Earthquake patterns in the Flinders Ranges - Temporary network 2003-2006, preliminary results

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Objectives

The Flinders Ranges region of South Australia is an area of high topographic relief and high seismicity. This, combined with the fact that several faults identified in the Flinders and Mt. Lofty Ranges region have relatively high Quaternary slip rates (Sandiford, 2004), indicates this is a region of pronounced neotectonic activity. However, we have a very poor understanding of what relationship exists, if any, between the earthquakes and faults. Similarly, because the tectonic stress field in this part of Australia is poorly determined (Hillis and Reynolds, 2000), we do not have a clear understanding of the relationship between the stress field and active faults.

The Flinders Ranges region also exhibits high heat flow (Cull, 1982; Neumann et al, 2000), which would suggest a shallow seismogenic crust, and yet earthquake hypocentres, albeit often highly uncertain, indicate that seismicity extends to lower crustal depths. Finally, this high heat flow and the unique crustal structure of the underlying Adelaide Fold Belt may lead to propagation characteristics of earthquake waves that differ from other parts of Australia.

During the period September 2003 – June 2005, a temporary seismograph deployment was established in the Flinders Ranges region, consisting of about 18 stations spaced at roughly 30 km intervals. Among the questions about the Flinders Ranges region which this deployment was intended to address were:

- Which faults are seismically active?
- What is the depth of the seismogenic crust?
- Is the earthquake ground motion similar to other parts of Australia?
- How can the regional stress field be characterised?

It was felt that this area would provide an excellent opportunity to answer such questions, since there were likely to be a sufficient number of earthquakes, plenty of exposed rock for good waveform recording, and easy access to useful recording sites.

Deployment

The equipment was provided by ANSIR, GA and PIRSA. It consisted of:

- Broadband (30sec) 3D Guralp seismometers with Reftek recorders (8)
- 1Hz 3D Guralp seismometers with Kelunji D recorders (4)
- Various 1D and 3D seismometers and accelerometers with Kelunji D and Classic recorders.

It also used data from permanent analogue and digital recorders in the area that are part of PIRSA's permanent seismograph network. Most recording was at 100 samples per second, with a few stations recording at 200sps. All of the temporary stations recorded continuously.

From September 2003 to June 2005 there were up to 18 digital recorders installed from Burra to slightly north of Hawker. It was clear that a considerable number of events were happening at the northern end of this network, so from June 2005 to June 2006 eight recorders were installed further north from Hawker to Blinman. Various equipment problems were encountered and at any one time a number of recorders could be expected to be not running, and in general data return was about 75% (see Figure 1). Data displayed here are up to June 2005.

Preliminary results and interpretation

Over 500 locatable earthquakes were recorded within the network and surrounding areas, with over 250 having 8 or more defining phases. These were located using model SH01 (Shackleford & Sutton, 1981). The largest event was magnitude 3.9, with three others above magnitude 3 within the network. There were very few foreshocks and aftershocks during the recording time. Figure 2 shows the data recorded during the survey in black, with error ellipses (2σ), along with the complete database (1840 – present) in grey. It is clear that many hypocentres, especially when recorded by too few stations, have large errors involved. Using the error ellipses and other calculation data, we removed events that had a large semi-major axis or large areas, significant depth error (or no depth), and a small number of recordings or large angular gap. The remaining 289 better quality locations are plotted with elevation in Figure 3 and with solid geology, mapped and interpreted faults and axial trends in Figure 4.

Closely spaced portable deployments give more accurate data, and more accurate data are more likely to lead to a better understanding of earthquake occurrence. It is clear that the new data exhibit a much tighter pattern of epicentres than has been visible before. There is far less scatter than in the existing database.

There are indications of some earthquake clustering within the area, which are outlined in Figure 4. In the south is a quite strong curvi-linear feature (1), in the north there is a cluster of activity (2), and in between there are indications of curvi-linear features (3). The first feature runs at an angle to the topography (Fig 3) and does not match any mapped fault. The second feature is in an area which is folded and faulted in more than one direction, giving the interesting topographic shape of Wilpena Pound. The final year of data may improve this area. The remaining features are not well defined.

