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TERRAIN PHOTOGRAPHY ON THE GEMINI IV MISSION: PRELIMINARY REPORT

by Paul D. Lowman, Jr., James A. McDivitt, and Edward H. White II

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Greenbelt, Md.

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ABSTRACT

During the 4-day Gemini IV flight in June 1965, about 100 color pictures of land areas were taken with a 70mm hand-held camera for geologic and geographic study, as part of the Synoptic Terrain Photography Experiment. This paper presents a brief summary of the objectives, methods and results of the experiment. Representative pictures of the southwestern United States, northern Mexico, and portions of Africa and the Arabian peninsula are presented and described. Preliminary study indicates that these pictures will be useful in studying regional structure, revising small-scale geologic maps and searching for and studying impact structures.

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by
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INTRODUCTION

During the Gemini IV flight in June 1965, color photographs of selected land areas were taken as part of the Synoptic Terrain Photography (S-5) Experiment (Gill and Gerathewohl, 1965). This paper presents a brief summary of the objectives, methods, and results of this photography.

The purpose of the S-5 Experiment was to obtain small-scale color photographs of land areas of geological and geographical interest. Similar attempts during Mercury flights MA-8 and MA-9 (Lowman, 1964), were successful enough to warrant further efforts. The camera used in these and in the Gemini IV flight was a hand-held modified Hasselblad 500C with a Zeiss Planar f/2.8 lens and haze filter. On the Gemini IV mission, five magazines, each loaded with approximately 60 frames of 70mm Ektachrome MS (SO-217) film on a 2 mil Estar base, with an ASA 64 rating, were carried. In addition to the S-5 Experiment, this film was used for general purpose photography and the Synoptic Weather Photography Experiment (S-6) (Nagler and Soules, 1965). Camera preparation, film calibration, and film processing were done by the Photographic Technology Laboratory of the Manned Spacecraft Center.

Coverage was requested for three major areas in the terrain photography experiment. First priority was given to photography of the southwestern United States because of the availability of ground control and geologic information. Second priority was given to northeastern Africa and the Arabian peninsula because of the geologic importance of the Great Rift Valley, a major study objective of the Upper Mantle Project. Third priority was given to northern Mexico. It was stressed in pre-flight briefings that good pictures of any land area would be of value, if the planned areas could not be covered.

Two techniques were used in the terrain photography. For systematic overlapping vertical coverage along the flight path, the command pilot (McDivitt) oriented the spacecraft, using the

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pulse mode, while the pilot (White) took pictures at 5-second intervals. Because of fuel and power restrictions, this technique was used only once, during the 32nd revolution. At other times the spacecraft was in drifting flight, and pictures were taken by either astronaut whenever opportunities arose. As far as possible, pictures were taken at high depression angles, with cockpit lights out, camera axis normal to the window, and the window in shade. A residue on the windows, probably caused by flashback during second stage ignition, had little effect on picture quality.

The experiment was highly successful. A continuous series of 39 overlapping, high depression angle pictures was taken covering northern Mexico and the southwestern United States from the Pacific Ocean to central Texas. Over 60 high-quality pictures of the other desired areas were taken. The coverage is summarized in Table 1. Detailed study of the terrain photographs is underway by several organizations. A full discussion would be beyond the scope of this paper; instead, a few representative pictures will be presented and briefly described.

Resolution of the photographs has been studied in two ways. Examination of enlarged prints showing cultural features of known dimensions permits estimation of ground resolution. For high-contrast, linear objects in dry areas, maximum ground resolution appears to be between 30 and 40 feet; for example, Rt. 5, a two-lane black-top road about 35 feet wide on the east coast of Baja California (Figure 2) is visible for most of its length in the photograph. A second technique for estimation of resolution is edge analysis. The Data Corporation, Dayton, Ohio, performed such an edge analysis by scanning a coastline (Figure 10) on the original flight film with a microdensitometer and then deriving the modulation transfer function for the resulting output (Reference 19). The resolution thus derived, for what was considered a medium contrast target, was 30 lines per millimeter.

Table 1

Photographic Data.

Film Identification	No. of Terrain Pictures*	Areas Covered	Comments
Magazine 8, Roll 3	54	Northern Mexico, southwestern United States, (continuous coverage), Florida and the Bahama Islands (intermittent coverage)	Continuous sequence of exceptional quality; intermittent pictures show considerable offshore detail.
Magazine 9, Roll 4	23	North Africa (18 pictures) Persian Gulf, southeastern United States	North African pictures generally good; United States pictures poor.
Magazine 16, Roll 5	17	Mexico (2 pictures), Arabian peninsula and adjacent areas, Mauritania (1 picture)	Arabian pictures very good; Mauritania picture shows Richat structures.
Magazine 7, Roll 2	10	Bahama Islands (5 pictures), Arabian peninsula	Bahama pictures show underwater topography.
Magazine 6, Roll 1	10	Northeastern Africa (7 pictures), Iraq, India, Pakistan	Nile River and surroundings well covered.

*All pictures showing recognizable land areas are included in these figures without regard to picture quality.

