UNITED STATES
DEPARTMENT OF THE INTERIOR
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INTERAGENCY REPORT: ASTROGEOLOGY 26

GEOLOGIC MAPPING ON VERY STEEP SLOPES USING TERRESTRIAL PHOTOGRAMMETRIC METHODS

By

Maurice J. Grolier, Sherman S.C. Wu, and
Francis J. Schafer

February 1971

Prepared under NASA Contract no. T-65253G

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Abstract

Terrestrial photogrammetric techniques are applied to topographic and geologic mapping of test sites at Wallula Gap, and other localities in the state of Washington. Wallula Gap, the main test site, is a water gap on the Columbia River 20 km. southeast of Pasco, Washington. The walls of the Gap are occupied by a sequence of congealed basaltic lava flows, partly covered by surficial debris. The bedrock units exposed here are typical of those underlying the Columbia plateau in large parts of the states of Washington, Oregon, and Idaho. In many respects they may also closely resemble the mare materials that occupy large parts of the lunar surface. The test area is therefore a suitable terrestrial analog of Hadley Rille near the Apennine-Hadley landing site of the Apollo 15 lunar mission. Problems in photometry, photogrammetry, and photographic targetting as they relate to the geologic analysis of the Apennine-Hadley landing site are reviewed.

Introduction

Many field situations, notably inaccessibility, prevent the geologist from making an on-the-spot examination of the terrain. Another problem frequently faced by geologists working in rugged terrain is that of delineating geologic contacts and structures on aerial photographs or topographic maps in areas of steep slopes or cliffs. In many instances both of these problems can be overcome through terrestrial photogrammetric techniques which make use of photographs taken with cameras located on or near the ground.

This paper describes geologic mapping from large scale terrestrial photographs taken at sites where topographic and geologic conditions are believed to simulate those that may be encountered at Hadley Rille. Five sites (figure 1) were selected

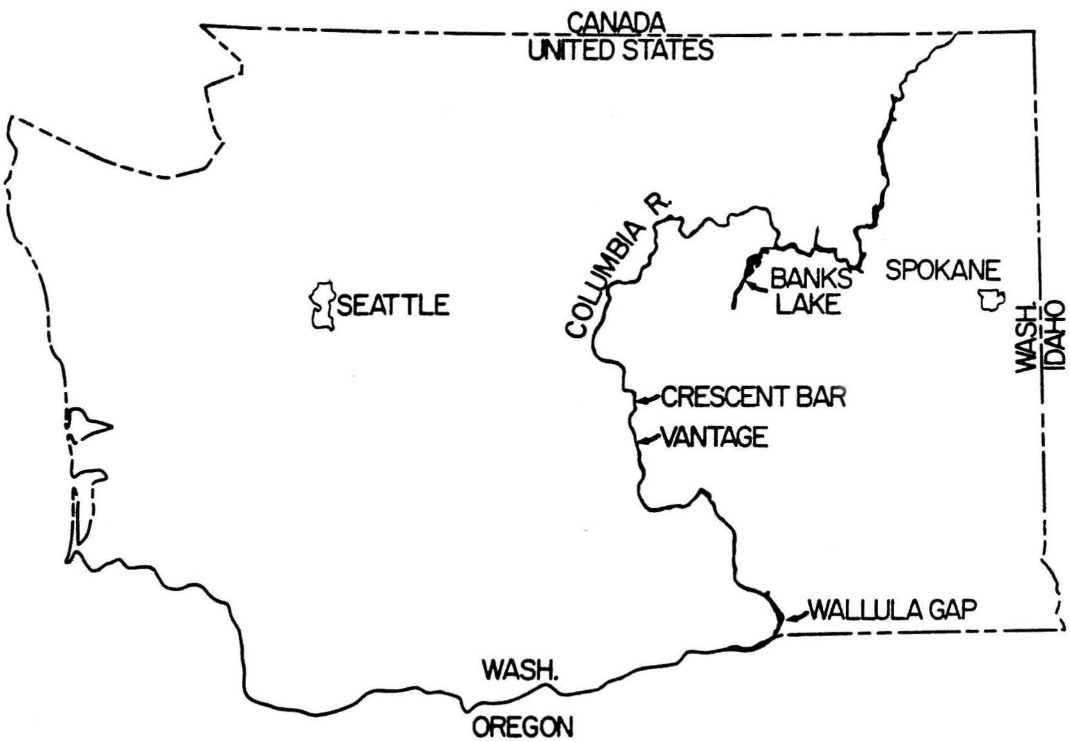

Figure 1.--State of Washington showing location of test sites along the Columbia River.

for study in the Columbia Plateau--a vast area of flood basalt occupying thousands of square miles in the states of Washington, Oregon, and Idaho. The sites are in the canyon of the Columbia River or in coulees marking earlier courses of the ancestrial Columbia River during Pleistocene time.

The basalt of the Columbia Plateau is composed of many layers of congealed lava flows or lava lakes, having an aggregate thickness of 2000 to 3000 feet. With respect to gross chemical composition, and possibly the lateral extent and thickness of flow units, flood basalts of this area are similar to materials filling the large mare basins on the Moon. In most of the Plateau the basalt is concealed under a few meters of volcanic ash, glacio-fluvial sand and gravel, or talus. This cover of debris to some extent simulates the regolith on the lunar surface. The largest areas of outcrop are in the steep, generally inaccessible canyon and coulee walls. In this respect too the geologic conditions simulate those that are anticipated at the Hadley site, where most large exposures of bedrock may be restricted to the walls of Hadley Rille.

Acknowledgments

Besides the authors shown on the title page, other persons from the Center of Astrogeology have directly contributed to this report. J.D. Crossen did much of the field work and surveying with F.J. Schafer. G.M. Nakata compiled the topographic map of the west wall of Wallula Gap and plotted the geologic overlay with the aid of M.J. Grolier. R.M. Jordan plotted the vertical profiles, and provided valuable suggestions toward alternate methods for survey-

ing steep canyon walls. All photogrammetrists in the section went beyond strictly photogrammetric tasks by helping to plot geologic information on the topographic map.

Rationale

In lunar exploration most topographic maps have been compiled from orbital photography, but with the recent advent of manned exploration of the lunar surface, terrestrial photogrammetry has been used by photogrammetrists to prepare topographic maps with photographs taken by hand-held cameras at the Apollo landing sites. Terrestrial photogrammetry appears particularly suitable for preparing post-mission maps of the Apollo 15 landing site near Hadley Rille, and for other rugged areas such as, for example, the central peak of the crater Copernicus. Hadley Rille itself and the highlands nearby have very steep slopes which will be inaccessible to the astronauts. The relief between the mare surface where the landing will occur and Hadley, a towering peak in the highlands nearby, is comparable to the relief in the European Alps on Earth. The rocks exposed in the walls of Hadley Rille may be typical of the upper part of the lunar crust there, and detailed geologic and topographic maps of such outcrops may be necessary for detailed stratigraphic analysis.

Earlier lunar mapping utilizing the terrestrial photogrammetric method

The photogrammetry section of the Center of Astrogeology has already gained considerable experience in the use of terrestrial photogrammetric techniques. Many special purpose lunar topographic maps were prepared using Surveyor images and ground level photographs taken during Apollo missions 11, 12, and 14.

The maps of the Surveyor landing sites were prepared by precisely locating many points of the lunar landscape with reference to the Surveyor camera. This procedure, called focus ranging, has been recently described by Shoemaker and others (1967). The elevations of these points below the lunar horizon are then determined by measuring the vertical angle between individual points and the horizon.

The hand-held photographs obtained during the first three Apollo landing sites were taken randomly through the LM window or while the astronauts traversed the lunar surface. This resulted in an almost infinite variety of angular orientations and base distances between photographs of stereoscopic pairs. Most of these unusual geometric conditions were overcome by use of the AP/C analytical plotter and a number of large scale maps were successfully prepared for detailed geologic and topographic analysis. (See following list.)

Topographic and geologic maps of Surveyor and Apollo 11, 12, and 14 landing sites prepared from Moon-based photography.

1. Maps of the Surveyor I, III, VI, and VII landing sites (Surveyor Investigator Team, 1968, figs. 3-16, 3-19, 3-24, and 3-26).
2. Map of the Apollo 11 landing site (Shoemaker and others, 1969, figure 3-8).
3. Unpublished special purpose topographic maps of the Apollo landing sites prepared by the U.S. Geological Survey.

Mission	Scale	Contour Interval	Date
11	1:15	5 mm	10/71
11	1:50	10 cm	8/69
12	1:25	5 cm	7/70
12	1:500	50 cm	3/70
14	1:10	5 cm	2/71
14	1:10	5 cm	2/71
14	1:20	1 cm	6/71
14	1:10	5 cm	4/71
14	1:10	5 cm	4/71
14	1:10	1 cm	4/71
14	1:10	1 cm	4/71
14	1:10	1 cm	4/71

Field work

Once the general area of the five geologic test sites (fig. 1) in the state of Washington was located on topographic quadrangles at a scale of 1:24,000, (see fig. 2 as an example of one such site) the canyon walls and coulee slopes to be photographed were exactly identified by the field crew. Field crews consisted of one surveyor and his assistant, and one geologist to provide stratigraphic expertise and to collect basalt samples. Substantial geologic investigations were conducted only at the Wallula Gap site.

Advance planning was carried out in the office to reduce the time spent in the field by the surveyors and geologists. The areas to be photographed were selected so that the photographic base lines could be measured in the least amount of time and with the least amount of physical effort. The base lines were selected in nearly level or gently sloping terrain, adjacent to roads and easily accessible, and the lengths of the base lines were determined from the standard condition that the base be longer than one fifteenth (1/15), but shorter than one fourth (1/4) of the distance between it and the scene to be photographed. The lengths of the base lines plotted on the topographic maps ranged from 350 to 2,000 feet. Existing horizontal and vertical geodetic ground control markers were noted where they could be sighted. Anticipating that some of the base lines might have to be relocated in the field, templets (fig. 3) showing the camera field of view were made as transparent plastic overlays to fit the 1:24,000 scale topographic quadrangles. These templets permitted field personnel to determine rapidly the area of stereographic coverage necessary for an adequate bridging of models.

