

GPS-geodetic monitoring of the South West Seismic Zone of Western Australia: progress after two observation epochs in 2002 and 2006

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Introduction

The Australian southwest seismic zone (SWSZ) is a north-south trending belt of intra-plate earthquake activity that occurs in the southwest of Western Australia, bounded by 30.5°S to 32.5°S and 115.5°E to 118°E. This is one of the most seismically active areas in Australia, with nine earthquakes over magnitude 5.0 occurring between 1968 and 2002, the largest of these was the M6.8 Meckering earthquake in 1968. Figure 1 shows the seismic activity in this region over the last 50 years. Since the SWSZ lies as close as ~150 km from the ~1.4 million population of the Perth region, it poses a distinct seismic hazard. However, little is currently known about the magnitude and orientation of this deformation, and whether there is any associated ongoing surface expression. It is also not known how this intra-plate activity compares with that observed elsewhere in Australia or elsewhere on Earth. Earthquake activity recorded by Geoscience Australia over the past four decades suggests that the SWSZ could be deforming with strain rates between 10^{-9} /yr and 10^{-8} /yr, or with displacements between 0.1 mm/yr and 1 mm/yr across the 200km width of the currently active SWSZ. This estimate is derived by applying the Kostrov formula for a moment release of 3.3×10^{19} Nm in the 34 years from 1968 to 2002. Whether this strain rate represents the long term moment release rate or a short-lived period of episodic seismicity is unknown. In order to obtain the data required to answer to this question was the key driver of developing this strain monitoring network. A related question is whether the deformation over the region is uniform or heterogeneous and if heterogeneous whether this could indicate areas of future seismicity.

Data

Early geodetic studies of the SWSZ that used both terrestrial and Global Positioning System (GPS) techniques were inconclusive, due mainly to the imprecision of the technologies used in relation to the likely small amount of any surface deformation. Therefore, in 2002 a new 48-point campaign-reoccupation GPS network (Figure 1) was established across the SWSZ (Featherstone et al. 2004) to attempt to detect surface deformation, using ground-level forced-centred monuments. The first two observational epochs were in May 2002 and May 2006. In both surveys, the dual-frequency carrier-phase GPS data were collected continuously at each monitoring point over a 5-8 day observation period. For both surveys a third of the stations were occupied at a time, with 4 “back-bone” stations being occupied for the entire 3 weeks. The data was analysed by Geoscience Australia (Hu 2007, Dawson 2002).

The equipment used was heterogeneous, with the bulk of the stations being one of three sets. 1 – Trimble antenna and 5700 data logger, 2 – Ashtech antennas of various models and UZ or Z data loggers, 3 – Leica antenna and data logger. For the 2002 epoch, all three types were used as well as a few other sets of equipment, which might not have a reliable antenna models. For the 2006 epoch the instruments were restricted to types 1 & 2. For the both campaigns, after excluding outlying sites (due to equipment malfunctioning), the estimated internal horizontal precision was better than 1.0 mm; the vertical precision was generally better than 4 mm.

Results

The data from the two observational epochs has been further processed using strain inversion software developed by IGNS. Figure 2 shows the change between the two observational epochs. Comparison of

these two repeat surveys (Figure 2) shows displacement vectors, which are on average $0.95 (\pm 0.95)$ mm/yr with small average errors of $0.39 (\pm 0.08)$ mm/yr. The 14 sites with vectors of length greater than 1mm/yr (eg. SZ41, SZ28, SZ19, SZ13, SZ17, SZ48, SZ08, SZ20) are thought to be due to either instrumental problems or monuments which are on floating boulders not bedrock. The stress inversion suggests that strain rates in the order of 10^{-9} /yr can, in principle, ultimately be resolved if the deformation across the SWSZ occurs uniformly, but that the four-year time interval between the existing two surveys is at present not adequate to detect deformation with confidence given the noise in the estimated coordinates at each epoch. The strain rate is thought to be around of 10^{-9} /yr. The azimuth of the axis of relative contraction being $133 (+21)$ degrees, which is consistent with direct (Reynolds and Hillis 2000) and indirect (Clark and Leonard 2003) measurements of the stress field orientation in SW Australia.

