UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Use of Grain-Shape Regularity Measurements in Determining Source Area in Secondary Pyroclastic Rocks, McLendon Volcano, Yavapai County, Arizona

By

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

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INTRODUCTION

Determination of the source area of pyroclastic rocks is based upon measureable sedimentological parameters that change with distance from the vent. Among these parameters, the most important are stratigraphic thickness, grain size, and grain regularity. The present study used grain regularity in an attempt to refine vent location of McLendon volcano in west-central Arizona. The study had only limited success, most likely as a result of not having measurements for enough outcrops to account for the variation within the pyroclastic rocks studied. Presentation of the details of the techniques used is considered desirable as a basis for possible future studies of a similar nature.

Primary pyroclastic deposits such as ash falls and ash flows are especially useful in determining vent location. Ash-fall deposits can be sieved so that grain size may be mapped. The resulting isopach map of the grain size distribution is typically elliptical or fan shaped with the coarse fraction being found toward the vent. Distribution and sorting of ash are commonly used to indicate the location of an eruptive source area (Eaton, 1963, 1964). Ash-flow tuffs generally thicken toward the vent and their increased degree of welding toward the vent may indicate source direction and initial thickness. Cautious use of isopach mapping is suggested by Walker (1980) because his studies show that maximum thickening may occur as much as 20 km from the vent.

Secondary pyroclastic rocks are those deposits generated during active volcanism and immediately reworked and redeposited under the influence of water and gravity. Lahars and some surge deposits are excellent examples of secondary pyroclastic deposits. Lahar clast sizes range from a millimeter or less in diameter to boulders that are several meters across. This range makes sieving impractical and lithification of the mudflows further impedes the use of size, sorting, or rounding measurements.

Exposed at McLendon volcano, 70 km northwest of Wickenburg, Ariz., is a thick section of volcaniclastic rock that includes primary and secondary pyroclastic deposits (fig. 1). Only the northeastern flank of this mid-Tertiary stratovolcano remains, because the larger portion has been removed through erosion or collapse (Brooks, 1982). Determination of the general location of the central vent is based on a gravity low centered to the southwest of the remnant of the volcano. Similarly, the southwest convergence of flow foliations indicates a southwest source. Pyroclastic rocks exposed at McLendon volcano offer additional evidence for defining the source area through the use of a grain shape factor measurement, known as regularity, that is an analogous method to grain-size contouring in mapping paleocurrent directions (Seeland, 1976).

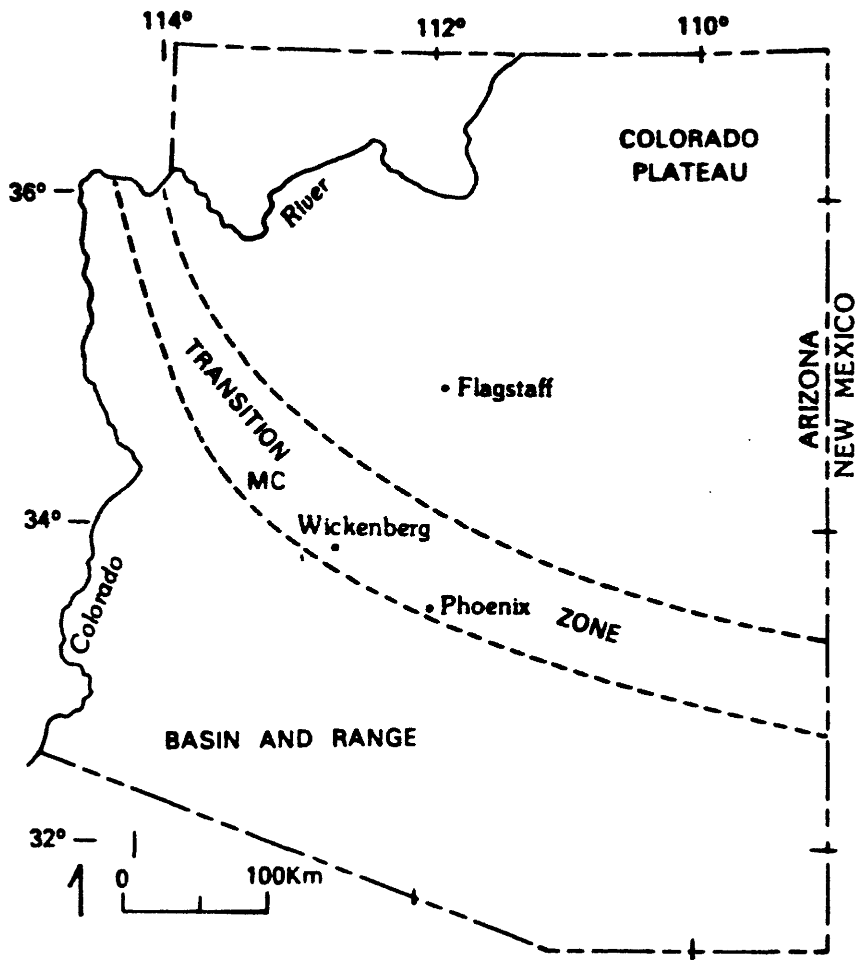
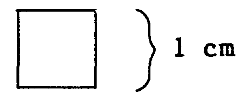