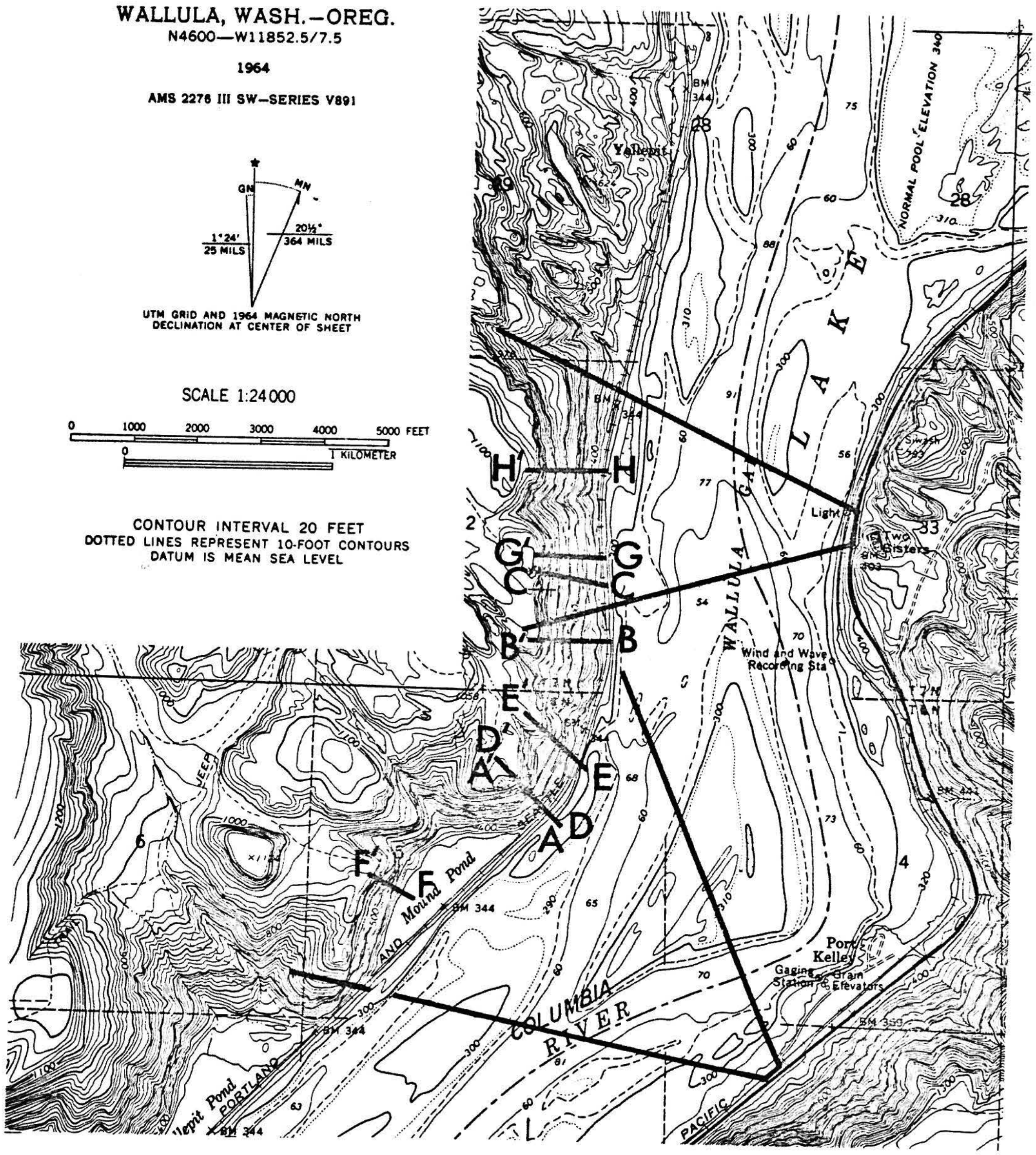

Figure 2.--The Wallula Gap test site. Part of the U.S. Geological Survey topographic quadrangle map, Wallula, Washington-Oregon. Scale as reproduced here is approximately 1:35,000. Heavy lines without letters show field of coverage of phototheodolite pictures taken from east side of gorge during the field test, and lettered heavy lines show lines of section along which topographic profiles were constructed.

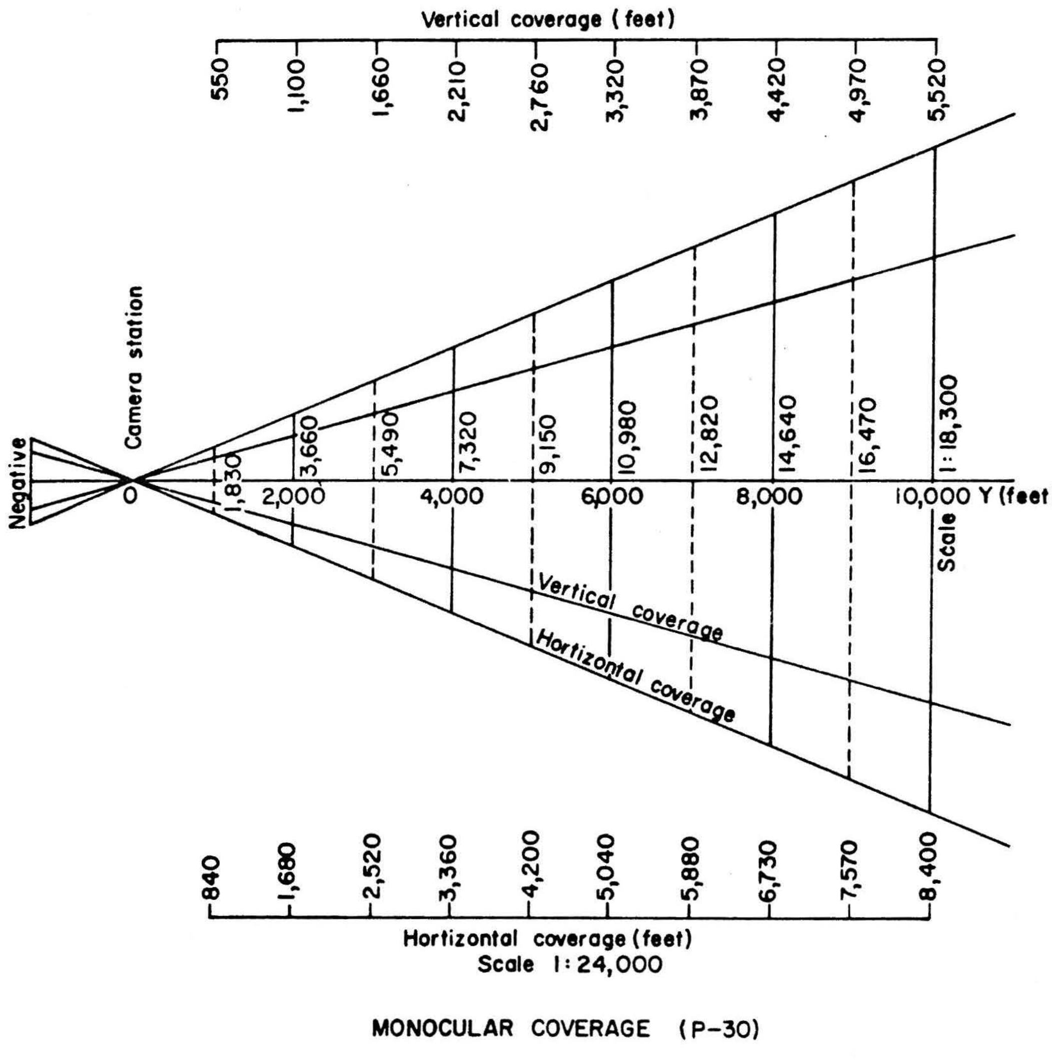

Figure 3.--Templet used during field tests for showing field of view of the Wild P-30 phototheodolite camera.

To obtain maximum stereoscopic overlap, the necessary orientation angles, between the normal to the base line and the camera optical axis, were computed for each camera station. Orthographic maps can easily be compiled from models at 45 degrees from the normal, but under most working conditions the practical limit appears to be 30 degrees, because, at larger angles from the normal, lines of sight are lost and topographic detail concealed. The above procedure permitted accurate determination of the number of photographic glass plates that would be used.

At each test site, the time of day at which the scene could be best photographed was determined by on-site examination, as was the orientation of the camera in relation to the scene to be photographed. The altitude and orientation of the canyon walls at the Wallula Gap test site are grossly similar to those at Hadley Rille on the Moon. Because of the low albedo of basalt, maximum topographic detail is obtained when sunlight strikes a steep, north-trending cliff at a relatively low angle, and when shadows therefore are few. At Wallula Gap these conditions are fulfilled when the sun is behind the camera (i.e., at 0 degree phase angle): early in the morning for the east-facing canyon wall, and late in the afternoon for the west-facing canyon wall. All five test sites were photographed in the period of June 11 - June 15, 1971, a time of the year when the height of the sun near the 45-degree latitude on Earth (latitude of Wallula Gap: 46° 2' 30" N) exceeds 45-degrees between 9:00 AM and 3:00 PM local time (Romanova, 1964, p. 150).

At each of the five test sites, the base line was measured twice with a 500 ft. tape, an operation that required from one fourth (1/4) to one half (1/2) of the total time spent in field work. All horizontal angles were measured at each end of the camera base by sighting with the phototheodolite along the base line. The height of the camera above ground was measured at each camera station at the ends of the base line, and a vertical angle measured at each camera station at the ends of the base line, and a vertical angle measured from one end of the base line to the other. Horizontal and vertical angles were also measured to a few spot locations consisting of prominent geologic index layers, such as top and bottom of lava flows, in order to obtain photogrammetric control on the thickness of individual flows, and apparent dips. The locations of these geologic features were marked on Polaroid photographs taken near each camera station.

Preparation of maps and profiles

One model of the Wallula Gap test site was tested in the analytical plotter (AP/C). The photographs had been taken with the optical axis at 90-degrees with respect to the plumb line, and unfortunately, the absolute orientation (the tilt angle, ω, equal to 90-degrees) could not be exactly recovered. This limitation probably is due to a shortcoming in the computer program of the plotter, in that it is not able to handle a 90-degree tilt angle. Therefore, any terrestrial photography taken for the purpose of compiling topographic maps or profiling on the AP/C plotter should be taken with the optical axis depressed at least five (5) degrees from the horizontal. On the other hand it is possible that the existing computer program can be modified to accept a 90-degree tilt angle.

A large-scale topographic base map (fig. 4) was, however, successfully compiled from the same stereoscopic model by use of a Wild A-5 universal plotter. Upon completion of the base maps, while the model was still set up in the plotter, recognizable geologic contacts were superposed on the topographic relief. The geologic units were defined and the contacts were drawn on the basis of topographic expression, albedo differences, and by reference to the Polaroid photographs with geologic annotations that were obtained during the field test. The formal names assigned to the units were based on correlations made by the geologist during earlier reconnaissance mapping studies. The units recognized at Wallula Gap are shown in figs. 9 and 10, which are typical of the phototheodolite pictures used in the A-5 plotter for preparing the map.

