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Some Aspects of the Cave Orientation in the SW Wisconsin Karst

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I. Introduction.

1. Karst landforms

In the southwestern Wisconsin Driftless Area there is significant surface and subsurface karst development in the Paleozoic carbonates of the Upper Mississippi Valley (Day, 1988). Karstic depressions (dolines) are developed particularly in the Ordovician limestones and dolostones of the Driftless Area uplands, where they occur in interfluvial ridge tops and on the upper side slopes of dry valleys. The karst system also contains over 200 caves, some 10,000 springs, thousands of dry valleys, overburden, and wind-blown silt (loess). To date over 250 dolines have been recorded and inspected.

2. Karst soils

The soil development in loess of southwestern Wisconsin is mainly controlled by bedrock, relief, and eolian additions. The soil horizons are particularly affected by contributions of dolostone and sandstone outcrops. Although the parent material is typically classified as Peorian loess, the texture of the entire soil profile is not silt but it is loam instead since the silt content is only 51.1 % in the solum (Oh, 1998).

3. Methods

It is essential to define what are the individuals to be sampled, and what is the population to which they belong. The bounds of the study area must also be defined. The population is the collection of all linears of a particular variable which lie within the bounds of the study area. The study area can be a particular geographic region delimited by natural or artificial bounds, or it could be delimited

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geometrically by a circle or square of given size. Sampling should be designed to give a sufficiently detailed representation of the population with a conservation of effort. Sampling must produce data capable of statistical analysis. Two approaches, to sampling have been suggested by (Abdel-Rahman, 1979): These are direct sampling and quadrat sampling. In the case of direct sampling, each linear measured within the study area is an individual, and the set of all linears measured is the sample population. Quadrat sampling involves randomly locating quadrats within the study area, and sampling linears only within these quadrats. Quadrats can be circles of a given radius. In the cases of quadrat sampling, the quadrat is the individual, and the set of all quadrats is the sample population. The choice of size and number of quadrats must be appropriate to the particular investigation. A table is created for each quadrat by recording the presence/absence of occurrence of linears for each azimuthal class. The data from all the quadrats can then be compiled in a frequency table by recording the frequency of quadrat presence for each azimuthal class. Quadrat sampling is especially appropriate if the study area is quite large.

II. Results

1. Segment Length of the Cave Orientation

In many types of investigations, geographers, geologist, and speleologists collect orientation data. This is data in which a compass direction is applied to a linear measurement. The linear measurement can be the magnitude of the phenomenon, its frequency, or its presence/absence for any particular sample location. The compass reading gives the direction, or orientation, in which the phenomenon occurs. Data can be collected by field measurement, from various types of maps, from aerial photographs, or from satellite images. When orientation data is collected in a particular investigation, it is commonly represented in a rose (or rosette) diagram. This is a convenient and appropriate way of visually representing the data, and provides a means of making visual comparisons of the azimuthal distribution of a variable in different locations. Rose diagrams also provide a means of visually comparing different variables in a single study area. The rose diagrams is a kind circular histogram in which the data are divided into classes of a certain number of compass degrees. The class size most commonly used is 10 degrees.

Thus the rose diagram is like a circle divided into 36 pie-slice-shaped sections each having 10 degrees of arc. The orientation of the data is indicated by where it is plotted in the circle, and the magnitude, frequency, or presence/absence of the data is represented by the distance the pie slice protrudes from the center of the circle. Alternatively, the data can be plotted on a semi-circle by first subtracting 180 from all compass readings greater than 180 degrees. Rose charts can be generated by computers, or hand drawn on circular graph paper. Some examples of the types of phenomenon which can be represented by rose charts include:

-Orientation of cave passages.

-Orientation of segments of streams.

-Orientation of valley bottoms.

-Long-axes/short-axed orientation of sinkholes.

-Orientation of stratigraphic strike and dip.

While rose charts serve as valuable research tools, there are some things one must be aware of in using them. It is important to understand that rose charts and histograms should serve only to provide a general visual idea of the data distribution. They should not be used as a sole means of drawing conclusions about a data set or comparing data sets. Statistical analysis must be used to determine the degree of similarity or dissimilarity between data sets. Statistical analysis is also necessary to determine if a data is distributed randomly, uniformly, or clustered.

