DETAILED RECORDING OF SWARM ACTIVITY: YEELANNA, EYRE PENINSULA, SOUTH AUSTRALIA

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ABSTRACT

A swarm of events near Yeelanna on Eyre Peninsula, South Australia, has been recorded in considerable detail. The events are shallow (2.8 ± 0.6 km), with a maximum magnitude of 3.3 and occur in a very small source area of less than 1 sq km. Many have been heard and felt by locals in the surrounding few kilometres. They have occurred over the last 12 months. Nakamura ratios, drop tests and multi-sensor recording were used during recording at Yeelanna with varying degrees of success. The events indicate horizontal compression, and appear to have quite similar focal mechanisms. A review of the complete catalogue of events for Eyre Peninsula shows that the general area of this swarm, which has relatively flat topography, has a history of similar swarms over the last 45 years. Much, if not most, of the activity in the Yeelanna area occurs in swarms, not isolated events, but the location of each swarm appears to be different. Evidence from intensity reports of previous swarms suggests that the swarms are shallow.

1. MONITORING OF THE SWARM

The author first became aware of the swarm in late October 2003 following a phone call from Yeelanna. The person reported feeling and hearing a number of events over the previous month. Calls to neighbouring properties outlined the general area where the events were being felt and pointed to the probable source. In late November three seismographs were sent to the area, and installed in a rough triangle about 4 km apart (YE1, YE2, YE3 in figure 1). These immediately recorded several events. Two weeks later more instruments were sent, and a total of 6 recorders with 11 sensors were installed within 5 km of the epicentre (YE1,2,4,5,6,7). A third visit was made in January 2004, and YE5 was moved to YE8. In April all except one recorder (YE6) were removed. Visits are marked by ^1 etc in figure 2. The remaining recorder indicates that the activity is still continuing although at a lower rate. Since visit number 4 none of the events recorded on YE6 has been visible on any stations of the permanent network. Residents are no longer feeling events. A few events have been recorded at other locations (different S-P times) in the near vicinity. The author is not aware of this rate of activity ever being recorded on any station of the permanent network in South Australia.

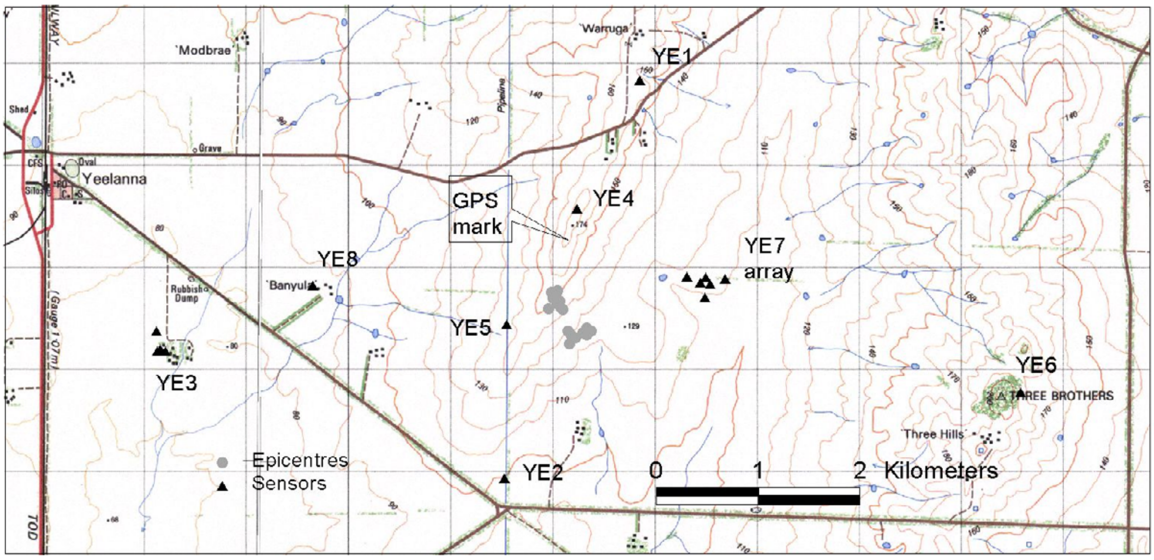

FIGURE 1 Yeelanna showing sensor sites (triangles) and best epicentres (dots).

