Size and shape measurements of ash particles from the May 18, 1980 eruption of Mount St. Helens

by

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Open File Report 81-114
1980

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Abstract

An automatic image analyzer was used to measure size and shape characteristics of air-fall ash from the May 18, 1980 eruption of Mount St. Helens. Nineteen samples collected at distances of approximately 100 to 800 km downwind from Mount St. Helens were provided by personnel of WRD. All samples were collected on May 18-21 and most were documented to have been untouched by rain. Grain size determined as the longest horizontal projected diameter ranges from below the 2 micrometer detection limit to approximately 0.75 mm. Abundant sub-micrometer-sized particles are present as (electrostatically attracted?) surface coatings on larger grains. Mean grain diameters for coarse-grained fractions (>63 micrometers) range from 183 to 93 micrometers and show the expected inverse correlation with downwind distance from source. Likewise, the mass fraction represented by particles greater than 63 micrometers diameter decreases from 87 to 06 weight percent. Differential rates of settling of particles are not indicated by changes in the mean diameter of the fine-grained size fraction (2 to 63 micrometers) because of the dominant numbers of particles of 2 to 10 micrometer diameter. Size frequency histograms indicate at least a bimodal size distribution with peaks at 80-125 and 2-8 micrometers. Grain shape measurements (Area/Perimeter2) interpreted as the degree of circularity indicate a statistically significant difference between the means of the two measured size fractions. Fine-grained particles are distinctly more angular and/or elongate. This observation and the bimodal size distribution of ash suggest that fine-grained particles are produced by abrasion of larger particles during gaseous transport in the volcanic plume.

Introduction

Size and shape measurements of air-fall ash from erupting volcanoes provide basic data for modeling the mechanics of particle transport and interaction in a turbulent volcanic plume as it moves downwind. Such measurements are particularly useful when performed on size fractions which can also be separated by physical means and measured for mass and/or volume distributions. In addition, rapid and accurate estimates of grain size and shape are critical for evaluating the environmental impact of air-fall ash because grain size and shape influence the rate of post-depositional transport and diagenetic alteration of ash. Finally, size distribution data combined with mineralogical and chemical estimates of uncombined crystalline silica (quartz, cristobalite, tridymite) allow assessment of the respiratory hazards from air-fall ash (Fruchter and others, 1980).

This study reports measurements of grain size (longest projected horizontal diameter) and shape (area/perimeter^2) performed in air-fall ash from the May 18, 1980, eruption of Mount St. Helens. Grain mounts on glass slides were observed through a standard petrographic microscope which is interfaced to a computer-based quantitative image analysis system (Quantimet 720, see below). This method offers many advantages over previously used methods of grain size measurement such as manual petrographic observation, bulk sample sieving and sedimentation. Many individual grains from a particular sample may be analyzed in an accurate, rapid, systematic way which minimizes subjective judgements by the analyst. Large amounts of accumulated size and shape data are then statistically analyzed by associated computer programs. Measurement of volcanic ash is a relatively new geologic application of this system (Zielinski, 1977, 1979; Fruchter and others, 1980) which has been previously used in sedimentological studies (Carver, 1971; Seeland, 1976; Sawyer, 1977). It is hoped that this report will stimulate interest in the use of image analysis for the study of volcanic processes and products.

Sample Locations and Collection

Nineteen samples were collected at distances of approximately 100 to 800 km downwind from Mount St. Helens at localities in Washington, northern Idaho and western Montana (fig. 1). All samples were collected by personnel of the Water Resources Division (WRD) of the U.S. Geological Survey on May 18-21, 1980. For purposes of other studies, most samples were documented to have been free from post-eruptive contact with water. Sampling sites and collection procedures were chosen to minimize contamination of ash by soil or dust. Ash collection sites included plastic boat covers, vehicle hoods and roofs of tall buildings. Samples were stored in sealed plastic bags or polyethylene bottles for shipment to WRD labs in Denver.

