X-644-71-359

PREPRINT

NASA TM X- 65682

GEOLOGIC USES OF EARTH-ORBITAL PHOTOGRAPHY

PAUL D. LOWMAN, JR.

AUGUST 1971

GSFC

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

X-644-71-359

GEOLOGIC USES OF EARTH-ORBITAL PHOTOGRAPHY

Paul D. Lowman, Jr.

August 1971

GODDARD SPACE FLIGHT CENTER

Greenbelt, Maryland

GEOLOGIC USES OF EARTH-ORBITAL PHOTOGRAPHY*

Paul D. Lowman, Jr.

Planetology Branch

ABSTRACT

This paper reviews the geologic applications of orbital photography, with four case histories of such applications to demonstrate its unique advantages. These case histories include discovery of unmapped faults in southern California, discovery of an unmapped volcanic field in northern Mexico, the finding of evidence that so-called Texas lineament is a broad zone of folding and dip-slip faulting, and the demonstration of the great importance of wind erosion as a land-sculpturing agent in North Africa. These examples show the advantages of orbital photography over aerial photography to be: (1) large area per picture, (2) adaptability to direct study of large areas by individual geologists, (3) coverage of areas inaccessible to aerial photography, (4) global coverage, and (5) availability and economy of color and multispectral coverage. Oribtal photographs can be used to check the accuracy of existing geologic maps, to compare the geology and geomorphology of widely separated areas, and to study specific geologic problems involving large areas. It is stressed that orbital photography is not simply high-altitude aerial photography, but essentially a new tool with new uses.

*Invited paper, XXII International Astronautical Congress, September, 1971, Brussels, Belgium

CONTENTS

INTRODUCTION

The earth is in many ways as mysterious as any body in the solar system. One of the most promising ways to explore the geology of this mysterious planet is through orbital photography, in much the same way as the moon and Mars have been explored. Several thousand pictures of the earth's surface have been taken from space since the end of World War II, and their geological uses are becoming fairly well-defined. The purpose of this paper is to review the geologic applications of earth orbital photography, with examples from various manned and unmanned missions.

HISTORY OF ORBITAL PHOTOGRAPHY

Photography of the earth from orbital altitudes began shortly after World War II, when photographs were taken by automatic cameras carried by V-2, Aerobee, and Viking sounding rockets. These have been reviewed by Lowman (1964). Despite the excellent quality of many of these (Fig. 1 - Viking), it was not until 1963 that a study of their geologic utility was published, by P. M. Merifield (1963). Shortly after, Morrison and Chown (1964) used the MA-4 Mercury photographs of North Africa in what is even today an outstanding piece of physical geography research. Merifield's work stimulated Lowman (1964) to propose synoptic terrain photography for the Mercury flights using hand-held cameras. A number of excellent pictures, chiefly of Tibet, were taken by the Mercury astronauts, leading to a similar terrain photography experiment for the Gemini flights. Because of the long duration of the Gemini missions and the availability of two men for in-flight experiments, the Synoptic Terrain Photography Experiment (S005) was extremely successful, with over 1100 photographs usable for geology, geography, or oceanography being returned. The experiment was summarized by Lowman and Tiedemann (1971).

Two terrain photography experiments were carried on the Apollo 7 and 9 missions. One was the same type of hand-held single camera photography (S005) that had been done on Gemini and Mercury missions, and was very successful, with several hundred high-quality color photographs (Fig. 2) being returned (Lowman, 1971 P3). The other was a multispectral terrain photography experiment (S065) in which four 70 mm cameras, each covering a different spectral region, were used (Lowman, 1969). This too was successful, returning over 350 usable pictures, and demonstrating the advantage of multispectral over single-camera orbital photography. The S065 experiment also provided vaulable experience in the acquisition and interpretation of multispectral photography that will prove useful in future earth resources satellites.

The unmanned Apollo 6 mission carried an automatic 70 mm camera that obtained a full revolution, minus dark areas, of high-quality color coverage, with overlapping vertical pictures. These have proven useful in a number of studies. Some geologic use has also been made of Nimbus and Tiros weather satellite images, but the low resolution of these systems makes them of interest chiefly for illustration of already-known geologic features (Fig. 3).

FOUR GEOLOGIC CASE HISTORIES

The geologic use of orbital photography can best be illustrated by presenting specific examples in which it has produced significant net geologic knowledge not previously uncovered by conventional methods (including aerial photography).

Structure of the Peninsular Ranges, California

The Peninsular Ranges of southern California are geologically the southern extension of the Sierra Nevada, consisting essentially of a block uplifted along faults on the east side and dipping westward into the Pacific Ocean. Lithologically they are also related to the Sierra Nevada in being composed largely of batholithic intrusions. Their regional setting is best shown by an Apollo 9 photograph (Fig. 4 - Ap. 9 oblique). Much of the Peninsular Ranges is in Baja California, whose remoteness is well-known, and for which the published geological mapping is of a reconaissance nature only. However, the northern end of these mountains is in southern California, within an hour's drive of several major colleges and universities. It would therefore be expected that the geology of this part of the Peninsular Ranges would be well-known. However, photographs taken as part of the S065 multispectral photography experiment on Apollo 9 have uncovered a number of unmapped faults and thrown new light on the relation of the Peninsular Ranges to the regional geology.

One of the best published pre-Apollo geologic maps of the Peninsular Ranges in San Diego County is presented in Figure 5 (Weber?). The predominance of northwest-trending wrench faults related to the San Andreas faults is apparent; examples include the San Jacinto and Elsinore faults. However, there are virtually no faults with a northeast trend in the block bounded by the Elsinore fault on the east. It was therefore a surprise to find, on the Apollo 9 photographs of this area, a number of northeast-trending lineaments (Fig. 6) several miles long. These lineaments are unusually straight valleys, for which structural control would be suspected. Field studies following the Apollo 9 mission has shown that some and possibly most of the lineaments are actually faults, which promote stream-erosion along their traces. Other lineaments are the expression of flow structure and metamorphic screens in igneous rock, metamorphic foliation, or joints, although the last-named are generally below the resolution of the photographs.

Orbital photographs of this area also promise to clarify the nature of movement on the well-known northwest-trending faults of the San Andreas system, in particular the Elsinore fault. Although there are no numerical estimates of the amount of displacement on the Elsinore fault, its association with the San Andreas would suggest several miles of right lateral movement. (Estimates of total displacement along the San Andreas are about 250 kilometers.)

Photographs taken from Gemini 5, Apollo 7, and Apollo 9 missions show clearly that several lineaments cross the Elsinore fault without major lateral displacement (Fig. 7 - Apollo 7 photo & map). One of these has been studied in some detail at its intersection with the Elsinore fault, and it has been found that the Elsinore fault must have an impossibly sinuous trace if it has had any appreciable lateral movement since the northeast trending fault was formed. The age of the latter is not known, but it is clearly great enough to show that the Elsinore fault is not moving laterally at anything like the one to five centimeters per year rate of the San Andreas fault. It is quite possible, judging from the photographs and the admittedly rapid field studies made to date, that the Elsinore fault is of primarily a dip-slip nature. Should this be proven, it would suggest re-examination of theories involving hundreds of kilometers of movement on the San Andreas system, and, more generally, of theories of continental drift depending on such movement.

Palomas Volcanic Field, Chihuahua

The Gemini 4 astronauts J. A. McDivitt and E. H. White, II, obtained a remarkably complete and cloud-free series of 39 overlapping pictures from Baja California to central Texas (Lowman, McDivitt, and White, 1967). Preliminary comparison of the photographs (8, 9) with published geologic maps showed what appeared to be an unmapped relatively young volcanic field in northern Chihuahua over 14 kilometers wide, with a large number of volcanoes. Further search of the Mexican and American literature revealed no mention of such a volcanic field. Accordingly, a short field reconaissance was made by the author and H. A. Tiedemann in 1967.

It was found that the feature is indeed a volcanic field with over thirty individual volcanoes. Its age appears to be on the order of several score thousand years (Lowman and Tiedemann, 1971), judging from the degree of erosion of cones and flows; there were no signs of activity. The only volcanic rock type found was a uniform olivine basalt very similar to, and doubtless related to, scattered vents and flows just to the north, in Luna County, New Mexico.

The Palomas volcanic field has no obvious geologic importance by itself, being but one of many such Quaternary volcanic features in the southwest United States and northern Mexico. However, its "discovery" in an easily-accessible area only two hours' drive from Ciudad Juarez and El Paso was an early demonstration of the use of orbital photography in correcting regional geologic maps. The vaule of such photography in initial mapping of remote areas is also strongly implied.

The Texas Lineament

The Texas lineament is a hypothetical linear structure of sub-continental extent, extending northwest from west Texas through New Mexico, Arizona, and possibly California. It has been proposed, by various geologists since 1902, to control ore deposits, topography, ground water, and other geologic features in the southwest United States and northern Mexico. Several tectonic syntheses, reviewed by Lowman and Tiedemann (1971), have considered the lineament to be a transverse fracture zone of continental or even inter-continental significance. On the other hand, several geologists intimately familiar with the geology of the southwest United States, including the type locality 150 kilometers southeast of El Paso, completely ignore the lineament in their published reports on this area. Thus we see that while many geologists consider this structure to dominate the regional geology, others do not even think it exists.

A key area for the understanding of the Texas lineament problem is the southwest corner of New Mexico, since all treatments of the problem consider it to go through there. This area has been repeatedly photographed from sounding rockets and spacecraft, and the author and H. A. Tiedemann have therefore examined these photographs in some detail. An Apollo 9 oblique gives a good regional view (Fig. 10).

The results of this examination and related field checks can not be presented here, but can be summarized as follows. First, it seems clear that no single fault goes through El Paso-Juarez to the northwest in the required direction; there is no hint of a fault trace, no alignment of Quaternary volcanoes in the necessary direction, and no major structural discordance between the Sierra Juarez and Franklin Mountains. Second, there is a broad zone of folding and dip-slip faulting in the N 60°W direction in southwest New Mexico, northern Mexico, and southeast Arizona, which grades into the structural continuation of the Sierra Madre Oriental in northern Chihuahua. This is shown in Figures 8 and 9 (GT-4 & structural sketch). Finally, the zone commonly referred to as the Texas lineament is not a zone of transverse faulting, but one reflecting the extent of the former Mexican geosyncline, at least in the area discussed here.

If this interpretation is correct, it has definite economic implications. For example, there would be little point in basing mineral exploration in west Texas on the supposed Texas lineament, since the original structure can be shown to be a minor structure satellitic to the Sierra Madre Oriental. More generally, a better understanding of the problem can hardly fail to help in the application of tectonics to economic geology in this area.

Wind Erosion in Deserts

The importance of wind as a desert erosional agent is controversial, although the existence of this controversy is not obvious unless one examines many geology texts. One then finds that some geologists, such as Thornbury (1954), consider wind erosion relatively unimportant, while others, such as Holmes (1965), hold the opposite view. American geologists in general consider desert erosional landforms to be almost entirely the work of running water, rather than of wind erosion.

