MONITORING OF EARTHQUAKES IN THE FLINDERS RANGES, SOUTH AUSTRALIA, USING A TEMPORARY SEISMOMETER DEPLOYMENT

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ABSTRACT:

We describe the use of a temporary seismometer deployment to monitor local earthquakes in the Flinders Ranges, South Australia. 16 seismograph stations were deployed over a 200 x 100 km area, which is one of the most seismically active regions in Australia. The instrumentation consisted of short-period and broadband Guralp seismometers combined with Reftek and Kelunji data loggers, which sample data continuously at 100-200 sps. Analysis of data from the period Sept.-Dec., 2003, resulted in the determination of hypocentres for over 175 earthquakes, most of which could not be located using PIRSA's permanent network. 54 of these earthquakes had depths resolved at 10 km or greater, and the proportion of deep events appears to increase from the southern to the northern part of the Flinders Ranges. The largest earthquake, ML≈4, occurred near Hawker on 22 November, 2003, and has a depth of 17±2 km, and a well-resolved normal focal mechanism.

INTRODUCTION:

Compared to the rest of continental Australia, the Flinders Ranges region of South Australia stands out not only because of its high topographic relief, but also because of its high seismicity and high fault density. The high density of faults combined with their relatively high Quaternary slip rates (Sandiford, 2004) indicate that the Flinders and Mt. Lofty Ranges comprise a region of pronounced neotectonic activity. Applying the accumulating body of neotectonic evidence to an assessment of earthquake hazard in South Australia requires determining what relationship exists, if any, between the earthquakes and faults. If it can be shown that the seismicity tends to cluster along faults, then neotectonic and paleoseismological studies focused on these active faults can help constrain the size and frequency of earthquakes. If there is no evidence of clustering, then an assessment of earthquake hazard will rely more heavily on the very short history of recorded earthquakes.

At present, the low accuracy of earthquake hypocenter determination makes it difficult to tell whether the events cluster along major fault lines. To address this question we conducted a dense deployment of seismometers to improve the precision with which earthquakes are located. We carried out a deployment of about 18 stations, with approximately 30 km inter-station spacing, which exploited some of the permanent stations in the region (Fig. 1). Over the 2-year course of the deployment we hope to record 300-600 locatable earthquakes. Although the main scientific goal of the experiment is to obtain precise hypocentre estimates, the largest events will also be used to assemble composite record sections, whose interpretation should yield an improved velocity structure, which can then be used to obtain an iterative improvement in the accuracy of hypocentre determinations. This improved velocity model can also be used to improve the accuracy of existing seismicity catalogues as well as future hypocentre determinations using the permanent seismograph networks.

The waveform data recorded by this experiment will also be used to establish a dataset for ground motion studies to assess the propagation characteristics of local earthquake signals in the SA region. Because so few data exist which can be used to infer these characteristics, all current models for seismic risk in Australia rely on ground motion models obtained elsewhere (typically eastern North America). Since the signal propagation characteristics are one of the most important components of a seismic risk analysis, use of inappropriate ground motion models may seriously bias seismic risk estimates. It is thus hoped that the data from this experiment will provide the basis for an unbiased seismic risk estimate for South Australia.

Finally, in contrast to the sparse coverage provided in South Australia by the permanent seismograph networks, the data from the relatively dense deployment of seismometers proposed here should provide enough azimuthal coverage of earthquakes in the Flinders Ranges to obtain well-constrained focal mechanisms estimates. This will not only aid in the identification of active faults, but will also provide a basis for better constraining the regional stress field. While the direction of maximum horizontal compressive stress in South Australia is thought to be roughly EW, there is considerable uncertainty in this estimate (azimuth 83°±30°). Furthermore, the concentration of seismicity in the Flinders Ranges suggests that it may be a low-strength feature capable of modifying the regional

tectonic stress field, and the focal mechanism data obtained by the experiment proposed here may be used to test this hypothesis.

