The use of Clementine spectral ratios for compositional analyses is warranted by the lack of spectral resolution and information beyond 1 μm in the UVVIS data. It is impractical to remove a slope or continuum curve from the UVVIS data as is commonly done to Earth-based spectral data to enhance the apparent shape and position of the 1.0-μm band [e.g., *McCord et al.,* 1981; *Fischer and Pieters*, 1994, 1996; *Tompkins and Pieters*, 1999]. The slope of such a continuum, along with overall reflectance and mafic absorption band strength, bears evidence of the amount of "space weathering" a mature mafic soil has undergone With increasing age, the continuum slope increases, and the overall reflectance and mafic band depth decreases. Although knowledge of these slope values is not available from the Clementine UVVIS data, the UV/VIS and 950/750 ratio values can also be interpreted in terms of relative soil maturity: a mature soil is "red" and has a relatively shallow 1.0-μm band, while a more immature soil is "blue," with a deeper 1.0-μm band [e.g., *Fischer and Pieters*, 1994]. These effects are complexly convolved with those due to the presence of titanium- and iron-bearing minerals in lunar soils [e.g., *Lucey et al.*, 1998a, b].

Recent work with the global Clementine UVVIS data has led to the development of geochemical estimates of FeO and TiO_2 abundances, along with relative soil maturity, based on empirical relationships between spectral properties and elemental abundances for lunar soils [e.g., *Lucey et al.*, 1994; 1998 a, b]. These estimates are based on correlations between geochemical data from lunar samples and reflectance at 0.415, 0.75, and 0.95 μm and they represent attempts to deconvolve the sometimes competing effects of composition and maturity on reflectance. The models account for the effects of the presence of ferrous iron, titanium, and opaques in minerals, as well as submicroscopic metallic iron produced by space weathering. A key assumption in the development of the models used to derive these estimates is that glass abundance in lunar soils is highly correlated with maturity. Impact glasses are the dominant form of glass on the Moon, and they are a major component of agglutinates formed as soils increase in age. Because the effects of volcanic glasses on this relationship are presently unknown, both the FeO and TiO_2 abundances and the maturity of soils developed on lunar pyroclastic deposits cannot yet be completely constrained by the same means.

Although both intimate and coarse mixing of components of variable composition play significant roles in the development of all lunar soils [e.g, *Pieters and Englert*, 1993, chap. 14] and the deconvolution of soil components as identified remotely has been the subject of intensive investigation in recent years [e.g., *Sunshine and Pieters*, 1993; *Mustard et al.*, 1998], the approach used here is to evaluate small pyroclastic deposit compositions on the basis of the dominant type of mafic minerals as observed in the spectral ratio parameters identified above. This first-order classification will serve as a comparison to previous Earth-based spectral analyses and will provide a basis for further characterizations of lunar volcanic deposits with the Clementine data.

3. Compositional Analyses of Small Pyroclastic Deposits

To characterize the compositions of the small pyroclastic deposits on the basis of Clementine UVVIS data, we focus on 15 small pyroclastic deposits at 11 sites broadly distributed across the Moon (Table 2; Figures 3 and 4): Alphonsus crater floor, Atlas crater North and South floor; near Crüger crater, Franklin crater floor; two deposits on the southeastern margin of Mare Frigoris, or Eastern Frigoris West and East, near Grimaldi crater, the southeast of the floor of J. Herschel crater, Lavoisier crater floor, Oppenheimer crater floor, and near Riccioli crater. In each case, probable vents, generally in the form of endogenic "dark-halo" craters or dark-rimmed irregular depressions, are identifiable [e.g., *Head and Wilson*, 1979]. Spectral data for three large pyroclastic deposits and several typical mare and highlands sites are included for comparison: (1) the annular ring of pyroclastic material along the southern margin of Orientale basin [e.g., *Bussey and Spudis*, 1997; *Weitz et al.*, 1998], the regional deposits at (2) Apollo 17/Taurus-Littrow and (3) Aristarchus, (4) the young highlands crater Menelaus, (5) the young mare crater Jansen, (6) the high-titanium mare of northern Mare Tranquillitatis, and (7) the low-titanium mare of southeastern Mare Imbrium. The Orientale pyroclastic deposit is enigmatic: because it is large, it has been modeled as a regional deposit [e.g., *Head et al.*, 1997; *Weitz et al.*, 1998], but its nearly circular form and its clearly visible vent are similar to those of small pyroclastic deposits. This comparison of compositional data for large and small pyroclastic deposits, including the Orientale deposit, may help to clarify the nature of this deposit. Spectra were obtained with sampling areas of 15x15-pixel or 25x25-pixel box sizes (at 100 m/pixel) within spectrally homogeneous, topographically flat units near the vent(s). The one exception to this spectral extraction method is the Orientale annular deposit ~80 km from the apparent vent; in this area, spectra were extracted within uniformly dark units spaced widely around the ringed deposit. In all cases, it is assumed that the spectra represent mature volcanic soils in which particle size has been homogenized by maturation processes. In each case, spectral extraction was restricted to a single-orbit strip to limit problems with interorbit brightness variations due to changes in viewing geometry [e.g., *Jolliff*, 1999]. Standard deviations of <2% at each wavelength are typical.

To characterize further the juvenile components in lunar pyroclastic deposits, the Clementine color ratio data can be used to evaluate subtle differences in composition among the small pyroclastic deposits and to compare them to other lunar units. In this section, a summary of the interpretation of the reflectance spectra for the small pyroclastic and comparative deposits is presented. These data are then used (1) to examine the spatial distribution of pyroclastic materials in the floor of Atlas crater to search for evidence of multiple eruptions at a single site and (2) to characterize the extent of compositional variations among representative examples of small and lunar pyroclastic deposits. These analyses set the stage for a summary discussion of the nature of the juvenile components of lunar pyroclastic deposits.

3.1. Spectral Interpretation

Clementine five-band UVVIS reflectance spectra for 14 lunar sites, including 10 pyroclastic deposits at 8 sites, are shown in Figure 5 (see also Figure 3 and Table 2). The small pyroclastic deposits, chosen as representative examples of the three compositional classes of *Hawke et al.* [1989], include those at Alphonsus West (near Alphonsus CA), Atlas South and North, Franklin, Eastern Frigoris East and West, and J.