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FOURIER GRAIN SHAPE ANALYSIS: A MEANS FOR CORRELATING ALLUVIAL DEPOSITS AT THE NEVADA TEST SITE

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October 18, 1978

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11

CONTENTS

Abstract	1
Introduction	1
Field Area	2
Sampling	4
Analysis	4
Mean Harmonic Amplitude Spectra	4
Shape Frequency Distributions	6
Sample Unmixing	8
Discussion and Conclusions	10
Acknowledgments	13
References	13

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ABSTRACT

Quartz sand derived from alluvial fans that drain different lithologies at the Nevada Test Site can be distinguished on the basis of grain shape as described by the Fourier series in closed form. Specifically, we examined tuff units from the Piapi Canyon and Indian Trail Formations as well as carbonate-bearing clastic units from the Eleana Formation.

Discrimination between rock types was accomplished by examining the mean harmonic amplitude spectra and the grain shape frequency distributions at those harmonics that exhibit "significant" chi-square values. The results of these analyses indicate that the tuffs can be easily distinguished from the clastics. However, differences between samples from genetically similar rock types are not as prominent. Grain shape frequency distributions of tuffs and clastics show such strong differences that they can be characterized by standardized distributions. By comparing the shape frequency distributions of mixed sediment samples, it is possible to determine the relative contribution of tuff and clastics to any sediment sample taken within the drainage network.

The Piapi Canyon, Indian Trail, and Eleana Formations have produced the thick alluvium sequence in the Rainier Mesa region of Yucca Flat. We believe it is likely that these grain shape relationships can also be applied to subsurface samples. Not only would this extended application enable more accurate correlation of alluvial layers, but more precise determination of the clastic-tuff contact within the alluvium sequence might also be possible.

INTRODUCTION

The physical properties of alluvium (e.g., bulk and grain density, resistivity) must be analyzed before the emplacement of each device at the Nevada Test Site (NTS). Because of the complexity of the alluvium, this is a tedious process requiring careful analysis of various geophysical logs. If we could correlate the alluvium by outlining zones possessing similar physical properties this necessary analysis would be greatly simplified. However, until now, only two methods—examining downhole stereo photographs to identify debris flow deposits, and analyzing electrical resistivity logs—have yielded even moderate success.¹ The major problem in correlating alluvial layers arises from the fact that they consist largely of loose gravels contributed from a variety of source rocks. The relative proportions of the gravels from each source

are very difficult to assess from geophysical logs and sidewall samples.

In this investigation, we wished to determine the extent to which shape analysis of quartz sand grains in an alluvial fan environment, such as the NTS, can be used to discriminate between source rocks. If different rock types and subsequently different alluvial fans yield characteristic grains, it should be possible to predict the relative proportions of various sediment types being contributed to any point of fan confluence in the drainage network. In addition, it should also be possible to gain some knowledge of the attrition rates of any rock type (source population) in relation to another because different rock types have variable resistances to chemical and mechanical effects with increased distance of transport.

Previous investigations have shown that the shapes of sand-size quartz grains reflect, to some degree, characteristics acquired during their original formation (e.g., due to pressure and temperature) and during subsequent transport and deposition after erosion.² On the basis of these premises, quartz has been used as a natural tracer to differentiate between source areas and to determine the relative proportions of sediment in a mixed source deposit.^{3,4} However, ours is the first attempt to use this process in an area where sediment movement occurs only by surges following flash storms, not by free flowing streams and longshore drift.

The grain shapes were measured using the Fourier analysis technique developed by Ehrlich and Weinberg.⁵ This technique utilizes a Fourier

series in closed form to describe each grain as precisely as desired. The Fourier series consists of a progression of terms (harmonics) in which each harmonic represents the contribution of a specific geometrical component to the total shape. For example, the amplitude of the second harmonic represents the contribution of a two-lobed grain shape (figure-eight), the amplitude of the third harmonic represents the contribution of a three-lobed grain shape (trefoil), and the amplitude of the n th harmonic represents the contribution of a grain shape with N lobes. Thus, grain shape can be measured as precisely as desired by progressively adding terms. In previous studies, we determined that the first 20 harmonics provide sufficient detail; thus, these were all we used in this present investigation.