Decisions about class intervals, and mean of fitted class, can greatly affect the appearance of a rose diagram. Assuming one uses the convention of 10 degree classes, variations in the mean of the fitted class will give a different visual representation of the data. As an example of this, consider the following portion of a data set and two classification schemes (Table 1-3):

Table 1. Bearing and length of the cave orientation

#	Bearing	Length
1	106	3.5
2	107	12.0
3	108	15.5
4	110	22.0
5	111	7.0
6	112	20.5
7	113	18.0

Table 2. Degree Class and Size

#	Degree Class	Class Size	Total Length for Class
1	90-99	0	0
2	100-109	3	31.0
3	110-119	4	67.5

Table 3. Degree Class and Size

#	Degree Class	Class Size	Total Length for Class
1	95-104	0	0
2	104-114	7	98.5
3	115-124	0	0

Also if one's compass face has numbers every ten degrees, and tick marks between numbers, (as is common) one's readings may become biased towards the printed numbers and values directly adjacent to them. One may find a lot of compass readings ending in [2,1,0,8,9] in his data. Because the conventional rose diagram uses 10 degree class intervals, biases of this kind will be heavily expressed. It has been suggested that the choice of 3,6, or 9 degree class intervals may mask such biases (Werner, 1978).

2. Degree Intervals of the Cave Orientation

Angular observations are seldom accurate to within one degree. In reality, errors in compass bearing of 2-3% (7.2-10.8 degrees) must be common (Gay, 1977). In addition, there are sure to be doubts as to how a particular variable should be interpreted with respect to orientation. Such doubts are a another source of error in data collection. This is the case if a feature being measured has a slight, but distinctive curve. Segments of streams, caves, or valley bottoms (as in this study) can also be difficult to interpret.

One must decide if it is appropriate to represent his data with a 180 degree projection, or a 360 degree projection. The key to making this decision is to determine if the feature are directional with respect to process, or simply display an orientation trend. Thus a variable is either directional or orientation. Stratigraphic dip is an example of a feature which is truly directional. Stream segments could also be regarded as directional if one takes into account the direction of stream flow.

In such cases it may be appropriate to represent the data on a 360 degree (full circle) projection. The majority of cases, however involve data with an orientation trend, and no direction of process. In these cases, a 180 degree (half circle) projection must be used. A full circle graph can still be produced by mirroring two half circle graphs. In plotting orientation data, 180 must be subtracted from every compass reading greater than 180 degrees.

Choice of statistical technique for analysis of the data will depend on weather or not parametric assumptions can be made about the population of linears. In most orientation studies, such assumptions can be made, and non-parametric statistical techniques should be used.Finally, a choice of class interval and number of classes must be made. Common class intervals for orientation studies are(Table 4):

Large class intervals tend to hide detail in the sample distribution, often lumping several individual peaks into a single class. The 3,6,9 degree class intervals tend to mask biases in compass readings toward 10 degree tics on the compass face.

Small class intervals are not appropriate for very small sample populations as the class frequencies would be quite low yielding a data set inappropriate to some statistical techniques (Such as Chi-Square).

Table 4. Class interval in degrees and number of classes

1	Class Interval in degrees	Number of classes:
2	3	60
3	5	36
4	6	30
5	9	20
6	10	18
7	12	15
8	15	12

Class intervals should not be smaller than the probable error in the data. The following is a list of caves which were included in this study (Table 5):

Thirteen data sets were collected. Ten were data from caves, and three were valley bottom orientations measured from 7.5 minute topo sheets. In two of the caves (Bogus Bluff and Star Valley) data were collected in field surveys. In seven of the caves, linears were measured from published cave maps. In the case of Pops Cave, the cave map also depicted joint traces, so these were measured, and treated as a separate variable. These particular caves were chosen because they all certain straight segments which could be measured for orientation. In the case of Bogus Bluff, measurements were taken from both field

Table 5. Tested Sample Caves

	Case	County	Location	Data collected	No.cases
1	Anderson's Cave	Richland	NE/NW/31/2E/11N	cm	7
2	Atkinson Mine	Grant	SW/SW/26/4N/5W	cm,vb	76,60
3	Bogus Bluff	Richland	NW/SW/35/9N/1E	fs,cm,vb	43,51,38
4	Pops Cave	Richland	SW/SE/34/11N/2W	cm,jt	21,12
5	Star Valley	Crawford	SW/NE/31/11N/4W	fs	41
6	Taylor Pit	Richland	SW/NE/31/11N/4W	cm,vb	21,12
7	Wauzeka Crack	Crawford	SE/NW/16/7N/5W	cm	9
8	Werley Cave	Grant	-	cm	23

cm-Data was collected from cave maps.

vb-Valley bottom data was collected off of topographic maps.

t-Joint trace data was collected from cave maps.

fs-A field survey was performed.

