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# TERRAIN PHOTOGRAPHY FROM GEMINI SPACECRAFT: FINAL GEOLOGIC REPORT

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GSFC

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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## ABSTRACT

This paper summarizes the objectives, methods, equipment, and main geologic results of the Synoptic Terrain Photography Experiment (S005) carried out by the astronauts during several Gemini missions in 1965-1966. The objective of the S005 experiment was to obtain 70 mm color photographs of the earth's surface for geologic, geographic, or oceanographic study. The pictures were taken by the crews using hand-held cameras with 38 mm, 80 mm, and 250 mm focal length lenses; approximately 1100 usable for geologic purposes were obtained, covering various areas between 32° N and 32° S. Geologic applications of these photographs reported here include the following. (1) An unmapped Quaternary volcanic field in northern Mexico has been discovered, including over 30 volcanoes and associated basalt flows and pyroclastics. (2) Pictures of northern Baja California indicate that the Agua Blanca fault has not had major lateral movement as a whole, and is not one of the transform faults along which the Gulf of California is thought to have opened by sea floor spreading. (3) The Texas Lineament in southwest New Mexico and southeast Arizona has been shown to be a broad belt of intergrading folds and faults, rather than a major wrench fault. (4) Several thousand square miles in North Africa have been found to be eroded primarily by deflation and wind abrasion, suggesting that the importance of wind erosion in the Sahara is far greater than in North American and other deserts. (5) High areas in deserts shown on Gemini photographs are almost invariably darker in color than low areas, except for irrigated farms, suggesting that the dark areas of Mars are relatively high regions of bedrock and the light areas lower regions of windblown sand. (6) Speculative thinking on tectonic questions of southwest Asia, India, and North America has been stimulated by unexpected views of regional geologic structure.

The S005 experiment has demonstrated the potential value of orbital photography in natural resource management, regional tectonic studies, geologic mapping,

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geomorphology, and geologic education. It has clarified the problems of orbital photogeology, including lithologic determination from space, vegetation and soil cover, time requirements for field checking, and resolution limits. Most important is the stimulus given to the NASA Earth Resources Program, to the USGS Earth Resources Observation Satellite Program, and to remote sensing in general. It has also provided a demonstration of the scientific value of man in space and of the Apollo lunar landing program (of which the Gemini missions were part).

Note: Dissemination of all NASA earth-orbital photographs is the responsibility of:

Technology Application Center
University of New Mexico
P.O. Box 181
Albuquerque, New Mexico 87106.

Most Gemini photographs have been printed, in color, in these publications

Earth photographs from
Gemini III, IV, V
(NASA SP-129; $7.00)

Earth photographs from
Gemini VI through XII
(NASA SP-171, $8.00).

These may be ordered from the U.S. Government Printing Office, Washington, D.C. 20402.

CONTENTS

# TERRAIN PHOTOGRAPHY FROM GEMINI SPACECRAFT: PRELIMINARY GEOLOGIC RESULTS

## INTRODUCTION

During the ten manned orbital flights of the Gemini Program, the astronauts took over 2400 70 mm color photographs for various purposes. Among these were pictures of the earth's surface taken as part of the Synoptic Terrain Photography Experiment (S005), whose objective was to obtain photographs of selected areas for geologic, geographic, and oceanographic study. The purpose of this paper is to summarize the objectives, methods, equipment, and main geologic results of the (S005) experiment. A further purpose is to discuss the advantages and disadvantages of orbital photography for geologic purposes in the light of experience from the Gemini Program.

The success of the terrain photography experiment was due to the work of many people and organizations. First among these are the astronauts (named in Table I) who took the pictures, frequently under difficult circumstances; it should be made clear that these men were cooperating scientists as well as engineering test pilots. Other Manned Spacecraft Center personnel who made vital contributions to the photography were R. D. Mercer and R. W. Underwood, experiment monitors, the members of the Experiments Section, Flight Crew Support Division, and the Photographic Technology Laboratory. Valuable support and encouragement were provided by Drs. John A. O'Keefe (Goddard Space Flight Center) and Jocelyn Gill (National Aeronautics and Space Administration). Field work in Baja California and Chihuahua was done in cooperation with Ings. G. P. Salas, F. Guerra Peña, and F. Garcia Castañeda, of the Consejo de Recursos Naturales No Renovables, Mexico, who are conducting an independent investigation with the Gemini photographs. Finally, we have benefited from geologic discussions with many colleagues, especially W. A. Fischer, S. J. Gawarecki, C. R. Warren, and W. R. Hemphill (U. S. Geological Survey), R. L. Stevenson (Bureau of Commercial Fisheries), H. W. Blodget and J. M. Mead, (Goddard Space Flight Center), E. Sherkarchi (U. S. Bureau of Mines), M. Abdel-Gawad (North American Rockwell), C. C. Reeves (Texas Technological College), P. E. Damon (University of Arizona), and J. W. Salisbury (Air Force Cambridge Research Laboratory).

The Gemini terrain photography experiment was the outgrowth of a similar experiment carried on the MA-8 and MA-9 Mercury flights in 1962 and 1963 (Lowman, 1964), in which a number of geologically usable pictures (chiefly of Tibet) were obtained. Earlier, several hundred 70 mm color high obliques, including many of North Africa, had been returned by the unmanned MA-4 flight;

Table I
Terrain Photography on Gemini Flights

| | Flight | Camera | Films | Geologically Usable Pictures | Land Areas Covered |
|---|---|---|---|---|---|
| V. Grissom, J. Young | 3 | Hasselblad 500C | Ektachrome | 7 | NW Sonora, Rio Grande Valley, Bermuda |
| J. McDivitt, E. White | 4 | Hasselblad 500C | Ektachrome | 100 | NW Mexico, SW U.S.A., N. Africa, Bahama Islands, Arabian Peninsula |
| L. Cooper, C. Conrad | 5 | Hasselblad 500C | Ektachrome<br>Super Anscochrome | 175 | SW U.S.A., Bahama Islands, South West Africa, Tibet, India, SW Asia, China, Australia |
| W. Schirra, T. Stafford | 6 | Hasselblad 500C | Ektachrome | 60 | NW, central and eastern Africa, Australia, Canary Islands |
| F. Borman, J. Lovell | 7 | Hasselblad 500C | Ektachrome<br>Ektachrome IR | 250 | N Africa, Arabian Peninsula, India, Caribbean Sea and adjacent land areas, Brazil, Mexico; infrared film: Gulf Coast, U.S.A.; northeast Brazil |
| T. Stafford, E. Cernan | 9 | Hasselblad 500C<br>Hasselblad SWC<br>Maurer Space Camera | Ektachrome | 160 | N Africa, northern South America, Caribbean Sea, Mexico |
| J. Young, M. Collins | 10 | Maurer Space Camera<br>Hasselblad SWC | Ektachrome | 75 | N Africa, China, Taiwan, NE South America |
| C. Conrad, R. Gordon | 11 | Maurer Space Camera<br>Hasselblad SWC | Ektachrome | 102 | N Africa, Arabian Peninsula, S India, NW South America, Gulf Coast of U.S.A. |
| J. Lovell, E. Aldrin | 12 | Maurer Space Camera<br>Hasselblad SWC | Ektachrome | 160 | Southern U.S., N Mexico, N Africa, SW Asia, Arabian Peninsula |

NOTE: Spacecraft altitudes in Gemini flights ranged from about 100 to 200 statute miles. On Gemini 10, an altitude of about 475 miles was attained in the 12th revolution. On the Gemini 11 flight, the orbit was changed for two revolutions from about 174 statute miles (circular) to 174 (perigee) and 850 (apogee) statute miles. Most of the pictures taken on Gemini 11 were from the two high revolutions, at altitudes of about 400 to 850 miles.

although not as good as later pictures, these were successfully used by Morrison and Chown (1964) in the first regional application of orbital photography. Valuable intensive analyses of sounding rocket photography were done by Merifield (1964). Reviews of the geologic application of orbital photography have been compiled by Lowman (1967, 1969) and Garcia (1966). An early version of this report was published in "Short Course Lecture Notes, Remote Sensing" (Reeves, et al., 1968).

A number of geologic studies using the Gemini and Apollo photography are in progress as this paper is written; these include investigations of the tectonics of the Red Sea by M. Abdel-Gawad, the tectonics of Saudi Arabia by H. W. Blodget, sedimentation phenomena by F. J. Wobber, geology of northern Baja California by G. P. Salas, G. Guerra Peña, and F. Garcia Casteneda, and structure of the Delaware Basin by R. V. Trollinger.

## THE SYNOPTIC TERRAIN PHOTOGRAPHY EXPERIMENT

### Objective and Methods

The original objective of the Synoptic Terrain Photography Experiment (S005) was to obtain high-quality, small-scale color photographs of selected land areas for geologic study (Lowman, 1966). However, the striking quality and coverage of the pictures from Gemini III, IV, and V demonstrated the value of such photography in other fields. Accordingly, the scope of the experiment was expanded from Gemini VI-A on to include areas of geographic and oceanographic interest as well. Meteorological photography was covered by the Synoptic Weather Photography Experiment (S006), with the same cameras and films. Principal investigators for this experiment were K. M. Nagler and S. D. Soules of the Environmental Science Services Administration. It should be stressed that the S005 and S006 experiments were only two of a total of fifty-two carried on the ten manned Gemini flights (Foster and Smistad, 1968). Furthermore, the experiments were all subsidiary to the main objectives of the Gemini Program, which were essentially to develop the capability for long, complex space missions (Mueller, 1967).

The areas for terrain photography were picked before each mission (Fig. 1) on the basis of previous coverage, availability (latitude, daylight, and probable weather), scientific value, and specific requests from cooperating agencies (chiefly the U. S. Geological Survey, Navy Oceanographic Office, and Bureau of Commercial Fisheries). The area list and priorities varied from one flight to another, but the areas generally desired were, in order of importance, the following:

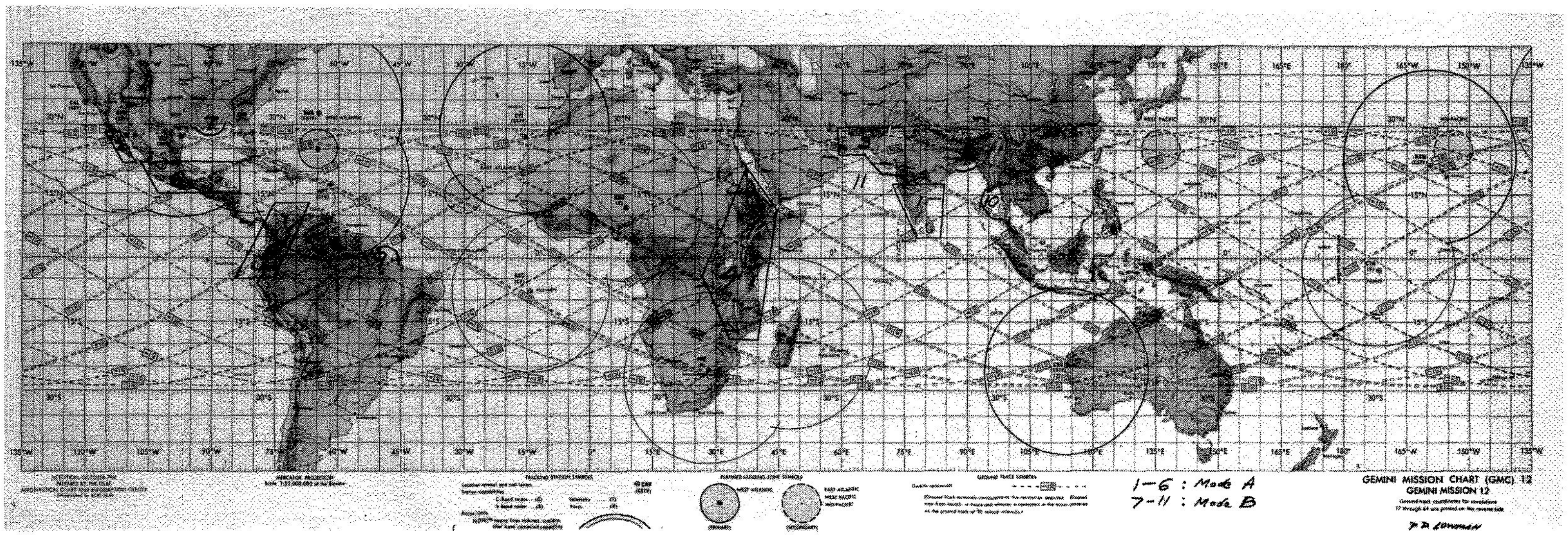



Figure 1. Flight path map for typical Gemini mission, showing targets selected for photography as part of the S005 experiment.

1. S.W. United States and northern Mexico (for coverage of a geologically important area with considerable ground truth available)

2. Northern Red Sea and adjacent land areas (for study of the Rift Valley)

3. North Africa (a well-exposed shield area; for study of regional fracture patterns, volcanic fields, vegetation zones, and possible impact structures)

4. East Africa (southern parts of the rift valleys)

5. Northern South America (Andean structure)

6. West Pakistan (area under study by U.S.G.S., with potential mineral deposits and considerable ground truth)

7. Southern India (area under study as part of Upper Mantle Project)

8. N.W. Australia (well-exposed shield area; to study regional fracture patterns and possible impact structures)

9. S.E. Brazil (shield area with mineral deposits; also, study of continental drift)

10. Ocean off major river mouths, such as the Mississippi, Amazon, Congo, Ganges, Irrawaddy, and others (effluent patterns and sedimentation).

In addition to these, a large number of relatively small, specific areas were included in the S005 experiment plan; many of these were oceanic islands requested by the Navy Oceanographic Office, or specific physiographic features. The crews on later missions were asked to photograph the glitter pattern (sun's reflection) whenever possible.

Because of the many types of photography required of the astronauts during the Gemini Program, they were intensively trained in this subject by the Photographic Technology Laboratory. For the terrain photography, the crews were given one or two briefings covering the following subjects.

1. Experiment objectives (Fig. 2): These were as stated previously. In briefings for later flights, some time was devoted to summarizing progress to date, with examples of good and bad photography from previous missions.

2. Areas to be covered: With the aid of flight path maps (Fig. 1), the areas desired were discussed in order of priority, with as much time as possible

## EXPERIMENT S-005

## SYNOPTIC TERRAIN PHOTOGRAPHY

### PURPOSE

To improve and extend the techniques of synoptic geologic and topographic aerial photography.

### SPACECRAFT SYSTEMS CONFIGURATION

1. Attitude control - PULSE

2. Unstow - 70mm Camera
   Ring sight
   Film magazine
   80mm lens

### PROCEDURES

1. Assemble and prepare camera and accessories for photography.

2. Record time, sequence or subject, mode, magazine number and frame number on the onboard voice recorder and/or log book.

3. Pitch spacecraft straight down, if possible, to obtain photographs of selected terrain.

4. Control roll as required to keep sun glare from spacecraft window.

MODE A - Strip photos - one frame every 5 sec.

| SEQ | LOCATION |
|---|---|
| 01 | Southern India |
| 02 | Lower Baja California |
| 03 | West Pakistan & Gulf of Cambay |
| 04 | African Rift Valley |
| 05 | Northwest So. America |
| 06 | South Mexico, Yucatan Penn, Yucatan Straits |
| MODE B - 2 or 3 frames | |
| 07 | Mississippi Delta |
| 08 | Ganges Delta |
| 09 | Amazon Delta |
| 10 | Bay of Bengal |
| 11 | Arabian Sea |

Figure 2. Instructions for S005 experiment in flight plan for Gemini 12 mission; areas listed are shown on flight path map (Fig. 1). Flight plan prepared by Flight Crew Support Division, Mission Operations Branch, Manned Spacecraft Center.

being spent on the geologic reasons for studying each region. In all briefings, it was stressed that good pictures of any land area would be of value if planned areas could not be covered because of clouds or other reasons.

3. Techniques (Fig. 3): The crews were requested to take vertical pictures at 5 second intervals to obtain 25-mile separation between photographs and roughly 60% overlap at normal altitudes (generally between 100 and 200 statute miles). Recommended time for photography was local noon plus or minus three hours, to avoid having to change camera settings, which were generally f 11 at 1/250 second for Ektachrome. Measures to avoid stray reflections and scattering from the windows were also discussed.

The crews followed the planned procedures (Fig. 4) as much as possible; their skill and perseverance in this is demonstrated by the quality and quantity of the pictures returned. Three main problems were encountered. First, fuel or electrical power restrictions (preventing use of the inertial platform) frequently prevented the crew from pointing the spacecraft straight down; because of this, many of the terrain pictures are high obliques. Second, cloud cover, especially over jungles, frequently obscured the primary areas. Finally, window obscuration by deposits from boost phase ablation, rocket exhaust during staging, and window gasket degassing degraded some pictures. This problem was especially severe on Gemini VII.

A detailed discussion of operational difficulties has been presented by Lowman (1969).

## Cameras and Films

Three 70 mm hand-held cameras (Fig. 5) were used during the 10 manned flights for operational, weather, and terrain photography (Thompson, 1967; Underwood, 1968)

1. Hasselblad 500-C — This camera, modified for space use and equipped with a 65-frame capacity magazine by Cine Mechanics, Inc., was the basic camera for most terrain photography. The lens used for most pictures was the standard 80 mm Zeiss Planar; a number of pictures were taken on Gemini VII with the 250 mm Zeiss Sonnar telephoto lens.

2. Maurer Space Camera — This camera was developed especially for astronaut use, and could accommodate a wide variety of components. Terrain photography with the Maurer was done with the 80 mm Schneider Lens.

3. Hasselblad Super Wide Angle — The 90° field of view of the Zeiss Biogon lens made this camera useful for general purpose photography, but a large

## EXPERIMENT S-5
## SYNOPTIC TERRAIN PHOTOGRAPHY

1. <u>CONFIGURATION:</u> NOT CRITICAL

2. <u>TIME</u> 33 GMT [illegible]

| RUN | AREA | TIME FROM | TIME TO | REV |
|---|---|---|---|---|
| 1 | AFRICA | 24:00 | 24:20 | 16 |
| 2 | AFRICA | 43:10 | 43:15 | 28 |
| 3 | U.S. | 48:50 | 49:00 | 31 |

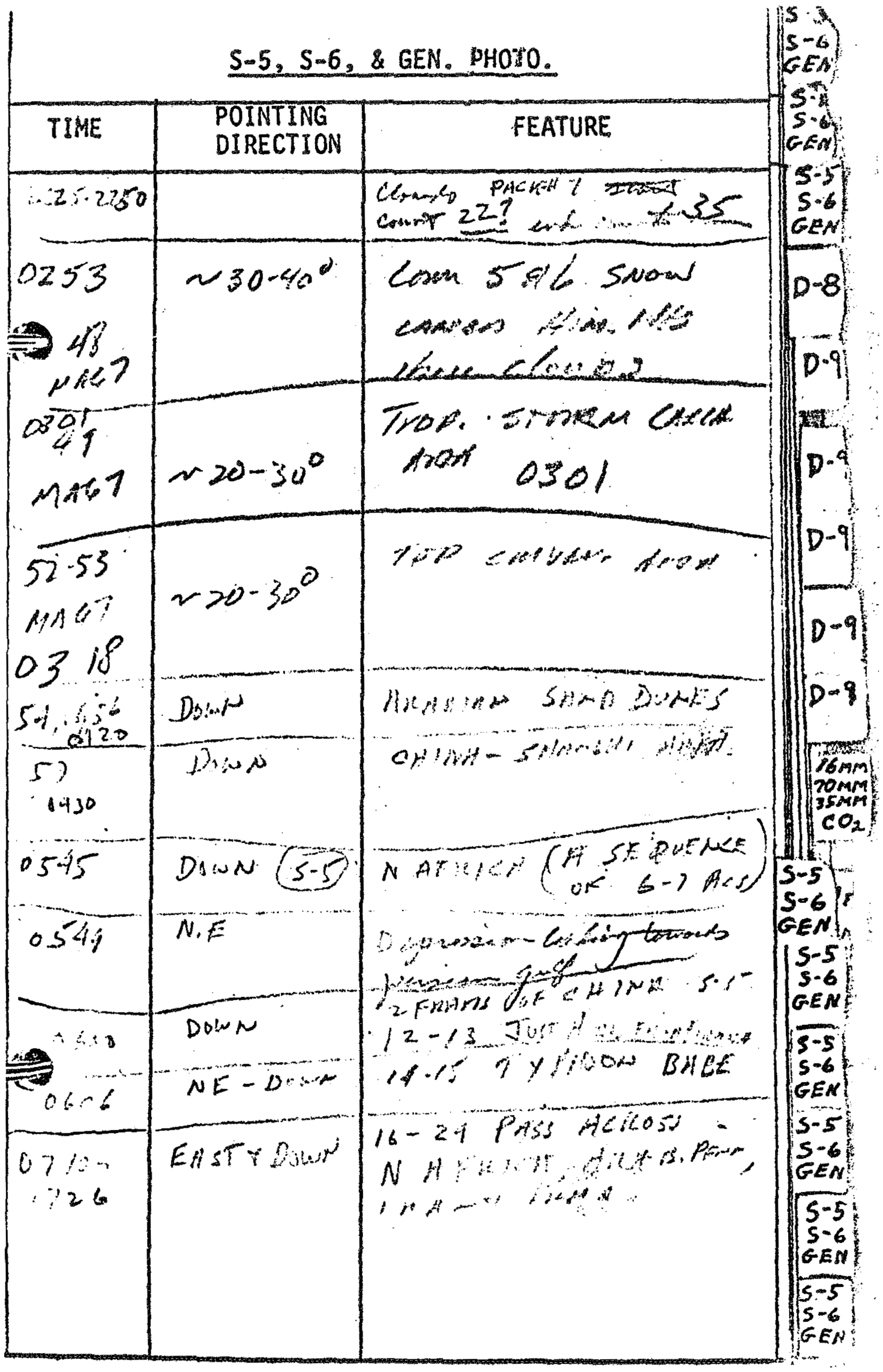
TAKE PHOTOS BETWEEN 0900 & 1500 LOCAL TIME

3. <u>PROCEDURES</u>

UNSTOW:
- HASSELBLAD CAMERA
- PHOTO-EVENT INDICATOR
- RING SIGHT
- UV FILTER
- FILM BACK

VERIFY AUX RECP - OFF
PREPARE THE HASSELBLAD CAMERA & ACCESSORIES FOR PHOTOGRAPHY
AUX RECP - ON
MARK TIME AND RECORD EXP TO BE ACCOMPLISHED ON ONBOARD VOICE RECORDER
ATT CNTL - PULSE
CONTROL S/C ATT AS REQ'D TO OBTAIN PHOTOS OF SELECTED TERRAIN
MARK EACH PHOTOGRAPH ON THE VOICE RECORDER
CONTROL ROLL AS REQ'D TO KEEP THE S/C WINDOW IN THE SHADE
IF WEATHER PERMITS, THE PASS OVER THE SOUTHWESTERN U.S. WILL BE USED TO OBTAIN STRIP PHOTOS (ONE PHOTOGRAPH EVERY 5 SEC, 35 PHOTOS)
IF WEATHER DOES NOT PERMIT STRIP PHOTGRAPHY OVER U.S., THEY WILL BE ATTEMPTED OVER EAST AFRICA & NORTHERN MEXICO IN THAT ORDER.

Figure 3. Instructions for S005 experiment in crew's flight booklet for Gemini 4; prepared by Flight Crew Support Division, MSC.



S-5, S-6, & GEN. PHOTO.

| TIME | POINTING DIRECTION | FEATURE |
|---|---|---|
| 2225-2250 | | Clouds PACK 7 COUNT 22? |
| 0253 48 MAG 7 | ~30-40° | Com 5&6 SNOW CAPPED MTS. NO clouds |
| 0301 49 MAG 7 | ~20-30° | TROP. STORM CHECK AREA 0301 |
| 52-53 MAG 7 0318 | ~20-30° | TOP CHIVAN AREA |
| 54, 55, 56 0120 | DOWN | ARABIAN SAND DUNES |
| 57 1430 | DOWN | CHINA - SHANGHAI AREA |
| 0545 | DOWN (S-5) | N AFRICA (A SEQUENCE OF 6-7 PICS) |
| 0549 | N.E | 2 FRAMES OF CHINA S-5 |
| 0606 | DOWN | 12-13 [illegible] |
| | NE - DOWN | 14-15 TYPHOON BABE |
| 0710 - 0726 | EASTY DOWN | 16-24 PASS ACROSS N AFRICA, [illegible] |

S-5 S-6 GEN D-8 D-9 16MM 70MM 35MM $CO_2$

Figure 4. Notes on S005 and S006 experiment taken during flight by Gemini 4 crew J. A. McDivitt and E. H. White, II. Details of photography recorded by crew were helpful in indexing and interpreting pictures.