Fig. 1

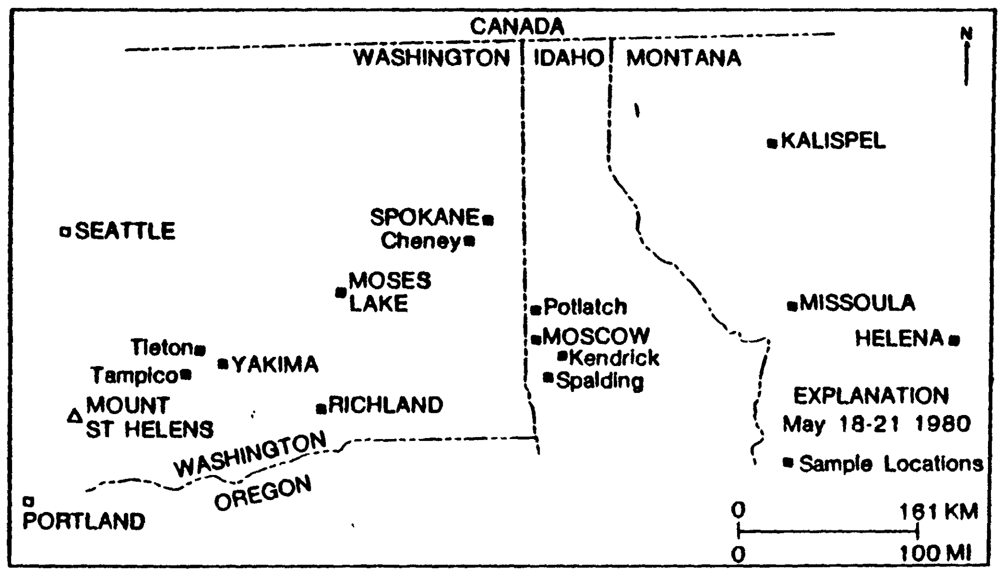

Figure 1: Sample locations.

Automatic Image Analyzer

A block diagram (fig. 2) and photograph (fig. 3) illustrate the principal components of the USGS automatic analysis system. Patterns of data flow are indicated in figure 2 by arrows connecting the various components. Measurements are made by a television scanner with a theoretical output of 720 scan lines. Each scan line is subdivided into 1024 measuring units called picture points (p.p.) which are square and touch at the edges. In practice, some picture points are lost in setting up the image and the actual video output is approximately 600,000 $(p.p.)^2$ in area. Only the central portion of this area is used for measurements. A complex logic system treats grains which fall partially outside the area of measurement, so as to avoid "edge errors" (Sawyer, 1977).

Grains are detected according to their shade of gray in the televised image. Settings are adjusted to optimize the degree of shading contrast between grains and background. The analyst may constantly monitor the fields of instrumentally detected image (grains) and undetected image (background) to verify the detection accuracy of the system.

Intersections of scan lines with each object of the proper shading (grains) are measured in picture points. Picture point sizes are calibrated according to the magnification of the microscope and may be automatically converted to micrometers, millimeters, etc. Grain dimensions which can be measured include area, perimeter and six types of diameter. In this study, horizontal Feret diameters were measured. The horizontal Feret diameter is the length of the projection of the detected left and right extremes of a grain onto a horizontal axis.

Up to 500 grains/sample may be measured. In addition, values of the mean, standard deviation, variance, skewness and kurtosis are calculated and printed. Additional programming provides for the plotting of size or shape distribution histograms. Data are stored on magnetic tape cassettes. For further details of the automatic image analysis system see Sawyer, 1977.

fig. 2

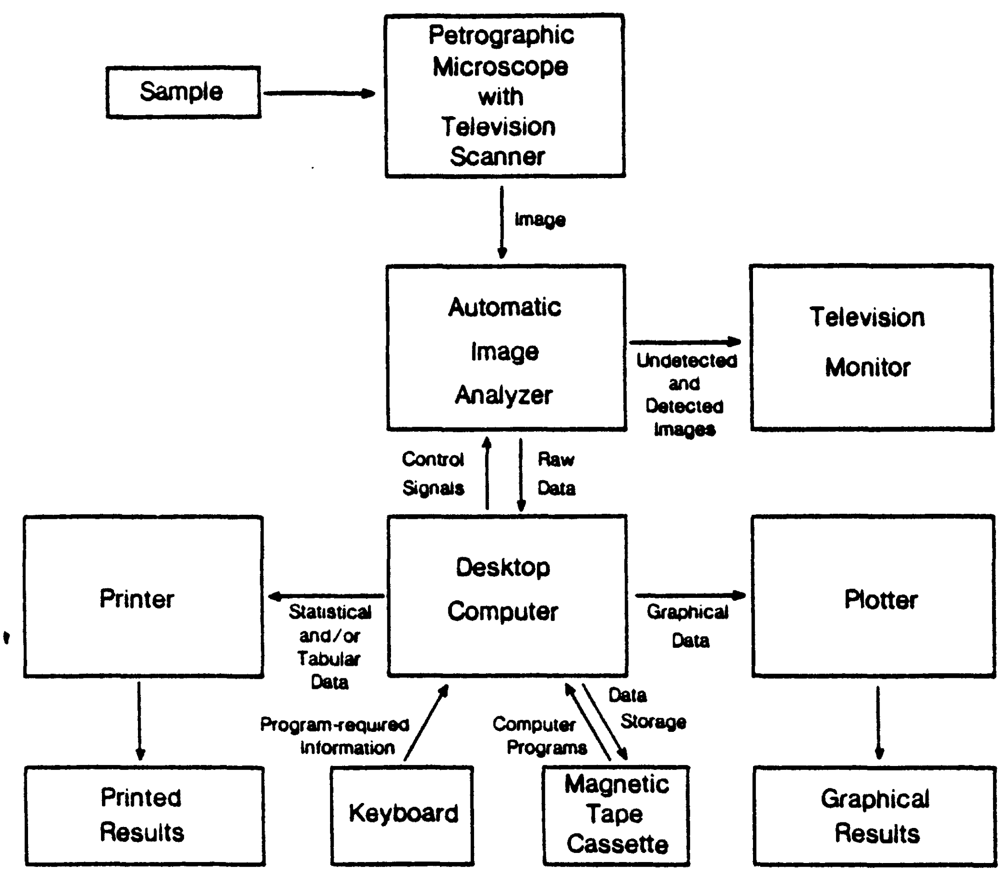

Figure 2: Block diagram of the USGS automatic image analysis system showing patterns of data flow.