Orbital photographs have thrown considerable light on the question, since the combination of low-inclination orbits and generally good weather in dry areas has permitted the accumulation of hundreds of excellent pictures of the world's great deserts. Study of these pictures has shown that wind erosion, by deflation and abrasion, has been a major though not necessarily the dominant land-sculpturing agent in north Africa and parts of the Middle East. In Figure 11 (Tanezrouft) for example, we see an area of several throusand square kilometers in which most visible landforms are the result of deflation (removal of fine-grained material by wind). In Iran, (Fig. 12), a Gemini 5 picture has shown an immense field of yardangs - ridges and grooves formed by wind erosion in the soft sediments of the Dasht-i-Lut (salt desert). Numerous other examples of north African landforms produced chiefly by wind erosion have been found on the Gemini and Apollo photographs (see Lowman and Tiedemann, 1971).

On the other hand, it seems equally clear, from orbital photographs, that most of the erosion in North American deserts is the result of running water, not wind. The reason for this difference between North American and African deserts can be illustrated with still another space photograph, this one taken from the Apollo 11 spacecraft shortly after trans-lunar injection at an altitude of several thousand kilometers (Fig. 13 - poster). Study of this picture shows that most North American deserts are part of the Basin and Range physiographic province, which consists largely of north-south trending fault block mountains. These are transverse to the prevailing winds, and thus the North American deserts are not subject to winds that can blow for hundreds of miles without obstruction, as in North Africa, which has only a few isolated massifs (Fig. 14 - poster zond 5 & sketch). The North American deserts, furthermore, receive considerably more moisture than does North Africa, as shown by the heavier vegetation along mountain trends.

Space photography, then, shows that the deserts of North America and North Africa are fundamentally different in tectonic structure and physiography, and that the relative unimportance of wind erosion in North America must not be extrapolated to the world's deserts as a group.

ADVANTAGES OF ORBITAL PHOTOGRAPHY IN GEOLOGY

The fore-going examples permit a summary of the advantages orbital photography offers the geologists. For a more general comparison of orbital and aerial photography, see Lowman (1969).

Large Area Per Picture

A single photograph from orbital altitude covers several thousand square kilometers or, from deep space, an entire continent, with usable resolution, and in color or with multispectral arrays. This is of course the most striking characteristic of space photography, and can not be duplicated by mosaics of aerial photography for several reasons. Color mosaics are impractical to produce; stereoscopic coverage is not provided by mosaics; dodging causes loss of tonal detail; constant sun angle over large areas is not provided; and mosaic coverage of large areas with similar film and scale is generally not available.

Personal Study of Large Areas

Important geologic structures, such as the Elsinore fault, are frequently so large that they can not be studied directly by individual geologists unless these geologists can devote several decades to the task. This is why the great syntheses of terrestrial geology are generally the work of men on the verge of retirement or death. Orbital photography, however, promises to remedy this unhappy situation. The large area per picture, just discussed, permits the geologist to actually see the entire length of, for example, the Elsinore fault at a glance; he can then map it, on photographs, as a whole in a relatively short time. Furthermore, the orbital photographs may show just what critical areas should be investigated in the field, thus sparing the geologist time-consuming (though enjoyable) mile-by-mile mapping on the ground.

Orbital photography, in summary, permits the direct personal investigation of extremely large structures or areas in a reasonably short time, providing continuity of thought and effort impossible with conventional methods.

Coverage of Inaccessible Areas

Darwin's observations during his world-circling voyage on H. M. S. Beagle transformed the sciences of biology and geology. And although Darwin was later to call on domestic pigeons for a proof of organic evolution, his key bird observations were made in the remote Galapagos Islands. It is often thus in geology, and orbital photography therefore presents a unique advantage by providing coverage of parts of the earth which are inaccessible for one reason or another, and which can neither be visited nor photographed from the air. The Apollo 7 photograph presented in Figure 15 (poster), for example, covers a part of Tibet so poorly mapped that positive identification of several lakes scores of kilometers long was not possible. Yet the area is of great geologic interest, since it may throw light on the theory that the Himalayas are the result of a continental collision (between India and Asia). Earth-circling spacecraft may permit any geologist to make his own "Voyage of the Beagle," and to see such critical but remote areas.

World-Wide Coverage

Related to, but not synonomous with, the coverage of inaccessible areas just discussed is the global photographic coverage possible from earth-orbiting vehicles. Provincialism has long been a weakness of geology, and stems at least partly from the simple fact that the earth is simply too big and too poorly-mapped for a valid global treatment of geologic problems. However, orbital photography reveals previously-unknown relationships, such as fact that the familiar Basin and Range province of North America (Fig. 13), is a tectonic freak. Nowhere else on earth is there such a broad region of block faulting, which appears to result from the intersection of the continent by the unusually broad East Pacific Rise. Furthermore, the south-central part of the North American Cordillera is now seen to be a tectonic montage in which the structures produced by block-faulting are superimposed on the earlier folded structures formed in the usual geosyncline-orogeny process.

Similarly, orbital photography will emphasize to every geologist facts which he may know but overlook. For example, the Ural Mountains have been ascribed by Hamilton (1970) to a continental collision between the European and Siberian cratonic blocks. Hamilton's evidence for this theory is impressive; but one familiar with orbital photography of the earth realizes that the Urals are but one of scores of similar folded mountain belts (Figs. 16, 17, 18). So Hamilton's theory therefore either violates Occam's Razor, or implies scores of inter-continental collisions, both tending to weaken it.

Orbital photography may thus help geologists to avoid the error of treating geologic features as special cases, by seeing them in a global context.

<u>Availability of Color and Multi-Spectral Coverage</u>

It is now generally realized that, for any area favorable for aerial photography in general, color coverage offers the geologist major advantages over black-and-white coverage. However, only small areas have yet been photographed from the air in color. Furthermore, even if the entire world could somehow be re-photographed with color film, the cost of reproducing and using color photography would be a major barrier to using it because of the great number of pictures required. Earth satellites, however, permit photography of entire continents in color with a relatively small number of prints, and substantial areas can be studied with even one print (e.g., San Diego County - Fig. 6).

The same argument applies to multi-spectral photography. As shown by the Apollo 9 S065 experiment (Lowman, 1969), multispectral coverage is not only desirable for orbital photography but necessary, because the great range of terrain, vegetative cover, and atmospheric conditions encountered in even single orbital photographs makes it impossible to get optimum rendition with one film/filter combination.

Obviously, the relatively low resolution of most orbital pictures must be taken into account in discussing the value of color and multispectral orbital photography. However, such photography could at least narrow down the areas for which the more expensive comparable aerial coverage would be justified.

SUMMARY AND CONCLUSIONS

The foregoing review has accentuated the positive side of orbital photography in geology. There is of course another side. Most of the photography taken so far has low ground resolution, and many of the obliques are of little use for anything but general illustration. All orbital photographic schemes must contend with the earth's dense cloud cover, and of course with the fact that most of the earth is covered by water, ice, soil, and vegetation.

A question not explicitly discussed so far is that of just how orbital photographs can best be used by geologists. For areas in which no photography at all is available, the answer is obvious: they simply substitute for air photos. However, three other approaches have also proven valuable. The first of these is simply comparison of orbital photographs with existing geologic or topographic maps. In many areas, such gross discrepancies will be found that several lines of inquiry will immediately be opened; an example is the Palomas volcanic field (Fig. 8). A second approach is comparison of orbital photographs of widely separated though generally similar areas, such as the deserts of North America and North Africa. Explaining the differences and similarities will frequently throw new light on old fact or uncover new facts. Still a third approach is problem-oriented, in which orbital photography is applied to a particular geologic problem that may involve large areas, perhaps in different countries; the Texas lineament problem is a good example of this approach.

In summary, I wish to stress that orbital photography is not simply aerial photography from extremely high altitudes. Although it can serve as such, it is actually so different as to represent a qualitatively new geologic tool. Properly used, it can provide geologists with new approaches to old problems, with a new outlook on what is nominally a well-explored planet, and perhaps most important, with recognition of totally new problems.

REFERENCES

Holmes, A., 1965, Principles of Physical Geology: The Ronald Press Company, New York, 1288 p.

Lowman, P. D., Jr., 1964, A review of photography of the earth from sounding rockets and satellites: NASA Technical Note D-1868.

Lowman, P. D., Jr., 1969a, Geologic orbital photography: Experience from the Gemini program: Photogrammetria, v. 24, p. 77-106.

Lowman, P. D., Jr., 1969b, Apollo 9 multispectral photography: Geologic analysis: X-644-69-423, Goddard Space Flight Center, Greenbelt, Maryland 20771.

Lowman, P. D., Jr., 1971, The Third Planet: Terrestrial Geology in Orbital Photographs: WELTFLUGBILD Reinhold A. Muller, Feldmeilen/Zurich, Switzerland.

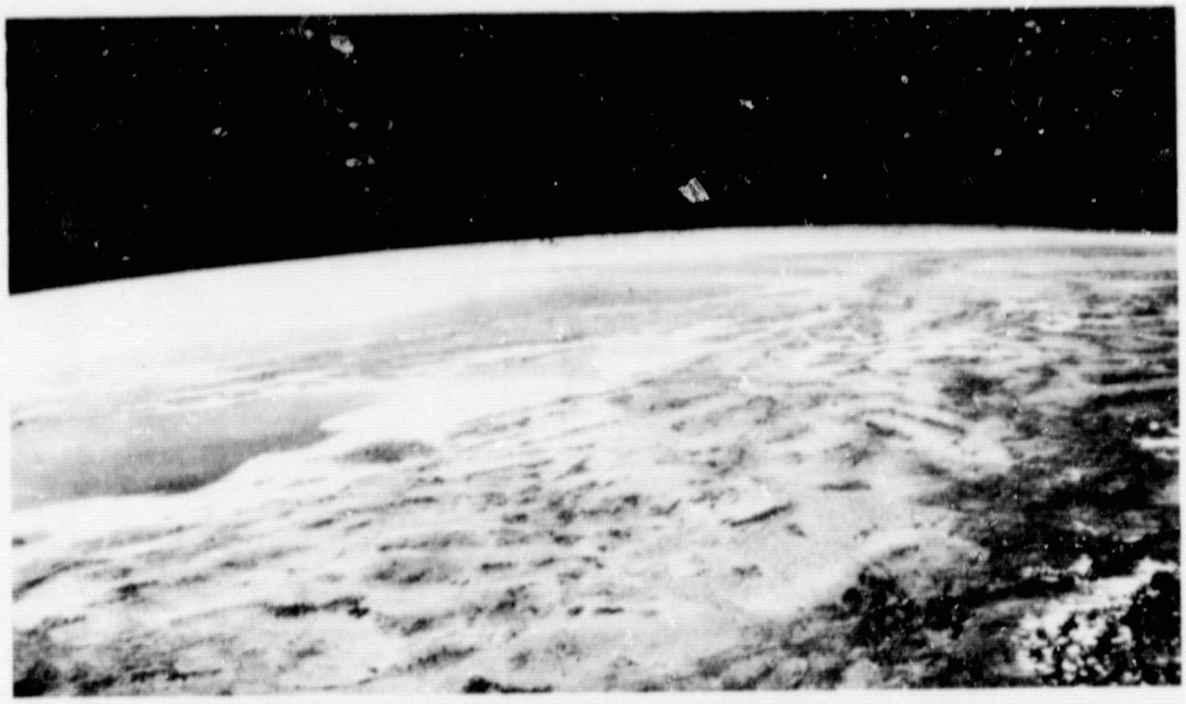
Lowman, P. D., Jr., McDivitt, J. A., and E. H. White, II, 1967, Terrain photography on the Gemini IV mission: Preliminary report: NASA Technical Note D-3982.