Interestingly, while epicentre patterns are emerging from what was previously a diffuse dataset, there is still no clear match with topography, mapped faults or geology. The recording undertaken is one of the best for local earthquakes that has yet been carried out in the country. The area has been well mapped, and has moderate to excellent geological exposure when compared to other parts of the country. If we cannot find a match in this region then should we be trying to force a direct match between earthquakes and mapped faults in other areas? The answers are likely to be more complex, or related to other data, and perhaps we should not jump to simple conclusions. To date there is no deep seismic reflection line across the region. This would be helpful.

The hypocentres have a range of depths from surface to about 24kms. If this is also the situation nearer Adelaide then it probably has implications for earthquake hazard. There is some indication of the deeper epicentres being nearer the centre of the ranges, with shallower events predominating near the sides of the ranges. This shape has been shown previously, (Greenhalgh & Singh 1988) but earlier depth results could not be relied upon due to the wide separation of permanent stations.

Focal mechanisms and stress inversion

Stresses can be estimated from focal mechanisms, but this requires that enough 1st motion picks are available for each individual event, and using the estimation of uncertainties is problematic. A better approach is to use the 1st motion data directly, because even events with too few first motions to determine a focal mechanism can contribute to the estimation of stress, and the estimation of uncertainties is more straightforward.

We used the MOTSI (Abers & Gephart 2001) stress inversion code which calculates the stress tensor from first motions rather than focal mechanisms. Many stress inversion algorithms use focal mechanisms directly and therefore do not account for mispicked first motions or a number of focal mechanisms for a set of first motions. MOTSI uses the standard Wallace (1951) and Bott (1959) hypothesis that slip on a fault plane occurs in the direction of maximum shear stress and the additional assumption that all motion on faults within a specified volume of crust are due to the same stress tensor. Motsi uses a grid search technique to estimate the four stress parameters; the maximum compressive stress (σ_1), the minimum compressive stress (σ_2), the intermediate compressive stress (σ_3) and the stress ratio (R). It also searches for focal mechanisms that best fit the first motion data and optionally the stress. A search is performed over a grid of fault planes and identifies for each event the focal mechanism that best fits the first motion data and avoids those that are inconsistent with the stress model. Uncertainties in the stress model are dependent on the data distribution and probability of mispicked first motions.

We selected 95 events that fitted our selection criteria, which were that each event have 5 or more clear first motion arrivals and have a reasonable variety of polarities and take-off angles. We weighted the first motions so that the clearly impulsive first motions had a weight of 2 and other first motions had a weight of 1. Nodal picks and emergent arrivals were not included in the inversion. All first motion picks were thoroughly reviewed so that we could minimise the probability of a mispick, as the MOTSI code includes it as a source of error. We used a 10 degree grid search for the stress orientations and a 0.1 increment search of R.

The chosen best solution for the stress inversion shows a predominantly reverse faulting regime as σ_1 is near horizontal and σ_3 is near vertical - the trend and plunge of the σ_1 and σ_3 principal stress directions are 101 and 18 degrees, and 344 and 55 degrees, respectively.

The future

Further detailed analysis and interpretation is required. Location review, and the use of relative relocation techniques such as double-differencing techniques are likely to improve hypocentres so that the validity or otherwise of proposed structures is clearer. Work on attenuation and stress inversion is in progress. It is possible that further focal mechanisms may be produced. There are also data available from teleseismic arrivals for tomographic and receiver function analysis.

It is clear that the survey would have been improved by a greater number of recorders, including extra recorders outside the area of interest, and also a greater density of recorders. When the number of running recorders drops, the reliability and accuracy reduction can quickly make the data of little value for validating features.