In addition, vertical profiles were compiled, but in a less direct manner. Point-by-point coordinates from the A-5 plotter were processed onto punched cards by computer and the cards fed to an X-Y-Z plotter which produced the profiles (figs. 5, 6, 7, 8). The lines of section along which the profiles extend are shown in fig. 4. The geologic contacts shown in the profiles correspond exactly with those shown on the geologic maps. Additional information on the techniques used for compiling the maps and profiles described here is included in Appendix A.

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Topography was compiled on a Wild A-5 Universal Plotter by G. Nakata, from photography taken with a Wild P30 phototheodolite with a focal length of 166.506mm.
Geology by M. Grolier, G. Nakata, and R. Jordan, 1971.

SCALE 1:2500

0 500 1000 2000 FEET

0 100 200 300 400 500 600 METERS

CONTOUR INTERVAL 4 METERS

WALLULA GAP, WASHINGTON

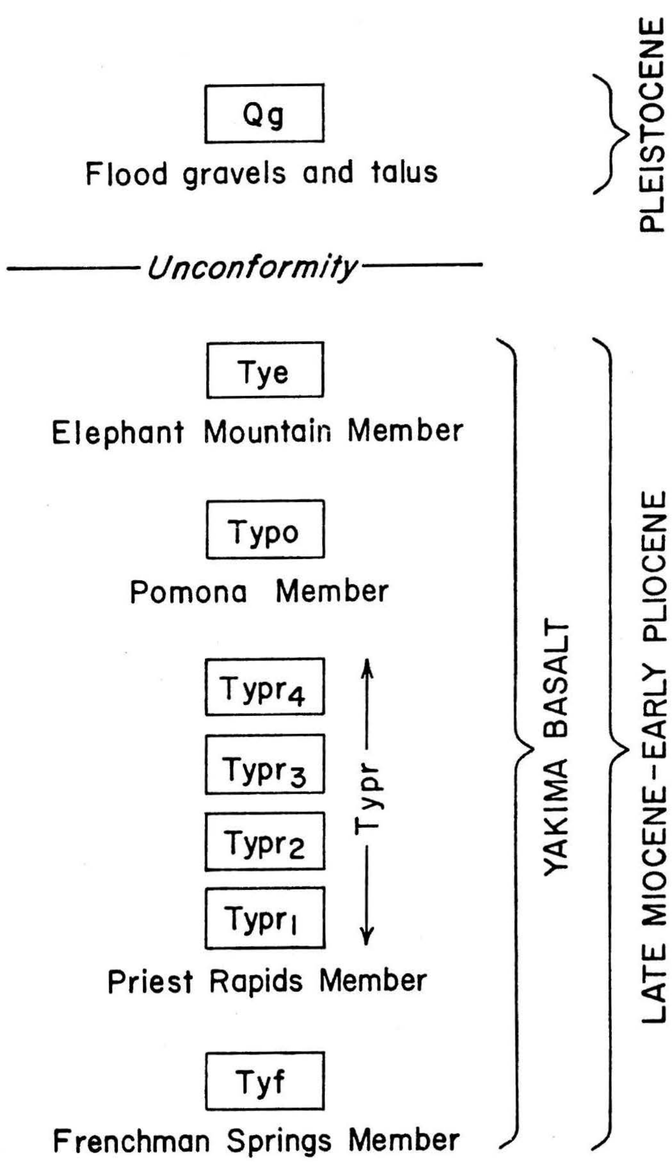

Figure 4b.--Skeletonized explanation of geologic units shown on map (Figure 4a). Units are described briefly in accompanying text.

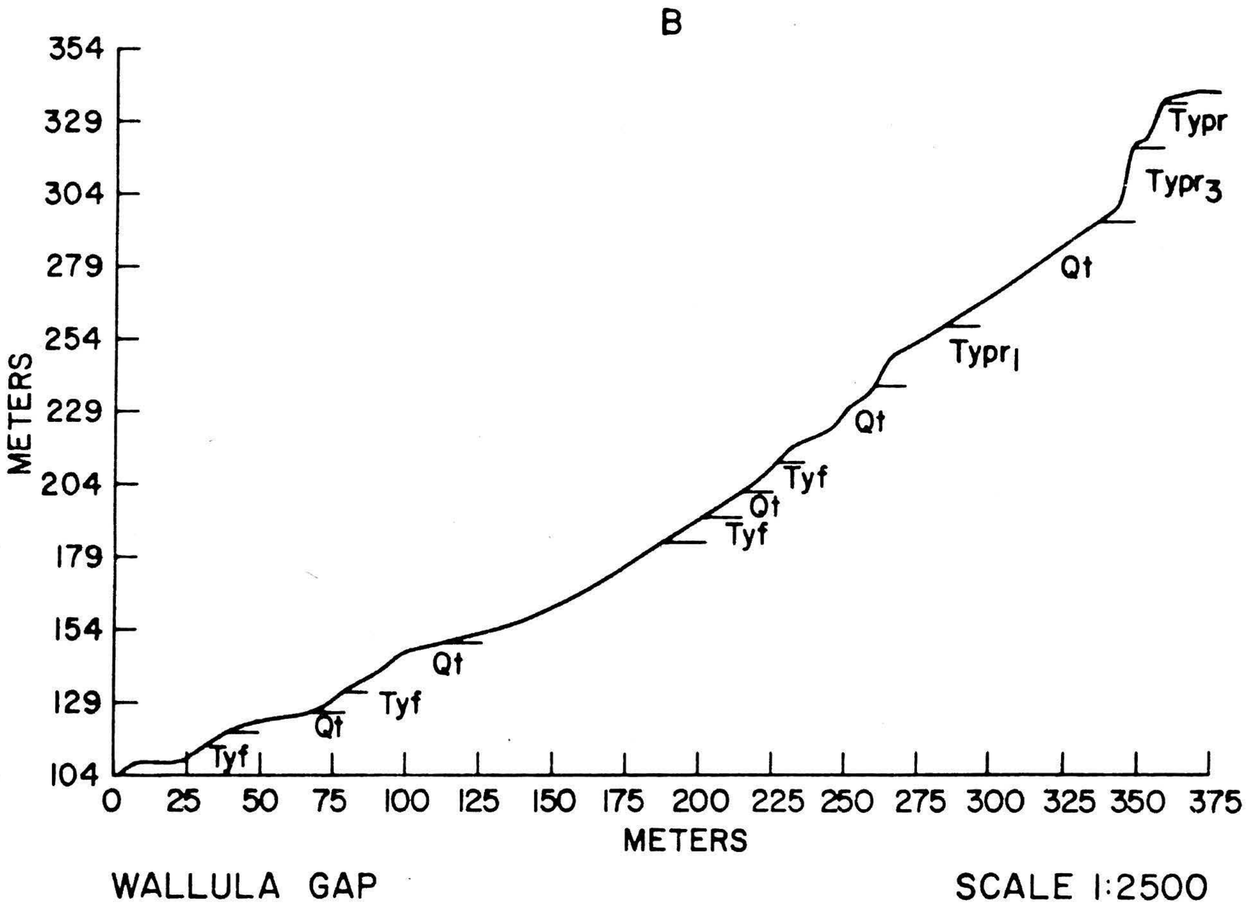

Figure 5.--Topographic-geologic profile along line of section B-B' of figure 4.

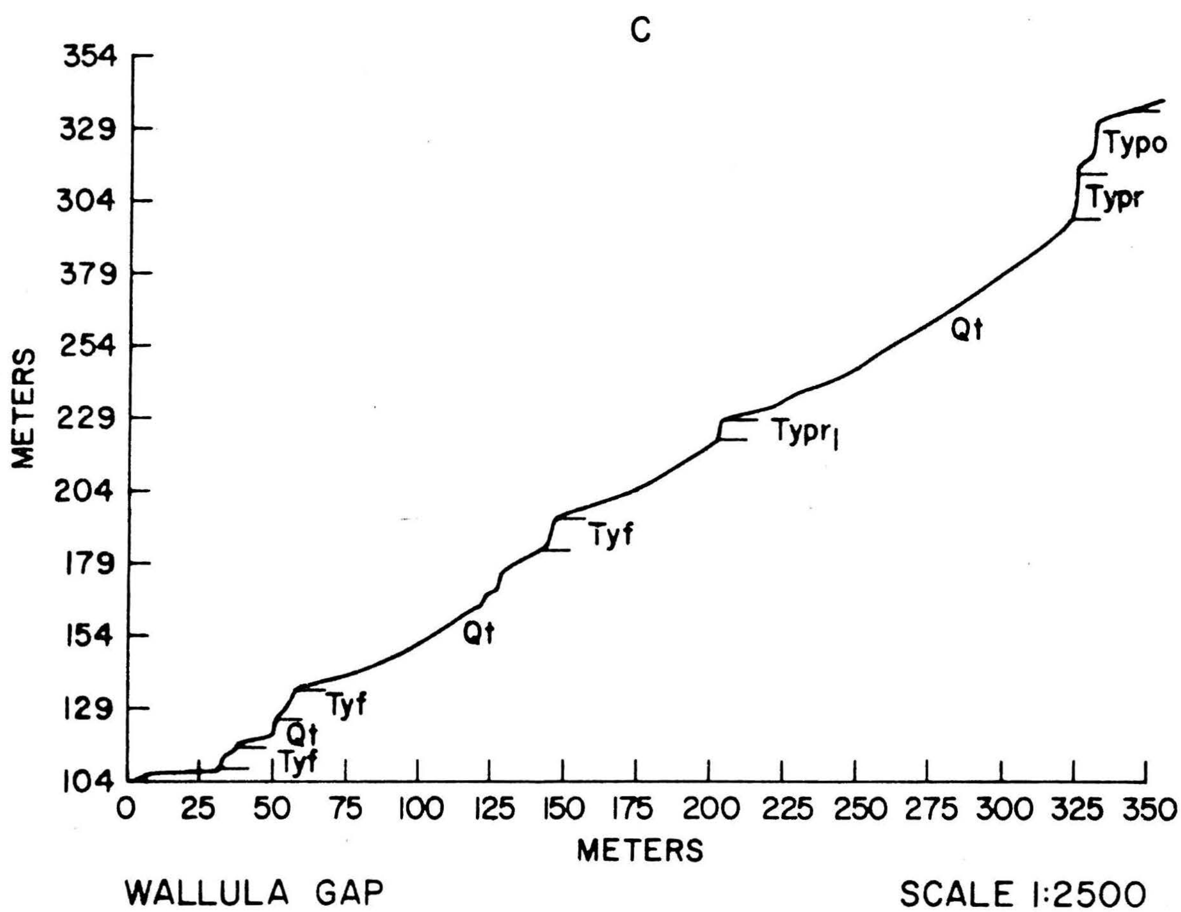

Figure 6.--Topographic-geologic profile along line of section C-C' of figure 4.

