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Differences between Proposed Apollo Sites

1. Synthesis[1]

Bruce C. Murray,[2] Alexander F. H. Goetz,[3] Hugh H. Kieffer,[2]
and Thomas B. McCord[4]

Recent observations of the spectral reflectivity and emissivity of the five prime Apollo landing sites are evaluated in the context of similar observations of other localities on the moon and of data returned from unmanned lunar probes. We conclude that those five sites differ significantly only in minor constituents and/or relative valence states and that those differences are more modest than the differences that characterize mare regions generally. Recommendations of priorities for the five prime Apollo sites are made based on their uniqueness for sample return. Sampling of other lunar localities displaying anomalous emissivities and extreme color differences will be required to ascertain the full range of lithologies that constitute the lunar surface.

Introduction

As lunar exploration reaches the historic point of sample return, the question of compositional differences in surface materials among the likely landing sites assumes special importance. The choice of the first landing site necessarily reflects maximum concern for mission safety. As confidence in the Apollo system is gained from actual experience on the lunar surface, however, the selection of subsequent landing sites is likely to reflect scientific considerations to a progressively greater degree. Thus, it is important to exploit ground-based techniques to the fullest, as well as the data returned from previous unmanned lunar flights, to ascertain if and how the candidate Apollo sites differ compositionally among themselves and from other lunar localities. Sample return from subsequent flights can thereby be made to complement and extend our knowledge of the spectrum of compositional variations represented in the lunar surface materials. Equally important, these same Apollo landing sites will constitute the only 'ground truth' for the vast number of physical observations already gathered by earth-based optical, infrared, and radio telescopes and radars. Hence, it is important that those sites necessary to insure an effective tie between the 'ground truth' and remotely sensed data be closely observed by high resolution earth-based systems.

With these needs in mind, a special effort was undertaken at California Institute of Technology during the summer and fall of 1968 to apply to the five prime Apollo sites two remote sensing techniques specially developed for lunar observations in previous studies [*Goetz*, 1967; *McCord*, 1968]. In addition, the Orbiter photography of the Apollo sites was carefully reviewed to ascertain if relative age information could be uniquely extracted from it. The results of these efforts are presented in the present paper (1, Synthesis) and the two accompanying papers in this issue, which contain the original observations (2, Spectral Reflectivity Evidence; and 3, Far Infrared Emissivity Evidence). In the present paper the significance of the new evidence is discussed as well as the significance of morphological and other evidence. Recommendations on Apollo site priorities are made

[1] Contribution 1633 of the Division of Geological Sciences, California Institute of Technology.

[2] Division of Geological Sciences, California Institute of Technology, Pasadena, California 91109.
[3] Bellcomm, Inc., Washington, D. C. 20024.
[4] Department of Earth and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139.

to maximize the chemical variety of the returned lunar samples. Suggestions are made for the selection of sites beyond the present five prime candidates.

Implications of Relevant Observations

In papers 2 and 3 it is shown that:

1. The Apollo sites differ significantly from each other in spectral reflectivity, but these differences do not include the variety evidenced over the moon as a whole or even over just the mare regions. Compositional differences can be inferred independently of age and/or texture effects. Differences in composition that are observed probably reflect differences in minor constituents or valence state.

2. The Apollo sites do not differ significantly from each other in spectral emissivity and are indistinguishable from the great preponderance of the lunar surface in that regard. However, Plato (and a previously studied locality in Mare Humorum [*Goetz*, 1968]) does differ significantly from the rest of the lunar surface.