FIELD AREA

The study area selected for this project is the Rainier Mesa region in the western portion of Yucca Flat, NTS (see Fig. 1) and covers portions of Areas 12, 8, and 2. This area has been mapped in detail by Gibbons *et al.*⁶ Gibbons *et al.*, have also made quite complete lithologic descriptions of the stratigraphic formations, each of which consists of a series of lithologic units (e.g., zeolitized and welded tuffs), hereafter referred to as units. The drainage system consists of a network of braided ephemeral streams that transport sediment from small alluvial fans to a single large "catchment" fan which covers much of Area 2 and the western portion of Area 9. The lithologic variation among the source areas and the relatively short distance of sediment transport create a good field laboratory in which to conduct such a study.

The rock types being eroded consist largely of carbonate units with associated clastics and volcanic tuff units. These same units occur at depth beneath the alluvium at NTS. Thus, this intermontane basin, Yucca Flat, is slowly being buried beneath the debris eroding off the surrounding foothills. Three different formations have been defined as the major sediment contributors to the drainage system. However, as stated above, there are essentially only two major rock types. The following lithologic descriptions, based primarily on the work of Gibbons *et al.*, describe each of the units sampled.

The sample 1 locality drains units E, F, and G of the Eleana Formation (Mississippian-Pennsylvanian). Similarly, sample 5 drains units E, I, and H of the same formation. These units consist of grey and brown quartzite and sandstone, con-

glomerate, crystalline limestone, and red and grey argillite.

Sample 2 is taken from a stream that drains an area underlain by dolomite of the Eleana Formation. The area where we took the sample should be influenced by all three of the dolomite units. These dolomite units consist of fine crystalline to fine grained dolomite with occasional crossbeds and ripple marks in the middle unit and white breccia in the upper unit.

Sample 3 was taken from fans draining Tertiary Tunnel Beds 1 through 4. These Tunnel Beds consist predominantly of zeolitic bedded tuffs with two zones of pisolite beds in Tunnel Bed 1.

Sample 4 was taken from a stream that drains an area underlain by two younger tuffs, the Survey Butte tuff and the Rainier Mesa member of the Timber Mountain Formation. The Survey Butte tuff consists of ash-fall tuff, locally reworked and locally zeolitized in the lower 100 ft. The Survey Butte tuff is probably a composite ash-fall tuff that is genetically related to all other members of the formation. In contrast, the Rainier Mesa tuff is a multiple-flow, compound-cooling unit of welded and nonwelded tuffs that grade into a nonwelded tuff at the base of the cooling unit. Rainier Mesa tuff is composed of rhyolite and quartz latite, and contains abundant phenocrysts of quartz, sanidine, and plagioclase. The welded tuffs are much more resistant and outcrop as cliffs. (From here on, this sample 4 will be referred to simply as the younger tuffs sample.)

Sample 6 is a mixed sample that may be influenced by source contributions from units characterized by samples 1, 3, and 4. However, in relation

Fig. 1. Map of the study area for this project. This is the Rainier Mesa region in the western portion of Yucca Flat, Nevada Test Site. This inset shows the outline of the NTS, the shaded block locates our study area. Sample locations are shown: (1) Eleana elastics, (2) Eleana dolomites, (3) Indian Trail tuffs, (4) Piapi Canyon tuffs, (5) Eleana elastics, (6) mixed sample, and (7) mixed sample.

to the total effective drainage area, the drainage from the Tunnel Bed units is minimal. The erosional surface area of the Tunnel Bed units is proportionately very small.

Sample 7 is also a mixed sediment sample. It was taken from the confluence of ephemeral streams that drain sample locations 2 and 3, mixing dolomite from the Eleana Formation with Tertiary tuffs from the Tunnel Beds. The drainage area from each source is roughly equal.

Sampling

Seven samples were analyzed. Five of them were taken from the bases of alluvial fans draining different formations and thus represent specific source areas. Care was taken to ensure that the fans selected drained only one formation. The remaining two samples are mixed source sands that were collected along ephemeral streams down drainage. One of these mixed sands was collected at the confluence of stream beds draining only two sources and was used to determine which of the two upstream fans is yielding the greater percentage of material. The remaining mixed sample was taken directly down drainage from the younger tuffs but appears to be receiving some drainage from part of the Eleana Formation as well. These mixed samples can be used to test hypotheses regarding which source is the predominant contributor of sediment.

