tions concerning man's support and response to this environment with the reality of the findings from the actual experience.

The space-flight environment predictions are compared with the actual observations in table 16–III.

The human responses to space flight which were predicted are compared with the observations in table 16–IV. There were more predicted system effects than were observed, though there were also several effects noted which were not predicted.

General Aspects of the Flight Program

In evaluating the results of flight programs, it is important to realize that man is being exposed to multiple stresses and that it is impossible at the present time to evaluate the stresses singly, either inflight or post-

TABLE 16–I.—*Project Mercury Manned Flights*

Flight	Crew	Launch date	Description	Duration, hr:min
MR-3	Shepard	May 5, 1961	Suborbital	0:15
MR-4	Grissom	July 21, 1961	Suborbital	0:15
MA-6	Glenn	Feb. 20, 1962	Orbital	4:56
MA-7	Carpenter	May 24, 1962	Orbital	4:56
MA-8	Schirra	Oct. 3, 1963	Orbital	9:14
MA-9	Cooper	May 15, 1963	Orbital	34:20

TABLE 16–II—*Gemini Manned Space Flights*

Gemini mission	Crew	Launch date	Description	Duration, day:hr:min
III	Grissom Young	Mar. 23, 1965	Three revolution manned test	0:04:52
IV	McDivitt White	June 3, 1965	First extended duration and extravehicular activity	4:00:56
V	Cooper Conrad	Aug. 21, 1965	First medium-duration flight	7:22:56
VII	Borman Lovell	Dec. 4, 1965	First long-duration flight	13:18:35
VI–A	Schirra Stafford	Dec. 15, 1965	First rendezvous flight	1:01:53
VIII	Armstrong Scott	Mar. 16, 1966	First rendezvous and docking flight	0:10:41
IX–A	S ford Cernan	June 3, 1966	Second rendezvous and docking; first extended extravehicular activity	3:01:04
X	Young Collins	July 18, 1966	Third rendezvous and docking; 2 extravehicular activity periods; first docked target-vehicle-propelled high-apogee maneuver	2:22:46
XI	Conrad Gordon	Sept. 12, 1966	First rendezvous and docking initial orbit; 2 extravehicular activity periods; second docked target-vehicle-propelled high-apogee maneuver; tether exercise	2:23:17
XII	Lovell Aldrin	Nov. 11, 1966	Rendezvous and docking; umbilical and 2 standup extravehicular activity periods; tether exercise	3:22:37

TABLE 16–III.—*Space-Flight Environment*

Predicted	Observed
Micrometeorite density	Low micrometeorite density
Loss of cabin pressure-vacuum	5 psi except during extravehicular activity
Loss of suit pressure-vacuum	Space suit, wear unpressurized (pressurized on extravehicular flights)
Toxic atmosphere	100-percent oxygen
Cabin and suit temperature	Minimal variation about comfort zone
Radiation levels	Insignificant
Isolation	None
Physical confinement	Physical restraint
Weightlessness	Weightlessness
Gravity loads	Gravity loads, no problem with performance
Vibration	Minimal vibration
Severe glare	Varying illumination
(a)	Workload higher than expected

[a] Not predicted.

TABLE 16–IV.—*Human Response to Space Flight*

Predicted	Observed
Dysbarism	None
Disruption of circadian rhythms	None
Decreased g-tolerance	None
Skin infections and breakdown	Dryness, including dandruff
Sleepiness and sleeplessness	Interference (minor)
Reduced visual acuity	None
(a)	Eye irritation
(a)	Nasal stuffiness and hoarseness
Disorientation and motion sickness	None
Pulmonary atelectasis	None
High heart rates	Launch, reentry, extravehicular activity
Cardiac arrhythmias	None
High blood pressure	None
Low blood pressure	None
Fainting postflight	None

[a] Not predicted.

TABLE 16–IV.—*Human Response to Space Flight*—Concluded

Predicted	Observed
Electromechanical delay in cardiac cycle	None
Reduced cardiovascular response to exercise	None
(a)	Absolute neutrophilia
Reduced blood volume	Moderate
Reduced plasma volume	Minimal
(a)	Decreased red-cell mass
Dehydration	Minimal
Weight loss	Variable
Bone demineralization	Minimal calcium loss
Loss of appetite	Varying caloric intake
Nausea	None
Renal stones	None
Urinary retention	None
Diuresis	None
Muscular incoordination	None
Muscular atrophy	None
(a)	Reduced exercise capacity
Hallucinations	None
Euphoria	None
Impaired psychomotor performance	None
Sedative need	None
Stimulant need	Occasionally before reentry
Infectious disease	None
Fatigue	Minimal

[a] Not predicted.

flight. Man is exposed to multiple stresses which may be summarized as: full pressure suit, confinement and restraint, 100-percent oxygen and 5-psia atmosphere, changing cabin pressure (launch and reentry), varying cabin and suit temperature, acceleration g-force, weightlessness, vibration, dehydration, flight-plan performance, sleep need, alertness need, changing illumination, and diminished food intake. Some of the stresses can be simulated in ground-based studies but the actual flight situation has never been duplicated, and more data from additional flight programs are necessary before flight observations can be applied to the ground situation.

It is necessary to provide the capability to monitor the physiologic state of man during flight activities. A great deal of consideration has been given to the definition of a set of physiologic indices which might be easily obtained in the flight situation and which could be meaningfully monitored. Routine parameters have included measurements of voice, two leads for electrocardiogram, respiration, body temperature, and blood pressure (fig. 16–1). Other functions were added for the experiments program, but were not monitored in real time. The monitoring of man's physiologic state in flight is necessary to provide information for real-time decision making concerning the accomplishment of additional flight objectives; to assure the safety of the flight crew; and to obtain experimental data for postflight analysis for predictions concerning the effects of long-duration flight upon man. The sensors and equipment should not interfere with the comfort and the function of the crew. Whenever possible, the procurement of data should be virtually automatic, requiring little or no action on the part of the crewmen. A great deal has been learned concerning the use of minimal amounts of data obtained at intermittent intervals while a spacecraft is over a tracking station. The extravehicular crewmen have been monitored by means of one lead each of electrocardiogram and of respiration-rate measurement obtained through the space-suit umbilical. Additional physiologic information, such as suit or body temperature and carbon-dioxide levels, could not be obtained due to the limited number of monitoring leads available in the umbilical.

FIGURE 16–1.—Gemini biosensor harness.

The medical objectives in the manned space-flight program are to provide medical support for man, enabling him to fly safely in order to answer the following questions:

(1) How long can man be exposed to the space-flight environment without producing significant physiologic or performance decrement?

(2) What are the causes of the observed changes?

(3) Are preventive measures or treatment needed, and if so, what are best?

Attainment of these objectives will involve tasks with different orientation. The most urgent task is obviously to provide medical support to assure flight safety through the development of adequate preflight preparation and examination, as well as inflight monitoring. The second is to obtain information on which to base the operational decisions for extending the flight duration in a safe manner. The third task differs from the operational orientation of the first two in that it implies an experimental approach to determine the etiology of the findings observed. Frequently, many things that would contribute to the accomplishment of the last task must be sacrificed in order to attain the overall mission objective. This requires constant interplay between the experimental and the operational medical approaches to the missions.

The medical profession requires a team effort by personnel with varied training and backgrounds in order to reach a common objective, the preservation or the restoration of health for mankind. This is no less true in a space-flight environment where a strong team effort is necessary, and a strong engineering interface is imperative. If man is to be properly supported, medical requirements concerning the spacecraft environment and the equipment performance must be supplied very early in the hardware development cycle. A very long leadtime is necessary to meet realistic flight schedules, and ample time must always be left for proper testing of the hardware. Flight-configured hardware should be utilized to collect the baseline physiologic data which will be compared with the inflight data.

Anticipated Problems Compared with Flight Results

The review of a number of aerospace or space medicine texts published since 1951 reveals a large number of anticipated problems involving man and the hardware or vehicle in the space environment. It appears logical to compare the predictions with the actual flight results.

Maintenance of Cabin Pressure

In regard to the vacuum of space, extrapolating from aircraft experience led to a prediction of difficulty with the maintenance of cabin pressure. To date, the spacecraft have maintained a cabin pressure of approximately 5 psia throughout the manned flights. The pressurization feature of the space suits was a backup to the cabin pressure, but was not required except during the planned excursions outside the spacecraft when the cabin was intentionally depressurized. The normal suit pressures have been approximately 3.7 psia.

Cabin Atmosphere

Reduction in cabin pressure to 5 psia, equivalent to a pressure altitude of 27 000 feet, and the further reduction to 3.7 psia in the space suit created some concern about the possible development of dysbarism. Before each mission, the crew was denitrogenated by breathing 100-percent oxygen for 2 hours; this, coupled with the further denitrogenation accomplished in the spacecraft, has proved to be ample protection. There have been no evidences of dysbarism on any of the missions.

Cabin and Suit Temperature

The maintenance of an adequate temperature in the cabin and in the extravehicular pilot's suit was also a matter of concern. The temperatures were generally within the comfort range around 70° F. During one mission, the crew reported being cold when the spacecraft was powered down and rotating. The extravehicular pilots generally have been warm while inside the spacecraft because the extravehicular suit contains additional layers of material.

Micrometeorites

Micrometeorites are a subject heading in every book relating to space flight. They are mentioned as a possible hazard to cabin integrity, to spacecraft window surfaces, and to extravehicular crewmen. No significant micrometeorite or meteorite density has been observed in the flights to date. There has been no evidence of micrometeorite hits on the extravehicular suits; however, a micrometeroite protective layer is provided.

Radiation

The radiation environment of space has been sampled by numerous probes and has been calculated at length. With one exception, the flights have not reached an altitude involving the inner Van Allen belt, but the flights have routinely passed through the

South Atlantic anomaly. The onboard radiation measuring system and the personal dosimeters attached to the crewmen confirmed that the radiation intensity was at the lower end of the calculated range. In a 160-nautical-mile orbit, the crew received approximately 15 millirads of radiation in each 24 hours of exposure. Table 16–V indicates the total doses received on the flights to date.

Light and Darkness

Many predictions were made concerning the effect of the changing light and darkness producing a day and a night every 90 minutes. It was generally predicted that this would totally disrupt the circadian rhythms, producing grave consequences. Certainly no overt effects of the 45 minutes of day and 45 minutes of night were observed on the short missions. As knowledge of sleep in the spaceflight environment increased, it was determined best to arrange the work-rest cycles so that sleep occurred at the normal Cape Kennedy sleep time. The spacecraft was artificially darkened by covering the windows, and as far as the crew were concerned, it was night. The physiological response in heart rate to the regime used on the 14-day flight is shown in figure 16–2.

TABLE 16–V.—*Radiation Doses on Gemini Missions*[a]

Mission	Duration, day:hr:min	Mean cumulative dose, mrad	
		Command pilot	Pilot
III	0:04:52	<20	42±15
IV	4:00:56	42±4.5	50±4.5
V	7:22:56	182±18.5	170±17
VI-A	1:01:53	25±2	23±2
VIII	13:18:35	155±9	170±10
VIII	0:10:41	<10	10
IX-A	3:01:04	17±1	22±1
X	2:22:46	670±6	765±10
XI	2:23:17	29±1	26±1
XII	3:22:37	<20	<20

[a] Dosimeters located in helmet, right and left chest, and thigh.

Gravity Load

During space flight, the increase of gravity load during launch and reentry, and the nullification of gravity load and production of a state of weightlessness during actual flight, were expected to produce detrimental effects. Actually, gravity loads during the missions were well within man's tolerances, with two 7g peaks occurring at launch, and with g-forces varying from 4 to 8.2g at reentry. Much concern was expressed about a decreased tolerance to gravity following weightless flight. No evidence of this has been observed; following 4 days of weightless flight, the Gemini IV crew sustained a peak of 8.2g without adverse effects.

Weightlessness has been the subject of innumerable studies and papers. It has been produced for brief periods in parabolic flight in aircraft, and simulated by water immersion and bedrest. The Gemini Program has produced a fair amount of evidence concerning the effect of the weightless spaceflight environment on various body systems.

Skin

In spite of the moisture attendant to spacesuit operations, the skin has remained in remarkably good condition through flights up to 14 days in duration. Following the 8-day flight, there was some drying of the skin

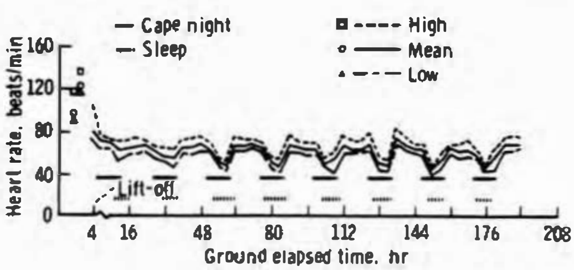


FIGURE 16-2.—Gemini VII pilot heart rate.

noted during the immediate postflight period, but this was easily treated with lotion. There have been no infections, and there has been minimal reaction around the sensor sites. Dandruff has been an occasional problem, but has been easily controlled with preflight and postflight medication.

Central Nervous System

The best indication of central nervous system function has been the excellent performance of the crew on each of the missions. This was graphically illustrated by the demanding performances required during the aborted launch of Gemini VI–A; the rendezvous and the thruster problem on Gemini VIII; the extravehicular activity on Gemini IV, IX–A, X, XI, and XII; and the many accurate spacecraft landings and recoveries. Psychological tests have not been conducted as distinct entities unrelated to the inflight tasks. Instead, the evaluation of total human performance has provided an indication of adequate central nervous system function. There has been no evidence, either during flight or postflight, of any psychological abnormalities.

The electroencephalogram (fig. 16–3) was utilized to evaluate sleep during the 14-day mission. A total of 54 hours 43 minutes of interpretable data was obtained. Variations in the depth of sleep from Stage 1 to the deep sleep of Stage 4 were noted in flight as in the ground-based data.

Numerous visual observations have been reported by the crews involving inflight sightings and descriptions of ground views. The actual determination of visual acuity has been made in flight, as well as in preflight and

FIGURE 16–3.—Electroencephalogram equipment.

postflight examinations. All of these tests support the statement that vision is not altered during weightless flight.

As previously noted, there has been much conjecture concerning vestibular changes in a weightless environment. There has been no evidence of altered vestibular function during any of the Gemini flights. Preflight and postflight caloric vestibular function studies have shown no change, and special studies of the otolith response have revealed no significant changes. There have been ample motions of the head in flight and during roll rates with the spacecraft. There has been no vertigo nor disorientation noted, even during the extravehicular activity with occasional loss of all visual references. Several crewmen have reported a feeling of fullness in the head similar in character to the fullness experienced when one is turned upside down, allowing the blood to go to the head. However, there has been no sensation of being turned upside down, and the impression is that this sensation results from altered distribution of blood in the weightless state. To clear the record, two of the Mercury pilots developed difficulties involving the labyrinth; the difficulties were in no way related to the space flights. One developed prolonged vertigo as the result of a severe blow over the left ear in a fall, but he has completely recovered with no residual effect. The other crewman developed an inflammation of the labyrinth some 3 years after his 15-minute space flight, and, while he continues to have some hearing loss, there have been no further vestibular symptoms. It is interesting to note this absolute lack of any inflight vestibular symptoms, in spite of the fact that a number of the pilots have developed motion sickness while in the spacecraft on the water.

Eye, Ear, Nose, and Throat

There have been two inflight incidents of rather severe eye irritation. One was the result of exposure to lithium hydroxide in the suit circuit; the cause of the other remains a mystery. In a few instances, some postflight conjunctival infection has been noted, but has lasted only a few hours and is believed to have been the result of the oxygen environment. During the early portions of the flights, normally the first 2 or 3 days, some nasal stuffiness has been noted. This also is undoubtedly related to the 100-percent oxygen environment and is usually self-limited. On occasion, the condition has been treated locally or by oral medication.

Respiratory System

Preflight and postflight X-rays have failed to reveal any atelectasis. Pulmonary function studies before and after the 14-day mission revealed no alteration. There have been no specific difficulties or symptomatology involving the respiratory system; however, some rather high respiratory rates have been noted during heavy workloads in the extravehicular activity. Even when these rates have exceeded 40 breaths per minute, they have not been accompanied by symptomatology.

Cardiovascular System

The cardiovascular system was the first of the major body systems to show physiologic change following flight; as a result, it has been extensively investigated by various means (fig. 16-4). As previously reported, the peak heart rates have been observed at launch and at reentry (table 16–VI); the rates normally reached higher levels during the reentry period. The midportions of all the missions have been characterized by more stable heart rates at lower levels with adequate response to physical demands.

The electrocardiogram has been studied in detail thoughout the Gemini missions. The only abnormalities of note have been very rare, premature, auricular and ventricular contractions. No significant changes have been detected in the duration of specific segments of the electrocardiogram.

Blood-pressure measurements obtained during the Gemini VII mission revealed that

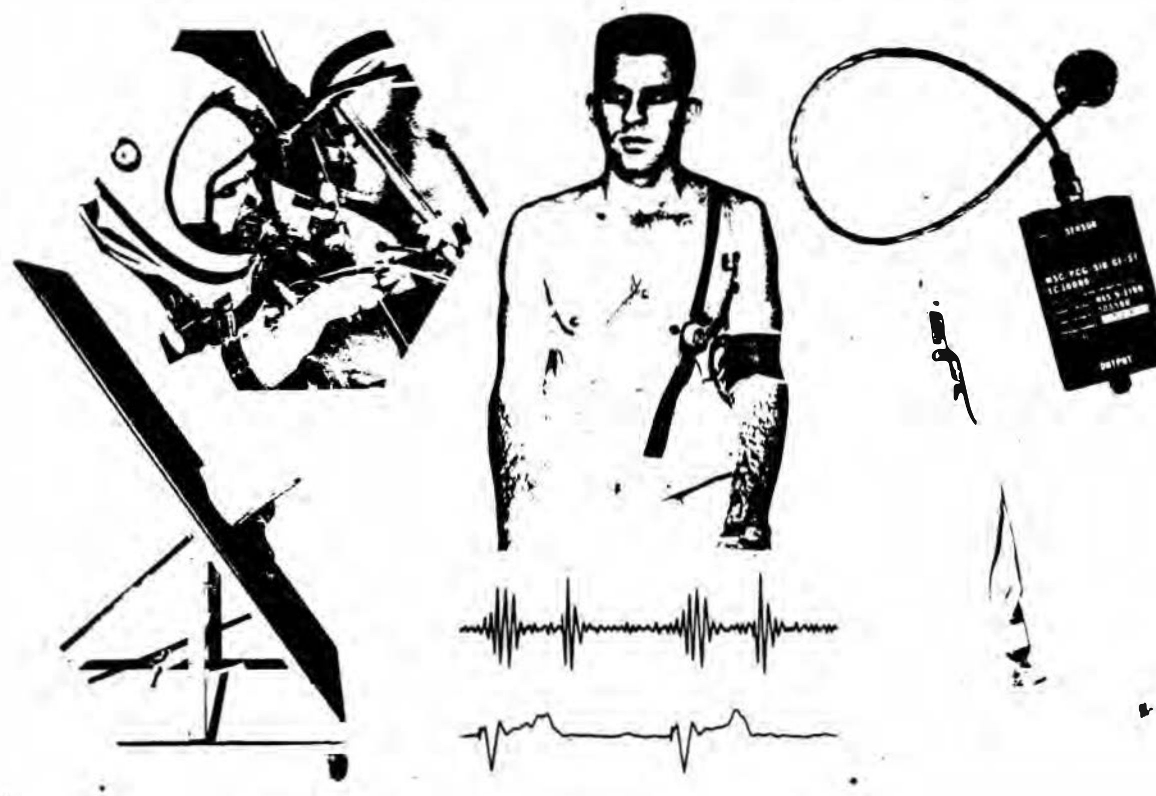


FIGURE 16-4.—Gemini cardiovascular evaluation techniques.

systolic and diastolic values remained within the envelope of normality and showed no significant changes throughout 14 days of flight. As previously reported, this included the pressures taken at the time of reentry.

Some insight into the electrical and mechanical phases of the cardiac cycle was gained during the Gemini flights. The data were derived through synchronous phonocardiographic and electrocardiographic monitoring. In general, wide fluctuations in the duration of the cardiac cycle, but within physiological limits, were observed throughout the missions. Fluctuations in the duration of electromechanical systole correlated closely with changes in heart rate. Stable values were observed for electromechanical delay (onset of ventricular activity, QRS complexes, to onset of first heart sound) throughout the missions, with shorter values observed during the intervals of peak heart rates recorded during lift-off, reentry, and extravehicular activity. The higher values observed for the duration of systole and for electromechanical delay in certain crewmembers suggest a preponderance of cholinergic influences (vagal tone). An increase in adrenergic reaction (sympathetic tone) was generally observed during lift-off, reentry, and in the few hours preceding reentry.

As a further measure of cardiovascular status, Experiment M003, Inflight Exerciser, determined the heart-rate response to an exercise load consisting of one pull per second for 30 seconds on a bungee device (force at full extension of 12 inches equaled 70 pounds). The responses for one crewman on the Gemini V mission are shown in figure 16-5. The results of the 4-day Gemini IV and the 14-day Gemini VII mission did not differ. This variant of the step test revealed no physical or cardiovascular decrement after

TABLE 16–VI.—*Peak Heart Rates During Launch and Reentry*

Gemini mission	Crewman[a]	Peak rates during launch, beats/min	Peak rates during reentry, beats/min
III	CP	152	165
	P	120	130
IV	CP	148	140
	P	128	125
V	CP	148	170
	P	155	178
VI–A	CP	125	125
	P	150	140
VII	CP	152	180
	P	125	134
VIII	CP	138	130
	P	120	90
IX–A	CP	142	160
	P	120	126
X	CP	120	110
	P	125	90
XI	CP	166	120
	P	154	117
XII	CP	136	142
	P	110	137

[a] CP indicates command pilot; P indicates pilot.

as much as 14 days in a space-flight environment.

In contrast to the Project Mercury results, orthostatism resulting from any Gemini mission has not been detectable except by means of passive tilt-table provocation. Typically, the heart-rate and blood-pressure response to a 15-minute, 70° tilt performed postflight are compared with identical preflight testing on the same crewmen. Consistently, such testing has demonstrated a greater increase in heart rate, a greater reduction in pulse pressure, and a greater increase in leg volume, as interpreted from lower limb circumference gages during the preflight tilt (fig. 16–6). The changes observed in these variables may be most significantly illustrated by examining the heart-rate changes observed during preflight and postflight tilt-table studies. When the postflight increases in heart rate during tilt are expressed as percent of the preflight tilt heart rate for each of the Gemini crews, the postflight increases are from 17 to 105 percent greater than those exhibited preflight. The increasing trend in these values was evident through the 8-day mission. A multiplicity of altered factors, such as better diet, more exercise, desuited periods, and no extravehicular activity, make the improved postflight response to the 14-day mission very difficult to interpret (fig. 16–7).

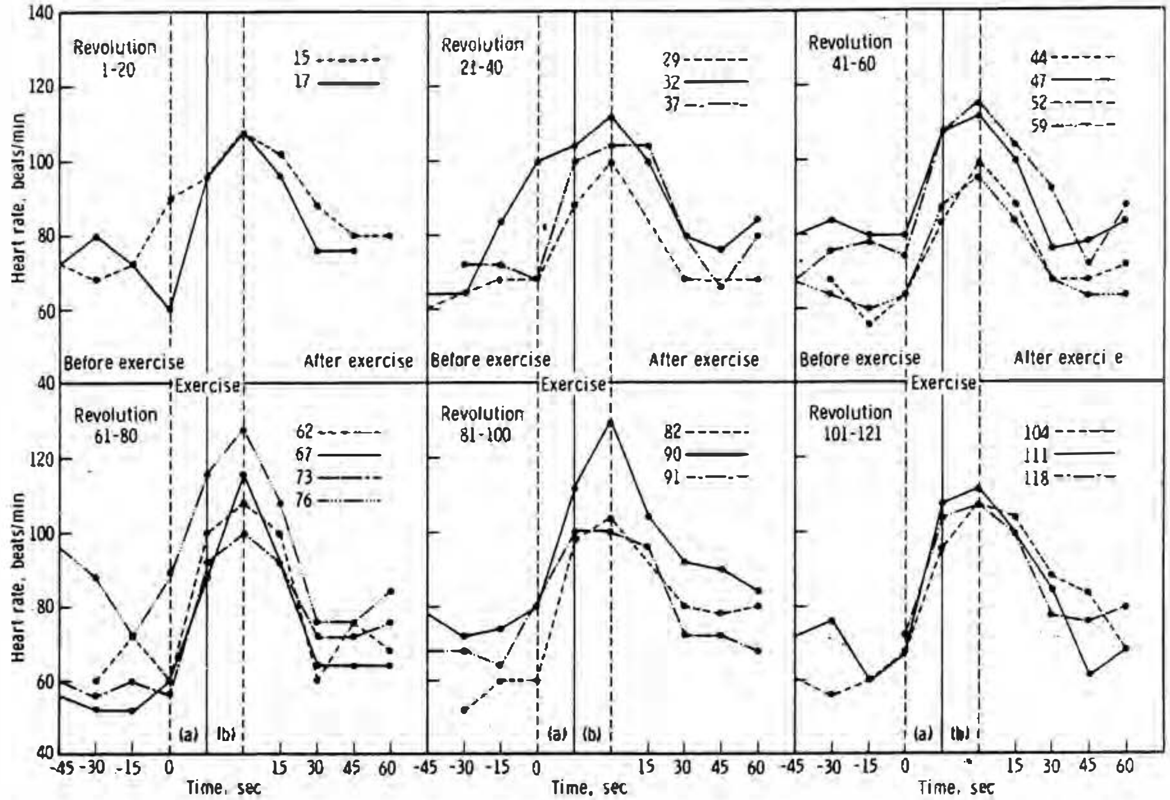
For purposes of comparison, flight data and data from bedrest studies were viewed in a like manner and show a very similar trend; however, the magnitude of the changes shows marked differences, again illustrating, perhaps, the influence of factors other than those simulated by bedrest.

When the tilt-table tests are considered, postflight leg volume was universally greater than preflight. Postmission observations ranged from 12 to 82 percent increase in volume over premission values.

The Gemini V pilot wore intermittently occlusive lower limb cuffs for the first 4 days of the 8-day mission. The Gemini VII pilot wore the cuffs for the entire 14-day mission; however, his heart-rate increases and pulse-pressure narrowing were greater than for the command pilot; the cuffs seemingly did not alter the variables.

Average resting heart rates have ranged from 18 to 62 percent higher after missions. In spite of higher resting pulse rates, the changes resulting from tilt were still greater. The exception presented by the Gemini VII crew is more apparent. The bedrest data are not remarkable.

To date, the observations of the effect of space flight on body systems have shown significant changes involving only the cardiovascular, hematopoietic, and musculoskeletal systems. Even these changes appear adaptive in nature and are measured principally during the readaptive phase to the 1g environment. It appears that adequate information has been obtained to permit anticipation of a nominal lunar mission without being surprised by unforeseen physiologic changes. Medical results from the U.S. space flights



[a] First 15 sec of exercise period.
[b] Second 15 sec of exercise period.

FIGURE 16–5.—Heart-rate response to bungee exercise, Gemini V pilot.

appear to differ from the results reported by the U.S.S.R., where there seems to be a unique problem in the area of vestibular response. In the cardiovascular area, the United States has not confirmed the U.S.S.R. reports of electromechanical delay in cardiac response, and the U.S.S.R. has not confirmed the U.S. findings of decreased red-cell mass.

The Gemini flights have also provided some excellent examples of human variability and have emphasized the necessity for care in making deductions. In making projections based on very limited results in a few people, the current trend is to bank heavily upon comparisons in a given individual; that is, differences between baseline data and responses observed during and after a flight. The crewmen who have flown twice have shown variability between flights in the same manner as have different men on the same flight. Figure 16–8 shows the heart rates for one crewman during the launch phase of both his Mercury mission and his Gemini mission. The two curves show little correlation and could as easily have come from different individuals. Obviously, confidence in the results and the definition of variability will be improved as more information is gained on future flights. Also, these are gross system findings, and much must still be accomplished in the laboratory and in flight if the mechanisms of the findings are to be understood.

Although physiological adaptation is difficult to define, it might be stated as any alteration or response which favors the survival of an organism in a changed environment. This

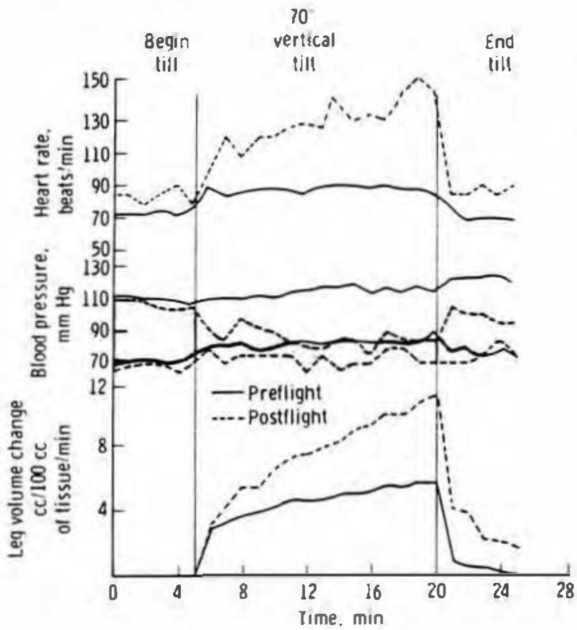


FIGURE 16-6.—Typical tilt-table response.

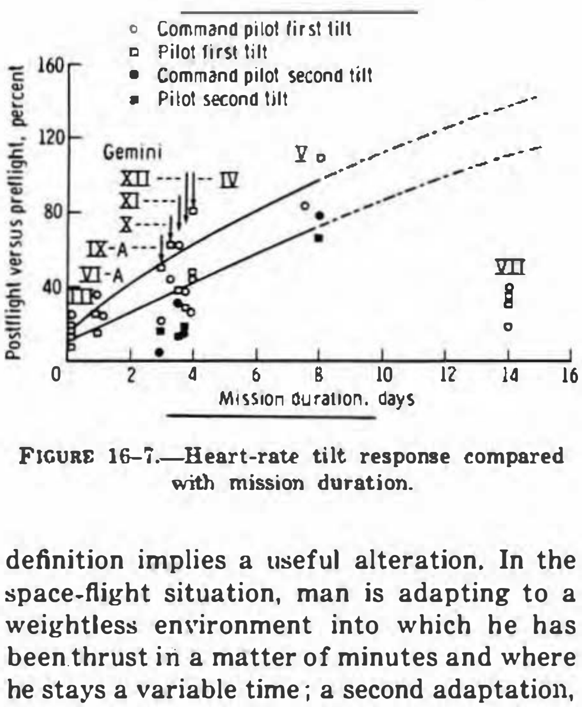


FIGURE 16-7.—Heart-rate tilt response compared with mission duration.

definition implies a useful alteration. In the space-flight situation, man is adapting to a weightless environment into which he has been thrust in a matter of minutes and where he stays a variable time; a second adaptation, required after return to the 1g environment of Earth, can be measured by direct observation. Some of the physiological changes return to normal over an extended time; for instance, the tilt responses have all

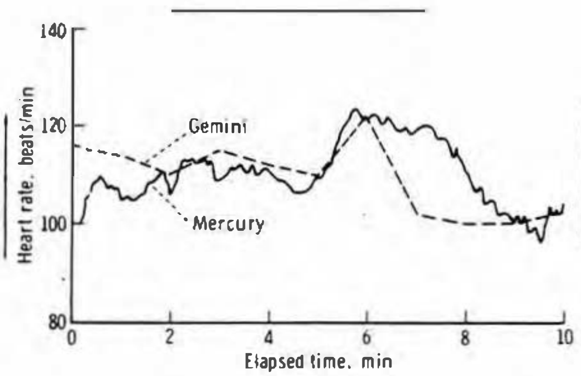


FIGURE 16-8.—Command pilot heart-rate comparisons.

returned to normal within a 50-hour period, regardless of the duration of exposure to the space-flight environment.