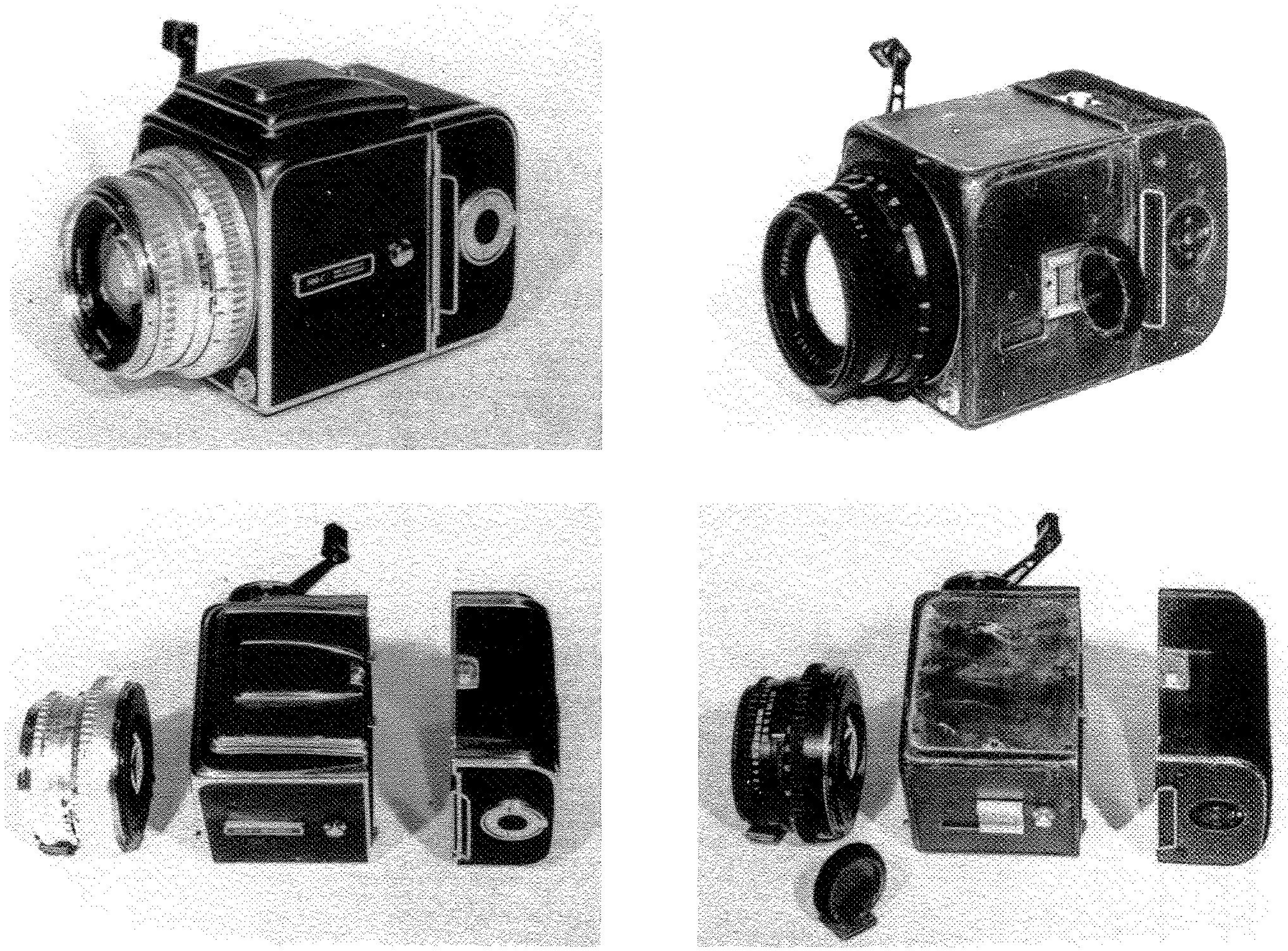


Figure 5. Commercial model Hasselblad 500-C camera at left; NASA-modified 500-C used for S005 and S006 experiments at right. Modifications included removal of single lens reflex viewing system and substitution of ring sight, darkening of exposed metal, space qualification, and addition of a magazine modified by Cine Mechanics, Inc. Camera modifications done by Flight Crew Support Division, MSC. Lens shown is 80 mm focal length Zeiss Planar f 2.8.

number of good terrain photographs were also taken with it despite the short (38 mm) focal length. It was used with the same magazine as the Hasselblad 500-C.

Although standard camera settings, determined by flight testing by the Photographic Technology Laboratory before the missions, were generally used, a NASA-modified Honeywell Pentax 1°/21° narrow-angle spot meter was used on some flights to determine exposures. This was especially useful in situations involving a wide brightness range, such as photographing other spacecraft during rendezvous.

Haze filters (Haze 50 or 63), cutting off light below 3400A, were fitted to the Hasselblads when they were used with ordinary color film. When used with Ektachrome Infrared, an infrared filter cutting off light below 5000 angstroms was fitted. No filters were used for terrain photography with the Maurer 70 mm camera. Polarizing filters were not used because the spacecraft windows were stressed, producing strain polarization.

Most of the terrain pictures were taken with Ektachrome S.O. 217 or S.O. 368 on a 2.5 mil Estar base. One magazine of Anscochrome D-50 was used on Gemini V, and one of Ektachrome Infrared, Type 8443, on Gemini VII.

## PROBLEMS IN PHOTOGRAPH REPRODUCTION

In the course of handling and studying many thousands of orbital photographs, we have encountered several persistent problems in processing and reproduction. Since the original film from orbital flights can be examined only under special conditions, all users must deal with multi-generation reproductions; thus any geologist who uses the Gemini or Apollo photography will encounter the same problems. The following discussion is intended to help avoid them. We are indebted for advice on these points to R. W. Underwood (MSC) and G. Ponder.

Obverse Prints—Standard darkroom technique for making paper prints is to have the negative emulsion facing the paper emulsion (i.e., negative facing down in the enlarger). Because of repeated copying and the use of internegatives (necessary to make color prints from transparencies), routine adherence to the emulsion-to-emulsion convention will frequently result in obverse ("flopped") prints, which are mirror images of the actual scene. The way to avoid this is, first, to warn the processing laboratory about the problem, and, second, to give the darkroom technician a correct print as a guide. A measure now taken by the Manned Spacecraft Center (starting with Apollo 6) is the pre-flight numbering of frames in such a way that when the numbers on the 70 mm film can be read without a mirror, the film is viewed properly.

Poor Color Balance—The flight films from Gemini and Apollo missions are developed with extreme care; for example, full-time chemists monitor the processing solutions, and water is drawn only from specified wells. However, the color balance of paper prints ordered by the ultimate users may be very poor unless certain precautions are taken. First among these, again, is close personal attention by the user to the printing order and process. Second, the darkroom technician should be given a print with proper color balance as a guide. Third, the pre-flight test frames of a standard gray scale, with which each roll of Gemini color film was started (Fig. 6), should be printed as a guide.

Contrast Loss in Black-and-White Prints—Black-and-white negatives made from color film generally have less contrast than the original, and consequently black-and-white prints of Gemini photos frequently have low contrast. This problem is serious if the photos are to again be reproduced for publications. It can be avoided partly by using high-contrast printing paper, but an even more useful technique is to make one or more successive generations of black-and-white negatives. Each generation has more contrast than the previous one, and if done carefully, little detail is lost.

Unknown Scale—Orbital photographs frequently appear in the literature with statements such as "The scale is 1:2,000,000," in which it is not made clear that this was the scale of the original image. This confuses the reader; the easiest way to prevent this is to put a graphic scale on each photograph, as commonly done with photomicrographs.

Cropping—Darkroom technicians frequently mask a small part of the picture edge when printing photographs, especially in 8" x 10" format. Although this does no harm in ordinary photography, the loss of even a few square millimeters from an orbital print means loss of information from as much as several square miles on the ground. Therefore, great stress must be placed on the avoidance of any cropping whatsoever; a black border should be left around all prints even if it looks like sloppy darkroom technique. Furthermore, since the later Gemini films and all Apollo 70 mm films have pre-flight frame numbers on the film margin, it may be helpful to print the entire width of the film (including sprocket holes).

Care of Film—Users who obtain Gemini or Apollo photographs on 70 mm roll film should be extremely careful to protect the film against dirt and scratches. Scratching is inevitable if the film is examined by rolling across a standard light table, as is necessary if it is not cut. On the other hand, cutting the film into individual frames makes it hard to keep track of the magazines, and tends to obscure the synoptic nature of the coverage on series of photos. A compromise that we have found helpful is to cut the film into 10-frame lengths, which are then kept in flat translucent polyethelyene sleeves. Single frames which are to be intensively studied should be copied individually and mounted in glass slides for protection.

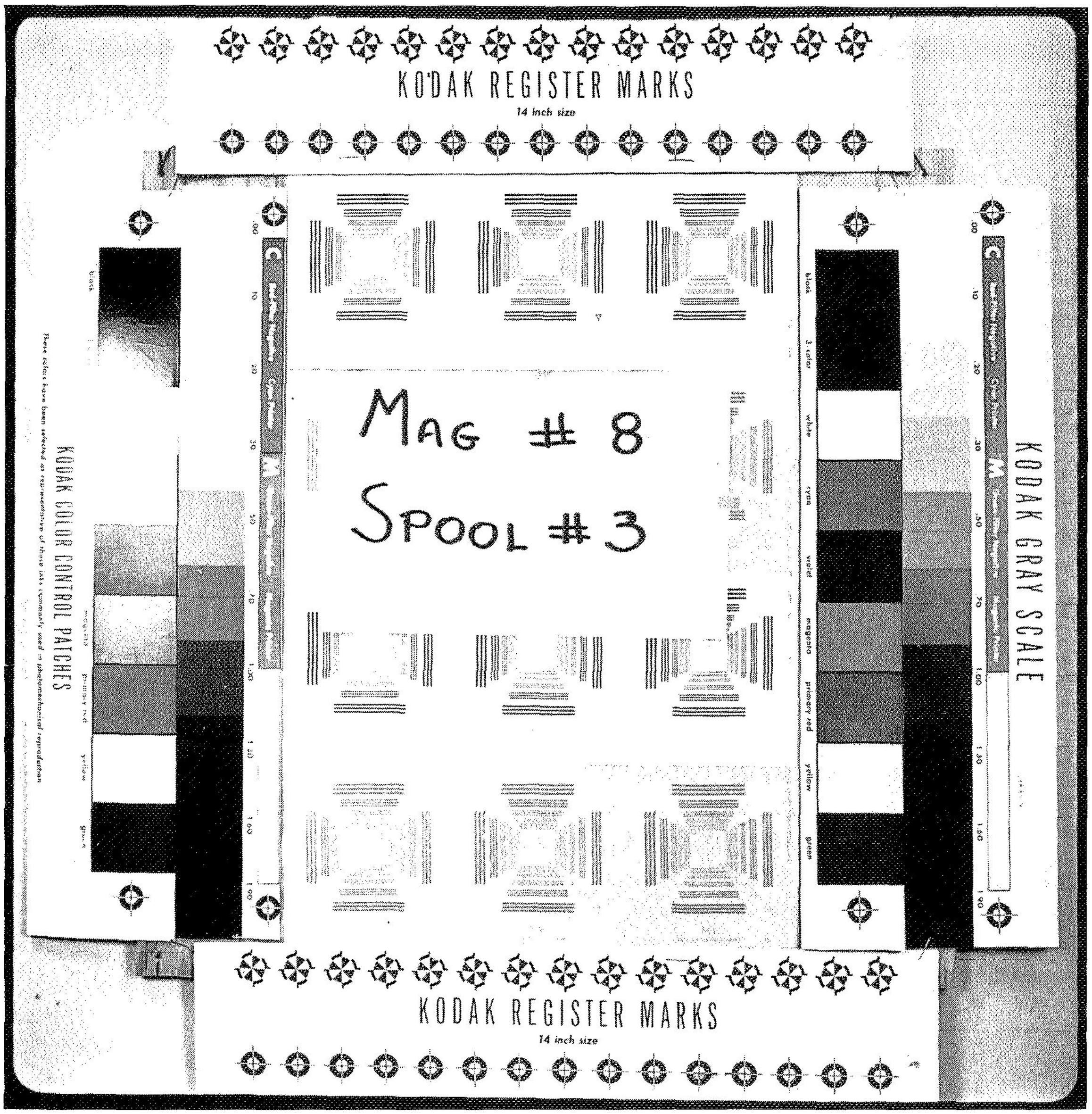



Figure 6. Black-and-white print of test frames exposed by Photographic Technology Laboratory, MSC, at beginning of each 70 mm magazine for control and calibration purposes. Chart includes color patches, gray scale, resolution targets, and register marks. Test frames for some later missions give color temperature of light source used in photograph. Users of 70 mm photography should provide test frames for each magazine to processors in making duplicates or prints.

To summarize, we stress that orbital photographs are in many ways a new medium despite their similarity to air photos, showing strange things from strange viewpoints, and they can not be reproduced successfully by routine procedures. Time spent by the user in cooperating with the processing laboratory will pay off in quality of prints, ease of interpretation, and economy.

## GEOLOGIC RESULTS OF THE S005 EXPERIMENT

### Palomas Volcanic Field

Preliminary examination of the Gemini IV photographs covering northern Chihuahua (Figs. 7, 8, 9, and 10) revealed a volcanic field over 200 square miles in area, southwest of Palomas, not shown on any geologic maps (e.g., Geologic Map of North America, 1965). Further inquiry failed to find any mention of this field in the geologic literature of Mexico or the United States; therefore, a 5-day reconnaissance was made in May, 1967, with the following findings.

There are more than 30 cinder cones or vents in the volcanic field, some of them multiple. Most of the cones are between 100 and 400 feet high, and are generally breached (Fig. 11). Some if not most are composite, consisting of interbedded flows and agglomerates. The age of the field is unknown, although it is evidently Quaternary. The flows correspond morphologically to Colton's Stage 2 of the San Francisco volcanic field in Arizona: the original flow fronts have been obliterated by erosion, but the approximate outline of the flow is still identifiable, especially from the air. The surfaces are generally smooth (Fig. 12) although remnants of the original ridges and possibly spatter cones are occasionally visible. The cones correspond to Colton's Stage 3, in that they are preserved but deeply gullied. In some examples, most of the upper layers of ejecta have been removed (Fig. 13). Colton considered flows in Stage 2 in the San Francisco field to be more than 50,000 years old, although the differences in altitude and climate between that area and northern Chihuahua make it risky to extrapolate such estimates. It seems safe to say that the Palomas volcanoes are no younger than several thousand years, and that the field as a whole is several score thousand years old.

Petrographic examination of samples from several cones and flows in the northeastern half of the volcanic field reveals only one rock type, occurring as flows, agglomerates, dikes, squeezeups, and pyroclastics. This is an olivine basalt composed of unzoned plagioclase ($An_{50}$), an unzoned magnesian olivine (partly altered to iddingsite), clinopyroxene, glass, and magnetite. Inclusions of clinopyroxene and olivine are locally abundant, and a few small dunite inclusions have been found. Some of the bombs found had granite cores.

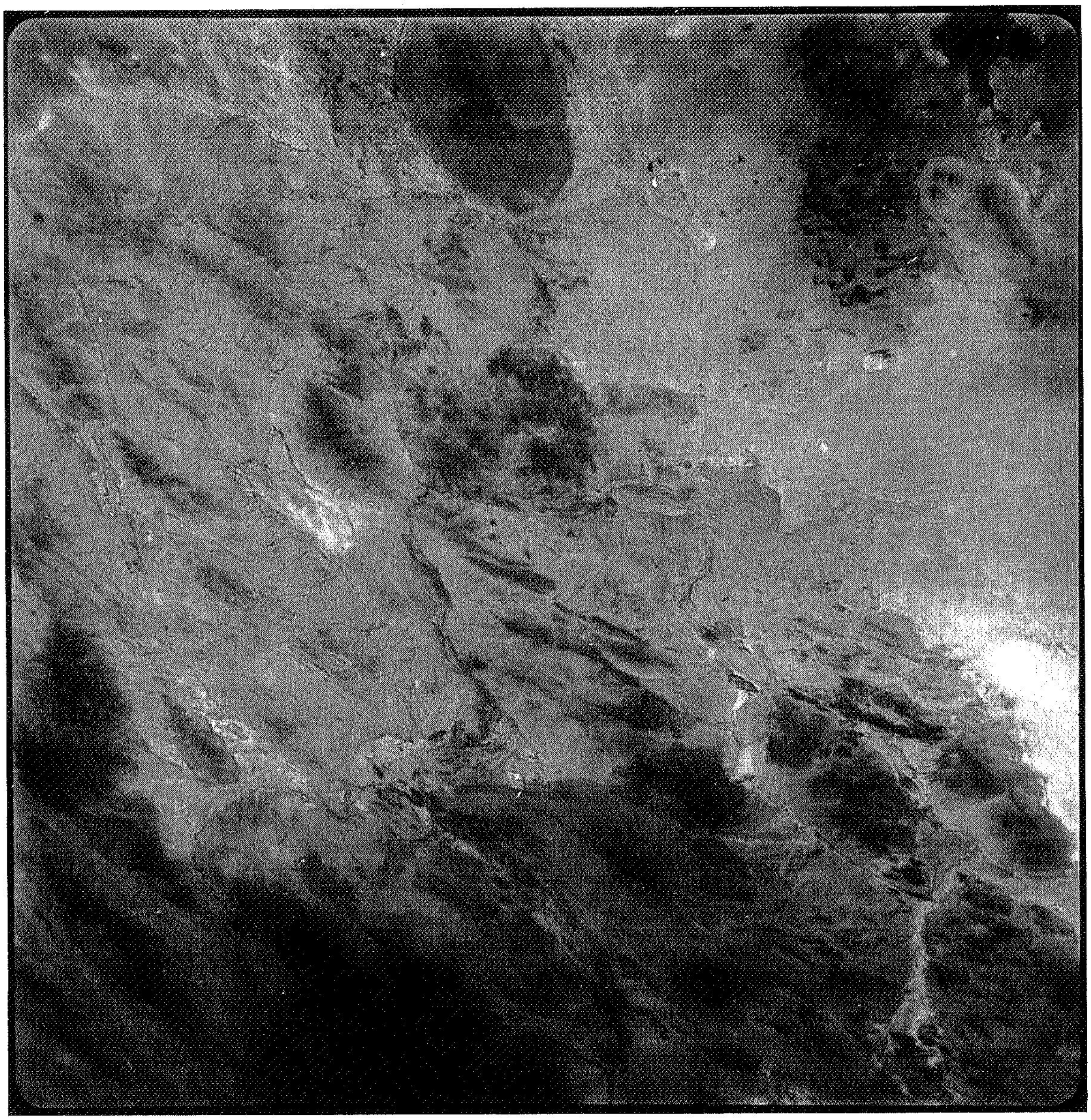
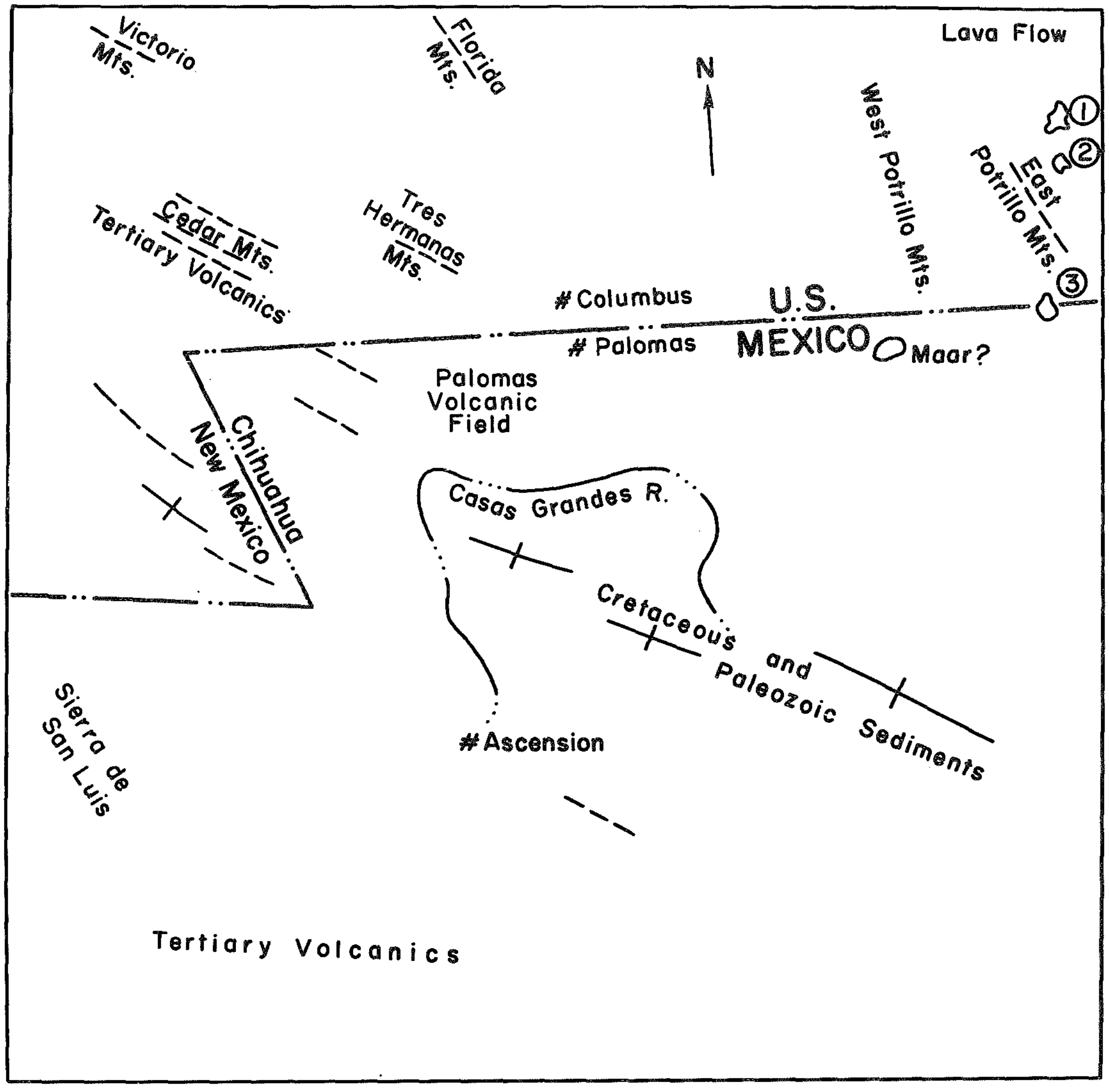


Figure 7. Gemini 4 photograph S-65-34689; see Fig. 8 (facing) for coverage. Note: view is oblique to south, causing considerable foreshortening; compare with Fig. 9.




STRUCTURAL SKETCH MAP
Gemini IV Photograph S-65-34689 (Not Rectified)

10 Miles — Approximate scale at center; Tilt is to South.

- - - - - Probable faults
——+—— Fold axes, generalized

Maars: (1) Kilbourne Hole
(2) Hunt's Hole
(3) Potrillo Maar

P.D. Lowman, 1968

Figure 8. Structural sketch map of Fig. 7.

