1. Apollo 16 Site Selection

N. W. Hinners[a]

INTRODUCTION

The Apollo 16 mission had two prime sampling objectives, the Cayley Formation and the Descartes Formation. Although both units had been hypothesized to be volcanic in site selection discussions, impact breccias predominate among returned samples. This result raises questions concerning the site selection process and the fundamentals of photogeology. Recognizing that many of the basic premission interpretations of the geology of the Apollo 11, 12, 14, and 15 sites have been correct, the job at hand is to improve the photogeologic technique, for this technique remains the prime method for extrapolation of Apollo findings to the entire Moon and to the planets.

The rationale that led to the selection of Descartes as the Apollo 16 site is briefly reviewed in this paper. A discussion of pertinent studies that took place after site selection but prior to the mission is also provided. The last section is devoted to lessons learned and to implications for future lunar or planetary site selection activities.

DESCARTES SITE SELECTION RATIONALE

The Apollo 16 landing site, Descartes, was selected after the Apollo 11, 12, and 14 missions, but before the Apollo 15 mission to Hadley-Apennine. The Apollo 11 and 12 flights had returned material which conclusively demonstrated that the mare fill is dominantly basalt of lava-flow origin and that the maria are actually very old, although they appear very young. The isotopic age information, when used in conjunction with data on crater densities and morphologies on many mare surfaces, suggested that mare lava generation might have been limited to the period between roughly 3 and 3.7 billion years ago. The Apollo 14 mission established that the Fra Mauro Formation is ejecta from the Imbrium Basin and that the Imbrium impact, one of the youngest basin-forming events, occurred about 3.9 billion years ago. Model ages of lunar soils from all sites indicate that the Moon originated about 4.5 billion years ago. The composition of Apollo 12 putative Copernicus ray material and of Fra Mauro samples indicated extensive premare igneous differentiation that created high-alumina basalts of relatively high radioactivity. Additionally, exotic fragments at all sites indicated that large regions of the highlands might be anorthositic.

The foregoing factors led to a consensus that the prime objective of both Apollo 16 and 17 should be direct sampling of highlands material that would be compositionally different from Fra Mauro and mare fill, and that would provide detail on lunar evolution before the Imbrium impact, 3.9 billion years ago. A second high-priority objective was to sample the youngest widespread lunar volcanics to determine whether the lunar heat engine really stopped 3 billion years ago.

The Apollo 16 site selection discussions commenced by considering many candidate sites. After the scientific attributes and the engineering and operational constraints were considered, two high-priority highland candidate sites remained: Alphonsus and Descartes, both multiple-objective sites in terms of photogeologic units. The crater wall of Alphonsus was argued to be made of pre-Imbrium highlands material, and the dark halo craters on the crater floor were thought to consist of relatively young postmare volcanic material, possibly originating at significantly great depth within the lunar interior. The third sampling objective at Alphonsus was the crater filling itself, represented as a type of upland basin fill, and at one time referred to as Cayley Formation.

Two prime sampling objectives were delineated for the Descartes site; the upland basin fill, or Cayley Formation, and the hilly and furrowed unit now known as the Descartes Formation. Crater densities and stratigraphic relationships indicate that in some

[a]National Aeronautics and Space Administration, Washington, D.C.

regions these formations are slightly older than the Imbrium impact, and in other regions, including the Apollo 16 site, slightly younger. An early (1962) interpretation by Eggleton and Marshall (ref. 1-1) of the origin of the Cayley and Descartes Formations was that they might be of impact origin and related to the Imbrium impact. However, in most subsequent, and especially in the recent, astrogeologic literature (refs. 1-2 to 1-7) and in all site selection discussions for which a record exists (Group for Lunar Exploration Planning (GLEP), GLEP Site Selection Subgroups, Ad Hoc Site Selection Committees, and the Apollo Site Selection Board), both the Cayley and Descartes Formations are overwhelmingly interpreted as volcanic units. More specifically, the Cayley Formation has been argued to have a lower iron and higher silica content than mare basalts because of its higher albedo and more hummocky terrain, the latter a result of higher viscosity. The prime reason for arguing the basalt-flow origin of the Cayley Formation is the characteristic location as a relatively flat fill in crater interiors and other topographic lows. The Descartes Formation, of higher albedo than Cayley, was thought to represent a more silicous, higher viscosity extrusive. It was further argued by H. Masursky before the Site Selection Board that the Apollo 16 site is located on the highest topographic region of the frontside highlands, indicating that the Descartes volcanics represent remobilized highlands, and that analysis of these volcanics would shed light on the basic process of highland formation.