Blood

Significant increases have been observed in white-blood-cell counts manifested as an absolute neutrophilia following most flights. This condition has always returned to normal within 24 hours. Hematologic data derived from Gemini missions of 4, 8, and 14 days demonstrated a hemolytic process originating during flight. Specific data points include red-cell mass deficits of 12, 20, and 19 percent (command pilot) following the Gemini IV, V, and VII missions, respectively (fig. 16-9). The 12-percent Gemini IV data point is probably inaccurate. This 4-day point was calculated from RISA-125 plasma volume and peripheral hematocrit data, a method predicted on a constant relationship between peripheral and total-body hematocrit. Subsequent direct measurements showed that alteration of the peripheral/total-body hematocrit ratios do occur, thereby introducing an obvious error into the calculations. Based upon the direct measurements, the Gemini IV calculated red-cell mass deficits were reexamined and found to more closely approximate 5 percent. Other hematologic tests corroborated this disparity; however, to date, no satisfactory explanation of the phenomenon exists. Complete interpretation of

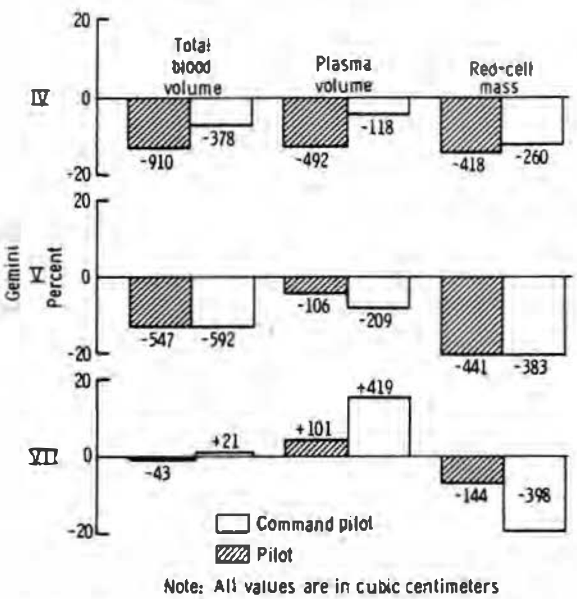


FIGURE 16-9.—Blood-volume studies for Gemini IV, V, and VII.

the red-cell mass deficit noted in the command pilot of the Gemini VII also required special consideration. It appears that no significant progression of the hemolysis occurs after the eighth day in orbit; however, this may be more apparent than real. Analysis of the related mean corpuscular volume values shows a significant increase in this parameter during the 14-day space-flight interval. If each individual erythrocyte increased in volume, a measurement of the total red-cell volume (red-cell mass) would not accurately reflect the actual loss of erythrocytes. Correcting for the postflight corpuscular volume shift, a 29-percent circulating red-cell deficit is derived. The latter figure more accurately describes the hemolytic event; therefore, it is possible that the true extent of the hemolytic process has not yet been determined.

Possible causative factors of the red-cell loss are hyperoxia (166-mm oxygen at the alveolar membrane), lack of inert diluent gas (nitrogen), relative immobility of the crew, dietary factors, and weightlessness. Only increased oxygen tension, immobility, and dietary factors are well known to influence the red cell. Dietary considerations may be of considerable importance; however, at this point no definite incriminations can be levied against the flight diet. A program to define certain diet levels of lipid soluble vitamins has recently been initiated. Specifically, alpha-tocopherol is an important antilipid oxidant and is essential in protecting the lipid at the red-cell plasma membrane. Immobility is effective in reducing red-cell mass by curtailing erythrocyte production; however, all flight observations support hemolysis as the significant event. Although not demonstrated by any previous studies, it is possible that weightlessness is a contributing factor in the hemolysis observed. Altered hemodynamics, resulting in hemostasis, could result in the premature demise of the cell. The role of a diluent gas (nitrogen) is not well understood; however, some investigators have shown significant reduction in hematologic and neurologic toxicity in animals exposed to high oxygen pressure when an inert gas is present. Therefore, the absence of an inert atmospheric diluent could be significant at the hyperoxic levels encountered within the Gemini spacecraft.

Of all the mechanisms previously stated, oxygen has the greatest proven potential as a hemolytic agent. Basically, two modes of oxygen toxicity are described. It has been demonstrated that red-cell plasma membrane lipids undergo peroxidation when exposed to conditions of hyperoxia. It has also been demonstrated that the lipid peroxides thus formed are detrimental to the cell. Specifically, lipid peroxides are known to affect enzyme systems essential for normal red-cell function. It is also possible that peroxidation of the erythrocyte plasma membrane lipids changes this tissue to curtail erythrocyte survival. The second mode of oxygen toxicity expression may be more direct, for inferential evidence is available showing a direct inhibitory effect on some glycolytic enzymes. Oxygen has several documented deleterious effects on red-cell plasma membranes and metabolic functions; any combination of these effects could be operative within a Gemini spacecraft.

Biochemical

The analysis of urine and plasma has been used as an indication of crew physiological status preflight, in flight, and postflight. Analyses of the results obtained on all three phases were performed on the 14-day Gemini VII flight, and essentially complete analyses were performed on the preflight and postflight phases of the 3-day Gemini IX-A mission.

The first attempt at accumulation of inflight data was essentially a shakedown and provided an *n* of 2, which for biological data is insignificant. Some of the data are presented, but interpretation is dependent upon more refined techniques and upon accumulation of a sufficient number of observations to establish variabilities and trends. The high degree of individual variation should be noted. The Gemini VII pilot and command pilot did not always respond qualitatively or quantitatively in the same way.

The biochemical determinations are grouped into several profiles, each of which provides information concerning the effect of space flight on one or more of the physiological systems. The first profile, water and electrolyte balance, is related to an examination of the weight loss which occurs during flight and the mechanisms involved in this loss. To this end, the levels of sodium, potassium, and chloride in the plasma were measured preflight and postflight, and the rates of excretion of these electrolytes in the urine were observed in all three phases of the study. Total plasma protein concentration measured both preflight and postflight was used as an indication of possible dehydration. Water intake and urine output were measured to determine whether the primary loss of weight was due to sweat and insensible losses or to changes in renal function. The vasopressin (antidiuretic hormone) and aldosterone hormones were measures in the urine in an attempt to establish the functional contribution of baroreceptors in a zero-gravity condition.

As may be expected, since one of the prime functions of the homeostatic mechanisms of the body is to maintain the composition of blood and extracellular fluid as nearly constant as possible, significant changes in plasma were not observed. As seen in figure 16–10, 48-hour pooled samples of flight urine indicate a slight reduction in the output of sodium during flight. As indicated by the hashed bars, this is associated with some increase in aldosterone excretion. Postflight, there is a marked retention of sodium. As expected, chloride excretion parallels the sodium excretion. Potassium excretion during flight (fig. 16–11) appears depressed, and in all but the command pilot of Gemini VII, it was depressed immediately postflight. This depression could be observed in total 24-hour output and in minute output. This antidiuretic hormone appeared elevated in only the first postflight sample of the Gemini VII pilot. The crudities of this biological assay may account for the inability to observe any gross changes. The retention of electrolytes is very closely associated with the retention of water postflight.

The second profile involves the estimation of the physiological cost of maintaining a given level of performance during space flight. This could be considered a measure of the effects of stress during space flight. Two groups of hormones were assayed: the first, 17-hydroxycorticosteroids, provides a measure of long-term stress responses; the second, catecholamines, provides a measure of short-term or emergency responses. The results obtained with the catecholamine determina-

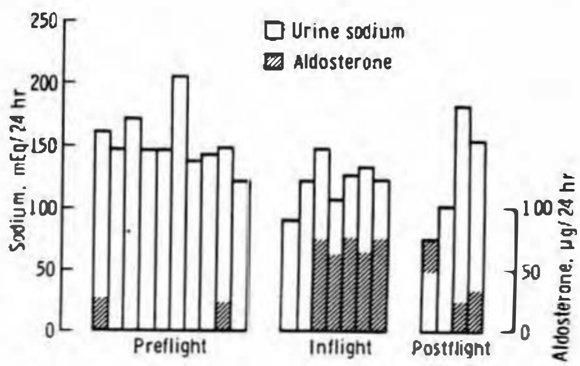


FIGURE 16–10.—Urine sodium and aldosterone, Gemini VII command pilot.

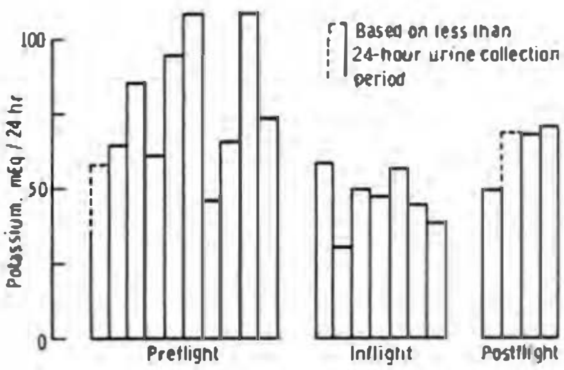


FIGURE 16–11.—Urine potassium, Gemini VII pilot.

tions are anomalous and changes observed could be considered well within the error of the methodology. As seen in figure 16–12, the 17-hydroxycorticosteroid levels are depressed during the flight. An elevation immediately postflight may be related to the stress of reentry and recovery. Although there may be considerable speculation regarding the low inflight steroids, it must be reemphasized that these results are from a single flight, and much more data will be essential before a valid evaluation is possible.

The third profile constitutes a continuing evaluation of the effects of space flight on bone demineralization. Calcium, magnesium, phosphate, and hydroxyproline are measured in plasma and in urine obtained preflight, in flight, and postflight. This is an attempt to determine whether the status, or the changes in the status, of bone mineral are accompanied by alterations in plasma calcium and hydroxyproline, and by alterations in urinary excretion of calcium, phosphate, magnesium, and hydroxyproline. The amino acid, hydroxyproline, is unique to collagen, and it was presumed that an increased excretion of hydroxyproline might accompany demineralization along with dissolution of a bone matrix (fig. 16–13). The first postflight plasma samples following the 14-day flight show a marked increase in the bound hydroxyproline, while larger quantities of calcium were excreted later in the flight than during the early phases of the flight. This is consistent with a change in bone structure.

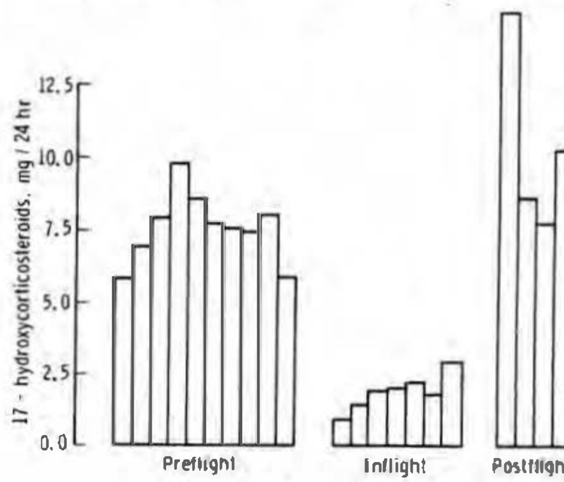


FIGURE 16–12.—Urine 17-hydroxycorticosteroids. Gemini VII command pilot.

The fourth group may be related to protein metabolism and tissue status. When total nitrogen was related to intake during flight, a negative balance was noted.

Gastrointestinal System

The design and fabrication of foods for consumption during space flights have imposed unique technological considerations. The volume of space food per man-day has varied in the Gemini missions from 130 to 162 cubic inches (2131 to 2656 cc). Current menus are made up of approximately 50 to 60 percent rehydratables (foods requiring the

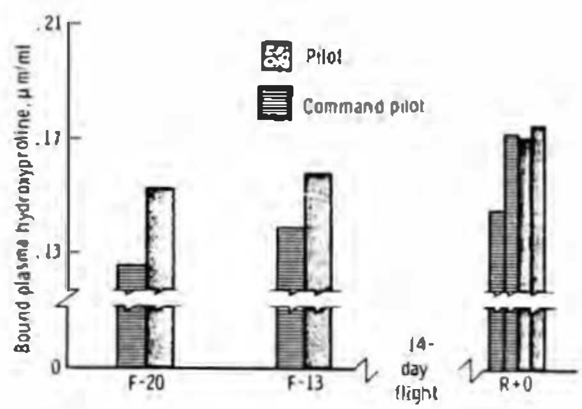


FIGURE 16–13.—Bound plasma hydroxyproline, Gemini VII.

addition of water prior to ingestion); therefore, food packaging is required that permits a method for rehydration and for dispensing food in zero gravity. The remaining foods are bite size; that is, food items which are ingested in one bite and rehydrated in the mouth. About 50 percent of the rehydratable and the bite-size foods are freeze-dried products; the remaining are other types of dried or low-moisture foods, some of which are compressed. A typical menu (table 16–VII) has an approximate calorie distribution of 17 percent protein, 32 percent fat, and 51 percent carbohydrate. Total calories provided and eaten per day varied from flight to flight. Food consumption during Gemini IV, V, and VII is summarized in figures 16–14 to 16–16. Food consumption during Gemini IV and VII was very good, but weight loss on the short-duration Gemini IV mission was definitely substantial. The anorexia of the Gemini V crew is unexplained, although many hypotheses could be presented. Although weight loss has occurred on all missions, it has not increased with mission duration (table 16–VIII). Obviously, more calories and water must be consumed in flight to maintain body weight at preflight levels.

Gastrointestinal-tract function on all missions has been normal, and no evidence exists of excess nutrient losses due to poor food

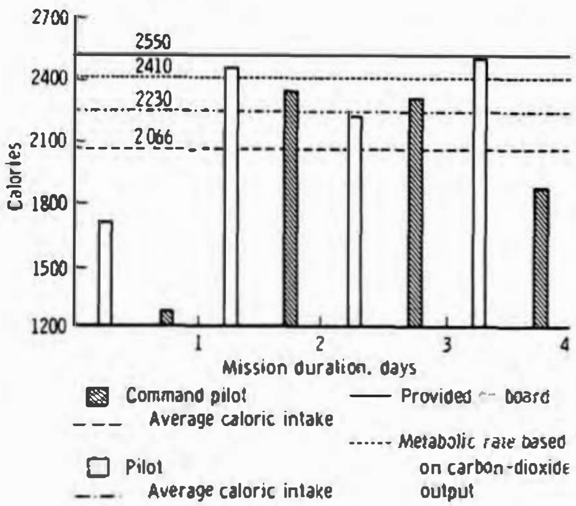


FIGURE 16–14.—Caloric intake on Gemini IV.

TABLE 16–VII.—*Typical Gemini Menu*

[Days 2, 6, 10, and 14]

	Calories
Meal A:	
Grapefruit drink	83
Chicken and gravy	92
Beef sandwiches	268
Applesauce	165
Peanut cubes	297
	905
Meal B:	
Orange-grapefruit drink	83
Beef pot roast	119
Bacon and egg bites	206
Chocolate pudding	307
Strawberry cereal cubes	114
	829
Meal C:	
Potato soup	220
Shrimp cocktail	119
Date fruitcake	262
Orange drink	83
	684
Total calories	2418

TABLE 16–VIII.—*Flight Crew Weight Loss to the Nearest Half Pound*

Gemini mission	Command pilot weight loss, lb	Pilot weight loss, lb
III	3	3.5
IV	4.5	8.5
V	7.5	8.5
VI-A	2.5	8
VII	10	6
VIII	(a)	(a)
IX-A	5.5	13.5
X	3.0	3.0
XI	2.5	0
XII	6.5	7

a Not available.

digestibility during flight. Before the missions, the crews ate a low-residue diet; on all flights beginning with the Gemini V mission, an oral and usually a suppository laxative were used within 2 days of launch. On the shorter extravehicular missions, this preflight preparation has generally allowed the crew to avoid defecation in flight.

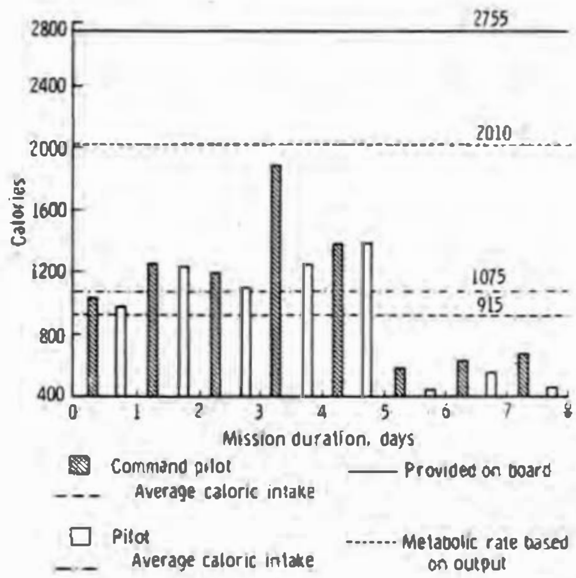


FIGURE 16-15.—Caloric intake on Gemini V.

Genitourinary System

There have been no difficulties involving the genital system. Urination has occurred normally both in flight and postflight, and there has been no evidence of renal calculi.

Musculoskeletal System

Here, again, interpretation of the information gathered to date on bone and muscle metabolism as affected by space flight must be cautious due to the very few subjects observed under varying dietary intakes and exposed to multiple flight stresses.

In figures 16-17 and 16-18, the bone demineralization (percent change in density) which occurred in the os calcis (heel) and phalanx 5-2 (little finger) during space flight is compared with the demineralization which occurred under equivalent periods of bedrest and analogous intakes of calcium. As compared with bedrest, the changes were definitely less in the 14-day flight where calcium intake approached 1000 mg per day and the crew routinely exercised. The phalanx changes are remarkable because significant differences in density have not been observed during 30 days of complete bedrest when calcium intake of over 500 mg per day has been adequate.

In all instances the data for the bones examined indicate a negative change, and the calcium-balance data collected on Gemini VII verify a negative balance trend. None of the changes are pathological, but indicate that further research is needed and that ameliorative methods for use during long-duration flights need to be examined.

The detailed 14-day inflight balance study revealed some loss in protein nitrogen.

Exercise Capacity Tests

Previous investigations have shown that a limitation of optimal cardiovascular and respiratory function exists when a heart rate of 180 beats per minute is reached during a gradually increased workload. With this in mind, an exercise capacity test was incorporated into the Gemini operational preflight and postflight procedures in order to determine whether changes occur in crew physiologic reaction to work.

The tests have been performed by the crewmembers of the Gemini VII mission and by the pilots of the Gemini IX-A, X, XI, and XII missions. All but one of the tested crewmen exhibited a decrease in exercise capacity as monitored by heart rate, and a concomitant reduction in oxygen consumption to a quantitated workload. These findings are graphically demonstrated in figure 16-19.

Additionally, the heart-rate/workload information collected preflight has been of value as a very rough index of the metabolic rate of crewmen during extravehicular activity. It is realized that many other stresses above and beyond the simple imposition of workload can and do affect heart rate. The heart rate as measured during extravehicular activity is not considered an exact index of the workload being performed, but rather as a reflection of total physiological and psychological strain.

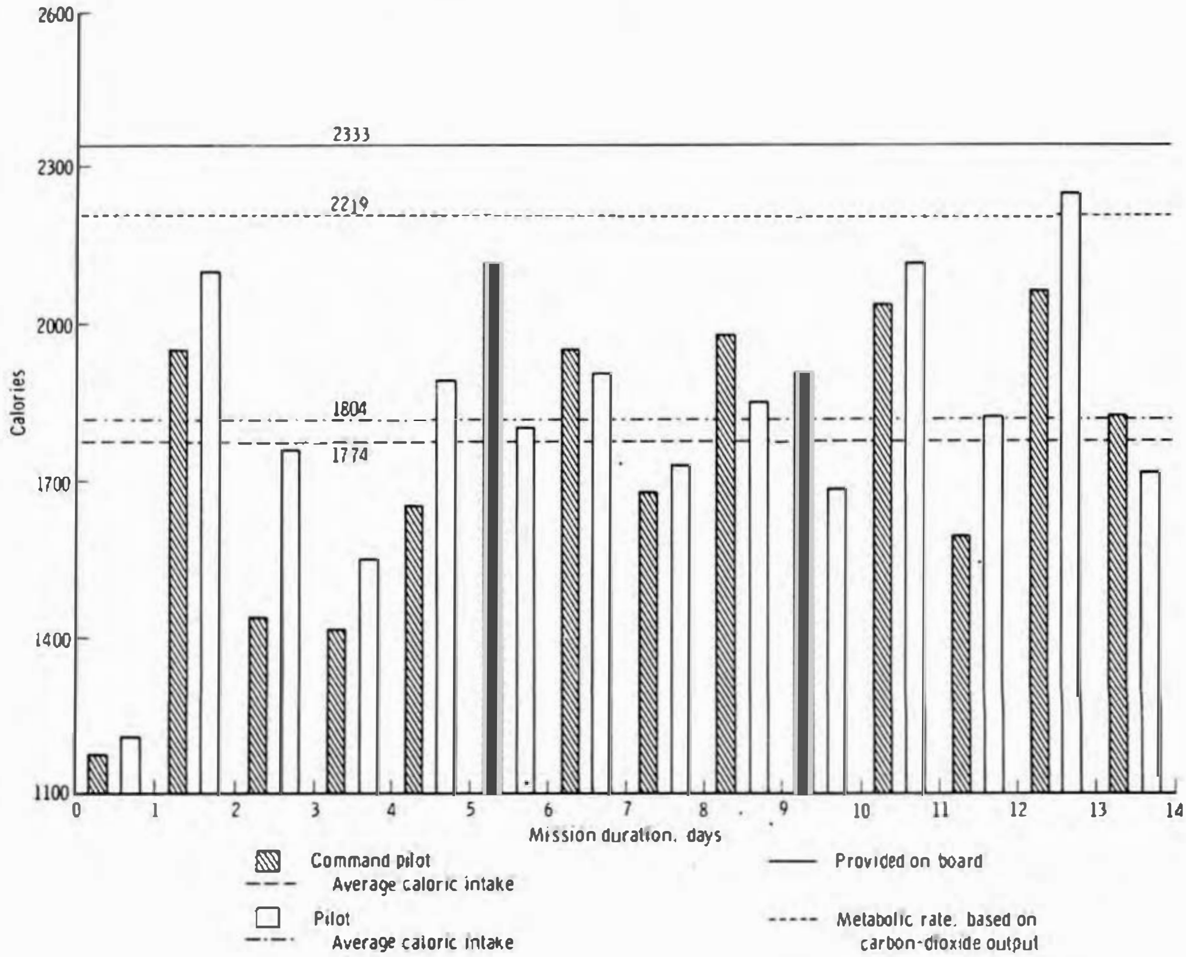


FIGURE 16-16.—Caloric intake on Gemini VII.

Inflight Metabolic Data

Metabolic measurement during U.S. space flights has been limited to the determinations of the total carbon-dioxide production by the chemical analysis of the spent lithium-hydroxide canister. This method is of value only in establishing the average heat-production rate for crewmen during space flight. Figure 16-20 shows close agreement between metabolic data from the U.S.S.R. and the American space flights. The higher metabolic rates observed during the Mercury flights are explained by the fact that these were short-duration flights in which the crewmen did not sleep.

Other Observations Concerning Weightless Flight

The crews have never slept well on the first night in space, and many factors other than weightlessness may be active in limiting the sleep obtained, regardless of flight duration. All crewmembers have reported a tendency to sleep with the arms folded at chest height and the fingers interlocked. The legs also tend to assume a slightly elevated position. On return to the 1g environment, the crews are aware of the readaptation period because they are aware for a short time that the arms and legs have weight and require effort to move. There has been some postflight muscle stiffness following the prolonged missions

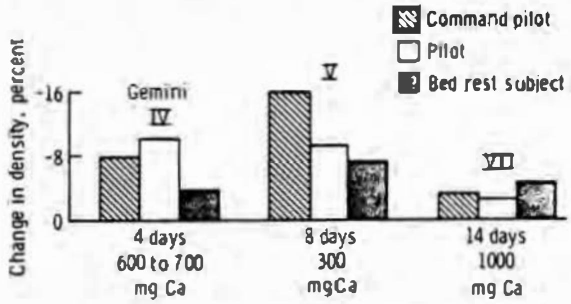


FIGURE 16–17.—Loss of os calcis density on Gemini IV, V, and VII missions.

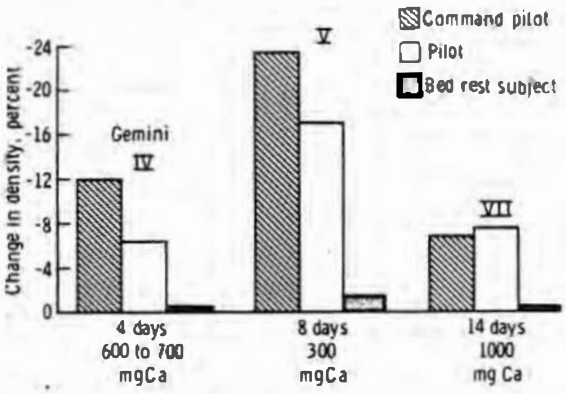


FIGURE 16–18.—Change in density of hand phalanx on Gemini IV, V, and VII missions.

that may be more associated with the confinement of the spacecraft than with weightlessness.

The amount of inflight exercise by the crew has varied even on the long-duration flights. On the 14-day mission, there were three 10-minute exercise periods programed and completed per day. On the short-duration flights with great demands upon the crew for rendezvous and extravehicular activity, no specific conditioning exercises have been conducted. There appears to be a need for a definite exercise regime on long-duration flights.

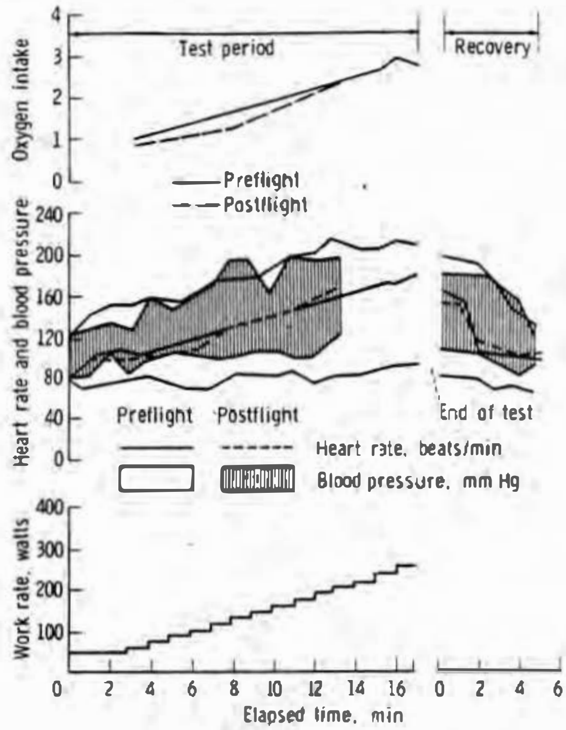


FIGURE 16–19.—Preflight and postflight exercise capacity test results, Gemini IX–A.

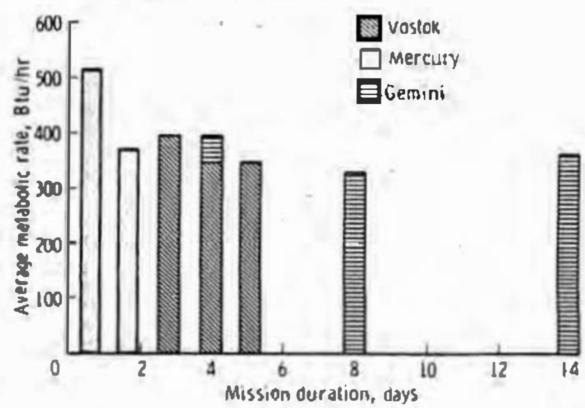


FIGURE 16–20.—Average metabolic rates during actual space flight.

Crew Performance

Strange reactions to the isolation and the monotony of space flight were originally predicted. Hallucinations and a feeling of separation from the world, described as the breakoff phenomenon, had also been predicted, along with space euphoria. The experience to date has shown no evidence of the presence of any of these responses. There have been no abnormal psychological reactions of any sort, and the flights have been far from monotonous. In the single-man flights of the Mercury series, there was always ample ground contact and certainly no feeling of isolation or monotony. In the two-man Gemini flights, the same was true; and of course there has always been a companion crewman, thus avoiding isolation. The crews have exhibited remarkable psychomotor performance capabilities, and by performing a number of demanding tasks under stress they have demonstrated a high level of central nervous system function.

Drugs

A number of predictions were made that man would require the assistance of drugs to cope with the space-flight environment. In particular, sedation prior to launch and stimulation prior to reentry have been mentioned. As a result of the early planning for space flight, a drug kit was made available for inflight prescription. The crews have been pretested to each of the drugs carried; thus, the individual reaction to the particular drug is known. Aspirin and APC's have been used in flight for occasional mild headache and for relief of muscular discomfort prior to sleep. Dextroamphetamine sulfate has been taken on several occasions by fatigued crewmen prior to reentry. A decongestant has been used to relieve nasal congestion and alleviate the necessity for frequent clearing of the ears prior to reentry. The anti-motion-sickness medication has been taken in one instance prior to reentry to reduce motion sickness resulting from motion of the spacecraft in the water. An inhibitor of gastrointestinal propulsion has been prescribed when necessary to assist in avoiding inflight defecation. No difficulty has been experienced in the use of these medications which have produced the desired and expected effects. None of the injectors has been used in flight.

Inflight Disease

Preventive medicine enthusiasts have predicted the possible development of infectious disease in flight as a result of preflight exposure and the lack of symptoms or signs which can be detected in a preflight examination.

Quarantine of the crews for a period of time preflight has been discussed, and has been rejected as impractical in the missions to date. The immediate preflight period is very demanding of crew participation, and efforts have been directed at screening the contacts insofar as possible to reduce crew exposure to possible viral and bacterial infections, particularly the upper respiratory type. A number of short-lived flulike syndromes have developed in the immediate preflight period, as well as one exposure to mumps and one incident of betahemolytic streptococcal pharyngitis. Each situation has been handled without affecting the scheduled launch and, in retrospect, the policy of modified quarantine has worked well. Stricter measures may have to be adopted as longer flights are contemplated.

Fatigue

It was predicted that markedly fatigued flight crews would result from the discomfort of flight in a suited condition, a confined spacecraft, and inadequate rest. In reviewing the flight program to date, it appears that the crews obtained less sleep than in similar circumstances on the ground, but were not unduly fatigued. Intermittent periods of fatigue have resulted from the demanding mission requirements and from the fascination of the crew with the unique opportunity to view the universe. This has been cyclic in nature and on the long-duration flights has always been followed by periods of more restful sleep. No interference with performance has been noted due to inflight fatigue.

Medical Support

In preparing for the medical support of manned space flights, the possibility of injury at the time of launch and recovery was carefully evaluated. A detailed plan of support involving medical and surgical specialists in the launch and recovery areas was evolved and modified as the program progressed. In retrospect, it might appear that the support of surgeons, anesthesiologists, and supporting teams in these areas has been overdone in view of the results. This is always a difficult area to evaluate, however, because none of the support is needed unless a disaster occurs. The best that can be said at the moment is that this support will be critically reviewed in the light of the experience to date and rendered more realistic in the demands placed on highly trained medical personnel.

When originally established, the preflight and postflight examinations were aimed at identifying gross changes in man resulting from exposure to the space-flight environment. The examinations have been tailored along standard clinical lines, and, although these techniques have been satisfactory, little in the way of change has been noted. The procedures have been modified to include more dynamic tests, such as bicycle ergometry, and to reduce the emphasis on those static tests which showed little or no change. Increased use of dynamic testing should continue in the support of future manned space-flight programs.

Concluding Remarks

There has been increased scientific interest in the effect of the space-flight environment on man. The scientific requirements for additional information on man's function must be evaluated in regard to operational and mission requirements and the effect upon future manned space flight. The input of the crews and the operations planners must be weighed along with the basic medical and scientific requirements, and a realistic plan must be established to provide needed medical answers at the proper time and allow projections of man's further exposure. This has been one of the most difficult tasks in the medical support area. The entire manned space-flight program has required the strictest cooperation and understanding between physician and engineer, and it is believed that this has been accomplished. The medical management of the diverse personnel necessary to provide proper medical support for manned space missions has provided experiences of great value to future progress.

In reviewing the flights, the orderly plan of doubling man's flight duration, and observing the results in relation to the next step, has been successful and effective. There is no reason to alter this plan in determining the next increments in manned space flight.

In general, the space environment has been much better than predicted. Additionally, man has been far more capable in this environment than predicted, and weightlessness and the accompanying stresses have had less effect than predicted. While all these items are extremely encouraging and are the medical legacy of the Gemini Program, it is important to concentrate on some of the possible problems of very long-duration future flights, and the application of Gemini knowledge. Consideration must be given to the following: (1) obtaining additional information on normal baseline reactions to stress in order to predict crew response; (2) determining psychological implications of long-duration confinement and crew interrelations; (3) solving the difficult logistics of food and water supply and of waste management; and (4) providing easy, noninterfering physiologic monitoring.

