



Quantifying Grain Shape Characteristics and Fragmentation in Raw and Processed Frac Sand from Western Wisconsin



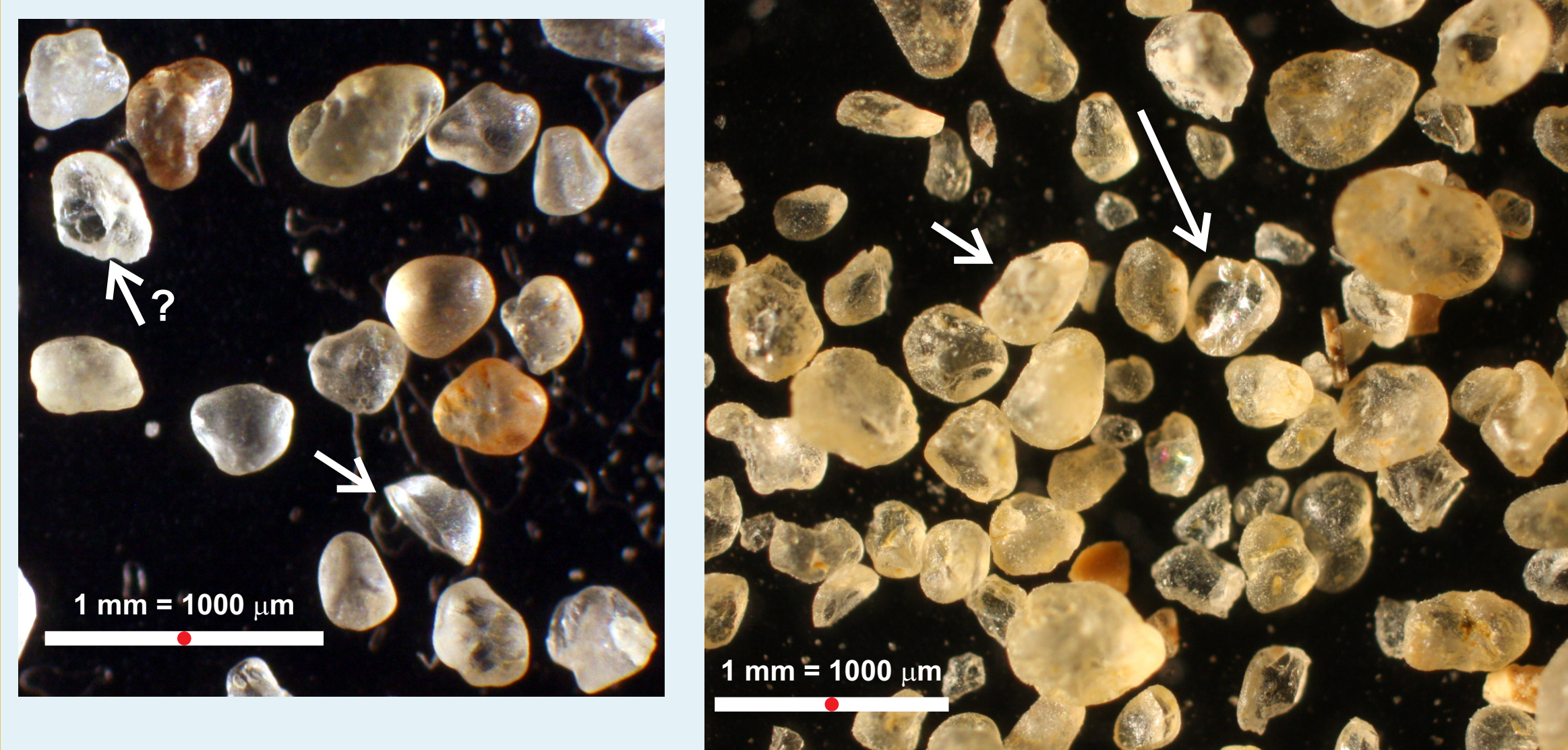
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Abstract

Different sand formations, including the Wonewoc and Jordan, are mined in western Wisconsin in part for frac sand, which is used in hydraulic fracturing for hydrocarbon extraction. Health concerns regarding frac sand mining exist in part due to the possible presence of fine grained respirable silica, which if inhaled by human lungs in high volumes over extended periods of time could cause a respiratory condition known as silicosis. One possible source for this respirable silica could be fracturing and fragmentation of sand grains during processing. To determine the extent of fracturing and fragmentation of sand grains, representative samples of raw and processed samples were analyzed manually and digitally. Samples were manually point-counted from different sand formations to determine a baseline for raw, unprocessed sand. Representative raw sand yield < 3.2% fractured grains while representative processed sand yield < 3.7% fractured grains. To further quantify characteristics of raw and processed sand including degree and size of fragmentation, digital image analysis techniques were utilized to examine grain shape characteristics, such as roundness, sphericity, circularity, and roughness. Comparing digital and manual results shows statistical similarity between the two methods. Digital image analysis allows for a rapid and more statistically robust of grain shape.