THE FLINDERS RANGES SEISMOMETER DEPLOYMENT:

The plan for a high-density seismometer deployment in the Flinders Ranges envisioned a network of about 20 stations with approximately 30 km station spacing distributed over an approximately 200 x 100 km area centred on the northern Flinders Ranges. Eventually, 16 stations were actually deployed (Fig. 2). All of these stations are sited on or near rock outcrop, and are using continuous 100sps (in a few cases 200 sps) recording. At 8 of the stations, Australian National Seismic Imaging Resource (ANSIR) instrument packages are deployed, consisting of Reftek data loggers (four 16-bit R72A-02s and four 24-bit R72A07s) and Guralp CMG-40T sensors. At the remaining 8 stations, Kelunji + Guralp CMG40T-1 seismometers were used.

The Reftek data loggers are manufactured in the USA and have been used in Australia since the 1990's to record broadband data from distant earthquakes, primarily for tomography and receiver function studies. The Kelunji is a data logger manufactured by Environmental Systems & Services, Melbourne, which is commonly used for recording local Australian earthquake data. To our knowledge, this project was the first attempt to use both Refteks and Kelunjis together in a single experiment (see Fig. 1). Also, the project was the first in Australia to use the Reftek recorders at high sample rates of 100 and 200 sps (the latter requiring a 2nd 60W solar panel to cope with more frequent disk access), and to use the Kelunjis in continuous recording mode as part of a temporary deployment.

Figure 1. Comparison of deployment styles for Kelunji (left, station FR03) and Reftek (right, station FR05) equipment. Both sites are east of Hawker, SA, near the eastern margin of the Flinders Ranges. Seismometers are buried in either case.

Each station is visited at approximately 6-weekly intervals, during which time it typically produces about 2 Gbytes of data (4 Gbytes for the 200 sps stations), so that the total data rate is over 20 Gbytes/month. Thus far, both types of instrumentation have performed well, with a data return of approximately 90%. Both Kelunji and Reftek data are converted to CSS3.0 format, and processed using the Antelope software package for environmental monitoring. STA/LTA detectors are run on high-pass filtered data

streams, and events are automatically associated using a suite of P-wave travel times calculated using the SH01 model (Shackleford & Sutton, 1981) on a 3-D grid encompassing the region of the deployment. Wider grids are also used to identify regional and teleseismic events. Finally, these events are manually scanned to discriminate local earthquakes from teleseismic events and quarry blasts, and refined estimates of local earthquake hypocentres are obtained using both P-wave and S-wave picks.

