C. APOLLO 16 TRAVERSE PLANNING AND FIELD PROCEDURES

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GEOLOGIC OBJECTIVES

The geologic objectives of the Apollo 16 mission were to understand better the nature and development of the highland area north of the crater Descartes, including an area of Cayley plains and the adjacent Descartes mountains, and to study processes that have modified highland surfaces. The objectives were to be met through the study of the geologic features both on the surface and from orbit and through analyses of the samples returned.

The plans for the mission finally evolved from backroom discussions and formal review between interested personnel: scientists, engineers, and, foremost, the astronauts themselves. The premission plan as finalized shortly before launch underwent modification during the mission as the science support team evaluated revised times available for traverses, problems that arose during the mission, and changing geologic concepts of the area being investigated.

Highlands materials had been collected at the Apollo 14 and 15 landing sites (fig. 1): from the continuous ejecta blanket of the Imbrium basin at Apollo 14; from the base of the Apennine front, the outer ring of mountains bounding the Imbrium basin, at Apollo 15. Each of these sites yielded highlands materials of different types that could be related to Imbrium basin formation.

At the Apollo 16 site, materials of both a widespread highlands plains unit and the rugged Descartes mountains were of interest; neither geologic unit had yet been sampled in the Apollo reconnaissance of the Moon.

Ray materials from two small but conspicuous Copemican craters, North Ray and South Ray, both on the Cayley plains, mantle a considerable part of the traverse area, on both plains and adjacent mountains

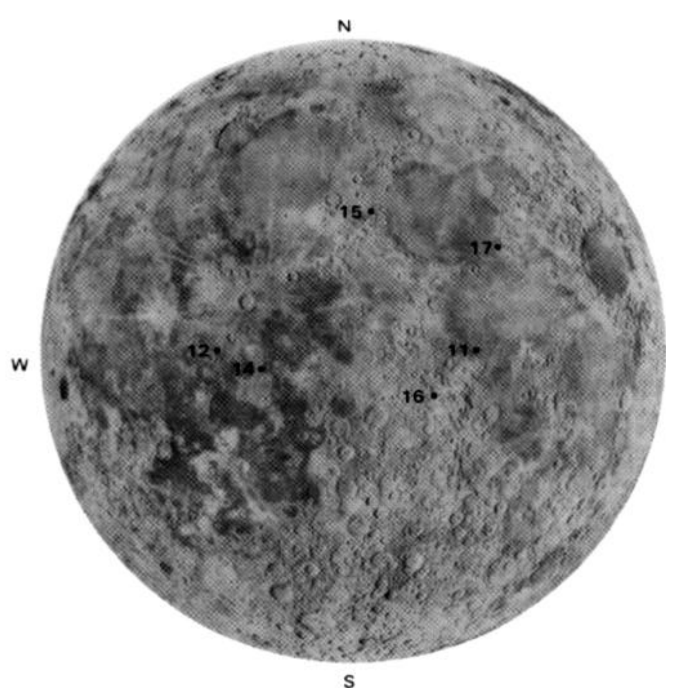


Figure l.--Near side of the Moon showing the Apollo landing sites

(Hodges, 1972a; Elston and others, 1972a, b). Impact craters of Imbrian to late Copernican age are prominent throughout the region (fig. 2). Rimless to low-rimmed, irregular depressions were mapped as craters of either secondary impact from Theophilus, 300 km to the east, or volcanic origin.

FIGURE 2.-Apollo 16 landing site, traverses, and regional lunar features. From AFGIT (1973) and Hodges and others (1973). Reprinted with permission of the American Association for the Advancement of Science and Pergamon Press.

Lithologic layering in the Cayley plains was suggested by albedo bands and ledges in the walls of several craters and by mounds in the floors of craters about 1 km in diameter. Lithologic layering in the materials of the Descartes mountains was suggested by topographic benches and bands of slightly varied albedo on the flanks of Stone mountain. Materials at depth beneath the Cayley plains were interpreted as including both the Fra Mauro Formation derived from the Imbrium basin and ejecta from the nearer but older Nectaris basin (Hodges, 1972a). Elston and others (1972b) projected the flank of a highly cratered pre-Imbrian hill beneath the traverse region. The depth to these units was unknown, but all were believed to be well below the depth of local cratering and therefore unlikely to be sampled in the traverse area.

PREPARATION FOR FIELD GEOLOGY AT DESCARTES

The name of the game in traverse planning is maximum science return. Most surface experiments and the central station of the Apollo Lunar Surface Experiments Package (ALSEP) that telemetered data to Earth required deployment by the astronauts, or required astronaut voice data transmission as in the procedure for the Lunar Portable Magnetometer. Each of these types of operations required rapid deployment (using minimum time), and a definite period of time was allocated to each experiment.

The geologic experiment was more difficult to structure, and the observations, sampling, and photography necessary to satisfy the collective geologic community required time and equipment beyond that available. For example, a fourth traverse or Extravehicular Activity (EVA) was requested by the Field Geology Experiment Team (with the concurrence of the astronauts) in order to study South Ray crater and its ejecta blanket. This request was denied because it would have gone beyond the time limits deemed safe for the LM systems. As time was extremely limited, an intricate system of priorities was established for both station locations and tasks performed at each station. The development of priorities involved many individuals and advocate groups for the various aspects of the traverse activities. The final system of priorities and contingency plans appeared in the “Lunar Surface Procedures” and “Science Contingency Plan” documents for the mission.

