AUTOMATED CLASSIFICATION OF LUNAR SPECTRAL REFLECTANCE DATA. M. J. Bielefeld, Computer Sciences Corporation, Silver Spring, MD. 20910 and C. M. Pieters, Dept. of Geological Sciences, Brown University, Providence, RI. 02912.

In the past decade, our understanding of the planetary objects of our solar system has been greatly advanced by the significant increase in the amount of data collected by various planetary projects. However, to achieve the long-range goals of NASA's ongoing exploration program will require the development of systematic approaches to handling and digesting the continuing growth of information. This presentation outlines an approach to handle in a systematic and automated fashion the information from telescopic reflectance spectroscopy in the visible and near infrared energy band. We will illustrate how a relatively small number of lunar spectral types can be deduced from a large amount of reflectance data.

Data. We have chosen a data set of approximately 600 relative reflectance spectra in the energy range of 0.3 to 1.1 μm (with 30 nm resolution). The measured objects are selected lunar regions (10 to 20 km in diameter). These spectra have been extensively studied (1-5) and form a good control for this study of automated classification. However, because of the statistical nature of the classification problem, the sparseness of lunar coverage in this data set is a drawback. The methodology presented here will actually work more efficiently as the number of spectra increases.

Data Compression. A typical spectrum (see Figure 1) contains twenty-five highly correlated measurements. This information has been compressed into five wavelength-dependent parameters by means of a least-squares cubic spline fitting routine. Four "knots" for the spine were chosen at 0.30, 0.45, 0.85, and 1.10 μm to faithfully reproduce the curvature of the majority of the 600 spectra. As can be seen in Figure 1, the second derivatives (S") are linear between the "knots"; the first derivatives (S'), quadratic; and the spline function (S), cubic. Given the four S" values and any instantaneous S' value, the complete S' function can be generated. Similarly, given S' and normalization of S to unity at 0.57 μm, the complete spline is determined. Therefore, all the information of the measured spectrum is uniquely defined by five parameters under the assumption of adequate goodness-of-fit. The five parameters are $S''_{.3}$, $S''_{.45}$, $S''_{.85}$, $S''_{1.1}$, and $S'_{.4}$.

Classification. By transforming the compressed information from 600 spectra into five pseudo-images of a single line with 600 pixels per line, use can be made of the highly developed technology of image classification. The pixel location within the pseudo-image identifies the spectrum; the pixel value, the magnitude of the particular derivative. Each spectrum can be located within a hypercube of a five-dimensional space defined by the five image coordinates. The non-parametric unsupervised classification scheme used in this analysis looks for high-density clustering within the hypercube to identify those spectra

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which have very similar derivative values, and therefore the same spectral signature. Cluster centers distinguish spectral types from one another. Spectra located at distances from these centers could be either subclasses or sui generis spectra. It is clear that a more uniform sampling of the lunar surface will help to determine whether non-clustering spectra are simply artifacts of the sampling procedure or real lunar anomalies.

The above classification scheme allows for simple introduction of new information about the lunar region, for example, albedo, geochemistry, or altimetry data. An additional psuedo-image would be constructed for each new parameter; the dimensionality of the hypercube expanded; but the methodology of classification would remain the same.

Results. The use of the five parameter classification has produced encouraging results. The discriminating character of $S'_{.4}$ and $S''_{1.1}$ has been found to be most influential in finding clusters. $S''_{.45}$ and $S''_{.85}$ seem to have redundant discriminating value, while $S''_{.3}$ is important in locating anomalous spectra.

The general lunar type MII of Pieters (1977), which are mare craters having a strong 1 μm spectral feature, is clearly extracted by our method. Additional analysis by this method should allow this group to be resolved into subgroups. The upland craters identified by Pieters (1977) as UIb are also resolved.

An indication of the sensitivity of this method is demonstrated in Figure 1 where the underlying similarity between Descartes 2 (a bright upland crater) and Descartes 3 (a bright mare crater) is seen in almost identical parameters $S''_{.45}$, $S''_{.85}$, $S''_{1.1}$, and $S'_{.4}$. The major distinction is found in $S''_{.3}$. This underlying similarity is not readily apparent in the noticeably dissimilar spectral signatures.

In summary, this methodology has several advantages: (a) wavelength-dependent parameters can be established which relate to the energy-dependent physical processes of spectral reflectance; (b) the use of derivatives as discriminating parameters for the smooth lunar spectra helps identify subtle differences in the spectra; (c) introduction of new information into the scheme is easy whether it is in the form of new spectra or new geochemical and geophysical parameters; and (d) automation of the painstaking process of visual classification leaves the geological scientist free to do that which he/she does best, namely, analysis and interpretation.