Manual Image Analysis

Point Counting Raw and Processed Sand Samples



Photomicrograph of Barron 40-70 processed sand (left) and unprocessed sand (right) that was carefully washed by hand. Note grain size range and grain shapes. Fractured grains and possible fractured grains are indicated by arrows. Grain fragmentation analyses determined by microscopic examination and identification of grain fragments and grains exhibiting "fresh" conchoidal fracture. Red dot in scale represents 60 μm, the smallest size analyzed digitally.

Counts	Value	%	Normalized %
182	No	60.7	98.4
3	Yes	1.0	1.6
115	Void	38.3	
300	Sum	100.0	

Counts	Value	%	Normalized %
220	No	73.33	97.78
8	Yes	2.7	3.7
82	Void	27.3	
300	Sum	100.0	

Counts	Value	%	Normalized %
187	No	62.3	99.5
1	Yes	0.3	0.5
112	Void	37.3	
300	Sum	100.0	

Counts	Value	%	Normalized %
184	No	61.33	95.83
8	Yes	2.67	4.17
108	Void	36	
300	Sum	100	

Counts	Value	%	Normalized %
220	No	73.33	97.78
5	Yes	1.67	2.22
75	Void	25	
300	Sum	100	

Counts	Value	%	Normalized %
202	No	67.33	97.58
5	Yes	1.67	2.42
93	Void	31	
300	Sum	100	

Counts	Value	%	Normalized %
253	No	84.3	99.6
1	Yes	0.33	0.5
101	Void	33.67	
300	Sum	100	

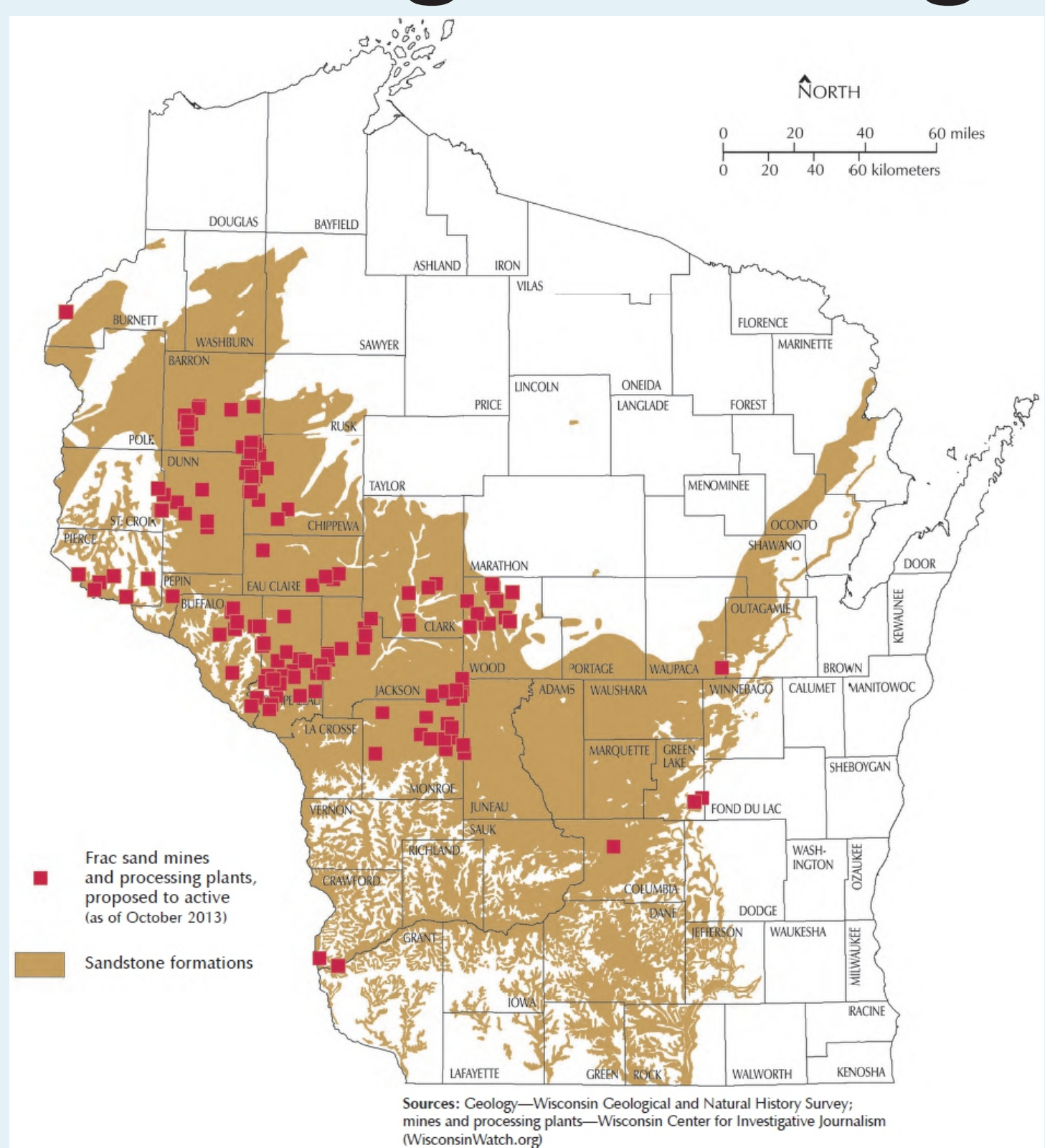
Counts	Value	%	Normalized %
198	No	66	99.5
1	Yes	0.33	0.5
101	Void	33.67	
300	Sum	100	

