Spatial Data Analysis of Aboriginal Rock Extraction Sites at Brewarrina, NSW, Australia

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ABSTRACT

This paper details an investigation of the spatial autocorrelation aspects of an aboriginal heritage site in central New South Wales, Australia. The site is on the top and side of a small hill, approximately 60 metres high, is an ancient rock quarry. The surrounding countryside is extremely flat. Over the millennia aboriginals have mined the site primarily for extracting grinding stones. These were used to prepare seeds from grasses growing along from the nearby Darling River system into a flour-like substance for the production of a ‘damper’ bread. The quarrying activities are evident today in the form of depressions up to 1.5 metres deep and roughly circular, radius 2 to 5 metres. They resemble an old gold digging site where miners made small surface depressions in a large rock field. A survey of the site was carried out in 2002 and 3D coordinates and a number of attributes (e.g. volume, area) were collected or derived. Spatial analyses have been performed on the data to determine if there are any spatial relationships. Our findings, given the data already to hand, indicate that there are few spatial relationships; moreover the holes seem to be random in size and position. The question remains then, what data could or would explain the locations of the pits? Archaeological evidence by others indicates that this is a significant quarry site for grinding stones. Such sites are rare, though similar sites are located nearby at Mt Oxley, 40km away, and another exists in northern Australia. An understanding of spatial patterns will add to the knowledge of use of these sites by aboriginals.

Keywords and phrases**:** spatial data analysis, aboriginal heritage, spatial autocorrelation, cluster analysis.

1.0 INTRODUCTION

The major river system in central and western New South Wales is that of the Darling and its numerous tributaries. The Darling River forms part of the border between New South Wales and Queensland and flows westward and eventually southward until it joins the Murray River near the junction of the New South Wales, Victorian and South Australian borders. The Murray eventually flows to the Southern Ocean through South Australia.

Figure 1.

This major inland river system was obviously extremely important to the early inhabitants of Australia. Many tribes of Aborigines were to be found along the river, relying on it for fish, hunting and as a water supply. Less well known is the fact that the early inhabitants of this land, seasonally nomadic, made a bread-like substance from grinding the grass seeds that grow along the river. They did not perform agriculture by cultivation, as Europeans understand the term, but rather took advantage of seasonal natural occurrences.

Nearly all the landscape in central and western New South Wales can be characterised as extremely flat, with the odd small hill or range of hills only occurring every 50 to 100km. Suitable raw materials for stone axes, spear points or grinding stones were in limited supply and it is known that trading routes for stone implements existed across the country.

Brewarrina is a small settlement on the Darling/Barwon River system some 750km northwest of Sydney. A further 100km west is the larger town of Bourke. Between these two populated centres there are basically only two hills. Yambacoona, also known as Mount Druid, is a small hill about 60m high, located 30km from Brewarrina and is the subject of this study. A more extensive outcrop is a further 40km towards Bourke (elevation about 170m above the surrounding plain) and is known as Mount Oxley (or Oombi Oombi to the indigenous population). On the top of both of these rocky hills are evidence of quarry sites for grinding stones.

Traditional stories (folklore) of the local Aborigines relate that the grinding stones from the top of the flat-topped Mount Oxley were under the control of certain elders of the local tribe and attracted a premium price. Those grinding stones quarried from pits on Yambacoona were of an inferior quality and could be extracted by anyone visiting the area. Visual inspection at both sites and recent meetings (September 2002) with the (now) traditional owner of the sites would certainly lend credence to these stories.

The geology of these sites is not the topic of this paper, and indeed it seems to be a matter for present-day contention amongst experts. Suffice to state that these hill-tops have outcrops of silcrete. Silcrete can manifest itself in various forms, from hard flint-like stones which can be splintered to make spear points and small knives, through to bedded layers resembling sand-stone which was sought for its excellent grinding characteristics of a uniform grain size and abrasiveness, to sections where the rock could be best described as conglomerate with a mixture of large, small and irregular stones cemented in a silt-like matrix. An example of a quarry pit at Yambacoona is shown in Figure 1.

The authors were introduced to these sites as a result of performing some surveying tasks at other nearby archaeological sites where the Department of Archaeology at the University of Sydney was undertaking some excavations. A simple ‘marriage of skills’ has taken place in the last few years between the University of Newcastle, where surveying is taught, the University of Sydney, where there is little or no capability for land surveying and the University of Otago for spatial data analysis. The plan for Yambacoona was to perform a detailed contour and topographic survey of the area before the archaeologists started any diggings. This survey took place in April 2002 and lasted for only a few days with two field parties using modern total station equipment to record the quarry sites.

