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FINAL REPORT

Remote Sensing and Geologic Studies of the Planetary Crusts

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I. Remote Sensing and Geologic Studies of Volcanic Deposits in the Lunar Highlands

A. Spectral reflectance studies of dark-haloed craters.

Schultz and Spudis (1979) have recently presented the results of a major study concerning the identification, origin, and distribution of dark-haloed impact craters. They suggested that basaltic volcanism may have pre-dated the last major basins, that early farside volcanism may have been widespread, and that at least some lunar light plains may be early volcanic deposits which were subsequently buried by varying thicknesses of impact ejecta.

Because of the key role dark-halo craters may play in the solution of several major lunar problems, we undertook a program to study these features using a variety of spectral and other remote sensing techniques (Hawke and Spudis, 1980). The over-all purposes of this investigation included the following: (1) to establish spectral criteria to distinguish dark-halo craters of impact origin from those formed by volcanic or other processes, (2) to confirm the existence of the postulated mare component in the ejecta of dark-haloed impact craters, (3) to investigate the compositions of the buried mafic units, and (4) to conduct regional studies to determine the extent and duration of early volcanic activity on the lunar nearside. The preliminary results of this effort have been presented (Hawke and Bell, 1981a, b).

In these papers, a summary of the nature and origin of lunar dark-halo craters was presented. New remote sensing data for both dark-haloed volcanic and impact craters were obtained and interpreted. A variety of spectral, thermal, radar, and photogeologic data were presented which confirmed the hypothesis that Copernicus H crater excavated mare basalt from beneath lighter deposits emplaced by the Copernicus impact event. Analyses of near-infrared spectra of dark-haloed impact craters in the Schickard-Schiller region support the hypothesis that basaltic material was excavated from beneath light plains. These light plains may have been emplaced as a result of the Orientale impact event. Additional evidence was presented which suggests that both pre- and post-Orientale volcanic activity was prevalent in this region. Analysis and interpretation of our most recent near-IR spectra have conclusively demonstrated that mare basalt was excavated by DHC's in the Schickard-Schiller region (Hawke and Bell, 1981c; Bell and Hawke, 1983) and the Balmer basin region (Hawke et al., 1982d). Newly obtained spectra for dark-haloed craters in other regions are currently being analyzed.

B. Remote sensing studies of regions which were sites of ancient volcanism.

Since the publication of our preliminary results, (Hawke and Spudis, 1980) additional work has been performed using the orbital geochemistry data sets as well as spectral data which support the hypothesis that light plains deposits which exhibit numerous dark-haloed impact craters are underlain by early mare basalts.

Particularly exciting is the observation that farside and east limb highland regions with abundant dark-halo craters also exhibit geochemical anomalies in the Apollo gamma-ray and x-ray data sets. While this correlation had been established earlier (Schultz and Spudis, 1979; Hawke and Spudis, 1980) for a few selected regions, it has now been extended to virtually all farside and east limb regions with a high dark-halo impact crater density (Hawke et al, 1982b, d). While additional work is necessary, we anticipate that the final results of this study will have very important implications for our understanding of the extent, volume, and composition of lunar volcanic products; the duration of extrusive igneous activity; and the composition of the highland crust.

C. KREEP basalt deposits in the Imbrium Region.

The past year has seen significant progress in our studies of KREEP basalt distribution in the Imbrium basin and adjacent regions of the Moon. All existing orbital geochemistry data sets were utilized and the results were presented in a series of papers (Clark and Hawke, 1981a, b; Hawke et al., 1981, 1982a; Etchegaray-Ramirez et al., 1983).

Clark and Hawke (1981a, b) used an improved orbital x-ray set to intensively study the Hadley-Apennine region. An improved technique was used to correct the x-ray data for variations in the solar x-ray flux. A major result of this study was that the Al/Si and Mg/Si concentration values derived from Apennine Bench Formation could only be produced by KREEP-rich material similar to the Apollo 15 igneous-textured KREEP basalts. Hawke et al. (1981, 1982a) presented the results of mixing model studies based on latest orbital geochemical data for the Archimedes region. It was concluded that the region was dominated by a large (~65%) component of KREEP basalt. Examination of orbital data for the portion of the region which contained the Apennine Bench Formation proved conclusively that the Bench is indeed composed of KREEP basalt (Clark and Hawke, 1981a, b; Hawke et al., 1981, 1982a). In addition, KREEP-rich material was excavated from beneath surface mare deposits by Timocharis and Lambert craters.

