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PHOTOGRAPHY OF THE EARTH FROM SPACE AND ITS NON-METEOROLOGICAL APPLICATIONS*

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ABSTRACT 21772

Photography from satellites and rockets constitutes a new source of information about the earth's surface. Advantages of space photography are that (a) an area hundreds of kilometers across can be shown in a single frame (b) photographic tones are comparable, and a stereo-effect is obtainable over this area, even if it is crossed by a political boundary, (c) uniform and frequent coverage of the entire earth can be obtained. Problems of light transmission through the atmosphere and of cloud cover are only a little greater than in aerial photography. Some existing space photography is usable, but a specially-designed system would yield better results. Apart from its illustrative value, space photography could assist in mapping: (a) relatively permanent distributions, e.g., geology, landforms, vegetation, generalized land-use, the extent of glaciers; and (b) ephemeral distributions, e.g., snow-cover, ice-cover on rivers, lakes, and the sea, forest fire burns, temporary lakes and streams, and ocean-water masses.

Author

Everyone carrying out research in the field has at some time sought the highest point in his area, from which to study the land, laid out like a map below him. With the invention of aircraft, this approach could be extended by observations from the air, or by the use of air photographs. In the past fifteen years, it has become possible to photograph the earth from even higher altitudes, from rockets and artificial satellites. Such photography constitutes a new source of information about the earth's surface.

Existing photographs of the earth from rockets have been taken between ground level and 1400 km; those from satellites between 150 and 800 km. Some have been exposed on photographic film which was returned to earth either in an armored casette, or in a capsule landed by parachute. Others have been obtained by television.

Advantages

From the point of view of geographical research and mapping, the main advantage of photography from these altitudes is the huge area which can be included in a single picture. If

*This paper is a shortened version of ref. 1, which should be consulted for full citation of sources and for full acknowledgments.

distributions over a region hundreds of kilometers in extent are being studied, it is valuable to have an overall view of the area, which hitherto has had to be improvised by means of air photo mosaics or photo-by-photo distribution mapping. In the same way that the conclusions of detailed ground investigations can be applied over a large area with the aid of aerial photography, so the usefulness of air surveys of limited areas can be extended by means of space photography.

A space photograph has definite advantages for such use. The variation in photographic conditions from one air photo to the next is absent. Photographic tones are comparable across the whole area. A single space photo can record transitions of tone which take place gradually over such long distances that a whole strip of air photos would be needed to span the transition zone. Such tone changes might indicate broad changes in the soil, vegetation, or groundwater conditions, perhaps related to zonal climatic differences, present or past (Fig. 3).

Even if the area studied is crossed by a political boundary, a space photograph will show no change in the type of coverage, as air photography might, and so will make comparisons across the boundary easier.

With a suitable pair of vertical space photographs it would be possible to obtain a continuous stereomodel over an area hundreds of kilometers in extent, in which height differences of hundreds of meters are distinguishable, thus assisting interpretation at these scales.

Space vehicles are best suited to producing photographs of a large area at a small scale with poor ground resolution, but photos of larger scale, or with better ground resolution, can be obtained by suitable choice of focal length and frame size, at the expense of either the area covered per frame or the number of pictures obtained. The advantages of taking larger scale photographs from a satellite would lie in their uniformity and in the ease of repeating the photography once the system was in orbit.

As a camera platform the satellite has advantages. Changes of position and orientation of the orbiting camera between exposures are strictly regular; successive 'flightlines' are spaced uniformly by the rotation of the earth beneath the orbit; vibration may be absent; and camera systems of long focal length, several meters for example, can be accommodated more conveniently than in an aircraft because of the absence of air resistance to the motion of a satellite (Refs. 1 to 7).

Problems

The many problems of taking and using space photographs can be largely overcome.

Pictures already obtained have demonstrated that photographic systems can be made to survive the extreme conditions of launch, operation in space, and recovery.

The effects of transmission through the atmosphere upon the image obtained reach their maximum in space photography, since the camera is outside the atmosphere. These include the reduction of tone contrast, and the blueish rendering of colors, both caused mainly by atmospheric scattering. Since 75% of the air and most of the dust particles and water are in the troposphere below about 11 km, these problems are only a little greater in space photography than in high altitude aerial photography, and can be partly solved, as in air photography, by filtering out some of the shorter-wave light. Atmospheric refraction of oblique rays makes the ground appear slightly closer to the camera than it really is, but the lift amounts to only a few meters. The problems of shimmer and scintillation, important in astronomical telescopes, are negligible unless extremely good ground resolution is sought. (Refs. 5, 10).

The curvature of the earth must be allowed for in photogrammetry carried out with space photographs (Ref. 8). Using verticals, for many purposes the earth's surface can be regarded as spherical; but measurements on oblique photos will often have to take into account the varying curvature of the earth.

The problem of cloud cover is no more serious than in aerial photography, since the proportion of time that a given area is cloud covered is not affected by the method of photographing it. If we think in terms of a system such as Nimbus, which can photograph the entire earth every 24 hours, a satellite is as capable of profiting from a clear period as an aircraft.

Thus there seem to be no insurmountable obstacles to satisfactory photography from space.

Existing space photography

There already exists a considerable body of space photography, some of which can be useful in studies of the earth's surface features. This can be summarized in three groups—photography from sounding rockets, from Mercury spacecraft, and from Tiros and Nimbus satellites (Fig. 1, Refs. 1, 7).

Photographs have been recovered from high altitude sounding rockets fired from the ranges at White Sands, C. Kennedy, Wallops I, and Churchill (Fig. 1a). The areas visible are limited to the vicinities of these ranges. The majority of the photos were taken on black-and-white or infrared film, at heights up to 250 km, yielding scales in the range 1:300,000 to 1:3,000,000. Very few are verticals. Many of those taken from White Sands are of use, especially since they range in date from 1946 to the present, and since many are as sharp as good aerial photos (Ref. 9), (Fig. 6).

Photographs were obtained from most of the spaceflights of Project Mercury, between 1960 and 1963 (Fig. 1b). The majority were on 70 mm color film. Three flights, MA-4, MA-5, and MA-9, yielded photos of extensive land areas free of cloud. In all of these the spacecraft orbited at heights from 160 to 270 km. Flights MA-4 and MA-5 were unmanned. An automatic camera obtained strips of overlapping high oblique photos covering the western Sahara (Figs. 2 to 5), northwest Mexico, and southeast U.S.A. (Fig. 7). On flight MA-9 Astronaut Cooper took individual low oblique or vertical photos showing parts of Tibet (Fig. 8), India (Fig. 9), Pakistan, Iran, Arabia, Morocco and elsewhere. In the foreground, scales ranged from 1:2,000,000 to 1:5,000,000, and ground resolution from 100 to 500 meters (Refs. 10, 11).