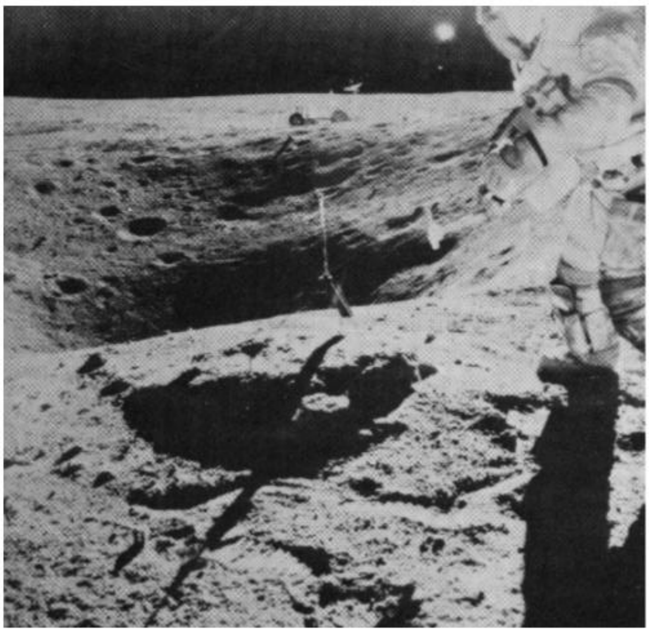
The field training of the astronauts developed their abilities to identify and describe the significant geologic features in view, to sample and document photographically the geologic units at a sampling site, to document the significant relations of areas remote from the traverse line by use of telephoto cameras and Description, and to integrate previous observations into a general geologic picture of the landing site.

Both sampling procedures and photographic techniques evolved with experience during training and throughout the actual missions. Sampling procedures focused on obtaining a truly representative collection of materials at the site while staying within severe weight restrictions. In addition to standard sampling procedures (illustrated in fig. 3), several special techniques were used to: (1) support studies of the surface character of the regolith, the optical properties of the

FIGURE 3.-Sampling equipment and techniques used on Apollo 16. *A*, Sample 61295 broken from large rock under gnomon. Regolith samples were taken from fillet surrounding rock. Photograph taken to include LRV to assist in locating sample areas. Station 1, Plum crater. AS16-109-17804. B, Gnomon in standard position with color chart leg toward sun and near sample to be collected. Gray scale and color chart on leg and wand gives true color; bands are 2 cm wide, for photographic scale; wand is mounted in gimbels to give local vertical. Station 5, cross-sun view. AS16-110-18024. C, Same as B but with sample 65035 removed. Station 5, cross-sun view. AS16-110-18025. *D*, Sampling area of B and C after collection of rake sample. Gnomon leg at right edge. Station 5, cross-sun view. AS16-110-18026. *E*, Sample 60018 being chipped from large rock by Astronaut Charles Duke. Rake being used for scale. Wires in rake are spaced 1 cm apart. Cuff checklist of notes strapped to astronaut’s wrist, above hammer. Camera lens sun-shade and sample bags hanging from a clip below the camera are visible. Station 10. AS16-11-18689. *F*, Astronaut John Young breaking chips from spa11 zone, Outhouse rock, North Ray crater. Sample bags being carried by hand because clip under camera fell off. Each bag is numbered and called out by astronaut when sample is placed in it. Camera and mounting bracket on astronaut’s chest, and cuff checklist clearly visible. AS16-116-18647. G, Tongs being used as scale for sample site. Astronaut John Young pulling rake. Rim of North Ray crater; LRV in background; white breccia boulder sampling area on skyline. AS16-106-17340. *H*, Tongs holding rock 60115, just removed from small depression (arrow) in which rock had lain on lunar surface. Station 10. AS16-114 18446. I, Closeup stereo view of boulder 1 at station 8 showing textural details of breccia not visible in small samples returned. AS16-108-17693/17694. J, Scoop being used as locator. Dark stripe on handle used as guide by the astronaut to give proper distance for closeup photography. Sample 60275 marked by arrow. Sampling station at LM. AS16-117-18833. *K*, Area of J after removal of sample 60275 with scoop. AS16-117-18835. L, Scoop, gnomon, and sample collection bag (SCB). The unlatched and open top shows two single core tubes (drive tubes) stowed within the bag. This bag can be carried by hand or attached to the astronaut’s life support system. Individual samples in their numbered bags are stored in the SCB. Station 4, down-sun, before sampling. AS16-107-17464. *M*, Double core attached to extension handle. Lower tube about half driven. Upper tube (number 29) visible. Station 8, AS16-108-17682. N, Double core hammered to total depth. Station 8, location changed from that shown in *M*. AS16-108-17686. 0, Hinged rack (in open position) on rear of LRV, showing (right-to-left) rake, both tongs, and penetrometer drum in stowed position for travel. Lunar portable magnetometer deployed at end of 15-m cable. Other equipment under seats. AS16-114-18433.

lunar surface, the unabraded surfaces of lunar rocks, boulder erosion and filleting, the adsorption of mobile elements in shaded areas, cosmic ray tracks in large and small boulders, and chemical homogeneity throughout single units and (2) support future studies on uncontaminated lunar soil. Horz and others described these procedures and special samples returned, including an X-ray description of the cores collected.