SOUTHWESTERN U.S. AND MEXICO

Figure 1, the first of the continuous series taken on Magazine 8, shows a portion of Baja California. It demonstrates the unique value of hyperaltitude photography by providing a synoptic view of the Agua Blanca fault, the lineament at lower left. This strike-slip fault was first described in 1960 by Allen, Silver, and Stehli (1960). Stream alignments on this and the succeeding photograph suggest that it is one of a group of at least three northwest-trending faults. Numerous additional northeast-trending lineaments, possibly representing complementary shear faults, are visible north of the Agua Blanca fault. Curiously, there is little photographic evidence of the major fault east of the Sierra Juarez shown by Beal (1948) and Allen, et al. (1960), although its existence has been confirmed by field mapping (C. R. Allen, personal communication).

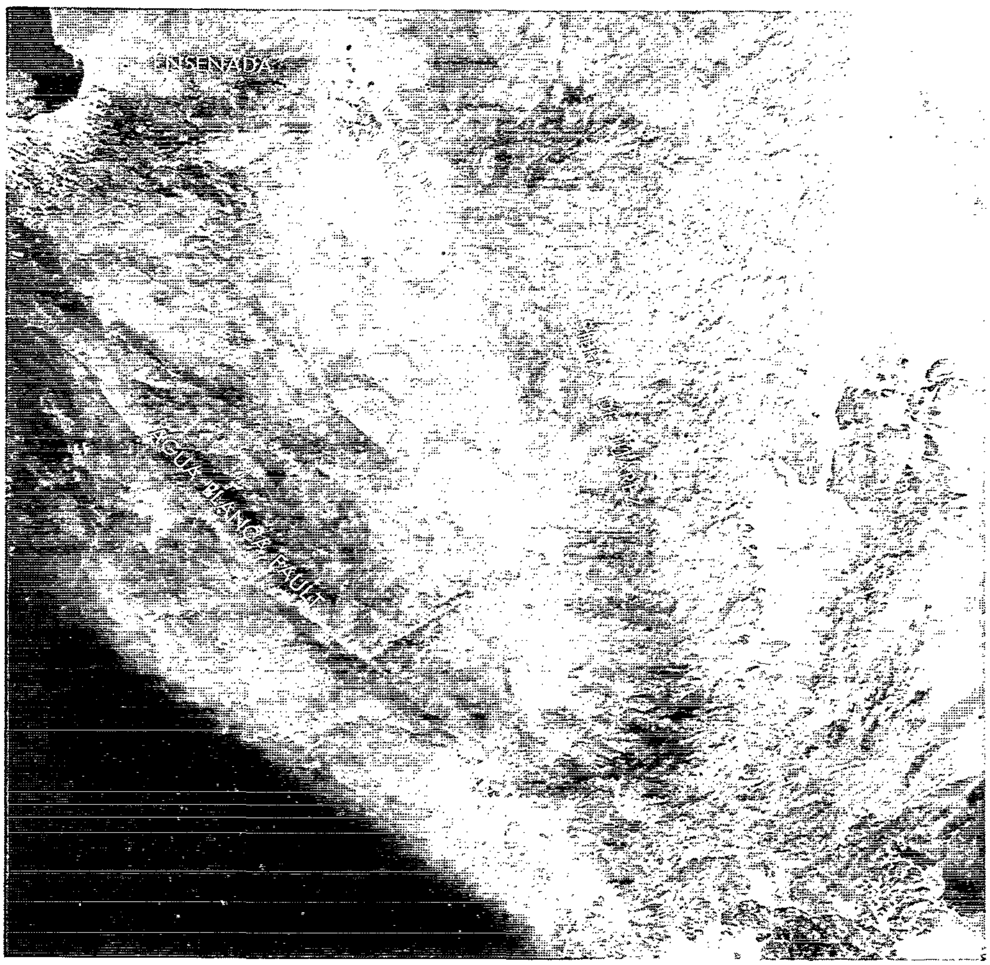

Figure 1—Northern Baja California, Mexico. Aqua Blanca fault is the lineament paralleling the spacecraft window (dark) at lower left. North at top. East-West distance at top of photograph about 80 miles.

This and the two succeeding photographs have been used by the Council on Non-renewable Natural Resources in Mexico to construct a photogeologic map at a scale of 1:250,000, showing a number of structures and lithologic contacts not previously mapped.

Figure 2, the third picture in the continuous 32nd revolution sequence, shows the mouth of the Colorado River, the north end of the Gulf of California and adjacent Baja California and Sonora. Considerable geologic detail is visible, such as the lineament sub-parallel to the edge of the Sonora Desert; this is a major fault of the San Andreas system (Moody and Hill, 1956). Of equal interest, however, are the many tonal gradations (color in the original transparencies) visible in the Gulf of California. Gettys (1965) has shown that they represent variations in water depth; asymmetric sediment distribution is apparent in the picture.