Analysis

Samples were wet sieved to separate material into coarse, medium, and fine sand fractions. This eliminates any size-shape interactions that might bias the results. Because of time constraints, we were only able to analyze the fine sand fraction of each sample. The other size fractions were set aside for possible later use. After sieving, the sand was poured through a magnetic separator to concentrate the quartz grains. The grains were then washed in a dilute solution of hydrochloric acid and stannous chloride to dissolve any carbonate minerals and to remove iron oxide coatings. Finally, the sands were immersed in a dilute hydrofluoric acid solution to break down the feldspars. After drying, the samples were divided into approximately 200-grain portions and mounted on petrographic slides.

Two-dimensional outlines of the maximum projection perimeters were drawn using a Leitz Wetzlar microscope with a viewing screen. These outlines were then digitized as a sequence of 48 X-Y coordinates and stored in computer memory. These raw data files served as input for computing the Fourier series of each sample. The harmonic amplitude values determined by the Fourier series are then normalized by dividing each value by the zeroth harmonic amplitude (mean radius). The first 20 harmonics were calculated for each grain. Each sample consisted of approximately 200 grains. Thus, each sample was characterized by 4000 data points.

MEAN HARMONIC AMPLITUDE SPECTRA

Mean harmonic amplitude spectra (MHAS) provide a quick and simple method for graphically displaying the "average" grain shape characteristics of a sample. By plotting the mean amplitude values at each harmonic (which requires only the output from the Fourier program), the MHAS often can be used without further sophisticated analysis to distinguish between different rock types. Two tuff samples are compared with the Paleozoic sedimentary units in Fig. 2, demonstrating the utility of MHAS. The harmonic numbers are plotted along the X-axis and the corresponding mean amplitude values are plotted along the Y-axis. There is a consistent divergence of the tuff and clastic curves at all harmonics except the third, indicating that the tuffs can be clearly distinguished from the clastic-bearing

sedimentary units. All samples demonstrate similar mean amplitude values at the third harmonics.

When we compare the younger tuffs and the Tunnel Bed tuffs, we see that the younger tuffs sample tends toward slightly lower mean amplitude values at most harmonics. Although this difference is small, it does reflect the fact that these grains more closely approach circularity than do those of the Tunnel Bed tuffs.

When we examine the MHAS curves of samples taken from the Eleana Formation, we see that the curves diverge from one another at some harmonics, but no systematic differences can be observed. Such a pattern indicates strong similarity in grain shape between samples.

Fig. 2. Plot of mean harmonic amplitude vs harmonic number for the five source locality samples: --- sample 4 (Survey Butte and Rainier Mesa tuffs), -.- sample 3 (Tunnel Bed tuff), — sample 2 (Eleana dolomite), ····· sample 1 (Eleana clastic), and - - - - sample 5 (Eleana clastic).

SHAPE FREQUENCY DISTRIBUTIONS

Yarus⁷ established that the underlying shape frequency distributions of single lithologies are often polymodal. Therefore, it is unlikely that the MHAS reflect all the distinguishing properties of these sediments. In an attempt to analyze these differences more precisely, we examined the shape frequency distributions.

In contrast to the MHAS, shape frequency distributions can precisely locate the differences. To obtain these distributions, the range of amplitude values at each harmonic is first divided into 20 equal intervals. Shape frequency distribution histograms are then constructed by plotting harmonic amplitude vs the number frequency at these specified intervals. Thus, each sample is characterized by 20 histograms.

Using chi-square contingency tables, we compared shape frequency distributions at each harmonic for different source rocks. The chi-square statistical test is preferred because it does not assume a normal distribution. It would be tedious and possibly statistically invalid to make all possible comparisons between rock types. Therefore, we chose a set of orthogonal contrasts with which to analyze for similarities and differences between sources.

Figure 3 presents the various comparisons made and the corresponding harmonics at which significant differences occurred. Significant chi-square values indicate large differences between samples and therefore mark those harmonics at which perceptible differences are likely to occur between histograms.

In the first comparison, we combined the three samples from the Eleana Formation and contrasted them with the two tuff samples. Significant dif-

ferences occurred at all harmonics except the third; 17 of the 20 harmonics showed significance at the 0.0005 alpha level. The sharp contrast between tuffs and clastic-bearing sedimentary units in Rainier Mesa, as observed by analysis of the MHAS, is verified with this probabilistic test. The largest of the significant values occurs at the second harmonic. When we examine the histograms for all samples at this harmonic, we see that the significant differences result from the presence of a large mode on the left of the clastic samples and the corresponding lack of low amplitude values on the left of the tuff histograms (Fig. 4). An equal but opposite effect applies to the right side of these two histograms. Thus, it appears that the clastics are characterized by a high percentage of "ovoid" grains at the second harmonic, whereas the tuffs are dominated by a high percentage of "elongate" grains.

