CADOUX SWARM SEPTEMBER 2000 – AN INDICATION OF RAPID STRESS TRANSFER ?

MARK LEONARD
AGSO GEOSCIENCE AUSTRALIA

AUTHOR:

Mark Leonard - In 1996 obtained a PhD from the Research School of Earth Sciences of the Australian National University, in seismology. Thesis: Noise characterisation and secondary phase detection using multicomponent seismic data. In 1986 obtained a B.Sc.(Hons.) from the University of Adelaide, in geophysics.

Has worked for AGSO - Geoscience Australia since 1990, in a number of roles including: Nuclear Montioring, Seismic Network Operations, Software Engineering, Earthquake Monitoring and Neotectonics. In 1987 to 1989 worked for several land seismic companies in central Australia.

Research interests include: the seismicity of Australia, correlating seismicity to geology, earthquake location, signal processing, onset time pickers, S phase detectors, microseismic noise, neotectonics of the Australian crust and developing a seismicity model of Australia.

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M. Leonard & P. Boldra AGSO - Geoscience Australia, GPO Box 378, Canberra ACT 2600, Australia

Introduction

An earthquake swarm occurred about 25km north of Cadoux during September and October 2000. The swarm consisted of 1700 recorded earthquakes, the largest of which was magnitude 3.6. As many of the locals remember the 1979 6.7 Cadoux earthquake, the swarm was of considerable interest to the local community. Seismologically swarms are a poorly understood phenomena and despite being relatively common in Australia have not been well studied. Swarms occur, on average, every 1-2 years in SW Western Australia and every 3-6 years in eastern Australia (Pers. Com. Gary Gibson). This paper analyses this swarm and notes some of the implications of this swarm for stress transfer in SW Western Australia.

The Earthquakes

Between September 10 (day 254) and October 8 (day 282) the seismic station BLDU, located 35-40km east of the location of the swarm, recorded 1700 earthquakes. On September 21 four temporary stations were deployed. Whilst these proved to be much less sensitive than the permanent stations, earthquakes that they did record were very well located as we had up to 3 stations with good azimuthal coverage within 20 km of the events. Unfortunately there was a problem with the stations which was located within 3 km of the bulk of the events and from which we obtained only about 10 events. Of the 1700 earthquakes we have magnitudes for 500, locations for 120 and accurate locations for 80. All the earthquakes are thought to be about 2km deep, with Rg being observed for several events and the well located events all having depth less than 5km.

An event is considered well located if the EW error + NS error is less than 30 km. Figure 1 shows the location of the 80 well located earthquakes and their associated error ellipses, several of which are large. Figure 2 shows that the seismicity lies in four clusters on a NS trend, with the majority of the earthquakes in clusters C The error ellipses of these 80 earthquakes are sufficiently small to be confident that these four clusters are real. Within the 95% error ellipses, it is possible to plot all the earthquakes onto just 4 points one for each cluster. Initial attempts to refine these locations using Joint Hypocentre Determination (JHD) methods failed to decrease the scatter of locations. This is due to inappropriate earth models and failure of the assumption that the azimuth from station to event is constant. Further work with more appropriate earth models and analysing the clusters separately will be performed in the near future.

Figure 3 shows a range of properties and features of the swarm. Magnitudes using BLDU data were calculated for 500 events, 114 of which also had KLBR magnitudes. The other southern WA stations were also used calculate magnitudes where possible. All the magnitudes were compared to ensure they were consistant and to confirm that BLDU shows no particular bias. There is a random error in any single station ML estimate and for this swarm I estimate the error is ± 0.4 ML. The 500 events are plotted in figure 3 and shows the swarm starting with two earthquakes on day 254 and two on day 259. Two ML 2+ events occur on day 260 followed by 200 events on that day including 1 ML 3+ event. The activity then gradually lessens with other peaks in activity on days 263/264, 269 and 283.

