WILLIAM R. HEMPHILL*
WALTER DANILCHIK
U. S. Geological Survey
Arlington, Va., and Denver, Colo.

Geologic Interpretation of a Gemini Photo

An orbital photograph of the Salt Range and Potwar Plateau of West Pakistan reveals the regional significance of some geologic features.

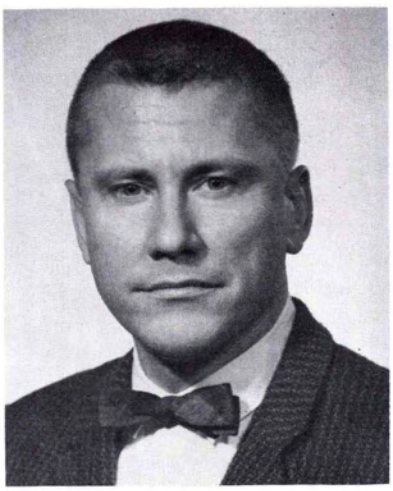
(*Abstract on page 154*)

INTRODUCTION

ASTRONAUTS COOPER AND CONRAD, during their 8-day Gemini V mission in August 1965, took more than 290 color photographs of cultural and terrain features from orbital altitudes over North and South America, Africa, Asia, and Australia. The photographs were taken with a handheld 70-mm. Hasselblad camera, Model 500, equipped with a Zeiss Planar lens of 80-mm focal length and an f:2.8 aperture. The film was Anscochrome D-50, ASA-50. Most of the photographs were taken as "targets of opportunity" presented themselves, and as other duties permitted. Because this was primarily a medical and hardware checkout flight, no attempt was made in premission planning to select more than a few specific subject areas or to define lighting conditions under which the photographs would be taken.

One of the orbital photographs obtained on the Gemini V mission is of the Salt Range and Potwar Plateau, a semiarid region of West Pakistan (Figure 1) between the Indus and Jhelum Rivers. This photograph (Front Cover) was taken on August 25, 1965, at 0436 hours Greenwich Mean Time (0924 hours Local Civil Time at longitude 72°E). The field of view covers about 7,000 square miles. The photograph was selected for study because the authors have studied adjacent areas in the field, where geologic and geographic features and conditions are similar to those in the area covered by the photograph. The purpose of the study was to assess the usefulness of an orbital photograph in providing geologic information pertinent to the interpretation of structure and identification of rock type.

Geographic features and place names annotated on the photograph are taken from the U. S. Air Force Operational Navigation Chart G-6 (U. S. Air Force, Aeronautical Chart and Information Center, 1963) and from Army Map Service Sheets NI-42 and 43 (U. S. Army Corps of Engineers, Army Map Service, 1945, 1956). Geologic features identified from personal knowledge of the area are identified on the photograph by number (Front Cover). The geologic and geographic features that may be delineated, or are judged interpretable by geologists with minimal knowledge of the area, are indicated by letter or geologic symbol. Annotation of structural features, such as faults and folds, is restricted to the local area on the photograph where evidence suggesting the existence of these features was observed directly.



WILLIAM R. HEMPHILL

* Publication authorized by the Director, U. S. Geological Survey. Presented at the Annual Convention of the American Society of Photogrammetry in Washington, D. C., March 1967.

FIG. 1. Index map of West Pakistan showing the area covered by Gemini V orbital photograph shown on the Front Cover.

GEOLOGIC SETTING

The Salt Range forms a steep, generally west-southwest-trending scarp; the average elevation rises abruptly from less than 1,000 feet in the plain of the Jhelum River in the south to more than 2,500 feet along the crest of the range. In the western part of the photographed area (Front Cover) the Salt Range curves northward toward the town of Kalabagh. Sedimentary rocks of Cambrian and Permian ages are exposed near the base of the scarp, and rocks of Triassic, Jurassic, and Eocene ages crop out near the crest of the range.

The Potwar Plateau north of the Salt Range is underlain mainly by rocks of Pliocene age that belong to the Siwalik Group. These rocks are gently folded into a broad east-trending syncline in the central part of the photographed area but are relatively closely folded and faulted in the north.