The small lunar reflectivity differences found in this study can be explained as the result of differences only in minor constituents or even only in relative valence state of iron, whereas emissivity differences imply differences in Si/O coordination number and, therefore, in major constituent abundances. Major and minor constituents are distinguished here on the basis of chemical abundance, not geologic importance. Thus, the surface materials of the Apollo sites can be regarded as probably representative of the general lunar surface in average Si : O ratio and as representative also of much of the Mare areas in minor element abundance or iron oxidation level. Sites Apollo 4 (III P-2) and Apollo 5 (II P-13) appear to be the most similar to one another, whereas sites Apollo 1 (II P-2) and Apollo 3 (II P-8) clearly differ from those two but show similarity to each other in the visible. Apollo 2 (II P-6) is most distinctive. Sampling one site from each of these three groups would be sufficient to ascertain the maximum compositional variations represented by the five sites. If only two sites were to be visited, then Apollo 2 and one western site may represent the best strategy, based on these inferred compositional differences.

If sites other than the five prime ones are to be sampled in the coming years, then first priority should be given to sample return from sites of anomalous spectral emissivity to delineate the maximum range of rock types exposed on the lunar surface. Secondly, samples should be sought from localities displaying maximum differences in spectral reflectivity in order to ascertain the range of minor constituent abundances or valence state. Spectral reflectivity measurements from the earth and from lunar orbit may prove to be the most useful single method for mapping the distribution of the variety of rock types exposed on the lunar surface. Hence, obtaining 'ground truth' representative of the principal classes of spectral reflectivity may warrant special priority in any systematic exploration of the moon.

There are two other possible sources of information on differences in chemical abundances among the Apollo sites and between those sites and the rest of the lunar surface: (1) the α-scattering experiment of Surveyors 5, 6, and 7, and, (2) the γ-ray observations of the Soviet lunar satellite Luna 10. The α-scattering experiment did not have sufficient sensitivity to resolve any chemical differences between the two mare sites with Surveyor 5 (near Apollo 2) and 6 (near Apollo 3) [*Jaffe*, 1969]. However, some differences were indicated between the surface materials of those sites and the site of the Surveyor 7 site, which is located in the uplands on what appears to be the Tycho ejecta blanket. It is not clear whether the observed minor difference in elemental abundance corresponds to a basic difference between surface materials of the uplands and the mare or whether it, instead, refers to the composition of rocks lying unknown kilometers below the surface of Tycho. In any case, the α-scattering data offer no positive basis of choice for sampling among the five prime Apollo sites and are only indirectly related to the question of sample return from other lunar sites.

The Soviet γ-ray data are of even less significance to the sampling question. Only a rather weak indication of a systematic difference between all upland areas and all mare areas passed over by Luna 10 could be extracted from the data by the investigators [*Vinogradov et al.*, 1967].

A good deal of information concerning the morphology of the five prime Apollo sites, as well as other lunar localities, has become available as a result of the highly successful Lunar Orbiter photographic missions. However, we are not aware of any valid compositional indications based on morphology alone. A recent investigation deduces differences in relative age between sites on the basis of variations in regolith thickness [*Oberbeck and Quaide,* 1968]. They state that Apollo sites 1, 2, 3, and 5 have intermediate thicknesses whereas Apollo 4 has a thinner surface layer. Clearly, the determinations of relative ages of surface materials will constitute a principal part of the geologic mapping of the moon. However, it is less clear how much independent priority should be accorded the sampling of sites on the basis of age differences alone. The results of the first few landings may prove helpful in deciding the relative priorities of differences in age and composition in the selection of subsequent sites.

Conclusions

Ground-based observations indicate that the five prime Apollo sites differ significantly from one another in minor constituent abundances or relative valence states but not in major constituent abundances. The differences among those sites are more modest than those of mare regions generally and those of the over-all lunar surface. All five sites appear to resemble most of the lunar surface in Si : O ratio. Hence, samples from any of the five sites probably are representative of the average lunar surface composition in major constituents and of the mare regions in minor constituents or relative valence states. Sampling of two of the five sites may be sufficient to understand the distribution of abundances represented.

We feel site selection for subsequent manned landings should place high priority on sampling areas of anomalous infrared emissivity and of maximum differences in spectral reflectivity in order to delineate the full range of crystalline rocks present on the lunar surface and to provide the necessary ground truth for the geologic mapping of the moon.

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