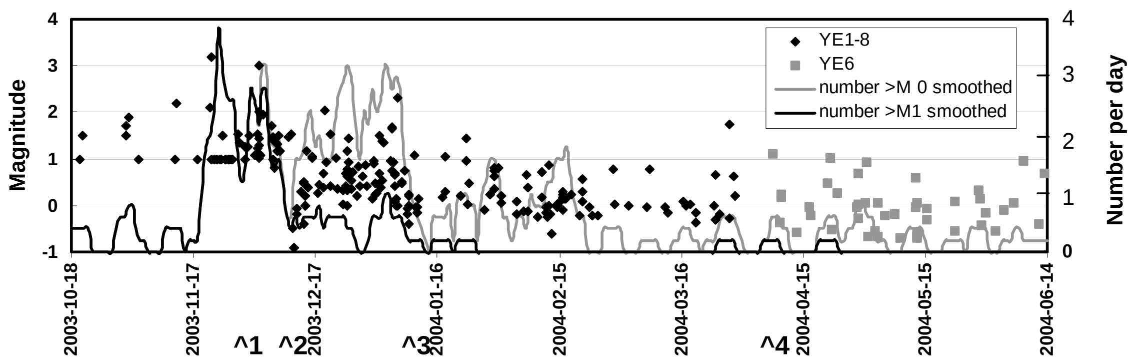

FIGURE 2 Event magnitude, smoothed activity rate and visits

2. INSTRUMENTATION AND METHODS

Installed sensors were a mixture of seismometers and accelerometers, mostly 3 axis. Recorders were run in triggered mode, at 100 to 400 samples per second with GPS timing. Accelerometers YE1 and YE4 recorded the fewest earthquakes. Sites YE1 and YE6 were on hard rock, others were on soil, with YE4 interpreted to be on very shallow soil.

2.1 CALCULATING HYPOCENTRES

Locations of the 12 most accurate solutions are shown in figure 1. These solutions were all from the period between visits 2 and 3 which had the largest number of working recorders. The locations occupy a very small area, with depth estimates ranging between 2.5 to 3.0 km, depending on the velocity model used. The velocity model was a single layer with Vp of 5.8km/s and Vs of 3.35. Time residuals are usually less than 0.04 secs, and the variation of residuals was rarely more than 0.01 sec from the mean for a given station and wave. The location program being used, Eqlocl, only presents output to two decimal places which is clearly inadequate for these situations. The locations suggest a lineation of about 600m in a NW – SE direction, with a shallowing to the NE, however this should only be considered tentative, as the uncertainties in the location process as calculated by Eqlocl are about 350m horizontally and 600m vertically. Horizontal accuracy and the ability to calculate Vp and Vs were compromised by having all recorders close to the epicentres. A better layout would have used extra recorders at greater distances. The addition or removal of arrivals from any one site (eg removing YE3 during visit 2, moving YE5 to YE8 during visit 3) had a significant systematic effect on the calculated locations. It is clear that more recorders (at least 8 well placed and working) are required. Double difference or joint hypocentre determinations may improve results from this survey.

2.2 MULTIPLE SENSORS - SMALL ARRAY RECORDING AND ANALYSIS

YE3 was one of the first sites installed. It was a 6 channel Kelunji, running at 400 samples per second, with a three axis L4C-3D seismometer at low gain, and three vertical SS-1 seismometers at high gain set up in an L shape array, with sides of 90m and 65m. The recorder was connected to the phone and regularly interrogated. From the varying arrival times it was estimated that the source was at an azimuth of 75º to 80º. The best locations (figure 1)were at 80º to 90º. Distance was estimated from S-P, but the S arrivals were not similar, possibly due to unmatched sensors. These initial azimuths and distances improved planning for visit number 2.