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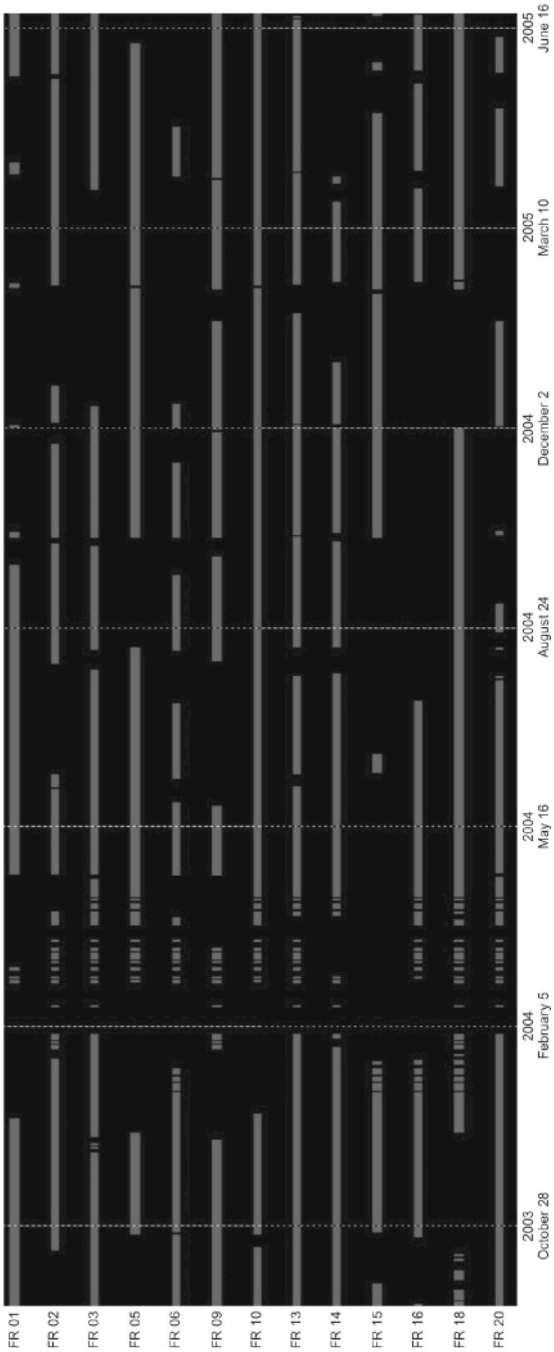

