B. APOLLO 16 REGIONAL GEOLOGIC SETTING

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Apollo 16 landed at approximately 15”30’ E., 9” S. on the relatively level Cayley plains, adjacent to the rugged Descartes mountains (Milton, 1972; Hodges, 1972a). Approximately 70 km east is the west-facing escarpment of the Kant plateau, part of the uplifted third ring of the Nectaris basin and topographically the highest area on the lunar near side. With respect to the centers of the three best-developed multiringed basins, the site is about 600 km west of Nectaris, 1,600 km southeast of Imbrium, and 3,500 km east-northeast of Orientale. The nearest mare materials are in Tranquillitatis, about 300 km north (fig.1).

GEOLOGIC DESCRIPTION OF CAYLEY PLAINS AND DESCARTES MOUNTAINS

The principal geologic objective of the mission was investigation of two major physiographic units, the Cayley plains and the Descartes mountains (fig. 2). Materials of both local units had been interpreted as volcanic before the mission (Milton, 1968; Wilhelms and McCauley, 1971; Milton, 1972; Hodges, 1972a; Elston and others, 1972a,b,c; Trask and McCauley, 1972; Head and Goetz, 1972), mainly on the basis of their topographic expression. Much of the surrounding central highlands was assumed to be largely primitive crustal material, bombarded repeatedly by impact.

The Cayley plains are of Imbrian age according to stratigraphic relations, crater size’-frequency distributions, and crater degradation models (Wilhelms and McCauley, 1971; Trask, and McCauley, 1972; Soderblom and Boyce, 1972). The type area of the Cayley Formation is east of the crater Cayley, north of the landing site (Morris and Wilhelms, 1967); the name was extended to the apparently similar plains material at the Apollo 16 site (Milton, 1972; Hodges, 1972a). These materials were presumed to be representative of the widespread photogeologic unit, Imbrian light plains, which covers about 5 percent of the lunar highlands surface (Wilhelms and McCauley, 1971; Howard and others, 1974). Characteristics include relatively level surfaces, intermediate albedo, and nearly identical crater size-frequency distributions.

The plains were first interpreted as smooth facies of Imbrium basin ejecta (Eggleton and Marshall, 1962), but as the characteristics and apparent age of the materials were better defined, a volcanic origin became the favored hypothesis (Milton, 1964; Milton, 1968; Wilhelms and McCauley, 1971; Milton, 1972; Hodges, 1972a; Elston and others, 1972a,b,c; Trask and McCauley, 1972). Frequency distributions of superposed craters are lower on the plains than on the Fra Mauro Formation (Imbrium ejecta), and plains materials are superposed on Imbrium sculpture, indicating that the plains postdate the Imbrium basin. This age relation is further supported by the crater-erosion model (Boyce and others, 1974). In morphology and mode of occurrence, the plains resemble mare materials; surfaces are relatively level, and the plains are confined to craters and broad depressions, suggesting local derivation and fluid emplacement. In the landing site area and elsewhere, craters 0.5 to 1.0 km in diameter commonly have conspicuous central mounds on their floors. Throughout the central highlands helms and McCauley, 1971), Cayley-type plains are especially prominent in large old craters-Ptolemaeus, Albategnius, and Hipparchus. Where adjacent to the maria, as at the type area of the Cayley Formation, the plains are embayed or overlapped by mare lavas. Orbital geochemical data obtained during the Apollo missions indicate that the higher albedo of the plains

FIGURE l.-Lunar near side. *A*, Location of major features mentioned in the text; Apollo landing sites indicated by numbers. B, Major rings of near-side multiring basins in relation to Apollo 16 landing site. From Wilhelms and McCauley (1971).

materials is produced by an aluminum-to-silicon ratio higher than in rocks of the maria (Adler and others, 1973).

In several places, large subdued craters appear to he mantled by Cayley-type materials, suggesting that a relatively thin deposit was emplaced on an older surface. To account for the apparent differential compaction in the upper layer, ash falls or flows, or possibly mass-wasted debris, were proposed as the depositional materials (Howard and Masursky, 1968; Cummings, 1972). In the large crater Alphonsus, dark conelike structures interpreted as volcanic vents occur along graben in the plains material, an association that supported the volcanic interpretation of the plains (McCauley, 1969).