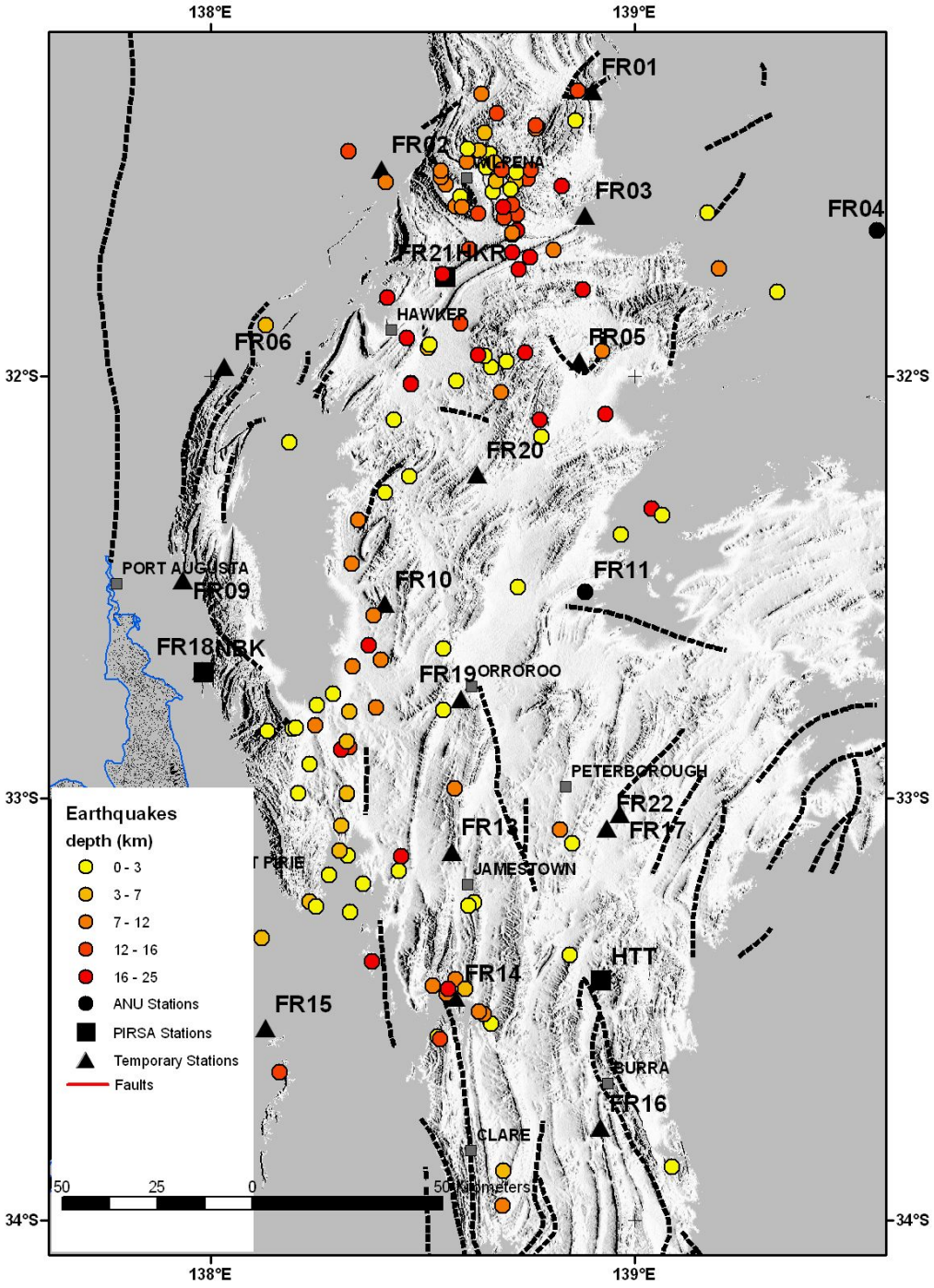

Figure 2. Hypocenters of earthquakes recorded by the Flinders Ranges temporary deployment from Sept-Dec 2003.

EARTHQUAKES RECORDED IN LAST QUARTER OF 2003:

For the period 28/9/03 to 31/12/03, hypocentres for 194 local and regional earthquakes were determined (Fig. 2). A comparison of the GA and Adelaide (ADE) catalogues (without regard to position) showed that out of the first GA list of 175 local events:

8 listed as quarry blast by ADE
47 located by ADE
10 events from Innamincka sequence (induced by well injection)
39 not located by ADE because too few stations
69 ignored or not recognised by ADE in scanning stage
(3 possible errors, and smaller quarry blasts)
2 uncertain

Within the region of interest, ADE located 51 events, compared with 123 events located by GA. This is an additional 140%. Within the region of interest, ADE located 51 events, compared with 123 events located by GA. This is an additional 140% (GA's permanent network only located 5 of these events).

Within the region of interest, both data sets show generally the same distribution of activity. The GA set shows a considerable increase in activity north of Hawker. Within this area ADE has been unable to locate smaller events. In both sets there is a sudden reduction of activity going north between Oraparinna and Blinman. There is a slightly less active area in the Ranges from Wilmington to Hawker, and slightly more activity between Wilmington and Spalding.

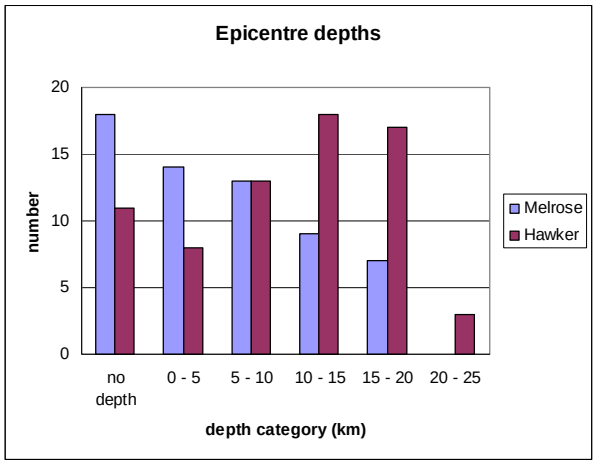

Figure 3. Histograms of the number of earthquakes as a function of depth, with the northern (Hawker) compared to the southern (Melrose) Flinders Ranges.