The first steps into space have provided a rich background on which to build. In addition to the information provided for planning future space activities, benefits to general medicine must accrue as smaller and better bioinstrumentation with wider applicability to ground-based medicine is developed; as normal values are defined for various physiologic responses in man; and as ground-based research is conducted, such as bedrest studies. These results should yield a large amount of information applicable to hospitalized patients. It has been observed how the human body can adapt to a new and hostile situation and then readapt in a surprisingly effective manner to the normal 1g Earth environment. Continued observation of these changes will help determine whether the space environment may be utilized for any form of therapy in the future. The spaceflight environment will certainly prove to be a vital laboratory, allowing study of the basic physiology of body systems, such as the vestibular system. Even incidental findings, such as the red-cell membrane changes which are markedly applicable to hyperbaric applications in medicine, may be of benefit to general scientific and medical research.

GEMINI ONBOARD EXPERIMENTS

17. GEMINI EXPERIMENTS PROGRAM SUMMARY

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Introduction

The Mercury Manned Space Flight Project emphasized the basic technological objective of placing a man in Earth orbit and returning him. Even during Project Mercury, man's potential in supporting and enhancing scientific activities in space was recognized. As a start toward the exploitation of man's capabilities, a few experiments, mostly of a visual or photographic nature, were accomplished during Project Mercury (ref. 1). Based on the limited experiences during Project Mercury, experiment programs of much greater scope were planned for the Gemini Program. The Gemini experiments were primarily additions to the basic spacecraft and missions.

The purpose of this paper on the Gemini Experiments Program is to describe briefly the general aspects, the operations, the scope, the integration of the experiments into the spacecraft and the mission, and selective experiment program summary data.

General Aspects

The selection of experiments for the program was based primarily on the requirement or desirability of crew participation. The planning phase and the management of experiment implementation at the Manned Spacecraft Center, Houston, progressed through several phases of development as the requirement for support expanded. In 1963, the Air Force Systems Command established a field office at the Manned Spacecraft Center with a primary purpose of providing central coordination for the experiments sponsored by the Department of Defense. The field office administered a spacecraft integration study to define and document the feasibility of incorporating 15 Department of Defense experiments into the Gemini missions.

In addition to the Department of Defense proposals, experiment proposals were also collected by the Manned Space Flight Experiments Board for potential experiment investigations submitted by the Manned Spacecraft Center, the Office of Space Science and Applications, the Space Medicine Office, and the Office of Advanced Research and Technology. The experiment proposals were transmitted to the Gemini Experiments Office of the Gemini Program Office for a determination of feasibility and for determination of which missions could best accommodate the experiments. Some of the proposals were for experiments which had either been flown on Mercury spacecraft or had been approved but not flown. Most of the experiments proposals, however, were for entirely new investigations.

The Gemini Program Office disseminated the proposals to other Manned Spacecraft Center organizations such as Recovery Operations, Flight Crew Support, Medical Office, and Flight Operations. The resulting comments and recommendations, plus engineering studies of integration of the experiment hardware into the spacecraft, were included in a final feasibility determination by the Gemini Program Office and subsequently presented to an Experiments Review Panel.

The Experiments Review Panel was comprised of representatives from all Manned

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Spacecraft Center organizations concerned with experiments support. The Panel reviewed the block of experiment proposals and the comments from each affected organization concerning the experiments. Minutes of the panel meetings reflected the Manned Spacecraft Center position of incorporating each experiment studied into a particular mission. This information was presented to the Manned Space Flight Experiments Board along with the recommendations of the Office of Space Science and Applications, the Office of Advanced Research and Technology, the Medical Office, and the Department of Defense. After reviewing the material, this Board would make specific mission assignments for each approved experiment.

The number of experiment proposals increased as the program approached the operational phase. In recognition of the expanding workload and in order to firmly aline the organizational support to the principal investigators, in 1964 the Manned Spacecraft Center formed and staffed an Experiments Coordination Office in the Engineering and Development Directorate. The purpose of this Office was to manage the overall implementation of experiments into manned missions.

In June 1965, the Experiments Coordination Office and the Gemini Experiments Office were combined as part of the newly formed Experiments Program Office. The scope of responsibility of the Experiments Program Office included the Apollo experiments program and future experiments programs and planning. The Experiments Program Office became part of the Science and Applications Directorate in December 1966.

Operations

The first three formal Gemini experiments were conducted during the first manned mission, Gemini III, on March 23, 1965. All three required crew participation and real-time communications. The Langley Research Center proposed that a reentry communications experiment be conducted similar to one which had been approved but not performed during Project Mercury. The experiment was highly successful and proved that communication was feasible through the blackout phase during reentry. It was also evident from this experiment that an increased capability for real-time mission operation support was necessary for successful experiment accomplishments. A second experiment was supplied by the Atomic Energy Commission to determine synergism between weightlessness and radiation on human blood. The experiment was successfully conducted as planned, and results seemed to indicate that synergistic effects did exist.

The third experiment was conducted for the Ames Research Center to determine effects of weightlessness on sea urchin egg growth. The experiment utilized modified equipment originally constructed for an unmanned satellite. The manual handle manipulator failed during the mission, and an internal seal prematurely leaked fixative into some of the egg chambers. Objectives of the experiment were compromised, and the failure served to realine the objectives of the Gemini Experiments Office from integration of supplied experiments to a more comprehensive role of integrating and assuring successful experiment operations.

A functional verification review of experiments assigned to a particular mission was initiated and conducted prior to the particular mission flight-readiness review. All affected elements of the Manned Spacecraft Center were represented in the review. After detailed evaluations of the experiment equipment design and test history, the functional verification review panel determined flightworthiness of the experiment or additional operations required to make the experiment flightworthy.

Late in the preflight phase of Gemini IV, three Department of Defense experiments were canceled due to the addition of extravehicular activity. Although many Gemini experiments were planned for two missions, with the second mission serving as an alternate, it became evident that the original objectives of some experiments had been expanded and required multiple missions. The Gemini IV experiment cancellations increased the emphasis on successfully accomplishing assigned experiments. Gemini IV also revealed that personnel involved with the development of an experiment and with a detailed understanding of the objectives must participate in real-time mission support so that continuity would not be lost and experiment objectives compromised. For the Gemini V mission, the Experiments Program Office increased the support to the crew-training program, and the Flight Operations organization included the Experiments Program Office in the decision-making cycle for the real-time mission planning related to experiments.

In the final preflight phase of Gemini VII, it was decided to incorporate equipment and crew procedures on the spacecraft to conduct a photographic study of dim-light phenomena. Photographic equipment for such a study was not readily available, and it was apparent that the stated objectives were not compatible with practical crew activity. Immediate action was taken to effect compatibility and the Gemini VII crew obtained the desired data.

Experience during Gemini showed that late perturbations to the general flight plan, to onboard equipment, and to crew activity should be expected. Since the nature of scientific investigations varies somewhat with the calendar and with the specific days in orbit, many of the perturbations are more directly related to the experiment-type activity than to the basic mission, and have to be resolved by the personnel concerned with the experiments program.

When Gemini VI–A was in the terminal phases of revised preflight planning for rendezvous with the Gemini VII spacecraft, the comet Ikey Seicki was discovered and was determined to be moving through the Sun's corona. It was decided to attempt to photograph the comet during the Gemini VI–A mission, and immediate preparations were made to perform this activity. However, the Gemini VI–A launch was delayed, and although the capability to photograph the comet was successfully accomplished, the actual launch time prevented the spacecraft from being in the correct location for obtaining photographs of the comet.

The Gemini VIII mission was prematurely terminated shortly after docking with the target vehicle. One onboard experiment package contained live frog eggs, and much data could be retrieved if certain onboard operations were conducted within a restrictive time period. Real-time operations proved successful in relaying information to the crew after the spacecraft had landed in the Pacific. Much of the experiment was saved by utilizing capabilities and supporting functions established as a result of knowledge gained from previous experiment missions.

Late in the Gemini XII preflight phase, the decision was made to obtain ultraviolet photographs of dust entering the Earth's atmosphere, to record information on an expected meteor shower as the Earth moved through the remains of the tail of a comet, and to rendezvous with the shadow of the Moon as it moved across the Earth. The Gemini XII mission had previously been extended from 3 to 4 days to accommodate the crew activity schedule. The personnel concerned with experiments assured availability of required equipment onboard the spacecraft, briefed the crew, and programed the mission for the added objectives without compromising previous mission planning. Subsequently, the launch was postponed until 2 days later than had been planned; however, it was decided to accomplish the objectives as previously planned. The immediate and effective response by operational personnel in adjusting the orbital mechanics displayed precision; the intricate rendezvous with the lunar eclipse was successful.

No experiment was deleted from a mission because of flight equipment not being available at launch time. The capability to support the experiments program was developed as necessary to meet expanding support requirements and was possible because of the flexible structure of the Manned Spacecraft Center organizations which allowed the Center to meet the demands of the program.

Scope of Program

The complement of experiments in the total Gemini Program numbered 52. In general, each experiment was flown several times to take advantage of varying flight conditions and resulted in 111 experiment missions, an average of 11 experiments per mission. The largest number of experiments, 20, was carried on the 14-day Gemini VII mission.

Table 17–I summarizes the experiments conducted during the Gemini Program. The large number of experiments, representing many disciplines, precludes a detailed description of all experiments in this paper. Reference 2 contains a brief description of the equipment and preliminary results of the experiments conducted during the Gemini III through VII missions.

The experiments were divided into three categories: scientific, technological, and medical. There were 17 scientific experiments conducted during the program. The 27 technological experiments were conducted in support of spacecraft development and operational techniques. The eight medical experiments were directed toward determining more subtle effects than might be determined from the regular operational medical measurements and preflight and postflight examinations.

TABLE 17–I.—*Experiment Program Summary*

Sponsoring agency	Number of experiments	Total experiment missions
Scientific:		
Office of Space Science and Applications	17	47
Technological:		
Office of Advanced Research and Technology	2	2
Office of Manned Space Flight, Manned Spacecraft Center	10	18
Department of Defense	15	26
Medical	8	18
Total	52	111

Principal Investigators and Affiliations

The Gemini experiments were proposed from many sources including universities, laboratories, hospitals, industry, and various Government agencies. Several investigators were often associated with a single experiment and they, in turn, may have had different affiliations. Table 17–II presents the principal investigators for the Gemini experiments and their affiliations, together with the missions for which the experiments were assigned.

Subsequent to the selections of the experiments and the principal investigators, a very close personal association was maintained among the experimenter, the spacecraft contractor, the crew, the mission planner, and the real-time operations personnel. Of these, the experimenter-crew relationship was of particular significance. The following paragraphs provide some insight into the integration of the experiments with the many program elements.

Experiment Equipment Integration

The selected experiments were integrated into the spacecraft on a minimum interference basis, based on the participation of the flight crew. Three specific examples illustrate the various categories. The simplest is the stowage category; the equipment is stowed in one of several areas or compartments, and is unstowed and operated according to a preplanned schedule. Examples of this type of equipment include the hand-held

TABLE 17-II.—*Principal Investigators and Affiliations*

Experiment description	Principal investigator	Affiliation	Mission No.
Scientific			
Office of Space Science and Applications:			
Zodiacal light photography	E. Ney	University of Minnesota	V, VIII, IX-A, X
Sea urchin egg growth	R. Young	NASA Ames	III
Frog egg growth	R. Young	NASA Ames	VIII, XII
Radiation and zero-g on blood	M. Bender	Atomic Energy Commission	III, XI
Synoptic terrain photography	P. Lowman	NASA Goddard	IV, V, VI-A, VII, X, XI, XII
Synoptic weather photography	K. Nagler and S. Soules	U.S. Weather Bureau	IV, V, VI-A, VII, X, XI, XII
Cloudtop spectrometer	F. Saiedy	Natl. Environ. Sat. Center	V, VIII
Visual acuity	S. Duntley	University of California	V, VII
Nuclear emulsion	M. Shapiro and C. Fichtel	NRL and NASA Goddard	VIII, XI
Agena micrometeorite collection	C. Hemenway	Dudley Observatory	VIII, IX-A, X, XII
Airglow horizon photography	M. Koomen	NRL	IX-A, XI, XII
Micrometeorite collection	C. Hemenway	Dudley Observatory	IX-A, X, XII
Ultraviolet astronomical camera	K. Henize	Dearborn Observatory, Northwestern University	X, XI, XII
Ion wake measurement	D. Medved	Electro-Optical Systems, Inc.	X, XI
Libration regions photographs	E. Morris	U.S. Geological Center	XII
Dim sky photographs orthicon	C. Hemenway	Dudley Observatory	XI
Daytime sodium cloud photography	Jacques-Emile Blamont	Centre Natl. de la Recherche Scientifique	XII
Technological			
Office of Advanced Research and Technology:			
Reentry communications	L. Schroeder	NASA Langley	III
Manual space navigation sighting	D. Smith and B. Creer	NASA Ames	XII
Office of Manned Space Flight:			
Electrostatic charge	P. Lafferty	NASA MSC	IV, V
Proton-electron Spectrometer	J. Marbach	NASA MSC	IV, VII
Triaxis fluxgate magnetometer	D. Womack	NASA MSC	IV, VII, X, XII
Optical communication	D. Lilly	NASA MSC	VII
Lunar ultraviolet spectral reflectance	R. Stokes	NASA MSC	X
Beta spectrometer	J. Marbach	NASA MSC	X, XII
Bremsstrahlung spectrometer	R. Lindsey	NASA MSC	X, XII
Color patch photography	J. Brinkman	NASA MSC	X
2-color Earth's limb photographs	M. Petersen	Massachusetts Institute of Technology	IV
Landmark contrast measurements	C. Manry	NASA MSC	VII, X

TABLE 17-II.—*Principal Investigators and Affiliations*—Concluded

Experiment description	Principal investigator	Affiliation	Mission No.
Department of Defense:			
Basic object photography	AF Avionics Lab	Wright-Patterson AFB	V
Nearby object photography	AF Avionics Lab	Wright-Patterson AFB	V
Mass determination	AFSC Field Office	NASA MSC (DOD)	VIII, XI
Celestial radiometry	AF Cambridge Lab	USAF-Hanscom Field	V, VII
Star occultation navigation	AF Avionics Lab	Wright-Patterson AFB	VII, X
Surface photography	AF Avionics Lab	Wright-Patterson AFB	V
Space object radiometry	AF Cambridge Lab	USAF-Hanscom Field	V, VII
Radiation in spacecraft	AF Weapons Lab	Kirtland AFB	IV, VI-A
Simple navigation	AF Avionics Lab	Wright-Patterson AFB	IV, VII
Ion-sensing attitude control	AF Cambridge Lab	USAF-Hanscom Field	X, XII
Astronaut Maneuvering Unit	AFSC Field Office	NASA MSC	IX-A
Astronaut visibility	S. Duntley	University of California	V, VII
UHF-VHF polarization	NRL	NRL	VIII, IX-A
Night image intensification	Air Development Center	U.S. Navy	VIII, XI
Power tool evaluation	AF Avionics Lab	Wright-Patterson AFB	VIII, XI
Medical:			
Cardiovascular conditioning	L. Dietlein	NASA MSC	V, VII
Inflight exerciser	R. Rapp	NASA MSC	IV, V, VII
Inflight phonocardiogram	R. Johnson	NASA MSC	IV, V, VII
Bioassays of body fluids	H. Lipscomb	NASA MSC	VII, VIII, IX-A
Bone demineralization	P. Mack	Texas Woman's University	IV, V, VII
Calcium balance study	D. Whedon	National Institutes of Health	VII
Inflight sleep analysis	P. Kelloway	Baylor Medical School	VII
Human otolith function	A. Graybiel	U.S. Navy, Naval Aerospace Medical Institute	V, VII

cameras used to conduct the zodiacal light, weather, and terrain photography experiments. Figures 17–1 and 17–2 are typical examples of stowage.

A second type of integration includes equipment mounted in the pressurized cabin area during the mission. This is exemplified by the radiation and zero-g effects on blood cells experiment (fig. 17–3) and the frog egg growth experiment (fig. 17–4), both of which were mounted on the spacecraft hatch.

The most complex type of integration involves equipment with some or all of the following requirements: structurally mounted; automatically deployed for taking measurements; thermally controlled; extensive data requirements involving onboard tape recordings of the measurement and radiofrequency transmission during the flight. These requirements are typified by the radiometry experiments D004 and D007. Figure 17–5 shows an outline of the spacecraft and the location of the elements of the equipment; figure 17–6 depicts the operational mission configuration of Gemini VII as viewed from Gemini VI-A.

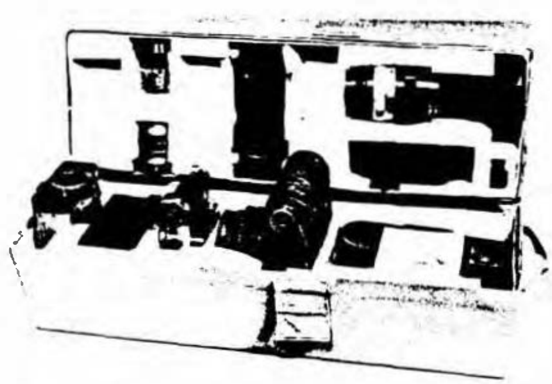

FIGURE 17-1.—Photographic equipment stowage.

FIGURE 17-2.—Photographic equipment stowage compartment.

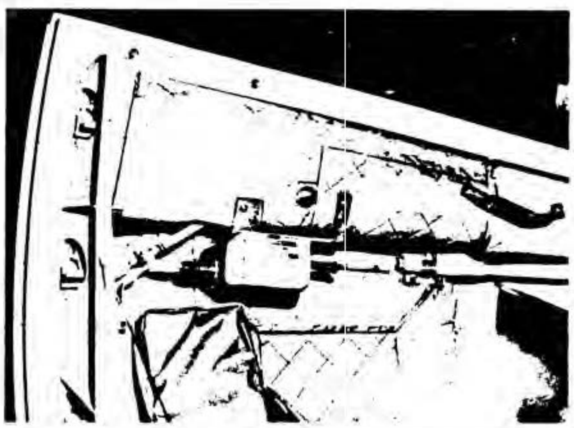

FIGURE 17-3.—Radiation and zero-gravity effects on blood cells experiment package.

Crew Integration

The diversity of the experiments required considerable training by the crew. The training began with briefings by the experimenter to explain the experiment, the proposed method of operation, the probable training required, and the expected results. It was often determined in such briefings that various constraints would prevent the spacecraft and/or crew from accomplishing the experiment in the manner originally desired. In these situations, either the crew or the engineering and operational specialists could generally propose and develop alternate techniques which allowed accomplishment of the experiment objectives within the capabilities of the crew and the spacecraft.

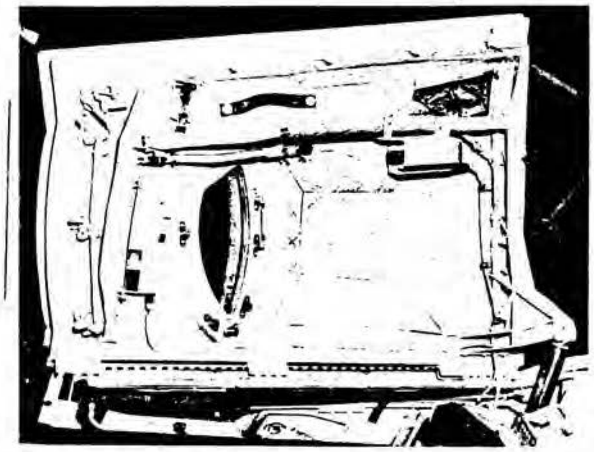

FIGURE 17-4.—Radiation and zero-gravity effects on frog-egg growth experiment package.

After the techniques were evolved for the various experiments, plans for crew training were developed. Planetarium briefings were included, as well as flight-simulator training with celestial backgrounds; aircraft flights to provide operational familiarity with hardware; zero-g aircraft flights for experiments requiring extravehicular activity; and baseline studies for medical and visibility experiments. These activities and others, coupled with continued discussions between crew and experimenters, were considered essential to the successful completion of the experiment. An understanding by the crew, not only of the mechanical operation of the experiment but also of the objectives and underlying principles, was required to allow the crew to exercise their selective and visual capabilities.

Mission Planning

In addition to integrating the hardware into the spacecraft, developing the experimental technique, and training the crew, the multitude of experimental operations had to

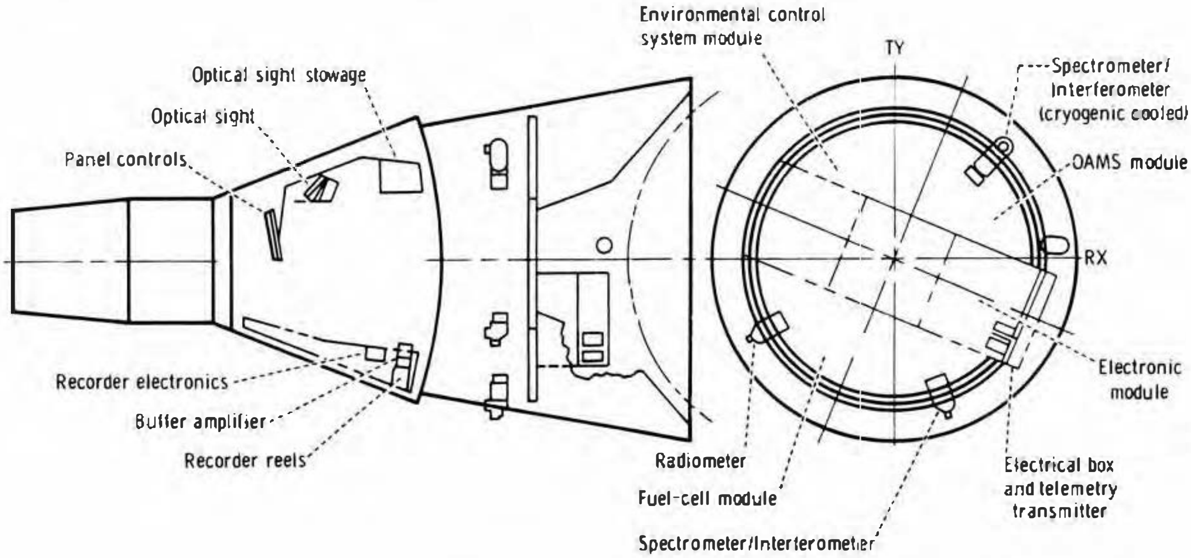

FIGURE 17-5.—Location of radiometry equipment for Experiments D004 and D007.

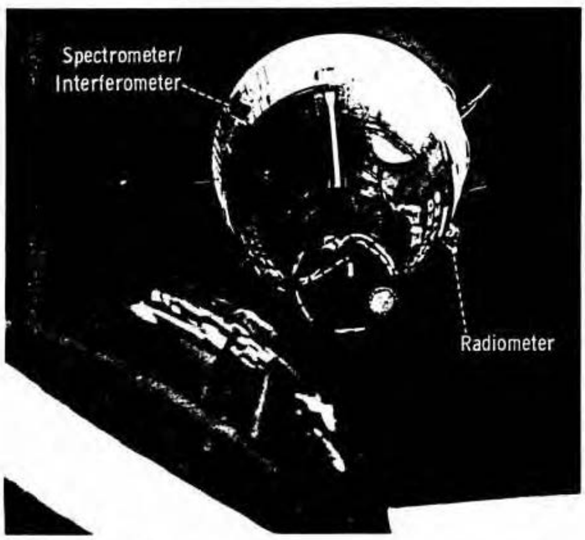

FIGURE 17-6.—Operational mission configuration for Experiments D004 and D007.

be integrated with the other primary mission activities. The experiments generally had a variety of requirements which often conflicted or interacted. The zodiacal light photography experiment was conducted only during nighttime conditions. The visual acuity experiment required clear skies and a constraining inclination angle above the ground patterns. The cloudtop spectrograph experiment cloud observations and recordings were performed in areas where airplanes could be deployed to make correlation measurements. During the Gemini VII mission, the radiometry experiments included a requirement for measurements at 36 different periods and locations. The conflicts and the potentially damaging interactions had to be resolved. The experimenter had a significant role in the planning. His knowledge of the flexibility in the experiment requirements maintained the integrity of the experiment without compromising the overall objectives. An optimum overall flight plan was thus achieved.

Prelaunch

The impact of experiments on the overall mission time line and spacecraft propellants is summarized in tables 17–III and 17–IV. The experiment hardware followed the same philosophy and supported the identical performance specifications and spacecraft checkout schedules as the operational spacecraft systems and crew-stowed operational equipment.

TABLE 17–III.—*Percentage of Mission Time Planned for Experiments*

Mission	Planned total mission time, hr[a]	Planned experiment activity time, hr[b]	Mission time planned for experiments, percent
III	9	0.5	5
IV	140	22	16
V	288	49	17
VI-A	66	8	12
VII	392	86	22
VIII	90	19	21
IX-A	90	19	21
X	90	33	37
XI	90	26	29
XII	122	37	30
Total	1377	299.5	22

[a] Two crewmen, less sleep time.
[b] Direct crew participation time only. Does not include total experiment equipment operating time.

TABLE 17–IV.—*Payload and Propellants for Experiment Activities*

Mission	Total experiment weight, lb[a]	Propellant allotted for experiments, lb
III	69	
IV	67	63
V	206	68
VI-A	22	26
VII	243	85
VIII	237	49
IX-A	275	16
X	133	78
XI	251	153
XII	140	165
Total	1643	703

[a] Does not include mounting provisions or ballast.

As previously mentioned, the inflight failure of equipment involved in one of the experiments on the first manned mission resulted in added responsibility for the Manned Spacecraft Center to assure confidence in the equipment to successfully accomplish experiment objectives. Previously, mission and spacecraft integration responsibilities were the definitive interface responsibilities. The added responsibility resulted in an additional scope of monitoring and approval of environmental testing, and of a more extensive checkout interface involving actual flight hardware in the spacecraft, together with additional bench checks.

From a practical standpoint, checkout performed at the spacecraft contractor's plant and at Kennedy Space Center identified engineering problems which could affect hardware design and mission performance. In these cases, the combined experience of the experimenter, the Gemini Program Office, and the spacecraft contractor team enabled the experiment to be conducted with little or no change to hardware procedures or mission planning.

Real-Time Mission Support

During the mission, many of the experiments required considerable real-time support by ground personnel and the experimenter. The visual acuity experiment is an example. The experimenter was located at the Mission Control Center—Houston. The two ground-test sites to be viewed by the flight crew were located near Laredo, Tex., and in Australia. Special communications were established between these sites and the closest network stations, Corpus Christi, Tex., and Carnarvon, Australia. This allowed the experimenter to contact the sites to determine weather conditions; to direct changes in the ground-test pattern; to receive crew reports; to perform analyses based on these inputs; and to interact with the ground controllers, who in turn passed information to the crew for the continuation of the experiment.

In summing up the experiment integration activity and looking forward to the future, it can be concluded that the success of an experiment is highly dependent upon the participation of the experimenter in many phases of the program. These phases include design integration, mission planning, crew training, checkout, and real-time support of the operation. Experiments requiring considerable amounts of integration activity can be accommodated and successfully implemented. Crew understanding is vital to achieve maximum benefit from man in space.

Experiment Performance

The overall success of the Gemini Experiments Program is indicated in numerical values in table 17–V. If mission problems are not considered, a remarkable success is indicated. Experiment equipment problems affected only 6 of the 111 experiments performed on all missions. This performance was the result of the close teamwork of all participants as well as the capability to readily incorporate equipment and mission modifications up to launch time.

Concluding Remarks

The success of the Gemini Experiments Program is measured by the new or confirmed information provided for engineering, management, and scientific disciplines. The experience gained from the Gemini Experiments Program has provided invaluable knowledge and experience for future manned space-flight programs.

TABLE 17–V.—*Experiment Performance Status*

Gemini mission	Number of experiments	Experiments accomplished[a]	Problems[b]
III	3	2	Experiment
IV	11	11	
V	17	16	Mission
VI–A	3	3	
VII	20	17	Experiment
VIII	10	1	Mission
IX–A	7	6	Mission
X	15	12	Mission
XI	11	10	Mission
XII	14	12	Experiment
Total	111	90	

[a] 80.3 per cent accomplished overall.

[b] 14.3 percent not accomplished due to primary mission problems; 5.4 percent not accomplished due to experiment equipment problems.

References

1. ANON: Mercury Project Summary, Including Results of the Fourth Manned Orbital Flight, May 15 and 16, 1963. NASA SP-45, 1963.
2. ANON: Gemini Midprogram Conference, Including Experiment Results. NASA SP-121, 1966.

18. SPACE PHOTOGRAPHY

By Richard W. Underwood, *Photographic Technology Laboratory, NASA Manned Spacecraft Center*

Introduction

The 10 manned Gemini flights produced a series of color photographs which are both striking in beauty and of immense scientific and academic value. Over 2400 photographs were secured and have demonstrated the value of space photography in such fields as geology, geography, oceanography, agriculture, hydrology, urban planning, environmental pollution control, meteorology, land management, cartography, and aerospace engineering. A representative selection of photographs from the various missions, as well as a short description of the informational content, are presented in this paper.

Camera Equipment

Figure 18-1 shows a selection of camera equipment used during the Gemini Program. The majority of the photographs were obtained with the NASA-modified 70-mm Hasselblad Camera, Model 500-C; both the 80-mm Zeiss Planar and 250-mm Zeiss Sonnar lenses were used. The Super Wide-Angle 70-mm Hasselblad Camera, Model SWA, was used on the Gemini IX-A through XII missions. Although designed primarily as an extravehicular activity device, the Model SWA camera recorded some of the most spectacular terrain photography of the program. The 70-mm Maurer Space Camera was also carried on Gemini IX-A through XII and permitted a unique versatility resulting from rapid interchangeability of components. The gray 80-mm Xenotar lens and magazine (50-frame capacity) secured conventional color photographs. The red f/0.95 Canon lens and magazine permitted scientific photography of very low light-level phenomena such as horizon airglow and libration regions. The blue lens, prism, grating, and magazine system were designed to work in the ultraviolet regions, primarily to record stellar spectrographs. Motion-picture equipment manufactured by J. A. Maurer, Inc., is also pictured. The 70-mm magazine especially built by Cine Mechanics, Inc., allow the Hasselblad systems to secure 65 frames instead of the conventional 12. A second-generation Cine Mechanics magazine with a capacity of about 160 frames was used on Gemini XII.

Table 18-I indicates the various 70-mm films carried on Gemini flights. The thickness of the film varied from about 0.007 inch to 0.0025 inch. Most of the film had emulsion coatings and bases especially formulated to NASA specifications. Figure 18-2 shows the machine manufactured by Hi-Speed, Inc., to process the Ektachrome film. Great care was used in processing the Gemini flight film. Prior to processing the film, the machine was thoroughly cleaned and then checked for precise sensitivity control; this included checks of the various photographic processing chemicals, exact temperatures, cycle durations, and chemical replenishments. The flight films were sent through the processor singly; this required a considerable amount of time but allowed very close surveillance. No flight film was lost due to laboratory malfunctions.