The Descartes mountains topography is virtually unique on the Moon. No other deposits of identical morphology have been recognized, although similar hilly and furrowed materials of Imbrian age have been mapped in several places (Wilhelms and McCauley, 1971). Sixty kilometers south of the landing site, the materials overlap and nearly fill the degraded 50-km crater Descartes; they are clearly depositional and perhaps 1 km or more thick (Milton, 1972). No genetic relation to a local impact crater is apparent, and the morphology of the hills and furrows suggested an origin analogous to terrestrial volcanic extrusions or fissure cones to Trask and McCauley (1972). A partly gradational relation with the Cayley Formation was proposed prior to the mission (Milton, 1972; Hodges, 1972a; Elston and others, 1972a,b,c). Although superposed crater populations indicate an Imbrian age for most of the Descartes mountains (Trask and McCauley, 19721, a patch of unusually high albedo near the north rim of the crater Descartes was interpreted as a Copernican pyroclastic deposit (Head and Goetz, 1972).

As a result of the wide acceptance of these volcanic interpretations, developed independently by several authors, premission models of lunar history generally incorporated: (1) a Moonwide, postbasin, premare episode of fluid or pyroclastic volcanism producing Cayley-type plains and (2) a later and more localized phase of relatively viscous extrusive activity, best exemplified by the Descartes mountains. The Apollo 16 mission was designed to test these hypotheses.

The impact origin of the rocks returned from the landing site forced reinterpretations of the geologic units (pl. 1), Textures of the highly feldspathic samples are nearly all indicative of shock metamorphism of various degrees. The rocks are mainly breccias, but even the relatively few crystalline rocks contain “ghost clasts” indicating thermal metamorphism and recrystallization.

New interpretations of the landing-site geology must now explain not only the brecciated nature of the rock samples but also all of the characteristics previously ascribed to volcanism. Extrapolation of the data from the Apollo 16 site to similar photogeologic units elsewhere imposes new constraints on the framework of lunar geologic history.

RELATION IN TIME AND SPACE TO BASINS AND CRATERS

Impact sources and emplacement mechanisms for the geologic units at the landing site and for similar materials elsewhere are not readily apparent. Although local derivation of the rocks has been suggested (Oberbeck and others, 1974a, b; Head, 1974), large multiringed basins now appear to have had pervasive influence throughout the Moon's geologic history (Howard and others, 1974) and probably contributed material to the landing site. Youngest and best preserved of these basins is Orientale, whose outer and most conspicuous ring is the Cordillera, 930 km in diameter. Next youngest-and largest on the near side-is the Imbrium basin, whose outer ring, the Apennine, is 1,340 km across; this basin and its ejecta (Fra Mauro Formation) form the stratigraphic and structural base of the Imbrian System (Wilhelms, 1970). The sequence of basin formation becomes progressively ambiguous with increasing age, but Nectaris, nearest the Apollo 16 site, is one of the best preserved of the pre-Imbrian basins on the near side. Its most prominent ring, the Altai, is 840 km in diameter. Its ejecta blanket, the Janssen Formation (Stuart-Alexander, 1971), denotes the base of the Nectarian System, immediately preceding the Imbrian System in the time-stratigraphic nomenclature established on the east limb and farside areas of the Moon (Stuart-Alexander and Wilhelms, 1975). Because of age and proximity, each of these enormous impact events almost certainly influenced the latest stratigraphic and structural development of the entire central highlands including the landing site area.

Inasmuch as multiringed basins formed throughout the Moon's early history, unraveling the stratigraphic column at any given place requires an estimate of the thickness of ejecta contributed by these basins as well as by locally derived material.

Nectaris basin.-The Apollo 16 area, only 600 km from the center of Nectaris, is well within range of the continuous ejecta from the Nectaris basin, but the Imbrian age of the Cayley and Descartes units sampled precludes their derivation from that basin. Further, no deposits as fresh in appearance as the Descartes mountains occur elsewhere around the Nectaris basin. The Nectaris ejecta that should be present at the site must be buried by these younger materials.

