Yongala Earthquake (South Australia) 4th September 2011 Magnitude 4.1

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Abstract

During 2011, a sequence of earthquakes occurred near Yongala in the Southern Flinders Ranges, north of Adelaide. After the mainshock of magnitude 4.1 on 4th September, an aftershock survey was rapidly mobilised. When the aftershock sequence continued for more than two weeks, further portable instruments were installed. All available data (from four organisations) resulted in one of the best surveys done in recent years in Australia. Hypocentres accurate to better than 500m were computed for some aftershocks, and seven focal mechanisms were obtained. There appears to be a 30 day period in later aftershocks. Better survey planning would have improved results significantly in two ways. Higher sample rates from some recorders would have resulted in more accurate waveforms, and initial station locations could have been improved by using all available information. Focal mechanisms did not show horizontal compression. The combination of local geology, aftershocks and focal mechanisms did not give a simple consistent picture in this case.

Keywords: earthquake, aftershock, survey, focal mechanism

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INTRODUCTION

On 4th September 2011 an earthquake of Magnitude 4.1 occurred in the Southern Flinders Ranges about 200 km north of Adelaide. The epicentre was near Yongala, between Jamestown and Peterborough (Figure 1). With activity continuing overnight after the mainshock, a detailed deployment was quickly arranged. When aftershocks continued in following weeks, the deployment was expanded. By combining data from all sources, there were sufficient nearby stations to get moderately accurate hypocentres which suggested a rupture plane, and some focal mechanisms for late aftershocks. The improved value of 500 samples per second over 100 was clearly demonstrated. There is an indication of periodicity in later aftershocks.

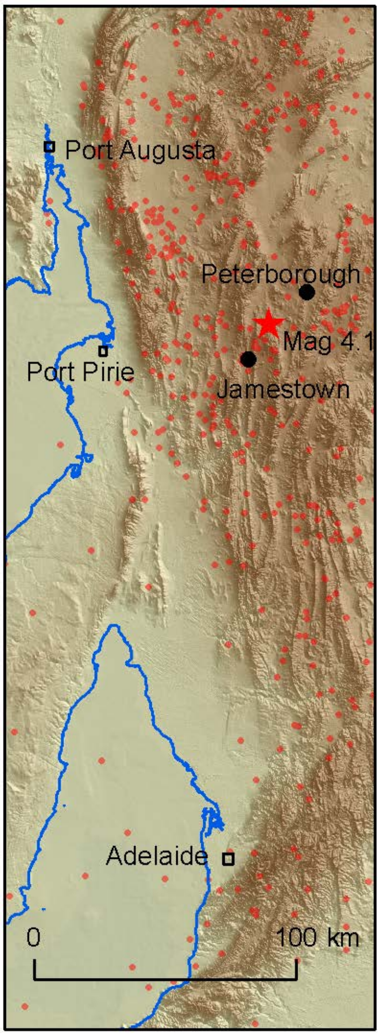

Figure 1

MECHANICS OF THE DETAILED DEPLOYMENT

Vic Dent had arranged the installation of PSN type seismographs at the Jamestown and Peterborough schools (JMS1 and PBR1 figure 2) and these began operating on 29th June, sending data to the Australian Centre for Geomechanics (University of Western Australia).

The earthquake occurred on Sunday 4th September at 8:45pm local time. It was preceded by foreshocks at 8:22, 8:43 and 8:44. There were numerous aftershocks, with at least nine over mag 2.0 during the night and a magnitude 3.3 at 9:18am on Monday morning. The Peterborough instrument was operating at the time of the mainshock, and the Jamestown one was operating the next morning.

Four rapid deployment instruments (Echos) from Geoscience Australia and one instrument (Echo) from PIRSA were packed, and David Love and Glen Kleinschmidt left for the area at 1pm on Monday 5th. The first two recorders were installed in the evening, and three more the following morning. The Jamestown School recorder was visited briefly before returning to Adelaide in the evening.

