MULTISPECTRAL MAPPING OF THE APOLLO 15 - APENNINE REGION: THE IDENTIFICATION, DISTRIBUTION, AND CHARACTERIZATION OF REGIONAL PYROCLASITC DEPOSITS. B. Ray Hawke, Donna MacLaskey, and Thomas B. McCord, Institute for Astronomy, University of Hawaii, Honolulu, HI 96822.

Introduction

Green, orange, and black droplets of probable endogenous origin were returned from the Apollo 15 and 17 landing sites. Strong chemical and petrographic evidence has been presented in support of a pyroclastic origin and includes (1) chemical homogeneity, (2) the absence of shocked debris, (3) the presence of euhedral phenocrysts, (4) surface morphology, and (5) the presence of surface-correlated volatile elements[1,2]. Attention has been focused on these pyroclastic materials because as endogenous liquids derived from the deep interior, they provide critical information concerning the lunar mantle. Studies of these volcanic glasses and the dark mantle deposits to which they are related have yielded valuable insight concerning the early portion of the sequence of mare filling[3] as well as the character of lunar eruption processes[4,5]. The purpose of this study was to identify and characterize dark mantle deposits of probable pyroclastic origin in the region around the Apollo 15 site and determine their relationship to the Apollo 15 samples as well as previously investigated dark mantle deposits.

Method

A variety of photography was utilized to locate and characterize possible dark mantle deposits in the Montes Apenninus region of the Moon (LAC 41). A preliminary map of deposit location and extent was prepared from Earth-based telescopic photographs using the criteria discussed by Head[3]. Lunar Orbiter and Apollo photography was used for detailed geologic analysis of individual deposits.

In order to investigate the spectral properties of the dark mantle deposits, multispectral maps were prepared for the Apollo 15-Apennine region. Digital vidicon images of this region were obtained at 0.40, 0.56, and 0.95 μm. Spectral ratio images were prepared by dividing images obtained at two different wavelengths (0.40/0.56 and 0.95/0.56 μm) and were noise filtered, contrast enhanced, and mosaicked for study. The resulting images are multispectral maps in which brightness changes represent differences in the reflectance of lunar areas at one wavelength relative to that at another. In the 0.40/0.56 μm images, relatively "bluer" areas, that is, areas with higher reflectance at 0.40 μm relative to 0.56 μm, appear brighter. In the 0.95/0.56 μm images, however, brighter means "redder", or higher reflectance at 0.95 μm relative to 0.56 μm. The reader is referred to McCord et al.[6] for a more detailed discussion of multispectral imaging.

Results

Numerous dark mantle deposits were identified in the region under study.

(1) Rimae Fresnel region (28.5°N, 4°E): The area is characterized by a very low albedo and relatively smooth surface. The dark mantling material appears to be draped over underlying terrain which it slightly subdues. Subjacent units include the Apennine Bench Fm., pitted plains material, and highland ridges associated with Imbrium basin[7]. The emplacement of the dark mantle must postdate the formation of these units. The distribution of the dark mantling material suggests an association with Rima Fresnel I and the source vents may be related to the bounding faults of this graben. The dark mantle deposit appears as a distinct unit in multispectral maps. In the 0.95/0.56 μm ratio image, a bright area denoting high 0.95/0.56 μm reflectance, corresponds closely to the area of low albedo. Relatively high reflectance at 0.95 μm is a property common to other lunar dark mantle deposits and indicates a low proportion of crystalline material to amorphous or glassy

material[6,8,9,10]. This observation is consistent with the presence of a large component of pyroclastic glass in the Rimae Fresnel region. The same area is slightly darker than its surroundings in the 0.40/0.56 images, denoting a lower 0.40/0.56 μm reflectance. Deposits with similar spectral and geologic characteristics are present in the highlands ∿50 km SE of the Rimae Fresnel region near the Mare Serenitatis-highland contact.

(2) Vicinity of the Apollo 15 site: Major accumulations of dark mantling material have been mapped[7,11,12] on Bennett Hill and partly surrounding the cleft at the source of Hadley Rille, both to the SW of the Apollo 15 site. Additional mantling material was identified in the highlands in the vicinity of the Hadley cleft and to the NE. The deposits exhibit a low albedo and a generally smooth surface. They appear to be draped over subjacent highland terrain but are overlapped in some areas by younger mare material[11]. The dark mantle material in the vicinity of Bennett Hill corresponds to the area of high Mg/Al ratios described by Schonfeld and Bielefeld[13] and which they interpreted to contain significant concentrations of pyroclastic glass. All of these dark mantled areas are distinct and display similar spectral characteristics. They are bright in the 0.95/0.56 μm image and slightly darker than their surroundings in the 0.40/0.56 μm image.

(3) Dark mantled valley (∿24°N, 1.5°E): Another major dark mantle deposit occurs about 15 km SW of Hadley cleft in a valley which parallels the base of the Apennine scarp. The unit overlies material mapped as the Apennine Bench Fm.[7,14] and highland material associated with the Imbrium basin. Though no source vent has been located, the distribution pattern suggests an association with a graben on the valley floor. In the multispectral maps, the area appears bright in the infrared but low in the ultraviolet.

(4) Two NW trending patches at ∿0°, 23°N: These patches of dark mantle are relatively thin and irregular in outline. Both are superposed on Imbrium basin material and are aligned along a major lineament. At least one source vent has been tentatively identified. The spectral signature of these patches is similar to that of the mantled areas described above, but they are less distinct.