Photographic requirements included two panoramas at each station, one taken immediately upon arrival at the station, the other just prior to leaving the station, so that the undisturbed surface could be studied, sample locations more easily identified. and a stereobase established for detailed study. Telephoto surveys were made from two stations to obtain a stereobase of Stone and Smoky mountains for analysis of lineaments like those first recognized on Mount Hadley during Apollo



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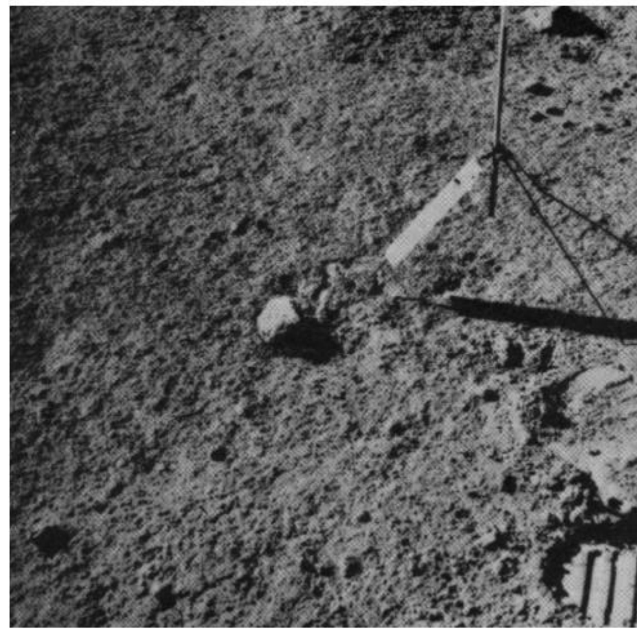

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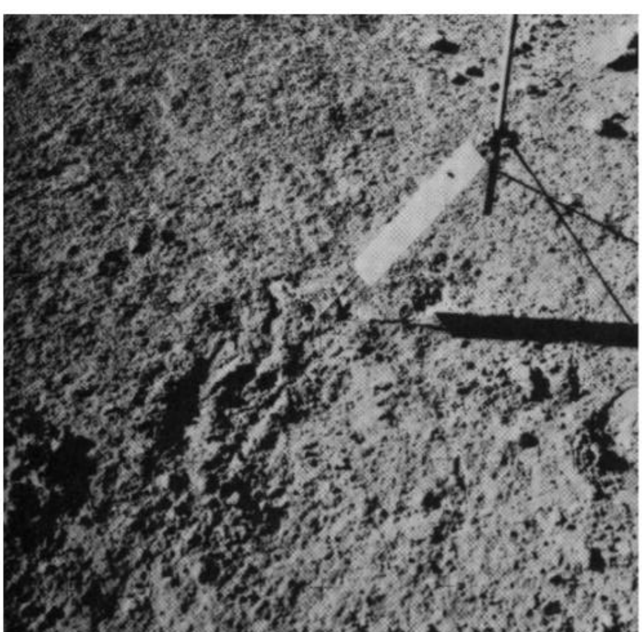

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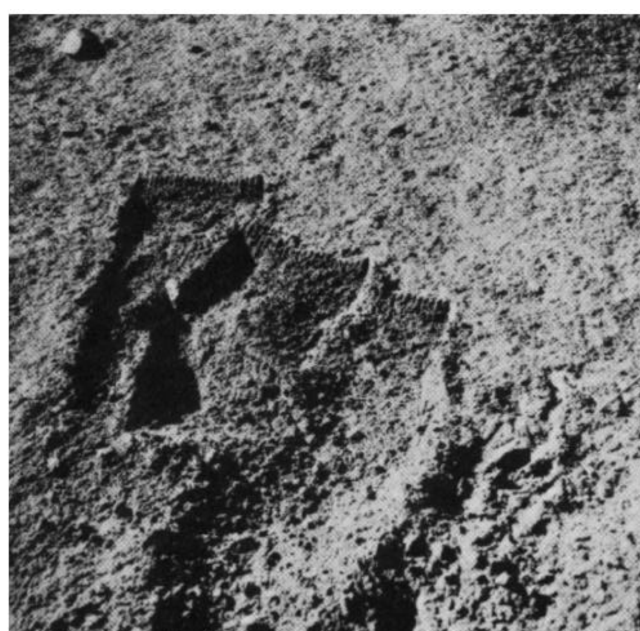

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15. In addition, two polarimetric surveys were made at station 11: one to establish calibration control in the near-field of a sampled area and one of the inaccessible interior of North Ray crater taken from the rim.

Finally, the photographs required included a standard set for sample documentation, closeup stereopairs for analysis of rock textures, and “flight-line” stereo, that is, a series of photographs perpendicular to a boulder that would provide a stereo base for study.