STRUCTURAL FEATURES

Delineations of faults are largely based on sharp linear truncations of outcrop pattern and color. The fault zone northeast of Kalabagh, for example, shows clearly on the orbital photograph (Front Cover); studies in the field and on aerial photographs corroborate its existence and strongly suggest that the predominant movement was horizontal, the eastern block, comprising the Salt Range and Potwar Plateau, moving southward. If more of the mountainous region west of the Indus River could be seen, it is believed that this relationship would also be strongly suggested on the orbital photograph. Field studies have identified numerous east-trending high-angle reverse faults north of the Indus and Soan Rivers that are not clearly expressed on the orbital photograph. These faults, individually, are less significant from a regional viewpoint than the strike-slip fault clearly shown northeast of Kalabagh.

Close inspection of the photograph indicates that many of the annotated linear features are expressed by alignments of short stream segments, particularly in the region

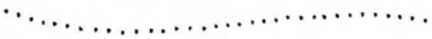
FRONT COVER. Gemini V Photograph of the Salt Range and Potwar Plateau in north-central West Pakistan (Magazine 4, frame 19, orbit 55, exposed at 0924 hours Local Civil Time on August 25, 1965). Geographic features and place names are from U. S. Air Force Operational Navigation Chart G-6 (U. S. Air Force, Aeronautical Chart and Information Center, 1963) and from Army Map Service Sheets NI-42 and 43 (U. S. Army Corps of Engineers, Army Map Service, 1945, 1956).

Geologic features, identified mainly on the basis of personal knowledge of the area, are labelled on the photograph by number and are described as follows:

1. Reddish-brown or generally dark-toned areas underlain mainly by clastic rocks of Cambrian age. Outcrop is limited to the eastern Salt Range.
2. Mostly limestone of the Zaluch Group, Permian age. Mainly detrital material along base of the south flank of the Salt Range where bedrock areas of the Zaluch Group are not readily distinguishable on the photograph from younger rocks. Light-brown or white band on the photograph is remarkably persistent and may be traced northward nearly to the Indus River.
3. Limestone of Eocene age and Mesozoic sedimentary rocks.
4. Light-toned band may be an outcrop of limestone of Eocene age.
5. Mainly red and brown sandstone and siltstone near the base of the Siwalik Group of late Tertiary age.
6. Light tone may be evidence of "water-logging," a process common to the Indus basin where leakage from irrigation canals saturate adjacent areas; subsequent evaporation leaves behind a saline concentrate which renders previously arable land unfit for cultivation.

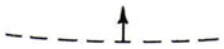
Geologic and geographic features that could be delineated and/or interpreted with minimal knowledge of the area are indicated by map symbol or letter as follows:

Fault. Queried where uncertain.



Linear feature. Alignments of short stream segments which are probably related to fractures in the underlying bedrock; distinction between some linear features and faults is arbitrary.

Folds. Showing trace of axial plane and bearing and plunge of axis. Queried where attitude of limbs and plunge of axis are not clear.



Inferred strike and dip of beds. Based on outcrop pattern and on topography as interpreted from stream position and drainage pattern.

Transportation route. Roads and railroads; annotated only in places where evidence of their existence may be observed.

a *Alluvial deposit.* Flood plain of the Jhelum River.

b *Fan deposit.*

c *Older alluvium (?).* Possibly flat-lying terrace and pediment deposits occupying interstream areas now undergoing dissection.

d *Bedding trace.*

e *Drainage feature.* May indicate more luxuriant vegetation or cultivation adjacent to streams where local ponding by either natural or artificial means has increased moisture in the soil relative to surrounding interstream areas.

f *Cultural feature.* May be aircraft emergency landing strip.

north and northeast of Nammal Lake. Such alignments are commonly developed parallel to fractures in underlying bedrock, and although no exhaustive (or conclusive) study of fracture orientation has been made in this area, this explanation seems to be reasonable. These linear features undoubtedly would be less apparent on conventional aerial photographs because of the limited areal coverage of single prints and the abundance of dis-

tracting detail resolved at larger scale. Some linear features in other parts of the photograph show up as abrupt linear breaks in color or outcrop pattern. Distinction between these linear features and those mapped as faults is arbitrary.