When activity continued, a further trip was arranged. The author drove to the area on the 22nd September and downloaded all 5 existing instruments, removing the furthest instrument (KLG5). In the evening a few events were analysed to improve the locations. Blair Lade drove to the area in the evening with 4 instruments (EchoPros) from Defence Science and Technology Organisation. Three of these and the removed instrument were installed the next day, along with a visit to the Peterborough School recorder. The last instrument was installed on Saturday morning 24th, before returning to Adelaide.

Activity decreased soon afterwards. Blair Lade removed all nine instruments on Saturday 15th October. From then on, further shocks were located just using permanent stations, including Peterborough and Jamestown.

The PSN and EchoPro seismographs only had vertical sensors, while the Echos all had triaxial sensors.

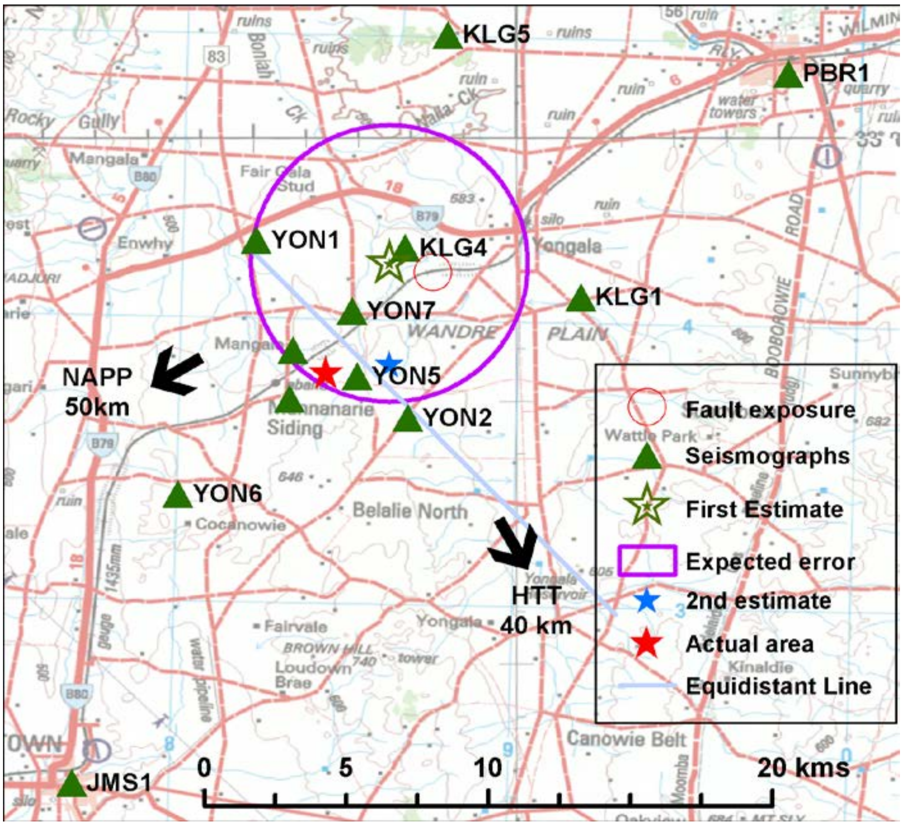

Figure 2 - showing the epicentral area, first epicentre estimate with uncertainty (purple circle 5km radius), second and third estimates. Seismograph sites are indicated. The line is equidistant from JMS1 and PBR1 recorders. Most events were closer to JMS1. Surface fault site is a red circle.

THE SEQUENCE, FORESHOCKS, MAINSHOCK, AFTERSHOCKS

There was some activity in the region prior to September. Within 10km of the epicentre, 2 small events occurred in 2010, and 5 events of mag 1.7 to 2.0 in 2011. The last of these was 14 days before the mainshock.

The main sequence began with a foreshock 25 minutes before the mainshock, then two more foreshocks in the 2 minutes before the mainshock.