Selected Photographs

The following representative photographs constitute about 2 percent of the total photographs secured during the Gemini Program, and contain information of value in

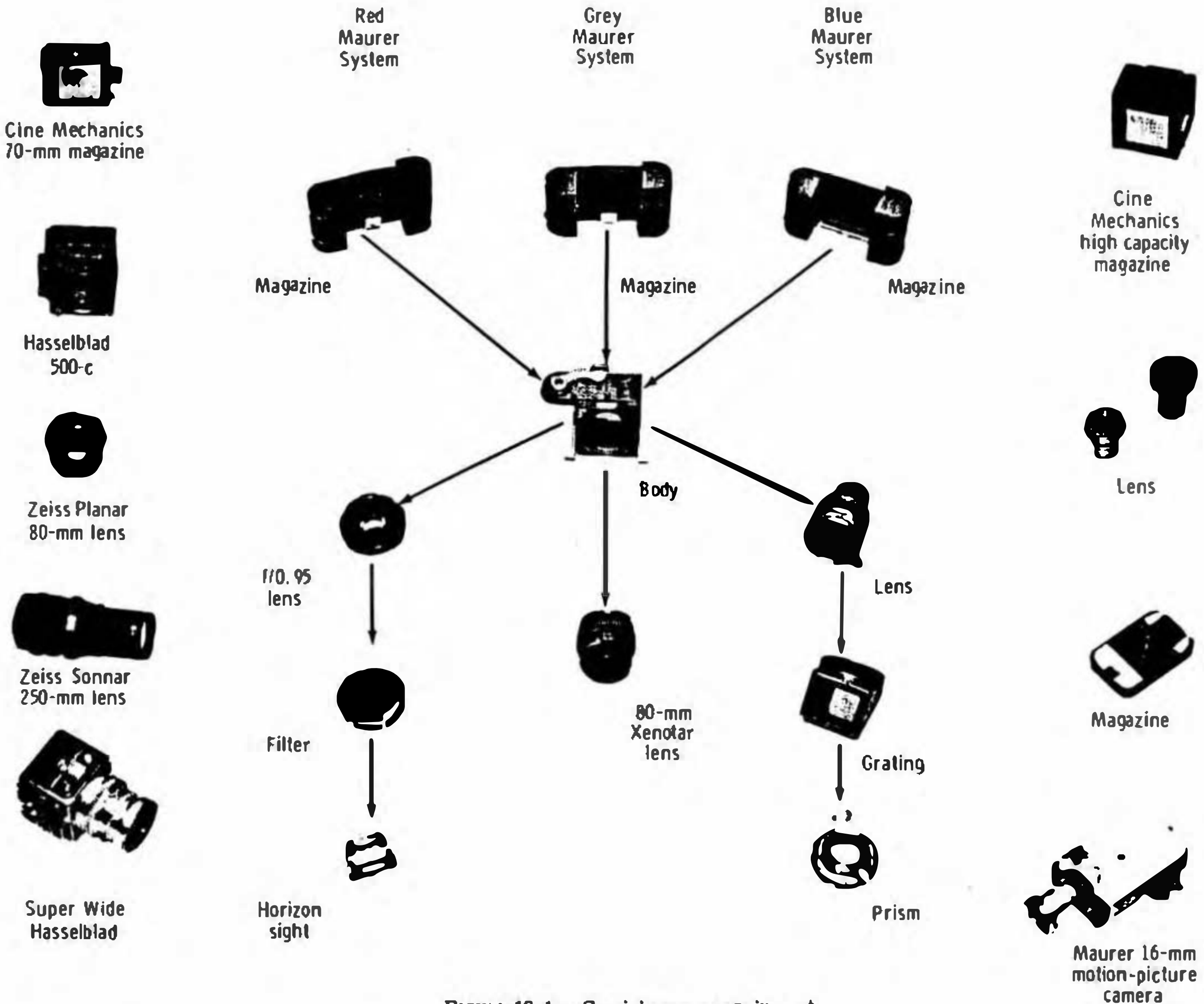

FIGURE 18-1.—Gemini camera equipment.

the various geoscientific or aerospace fields. The serious geoscientist would have to examine the entire collection in order to determine the total value to his field of interest.

TABLE 18-I.—*Gemini 70-mm Film*

Name	Type	Mission
S.O. 217	Ektachrome transparency	III, IV, V, VI-A, VII, VIII, IX-A, X
S.O. 368	Ekt chrome transparency (improved)	XI, XII
D-50	Anscochrome transparency	V
8443	Ektachrome, infrared	VII
S.O. 166 (0-85)	Ultrahigh speed (ASA = 6000)	XI, XII
3400	Pan-Atomic X (ASA = 80)	VII
2475	High-speed (ASA = 1200)	VI-A, VII
103-D	Spectrographic (4500 Å-6100 Å)	IX-A, XI
I-0	Spectrographic (2500 Å-5000 Å)	X, XI, XII

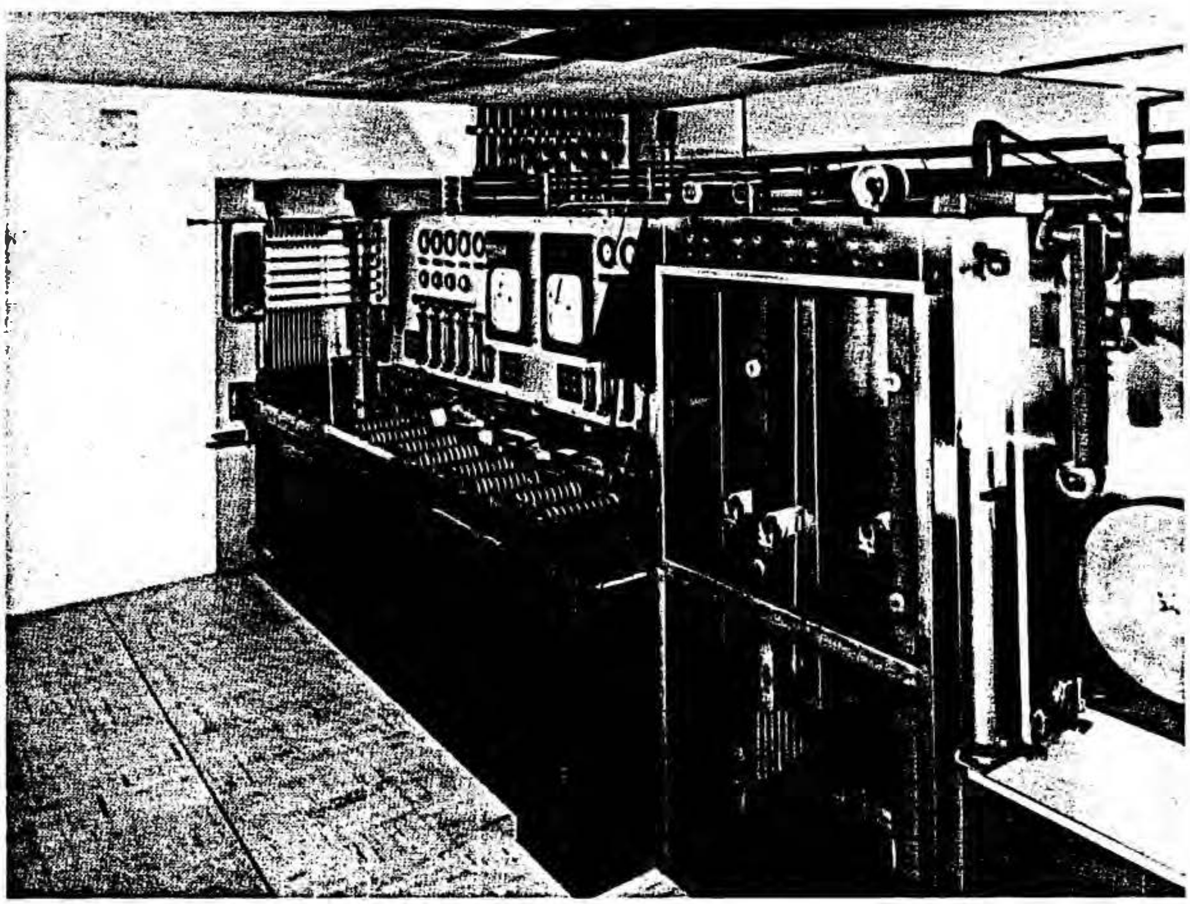

FIGURE 18-2.—Film processor.

Synoptic Terrain Photography

Figure 18–3 was taken from an altitude of 110 miles during the Gemini IV mission and has become a classic for obvious reasons. The Nile Delta is clearly visible, as well as the Sinai Peninsula, the Dead Sea, and the entire Suez Canal connecting the Red and Mediterranean Seas. The horizon is about 800 miles to the east, across Iraq and Saudi Arabia. The photograph shows both branches of the Nile River (Rosetta and Damietta) from Cairo, across the fertile and densely populated delta, to the Mediterranean Sea. Note the sharp contrast between the irrigated delta lands and the great deserts of Africa and Asia.

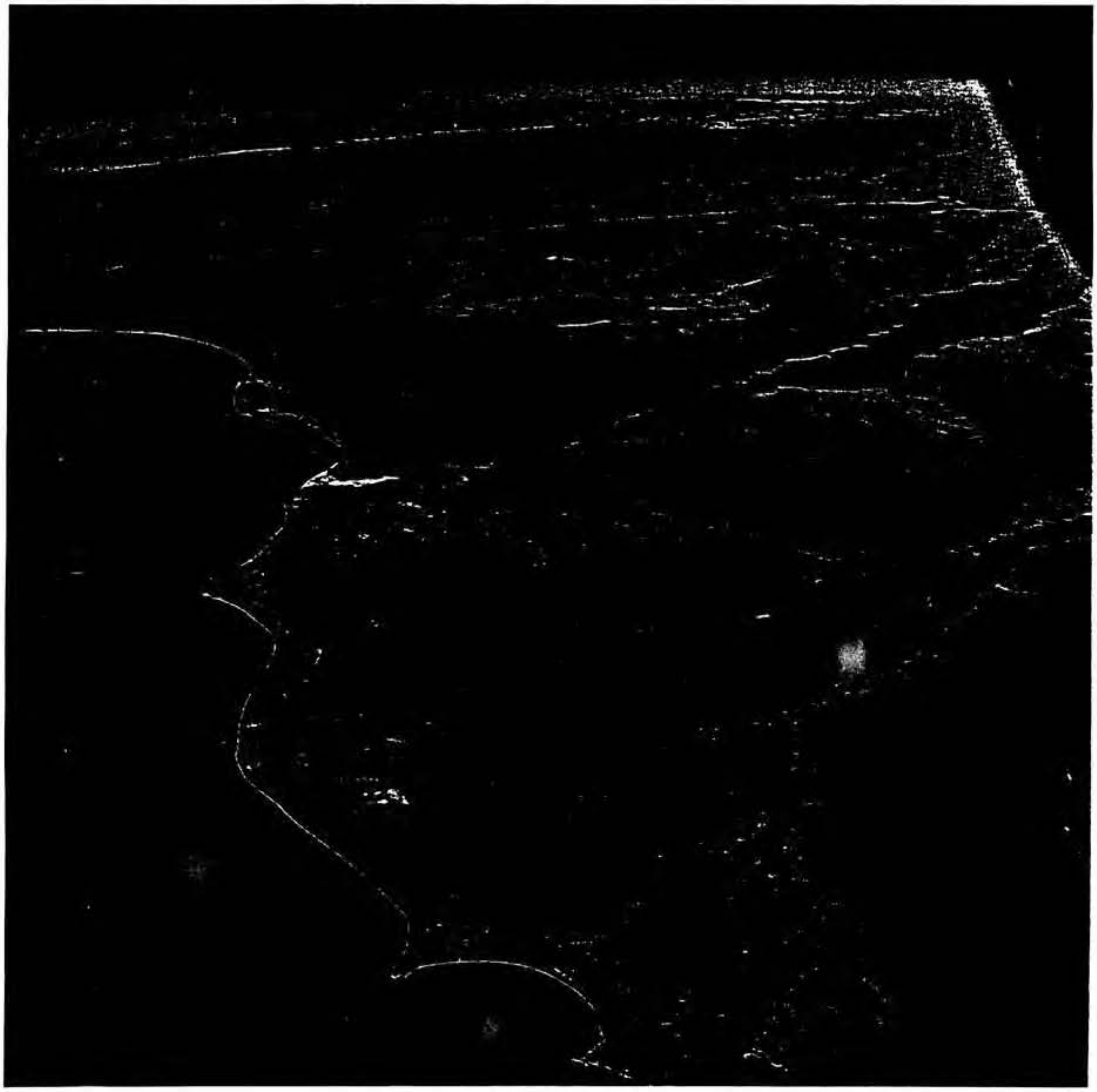

FIGURE 18–3.—Nile Delta.

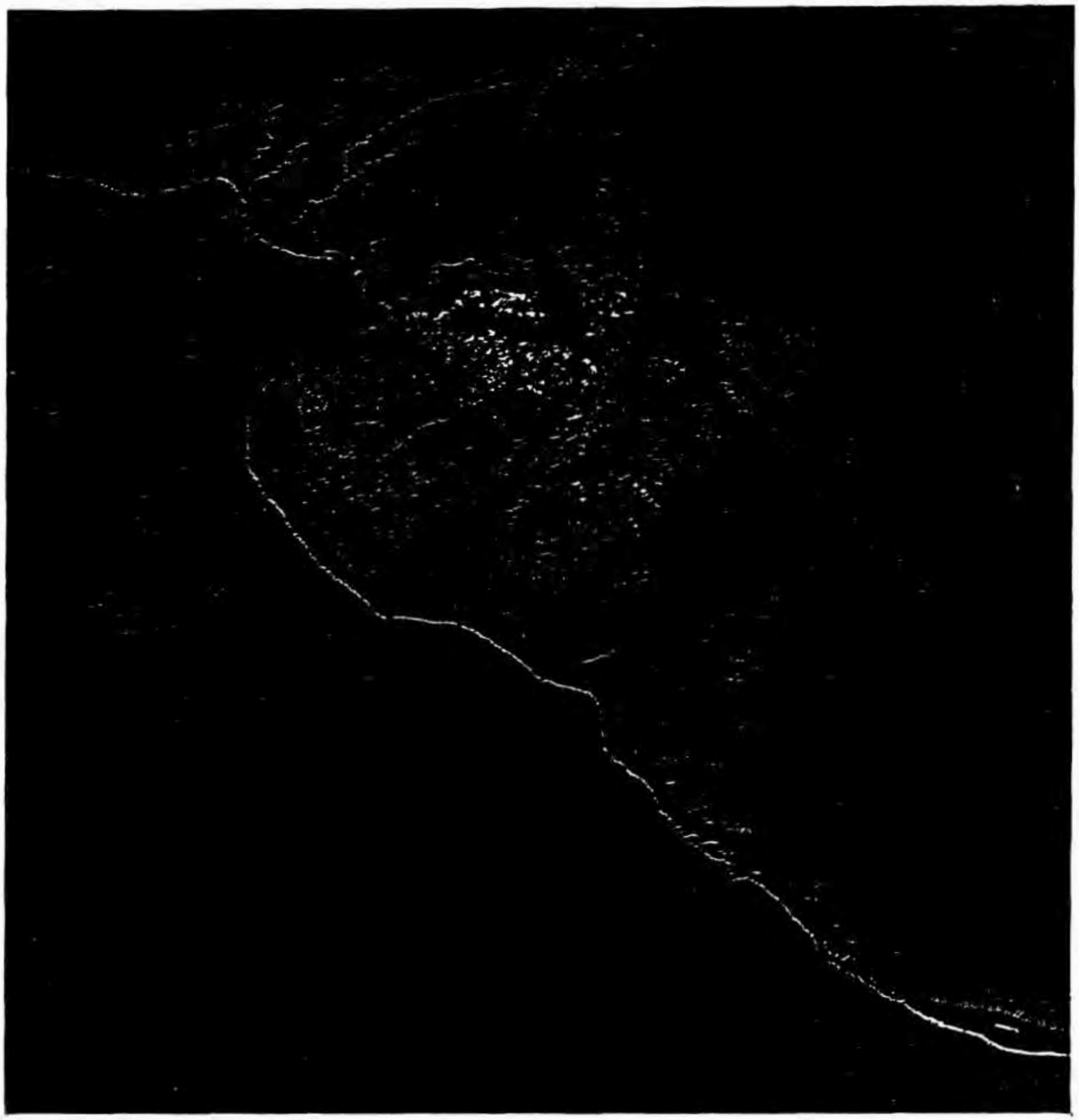

FIGURE 18–4.—Nile River.

Figure 18–4 shows how the geology controls the course of the Nile River for some 200 miles in Sudan and the United Arab Republic. The river hugs the contact zone between the black basaltic intrusives east of the river and the sedimentary rocks to the west. Much of the area visible in this Gemini IV photograph will be inundated when the Aswan Dam is completed and the 400-mile-long Lake Nasser is created in the Sahara.

FIGURE 18-5.—Ras Al Hadd.

Figure 18-5 was taken during Gemini IV from an altitude of 120 miles. The Ras Al Hadd area of Muscat and Oman appears in fine detail; airport runways can also be seen at the point. Several oases are perceptible at the base of the pediment where ground water reaches the surface. Long seif dunes at the eastern extremities of the Rub Al Kahli (Empty Quarter) are visible and provide information of meteorologic value.

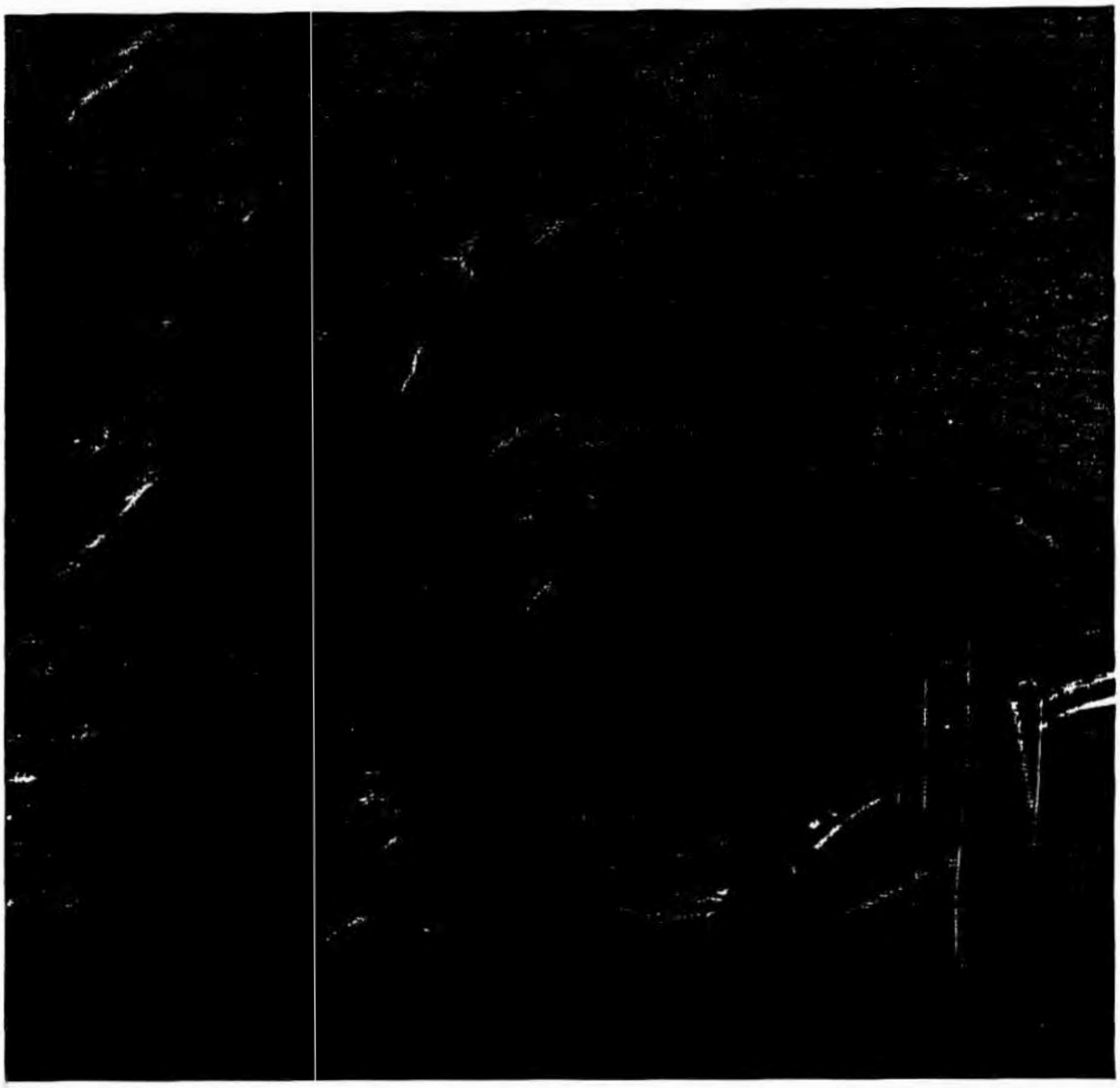

FIGURE 18–6.—Richat structure.

A view of large geologic structures can be captured in a single photograph such as figure 18–6 which shows Mauritania's Richat structure in excellent detail. The structure was possibly formed by a large meteorite-type impact, or possibly from the erosion of a volcanic plug or intrusion. This Gemini IV photograph has regenerated scientific interest in the structure in relation to the geology of the entire area.

FIGURE 18-7.—Florida Keys.

In figure 18–7, the Florida Keys are dramatically visible from the Gemini IV spacecraft at an altitude of 115 miles. The entire chain from Key Largo to Boca Chica Key is visible, thereby providing a regional study from a single photograph. The Overseas Highway, which is never more than 30 feet wide, can be clearly seen. Many boat wakes in the Florida Strait are emphasized in the solar highlight. A large portion of the Everglades is visible in the upper right. On the underwater reefs visible at the right, Florida has established the John Pennekamp State Park to preserve the ecology of the area.

FIGURE 18-8.—Mouth of Colorado River.

Figure 18–8 was photographed during the Gemini IV mission, and shows quite clearly the mouth of the 1500-mile-long Colorado River and the related geology. The photograph, one of 39 made in a 4-minute rapid sequence between Baja California and central Texas, was taken from an altitude of 110 miles. The Mexican States of Baja California to the west and Sonora to the east, as well as the Golfo de California, constitute the extent of the photograph. A white streak to the right of the river is the saltpan bed of the old river channel before upstream irrigation removed most of the water volume. A straight line just to the right (east) of the old channel is a portion of the San Andreas fault system. The distinct change in topography and in geologic structure is most evident, and was caused by the linear horizontal movement of the fault during the geologic past. To the right of the San Andreas fault are the sands of the Great Sonora Desert. The line of contact between the delta sediments brought down the river and the block-fault mountains and pediments of Baja California appears near the left (west) edge of the photograph. Suspended sediments carried down the river are clearly visible around the mouth.

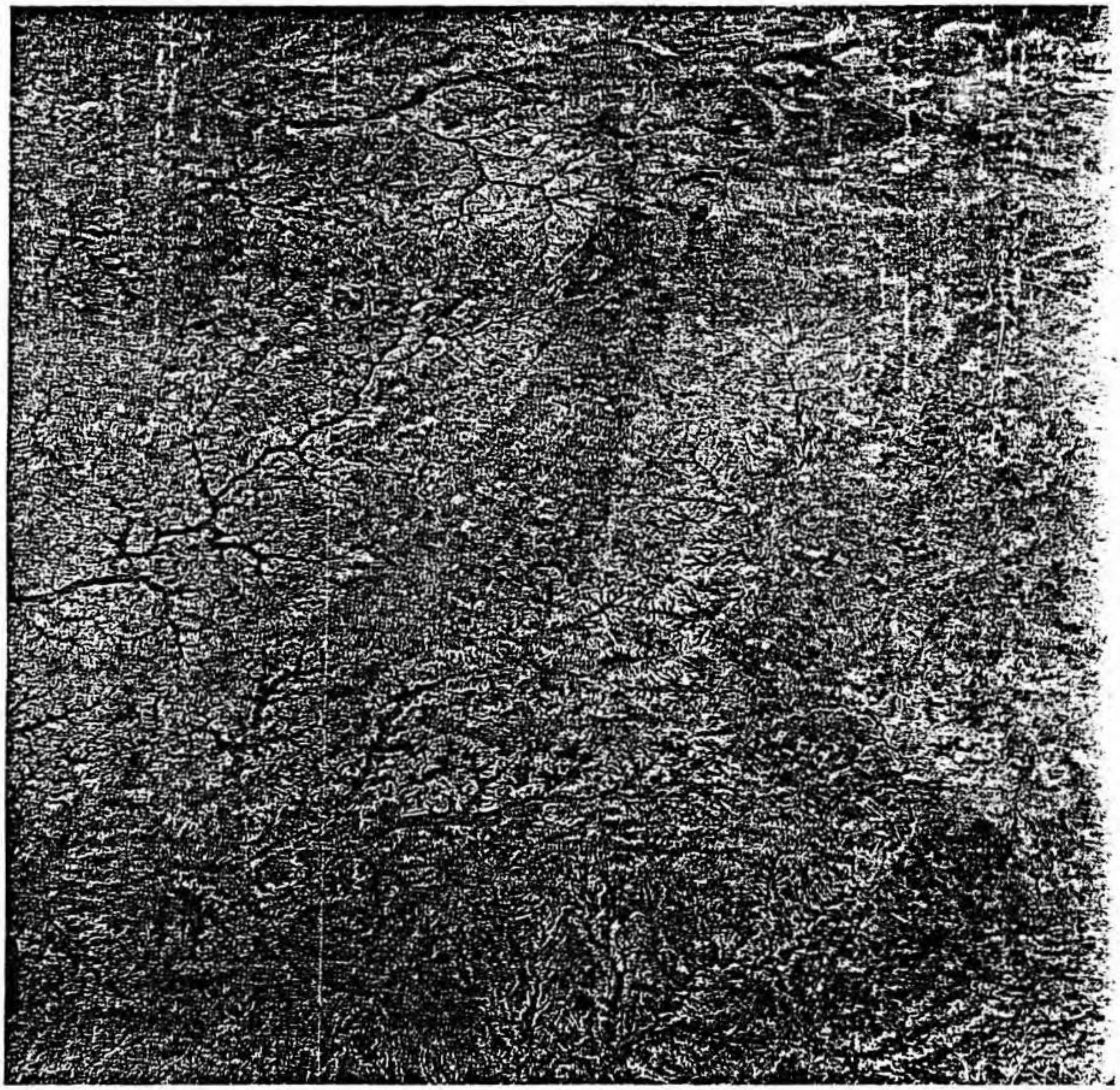

FIGURE 18-9.—West Texas.

Figure 18-9 is a portion of the Edwards Plateau area of Texas photographed during the Gemini IV mission. The view is to the west and shows the cities of Odessa, Midland, and Big Spring along the right edge. The unique darker areas in the left and lower left show the effect of a rain storm the previous evening, and how quickly vegetation demonstrates growth in a semiarid area. The dendritic drainage of the upper Concho system is quite evident due to the lush vegetation along these streams.

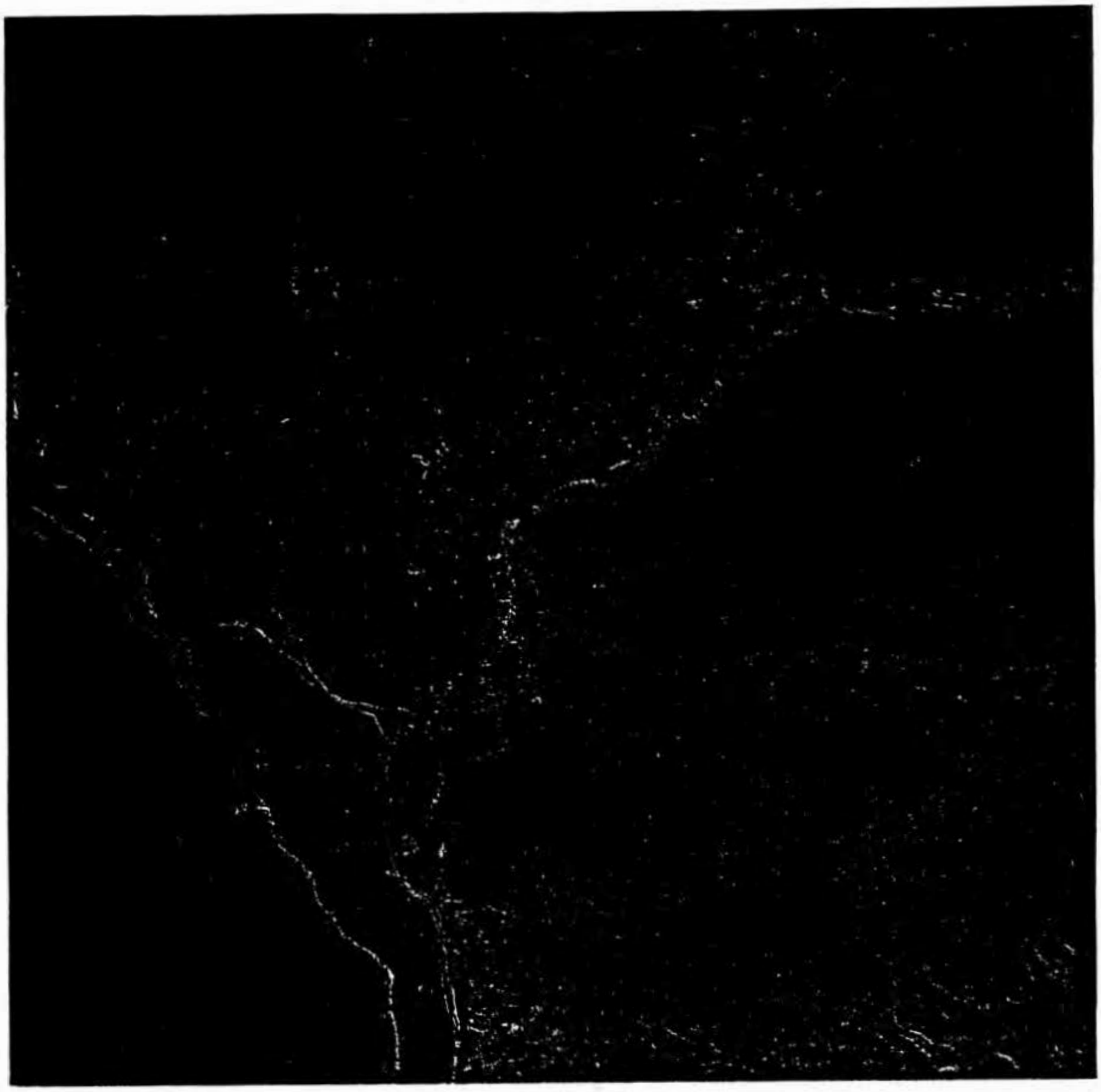

FIGURE 18-10.—Nile Delta.

Figure 18-10, showing a major portion of the Nile Delta, was taken during Gemini V from an altitude of 100 miles. With the 30 million people in the delta area and a high population growth rate, rapid regional information changes are most important. The photograph shows Cairo with a population of over 5 million; the distribution of cities and towns in the delta; and the networks of roads, railroads, and canals.

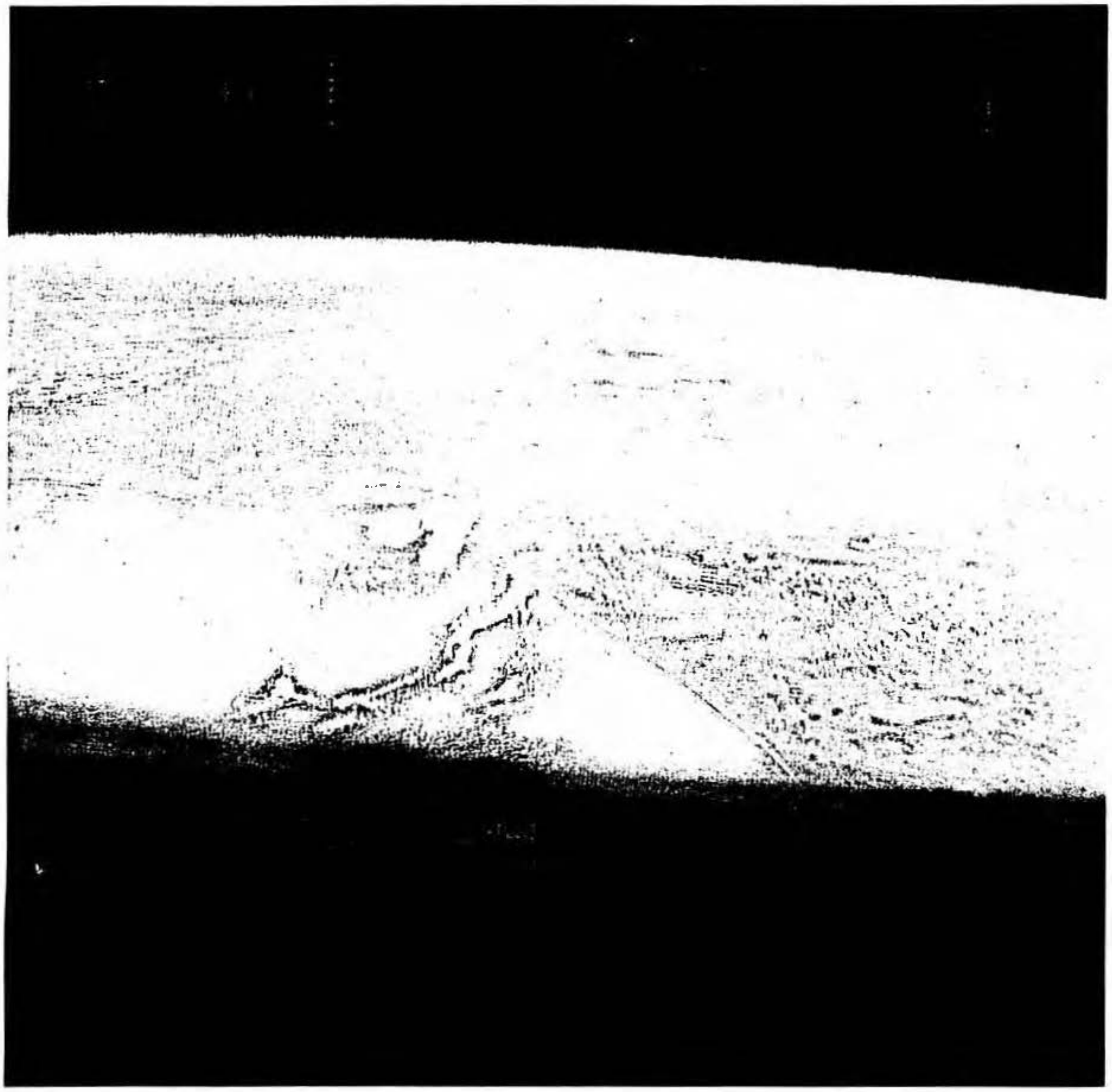

FIGURE 18-11.—Strait of Gibraltar.