TRAVERSE DESIGN

The three traverses (one per EVA) were designed to optimize investigations of the Cayley plains and the Descartes mountains (fig. 4). For that purpose, a preliminary photomosaic and topographic base map, plate 2, was prepared from existing Apollo 14 Hasselblad photographic coverage 9 months before the mission. This allowed detailed traverse planning to start

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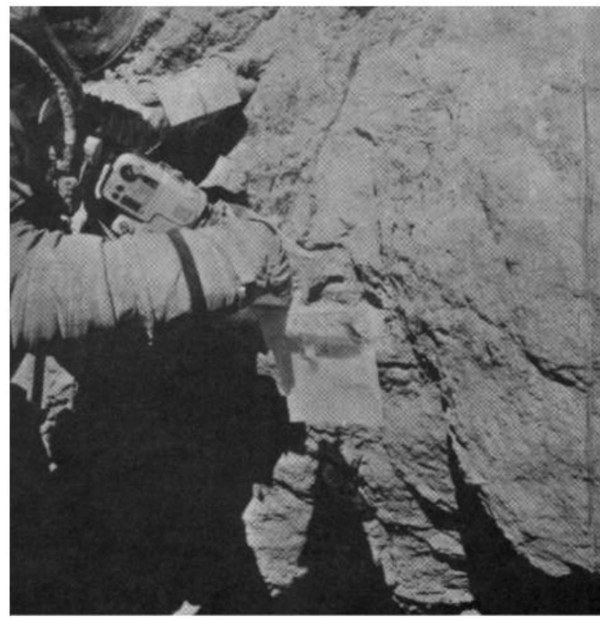

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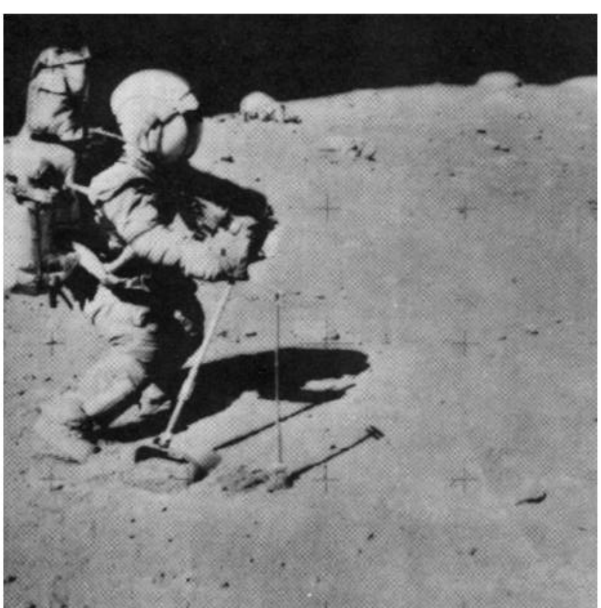

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spite the low resolution of the photography and long before more accurate maps became available. The Cayley Formation was to be sampled during each traverse in order to determine lateral variations of the stratigraphic section between North Ray and South Ray craters, the petrology of the formation throughout the area, and the characteristics of the upland plains regolith. The prime sampling areas were located at Flag and Spook craters and in the vicinity of the LM and ALSEP, where crater dimensions suggested that the unit might be sampled to depths of approximately 60 m. Avoiding ray material so as to obtain locally derived samples of Cayley Formation was a major consideration in the LM-Spook-Flag sampling areas. Prime sampling sites for deeper parts of the Cayley were in the ejecta of North Ray and South Ray craters.

The short distance between Flag and Spook craters, about 1 km, made it possible early in the lunar surface activities (EVA-11 to test the lateral continuity of bedrock layers. Good stratigraphic correlations in these craters could provide a solid base for extending the stratigraphy into the LM-ALSEP area and a geologic basis for the interpretation of the Active Seismic Experiment profile. It was hoped that the stratigraphy could then be carried northward through Palmetto to North Ray crater and southward to South Ray crater. Both Flag and Spook craters are degraded and have a veneer of South Ray ejecta across or near them. Station

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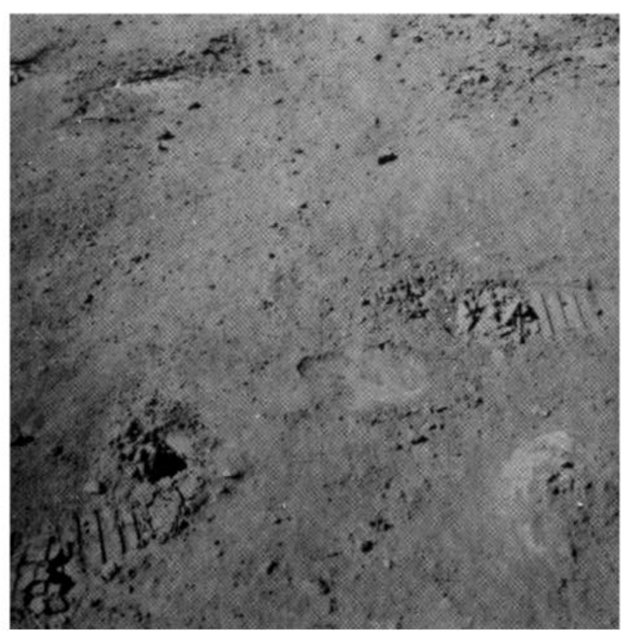