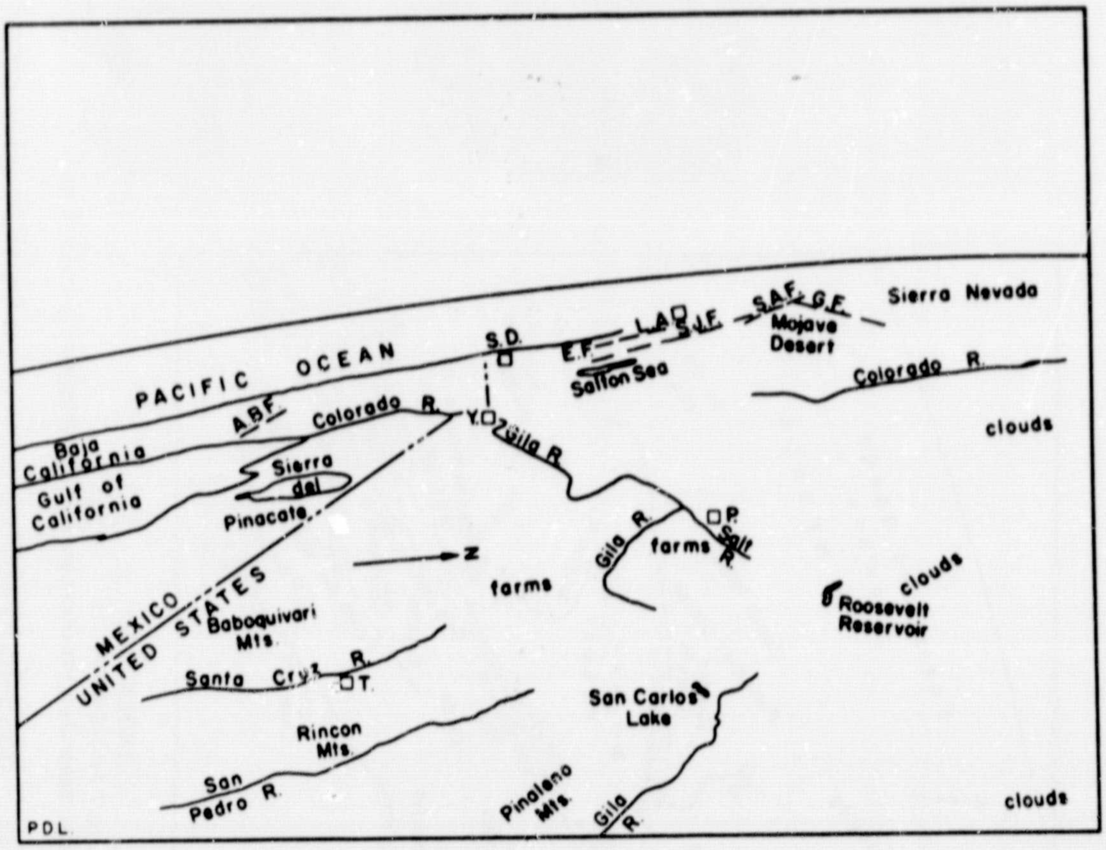
Lowman, P. D., Jr., and Tiedemann, H. A., 1971, Terrain photography from Gemini spacecraft: Final geologic report: X-644-71-15, Goddard Space Flight Center, Greenbelt, Maryland 20771.

Merifield, P. M., 1963, Geologic application of hyperaltitude photography, Ph.D. Thesis, University of Colorado, Boulder, Colorado.

Morrison, A., and Chown, M. C., 1964, Photography of the western Sahara desert from the Mercury MA-4 spacecraft: NASA Contractor Report CR-126.

Thornbury, W. D., 1954, Principles of Geomorphology: John Wiley & Sons, New York, 618 p.

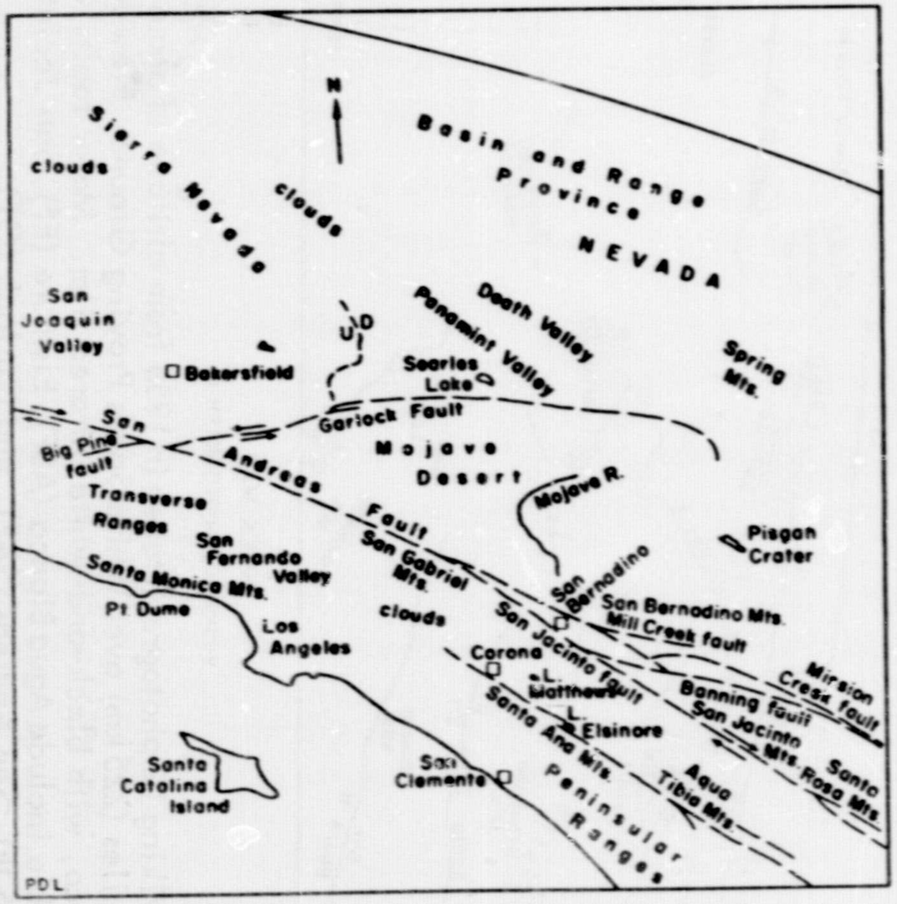




INDEX MAP

VIKING 12, PHOTOGRAPH 14

Figure 1. Viking 12 photograph taken in 1955 from altitude of about 140 miles (225 km) over White Sands Proving Ground, New Mexico, with black-and-white infrared film. Major faults visible include Agua Blanca (ABF), Elsinore (EF), San Jacinto (SJF), San Andreas (SAF), and Garlock (GF).



INDEX MAP
APOLLO 7 PHOTOGRAPH AS 7-11-2022
Note: Scale variable; Bakersfield-Searles Lake distance 95 miles.

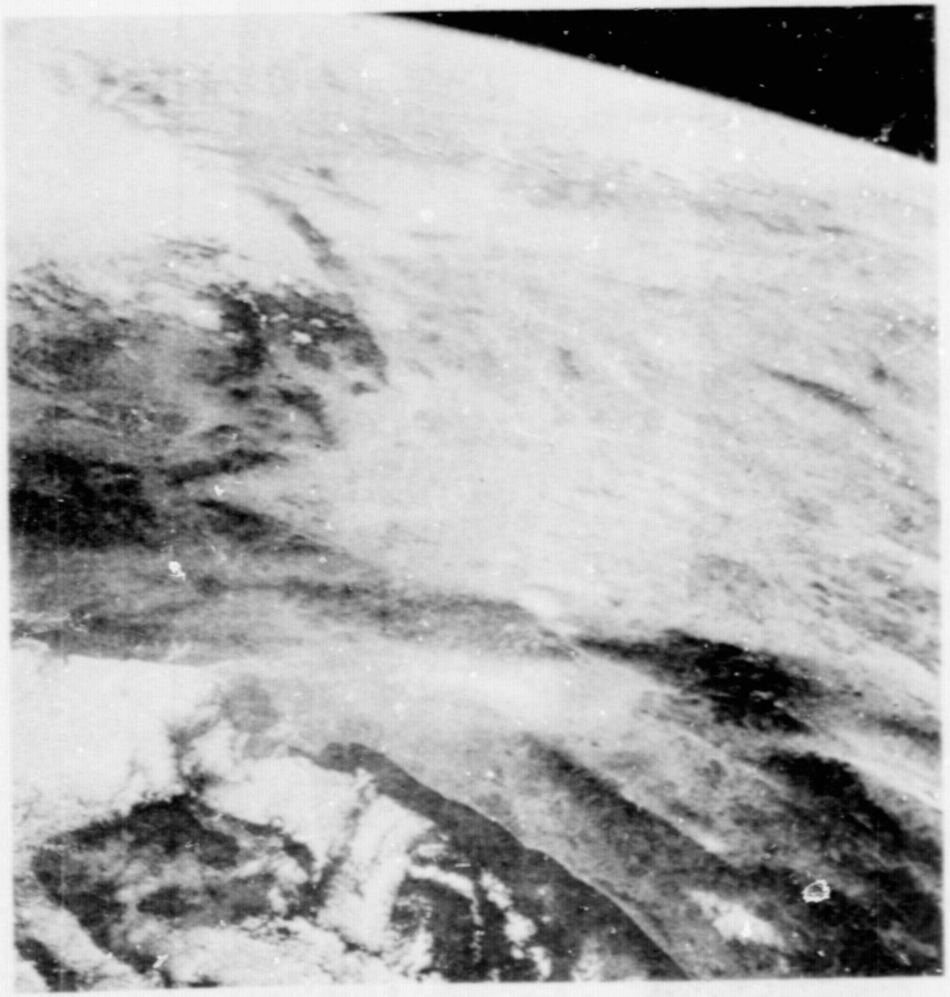
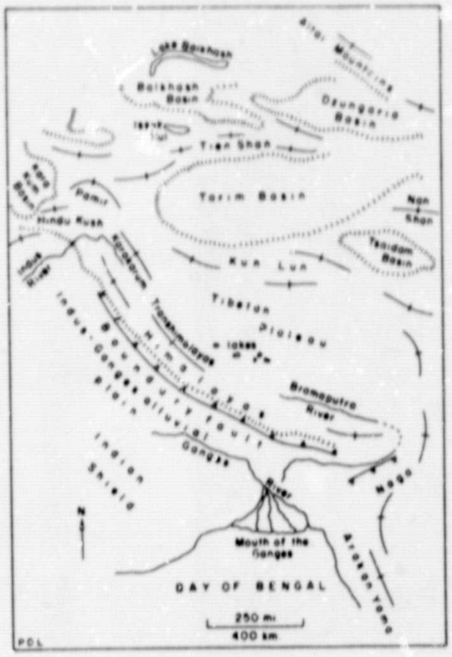
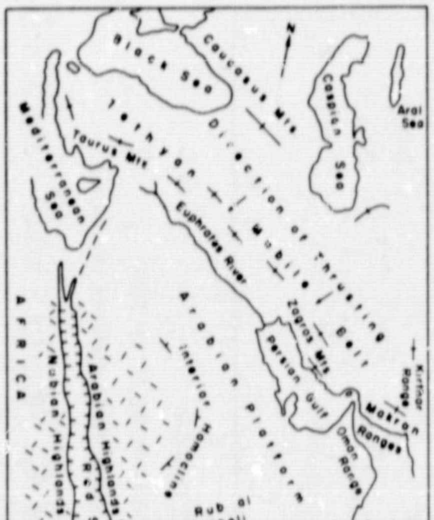


Figure 2. Apollo 7 hand-held photograph taken in 1968 with color film, with main physiographic and structural features shown on index map.