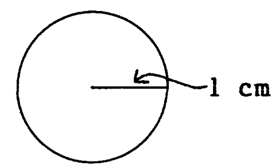
Figure 1.--Location map for study area (MC-McLendon volcano).

MEASUREMENT OF GRAIN REGULARITY

Regularity of a two-dimensional form is defined as the area divided by the perimeter squared, a nonareal number. This calculation, which results in a dimensionless number, is determined below for two geometric forms, a square and a circle, each having different regularity:



a. area (A) = 1 cm^2
perimeter (P) = 4 cm
perimeter^2 (P^2) = 16
A/P^2 = 1/16 = 0.0625 (~0.063, subrounded)



b. area (A) = πr^2
= 3.1416 cm^2
perimeter (P) = circumference
= $2\pi r$ = 6.2832 cm
perimeter^2 (P^2) = 39.4784
A/P^2 = 3.1416/39.4784 = 0.0796 (~0.080, well-rounded).

Seeland (1976) has shown that contouring of two parameters, phi (grain-size) and regularity measurements, agree with each other. Accordingly, use of the regularity measurement is made in this study to map changes in regularity that might indicate direction to source.

Six high-contrast black-and-white photographs of the secondary pyroclastic unit were taken (fig. 2a). Each photograph displays approximately 6 m^2 of outcrop and is considered representative of either proximal or distal volcaniclastic facies (Williams and McBirney, 1979). A hand-drawn overlay of each photograph was made that selectively eliminated dessicated matrix and clasts where outlines were uncertain due to shadow from conspicuous clasts (fig. 2b).

Each overlay was then examined on an image analyzer (Sawyer, 1977) that uses a scanning beam of light to measure two-dimensional geometric properties of high contrast images. Geometric test forms were also measured in order to understand the regularity of some common geometric forms (fig. 2c).

Seventy to ninety clasts were measured for each outcrop, for a total of 517 clasts. Matrix material that had desiccated into polygonal fragments was not counted nor were clasts counted that had uncertain or overlapping boundaries. The scale of the photograph does not allow resolution of grains less than 3.0 cm. A discussion of the mechanics and use of the image analyzer is given in Sawyer (1977) and in Seeland (1976).

TESTING PROCEDURE

The primary assumption in analyzing the regularity of the clasts is that abrasion will change the shape of clasts as they tumble downslope from the vent. Accordingly, measurements for each outcrop were determined in order to define regularity at that location. Mean and standard deviation of regularity at each outcrop population were computed (table 1) and an analysis of variance was done (table 2).