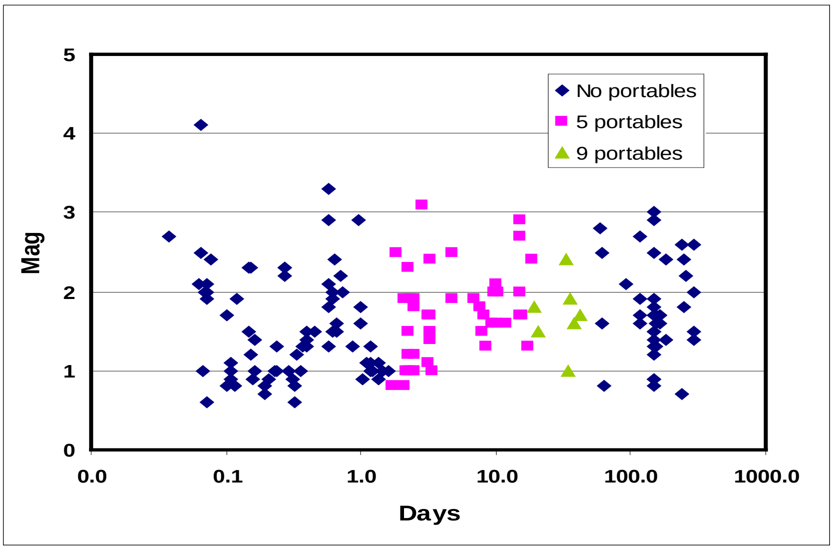

Figure 3 - Aftershock sequence in log time approximately with respect to mainshock

The mainshock was 0.8 magnitude units larger than the largest aftershock, magnitude 3.3. Since then, the maximum magnitudes have not decreased much, but the rate of activity has decreased roughly according to a logarithmic scale (Figure 3). There was a brief burst of renewed activity on 2nd February 2012.

When plotted in a linear fashion with 30 day markers, there is a very clear periodic pattern from November to May (Figure 4).

There is an active area about 20 km east, where many small events have occurred in the past, including a swarm during March 1990.

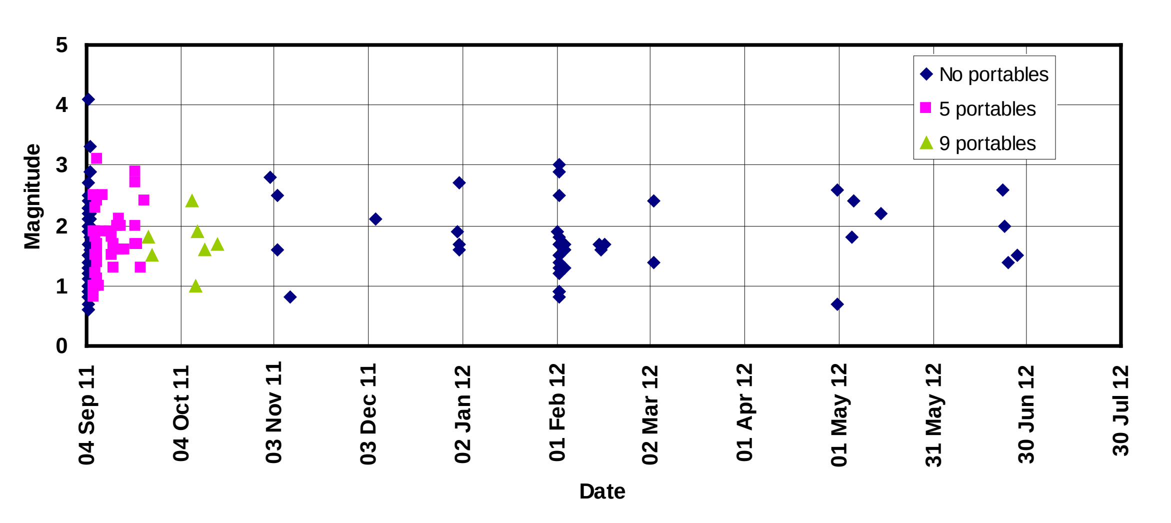

Figure 4 - showing periodicity from Nov 2011 to May 2012

WAVEFORMS

Figure 5 shows the spectacular improvement going from 100 to 500 samples per second (sps). 100 sps had degraded arrivals caused by digital filtering. At 500 sps no degradation was apparent. About 60% of 100 sps records were difficult to pick, resulting in arrival times with errors 5 to 20 times greater than the 500 sps. The degradation also applied to polarity estimation. The Echos were operated at 100 sps and EchoPros at 500 sps.