The Tiros satellites were designed to obtain pictures of the cloud cover of the earth for meteorological purposes. Eight have been launched since 1960, so timed that usually at least one was producing pictures. Each carries two television cameras. The satellites travel in orbits which lie mainly between 650 and 850 km above the earth and which confine the areas photographed to between 65°N and 65°S. When a Tiros satellite is within range of one of the receiving stations in the United States, television pictures can be relayed directly from the satellite and are recorded. Pictures taken of other parts of the world are stored on tape until the satellite is within range of one of these stations, and are then relayed to earth. Photographs are taken only when the cameras are pointing towards part of the earth that is in daylight. Three types of lens have been used, giving pictures 1000, 700, or 100 km square when the camera is pointing directly downwards. The best ground resolution obtainable is about 3 km for wide angle cameras, 2 km for medium angle and 0.3 km for narrow angle.

Less than one per cent of Tiros pictures can be used for studies of the land surface (Figs. 1c, 10 to 13). The remainder are made useless by cloud cover, ocean surface, obliqueness, low contrast, electronic noise, defocussing, or (for narrow-angle) difficulty in locating them (Refs. 12-17).

Applications

In each distribution which can be seen on space photographs lies a potential application. In discussing whether a potential application is a practical application static distributions should be distinguished from rapidly-changing distributions.

The relatively permanent elements visible on space photos include vegetation or cover-type, landforms, shallow submarine forms, geology, generalized land-use, and the extent of glaciers. These features have already been mapped in most parts of the world with resolution comparable to that of Tiros photos, but often not in as much detail as is revealed by Mercury photos. Where space photos show more detail than existing maps, they can be of practical use in mapping, in conjunction with conventional sources, i.e., literature, maps, air photographs and field investigation. Where there are maps showing detail comparable to that on existing space photos, the patterns need not correspond closely, because the maps' categories may differ from the distributions conspicuous on the photos, but in a few areas it is so difficult to relate maps and photos that re-assessment of the maps appears necessary. In well-mapped areas space photos may prompt new ideas about inter-relationships between known features over large areas, e.g., in suggesting the unity of geological structures not previously associated. Thus in studying static features the advantages of space photos are the large area shown uniformly by each frame and the worldwide coverage.

The application of space photos to the mapping of rapidly changing distributions is even more promising, since it is difficult to survey these over large areas promptly and frequently by any other means. When photos as good as the best Tiros photos are obtained regularly, it will be possible to follow in detail the changes in many features, including the following: location and movement of sea ice, freeze-up and break up of major rivers and lakes, extent of snow cover, to some extent nature of snow cover, height of snow-line in mountains, variations in the extent of swamps and flooded areas, leafing of trees and leaf-fall, changes in the extent of forests due to lumbering, clearing, or burning, extent of ocean winter-masses made visible by silt-content or by their effect on clouds. Immediate information on some of these distributions is obviously economically useful, and some are already being developed (refs. 18, 19, 20). All could be of scientific value.

Most of these applications should become practical when pictures from Nimbus are regularly available. These have a resolution of about 1 km, are always vertical, and cover the whole earth every day. Nimbus I was launched on 28 August 1964.

If it is to be useful, information on these ephemeral distributions must reach the user promptly. This is the value of the Automatic Picture Transmission (APT) System, incorporated in Tiros VIII and Nimbus I. This enables a user in any part of the world to receive pictures of the surrounding area as soon as they are taken, as long as the satellite is above his horizon.

With resolution somewhat better than that of Mercury photos, many further applications are possible, e.g., it should be possible to see where rain has fallen in arid areas and so assist the search for pasture; to follow the build-up of mountain lakes dammed by glaciers or landslides and threatening populated areas; to determine at once the areas damaged by floods or tidal waves even if communications are disrupted.

Specifications

If space photographs are to be widely applied in any of these ways, then future satellite photographic systems must be specified with these applications in mind. The specifications for systems to use frequently repeated photography to guide immediate action, e.g., in the relief of flooded areas, are too varied to generalize here, but applications which take advantage of the wide coverage of space photos probably have similar requirements. One would probably specify as the ideal that all land areas should be photographed uniformly by vertical photographs on film, overlapping stereoscopically, with a ground resolution of 100 m or better, in frames covering at least say 100 to 300 km on a side. If there were no clouds, this could be accomplished in a few days. In practice the camera would have to remain in orbit for several months, to await cloudless conditions over each part of the earth in turn, and the resulting system would be less elegant.

No satellite photographic system is complete unless the photographs are readily available to users in all countries. Otherwise they may find existing methods more convenient. An international office is needed, perhaps under UNESCO, to provide information, maintain indexes, and sell copies of existing and future space photographs.

Plans are already being made for the launch of between 10 and 20 satellites in the next five years which are definitely or potentially camera platforms. The usefulness of the results will depend on the effectiveness of consultation with potential users in all countries before the designs are far advanced.

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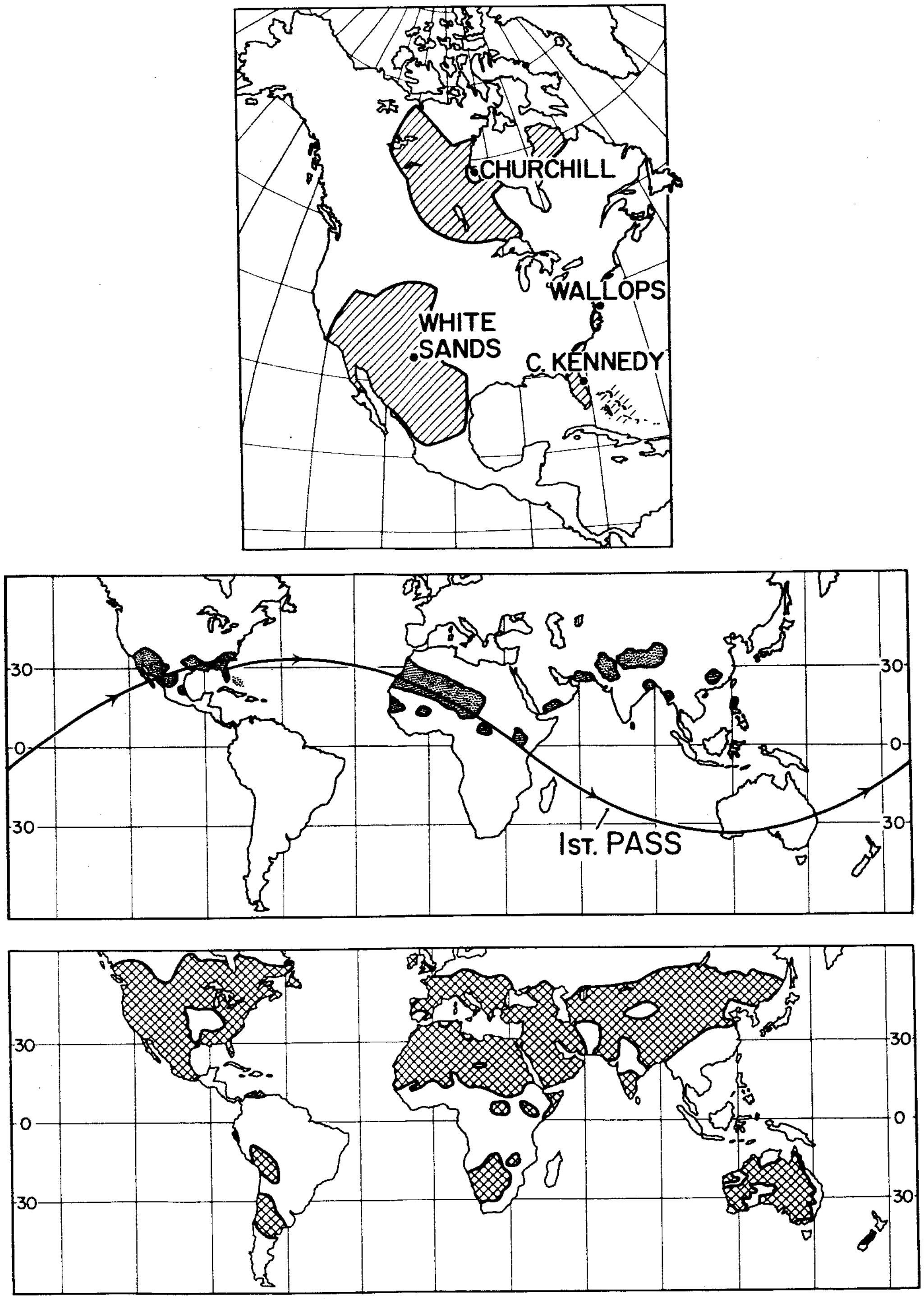