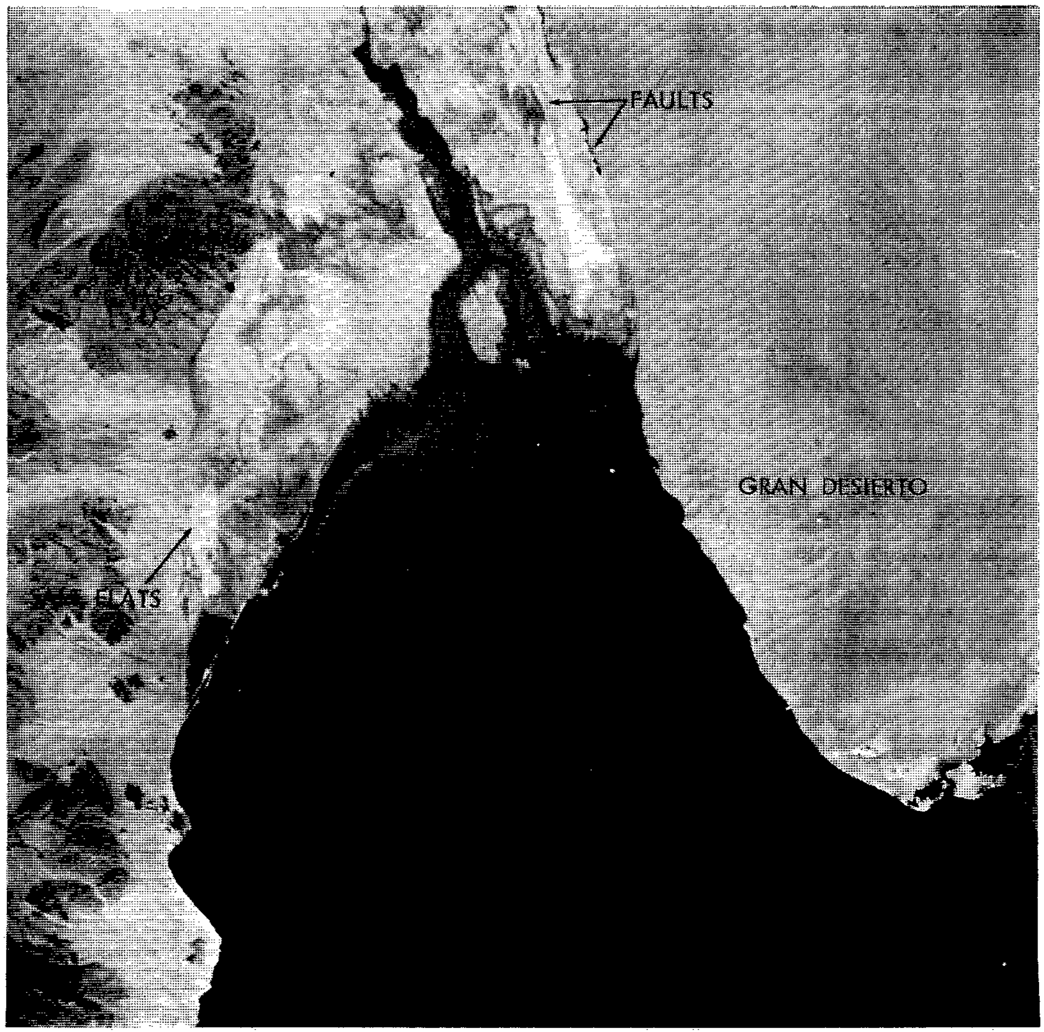

Figure 2—Mouth of Colorado River, emptying into the Gulf of California. Sinuous feature at left is an ephemeral stream. Great Sonora Desert at right; note sand dunes.

Figure 3, the fifth picture in the sequence, shows Sierra del Pinacate and adjacent Sonora and Arizona. Most or all of the large maars and cinder cones are visible in the Pinacate volcanic field, and the extent of the field as a whole is easily delineated. In addition, considerable geologic detail to the north can be identified with the aid of the Geologic Map of Yuma County, Arizona (Wilson, 1960). Contacts between Mesozoic granites and foliated metamorphic rocks are distinct, as are the northward trending fractures just north of the Pinacate field. The fact that much of the detail shown on the 1:375,000 Yuma County map can be seen on this picture, whose original scale was about 1:2,200,000, demonstrates the possibility of retaining useful resolution in extremely small-scale photographs.

Figure 4 was taken in the 32nd revolution sequence, over southern New Mexico. It demonstrates two potential geologic uses of hyperaltitude photography. The first use, revision or