Fig. 3

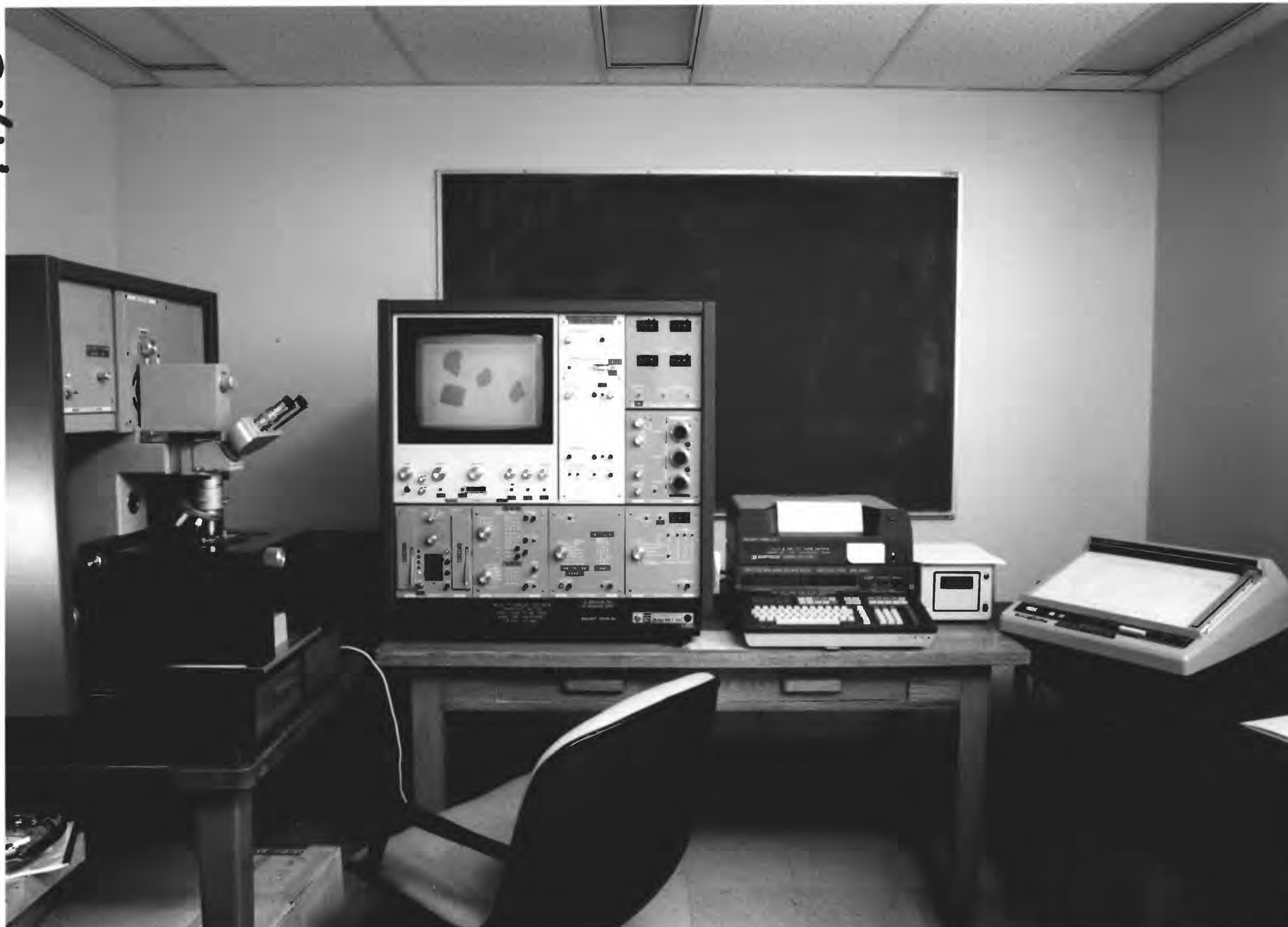

Figure 3: Photograph of the USGS automatic image analysis system.

Analytical Procedure

Preliminary qualitative examination of ash samples with both optical microscope and scanning electron microscope (SEM) indicated a very wide range of grain sizes in each sample. Typical sizes ranged from fractions of a millimeter to fractions of a micrometer. Most of the sub-micrometer-sized particles were present as (electrostatically attracted?) surface coatings on larger grains rather than as discrete particles. No particle diameters smaller than approximately 2 micrometers were measured in this study because picture point sizes at the highest practical magnification (400X) become a significant fraction of the grain diameter (approximately 10 percent) thereby reducing the accuracy and precision of measurements. In addition, shape measurements of very small grains under high magnification are complicated by light refraction at grain edges, which alters shading contrasts between grain and background and which can cause erroneous measurements of area and/or grain perimeter.