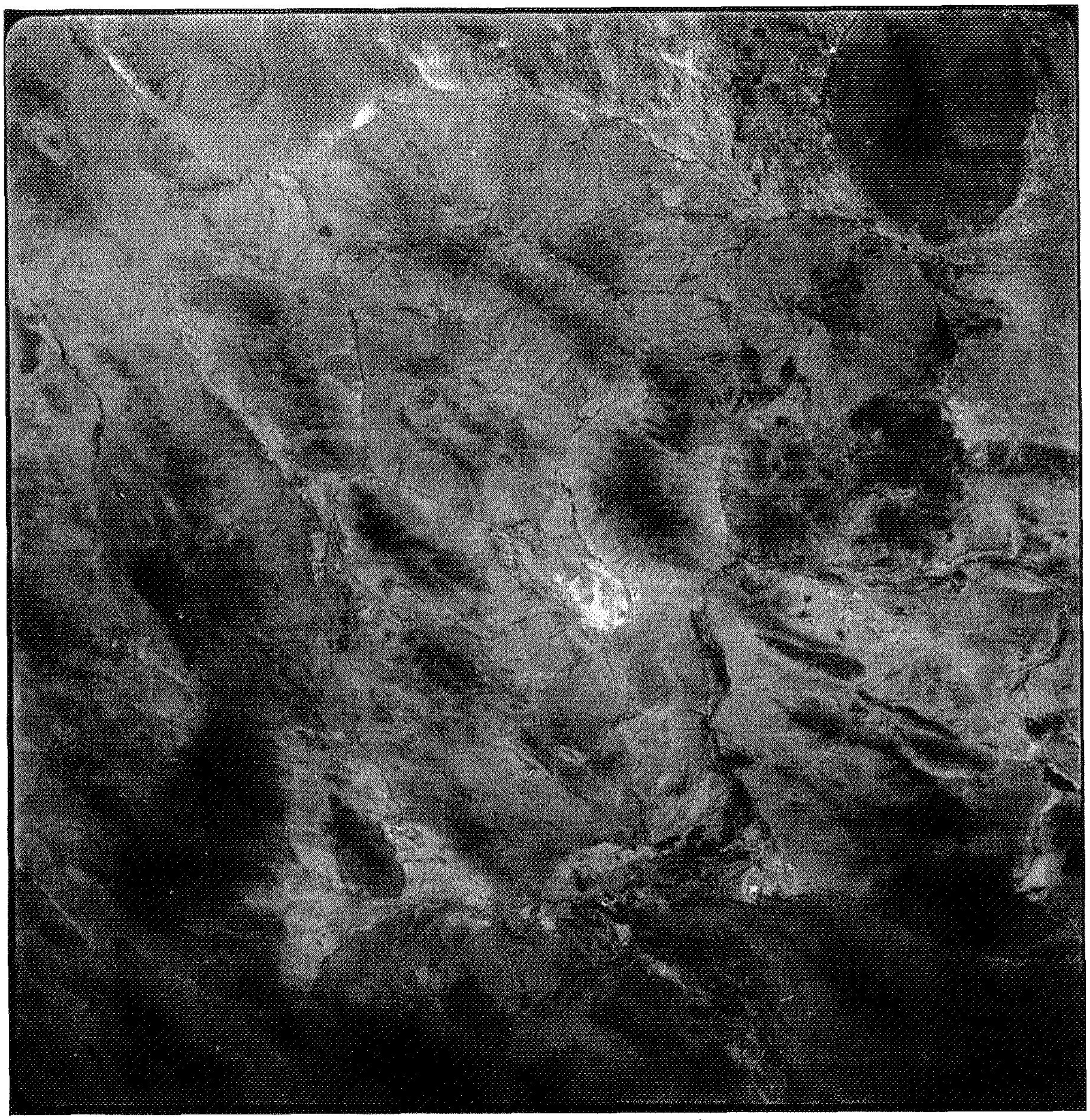
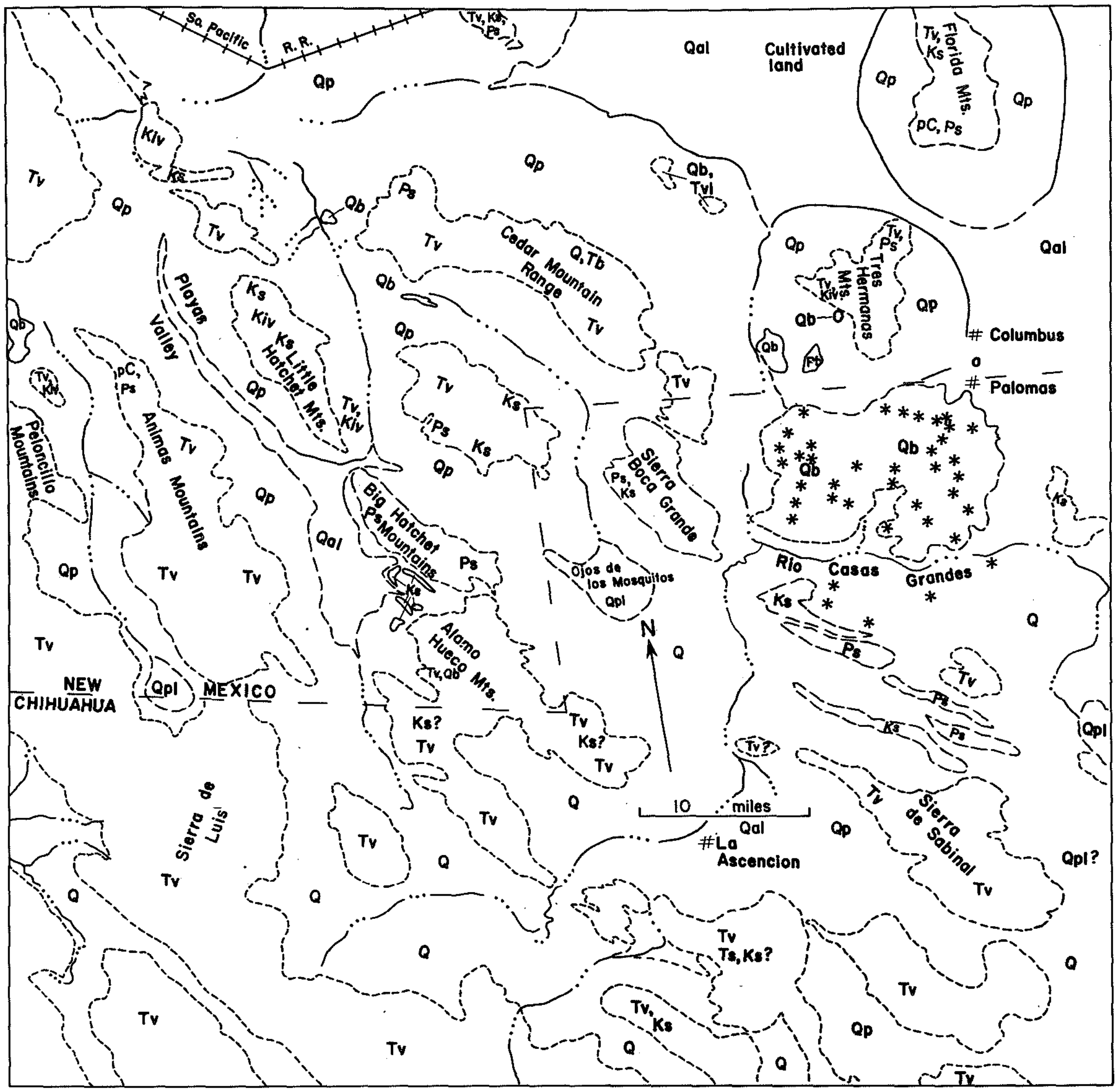


Figure 9. Gemini 4 photograph S-64-34687; see Fig. 10 (facing) for coverage.




P. D. Lowman, Jr.

April, 1968

**GEOLOGIC SKETCH MAP**
**Gemini IV Photograph S-65-34687 (unrectified)**
**Southern New Mexico, Northern Chihuahua**

⟼ 10 miles ⟻
(at center of photo; E-W distance)

Legend

Qal — Quaternary alluvium
Qp — " " pediment deposits
Qb — " " basalt (* marks volcano)
Qpl — " " playa deposits
Tv — Tertiary volcanic rocks (Tvl, latite)

Ts — *Tertiary sedimentary rocks*
Kv — Cretaceous volcanic rocks
Ki — " " intrusive rocks
Ks — " " sedimentary rocks
Ps — Paleozoic sedimentary rocks
pC — Precambrian rocks (undifferentiated)

Lithology from Dane and Bachman (1964);
most of area not field-checked.

Figure 10. Geologic sketch map of Fig. 9.

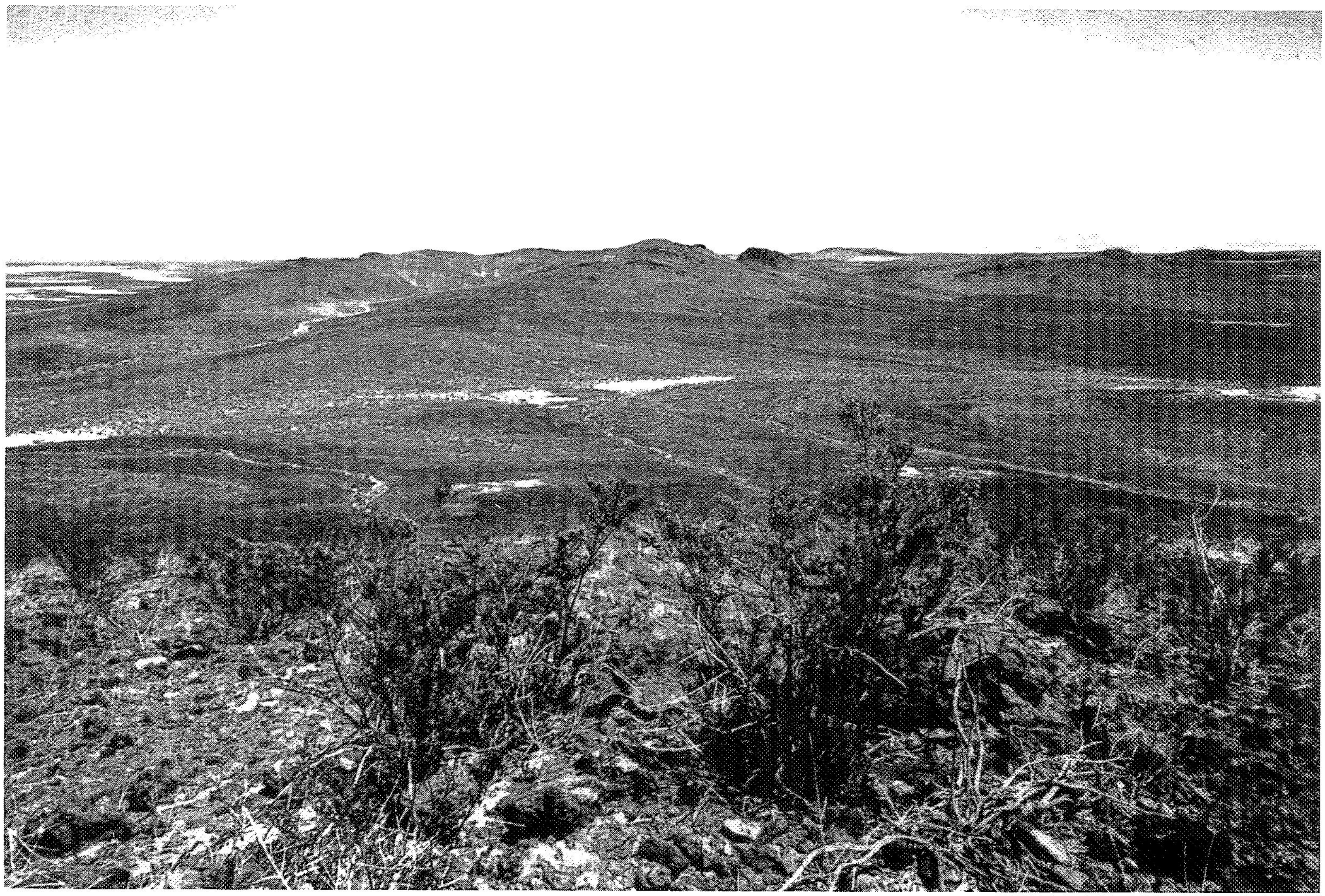


Figure 11. View to south showing typical eroded volcano in northeast part of Palomas volcanic field. Mountains on horizon at far right are Sierra Boca Grande (folded Cretaceous and Paleozoic sediments).

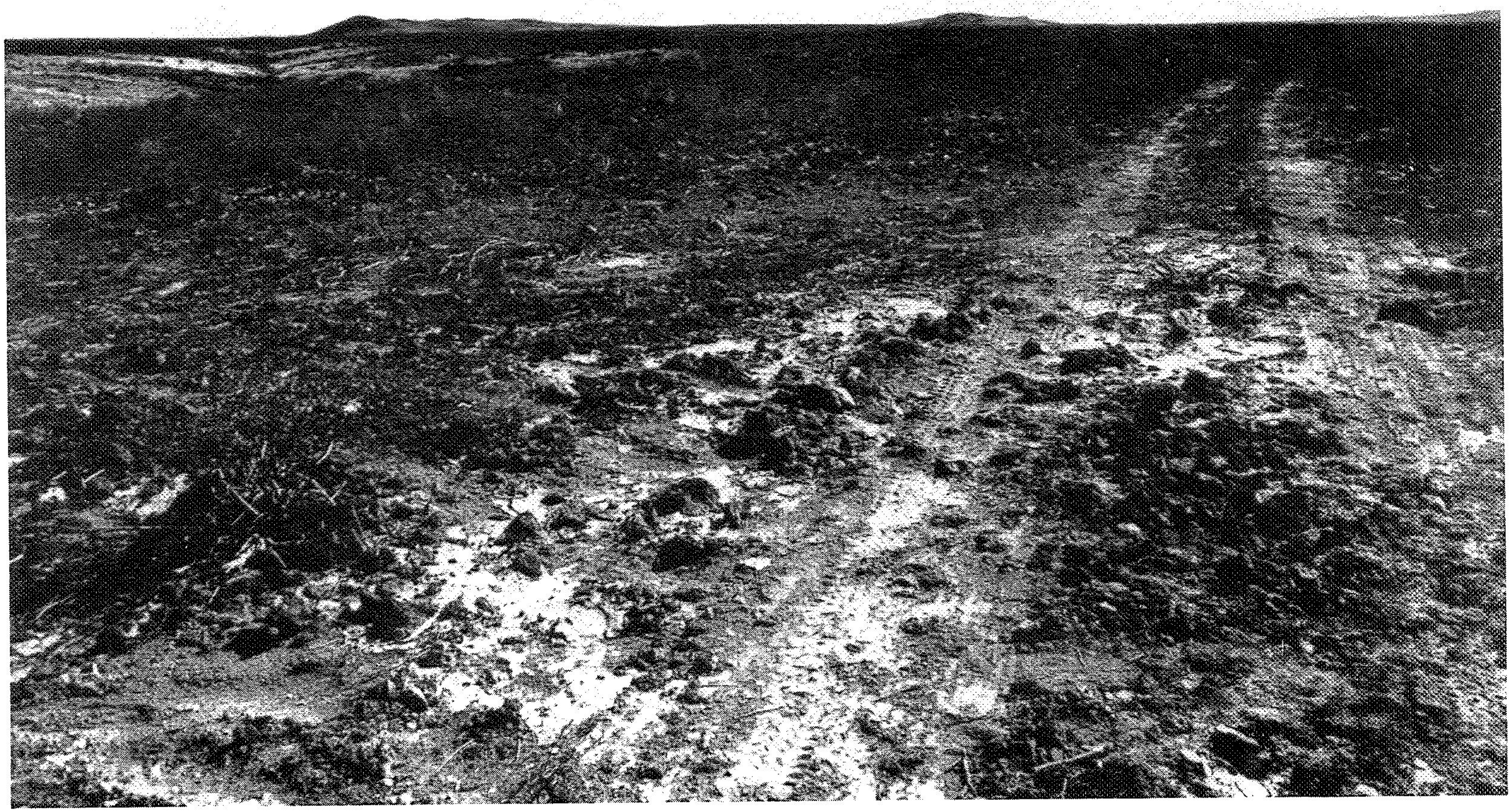


Figure 12. View to west, taken just west of Palomas cemetery south of Palomas, showing typical surface of basaltic lava flows in northeast part of volcanic field.

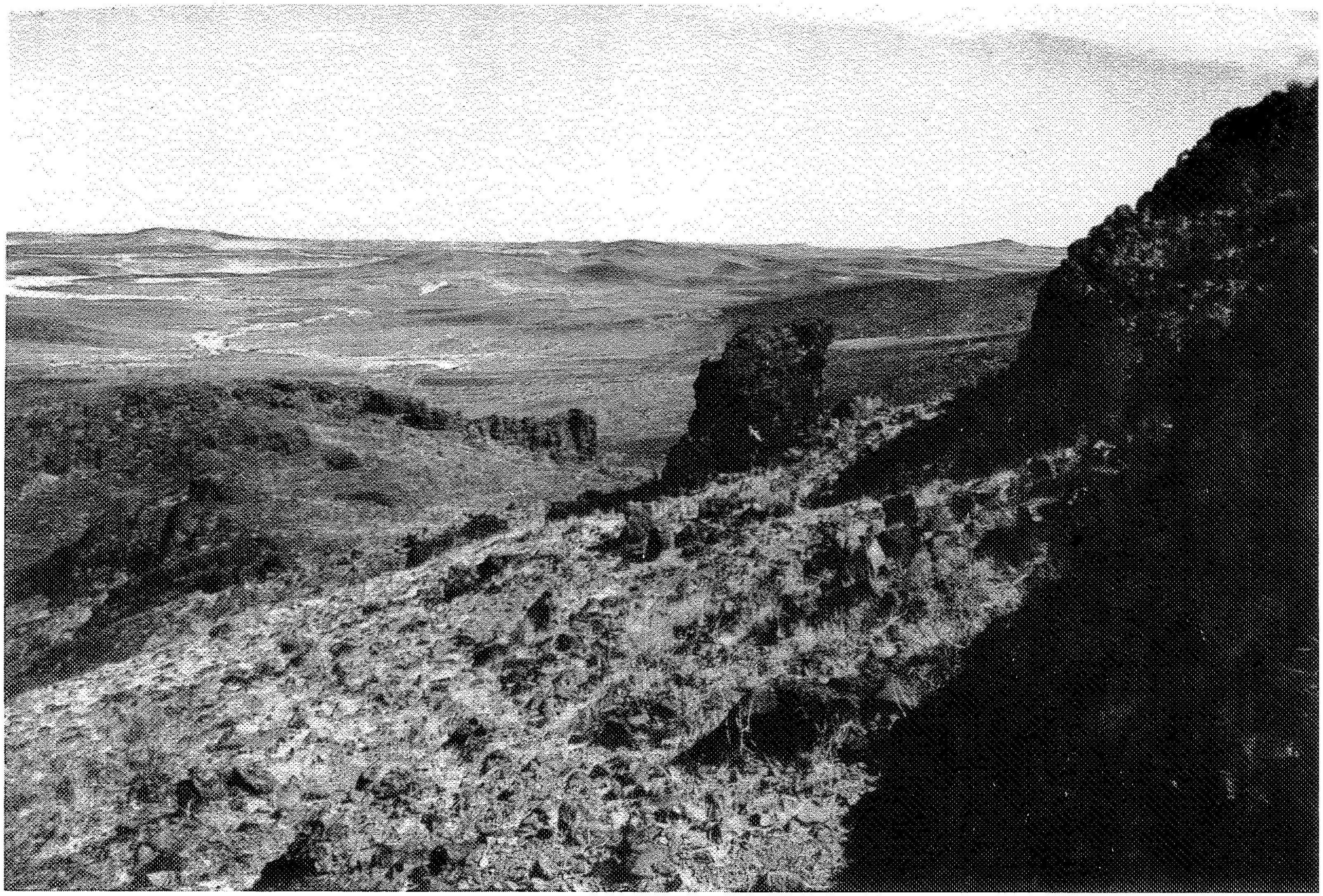


Figure 13. View to south, taken on flank of volcano in center of Palomas volcanic field, showing erosional remnants of interbedded flows and agglomerates. Man at center gives scale.

The Palomas volcanoes are clearly related to those mapped by Balk (1962) in the Tres Hermanas Mountains just across the United States border, and probably to the Quaternary basalts in a larger area of southern New Mexico. It would appear that they, and the volcanoes of the West Potrillo Mountains, represent the latest stages of a long period of Cenozoic volcanic activity, although Griswold (1961) cautions against confusing Tertiary and Quaternary basalts in Luna County. The uniformity of the Palomas basalt and the absence of evidence of reaction or assimilation suggests that it was generated (presumably in the mantle) and erupted rapidly, with little modification. There is no obvious structural control in the location of the Palomas volcanoes, unlike the West Potrillo Mountains, although they lie in a region dominated by northwest-trending folds and faults (Fig. 8).

Although probably related to the Potrillo Mountains rather than to Palomas volcanic field, another volcanic feature not shown on existing maps of the area was noticed on the Gemini IV photographs. This is a shallow depression occupied by a playa, about two miles in the longest dimension, located about six miles southwest of the Potrillo Maar (Fig. 14) (itself reported for the first time by Reeves and De Hon only in 1965). Although the depression could not be visited, pictures taken on a reconnaissance flight at 2500 feet altitude show it to be rimmed on the northeast by lava flows, indicating its volcanic nature. The depression is much more like the Potrillo, Hunt's and Kilbourne Maars than the volcanoes of the West Potrillo Mountains, and it seems possible that it too is a maar. However, C. C. Reeves (personal communication) has recently made an aerial reconaissance of the feature, and does not consider it one.

## Tectonics of Northern Baja California

The first few pictures of the overlapping strip of 39 taken over North America by McDivitt and White on Gemini IV have been unusually valuable for the study of northern Baja California. There have been few published papers of this area; chief among these are the comprehensive memoir on Baja California by Beal (1948), the initial report on the Agua Blanca fault by Allen, et al. (1960), and regional investigations by Krause (1965) and Allen, et al. (1965). Salas, et al., (1967) have produced a 1:250,000 scale geologic map and a comprehensive report from the Gemini IV photographs. We present here a more specialized though preliminary analysis of the structure shown by the first two photographs of the Gemini IV series.

A fracture map has been constructed from 10-1/2" by 10-1/2" black-and-white unrectified prints (Figs. 15 and 16). Although a thorough discussion of the tectonics of northern Baja California would be beyond the scope of this paper, a few major inferences can be made.

Figure 14. View to west from 800 meters (2500 feet) altitude, showing playa and associated lava flows southwest of Potrillo Maar (see Figs. 7 and 8 for location). Playa is about two miles in longest dimension. Area is Chihuahuan Desert; sparsity of vegetation has probably been accentuated by grazing.

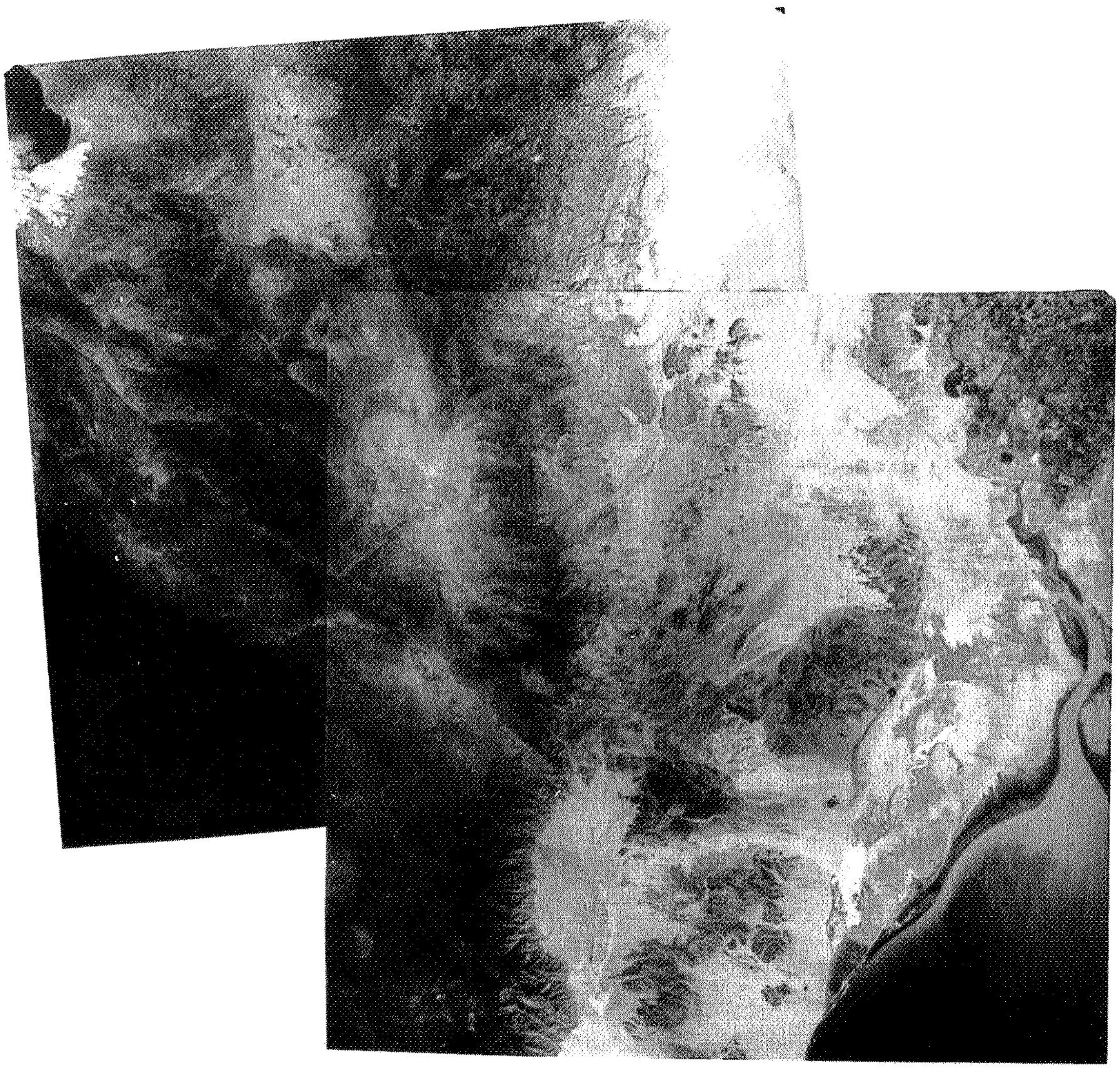


Figure 15. Black-and-white prints of Gemini 4 photographs S-65-34671 (left) and S-65-34672 (right), showing northern Baja California, Mexico. See Fig. 16 (facing) for location.