Counts	Value	%	Normalized %
73	No	24.33	97.3
2	Yes	0.67	2.7
225	Void	75	
300	Sum	100	

Counts	Value	%	Normalized %
98	No	32.67	98
2	Yes	0.67	2
200	Void	66.67	
300	Sum	100	

Counts	Value	%	Normalized %
152	No	50.67	95
8	Yes	2.67	5
140	Void	46.67	
300	Sum	100	

Geologic Setting



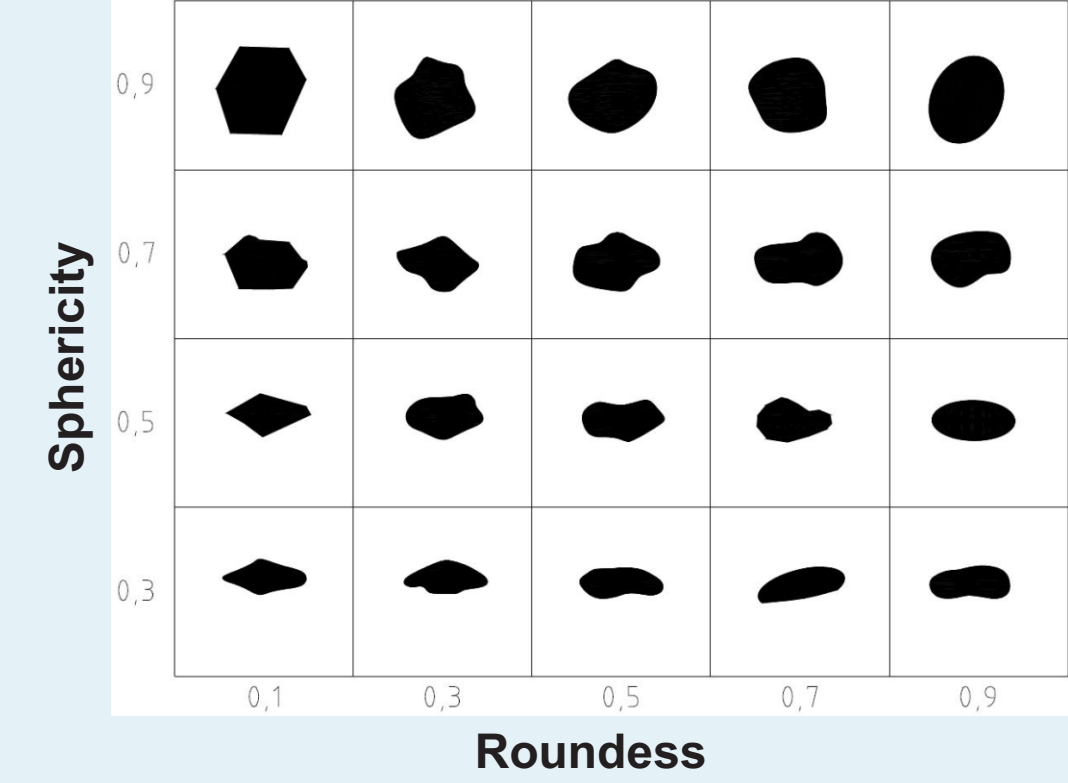
The map above shows a simplified distribution of sedimentary strata deposited in the Cambrian unconformably on top of Precambrian basement (Mahoney et al., 2014). The Cambrian strata consist of several medium to coarse grained sandstone formations including the Wonewoc and Jordan Formations. These two formations are the primary targets in western Wisconsin for frac sand. This sand is mined and processed for use in the petroleum industry for hydraulic fracturing (i.e., fracking). Samples analyzed in this study come from both the Wonewoc and Jordan Formations.