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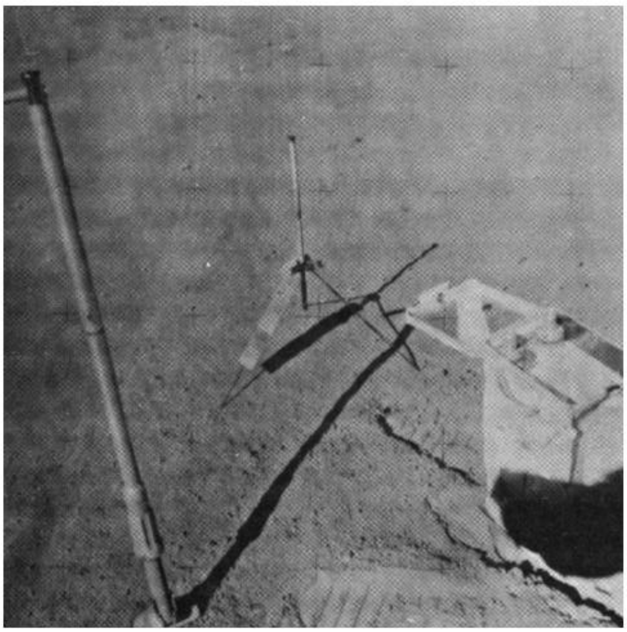
1 was located on Plum crater, a small fresh crater on the rim of Flag crater, thought large enough to have penetrated the entire Flag crater ejecta blanket, and station 2 was on Buster crater, thought to have penetrated the upper layer of the underlying Cayley Formation even though it lies on the outer part of the ejecta blanket of Spook crater. A third station, for sampling, coring, and experiments in soil mechanics in the ALSEP area, was moved late in the planning stages to the end of EVA-2 so that maximum sampling time could be spent at Flag and Spook craters.

Deeper parts of the Cayley Formation were assumed to have been excavated by the larger North Ray and South Ray impacts and exposed near the rim of North Ray crater (stations 11,12, and 13, fig. 4) and in the ray deposits of South Ray crater (station 8).

On the second traverse, stations 4, 5, and 6 on the flank of Stone mountain were the principal sampling



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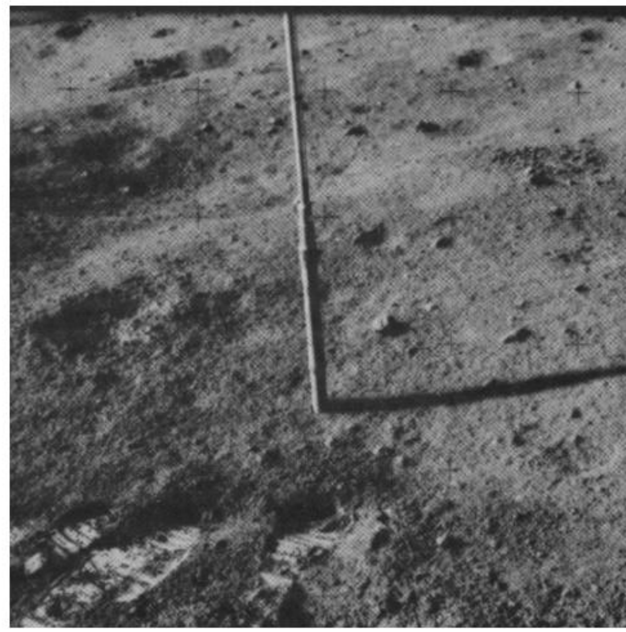

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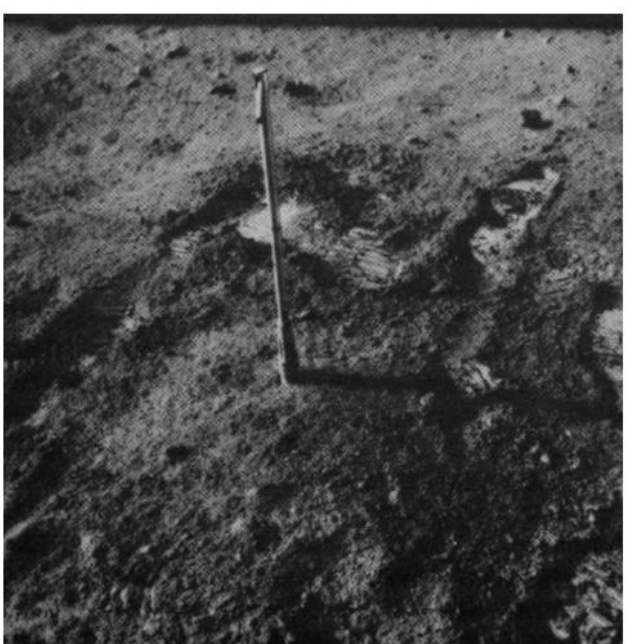

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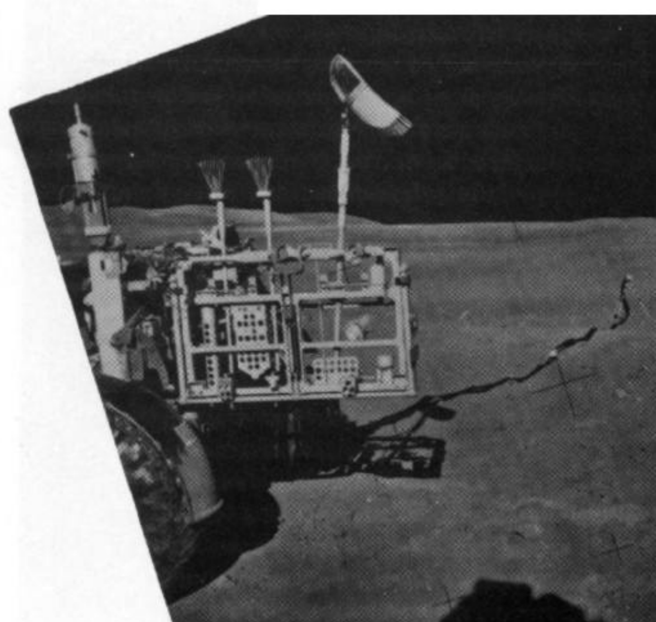