During the past grant year, this P.I. continued his collaborative work with Dr. A. Metzger concerning the Th concentrations in the Imbrium basin and adjacent regions. Our Th deconvolution studies have been extended to cover western Imbrium, eastern Procellarum, and the Aristarchus Plateau (Metzger et al., 1980; Etchegaray-Ramirez et al., 1983; Hawke et al., 1981). The most significant results of this work was the discovery of a Th-rich mare basalt unit in Mare Imbrium. There is a correlation between a region of enhanced Th values (7-10 ppm) and certain flows of late-stage, Ti-rich mare basalt. This demonstrates the existence of mare basalts with greater concentrations of Th (and probably other LIL elements) than the samples returned by the Apollo and Luna missions. Other major conclusions of this work include the following:

a) Aristarchus crater and its ejecta contain high Th abundances (~20 ppm). Such Th levels are compatible with the presence of large amounts of KREEP basalt or lesser quantities of more evolved KREEP plutonic rock.

b) The Th levels exhibited by the Aristarchus Plateau are compatible with a mixture of KREEP-rich material and dark mantling material of probable pyroclastic origin.

Preliminary Th deconvolution modeling has begun for the Fra Mauro region. The initial results suggest that Th enhancements are associated wih the Riphaeus Mountains, the terrain south of Fra Mauro crater, and the highlands west of Ptolemaeus crater. The final results of this effort should have important implications for the origin of the Fra Mauro Formation as well as ancient KREEP volcanism.

D. The relationship between geology and geochemistry in the Undarum/Spumans region.

Clark and Hawke (1982a, c) presented the results of a detailed study of geochemical variation in the Undarum/Spumans region. Regional maps derived from each of the orbital geochemical variables (Mg, Al, Fe, Ti, and Th) were studied individually, then correlated to one another and to photogeological maps. There is a distinct dichotomy in the geochemical characteristics of the mare deposits in the region. While most of the highland terrain is anorthositic, some light plains appear to be contaminated with basaltic material.

In addition, we have been investigating a variety of techniques for global geochemical unit definition and mapping. The initial results were encouraging (Clark and Hawke, 1982b) and additional work is in progress.

II. Remote Sensing Observations of the Reiner Gamma Formation

The Reiner Gamma Formation, an albedo and magnetic anomaly in western Oceanus Procellarum, is currently the focus of a major controversy concerning the nature and origin of lunar swirls. In order to investigate the composition and origin of Reiner Gamma, new near-infrared spectra and vidicon images were obtained and interpreted. Analysis of the near-infrared spectra of various portions of the formation indicated the presence of major amounts of fresh mare basalt. Spectral mixing models indicate that the Reiner Gamma spectra can be reproduced by mixing major amounts (~90 - 95%) of local fresh mare material with small amount (~5 - 10%) of fresh highlands material. No evidence was found for the presence of "exotic" components (i.e., magnetite, free iron, cometary material). Together with photogeologic considerations, these results suggest that Reiner Gamma is quite young and is composed of a mixture of minor amounts of fresh highland material with much larger quantities of fresh local mare basalt. This composition and age are inconsistent with an origin as a Cavalerius crater deposit (Hood et al., 1979) and place strong but not unreasonable constraints on the cometary-impact theory for the origin of Reiner Gamma (Schultz and Srnka, 1980). These findings have been presented in a series of publications (Bell and Hawke, 1980a, b; 1981a, b). We have recently obtained, reduced, and analyzed additional higher-resolution spectra fo Reiner Gamma and related features. These spectra show that Reiner Gamma is unlike nearby crater rays and that the "red halo" which surrounds Reiner Gamma is composed of mature mare basalt. Spectra of a swirl-like feature in the central highlands appear to be identical to those obtained for nearby fresh highland craters. This new data is being prepared for publication.

III. Studies of Impact Cratering Mechanics and Processes

A. Shock levels in crater and basin ejecta.

Research efforts are underway which should allow the shock levels exhibited by the various lunar highland samples to set constraints on their provenance. We are attempting to better define the relationships among ejection velocity, pre-ejection particle velocity, and peak shock pressure. The final results should allow estimates to be made of the minimum shock pressures which material must have been subjected to have been ballistically transported to a given distance from an impact structure. With this information, an examination of the shock levels exhibited by the samples from the various landing sites would allow constraints to be set on the provenance of the material.