2.0 ANALYTICAL APPROACH

The analyses presented in this paper employ an exploratory spatial data analysis approach to a discrete point data set representing the location of pits where rock was reputedly extracted at Yambacoona. The survey at Yambacoona identified and measured some 198 pits spread across the hill (see figure 1). At each pit x, y and z coordinates were measured at the centre of the pit as well as from several points around its perimeter. No other attributes were recorded during the survey, but attributes describing the surface area, depth and volume were later derived mathematically for each pit. The value of the volume attribute is calculated on the assumption that the profile of each pit is shaped like an inverted cone or pyramid. There are two distinct rock extraction areas at Yambacoona that are evident in Figure 2. Points from each area were divided into separate data sets for the north and south sections of the hill accordingly and analysed separately to identify and describe any spatial

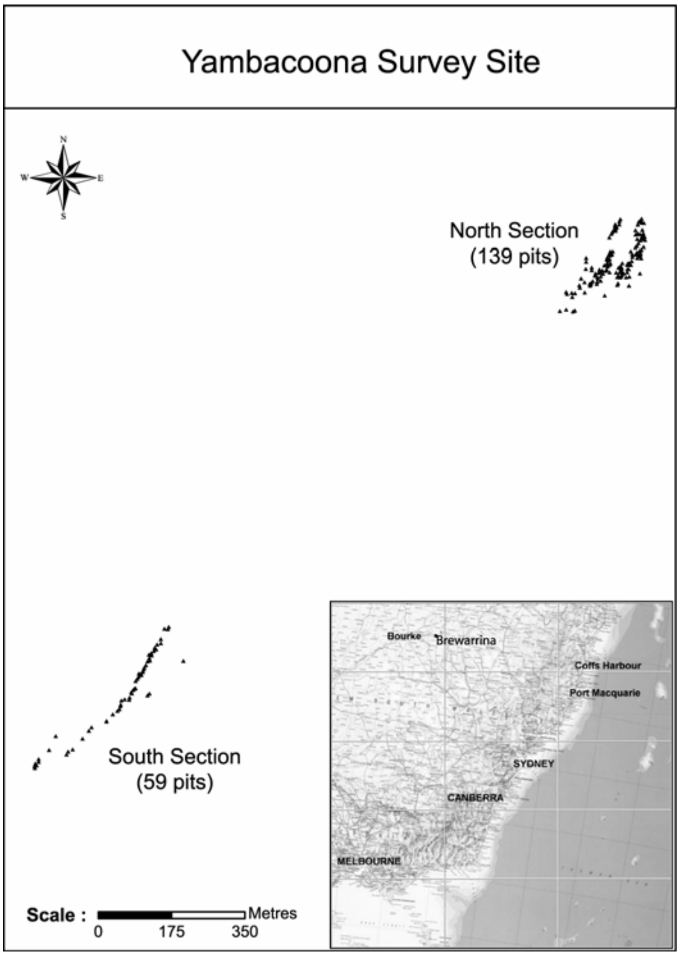

Figure 2.

patterns that may exist. Having identified any patterns extant in the Yambacoona data, the next stage of this project is to seek possible explanations for their existence.

Spatial data analysis is primarily concerned with observational data – the locations where rock was extracted from Yambacoona in this case. These observational data are assumed to be the result of some phenomena or process that operates in a spatial and possibly cultural context. The analysis of them seeks to describe, explore or explain the phenomena, process or even possible relationships with other spatial phenomena. The object of the analysis is to develop an increased understanding, to assess evidence in order to test hypotheses, or perhaps to make predictions in areas where no observations have been made. The methods used to conduct spatial data analysis are therefore often concerned with statistical description and/or modelling of the observed data (Bailey and Gatrell, 1995).

The analysis process employed for the Yambacoona data begins by deriving basic descriptions of point frequency and density for both the north and south sections of the hill, followed by some more complex descriptors of the spatial arrangement of each set of points. This stage includes deriving the nearest neighbour indices (NNI) and spatial autocorrelation indices (Moran's I and Geary's C). The results from these tests indicate some degree of clustering is evident in the rock extraction points, therefore cluster analysis was employed to identify individual clusters of points in each data set. Following this the spatial arrangement of the points in each identified cluster was re-assessed and described.