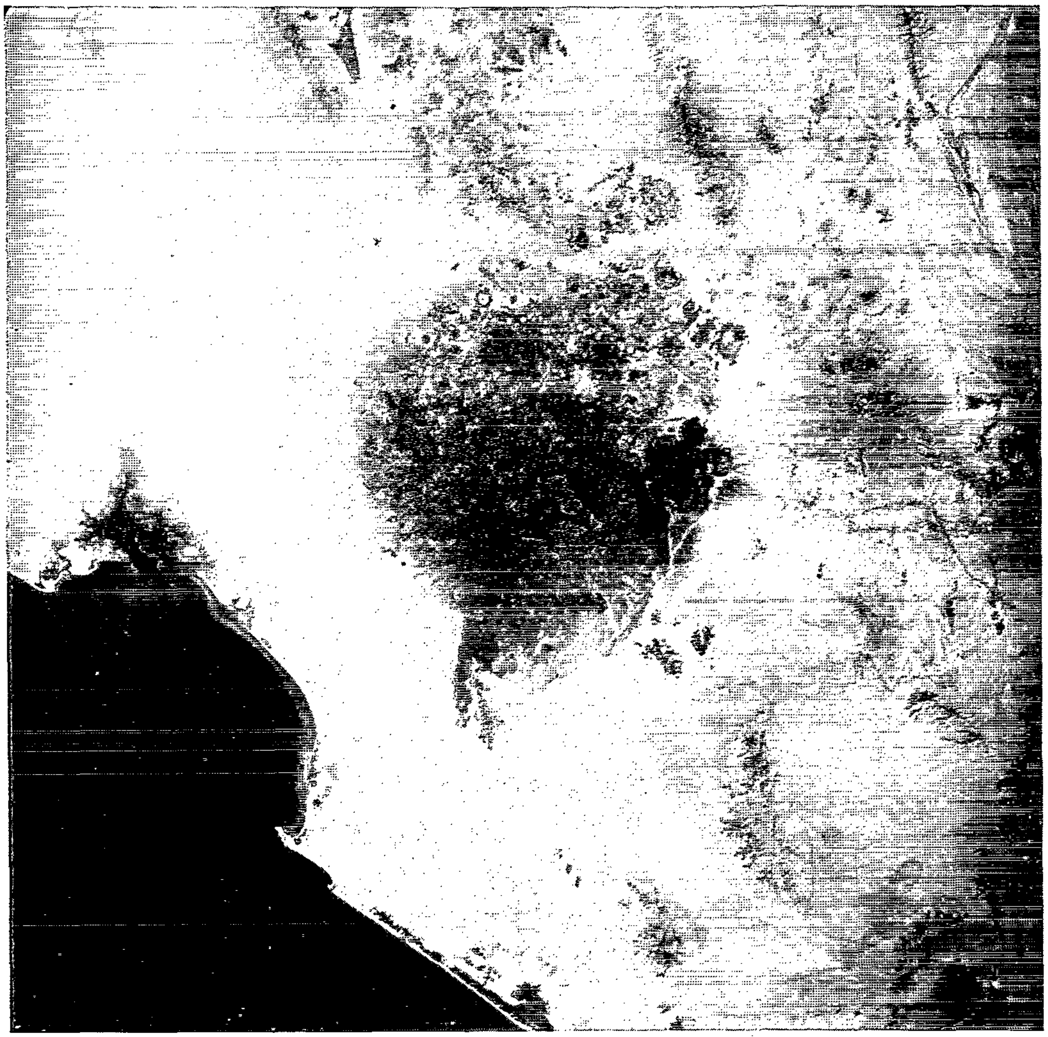

Figure 3—Northern Sonora, Mexico; Pinacate volcanic field (Sierra del Pinacate). Gulf of California at lower left. East-West distance at top of photograph about 80 miles.