In the second comparison, sample 1 was contrasted with sample 2. Sample 1 is from the Eleana clastics and sample 2 represents Eleana dolomite units. The chi-square table indicates that significance occurs at only 5 of the 20 harmonics; the largest significant value occurs at the 18th harmonic. When we examine the contributing factors to the chi-square statistic and histograms at the 18th harmonic, we see that this significant difference is largely the result of a high central mode in the sample 1 distribution.

Sample 1 was also contrasted with sample 5. Both samples are from clastic units of the Eleana Formation. Although sample 1 was taken from drainage off units E, F, and G, and sample 5 represents sediment influx from units E, I, and H, they should both reflect a similar depositional history.

Fig. 3. Diagram of various grain shape comparisons illustrating the harmonics at which significant differences occurred: (a) dolomites and clastics vs tuffs (samples 1, 2, and 5 vs samples 3 and 4), (b) clastic vs dolomite (sample 1 vs sample 2), (c) clastic vs clastic (sample 1 vs sample 5), and (d) tuff vs tuff (sample 3 vs sample 4).

Fig. 4. Second harmonic grain shape frequency distributions of source locality samples. The vertical axis indicates the number of grains and the intervals along the horizontal axis indicate the harmonic amplitude (increasing to right).

Consequently, one would expect these samples to possess similar shape characteristics. Chi-square analysis confirms this conjecture. Signification differences between the two samples were found only at four of the 20 harmonics.

Lastly, we compared the younger tuffs and the Tunnel Bed tuffs. The only significant contrast occurs at the 18th harmonic. This difference results from the presence of three small modes within the body of the sample 3 (Tunnel Bed tuffs) distribution that are not present in the sample 4 (younger tuffs) distribution.

The results of these chi-square analyses indicate that differences between the tuffs and the clastic samples from the Eleana Formation are expressed at most of the 20 harmonics. However, variation within the clastic samples or within the tuffs is only evident at a few of the harmonics

analyzed. This supports the conclusions of Przygocki⁸ that genetically different rock types must produce different shape frequency distributions; conversely, rock types of similar origin commonly yield similar shape frequency distributions.

The shape frequency distributions of the tuffs and clastics are so inherently different that it is possible to describe them by generalized shape frequency distributions. These generalized distributions provide standards to which we can compare the mixed sediment samples. The clastics typically have a large mode on the left side of the histogram that steadily diminishes toward the right. The tuffs, however, possess a large mode on the right side that tails off to the left. This behavior is best illustrated at the second harmonic (Fig. 4) but is characteristic of most other harmonics at which chi-square significance occurs.

SAMPLE UNMIXING

To demonstrate the feasibility of unmixing sand samples into their various source components, a mixed sample (7) was collected from the confluence of streams draining only two lithologies, Eleana dolomite and the Tunnel Bed tuffs. Because of the proximity of the source fans and the absence of other sources, we expect this mixed sample to contain grains from each of these units in unknown proportions. In Fig. 5, the MHAS of samples from all three of these areas are compared. The graph clearly indicates that the mixed sample curve most closely approaches that of the dolomite. Thus we conclude that the majority of grains contributed to the mixed sample are from the dolomite units.

To further analyze these results, we used a chi-square contingency table and proposed hypotheses to test for differences between the three samples (Fig. 6). The results confirm the initial findings of the MHAS as in Fig. 5. The only significant differences between the mixed sample and the dolomite occurred at the 4th, 7th, and 10th harmonics. However, the mixed sample and the tuff differed significantly at 10 of the 20 harmonics calculated. Both sources differed significantly from the mixed sample at the 10th harmonic. More importantly, the 10th harmonic showed the highest statistical significance of the 20 harmonics when we compared the two source samples.

To better understand these relationships, the shape frequency histograms at the 10th harmonic were contrasted for the three samples—dolomite,

tuff, and mixed sample. Figure 7 illustrates the portions of the mixed sample histogram influenced most by the respective source areas. We note that the mixed sample has a high proportion of "low amplitude" grains, as indicated by the large left mode, and a corresponding dearth of high amplitude values, as illustrated by the small right mode. Both features are dominant characteristics of the dolomite standard.