There was no clear consensus among the scientists involved in the site selection as to the better site. Those favoring Descartes argued that the Alphonsus crater wall might be mantled by Cayley volcanics and that the Alphonsus floor fill is not typical Cayley. On the other hand, Alphonsus protagonists felt that relatively young highland volcanics at Descartes was not significant when contrasted with more primitive highlands. When pro and con arguments were presented before the Apollo Site Selection Board, there were no compelling discriminators. Two factors led the Board to recommend Descartes. First, the Apollo 14 samples (not yet thoroughly analyzed) and the samples to come from the Apollo 15 mission to Hadley-Apennine might yield pre-Imbrian highland material similar to that sought at Alphonsus. If not, the opportunity would exist to go to Alphonsus on Apollo 17. Second, the Cayley and Descartes Formations cover about 11 percent of the lunar near side; and, thus, regardless of the details of their origin, these formations must represent significant lunar units that should be sampled.

POSTSELECTION STUDIES

Site selection discussions were based on the most recent photointerpretations available. Because of the large number of candidate landing sites and limitations of manpower, the site photogeologic maps and interpretations have usually been of a preliminary nature. It is only after the site has been selected that detailed mapping commences.

The 1:250,000, 1:100,000, and 1:50,000 scale maps of the Descartes region, prepared for the mission by Milton and Hodges (ref. 1-2), and Elston et al. (refs. 1-5 and 1-6), are dominated by volcanic interpretations for both the Cayley and Descartes Formations. The emphasis is so strong that aspects of the morphology, which might argue against a volcanic interpretation (i.e., the paucity of ridges and flow front scarps), were interpreted as suggesting "... that the Cayley may consist of ash-flow deposits rather than lava beds." However, evidence that these interpretations might be incorrect was provided by Oberbeck (ref. 1-8), who found that the apparent regolith thickness was less than one would predict (based upon the number of craters assumed to be of impact origin) and that the craters appeared more subdued than expected. Oberbeck's preferred interpretation was that a deep regolith that has been mantled by a deposit indurated after deposition underlies the area. However, he suggested that the mantling deposit might be a welded-ash from the volcanic terrain (Descartes Mountains) south of the site. Support for this interpretation can be found in a study by Head and Goetz (ref. 1-9) who use Orbiter photography, Apollo 12 multispectral photography, Earth-based spectrophotometry, and thermal infrared and radar data in concluding that there has been Copernican-age volcanism in the Descartes Mountains.

RETROSPECT AND LESSONS LEARNED

The discovery of a large preponderance of apparent impact breccias at the Apollo 16 site must be treated with caution; it would be foolhardy to immediately postulate an impact origin for all lunar units labeled Cayley or Descartes. First, it is not certain that the Descartes Formation was adequately sampled. Second, it has long been recognized that the Cayley is not everywhere morphologically identical (e.g., Wilhelms, ref. 1-4). Further evidence for the inhomogeneity of the Cayley comes from the Apollo 16 orbital X-ray spectrometer results, which indicate that the Apollo 16 materials are significantly compositionally different from what is called Cayley in the crater Ptolemaeus (Adler et al., ref. 1-10). Interestingly, the X-ray results are consistent with an interpretation of the Ptolemaeus Cayley as material intermediate in composition between low-alumina mare basalts and the high-alumina terra. Just as interesting and somewhat ironic are the X-ray data, confirmed by analysis of returned samples, that indicate the Apollo 16 site is representative of large regions of the type of highlands thought to exist in the wall of Alphonsus.