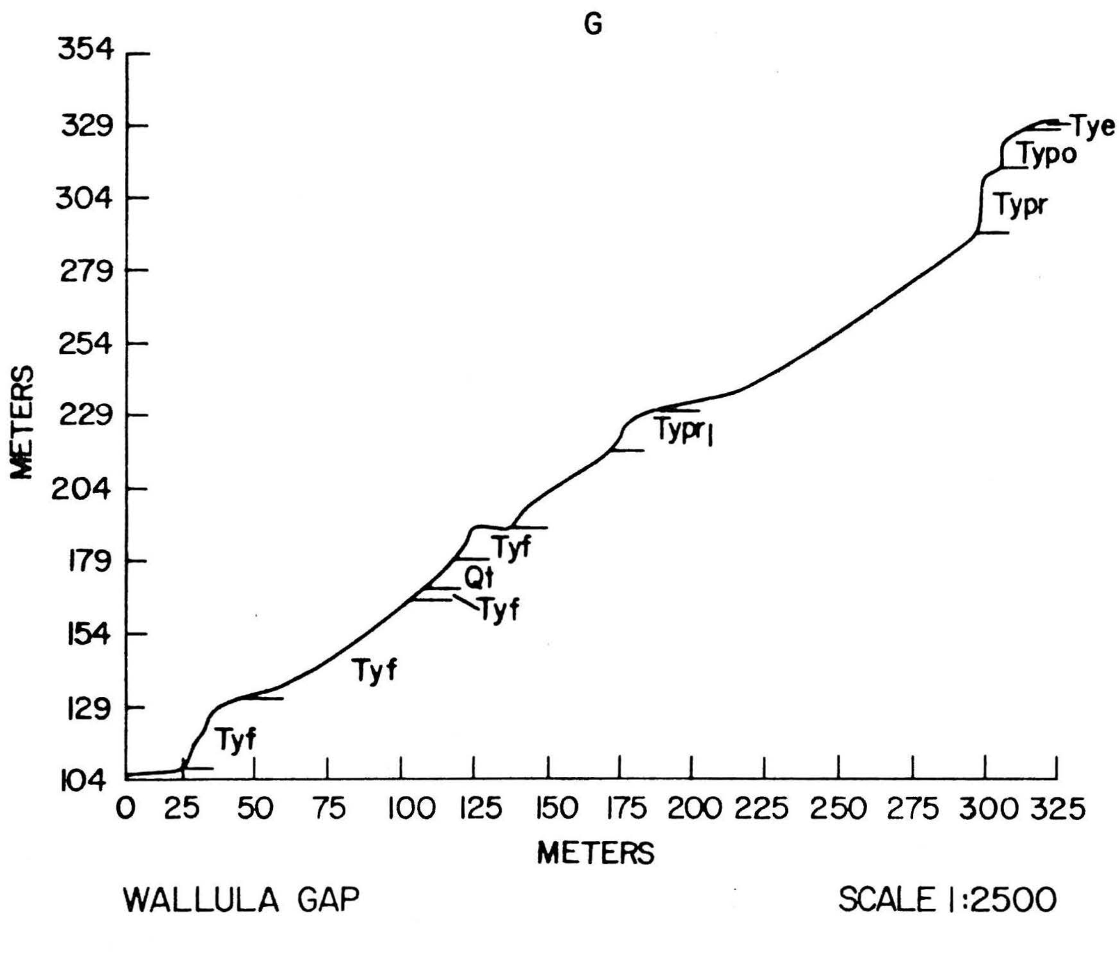

Figure 7.--Topographic-geologic profile along line of section G-G' of figure 4.

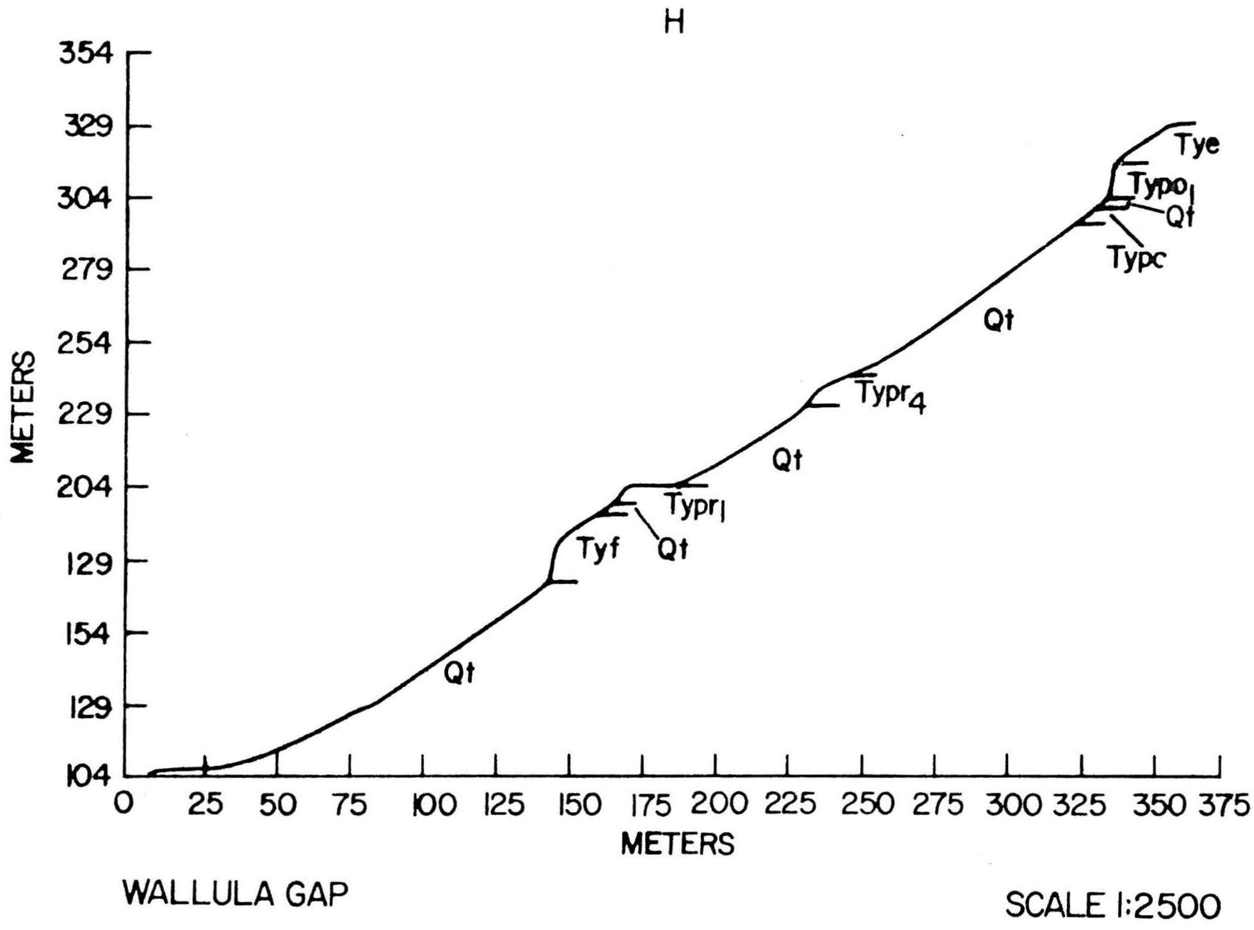

Figure 8.--Topographic-geologic profile along line of section H-H' of figure 4.

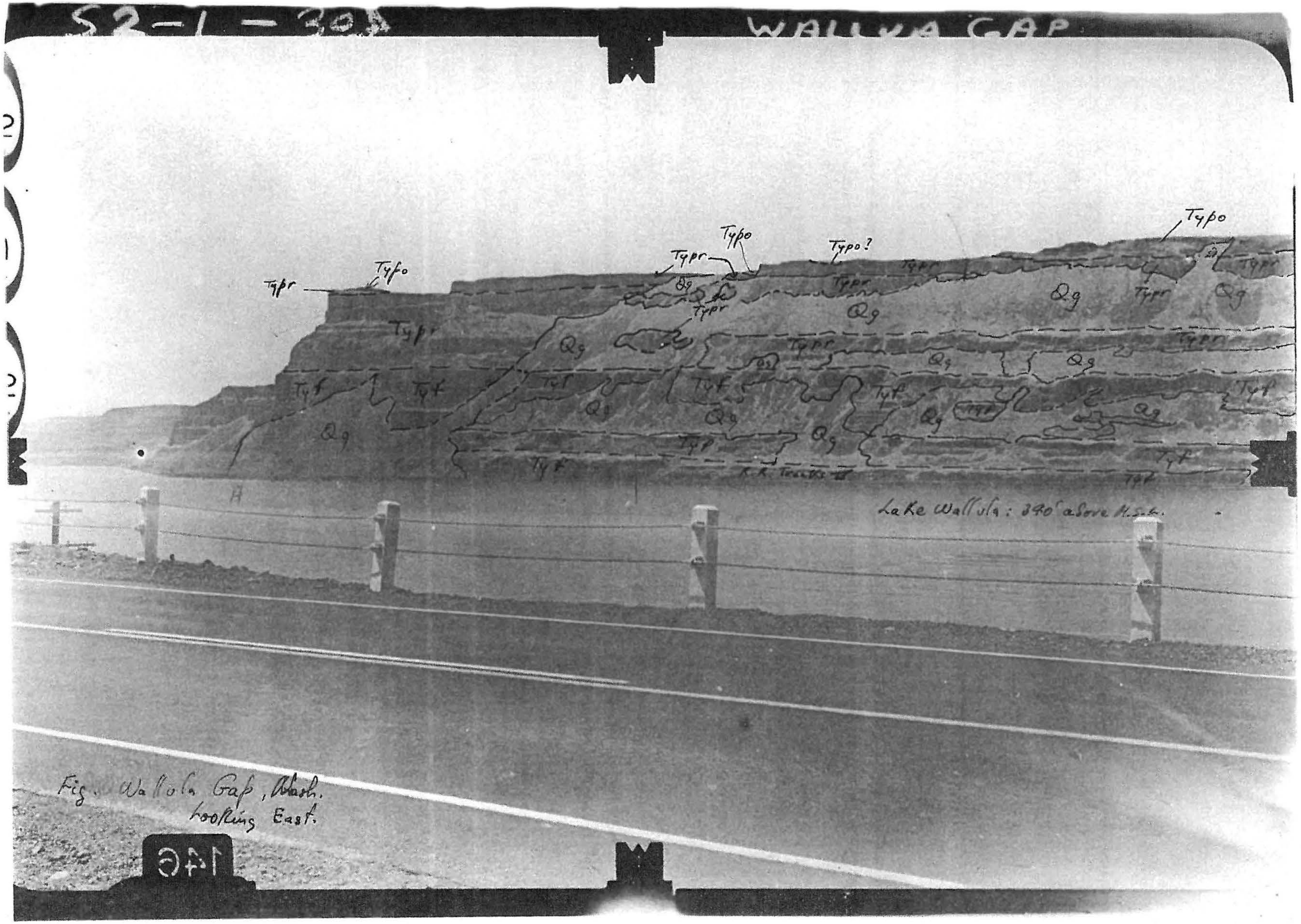

Figure 9.--Phototheodolite view of southern part of west bank of Columbia River gorge at Wallula Gap. Recognizable geologic units sketched in and identified by symbols.