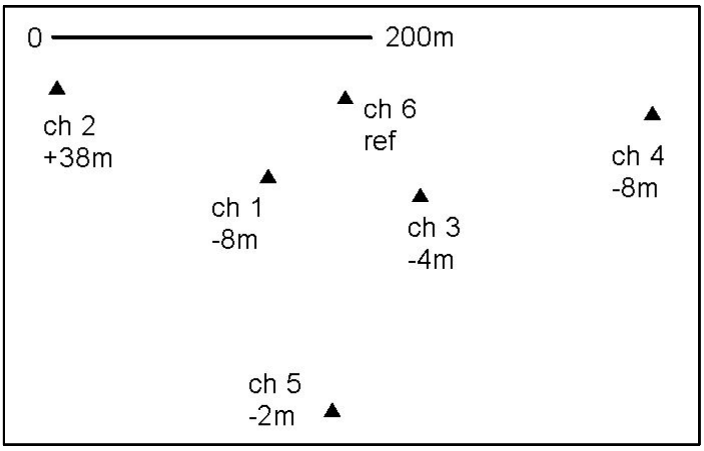

FIGURE 3 Site YE7 array and bedrock depth

YE7 was an array of six vertical seismometers, three L4C (well matched) and three SS-1 (not matched), covering an area roughly 400 by 200m (figure 3). The area had a gentle slope with about 7 m variation in elevation across the array (10m contours in figure 1). Due to problems with cable breaks, only a small number of events were recorded with all six channels. It was hoped that variations in arrival times would indicate different directions to each event but the recorded P arrival times were not in the expected order. The channel nearest to the activity (2) had a considerable delay. The discrepancy in arrival times was assumed to be due to differing depth to bedrock. A large concrete block was dropped from about 3 m height at each seismometer site in an attempt to measure surface velocity. Unfortunately this was not very successful. Using a P wave velocity at surface of about 1500m/s and using channel 6 as a reference produces bedrock depth variations of 38m deeper for channel 2 and 8m shallower for channel 3. Other channels did not vary much from expectations, becoming slightly deeper to the south and east. Channel 2 is closest to the bedrock outcrop at the nearby hill and GPS site, and so would be expected to have the thinnest soil cover. This is at odds with the conclusion that the bedrock beneath channel 2 is 38 metres deeper than that beneath the reference channel. The variation of bedrock, coupled with the unmatched sensors meant that useful azimuths and emergence angles could not be calculated.

An attempt was made to estimate difference in azimuth and emergence angle between events from variations in P arrival times. Without purpose-built software this has not yet been successful. It is possible to estimate P arrival time differentials (between separate events) to better than 1 sample (0.025 sec) in some cases. As the array is very close to the source, the azimuth and emergence are not equal across the array. In one case, a nodal plane has been very close to channel 4. This makes it very difficult to pick P differentials reliably because the wave-form changes.

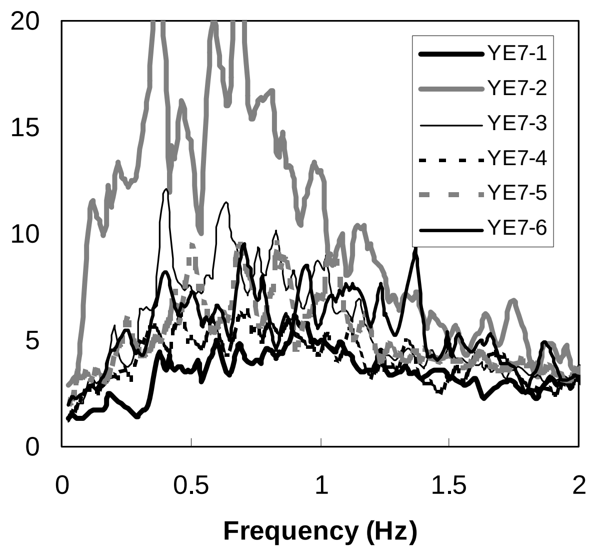

FIGURE 4 Nakamura ratios for site YE7

2.3 NAKAMURA RATIOS

Nakamura ratios were calculated for each channel of site YE7 using an L4C-3D seismometer, and these are shown in figure 4. It was hoped that there would be differing frequency peaks to indicate depth to bedrock, but the results were not easy to interpret. Channel 2 gave the greatest ratio and channel 3 the lowest. Channel 2 peak was a somewhat lower frequency than most of the others, but peaks were not clear.