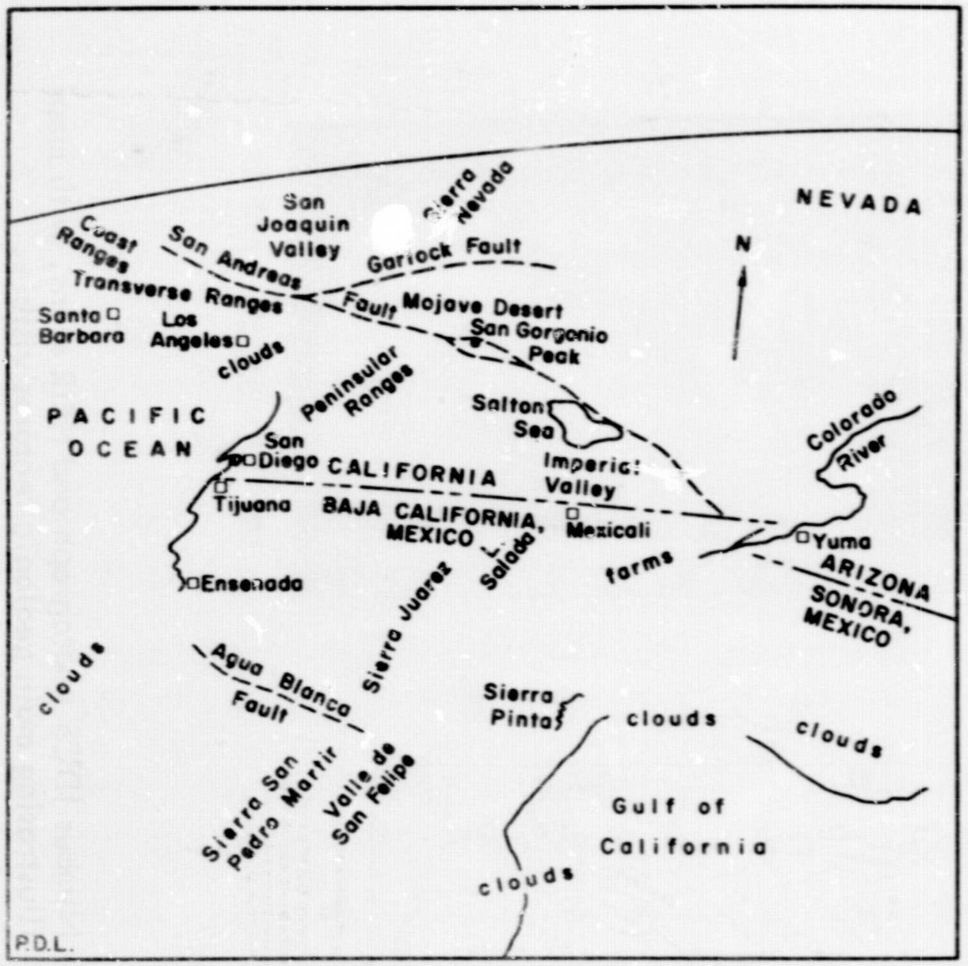
TECTONIC INDEX MAP
OF
SOUTH-CENTRAL ASIA
BASED ON NIMBUS III IDCS PHOTOGRAPHS
Clouds not labeled



TECTONIC INDEX MAP
OF
THE MIDDLE EAST
BASED ON NIMBUS III INFRARED
RADIOMETER DAYTIME SCAN
ORBIT 711, 6 JUNE 1969

NIMBUS III HRIR DAYTIME ORBIT 711 6 JUNE 1969
ASIA MINOR

Figure 3. Nimbus IDCS photograph and HRIR scans, with maps illustrating main geologic features visible.



INDEX MAP

APOLLO 9 PHOTOGRAPH AS 9-21-3263

Note: Scale variable; San Diego-Yuma distance 145 miles.

Figure 4. Apollo 9 hand-held photograph taken in 1969 with color film.

Figure 5. Geologic map of San Diego County, Califormia, by Weber (1963). Note virtual absence of north-east trending lineaments west of Elsinore fault.

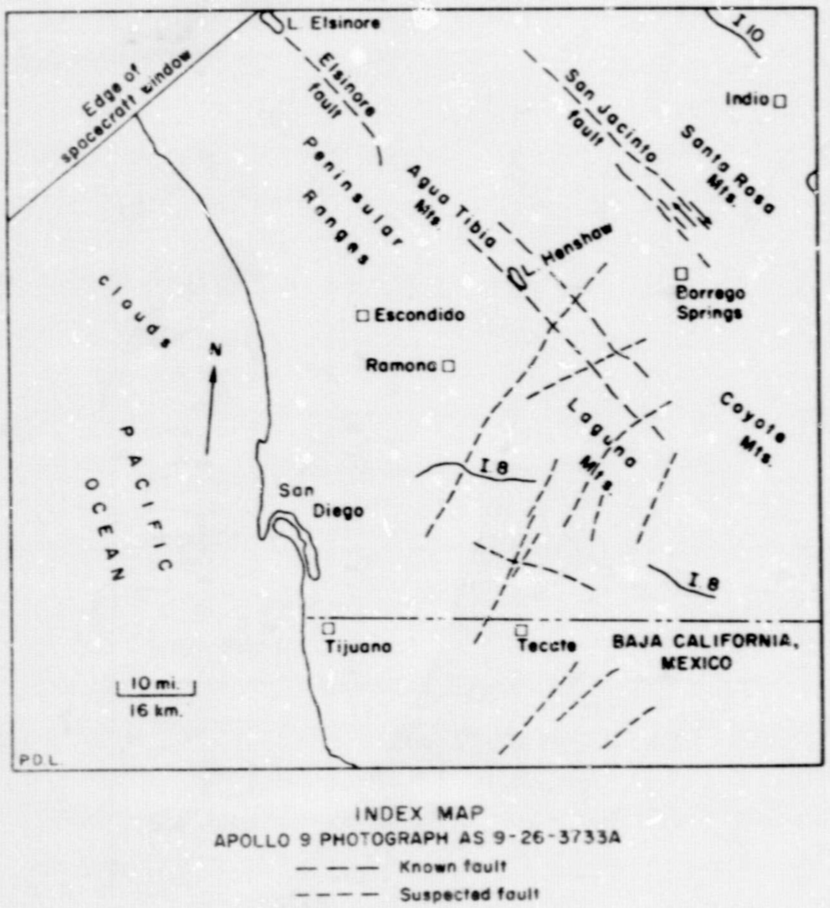
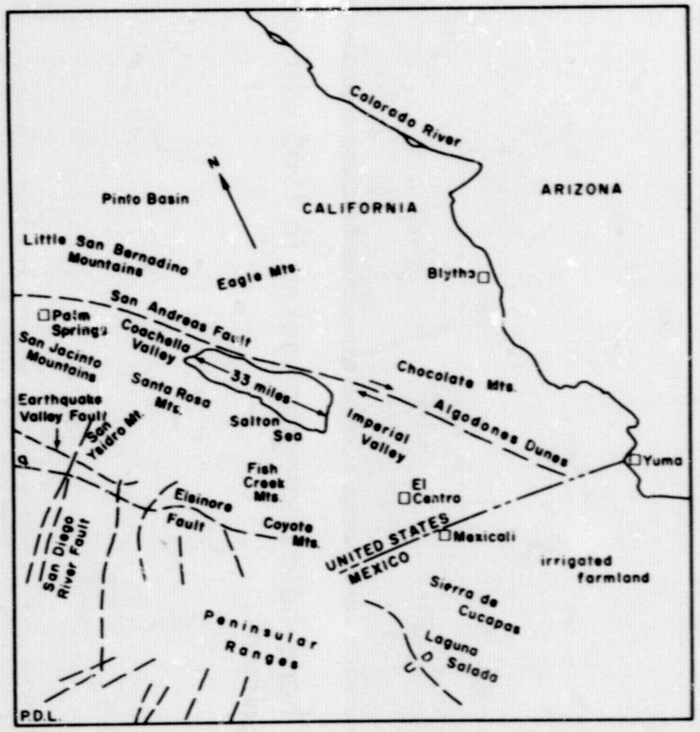


Figure 6. Color infrared photograph of San Diego County, California; one of four views photographed simultaneously with different film-filter combinations as part of the S065 experiment (Lowman, 1969).



INDEX MAP
APOLLO 7 PHOTOGRAPH AS 7-11-2023

Figure 7. Apollo 7 hand-held photograph taken in 1968 with color film.