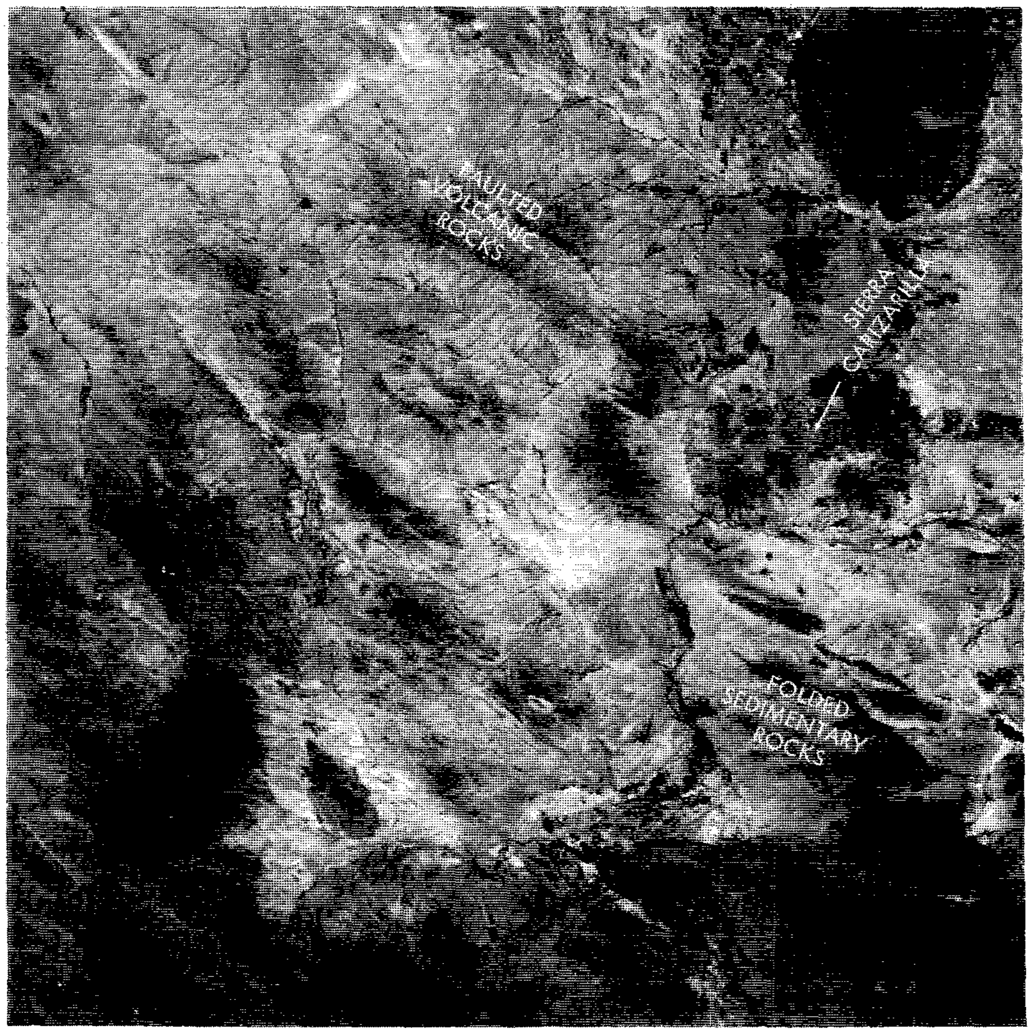

Figure 4—Northern Chihuahua, Mexico, and southwestern New Mexico. Cedar, Hatchet, and Florida Mountains. Sierra Carrizarilla (right center) is large volcanic field.

compilation of regional geologic maps, is illustrated by the Sierra Carizarilla. These mountains are clearly a major volcanic field comparable to the Pinacate field in size and possibly in age (probably Pleistocene or Recent, judging from the relatively slight degree of dissection). However, the most recent maps covering this area show only scattered outcrops of Middle Cenozoic volcanics. Both the extent and assigned age appear inconsistent with the Gemini photograph.

A second potential application of hyperaltitude photography, the study of regional tectonics, is also demonstrated by Figure 4. This picture and the two adjoining ones (not shown) make it possible to see at a glance the transition zone between the folded Mesozoic rocks of northeastern Mexico (Ramirez and Acevedo, 1957) and the block-faulted volcanics of southwestern New Mexico (Dane and Bachman, 1964). The essential parallelism of fold axes in Chihuahua and fault-controlled ranges, such as the Cedar Mountains (Bromfield and Wrucke, 1961) and Dog Mountains (Zeller, 1958) in New Mexico, indicates considerable control of the faults by pre-existing folds, as proposed by Jones (1961).

Other features of geologic interest in Figure 4 are the conspicuous pediments surrounding the Florida, Cedar and Hatchet Mountains, and others. Being covered by Quaternary alluvium, these surfaces are not delineated at all on geologic maps, and are delineated on topographic maps only to the extent that they reflect topography. Hyperaltitude photographs such as Figure 4, however, provide color coverage of entire pediments without the degradation inherent in mosaics, and should be useful in studying relations between pedimentation and structure, lithology, and topography.

NORTH AFRICA AND ARABIAN PENINSULA

Figure 5, taken over Mauritania during the 12th revolution, is a good example of opportunistic photography carried out during the flight. The Richat structures were not specifically listed as

Figure 5—Richat structures, Mauritania; north at lower left. Smaller structure is just above and left of spacecraft nose.

subjects, although the crew had been asked to look for any large circular features which might be the roots of impact structures. The Richat structures are of considerable interest because of the reported discovery of coesite in breccia from the center of the large feature by Cailleux, et al. (1964). This picture throws no obvious light on the problem of origin, but is of value in demonstrating the ability of hyperaltitude photography to show large structures in their entirety and in relation to surrounding areas.

Figure 6 shows a portion of the Tibesti Mountains in the Republic of Chad, North Africa; the crater at left center is Emi Koussi, a recent volcano. Although not taken under optimum conditions—note, for example, the scattered light on the window and the extreme foreshortening—this picture is of considerable geologic interest. The concentric pattern in the foreground, a combination of fractures and longitudinal sand dunes, is not shown in its entirety on even the latest topographic maps of the area (the Largeau 1:1,000,000 sheet, Institut Géographic National, Paris, 1961), nor is there any known mention of it in recent geologic references (Gerard, 1958). This picture again demonstrates the usefulness of hyperaltitude photography in studying regional fracture patterns, as suggested by Lowman (1964) and Morrison and Chown (1964).

Another feature not previously mentioned in the geological literature is the circular structure below and to the right of Emi Koussi (110 kilometers S, 42° W of Emi Koussi). It appears to be a series of concentric ridges, with a maximum diameter of 18 kilometers, in what Gerard (1958) shows as Upper Devonian sandstone. The nearness of the structure to the Quaternary volcanics of the Tibesti Mountains suggests an igneous origin (e.g., a laccolith) for it. However, its similarity to probable fossil impact structures such as the Clearwater Lakes (Dence, 1965) and to the Richat structures suggests that this possibility be investigated.

Figures 7, 8, and 9 are an overlapping series taken in drifting flight during the 24th revolution over Yemen and the Aden Protectorate, in the southwest part of the Arabian Peninsula. They provide an excellent synoptic view of an area which has to date been mapped only on a reconnaissance scale (see "Geologic Map of the Arabian Peninsula, 1:2,000,000; 1963; U.S. Geological Survey).