To quantify fractured grains in both raw and processed samples, statistical point-count analyses were performed. Grain mounts were made by pouring an aliquot of sand onto a petrographic slide containing double-sided tape. Petrographic slides were analyzed at 2x magnification using a Petrog digital stepping microscope stage. The stepping stage was configured to allow at least 300 grains per sample to be analyzed on a grid system. At each point, visual inspection determined whether a grain was fractured or not. Data is summarized in the tables above.

Manual Image Analysis Summary

Sample	# of Grains	Axial Ratio	IC Sphericity
40-70-1	350	1.36	0.86
40-70-2	350	1.41	0.85
40-70-3	330	1.37	0.86
40-70-avg	343	1.38	0.86
30-50-1	330	1.38	0.86
30-50-2	290	1.38	0.86
30-50-3	286	1.35	0.87
30-50-avg	302	1.37	0.86
RO-5-12-1	350	1.47	0.84
RO-5-12-2	350	1.40	0.86
RO-5-12-3	340	1.44	0.85
RO-5-12-avg	347	1.44	0.85
Bay City-1	330	1.31	0.89
Bay City-2	350	1.35	0.87
Bay City-3	315	1.35	0.87
Bay City-avg	332	1.34	0.88

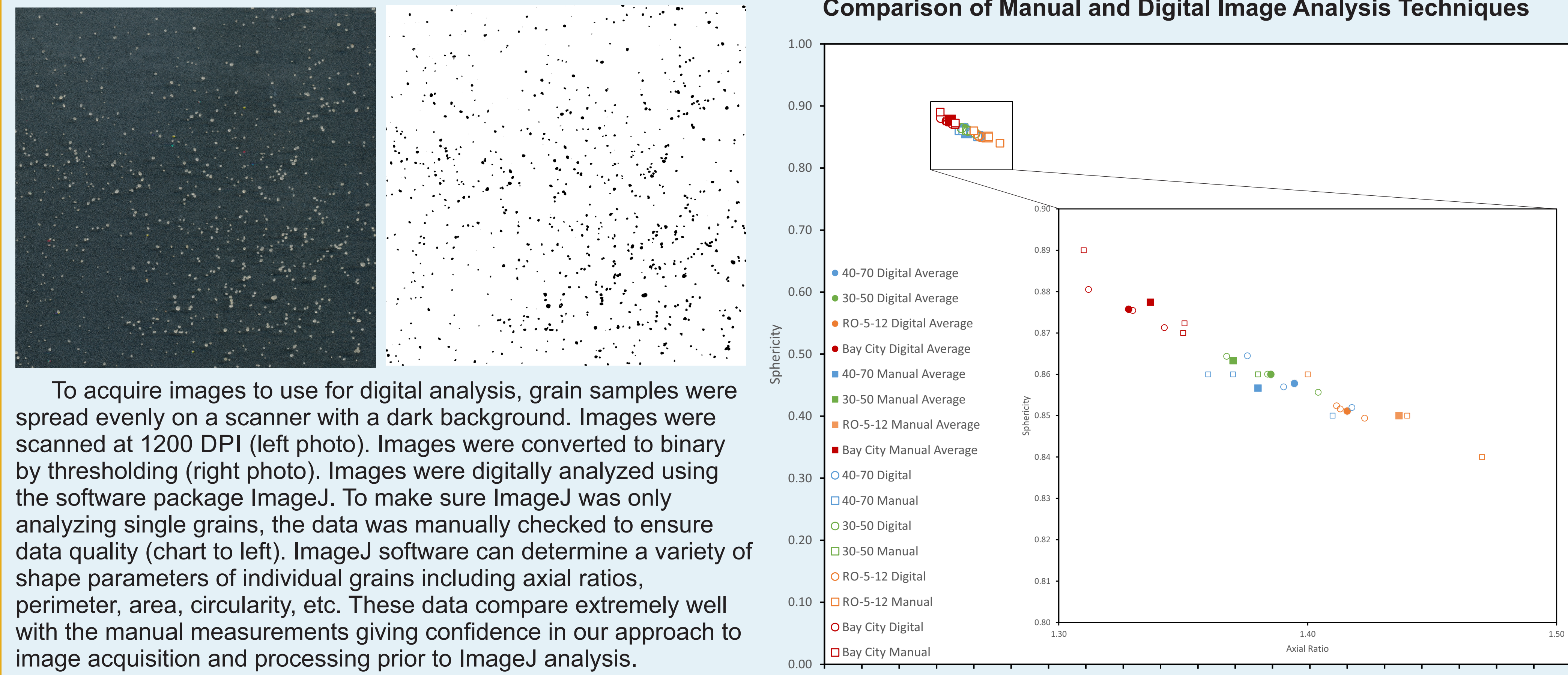
Visual Determination of Sand Grain Sphericity and Roundness