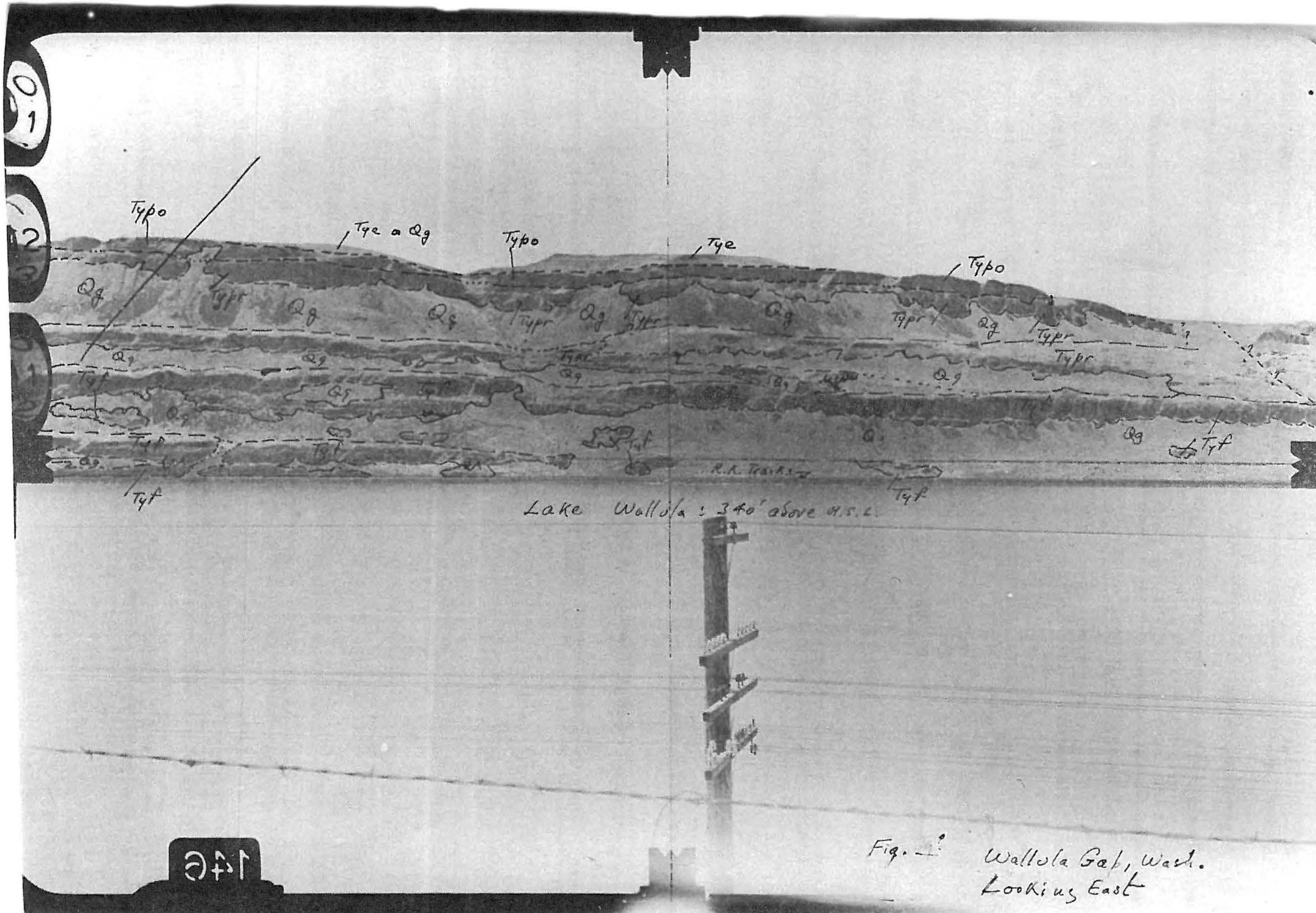

Figure 10.--Phototheodolite view of northern part of west bank of Columbia River gorge at Wallula Gap. This view overlaps with figure 9.

Geology

Processes of extrusion, the regional geologic setting, detailed chemical similar composition and texture certainly are different for terrestrial flood basalts, of the Columbia Plateau (and other areas of the world) than for the basalts that partly fill the lunar maria (Mason and Melson, 1970). Nevertheless, similarities in the volumes of molten rock extruded, the area extent of the extrusions, their horizontality, and grossly similar chemical composition suggest that terrestrial flood basalts will serve as suitable analogs to the mare materials of the lunar basins.

The Columbia Plateau, in the states of Washington, Oregon, and Idaho is underlain by extensive sheets of flood basalt, individually 15 to 30 meters thick and hundreds of kilometers in extent. The flood basalts have an aggregate thickness exceeding 2,000 meters in the center of the lava field. The lava flows were extruded in late Miocene and early Pliocene time, although some groups of flows in the eastern part of the lava field in Oregon and Idaho may be much older.

Stratigraphically the Columbia Plateau consists of a succession of basalt flows, grouped into two formations: The older Picture Gorge Formation and the younger Yakima Basalt (Waters, 1961, p. 588-591). While these two units have been mapped over large areas, relatively little detailed stratigraphy has been done at the level of individual flow units.

At Wallula Gap, only the upper part of the Yakima Basalt is exposed, perhaps no more than the upper tenth of its total thickness. The members recognized at this locality are rock-stratigraphic units, chosen so that they will correspond to magnetic units. Accordingly, two of them, the Frenchman's Springs and the Priest Rapids consist of more than one flow. The field identification of individual flows (and flow units) in the Yakima requires the identification in the field of interflow contacts, some of which may be welded. Individual flows commonly are vesicular near their tops and bottoms and dense in the center. Chemical weathering through circulating ground water, sub-aerial weathering, phenomena that developed before deposition of the overlaying flow, as well as late chemical alteration when the flow was cooling, may be present along flow contacts. Prominent nearby horizontal platforms at the top of some flows commonly denote the presence of soft, easily eroded tuffaceous or diatomaceous sandstone beds interbedded between lava flows.

The field identification of the groups of flows or flow units that make up a member of the Yakima Basalt requires an evaluation of characteristics such as stratigraphic position, thickness, and color; the number, size, and types of phenocrysts; the size and shape of vesicles; texture, grain size, and jointing habit. The refractive index of glass beads and chemical analyses also are often diagnostic and may help identify groups of flows (Waters, 1961). The various members of the Yakima Basalt have been identified by these characteristics by Laval (1956), Mackin (1961), Waters (1961), Grolier (1965), Bingham and Grolier (1966), and Schmincke (1967). From oldest to youngest the units mapped are characterized most briefly by the following criteria: 1) The Frenchman's Springs member is porphyritic. 2) The Priest Rapids member is uniformly medium grained and non-porphyritic. The Pomona member is also non-porphyritic, but contains abundant olivine in grains coarse enough to be seen by the naked eye. The Elephant Mountain member is also non-porphyritic but lacks olivine. The stratigraphic sequence recognized and mapped is shown schematically in figure 4b.

Manned photographic exploration of Hadley Rille and environs

The projected Apollo 15 landing site is located about 1.55 km northeast of Hadley Rille in an embayment of Mare Imbrium along the western front of the Apennine Mountains (fig. 11). The landing site is situated on mare material between the rille to the east and the mountain from to the south and east.

Hadley Rille originates at an irregular, elongate crater at the contact between mare and highland about 54.5 km southwest of the landing site. The rille follows a sinuous northward course, sub-parallel to the mountain front. It gradually decreases in width and depth with increasing distance northward from its point of origin. The course of the rille consists of many reaches (or stretches) changing orientation abruptly. In the vicinity of the landing site, the rille is about 1.5 km wide and 400 m deep. Its walls slope downward from surface of Mare Imbrium to the floor below at an angle of approximately 28 degrees.