Figure 1. Areas covered by usable photography from (a) sounding rockets, including Mercury sub-orbital flights; (b) Mercury spacecraft; and (c) Tiros satellites I, III, and IV (based on the 58 reels used for ref. 17). 'Usable' photographs show the ground fairly free of cloud, not very obliquely, with some tone-variation discernible on it.

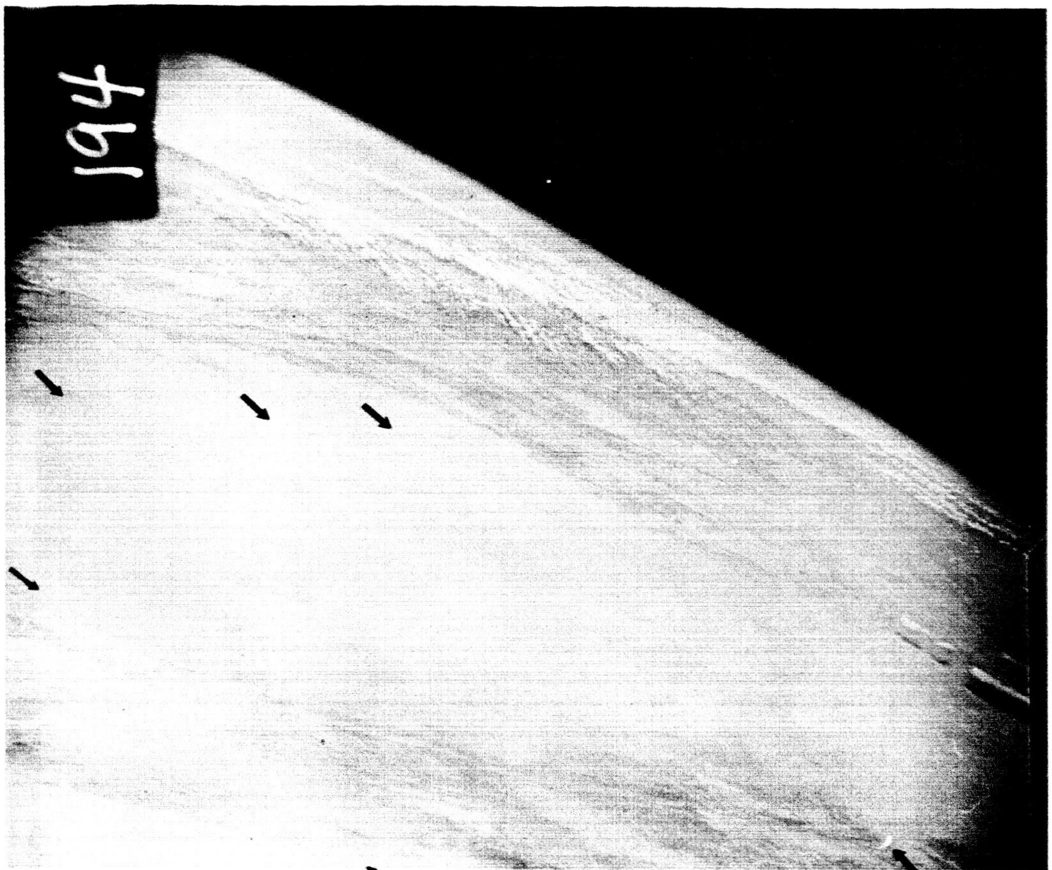


Figure 2. Tindouf structural basin in northwest Sahara. Light-toned area (near foreground) is Yetti, an area of subdued relief developed on Precambrian basement rocks. Dark stripes (foreground) are escarpments developed on outcrops of Paleozoic sandstones and limestones dipping away from the camera. Saltflats occur in many of the intervening vales. Light area (middle distance) is Hamada du Dra, a plateau of flat-lying Pliocene limestone. Beyond, forming the other limb of the downfold, is another scarpland developed on beds dipping towards the camera, and another Precambrian area, the Anti Atlas, partly cloud-covered. On the original photos, five families of structural lineaments are apparent on the Hamada du Dra. The most persistent family (arrows) trends N.W.-S.E. and can be followed across the hamada and the Paleozoic and Precambrian rocks to the S.E. for a total of 800 Km. (500 mi.). They must represent deep-seated fractures in the basement rocks, and seem to be regularly spaced about 50 Km (30 mi.) apart. Photograph from Mercury MA-4 satellite. Frame 194. Height 165 Km. (102 stat. mi.) above position 24.90° N, 8.74° W. Exposed about 2:30 p.m. local time (GMT), 13 Sept. 1961. Principal axis of camera was inclined 65° from vertical and pointed in direction N21°E. 70 mm Super Anscochrome color film. 1/500 sec at f/8. f=75mm. Field of view 45°. (Figs. 2, 3, 4, 7, 8, 9, courtesy NASA Manned Spacecraft Center).