Quantitative measurements of grains with diameters greater than 2 micrometers were performed at two magnifications. Grains of 2-63 micrometers diameter were measured at 400X and grains larger than 63 micrometers at 25X. In each case, the lower limit of size measurement was set instrumentally. Upper limits of size measurement at a given magnification were reached when the horizontal diameter of grains equalled the horizontal dimension of the field of view. At 400X this was approximately 60 micrometers. Size discrimination at 63 micrometers was also performed by sieving 1-g samples with a stainless steel Tyler mesh screen of 250 mesh (63 micrometers) opening. Sieved fractions were weighed to determine their contribution to the total sample weight. In order to assure adequate representation of the proper size range on a given grain mount, measurements were performed on the coarse-grained fractions (25X) and on mounts of the original sample (400X).

Each sample was split with a microsplitter to obtain amounts which provided good coverage of a standard 25 to 75 mm petrographic slide while minimizing grain-to-grain contact. The typical amount of material mounted was <30 mg. Coarse-grained fractions of >63 micrometer grain diameter were mounted by simply sprinkling onto the slide from a piece of waxed weighing paper. Care was taken to mount the entire split. Whole-ash samples of predominantly finer particle size were mounted as a slurry of ethyl acetate from an eye dropper. This procedure was necessary to reduce interparticle contact caused by electrostatic attraction. Limited testing with different organic solvents showed ethyl acetate to perform better as a mounting medium than acetone or benzene.

A total of 300 grains/sample were measured for size determinations and 100 grains/sample for shape measurements. Care was taken to count grains from widely spaced areas on the glass slide. Problems with individual grains such as grain-grain contact or erroneously detected grain areas or perimeters could generally be avoided by careful monitoring of the viewing screen and the detected image. Problem grains could be avoided by repositioning the field of view so as to exclude them from detection. Average time for measurement of 300 grains was about 20 minutes, including data printout and statistical analysis.

Results and Discussion

Grain size determined as the longest horizontal projected diameter ranged from below the 2 micrometer detection limit to approximately 0.75 mm (table 1). Mean grain sizes for coarse-grained fractions (>63 micrometers) ranged from 183 to 93 micrometers and show the expected inverse correlation with downwind distances from source (fig. 4). The data indicate a much slower rate of change of mean particle size with distance at distances beyond 400 km, and reflect the removal of most of the coarser particles of this size fraction. The mass fraction represented by particles greater than 63 micrometers diameter also decreases with distance in a parallel manner and appears to stablize at about 5-10 weight percent at distances of 400 to 800 km downwind (fig. 5). Mean diameters of ash particles of the 2 to 63 micrometer size fraction range from about 4 to 7 micrometers with no obvious relation to distance from source (fig. 6). Values for samples collected in and around Spokane, Wash., at 400 km distance encompass almost the entire range of measured means. In the case of dominantly fine-grained samples, means based on measurements of a fixed number of grains (grain count) are heavily weighted by the dominant numbers of particles of 2 to 10 micrometer diameter which represent small fractions of the sample volume and mass (this study, table 1; Fruchter and others, 1980). The data of figure 6 and perhaps figure 4 (at distances > 400 km) provides little indication of the differential rates of settling of fine-grained particles because of the buffering effect of dominant numbers of smallest particles. Grain size distribution histograms that are dominated by smaller sizes are typical for most measured size fractions (fig. 7a-g).

Analytical precision was determined by replicate measurements performed on the same grain mount as well as an additional grain mount. Estimated analytical precision is reported as ± 1 standard deviation of the replicated means (figs. 4,5,6). Some pairs of samples collected around Spokane have differences in mean grain size that exceed the estimated analytical precision (± 1 sigma). This may reflect size fractionation occurring during ash transport, deposition, and field sampling. Poorer analytical precision for the coarse-grained size fraction from Tampico, Wash. (124 km), reflects the influence of a sizable but variable subset of larger grains (0.25-0.75 mm) which exert disproportionate influence on calculated mean diameters. In this case, the number of large grains and the differences between grain sizes are large enough that the mean value is not effectively buffered by greater numbers of smaller grains. Coarse-grained fractions affected by a significant subpopulation of large grains exhibit a bimodal size distribution histogram (fig. 7a). Bimodality of coarse-grained fractions was most clearly observed in the samples collected closest to source.

Although the shapes of histogram graphs are somewhat dependent upon the size of the class interval and the choice of limiting values, measured size fractions (2 to 63 micrometers; >63 micrometers) suggest that most of the measured ash samples have at least bimodal size distributions with peaks at 2-8 micrometers and 80-125 micrometers. This tendency to bimodality was confirmed by measured size distribution histograms of whole-ash samples which spanned the size range between the two postulated peaks (fig. 7c). As expected, near-source samples with larger numbers of coarse grains were best for exhibiting bimodality on a grain count basis. Size bimodality may reflect fine abrasion of surfaces of large grains during eruption and transport.