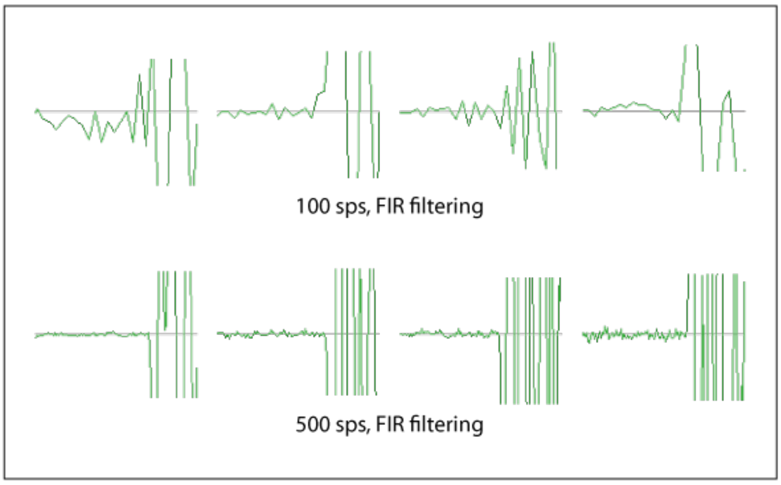

Figure 5 - showing improvement at 500 samples per second over 100 samples

The high sample rate recorders showed considerable energy at high frequency, occasionally up to 80 Hz, although more commonly to 50 to 60 Hz. This suggests that even an increase to 200 sps could have significantly improved the situation.

Data from JMS1 and PBR1 were normally at 50 sps, but 200 sps was available when required. These stations were around 16 km from the hypocentres, and produced good waveforms.

The author considers that for aftershock sequences over most of Australia, the default sample rate should be 500. At close range in Western Australia, 1000 sps should be considered.

DEPTHS OF BEST LOCATED EVENTS ABOUT 5KM

Velocity models were tested with variable results. At close range SA1A was not as good as DAL1A and VIC5A, but at moderate distances SA1A was generally better. In Figure 6, events 1 to 6 used the first five portables, plus other stations out to 55 km, with the hypocentral depth set at 5 km, which was about the average. This included JMS1, PBR1, HTT and NAPP, but the S phase from KLG1 was excluded. Events 7 to 12 included nine portables, but no other stations. For the latter set, depths were calculated, not fixed, and this resulted in estimated errors (2 σ) of 200 to 350 m in the horizontal plane.

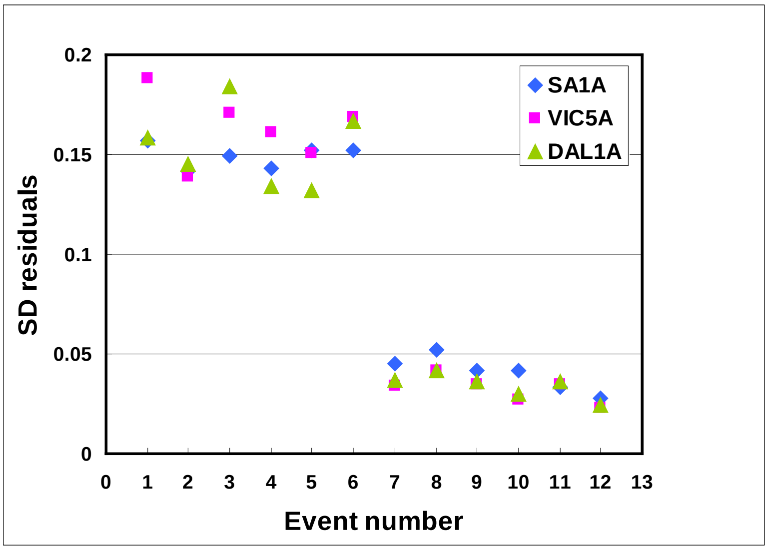

Figure 6 - showing residuals of 12 events using different velocity models

This suggests that there may be some very shallow, lower velocity layers, but that the P and S velocities in the SA1A layer are a good estimate for the bulk of the shallow depth.