2.1 Basic Spatial Descriptors

The distribution of a set of points can be described in terms of frequency, density and spatial dispersion. Each requires only the use of basic statistics to describe the properties of any given set of points. More complex measures are used to describe the spatial arrangement of point features and this is discussed in the next section. Frequency and density measures are really only of any use when two or more sets of points are to be compared or when a set of points is to be evaluated at two or more points in time. The frequency of the distribution is simply the number of points in the set. However, the comparison of the frequency of two sets of points is often misleading if the area of the distribution is not also taken into account by measuring the density of the distribution (frequency/area). The frequency and density of the pits in the north and south sections of Yambacoona hill are shown in Table 1. Note, however, that comparison of density measures is highly dependant on the selection of a boundary for the set of points.

	Area (km^2)	Frequency	Density (pits/km^2)
North	0.029	139	4,793.1
South	0.066	59	893.9

Table 1.

The spatial dispersion of a set of points may be described by the standard deviation of the X and Y coordinates for the set. In a simple point pattern, the dispersion is concentrated if the standard deviations of both X and Y are small. Conversely, the dispersion can be considered scattered if the standard deviations are large. However, a dispersion measure based on standard deviations is not appropriate when the point pattern has a linear or more complex form, which is the case at Yambacoona. The point distributions at Yambacoona exhibit a potentially interesting linear pattern; they lie at an angle of approximately 40º East of North. Coincidently the bearing between the other rock extraction site at Mt. Oxley and Yambacoona is approximately 38º. This may indicate a local or regional geological pattern, a cultural influence or it may be entirely coincidental.

2.2 Spatial Arrangement Descriptors

An important characteristic of spatial pattern is the arrangement of points in a distribution. If there is some process or spatial phenomena in effect this will likely have a significant affect on the distribution of the point features. This can be further tested and described. There are three general forms of spatial arrangement:

- Clustered. Points are concentrated in one or more areas forming groups.
- Scattered/uniform. The points are distributed evenly.
- Random. The points are neither clustered nor scattered.

There are several methods for measuring spatial arrangement. The two techniques used to assess the arrangement of the Yambacoona pits were the nearest neighbour index (NNI) and spatial autocorrelation measures.

Nearest Neighbour Index

The NNI is a simple and straightforward measure of spatial arrangement. It measures the amount of spatial dispersion in a set of point features based on the (linear) distance of any point to its nearest neighbour. In general, if the distribution of the points is clustered the average distance between nearest neighbours will be shorter than that of a scattered distribution. A random distribution will be characterised by an average inter-point distance that is both larger than that of a clustered distribution and shorter than that of a scattered one. The NNI measure is defined as the ratio of the average inter-point distance between nearest neighbours *Ad* to the expected value of the average inter-point distance between randomly dispersed nearest neighbours *Ed*:

$$NNI = Ad/Ed$$

Where $Ad = \left(\sum_i d_i\right)/n$, and

$$Ed = 1/2\sqrt{A/n}$$

Where *n* is the number of points and *A* is the map area. The NNIs for the extraction points in the north and south sections at Yambacoona are given in Table 2.

	Area *A* (m^2)	Frequency	*Ad*	*Ed*	NN-Index	*z*
North	28,464	139	6.077	7.155	0.849	-3.401
South	66,038	59	8.974	16.728	0.537	-6.814

Table 2.

The value of the NNI can range between the theoretical extremes of 0 (where all points are at the same location) and 2.1419. Values that approach the upper limit indicate that the distribution is scattered or uniform while a value approaching 1 indicates that the distribution is random because *Ad* is similar to *Ed*. In general, small values of the NNI indicate a clustered pattern and large values indicate a scattered one. However, to test if the calculated NNI is statistically significantly different from that of a random process it is necessary to calculate the standard normal deviate of the distribution, z:

$$z = \left(Ad - Ed\right)/\sigma_{Ad}$$

Where σ_{Ad} is the standard deviation of Ad:

$$\sigma_{Ad} = \sqrt{\frac{0.0683A}{n^2}}$$

To test significance the value of z is compared with a normal distribution. If the value is greater than 1.96 (or less than –1.96) the distribution of points is significantly different from random at the 95% confidence level. The NNIs and standard normal deviates of the point distributions at Yambacoona indicate that both sets of points exhibit some degree of clustering.

The NNI is a simple measure of spatial arrangement and it is therefore subject to several limitations. Apart from inaccuracies in the interpretation of results it also suffers from requiring the use of artificial boundaries to compute map area. This can introduce bias into data that are on or near the edge of the study boundary (Boots and Getis, 1988). Because the NNI considers only the distance to the *nearest* neighbouring point it is somewhat insensitive to complex patterns and it does not consider the *overall* spatial arrangement of points in the distribution (Chou, 1997). To evaluate points for overall pattern it is necessary to employ more advanced analytical techniques such as spatial autocorrelation indices.