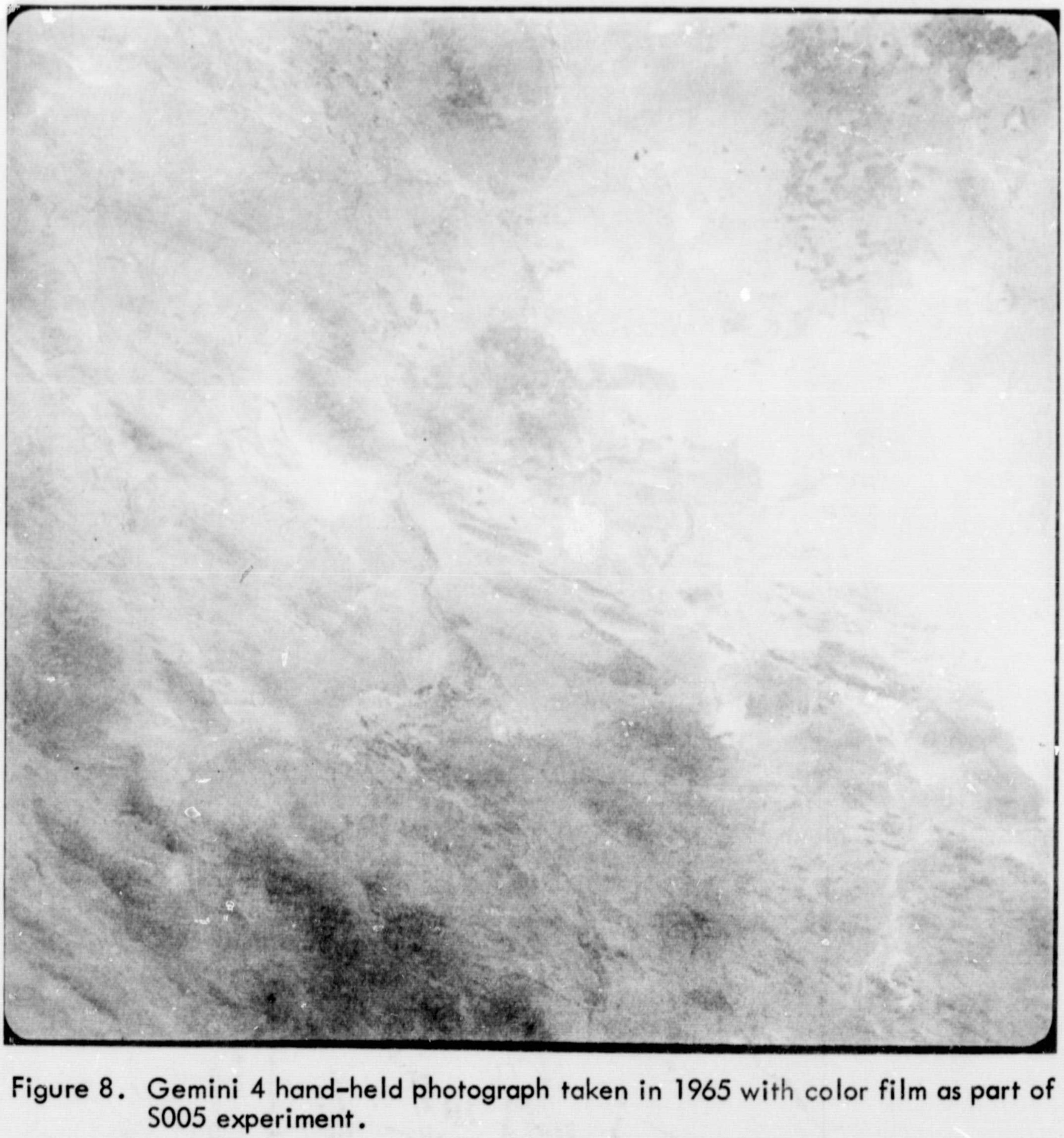
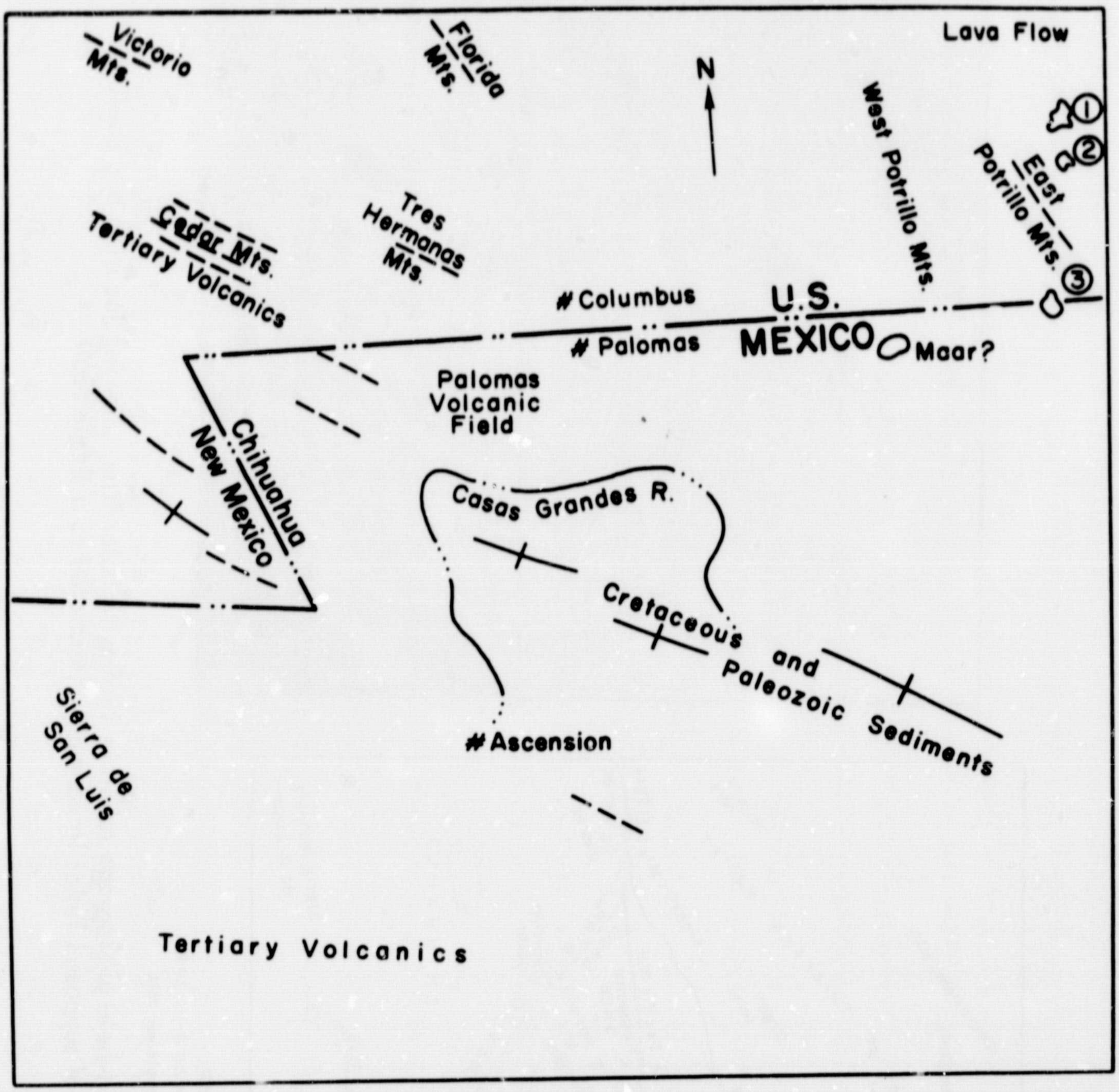


Figure 8. Gemini 4 hand-held photograph taken in 1965 with color film as part of S005 experiment.



STRUCTURAL SKETCH MAP

Gemini IV Photograph S-65-34689 (Not Rectified)

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

– – – – – Probable faults

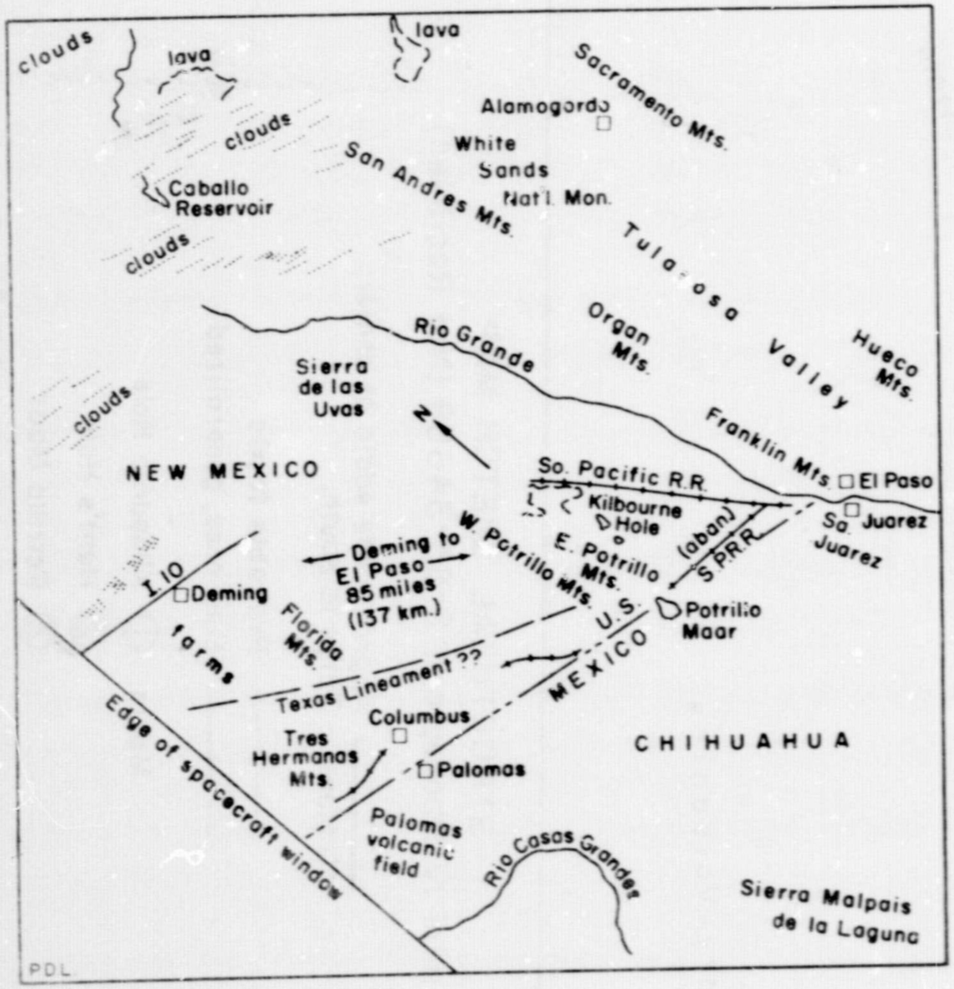
—+— Fold axes, generalized

Maars: ① Kilbourne Hole

② Hunt's Hole

③ Potrillo Maar

Figure 9. Structural sketch map of Figure 8.



INDEX MAP
APOLLO 9 PHOTOGRAPH AS 9-21-3282
Oblique view to N.E., scale variable.

