

Feature Article

Particle Characterization of Volcanic Ash by Dynamic Digital Image Analysis

Michael C. Pohl

Digital Image Analysis is one of the fastest growing methods for determining particle size and shape. The Dynamic version of this technique as seen in the HORIBA Camsizer-L is gaining in popularity very rapidly. This instrument has been applied to many fields including glass beads, fertilizer, expanded polymers and soils and sediments. The capability to determine size and shape in one measurement in five minutes or less is very attractive. A logical extension of the work on soils and sediments is to migrate to samples originating from volcanic eruptions. This article will explore the proper measurement of these samples and how the data can be used to construct plume dispersal models.

INTRODUCTION

When researchers use the term particle characterization, they are talking about all aspects of a particle or ensemble of particles. This would include size, shape, morphology, texture, transparency and many other characteristics. For several hundred years this type of data could only be derived from looking at microscopic images of the particles. Due to the slow, tedious nature of this measurement, other less direct measurement methods were developed. These include laser light scattering, sedimentation measurements, electrical sensing zone determinations, light obscuration and many other “indirect” methods. These methods produced data considerably faster but the typical result was expressed as an “Equivalent Spherical Diameter” as a single parameter.

The speed, and in some cases the availability Particle Size Distribution, made these newer methods more attractive, but a great deal of information got lost in these measurements. Due to this major limitation, the Optical Microscopy Method remained the “gold standard” to which all other methods were compared. During the last 50 or so years the existing methods were optimized and new ones developed to improve the correlation to the microscopic results. This drove these techniques to new levels of accuracy, repeatability and reproducibility.

While this benefited a wide variety of industries, it did not overcome the fundamental problem which is the limited amount of information which the techniques produce.

The 1980’s saw the advent of powerful computers which were able to automate the collection and analysis of raw images directly from the microscope. This greatly accelerated the capture of the data and its analysis while also greatly reducing the tedium of visually examining each and every particle. While this did accelerate the process, it was still requiring many minutes per analysis. This challenge originates from the need to scan around the microscope slide to different fields to look for individual particles. Even when this is done by a computer, it requires a long time. Eventually in the late 1990’s this static image analysis approach began to be displaced by a dynamic image analysis approach which greatly accelerated this process. This approach presented a large number of particles to the camera simultaneously to greatly enhance the data collection capability.

THEORY: USEAGE OF PARTICLE CHARACTERIZATION DATA

The new approach is embodied in the Camsizer design shown in Figure 1. In this instrument the particles are

CAMSIZER is a compact laboratory instrument developed by RetschTechnology (<http://retsch-technology.com>). It uses two high resolution CCD cameras for the simultaneous measurement of particle size distribution and particle shape of incoherent materials in the range of 30 μm to 30 mm. CAMSIZER bases on dynamic digital image processing and permits to obtain measurements of shape parameters on a high number of particles.