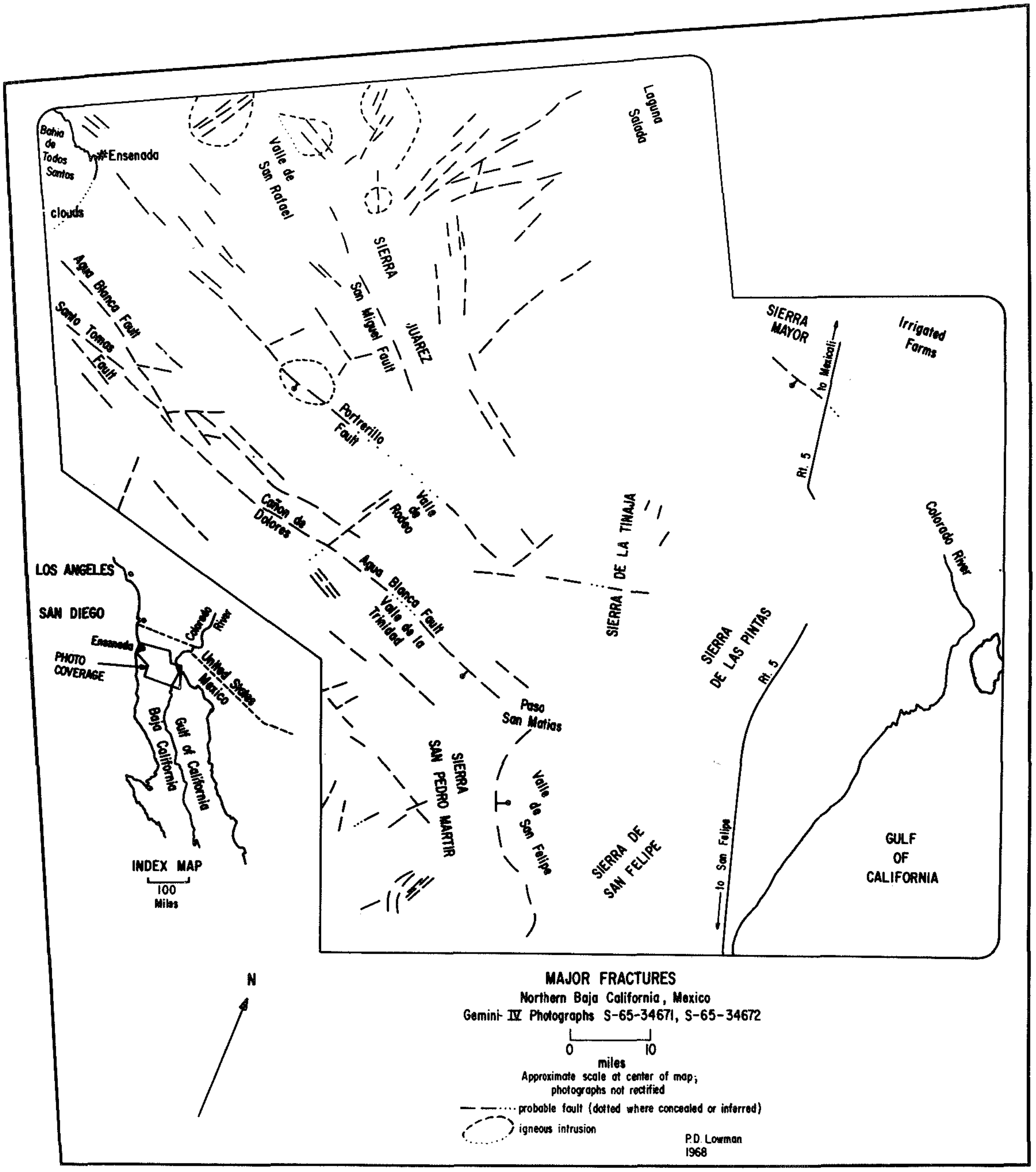



Figure 16. Structural sketch map of Fig. 15.

1. The Agua Blanca fault is but one of a series of roughly parallel faults trending about N75°W in a zone 20 to 30 miles wide. The next most prominent, mapped for the first time by Salas, et al., and named the Portrerillo Fault, is best displayed about 15 miles north of Cañon Dolores. There are a few minor northwest-trending fractures south of Paso San Matias, but the Agua Blanca fault appears to be the southernmost of the long faults with this trend. Preliminary study of Apollo 6 photographs indicates that south of the Agua Blanca fault, the regional structure trends (chiefly sedimentary strata) are about N30°W.

2. The Portrerillo fault shows no evidence on the photograph of lateral displacement. The elliptical features at the approximate middle of the fault is a granitic intrusion, exposed north of the fault and covered by the San Telmo formation to the south, which is not measurably displaced horizontally; the outcrop pattern points to essentially vertical displacement. Similar evidence of vertical rather than horizontal movement is seen in other faulted intrusions northeast of Valle de San Rafael.

3. There is no noticeable horizontal displacement of the eastern mountain front at Paso San Matias, at the southeast end of the Agua Blanca fault, and it is questionable (see also Salas, et al., 1967) if the fault extends to the southeast past this point. This observation is consistent with the conclusion of Allen, et al., (1960) that both recent activity and total displacement decrease to the east. It suggests, however, that, despite the clear evidence of recent right-lateral displacement found by Allen, et al., there has not been major horizontal movement along the fault as a whole. Furthermore, when the apparently vertical movement on the Portrerillo and other faults to the north is taken into account, it appears that strike-slip faulting may be a relatively minor and late characteristic of the tectonics of this area.

4. There is a major NE-SW fracture system north of the Agua Blanca fault. Although not as strongly expressed physiographically as the Agua Blanca fault and its companions, it is widespread and distinct, and evidently of the same general age as the Agua Blanca system since the faults cut several of the igneous intrusions. These two fault directions form a surprisingly systematic pattern whose meaning is not clear, although many apparently similar examples are found in the geologic literature (e.g., Anderson, 1951, p. 32). They are evidently not conjugate shear systems, since the displacement is primarily vertical on both and the angle between them is about 100° as against the 45° to 60° angle that would be expected. Shearing under east west compression also appears unlikely because of the orientation of the right-lateral San Jacinto fault; also, the northwest-trending faults are normal. There is no obvious relation to the theoretical wrench-fault directions tabulated by Moody and Hill (1956); even neglecting the lack

of evidence for major horizontal displacement; the Agua Blanca fault can not qualify as a second order wrench complementary to the San Jacinto fault (which represents the San Andreas system in this area) because the Agua Blanca horizontal movement is right-lateral. The orientation and sense of the Agua Blanca fault would dictate a northeast-trending first-order wrench to which it would be complementary, but there is no evidence at all for such a fault direction here or in southern California.

Although a detailed interpretation of the fracture pattern revealed by the Gemini photographs can not be made without extensive field work and study of the regional structure, a tentative suggestion can be made in the light of recent studies by Larson, et al. (1968), and Moore and Buffington (1968). These authors present evidence that the Gulf of California has opened, within the last 4 million years, at the south end by sea-floor spreading along a series of northwest-trending transform faults, the general process being related to the intersection of the East Pacific Rise with the North American continent. If the Agua Blanca fault developed first as a fault with vertical displacement, and has only recently moved horizontally, it may represent the beginning of dilation of the northern Gulf of California. Northward migration of the dilation process would be consistent with the lack of horizontal displacement along the Portrerillo fault, which might eventually turn into a wrench fault. The Agua Blanca fault would, under this hypothesis, be considered an incipient transform fault. This would be partly in accord with the interpretation presented by Moore and Buffington; however, there is no evidence northeast of Ensenada of a terminating rift, nor any strong evidence that the Agua Blanca fault continues southwest to the Gulf of California.

### The Texas Lineament

The Texas Lineament is a hypothetical shear zone of regional extent reaching from west Texas to southern California. Its nature and indeed its existence are controversial: Mayo (1958) considers it one of the most important controls of economic mineral deposits in the southwest, yet several authoritative treatments of regional geology (e.g., Eardley, 1962; Anderson, 1966) do not even mention it. A number of Gemini and Apollo photographs provide excellent coverage of the supposed Lineament, and they have therefore been used to study the problem. The following discussion should be considered a progress report, since it is hoped to extend the investigation to the entire length of the Lineament with other photographs.

The problem of the Texas Lineament can be summarized only briefly here. The term was first proposed by Ransome (1915) for an east-west-trending structural zone noticed earlier by Hill (1902) east and west of Fort Stockton, Texas. Baker (1934) tabulated a list of major geologic contrasts between the areas north and

south of the zone, such as facies changes, great differences in thickness of the Cretaceous section, and abundance of volcanics. He considered the Lineament to extend from Point Conception, California to the eastern tip of Brazil, and to be "probably the greatest single structural line of the Western Hemisphere." Albritton and Smith (1956) reviewed the problem, and proposed that the type locality for the Texas Lineament should be the 55-mile segment including the Hillside fault running from Van Horne northwest through Sierra Blanca (A-B, Fig. 17) and beyond (Fig. 18). They compiled further evidence for the Lineament as a major geologic boundary, but found little evidence for transcurrent faulting.

Moody and Hill (1956), in their well-known paper on wrench-fault tectonics, proposed that the Lineament was controlled by a left-lateral wrench fault, partly on the basis of left-lateral movement along the Hillside fault, which they considered an element of the Lineament. (Moody later (1966) suggested that the Lineament might be a relatively broad belt of tectonism.) Mayo (1958) described the Lineament as a "belt of transverse structures" more than 150 miles wide in southern Arizona and extending from trans-Pecos Texas to the Transverse Ranges of southern California. He presented evidence that the Lineament is one of the most important structures localizing ore deposits in the southwest United States, and recommended its intersections with other transverse zones as prime sites for investigation. Griswold (1961) stated, in his report on the geology and mineral deposits of Luna County, New Mexico, that the Lineament "most certainly" goes through that county, probably between the Florida and Tres Hermanas Mountains in a northwest direction (Figures 19, 20). Muehlberger (1965) integrated the Texas Lineament into a regional scheme for explaining the relations between the clearly related but now disconnected Appalachian, Ouachita, and Marathon Paleozoic fold belts. He proposed that the Marathon belt had been severed from the Ouachita belt by some 200 to 250 miles of right-lateral movement on the Texas Lineament during the late Paleozoic (with an analogous movement between the Ouachita and Appalachian belts on a parallel Lineament to the north). Perhaps the broadest view of the nature of the Lineament in recent literature is that of Schmitt (1966). Calling it a "zone of structural chaos of at least subcontinental extent," he proposed that it might be a zone of left-lateral wrench-faulting along which continental drift had taken place, and summarized evidence that it might extend to the Mid-Atlantic Ridge at the Equator. Citing Schmitt's views, Guilbert and Sumner (1968) endorsed the idea that the Texas zone, a "continental crust analog" of the great marine fracture systems, was probably a transform fault system in Laramide time. They pointed out its possible role in localizing the porphyry copper deposits, and recommended further exploration along the Lineament in west Texas. King (1969, Fig. 14) labeled the Lineament a "nonfaulted transverse zone" extending from west Texas to the Garlock fault, implying that the latter may be related to the Murray fracture zone, though he stated that the Lineament is not a fault.

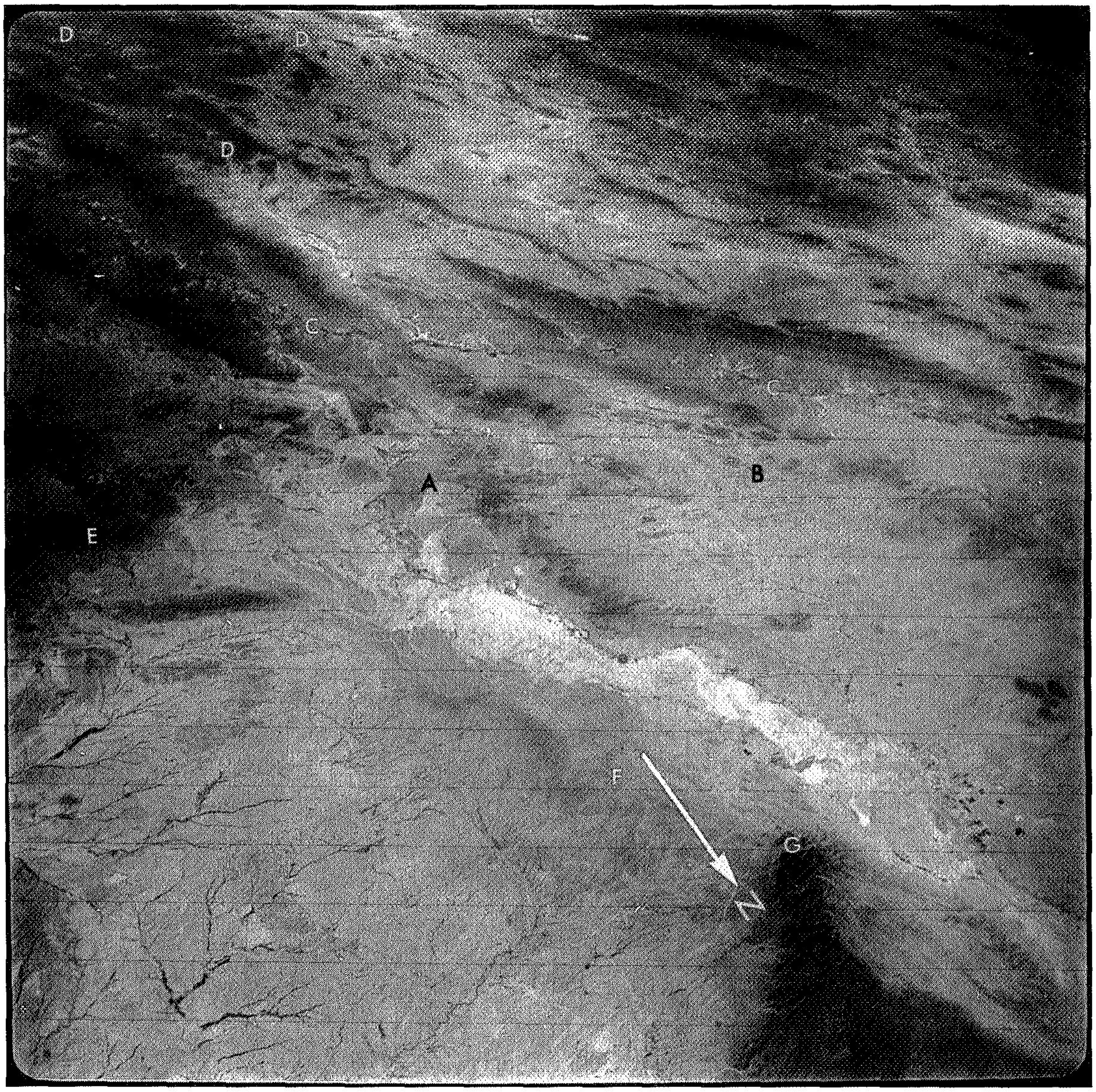



Figure 17. Gemini 4 photograph S-65-34697. Oblique view to southwest over west Texas, showing type locality of Texas Lineament, as defined by Albritton and Smith (1956), the Hillside fault between Van Horn (A) and Sierra Blanca (B). A-B distance about 65 miles (104 km). Sharp line is trace of Texas and Pacific Railways and U.S. 80 - Interstate 10. Rocks south of Hillside fault near Van Horn are nearly vertical north-striking Precambrian metasediments, visible as aligned ridges, dragged to west along fault; rocks to north of fault are gently-dipping Cretaceous sediments. Other landmarks include: Rio Grande (C); Sierra Madre Orientale (D); Davis Mountains (E); Delaware Mountains (F); El Capitan (Guadalupe Mountains) (G).

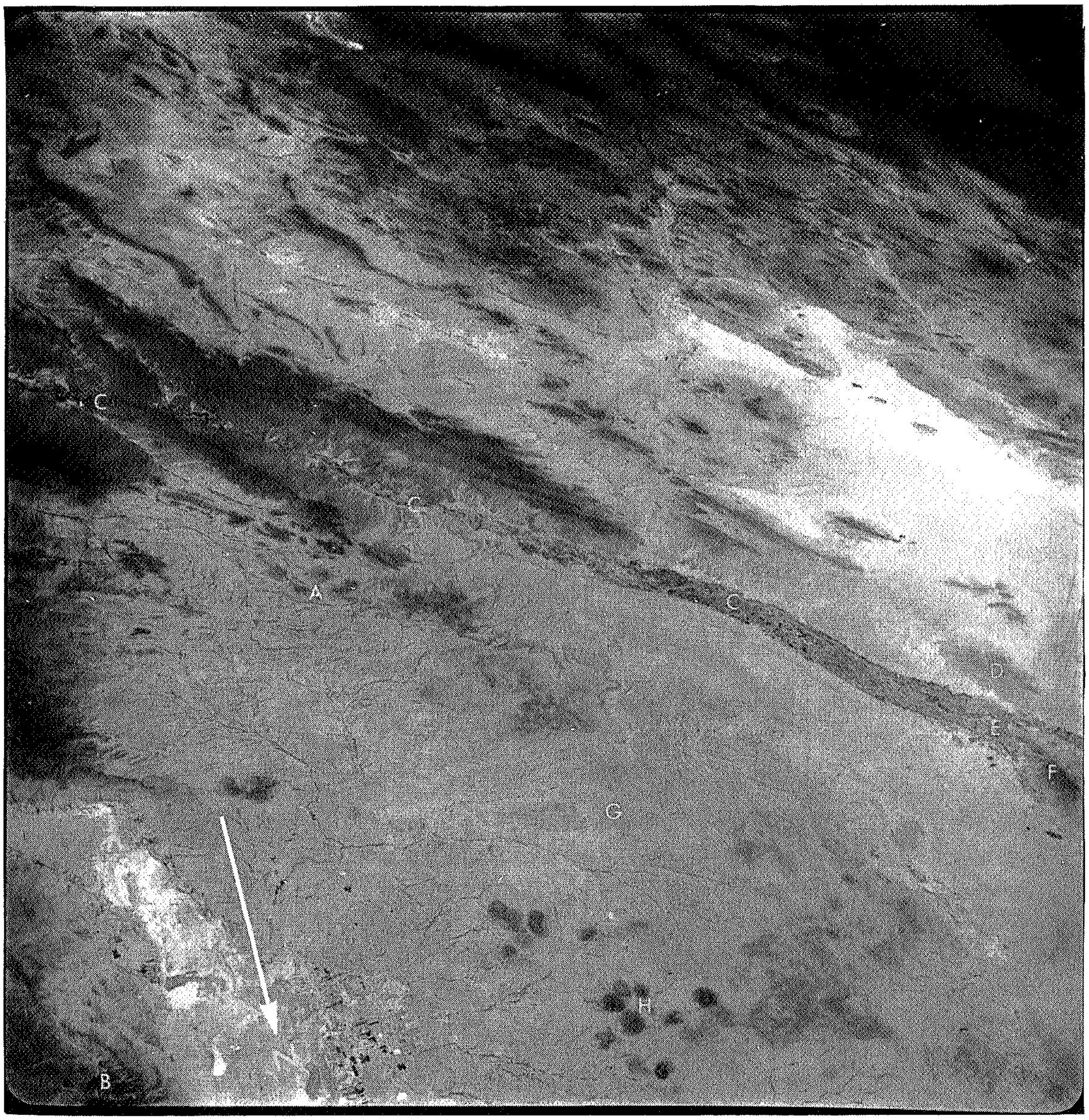



Figure 18. Gemini 4 photograph S-65-34695. Oblique view to southwest over Rio Grande valley, showing supposed location of Texas Lineament between Sierra Blanca (A) and El Paso (E). Adjoins area of previous photograph. No topographic expression of Lineament visible, with possible expression of scarp of Diablo Plateau. Landmarks include: Rio Grande (C); Sierra Juarez, Chihuahua (D); Franklin Mountains, Texas (F); Diablo Plateau (G); El Capitan (B); Cornudas Mountains (Tertiary intrusions) (H). Sierra Blanca to El Paso distance 80 miles (129 km).