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sites for Descartes mountains materials (fig. 4). These stations were on benches delineated on the premission topographic map (U.S. Army Topographic Command, 1972). The station farthest upslope (station 4) was located between Cinco *d* and e, a pair of craters that must penetrate the regolith, excavating blocks of Stone mountain material. It was hoped that ray material from South Ray crater, anticipated at these stations, could be recognized and avoided. In addition to employing a wide variety of sampling techniques, penetrometer tests of soil were to be performed; the elevation of the station would permit good telephoto viewing of the rim and interior of South Ray and Baby Ray craters on the plains. Locations of the lower stations on Stone mountain (5 and 6) were spaced at equal intervals down the slope but subject to change if the astronauts observed outcrops, blocky-rimmed craters, or other features of particular interest on their outbound traverse. Station 14, on the lower slopes of Smoky mountain, was planned for the third traverse in order to compare the two mountain units.

The rim of North Ray crater, nearly 1 km in diameter and more than 200 m deep, was the prime site for obtaining the deepest samples of Cayley plains. The younger South Ray crater was believed inaccessible because of the blockiness of the ejecta blanket and the large deep craters (Trap-Wreck-Stubby) that obstructed the direct route from the LM. Although many large blocks were observed in the ejecta of North Ray crater, there appeared to be relatively smooth approaches along which the astronauts could drive to the crater rim or at least to within walking distance of it. Seven stratigraphic layers within the crater were interpreted on the basis of albedo differences (Elston and others, 1972a, b, c) visible on premission photographs having a resolution no better than 5 m. Lateral variations in these bands across the crater, a large dark central mound on the crater floor, and a 25-m-long dark boulder on the crater rim were identified as features of interest. Stations 11 and 12, approximately 200 m apart on the crater rim, were located as end points of a sampling strip that would provide materials representative of all layers penetrated, except possibly the top one. Station 12 was at the huge dark block named “House rock” by the astronauts, assumed, in premission planning, to be visible from a distance and therefore useful as a navigation aid. To guarantee samples from the uppermost layers of the Cayley

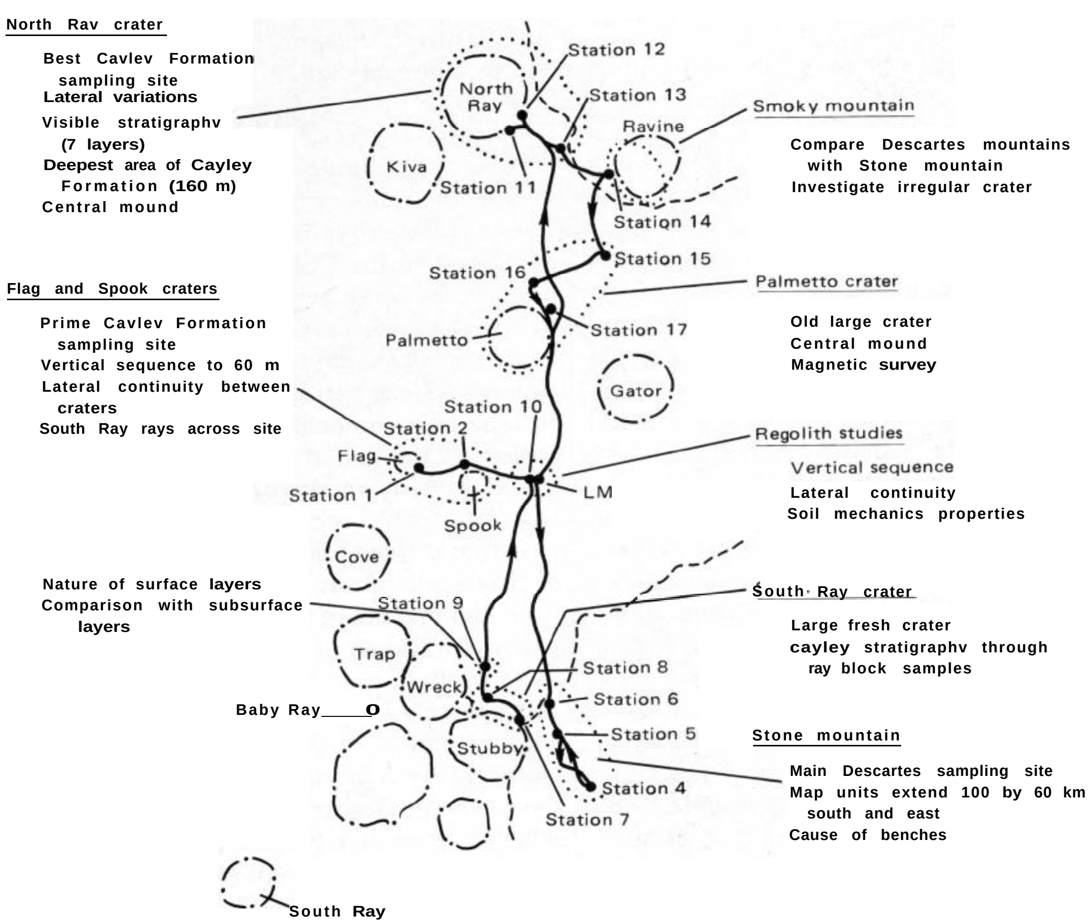

FIGURE 4.-Planned traverses and geologic objectives.

plains, station 13 was established far out on the ejecta blanket. A wide variety of photographic techniques was planned to document the compositional, textural, and stratigraphic relations of the returned samples: panoramas from several locations for stereoviewing, 500-mm telephotography of far crater wall, near- and far-field polarimetric surveys, close-up stereo for textural details of individual boulders, "flight-line" stereo of large boulders, as well as conventional photographic documentation during sampling.