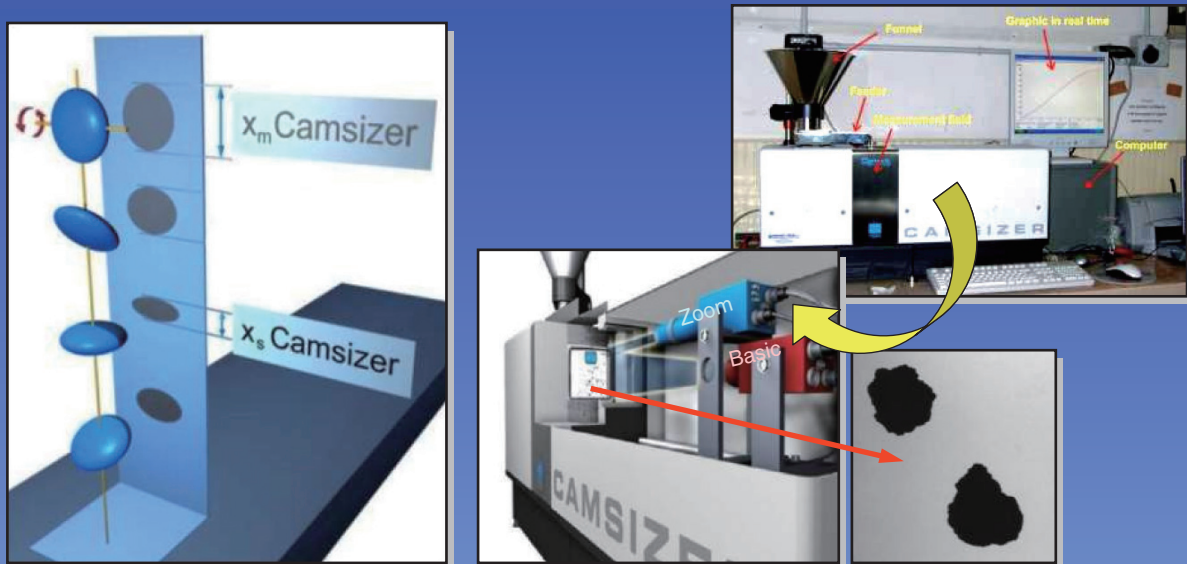


Figure 1 METHODOLOGY

fed at a controlled rate from a hopper to a vibrating chute. The chute vibrates the particles causing them to fall in front of the two cameras at a constant amount of obscuration. The two cameras simultaneously measure the size and shape of the particles as they fall. This patented two-camera system allows particles between 30 μm - 30 mm to be measured quickly and accurately. The instrument features a Basic Camera to measure larger particles and a Zoom Camera to measure the smaller ones. This product features very high counting statistics which produce stable, accurate results. Shape and size data is now readily available in what typically amounts to a 5 minute analysis.

Particle Characterization is a physical test which has some unique features as compared to other analytical methods. The actual raw data is interesting in its own right, but it must be correlated to another physical test in order to have any physical significance. A good example of this would be the determination of the hiding power of paint pigments. This is a very time consuming manual test performed by painting a panel with a pre-existing color, painting on a second color and optically determining the amount of color visible from the first coat of paint showing through the second. This hiding power is determined by the pigment particle size used to prepare

the paint formulation. If the pigment size is determined and the correlation to the hiding power properly established, a several-day test is reduced to five minutes. This is an example of how Particle Sizing would be implemented in an industrial setting in order to predict final product performance.

An early application of the Camsizer was the determination of the size and shape of glass beads. One of the large uses for these beads is as a coating for the paint stripes on roads. In this application the beads are added to the paint striping to permit drivers to see the stripes at night, especially during rainy conditions. This property relating to light from car headlights striking the beads and being reflected back to the driver's eye is called retroreflectivity. There is an actual instrument which makes this measurement as a test vehicle moves along the striping and produces a retroreflectivity number. This is difficult and time-consuming to do on real roads especially in remote areas and so a physical test (particle size and shape) has been developed to replace it.

The new test consists of measuring the size and shape of a representative sample of the glass beads prior to their being introduced into the paint which is being sprayed onto the road. The key parameters determined are the

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median bead size and the particle sphericity. These tests can be done for all types of commercial glass beads typically in five minutes or less. The correlation is that large, very round beads will have the highest possible retroreflectivity, which is the desired property. Thus, a laboratory based test of a lot of beads can accurately predict the behavior of the beads before it is shipped out to the state Departments of Transportations (DOT's) for the striping of the roads. All glass bead manufacturers and most state DOT's use this technology to specify the beads that will be accepted. The Camsizer has now become the de facto standard for this industry. An American Society for Testing and Metrials (ASTM) Method is expected to issue any day.

In the case of soil and sediment samples the size and shape of the particles is critical to determine where these materials will deposit in a lake, stream or ocean. These sedimentation issues are important as they relate to the dredging of harbors, the deposition of stream sediments in the ocean and the characteristics of materials at the bottom of lake beds. For many years sedimentation size measurements were the method of choice because the technique mimics the actual physical process. The

limited applicability of this method to only silt and clay particles made alternative methods quite attractive. For many years the Camsizer has been used for making these measurements on the larger particles to predict the depositional patterns for the sediments.