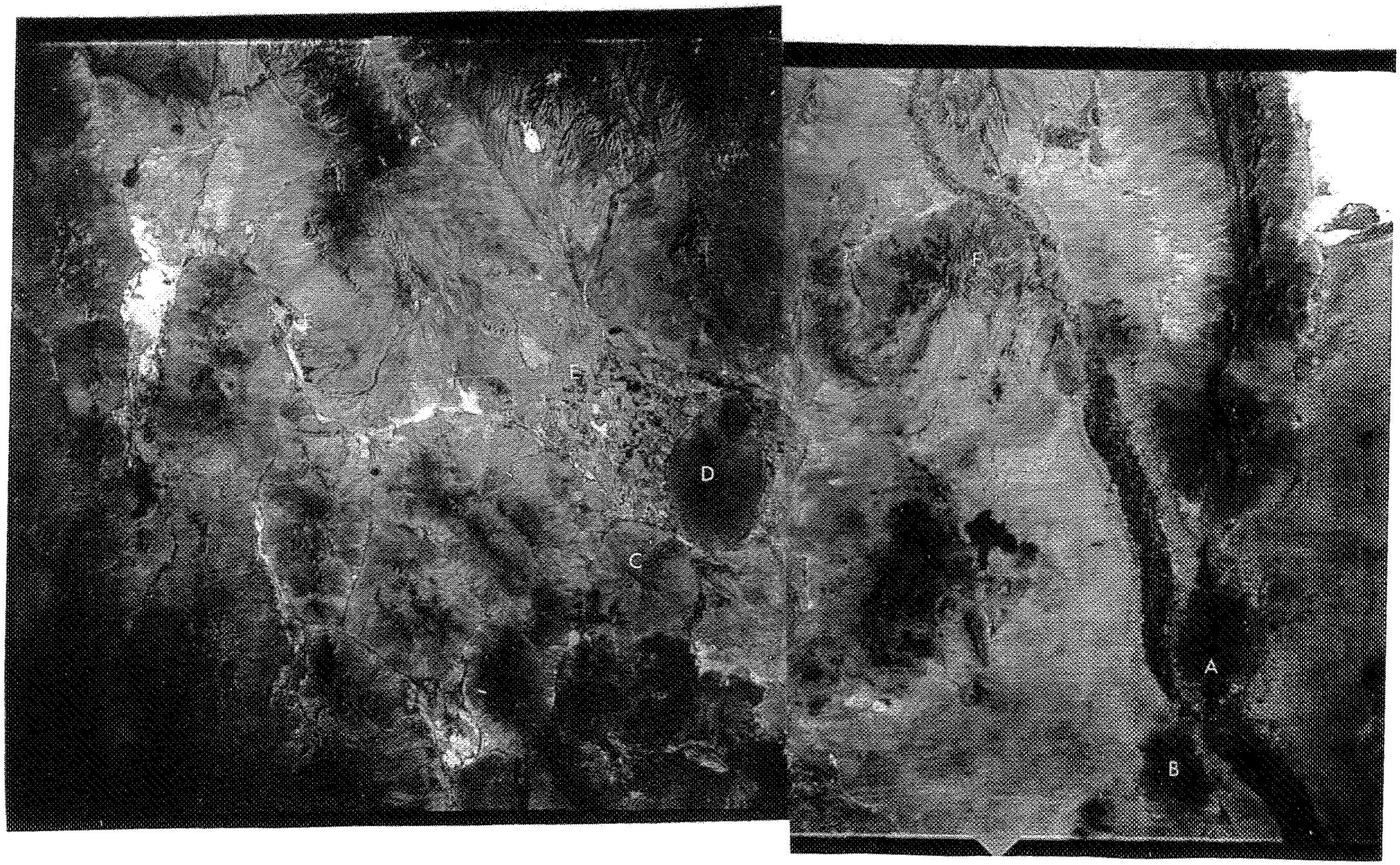
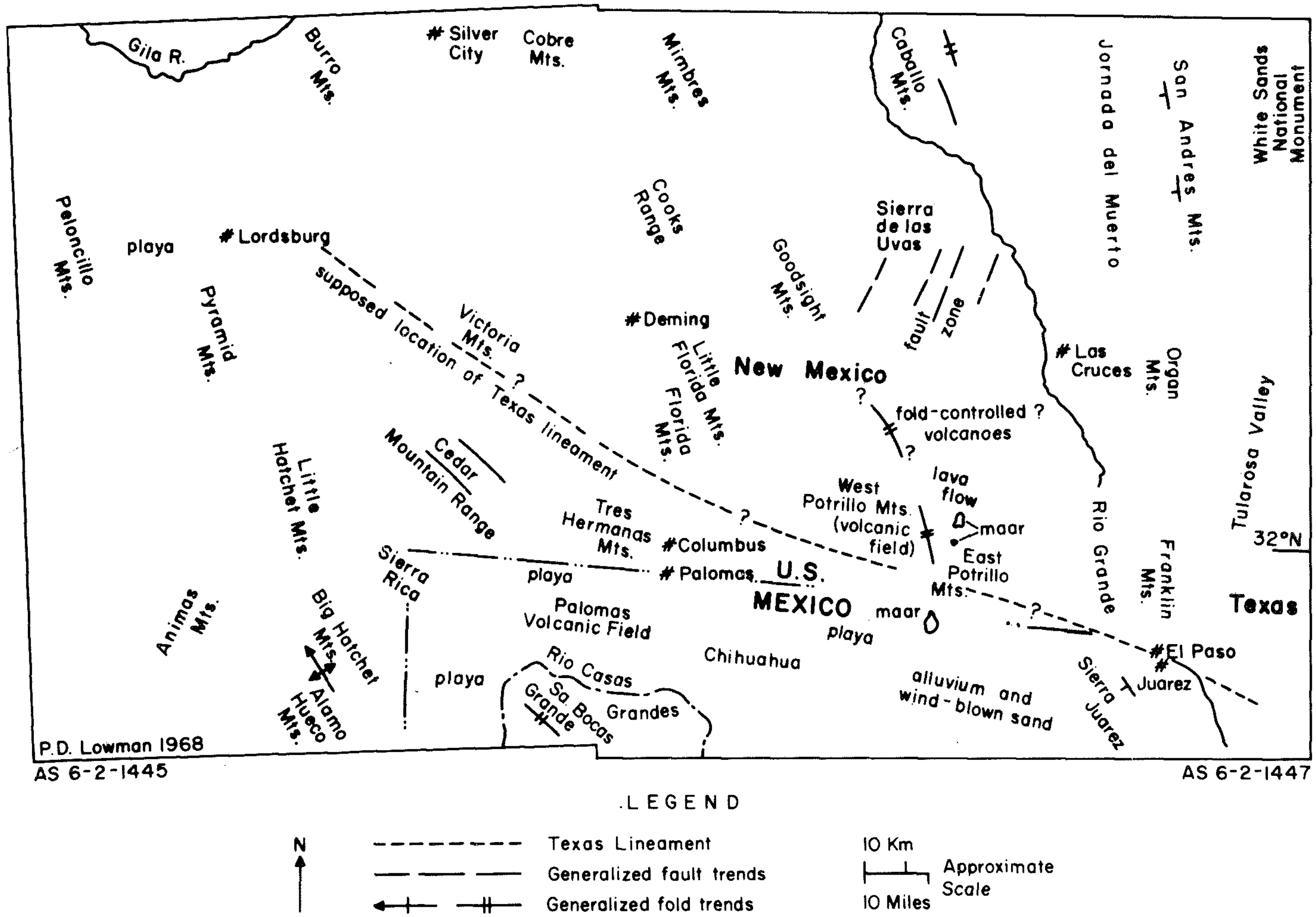



Figure 19. Apollo 6 vertical photographs AS 6-2-1445 (left) and AS 6-2-1447 (right), showing area of southwest New Mexico through which Texas Lineament is supposed to pass; see Fig. 20 for trace. Landmarks include: Franklin Mountains (A); Sierra Juarez (B); Tres Hermanas (C); Florida Mountains (D); Interstate 10 (D); Sierra de las Uvas (F).




SUPPOSED LOCATION OF THE TEXAS LINEAMENT IN NEW MEXICO
(from Apollo 6 photographs AS 6-2-1445 and 1447)

Figure 20. Sketch map of Fig. 19.

Study of Gemini, Viking, and Apollo 6 photographs leads to the following tentative conclusions about the existence, location, and nature of the Texas Lineament.

1. There is no single large fault of Cenozoic age in the Texas direction (N60°W) (the term used by Moody and Hill) west of El Paso in New Mexico or southeastern Arizona. Referring to Figs. 19 and 20, this is inferred from the following evidence.

   (a) There is no northwest alignment of the volcanoes in the West Potrillo Mountains. These, and the three maars shown, appear to be controlled instead by the southwest-trending faults of the Sierra de las Uvas (Reeves and De Hon, 1965; Kottlowski, 1960), or by north-trending fold axes (Merifield, 1964). N. M. Short (personal communication) has pointed out that wrench faults, being primarily shear rather than extensional features, do not commonly localize volcanoes. However, since localization of igneous intrusions is cited as evidence for the existence of the Texas Lineament, it is necessary to search for comparable control of volcanic centers where feasible.

   (b) There are no obvious features typical of recent faulting, such as vegetation lines, aligned or offset streams, or fault scarps, with a N60°W trend between El Paso and the Victorio Mountains, although Baker (1934) ascribed alignment of springs in trans-Pecos Texas to the Texas Lineament. (He also noted that the Yates oil field was on it.)

   (c) An oblique Viking 12 photograph (Fig. 21) looking along the supposed course of the Lineament through central Arizona toward the Mojave shows no aligned mountain passes, stream segments, rifts, or volcanic centers, although the viewing angle would emphasize such aligned features if they were present. This conclusion is most tentative, pending study of vertical orbital photographs along the supposed trace of the Lineament.

2. The "Texas direction" (Moody and Hill, 1956) is a real tectonic feature, but consists of a broad band of folds and dip-slip faults related to the Mexican fold belt now comprising the Sierra Madre Oriental and formerly (in the Mesozoic) extending much farther northwest (Anderson, 1966). This conclusion is based on Gemini 4 photographs (Figs. 7 and 8) of northern Chihuahua which indicate that folds of the northwestern Sierra Madre Oriental grade smoothly into the fault trends of the Basin and Range Province, both sharing a N60°W direction in this area (Lowman, McDivitt, and White, 1967). The reason for this similarity of trend is probably that, as implied by Jones (1963), the Basin and Range faults in this area parallel pre-existing fold axes. The folded sediments are frequently covered by Tertiary or

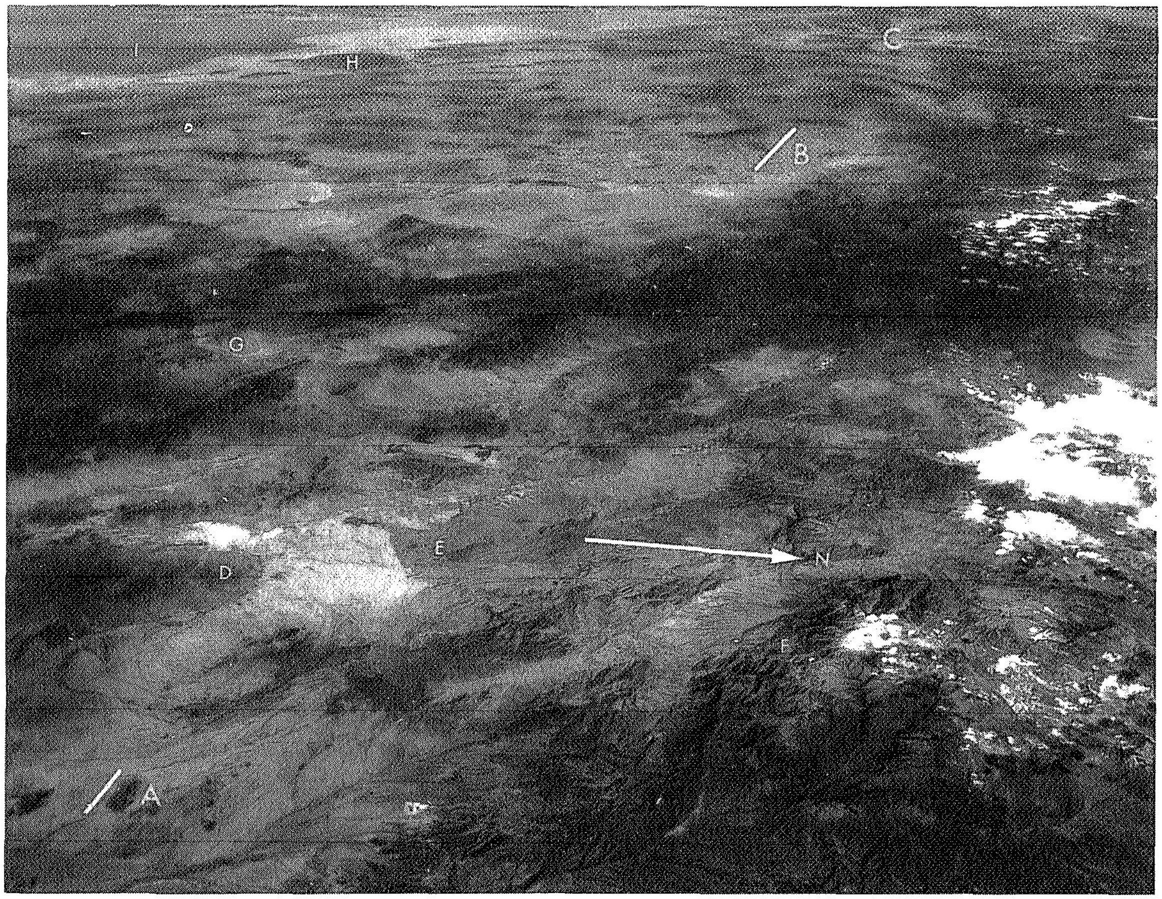



Figure 21. Viking 12 oblique view (infrared film) from 120 miles altitude over White Sands, New Mexico, to southwest, showing supposed location of Texas Lineament interpreted as a single fault, according to Moody and Hill (1956) and Griswold (1961). Lineament passes near Victorio Mountains (A), Phoenix, Arizona (B), and across Colorado River. Other landmarks include: Pyramid Mountains (D); Gila River (E); Mogollon Mountains (F); Willcox Playa (G); Pinacate volcanic field (H); Gulf of California (I). Distance from Victorio Mts. (A) to Phoenix (B) about 260 miles (420 km). Foreground overlaps Fig. 19; left center overlaps Gemini 4 coverage.

Quaternary volcanics, and it appears that the extent of volcanics to the southeast coincides roughly with the extent of block-faulting (faults and volcanics being relatively minor in the Sierra Madre Oriental). If verified, this would support the suggestions of Mackin (1960) and Eardley (1963) that magma generation and vulcanism are genetically related to uplift and subsidence (see also Damon's (1968) discussion of the correlation between magmatism and Basin and Range orogeny).

The regional extent and width of the northwest-trending zone, as outlined by authors such as Guilbert and Sumner (1968), are illustrated by a Gemini photograph of southern Arizona (Fig. 22). The apparent dominance of northwest trends over those of any other direction, in particular northeast trends illustrated by Badgley (1965), is somewhat surprising.

3. The type locality Texas Lineament, as redefined by Albritton and Smith (1956) to mean the belt of northwest-trending faults south of the Diablo Plateau in west Texas, is a relatively minor feature satellitic to the Sierra Madre Oriental fold belt. This is inferred from, first, the evidence just cited that the Texas direction west of El Paso is structurally the extension of the Sierra Madre, and second, from Gemini 4 photographs such as Fig. 17showing the regional dominance of the fold belt. The Gemini photographs also show no obvious physiographic connection between the type locality of the Lineament and the El Paso area. They do, however, support the characterization by Albritton and Smith of the Lineament as "the boundary between two geologic provinces," the cratonic Diablo Plateau and the mobile Sierra Madre.

4. The regional fold and fault directions in a large area centered on El Paso are a virgation, or branching, rather than the result of major horizontal dislocation by wrench faulting along the Texas Lineament. The divergence takes place around El Paso, with one branch, including the Franklin-Organ-San Andres Mountains, turning north and the other, including the Sierra Juarez and the East Potrillo Mountains, turning northwest. This concept is in agreement with Eardley's (1962, p. 399) interpretation of the Rio Grande depression and the Tularosa Valley as fold-controlled zones of block-faulting.

   This inferred virgation is based solely on inspection of the Gemini photographs. A field check might be made by comparing the stratigraphy and structure of the Franklin-Organ-San Andres Mountains with their possible Mexican extension, the Sierra de San Ignacio, and of the Sierra Juarez with the Sierras de Guadalupe and del Presidio. Although the Franklin-San Andres ranges are shown on the Geologic Map of North America (Goddard, 1965) as Paleozoic and Precambrian rocks, and the Mexican ranges as Cretaceous, the discrepancies in geologic maps revealed so far by orbital photographs

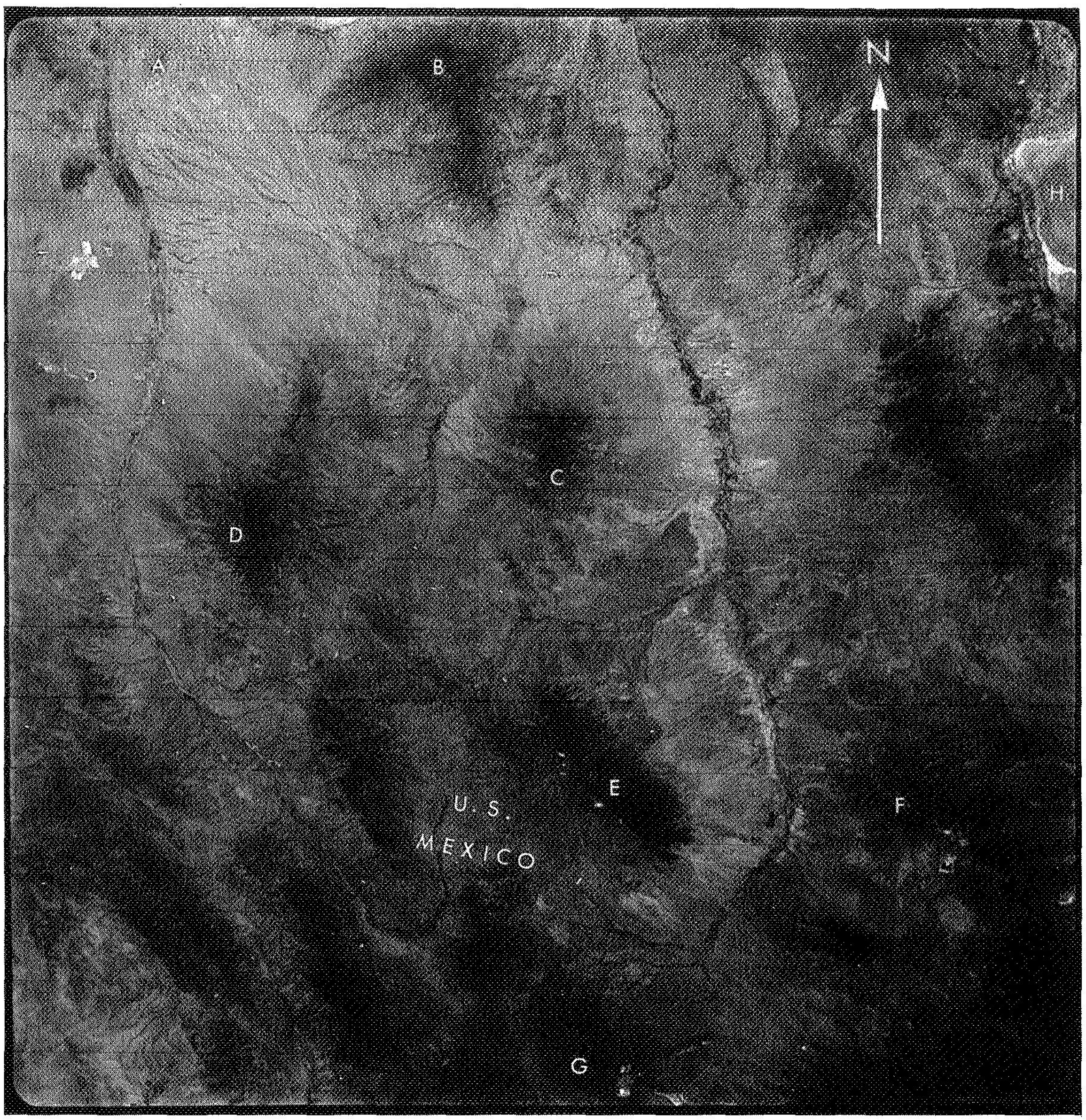



Figure 22. Gemini 4 photograph S-65-34681. Oblique view to south over southern Arizona and northern Sonora, showing pronounced northwest-trending regional fracture pattern considered part of the Texas zone. E-W distance at north edge of photo about 70 miles (112 km). This and adjoining Gemini 4 photos are discussed by Titley (1968) and Haynes (1968). Landmarks include: Tucson (A); Rincon Mountains (B); Whetstone Mountains (C); Santa Rita Mountains (D); Huachuca Mountains (E); Mule Mountains with Bisbee copper mines visible (G); Wilcox Playa (H).

indicate that such a field check might be worthwhile. Unfortunately, while a positive result (similar lithology and stratigraphy) would definitely support this interpretation, a negative result could be explained by southeastward plunge of the Franklin Mountains structure, without disproving it.

It is concluded that the so-called Texas Lineament is not a single fault or even a discrete fault zone in New Mexico, Texas, and Mexico. It appears to be instead a broad belt of folds and dip-slip faults closely related to, and coincident with, the northwest arm of the Mesozoic Mexican geosyncline as delineated by Eardley (1962) and Hunt (1963). Since the folding and faulting in this former geosyncline appear to have resulted chiefly from stresses normal to its trend (i.e. southwest-northeast directed), the concept of the Texas Lineament as a wrench fault or shear zone seems unjustified. It should at least not be considered as structurally and chronologically equivalent or closely related to the major Pacific coast wrench faults.

The value of the Texas Lineament concept in searching for mineral or oil deposits is open to question in view of its great width and variability. However, if the "Texas zone" (Schmitt's term) is used as a guide in regional exploration, it would appear that efforts should be concentrated in northern Sonora and Chihuahua, rather than in west Texas as suggested by Guilbert and Sumner (1968).

## Comparative Importance of Wind Erosion in Africa and North America

One of the more obvious benefits of the Gemini photographs is the comparative view they provide of North American and North African deserts. In particular, they appear to throw light on the relative importance of wind as an erosive agent in the two regions.

It is axiomatic, at least in American textbooks, that wind erosion is of minor importance as a major land-sculpturing process. Thornbury (1954), for example, states; "Wind abrasion may aid in the shaping of the details of major forms but is itself hardly capable of producing features of great areal extent." Comparable statements are found in many texts, and probably reflect the influence of Blackwelder's (1934) views (although Blackwelder also introduced to the American literature the term yardang for wind-eroded grooves). Holmes (1965), on the other hand, ascribed the origin of the southeasterly-trending depressions of western Egypt to wind erosion. Smith (1963) discussed residual rock knobs and ridges, with examples from North Africa, but evidently considered them to be of only local occurrence.

The Gemini photographs of North Africa indicate that wind erosion has been a major land-forming process over many thousands of square miles. It can be discussed under two headings: deflation and abrasion.

Deflation, or removal of loose material by wind, has long been recognized as an important though localized erosive agent in deserts (Smith, 1963), and particularly in the Sahara. The Gemini photographs are therefore chiefly of interest in presenting examples of at least one large area (Fig. 23) in which it is the dominant process. In this region, which is probably near the one shown by Smith, deflation has carved basins on structural highs and lows over an area of about 5000 square miles. The fact that these particular basins are in well-consolidated sedimentary rocks of Devonian and Carboniferous age, rather than in loose soil, tends to support the suggestion of Ball (1927) that large depressions of this sort are formed by stream erosion around the rim and deflation of the alluvium from the center.

Of considerably more interest is the large number of apparent wind abrasion features shown by the Gemini North Africa photos. Perhaps the best of these is the area surrounding the Tibesti Mountains of northern Chad (Figs. 24 and 25), which are nearly surrounded by arcuate linear features tens or scores of miles long. These are at least partially depositional, resembling sand streamers or longitudinal dunes localized by various topographic features. However, Grove (1960), in a comprehensive paper on the geomorphology of western Tibesti, mapped these in part of the area shown in Fig. 25 as erosional remnants of sandstone, shale and schist, and suggested that they might have been eroded by the prevailing north-easterly winds. The example of similar wind eroded bedrock ridges presented by Smith (1963, Fig. 3), also strongly supports this possibility. The process responsible for the Tibesti features appears to be self-perpetuating wind abrasion of the bedrock, perhaps along pre-existing joints or faults, and then deposition of sand in long streamers down-wind from the grooves and valleys so formed.

Similar fields of what appear to be residual knobs or ridges and dunes are shown on the Gemini photos in several other parts of the central Sahara (Figs. 26, 27 and 28); although it is hard to tell, without low altitude coverage, just how much of this topography is erosional and how much depositional, the overall effect of erosion has clearly been considerable. Some of the rock ridges in An Nafud, in the northern Arabian Peninsula, may be partly erosional. Another interesting example of wind erosion (Fig. 29) is the Dasht-i-Lut of southeastern Iran, in which evaporites and clays have been carved into ridges and valleys scores of miles long by the wind (Charles Warren, personal communication).