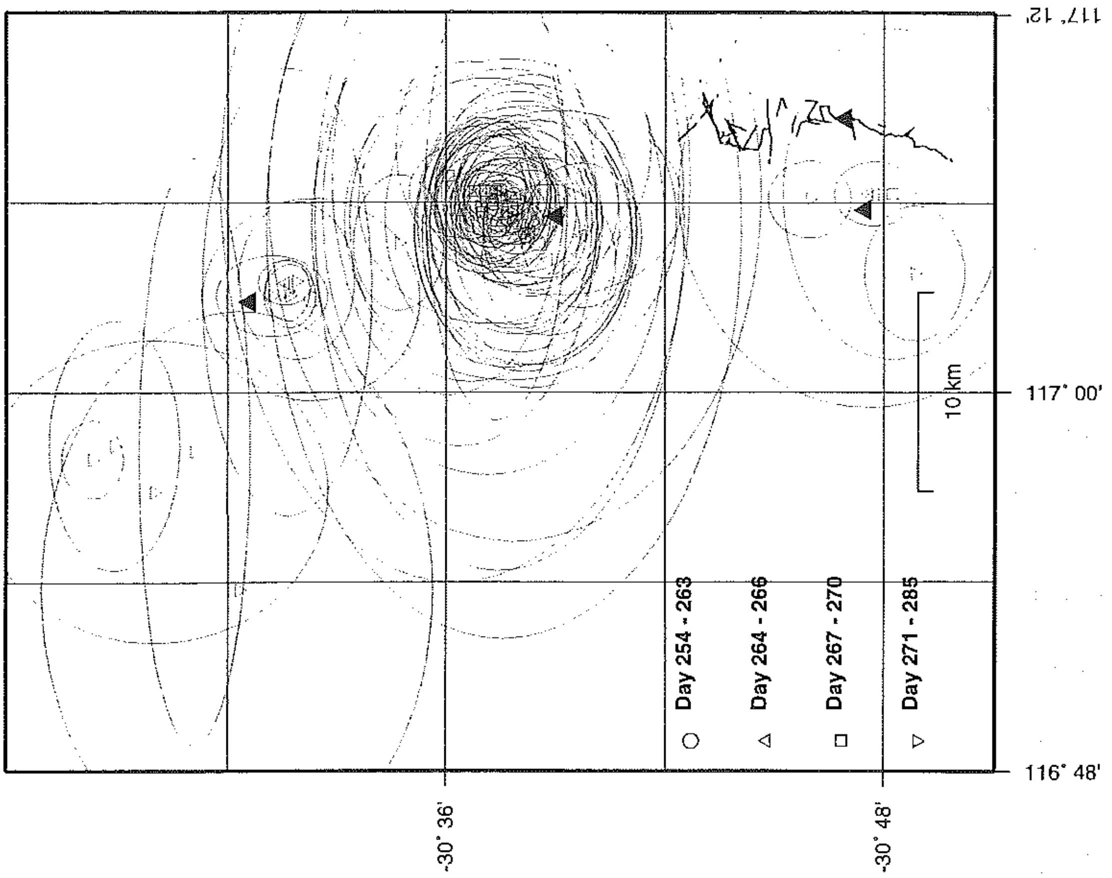

Figure 1: The 79 well located events with their 95% error ellipses plotted, the closest 3 seismographs and the fault trace of the 1979 earthquake.

