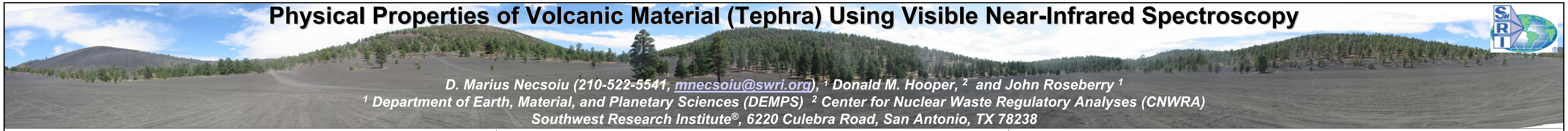

Physical Properties of Volcanic Material (Tephra) Using Visible Near-Infrared Spectroscopy

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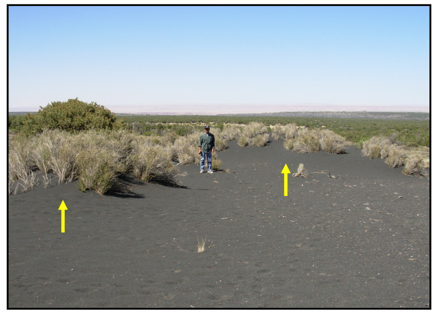
INTRODUCTION

Sunset Crater, Arizona, has been studied as an analog area for latent eruption and posteruption surface processes near the potential high-level waste repository at Yucca Mountain, Nevada. The evolution of basaltic tephra deposit in a semiarid climate is of particular interest and can be evaluated by studying the relationship between visible near-infrared (NIR) reflectance and physical properties of volcaniclastic (eolian) material.

Several previous studies (e.g., Leu, 1977; Johnson et al., 1992; and Okin and Painter, 2003) have investigated the relationship between reflectance spectroscopy and the grain size of unconsolidated or powdered rocks and minerals. The objective of this research is to understand the relationship between physical properties of tephra and NIR reflectance and compare these results to the expected relationship noted by previous studies.

EOLIAN TEPHRA DEPOSITS

Eolian tephra deposits were sampled because they offer the opportunity to examine basaltic volcanic material that has been reworked by surface processes and redistributed. Additionally, eolian deposits are easily sampled over a grain-size range from 0.106 to 2 mm [0.004 to 0.078 in]—the desired range for spectroscopic analyses.



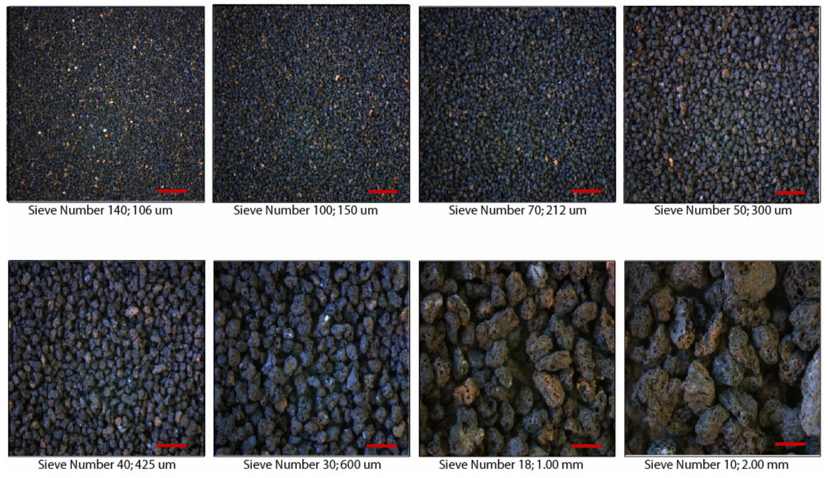
Coppice dunes (arrows) are composed of eolian redistributed tephra from the Sunset Crater eruption.