Figure 18–11, photographed by the Gemini V crew, is a classic astronaut view of the Earth. The Strait of Gibraltar and the continents of Europe and Africa are pictured. The valley of the Guadalquivir River and the Sierra Morena in Spain, as well as Point Europa (Rock of Gibraltar), are clearly visible in the upper left. To the right are Morocco and Algeria. Unique cloud formations are visible on the Atlantic side of the strait.

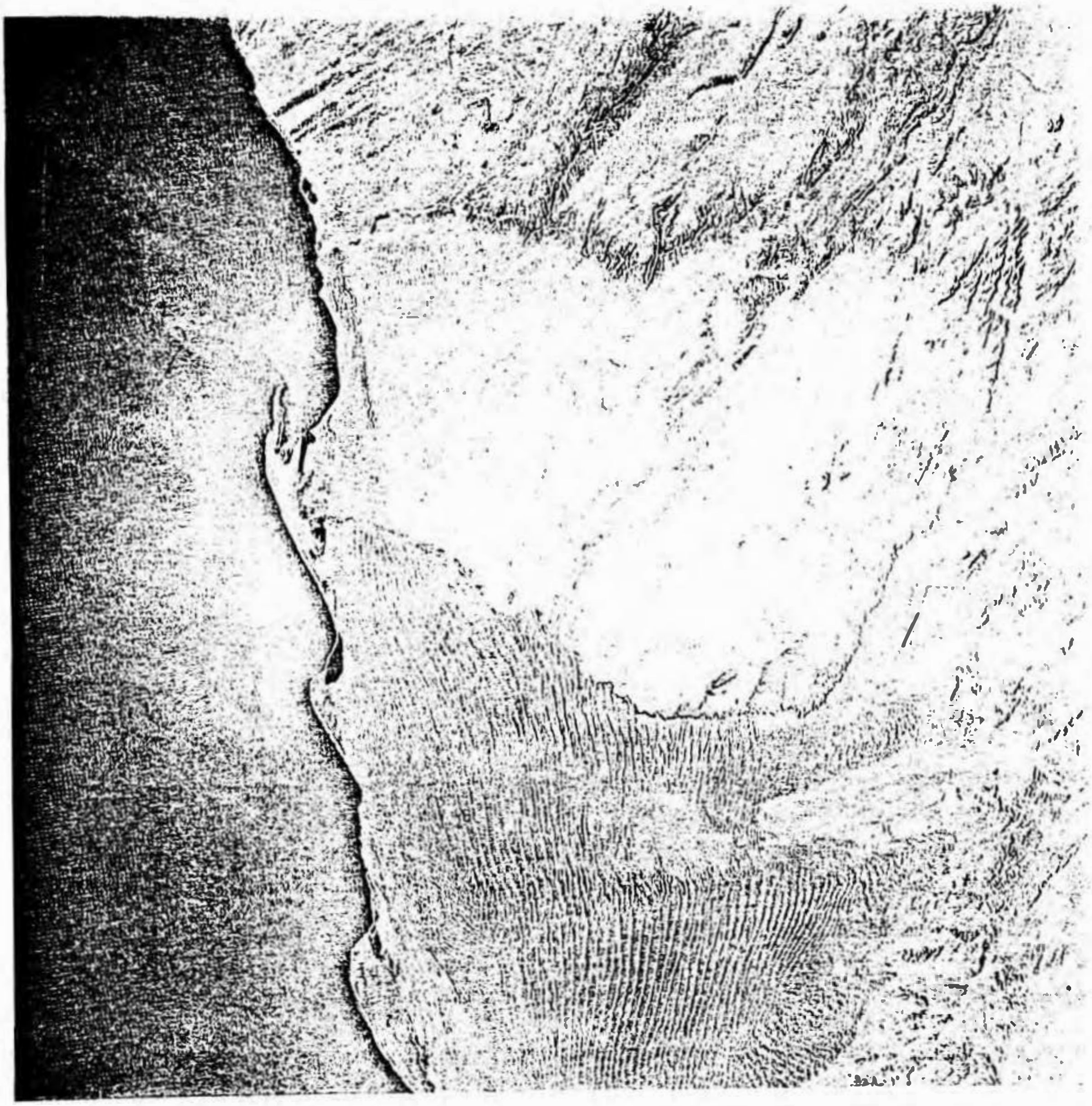

FIGURE 18–12.—Southwest Africa.

A Gemini V photograph (fig. 18–12), taken from an altitude of 200 miles, clearly demonstrates the forces of wind and sea in the Namib Desert of Southwest Africa. This is one of the driest areas of the world, and the sole productivity is diamonds buried in the sands. The seif-type dunes extend over 100 miles across the southern part of the area. As the prevailing winds carry the sand into the Atlantic Ocean, the strong Benguela Current causes the northward waterborne migration of the sands and the formation of the three very large sand hooks. The northernmost hook is 50 miles long, and the port of Walvis Bay is located on the lee side. The area is known as the Skeleton Coast, a name that goes back nearly 500 years when early navigators in galleons attempted to use this route from Western Europe to Asia. In order to reprovision, they had to fight strong northward currents and prevailing winds from the mouth of the Congo River to the Cape of Good Hope in ships which sailed poorly to windward. Failure to reach their destination was disastrous for ship and crew. Navigators such as Columbus believed that the riches of Asia could be obtained with less hardship by sailing westward across the Atlantic.

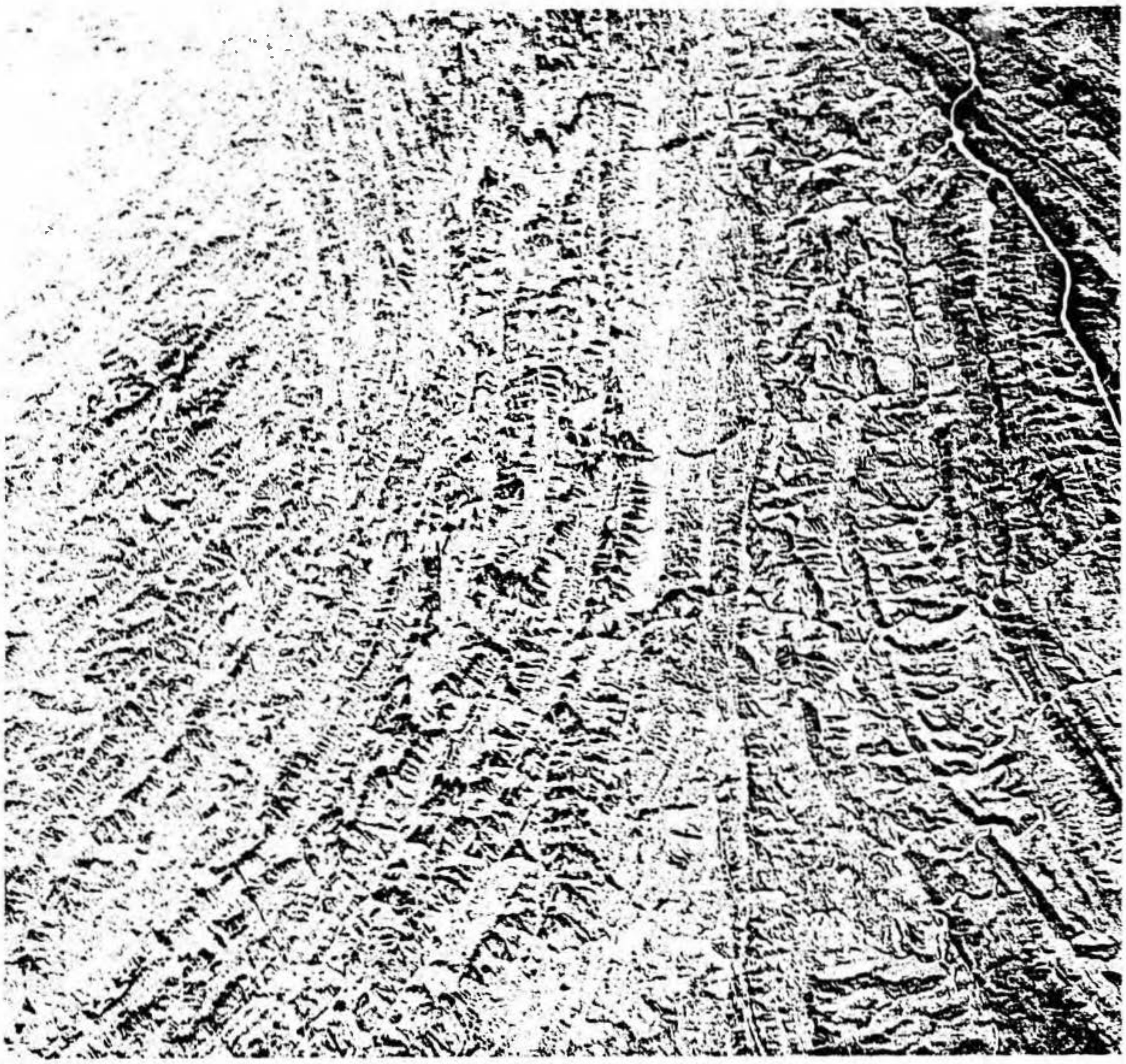

FIGURE 18–13.—China basins.

The line of intersection of two large basins located in Szechwan Province, China, is visible in figure 18–13. The photograph was taken during the Gemini V mission and shows the Yangtze River along the right edge. The long folded sedimentary ridges with intermediate softer beds control the drainage pattern of the area. The synoptic view from orbital altitudes reveals much information which cannot be discerned from the lower altitudes attained by airplanes.

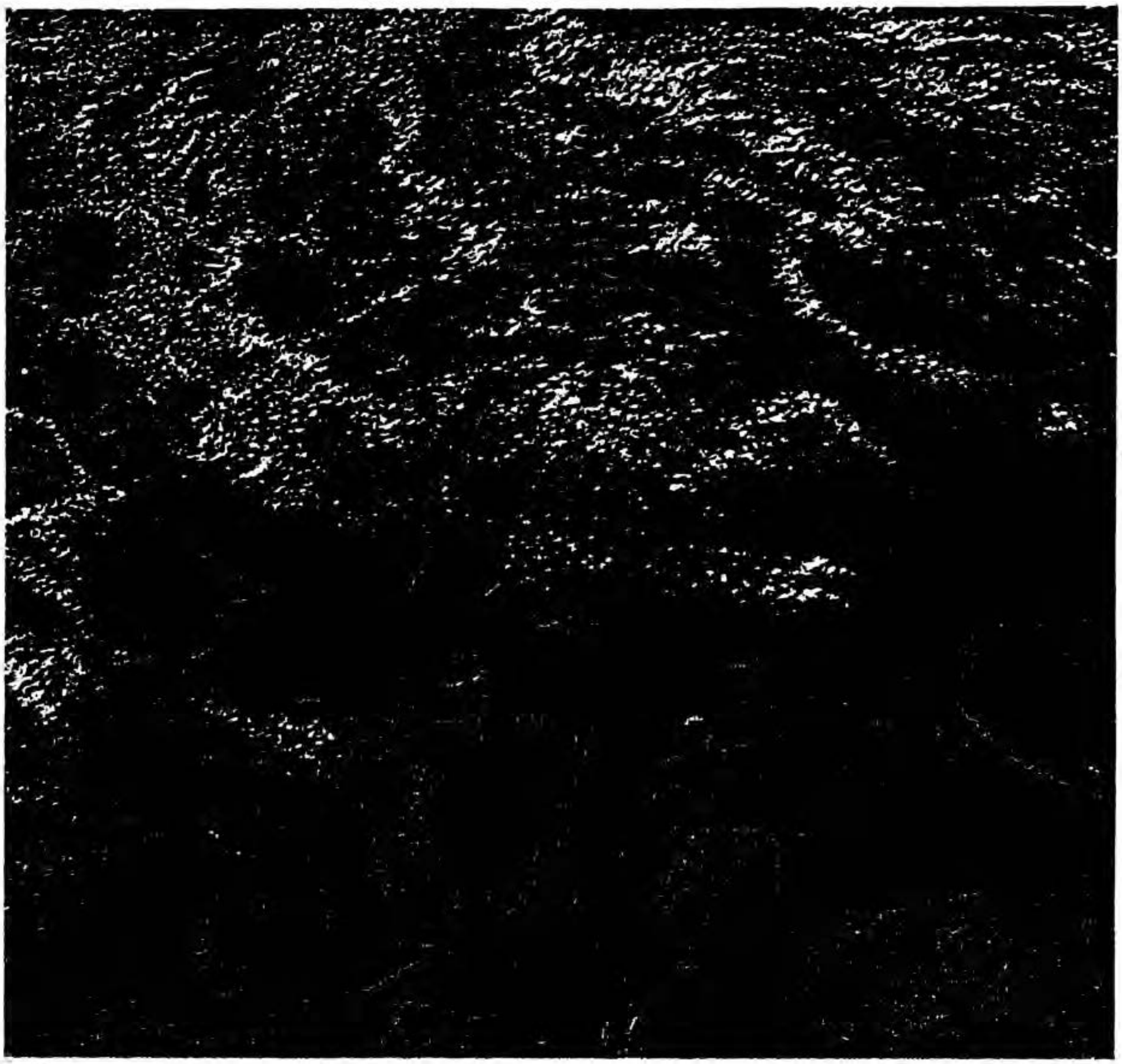

FIGURE 18–14.—Hunan Province, China.

Figure 18–14 was taken during the Gemini V mission, and shows a large natural floodway in Hunan Province, China, with the Yangtze River at left center. The open water of the floodway is Tung 'ting Hu, a lake about 100 miles long. The Hsiang River flows into the lake from the right and the photograph clearly shows the relationship of the floodway system to the surrounding topography.

FIGURE 18-15.—Mount Godwin-Austen (K-2).

The boundaries of China (Sinkiang), India, Pakistan (Kashmir), Afghanistan, and U.S.S.R. (Tadzhik) meet in the Karakoram Range of the Himalayas (fig. 18-15). The mountains are snow covered above 20,000 feet. The world's second highest peak, Mount Godwin-Austen (K-2) with an elevation of 28,250 feet, is near the upper edge of the photograph and the Indus River is located in the lower portion. The upper right shows the basin of the distant Takla Makan Desert. The Gemini V photograph was

FIGURE 18–16.—Bahama Banks.

taken at the time of minimum snowcover, and indicates that space photography can provide data on the water runoff from snowfields of remote and poorly explored mountain ranges.

Oceanographers are interested in photographs such as figure 18–16, a view of the Great Bahama Bank taken from Gemini V. Except for the small land areas of Great Exuma Island, Cat Island, and Long Island, all the informational content concerns the floor of the ocean. Along the edge of the Tongue of Ocean, which is over a mile deep, the canyons cut in the coral banks are visible. Exuma Sound in the center drops abruptly from rocks awash to a depth of 8000 feet. Space photography for the first time affords an opportunity to photograph large areas of the world's oceans.

FIGURE 18-17.—Salton Sea.

Figure 18–17, taken by the Gemini V crew, shows the southwestern corner of the United States and portions of Baja California and Sonora in Mexico. The frontier cutting across the Imperial Valley is easily located due to the marked difference in the land division systems. The city of Mexicali on the border and the All-American Canal along the frontier are visible. A unique and unexplained gyre can be seen in the Salton Sea. The overall relationships of the many basins and ranges, which are the predominant geologic features of the area, can easily be studied. The Colorado River is visible from just above the mouth, through the entire Grand Canyon, to beyond Lake Powell in southeast Utah.

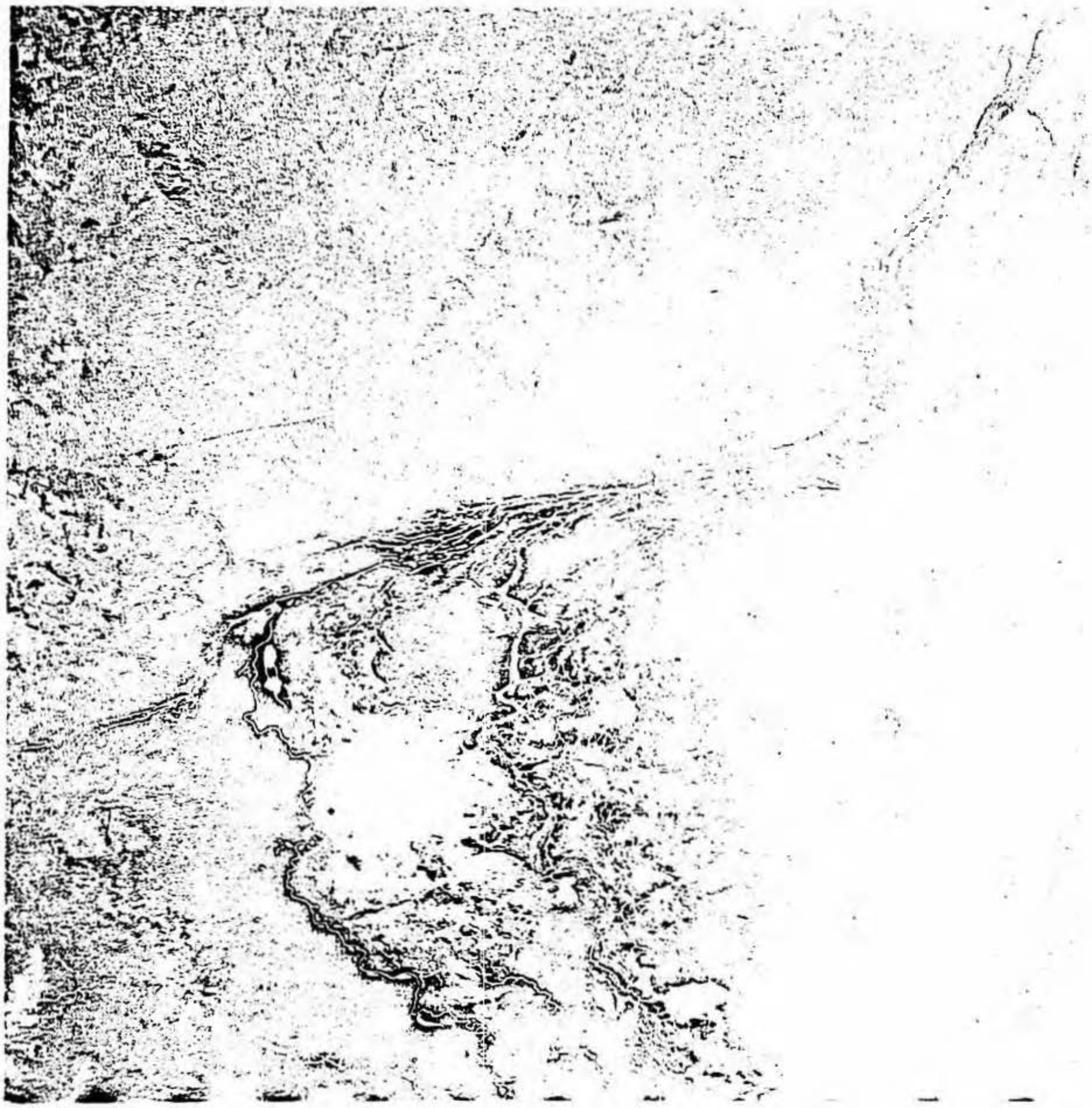

FIGURE 18-18.—The Sudd.

The area known as the Sudd, Arabic for the barrier or stopper, was dramatically photographed (fig. 18-18) from the Gemini VI-A spacecraft at an altitude of 185 miles. The main feature in the photograph is perhaps the world's largest swamp; the area is larger than the State of Pennsylvania. The White Nile flows out of the Great Rift Valleys of East Africa into Sudan and loses over 80 percent of its volume in a tangled mass of marsh, water hyacinth, and 15-foot papyrus grass. The river loses itself in many channels which open and close at random, as floating islands of papyrus block old and create new channels. Lightning often causes the grass to catch fire. The hostile terrain of this area has historically separated the cultures of Arab Africa from Negro Africa. Continued surveillance from manned spacecraft can provide much information on the river and the swamp vegetation, and may lead to an eventual triumph by man.

FIGURE 18-19.—Western Algeria.

The fine geologic details of the Sahara Desert in Western Algeria (fig. 18-19) were recorded by the Gemini VII flight crew. The dunes are long longitudinal ridges from 5 to 10 miles apart, 500 to 800 feet high, and up to several hundred miles long. A long ridge of upturned sedimentary beds is visible from the upper center to the lower right edge of the photograph. A wadi, a usually dry stream bed, follows the right edge of the ridge; just off the photograph, the wadi passes through a water gap and

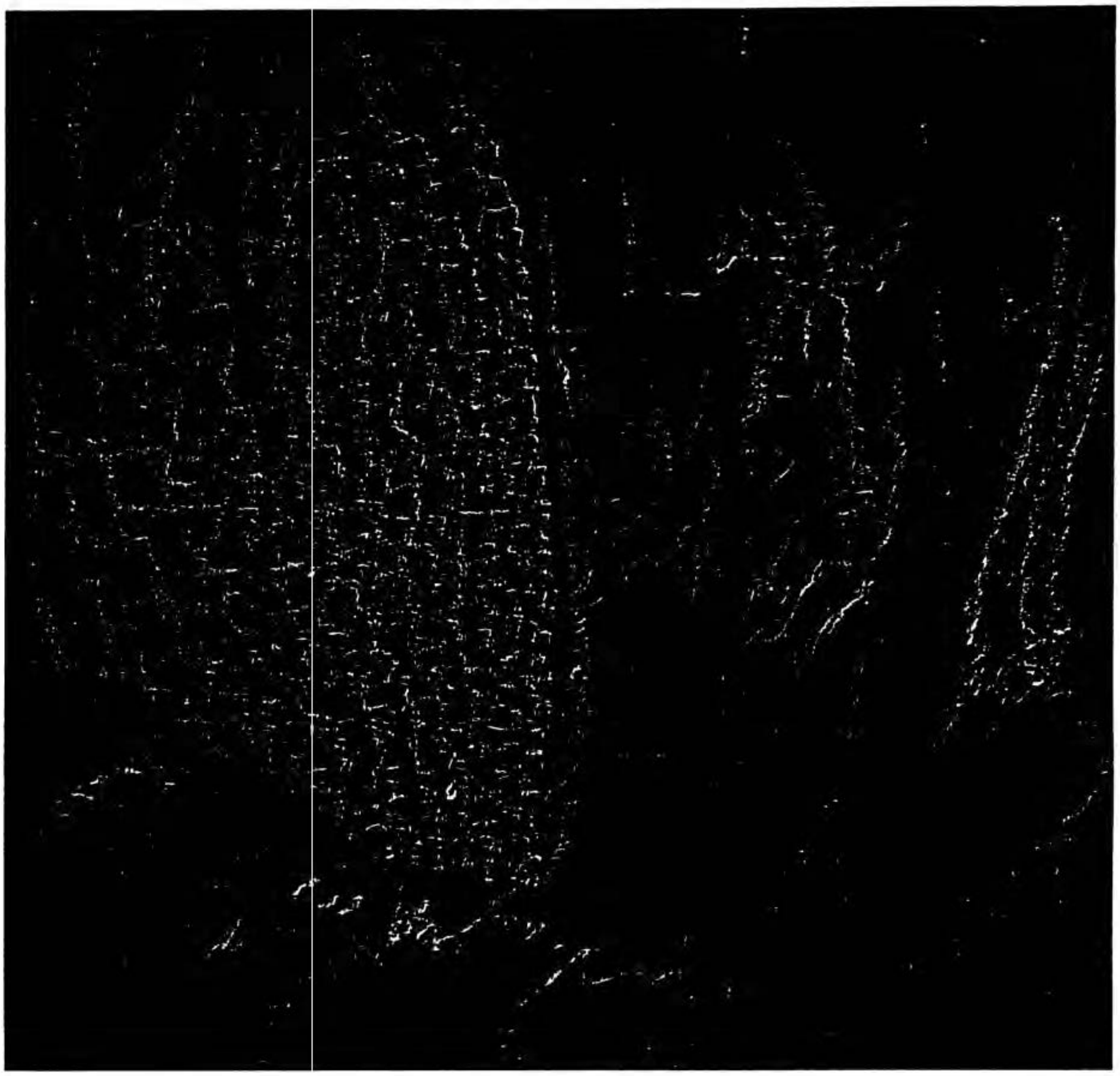

FIGURE 18–20.—Tifernine Dunes.

continues in the opposite direction down the other side of the ridge terminating in a large salt flat. The photographs of this usually dry country were made shortly after very heavy rains; the wadi is carrying surface water and the salt flat is inundated.

Figure 18–20 was obtained with a 250-mm Zeiss Sonnar lens, and shows the structure of a unique geologic feature, the Tifernine Dunes of Eastern Algeria. These dunes are probably the world's highest (1500 feet), and are trapped in a basin surrounded by mountains of basalt. The remote area had been poorly photographed prior to the Gemini VII mission.

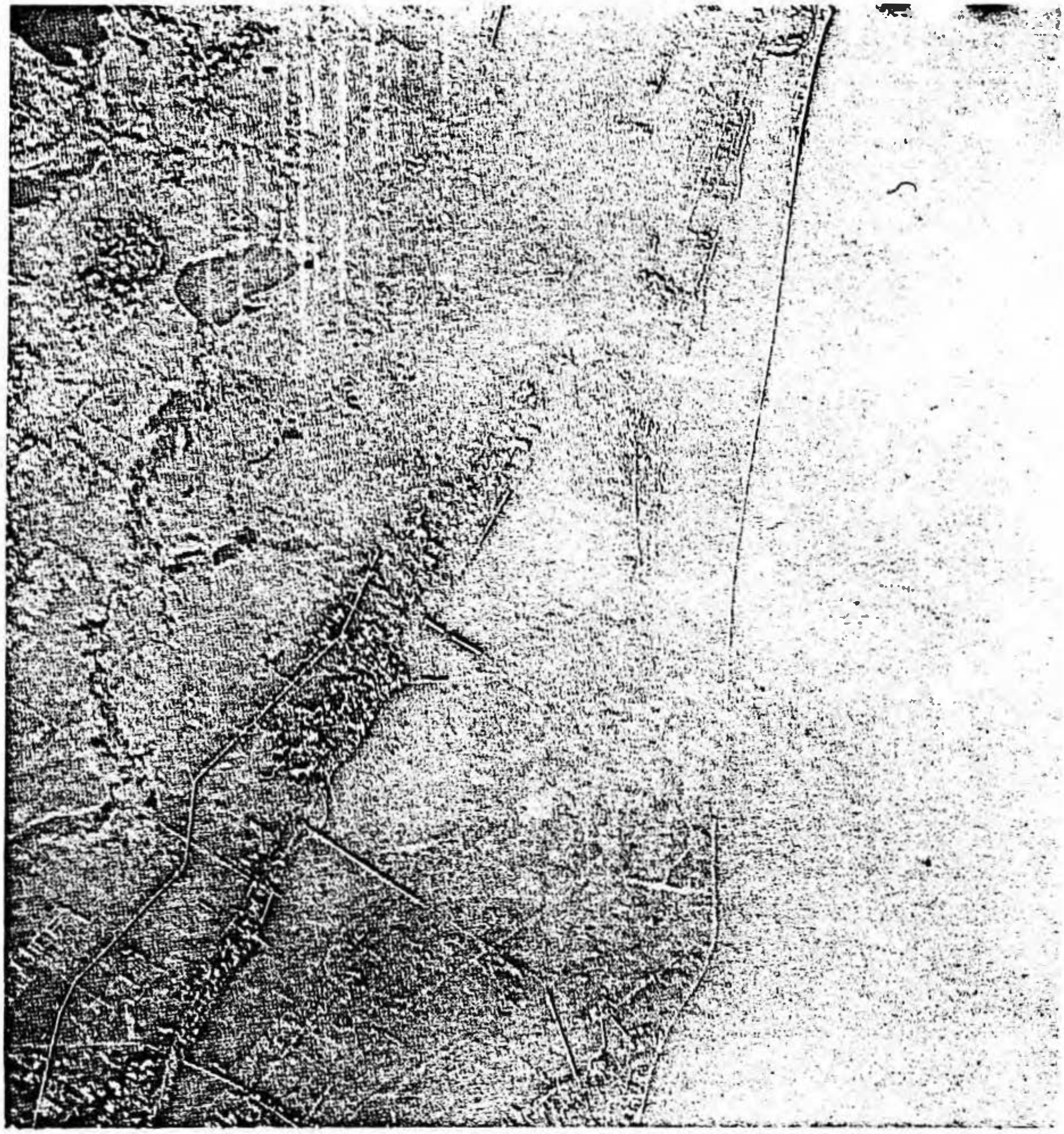

FIGURE 18-21.—Kennedy Space Center, Florida.

The potential value of space photography to the urban planner is represented by figure 18–21. The Gemini VII crew photographed the Kennedy Space Center, Fla., and vicinity while directly overhead at an altitude of 140 miles. Launch Complex 19, where the spacecraft was launched 2 days before, can be clearly seen as part of Missile Row. Launch Complex 39, which includes the Vertical Assembly Building, the crawlerways, and the two launch pads, is partially obscured by a cloud. Other manmade features which are clearly visible include freeways, city streets, buildings, causeways, railroads, bridges, piers, runways, and taxiways. The channel of the Intracoastal Waterway can be located beside the series of white dots in the Indian River; the white dots are small islands of spoil piles resulting from dredging. Space photography can be utilized by urban planners to study and make important decisions regarding the fierce competition for land among industrial, commercial, residential, agricultural, and recreational users. Government personnel can update planning documents, such as master plans, or tax and transportation maps, and quickly see what changes have taken place in land use.