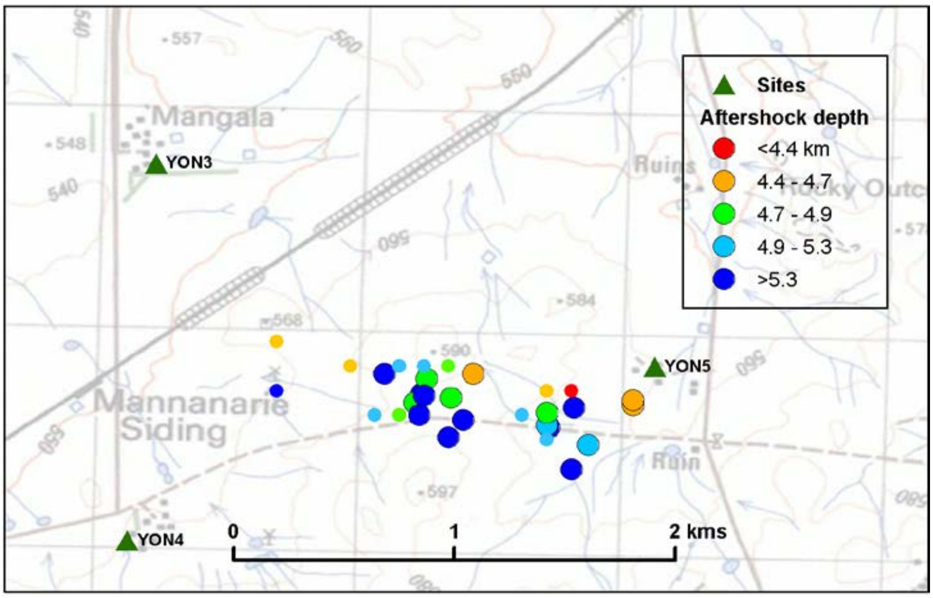

Figure 7 - detailed map of selected aftershocks: small symbols using all portables, large symbols using 500sps recorders only.

Comparing this with figure 7, we can see that the theoretical errors are about one third of the east-west scatter of epicentres. While this suggests that we do have a real lineation, the evidence is not particularly powerful. A magnitude 4.1 event may lead to a rupture of 1 sq km, but late aftershocks may only be coming from a limited number of points on the edge of the rupture zone.

An attempt was made to locate some events using just waveforms from the EchoPros at 500 sps. These recorders were very close together. The results are shown in figure 7 as larger dots. Using 4 P phases and an S phase from YON5 (best), hypocentres cover a zone 1 km by 400 m with depths of 4.5 to 5.5 km. Phase residuals were highly systematic. After removal of average station delays -0.007 to +0.009 sec, no remaining residuals exceeded 0.004 sec (2 samples).

FOCAL MECHANISMS

Focal mechanisms were produced for seven small events (figure 8). These are all upper hemisphere depictions. Six of these occurred while all portables were installed. Combined with the nearest four permanent sites, it was possible to get reasonable mechanisms without problems of uncertain polarity and uncertain departure angle. All arrivals were direct, not refracted, although angles would vary slightly between models. Thus most arrivals are clear (impulsive) apart from the filtering artifacts mentioned previously. For the mainshock, there is uncertainty in the polarity of many arrivals, and also uncertainty in the departure angles, with some possibly being refracted, making it difficult to produce a focal mechanism. Apart from one event on 9th October, the aftershocks give consistent results with the average nodal planes being:
1 – near vertical (dip 75° SE), striking NE – SW (55°)
2 – very shallow (dip 25° NE) striking WNW – ESE (115°)
Surprising, it is only the odd mechanism that is compressional.

The nearest previously computed focal mechanisms are over 70 km away, and do not follow a consistent pattern.