Spatial Autocorrelation

Spatial autocorrelation measures the degree to which a spatial phenomena is correlated to itself in space (Cliff and Ord, 1973), or put another way, spatial autocorrelation is concerned with the degree to which objects or events that occur at some place in geographic space are similar to other objects or events that are located nearby (Goodchild, 1986). This definition reflects Tobler's first law of geography, which states that "everything is related to everything else, but near things are more related than distant things".

A measure of spatial autocorrelation is a useful statistic for evaluation of overall pattern in a set of spatial features. If a process is in effect that tends to attract entities the autocorrelation will be positive and the distribution will be characterised by clusters of similar entities. On the other hand if a competitive process dominates entities tend to be repelled from each other resulting in a scattered pattern with a negative autocorrelation. If neither attraction nor repulsion forces dominate the distribution of entities will be random and have no significant autocorrelation (Chou, 1997).

Two commonly used measures of spatial autocorrelation indices are the *Moran's I* and *Geary's C*. The Moran's I is a weighted correlation coefficient in which weights represent geometric proximity, and is used to evaluate overall spatial pattern, i.e. are entities clustered together or dispersed? Moran's I is calculated as follows:

$$I = \frac{n}{\sum_{i=1}^{i=n}\sum_{j=1}^{j=n} W_{ij}} \times \frac{\sum_{i=1}^{i=n}\sum_{j=1}^{j=n} W_{ij}\left(x_i - \bar{x}\right)\left(x_j - \bar{x}\right)}{\sum_{i=1}^{i=n}\left(x_i - \bar{x}\right)^2}$$

Where n is the number of points, W_{ij} denotes the spatial weight matrix, and x denotes the frequency of the phenomena in question. The Geary's C index is similar to the Moran's I but makes paired comparisons between juxtaposed points. Where the Moran's I includes the difference of each variate from the mean, the Geary's C includes the difference of each variate from all other variates (Sawada 2002). Geary's C is calculated thus:

$$C = \frac{(n-1)\sum_{i=1}^{i=n}\sum_{j=1}^{i=n} C_{ij}\left(x_i - x_j\right)^2}{2\left(\sum_{i=1}^{i-n}\sum_{j=1}^{i-n} C_{ij}\right)\sum_{i=1}^{i=n}\left(x_i - x\right)^2}$$

The Moran's I tends to be the more commonly used spatial autocorrelation measure, capturing patterns cleanly and providing results that are easier to interpret. The methods of interpreting the value ranges for each coefficient are shown in Table 3.

Interpretation	**Geary's C**	**Moran's I**
Similar, regionalized, smooth, clustered.	$0 < C < 1$	$I > 0^*$
Independent, uncorrelated, random.	$C \approx 1$	$I \approx 0^*$
Dissimilar, scattered, checkerboard-like.	$1 < C < 2$	$I < 0^*$
* 0 = 1/n(n-1) where n is the number of objects		

Table 3.

Spatial autocorrelation indices deal simultaneously with location and attribute values at the location. The Moran's I and Geary's C indices were calculated for each attribute of the north and south point sets at Yambacoona, and are shown in Table 4.

	Moran's I		***Geary's C***	
Attribute	**North**	**South**	**North**	**South**
Elevation	1.143595	0.768703	0.009995	0.020095
Area	0.291482	0.663841	0.335044	0.452283
Depth	0.409002	0.620943	0.480310	0.628215
Volume	0.264343	0.708597	0.304179	0.723957
NN-distance	0.323038	0.136774	0.036653	0.007414
Depth (revised*	0.409081	0.464038	0.555746	0.689661
Volume (revised)	0.276663	0.664589	0.243496	0.724316
* Depth was recalculated from the deepest point of the pit instead of its geometric centre.				

Table 4.

The results of the spatial autocorrelation tests shown in Table 4 appear to confirm the results of the NNI tests, namely that a degree of clustering appears to be evident in the two sets of points. Differences between the Moran's I and Geary's C indices may be explained by the Geary's C being more sensitive to local variations than the Moran's I which better describes global pattern. The next stage of the analysis was to perform cluster analyses in an attempt to identify the individual clusters of pits with similar values that the descriptive statistical tests seem to indicate exist.

2.3 Cluster Analysis

Cluster analysis is a technique for the classification of data based on the values of multiple attributes. As an exploratory technique it has found favour as one approach to data mining. Cluster analysis may be used as a stand-alone tool to gain insight and understanding of the nature of any patterns that may exist in a data set, for example to focus further analysis and/or data processing. Alternatively it may also be used as a pre-processing stage to separate data items or spatial features for testing by other means. In a spatial context cluster analysis combined with mapping can be especially useful since the clusters that result from the analysis may clarify previously unnoticed geographic patterns and relationships between attribute data.