Our preliminary results have been presented (Austin et al., 1980; Austin and Hawke, 1981). A model was presented and minimum shock pressure estimates were made for material transported from Imbrium and Orientale basins to various Apollo landing sites. Additional work has been completed but the results have not yet been presented.

B. Experimental impact cratering studies.

A series of cratering experiments were conducted in June, 1981 utilizing the Ames vertical gun. Impacts were made into the following targets: (1) ice (half-space and quarter-space), (2) sulfur, (3) clay, (4) irregularly-shaped targets, and (5) basalt. The series was generally successful and abundant data were collected. These data are currently being analyzed and interpreted.

IV. Spectral Variations on Asteroidal Surfaces

The purpose of rotational spectral studies is to determine the mineralogy, petrology, and lateral extent of units on the surfaces of asteroids in order to provide an improved understanding of their composition and surface processes, and hence to shed light on the origin and evolutionary history of an important class of solar system objects. High precision two-beam photometer (0.3-1.1μm) and CVF spectrometer (0.6-2.5μm) rotational spectral data have been collected using the U of H 2.2 meter and NASA Infrared Telescope on Mauna Kea. Our initial results for the sixteen asteroids so far observed have been presented (Gaffey et al., 1982a, b).

Definite or probable rotational spectral variations have been found associated with nine asteroids (1 Ceres, 3 Juno, 4 Vesta, 6 Hebe, 7 Iris, 15 Eunomia, 16 Psyche, 44 Nysa, and 349 Dembowska) which exhibit a wide range of diameters (68 km-957 km) as well as types (C, S, M, E, R, and U). Two general modes of rotational spectral variation have been identified. The first can be demonstrated to be due to sharply bounded features. The second type is more gradational in nature and appears to reflect hemispheric compositional differences. Although the spectral variations are often subtle (i.e., only a few prcent deviations from the mean), the mineralogic and petrologic surface heterogeneity which these indicate is often major (i.e., spanning an entire suite of meteorite assemblages).

It seems likely that rotational spectral variations are related to the accreticnal, thermal, and impact histories of the asteroid parent bodies. We have presented a preliminary assessment of the processes responsible for spectral variations. In many instances, a complex combination of processes may have been operative. A major task for future work will be to use the nature of spectral differences to unravel the complex surface histories of the asteoids.

V. Albedo and Color Variations on Ganymede: Implications for Surface Processes and Crustal Evolution

During the past year, we have initiated projects designed to provide and improve our understanding of albedo and color variations on Ganymede.

A. The origin of dark-halo/ray craters.

An understanding of the origin of dark-haloed and dark-ray craters (DHRCs) is important because of the information that may be provided concerning: (1) the presence of "silicate"-rich layers at depth, (2) the processes responsible for the formation of these dark layers, (3) the composition and velocity of at least a portion of the projectile which bombarded Ganymede, and (4) impact processes on an ice-rich body. We anticipate that our results will be useful in constraining hypotheses for the composition, history, and evolution of Ganymede's crust.

We intend to use digital images of selected surface regions obtained at 3 or 4 wavelengths. This digital data can be used to produce multispectral ratio images, spectral units maps, and, when stacked in an image cube, 3- or 4-point spectra of selected features or units. We have identified the relevant digital imaging and have taken the necessary steps to obtain these data.

Additional tasks are in progress. We have devised a new classification scheme for dark-halo and dark-ray craters. We are searching for previously unidentified DHRC's, re-evaluating the distribution of DHRC's as a function position and terrain-type, comparing the size distribution of DHRC's on cratered terrain with that on grooved terrain, and investigating the relationship between the relative age of DHRC's (based on crater morphology) and the preservation state of the ejecta deposit. Our initial results suggest that the interpretation of dark-haloed craters on Ganymede presented by Conca (1981, Proc. Lunar Planet. Sci. Conf. 12th) is incorrect.

B. Fresh crater deposits on Ganymede.

We are conducting studies of selected fresh, large impact craters on Ganymede. Particular emphasis is being placed on Osiris crater because of its size (D~100 km), the variety of albedos displayed by its ejecta, and the availability of high resolution images at four wavelengths. The necessary digital data has been identified and acquired. Geologic mapping is in progress.