The GA data set does not show clear lineations relating to faults, however this may still change as more data becomes available and data quality is investigated in more detail.

After removing events for which a depth was not calculated, the Hawker area shows a predominance of events between 10 and 20 km, with a few over 20kms (Fig. 3). By contrast the Melrose area shows a predominance of depths under 10 km with none over 20km. Despite the inaccuracies inherent in the broadly spaced permanent network, these 2 plots show considerable similarity to those in Greenhalgh et al (1994). After more data are available and a review of quality, it will be interesting to see if the same result still applies. In particular, the high proportion of hypocenters with depths > 10 km may suggest that the depth to brittle-ductile transition in the Flinders Ranges is deeper than has been inferred from heat flow data (Pulford & Braun, 2004).

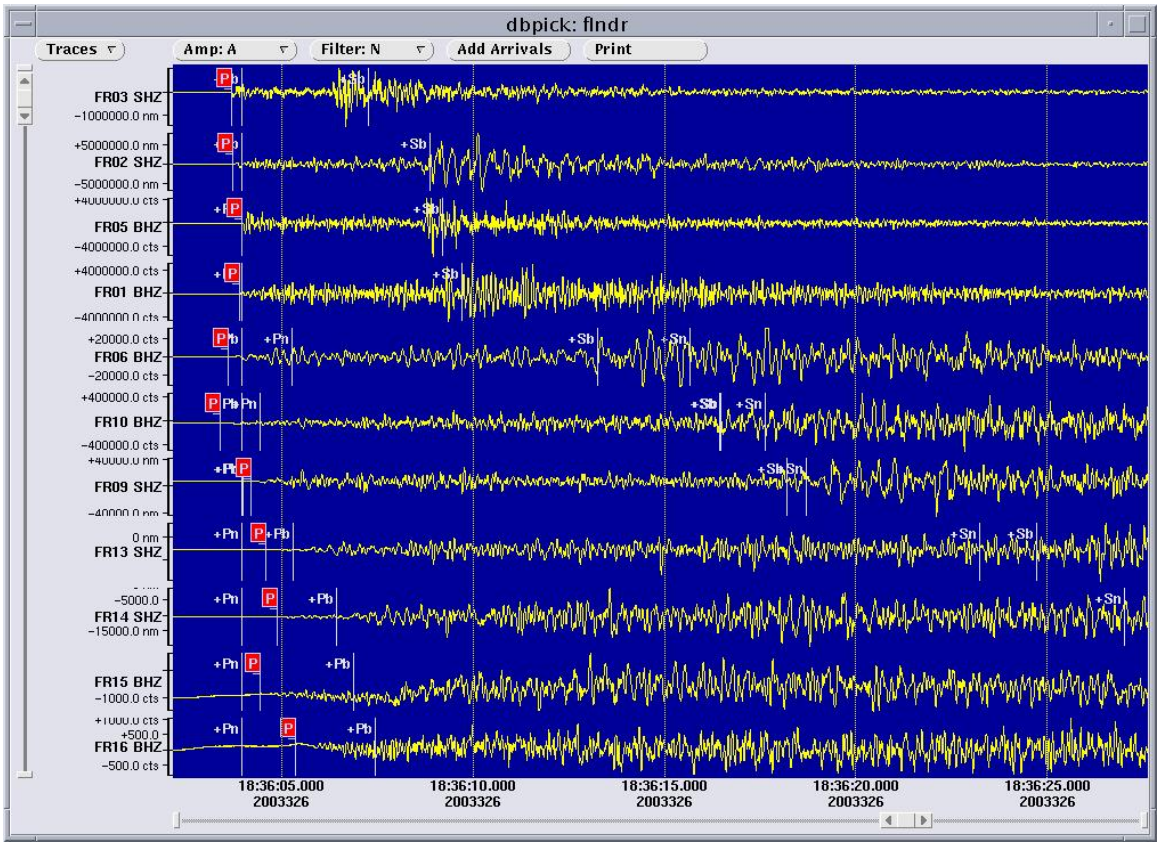

Figure 4. Vertical-component waveforms recorded during the 22 November, 2003 ML 3.9 earthquake near Hawker, SA.

