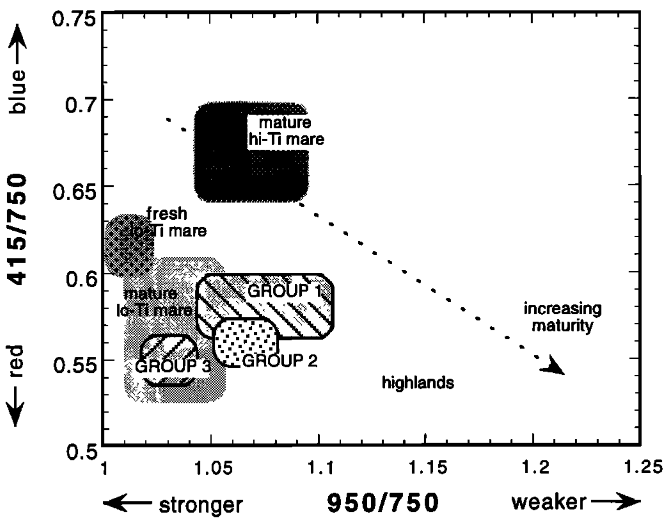

Figure 9. Ranges of typical Clementine color ratios (415/750 versus 950/750) for three classes of small lunar pyroclastic deposits and for typical mature and fresh mare and highlands soils. As indicated by the dashed arrow, lunar soil maturity for mare soils increases downward to the right.

in clearly distinguishing the three compositional classes among these deposits indicates that this classification will break down with additional data. This observation suggests that the compositional variation among the majority of small pyroclastic deposits can best be explained as mixing of juvenile volcanic components with a continuum of nearby mare and highlands components. To explore possible compositional relations of the small pyroclastic deposits with those of typical highlands and mare materials, we examine color ratio data (Figure 9) for typical highlands and mature and fresh maria (both low- and high-titanium; fresh high-titanium deposits are off-scale at the high 415/750 and low 950/750 values). Although the systematics have not been resolved for application to lunar pyroclastic deposits [e.g., *Lucey et al.*, 1998a, b], color ratio data can be interpreted in terms of relative maturity for mare soils: a mature soil is red and has a relatively shallow 1.0-μm band, and an immature soil is blue, with a deeper 1.0-μm band [e.g., *Fischer and Pieters*, 1996]. This trend of increasing maturity with increasing 950/750 and decreasing 415/750 values for the shaded areas of typical mare soils is marked with a dashed arrow in Figure 9. Note that the color ratio data for the small pyroclastic deposits, shown as shaded areas, are approximately orthogonal to the maturity trend, and so maturity variations are unlikely to account for most of the compositional variations observed among these deposits.

As indicated by the degree of overlap in the shaded regions in Figure 9, the small pyroclastic deposits all show the greatest similarities in color ratios with mature highlands and mature low-titanium maria. The Group 1 deposits show a substantial degree of overlap, and thus strong compositional affinities, with typical lunar highlands, as indicated previously by *Hawke et al.* [1989]. As further noted by *Hawke et al.* [1989], Group 2 deposits have spectral characteristics similar to mature mare soils, especially those with low titanium contents. Color ratio data for the single Group 3 deposit, J. Herschel, resemble those of mature low-titanium maria and are unique in this analysis. With the exceptions noted above, these observations generally confirm previous classifications by *Hawke et al.* [1989] of interdeposit compositional variation for small pyroclastic deposits. Group 1 pyroclastic deposits probably consist of feldspar-bearing mafic assemblages dominated by low-Ca orthopyroxene, and a likely explanation for their provenance is that they are mixtures of highlands-rich country rock and glass-rich juvenile material with small amounts of basaltic cap rock material. Group 2 deposits show strong affinities with mature mare deposits dominated by clinopyroxene, and they may be fragmented plug rock material, with insignificant amounts of highlands and/or juvenile materials. The single Group 3 deposit at J. Herschel has the strongest mafic absorption band and shows evidence of orthopyroxene and possibly olivine; the orthopyroxene is likely to have been emplaced as a result of erosion and entrainment of the wall rock, and the olivine may be the dominant juvenile material. It appears that the coarser spatial resolution of the Earth-based spectral data has successfully characterized the small pyroclastic deposits.

4. Juvenile Pyroclastic Materials on the Moon

Compositional data from Clementine for small lunar pyroclastic deposits generally confirm previous results and indicate that the observed range of compositions among the small deposits is consistent with an origin as products of explosive volcanic eruptions incorporating and distributing various amounts of nonjuvenile and juvenile pyroclastic material. As noted by *Head and Wilson* [1979] for small endogenic deposits at Alphonsus, the low-albedo pyroclastic deposits may consist of 50 to 100% redistributed country rock; this possibility is consistent with our observed compositional differences between the two small pyroclastic deposits at Atlas. Non-juvenile materials can consist of the complete range of lunar surface and subsurface materials in various states of maturity, with fragmented country rock (including reworked basaltic plug rock and older local mare and highlands rocks) and highlands and mare soils as the major components. Juvenile components of lunar pyroclastic eruptions are likely to be very small (submillimeter to millimeter in size [*Wilson and Head*, 1981]; ~40-µm average at Apollo 17 [*McKay and Waits*, 1978]), to include volcanic spheres (as single and compound droplets, both quenched and crystalline), crystals and crystal fragments (primarily pyroxene and olivine), and fragmented basaltic particles resulting from disruption of a foamy layer, and they may be friable or partially consolidated after deposition [e.g., *Nagle*, 1978; *Head and Wilson*, 1979]. Although known samples of small pyroclastic deposits are not recognized, a comparison of spectral data for the small deposits and those of sampled (Apollo 17/Taurus-Littrow deposit) and unsampled large deposits provides a basis for discussion of the nature of the juvenile components of both types of deposits.

As noted by *Hawke et al.* [1989], Earth-based spectral evidence for juvenile materials among the small pyroclastic deposits is strong but indirect: some component (previously referred to as a "darkening or coloring agent") is reducing the albedo of these deposits and, particularly in the case of the Group 1 deposits, broadening the long-wavelength arm of the mafic absorption feature. For Group 1 deposits, this agent has been identified as an iron-bearing pyroclastic glass [e.g.,