2.4 JOINT FOCAL MECHANISM

First motion polarities at each station (Table 1) were consistent between events, indicating a consistent stress direction, with stress only partially relieved. The consistency also indicated that polarity results could be combined to produce a joint focal mechanism. As only 6 recorders were available, not all sites in Fig 1 were occupied at once. The focal mechanism (figure 5) which is of the upper hemisphere, was formed from the portable stations which were all within 5 km and had impulsive arrivals (big symbols), and a few permanent network stations, which were all distant and had emergent or doubtful arrivals (small symbols). This consistency of polarity which has been noted in other cases (eg Moralana 1992 sequence,

Site	U	?	D
YE1	12		
YE2	102	2	
YE3	24		4
YE4	12		
YE5	40		
YE6	2		28
YE7	86		1
YE8	24		1

TABLE 1 Site polarity

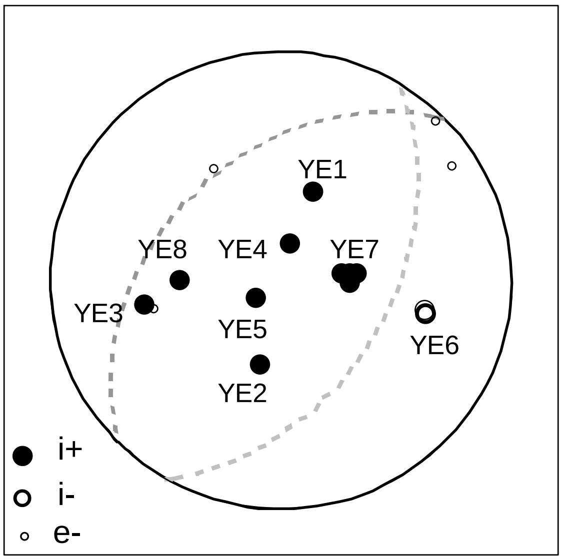

FIGURE 5 Joint focal mechanism

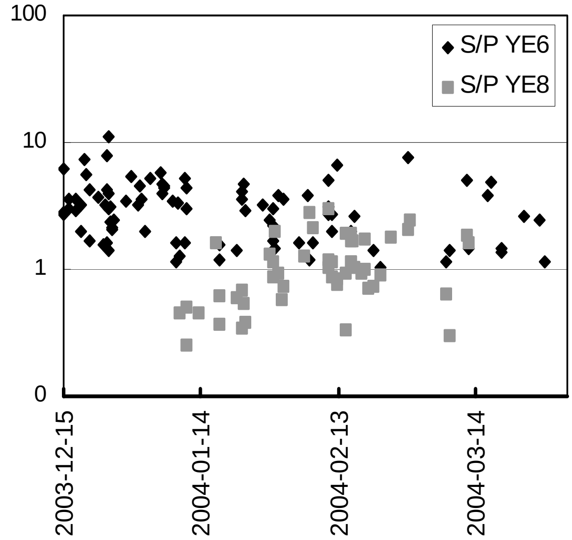

FIGURE 6 Sv/P amplitude ratios

Greenhalgh et al 1994) suggests that stations could have been moved to obtain polarities at other points. While this is essentially true, the variation of station layout would have upset accurate hypocentre location.

The mechanism is clearly due to horizontal compression, but the nodal planes are poorly constrained. One possible solution is shown, but others are possible. These nodal planes have a similar strike to the topography and geology (a NNE striking fault is implied along the west side of the hill) and as indicated by gravity and magnetic surveys.

To investigate the stability of the focal mechanism over time, amplitude ratios (Sv/P) have been measured for events at sites YE6 and YE8 (figure 6). There is a general pattern, with YE8 beginning at less than one and increasing over time, and YE6 being nearly always greater than 1 and possibly decreasing with time. There is also a considerable degree of scatter.

2.5 VELOCITY SPECTRA

Instruments were operated at varying rates from 100 to 400 samples per second. YE6 (on rock) ran at 250 samples per second with a 50Hz anti-alias filter. The YE7 array (on soil) ran at 400 samples with a 125 Hz filter. Figure 7 shows the velocity spectra from vertical channels at these 2 sites. The sample rate is inadequate to define the high frequency roll-off in YE6. This and the very small residuals of the locations demonstrate that sample rates of at least 400 and preferably higher should be used for recording at close proximity, particularly on rock.