In some parts of the photographed area, attitude of the strata may be inferred from outcrop pattern and topography as indicated by stream pattern. Strike and dip symbols indicating a gentle northward dip have been annotated near the crest of the Salt Range and in the southern part of the Potwar Plateau. North of the Soan River, beds are more tightly folded, as is indicated by bedding traces and stream pattern. Although several fold axes may be clearly seen, direction of dip along the limbs of the fold can be easily misinterpreted because of the small scale of the orbital photograph. Anticlinal axes can be differentiated from synclinal axes in this region by observation of minute outcrop detail in the area of the fold axis with the aid of a magnifying glass. Interpretation of bedding attitude is also aided by the knowledge that in this region anticlines are normally closed narrow structures, whereas synclines are commonly open folds several miles across.

Lithologic Information

Surficial deposits such as alluvial fans, meander scars, and alluvial deposits along the Jhelum River may be readily identified on the orbital photograph (Front Cover) by the distinctive shape and position of these features with respect to present drainage systems. In the Potwar Plateau the predominant sedimentary rock type is revealed by numerous open folds, continuous linearity of outcrop pattern, and fold axes that are normally more typical of terrain underlain by sedimentary rocks than of terrain underlain by metamorphic or igneous rocks. Conceivably, some of the dark-toned irregularly shaped areas (Symbol 1 on Front Cover) in the southeastern part of the photograph could be interpreted as underlain by intrusive rocks; however, field studies have identified sedimentary rocks of Cambrian age in these areas. Dark-toned features in the interstream areas in the east-central part of the photograph (Symbol *c* on Front Cover) could be interpreted as flat-lying lava flows now being dissected. Although these features have not been visited in the field, they may be terrace and pediment deposits whose dark tone is due to desert varnish deposited on boulders and cobbles that are known to compose the surface of many older alluvial deposits in this region. The dark tone could also be due to scrub thorn bush covering hillslopes between alluvium-filled intermittent streams.

Although specific rock types cannot be identified unequivocally from the photograph without supporting information obtained in ground studies, it may be pointed out that outcrop pattern and tone strongly suggest the regional continuity of some of the strata. The beds exposed at 5, Front Cover (identified on the basis of field evidence as Lower Siwalik), are an example where distinctive tone and outcrop pattern permits tracing of the unit for more than 50 miles. Light-toned beds at the base of the southern and western Salt Range (identified on the basis of field evidence as detritus and bedrock of the Zaluch Group of Permian age) also exemplify the use of small-scale photos in tracing the regional continuity of some outcrops.

Conclusions and Suggestions for Future Work

The regional significance of some geologic features may be more readily recognized and interpreted from a single photograph taken from orbital altitude than on conventional aerial photographs of larger scale where hundreds of prints would be required to view the same area. The Gemini V photograph of the Salt Range-Potwar Plateau region of West Pakistan covers 7,000 square miles; with minimal previous geologic and geographic knowledge of the area, structural features such as folds and faults may be delineated on the basis of rock-outcrop pattern, color or tone, and drainage pattern. Some stratigraphic relationships may also be recognized, but identification of specific rock type requires additional ground information and generally is less conclusive or reliable than interpretation of structure.

Nearly all orbital photographs to date have been taken with conventional color films. Color rendition of certain features known or believed to be brightly colored on many of these photographs is poor, partly because excessive atmospheric scattering of shorter wavelengths in the visible spectrum imparts a blue cast to the color exposure; as a consequence, image contrast and color saturation at longer wavelengths in the green and red are reduced. For example, although red and brownish red are diagnostic of rocks of the Siwalik Group that underlie the Potwar Plateau, these colors are poorly expressed on the Gemini V photograph of this region.