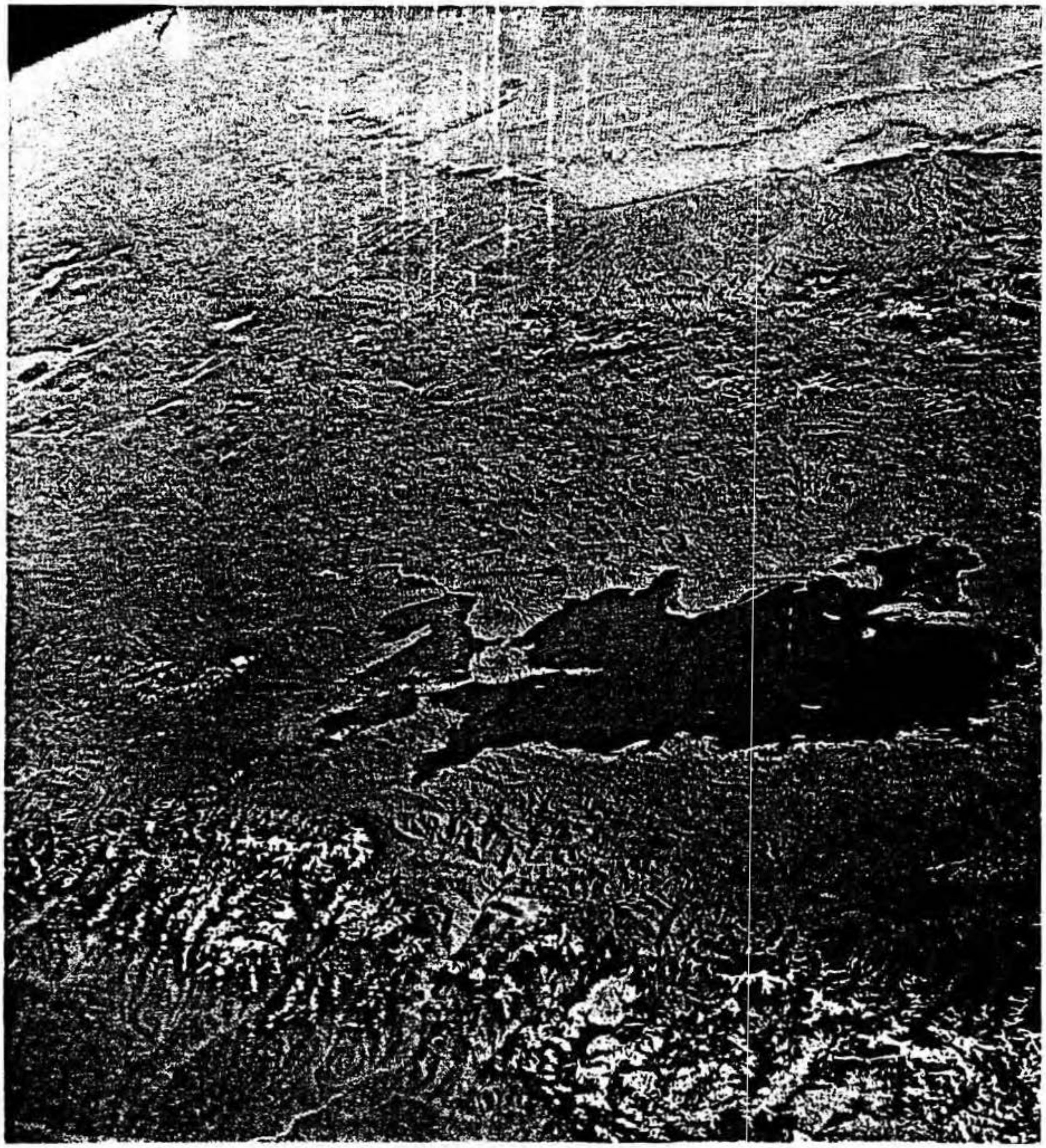

FIGURE 18-22.—Lake Titicaca, Peru.

Lake Titicaca, located between Peru and Bolivia at an elevation of 12 506 feet, was photographed (fig. 18–22) by the Gemini IX–A crew. The photograph also shows portions of Chile and Argentina, and the Pacific Ocean in the background. The snow-covered peaks of the Cordillera Real (Royal Mountains) rise to over 21 000 feet and are visible in the lower left. The high Salars or salt flats, on the left margin, are higher than any point in the continental United States and are as large as the Bonneville Salt Flats. Drainage, from the lower left, is about 3700 miles down the Amazon to the Atlantic Ocean.

FIGURE 18-23.—Peru.

The Cordillera Blanca (White Mountains) of Peru were photographed (fig. 18–23) by the Gemini IX–A crew less than 1 minute prior to figure 18–22. Clearly visible is Huascaran Volcano (22 205 feet), the highest point in Peru; the snowline is at 18 000 feet. A thin white line down the west slope of the volcano marks the path of a destructive avalanche which killed several thousand people in the Santa River Valley in January 1962. Over 250 miles of the Pacific coast can be seen. The rivers in the upper right of the photograph flow down the Amazon system for over 3500 miles to the Atlantic. In areas which still require accurate and detailed mapping, space photography will be a valuable asset. Great effort is required to obtain accurate information on the amount of snow on these mountains and the predicted water runoff. Space photography can reduce the hardships encountered by topographic survey parties at altitudes in excess of 20 000 feet, and eliminate the frequent loss of life. In over 40 years of aerial photography, only a quarter of Peru has been photographed; the Gemini IX–A crew photographed over three-quarters in 3 minutes.

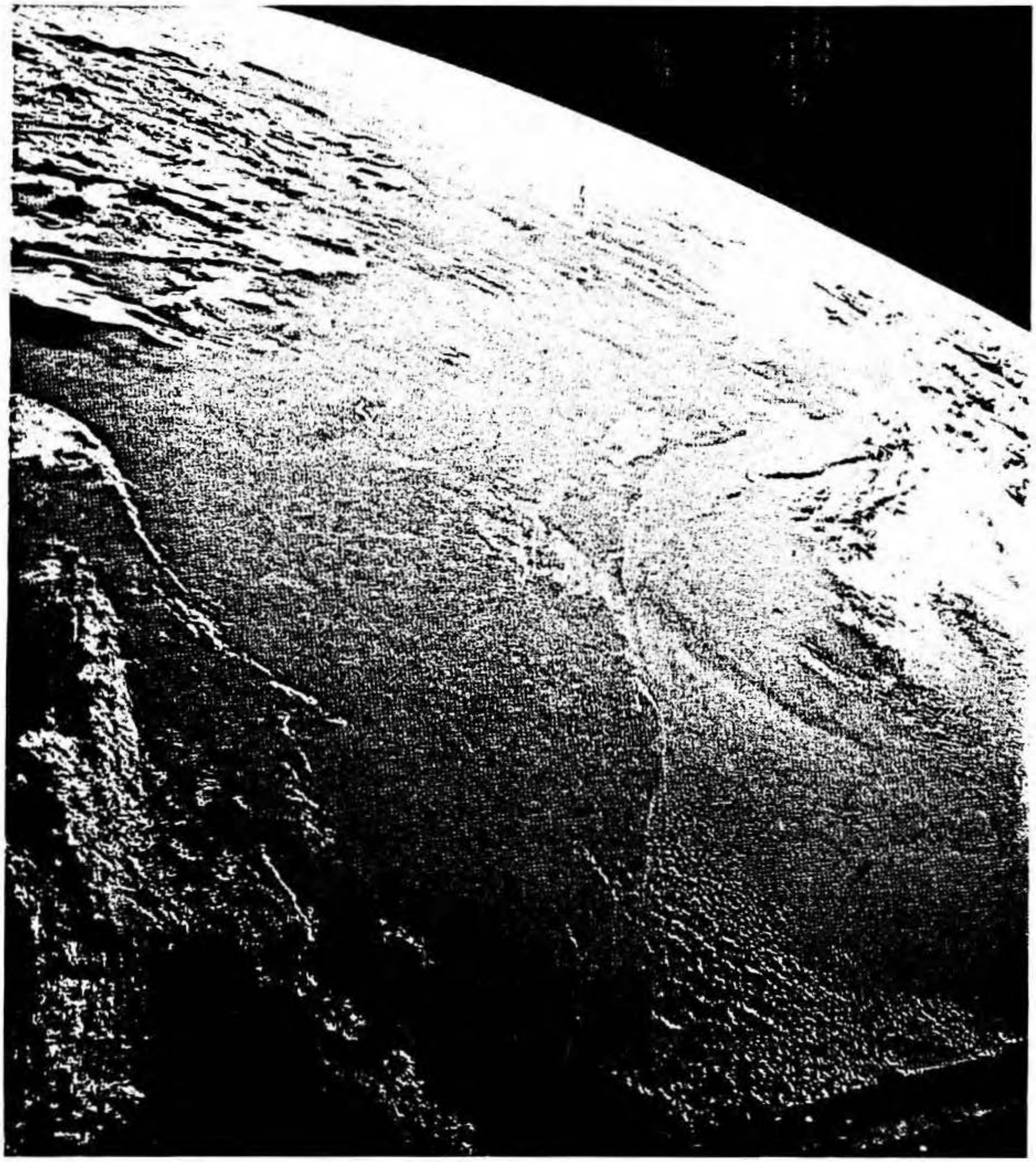

FIGURE 18-24.—Texas-Louisiana Gulf coast from Gemini XI.

Figure 18–24 is a very interesting study of the sources and distribution of air pollution along the Texas-Louisiana Gulf Coast. This photograph was taken through the open hatch of the Gemini XI spacecraft shortly after dawn. Large sources of air pollution can be seen originating from smokestacks in Houston, Texas City, Freeport, and Port Arthur, Tex., and in Lake Charles, Baton Rouge, and Bogalusa, La. As shown in the photograph, the air pollutants in the Houston area move northeastward at the lower levels until winds aloft carry the pollutants southward over the Gulf of Mexico. In the future, space photography will provide a worldwide aid in the detection of sources, and the collection and movement of airborne pollutants.

FIGURE 18–25.—Texas-Louisiana Gulf coast from Gemini XII.

Figure 18-25 was taken by the Gemini XII crew along the Texas-Louisiana Gulf Coast and shows Houston, the Manned Spacecraft Center, the Harris County Domed Stadium, the Houston Ship Channel, and many other features of the area. Of greater geoscientific importance, the distribution of very polluted water in Galveston Bay and other waterborne sediment in such passes as Bolivar Roads, Sabine, and Calcasieu can be clearly seen. The movement of currents in the Gulf of Mexico is also quite evident, and has afforded the oceanographer the opportunity to learn a great deal about the movement and distribution of larval commercial shrimp so important to area economy. The photograph also demonstrates the potential uses of space photography in the observation of causes and distribution of polluted water.

FIGURE 18-26.—Northern half of Mexico.

During the Gemini XII standup extravehicular activity, a striking panoramic series of photographs was obtained showing the entire length of Mexico from Guatemala to Arizona. Figure 18-26 shows the northern half of Mexico including the cities of Monterrey, Reynosa, Chihuahua, and Ciudad Juarez. Features visible in the United States include White Sands

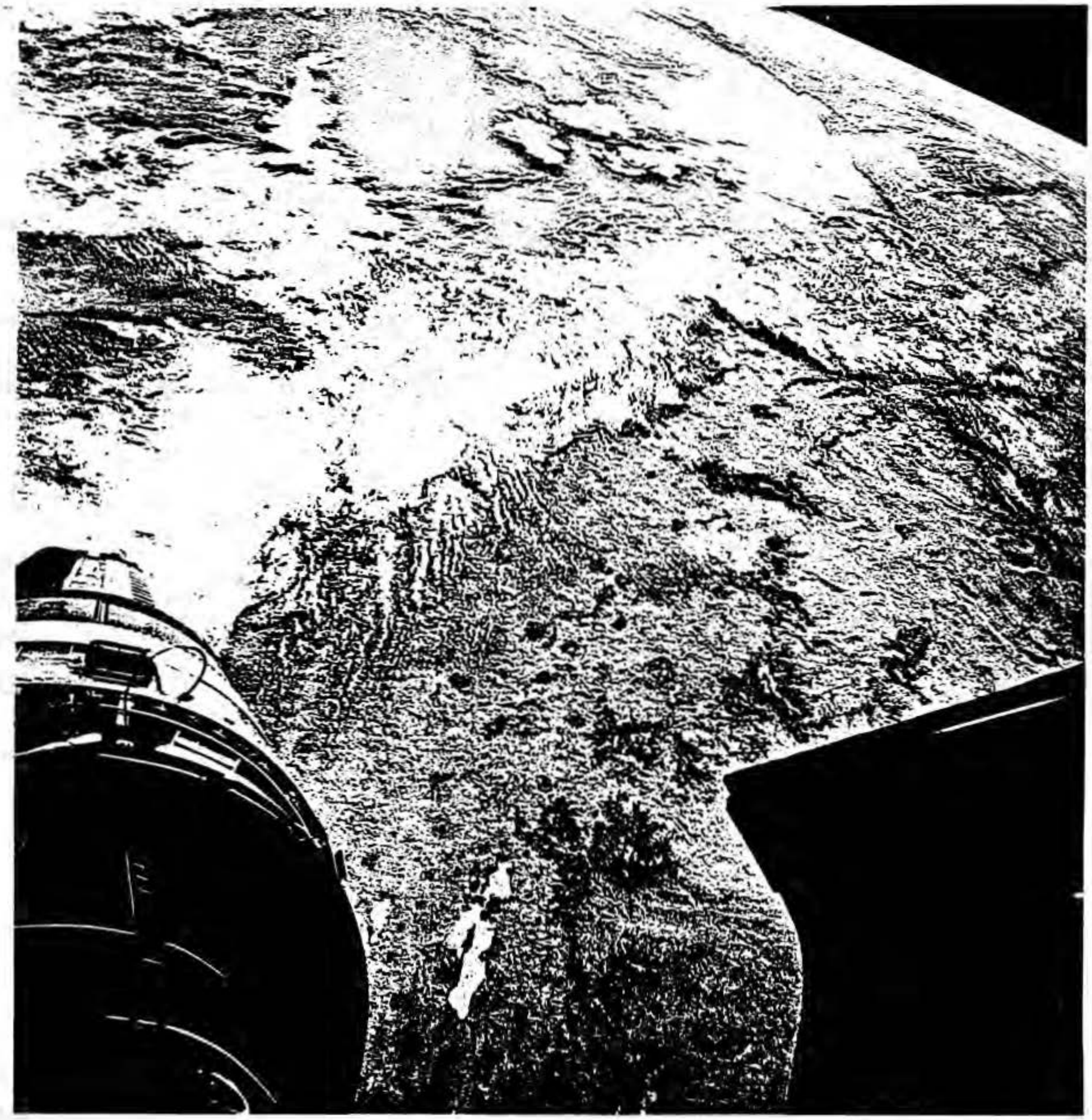

FIGURE 18–27.—Southern half of Mexico.

National Monument in New Mexico and Galveston Bay in Texas. Figure 18–27 taken a few seconds later shows the southeast half of the country including the Mexico City area (note the air pollution), the great snow-covered volcanoes such as Popocatepetl, the Isthmus of Tehuantepec, and the Yucatan Peninsula.

High-Apogee Photography

A series of superb photographs was taken by the Gemini XI flight crew while increasing the orbital altitude from 185 miles to a record 851 miles. Figure 18-28, taken approximately 200 miles above the Earth, shows a land area of almost 1 million square miles in the Sahara countries of Libya, United Arab Republic, Chad, Niger, Sudan, and Algeria. Clearly visible are the great sand deserts separated by mountains and escarpments of sedimentary or igneous origins. Two large volcanic areas, the Black Haruj and the Tibesti Mountains, are visible. The unique striations in rock and sand in the upper right demand more investigation by the geologist.

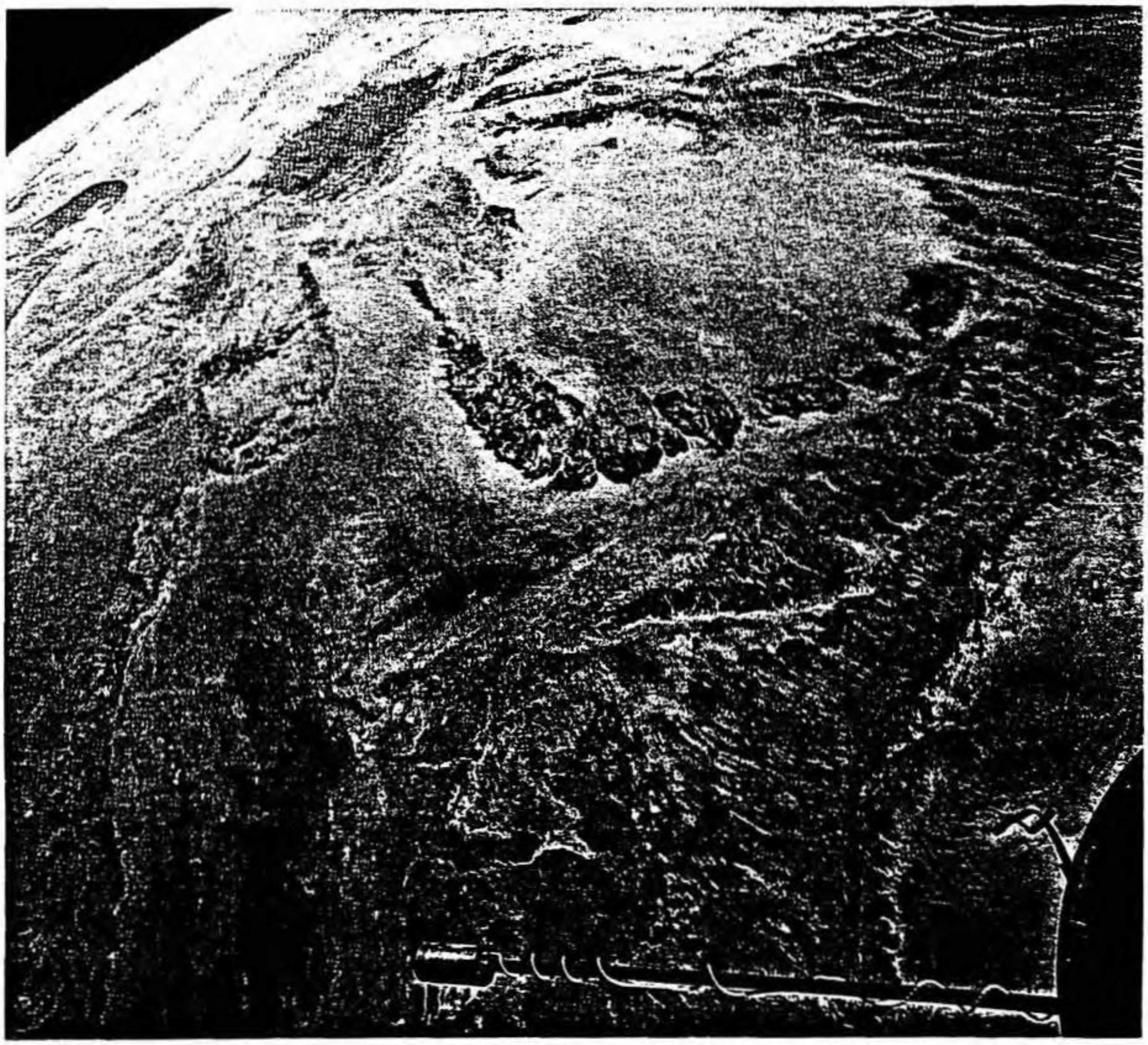

FIGURE 18-28.—Sahara area.

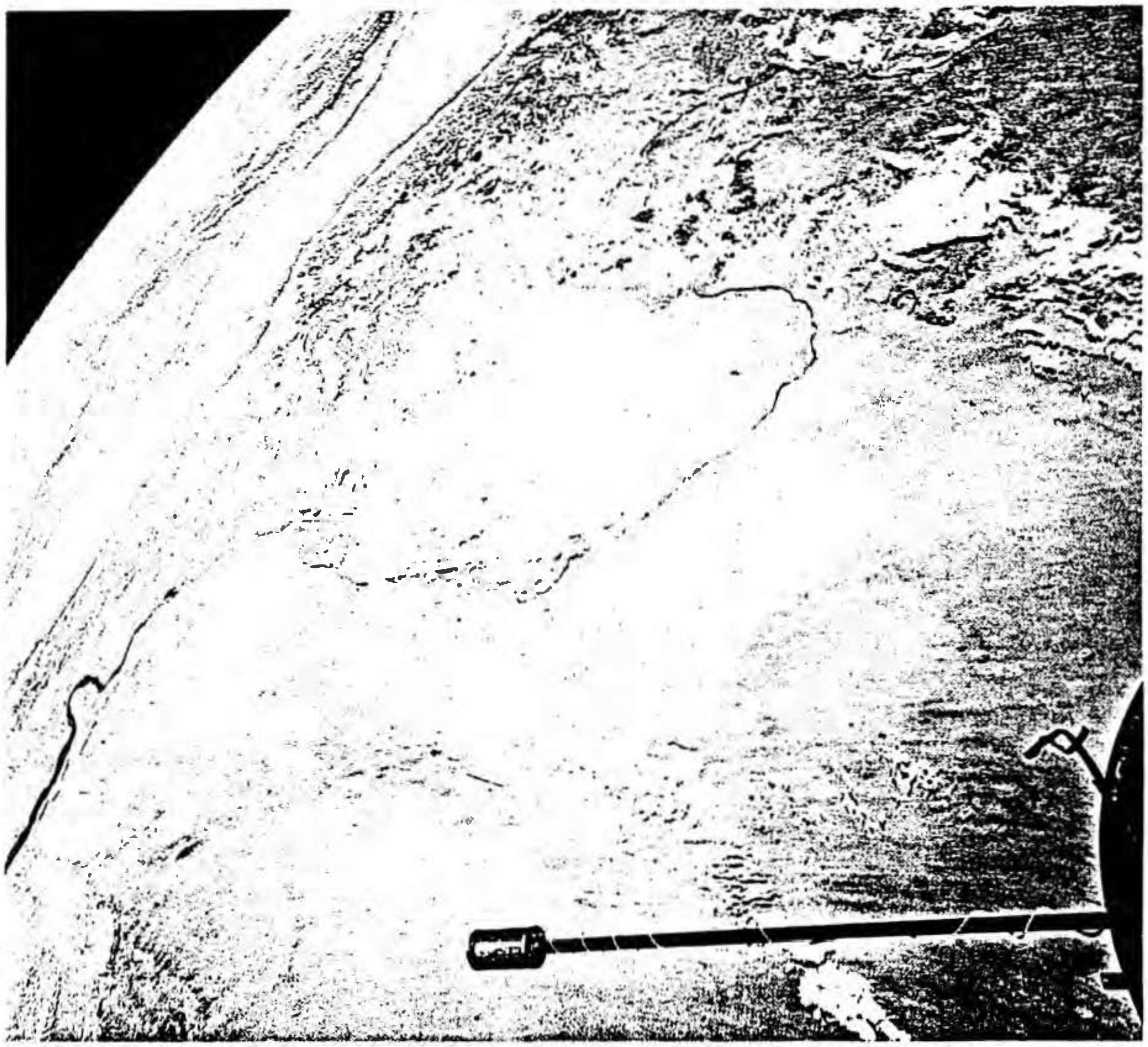

FIGURE 18-29.—Nile River.

Some 2 minutes later, the Gemini XI crew photographed approximately half of the 4200-mile-long Nile River (fig. 18–29). Taken from an altitude of about 220 miles, this synoptic view permits regional studies which cannot be accomplished by other means. The relationship of the world's longest river to the regional geology is clearly indicated from Bida (above Cairo) in the United Arab Republic southward to Kosti (above Khartoum) in the Sudan. The Red Sea and Arabia lie beyond.

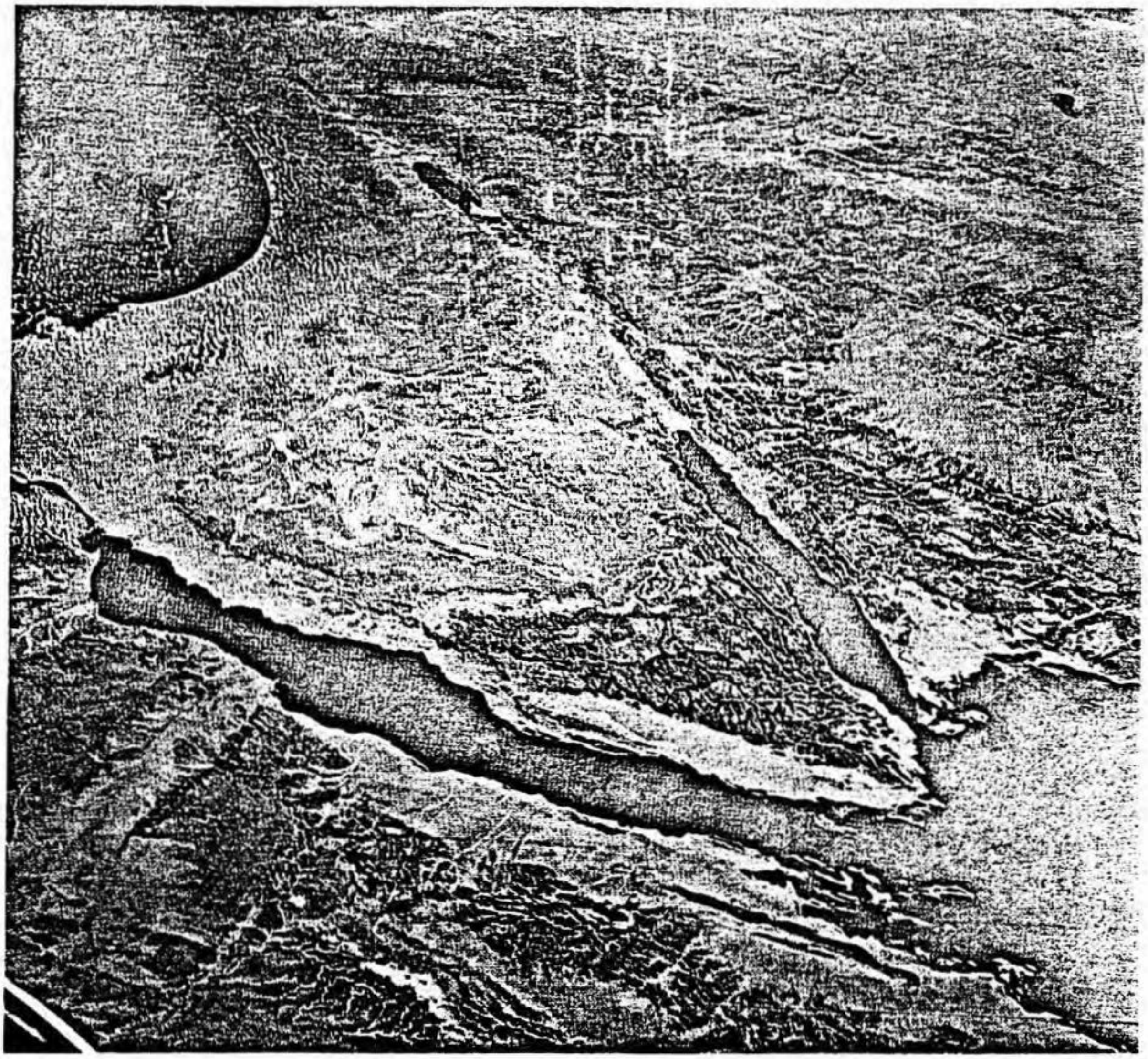

FIGURE 18–30.—Middle East.

Figure 18–30 was taken during Gemini XI from an altitude of about 200 miles, and shows all of Israel and Jordan and portions of Turkey, Lebanon, Syria, Iraq, Saudi Arabia, and the United Arab Republic. The capitals of Beirut, Damascus, Baghdad, Amman, and Jerusalem, as well as the Red Sea terminus of the Suez Canal, are visible. The entire Sinai Peninsula and such sub-sea-level lakes as the Dead Sea and Sea of Galilee are visible. A break in the Trans-Arabian pipeline occurred near Badanah, Saudi Arabia, shortly before the photograph was made, and the resulting fire, smoke, and shadow are recorded in the upper right.

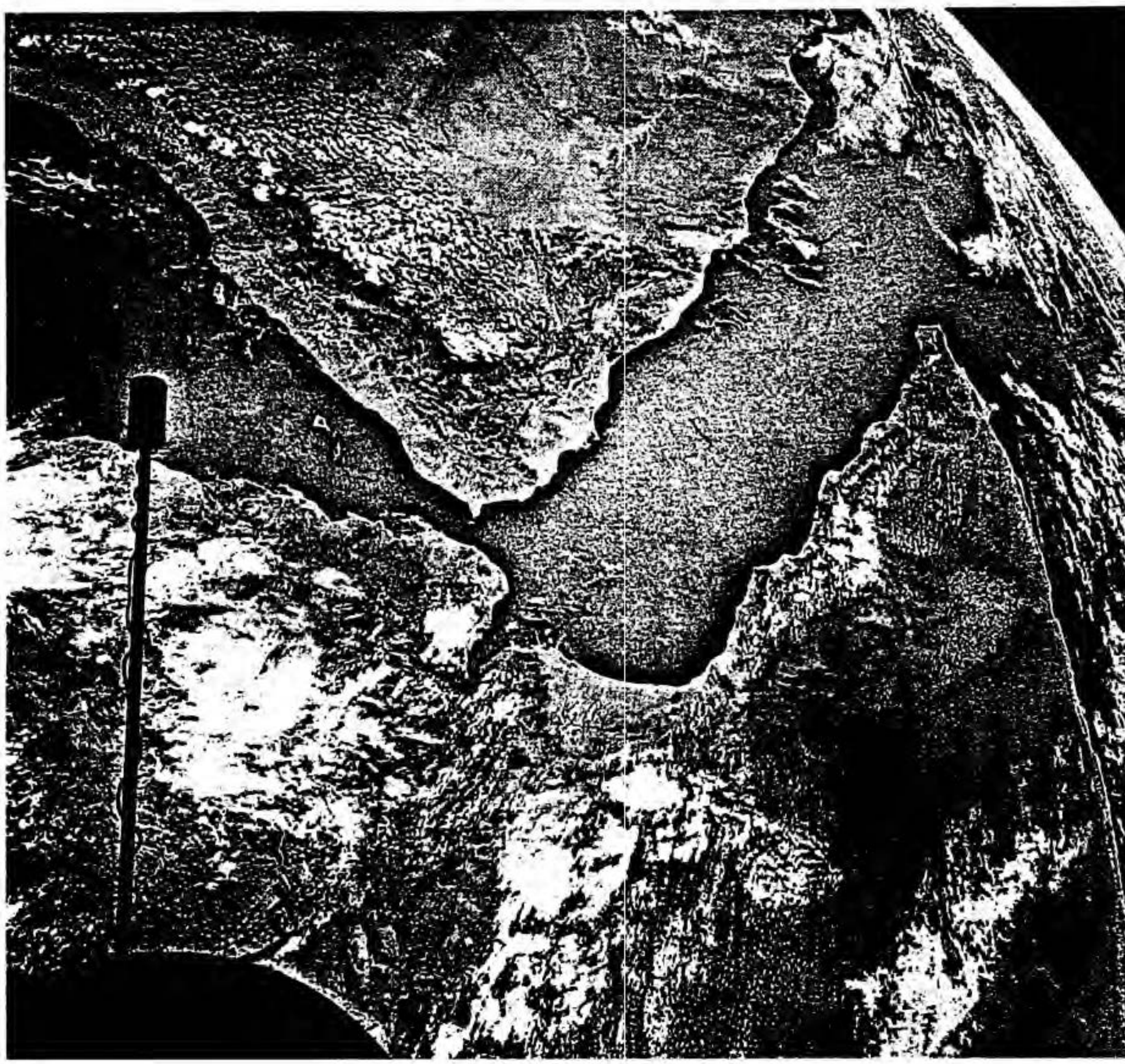

FIGURE 18-31.—Arabia-Somali.

From an altitude of about 410 miles, the Gemini XI crew photographed the junction of the Red Sea and the Gulf of Aden (fig. 18-31). Parts of Yemen, South Arabia Federation, Saudi Arabia, and the Muscat and Oman Sultanate are visible in the upper portions of the photograph, while parts of Somali, Ethiopia, and all of French Somaliland are in the foreground.