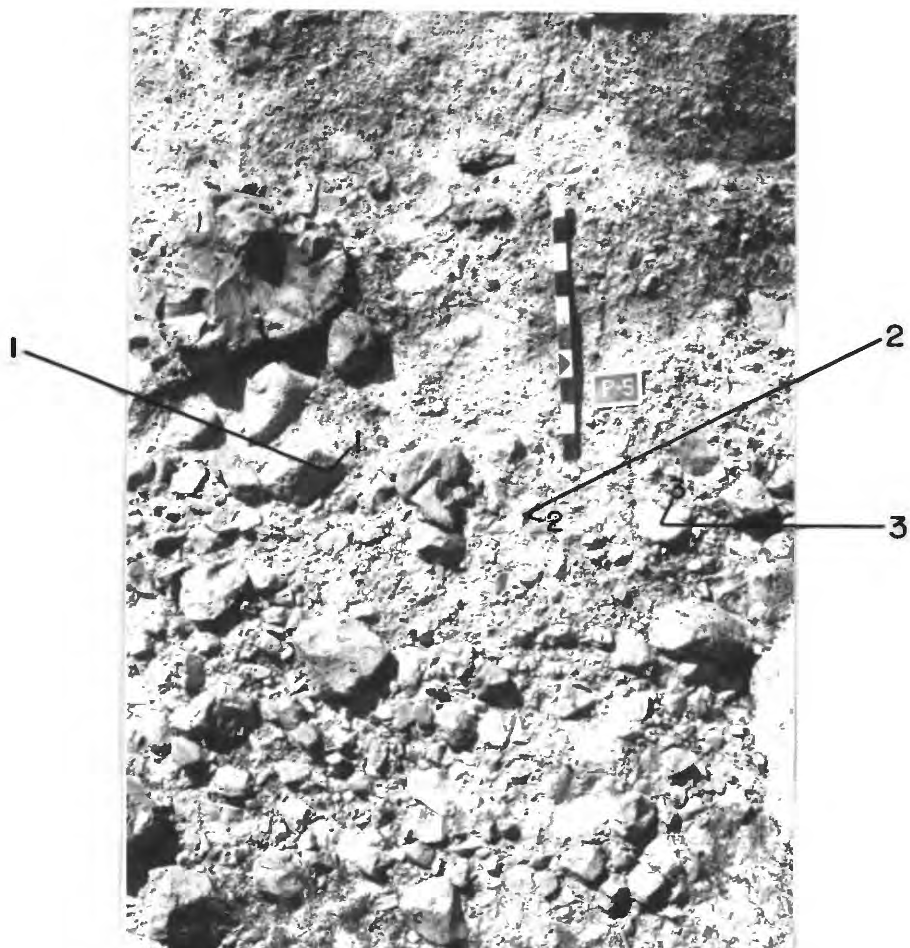


Figure 2a.--Volcaniclastic outcrop 5 (interpreted as representing distal facies); scale is 1 m. Numbers on this photograph are keyed to silhouettes shown in figure 2b.

Figure 2b.--Silhouettes of clasts at outcrop 5; same area as figure 2a.

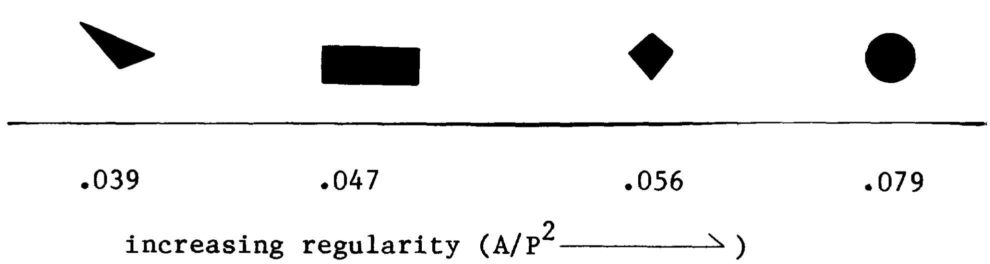


Figure 2c.--Area/Perimeter^2 measurements for geometric test forms used on image analyzer.