The area shown in Figure 7 is underlain chiefly by Precambrian granite gneiss (to the north) and Upper Jurassic limestones, marls, and shales, separated by a major normal fault, according to the USGS 1:2,000,000 map. The fault is expressed by what may be an erosional scarp, judging from the presumed relative resistance of the two major rock types. This picture would appear to be of great value in studying the structure of the area: in addition to the fault shown on the map, several directions of jointing and faulting not shown are obvious. The alluvium/bedrock contact could also be delineated more precisely.

Figures 8 and 9 are oblique views to the southeast. In addition to the structure of Precambrian areas in the foreground (also covered by Figure 7) and top center, they show an extensive field of longitudinal dunes in the Empty Quarter. The dunes appear similar to those in the Sahara Desert classified as "complex longitudinal" dunes by Smith (1963). These photographs provide an excellent overall view of the dune field permitting, for example, study of changes in morphology as a function of distance from the crystalline highlands. The availability of color photographs, whose potential value in dune studies is cited by Smith (1963), adds to the usefulness of hyperaltitude photography.

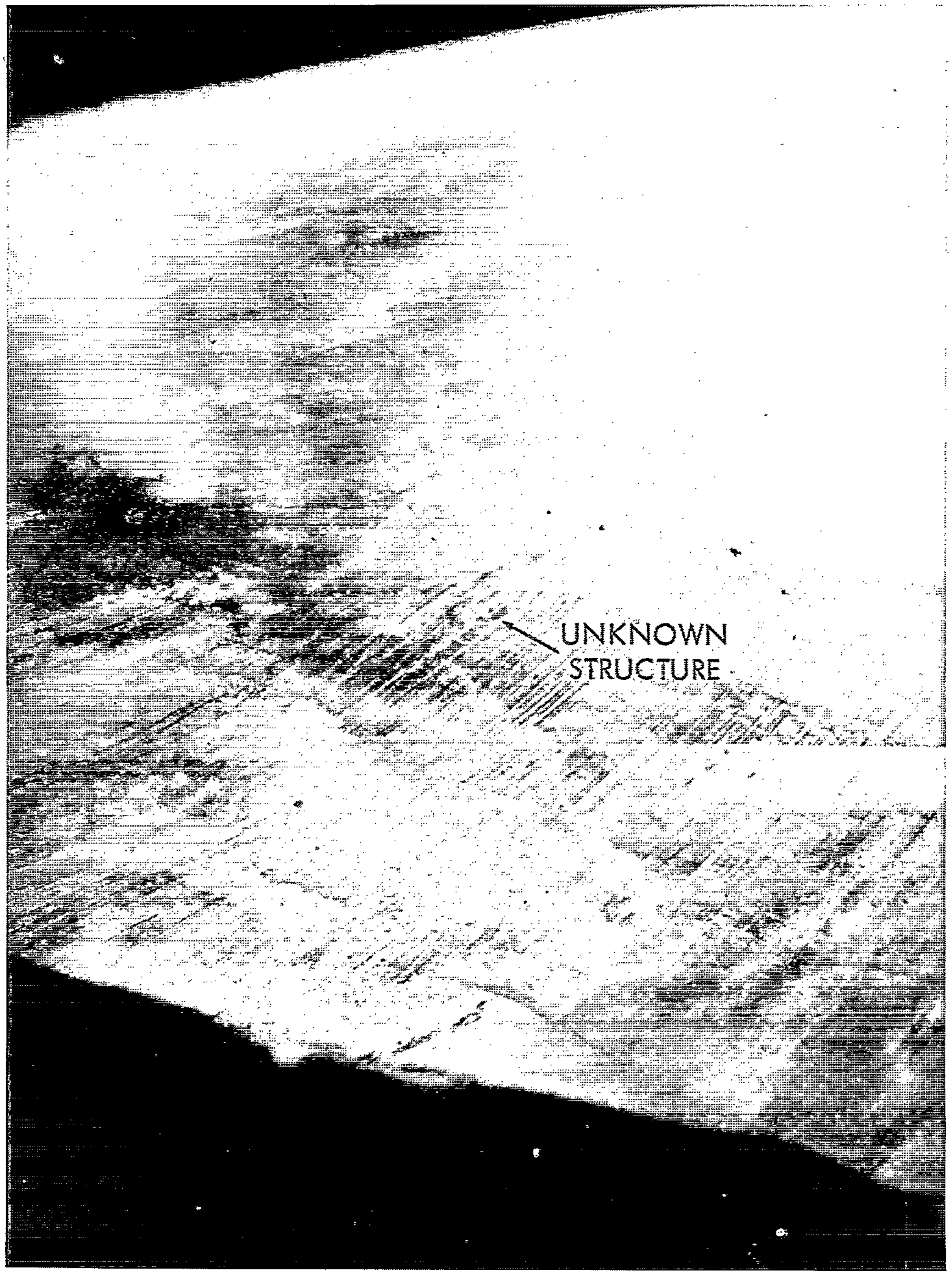

Figure 6—Tibesti Mountains, Republic of Chad; view to northwest. Prominent crater in mountains (left center) is Emi Koussi, highest point in Sahara Desert.

Figure 7—Mountains in southwestern part of Arabian Peninsula; Empty Quarter at lower right. Chiefly Precambrian crystalline rocks, considerably jointed and faulted.