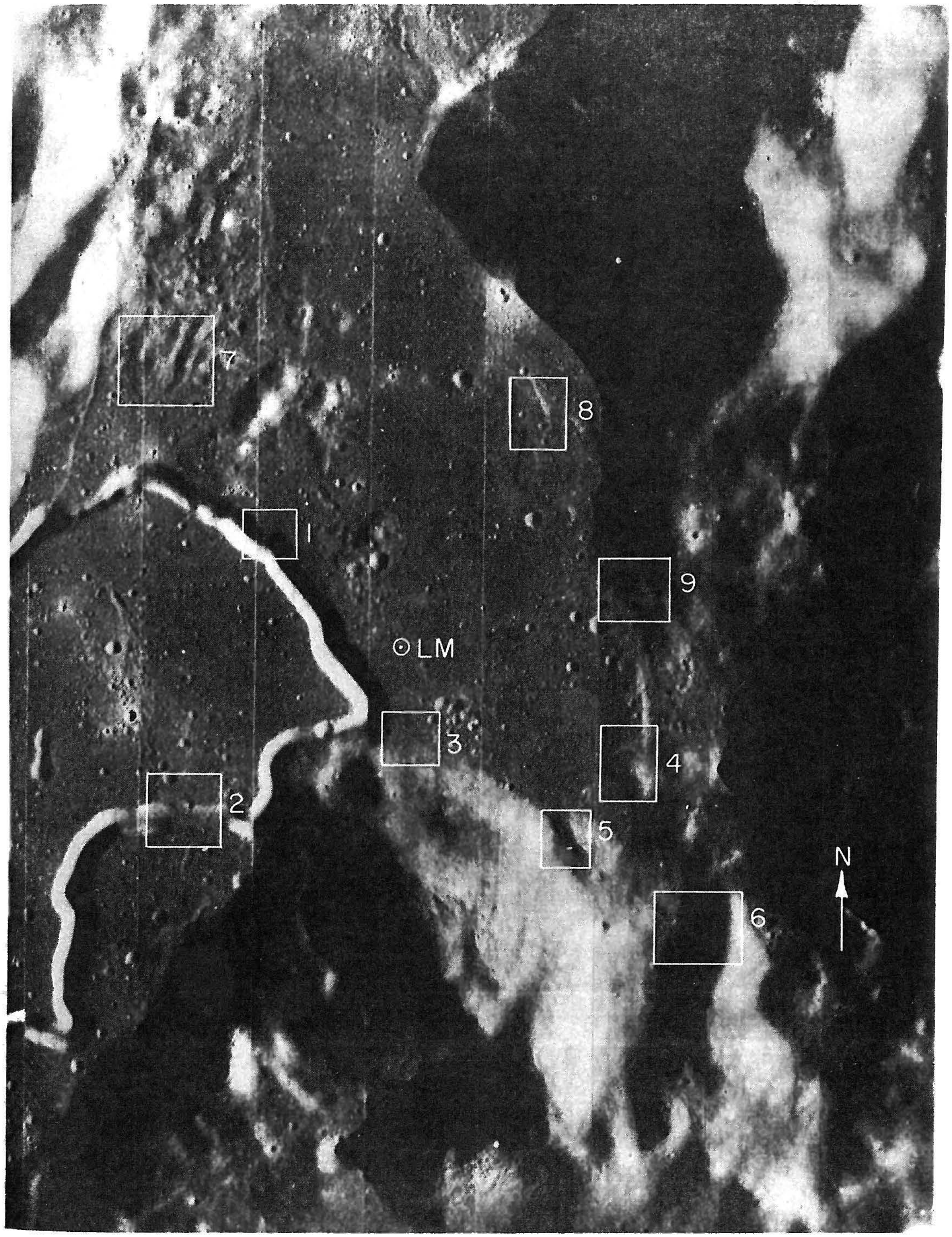

Figure 11.--The Apennine-Hadley landing site. Designated landing marked by symbol at LM. Hadley Rille is the sinuous gorge in left-center of picture. Apennine Mountains occupy southern and easternparts. Numbered rectangles show photographic targets discussed later in this report.

In order to compile topographic maps from surface-based photography, both camera interior and exterior orientations must be known, as explained earlier in this report. The interior orientation of the camera is determined during camera calibration tests. The exterior camera orientation requires a precisely known stereo-base (distance between camera stations), and also the angular orientation of the camera optical axis with respect to that base. The method does not require that ground control (XYZ) be established in the area or object to be mapped, but the accuracy of the map (both scale and contour interval) is directly affected by the accuracy with which the base line has been determined on the ground.

Orbital photographic coverage of the site and environs is planned from the orbiting command module, using a 500 mm F.L. Hasselblad camera, and a 610 mm F.L. Itek panoramic camera. Provided that the orbital altitude is low enough to yield sufficiently high resolution, the orbital stereoscopic photography may be used as a substitute for stereo-base measurements on the ground for determining scale. If ground measurements are made on the surface, orbital photography can, of course, also be used as a check against their accuracy.

In order to optimize the usefulness of orbital and surface-based photography for mapping purposes it is essential that prominent features along the horizon and also along the west rim of Hadley Rille be identified on orbital and surface-based photography. It is also essential that <u>both</u> the horizon and the rim of the rille be imaged on all surface-based photography. The angular field

(50°) of the 60 mm F.L. Hasselblad camera is large enough to image the entire height of the rille wall, even when the camera is held with the optical axis in the horizontal plane. The field of view of the 500 mm F.L. Hasselblad is only 3 degrees, and therefore it will be very difficult to obtain stereoscopic coverage with it. This shortcoming of the narrow angle lens can be overcome by imaging prominent objects that can be definitely identified at both ends of the camera base-line. Both the 60 mm and 500 mm F.L. cameras should be tilted at least 5 degrees from the horizontal to ensure that the AP/C analytical plotter can be used for compiling topography.

The traverses to be conducted during three successive EVA's after landing at the Apollo 15 site (figs. 12 and 13) have been defined in the Bellcom memorandum for file (Head, 1971, figs. 2 and 3). One traverse aboard a lunar roving vehicle (LRV) and one alternate walking traverse have been planned along or near the eastern edge of the rille. Each traverse has four stations offering panoramic views of the Hadley Rille, the mare surface and the Apennine mountain front to the north, south, and east. The detailed instructions for the astronauts to make geologic observations and to photograph features of interest are contained in the Bellcom memorandum referred to above. In this report, problems in viewing a few geologic features of major interest under varying illumination and field of view are being reviewed.

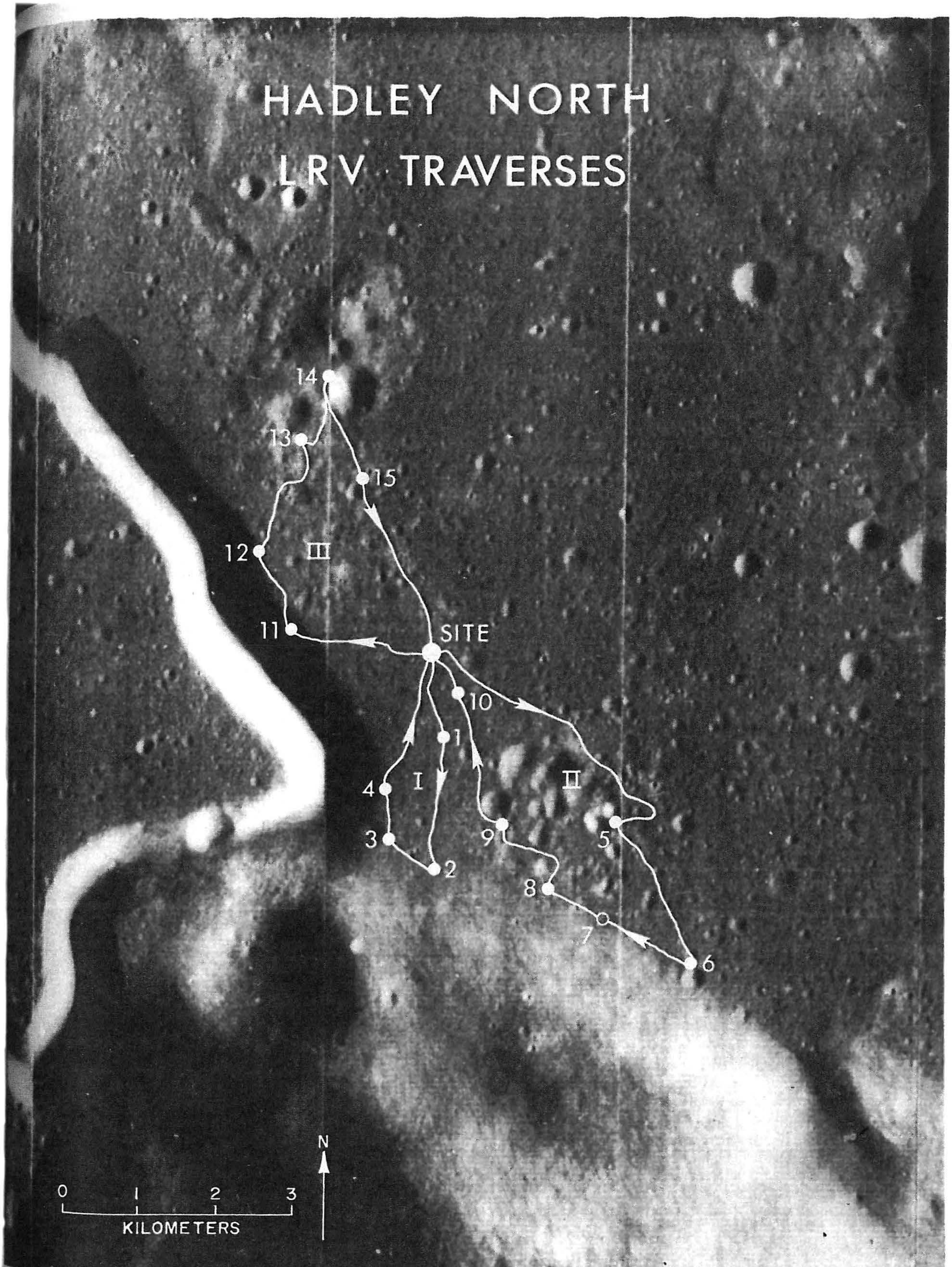

Figure 12.--Planned traverses to be made aboard the Lunar Roving Vehicle (LRV) from the Apennine-Hadley landing site. (From Head, 1971).

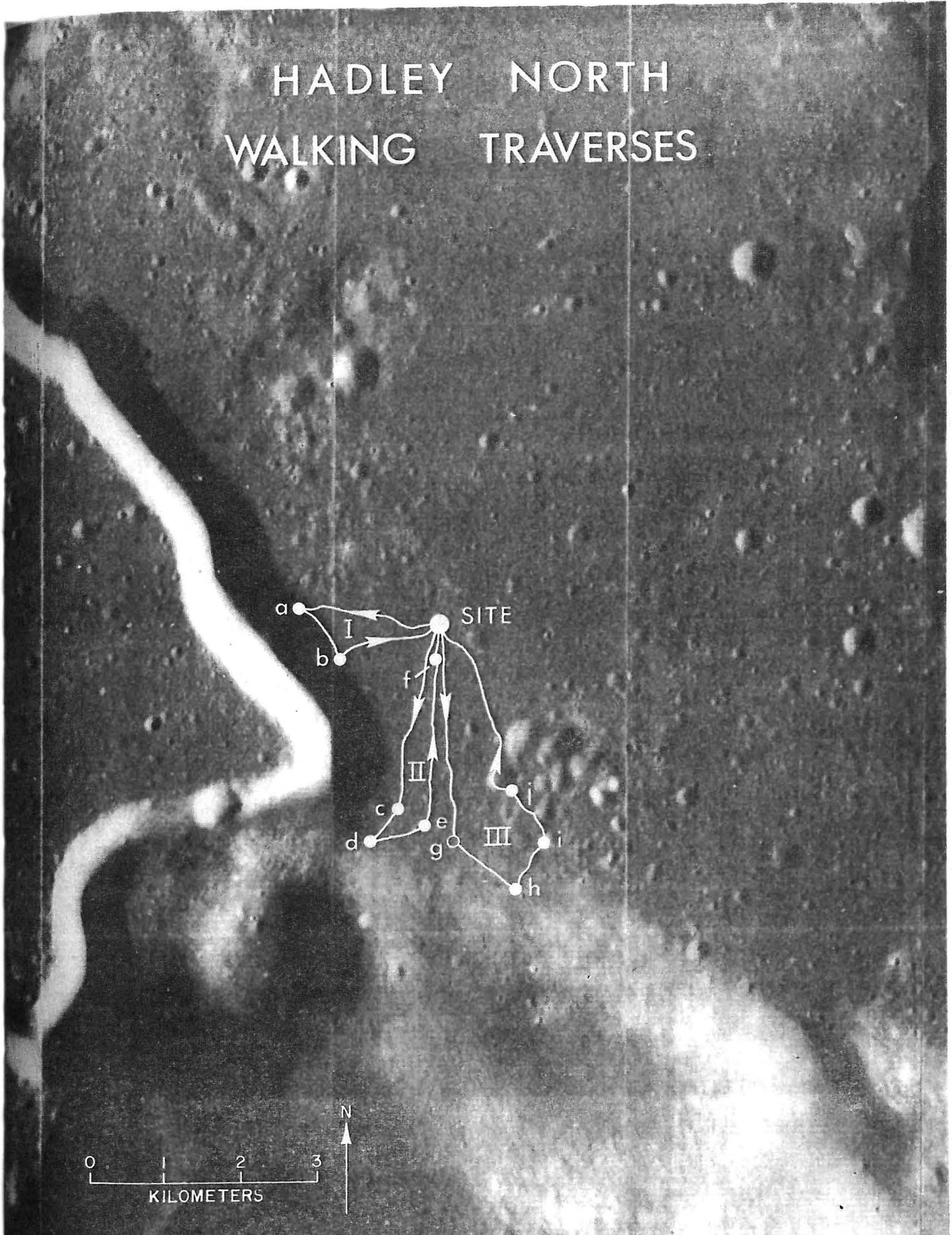

Figure 13.--Walking traverses planned for the Apennine-Hadley mission. (From Head, 1971).