VI. Remote Sensing and Geologic Studies of Lunar Impact Structures

A. Spectral studies of fresh lunar craters.

Spectral studies of fresh lunar craters were needed in order to provide mineralogical and compositional data concerning the upper levels of the lunar crust as well as to provide insight into impact cratering pocesses. Near-infrared reflectance spectra (0.6-2.5μm) and vidicon images at eight to twenty wavelengths have been obtained for the interior, exterior, and ray deposits of a number of craters including: (1) Tycho, (2) Copernicus, (3) Aristarchus, (4) Proclus, (5) Lalande, (6) Kepler, (7) Aristillus, (8) Theophilus, (9) Langrenus, (10) Menelaus, (11) Conon, (12) Taruntius, (13) Censorinus, (14) Dionysius, and (15) Eratosthenes. A preliminary analysis of a portion of this data was presented by Hawke et al. (1979). In this study, multispectral ratio images (eight wavelengths) and reflectance spectra for Tycho, Aristillus, Lalande, and Kepler craters were utilized to investigate upper crustal stratigraphy and impact cratering processes. No evidence from variation in the near-surface crustal structure in the Tycho region was found. The spectral characteristics of the Tycho dark halo were interpreted to indicate the presence of a significant component of impact generated glass. Aristillus, Lalande, and Kepler craters also have dark deposits similar to those around Tycho which exhibit similar spectral properties. These deposits should also contain major component of impact melt glass. This study demonstrated the utility of the multispectral imaging technique in identifying and mapping lunar crater deposits.

Our more recent efforts have centered around a study of Aristarchus crater and the Aristarchus Plateau region in general. Analysis of near-infrared spectra for Aristarchus crater have demonstrated that while the crater interior is composed of feldspar-rich highland material, the dominant pyroxene is a relative high-Ca clinopyroxene (augite) (McCord et al., 1981a, b). This augite may be derived from an unusual igneous unit within the Arista chus site (KREEP plutonics?).

Lucey et al. (1982) presented the results of an analysis of twenty newly obtained near-IR spectra of the Aristarchus region. All spectra associated with Aristarchus crater are basically similar and indicate the presence of feldspar-rich highlands material with a high-Ca clinopyroxene. Material with a similar composition underlies the dark mantle deposits on the plateau itself. Spectra of the mantling material exhibits a major absorption feature that is best explained by the presence of Fe-bearing glass.

A multispectral units mapping technique has been applied to the Aristarchus region (Lucey et al., 1981). Since the region is geologically complex and exhibits extreme spectral contrast, it is particularly suitable for analysis by multispectral 2-parameter unit mapping techniques originally developed at the University of Hawaii [see McCord et al., Lunar and Planetary Science XI, Part 2, 697-699 (1980)]. Vidicon images of the region were recently obtained at eight wavelengths. The units mapping program operates on two images so two diagnostic pairs of images of the following three were used in the analysis: the .95/.56 μm ratio image which shows the presence and relative band strength of the shorter pyroxene band; the .40/.56 μm ratio image which indicates the slope of the local spectral continuum; and the .56 μm image which shows visual albedo. Units are mapped from a two dimensional histogram of pixel values from the pairs of images. Two units maps were produced, one from a histogram of versus .40/.56 ratio. The two unit maps basically agree though the units were defined independently. It is apparent from the maps and histograms of the three important parameters that real spectral populations exist in the Aristarchus region. Some of the spectral units can be associated with regional geologic units such as the Aristarchus dark mantling deposit.

We are conducting spectral studies of lunar crater rays. We have concentrated our initial efforts on Olbers A and Tycho rays. Both craters are in the highlands but their rays extend onto mare surfaces. The preliminary results suggests that major amounts of highland material are required to account for the spectra of these rays. Additional work is in progress.

B. Spectral reflectance studies of lunar basin deposits.

Our efforts to date have centered on the acquisition and reduction of spectral data for this study. Near-infrared spectra were obtained during observing runs in January and August 1981 at the 2.24-meter MKO telescope. Initial processing and reduction are complete and the spectra are of high quality. Basin-related units for which spectra were obtained include the following: (1) the Apennine Mountains (eight separate areas), (2) the Imbrium backslope (10 areas), (3) the Apennine Bench Formation (4 areas), (4) Archimedes, Autolycus, and Aristillus craters, (5) key areas of the Central Highlands, (6) the Fra Mauro region, (7) Aristarchus crater and highlands associated with the Aristarchus Plateau, and (8) portions of the highlands associated with Serenitatis Basin. Multispectral images (at eight and twenty wavelengths) were obtained during two separate observing runs at the the 2.24-meter MKO telescope. Analysis and interpretation of this data proceeded during the past year and the results were presented in a number of publications (McCord et al., 1981a, b; Hawke et al., 1980a; Lucey et al., 1981, 1982; Spudis and Hawke, 1980). The more significant results of the McCord et al. (1981a, b) publications were described in a previous section.