Palmetto crater, about the same diameter as North Ray crater, is older and very subdued; a few large fresh craters occur near its rim. Stations 16 and 17 (fig. 4) were selected as the best places for sampling Palmetto ejecta. In addition, the outbound traverse was specifically planned along the Palmetto rim so that the astronauts could observe features within the crater and on its ejecta blanket not visible on the premission photographs and thereby recommend changes in the plan for the end of the traverse. Station 15 was planned at a small fresh crater for sampling the local top layer of the Cayley Formation to establish lateral continuity. Stations 15, 16, and 17 were also planned as magnetometer stations designed to determine whether magnetic anomalies occur around a large crater (Palmetto).

Rays from South Ray crater were visible across much of the landing site area on premission photographs, but the nature of the ejecta in rays was unknown. Either a blanket of debris of various sizes or a string of blocks and associated fines that produced secondary craters, or perhaps a combination of both, was thought to account for the apparent characteristics. Ascertaining the composition of rays was essential in order to assign samples collected to their proper source craters.

Ideally the procedure for sampling these rays would have included intensive study of several widely separated patches, as each patch represents only a small volume of the crater ejecta. The more patches studied, the better the stratigraphic sampling of the crater, despite the fact that most ray material in the vicinity of the LM was likely derived from only the upper quarter or less of the crater. South Ray material was expected in cores from the LM/ALSEP and station 8 areas and in some of the surflcial samples returned. Station 8, near the rim of Stubby crater in the brightest ray patch accessible, was planned specifically to obtain materials from South Ray crater. Sampling by all techniques available was designed to obtain a variety of rock types representative of stratigraphic units. Trenching and coring was expected to indicate the thickness of near-surface units; special samples from the top and bottom of large boulders and from the soil beneath such boulders might provide an exact date of the South Ray impact. Photographs of secondary craters and the boulders that formed them would indicate azimuths toward the source.

The objectives of station 9 required a mature regolith surface, free of recent contamination by ejecta from fresh young craters. The station location had to be selected by the crew as they traveled, although the general area was delimited prior to the mission. The primary purpose of this station was to study the surface of the regolith visible in photographs and telescopes and analyzed by nonpenetrating geochemical and geophysical devices. The station had to be in a patch of Cayley Formation of "typical" or "average" albedo such that the data could be extrapolated regionally. A series of successively deeper samples were to be collected to determine the nature of the regolith. Samplers were designed to collect uppermost layers of surface grains, and a surface skim sample was to be collected, as well as a deeper scoop sample directly under the skim. A special vacuum-sealed short core was designed to protect the most pristine sample yet returned from the Moon, and several padded bags were included to preserve fragment surfaces (see Horz and others, 1972, for details).

A very readable booklet on details of premission planning for various surface and orbital experiments and hardware aboard the Apollo 16 mission was written by Simmons (1972).

THE MISSION

Several mechanical and operational problems arose during the mission that prevented exact execution of the premission plans. Because a mechanical problem developed in the CSM engine, the lunar landing was delayed for three revolutions, or nearly 5 hours. This delay changed the mission plans. To keep the astronauts' work day within acceptable medical limitations, a sleep period was assigned first upon landing instead of an immediate EVA. This change precluded observing the flanks of Stone mountain for lineaments like those seen on Mount Hadley at the Apollo 15 landing site. The second of two planned telephoto panoramas to be taken during EVA- 1 for stereo study of Stone mountain was cancelled because of lack of time and was taken instead at the start of EVA-3. This panorama, taken at high sun angle, shows no shadow, lineaments.

During EVA-2 (fig. 5), problems with the LRV navigation system, a lack of landmarks, and difficult trafficability combined to stop the astronauts short of the prime goal near Cinco e. In order to preserve the schedule at station 8 and 9 and to keep enough time at station 10 to do the preplanned tasks and, if required, to remove the broken cable on the Heat Flow Experiment, station 7 was cancelled. This station, planned for 15-minutes duration, was intended for sampling of a