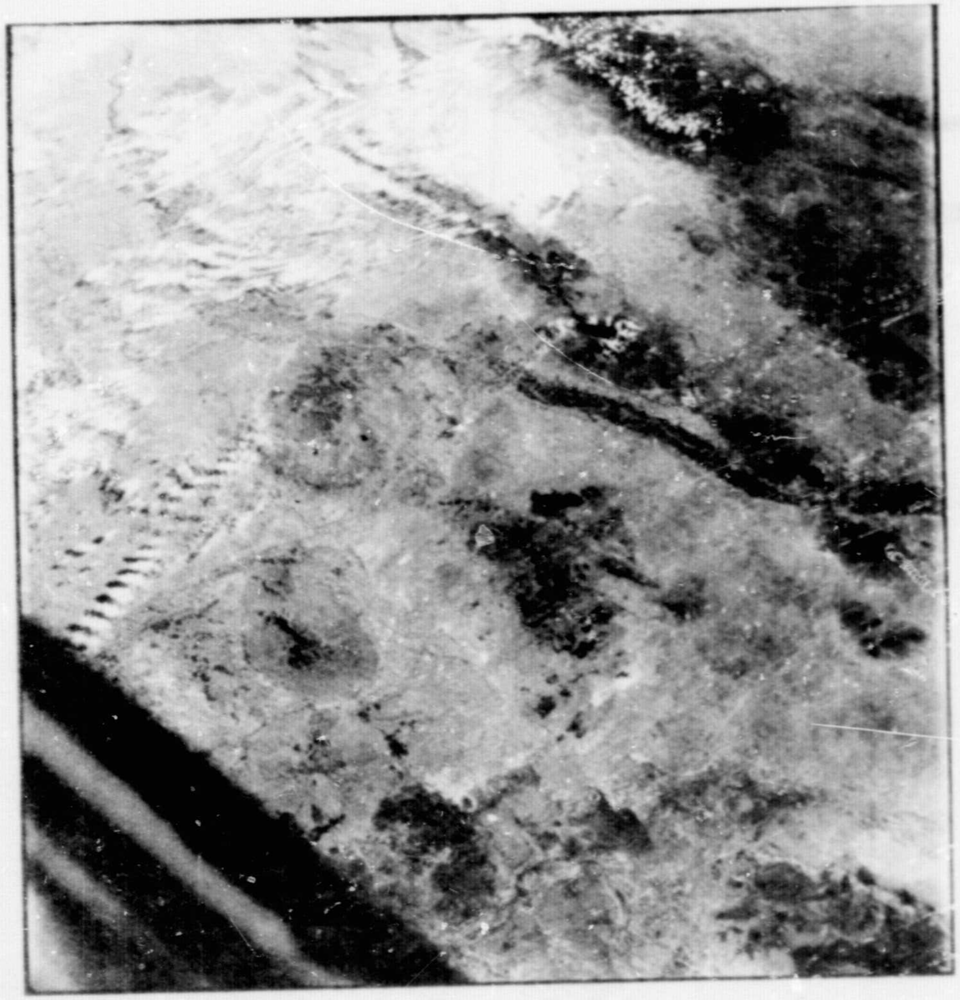
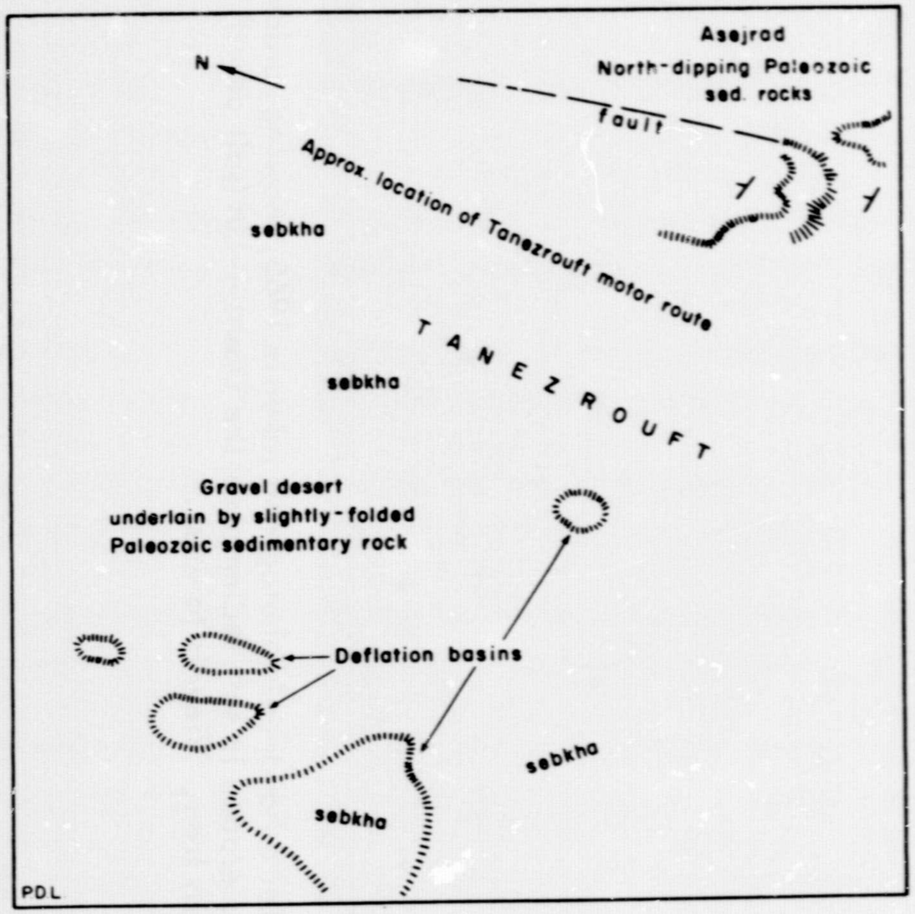


Figure 10. Apollo 9 hand-held photograph taken in 1969 with color film, showing location and geologic environment of supposed Texas lineament, interpreted as a single fault.



INDEX MAP

APOLLO 9 PHOTOGRAPH AS 9-19-3034

Figure 11. Apollo 9 hand-held photograph taken in 1969 with color film, showing deflation basins in southern Algeria.

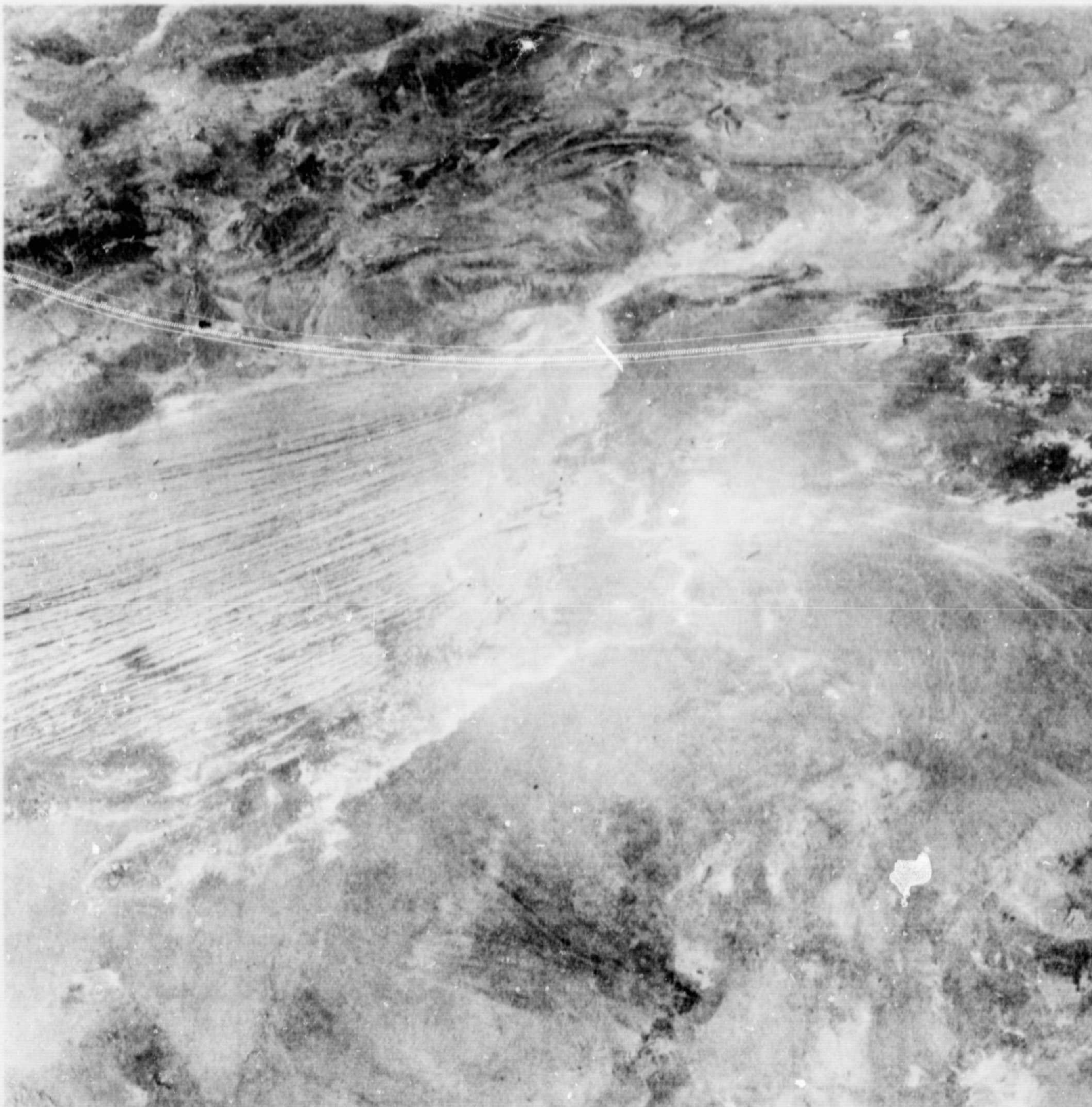
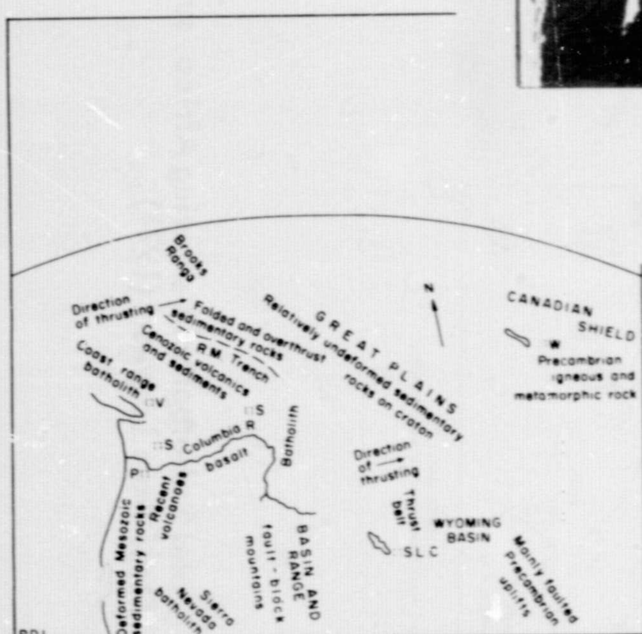
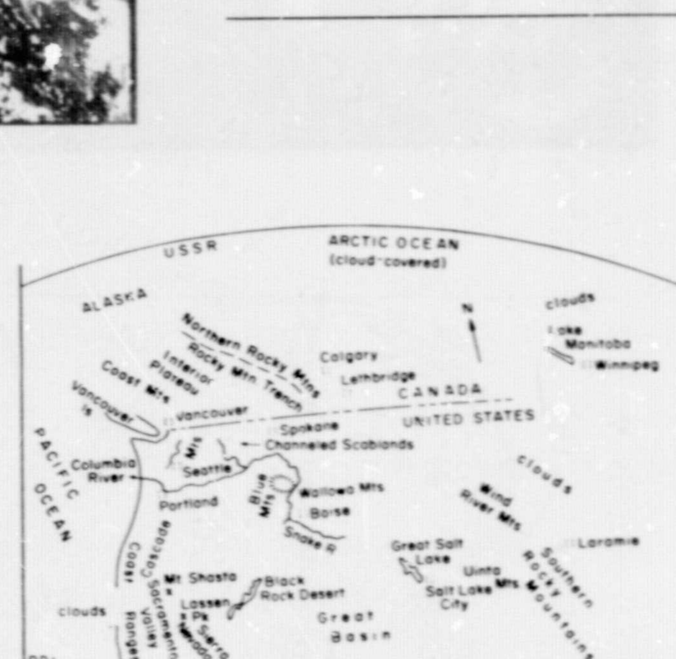


Figure 12. Gemini 5 hand-held photograph taken in 1965, showing yardangs - linear ridges eroded in soft sediments of the Dasht-i-Lut (salt desert) of south-eastern Iran. View is to west.