Imbrium basin.-The Apollo 16 site is about 1,600 km southeast of the center of the Imbrium basin and

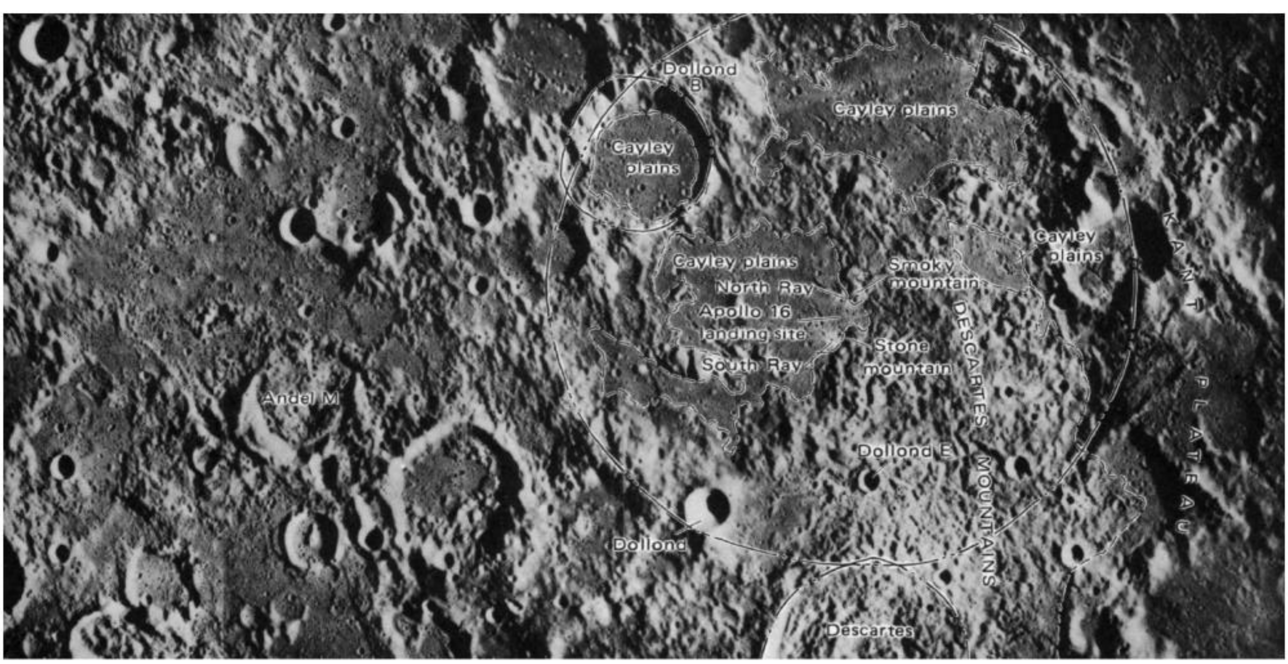

FIGURE 2.-Apollo 16 landing site and vicinity. Andel M, 130 km west of the site, may be filled with as much as 1 km of mixed Imbrium ejecta and debris from its destroyed north rim. Prominent ridges and furrows trending predominantly southeast reflect Imbrium sculpture (secondary cratering) and possible flow lineations in primary ejecta. (Apollo 16 mapping-camera frames 439, 440, 441, 442.)

within a well-defined belt of plains peripheral to that basin in both the central highlands (Eggleton and Schaber, 1972) and on the north (Lucchitta, 1978). Although the site is beyond the range of Imbrium ejecta previously mapped (Wilhelms and McCauley, 19711, this spatial association of plains and basin suggests a genetic relation (Eggleton and Marshall, 1962; Eggleton and Schaber, 1972). Size-frequency distribution of superposed craters, crater degradation models, and stratigraphic relations indicate that the central plains are younger than the Fra Mauro Formation (Wilhelms and McCauley, 1971; Greeley and Gault, 1970; Soderblom and Boyce, 1972), whereas two patches of northern plains are equivalent in age to Fra Mauro Formation (Boyce and others, 1974).