The sun elevation above the horizon will be 12 $\pm$ 1/2 degree at the presently scheduled time of landing and will have increased to 47 degrees at time of take off two and one-half days later. The actual sun angles that will be encountered at stations along the LRV and walking traverse are reported in table 1 and 2, respectively so that areas in total darkness can be evaluated.

Topographic and geologic detail will not be visible in total darkness and unless the phase-angle is greater than 90 degrees, sunlit areas will back-scatter light toward the sun and very little topographic or geologic detail other than albedo differences will be detected. The penumbra, the transition zone between areas of total darkness and total illumination will provide the best area for photographing detail.

As the sun angle increases into the mission, viewing conditions for photographs will also improve with an increasing phase angle. At low sun angles, the least favorable direction to point the camera will be eastward where sunlight may impinge on the camera lens, and the west slope of the Apennine Mountain may be in total darkness. Unfavorable viewing conditions will also exist when the camera is pointed away from the sun because the sunlight will be back-scattered toward it and only albedo differences, if any, will be detected. The most favorable viewing conditions will occur when the phase angle exceeds 90 degrees. Even when pointing the camera northwestward from station number 3 (fig. 12), right down the longitudinal axis of the rille, the phase angle will not exceed 55 or 60 degrees assuming a 30-degree phase angle (or twice the value

Table 1.--Sun Elevations, LRV Traverses

Landing Stations	Time elapsed after touchdown	Sun Elevation (degrees)
LM (exit)	4:00	14.00
1	4:16	14.14
2	5:14	14.62
3	6:17	15.14
4	6:29	15.24
LM (return)	7:30	15.75
Rest	21:30	22.75
LM (exit)	22:08	23.07
5	23:26	23.72
6	24.47	24.39
7	25:31	24.75
8	26:06	25.05
9	27:01	25.51
10	27:37	25.81
LM (return)	28:30	26.25
Rest	42:30	33.25
LM (exit	43:08	33.57
11	44:05	34.04
12	44:38	34.34
13	45:30	34.75
14	46:39	35.33
15	47:15	35.63
LM (return)	48:30	36.25

Table 2.--Sun Elevations, Walking Traverses

Stations	Time elapsed after touchdown	Sun Elevation
LM (exit)	4:00	14:00
A	5:21	14.68
B	6:07	15.06
LM (return)	7:17	15.64
Rest	21:17	22.64
LM (exit)	21:55	22.96
C	23:31	23.75
D	24:44	24.37
E	25:32	24.77
F	26:31	25.25
LM (return)	27:25	25.71
Rest	41:25	32.71
LM (exit)	42:03	33.03
G	43:38	33.82
H	44:15	34.13
I	44:48	34.40
J	45:26	34.72
LM (return)	47:09	45.58

of the expected one). Under those conditions little topographic or geologic detail is to be expected on photographs of the rille, except along the penumbra and in areas illuminated by sunlight striking the surface at 10-12-degrees from the grazing angle.

At station 3 the expected sun angle will be 15.1-degrees (table 1). At this angle most of the rille is in total darkness but the upper part of the west wall is in sunlight over 75 percent of its length. Complete panoramic coverage of the rille wall with the 60 mm F L. camera should be taken between azimuths of about 260 degrees and 330 degrees. A total of eight (8) photographs at 10-degree intervals taken from this station will provide seven (7) stereoscopic models with 90 percent stereoscopic overlap. Should time and film be at a premium, four photographs taken at 20-degree intervals will yield three (3) stereoscopic models with 50 percent overlap.

From station 3 the shortest distance to the opposite or west wall is about 1,500 meters. To achieve the best stereoscopic geometry for the object viewed at this distance, the stereo-base should be from 100 to 375 meters. Such a base line, preferably parallel to the west wall could be paced, measured with an odometer on a LRV, or could be computed from a photograph taken at one end of the base-line of a known object (another astronaut, core tube, etc.) located at the other end of the base-line. The photographic foot print on the ground (or rather on an uncontrolled photo mosaic at a scale of 1:25,000) for both the 60 mm F.L. and 500 mm F.L. photographic coverage is shown in figure 14.

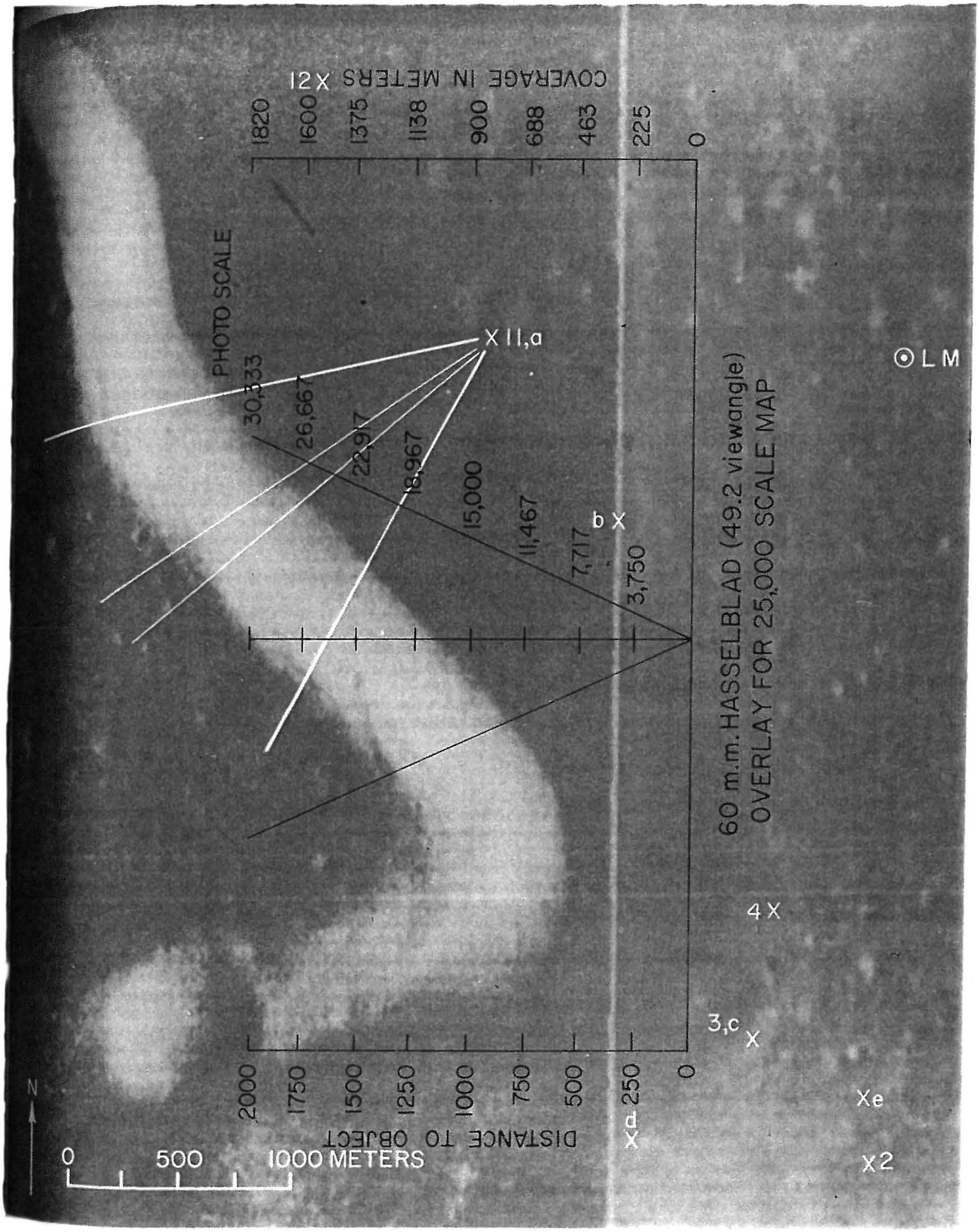

Figure 14.--Photographic foot prints (fields of coverage) of 60 mm and 500 mm F.L. hand-held cameras superposed on 1:25,000-scale photomosaic of part of the Apennine-Hadley landing site area. Numbers and letters, which mark location of stations along pre-planned LRV and walking traverses respectively, are from Head (1971).

The vertical angle between the horizon and the edge of the shadow area along the west wall of the rille, as subtended at station 3, is less than the half-field of view of the 60 mm F.L. camera. Therefore, the entire visible wall will be imaged even when the 60 mm F.L. camera is held horizontally. With the 500 mm F.L. camera, the half-field of view is only 3-degrees, and therefore prominent features such as boulders, spurs, penumbra line, etc., must be included in the field of view so that the area photographed can be located on the corresponding 60 mm F.L. photograph. In addition, the same prominent features must be photographed with the 500 mm F.L. camera at both ends of the base-line in order to obtain stereoscopic coverage.

The scale of the photographs taken of the nearest part of the far wall with the 60 mm F.L. camera will be approximately 1:25,000; the 500 mm F.L. camera will yield photographs of the same area at a scale of 1:3,000. The field test conducted at Wallula Gap, Washington indicated that with photographs at a scale of 1:25,000 topographic and geologic maps can be compiled at a scale of 1:2,500 and with a minimum contour interval of 10 or 12 meters. Maps at a scale of 1:300 with a minimum contour interval of 0.25 to 0.5 meters were compiled from phtographs at 1:3,000 obtained at other test sites.