The x and y-axes of a minimum of 250 grains were measured and used to calculate the grain axial ratios and sphericity manually for a subset of samples.

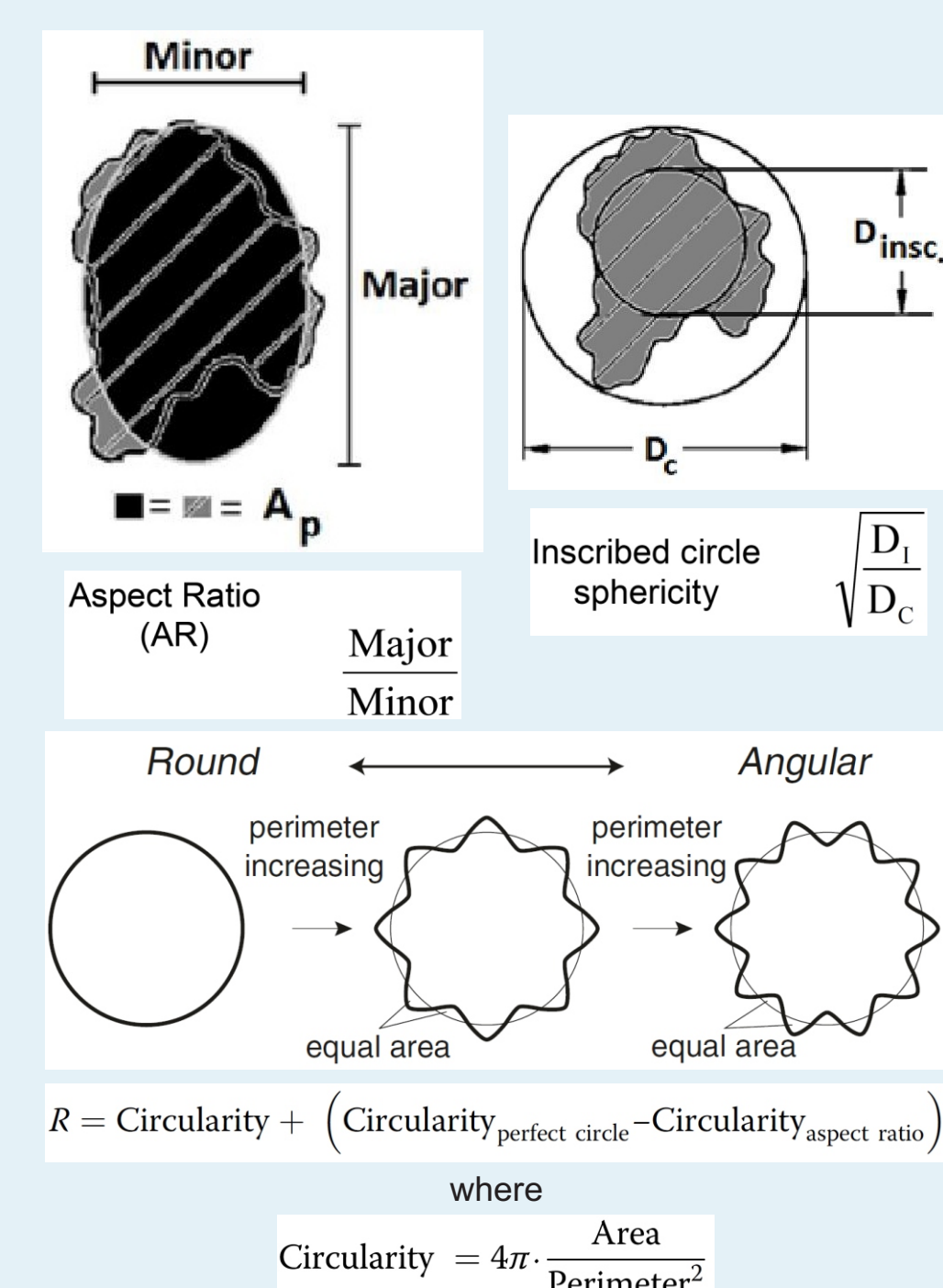
Frac Sand Shape Characteristics and Fragmentation