The contrast between the deserts of North Africa and North America covered by the Gemini photos is remarkable. Examination of Fig. 30 and other photos of the southwestern United States and northern Mexico reveals few if any erosional features that can be attributed to wind. This is also true, with rare exceptions such as the Dasht-i-Lut, of other deserts in the Arabian Peninsula, southwest Asia, and western South America. (Good coverage of Australia has been too

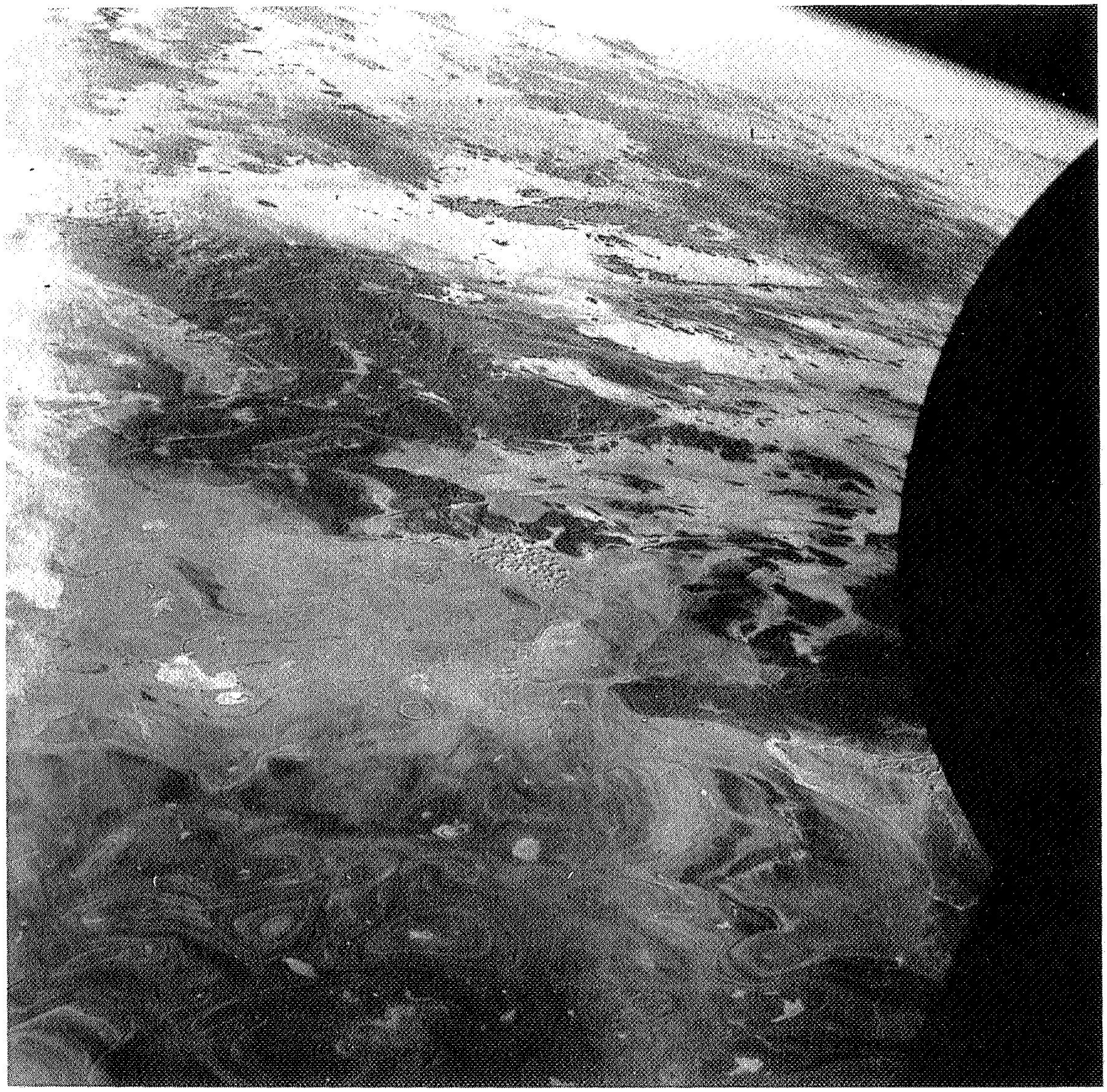


Figure 23. Gemini 7 photograph S-65-63785. View to southeast over central Sahara, in southern Algeria; center of photo at about 25°N, 4°E. Distance from bottom of photo to dark mountains (the Ahaggar) at upper right about 250 miles (400 km). Irregular closed basins in foreground are deflation features on gently folded Paleozoic sediments. Dark mountains at left center are the Emmidir (Mouydir), part of the belt of tassilis surrounding the Ahaggar massif (at upper right above the spacecraft nose). Some deflation basins are occupied by sebkhas (playas). Light-toned hills at center are sand dunes of an un-named erg.

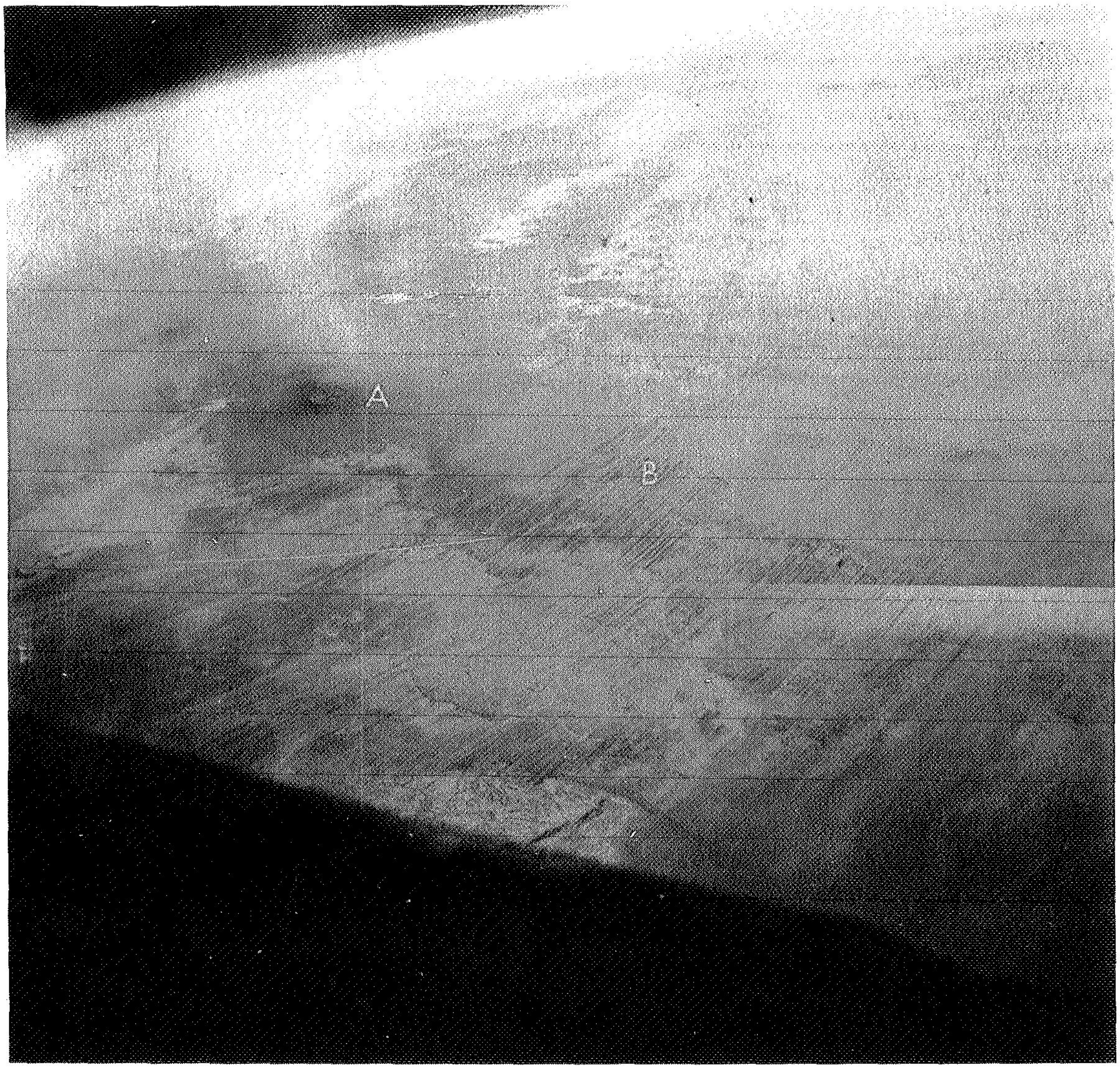



Figure 24. Gemini 4 photograph S-65-34778. View to northwest over Chad and Libya; Tibesti massif at left. Prominent volcano (A) at left is Emi Koussi; concentric structure (B) at center is in Devonian sandstones, and suggested by Lowman, et. al., (1967) to be expression of an unmapped igneous intrusion. Concentric linear features are composite linear sand dunes and wind-eroded grooves (yardangs?) possibly controlled by tension fractures related to the uplift of the Tibesti massif.

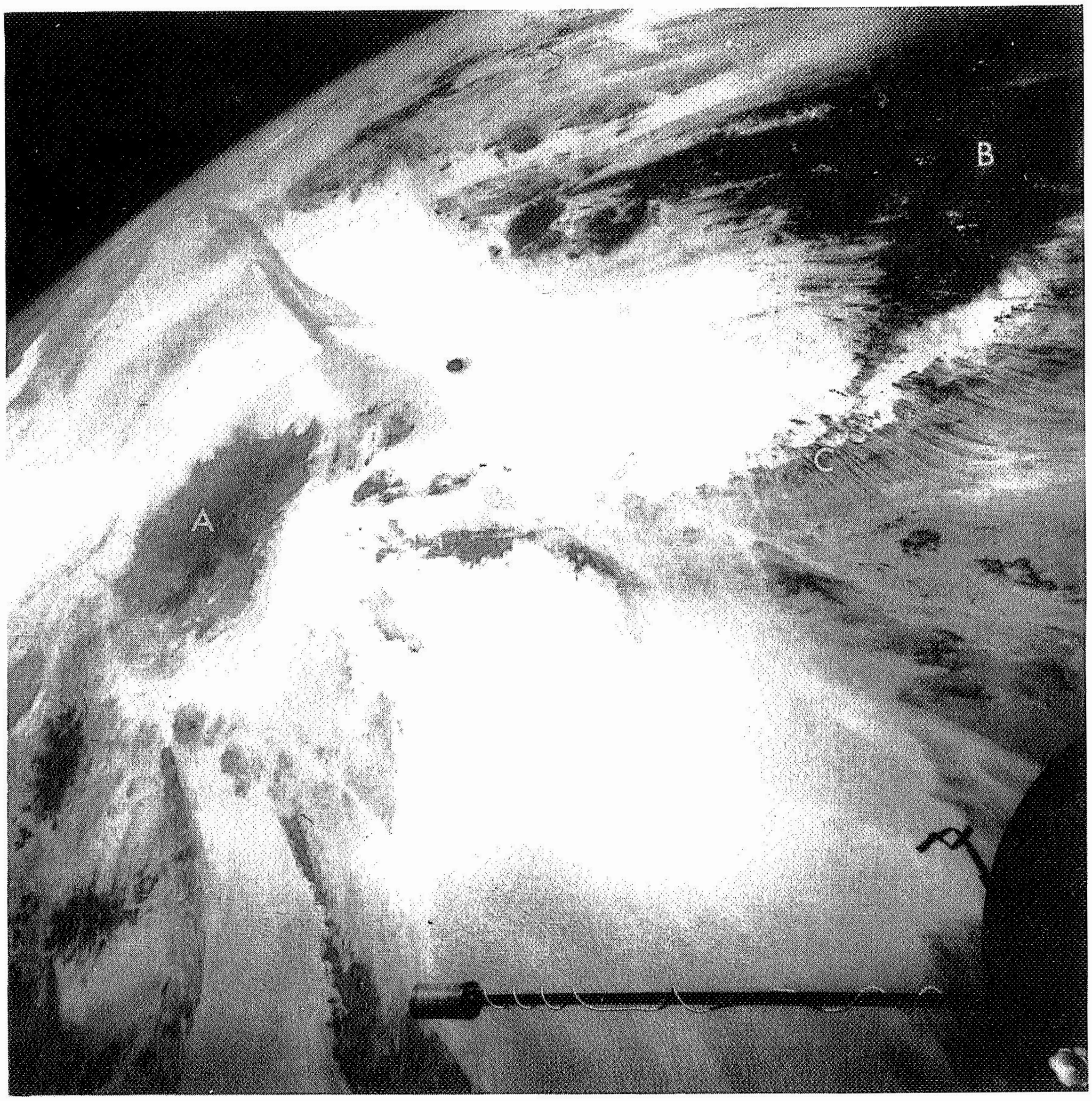



Figure 25. Gemini 11 photograph S-66-54527. View to northeast over Libya. Marzuq Sand Sea, 250 miles (400 km) wide at bottom under Agena antenna. Haruj al Aswad (volcanic field) at left (A); Tibesti massif at right (B). Linear features (C) are believed to be composite dunes and erosion grooves similar to those east of Tibesti massif (Fig. 24).

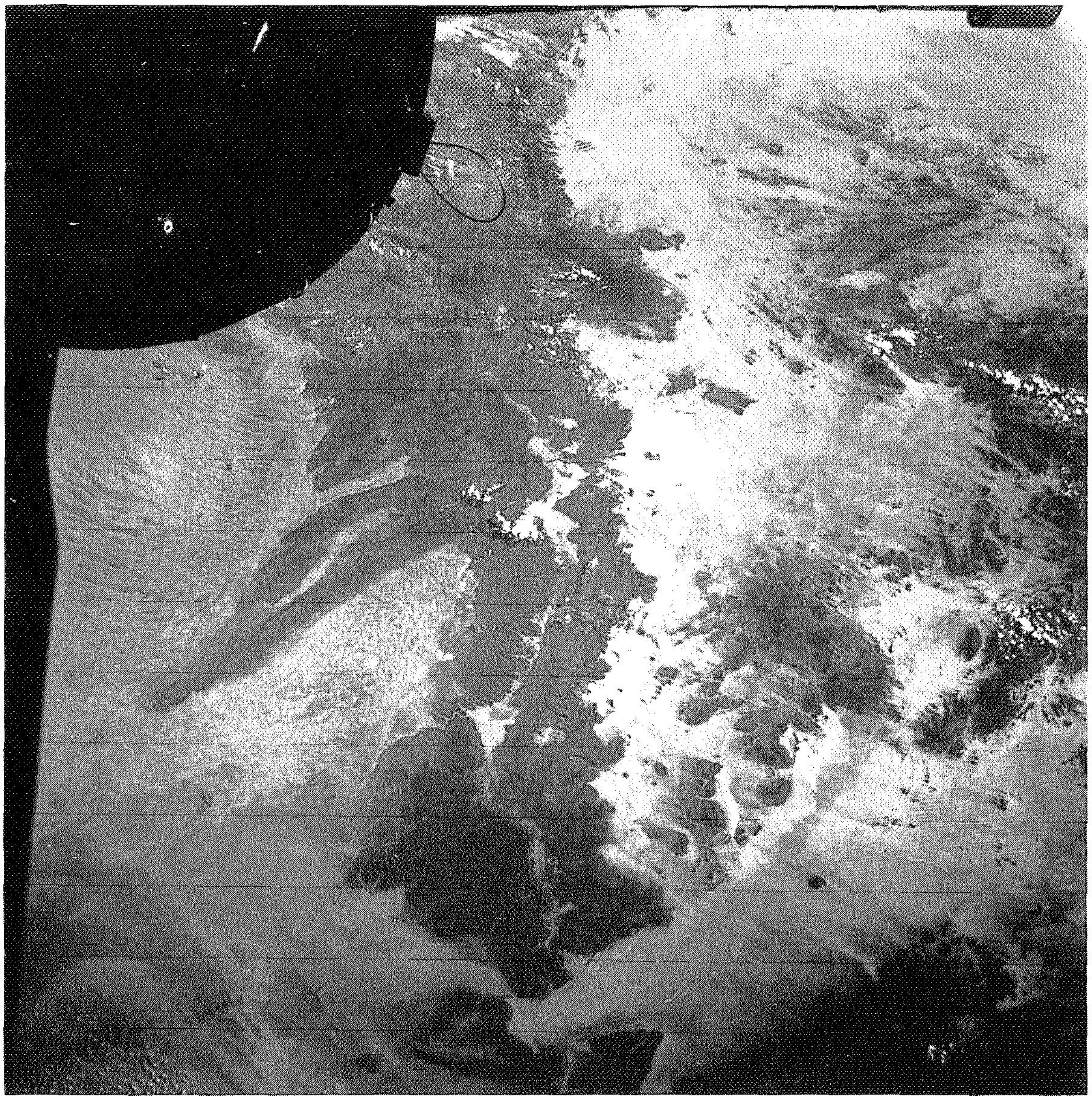


Figure 26. Gemini 12 photograph S-66-63474. View to east along Tassili Najjer, a series of northward-dipping cuestas bounding the Ahaggar massif on the north; center of picture about 26° N, 6° E. Tiffernine dunes, in foot-shaped depression about 80 miles (128 km) long, are shown by Raisz (1952) as being 1000 feet (330 meters) high. Linear features at right are thought to be partly wind-eroded knobs and ridges and sand streamers. Bedrock chiefly basalt.

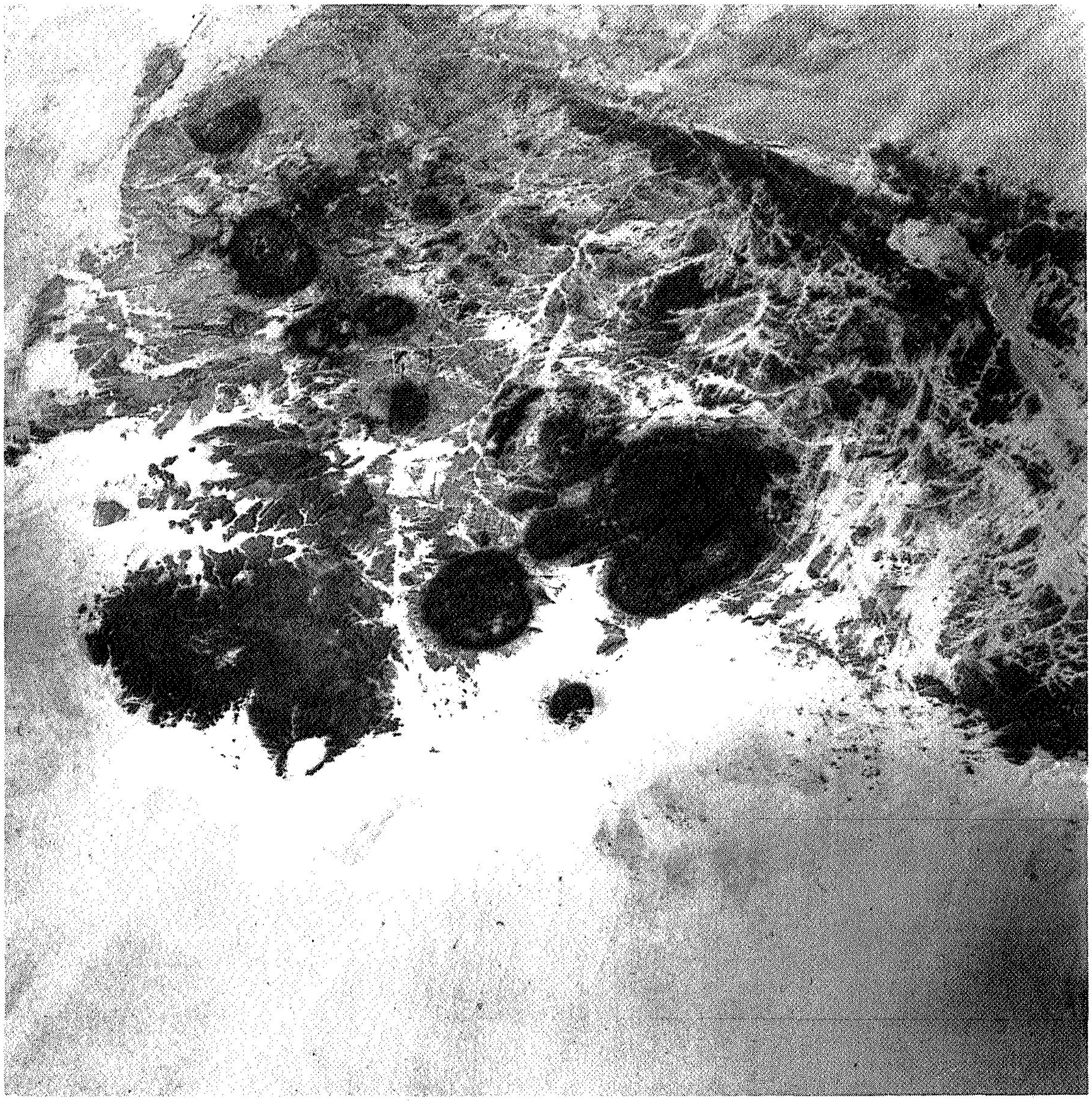


Figure 27. Gemini 6-A photograph S-65-63158. View to southwest over Niger. Desert with sif dunes in foreground is the Tenere; Air Mountains at center (about 19°N, 8°E). Dark masses are peralkaline granite intrusions; largest (at center) is Mont Tamgak, roughly 30 miles (48 km) wide, intruding metamorphic rocks. Plateau of Irhaouriten, underlain by sandstone, in upper right. Linear features north of Mont Tamgak appear to be wind-eroded ridges and sand streamers; note continuity with sif dunes in foreground. Steep-cliffs around intrusions are suggestive of examples of wind erosion pictured by Holmes (1965).

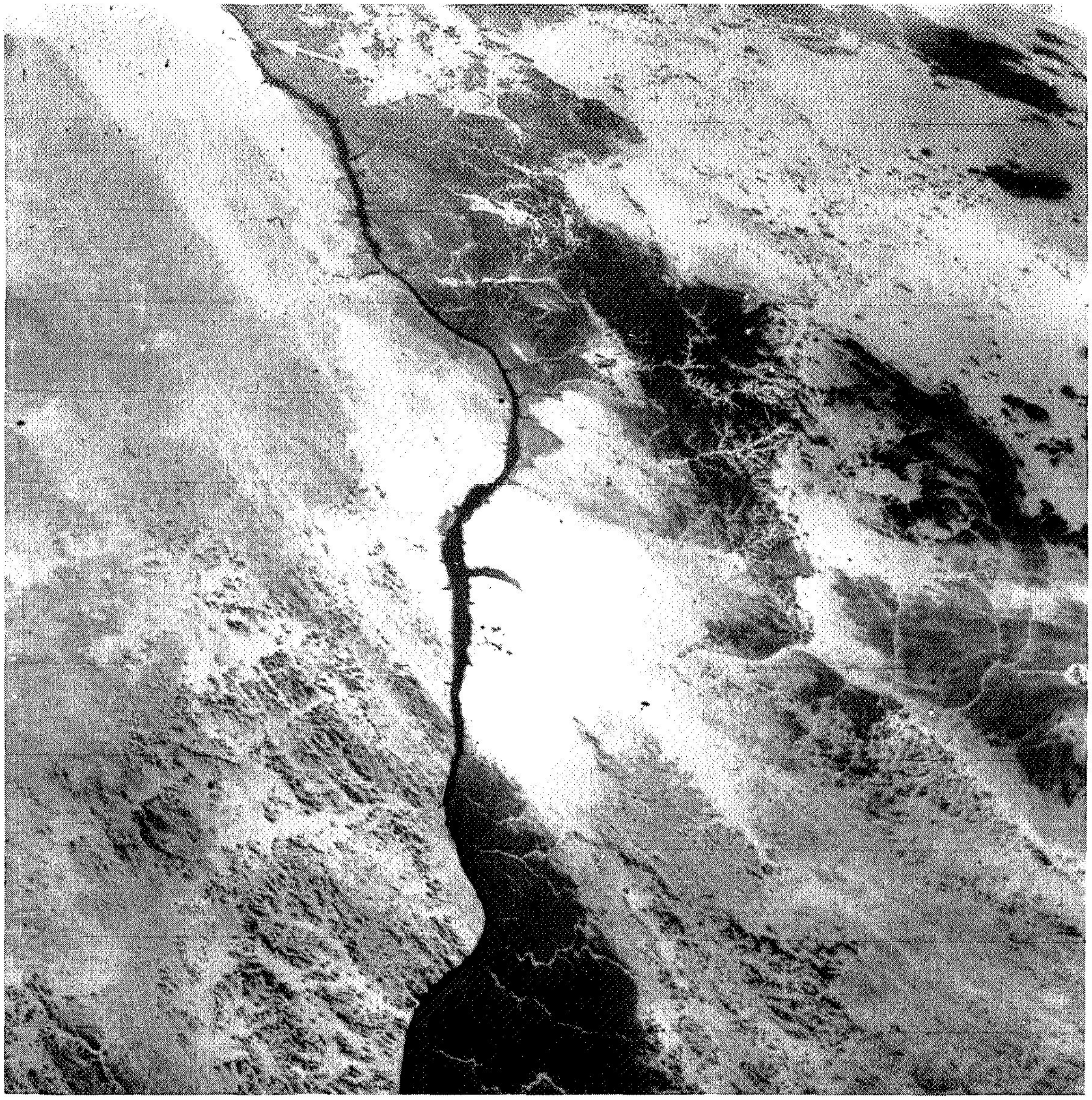


Figure 28. Gemini 4 photograph S-65-34781. View to northeast over Nile River in southern Egypt; center of picture about 23-1/2°N, 33°E. Distance from area at bottom of picture to north, near Aswan Dam (arrow) about 100 miles (160 km). Linear features trending from upper left to lower right apparently sand dunes and wind-eroded knobs and ridges of bedrock, mapped by Said (1962) as chiefly Cretaceous Nubian sandstone west of Nile and Nubian sandstone and Archean crystalline rocks east of Nile.