Table 1.--Mean diameter and mass fraction of two size fractions of Mount St. Helens Ash

Leaders denote no data

Sample No.	Location	Straight Line Distance from Mount St. Helens (Km)[1]	2 to 63 micrometers Wt. percent[2]	2 to 63 micrometers Mean Diameter (micrometers)	>63 micrometers Wt. percent	>63 micrometers Mean Diameter[3] (micrometers)
MSH 1-80	Spokane, WASH.	404	86	4.24	14	102.9
2-80	"	"	73	4.08	27	100.3
3-80	"	"	83	6.33	17	101.3
4-80	"	"	86	5.73	14	113.0
4-80(repeat)	"	"	85	6.56	15	111.8
4-80(repeat)	"	"	84	----	16	102.7
5-80	Moses Lake, WASH.	245	63	6.66	37	150.1
6-80	Helena, MONT.	783	94	6.47	06	98.5
7-80	Tampico, WASH.	124	13	5.65	87	103.2
7-80(repeat)	"	"	--	----	--	153.0
7-80(repeat)	"	"	--	----	--	160.1
8-80	Spokane, WASH.	404	85	4.92	15	107.4
9-80	Richland, WASH.	222	28	4.44	72	155.4
10-80	Tampico, WASH.	124	14	5.08	86	160.7
11-80	Kalispel, MONT.	---	--	5.45	--	-----
12-80	Spalding, IDAHO	---	--	6.94	--	-----
13-80	Cheney, WASH.	370	81	5.17	19	111.5
14-80	Moscow, IDAHO	402	86	6.00	14	101.6
15-80	Missoula, MONT.	630	92	6.35	08	93.0
16-80	Potlatch, IDAHO	413	93	5.82	07	97.6
17-80	Kendrick, IDAHO	428	90	6.11	10	102.2
18-80	Tieton, WASH.	141	23	5.72	77	170.5
19-80	Spokane, WASH.	404	84	4.14	16	103.4

[1] Straight line distance estimates provided by the F.A.A.

[2] Mass fraction of grains less than 2 micrometers in diameter is assumed negligible and is included in these figures.

[3] Grain sizes typically ranged upwards to fractions of a mm. Largest grain observed was .79 mm(Tampico, WA.).