The surprising findings at the Apollo 16 landing site have forced a re-evaluation of the process of photogeology and site selection. The following are lessons that have been learned and that should be considered in any future work.

(1) Care must be taken to separate observation (basically, what is shown in maps) from interpretation. Photointerpretation is not foolproof. Trask and McCauley (ref. 1-7) note that, regarding the Descartes materials, "photogeologic interpretation alone cannot rule out the possibility that all the hilly and gently undulating terrain belongs to one or more of the hummocky ejecta blankets surrounding the large circular basins."

(2) The art of lunar (and planetary) photogeology could benefit by using the method of multiple working hypotheses.

(3) When lacking other definitive data, it is reasonable to select a site in an extensive morphologic unit previously unsampled. Although what was found on the Apollo 16 mission was not expected, the samples are nevertheless just as, or possibly more, valuable. Those who predicted a volcanic terrane did so for good reason; thus, the observations that led to the supposition of volcanism must be explained. It is probable that we will now decipher many previously unknown characteristics of large impacts and ejecta mechanics. This information is essential to the future extrapolation of Apollo results when using photogeologic techniques.

(4) It is highly desirable that detailed site mapping be done prior to site selection and that alternate interpretations be examined thoroughly. Identical interpretations of similar morphologic units at great distances from each other should be examined thoroughly and treated with caution.

(5) Compositional data acquired from orbit (and, in the case of the Moon, from Earth-based observations) can be an invaluable aid in site selection. These data enable discrimination among morphologically similar-looking units that may not be genetically related.

REFERENCES

1-1. Eggleton, R. E.; and Marshall, C. H.: Notes on the Apenninian Series and Pre-Imbrian Stratigraphy in the Vicinity of Mare Humorum and Mare Nubium. Astrogeologic Studies Semiannual Progress Report, Feb. 26, 1961, to Aug. 24, 1961. U.S. Geol. Survey Open-File Rept., 1962, pp. 132-137.

1-2. Milton, D. J.; and Hodges, C. A.: Geologic Maps of the Descartes Region of the Moon: Apollo 16 Pre-Mission Map. U.S. Geol. Survey Misc. Geol. Inv. Map I-748, 1972.

1-3. Wilhelms, D. E.; and McCauley, J. F.: Geologic Map of the Near Side of the Moon. U.S. Geol. Survey Misc. Geol. Inv. Map I-703, 1971.

1-4. Wilhelms, D. E.: Summary of Lunar Stratigraphy – Telescopic Observations. U.S. Geol. Survey Professional Paper 559-F, 1970.

1-5. Elston, D. P.; Boudette, E. L.; and Schafer, J. P.: Geology of the Apollo 16 Landing Site Area. U.S. Geol. Survey Open-File Rept., 1972.

1-6. Elston, D. P.; Boudette, E. L.; and Schafer, J. P.: Geologic Map of the Apollo 16 (Descartes) Region. U.S. Geol. Survey Open-File Rept., 1972.

1-7. Trask, N. J; and McCauley, J. F.: Differentiation and Volcanism in the Lunar Highlands: Photogeologic Evidence and Apollo 16 Implications. Earth and Planetary Science Letters, Vol. 14. 1972, pp. 201-206.

1-8. Oberbeck, V. R.: Implications of Regolith Thickness in the Apollo 16 Landing Site. NASA TM X-62089, 1971.

1-9. Head, J. W., III; and Goetz, A. F. H.: Descartes Region: Evidence for Copernican-Age Volcanism. J. Geophys. Res. Vol. 77, 1972, pp. 1368-1374.

1-10. Adler, I.; Trombka, J.; Gerard, J.; Lowman, P., Schmadebeck, R.; Blodget, H.; Eller, E.; Yin, L.; Lamothe, R.; Osswald, G.; Gorenstein, P.; Bjorkholm, P.; Gursky, H.; and Harris, B.: Apollo 16 Geochemical X-ray Fluorescence Experiment: Preliminary Report, X-641-72-198,, preprint, NASA Goddard Space Flight Center, 1972.