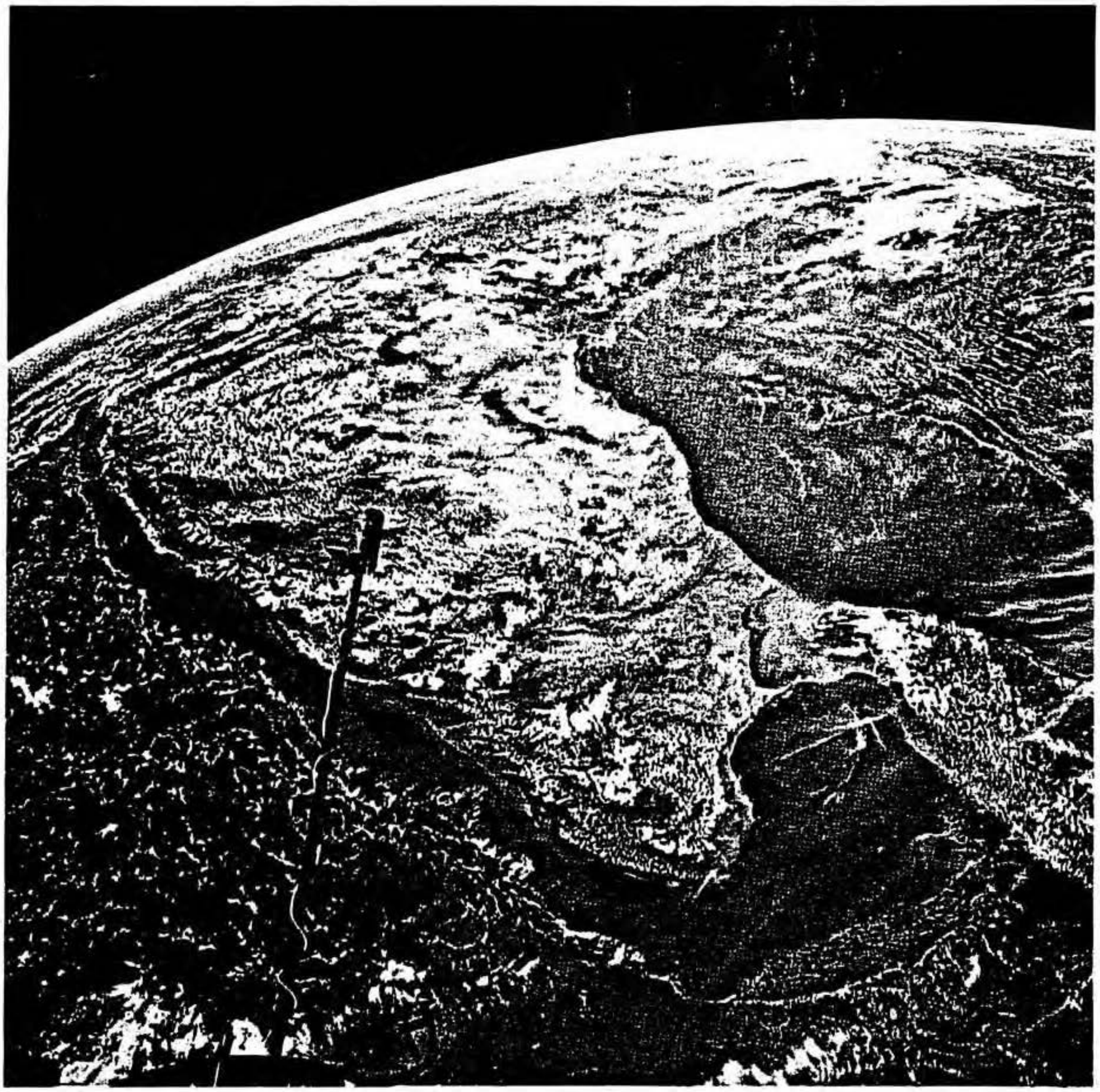

FIGURE 18-32.—India.

From an altitude of about 500 miles, the Gemini XI crew recorded a striking and beautiful view of the Indian subcontinent (fig. 18-32). The island of Ceylon is to the lower right. The climatic difference along the divide of the Western Ghats in India is clearly visible, with the lush jungle to the west and the semiarid regions to the east. Much valuable information is available concerning the meteorological conditions over such a vast area as the subcontinent and the adjacent Arabian Sea to the left and the Bay of Bengal to the right.

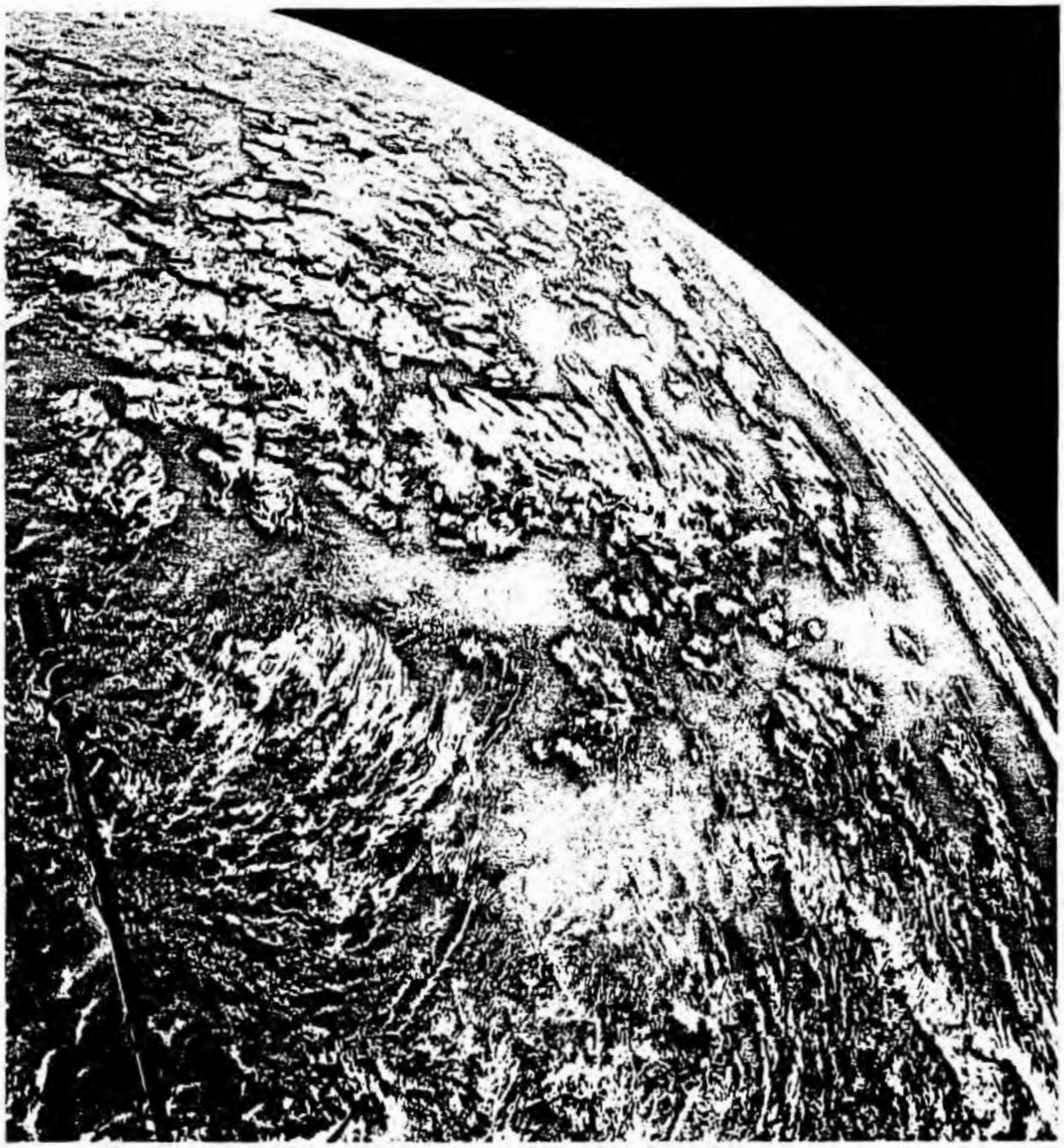

FIGURE 18–33.—Indonesia.

In figure 18–33, the cloud-covered Indonesian Islands were photographed during Gemini XI from about 740 miles above the Earth. The curved horizon is over 2000 miles to the east.

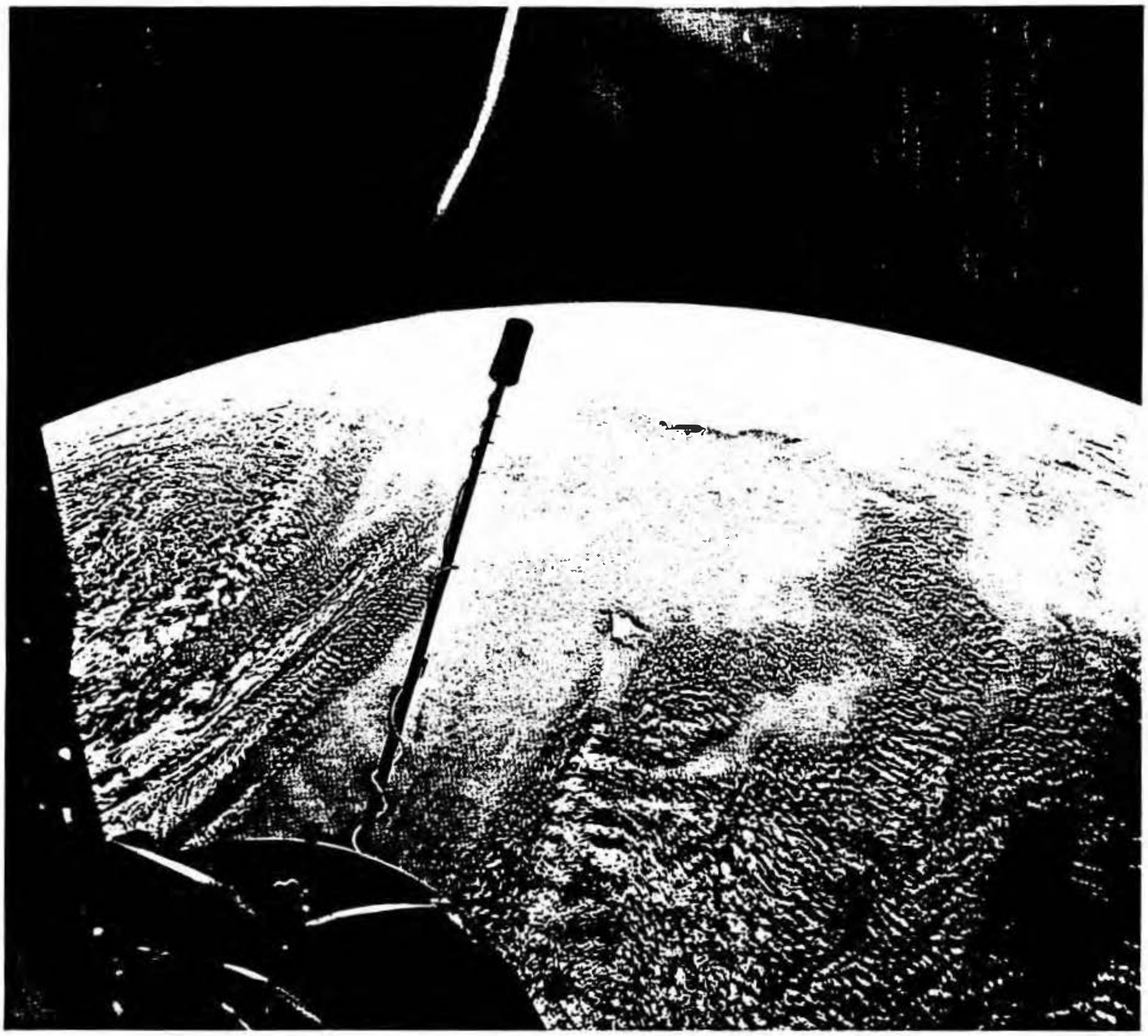

FIGURE 18-34.—Australia.

Figure 18–34 was taken while the Gemini XI spacecraft was 851 miles above the Earth, the highest altitude from which any photograph has been taken by man. The western half of Australia with the sunlit Indian Ocean beyond is visible. The horizon is nearly 3000 miles to the westward. The photograph was made near sunset, and ground detail is poor due to low light levels on the ground.

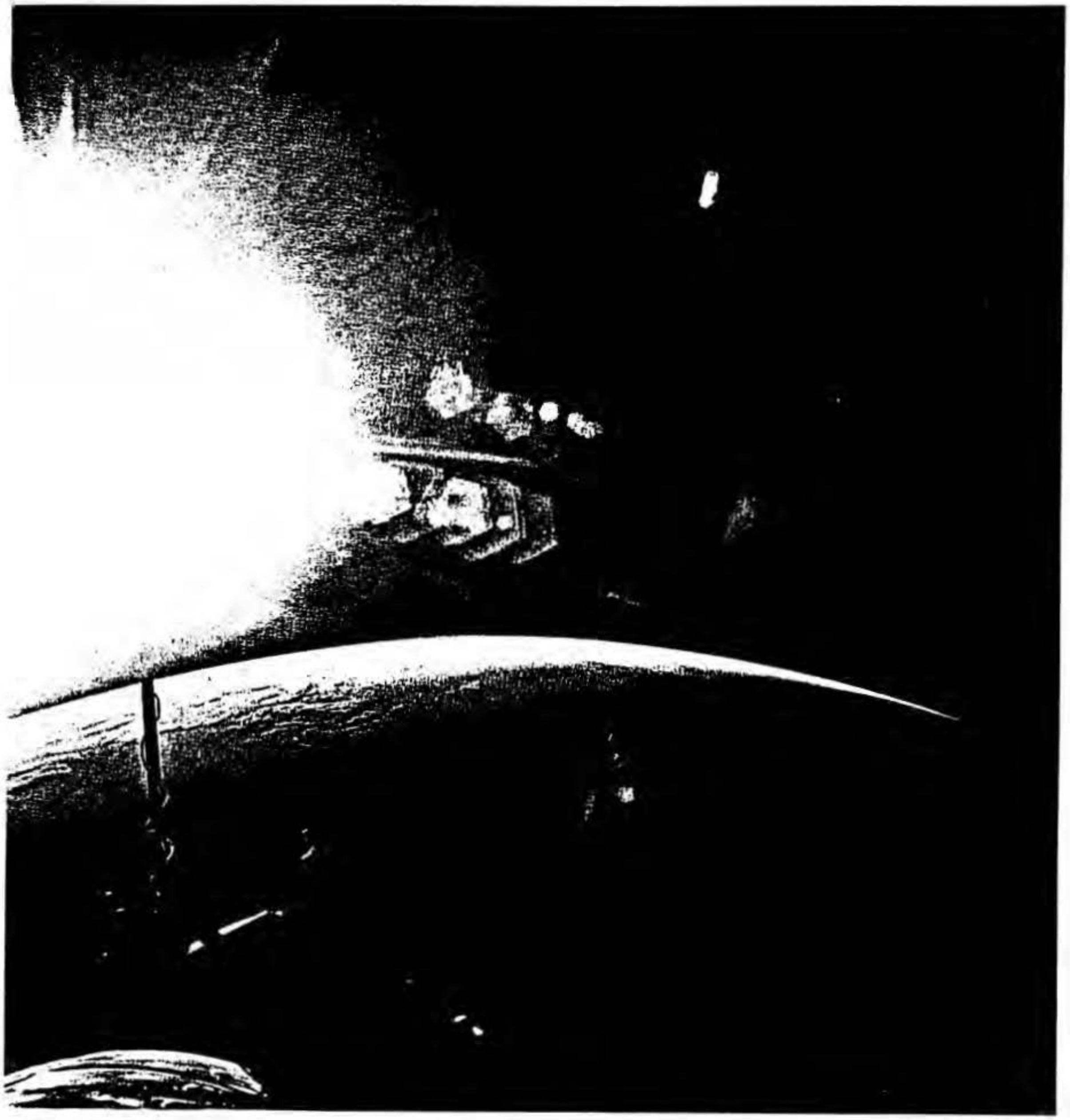

FIGURE 18–35.—Sunset.

The Gemini XI crew recorded the striking photograph of a sunset (fig. 18–35) from approximately 850 miles above the Earth. The sunset terminator is visible over 1000 miles to the west of the spacecraft and the Earth's limb about 3000 miles to the west. Due to the spacecraft altitude, however, the Sun is clearly visible well above the horizon.

Synoptic Weather Photography

The meteorologist has secured much valuable data from some 2000 Gemini photographs. The unmanned meteorological satellites are providing a great deal of valuable information and have been supplemented with the finer details and color of the photographs obtained from Gemini. The study of vortices is of particular importance in that the ultimate vortex may result in a destructive tornado, hurricane, or typhoon. Figure 18–36 was taken during the Gemini V mission, and shows the mile-high Mexican island of Guadalupe (200 miles off Baja California) interrupting the orderly flow of winds to create a bowed shockwave effect in the clouds to windward. Two vortices have developed to the lee of the island.

FIGURE 18–36.—Vortex off Mexico.

FIGURE 18-37.—Vortex off Morocco.

Figure 18–37 shows a very well developed vortex which has been caused by windshear at the coastal prominence of Ras Rhir in Morocco. The photograph clearly shows the eye of the vortex and the rotational effects on the periphery. This Gemini V photograph has become a classic example of the meteorological data which can be obtained from manned space-flight photography. It would be difficult to provide a machine with the ability to select and photograph phenomena of greatest value to the scientist.

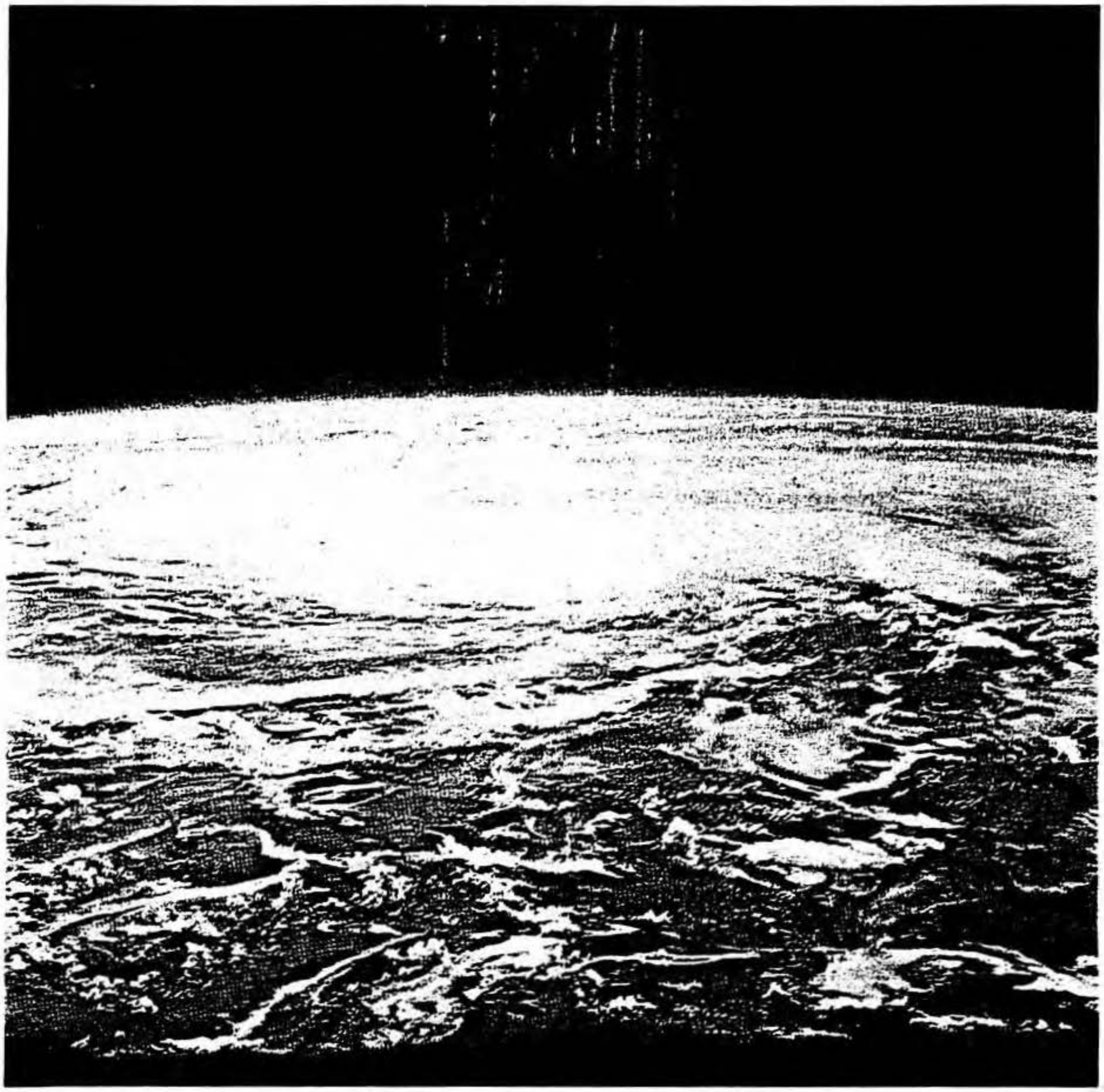

FIGURE 18-38.—Typhoon in Pacific Ocean.

A large mature typhoon moving across the central Pacific Ocean was photographed (fig. 18-38) by the Gemini V crew. The diameter of the system was approximately 400 miles and the circular motion can be distinguished in the photograph.

Near-Object Photography

Figure 18-39 is of great interest to the aerospace engineer, and shows the first Gemini extravehicular activity. The cloud background is over the Pacific Ocean between Hawaii and California. This is one of 16 photographs of the Gemini IV extravehicular activity, and is evidence that much can be learned not only of the pilot but also of the maneuvering unit, camera, space suit, and umbilical cord.

FIGURE 18-39.—First extravehicular activity.

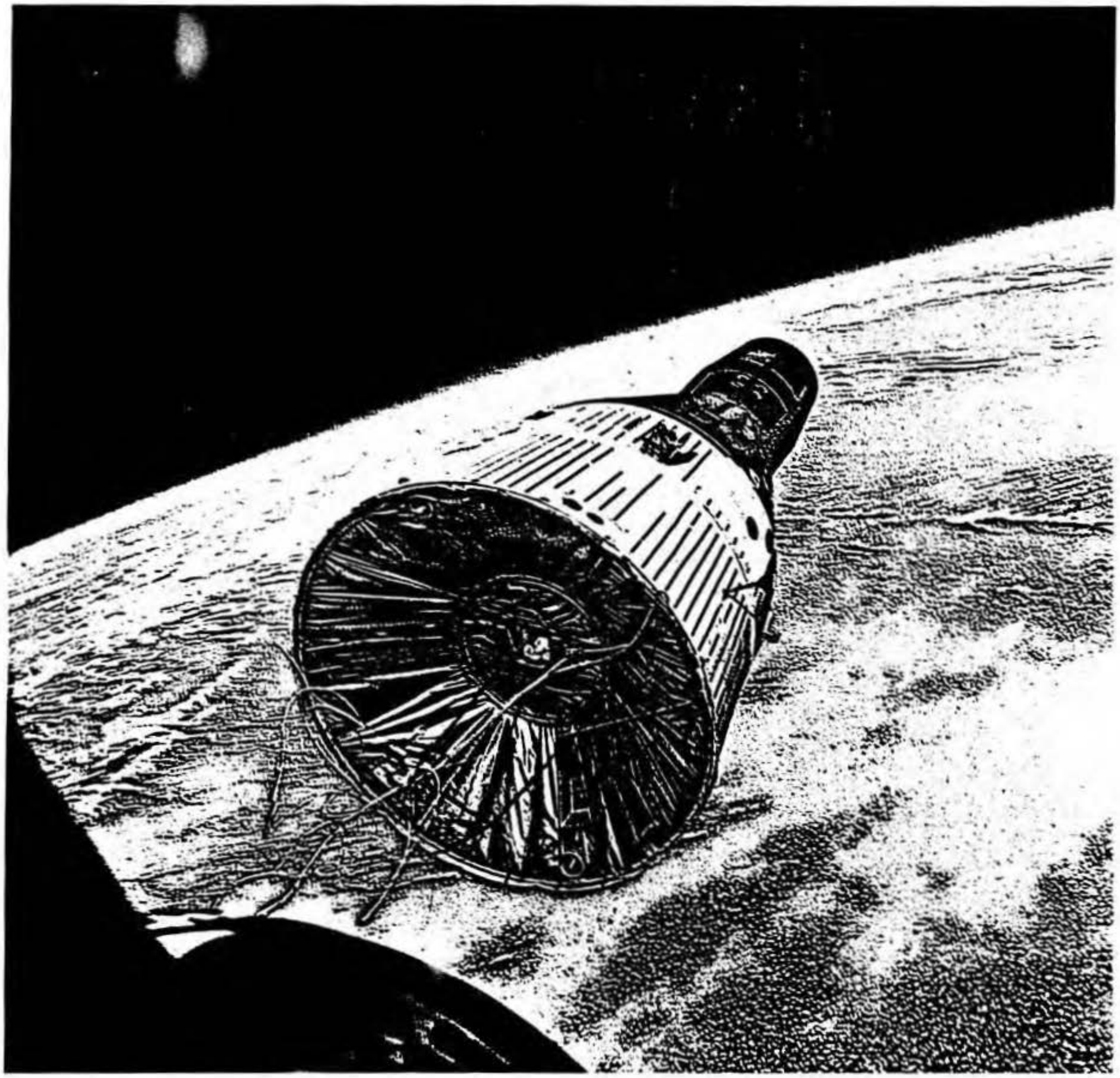

FIGURE 18–40.—Gemini VII from Gemini VI–A.

The historic first rendezvous of two manned space vehicles, Gemini VI–A and VII spacecraft, produced a series of 117 striking and informative still photographs and several hours of motion pictures. As the two vehicles moved through space some 185 miles above the Pacific Ocean, the Gemini VII spacecraft was photographed (fig. 18–40) from a distance of 20 feet by the Gemini VI–A flight crew.

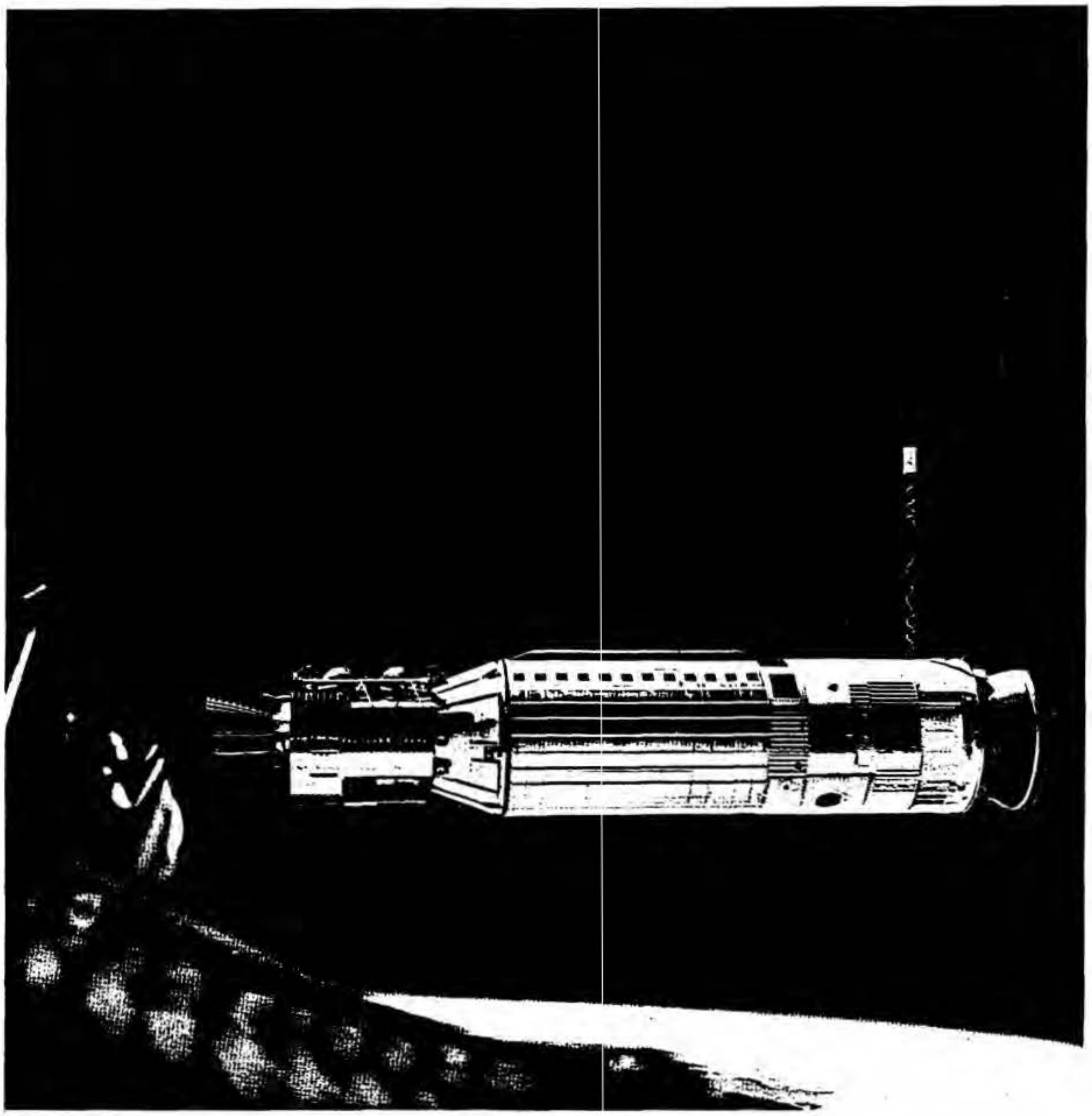

FIGURE 18–41.—Gemini VIII target vehicle.

Even though the Gemini VIII mission was terminated early due to a thruster malfunction, the aerospace engineering field has greatly benefited from the motion-picture and still photographic documentation of the first rendezvous and docking of a spacecraft with a target vehicle. In figure 18–41, the Gemini Agena Target Vehicle is approximately 50 feet from the spacecraft. This photograph was taken just prior to the docking maneuver and is one of a stereo pair which permits precise distance measurements. The motion-picture footage of the difficulties encountered at the time of undocking clearly illustrates the seriousness of the situation.

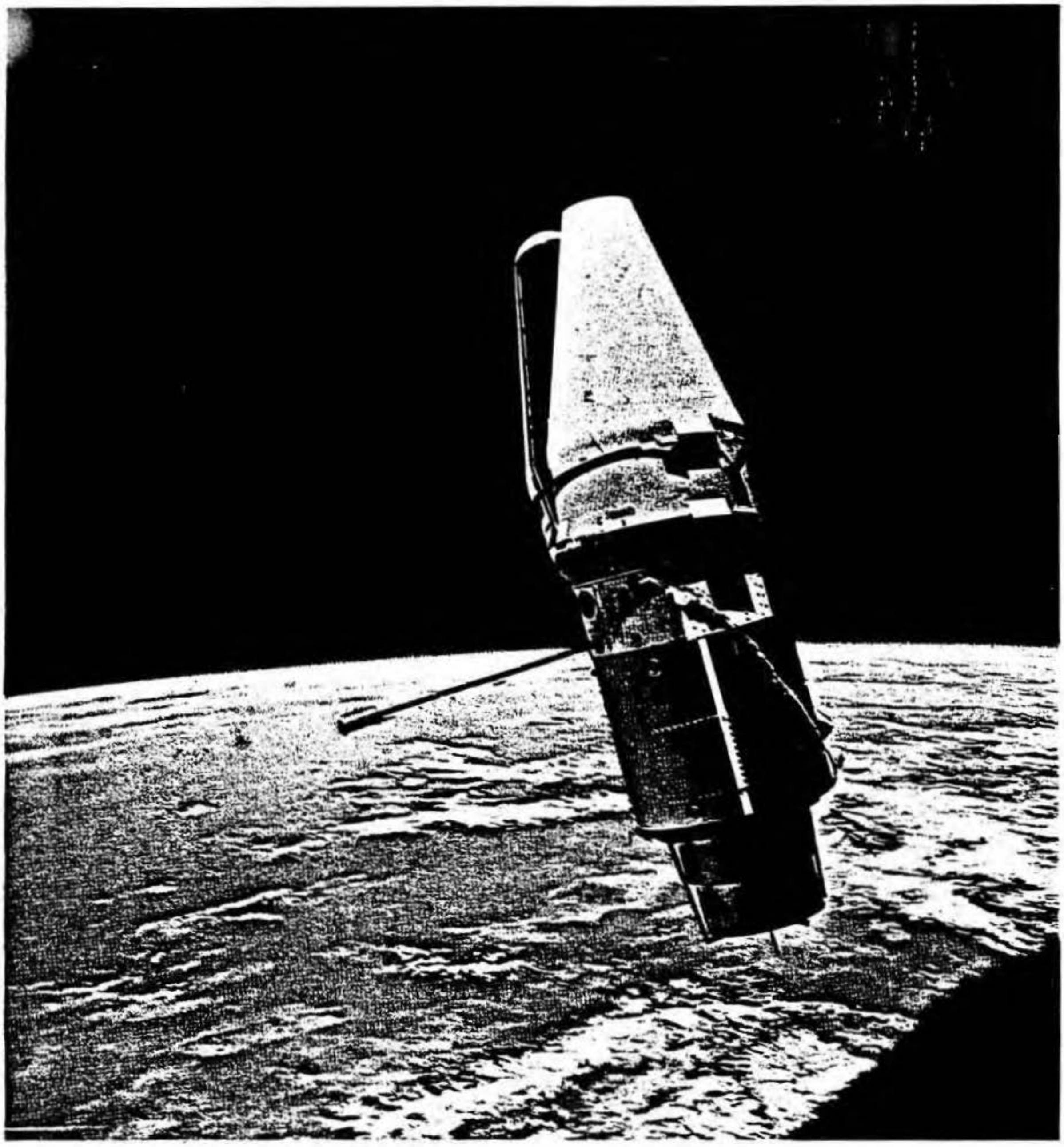

FIGURE 18–42.—Augmented Target Docking Adapter.