Comparison of Manual and Digital Image Analysis Techniques



To acquire images to use for digital analysis, grain samples were spread evenly on a scanner with a dark background. Images were scanned at 1200 DPI (left photo). Images were converted to binary by thresholding (right photo). Images were digitally analyzed using the software package ImageJ. To make sure ImageJ was only analyzing single grains, the data was manually checked to ensure data quality (chart to left). ImageJ software can determine a variety of shape parameters of individual grains including axial ratios, perimeter, area, circularity, etc. These data compare extremely well with the manual measurements giving confidence in our approach to image acquisition and processing prior to ImageJ analysis.

Parameters Used to Quantify Grain Shape Characteristics of Frac Sand



The images and equations above represent those used in manual and digital image analysis calculations both for comparison of manual and digital techniques and for general characterization of frac sand grain shapes.

The image to the right is an example of an individual fractured grain chosen for image analysis to compare the grain shape characteristics of the entire population of grains to the grain shape characteristics of **only** fractured grains. Data from all analyses summarized in tables to the left.

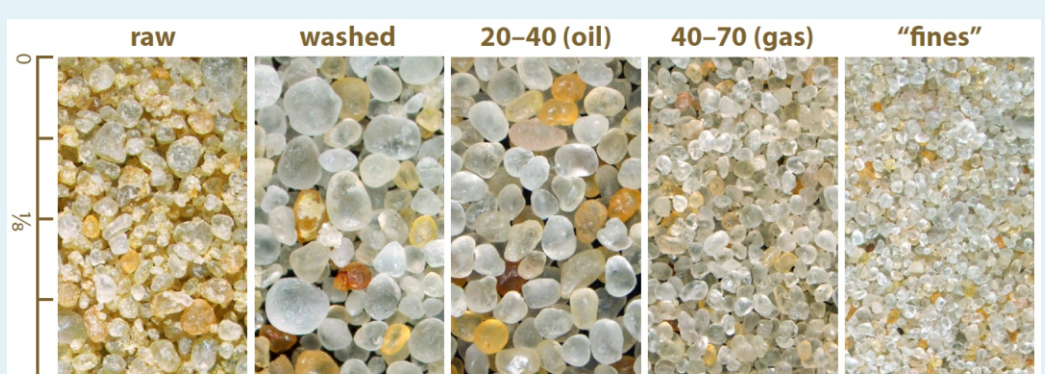
Sample	# of Grains	Axial Ratio	IC Sphericity	Roundness	Roundness (2016)
40-70-1	1431	1.38	0.86	0.75	0.90
40-70-2	874	1.39	0.86	0.74	0.91
40-70-3	947	1.42	0.85	0.73	0.91
40-70-avg	1084	1.39	0.86	0.74	0.91
30-50-1	646	1.38	0.86	0.75	0.90
30-50-2	489	1.40	0.86	0.74	0.89
30-50-3	436	1.37	0.86	0.75	0.89
30-50-avg	524	1.39	0.86	0.75	0.89
RO-5-12-1	861	1.41	0.85	0.73	0.93
RO-5-12-2	1747	1.41	0.85	0.73	0.93
RO-5-12-3	1334	1.42	0.85	0.73	0.92
RO-5-12-avg	1314	1.42	0.85	0.73	0.93
Bay City-1	977	1.34	0.87	0.76	0.91
Bay City-2	1007	1.31	0.88	0.78	0.91
Bay City-3	667	1.33	0.88	0.77	0.91
Bay City-avg	884	1.33	0.88	0.77	0.91
SES 20-40-1	209	1.24	0.90	0.82	0.99
SES 20-40-2	226	1.31	0.88	0.78	0.90
SES 20-40-3	217	1.30	0.89	0.79	0.90
SES 20-40-avg	217	1.29	0.89	0.79	0.93
SES 30-50-1	534	1.28	0.89	0.80	1.01
SES 30-50-2	223	1.32	0.88	0.78	0.90
SES 30-50-3	220	1.32	0.88	0.78	0.91
SES 30-50-avg	326	1.30	0.88	0.79	0.94
W 20-40-1	452	1.28	0.89	0.80	1.01
W 20-40-2	363	1.29	0.89	0.79	1.01
W 20-40-3	373	1.24	0.91	0.83	1.01
W 20-40-avg	396	1.27	0.90	0.81	1.01
W 35-1	428	1.22	0.91	0.84	1.01
W 35-2	288	1.23	0.91	0.84	1.01
W 35-3	368	1.23	0.91	0.84	1.01
W 35-avg	361	1.22	0.91	0.84	1.01
W 45-50-1	346	1.18	0.93	0.87	1.01
W 45-50-2	346	1.19	0.93	0.86	1.01
W 45-50-3	426	1.21	0.92	0.85	1.01
W 45-50-avg	373	1.19	0.93	0.86	1.01
Fractured Grains	50	1.44	0.84	0.72	0.81