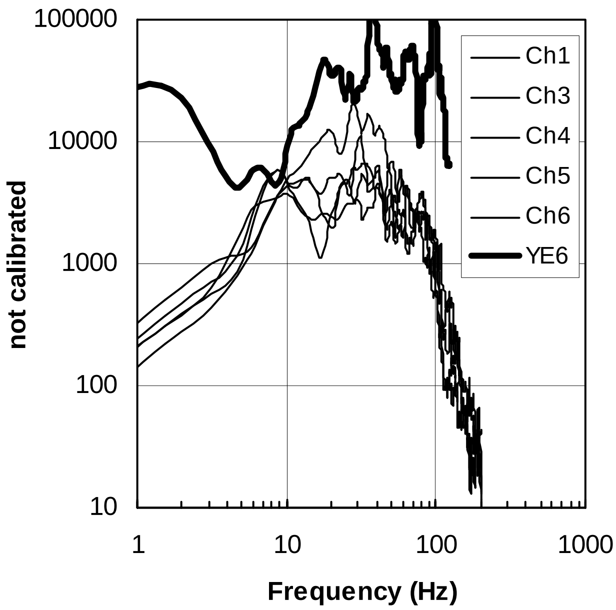

FIGURE 7 Velocity spectra

3. REVIEW OF PAST ACTIVITY ON EYRE PENINSULA

3.1 DATA BASE REVIEW

Malpas (1993) lists only a few events in this area before 1959. Post 1959 there are a significant number of events in the region. Review of these events showed that the locations recorded in the data-base did not accord with all information. Prior to 1988 it was normal practice to list the name of any place that felt the event. There are 3 events within one month (August 1960) with place name Ungarra, however the coordinates listed are spread across more than 100km. It is presumed that this is the result of a one station (3 axis) location from station ADE at Adelaide. A review of the data-base revealed a number of events that may have been members of swarms. A cursory editing process was carried out, moving some swarms to a single position.

3.2 STYLE OF SEISMICITY

Epicentres on the peninsula were briefly classified according to the following scheme: Where there was a clear mainshock, with aftershocks (and some foreshocks), these were labelled as foreshock, mainshock and aftershock. A group of events were labelled as a swarm if they occurred over a limited time span, close to one another (within the expected accuracy of location) and with less than about half a magnitude unit between the three largest events of the group. There were a number of occasions where there were two events of similar magnitude. These were each called members of a pair. Some events were also labelled as uncertain pairs. These could be indicators of other swarms.

No	Events	Name	Date	M1-M3	Mmax
1	3	Ungarra	1960	0.1	4.4
2	9	Cockaleechie	1973	0.4	2.9
3	4	Edillillie	1979	0.3	2.5
4	15	Brooker	1982	0.2	3.4
5	9	W of Brooker	1983	0.3	2.6
6	5	Arno Bay	1986	0.6	2.1
7	3	Cockaleechie	1987	0.3	2.5
8	12	Arno Bay	1989	0.3	2.6
9	6	Wharminda	1991	0.6	2.8
10	7	Kielpa	1991	0.3	2.1
11	24	Spencer Gulf	2001	0.3	3.1
12		Yeelanna	2003		3.3

TABLE 2 Identified swarms

3.3 RESULTS OF RELOCATION AND CLASSIFICATION

Table 2 lists 12 swarms that were identified. Following the relocation of swarm points the seismicity on Eyre Peninsula (figure 8) had a much clearer pattern. The bulk of the activity occurred in the hilly area in the north-east of the peninsula. Another cluster of activity occurred in the south-central part of the peninsula. There were a few other centres of activity. There was a smaller amount of residual activity elsewhere across the peninsula.

The cluster in the south-central part of the peninsula was predominantly associated with swarm activity. While it is close to a hilly area, it is considered that most of the activity is in flat or gently undulating areas. Felt report forms were examined in detail, and a few forms listed many events being felt. It was assumed that these reports were close to the source of the swarm. In one case, however, a site about 20kms away was clearly experiencing amplification and feeling even small tremors. Considering all information it appears that the swarms in the south-central area occurred at various scattered places in a zone about 20 km NS by 10 km EW. All except one swarm on the peninsula appear to be in flat or gently undulating areas, including the long term one in Spencer Gulf. Most of the mainshock sequences occurred in the hilly area of the peninsula.