MEASUREMENTS ON VOLCANIC ASH

It does not represent a huge technological stretch to apply this same approach to particles that are in the dry state in nature. In the case of soil and sediment measurements it is quite a bit more complicated due to the requirement to first dry and prepare the samples for analysis. The extension of the sample type has happened when soils and sediments were replaced by volcanic ash samples. A good example of this new application is illustrated in Figure 2 below. As is readily apparent these particles consist of a wide variety of sizes, shapes and colors of particles. This sort of a complex mixture is perfect to show the power of dynamic, digital image analysis. While the measurement is easy, some additional analytical techniques are required to properly use this information. These new adaptations are the basis for this article.

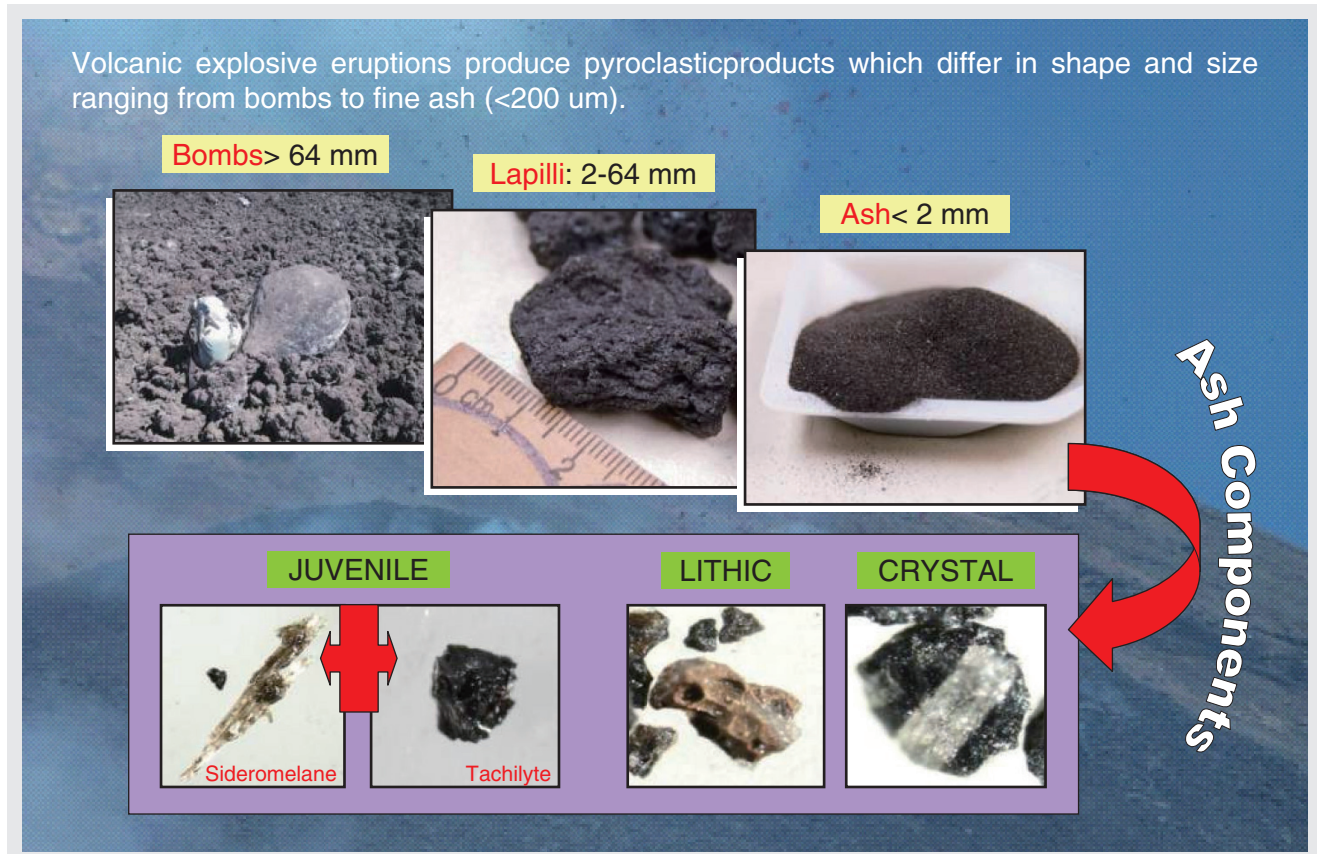


Figure 2 Volcanic particles: typologies and characteristics

The importance of this type of measurement is illustrated in Figure 3. The actual size and shape of the particles are determined by a number of characteristics of the volcano itself. Examples of these processes are shown on the left hand side of the figure. The study of these characteristics is outside the scope of this article. The effect that these particles have on the deposition of the plume is illustrated on the right side of the figure. In order to correctly predict this dispersal, the particles have to be correctly characterized and the results correlated to the settling rate. As indicated, the assumption that it is a collection of spherical particles that will behave according to Stokes' Law has no chance of succeeding. Thus, the challenge for the Camsizer is to produce results that will allow the models to correctly predict the plume dispersal.