SAMPLE DATA COLLECTION AND PREPARATION

The geologic samples collected in the field were analyzed in the laboratory with the Analytical Spectral Devices FieldSpec® 3 portable spectroradiometer. Diffuse-reflectance spectra were collected from five samples with each of the samples being sieved into 8 different sieve fractions (splits). Each spectral measurement was performed without interference from specular reflectance. The setup configuration, such as the angle of incident light and the distance of light illumination and sample surface, were consistent through the measurement process. Because random noise is reduced by the square root of the number of spectra averaged, a large number of samples (e.g., 60) were averaged per measurement. In addition, several measurements were performed on different locations of the sample to obtain measurement results that are more representative of the entire sample.

Five eolian redistributed tephra samples were selected for sieving and spectral analysis (MN62406-5, MN62406-6, MN62606-13, MN62706-27, MN62906-32). Each sample was sieved with standard mesh sizes. Volume of fractions less than 0.106 mm [0.004 in] was too small for collection of spectral data.

Sieve No.	Mesh size (Diam, inches)	Mesh size (Diam, mm)	Phi Units (-$\log_2$ Diam)
10	0.078	2	-1.0
18	0.039	1	0.0
30	0.024	0.6	0.75
40	0.017	0.425	1.25
50	0.012	0.300	1.75
70	0.008	0.212	2.25
100	0.006	0.150	2.75
140	0.004	0.106	3.25



Sieve Number 140; 106 um
Sieve Number 100; 150 um
Sieve Number 70; 212 um
Sieve Number 50; 300 um
Sieve Number 40; 425 um
Sieve Number 30; 600 um
Sieve Number 18; 1.00 mm
Sieve Number 10; 2.00 mm

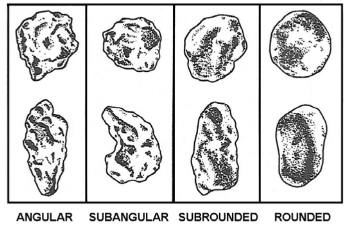
Sieved Sample MN62906-32. Grain-size range from 0.106 mm to 2 mm. Scale bar represents 2 mm.

CLASSIFICATION SCHEME

Grain Shape:
Angular, subangular, subrounded, rounded.

Grain Texture by Degree of Vesicularity:
Vesicularity was classified as very high when the majority of grains predominantly comprised vesicles (bubble voids) grading, through high, medium, low, and very low when there were few or no vesicles.

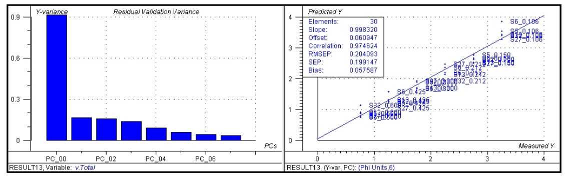
Modified from Lindholm (1987)



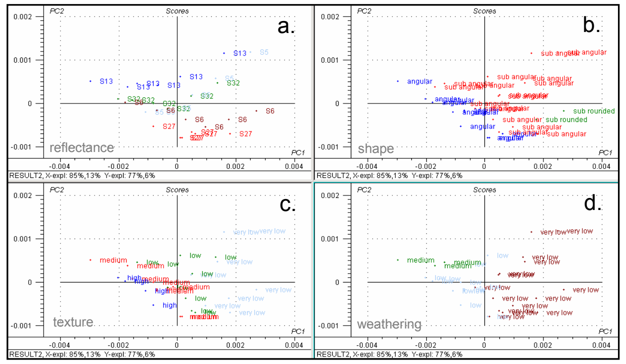
Weathered Material:
The amount of weathered material (mostly postdepositional) in vesicles or on the grain surface was classified as very high when most grains were predominantly or totally coated in weathered material, grading through high, medium, low, and very low when most grains had little or no weathering.

DATA ANALYSIS AND RESULTS

Quantitative and qualitative analyses were performed on tephra modified by eolian processes to investigate the effects of grain size, shape, texture, and weathering on spectral response. Each reflectance spectra was jump corrected at 1000 and 1800 nm (i.e., spectral discontinuities due to the spectrophotometer), and multiple measurements were averaged per sieving. Principal component analysis (PCA) was applied to decompose data by finding maximum variances so the complexity of tephra samples could be interpreted. Partial least squares was used for developing a linear calibration model between grain size (0.106 to 0.6 mm) [0.004 to 0.024 in] and spectral reflectance of sieve fractions.