Table 1.--Grain-regularity statistics for secondary pyroclastic outcrops, McLendon volcano, Yavapai County, Arizona

	Outcrop 1	Outcrop 2	Outcrop 3	Outcrop 4	Outcrop 5	Outcrop 6	Average
Minimum------	0.044	0.048	0.041	0.046	0.042	0.048	0.044
Maximum------	.074	.075	.075	.076	.075	.073	.075
Mean---------	.061	.064	.061	.062	.062	.064	.062
Std. dev.----	.005	.005	.007	.006	.006	.005	.006
Var.---------	2.987e-05	2.948e-05	4.944e-05	3.817e-05	3.673e-05	2.596e-05	3.494e-05
No. of clasts measured---	86	87	90	84	80	90	86

Table 2.--Analysis of variance

Source of variation	Sum of squares	Degrees of freedom	Mean square	F
Between outcrops---	0.004	5	0.0008	13.33
Within outcrops----	.033	510	.00006	
Total------------	.037	515	--	

The analysis of variance (Dixon and Massey, 1969) was used to determine if there are any statistically significant differences between the average values (means) of the area/perimeter^2 data values (appendix A) for any of the six outcrops. Table 2 presents the summary of the calculations. The F value of 13.33, which is derived by dividing the mean square value of 0.0008 for variations between outcrops by the mean square value of 0.00006 for variations within outcrops (error mean square), is larger than the tabled value of 4.10 (Dixon and Massey, 1965, table A-7c) for 5 and 510 degrees of freedom at the 99 percent confidence level, and hence is interpreted as meaning that one or more of the outcrops differs from the others. The analysis of variance does not tell which of the outcrops are different, and therefore Duncan's test described below is used to tell which of the means are different.

Duncan's test

The following procedure for Duncan's test is taken from Steel and Torrie (1960, p. 108):

1. Determine

$$s\bar{x} = \sqrt{(ems)/r}$$

$s\bar{x}$ - standard error
ems - error mean square (from table 2, mean square within outcrops)

r - average population

$$s\bar{x} = \sqrt{0.00006/86}$$
$$= \sqrt{0.0000007}$$
$$= 0.00083$$

For the 5 percent multiple range test enter Table A.7 of Steel and Torrie (1960, p. 442-443) at row ∞ (because degrees of freedom are 510) and extract the SSR (Significant Studentized Ranges) for p (outcrop 2-6), the sizes referring to the number of means involved. The ranges are multiplied by: $s\bar{x}$ = 0.00083 to give the LSR (least significant ranges) below:

value of p	otc 2	otc 3	otc 4	otc 5	otc 6
SSR	2.77	2.92	3.02	3.09	3.15
LSR	0.00229	0.00242	0.00250	0.00256	0.00261

2. Rank the means:
(increasing regularity ———>)

otc 3	otc 1	otc 4	otc 5	otc 6	otc 2
0.0614	0.0615	0.0624	0.0625	0.0640	0.0644

3. Test the differences in the following order: largest minus the smallest, largest minus second smallest, largest minus second largest, and so on down to second largest minus second smallest. With one exception, each difference is declared significant if it exceeds the corresponding least

significant range, otherwise it is declared not significant. This exception is that no difference between two means can be declared significant if the two means concerned are both contained in a larger subset with a nonsignificant range.

In detail:

				LSR	
otc 2 - otc 3	= 0.0644 - 0.0614	= 0.0030	>	0.00261	S
otc 2 - otc 1	= 0.0644 - 0.0615	= 0.0029	>	0.00256	S
otc 2 - otc 4	= 0.0644 - 0.0624	= 0.0020	<	0.00250	NS
otc 2 - otc 5	= 0.0644 - 0.0625	= 0.0019	<	0.00242	NS
otc 2 - otc 6	= 0.0644 - 0.0640	= 0.0004	<	0.00229	NS
otc 6 - otc 3	= 0.0640 - 0.0614	= 0.0026	>	0.00256	S
otc 6 - otc 1	= 0.0640 - 0.0615	= 0.0025	>	0.00250	S
otc 6 - otc 4	= 0.0640 - 0.0624	= 0.0016	<	0.00242	NS
otc 6 - otc 5	= 0.0640 - 0.0625	= 0.0015	<	0.00229	NS
otc 5 - otc 3	= 0.0625 - 0.0614	= 0.0011	<	0.00250	NS
otc 5 - otc 1	= 0.0625 - 0.0615	= 0.0010	<	0.00242	NS
otc 5 - otc 4	= 0.0625 - 0.0624	= 0.0001	<	0.00229	NS
otc 4 - otc 3	= 0.0624 - 0.0614	= 0.0010	<	0 00242	NS
otc 4 - otc 1	= 0.0624 - 0.0615	= 0.0009	<	0.00229	NS
otc 1 - otc 3	= 0.0615 - 0.0614	= 0.0001	<	0.00229	NS

The results may be stated:

a. The mean regularity of outcrop 2 is significantly different from (more rounded than) the mean regularity for outcrops 3 and 1 (table 1).

b. The mean regularity of outcrop 6 is significantly different from (more rounded than) the mean regularity for outcrops 3 and 1 (table 1).

INTERPRETATION

At McLendon volcano each pyroclastic outcrop used for regularity analysis was chosen based on its location (fig. 3) within the generalized volcanic facies zones described by Williams and McBirney (1979, p. 312) for other volcanic centers. Diagnostic features of these zones are:

central facies

- within 0.5 to 2 km of the central vent
- dikes that are radial or randomly oriented
- breccia pipes
- hydrothermal alteration
- steep dips
- thin lava flows that are volumetrically subordinate to fragmental ejecta