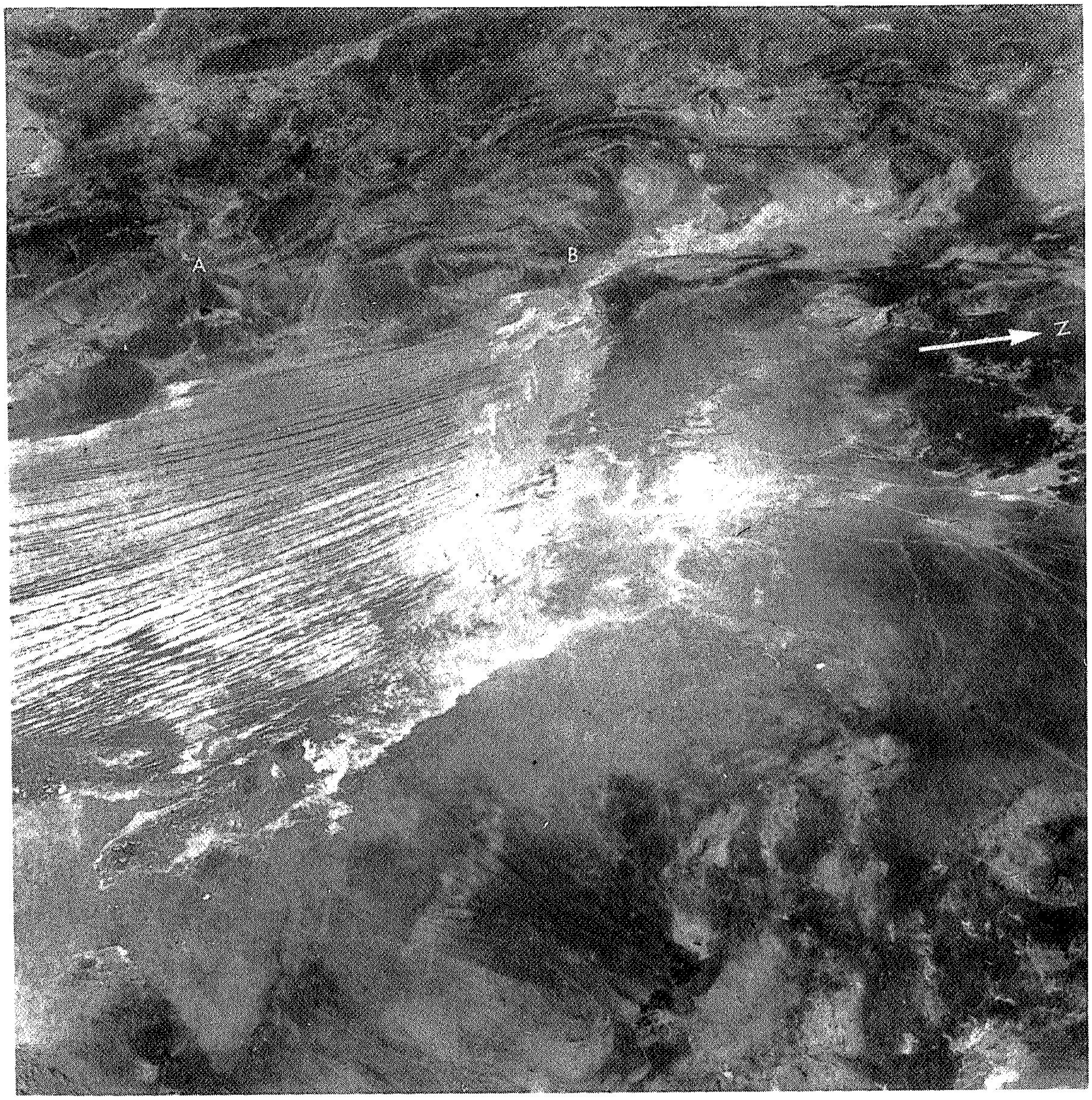



Figure 29. Gemini 5 photograph S-65-45723. View to west over eastern Iran toward city Kerman; center of picture about 31°N, 58°E. Linear features at left center are wind-eroded grooves in salt and soft sediments of the Dasht-i-Lut, a large salt desert. Mountains west of the salt desert are complexly folded sediments related to the Zagros Mountains to the west. Note fault (A-B).

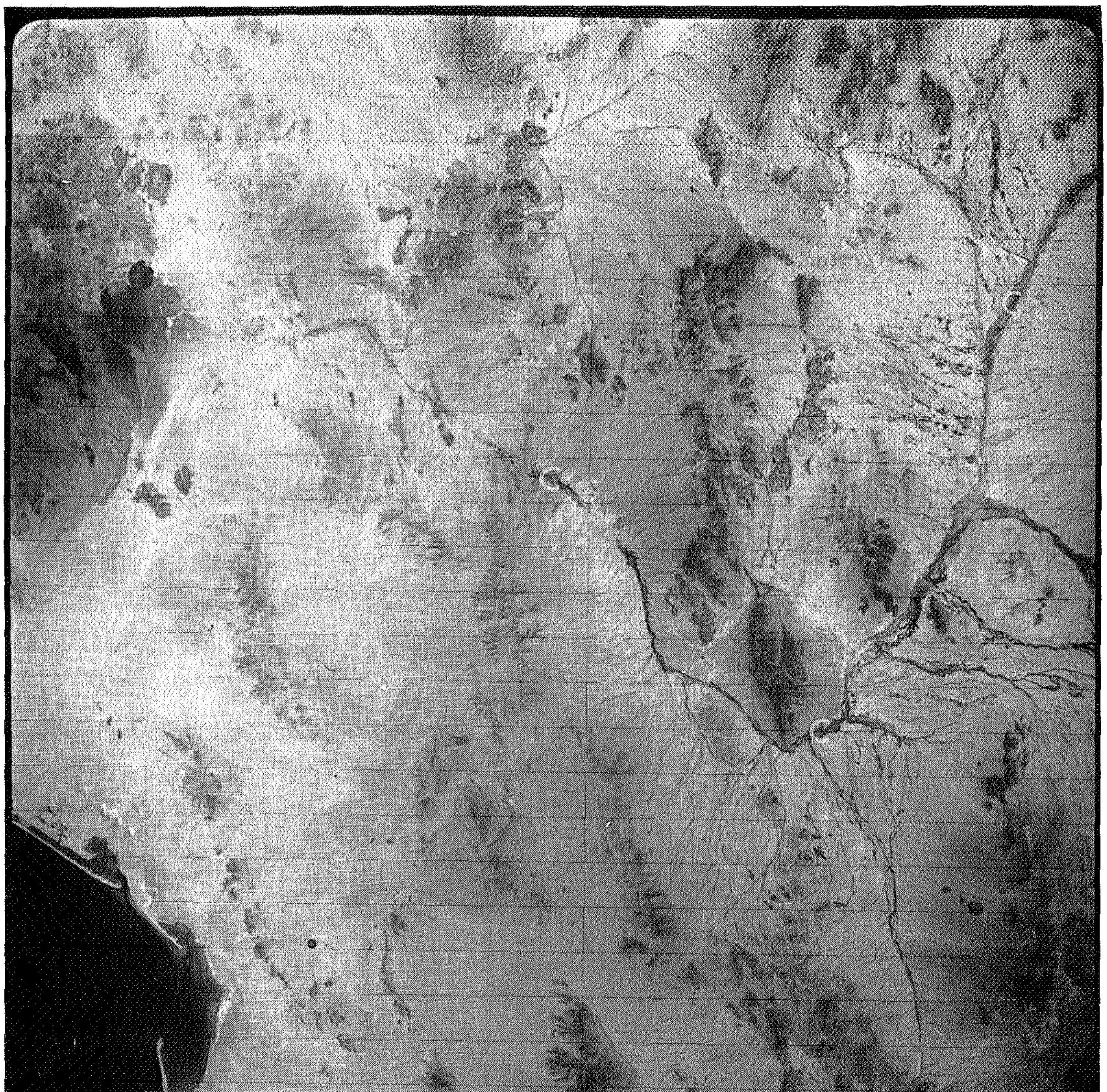


Figure 30. Gemini 4 photograph S-65-34676. Near-vertical view (slightly oblique to south) of northwest Sonora and southwest Arizona (north at top). Area is in Basin and Range Province. Pinacate volcanic field at far left; Sonoita River (C-C-C) at center, outlined by vegetation (cottonwoods and similar plants). Area covered about 70 miles wide.

limited to permit generalization about wind erosion there.) But it appears that the theory that stream erosion is dominant in deserts does not apply to large parts of the greatest desert of all, the Sahara. (As a check on this statement, note the scarcity of pediments in the photographs of the Sahara.) Many individual regions, probably totaling several score thousand square miles, seem to have been deeply eroded by wind abrasion and covered by dunes associated with the erosion.

A detailed analysis of the reasons for this unique characteristic of the Sahara would be beyond the scope of this report, but a few should be mentioned. First is the fact that most of North Africa (and all the areas illustrated here) are south of 30° latitude, and lie in the belt of northeast trade winds (locally called the harmattan); the Basin and Range Province, on the other hand, is north of 30° in the belt of prevailing westerlies (Gentilli, 1968). The physiography of North Africa — essentially an immense shield with a few high massifs such as the Ahaggar and Tibesti — permits these northeast winds to blow without interruption for hundreds or thousands of miles, while the north or northwest trending ranges of North America break the westerly winds. Another reason for the dominance of aeolian features in North Africa is simply the extremely low rainfall; unlike the North American deserts, many parts of the Sahara outside the massifs have rain only at intervals of years. Wind erosion may thus win by default in North Africa.

## The Physiography of Mars

Because of the low inclination of the Gemini orbits and the generally clear desert weather, many of the Gemini photographs are of deserts. Since Mars is generally thought to be essentially desert-like, it is of interest to compare the physiography of Mars with that of terrestrial deserts.

The main problems of Martian physiography (Loomis, 1965; Michaux, 1967) are the nature of the light and dark areas (Fig. 31). In particular, it is still not agreed, despite the achievements of Mariner IV, whether the dark areas (maria) are lower (and possibly vegetated) or higher than the light areas. Related to this is the question of what the canals are; as pointed out by Sagan and Pollack (1966), their location, tone, and periodic color changes suggest some connection with the dark areas.

Examination of the Gemini photos of deserts, especially the Sahara (Fig. 25), shows their general similarity to sketches of Mars made at rare moments of good seeing and, to a lesser degree, to color photographs such as those of Finsen (1961). (This similarity does not of course extend to the craters photographed by Mariner IV.) The major dark areas of terrestrial deserts are, almost without exception, higher than the light areas; specifically, they are usually plateaus or mountains of bedrock surrounded by lighter-colored wind or

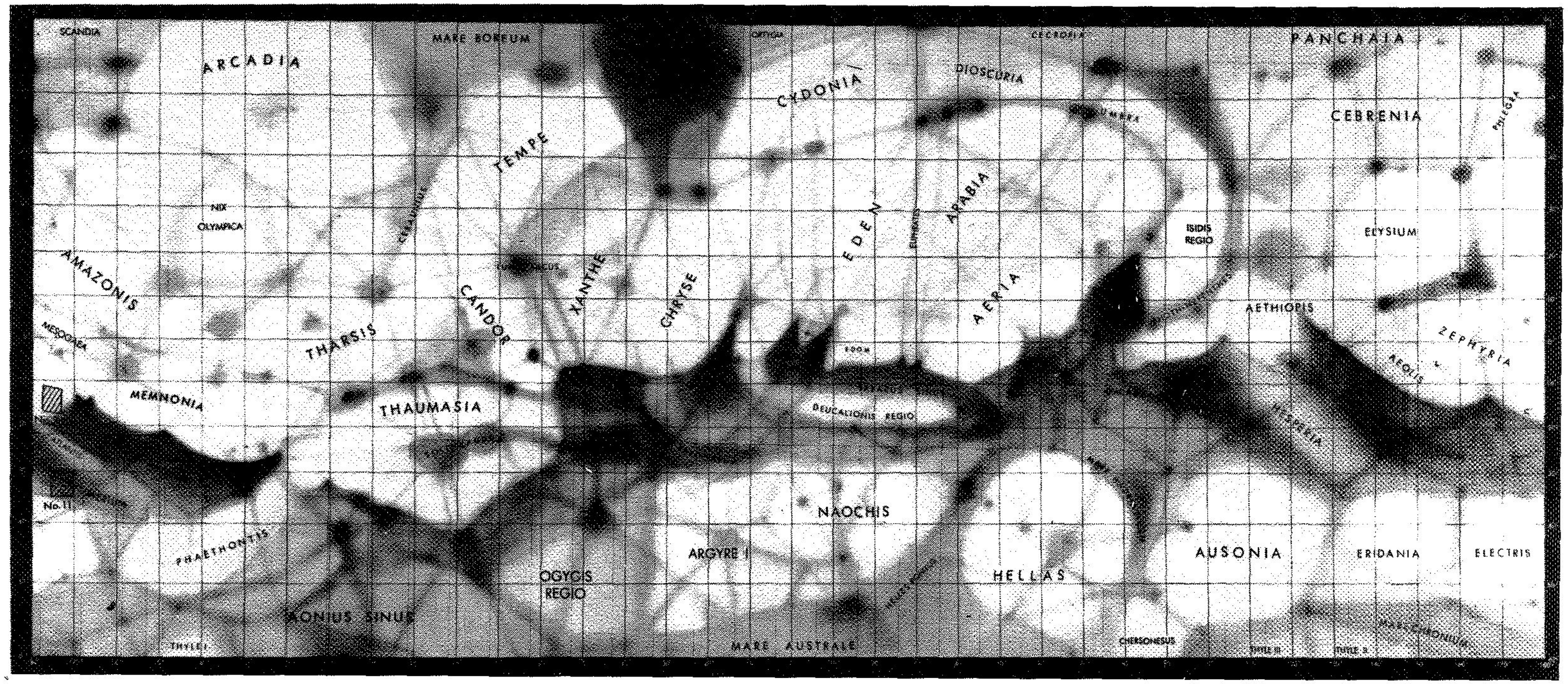



Figure 31. Portion of U.S. Air Force Aeronautical Chart and Information Center Mars map, showing light and dark areas as seen with telescopic resolution. North at top.

water-deposited sediments. This generalization does not necessarily hold for smaller features or areas; for example, in Fig. 32, chains of light-colored seif dunes overlie dark bedrock. Also, the few large lakes in some deserts are darker than their surroundings, but this possibility can safely be ignored for Mars. It seems safe to say that if deserts on the earth were viewed at the same resolution with which we view Mars, the dark areas seen would be highlands and the light areas lower terrain consisting of less consolidated material. This is in agreement with the interpretations of Martian topography by Tombaugh (1966) and Sagan, et al. (1966), in which it is proposed that the dark areas and canals are plateaus and ridges, and the light areas deserts of wind-blown sand or dust.

The foregoing arguments do not by themselves eliminate the theory that the maria of Mars are low areas in which vegetation is localized. However, the Gemini photographs reveal no such large features of natural origin in terrestrial deserts. In Fig. 30, for example, part of the Sonora desert (relatively lush as deserts go) is shown; although the ephemeral Sonoita River and its tributaries are dark because of the vegetation along them, these are relatively small. From Mars, the dark features seen in this area would be the mountains. The only large, dark low areas in deserts are those formed by artifical irrigation, as in the Imperial Valley of California and the Nile Valley of Egypt (Fig. 33).

Another problem of Martian physiography is the cause of the reddish color of the bright areas. It is generally agreed that this is due to limonite, but there is disagreement on its concentration. From astronomical studies (summarized by Michaux, 1967), several workers have concluded that the material of the light areas must be largely limonite. However, Van Tassel and Salisbury (1964) point out that silicate grains coated with limonite are much more likely on geological grounds. The Gemini photographs of terrestrial deserts appear to support the latter concept: many deserts are as red or redder than those of Mars, but almost invariably consist of quartz or other silicates with a very small percentage of iron oxides.

The Gemini photographs shed no obvious light on other problems of Martian topography, such as the cause of the wave of darkening, which Sagan and Pollack (1967) attribute to seasonal deposition and removal of dust. It will be of interest to examine repetitive orbital photographs of deserts from future missions to see if there is any terrestrial analogue.

In summary, the simplest interpretation of Martian physiography in the light of the Gemini photographs is that the dark areas and possibly the canals are relatively high plateaus or ridges, and the light areas deserts of eolian silicate sand and dust with a small proportion of iron oxides. The general pattern of the Martian dark areas is strongly suggestive of the basin-and-swell physiographic pattern of North Africa (e.g., Holmes, 1965, Fig. 763), but this interpretation is little more than speculation.

Figure 32. Gemini 7 photograph S-65-63786. View to southeast over northwest Algeria toward the Tademait Plateau; center of picture about 28° N, 1°W. Ridges at left are the Tabelbala and Ougarta Ranges, Hercynian folds at right angles to the trend of the Atlas Mountains (Tertiary). Note light-colored dunes of the Erg Iguidi in right foreground overlying dark bedrock.


Figure 33. Gemini 4 photograph S-65-34668. Oblique view of northern Egypt. Nile delta at top (A); El Faiyum (B) lower right is a depression irrigated by water from the Nile and partly filled by the Bohirat Quiron (C), a lake 148 feet (46 meters) below sea level. Dark areas are irrigation-supported vegetation, light areas sandy desert. Cairo (D) at upper right.

Study of Mariner 6 and 7 photographs of Mars is underway to test the suggestions made here.

## GEOLOGIC SPECULATIONS

The foregoing applications of the Gemini photography have been relatively conventional, being essentially photogeology from extreme altitudes. However, in the course of indexing and studying the 1100 pictures, a number of intriguing questions have arisen, leading to the following speculations.

### Nature of the Oman Line

As shown in Figs. 34 and 35, there is a sharp discordance in the Zagros-Makran Ranges of southwest Asia opposite the Musandam Peninsula. This feature has been known for some years, and has been studied in particular by Gansser (1955, 1964). Gansser has suggested that this is a rejuvenated tectonic line of strike-slip faults, and is the continuation northward of the Oman Range structure under the Zagros-Makran Ranges. He further speculates on the possible importance of overthrusting in this area.

The Gemini photos of this area, in particular Fig. 34 provide a remarkably good view of the regional structure. Of particular interest is the remarkable resemblance, especially when viewed from the west, of the Makran Range to the Pine Mountain overthrust and similar structures; at first glance, the Makran Range looks like an enormous thrust plate that has been displaced to the south. That this is not simply an optical effect is indicated by the strike-slip nature of the faults along the north-east coast of the Strait of Hormuz (Gansser, 1955; see also the British Petroleum Company Geologic Map of Iran, 1:250,000 series, Bandar'Abbas and Strait of Hormuz sheets, 1963). Further support is given by the fact, as shown on Figs. 35 and 36, that the northern limit of marine Miocene and Pliocene rocks in the Makran is 50 to 100 miles farther south than the expected continuation of this boundary from the Zagros Mountains.

Before considering this speculation further, let us consider the physical plausibility of such major overthrusting. The Zagros Mountains are underlain by the Cambrian Hormuz Formation, a salt layer which has given rise to the well-known salt plugs of the Persian Gulf (Fig. 35). The Salt Range of India, 1400 miles to the northeast, is also underlain by a Cambrian salt layer, the Saline Series, which Gansser (1966, p. 26) suggests may have played a part in overthrusting. In contrast to the Zagros Mountains, there are practically no salt plugs in the Makran Range or in the Salt Range; referring to the latter, Gansser suggests that thrusting may prevent "...a more diapiric rise of the underlying salt zone." Conditions for major overthrusting by gravitational gliding in the Makran Range


Figure 34. Gemini 12 photograph S-66-54667. View to northeast from about 350 miles (560 km) during high revolutions. Landmarks labeled as follows: Persian Gulf (P); Oman Range (O); Makran Range (M). Thrust-like form of Makran Range well illustrated, but note that east end of range (in West Pakistan) extends farther north than west end (across from north end of Oman Range).

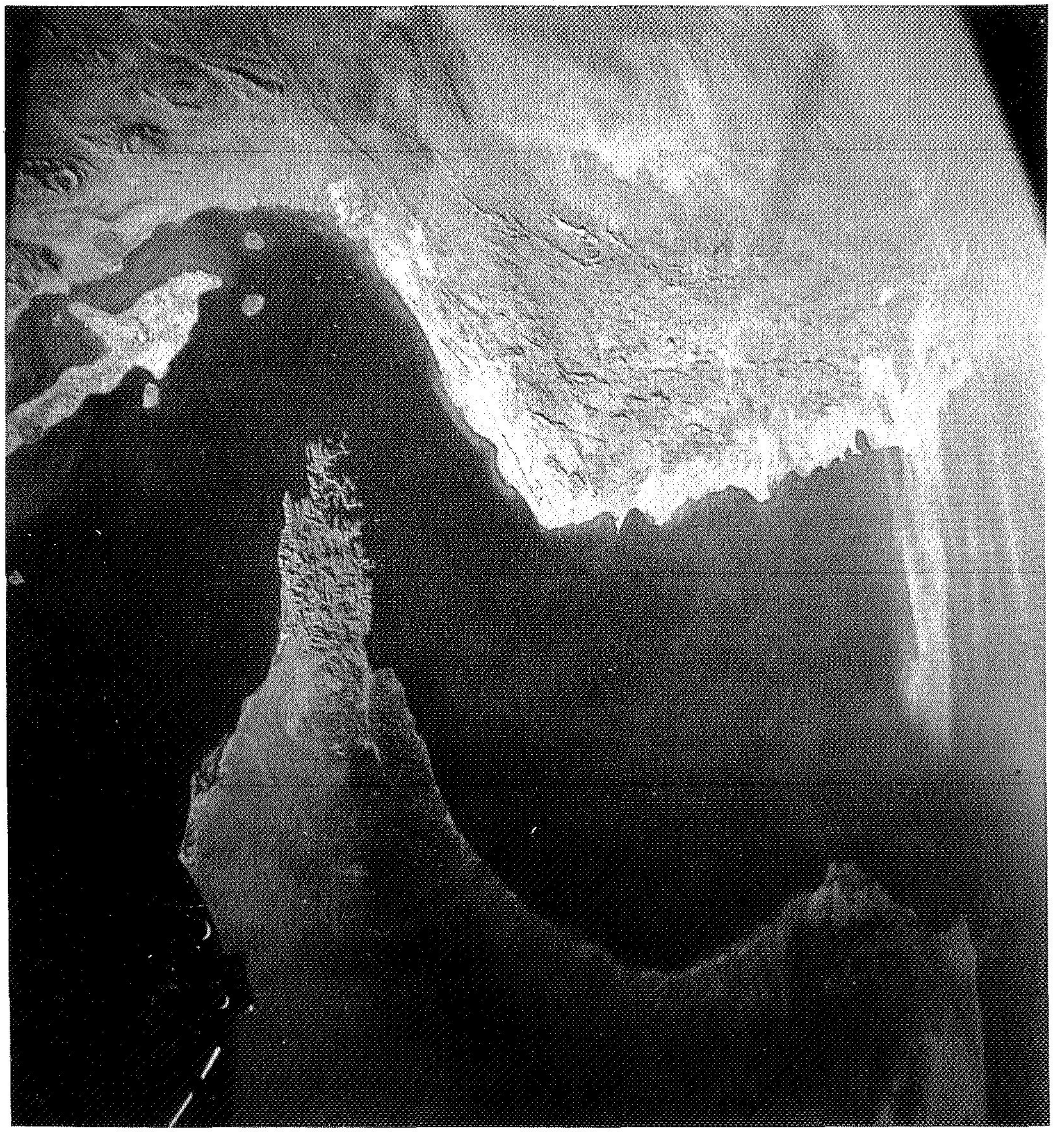
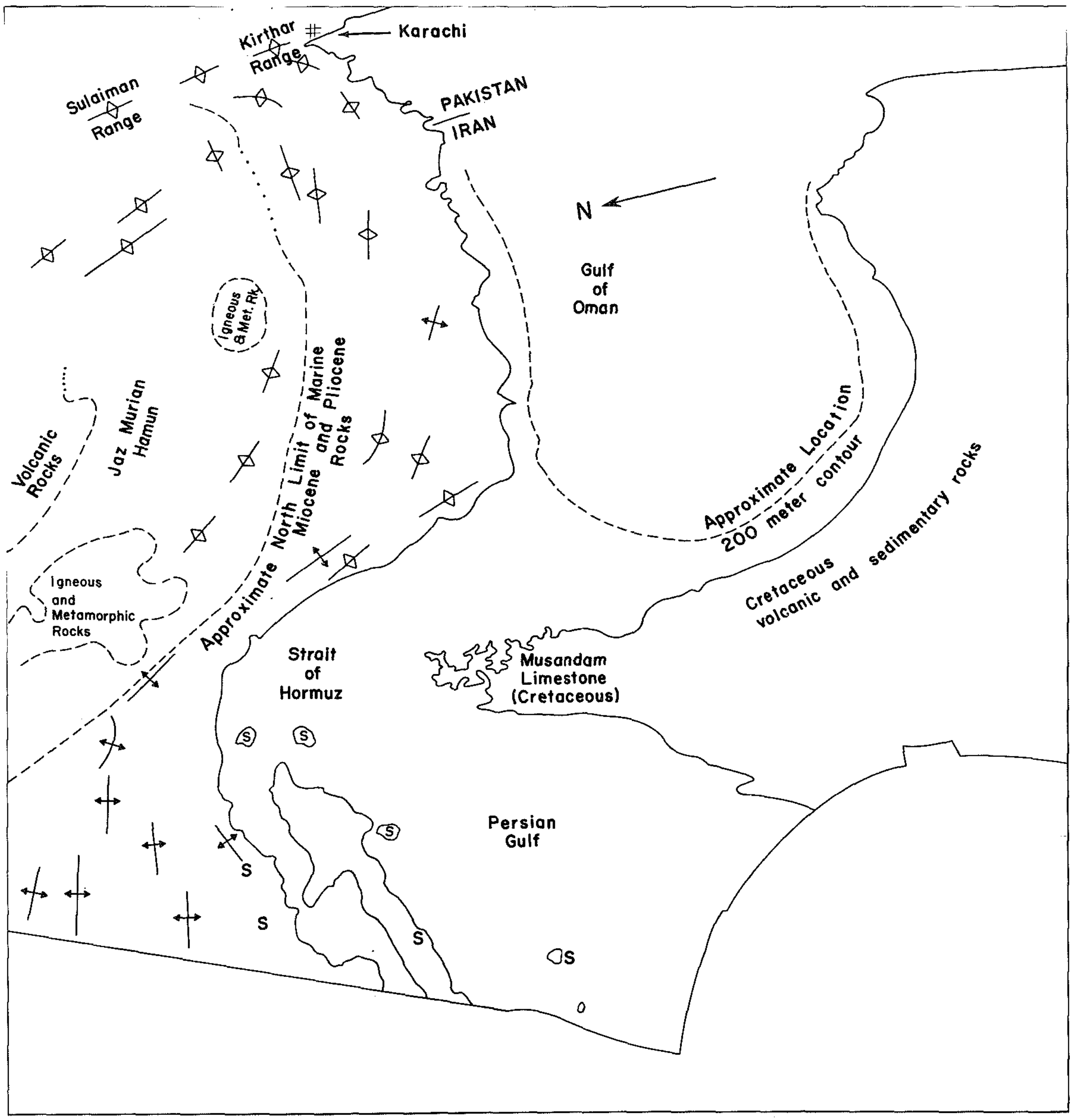