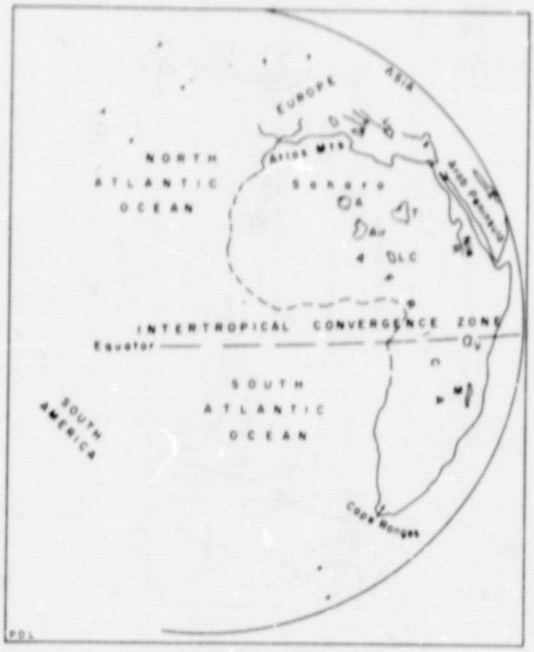
GEOLOGY

APOLLO II PHOTOGRAPH AS 11-36-5302

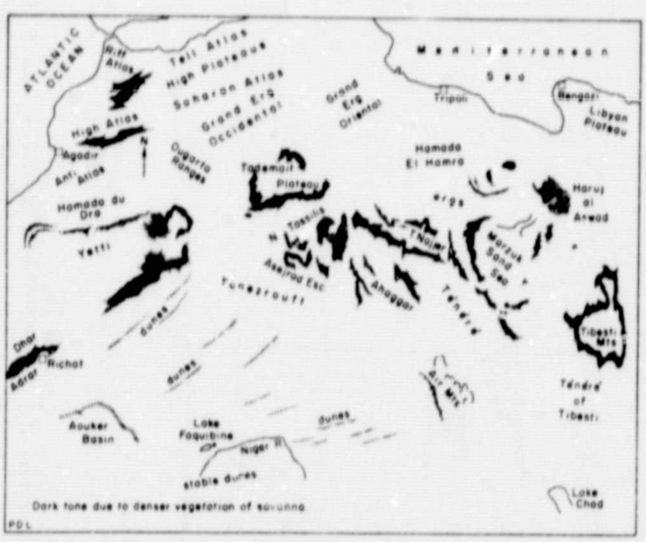


GEOGRAPHY

APOLLO II PHOTOGRAPH AS 11-36-5302



INDEX MAP
ZOND 5 PHOTOGRAPH
Taken 21 Nov 1968, altitude 90,000 km (54,000 mi)
Photograph courtesy of B.V. Vinogradov



INDEX MAP
ZOND 5 PHOTOGRAPH, COURTESY B.V. VINOGRADOV

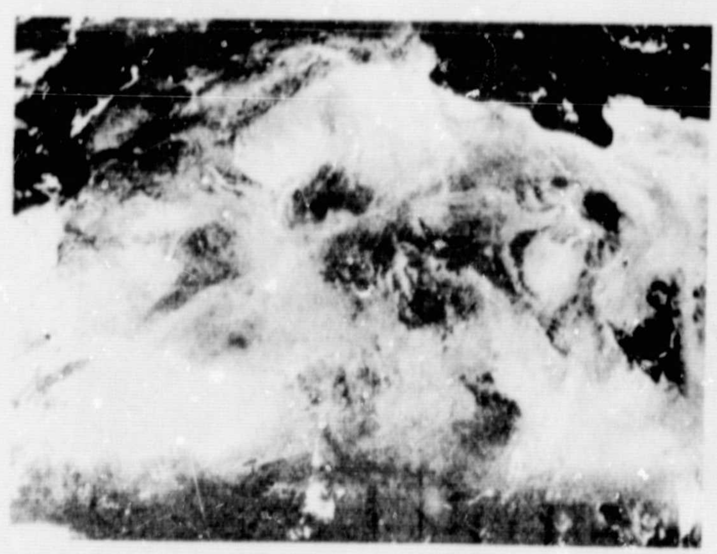
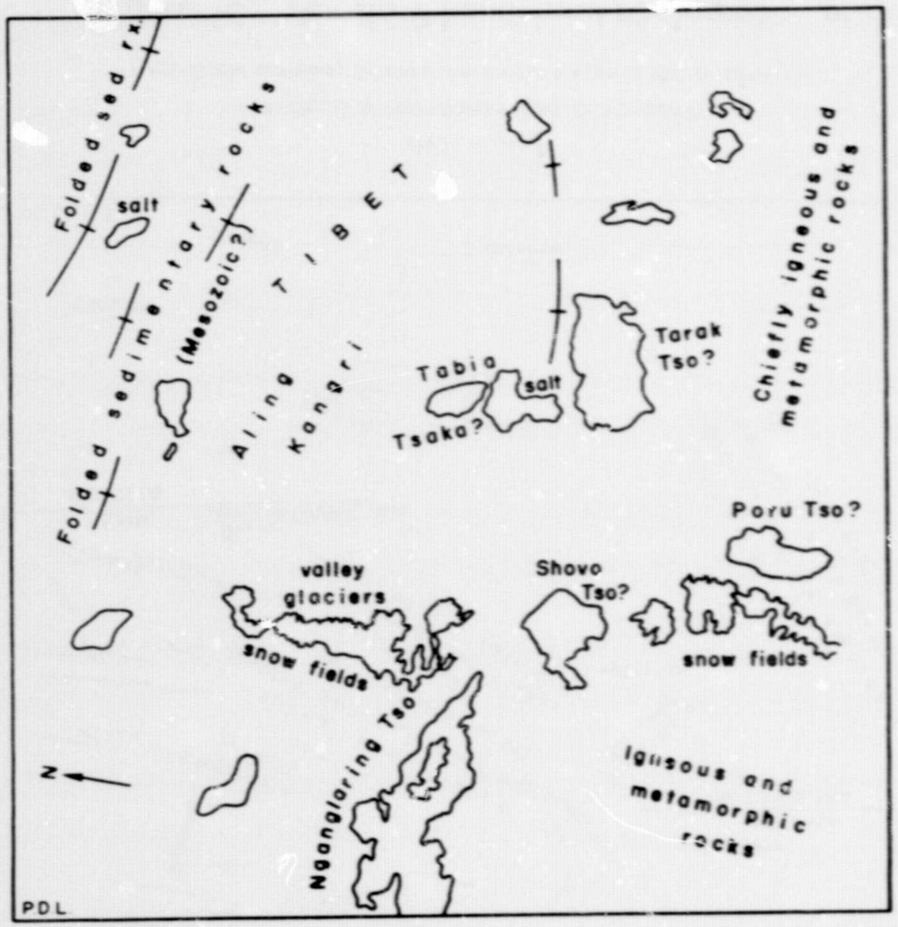


Figure 14. Zond 5 photographs showing Africa, supplied by Prof. B. V. Vinogradov. Maps from Lowman (1971).



INDEX MAP

APOLLO 7 PHOTOGRAPH AS 7-5-1617

Note: Map reliability poor; area covered only by expedition reports.
Center of Lake Nganglaring is at about 83°E, 31°40'N.