There are a variety of clustering techniques available, many of which employ one of four general approaches (see Han *et al*, 2001):

- *Partitioning methods.* Objects are placed into *k* clusters such that the deviation of each object from its cluster centre is minimised.
- *Hierarchical methods.* A set of objects is hierarchically decomposed to form a dendrogram from recursive splitting of the data set.
- *Density-based methods.* Unlike the methods above which form clusters on the basis of distance, density-based methods regard clusters as regions of objects with a high density. These methods have the advantage of being able to exclude outliers in the data set.

- *Grid-based methods.* Represent space as a uniform raster to improve the efficiency of a density-based search, particularly in very large databases or where there are a large number of attributes (i.e. dimensions) to be evaluated.

The cluster analysis on the Yambacoona data was carried out using the Cluster Analysis Tool plug-in for ArcGIS 8 (and can be downloaded from the ArcObjects Online web site). The plug-in is a hierarchical clustering

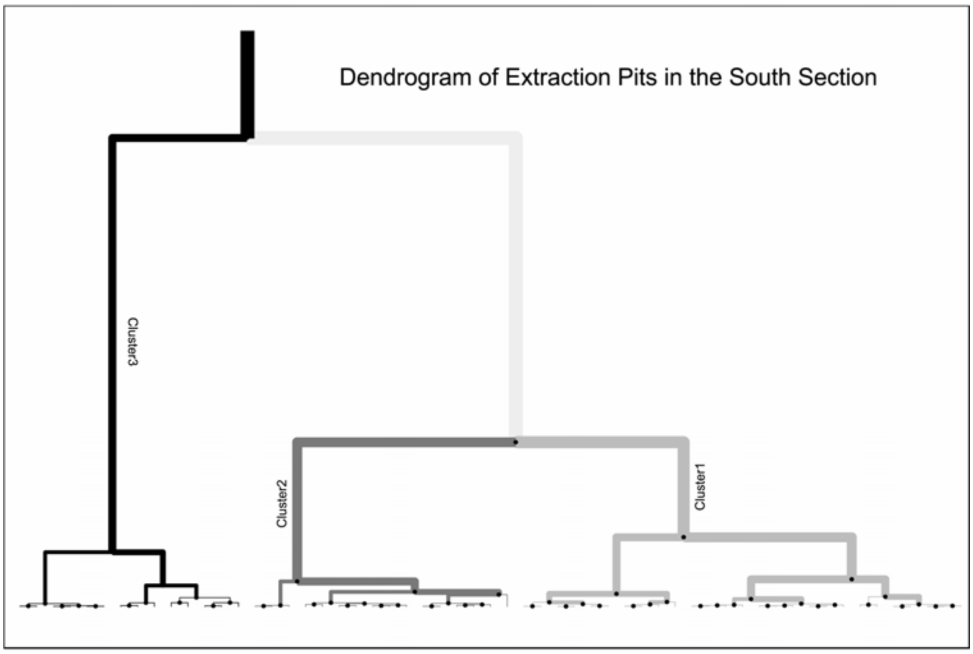

Figure 3.

