METAL-ORTHOPYROXENE AND METAL-OLIVINE MIXTURES: SPECTRAL REFLECTANCE PROPERTIES AND IMPLICATIONS FOR ASTEROID SPECTROSCOPY.

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Introduction: Metal-mafic silicate assemblages are characteristic of a number of meteorite classes, including achondrites such as pallasites, mesosiderites, IAB and IIICD irons, primitive achondrites, such as lodranites, and winonaites, and primitive meteorites such as enstatite and ordinary chondrites [1, 2]. Understanding the spectral reflectance properties of such assemblages is necessary if we are to identify asteroiddal parent bodies, characterize their surface assemblages, and possibly discriminate primitive from evolved assemblages. In order to provide the necessary supporting laboratory data, we have characterized a series of meteoritic metal+orthopyroxene and meteoritic metal+olivine powdered mixtures. Such measurements are necessary because of the difficulty in measuring representative spectra of metal+silicate bearing meteorites, such as pallasites and mesosiderites.

Experimental Procedure: A sample of the Odessa octahedrite iron meteorite was hand-ground with emery paper to produce a fine-grained (<45 and 45-90 µm) metal meteorite powder for the intimate mixtures. Orthopyroxene ($Fs_{12.8}$) and olivine ($Fa_{9.6}$) were ground by hand in an alumina mortar and pestle and dry sieved to produce <45 and 45-90 µm sized powders. The <45 µm fractions were used to produce intimate mixtures of metal+orthopyroxene and metal+olivine at 10 wt. % intervals. Additional (50:50) mixtures were also produced using 45-90 µm sized powders.

Reflectance spectra were measured with the University of Winnipeg's PSF ASD FieldSpec Pro HR spectrometer which outputs data from 0.35 to 2.5 µm with a 1 nm sampling interval. Sample spectra were measured at i=30° and e=0° relative to Spectralon® and corrected for minor irregularities in Spectralon's® absolute reflectance. Straight line continua, tangent to the spectra on either side of the 1-µm region absorption band (Band I), and tangent to the spectrum near 1.4 µm and fixed at 2.5 µm for the 2-µm region band (Band II), were divided out to recover band centers.

Results – Metal+Orthopyroxene Mixtures: The 10 wt. % series of metal+orthopyroxene are shown in Figure 1. With increasing metal content, both major absorption bands exhibit a decrease in depth and an apparent shift in band minima to shorter wavelengths, due to the red slope of the metal. However, band centers in the 1-µm region show almost no change with metal content up to 90 wt. % (Table 1). The wave-length position of the 2-µm region band "center" shows an overall increase with increasing metal content, suggesting that this type of continuum is not ideal for recovering this band's position.

Results – Metal+Olivine Mixtures: The metal+olivine mixture spectra are shown in Figure 2. Olivine spectra are characterized by a broad absorption feature in the 1-µm region. With increasing metal content, the Band I minimum moves to shorter wavelengths, but the continuum-removed center shows very little deviation, with the exception of the most metal-rich spectrum (Table 2). Also, as expected, band depth decreases with increasing metal content.

Grain Size Effects: The selected mixtures that were run using 45-90 µm sized end members (50:50) can be compared to the fine-grained sample spectra. For the metal+orthopyroxene mixtures, band center is largely invariant from the pure end member. The Band I depth of the coarse-grained mixture shows a smaller decrease as compared to the end member (39 vs 80%, a 51% reduction) than the fine-grained mixture (17 vs 50%, a 67% reduction).

The 50:50 metal+olivine mixture shows a greater decrease in band depth for the finer-grained 50:50 mixture (6 vs 34%: 82% reduction) than the coarser-grained mixture (18 vs 63%: 71% reduction).

Discussion: A number of observations can be derived from these results. In both mixture series, mafic silicate absorption bands remain resolvable for metal abundances up to 90 wt. %. This suggests that spectrally featureless (and presumed metal-rich asteroids) probably contain <10 wt. % silicates on their surfaces, with the assumption that the mafic silicates have roughly the same Fe^{2+} content as those used in our mixtures. More Fe^{2+}-poor mafic silicates would show shallower band depths for a given grain size, and their absorption bands would "disappear" at lower metal contents. The extreme case is the enstatite chondrites, whose spectra show no mafic silicate absorption bands, due to their essentially Fe^{2+}-free silicate composition, and in spite of silicate abundances at the few tens of percent level. Conversely, mafic silicates more Fe^{2+}-rich than those used in this study would exhibit deeper absorption bands for a given grain size and the bands would persist to even higher metal contents.