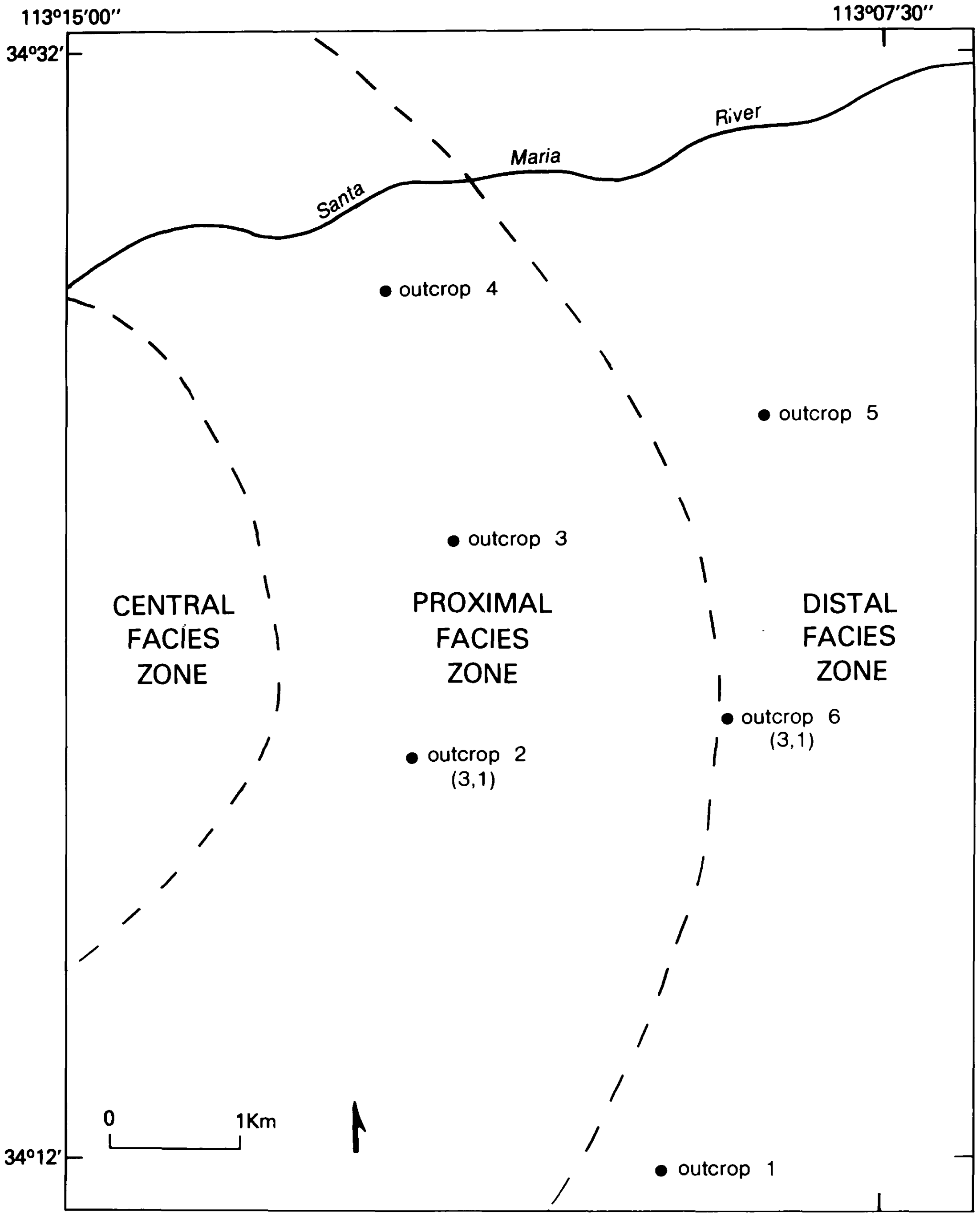


Figure 3.--Sampled pyroclastic outcrops showing facies zones (dashed lines) mapped on the basis of ratio of volcaniclastic to volcanic flow material as well as the size of the blocks within the volcaniclastic section (Williams and McBirney, 1979). Numbers within parentheses indicate the outcrops whose regularity means are significantly different from outcrops 2 and 6.

proximal facies

- from 5 to 15 km from the central vent
- broad, thick lavas
- lahars with angular or subangular blocks up to 10 m in diameter
- tephra layers with good sorting and grain sizes in the lapilli to coarse ash range
- clastic debris reworked by water
- ignimbrites with moderate to strong welding

distal facies

- more than 15 km from the central vent
- finely layered tephra
- lahars with blocks that rarely exceed 1 m in diameter and have rounded or sub-rounded particles in the matrix
- ignimbrites with moderate to weak welding

The above information shows a change in lahar clast size and matrix rounding with increased distance from the vent. Possibly, then, regularity would also change in a predictable manner. However, the mean regularities of 0.061 and 0.062 occur in both zones:

proximal facies

outcrop 2	mean regularity	0.064
outcrop 3	mean regularity	0.061
outcrop 4	mean regularity	0.062

distal facies

outcrop 1	mean regularity	0.061
outcrop 5	mean regularity	0.062
outcrop 6	mean regularity	0.063

The model of increased regularity with distance is not especially strong in this case, perhaps due to the limited number of outcrops that were studied or because of the irregular distribution pattern of the volcaniclastic rocks that may overlap, follow different channels, or originate from different elevations on the volcano. The addition of previously reworked material to the most recent deposit would also explain the variation within zones. The histograms on figure 4 indicate that the statistical interpretation to understanding mudflow regularity is not clear. Ideally, the most distal outcrops (5 and 6) should be the most regular (mean approaching 0.080), but outcrop 2, the most regular (mean regularity of 0.0644) is proximal, based on its up-dip location.