RESULTS AND DISCUSSION

As Figure 2 illustrates, these Volcanic samples are composed of a wide variety of particle type, sizes, colors and shapes. When such a broad spectrum of types exists, the data generated has to be handled in a unique fashion. For this particular study it was decided to attempt to do a cluster analysis to identify some clusters of similar particles in the data in order to use them for the correlation properties. If a small number of clusters can

be identified, then the characteristics of the cluster can replace the millions of individual particles. If everything works, the sum of all of the cluster properties should correlate to the physical property of interest. The methodology behind this analysis is shown in Figure 4. It is a well established procedure for complex mixtures of samples, but had to be analyzed with programs external to the Camsizer software. These additional programs are identified by name in Figure 4 above.

In this methodology the raw data from the Camsizer was put through programs to produce the Features Extraction. This approach correlates certain parameters, in this case particle shape parameters to cause the data to cluster in distinct regions. This serves to identify the proper shape features to evaluate. With these shape parameters identified, a cluster analysis is performed to find groupings of shapes that all appeared in the same quadrant of the graph. This permits a few shape characteristics to replace a very large number of real particles that were studied. Since this was the first time to attempt this for volcanic types of particles, it was decided to first test it for known, well characterized geometrical shapes. This data simulation was first attempted with a mixture of cubes, spheres and cylinders.