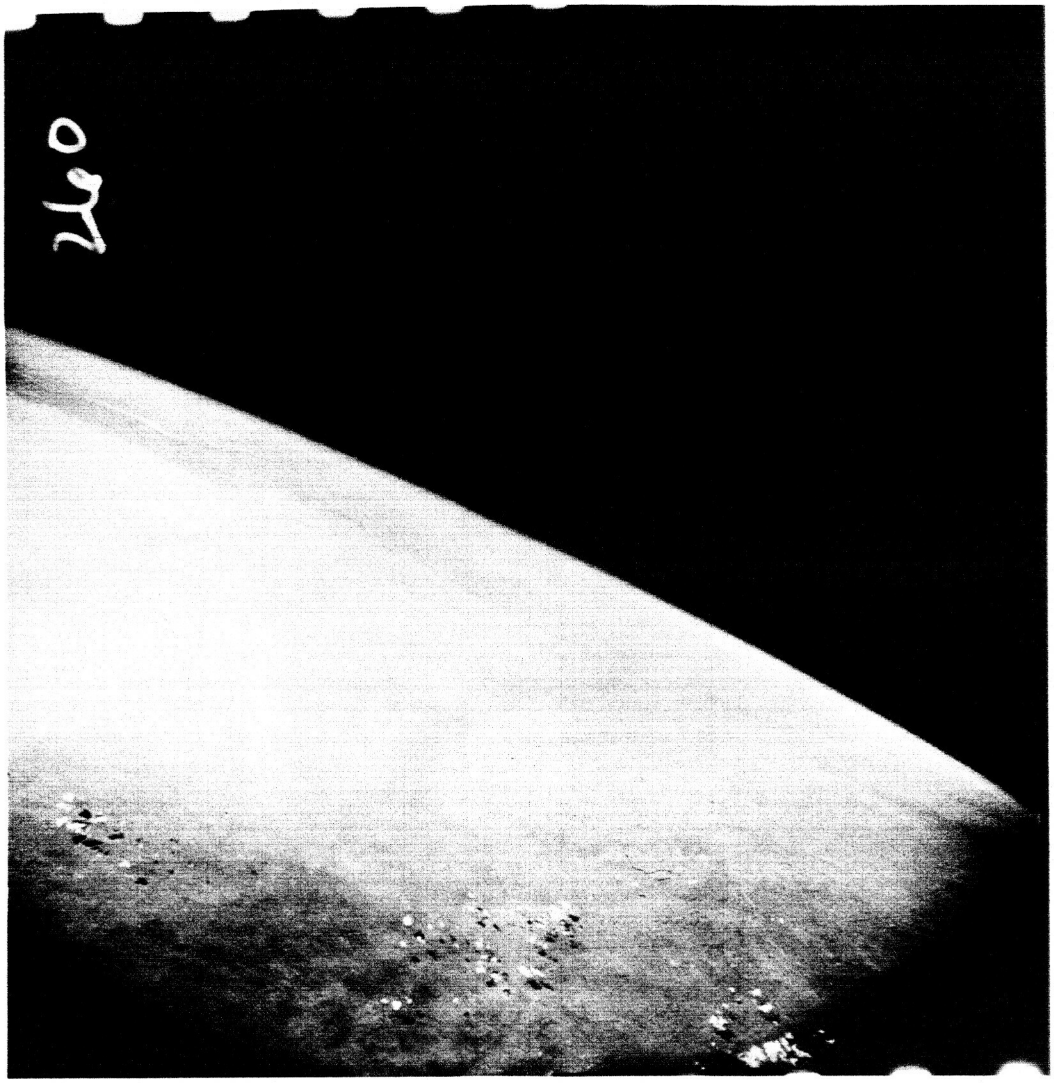


Figure 3. Southern edge of Sahara N of L. Chad. The darkening in tone between middle distance and foreground is the transition from sub-desert steppe (low perennial plants widely spaced) to wooded steppe (drought-resistant shrubs and low trees, discontinuous short grass after the rains). Dark area (left background) is Tibesti, a mountainous area of basalt, which rises abruptly to over 3300 m (11,000 ft.). Borkou (middle distance and foreground), a basin only a few hundred feet in altitude, extends from Tibesti to L. Chad (not visible, directly beneath the camera). It is floored with alluvium, lacustrine limestones, and diatomites, the deposits of an immense lake which covered this area during the Pleistocene. A few clouds appear in the foreground and over Tibesti. Photograph from Mercury MA-4 satellite. Frame 260. Height 175 Km (109 stat. mi.) above position 12.70°N, 15.27°E. Principal axis inclined 76° from vertical and pointed N32°E. Other details as fig. 2.

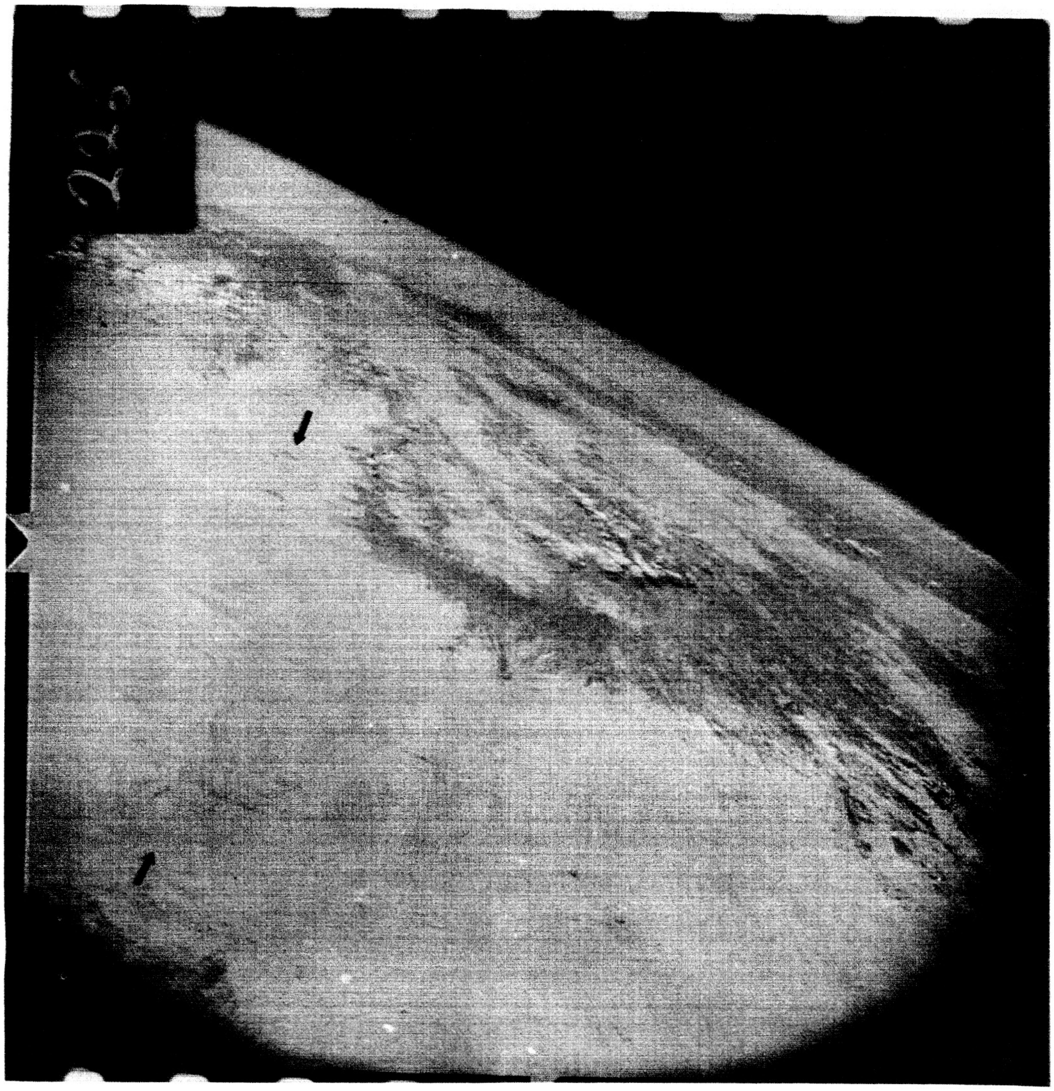


Figure 4. Dark area (right middle distance) is Ahaggar, central massif of Sahara, which reaches 3003 m (9900 ft.). A few clouds lie over it. It is mainly composed of metamorphosed Precambrian sediments. A N-S structural trend is obvious and an E-W trend also discernible. Light-toned area (foreground) is part of Tanezrouft, a gravel desert developed on Precambrian rocks. Straight feature (left foreground, arrows) is a low escarpment, facing W, very likely developed along a fault. Wadis crossing it appear dark. It does not appear on the 1:2,000,000 maps either as a fault or as a continuous rock-type boundary. Long dark area (background) is the Tassili n'Ajjer. (Compare figs. 5 and 11). Photograph from Mercury MA-4 satellite. Frame 226. Height 169 Km (105 stat. mi.) above position 19.41°N, 3.40° E. Principal axis inclined 67° from vertical and pointed N26°E. Other details as fig 2.