The Descartes mountains may be composed of Imbrium ejecta banked against the Kant plateau, analogous to the deceleration ridges (Trask and McCauley, 1972) of the Hevelius Formation trapped by preexisting crater walls around Orientale (Hodges, 1972b; Hodges and others, 1973). Smaller scale analogs have been described within the ejecta blanket of a crater only 3.5 km in diameter (Head, 1972). Discontinuous Fra Mauro materials occur west of the site where the crater Andel M (fig. 2) appears to have been partly filled by Imbrium ejecta that destroyed its north rim (Moore and others, 1974).

Orientale basin.-The Apollo 16 site is about 3,500 km from the center of Orientale-well beyond any previously recognized extent of that basin's ejecta. The Cayley-type plains, however, appear to be contemporaneous with the Hevelius Formation (McCauley, 1967), which is the continuous ejecta from Orientale and which includes a conspicuous planar facies of broad extent, mainly at the distal margin of the textured ejecta (Soderblom and Boyce, 1972; Hodges and others, 1973). In order to account for the age of the plains surfaces, as deduced from cratering models, Orientale was proposed as the source of the uppermost deposits of both mountains and plains at the Apollo 16 site (Chao and others, 1973; Hodges and others, 1973). Theoretical analyses of ejecta volume argue that ejecta from Orientale may be dispersed over the entire Moon (Moore and others, 1974); broad distribution of crater ejecta is demonstrated photogeologically by young craters such as Tycho, whose rays extend more than 3,000 km (Baldwin, 1963).

Local craters. -Because of stratigraphic constraints, local craters are an unsatisfactory source for the materials at the Apollo 16 site. The Cayley plains are younger than any large adjacent craters, all of which have clearly been sculptured by Imbrium ejecta. A pre-Imbrian crater 150 km in diameter centered on the landing site has been conjectured (Milton, 1972; Head, 19741, but materials formed by such a crater would be several kilometers deep at the landing site and are not likely to have been included in the sample collection. Head (1974) proposed that the plains were essentially floor materials of a 60-km crater whose rim crest includes Stone and Smoky mountains. This seems impossible, however, for such a crater would have to be younger than the Descartes mountains of Imbrian age, yet older than the pre-Imbrian crater Dollond B (fig. 2), an obvious incongruity; even allowing the Descartes mountains and the plains to be pre-Imbrian would require the plains to be sculptured, and they are not. Furthermore, this mechanism, requiring local origin within craters, cannot be extrapolated, inasmuch as craters containing Cayley-type plains are generally considerably older than the enclosed plains, and some plains (for example, at the Cayley Formation's type locality) are not within craters.

A possible derivation of plains materials by local secondary cratering was advocated by Oberbeck and others (1975), who demonstrated that the mass of ejecta from a secondary crater far exceeds the mass of the primary projectile at increasing distances from the continuous ejecta blanket. The pervasiveness of Imbrium sculpture caused by secondary projectiles around the Apollo 16 site indicates that such cratering, together with mass wasting and extensive lateral transport, could have concentrated material in topographic lows, although the crater size-frequency distributions of the surficial plains suggest a younger age for the deposits than is accountable by this postulate. The potential sources for rocks returned from the Apollo 16 mission are reexamined in Hodges and Muehlberger (this volume) after presentation of field data and pertinent orbital information.

To summarize the position of the Cayley plains and Descartes mountains in space and time: (1) The units are Imbrian in age, and the uppermost plains deposits are essentially contemporaneous with the formation of the Orientale basin; cratering ages of the Descartes materials are not so well defined because of their rugged topography, but they are at least as old as Imbrian. (2) Because of proximity to the Nectaris basin, stratigraphy at the Apollo 16 site must surely include Nectaris ejecta at depth, but the basin is too old to have produced the materials now at the surface. (3) The site is within the "sphere of influence" of the Imbrium basin, as indicated by the sculpturing produced by gouging of secondary projectiles, and Imbrium deposits may well be present. (4) The hypothesis that Orientale ejecta reached the site is based largely on the apparent contemporaneity of that basin with the surficial plains deposits. Deposition of Orientale ejecta on the order of several tens of meters (a speculation not represented on the accompanying geologic map, pl. 1) seems required to "reset" the Imbriuni "crater clocks."