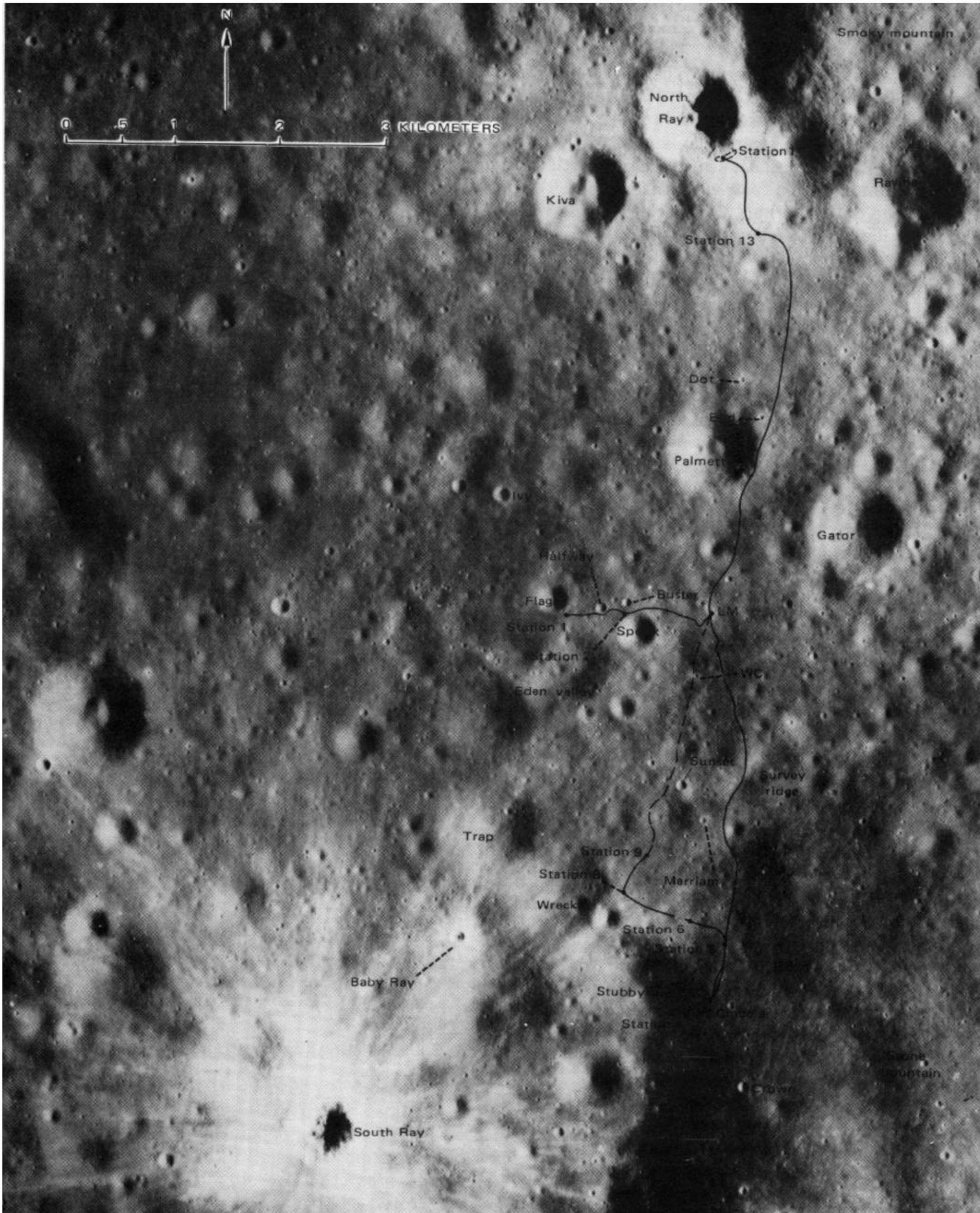

FIGURE 5.-Actual traverses. Apollo 16 panoramic-camera frame 4618.

fresh crater near the mapped Descartes-Cayley contact and a telephoto survey of Smoky mountain and the interior of Stubby crater.

EVA-3 was shortened from 7 to 5 hours when it was decided to lift off from the lunar surface at the preplanned time rather than extend the lunar surface stay and risk problems with nearly depleted LM systems. All activities other than those scheduled for North Ray crater were cancelled. The astronauts drove the LRV to the rim of the crater without difficulty, allowing time for nearly all of the preplanned tasks for stations 11 and 12 to be accomplished. The near-field polarimetric survey was cancelled and a second abbreviated telephoto panorama into North Ray crater was taken from near House rock. The operational aspects of the mission are described in the Apollo 16 preliminary science report (Baldwin, 1972). Despite exigencies that developed through the mission, all of the primary geologic tasks were carried out: sampling of the Cayley plains, of ejecta from North Ray and South Ray craters, and of materials from Stone mountain, representative of the Descartes mountains; photographic coverage of all sampling areas, the entire traverse route, and telephoto views of all important points remote from the traverse route.

HINDSIGHT

Photogeologic interpretations for this mission were hampered by the low resolution of the best available premission photographs. As it turned out, nearly all the large blocks (5 m or larger) had been located (Boudette and others, 1972), but because the announced resolution of the photographs was 5 m or poorer, it was not certain whether features at or near the limit of resolution were real or simply artifacts of photoprocessing. The number of boulders identified and the blockiness predicted from radar studies of the site convinced us that travel through the rays from both South Ray and North Ray craters would be difficult if not impossible. The virtual absence of rocks on North Ray, except for those identified before the mission, was startling. Had the spacing of blocks on South Ray rays been known, the mission might have been designed differently: an alternative considered was a dash to Stone mountain along with deployment of the ALSEP on EVA-l, followed by EVA's to South Ray and Baby Ray craters, and then to North Ray crater. Better geologic data from the youngest crater rims could have helped immeasurably to determine the nature of the Cayley Formation, its composition, and stratigraphic makeup. Data from a fresher or larger crater on Stone mountain, remote from South Ray crater ejecta, could have better defined the character of the materials composing the Descartes mountains.

Certainly if we had better understood, before the mission, the enormity of the events forming the Imbrium and Orientale basins and the potential extent of their ejecta, we would have considered geologic alternatives to the volcanic interpretation of the units at the Apollo 16 site. The geologic field training might thus have been different, many of the special sampling experiments might never have been scheduled for this mission, and as a result, the time available for geologic traverses would have been allocated differently.