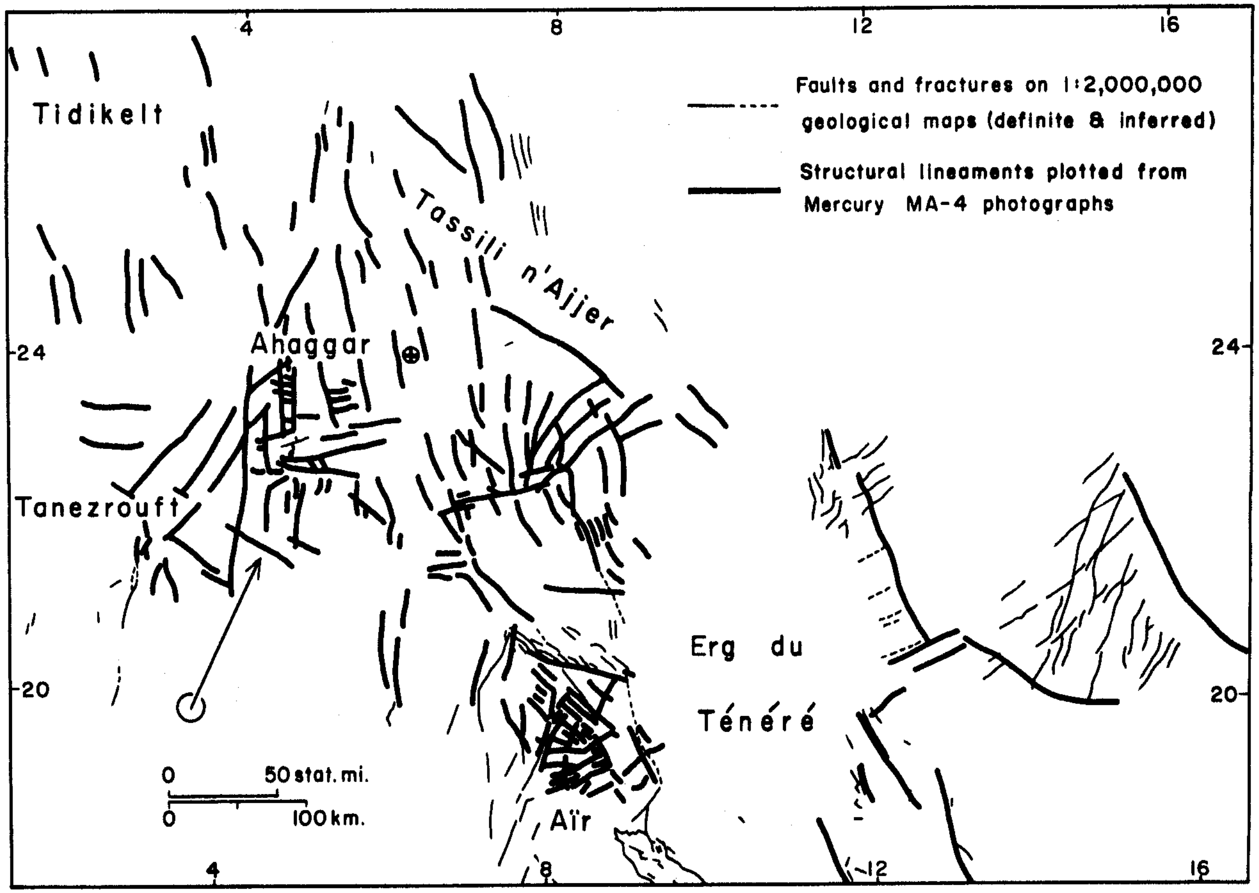


Figure 5. Structural lineaments of the central Sahara plotted from Mercury MA-4 photographs. Arrow shows direction camera was pointing when figure 4 was taken. Circled cross marks location of center cross of figure 11.

Figure 6. At top of picture (north) is city of El Paso. Just N.E. of it are runways of two airfields. Lines radiating from city are roads and railroads. A dark ribbon of irrigated cultivation extends S.E. from it along Rio Grande. Lines of bluffs bound the river valley. In S.W. (Mexican) half of photo ranges of hills (dark) trend parallel to Rio Grande. Playa-like deposits (white) occupy lowest parts of intervening basins. (Ref. 9). Photograph from Aerobee rocket NASA 4.87, 161 Km (100 stat. mi.) above White Sands Proving Ground. Camera 1, frame 63611. Fired about nnon, 17 June 1963. 70 mm Kodak Aerographic infrared film with Wratten 25A filter (red). 1/1000 sec at f/11. f=150mm, giving 30° angle of view. (Photo courtesy NASA Goddard Space Flight Center, Sounding Rocket Branch).

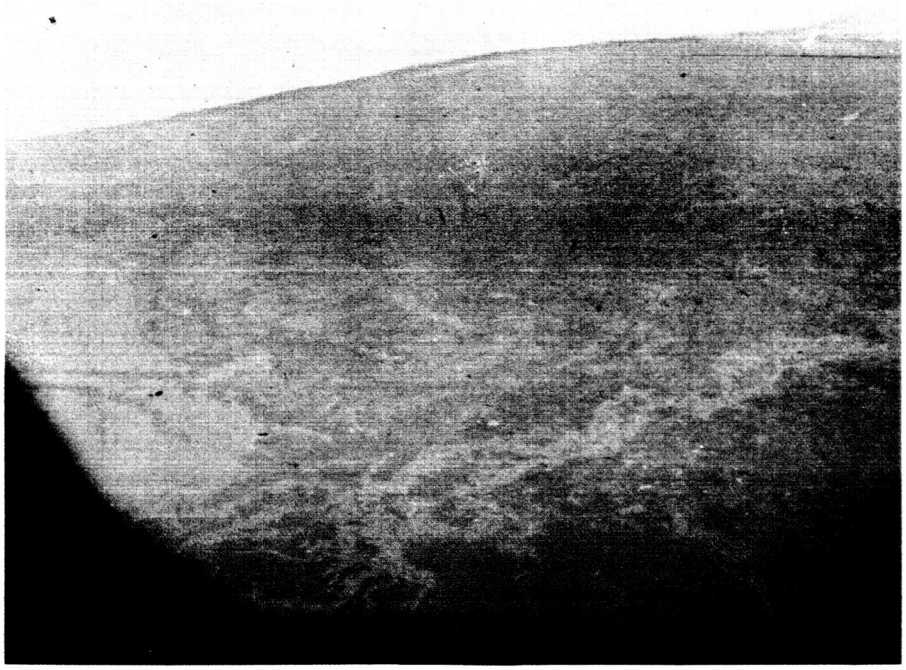


Figure 7. View west over N.W. Louisiana and (foreground) part of the Mississippi-Red River delta. White area (background) is stratus cloud over Texas. Edge of cloud is approximately along Texas/Louisiana boundary. Dark areas on ground are forested, while light areas are not. Over most of this area rivers and former rivers are followed by bands of non-forested land. The most conspicuous band follows the Red River. Southern part of area is generally grassland, and forest occurs only along streams. The rivers themselves are not easily visible. Photograph from Mercury MA-5 satellite. Frame 94. Height about 158 Km (98 stat. mi.). Position about 32°N, 90°W. 29 November, 1961. 70 mm Super Anscochrome color film. 1/500 sec at f/6.3. f=75 mm. Field of view 45°.