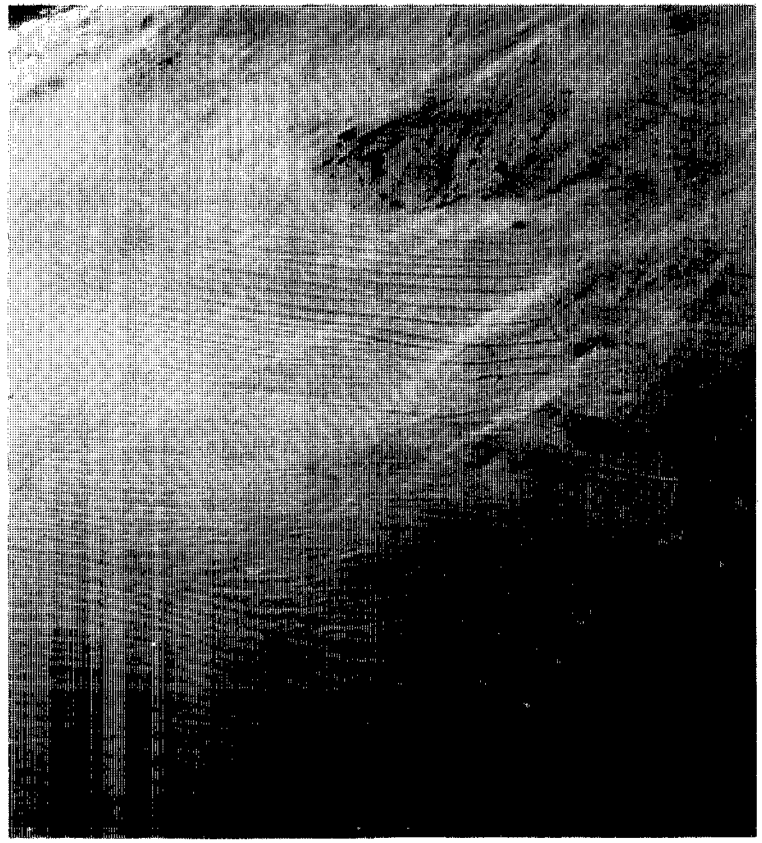

Figure 8—Southwestern part of Arabian Peninsula, overlapping area of Figure 7 (lower right). Seif dunes in Empty Quarter.

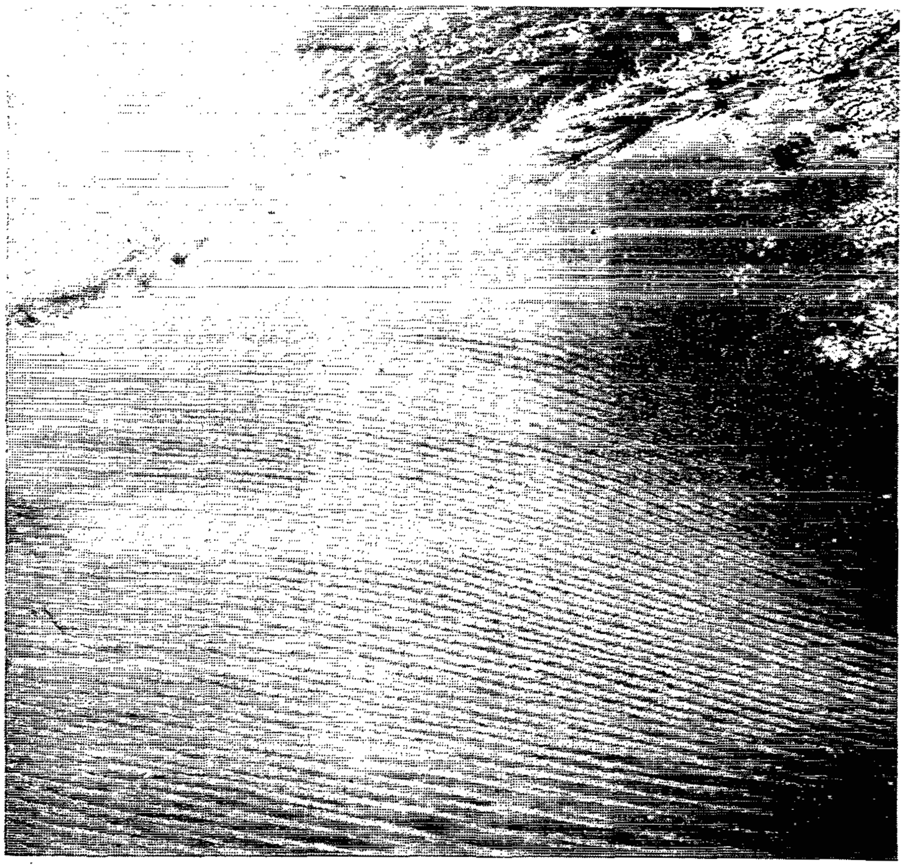

Figure 9—Southwestern part of Arabian Peninsula, just east of Figure 8; seif dunes in Empty Quarter. Northern edge of Hadramaut Plateau in background.