(5) NE trending valley at the base of Mons Huygens and Mons Bradley: Several patches of low albedo material were noted in the valley floor. The patches are not distinct in the 0.95/0.56 μm image but do appear slightly darker or "redder" than their surrounding in the 0.40/0.56 μm image. Study of Apollo metric photography revealed the presence of small ponds of post-Imbrium basalt. These flat, low albedo ponds have fewer large subdued craters than the fractured material which they embay, which has been mapped as equivalent to the Apennine Bench Fm.[14]. The younger volcanic material clearly embays and truncates fractures and graben developed in the older Apennine Bench material. This area is of considerable interest because of the insight it provides into processes related to incipient volcanic flooding of highland terrain.

(6) Other possible pyroclastic deposits were located in the course of this study but will not be described in detail here. They include deposits in the Apennine Mts. south of Mons Huygens and near the Mare Imbrium-Apennine Bench Fm. contact NE and SE of Beer crater.

Discussion and Implications

(1) Structural control of deposit distribution: The major pyroclastic deposits described above are concentrated in, but not restricted to, a zone parallel to the fault-bounded Apennine ring of Imbrium basin. Most appear to have sources related to major structural features concentric and radial to Imbrium. The dark mantle deposits' restricted occurrence and association with major structural elements supports an origin as the products of pyroclastic

eruptions. In addition, the occurrence of regional dark mantle deposits along structurally controlled volcanic vents suggests a possible deep source[8]. These relationships also emphasize the importance of fracturing and faulting associated with basin formation and modification in providing conduits for magmas generated at depth.

(2) Compositional inferences: The spectral properties of the dark mantle deposits described above were compared with those of other regional dark mantles and the pyroclastic glasses. Adams et al.[8] concluded that the lunar "black spots" or dark mantles described by Pieters et al.[9] contained a large component of material similar to the Apollo 17 black spheres. The laboratory reflectance spectrum of these black spheres shows high reflectance in the blue-ultraviolet and the near infrared and the telescopic black spots also exhibit high reflectance in these spectral regions[8,9]. While the dark mantle deposits in the Apollo 15-Apennine region are high in the near infrared, they do not exhibit the high reflectance in the blue-ultraviolet and are unlikely to contain a major component of black spheres.

The spectral signature of Apollo 15 green glass suggests that major accumulations on the lunar surface could easily be identified[8]. The reflectance of green glass is relatively low in the near infrared whereas the Apollo 15 dark mantle deposits were all relatively high in this spectral region. These deposits are apparently dominated by material with a spectral signature incompatible with green glass. Green glass deposits in the region may be too small to be resolved, may have been largely buried by mare basalt, or be so thoroughly mixed with other material (regolith or other pyroclastic material) that their spectral properties are masked.

Of the three lunar pyroclastic materials for which laboratory spectral reflectance data are available[8], only Apollo 17 orange glasses have spectral signatures comparable to those of the dark mantle material in the Apollo 15-Apennine region. Even in this comparison, the orange glass has slightly higher reflectance at .40 μm. While red glass spheres with a bulk composition similar to the Apollo 17 orange glass have been found at the Apollo 15 site[15,16,17], they are present in only trace amounts, are the least abundant of mare-type glasses reported by Reid et al.[17], and may not be of pyroclastic origin. If Apollo 17-type orange glass were the dominant component in dark mantle deposits in the Apollo 15 region, much higher abundances would be expected in the Apollo 15 regolith.

A more likely candidate for the material comprising the regional dark mantle deposits described in this study is the Apollo 15 brown glass ($TiO_2 \cong 3.6\%$) which Butler[1] has recently demonstrated to be an endogenic melt of probable pyroclastic origin. The work of Bell et al.[18] concerning the spectral properties of various lunar glasses suggests that glasses with the composition of the Apollo 15 brown glass would have a spectral signature in the infrared similar to that of the dark mantle deposits we have investigated.

Additional information concerning the composition and distribution of the pyroclastic material in the Montes Apenninus region will be provided by mapping the region at additional wavelengths and obtaining laboratory reflectance spectra for the Apollo 15 brown glass and other glasses of possible pyroclastic origin[1,19].

References: 1) P. Butler (1978) PLPSC 9, (in press); 2) G. Heiken et al. (1974) GCA, 38, 1703; 3) J. Head (1974) PLSC 5, 207; 4) T. McGetchin and J. Head (1973) Science, 180, 68; 5) J. Head (1975) LS VI, 349; 6) T. McCord et al. (1976) Icarus, 29, 1; 7) M. Carr et al. (1971) USGS Map I-723; 8) J. Adams et al. (1974) PLSC 5, 171; 9) C. Pieters et al. (1973) JGR, 78, 5867; 10) C. Pieters et al. (1974) Science, 183, 1191; 11) K. Howard and J. Head (1972) NASA Spec. Publ. SP-289, 25-53; 12) K. Howard et al. (1972) PLSC 3, 1; 13) E. Schonfeld and M. Bielefeld (1978) LPS IX, 1015; 14) D. Wilhelms and J. McCauley (1971) USGS Map I-703; 15) W. Quaide (1973) LS IV, 606; 16) W. Ridley et al. (1973) Physics of the Earth and Planet. Inst., 7, 133; 17) A. Reid et al. (1972) Meteoritics, 7, 395; 18) P. Bell et al. (1976) PLSC 7, 2543; 19) M. Norman, personal communication.