Other effects incurred during transport, and factors such as a tumbling and roller-ball effect in the vent area can also influence regularity. The relationship between regularity and distance of transport is unclear, but a larger number of samples taken in a known mud-flow source area would hopefully benefit evaluation of regularity as a source area predictor.

```
outcrop 1 (distal facies zone)
mean regularity = 0.061

.043-.044 x
.045-.046 -
.047-.048 -
.049-.050 -
.051-.052 xxx
.053-.054 xxxxx
.055-.056 xxxxxxxxx
.057-.058 xxxxxxxx
.059-.060 xxxxxxxxx
.061-.062 xxxxxx
.063-.064 xxxxxxxxxxxxxxxxxxx
.065-.066 xxxxxxxxxxxxx
.067-.068 xxxxx
.069-.070 xxxxxx
.071-.072 x
.073-.074 x

outcrop 2 (proximal facies zone)
mean regularity = 0.064

.047-.048 x
.049-.050 x
.051-.052 -
.053-.054 xxxx
.055-.056 xx
.057-.058 xxxxxx
.059-.060 xxx
.061-.062 xxxxxxxxxx
.063-.064 xxxxxx
.065-.066 xxxxxxxxxxxxxxxxxxx
.067-.068 xxxxxxxxxxxxxx
.069-.070 xxxxxxxxxxxxxx
.071-.072 xxxxx
.073-.074 x
.075-.076 x

outcrop 3 (proximal facies zone)
mean regularity = 0.061

.041-.042 xx
.043-.044 x
.045-.046 xx
.047-.048 x
.049-.050 -
.051-.052 xx
.053-.054 xxxxx
.055-.056 xxxxx
.057-.058 xxx
.059-.060 xxxxxxxxxxxxx
.061-.062 xxxxxxxxxxxx
.063-.064 xxxxxxxxxxxxxxxxx
.065-.066 xxxxxxxxxxx
.067-.068 x
.069-.070 xxxxxxx
.071-.072 xxxxxx
.073-.074 x
.075-.076 x

outcrop 4 (proximal facies zone)
mean regularity = 0.062

.045-.046 xx
.047-.048 x
.049-.050 xx
.051-.052 -
.053-.054 xx
.055-.056 xxxx
.057-.058 xxxxxxxxxx
.059-.060 xxxxxxxxxx
.063-.064 xxxxxxxxx
.065-.066 xxxxxxxxxx
.067-.068 xxxxxxxxxxxx
.069-.070 xxxxxx
.071-.072 xx
.073-.074 xxx
.075-.076 x

outcrop 5 (distal facies zone)
mean regularity = 0.062

.041-.042 x
.043-.044 -
.045-.046 -
.047-.048 -
.049-.050 -
.051-.052 -
.053-.054 xxxxxx
.055-.056 xxxxxxx
.057-.058 xxxxxxx
.059-.060 xxxxxxxx
.061-.062 xxxxxxxxxx
.063-.064 xxxxxxxxx
.065-.066 xxxxxxx
.067-.068 xxxxxxxxxxxxx
.069-.070 xxxxxx
.071-.072 xxx
.073-.074 xx
.075-.076 x

outcrop 6 (distal facies zone)
mean regularity = 0.064

.047-.048 x
.049-.050 xx
.051-.052 x
.053-.054 x
.055-.056 xxx
.057-.058 xxx
.059-.060 xxxxxxx
.061-.062 xxxxxxxxxxxxx
.063-.064 xxxxxxxxxxxxx
.065-.066 xxxxxxxxxxxxxxxxxx
.067-.068 xxxxxxxxxxxxxxx
.069-.070 xxxxxx
.071-.072 xxxxxx
.073-.074 x
```

Figure 4.--Histograms showing array of regularity values (A/P^2) at six outcrops of secondary pyroclastic rocks at McLendon volcano, Yavapai County, Ariz. For outcrop and facies zone locations, see figure 3.