A remote sensing study of the Apollo 16-Descartes region was conducted. Emphasis was placed on spectral reflectance studies (both 0.3-1.1μm and 0.6-2.5μm spectra) multispectral imagery, spectral units mapping techniques, Earth based radar (3.8 cm and 70 cm) and thermal IR data, and the Apollo orbital geochemistry data. It was concluded that while no major differences between Cayley Formation and Descartes Mts. material could be detected in the immediate vicinity of the landing site, major compositional differences do exist in the central highlands. These findings were further elaborated by Spudis and Hawke (1980). Studies of both the orbital geochemistry and spectral data sets indicate that the central highlands around the Apollo 16 landing site are chemically heterogeneous. Several possibilities exist to explain this relationship. Igneous processes associated with original crustal formation may have produced chemical heterogeneities in the highland crust. It has been shown that volcanism was active early in lunar history; significant regions of the lunar crust may have been volcanically resurfaced, producing compositional variations that would be unaccompanied by morphologic evidence for volcanic activity. Finally, the formation of the youngest large lunar impact basins have probably contributed to the observed regional chemical differences both by the deposition of basin ejecta and redistribution of preexisting local materials.

C. Orbital geochemistry studies of lunar basin deposits.

The orbital geochemistry data sets were used to investigate the composition of lunar basin deposits. The results were presented in a number of publications (Hawke et al., 1981, 1982a; Clark and Hawke, 1981a, b). Significant results of our Th deconvolution program were discussed in a previous section (Etchegaray-Ramirez et al., 1983). Both the Clark and Hawke (1981a, b) and Hawke et al. (1981, 1982a) publications dealt with the composition of Imbrium ejecta in the Apennine Mts. and the Imbrium backslope. Based on the available x-ray and gamma-ray data it was concluded the surface deposits on the backslope consist of anorthositic gabbro, medium-K Fra Mauro basalt, low-K Fra Mauro basalt, and very minor amounts of pyroclastic material. It seems likely that both anorthositic material and Fra Mauro basalt (low and medium-K) were excavated and deposited by the Imbrium impact event. Low-K Fra Mauro basalt is more abundant in the highlands north of the Apollo 15 site. It was firmly established that the Apennine Bench Formation is composed of Apollo 15 medium-K Fra Mauro basalt which is likely to be of extrusive igneous origin as opposed to Imbrium impact melt. Within Imbrium basin, large post-mare craters have excavated KREEP basalt from beneath mare basalts.

D. Chemical mixing model studies of lunar basin deposits.

Our efforts to model basin ejecta compositions in terms of chemically-defined and pristine rock types have been very successful and the results have been published (Hawke et al., 1980a, b; Spudis and Hawke, 1980, 1981a, b; Hawke et al., 1982a, c). Orbital geochemical data were assembled for portions of the ejecta deposits surrounding Crisium, Nectaris, Imbrium, and Orientale basins. The results indicate that the highlands around Crisium and Nectaris basins can be modelled as a mixture of anorthositic gabbro and low-K Fra Mauro basalt with minor amounts of mare basalt near mare-highland contacts (Hawke et al., 1980b). In contrast, Orientale ejecta can be modeled as a mixture of gabbroic anorthosite and anorthositic gabbro (Hawke et al., 1982c). Very little low-K Fra Mauro basalt is present in the Orientale region.