Sample	# of Grains	Axial Ratio	IC Sphericity	Roundness	Roundness (2016)
40-70-avg	1084	1.39	0.86	0.74	0.90
30-50-avg	524	1.39	0.86	0.75	0.89
RO-5-12-avg	1314	1.42	0.85	0.73	0.93
Bay City-avg	884	1.33	0.88	0.77	0.91
SES 20-40-avg	217	1.29	0.89	0.79	0.93
SES 30-50-avg	326	1.30	0.88	0.78	0.94
W 20-40-avg	396	1.27	0.90	0.81	1.01
W 35-avg	361	1.22	0.91	0.84	1.01
W 45-50-avg	373	1.19	0.93	0.86	1.01
Fractured Grains	50	1.44	0.84	0.72	0.81

Grains	AR	Round	IC Sphericity	Roundness (2016)
SES 50-140-23	1.08	0.93	0.97	0.86
SES 50-140-28	1.04	0.97	0.98	0.81
SES 50-140-31	1.58	0.63	0.80	0.79
SES 50-140-41	1.23	0.81	0.90	0.82
SES 50-140-48	1.68	0.59	0.77	0.81
Average	1.32	0.79	0.88	0.82
SES 40-70-59	1.55	0.64	0.80	0.84
SES 40-70-67	1.47	0.68	0.82	0.82
SES 40-70-75	1.38	0.72	0.85	0.86
SES 40-70-76	1.55	0.65	0.80	0.79
SES 40-70-81	1.41	0.71	0.84	0.85
Average	1.47	0.68	0.82	0.83
SES 20-40-82	1.40	0.72	0.85	0.80
SES 20-40-84	1.56	0.64	0.80	0.76
SES 20-40-88	1.41	0.71	0.84	0.85
SES 20-40-92	1.24	0.80	0.90	0.80
SES 20-40-95	1.09	0.92	0.96	0.83
Average	1.34	0.76	0.87	0.81
SES 30-50-98	2.02	0.50	0.70	0.85
SES 30-50-9	1.23	0.82	0.90	0.78
SES 30-50-14	1.14	0.88	0.94	0.80
Average	1.46	0.73	0.85	0.81
Washed 20-40-19	1.33	0.76	0.87	0.78
Washed 20-40-25	1.93	0.52	0.72	0.72
Washed 20-40-30	1.23	0.81	0.90	0.77
Average	1.49	0.70	0.83	0.76
Washed 35-150-31	1.45	0.69	0.83	0.74
Washed 35-150-35	1.32	0.76	0.87	0.82
Washed 35-150-43	2.05	0.49	0.70	0.85
Washed 35-150-44	0.89	0.53	0.73	0.77
Washed 35-150-48	1.81	0.55	0.74	0.82
Average	1.70	0.60	0.77	0.80
Washed 45-50-54	1.18	0.85	0.92	0.82
Washed 45-50-62	2.18	0.46	0.68	0.83
Washed 45-50-63	1.20	0.84	0.91	0.81
Washed 45-50-66	1.58	0.63	0.80	0.79
Average	1.53	0.69	0.83	0.81
Barron 40-70-1	1.55	0.65	0.80	0.83
Barron 40-70-5	1.60	0.63	0.79	0.80
Barron 40-70-15	1.19	0.84	0.92	0.72
Average	1.45	0.70	0.84	0.78
Barron 30-50-25	1.38	0.73	0.85	0.82
Barron 30-50-28	1.13	0.89	0.94	0.82
Barron 30-50-29	1.07	0.94	0.97	0.78
Average	1.19	0.85	0.92	0.81
Bay City-35	1.34	0.75	0.87	0.83
Bay City-40	1.48	0.68	0.82	0.83
Bay City-41	1.17	0.86	0.92	0.84
Bay City-42	2.13	0.47	0.68	0.82
Bay City-44	1.53	0.65	0.81	0.74
Bay City-47	1.36	0.74	0.86	0.72
Bay City-48	1.47	0.68	0.83	0.84
Average	1.50	0.69	0.83	0.80
RO-5-12-50	1.42	0.70	0.84	0.82
RO-5-12-53	1.44	0.70	0.83	0.79
RO-5-12-56	1.15	0.87	0.93	0.87
RO-5-12-58	1.32	0.76	0.87	0.75
RO-5-12-59	1.50	0.67	0.82	0.86
RO-5-12-60	1.26	0.79	0.89	0.85

Purpose