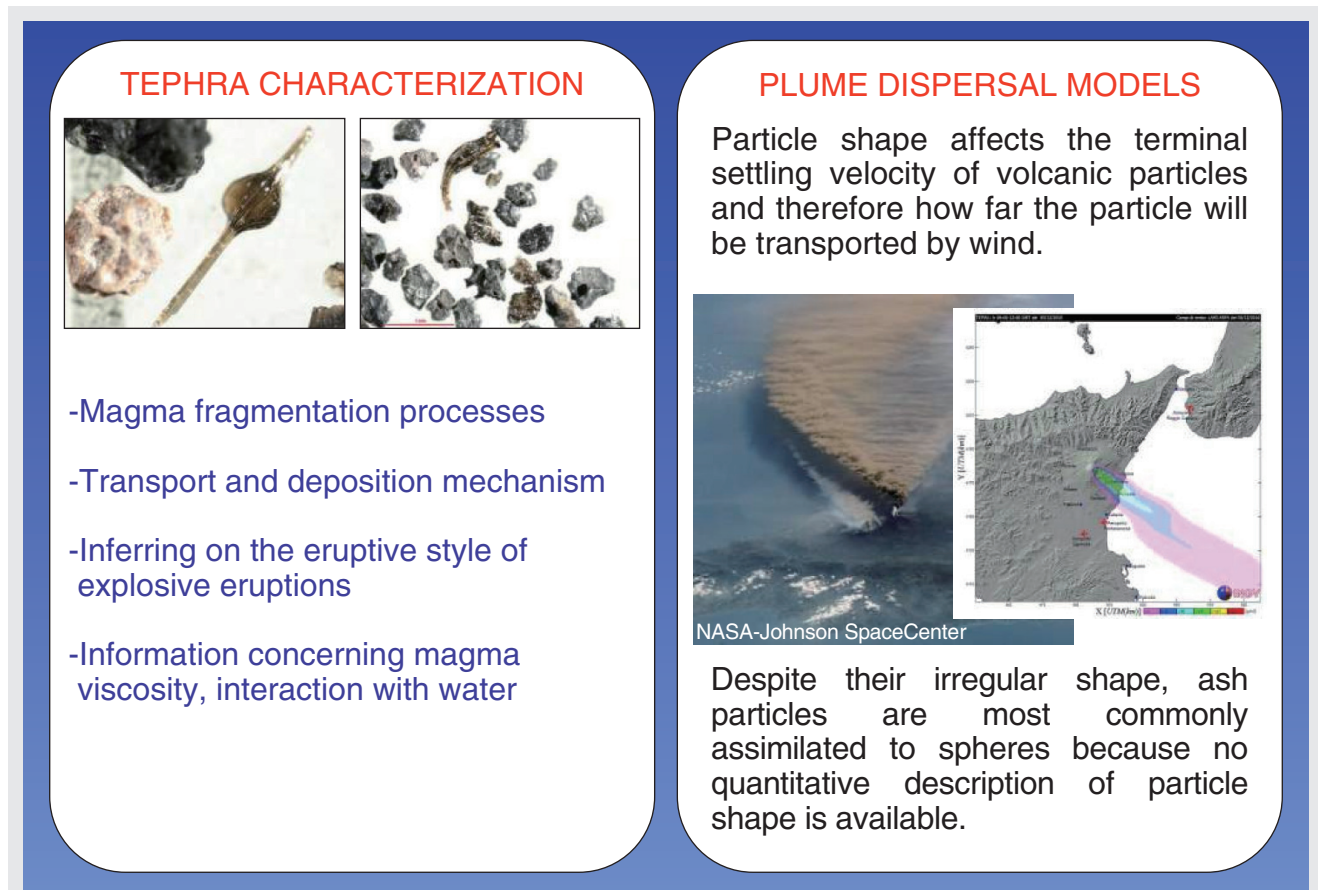


Figure 3 Importance of particle shape in volcanology

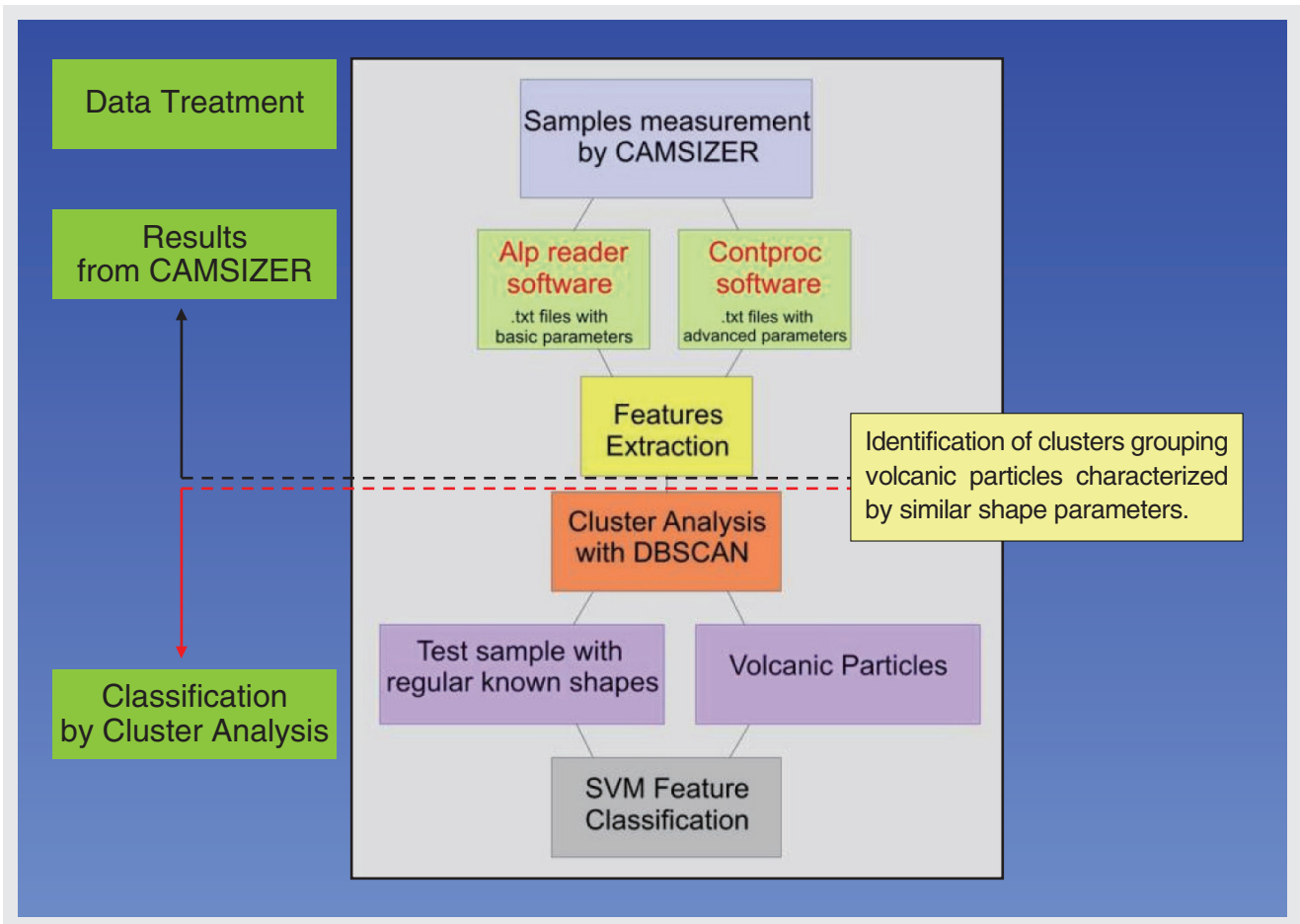


Figure 4

The results of this procedure is illustrated in Figure 5 below. In this theoretical study, three distinct shape characteristics were determined during the Features Extraction portion of the procedure. They were Sphericity (SPHT), b/l and Epo1. These shape characteristics were assumed to be significantly enough different to distinguish between the three shapes that were arbitrarily mixed together. As the three dimensional plot indicates the various shapes do, in fact, cluster in different regions of space. By identifying the number of dots in each cluster, the numbers of particles of each type could be identified. Thus such an analysis could identify the precise number of particles of each shape. Since the aspect ratio of these particles is quite similar, the initial results were quite encouraging.

The next step was to attempt this type of analysis on actual volcanic samples. A number of these were performed on several different sets of samples obtained from two different volcanoes. In each case the samples were first sieved in order to restrict the analysis to similarly sized particles. This was necessary in order to

remove the effect of the size of the particles on the shape that was being determined. For simplicity's sake, the plotting was reduced to two dimensions instead of three. Typical data from this procedure is shown in Figure 6 below for a lapilli sample from the Mount Etna volcano. This shows two quite distinct clusters of particle shapes for the real sample. The other samples showed very similar types of correlations as this illustration.

In this example for similarly sized particles the correlation was once again SPHT versus b/l. As can be seen the more spherical particles are clustered in the upper right hand corner while the more angular, irregularly shaped particles are clustered in the lower left hand corner. There is a small bit of overlap between the clusters, but the two groupings are very distinguishable from each other. This would indicate the general approach adopted in the study is valid for the samples which were investigated. It does, however, open up many additional issues requiring further investigation.