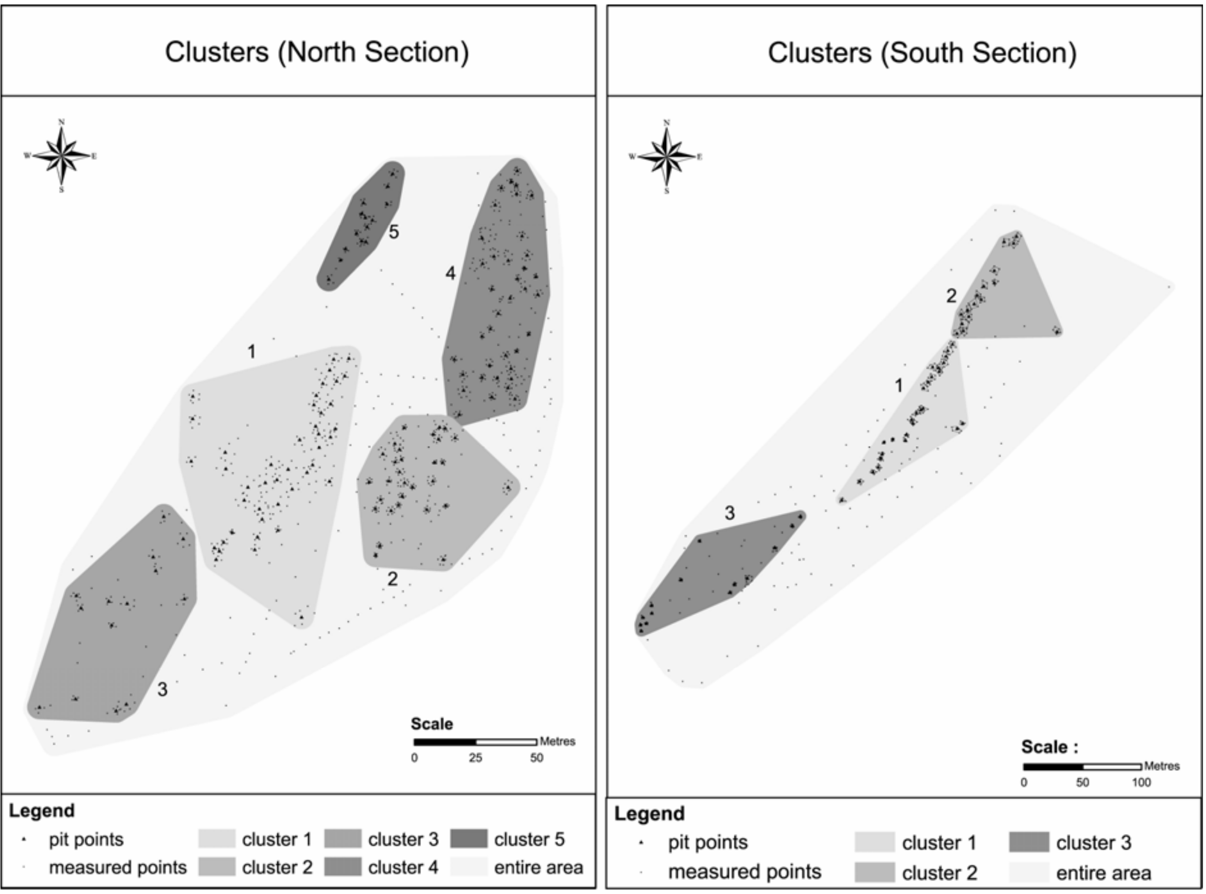

Figure 4.

algorithm that uses a bottom up, or agglomerative, approach to forming the cluster dendrogram, or tree diagram. This approach begins with single objects in the data set and successively merges them into clusters based on their “nearness” to each other in a multi-dimensional data space (in which each dimension is represented by a different attribute of the object) until all objects are finally agglomerated into one cluster. The resulting dendrogram is then evaluated and the number of clusters to be used or explored further is decided by the user based on the nature of the node and branch structure of the diagram.

The dendrogram derived from all attributes for the extraction pits in the southern part of Yambacoona is shown in Figure 3. From this diagram three quite distinct clusters of points are shown. These clusters and the five identified in the north section of the hill are mapped in Figure 4. There are general guidelines as to which clusters to select based on interpretation of the structure of the dendrogram in terms of the percentage of individual observations that fall within each cluster, the similarity of the elements in a cluster and how different each cluster is from its nearest neighbour. But the final decision regarding how many clusters to select remains somewhat arbitrary. Having said that, it is possible to choose different numbers of clusters and explore how the mapped patterns of clusters are distributed. It is important to note that the cluster analysis described here is based on non-normalised data and will be biased by the magnitude of the X and Y coordinate values compared with the other attributes. This was a sensible approach to take in the initial stages of the analysis and further exploratory work will be undertaken to include different combinations of pit attributes using normalised data values.

Having selected what seems to be an appropriate number of clusters for each data set based on both the structure of the dendrogram and map patterns, the final phase of the analysis concerns repeating the descriptive statistical tests described above *within* each cluster. The objective is to determine the characteristics of the pits within each cluster in terms of their similarity. The results of these tests should provide some additional directions for

	Moran’s I North Section				
Attribute	**Cluster 1**	**Cluster 2**	**Cluster 3**	**Cluster 4**	**Cluster 5**
Elevation	0.207	0.578	0.632	1.232	0.196
Area	0.386	0.007	-0.664	0.068	-0.186
Depth	0.224	0.175	-0.196	0.048	-0.058
Volume	0.310	0.038	-0.433	-0.433	-0.048
NN-distance	0.202	0.226	0.684	1.042	0.660
Depth (revised)*	-0.033	0.203	0.773	0.115	0.201
Volume (revised)	0.325	0.136	-0.338	0.012	0.111
	Geary’C North Section				
Elevation	0.040	0.078	0.174	0.011	0.093
Area	0.313	0.693	1.762	1.064	0.695
Depth	0.548	0.583	1.453	1.409	0.414
Volume	0.287	0.728	1.873	1.774	0.590
NN-distance	0.023	0.014		0.239	0.122
Depth (revised)*	0.988	0.563	0.392	1.285	0.364
Volume (revised)	0.239	0.449	1.725	1.636	1.128

*Depth was recalculated from the deepest point of the pit instead of its geometric centre.