Figure 10 shows the eastern end of the Arabian peninsula. The shoreline at far right (arrow) is that used in the edge analysis described previously. The land area shown is underlain by a variety of Tertiary and Cretaceous sedimentary rock; the linear ridges at lower left are sand dunes.

Figure 11 was taken over the southern part of the Arabian Peninsula, looking over the Hadramaut Plateau toward the Gulf of Aden. It provides an excellent example of stream piracy (arrow), in which one stream (the Wadi Adim) has cut headward under structural influence and intercepted the headwaters of other streams (such as the Wadi al Ayn); these wadis are now usually dry. It is interesting to note that this feature is not apparent on the 1:2,000,000 scale Geologic Map of the Arabian Peninsula, although this scale is larger than that of the original Gemini photograph. The picture is also of interest as a striking example of a dendritic drainage pattern in a morphologically youthful region.

Figure 10—Eastern end of the Arabian Peninsula; Ras al Hadd at far right. Linear features at lower left are the Wahibah Sands, a large dune field. Mountains underlain by Cretaceous and Tertiary igneous and sedimentary rocks.

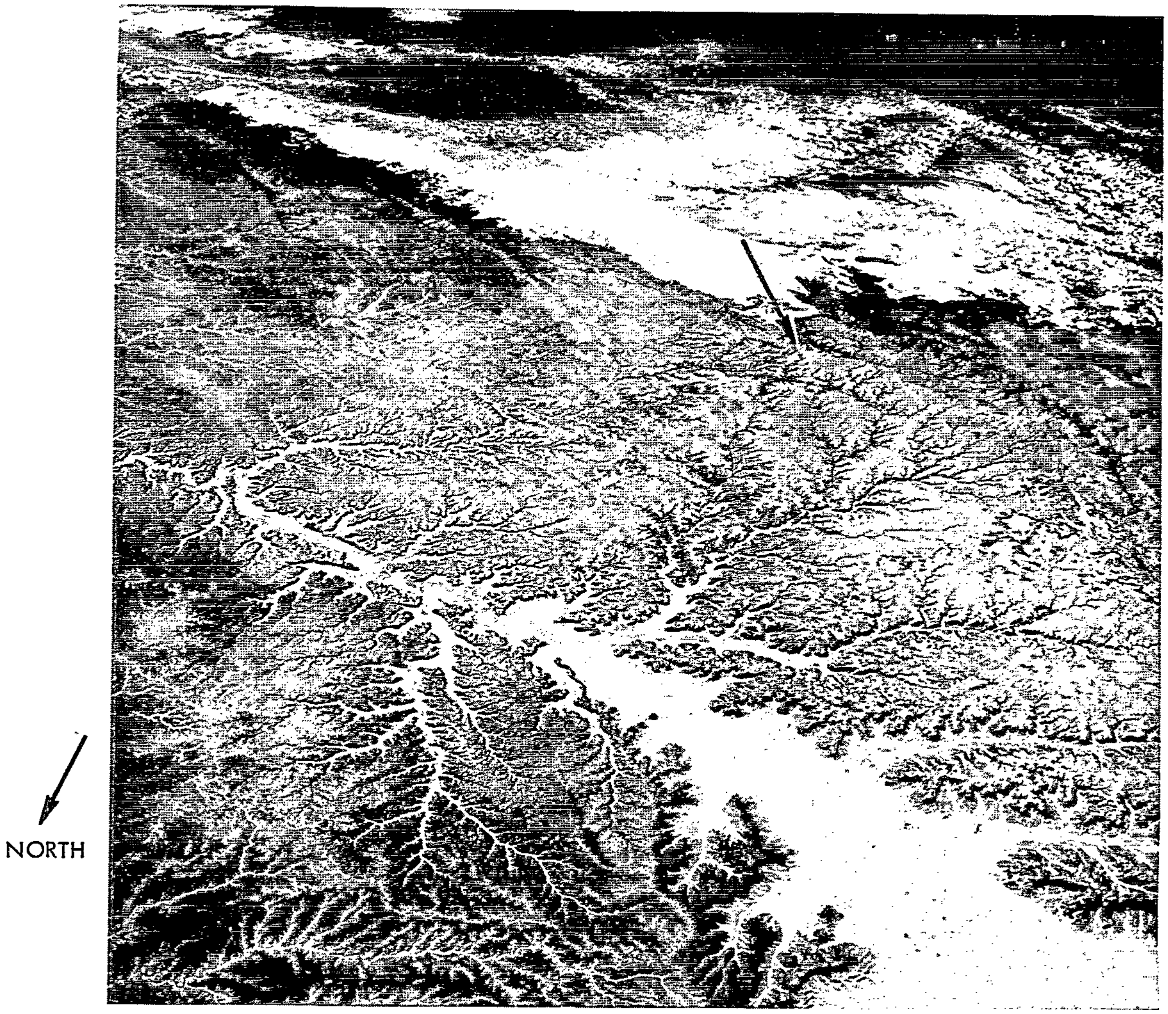

Figure 11—View to southeast over the Hadramaut Plateau, showing the Hadramaut Wadi, a dendritic drainage pattern of canyons. Plateau is underlain by nearly flat-lying or gently dipping Cenozoic sedimentary rocks.

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