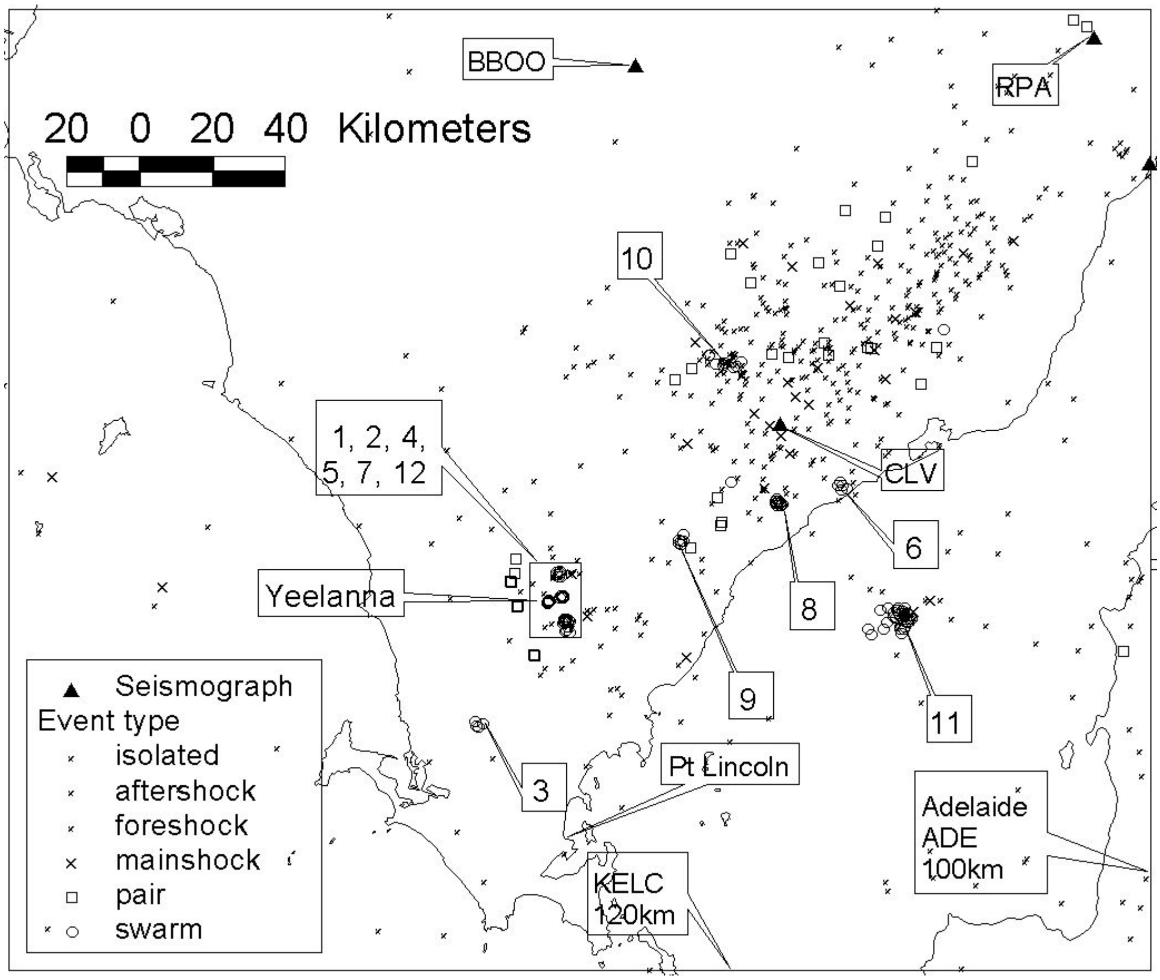

FIGURE 8 ACTIVITY ON EYRE PENINSULA AND IDENTIFIED SWARMS

4. CONCLUSIONS

Swarm activity has probably been occurring in a small area of south-central Eyre Peninsula since european settlement in 1840. This may be long term adjustments following an earlier large earthquake. Few events over magnitude 4 have occurred, resulting in little or no reporting until 1959. Many small events are not being recorded on the nearest permanent seismograph, indicating that sequences may be much longer than recognised in the catalogue, and may sometimes be missed entirely. The swarms are shallow and occur at various locations throughout the small area. The latest swarm clearly indicates horizontal compression, with repeated events of similar focal mechanism indicating that stress is only partially relieved. The dip and strike of nodal planes are poorly constrained. More detailed monitoring, by at least 8 instruments at 400 samples per second or better, will produce good quality results in similar swarms.

REFERENCES

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