Table 5.

	Moran’s I North Section		
Attribute	**Cluster 1**	**Cluster 2**	**Cluster 3**
Elevation	0.810	0.172	0.790
Area	0.570	-0.302	0.144
Depth	0.218	0.298	-0.375
Volume	0.492	0.063	0.205
NN-distance	0.266	0.081	0.383
Depth (revised)*	0.291	0.310	-0.277
Volume (revised)	0.292	0.016	0.238
	Geary’C North Section		
Elevation	0.045	0.148	0.046
Area	0.339	1.559	0.434
Depth	0.560	1.041	1.623
Volume	0.457	1.401	0.388
NN-distance	0.051	0.005	0.007
Depth (revised)*	0.766	0.886	1.544
Volume (revised)	0.504	1.361	0.362

*Depth was recalculated from the deepest point of the pit instead of its geometric centre.

Table 6.

subsequent field surveys to pursue.

2.4 Intra-cluster Analyses

The first step of the intra-cluster analyses involved repeating the spatial autocorrelation tests for points within each cluster. The results are shown in Tables 5 and 6. The autocorrelations between the elevations of the pits in most of the clusters can be safely ignored; the terrain at Yambacoona hill is not highly variable so it is natural to expect that the pits close to each other will be at a similar altitude. In the northern section of the study area cluster 3 exhibits a strong positive autocorrelation for depth, with both the Moran's I and Geary's C indicating that a scattered pattern exists in this cluster with respect to the other attributes. The Geary's C index for cluster 4 in the northern section also indicates the presence of a scattered pattern whereas the Moran's I indicates a random pattern exists in this cluster. The other clusters in this section generally display quite weak positive autocorrelation.

In the south section of the study area cluster 1 shows some positive autocorrelation for the area and depth attributes in the Moran's I test. Cluster 2 shows some negative autocorrelation for area in the Moran's I, and also for the area, volume and revised volume attributes in the Geary's C test that would indicate a scattered pattern. Cluster 3 shows some quite strong negative autocorrelation for depth in the Geary's C test.

		North Section ***Cluster 1 (43 Points)***		
Attribute	**Standard Deviation**	**Mean Value**	**Minimum Value**	**Maximum Value**
Elevation	1.869	156.337	150.204	160.278
Area	9.803	13.285	1.582	35.682
Depth	0.253	0.574	0.005	1.194
Volume	3.006	2.957	0.01	14.201
NN-distance	4.822	6.185	2.389	33.516
Depth (revised)*	0.249	0.620	0.180	1.222
Volume (revised)*	3.201	3.129	0.161	14.538
		Cluster 2 (30 Points)		
Attribute	**Standard Deviation**	**Mean Value**	**Minimum Value**	**Maximum Value**
Elevation	0.673	160.123	159.047	161.349
Area	2.912	5.231	1.269	12.222
Depth	0.112	0.277	0.118	0.567
Volume	0.345	0.485	0.106	1.385
NN-distance	5.288	5.786	2.369	26.530
Depth (revised)*	0.134	0.289	0.041	0.658
Volume (revised)*	0.429	0.513	0.068	1.606
		Cluster 3 (14 Points)		
Attribute	**Standard Deviation**	**Mean Value**	**Minimum Value**	**Maximum Value**
Elevation	1.083	155.454	153.395	157.694
Area	7.115	8.996	2.591	26.196
Depth	0.187	0.329	0.083	0.900
Volume	2.004	1.325	0.072	7.857
NN-distance	4.298	9.156	4.879	16.539
Depth (revised)*	0.156	0.382	0.124	0.805
Volume (revised)*	1.771	1.376	0.107	7.026
		Cluster 4 (38 Points)		
Attribute	**Standard Deviation**	**Mean Value**	**Minimum Value**	**Maximum Value**
Elevation	2.204	156.383	151.908	159.394
Area	4.979	7.018	1.410	20.872
Depth	0.145	0.376	0.149	0.777
Volume	0.913	0.973	0.099	4.405
NN-distance	1.573	5.780	2.552	8.971
Depth (revised)*	0.145	0.408	0.158	0.877
Volume (revised)*	0.918	1.022	0.134	4.295
		Cluster 5 (14 Points)		
Attribute	**Standard Deviation**	**Mean Value**	**Minimum Value**	**Maximum Value**
Elevation	0.615	151.251	150.161	152.208
Area	1.653	3.483	0.776	6.503
Depth	0.115	0.438	0.233	0.568
Volume	0.246	0.490	0.143	0.986
NN-distance	2.179	4.304	1.741	9.279
Depth (revised)*	0.150	0.522	0.247	0.736
Volume (revised)*	0.307	0.584	0.190	1.114
* Depth was recalculated from the deepest point of the pit instead of its geometric centre.				