Discussion

Figure 3 shows the frequency distribution of the 45 vector lengths in 0.1mm/yr bins. The smallest 24 of the 45 velocities follow a normal distribution between, 0.1 and 0.7, centred on 0.4mm. These 24 sites all have velocities of less than 0.65 mm/yr, and the smallest 27 have velocities of 0.8mm/yr or less. These 24 or 27 sites are considered the “best” sites. This suggests that the repeatability of occupation is potentially less than 1.0mm/yr. Displacements above ≈ 1.0 mm/yr are thought to be erroneous and likely due to either problems with antenna models or the monuments being attached to buried boulders not bedrock. Almost all of the sites are in areas of mapped bedrock on granite or high grade metamorphic rock, and whenever possible were selected so they are on largest outcrop of local bedrock. There are only a few sites which are considered geologically to be “less than ideal” and even if some sites are on buried house sized boulders these are unlikely to move more than a fraction of a mm during a 4 year period. It is hoped that over the next year or two a geologist will be able to visit many of the sites, including all the sites in question, to assess their geological stability.

The other potential source of error in the uncertainty in the accuracy of the antenna phase centre. 18 sites had Trimble equipment for both occupations and 15 of these has identical antenna for both occupations. Ten sites had Ashtech choke-ring antennae for both occupations and 6 of these has identical antenna for both occupations. Of the 24 “best” sites: 17 had Trimble equipment during both occupations, including all 15 with identical antenna; three had Ashtech choke-ring antennae during both occupations, all three of which had identical antenna; the other three had mixed equipment. Of the 28 sites with identical antenna during both epochs three Ashtechs had velocities greater than 0.7mm/yr (0.98, 1.05, & 1.26mm/yr) and one Trimble (0.80mm/yr). These results suggest that some antennae are not modelled to the sub-millimetre accuracy commonly claimed. Possible sources of this uncertainty include: the initial antenna models; the antenna drifted with time; or they have been damaged between occupations. We don't have sufficient data to determine which if any of these are the source of the problem. Testing all antenna involved in the occupations should enable us to diagnose whether or not antenna problems are causing the displacements above 1.0mm. Although it is not known if all of the old antennas are even available, when tested and found to be good this it would give us confidence in the results. When tested and found to have errors this might not necessarily mean we can correct for it as we cannot be sure what error existed at the time(s) of their use.

Conclusion

These preliminary results suggest that the higher range of strain rates (10^{-8} /yr) estimated from seismic moment release is unlikely and the actual strain rate is likely around 10^{-9} /yr or less. The azimuth of the axis of relative contraction is estimated as $133 (+21)$ degrees, which is consistent with the east-west orientation of the stress field in this region. A strain rate of 10^{-9} /yr suggests that the moment release from seismicity in the last 50 years is at least 5 times higher than the long term strain accumulation rate.

Solving the site and/or instrument problems is going to be important if we are to resolve these low strain rates. As mentioned above, over the next couple of years we plan to inspect every site for a possible geological explanation. It would appear that the repeatability of antenna is not as ideal as would be expected and needs to be taken into account when designing the experiment. One possibility is to routinely test all antennas before and/or after each campaign.

Further repeat surveys after, say, eight and 12 years should begin to reveal any observable deformation significantly in excess of the observational error. A related question is whether the deformation over the region is uniform or heterogeneous and if heterogeneous whether this could indicate areas of future seismicity. To resolve this question will require the site and/or instrument problems discussed to be resolved. To properly test this hypothesis would require a similar network to be built in an area with low contemporary seismicity but which is geologically and geodynamically similar to this area. One possibility is the area immediately west of this network.