Having made the assumption that the only two contributing sources (approximately equal in area) to the mixed sample locality are the dolomite and the tuff, we can calculate the relative proportions contributed from each. To avoid possible complex shifting of internal modes, it is best to compare histograms at a harmonic where the tails vary greatly. Thus, we selected the 10th harmonic where 46% of the grains from the tuff have an amplitude greater than 0.010664, but only 21% of the dolomite grains have amplitudes greater than 0.010664. Surprisingly, 21% of the mixed sample grains fall in this amplitude range.

The seemingly obvious reason for the identical percentages of the dolomite and mixed samples in the high amplitude range is that little, if any, of the sediment in the mixed sample locality comes from the tuff. Although this is true for the particular sample analyzed, we must answer several questions before we can extrapolate this conclusion to the entire area sampled. Namely, is the tuff being eroded

Fig. 5. Plot of mean harmonic amplitude vs harmonic number for sample 3 — (Indian Trail toff), sample 2 — (Eleana dolomite), and sample 7 - - - - - (mixed sample).

Fig. 6. Diagram of two grain shape comparisons illustrating the harmonics at which significant differences occur: (a) dolomite vs mixed sample (sample 2 vs sample 7) and (b) tuff vs mixed sample (sample 3 vs sample 7).

at a rate similar to that of the dolomite? If it is, are all sand sizes transported from the sources in the same proportions or are the above percentages unique to the fine-sand class? Also, what is the relative percentage of quartz in the parent rocks? Finally, is the sediment stratified? Such questions would be answered much more easily if we could use a scanning digitizer in conjunction with a microscope; with such hardware, thousands of grains could be analyzed in just a few hours.

Sediment stratification may well be the dominant sedimentation process. For example, during a flash thunderstorm, sediment may be eroded from one canyon, but an adjacent canyon may remain dry and experience little or no sediment erosion. Such a phenomenon would produce a layering effect downstream of homogeneous deposits that represent a single lithology, not a uniform mixture of sediments. The possible occurrence of such a phenomenon needs to be further evaluated before our analysis can be extended to subsurface correlations.

Another mixed sample (6) was taken at the confluence of streams that drain the sample 4

locality, the Tertiary Tunnel Beds, and the Eleana clastic units D, E, and F. Because the Tunnel Beds represent a very small exposure in relation to the total effective drainage area and because they are statistically quite similar in grain shape to the younger tuffs, only samples 4 and 1 (representing the Eleana clastics) were contrasted with the mixed sample 6.

As expected, the tuff sample differs significantly from the clastic sample at 14 of the 20 harmonics. Also, the clastic sample is significantly different from the mixed sample at 12 of 20 harmonics. The tuff sample, however, does not differ significantly from the mixed sample at any harmonics. These results imply that, as with mixed sample 7, almost all the quartz sand in the sample sediment is being contributed from one rock type alone. In sample 6, the tuff is the major sediment supplier; in sample 7, the dolomite units are the dominant source. However, with sample 6, the results were more predictable because the greater percentage of drainage area is from the tuffs. Only two small feeder streams are entrenched in the Eleana outcrops.

DISCUSSION AND CONCLUSIONS

Fourier grain shape analysis has enabled us to investigate differences in quartz grain shape in sediments draining areas underlain by Tunnel Beds, Survey Butte, and Rainier Mesa tuffs, as well as clastic units of the Eleana Formation. It is a relatively simple matter to discriminate between tuffs and clastics, but differences between genetically similar rock types are not as prominent.

The tuffs are volcanic in origin and thus contain quartz shards that are, by definition, quite

angular. The shapes of these quartz grains reflect the complex interaction of cooling rate and pore space available at the time when the tuff was formed. The tuff has since undergone erosion, producing the sand we sampled. However, the flash floods characteristic of a desert alluvial fan environment apparently have not significantly altered this angular quality.

In contrast, the quartz grains within the sedimentary units of the Eleana Formation may

Fig. 7. Tenth harmonic grain shape frequency distributions of the mixed sample (7) histogram showing portions of the histogram most influenced by the respective source areas. The vertical axis indicates the number of grains and the intervals along the horizontal axis indicate the harmonic amplitude (increasing to right).

have undergone several cycles of erosion, transport, and deposition before reaching the sampling sites at NTS. Although some shape components charac-

teristic of their origin may remain, their present shape most probably reflects their depositional history.