This study addresses whether sand grains are fractured during processing (crushing/washing) for use in frac sand applications. Specifically whether the shape characteristics of raw, unprocessed sand are significantly different than sand that has been processed (washed/dried/sorted). Another aspect of this study is to determine if digital analysis is a faster and more effective method to quantitatively analyze sand grain shapes compared to industry standard visual analysis.



Summary

- Manual and digital image analysis of grains using ImageJ software are statistically identical. This result indicates that other grain parameters can be effectively acquired digitally to calculate grain shape characteristics that are not easily accessible manually.
- Point counting data indicates "fresh" fracturing of raw sand grains is minimal and processed sand grains is minor (<4%) suggesting no significant fracturing of grains during industrial processing.
- Visual estimates of fractured grains indicates that fragments are generally large (>100 μm) which are not respirable.
- Data for shape characteristics from digital image analysis of fractured grains, where both sphericity and particularly roundness are statistically different than the entire population, suggests that using this technique and these parameters on raw and processed samples could determine whether grains are being fractured during processing.

References

Mahoney, Brian J., Syverson, Kent M., Runkel, Anthony C., Industrial Sand Deposits in Western Wisconsin: Geology, Resource Distribution and Extraction Techniques, 2014, SME Guidebook, SME Wisconsin Annual Conference.
Particle Size Analysis Standard Operating Protocol, Dune Sciences, Inc., 2011, www.dunesciences.com
Rasband, W.S., ImageJ, U. S. National Institutes of Health, Bethesda, Maryland, USA, <http://imagej.nih.gov/ij/>, 1997-2014.
Recommended Practice for Measurement of and Specifications for Proppants Used in Hydraulic Fracturing and Gravel-packing Operations, API Recommended Practice 19C, American Petroleum Institute, 2014.
Rodriguez, J.M., Johansson, J.M.A., Edeskar, T., 2012, Particle Shape Determination by Two-Dimensional Image Analysis in Geotechnical Engineering, Proceedings of Nordic Conference on Soil Mechanics and Geotechnical NGM. Vol. 207. Copenhagen.
Takashimizu, Yasuhiro and Liyoshi, Maiko, 2016, New Parameters of Roundness R: Circularity Corrected by Aspect Ratio, Progress in Earth and Planetary Science, 3:2.
Wisconsin Geological and Natural History Survey, 2014, Frac Sand in Wisconsin, Factsheet 05.