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APPENDIX A

Area/Perimeter^2 Data Values

Outcrop 1

X	X	X	X
0.052	0.053	0.060	0.065
.053	.063	.055	.060
.067	.063	.064	.070
.068	.060	.066	.060
.056	.056	.055	.059
.067	.064	.055	.071
.057	.057	.066	.058
.064	.054	.064	.069
.064	.063	.061	.063
.056	.059	.056	.061
.066	.063	.070	.063
.066	.064	.052	.065
.055	.063	.065	.065
.052	.066	.063	.068
.057	.058	.070	.054
.059	.064	.065	.064
.054	.070	.062	.063
.062	.068	.062	
.066	.064	.057	
.060	.065	.063	
.044	.057	.065	
.062	.055	.074	
.057	.060	.070	

Outcrop 2

0.070	0.070	0.067	0.067
.065	.048	.056	.067
.066	.049	.068	.065
.065	.069	.065	.066
.071	.066	.064	.062
.061	.066	.068	.062
.065	.068	.067	.066
.063	.065	.069	.069
.062	.065	.053	.071
.064	.069	.065	.066
.059	.059	.063	.066
.058	.061	.067	.062
.071	.054	.070	
.067	.064	.063	
.057	.074	.066	
.069	.070	.067	
.069	.054	.065	
.060	.075	.065	
.062	.068	.070	
.061	.069	.072	
.069	.057	.066	
.067	.068	.056	
.062	.058	.062	
.071	.057	.068	
.070	.053	.057	

APPENDIX A--Continued

Outcrop 3

X	X	X	X
0.072	0.059	0.063	0.066
.072	.066	.064	.063
.063	.069	.072	.060
.064	.070	.065	.072
.051	.045	.064	.051
.071	.062	.064	.064
.071	.062	.063	.070
.063	.060	.057	.044
.061	.068	.060	.065
.055	.056	.062	.063
.070	.062	.041	.060
.061	.053	.055	.065
.066	.064	.041	.060
.060	.063	.061	.046
.047	.062	.061	.065
.069	.064	.062	
.064	.061	.066	
.053	.063	.060	
.062	.059	.060	
.070	.060	.055	
.059	.055	.066	
.054	.054	.063	
.073	.065	.057	
.070	.058	.075	
.059	.065	.054	

Outcrop 4

0.065	0.065	0.058	0.066
.068	.067	.056	.060
.073	.069	.061	.059
.072	.063	.064	.057
.062	.072	.057	.063
.056	.061	.068	.062
.059	.066	.056	.063
.069	.053	.063	.073
.067	.066	.064	.048
.064	.049	.059	
.060	.066	.054	
.076	.068	.059	
.061	.069	.060	
.049	.058	.068	
.046	.059	.058	
.065	.068	.056	
.062	.057	.058	
.061	.066	.067	
.067	.058	.065	
.060	.058	.061	
.064	.068	.061	
.070	.057	.070	
.067	.066	.060	
.062	.046	.067	
.073	.063	.070	

Outcrop 5

X	X	X	X
0.060	0.067	0.066	0.064
.066	.075	.060	.064
.057	.057	.056	.062
.062	.061	.055	.067
.070	.073	.061	.063
.069	.061	.057	
.056	.061	.065	
.067	.056	.066	
.054	.074	.059	
.062	.053	.065	
.053	.068	.064	
.058	.055	.053	
.069	.063	.067	
.058	.068	.065	
.067	.070	.064	
.060	.064	.061	
.059	.053	.070	
.042	.068	.066	
.059	.068	.058	
.071	.061	.059	
.060	.070	.068	
.063	.058	.072	
.055	.072	.067	
.054	.067	.064	
.056	.061	.067	

Outcrop 6

0.065	0.068	0.060	0.068
.066	.066	.070	.063
.068	.060	.062	.064
.063	.067	.067	.056
.072	.072	.065	.070
.057	.071	.066	.071
.065	.050	.059	.068
.063	.048	.065	.066
.063	.068	.072	.073
.066	.062	.054	.064
.063	.063	.063	.066
.050	.070	.062	.069
.059	.058	.070	.071
.066	.061	.062	.052
.062	.066	.067	.068
.068	.062	.064	
.060	.067	.069	
.060	.060	.068	
.065	.064	.058	
.066	.065	.062	
.065	.068	.055	
.061	.061	.062	
.061	.064	.067	
.068	.065	.065	
.062	.055	.064	