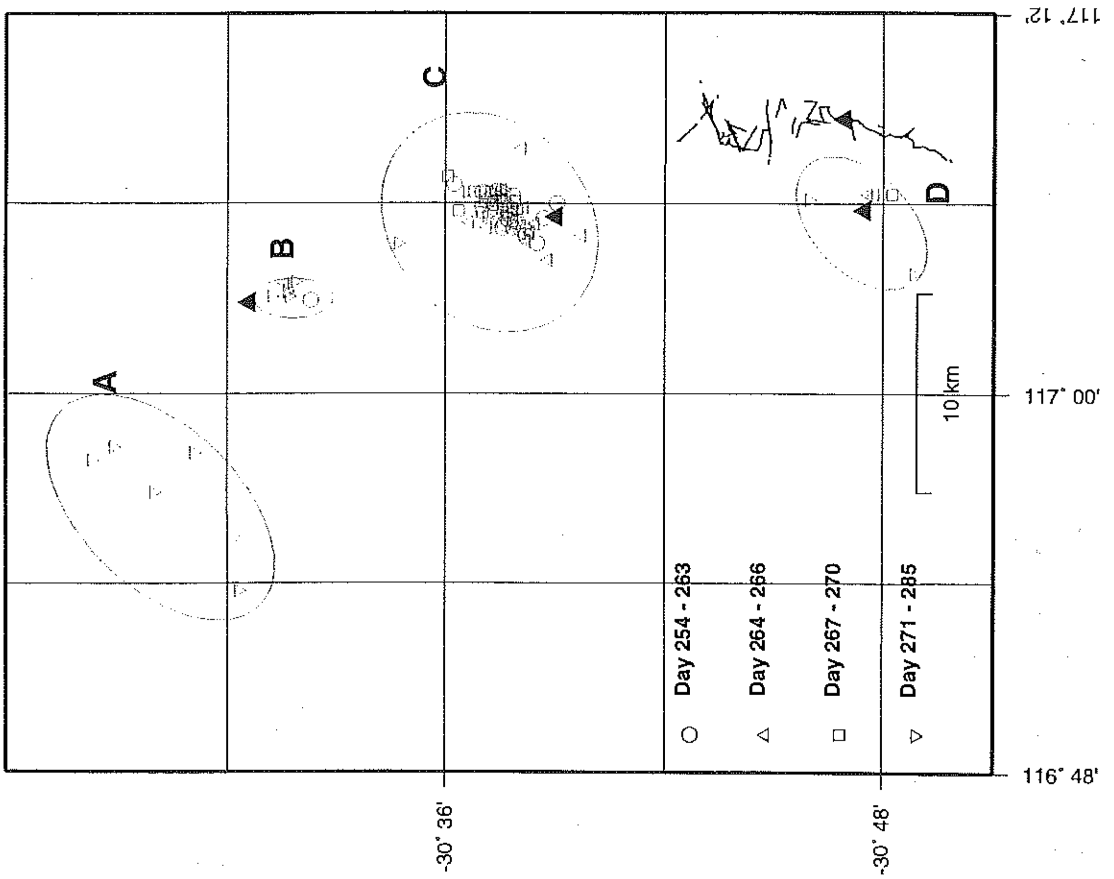

Figure 2: The 79 well located events and the four clusters within which they are located.

	A	B	C	D	Total
254-263	0	1	19	0	20
264-266	0	1	17	2	20
267-270	0	0	19	1	20
271-285	5	5	7	2	19
Total	5	7	62	5	79

Table 1: Summary of the number of well located events in each cluster for different times during the swarm.

The next plot in figure 3 shows the number of earthquakes per day, the cumulative number of the 1700 earthquakes observed on BLDU and the cumulative number of the 500 earthquakes for which magnitudes could be calculated. These all reflect the activity level discussed above. The similar shape of the two cumulative plots suggests that the 500 events are a consistent 30% of the total number of events per day. ab plots indicate that the b value during the swarm remained constant and that the data is complete down to magnitude 0.6, below which the data is very incomplete. This suggests that almost all the extra 1100 events have magnitudes less than ML 0.6.

The next plot in figure 3 shows the cumulative energy release during the swarm and cumulative area of fault ruptured by the swarm. They were calculated from the 500 events for which a magnitude was determined. The 6 largest earthquakes account for more than 50% of the energy released by the 500 events and, given the very small size of the other 1100 events, probably 50% of the total energy released by the swarm. This confirms that for this swarm, the well known phenomena of the bulk of the energy released by earthquakes is released by the largest handful of events. The largest events also account for most of the rupture area but not to the same extent as they do for the energy. A magnitude 3 earthquake has an area of 0.1 km^2 with a displacement of 16 mm and a magnitude 2 has an area of 0.005 km^2 and a displacement of 3 mm. I estimate that the area of the other 1100 events is approximately counter balanced by many of the smaller events re-rupturing areas of the fault. Given these uncertainties and the uncertainty of the formula for calculating the area of a fault, the area could easily vary by 50%.

Rapid stress transfer

Figure 2 shows the data clustered into 4 areas. The location errors are sufficiently large that, within their 95% error ellipses, all the earthquakes can be relocated to just four points, one for each of the clusters. Whilst we can't prove that this is the case, the clusters are real and within their 95% error ellipse the earthquakes cannot be relocated to one point. The 79 earthquakes have been plotted using different symbols based on when during the swarm they occurred. It is clear from figure 2 that the four clusters have a temporal pattern, with earthquakes in cluster A only occurring in the last 20 earthquakes. Table 1 summarises the distribution of earthquakes with time. Clusters A and B are much more active in the last phase of the swarm and cluster C is relatively quiet in the last phase.