No.Cases-Refers to the number of segments surveyed.

survey, and a cave map. This was done in part to see how reliable measurements from cave maps would be.

There were discrepancies between the two Bogus Bluff cases where what appeared as a single straight segments on the cave map would appear in the field as several smaller segments with distinct orientations. This problem of interpretation was the greatest source of doubt in data collection. This was also the case with valley bottom measurements. It is sometimes uncertain whether the overall direction of a valley should be measured, or the orientations of its small segments. This becomes a question of scale where large valleys tend to get every segment measured, regardless of subtlety, and small tributary valleys get measured with respect to overall trend.

It is realized that there is much objectivity in interpretation of linears, so an effort is made to standardize ones approach.

In each of the caves, all straight segments were measured except for those which were heavily broken down and could not be interpreted as linear features. Valley bottoms were measured for a radius of about two miles in the area centered on the associated cave location.

3. Data Analysis

Once all the data were collected, two different types of analysis were performed. The data were first plotted on rose diagrams with 10 degree class intervals. A 180 degree plot was used, but mirrored to form a complete circle. The class frequency for the initial plot was determined as total length of linears in each in each class as a percentage of total length of linears surveyed. Upon viewing of the rose charts, it appeared that in every case, there were definite peaks and troughs in the data. The analysis performed were a test of significant peaks and troughs, and a peak width analysis. A nine degree class interval, and a 99% confidence level was used in each analysis. A nine degree class interval was chosen because some of the data sets were very small. The data sets contained from 7 to 76 measurements. Had the data sets been larger, a smaller class interval would have been chosen.

A. Significant peaks and troughs in the data distribution.

Two types of analysis were performed on the data in this study.

1) Identification of peaks and troughs at a given level of significance.

2) Peak width analysis.

A primary interest of orientation studies is to identify peaks in the data. Visual analysis of the rose diagrams suggested that there were peaks in the data distribution. A criterion was desired to significantly identify peaks and troughs. Much literature has been devoted to this subject. A method involving the use of Chi-Square for peak identification is described by Hay and Abdel-Rahman, 1974. The method chosen here involves the use of poisson, and is described by Abdel-Rahman (1979). The first step in the analysis is to plot the data values for a particular variable as presence/absence of occurrence in degree classes of a rose chart. Each class contains the total number of data values having orientations within the range of the class. The number of data classes is determined as 180 divided by the class interval. The mean number of observations per class is then calculated as the number of data values (N) divided by the number of classes. The equation for poisson probabilities is then used in the process of determining the criteria for peaks and troughs (Equation 1).

Equation 1. Poisson probabilities:

$$p(n) = \frac{e^{-x}x^{n}}{nl}$$

Where n is the number of observations falling in any one class, e is the base of natural logarithm, approximately 2.7182818, x is the mean number of observations per class, or the total number of observations divided by the number of classes, and p(n) is the minimum percentage of observations which should fall into a class of size n to reject the assumption that the data are randomly distributed. The equation is used to calculate p(n) for frequencies n=0, n=1, n=2,··· until p(n)= .000001. Then starting from the tail of the distribution where p(n)=.000001, values of p(n) are summed until the sum of the values of p(n) exceeds a pre-decided significance level. A significance level of .01 (99%) was used in this case. When the sum of p(n) just exceeds .01, the value of n+1 is used as the minimum number of values in an orientation class needed to determine a peak with 99% confidence.

A trough is determined by the maximum number of observations which can fall in any one class. The process of calculating maximum trough size is similar to that of calculating minimum peak size except that the summing of p(n) begins at the head of the poisson distribution. p(n) is summed from n=0, n=1, n=2,··· until the sum of p(n) exceeds the confidence level. When the sum of p(n) exceeds .01, the maximum number of observations falling in a class must be less then n-1 for that class th be considered a trough with 99% confidence. In many data sets a value of 0 will be the criteria for trough determination.

