 6. Cross-section- NW (left) to SE. Weak indication of possible rupture plane.

5 Magnitude

5.1 SAA calculations

The magnitude was initially listed by SAA as MLv 4.7 using the Bakun and Joyner formula (Bakun and Joyner, 1984), with displacements automatically calculated by Waves for 21 stations in SA and Victoria. It was listed as 4.8 by GA using the Michael-Leiba and Malafant formula (M-L+M, Michael-Leiba and Malafant, 1992). SRC also listed it as 4.7 using M-L+M.

Using Waves, 67 waveforms were carefully reviewed and peak displacements measured, applying a band pass of 0.2 to 20 Hz. Waves uses a default 2 to 10 Hz filter, however higher magnitudes produce more low frequency energy, so a lower frequency cut-off is advisable. On subsets of the waveforms, using a 2 to 10 Hz filter instead of 0.2 to 20 Hz resulted in a magnitude reduction of 0.3 for 1 Hz instruments, and 0.4 to 0.7 for broadband (BB) instruments. Waves currently uses only a flat gain, ignoring the response roll-off below the natural frequency.

Clearly displacement amplitudes of larger events need to be measured after correcting for instrument response at low frequencies.

SAA values using both the Greenhalgh formula (Greenhalgh and Singh, 1986) and the M-L+M formula are shown in Table 1. The M-L+M formula was intended to be used up to 1500 km, so the distance range is indicated in the table. A flat Wood-Anderson (W-A) gain of 2080 was used here, although the Greenhalgh formula assumes a gain of 2800 and variation with frequency.

Equation	Type	Distance	Number	Magnitude	Std Dev
ML(SA)	1Hz	< 600 km	12	4.92	0.28
	BB	< 600 km	9	5.03	0.37
ML(ML+M)	1Hz	< 600 km	12	5.01	0.28
	BB	< 600 km	9	5.12	0.36
ML(ML+M)	1Hz	All	27	5.07	0.28
	BB	All	39	5.45	0.38

Table 1. SAA calculations, including type of instrument, and distance range used.

5.2 GA calculations

GA normally applies the complete instrument response information to recover the waveform. This also includes conversion to equivalent W-A waveform. Unfortunately the W-A response is considerably reduced below 2 Hz, so that the resulting magnitudes begin to saturate.

GA kindly supplied an xml file containing all calculations for this event. It included magnitudes from the AU network and also the S1 network (Seismometers in Schools). These are presented separately in Table 2 below. One key difference is that many GA stations are on rock, and most S1 stations are on soil.

Using the M-L+M formula, the indicated distance range, but not including any station corrections, the magnitudes are given in Table 2.

Network	Distance	Number	Magnitude	Std Dev
AU	< 600 km	12	4.55	0.20
S1	< 600 km	5	5.20	0.21
AU	All	25	4.66	0.26
S1	All	12	5.18	0.19

Table 2. Results from GA xml file

5.3 Discussion and recommendations

It would appear that the magnitude of this event is higher than initially presented by SAA or GA. It is unclear what the correct magnitude ought to be.

An attempt was made to compare SAA and GA values, but since SAA calculations do not include full instrument response and W-A response, this was not possible. In order to have confidence in magnitudes, it is necessary to have a few (preferably at least three) programs to calculate magnitudes, and compare these in detail, to iron out the differences and errors. Another factor in this the careful attention needed to the level of low frequency background noise in records.

The M-L+M study states “Because this study is based on a relatively small number of observations (181 measurements on 36 earthquakes), the results should be regarded as preliminary.” A more thorough study should be attempted.

The use of W-A corrections presents two particular problems. Firstly there has been variation between the gain, damping and natural frequency values used by various authors. Secondly there is the problem of saturation that occurs when lower frequencies start to dominate the waveform. One solution is to use a scale based on displacement without W-A factors, and tie it with other formulae at some moderately close distance. This would be very useful for Australia where we occasionally have magnitude 5 events, but rarely magnitude 6. The resulting scale would be less prone to saturation.

Station corrections have not been used in this study, but clearly they are a vital part of improving magnitude scales that has been mostly ignored in recent times.

6 Macroseismic effects

Geoscience Australia received over 300 felt reports. In the northwest direction the furthest were about 25 reports in the Adelaide suburbs, at a distance of approximately 225km. In the southwest direction the furthest were east of Melbourne over 500km away. Melbourne had a similar number of reports to Adelaide. Due to the sparseness of reports nearer the epicentre, no clear increase in intensity can be seen.

A detailed isoseismal map was produced for the 1987 event from about 175 detailed report forms (McCue et al, 1990). It indicated no felt reports in Adelaide suburbs, and no felt reports east of Kerang, Bendigo, Ballarat and Warrnambool. The isoseismal contours were close to circular. Both earthquakes were in the early morning hours.

At Pinnaroo, some damage was noted on a community hall. On examination, it appeared that there had also been previous similar damage (figure 7). The prior damage may have been from the 1987 event, as damage was reported from Nhill, Yanac and Bordertown.

Figure 7 Damage from 2021 event over repaired damage from previous event. Previous angle iron strengthening on corner.

7 References

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