Table 7.

South Section
Cluster 1 (27 Points)

Attribute	Standard Deviation	Mean Value	Minimum Value	Maximum Value
Elevation	0.659	114.419	113.354	115.436
Area	7.856	14.911	2.501	30.116
Depth	0.118	0.295	0.108	0.544
Volume	1.244	1.594	0.167	4.954
NN-distance	3.911	6.040	2.462	22.009
Depth (revised)*	0.162	0.337	0.121	0.831
Volume (revised)*	1.301	1.743	0.187	4.696

Cluster 2 (16 Points)

Attribute	Standard Deviation	Mean Value	Minimum Value	Maximum Value
Elevation	0.401	112.770	112.385	113.995
Area	8.622	25.481	12.502	42.401
Depth	0.127	0.405	0.253	0.734
Volume	2.282	3.639	1.450	10.367
NN-distance	15.344	10.682	4.887	67.894
Depth (revised)*	0.123	0.435	0.228	0.682
Volume (revised)*	2.225	3.871	1.422	9.634

Cluster 3 (14 Points)

Attribute	Standard Deviation	Mean Value	Minimum Value	Maximum Value
Elevation	0.725	114.499	113.622	115.507
Area	7.436	5.917	1.020	30.144
Depth	0.103	0.166	0.002	0.435
Volume	0.448	0.328	0.003	1.728
NN-distance	10.647	12.693	5.039	36.872
Depth (revised)*	0.093	0.158	0.040	0.427
Volume (revised)*	0.319	0.280	0.0517	1.260

* Depth was recalculated from the deepest point of the pit instead of its geometric centre.

Table 8.

The final step in the analytical process was to examine the mean and standard deviations of the pit attributes in each cluster. If the values for any one attribute are similar across the whole cluster this will be reflected in a low standard deviation in comparison to the mean value of the attribute in question. These are shown for the north section of the hill in Table 7 and for the south section in Table 8.

There are perhaps a couple of interesting conclusions that might be drawn from assessing the variation of intra-cluster attribute values. In general the standard deviations for clusters in the north section of Yambacoona are greater than those in the south section, suggesting that the terrain is more variable. Pit volumes in both the north and south sections are roughly similar. The area of the pits in the north section are approximately twice that of the south section and are therefore shallower. There also appears to be a low variance in both elevation and depth in each cluster which may suggest that the rock extracted from the pits was taken from a geological micro feature that was at a consistent depth in the sub-surface of the hill.

Finally, examination of the mean and maximum value of the nearest neighbour distance attribute for each cluster appears to provide some useful information for verifying the suitability of the clusters selected from the cluster analysis. It can be seen that the mean of the nearest neighbour distance is quite low compared to the maximum for clusters 1 and 2 in the north section and also for clusters 1 and 2 in the south section which may indicate the presence of outliers in these clusters. When the map of the clusters and pits point in figure 4 is examined there does indeed appear to be some outlier pits in these clusters.

CONCLUSIONS

It must be said that, at this stage, results are largely inconclusive given the data at hand. It is clear that an attempt should be made to extend the data set to include additional attributes concerning the quarry pits at Yambacoona. Attributes concerning the micro geology of the area and perhaps also attributes concerning cultural values inherent in the site may prove to be interesting.

The cluster analysis described in this paper was also largely inconclusive. The existence of outliers in the clusters identified by the hierarchical clustering algorithm complicated the interpretation of the subsequent intra-cluster tests. Further work needs to be carried out to exclude outlier pits from clusters and other possible clusters of pits should also be explored. The cluster analysis carried out included non-normalised data values from all attributes in the data set so it will be worth performing several cluster analyses using different combinations of attributes and normalising their data values.

A significant problem with the approach reported here lies in deriving the depths of the quarry pits from a triangulated irregular network (TIN) that was interpolated from the points recorded during the field survey. The perimeter and bottom of the pits proved to be difficult to distinguish in the terrain and in some cases data points describing the pit feature are very sparse. If the physical attributes of the pits are an important distinguishing factor then some effort will need to be made to capture these attributes accurately during the field survey. Perhaps by explicitly measuring and recording pit diameter, repose angles and depth.

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