Determining the Composition of Olivine on Asteroidal Surfaces. Jessica M. Sunshine and Carle M. Pieters, Department of Geological Sciences, Box 1846, Brown University, Providence, RI, 02912.

Olivine has been remotely identified as a major component on many S- and A-type asteroids based on qualitative analyses of broad absorption features near 1.0 μm in their telescopic reflectance spectra. Laboratory studies have shown that this diagnostic olivine absorption feature is composed of three individual absorption bands resulting from electronic transitions of Fe\textsuperscript{2+} in distorted M1 and M2 sites [e.g. 1]. Both the overall absorption feature [1,2] and each of the individual absorption bands are also known to vary systematically as a function of olivine composition [1,3]. Thus, it should be possible to remotely determine the composition of olivine present on the surfaces of the various olivine-rich asteroids. However, extrapolation of laboratory studies to compositional interpretation of asteroid spectra is complicated by several factors: observational noise; lower spectral resolution; compositional heterogeneities (including the presence of other phases such as pyroxenes and/or metal); and the effects of alteration processes.

In order to address such complex problems, a quantitative approach to spectral analysis, the modified Gaussian model (MGM) was developed by Sunshine et al. [4] which deconvolves spectra into their constituent absorption bands. The MGM, a refinement of the Gaussian model, more accurately adheres to the physical processes involved in electronic transition absorptions. Under the MGM, each spectrum is modeled in log reflectance and energy as a sum of absorption bands superimposed onto a baseline or continuum. Each absorption band is described by three model parameters (center, width, and strength) which can be interpreted and used to infer composition [4,5,6,7]. One of the strengths of the MGM is that it allows compositional information to be extracted directly from measured spectra and is therefore complementary to other approaches to modeling asteroid spectra which require the use of meteorites and/or terrestrial samples as spectral analogs.

A quantitative understanding of the properties of olivine absorptions was established by using the MGM to analyze a laboratory suite of spectra spanning a full range of olivine compositions. The MGM model fit to a Fo97 olivine spectrum is shown, as an example, in Figure 1. Initial analysis of the entire suite of olivine spectra reveals several relationships among the absorption band parameters as a function of both composition and absorption site [3]. The solid lines in Figure 2 illustrate that the centers of each of three primary olivine absorption bands shift towards longer wavelengths with increasing iron content at a rate determined by the absorption site (M1 vs. M2). Subsequent analyses indicate that the widths and relative strengths of the olivine absorptions are also controlled by the absorption site and vary systematically with composition. These systematic variations reveal inter-relationships among the band parameters that can be used to establish rigorous bounds on acceptable values for absorptions in olivine spectra.

The analysis of laboratory spectra also provides criteria for evaluating the results of MGM modeling of the spectra of olivine-rich asteroids. For example, the best model fit to the spectrum of 246 Asporina [8] (i.e. the minimum mathematical solution) is found to be inconsistent with laboratory results. As illustrated in Figure 2 (unconstrained data), the bands centers derived for each of the three primary olivine absorptions each imply a different Fo# for the asteroid, clearly a physically unrealistic result. Although there is insufficient information in the spectrum of 246 Asporina to obtain a reasonable solution, one can successfully model the spectrum by explicitly including the laboratory definitions of olivine absorption bands as constraints on the fitting process. Two endmember solutions to 246 Asporina are tested: one using band widths and relative strengths typical of fosteritic olivines; and one using widths and strengths of fayalitic olivines. Both of these solutions appear to adequately model the spectrum of 246 Asporina (Figures 3 and 4), yet lead to very different values of absorption band centers. The derived band centers can be compared to laboratory results and used to discriminate between the two solutions. As indicated on Figure 2, in order to satisfy both the data and the fayalitic constraints, the
fayalitic model results in band centers that are physically unreasonable and completely at odds with a fayalitic compositions. In contrast, the fosteritic solution yields band centers that are fully consistent with a fosteritic composition. Thus, MGM analysis strongly suggests that the olivine component of 246 Asporina is distinctly fosteritic. Further refinements on the Fo# of 246 Asporina will be undertaken. In addition, the spectra of other olivine-rich asteroids will be examined to evaluate the compositional diversity among the olivine-rich asteroid population.

Figure 1: MGM fit to laboratory forsterite (Fo 97) consisting of three primary absorptions (denoted by their site assignments), superimposed on a continuum (dashed line). The residual error between the modeled spectrum and actual spectrum (top line) is offset 10% for clarity.

Figure 2: Band centers of primary olivine absorptions as a function of composition. Solid lines represent best fits to the suite of 18 laboratory spectra. Symbols are derived band centers resulting from MGM modeling of 246 Asporina: Unconstrained Model, Fosteritic Model (Figure 3), and Fayalitic Model (Figure 4).

Figure 3: MGM model to 246 Asporina using band widths and relative band strengths that are typical of fosteritic olivines. Lines are as in Figure 1.

Figure 4: MGM model fit to 246 Asporina using band widths and relative band strengths that are typical of fayalitic olivines. Lines are as in Figure 1.

References:

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