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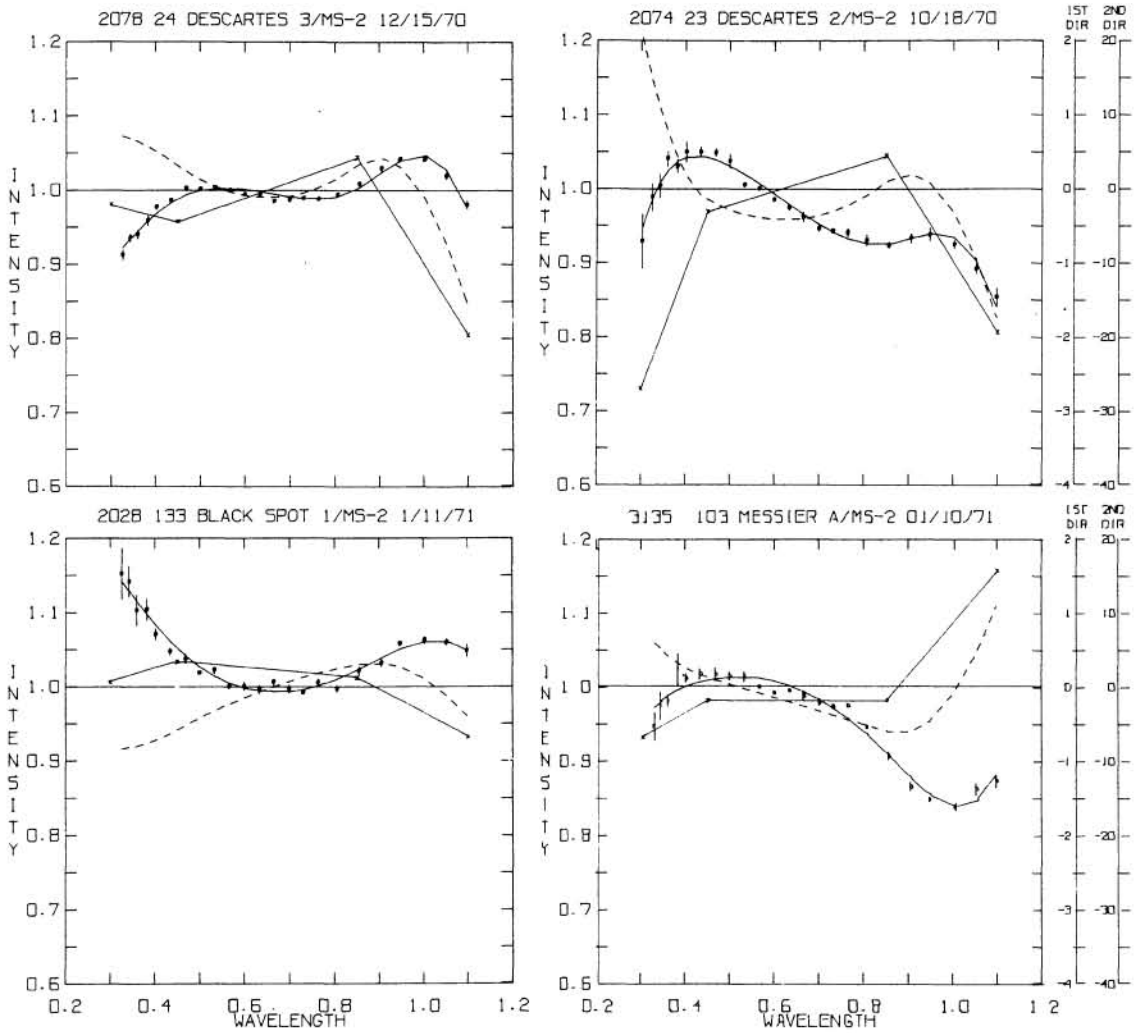

Figure 1. Relative reflectance spectra of four lunar regions. These spectra have been divided by a standard spectrum (MS-2) from Mare Serenitatis and have been normalized to unity at 0.57 μm. The data have been fitted with a least-squares cubic spline with "knots" at 0.30, 0.45, 0.85, and 1.10 μm. The first derivative (---) and the second derivative (x —— x) of the fitted function are also plotted with appropriate scale values to the right. Note the variety of spectral signatures which can be fit with four "knots".