THE HAWKER ML 3.9 EARTHQUAKE OF 22 NOVEMBER, 2003:

The largest earthquake recorded during the course of the experiment, which was widely felt near Hawker, SA, was the ML 3.9 (GA's original estimate was ML 4.2) Hawker earthquake of 22 November, 2003. This earthquake was widely felt in the Hawker region, and it was well recorded at over 11 stations (Fig. 4) of the temporary seismometer deployment. Most significantly, the depth was determined to be 17 km and the focal mechanism (Fig. 5) was normal. Such normal faulting events have occurred in the Flinders Ranges in the past, but their mechanisms and depths have been poorly constrained.

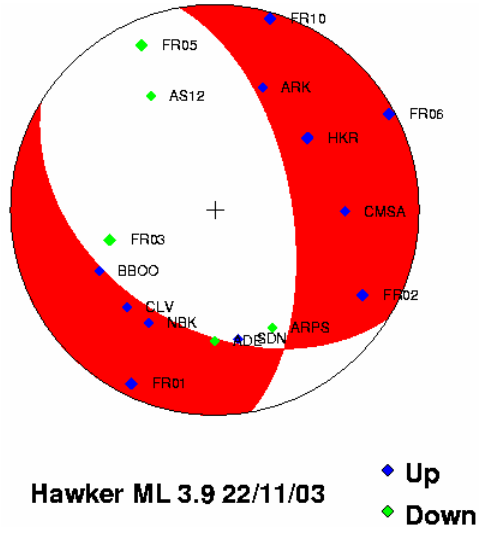

Figure 5. Hawker event focal mechanism.

The extensional focal mechanism calculated from the Hawker earthquake raises important questions about the stress in the area, and its heterogeneity. This was the largest earthquake of the year, the depth of 17± 2 km was moderately well determined and the mechanism well constrained. Such normal faulting events may have occurred in the Flinders Ranges in the past, but their mechanisms have been very poorly constrained. Given the number of other epicentres at considerable depth, it should be possible over the course of the experiment to construct a number of other focal mechanism solutions, which may provide important constraints on the stress field.

CONCLUSIONS:

Geoscience Australia and Primary Industries and Resources, SA are collaborating in a temporary seismometer deployment to monitor earthquake activity in the Flinders Ranges, SA. The 16 stations deployed over an area of approximately 200 x 100 km with 30 km station spacing are using continuous, 100-200 sps recording of 3 component seismometers. For the period Sept.-Dec. 2003, these data have resulted in hypocenter determinations for over 175 local earthquakes, most of which were not resolved by the existing, permanent seismograph network.

Over 30% of the earthquakes located so far occur at depths greater than 10 km, with the proportion of deep events increasing from south to north in the Flinders Ranges, and a few events appear to have focal depths greater than 20 km. This suggests that the depth to brittle-ductile transition in the Flinders Ranges may be deeper than has been inferred from heat flow data (Pulford & Braun, 2004).

The largest earthquake recorded during the course of the experiment was the ML 3.9 Hawker earthquake of 22 November, 2003. This earthquake had an estimated depth of 17 km, and a well-constrained normal focal mechanism. Since the stress regime in this part of Australia is widely thought to be thrust (Hillis & Reynolds, 2000; Burbidge, 2004; Pulford & Braun, 2004), and the only evidence of Quaternary fault movement is attributed to thrust faults (Sandiford 2002), the occurrence of normal faulting earthquakes may have interesting implications for the heterogeneity of stress and the nature of the response of the crust to the regional stress field.

Finally, we note that much work still needs to be done, not only in analysing the more recent data recorded during the course of the experiment, but also in more sophisticated analysis of the 2003 data. In future we hope to model these data using synthetic seismograms, to infer source properties such as stress drop and faulting mechanism. Also, it is hoped that eventually these data can be used as a basis for developing a spectral attenuation model for ground motion in South Australia.

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