References

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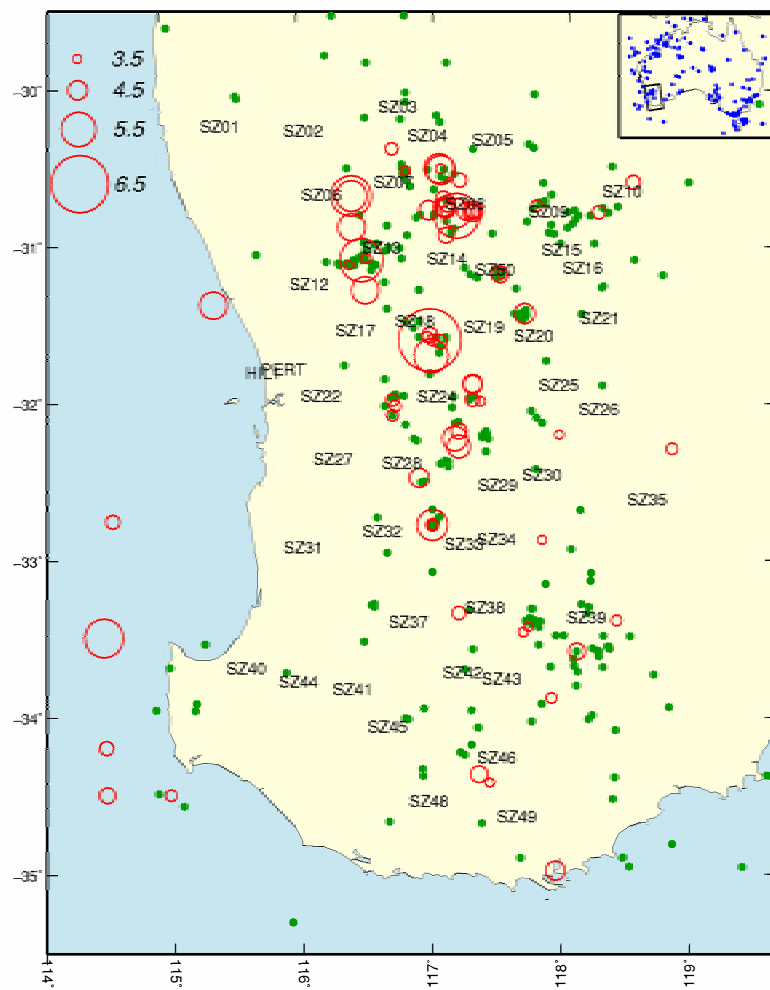


Figure 1 The location of the SW WA GPS-Geodetic network. The earthquakes between ML2.5 & 3.4 are plotted as green dots, with the larger earthquakes larger being scaled red circles.