fig. 4

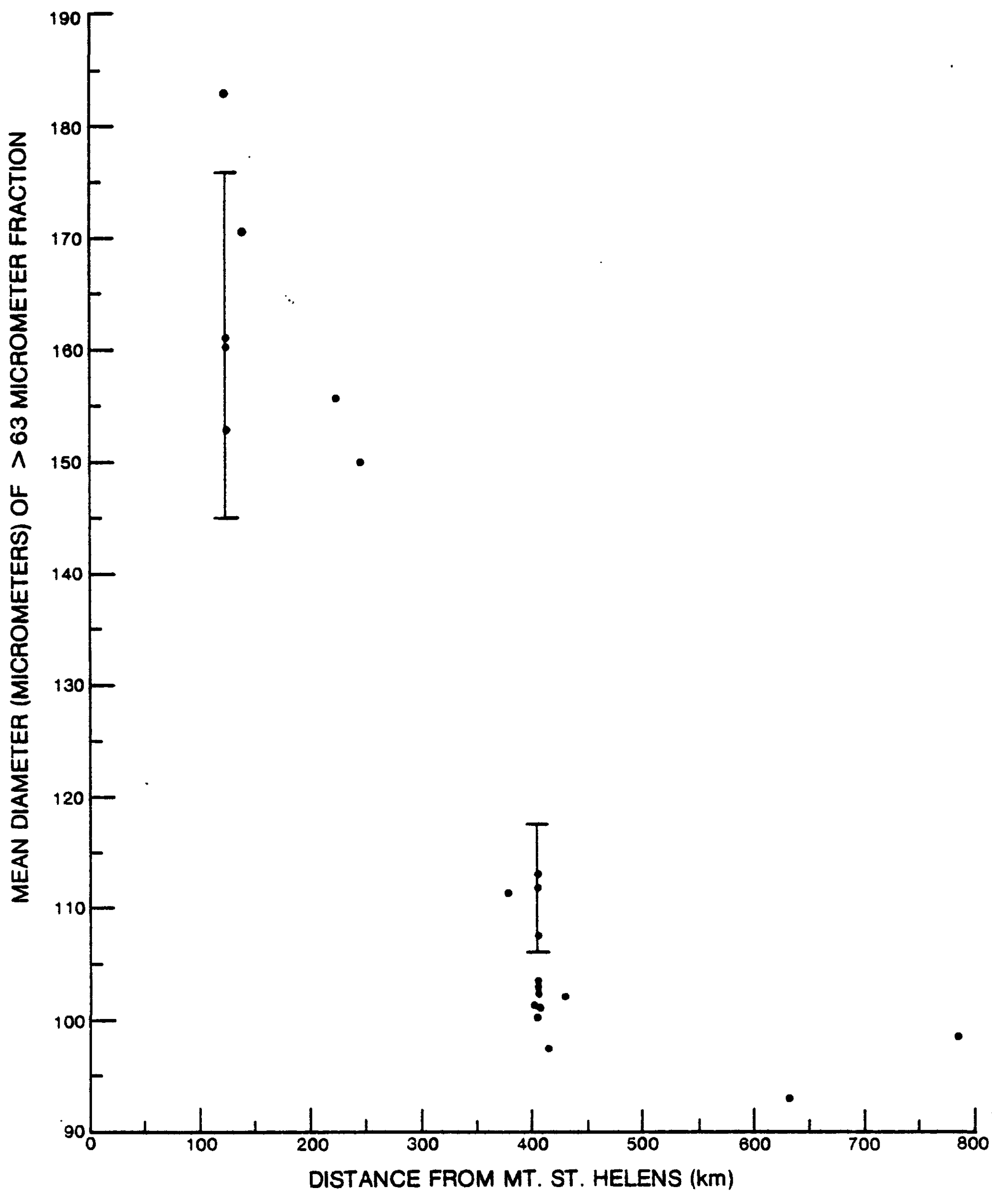

Figure 4: Mean diameter (micrometers) of the >63 micrometer size fraction of air-fall ash plotted as a function of distance from Mount St. Helens. Vertical error bars are ± one standard deviation, based upon replicate determinations of typical samples.

fig 5

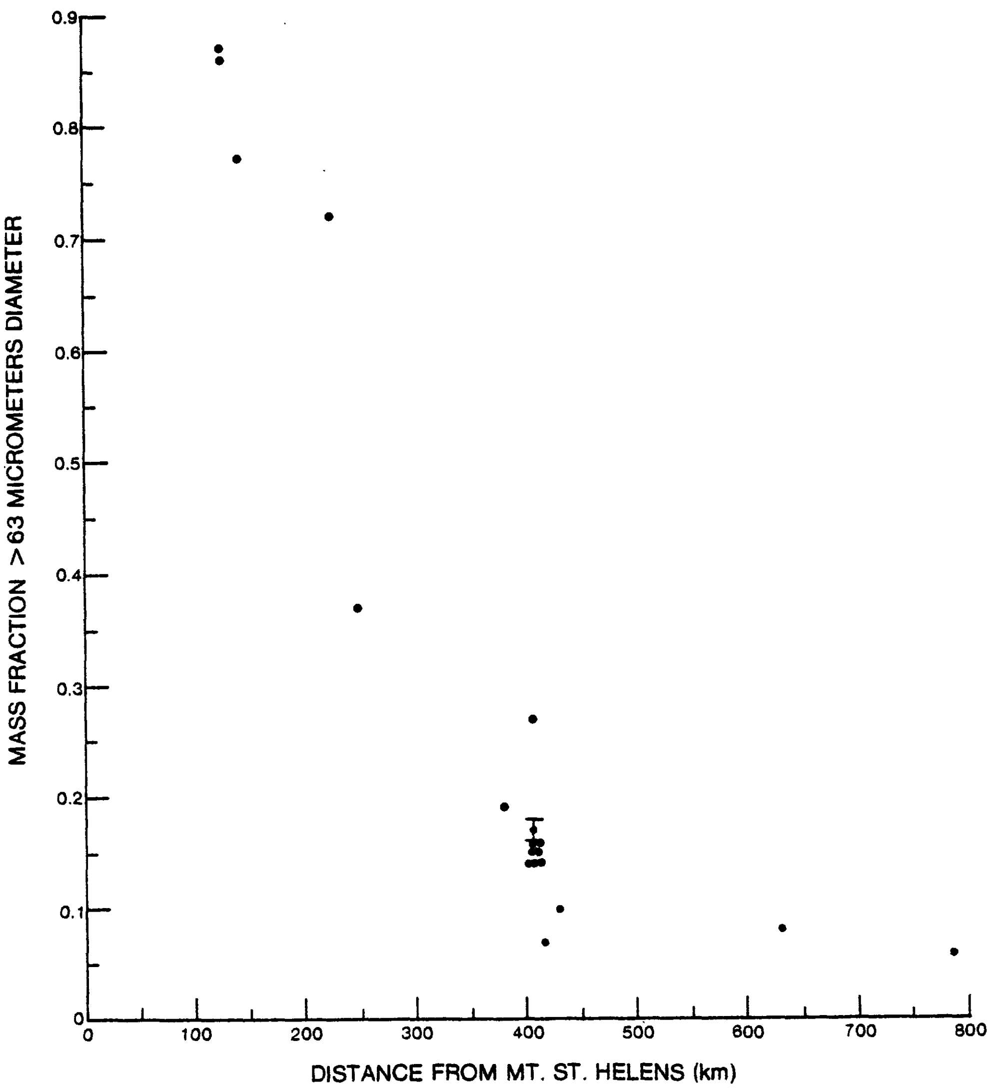

Figure 5: Mass fraction of the >63 micrometer size fraction of air-fall ash plotted as a function of distance from Mount St. Helens. Vertical error bars are ± one standard deviation, based upon replicate determinations of typical samples.