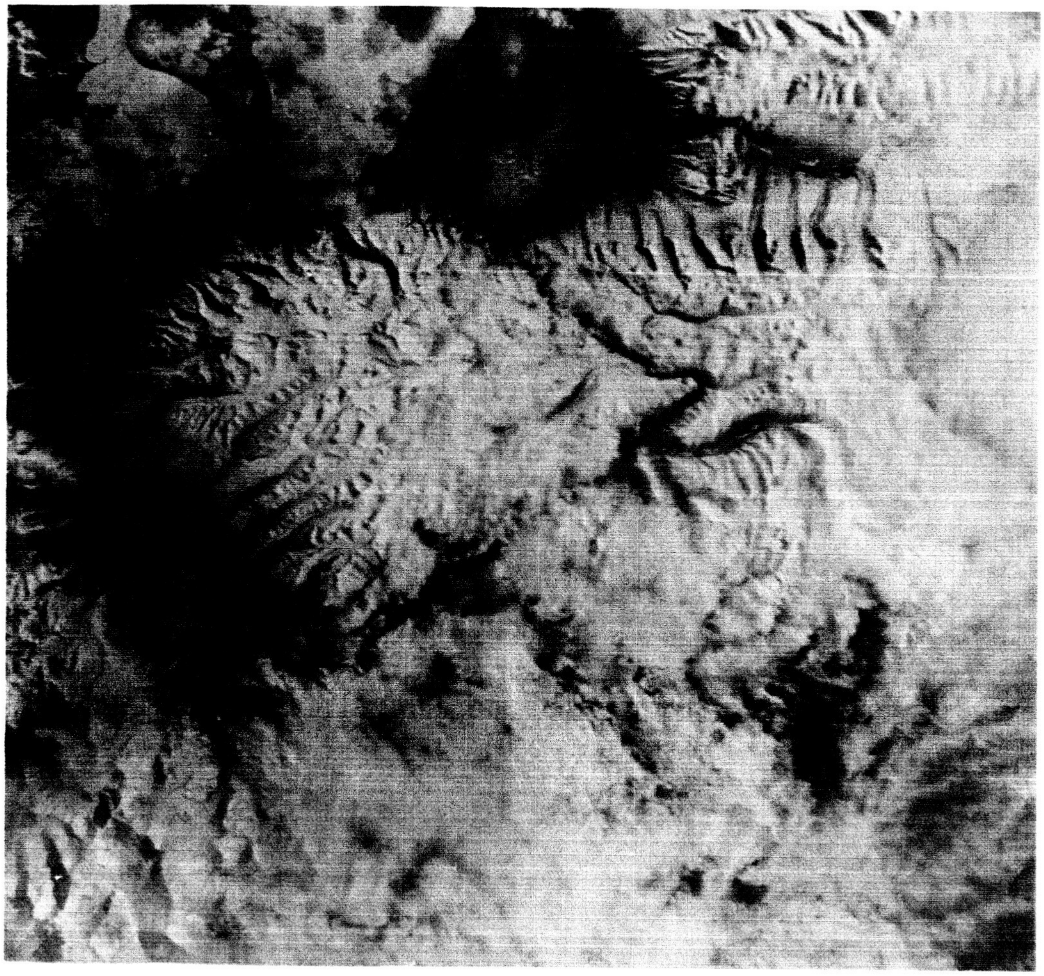


Figure 8. Part of Himalayas in Tibet. Center at 30°25'N, 81°21'E. North is at top. In N.W. corner are Manasarowar and Rakshas lakes, ice-covered, surface elevation 4550 m (15,000 ft.). Center is Gurla Mandata mountain group, which rises above 7700 m (25,000 ft.). In W is valley of Humla Karnali R. In its tributary valleys, one can distinguish on the original what are probably glacier-dammed and moraine-dammed lakes. Sudden discharge of such lakes could cause disastrous floods in the populated Ganges plain, to which they drain. The extent of snow cover is obvious. The photo can probably add to knowledge of the basic planimetry of the area. S.E. half of photo obscured by cloud. Taken by Astronaut Cooper during Mercury flight MA-9, 15 May 1963. 120-size Anscochrome color film, 1/250 sec at f/16, f=80 mm. Field of view 52°.

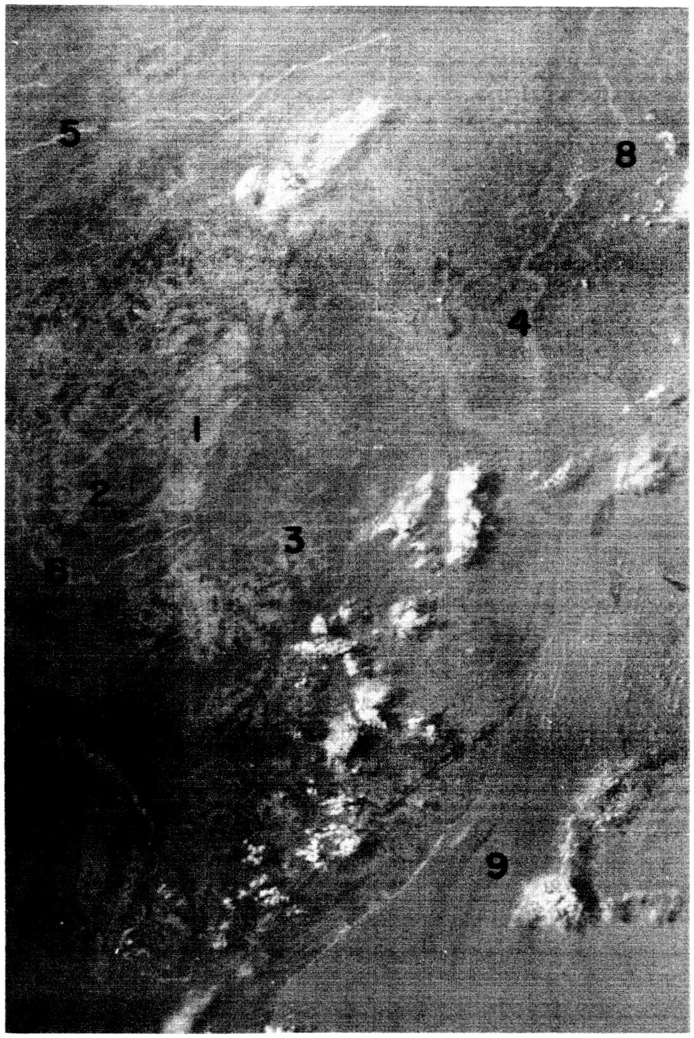


Figure 9. West Bengal. North is at top. In the W. the main tone-contrast is between forests (dark) and non-forested areas (light). One can rapidly distinguish several regions of differing land-use pattern, reflecting no doubt differences of rock, soil, relief, and groundwater conditions, e.g. a belt almost lacking forests (1), an area of cleared valleys and forested interfluves (2), an area of forested valleys and cleared interfluves (3). Rivers are Hooghly (4) Damodar (5), Kasai (6), Subarnarakha (7). Calcutta (8) is only discernible as the absence of the rural land-use mosaic. Clear and silt-laden water can be distinguished in the Bay of Bengal (9). Portion of photo from Mercury flight MA-9. Details as for fig. 8.