This temporal and spatial distribution of earthquakes suggests that there has been a stress transfer from around clusters C during the first 16 days (10 days if the two events on September 10 are ignored) of the swarm, to cluster A during the last 14 days. The total area of faults in this swarm was about 1.5 km^2 with an average displacement of about 10mm. The transfer of sufficient stress the 20 km between cluster C and A to trigger earthquakes in cluster A is surprising. Further investigations of stress transfer is

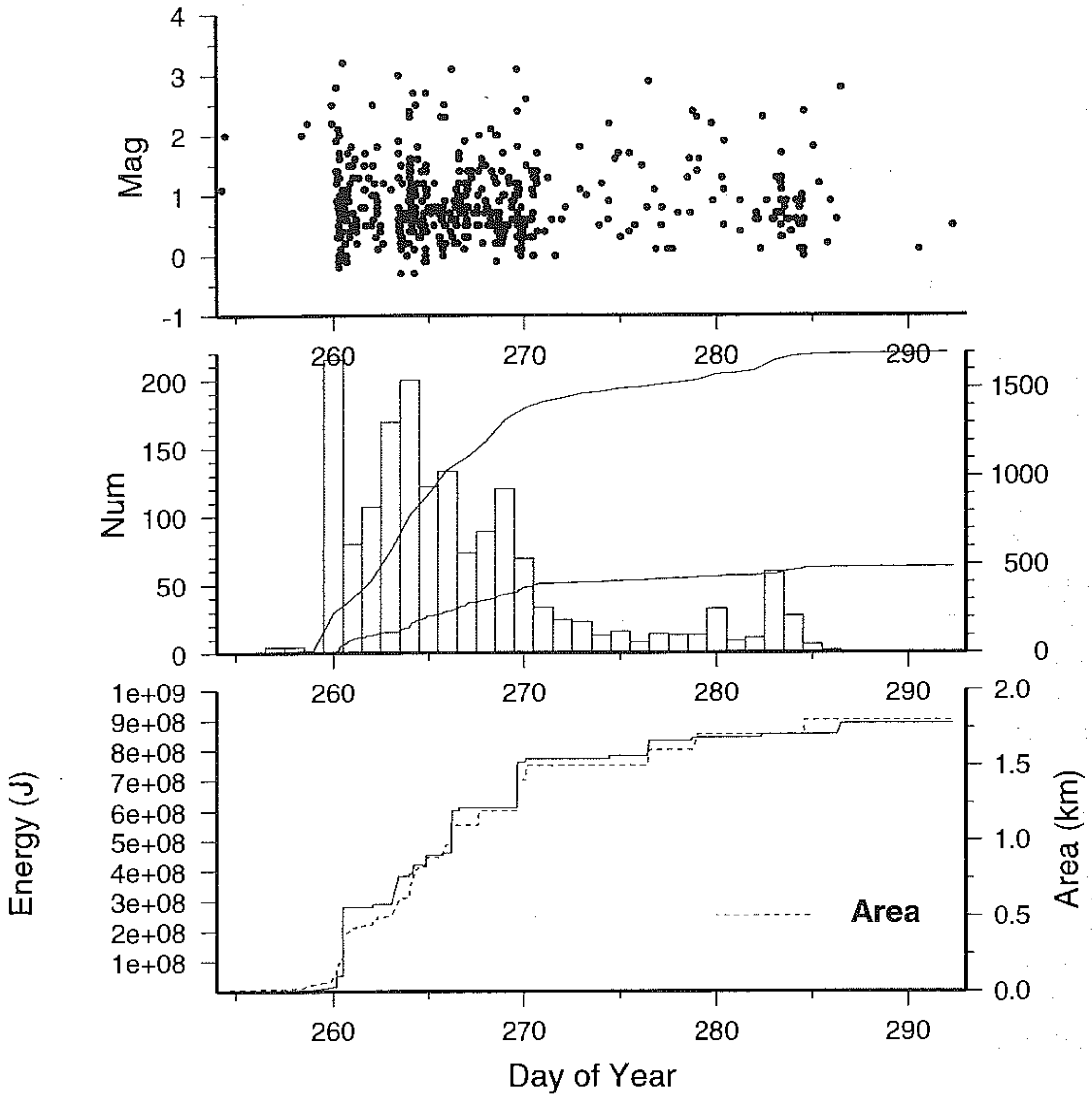

Figure 3: Some features of the earthquake swarm. In plot 1 each of the 500 earthquakes for which magnitudes were calculated are plotted. Plot 2 is the number of earthquakes per day recorded on BLDU, with the scale on the left. The two curves are the cumulative number of earthquakes recorded on BLDU and the cumulative number for which magnitudes were calculated. Plot 3 is the cumulative energy released and cumulative area ruptured by the swarm.

required but this result does raise questions of; how much stress can be transfered by small earthquakes, how fast this stress can be transfered distances of tens of kilometers and how close to failure this area of the Australian crust might be?