fig 6

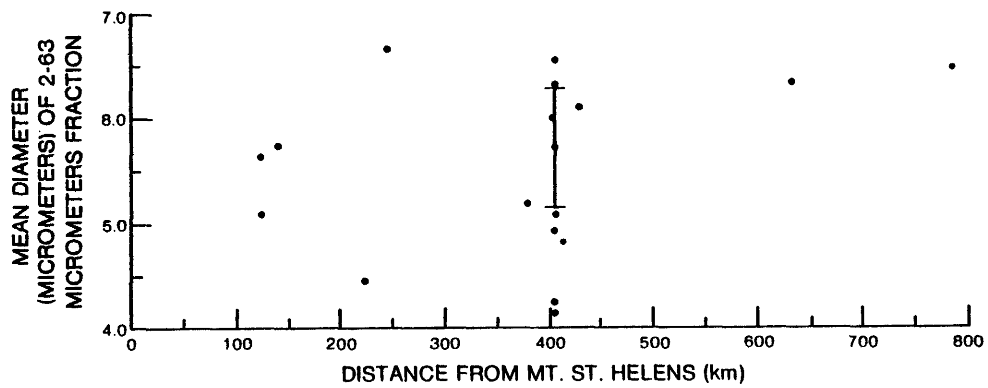

Figure 6: Mean diameter (micrometers) of the 2-63 micrometer size fraction of air-fall ash plotted as a function of distance from Mount St. Helens. Vertical error bars are ± one standard deviation, based upon replicate determinations of typical samples.