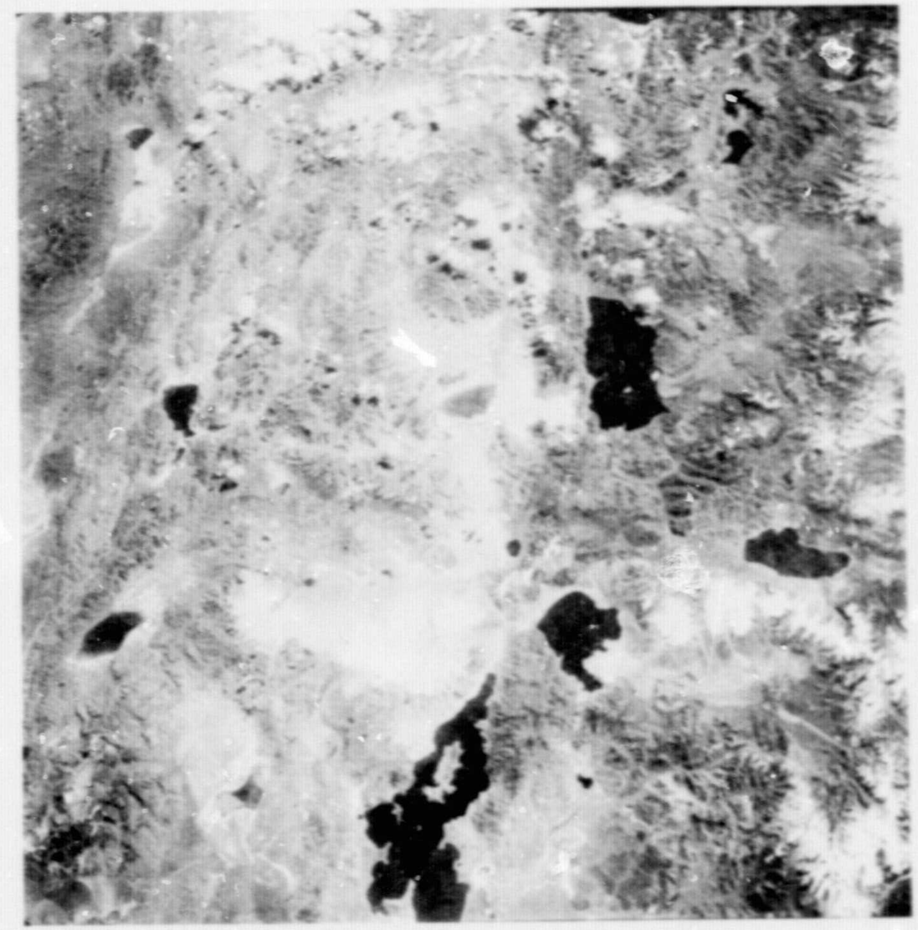
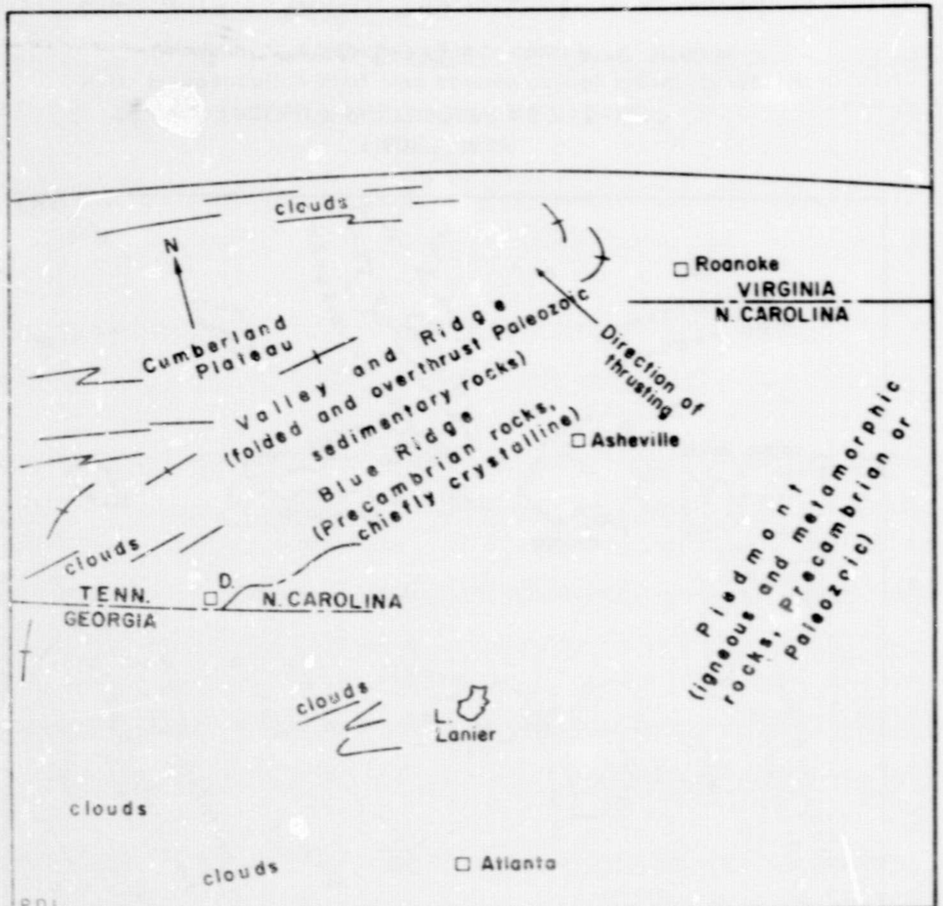


Figure 15. Apollo 7 hand-held photograph taken in 1968, showing south-central Tibet, with view to east.



INDEX MAP

APOLLO 9 PHOTOGRAPH AS 9-20-3147

Note: Scale variable; Atlanta-Asheville distance 150mi. (240Km.)

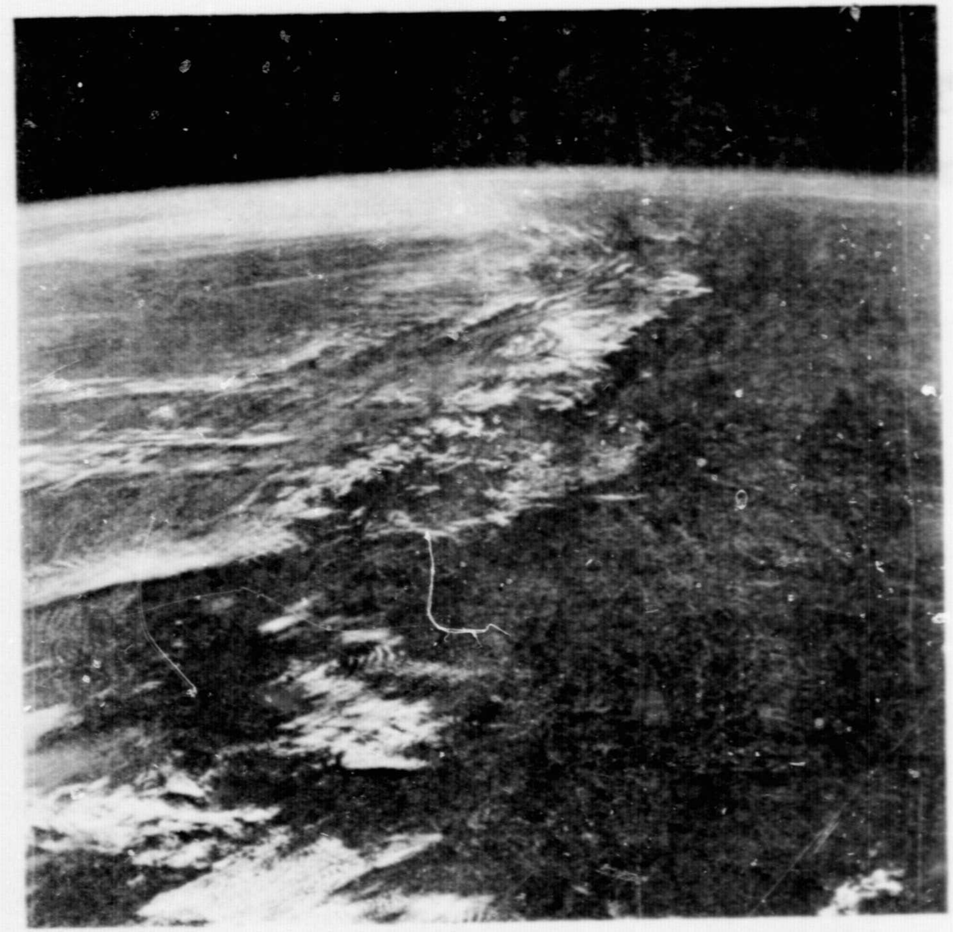
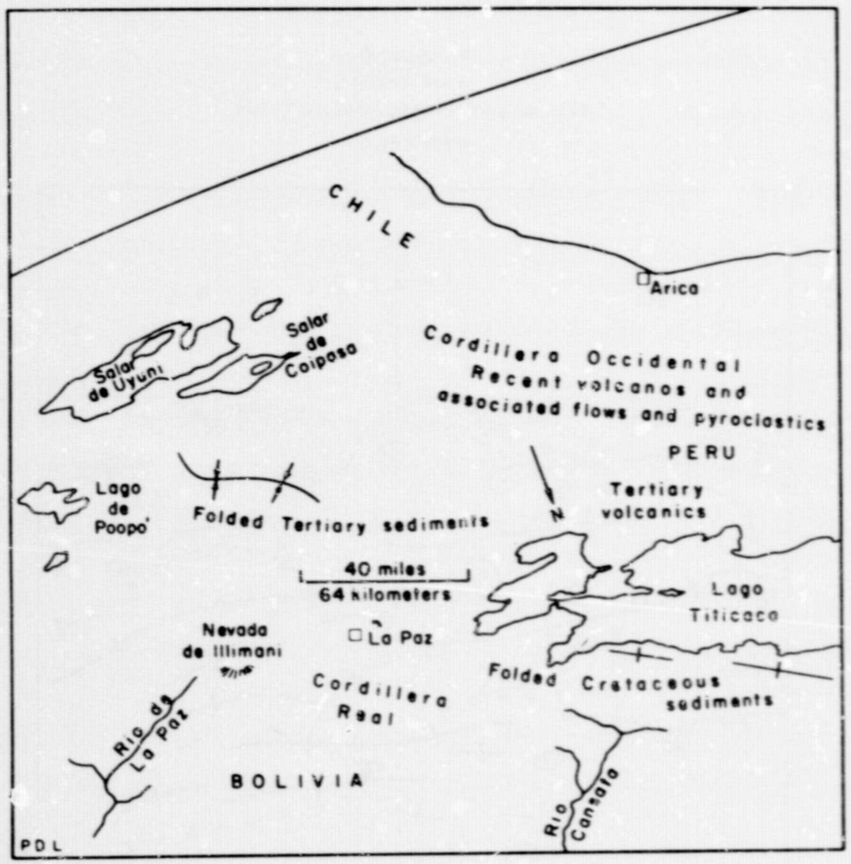


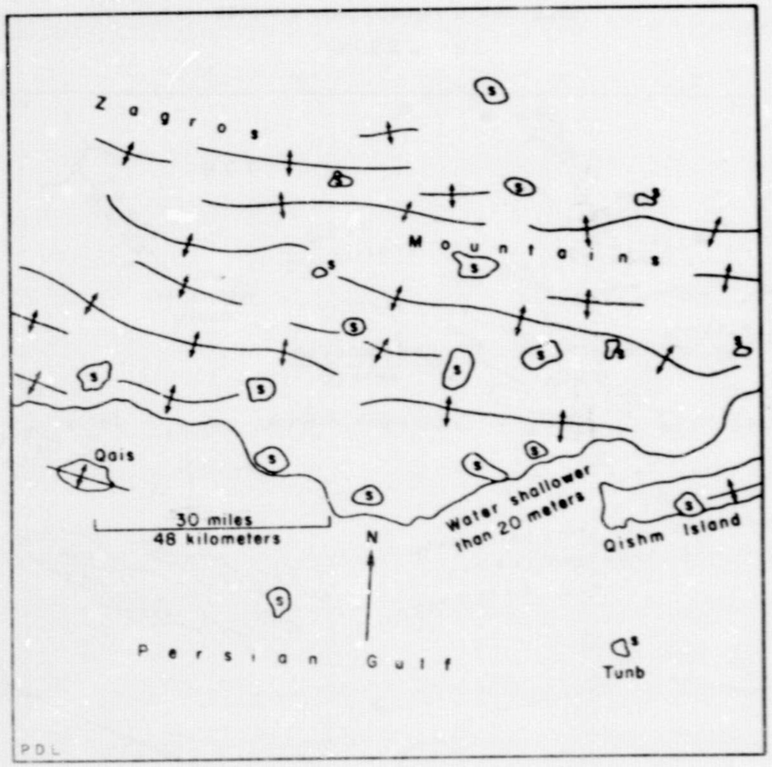
Figure 16. Apollo 9 hand-held photograph, original in color, looking north along Appalachian Mountains.



INDEX MAP

GEMINI 9 PHOTOGRAPH S-65-38313

Figure 17. Gemini 9 photograph taken in 1966, showing structure of Andes Mountains.



INDEX MAP
APOLLO 7 PHOTOGRAPH AS 7-5-1615
(s) salt dome
anticline

Figure 18. Apollo 7 hand-held photograph taken in 1968, showing Zagros Mountains in Iran; view to north.