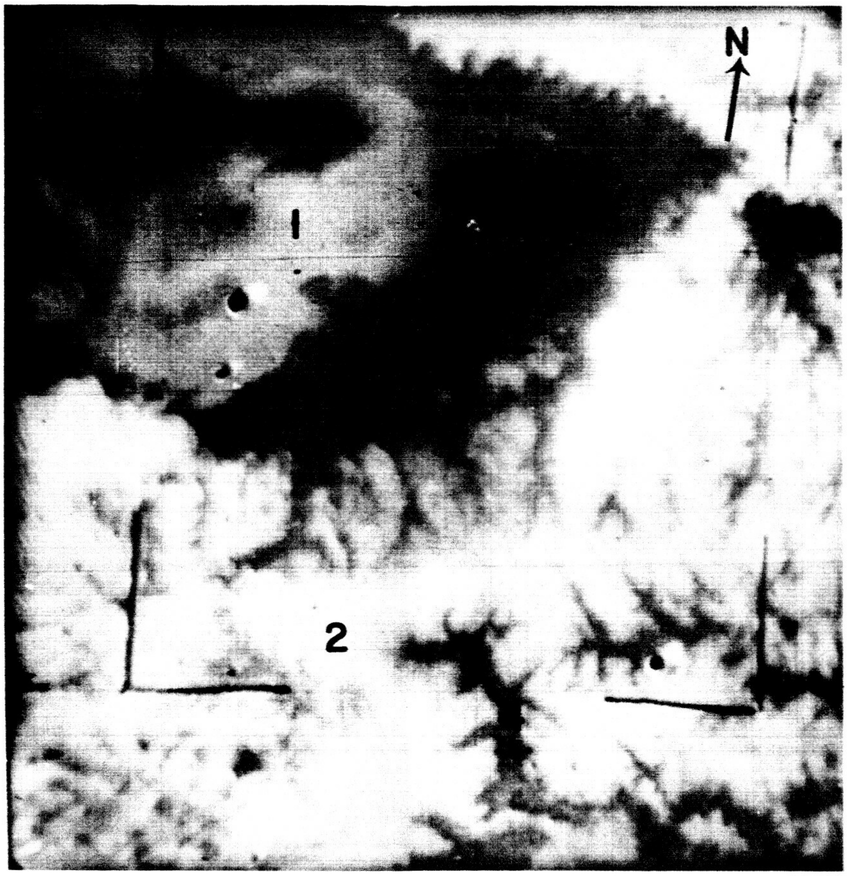


Figure 10. Narrow-angle Tiros picture of Central Asia. 1. Eastern half of Issyk-Kul, a salt lake, surface elevation 1600 m (5300 ft.), ice-covered. 2. Snow-covered mountain ranges, part of the Tien Shan, rising above 5000 m (16,000 ft.) in places. 3. Dark areas are valleys and lowlands free of snow. 4. Valley of the Uch Kul. Tiros I, sequence 724 T1, frame 11, 21 May 1960, 0813 GMT. Center cross at 42.5°N, 78°E. The volcano-like holes are flaws on the TV camera's receiving vidicon tube.

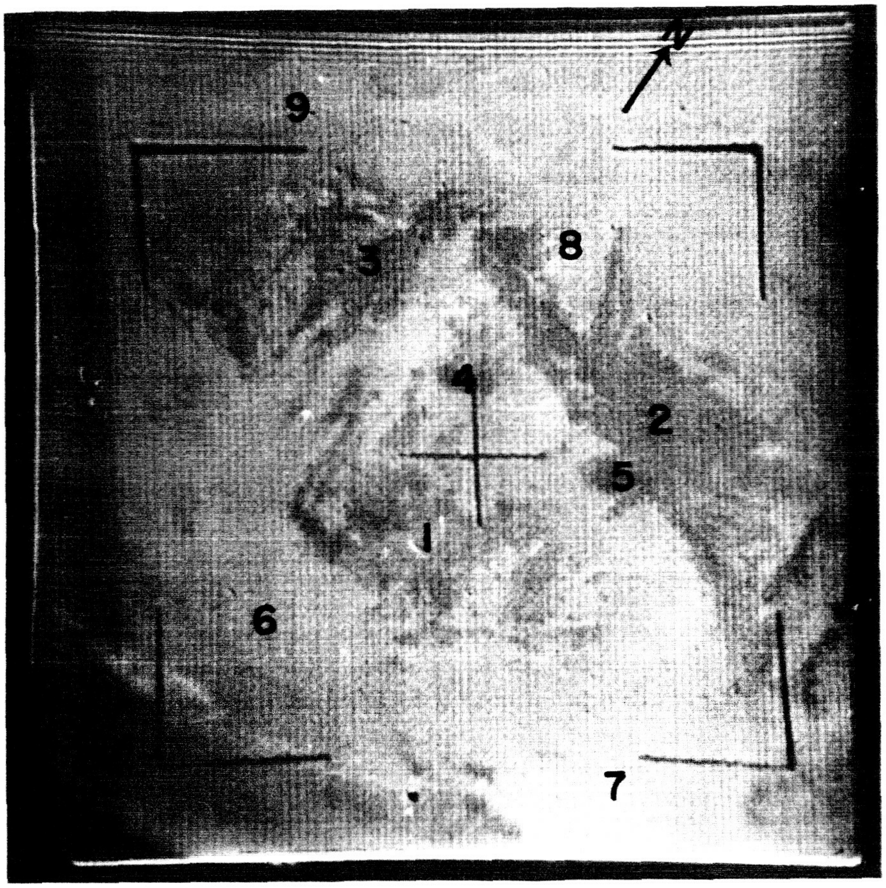
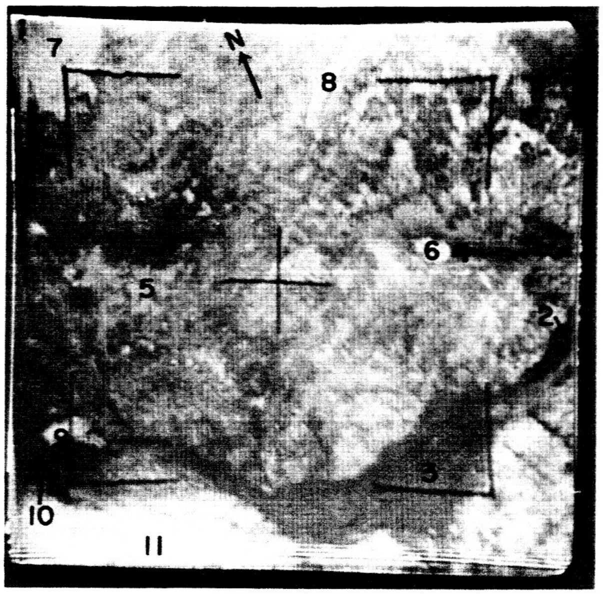