fig 7

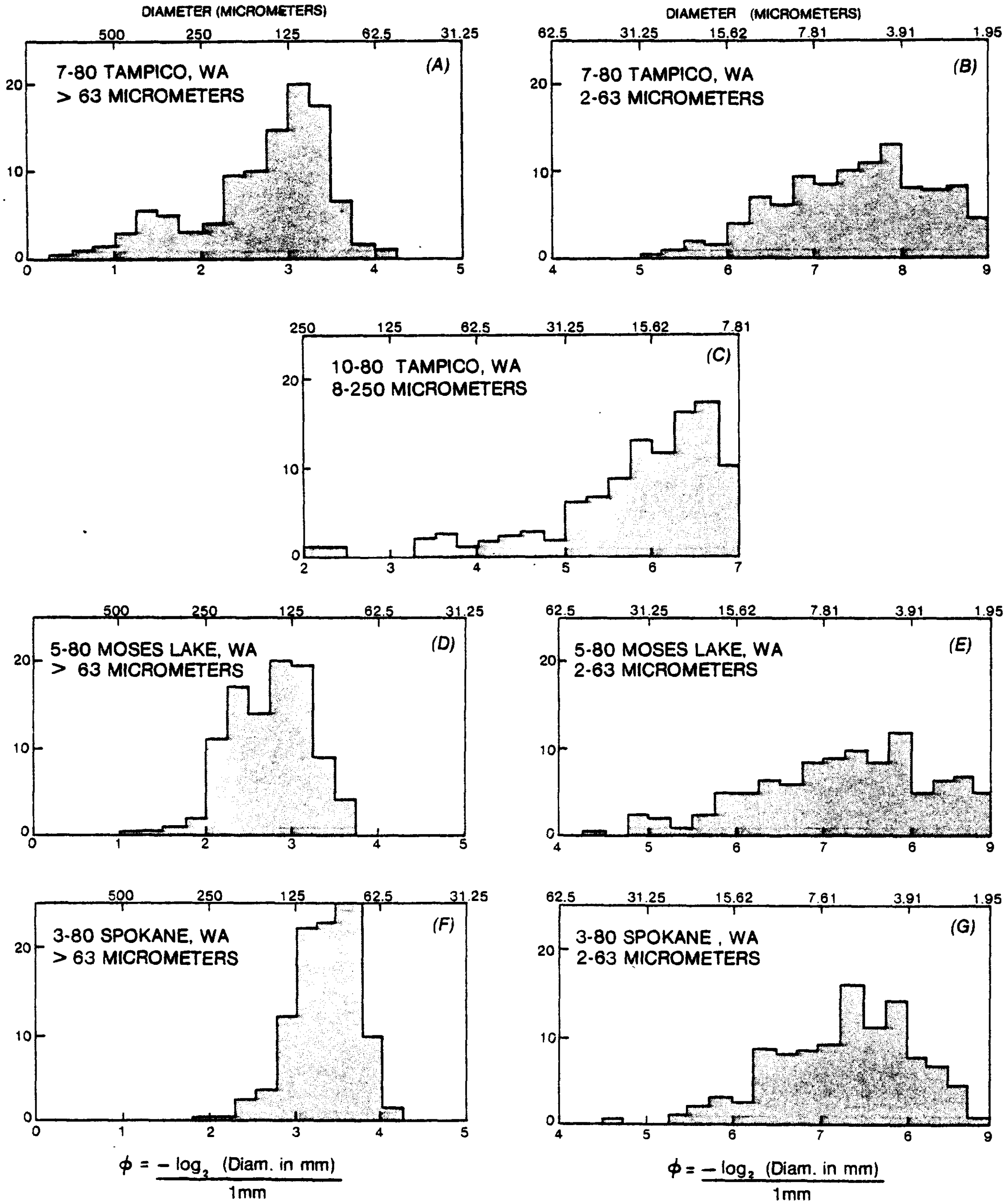

Figure 7:(a-g) Size distribution histograms for measured size fractions of some representative ash samples.

Grain shape measurements (area/perimeter^2) were performed on a few representative samples from each of the two size fractions (table 2). The dimensionless shape parameter is an indication of the degree of circularity. A value of ≈0.08 $[\pi r^2/(2\pi r)^2]$ indicates a perfect circle; lower values reflect increasing angularity and/or elongation. Means for the fine-grained size fraction cluster tightly around .045 compared to .062 for coarse-grained fractions. The difference in means is statistically significant at the 99 percent confidence level and reflects increasing angularity of finer grained material. This tendency is well known to sedimentologists and is caused by preferential mutual abrasion of more massive particles during transport. A similar explanation is postulated here except that the transporting medium is not water but the turbulently flowing gas of the volcanic plume.

Table 2.—Shape Measurements (Area/Perimeter^2) of Mount St. Helens Ash

Sample	Size Fraction	Mean+	Std. Deviation
MSH 3-80	2-63 micrometers	0.042	0.01040
MSH 3-80(repeat)	------do-------	0.048	0.00968
MSH 7-80	------do-------	0.049	0.00873
MSH 10-80	------do-------	0.045	0.00884
MSH 6-80	>63 micrometers	0.062	0.00632
MSH 7-80	------do-------	0.062	0.00549
MSH 10-80	------do-------	0.061	0.00625
MSH 19-80	------do-------	0.063	0.00606
MSH 19-80(repeat)	------do-------	0.061	0.00682

+based on 100 grains/sample. A value of 0.08 indicates a perfect circle.

Future Study

It is hoped that this preliminary report will encourage continued use of the automatic image analyzer in volcanological studies. Clearly, further subdivisions of grain sizes are possible and measurements of size and shape of grains coupled with mass and volume fraction determinations serve to amplify and clarify the types of observations reported here. Also, further investigations of grain mounting media and techniques would greatly aid image analysis studies of fine-grained particulates. For example, mounting in refractive index oils might reduce the grain-edge refraction problem and permit grain observations at higher magnifications (1000X).

Acknowledgements

Thanks are extended to H.E. Taylor for supplying ash samples collected by USGS personnel and to W.W. Emmett for access to the image analyzer. Sample processing and mounting were aided by D.B. Smith and R. Reed. Distances of sample localities from Mount St. Helens were provided by M. Nottie of the F.A.A. Flight Service Office, Denver, CO.

References Cited

Carver, R.E., ed., 1971, Procedures in sedimentary petrology: New York, Wiley-Interscience, 652 pp.

Fruchter, J.S., Robertson, E.D., Evans, J.C., Olsen, K.B., Lepel, E.A., Laul, J.C., Abel, K.H., Sanders, R.W., Jackson, P.O., Wagman, N.S., Perkins, R.W., Van Tuyl, H.H., Beauchamp, R.H., Shade, J.W., Daniel, J.L., Erichson, R.L., Sehmel, G.A., Lee, R.N., Robinson, A.V., Moss, O.R., Briant, J.K., and Cannon, W.C., 1980, Mt. St. Helens ash from the May 18, 1980 eruption: Chemical, physical, mineralogical and biological properties: Science, v. 209, p. 2226-1125.

Sawyer, M.B., 1977, Image analysis as a method for determining grain-size distributions in sandstone: U.S. Geological Survey Open-File Report 77-280, 13 p.

Seeland, D.A., 1976, Relationships between Early Tertiary sedimentation patterns and uranium mineralization in the Powder River Basin, Wyoming, in Laudon, R.B., Currey, W.H., III, and Runge, J.S. eds., Geology and Energy Resources of the Powder River: Wyoming Geol. Assoc. Guidebook, 28th Ann. Field Conf., Sept. 1976, p. 53-64.

Zielinski, R.A., 1977, Uranium mobility during the interaction of rhyolitic glass with alkaline solutions: dissolution of glass: U.S. Geological Survey Open File Report 77-744, 36 pp.

Zielinski, R.A., 1979, Uranium mobility during interaction of rhyolitic obsidian, perlite and felsite with alkaline carbonate solution: $T=120^{\circ}C$, $P=210 kg/cm^2$: Chem. Geol., v. 27, p. 47-63.