Further experimentation may demonstrate

the usefulness of color infrared film (also known as *camouflage detection* film from its use by the military during World War II) in providing high color contrast between natural features photographed from orbital altitude. The long-wavelength sensitivity of color infrared extends to about 8500A, and, properly filtered, the film is insensitive to blue light (Tarkington and Sorem, 1963). It is believed that color infrared photography from orbital altitude would combine broad bandpass sensitivity with atmospheric penetration qualities that are superior to conventional color film. Although color rendition is distorted on color infrared photographs—that is, features are imaged in colors other than their true natural colors—this quality is not judged a shortcoming for interpretation of many geologic and terrain features, particularly as the improvement of atmospheric penetration would also improve color contrast.

The limited number of color infrared photographs obtained on Gemini VII over the Gulf Coast of the United States and Brazil are difficult to evaluate because of adverse lighting conditions, filtering problems, and inadequate exposure time.* In further orbital photography experiments with color infrared film, it would be desirable to photograph areas where bedrock is well exposed, such as arid regions in the southwestern United States, the west coast of South America, Saudi Arabia, and West Pakistan.

Use of hand-held cameras will continue on Apollo flights. Brinkmann (1966) describes some features of precision 70-mm. cameras of advanced design for use by astronauts in a space environment. There undoubtedly will be future opportunities to obtain orbital photographs of the Salt Range-Potwar Plateau region. Stereo coverage would greatly facilitate geologic interpretations, particularly of structural features of regional significance. Where hand-held cameras are used, photographs could be exposed in accordance with the principles of convergent photography introduced several years ago (Brucklacher, 1958; Theis, 1958) as a procedure to increase parallactic image displacement of features and effectively increase the vertical scale with respect to the horizontal scale of aerial photographs used in precision photogrammetric mapping. This approach would facilitate detection of relief differences that are small in comparison with orbital altitude.

It is believed that in some areas the expression of topographic relief on orbital photographs could be improved or observed more clearly by deliberately photographing the terrain at low sun angle. In the Potwar Plateau for example, rocks of the Siwalik Group commonly crop out as a series of parallel hogback and cuesta ridges, generally less than 200 or 300 feet high. Shadow expression of relief that would be obtained on photographs taken at low sun angle would greatly assist in the recognition of outcrop pattern and structure. Shadow expression would be particularly valuable where topography is well adjusted to structure and where stereo coverage is not available.

* Richard Underwood, Manned Spacecraft Center, Houston, Texas, personal communication.

References

Brinkmann, J. R., 1966, Space photography: *Space/Aeronautics*, v. 45, no. 2, p. 72–81.

Brucklacher, W. A., 1958, Wide-angle convergent photography with angles of convergences of 27° or 40°: *Photogrammetric Engineering*, v. 24, no. 5, p. 786–789.

Tarkington, R. G., and Sorem, A. L., 1963, Color and false-color films for aerial photography: *Photogrammetric Engineering*, v. 29, no. 1, p. 88–95.

Theis, J. B., 1958, Increased base: height ratio: *Photogrammetric Engineering*, v. 24, no. 1, p. 127–132.

U. S. Air Force, Aeronautical Chart and Information Center, 1963, Operation navigation chart: St. Louis, Mo.

U. S. Army Corps of Engineers, Army Map Service, 1956, Kabul, Sheet NI-42: Washington, D. C.

U. S. Army Corps of Engineers, Army Map Service, 1945, Kashmir, Sheet NI 43: Washington, D. C.

ABSTRACT: *Study of the Gemini V photograph of the Salt Range and Potwar Plateau, West Pakistan, indicates that small-scale orbital photographs permit recognition of the regional continuity of some geologic features, particularly faults and folds that could be easily overlooked on conventional air photographs of larger scale. Some stratigraphic relationships can also be recognized on the orbital photograph, but with only minimal previous geologic knowledge of the area, these interpretations are less conclusive or reliable than the interpretation of structure. It is suggested that improved atmospheric penetration could be achieved through the use of color infrared film. Photographic expression of topography could also be improved by deliberately photographing some areas during periods of low sun angle.*