Now the data can be examined for peaks and troughs. We have also calculated a value x which is the mean class size. It is apparent that orientation classes can be divided into four groups based on their relative number of members:

1) Classes with very few members may be viewed as significant troughs.

2) Some classes may not be significant troughs, but will fall below the mean number of observations per class.

3) Some classes will fall in the range

between the mean number of observations per class, and criteria for significant peaks.

4) Some classes will be of sufficient size to be considered as significant peaks.

Peak and trough criteria having been determined, the procedure for peak width analysis is as follows: The general scheme is to combine classes into single peaks trough a combination of ranking, testing and lumping. The first thing to do is determine the locations of all troughs. The location of troughs is one of the factors which delimits the range of peak width. The class with the highest frequency is then located. Use poison to determine the probability that the frequency of the class is non-random at the significance level. If the probability exceeds 99% then the class should be regarded as a peak, and designated as A1. If there are ties for highest rank, the tied classes are designated B1, C1, etc. Look at the classes adjacent to A1, if they are tied, examination both of them, otherwise look at the highest one. Use poisson to determine if the class formed by lumping A1 with the class (or classes) adjacent to it could be considered as random. then designate A1's neighbor as A2. In using the poisson to calculate probability of randomness for multiple classes, the value for x must be multiplied by the number of classes being tested together. This is because the total number of classes is being decreased.

Once a class has been formed by A1 and its adjacent class, repeat the procedure on the classes adjacent to the newly lumped class. If at any time a class which has been determined to be a trough bounds the expanding peak, analysis is stopped in the direction of trough. When the class can no longer be expanded, analysis is stopped on class A and class A can be regarded as a single peak with a peak width of the number of classes which have been lumped times the class interval. Analysis is continued on a tied class, or on the next highest class. If class B1 or subsequent new peaks are found to have a value below the mean number of observations per class, analysis is stopped. If an expanding peak runs into another peak, analysis is stopped in that direction. A computer program was written as part of this project to perform peak/trough, and peak width analysis. All results of this analysis are included with this paper.

B. Features of the Driftless Area of

Wisconsin.

The Driftless Area is associated with the southwestern portion of Wisconsin, but also include portions of Minnesota. Iowa, and Illinois. It is believed that this area was never subjected to the glacial episodes of the Pleistocene. The Driftless Area is a maturely dissected karst upland. The landscape is very hilly. Local relief is in the order of 300-600 feet. Karst features of the Driftless Area include caves, sink holes, springs, and dry valleys. There are over 200 caves in the Driftless Area. All are small caves which occur in hillsides or have sinkhole entrances. Atkinson Mine is the longest cave in Wisconsin. It has over two miles of mapped passage.

Most of Wisconsin's caves, however, have a few hundred feet of passage or less. Several of the caves have been modified to a great extent by lead and zink mining which took place in Wisconsin from the 1820's to the 1860's. Bogus Bluff, and Atkinson Mine are good examples of this. Modification was in the form of passage enlargement, and probably did not effect passage orientation. The soils are underlain by carbonates and sandstones of Cambrian, Ordovinvian, and Silurian age. Principle formations are the Prairie du Chien, Platville, and Galena dolomites, and the St. Peter and Galesville sandstones. There is a gentle regional dip south-south west. Jointing is well developed in the Driftless Area, and there is evidence of joint controlled drainage. (Judson and Andrews, 1955.) (Hobbs,1905).

III. Conclusions

Karst in southwestern Wisconsin displays significant surface and subsurface developments in the Upper Mississippi Valley. In each of the cases, significant peaks were found. The peak width analysis seems to agree well with the visual interpretation of the rose diagrams. There are two more tests which should be performed before real conclusions can be drawn about the data sets:

1) The data set need to be compared to a theoretical random distribution to determine if the distribution of data is random or significantly non-random.

2) A correlation should be performed between the valley bottom measurements and cave measurements.

If there is found to be a significant correlation between cave orientation and valley bottom orientation, then it can be assumed that the control mechanism in valley formation and cave formation is the same. These analysis have not yet been performed.

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