Chemical mixing model studies of lunar geochemical data for the central and Taurus-Littrow lunar highlands were performed utilizing pristine highland rock types as end member compositions (Spudis and Hawke, 1981a, b). The central highlands show considerable diversity in composition; anorthosite is the principal rock type in the Apollo 16/Descartes region while norite predominates in the highlands west of the landing site. This change in crustal composition is coincidental with a major color boundary seen in earth-based multispectral data and probably represents the presence of distinct geochemical provinces within the central highlands. The Taurus-Littrow highlands are dominated by norite; anorthosite is far less abundant than in the central highlands. This suggests that the impact target for the Serenitatis basin was different than that of the Nectaris basin and further strengthens the hypothesis that the lunar highlands are petrologically heterogeneous on a regional basis. We suggest that the lunar highlands should be viewed in terms of <u>geochemical provinces</u> that have undergone distinct and complex igneous and impact histories. Additional work has been completed for other lunar regions but has not yet been presented.

VII. Publications Resulting From NASA Support of NAGW 42

1. Hawke, B.R., and Spudis, P.D. (1980). Geochemical Anomalies on the Eastern Limb and Farside of the Moon. _Proc. Conf. Lunar Highlands Crust_, 467-481.

2. Metzger, A.E., Haines, E.L., Etchegaray-Ramirez, M.I. and Hawke, B.R., (1980). Thorium Concentrations in the Imbrium and Adjacent Regions of the Moon. _Lunar and Planet. Sci. XI_, 729-731.

3. Hawke, B.R., and Bell, J.F. (1981a). Spectral Studies of Lunar Dark-Halo Craters: Preliminary Results. _Lunar and Planet. Sci. XII_, 412-414.

4. Hawke, B.R., and Bell, J.F. (1981b). Remote Sensing Studies of Lunar Dark-Halo Impact Craters: Preliminary Results and Implications for Early Volcanism. _Proc. Lunar and Planet. Sci. Conf. 12th_, 665-678.

5. Clark, P.E. and Hawke, B.R. (1981a). Compositional Variations in the Hadley Apennine Region. _Lunar and Planet. Sci. Conf. XII_, 148-150.

6. Clark, P.E. and Hawke, B.R. (1981b). Compositional Variations in the Hadley Apennine Region. _Proc. Lunar and Planet. Sci. Conf. 12th_, 727-749.

7. Hawke, B.R., Etchegaray-Ramirez, M.I., Haines, E.L., and Metzger, A.E. (1981a). Geochemical Studies of the Apollo Orbital Gamma-ray Data for the Imbrium Basin and Adjacent Regions. _Lunar and Planet. Sci. XII_, 415-417.

8. Hawke, B.R., Etchegaray-Ramirez, M.I., Haines, E.L., and Metzger, A.E. (1982a). Geochemical Studies of the Imbrium Basin and Adjacent Regions. To be submitted to GCA.

9. Bell, J.R., and Hawke, B.R. (1980a). A Spectral Reflectivity Study of the Reiner Gamma Formation. _Meteoritics_, _15_, 264.

10. Bell, J.F. and Hawke, B.R., (1980b). The Reiner Gamma Lunar Magnetic Anomaly as Studied via Telescopic Reflectance Spectra. _Bull. Am. Astro. Soc._, _12_, 660-661.

11. Austin, M.G., Thomsen, J.M., Ruhl, S.F., and Hawke, B.R. (1980). Cratering ejecta velocity and Flow Field Relationships. _Meteoritics_, _15_, 261.

12. Austin, M.G. and Hawke, B.R. (1981). Tentative Speculations on Lunar Sample Transport. Lunar and Planet. Sci. XII, 732-734.

13. Bell, J.F. and Hawke, B.R. (1981a). Reiner Gamma: Preliminary Results from Telescopic Remote Sensing. Lunar and Planet. Sci. XII, 732-734.

14. Bell, J.F. and Hawke, B.R. (1981b). The Reiner Gamma Formation: Composition and Origin as Derived from Remote Sensing Observations. Proc. Lunar and Planet. Sci. Conf. 12th, 679-694.

15. McCord, T.B., Clark, R.N., McFadden, L.A., Owensby, P.D., Hawke, B.R., Pieters, C.M., and Adams, J.B. (1981b). Moon: Near-Infrared Spectral Reflectance, A First Good Look. J. Geophys. Res., 87, 3021-3032.

16. Etchegaray-Ramirez, M.I., Metzger, A.E., Haines, E.L., and Hawke, B.R. (1983). Thorium Concentration in the Lunar Surface: IV. Deconvolution of the Mare Imbrium, Aristarchus, and Adjacent Regions. Proc. Lunar and Planet. Sci. Conf. 13th, 529-543.