Figure 11. This medium-angle Tiros picture shows the same area of the central Sahara that figs. 4 and 5 show. The dark areas represent rocky uplands, e.g. Ahaggar (1), which is composed of Precambrian crystalline rocks; and Tassili n'Ajjer (2) and Mouydir (3), which are composed of Paleozoic sandstones. The darkest areas are basaltic, e.g. the central and western Ahaggar (1), Edjere (4), and Adrar des Ajjers (5). Light areas have surfaces which are gravelly, e.g. Tanezrouft (6); sandy, e.g. Erg du Ténéré (7), Erg Tifernine (8); or clayey, e.g. Tidikelt (9). Tiros IV, sequence 1162T2/61, frame 8, 30 April 1962, 1000 GMT. Center cross at 24.3°N, 6.5°E.



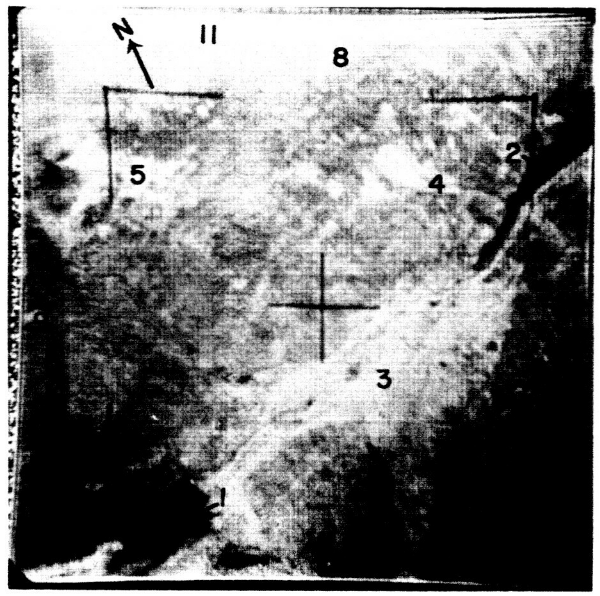
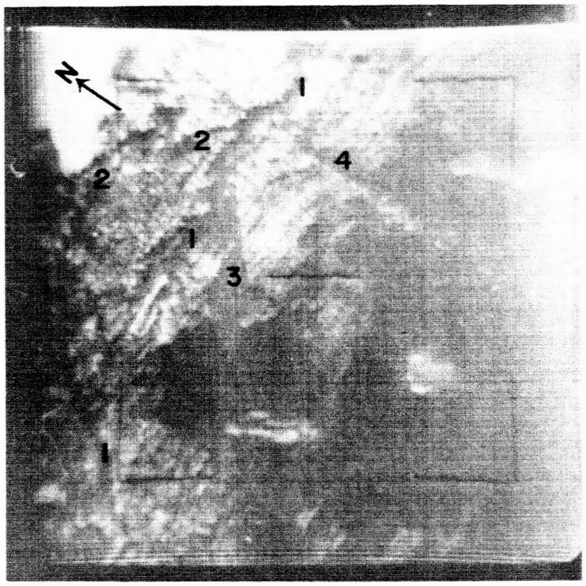


Figure 12. Medium-angle Tiros pictures of southern Quebec.

In fig. 12a (above), taken on 4 April 1962, all water bodies are ice-covered except L. Ontario (1) and St. Lawrence estuary (2). The whole ground is snow-covered, but the cleared areas of the St. Lawrence lowlands (3), L. St. John lowlands (4), and the Clay Belt (5) appear lighter than the surrounding forested areas because in the latter the snow-cover is obscured by trees. The snow-cover brings out details in the St. Lawrence lowlands, but L. St. John cannot be distinguished from the surrounding snow-covered fields. Tiros IV, sequence 792D2, frame 3, 1835 GMT.

Figure 12b (below) was taken only 14 days later, on 18 April 1962. By this time snow had disappeared from the St. Lawrence and L. St. John lowlands, but not completely from the Clay Belt. L. St. John (6), still ice-covered, is now conspicuous. Snow remains in the forests because it is shaded by trees, and is at a higher elevation. Consequently, these areas now appear lighter than the cleared areas. Tiros IV, sequence 992D2, frame 24, 1516 GMT.

Other landmarks on figures 12a and b include James Bay (7), L. Mistassini (8), L. Nipissing, (9), Georgian Bay (10). Cloudy areas are marked 11.



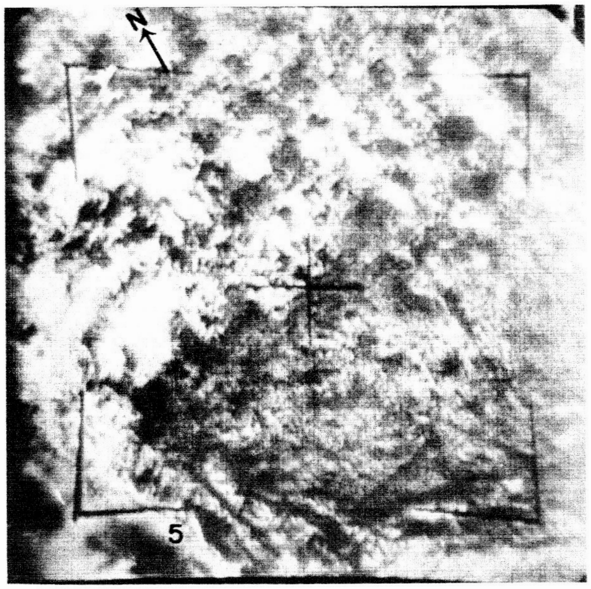


Figure 13. Wide-angle Tiros pictures of Amazon basin. White areas are clouds, mainly the cumulus or cumulonimbus typical of tropical afternoons, while dark areas are forested surface below.

In figure 13a (above) valleys of Amazon (1), Rio Negro (2), Purus (3), and Aripuana (4) are cloud free. This may be because the valleys contain so many rivers, lakes and swamps that daytime temperatures remain lower than in intervening areas, and convective clouds do not form. The clouds emphasize straightness of edges of Purus and Aripuana valleys, which can only be of structural origin. Tiros III, sequence 508T2/06, frame 18, 16 Aug. 1961, 1800 GMT.

In figure 13b (below), straight lines, probably of similar origin, are visible in S.E. corner, just E. of Andes (5). Center cross is approximately at $2^{o}S$, $76^{o}W$. Tiros III, sequence 77T1/76, frame 10, 17 July 1961, 1802 GMT.