Figure 35. Gemini 12 photograph S-66-63846. View to east along Makran Range from about 168 miles (272 km) altitude. Photograph keyed to Fig. 26. Note the dust clouds at top center being blown from the Asian mainland into the Gulf of Oman by northeasterly winds.




GEOLOGIC SKETCH MAP
SOUTHWEST ASIA
Based on Gemini XII Photograph S-66-634-86

Legend

generalized fold trends

anticline

S salt plug (Hormuz salt)

Scale variable; photo area is 800 miles E-W and 350 miles N-S (at center). Lithology from geologic maps of British Petroleum, Ltd., and U.S. Geological Survey

P. D. Lowman, Jr. - 1967

Figure 36. Geologic sketch map of Fig. 35.

appear to be favorable, including a thick sedimentary section, rapidly deposited, and a stratum that can serve as a lubricating layer (Hubbert and Rubey, 1959). Finally, the John Murray Expedition (Wiseman and Sewell, 1937), discovered submarine ridges parallel to and some 60 miles south of the Makran Coast that might be the toe of the hypothetical thrust plate. It is interesting, in this general connection, to recall the proposal by Rich (1951) that the syntaxial bends in the mountains of southwest Asia might be the result of major overthrusting to the south.

There are, of course, obvious difficulties with the concept of the Makran Range as a giant thrust plate. First, the "plate" is not symmetrical, the eastern boundary (probably represented by the ranges of Baluchistan) extending much farther north. Second, the northwest-trending range just east of the Iran/Pakistan border (Fig. 35), which has no name as a unit, does not fit the overthrust pattern very clearly unless it is a separate thrust plate which has, so to speak, caught up with the Makran thrust plate in Pakistan. Finally, no such major thrusting has been recognized by those who have mapped the Makran Range in Iran and Pakistan (John Reinemund, personal communication).

In summary, it appears that the Oman Line is, as Gansser suggested, a zone of major wrench faulting and parallel folds. Whether the entire post-Cambrian section has slid to the south, singly or in slices, remains an intriguing but totally unproven possibility. Perhaps the most definitive test would be drilling of the ocean floor south of the Makran coast; if rocks similar to the Fars limestone and other units of the Zagros Mountains were encountered, it would tend to support the theory.

## Discordant Coastlines

It was proposed by E. Suess in the last century that there are tectonically speaking two types of coastlines: the Atlantic type, in which the regional structure is truncated by the coast, and the Pacific type, in which the regional structure is generally parallel to the coast. The Indian Ocean is generally thought to be of the Atlantic type. It is interesting to see if the Gemini photos support this relatively simple classification.

Some of the Atlantic coastlines covered are clearly discordant; for example, the Precambrian structures of South West Africa strike into the sea, as shown by Brock (1956). However, there is at least one confusing exception to Suess' classification; as shown in Fig. 37, the Hercynian folds of the Anti-Atlas Mountains tend to parallel the coast while the Cenozoic folds of the High Atlas are truncated by it. This does not appear easily explained by continental drift; one would expect the pre-drift (pre-Cretaceous?) structures to be truncated and the

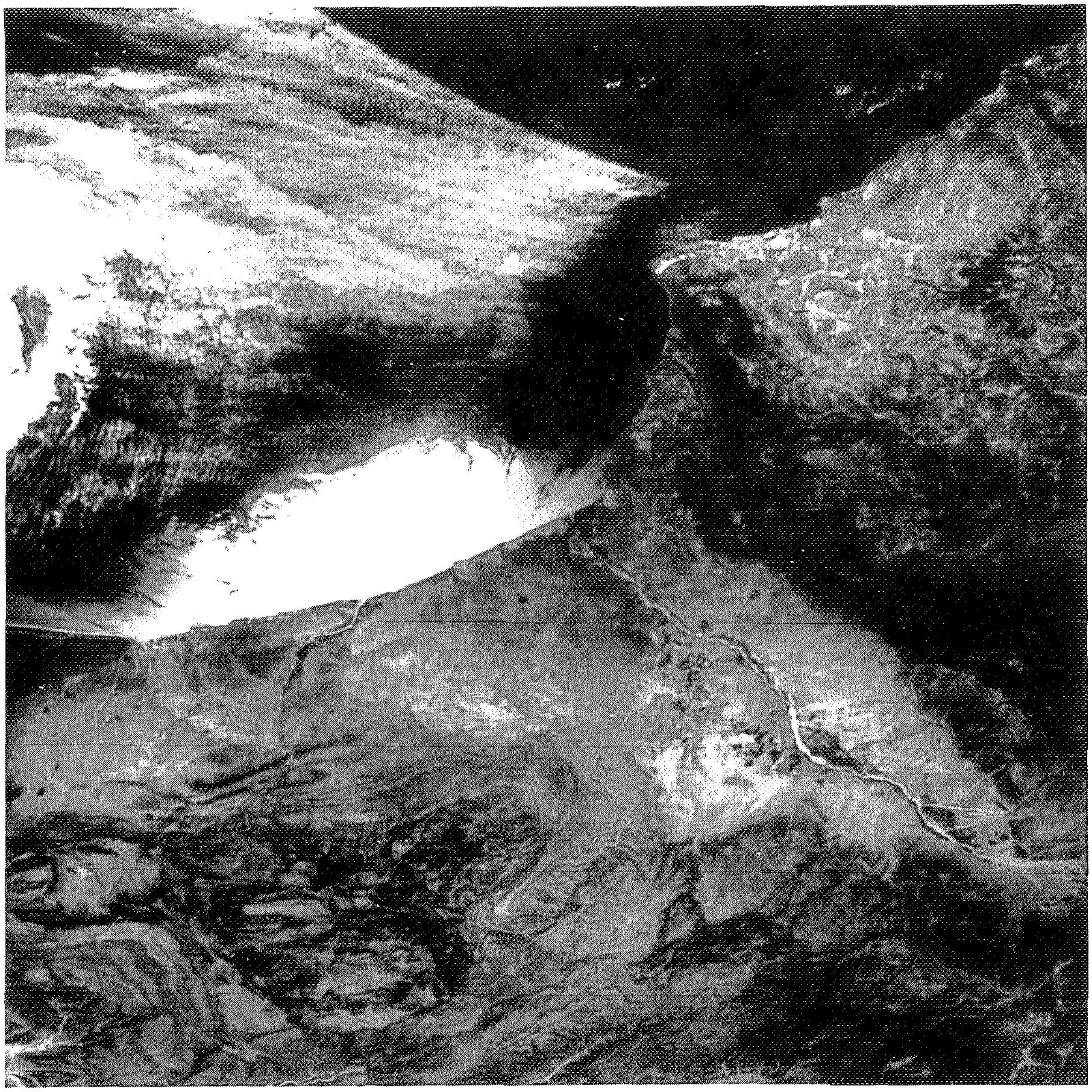


Figure 37. Gemini 5 photograph S-65-45664. Near-vertical view of west coast of Morocco, with north at upper left. Atlas Mountains (top) are discordant to coast, though Tertiary; South Atlas Mountains (lower right) are concordant, though Paleozoic. Atlas Mountains bounded on south by the south Atlas structural line (Furon, 1963), a major fault zone separating the Tertiary-Quaternary fold belt from the now-stable African craton. White patch at center along coast is sun glitter; cloud mass at bottom is an anticyclone (not a storm).

post-drift (Tertiary ?) structures to parallel the coastline. We have no explanation to offer for the reverse arrangement noted here, but it seems clear that Suess' classification can not be universally applied to the shores of the Atlantic.

Another exception to the supposed classification in this case of the Indian Ocean, is seen in Fig. 38. Study of this photo and others, in conjunction with the U. S. G. S. Geologic Map of the Arabian Peninsula (1963), demonstrates that the axis of the Oman Range turns due south and then southwest along the Batain Coast, rather than striking out into the Arabian Sea as commonly depicted (e.g., Carey, 1958). The east end of the Arabian Peninsula would thus be of the Pacific rather than the Atlantic type. This relation, with other criteria, has been used elsewhere (Lowman, 1967) as evidence that the Arabian Sea is not a sphenochasm, as proposed by Carey (1958).

It will be worthwhile to examine photographs of coastlines from future orbital missions to further check the usefulness of Suess' classification; these preliminary studies indicate that it may not be applicable in certain regions or above certain scales.

Uniqueness of the Basin-and-Range Province

Gemini photos of northern Mexico and the southwestern United States have provided an excellent view of the physiography of a significant portion of the Basin-and-Range Province. Comparison of these with other photos in the 35°N-35°S latitude band shows that the Basin-and-Range Province is unique in that no other continent has such a large area of closely spaced horst-and-graben terrain. The Andes Mountains are a relatively narrow band of chiefly folded structure; most of Africa is clearly on basin-and-swell; and most other mountains in Asia belong to the Tertiary folded belt extending from Indonesia to the Atlantic. Examination of any good physical map of the world, moreover, suggests that nothing like the Basin-and-Range Province will be found outside the Gemini latitude band.

This uniqueness can not be easily explained. However, it appears to support Menard's (1961) suggestion that the Basin-and-Range Province is the result of the intersection of the East Pacific Rise with the North American continent. There are few other places where an oceanic rise intersects a continent, one of them being the Red Sea, whose structure is essentially like that of the Basin-and-Range Province but narrower.

This curious relationship, regardless of its cause, furnishes a good example of the stimulus to geologic thinking that can be provided by the global coverage of orbital photography.

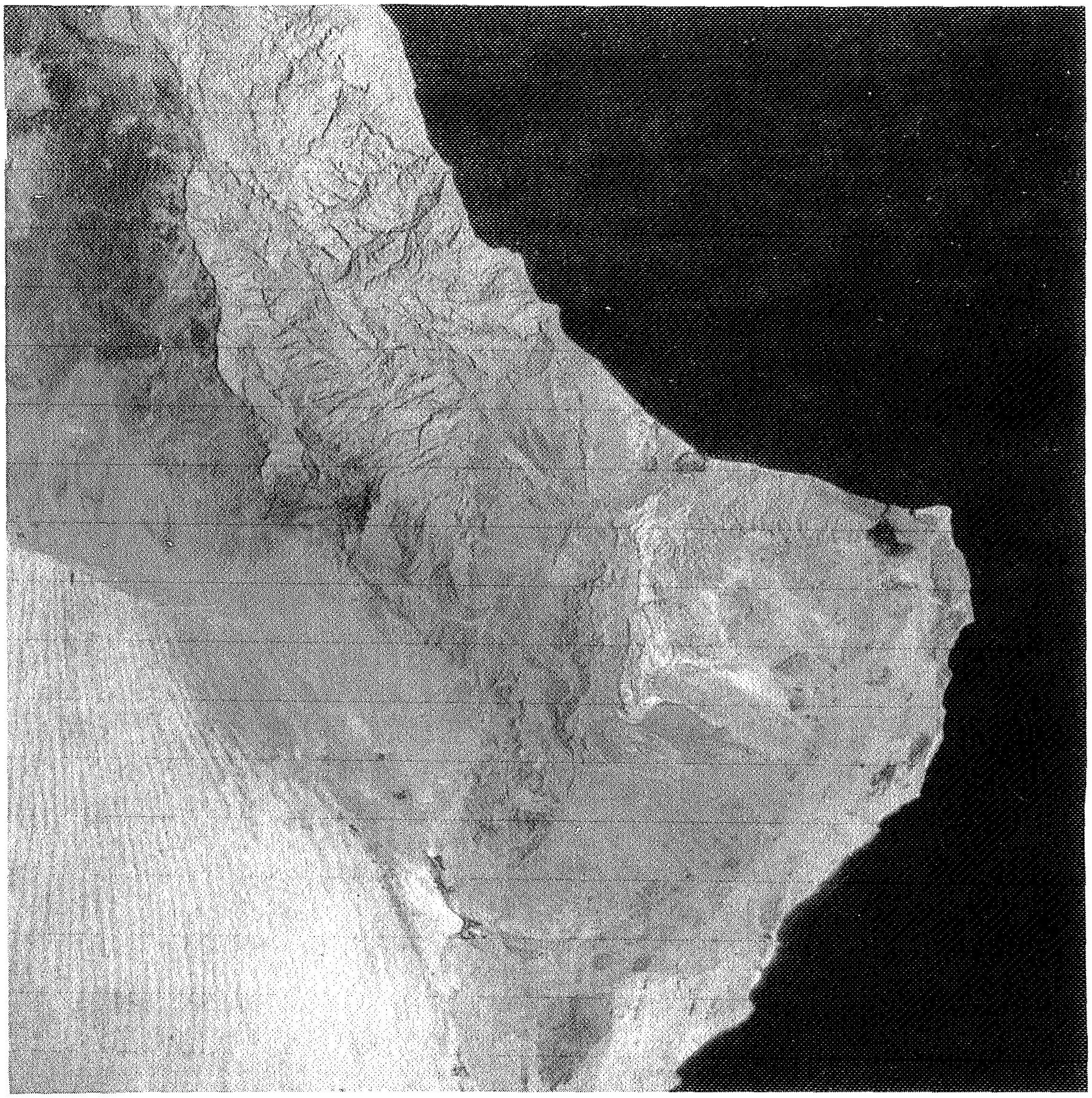


Figure 38. Gemini 4 photograph S-65-34661. Vertical view of the east end of the Arabian Peninsula, showing concordance of fold trends to coastline. Area shown is about 65 miles (104 km) wide; north at top. Light-toned area at top is chiefly northward-dipping Tertiary sediments, covering the ophiolites of the Hawasina and Semail igneous complexes that form the core of the Oman Range (see Fig. 34 for a regional view of this range). Light areas at lower left are the Wahibah sands ('urug dunes).

## SUMMARY AND CONCLUSIONS

The success of the S005 experiment can not be adequately judged from the number of planned areas actually photographed. Those not covered, or at least not covered with usable pictures, include the southern part of the African rift valleys, much of northern South America, southern India, Australia, and Brazil. But balanced against these gaps is photography of unscheduled though geologically important areas, such as South-West Africa, Peru, and Tibet. Overall, it seems safe to say that despite departures from the pre-flight plan, the terrain photography experiment was highly successful in terms of quantity and quality of coverage.

Perhaps the major general result of the S005 experiment was a clear idea of just what the main geologic uses of orbital photography will be (see also Lowman, 1967). The following list is a conservative one.

1. Natural resource evaluation, use, and conservation: Investigating relation of mineral deposits to geologic structure, evaluation of surficial deposits (e.g., sand and gravel), locating unsuspected extensions of mineralized zones or oil-bearing structures, fundamental research on nature of regional ore controls, location of potential mineral or oil-bearing structures for intensive ground study, detection of sediment pollution sources and incorrect surface mining practices.

2. Regional tectonics: Studies of major fracture patterns, structures associated with batholiths, relation of regional structure to vulcanism, nature of displacement on wrench faults, intercontinental correlation of structure.

3. Geologic mapping: Reconnaissance mapping of remote areas, correction of small-scale maps, correlation of geology with geophysical surveys, mapping of Quaternary volcanic rocks.

4. Geomorphology: Evolution of desert landscapes, origin of pediments, sand dune mapping, soil mapping, studies of fluvial and coastal erosion and sedimentation, world-wide monitoring of glacial advance and retreat.

5. Geologic education: Teaching world geology, tectonics, geomorphology, and coordinated earth science courses (e.g., ESCP), illustrating geologic hazards (e.g., faults) in public press.

An equally important result of the S005 experiment is greater knowledge of the limits of orbital photography. The operational restrictions, such as orbital characteristics, cloud cover, and daylight availability have been treated elsewhere (Lowman, 1969). In addition to these, orbital photography has certain limitations as a geologic tool, some of which are shared with aerial photography:

1. Composition determination: Determination of rock types on photographs has always been difficult, and has relied heavily on indirect indicators such as characteristic drainage patterns, plant cover, and karst topography. Tone or color are also used, but are frequently ambiguous (von Bandat, 1962). Orbital photography has not eliminated this problem; if anything, the low resolution generally characteristic of orbital photographs aggravates it. Multispectral sensing has considerable promise. However, there are few if any broad spectral peaks in the photographically accessible part of the spectrum (0.3 to 0.9 microns), so that remote rock identification will probably have to be done with non-film sensors operating in the 10 micron vicinity. Even then severe problems remain: the speed of the spacecraft, incomplete atmospheric transmission, and resolution. Field checking and sampling will probably always be required; it should be remembered that despite several decades of persevering astronomical efforts at remote sensing par excellence, the composition of the moon's surface was essentially unknown until samples were returned by the Apollo missions.

2. Vegetation and soil cover: Like aerial photography, orbital photography depends on reflected radiation from the surface of the earth, and so is limited in usefulness where the bed rock is covered by vegetation and soil. Even in areas of generally good exposure, the superficial nature of photography can be a handicap. For example, in Fig. 7, a dark tongue of material can be seen extending several miles east from the Palomas volcanic field, and was interpreted before field checking as a lava flow. But it was later discovered to be a thin residual gravel deposit consisting largely of quartz and chert pebbles with a coating of desert varnish; the photographic tone was thus produced by an oxide coating a few microns thick on a layer of pebbles only a few centimeters thick.

3. Great areal coverage: The immense area per photo provided by orbital altitudes is a handicap as well as an advantage because of the great amount of time required for ground checking. To make a reconnaissance of even one orbital photograph involves hundreds of miles of travel and at least several weeks time. Therefore, for really effective use of orbital photographs in geology, fast transportation is absolutely necessary. The ideal solution would be a helicopter; failing that, low-altitude airplane reconnaissance, coupled with standard air photos, should be considered essential in field work with orbital photography. Furthermore, when on the ground the geologist should suppress his love of hiking and drive as close to points of interest as he possibly can; otherwise he will spend several days covering a few square millimeters of his photograph. Finally, field checking on orbital photographs should be carefully planned to include only the most critical points; systematic contact walking and fault-chasing on 1:1,000,000 scale photographs is hopelessly inefficient.

4. Resolution: The subject of ground resolution on orbital photographs has been discussed before (Lowman, 1967 and 1969). However, it should be stressed here that the comparatively low resolution of orbital photographs, compared to aerial photographs, means that in addition to loss of topographic detail, the tone or color of any one point on the photograph may represent a wide variety of rock types. This is especially true in areas of steeply dipping stratified or foliated rocks with varied lithology. This problem intensifies the difficulty already discussed of determining rock composition from orbital photography. As pointed out elsewhere (Lowman, 1969) very long focal lengths can increase resolution to nearly aerial standards, but only at the cost of narrow fields of view.

We shall close this report with some general comments about the long-range results of the S005 experiment. The pictures taken by the Gemini astronauts have proven useful both by themselves and as a demonstration of the geologic value of orbital photography. But the experiment had totally unexpected benefits in addition. First among these was the great stimulus given to the NASA earth resources program and to remote sensing in general (from spacecraft and aircraft). It is not widely known that before the Mercury and Gemini photographs became available, there was virtually no appreciation of the potential value of orbital surveys in the management of earth resources. This is demonstrated in many publications of the early space age. For example, an authoritative report, "The Next Ten Years in Space," published in 1959 for the Select Committee on Astronautics, U. S. House of Representatives, made no mention of orbital photography of the earth's surface except as a military reconnaissance technique. The "New Space Handbook," published as recently as 1963, mentioned only mapping and military reconnaissance as applications of earth orbital photography. Serious planning for orbital earth resource surveys dates from late 1963, when the final report on terrain photography from Mercury flights was published (O'Keefe, et al., 1963). The Earth Resources Observation Satellite (EROS) program of the U. S. Geological Survey was, according to the Director of the Survey, "conceived in 1966 largely as a direct result of the demonstrated utility of Mercury and Gemini orbital photography to earth resource studies" (Pecora, 1969). The NASA Earth Resources Technology Satellite (ERTS) and the Skylab earth resources experiment package have also drawn heavily on Gemini and Apollo terrain photography experience in program planning and in anticipating data reduction problems.

There are further benefits from the S005 experiment that are, we feel, largely unrecognized. The terrain photographs were taken primarily for scientific research in the fields of tectonics, geomorphology, and petrology, but have proven to be of great applied value in attacking problems such as mineral shortages, land use, and water pollution. The S005 experiment thus provides an

excellent example of the practical value of basic research, a matter of much concern when not only the space program but scientific research in general must prove they are "paying their way."

Finally, we wish to point out that any results from Gemini and Apollo photography must ultimately be credited to the Apollo lunar landing program (of which the Gemini flights were part). One of the justifications given for the Apollo program by its early supporters was the probability of unexpected by-products. It has now become clear that the photographs of the earth taken, in effect, by astronauts on the way to the moon will eventually prove to be invaluable in the study and management of our home planet.

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