Differences between the tuff and clastic units are so great that simple inspection of the mean harmonic amplitude spectra provides sufficient detail for discriminating between them (Fig. 2). The chi-square analysis of contingency tables further documents these differences. Using the significant chi-square values as a guide, we can compare histograms at the second harmonic for all source samples (Fig. 4). These results indicate that the tuff and clastic sample groups can be described by standard shape frequency distributions. The tuffs are characterized by a large percentage of high amplitude values and a relatively small proportion of low amplitude values. A roughly equal but opposite relationship characterizes the clastics.

On the basis of these observations, we should be able to determine whether there has been a significant influx of sediment from carbonate-bearing outcrops to any point of confluence in the drainage system. We can obtain a crude estimate of the proportion of carbonate-bearing sediment present in a mixed sample simply by calculating the percentage of grains in the sample possessing very high amplitude values. Preliminary estimates based on our analysis of the five source samples indicate that in sands derived only from tuff units, at least 13% of a 200-grain sample will have amplitudes greater than 0.3679 at the second harmonic. In contrast, in sands derived from clastic units, less than 5% of the total sample will have amplitudes greater than 0.3679. Accordingly, if these percentages hold true for additional tests, we would expect that in a variable mixture of sand from both source lithologies, between 5 and 13% the total sample will have amplitudes greater than 0.3679.

We examined a mixed sediment sample taken from an area that exclusively drained dolomite outcrops and tuffs, and attempted to "unmix" the sample using the MHAS technique, the chi-square tests, and the grain shape frequency histograms. Results indicate that the dolomite was the major contributing lithology, even though the drainage area encompassed by each lithology is roughly comparable. However, it is impossible to draw conclusions concerning relative rates of sediment input in this location from the two sources on the basis of the one sample. One possible explanation for the appearance of dolomite as the predominant constituent is that the sediment sample from within this drainage network is characterized by a layering effect in which sediment derived from individual sources is deposited as overlapping layers instead of as homogeneous mixtures. Such a phenomenon could conceivably occur as a result of a time interval

marked by a lack of free flowing water followed by a resumption of flow (e.g., drought followed by flash floods).

Another mixed sample, taken from an area that drains tuff units of the Survey Butte, Rainier Mesa, and Tunnel Beds, as well as clastic units of the Eleena Formation, was analyzed. Again, the results reveal that almost all the sediment influx was from one rock type—in this case, the tuffs. However, for this sample, most of the drainage was from the tuff outcrops, and thus, we could better predict the results.

The next step desired in sediment unmixing is to determine the percent contribution of the various source components to any given sample. This was not possible within the constraints of our study. However, from the strong differences among the source lithologies examined, it appears that factor analysis may provide such useful information.

Because the alluvium within Yucca Flat is merely the erosional product of the surrounding foothills, it is likely that the same shape characteristics used to unmix sediment samples in the surface drainage system could be applied to the subsurface as well. If this is true, Fourier shape analysis will be an invaluable tool for correlating lithologies in the subsurface alluvium.

If we make the conservative assumption that we can distinguish only tuff-derived sand from that of clastic sources in the subsurface, several very important possibilities still present themselves. Because only 150 to 200 quartz grains are required for a sample analysis, the sidewall samples will provide the necessary material. Thus, the samples needed for grain shape analysis have already been taken for most drill holes at the NTS and no additional sampling is needed for preliminary subsurface studies.

With grain shape analysis, we should also be able to determine the depth at which sand from carbonate sources is first deposited within the alluvium. That is, because of the reversed stratigraphy effect,⁹ tuff units surrounding Yucca Flat will be eroded and deposited as alluvium before downcutting of the Eleena Formation occurs. In the alluvium, the proportion of carbonate sediment should be zero below a certain depth; above this depth, the carbonate portion should increase dramatically. Therefore, to determine the tuff-clastic boundary within the alluvium, all we may need to do is examine histograms of various samples at the second harmonic and identify the percentage of grains with high amplitude values (tuff grains).

An additional application of this simple procedure would be to analyze the grain shape frequency distributions of sidewall samples from depth

zones tentatively identified as debris flow deposits. True debris flows should involve little or no sediment mixing. Consequently, sand grains from flows draining carbonate units should be readily identifiable at the second harmonic.

The potential for unmixing sediment samples

on the basis of these results is very promising. However, the efficiency of the analysis would be greatly enhanced if (1) we could apply factor analysis to provide a more accurate breakdown of the samples and if (2) we could use a scanning digitizing system.

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