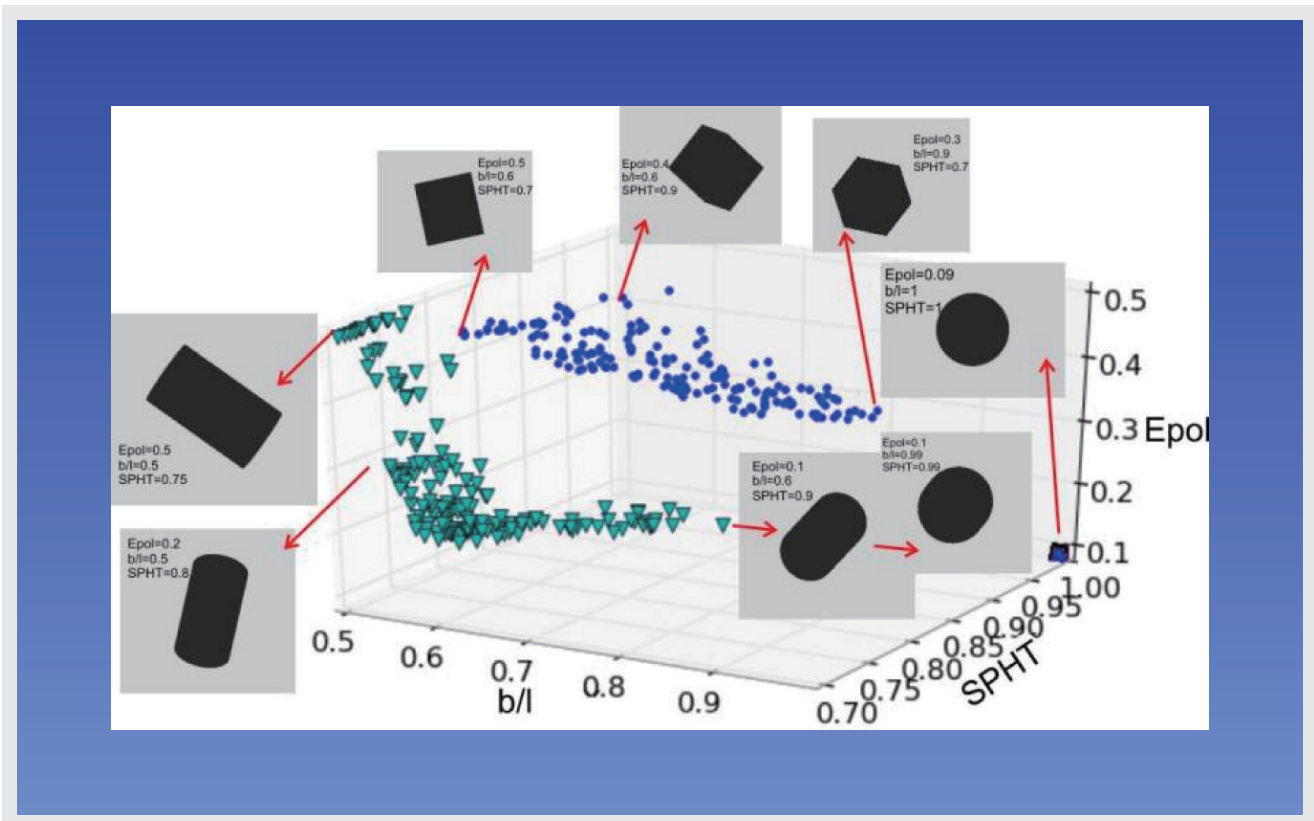


Figure 5 CLUSTER ANALYSIS: Simulation data with cubes, spheres & cylinders

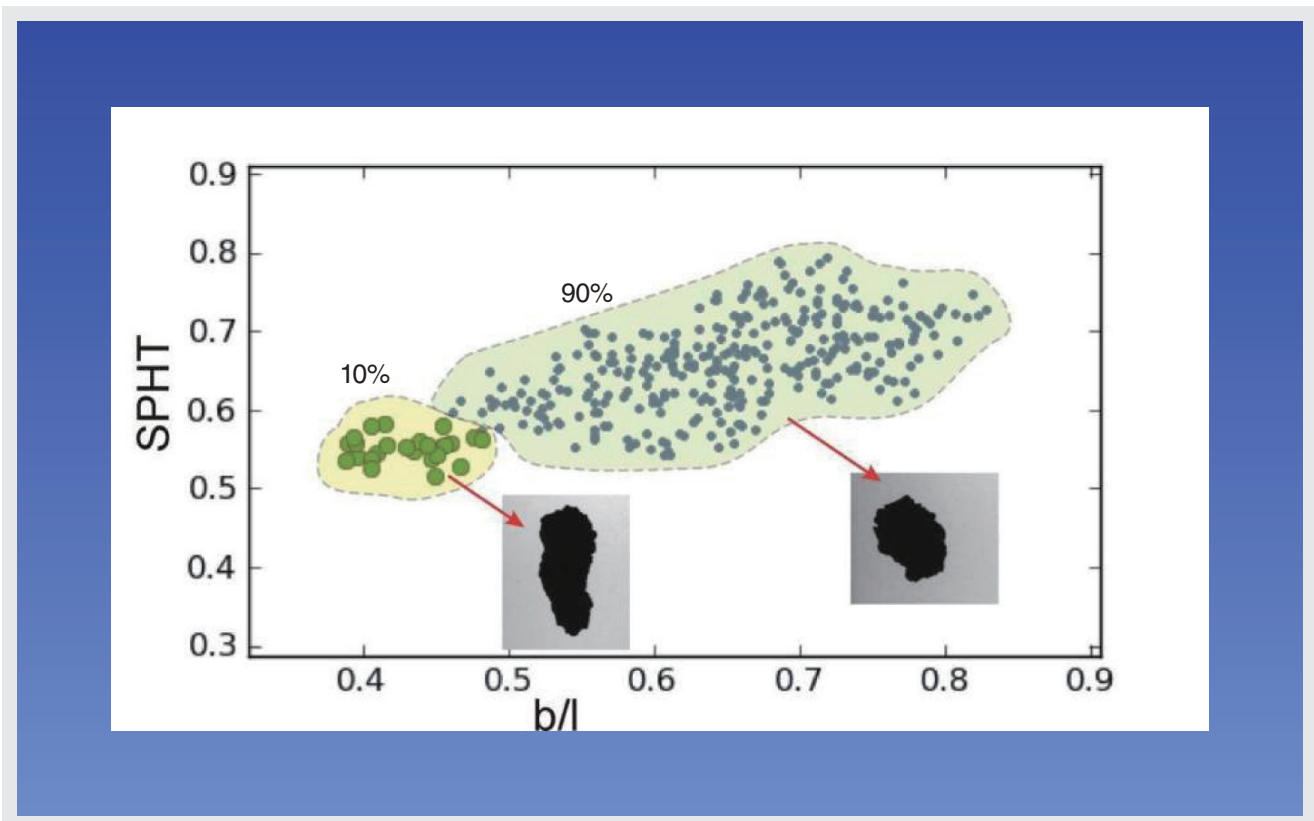


Figure 6 CLUSTER ANALYSIS: Lapilli from Etna volcano

CONCLUSIONS

Probably the first question is how general is this approach to the description of volcanic ash? This data is from separate sets of samples from two volcanoes. Would it be observed for most all volcanic material? Assuming that the answer to this question is affirmative, could each cluster be individually characterized so that these clusters could be used to predict plume behavior? This is very critical because the penultimate goal is to reduce the characteristic shape and size from millions of ash particles into a few useable cluster parameters that would have some predictive value. Once these clusters are identified, next their behavior characteristics must be measured for the parameter of interest, settling velocity.

The next step would be to sum up the characteristics of each cluster into a total sample characteristic. If the hypothesis is correct, this final sample characteristic would correlate to the plume dispersal. The model would then be tested with a number of different eruption samples to determine the applicability of the sample characteristic. If most samples correlated to the plume dispersal which would be independently determined, this would be validation for cluster analysis model. This final determination is a number of years away, but at least a test protocol exists to examine actual sample data.

If this model proved correct, it would prove valuable in a variety of ways. It could predict the dangers associated with living in the general area of an active volcano. It could be used to predict the danger of the plume to general aviation in the immediate vicinity. It could also be used for weather predictions based upon the effect of the volcanic explosion. These are still a bit off in the future, but the first steps toward the predictions have been taken.

ACKNOWLEDGEMENTS

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Reference

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Michael C. Pohl

Vice President
Scientific Instruments
HORIBA Instruments, Inc.
Ph. D.