17. McCord, T.B., Clark, R.N., Hawke, B.R., McFadden, L.A., Owensby, P.D., Pieters, C.M., and Adams, J.B. (1981a). Remote Detection of Olivine, Pyroxene, and Plagioclase: Analysis of Three Lunar Sites. Lunar and Planet. Sci. XII, 679-681.

18. Hawke, B.R., Spudis, P.D., Head, J.W., and McCord, T.B. (1980a). Remote Sensing Studies of the Apollo 16 Descartes Region. In Apollo 16 Workshop, 44-46.

19. Spudis, P.D. and Hawke, B.R. (1980). Geochemical Provinces in the Central Lunar Highlands and Relation to the Apollo 16 Landing Site. In Apollo 16 Workshop, 129-131.

20. Hawke, B.R., Spudis, P.D., and Metzger, A.E. (1980b). Lunar Basin Eject Deposit Compositions: A Summary of Chemical Mixing Model Studies. In papers presented to the Conf. Multi-Ringed Basins Formation and Evolution, 42-44.

21. Spudis, P.D. and Hawke, B.R. (1981a). Chemical Mixing Model Studies of Lunar Orbital Geochemical Data: Apollo 16 and 17 Highlands Compositions. Lunar and Planet. Sci. XII, 1028-1030.

22. Spudis, P.D., and Hawke, B.R. (1981b). Chemical Mixing Model Studies of Lunar Orbital Geochemical Data: Apollo 16 and 17 Highlands Compositions. Proc. Lunar and Planet. Sci. Conf. 12th, 781-789.

23. Lucey, P., Hawke, B.R., Pieters, C.M., and McCord, T.B. (1981). Multispectral Unit Mapping of the Aristarchus Region of the Moon. Bull. Am. Astro. Soc., 13, 711.

24. Bell, J.F. and Hawke, B.R. (1981c). Telescopic Remote Sensing of a Suggested Lunar Comet Impact Site. Bull. Am. Astro. Soc., 13, 699.

25. Hawke, B.R. and Bell, J.F. (1981c). Remote Sensing Studies of Lunar Dark-Halo Craters. Bull. Am. Astro. Soc., 13, 712.

26. Gaffey, M.J., King, T., Hawke, B.R., and Cintala, M.J. (1982a). Spectral Variations on Asteroidal Sufaces: Implications for Composition and Surface Processes. Workshop on Lunar Breccias and Their Meteoritic Analogs, LPI Tech. Rpt. 82-02, 40-42.

27. Gaffey, M.J., King, T.V.V., Hawke, B.R., and Cintala, M.J. (1982b). Asteroid Spectral Variations: Implications for Composition and Surface Processes. Lunar and Planet. Sci. XII, 247-248.

28. Hawke, B.R., Spudis, P.D., and Clark, P.E. (1982b). The Origin of Selected Lunar Geochemical Anomalies of the Lunar Suface. Lunar and Planet. Sci. XIII, 308-309.

29. Clark, P.E. and Hawke, B.R. (1982a). Relationship Between Geology and Geochemistry in the Undarum/Spumans Region. Lunar and Planet. Sci. XIII, 113-114.

30. Hawke, B.R., Jackowski, T.L., Spudis, P.D., and Metzger, A.E. (1982c). Chemical Mixing Model Studies of the Orientale Basin Region. Lunar and Planet. Sci. XIII, 306-307.

31. Lucey, P.G., Hawke, B.R., McCord, T.B., Pieters, C.M., and Head, J.W. (1982). Visible and Near-Infrared Spectral Studies of the Aristarchus Region. Lunar and Planet. Sci. XIII, 449-450.

32. Hawke, B.R., Spudis, P.D., and Clark, P.E. (1982d). The Origin of Selected Lunar Geochemical Anomalies: Implications for Early Volcanism and the Formation of Light Plains. J. Geophys. Res., in prep.

33. Clark, P.E. and Hawke, B.R. (1982b). Geochemical Classification of Lunar Terrain. Trans. Amer. Geophys. Union, 63, 364-365.

34. Clark, P.E. and Hawke, B.R. (1982c). The Relationship Between Geology and Geochemistry in the Undarum/Spumans Region. *J. Geophys. Res.*, in prep.

35. Bell, J.F. and Hawke, B.R. (1983). The Origins of Lunar Dark-Haloed Craters: Implications for Early Volcanism and Light Plains Formation. *J. Geophys. Res.*, in press.