Residual validation variance for the model and predicted versus measured Y plot.



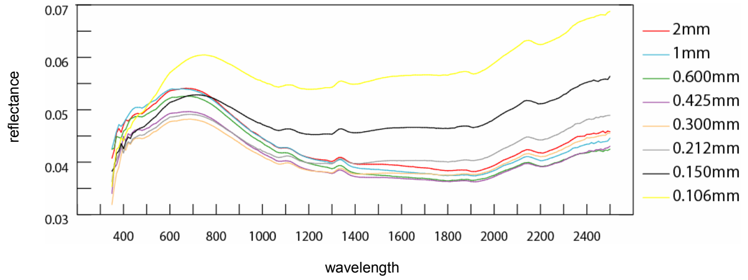
Over 98% of the variance in the data was explained by the first two components of the PCA.

Scores were used to detect sample patterns, groupings, similarities or differences. Sieved reflectance spectras were grouped by a) sample number b) shape c) texture and d) degree of weathering.

DISCUSSIONS

The trends observed in the spectral reflectance of the analyzed fractions of tephra samples showed that an orderly relationship exists between reflectance and geometry, grain size, and mixing with nontephra grains.

In the near-infrared wavelength range, the grain size of a homogenous sample generally affects the reflectance properties such that an increase in grain size produces a decrease in reflectance (Clark, 1999). This observation seems to generally agree with our eolian samples such that an increase in grain size produces a decrease in reflectance. This trend is particularly true for grain-size sieve fractions less than 0.6 mm [0.024 in]. For grain-size sieves greater than 0.6 mm [0.024 in], the effect is reversed, probably due to the presence of weathering material on the surface of individual grains.



Spectral response of a tephra-sieved sample (MN62906-32). Spectral range 350-2400 nm.

The analysis reveals a subtle grain shape change from angular to subangular as grain size decreases from 2 to 0.106 mm [0.078 to 0.004 in]. This may be related to the change in vesicularity and its overall effect on grain texture and morphology (coarser particles being more vesicular than finer particles). This agrees with the observation by SNL (2007) that larger particles tend to have a higher fraction of vesicles than small particles.

High spectral response of the fine grain sizes is also related to the degree of mixing. The percentage of nontephra grains increases in the finer grain-size splits, where the finest grain-size split is the most mixed. This is due to fine-grained eolian sand and dust (mostly quartz), which may not be related to the basaltic tephra from Sunset Crater.

The coarser grain-size splits display slightly more weathering. Broadly, this includes oxidation, possible development of a weathering rind (usually best observed on larger particles), mineralization and cementation (may include clay minerals or a calcium carbonate coating), and similar processes that coat individual grains and fill vesicles or other pores. The observation that coarser grains are more weathered may be due to another observation that coarser grains are more vesicular than fine-grained particles. These bubble voids appear to be the focus of most postdepositional mineralization.

CONCLUSIONS

NIR spectroscopy is a successful technique to characterize volcanic materials based on their physical properties. A model that relates spectral response to grain size was developed and successfully validated using a systematic cross-validation method; however, the test was performed on a small number of samples. Results indicate that physical characteristics of analyzed samples—shape, texture, and weathering—are highly correlated. Samples with a high degree of weathering were identified as being angular with high vesicularity. These characteristics appear to be independent of the percent of black tephra mixing with oxidized tephra and nonvolcanic material. Tephra samples appear to be distinguishable based on the degree of oxidized tephra and nontephra material.

This research improves our understanding of the relationship between physical properties and spectral response of basaltic tephra in the visible and near-infrared regions. These relationships can be used to support investigations of Strombolian eruptions, models of tephra dispersal, the extent of tephra deposit remobilization and redistribution, rates of weathering and erosion of tephra deposits, and grain-size characteristics.

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