Figure 18–42 shows the Augmented Target Docking Adapter during one of three rendezvous accomplished by the Gemini IX–A crew. Docking could not be accomplished because the ascent shroud covering the docking adapter did not deploy after the vehicle was placed in orbit. The Gemini IX–A crew maneuvered the spacecraft to within inches of the Augmented Target Do ng Adapter and secured 109 excellent photographs of the rendezvous nd station-keeping activities. The ablative effect of launch heat on the shroud was photographed for the first time.

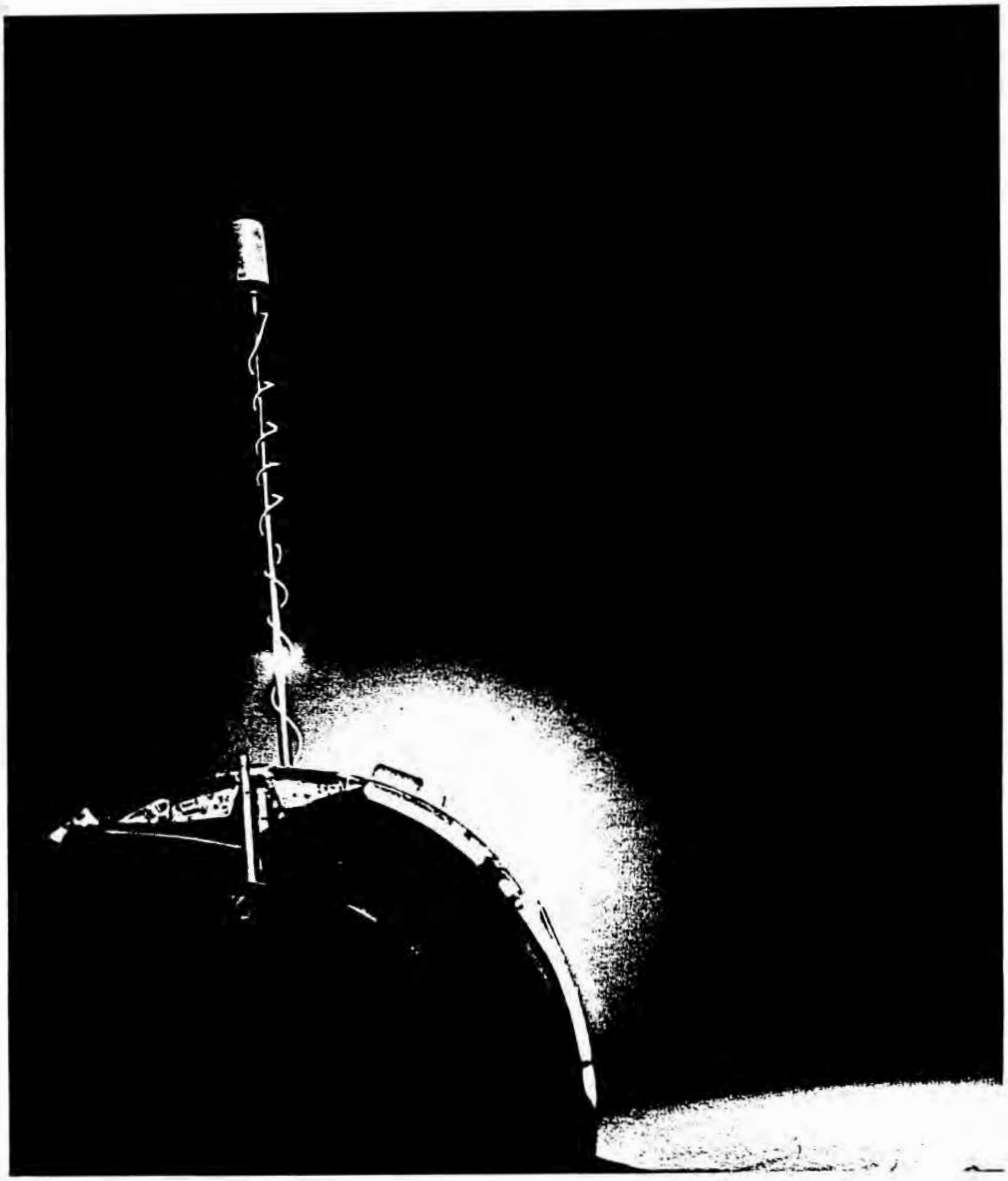

FIGURE 18–43.—Gemini X Primary Propulsion System firing.

Figure 18–43 is a photograph of the Gemini X spacecraft docked to the target vehicle with the target-vehicle status display panel and erected L-band antenna clearly visible. The glow around the target vehicle is caused by the firing operation of the Primary Propulsion System.

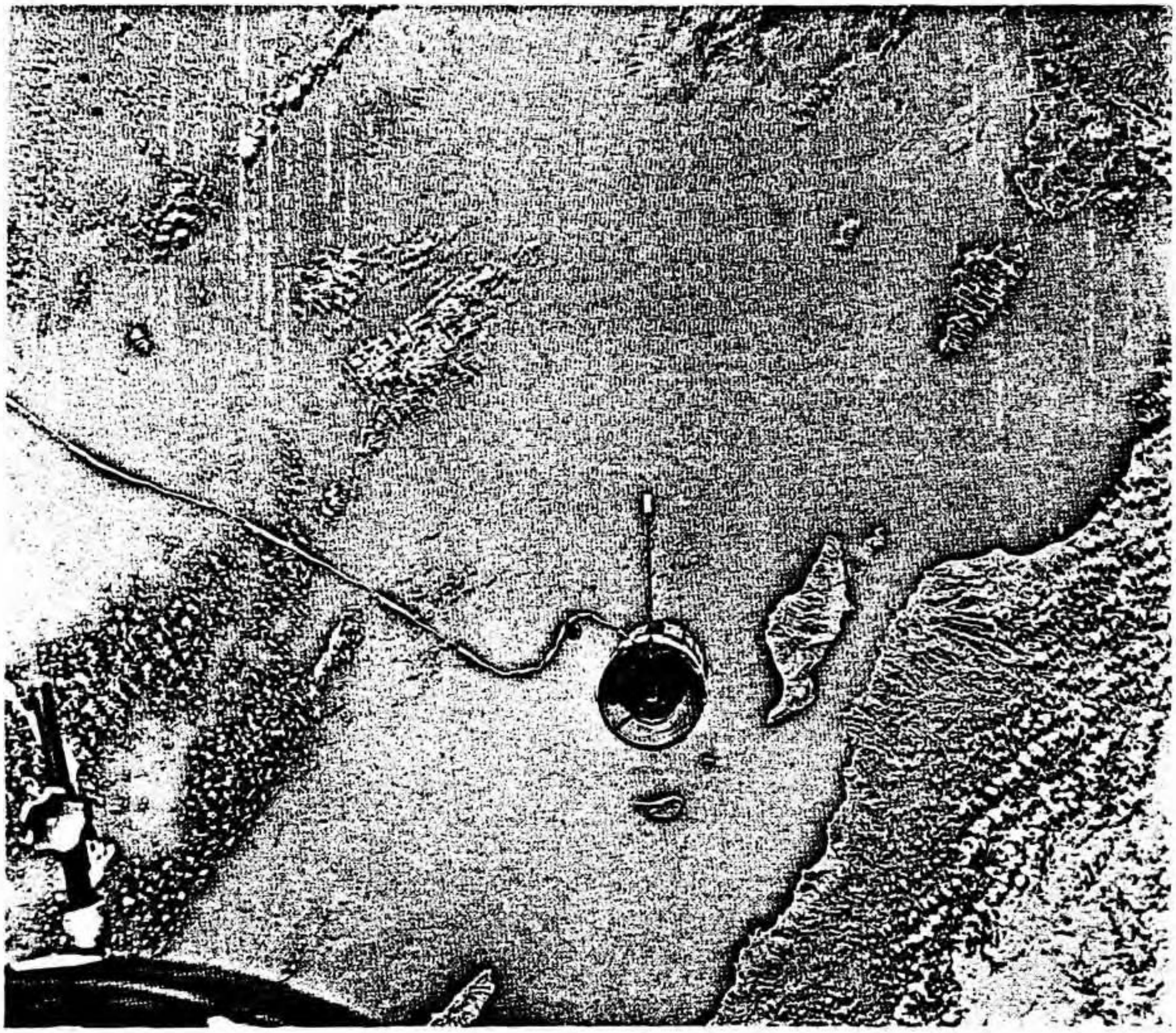

FIGURE 18-44.—Tethered target vehicle.

During the Gemini XI spacecraft/target-vehicle tether evaluation, a series of photographs was taken to show the exercise from the undocking and deployment of the tether until after the tether was jettisoned. Figure 18-44 was taken over Baja California at an altitude of about 185 miles and shows the target vehicle and the 100-foot Dacron tether.

FIGURE 18-45.—Extravehicular activity.

Figure 18-45 is one of a series of still and motion pictures taken of the Gemini XII extravehicular pilot working quite effectively while tethered to the target vehicle. This series of photographs demonstrates that man can do valuable and constructive work while extravehicular in space if the proper restraining devices are provided.

Concluding Remarks

The Gemini VII photograph of a distant full moon provides a fitting conclusion to a discussion of the photographic accomplishments of the Gemini Program (fig. 18–46). The 2400 exposures secured are all valuable, and a large number have provided information previously denied to the scientist. The two most important considerations furnished by this photographic record are found in the excellent historic documentation of the 10 manned missions, and in a clear demonstration of the feasibility of continuing with far more sophisticated photographic systems specifically designed to provide new and better information to the worldwide geo-scientific community.

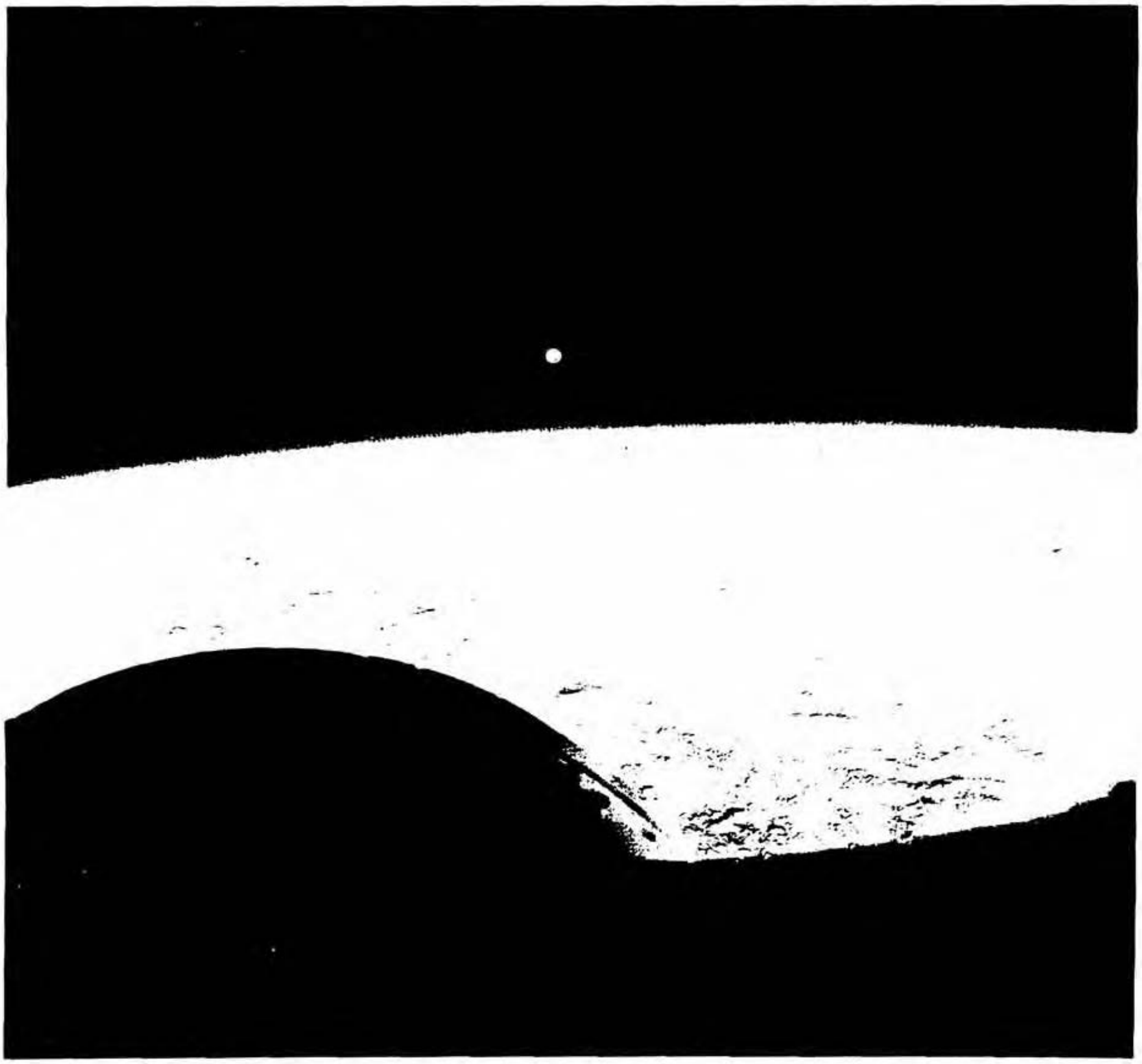

FIGURE 18–46.—Moon.

19. SCIENCE EXPERIMENTS SUMMARY

By JOCELYN R. GILL, *Office of Space Science and Applications, NASA; and* WILLIS B. FOSTER, *Director, Manned Flight Experiments, Office of Space Science and Applications, NASA*

Introduction

Results of the scientific experiments conducted during the Gemini Program through Gemini IX–A have been reported in a series of NASA publications (refs. 1 to 4) and in the scientific journals (refs. 5 to 7). This paper will therefore emphasize experiment results from the Gemini X, XI, and XII missions, but with some reference to results from earlier missions to emphasize the highlights of the program.

Gemini Science Experiments

Nineteen science experiments were flown during the Gemini Program (table 19–I). The table includes the principal investigators and their affiliations. The program was interdisciplinary in character, and was com-

TABLE 19–I.—*Gemini Science Experiments*

Number	Title	Principal investigator	Affiliation
S001	Zodiacal Light and Airglow Photography	E. P. Ney	University of Minnesota
S002	Sea-Urchin Egg Growth Under Zero-G	R. S. Young	NASA Ames
S003	Frog Egg Growth Under Zero-G	R. S. Young	NASA Ames
S004[a]	Synergistic Effect of Zero-G and Radiation on White Blood Cells.	M. A. Bender	Atomic Energy Commission, Oak Ridge National Laboratory.
S005	Synoptic Terrain Photography	P. D. Lowman	NASA Goddard
S006	Synoptic Weather Photography	K. Nagler	U.S. Weather Bureau
S007	Spectrophotography of Clouds	F. Saiedy	U.S. Weather Bureau and University of Maryland.
S008	Visual Acuity in the Space Environment.	S. Q. Duntley	University of California, Scripps Institute.
S009	Nuclear Emulsions	M. M. Shapiro and C. Fichtel.	Naval Research Laboratory and NASA Goddard
S010	Agena Micrometeorite Collection	C. Hemenway	Dudley Observatory
S011	Airglow Horizon Photography	M. J. Koomen	Naval Research Laboratory
S012	Gemini Micrometeorite Collection	C. Hemenway	Dudley Observatory
S013	Ultraviolet Astronomical Photography	K. G. Henize	Dearborn Observatory
S026	Gemini Ion Wake Measurement	D. Medved	Electro-Optical Systems
S028[b]	Dim Light Photography	L. Dunkelman	NASA Goddard
S029	Libration Regions Photography	E. Morris	U.S. Geological Survey
S030	Dim Sky Photography/Orthicon	E. P. Ney and C. Hemenway.	University of Minnesota and Dudley Observatory.
S051	Sodium Cloud Photography	J. Blamont	Centre National de la Recherche Scientifique.
S064[c]	Ultraviolet Dust Photography	C. Hemenway	Dudley Observatory

[a] White blood cells and neurospora on Gemini XII.
[b] Flown on Gemini VI–A and VII as an operational experiment only.
[c] Flown on Gemini XII as an operational experiment only.

prised of investigations in the fields of astronomy, biology, geology, meteorology, and physics. Over half of the experiments were photographic in technique, indicating that the investigators wished to take advantage of the flight crew being available to guide and select the targets and to return the film for permanent record. A photograph frequently clarified data which otherwise were ambiguous.

Table 19–II shows the flight assignments of the science experiments and indicates that they were concentrated in the last half of the Gemini Program. There were 16 experiments with a total of 34 flight assignments in the last five Gemini missions.

Terrain and Weather Photography Experiments

Experiment S005, Synoptic Terrain Photography.—Experiment S005, Synoptic Terrain Photography, was devoted to a study of the Earth terrain, and was successfully performed on the Gemini IV, V, VI–A, VII, IX–A, X, XI, and XII missions; numerous useful pictures were also taken during Gemini III. Approximately 1400 color pictures were obtained, and are usable for geology, geography, or oceanography.

One of the most useful photographs (fig. 19–1), taken by the Gemini IV flight crew, shows an area about 80 miles wide of northern Baja California, Mexico. The geologic structure of this mountainous region is shown with remarkable clarity. For example, the Agua Blanca fault is visible as the series of alined valleys at lower left in the photograph, parallel to the frame of the spacecraft window. Numerous other faults, similarly expressed, are visible north of the Agua Blanca fault. The great need for more geologic information of this area is suggested by the fact that the Agua Blanca fault, one of the most prominent geologic structures in Baja California, was not discovered until 1956.

TABLE 19–II.—*Flights of Gemini Science Experiments*[a]

Experiment	Gemini mission										Number of flights
	III	IV	V	VI–A	VII	VIII	IX–A	X	XI	XII	
S001			+			−	+	+			4
S002	−										1
S003						−				+	2
S004	+								+		2
S005		+	+	+	+			+	+	+	7
S006		+	+	+	+			+	+	+	7
S007			+			−					2
S008			+		+						2
S009						−			+		2
S010						+	+	+		−	4
S011							+		+	+	3
S012							+	−		−	3
S013								+	+	+	3
S026								+	+		2
S028				+	+						2
S029										−	1
S030									+		1
S051										−	1
S064										−	1
Total											50

[a] + indicates experiment was successful; — indicates experiment was incomplete.

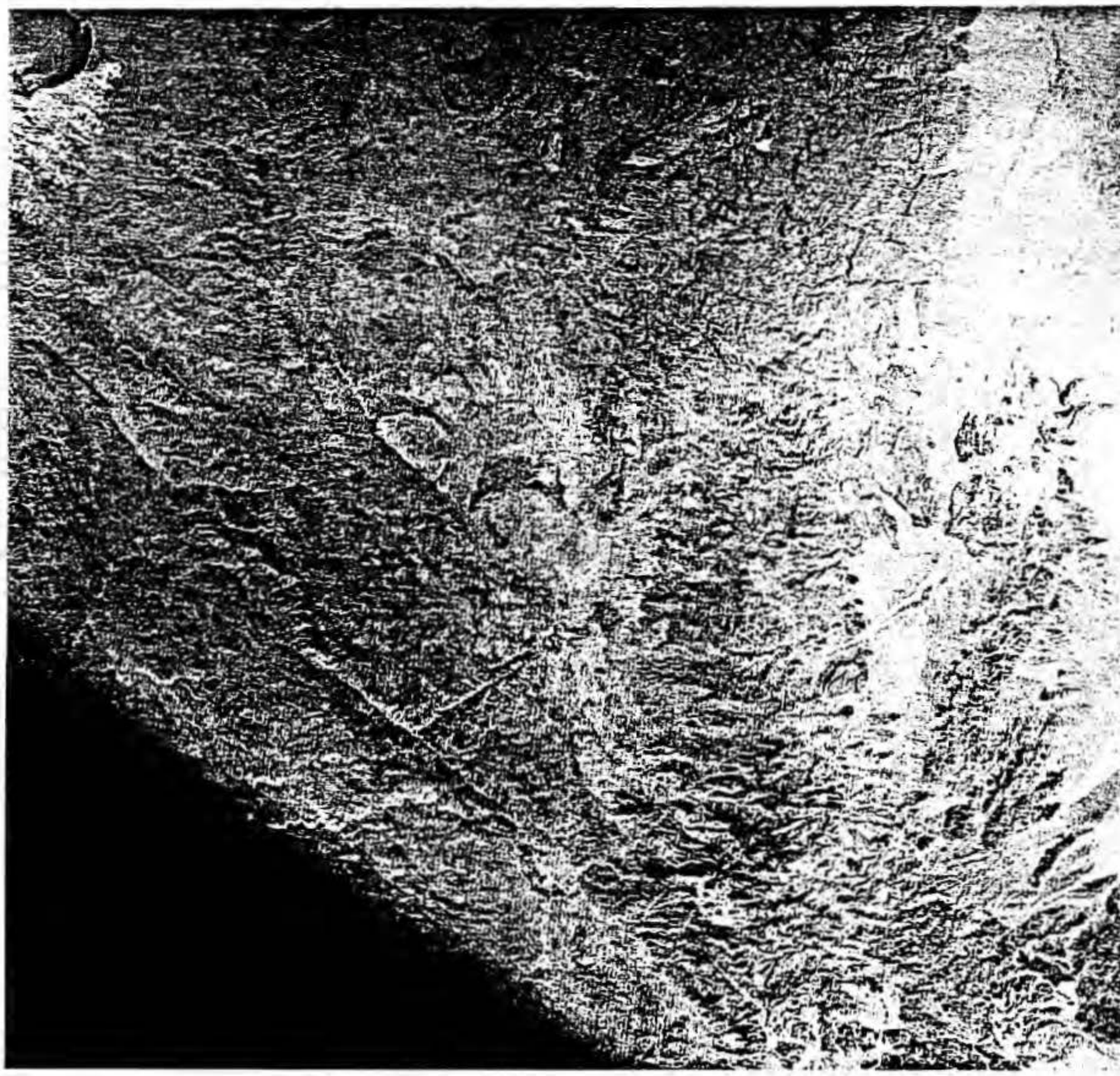

FIGURE 19-1.—Baja California.

One of the photographs (fig. 19-2) taken on Gemini XII appears to have considerable potential value in the study of continental drift. Proponents of this theory consider that the Red Sea, which structurally is a large graben or down-dropped block, represents incipient continental drift; that is, the Arabian Peninsula is considered to be drifting away from Africa and rotating. The photograph may provide new evidence on this possibility by providing a synoptic view of the regional geology.

Another Gemini XII photograph (fig. 19-3) demonstrates the potential value of orbital photography in studies of recent sedimentation. The portion of the Gulf of Mexico shown in the photograph has been extensively studied; and, when used in conjunction with the other photographs from space, may provide an extremely useful standard area for interpretation of similar pictures of other near-shore areas.

Experiment S006, Synoptic Weather Photography.—Figure 19-4 is a photograph

FIGURE 19–2.—Arabian Peninsula and the Red Sea.

taken during Experiment S006, Synoptic Weather Photography. The view is northwest over Camaguey Province, Cuba, and was taken August 23, 1965, by the Gemini V crew. A number of thunderstorms are visible along the southern coastline of Cuba. At the lower left of the photograph, some cumulus clouds off the northern coast appear to be

FIGURE 19–3.—Gulf of Mexico.

arranged in polygon-shaped, open cells. Several are hexagonal with taller cumulus clouds where the cell corners touch. The patterns illustrate a mesoscale cellular convection system that normally develops when relatively cool air passes over warmer water. Air is tending to sink within the cell and to rise near the borders where the cumulus clouds have formed. These open cells would be undetected by a standard satellite televi-

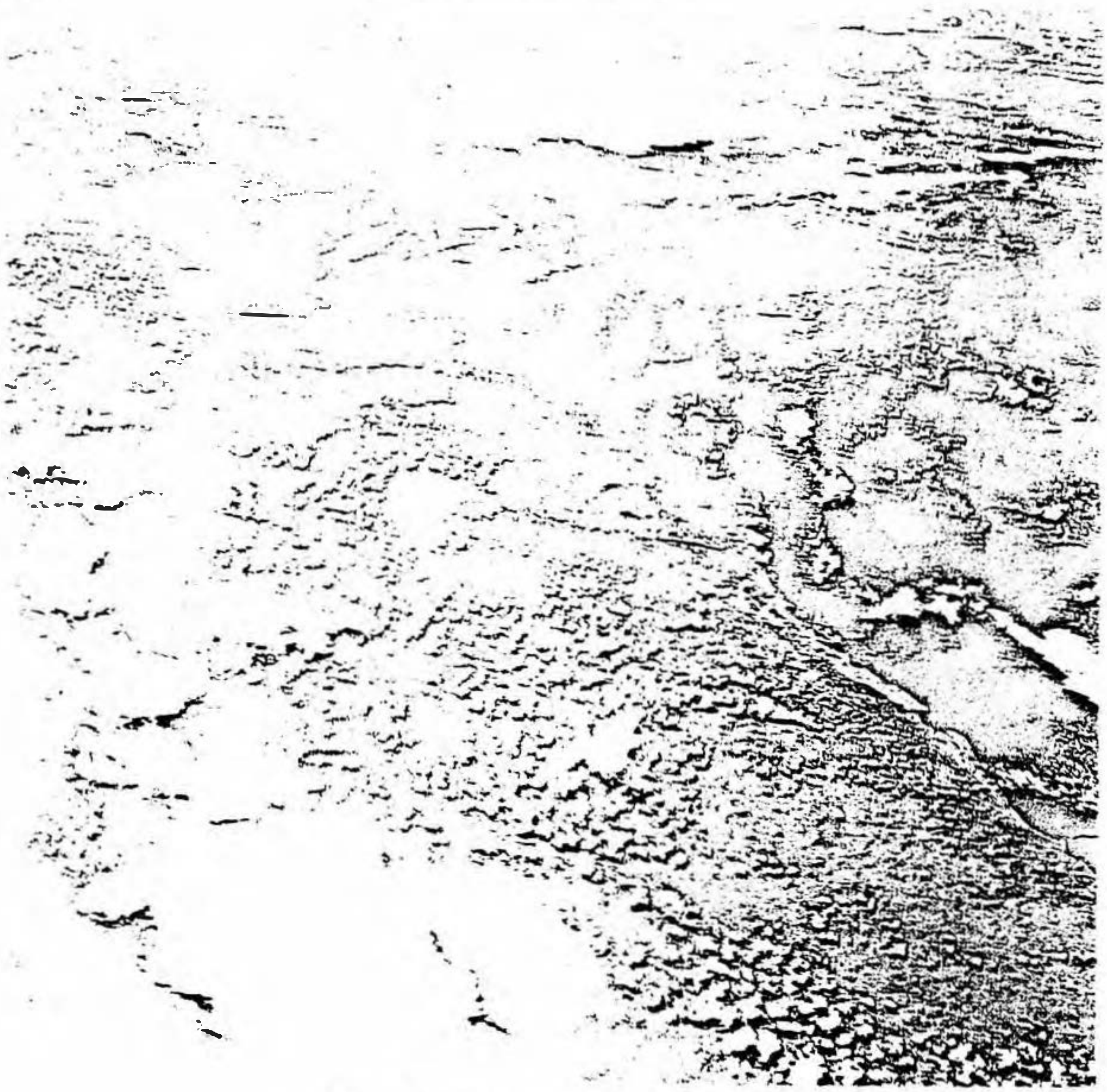

FIGURE 19-4.—Camaguey Province, Cuba.

sion picture because the cell walls are too thin, and the diameter is very small (ref. 8).

The photograph of southern India and Ceylon (fig. 19-5) was taken by the Gemini XI crew on September 14, 1966, with a super-wide-angle lens attached to a 70-mm still camera. A clear zone, nearly free of clouds, and varying from 30 to 50 miles in width, extends along the west coast of India. The zone continues around the southern tip of India and into the Bay of Bengal where a line of convective clouds has formed several hundred miles offshore. The reason for the clear region is not entirely understood, but two possibilities have been suggested. First, the lack of clouds may be the result of drier air subsiding offshore which would have the tendency to suppress any cloud development. The sea breeze, or low-level winds which move the air toward land, may have caused

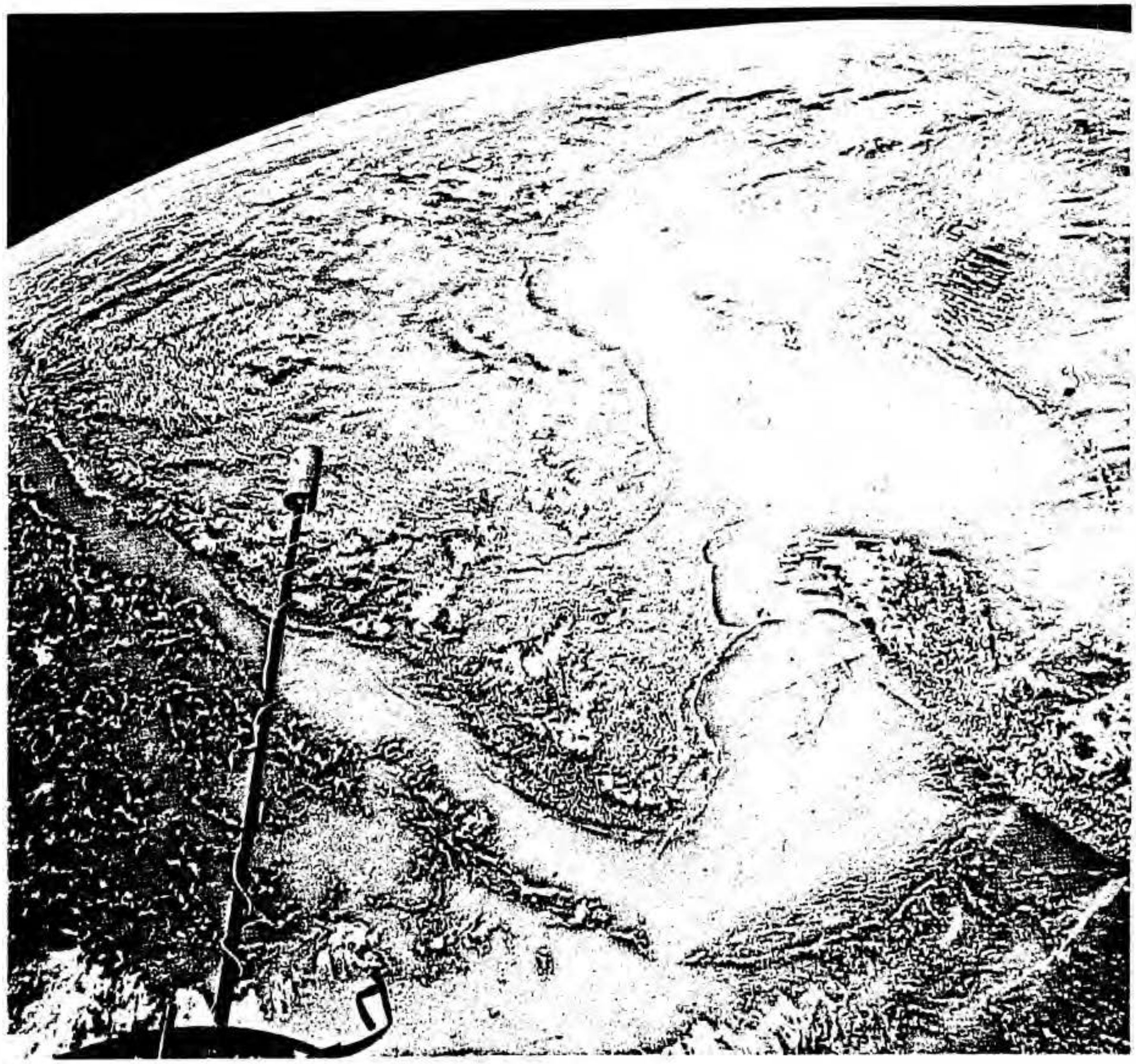

FIGURE 19–5.—India and Ceylon.

the air to descend in the clear region. Second, there may have been cold water welling up along the coast. Surface winds in India are northwesterly along the west coast and southwesterly along the east coast. The northwest winds will transport the surface water southeastward; however, the coriolis force will tend to deflect the water toward the southwest and away from the land. This would permit the welling up of cooler water along the coastline; also, the water temperature may have been sufficiently low to inhibit the development of cumulus clouds. A surface temperature change of about 1° may be enough to accomplish this. Southwest winds prevail to the east of India, and the coriolis force would act to transport the surface water in an easterly direction. Again, this would produce a favorable condition for water to well up near the coast. Measurements of seawater temperatures from ships are scarce, but the few available reports indicate that