Olivine is a less intense absorber than orthopyroxene, and even though the Fe^{2+} contents of our samples

are similar, olivine band depths decrease at a faster rate than orthopyroxene. Band depth reduction to 50% of the mafic silicate end member value occurs for a metal content of ~35% for orthopyroxene Band I, ~20% for orthopyroxene Band II, and ~15% for the olivine band.

The red-sloped nature of the metal+mafic silicate mixtures is apparent from the spectra (Figures 1 and 2). The laboratory results suggest that the red-sloped spectra of S-class asteroids, long believed to consist of different types of metal+mafic silicate assemblages, are consistent with this interpretation. The laboratory data also indicate that band centers in the 1-μm region can be successfully recovered over a wide range of metal contents, allowing mafic silicate compositions and end member abundances to be constrained. However, additional work is required to develop improved continuum removal procedures for the 2-μm region.

References: [1] Mittlefehldt, D. W. et al. (1998) In *Planetary Materials, MSA vol. 36, chap. 4* .[2] Brearley, A. J., and Jones, R. H. (1998) In *Planetary Materials, MSA vol. 36, chap. 3.* [3] Cloutis, E. et al. (2006) *LPS XXXVII,* Abstract #2121.

Table 1. Continuum-removed band centers (in μm) and band depths (in %) for <45 and 45-90 μm sized metal+orthopyroxene (opx) mixtures.

Wt.% metal	Wt. % opx	Band I center	Band II center	Band I depth	Band II depth
<45 μm series					
0	100	0.916	1.875	50.3	31.7
10	90	0.915	1.868	40.0	22.1
20	80	0.915	1.868	33.0	16.8
30	70	0.915	1.888	27.3	13.4
40	60	0.915	1.884	20.8	9.7
50	50	0.915	1.876	17.0	7.8
60	40	0.916	1.903	17.5	8.7
70	30	0.917	1.903	10.0	4.8
80	20	0.915	1.922	6.1	3.1
90	10	0.917	1.720	2.5	1.6
45-90 μm series					
0	100	0.911	1.855	79.6	67.4
50	50	0.909	1.856	38.9	27.0

Table 2. Continuum-removed band centers (in μm) and band depths (in %) for <45 and 45-90 μm sized metal+olivine (olv) mixtures.

Wt.% metal	Wt. % olv	Band center	Band depth
<45 μm series			
0	100	1.054	33.8
10	90	1.054	19.7
20	80	1.053	13.3
30	70	1.051	10.4
40	60	1.052	8.1
50	50	1.055	6.1
60	40	1.055	4.2
70	30	1.048	2.3
80	20	1.054	1.5
90	10	1.045	0.8
45-90 μm series			
0	100	1.056	62.6
50	50	1.053	18.4

Metal+orthopyroxene mixtures: <45 μm (MET101+PYX042), ASD data
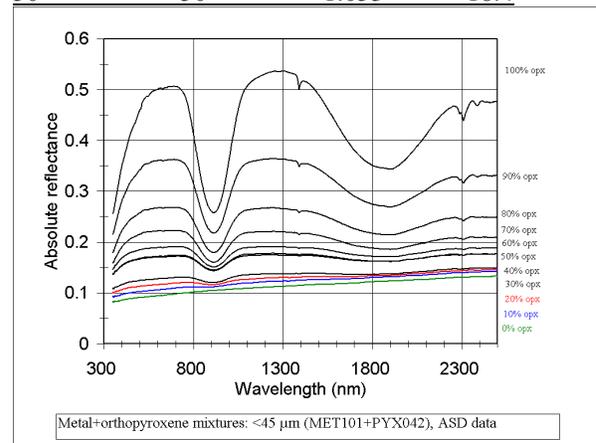
Figure 1. Reflectance spectra (0.35-2.5 μm) of metal+orthopyroxene mixtures.

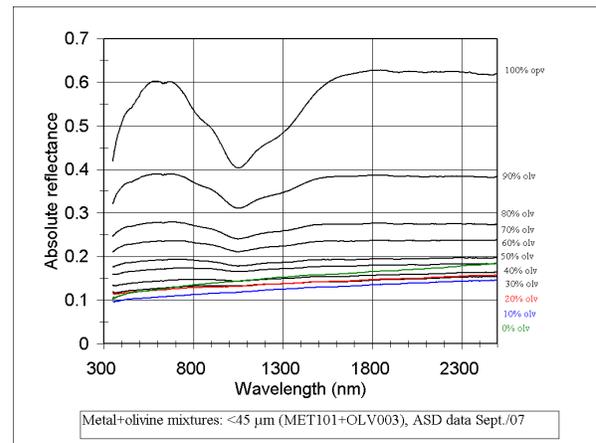Metal+olivine mixtures: <45 μm (MET101+OLV003), ASD data Sept./07

Figure 2. Reflectance spectra (0.35-2.5 μm) of metal + olivine mixtures.