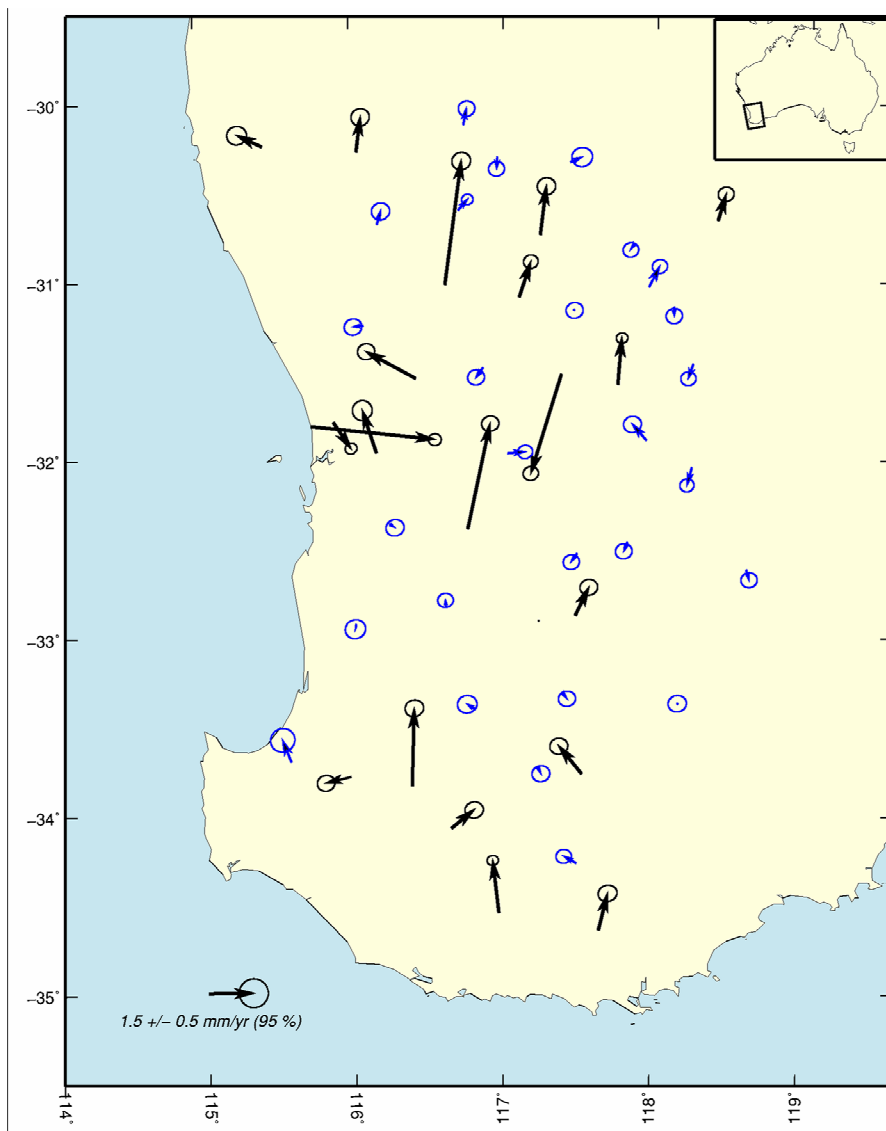


Figure 1 Displacement vectors, based on the difference between the 2002 and 2006 occupations, for the GPS stations in the SW WA GPs network. The “best” (see text) 27 sites are plotted in blue. The vectors above 1mm/yr are thought to have either monument or antenna problems.

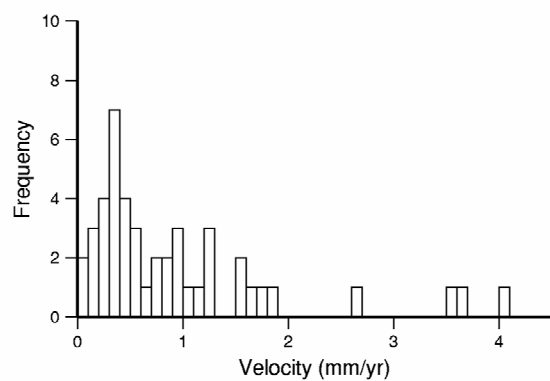


Figure 2 The distribution of site velocities in 0.1 mm/yr bins. The 24 sites comprising the symmetrical peak centred on 0.4mm/yr are considered the good sites. There are 27 sites with a velocity of 0.8mm/yr or less and these are considered to be unaffected by monument or antenna problems.

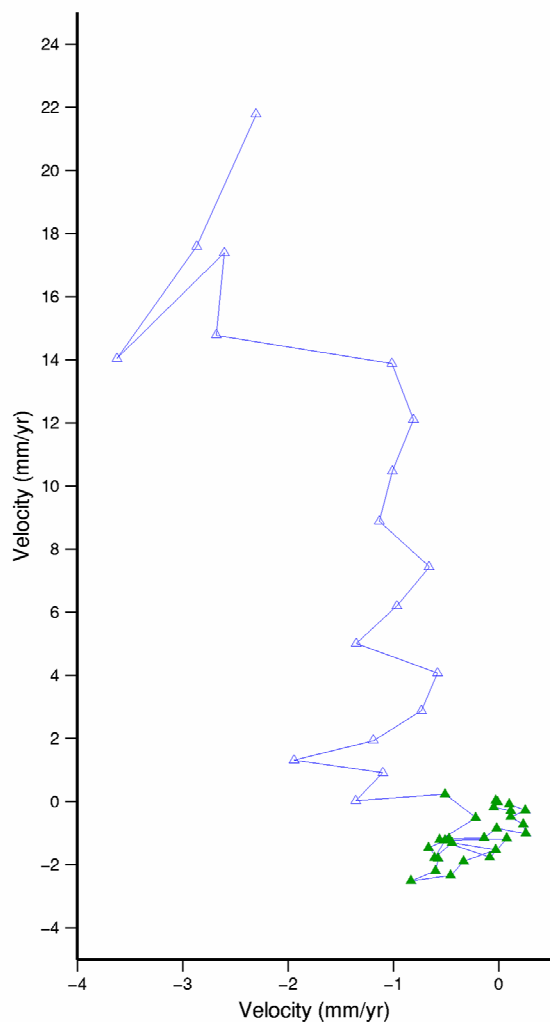


Figure 3 A vector walk of the vectors sorted by absolute length. The solid green triangles include the 27 best stations which includes all stations which had identical antenna during both stations. After this point the walk drifts steadily northwards.