From a geologic standpoint, it is important that some of the successive models making up the panoramic view of the rille wall (or of any other landscape feature of major geologic interest) be taken at low phase-angle in order to enhance any inherent albedo differences that may exist. The property of albedo is significant because it is to some extent a measure of composition and of surface texture. Low phase-angles at times of low sun elevation will be obtained when the camera is pointed westward away from the sun. Under such conditions, so much sunlight would be back-scattered from the west wall of the rille that topographic detail will be lost at the expense of enhanced albedo differences. Zero-phase or low-phase angle photographs taken with the 500 mm F.L. camera may yield supplemental albedo information that may help the geologist understand lunar surface conditions at the micro-scale. Patient analysis of albedo differences along the string of panoramic models, when related to topographic details, can be of immense value to the photogeologist trying to analyse and interpret the geology of the Apollo 15 landing site.

Besides panoramic views of the west wall of Hadley Rille, there are smaller areas in Hadley Rille that are interesting enough to be recommended as potential photographic targets (see figure 11 and table 3). (1) A small east trending ridge of the east wall, in which layered and steeply dipping rock is exposed under grazing light conditions. This target is 3.7 kms northwest of LRV station 12. (2) Loose boulders and possibly solid rock exposed in both rille walls in an east-trending stretch of the rille, 11.7 kms southwest of station 14. However, as the traverses are presently planned, this area probably will not be visible to the astronauts. (3) A stretch of the rille southwest of station 3 that impinges against highland material along the base of the Apennine front.

Table 3.--Areas of Special Interest
(Located in Figure 11)

Area	1		2		3		4		
	LRV	Walk	LRV	Walk	LRV	Walk	LRV	Walk	LRV
Station to photograph from	12		13,14,15		12, 11	a - b	5 & 6	c,d,e	5 & 6
Expected sun angle degrees	34.34		34.8-35.6		14.1°	14-14.6	23.7-24.4	23.8-24.8	23.7-24.4
Distance to object (M)	3,750		11,750		2,000	3,500	3,750	6,750	2,000
Recommended camera base (M)	250 900		780 minimum		133 500	233 875	250 900	450 1,700	130 500
Photo scale 60 mm F.L. lens	62,500		195,800		33,300	58,300	62,500	112,500	33,333
Photo scale 500 mm F.L. lens	7,500		23,500		4,000	7,000	7,500	13,500	4,000

Area	5	6		7		8		9	
	Walk	LRV	Walk	LRV	Walk	LRV	Walk	LRV	Walk
Station to photograph from	Landing Site	6	Landing Site	12		5	j	5.6	i, j
Expected sun angle degrees	35°	24.4	35°	34.3		23.7	34.7	23.7-24.4	34.4-34.7
Distance to object (M)	9,000	9,750	14,250	11,250		9,250	10,500	7,500	9,250
Recommended camera base (M)	600 2,250	650 2,400	950 3,000	750 2,800		600 2,300	700 2,600	500 1,800	619 2,300
Photo scale 60 mm F.L. lens	150,000	125,000	237,500	187,500		154,166	175,000	125,000	154,000
Photo scale 500 mm F.L. lens	18,000	15,000	28,500	22,500		18,500	21,000	21,000	18,500

An attempt to record the albedo differences along the contact between mare material and highland material (or between the regoliths derived therefrom) should be made. Also if not hazardous, a boulder of known lithology and diameter should be loosened at the top of the east wall, and sent crashing down the east slope to the floor below. Photographs of the rolling or bounding boulder and its tracks should be taken possibly from the vicinity, stations 11 and 12, from which point both the east wall and the floor will be in sunlight.

The photographic parameters under which surface based photography of the west wall of Hadley Rille is optimized at the various stations of the LRV and walking traverses are shown in table 4.

At stations 11 and 12, where the expected sun angle is approximately 34-degrees, the east wall of Hadley Rille can be photographed under an illumination exceeding the grazing light angle by a few degrees. Excellent topographic and geologic detail can be obtained under such conditions. The west slope of the Apennine Mountains to the north and south of Hadley Rille could also be photographed advantageously from stations 11 and 12 (table 3).

Stereoscopic photographs of any interesting geologic features observed in Hadley Rille should be taken in addition to the panoramic photographic coverage. Many features or phenomena are helpful in providing clues for interpreting the genesis of the rille, and the original nature of the mare and highland materials. Among them are: (1) areas of exposed bedrock in the rille wall, (2) any indications of layering or stratification of rock in rille walls,

Table 4.--Rille Photography

	LRV			Walk			
Station	3	11	12	a	b	c	d
Sun Angle (degrees)	15.1	34.0	34.5	14.7	15.1	23.8	24.4
Distanct to object	1,500	1,375	1,375	1,250	1,250	1,500	1,250
Stereo base dist.	100 375	100 300	100 300	83 313	83 313	100 375	83 313
Photo scale 60 mm F.L. lens	25,000	22,917	22,917	20,833	20,833	25,000	20,833
Photo scale 500 mm F.L. lens	3,000	2,750	2,750	2,500	2,500	3,000	2,500
Expected map scale 60 mm	12,000	10,000	10,000	10,000	10,000	1:1200	10,000
Expected C.I. 60 mm (meters)	15	10-12	10-12	10-12	10-12	15	10-12
Expected map scale 500 mm	300	300	300	300	300	400	300
Expected C.I. 500 mm (meters)	0.25-0.5	0.25-0.5	0.25-0.5	0.25-0.5	0.25-0.5	0.25-0.5	0.25-0.5
# of photographs	8: Should be taken from about 480° E to N 20° W in 10° intervals. This will give about 90% stereo overlap.			18: Should be taken at 10° intervals from S 30° E to N 20° W. This will give 17 stereo models with 90% stereo overlap.		8: Should be taken from about 580° E to N 30° W at 10° increments. This will give 7 stereo models with 90% overlap.	

and the altitude of the layers, (3) color, texture, and structure differences between mare and highland material exposed in rille walls, (4) loose boulders on the walls or floor of the rille, (5) boulder tracks in the rille, (6) detailed topography of contacts between layers in the rille walls, (7) crater frequency distributions in walls and floor of the rille, (8) linear trends of craters.

Outside Hadley Rille many other lunar land froms should be photographed stereoscopically (fig. 11). Some of these are: (1) A triangular hill of highland material at the mare-highland contact (area 4, fig. 11) 3.7 kms due east of station 6. Surface structure of the regolith on the hill, such as slumps, terracettes, and boulders are worth imaging at high resolution with the 500 mm F.L. camera. (2) A narrow northwest trending cleft debauching from the mare into the highland, 2.6 km southeast of station 6 (area 5) and a steep westerly facing ridge beyond it about 10 km away from station 6 (area 6); (3) An apparently tilted northeasterly trending bench at the mare-highland contact 11.25 km northwest of station 12, (area 7)--if visible from that station, (4) A mare ridge (area 8) bordering a diamond-shaped plateau 9 km northeast of station 5--if high enough to be visible, (5) The tonal contrast between large exposures of layered rock and the regolith on the mountain slopes N 40° E exposures of station 5 and south of station 6 (area 9).

Conclusions and recommendations

The terrestrial photogrammetric method has been successfully utilized in many special mapping projects. It can be used for mapping the topography and geology of steep canyon and coulee walls, where the scale of aerial photography and conventional topographic maps compiled from them is too small, and where the projection of steep walls on a horizontal plane is so narrow that it cannot be annotated. When terrestrial photogrammetry is applied to geologic mapping, distant and inaccessible walls can be readily mapped. The thicknesses of the individual layers exposed in canyon walls can be read off directly from the contours on the map or they can be very accurately computed from spot elevations measured on profiles of the wall with an analytical or universal plotter. The layers can also be delineated and traced laterally on hand held photography and on the maps compiled from them.

The use of surface based metric cameras during the Apollo 15 mission makes it imperative that photographic targeting as well as the selection of photographic parameters for a given target be optimized. Once the geologic targets are defined in detail, the sun angle, the phase angle, and the brightness longitude at a given phase angle must be optimized. This systematic approach to surface-based photography on the Moon is within the scope and philosophy of a manned mission.

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APPENDIX A

Complete absolute orientation of a model in thé Wild A-5 plotter is obtained by setting the camera interior orientation (calibration data) and field survey data (camera exterior orientation) into the plotter. The main advantage of this type of mapping is that no ground control is necessary other than that obtainable by means of phototheodolite. In other words, a field survey is unnecessary.

To obtain the photo coordinates (the coordinates with respect to the principal point), x_1, z_1 and x_2, z_2, the glass plates are placed in a Wild Pug III, and selected-common ground points are marked on both plates. The points selected for ground control are chosen on the basis of geometric strength of figure and image sharpness, and they must be common to photographs of adjacent models to be able to bridge from one model to the next. The plates are then placed in a Mann comparator, and three sets of measurements to the four camera fiducial marks and the pugged ground control points are made. The Mann comparator measurements are then entered into an IBM Fortran program, and the coordinates of the ground control points are computed, using the following equations (AFM 200-52, 1955, p. 74).

$$X_G = Kx_1 \qquad Y_G = Kf \qquad Z_G = H_I + Kz$$

where

$$K = \frac{B}{Px}, \; Px = x_1 - x_2, \text{ and } z = \frac{z_1 + z_2}{2}$$

x_1, z_1 and x_2, z_2 are photo coordinates of left and right camera stations respectively.

f = camera focal length

B = base distance between camera stations

H_I = instrument height

These equations assume that the camera axes are parallel and that they lie in the same horizontal plane (no vertical angle). The following equations can be used where the camera axes are not parallel but both still lie in the same horizontal plane.

$$X_G = Y \tan \theta_1$$

$$Y_G = \frac{B \cos \theta_1 \cos (\emptyset_2 + \theta_2)}{\sin (\emptyset_1 - \emptyset_2 + \theta_1 - \theta_2)}$$

$$Z_G = H_I + \frac{Yz_1}{f}$$

where

$$\tan \theta_1 = \frac{x_1}{f}, \text{ and } \tan \theta_2 = \frac{x_2}{f}$$

z_1, x_1, x_2 are measured photo coordinates; and $\emptyset_1$ and $\emptyset_2$ are angles of camera axis 1 and 2 respectively to the lines normal to the camera base.

The ground control points can be plotted on the topographic map, and can be used as a check to ensure that the map scale is being maintained when adjacent models are bridged.

The Wild A-5 universal plotter is not digitized to provide for the readout of coordinate information, and therefore vertical profiles cannot be plotted out directly on the coordinatograph (plotting table). Instead, the operator must record the x, y, z values form the instrument settings.

These values are then punched on IBM cards, and read into an incremental plotter (the U.S. Geological Survey XYZ plotter in Flagstaff, Arizona). Vertical profiles may also be obtained analytically, but this is a time-consuming method because each point has to be pugged and measured on the Mann comparator.