Figure 1 Data completeness

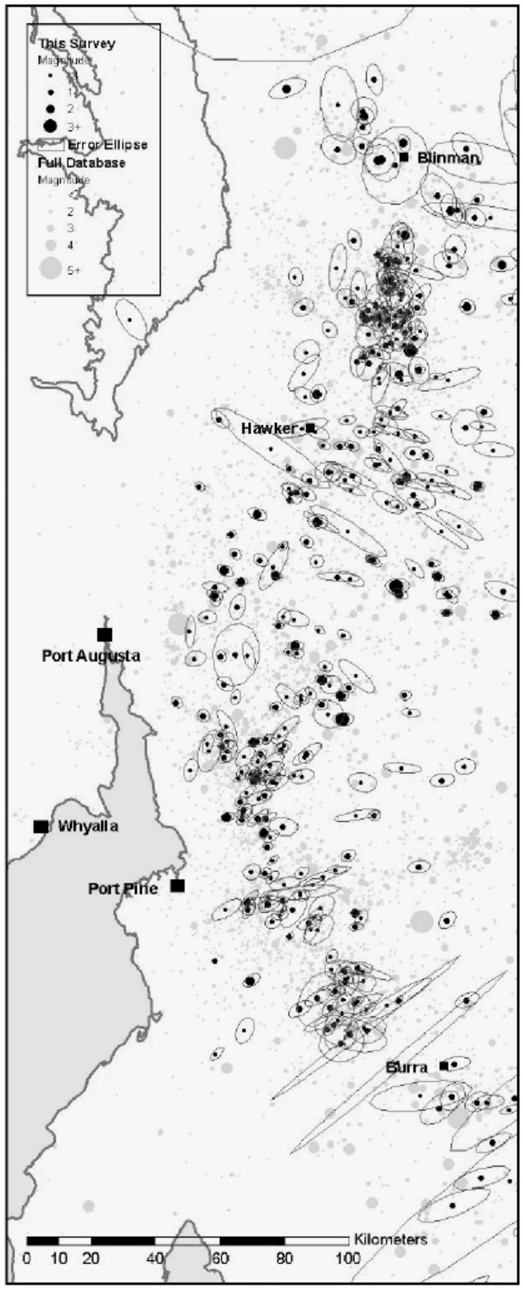

Figure 2 Full database and all data from current survey

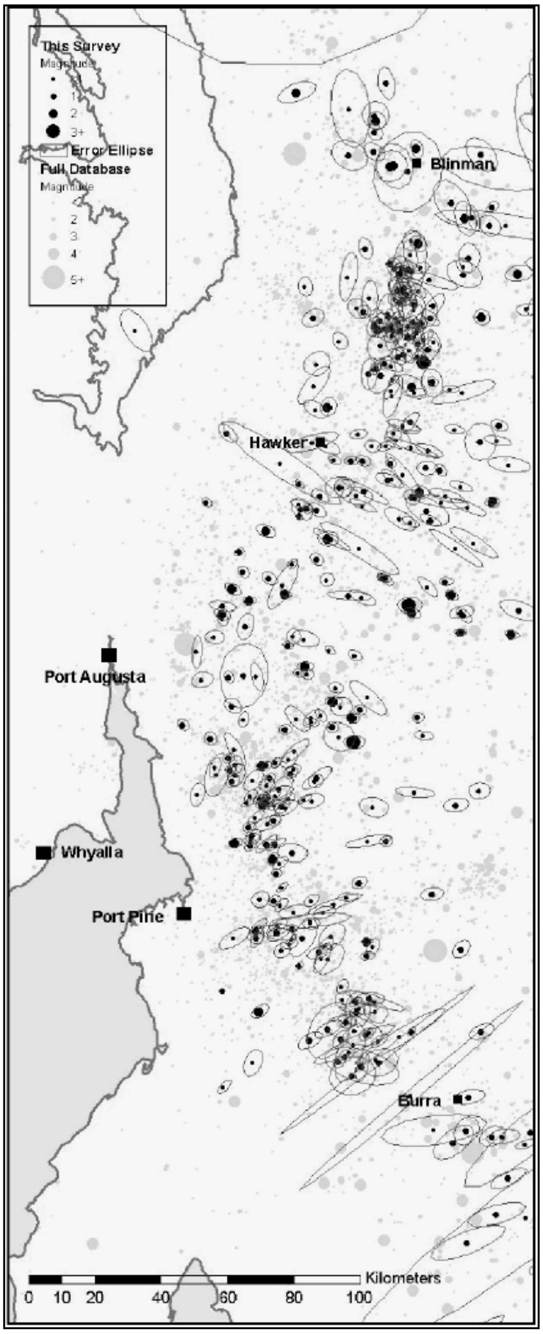

Figure 3 Accurate data from current topography.

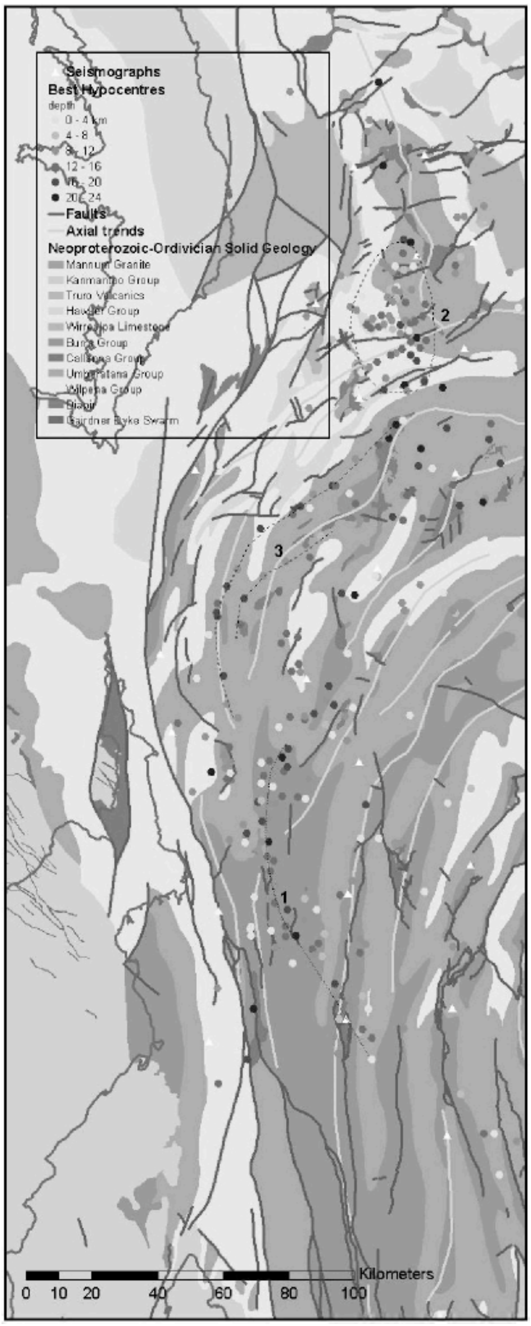

Figure 4 Accurate data from current survey survey with solid geology, trends and faults