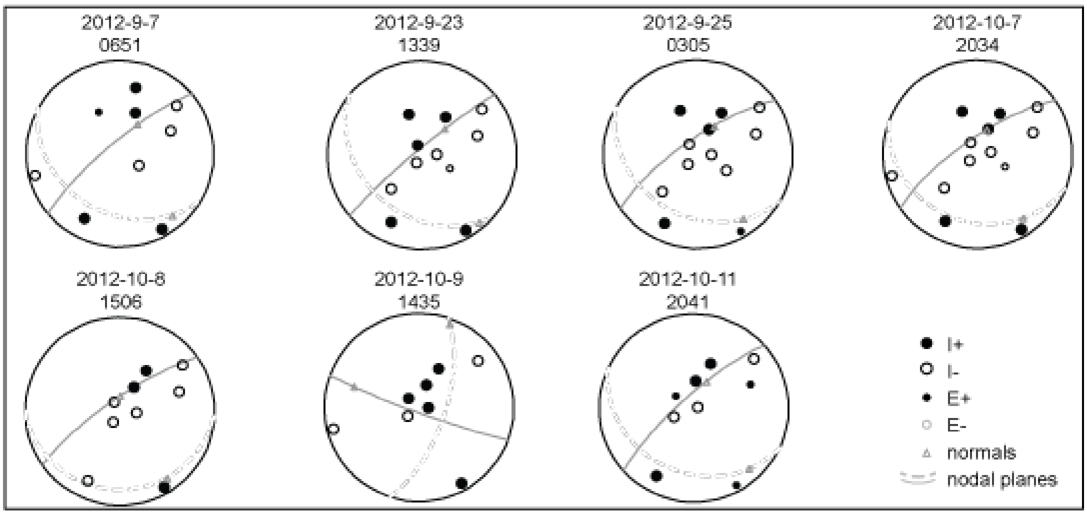

Figure 8 - focal mechanisms (upper hemisphere) for 7 small events late in aftershock sequence. Note that some are not well constrained.

OTHER SURFACE FAULTING IN THE AREA

In a railway cutting a few km to the NE (marked in figure 2) an exposed fault has been examined. It shows probble Tapley Hill Formation shale (Neoproterozoic) thrusting over Tertiary gravels (photo – figure 9). It has a strike of 12° and a dip of 50°E. It was not possible to see if there was a small offset in Quaternary sediments.

Figure 9 - Thrust fault exposed in railway cutting

IMPROVEMENTS IN SURVEY PROCEDURE

Given that only generic velocity models are usually used, inaccuracy in the first location must be assumed. We could have improved our first trip layout with the aid of extra information. One school recorder was not working on the night of the mainshock, but was working the next day. The Jamestown recorder was marginally closer to the activity than the Peterborough recorder. Figure 2 shows the line equidistant from Peterborough (PBR1) and Jamestown (JMS1) schools. This fact would have alerted us to the more likely epicentral area. Immediately after the second portable recorder was installed in the evening, an earthquake was felt. In hindsight, we should have immediately downloaded the event and made use of the information. Another piece of information the author overlooked was the farms that were reporting feeling the most events (at YON3 and YON4 in figures 2 and 7). This would have been a valuable guide for the starting stations.

Figure 2 shows the first epicentre estimate with a 5 km circle (estimated error) around. This was followed by the second estimate which was quite close to the final area.

DISCUSSION

The data from this survey was much higher quality than most others in Australia in recent times, and resulted in some relatively good aftershock locations, and some focal mechanisms. However it was still a little short of producing a coherent and comprehensive picture of the event.

There is not good agreement between the focal mechanisms and the suggested plane of aftershocks. The east-west lineation of aftershocks could relate to the shallow dipping nodal plane striking WNW, except that it is dipping in the wrong direction, the calculated hypocentres shallowing north, and the focal mechanism deepening north. It is possible that the lineation and estimated planar surface are only due to the inaccuracy of phases and the station geometry. It is also possible that the aftershocks are more in a volume (eg Cadoux 1979, Everingham et al 1982) than a plane.

The near vertical nodal plane striking 55° (approximately NE) does point towards where a fault is exposed in a railway cutting. Both also dip in an easterly direction. However the mechanism has a strike of 55° while the outcrop has a strike of 12°, and the mechanism is normal while the outcrop is reverse.

If the five Echo portables first installed had been able to run at 500 sps, and the placement had been improved, it is likely that there would have been significantly better results.

ACKNOWLEDGEMENTS

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REFERENCE

Everingham, I B, McEwin, A and Denham, D (1982) Atlas of isoseismal maps of Australian earthquakes. Bureau of Mineral Resources, Canberra, Bulletin 214.