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# A Search for Life on Earth at Kilometer Resolution

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A search for life on Earth at kilometer resolution, using several thousand photographs obtained by the Tiros and Nimbus meteorological satellites, has been undertaken. No sign of life can be discovered on the vast majority of these photographs. Due principally to the small contrast variations involved and the difficulty in reproducing observing conditions at satellite altitudes, no seasonal variations in the contrast of vegetation could be detected. Of several thousand Nimbus 1 photographs of essentially cloudfree terrains, one feature was found indicative of a technical civilization on Earth—a recently completed interstate highway—and another suggestive feature was discovered, possibly a jet contrail. A striking rectilinear feature was found on the Moroccan coast; however, it appears to be a natural peninsula. An orthogonal grid, discovered in a Tiros 2 photograph, is due to the activities of Canadian loggers, and is a clear sign of life. It appears that several thousand photographs, each with a resolution of a few tenths of a kilometer, are required before any sign of intelligent life can be found with reasonable reliability. An equivalent Mariner 4 system—taking 22 photographs of the Earth with a resolution of several kilometers—would not detect any sign of life on Earth, intelligent or otherwise.

## INTRODUCTION

The United States spacecraft, Mariner 4, was designed to acquire a maximum of 22 photographs of the planet Mars, each containing about $2 \times 10^5$ bits, and with a ground resolution of a few kilometers. The scan pattern crossed the Martian deserts Phlegra and Zephyria—west of Amazonis—and into the dark area Mare Sirenum. Each of these regions contains a network of "canals," according to Lowell and his followers (see, e.g., Slipher, 1962). The brilliant success of the Mariner 4 photographic mission should not obscure the fact that it was designed for geological investigation and not for a remote biological reconnaissance of Mars. Speculation has appeared—and not in the popular press alone—that the Mariner 4 photographic mission represents a search for life on Mars. In order to obtain some calibration of the possibility that kilometer resolution photography may detect life on Mars, let us consider the situation reversed, and investigate the prospects of detection of life on Earth by kilometer resolution photography.

## THE TIROS AND NIMBUS SYSTEMS

Several hundred thousand photographs of the Earth are available in the 0.2- to 2.0-km resolution range, pictures obtained by the Tiros and Nimbus meteorological satellites of the National Aeronautics and Space Administration. These systems, managed by the Goddard Space Flight Center, are designed primarily for meteorological observations of the Earth's cloud cover. But since the Earth is not perpetually cloudbound, the photographs can also be used in a search for life on Earth. Through late 1964, there have been eight Tiros satellites launched. Their characteristic scientific payload is $\sim$300 pounds. The satellite is launched into an approximately circular orbit with nominal altitudes of 400 statute miles. Tiros is equipped with a 500-line vidicon system, with three lens subsystems having 12°, 76°, and 104° fields of view. Each of the Tiros vehicles has some combination of these three lens subsystems. At the nominal altitude, the 12° lens gives a resolution of about 0.2 km; the 104° lens, about 2.0 km.

The Nimbus I meteorological satellite has a payload of $\sim$800 pounds, and was launched into an orbit nominally ranging from 260 to 580 statute miles. Photographs from 300 miles altitude with a 36.5° field of view give a ground resolution of $\sim$0.4 km.

The wide-angle lens of the Tiros system observes an area approximately $1000 \times 1000$ km. The perpendicular field of view of the narrow-angle lens is approximately $100 \times 100$ km. The Tiros pictures have an information content of about $1.5 \times 10^6$ bits. The Nimbus vidicon system, observing the same area, can accommodate $3.8 \times 10^6$ bits. For comparison, hand-held 35-mm cameras from manned orbiting missions yield pictures with $\sim 10^9$ bits information content. The frequency response of both Tiros and Nimbus optical frequency systems lies in the 0.45- to 0.8-micron range.

In short, there is a large body of data on satellite photographic reconnaissance of the Earth, with resolution superior to the Mariner 4 ground resolution on Mars.

## A Priori Estimates of the Detectability of Life on Earth

Before representative Tiros and Nimbus photographs were actually examined, we attempted to evaluate the possible range of terrestrial surface features attributable to biological activity and detectable with kilometer resolution. We wish to emphasize from the outset that there is a great difference between photographic reconnaissance with and without ground truth. In the case of the Earth, we know, or can deduce, from observations with vastly superior resolution, the significance of features with kilometer resolution. In the case of Mars, we lack such ground truth, and our interpretation of the significance of kilometer resolution features can only be based on first principles or on terrestrial analogy. Photographic reconnaissance for indigenous life on Earth is vastly simpler than the analogous problem for Mars. Yet, if kilometer resolution biological reconnaissance of the Earth proves inconclusive, it must certainly follow that kilometer resolution reconnaissance of Mars will also be inconclusive—unless the very unlikely (Sagan, 1965*a*) case materializes that a technological civilization in substantial advance of our own exists on Mars. On the other hand, if there are some manifestations of life on Earth which are clearcut and readily interpretable at kilometer resolution, then such features might profitably be sought for on Mars.

It appeared to us that no manifestation of animal life on Earth, short of the artifacts of a technological civilization, could be discernible at kilometer resolution. The most readily detectable indication of noncultivated vegetation on the Earth would appear to be seasonal changes, e.g., of deciduous trees, in the temperate zones. Much more readily visible should be the seasonal contrast changes of cultivated crops, particularly those of high contrast with the underlying ground, such as cotton. Large fields of a single crop—for which time variations occur synchronously throughout the field—are common with wheat, corn, and cotton. Among the areas producing the largest amounts of these crops are the United States, Canada, the Soviet Union, and China. Among the times and places of particular interest in this regard are those listed in Table I (van Royen, 1954; Time, Inc., 1961).

TABLE I
TIMES AND PLACES OF EXTENSIVE CULTIVATION OF REPRESENTATIVE CROPS

| Crop | Areas | Latitude | Longitude | Time of planting | Time of harvesting |
|---|---|---|---|---|---|
| Summer Wheat | North America | 112°W–98°W<br>102°W–96°W | 49°N–52°N<br>44°N–49°N | April–<br>May | August |
| | China | 114°E–120°E | 33°N–40°N | April–<br>May | September–<br>October |
| Winter Wheat | North America | 102°W–98°W | 36°N–40°N | September 1<br>(north)–<br>October 21<br>(south) | June 1<br>(south)–<br>July 11<br>(north) |
| | China | 114°E–120°E | 33°N–40°N | September–<br>October | May–<br>June |
| | U. S. S. R. | 40°E–65°E | 50°N–54°N | August<br>(north)–<br>October<br>(south) | July<br>(south)–<br>September<br>(north) |
| Corn | United States | 99°W–85°W | 40°N–44°N | April–<br>May | September–<br>October |
| Cotton | United States | 102°W–80°W | 32°N–36°N | March 20<br>(south)–<br>April 20<br>(north) | August<br>(south)–<br>January 1<br>(north) |

It should be noted that the detection of seasonal or secular contrast variations is accompanied by some serious difficulties. Not only must several satellite observations be made of the appropriate area during the appropriate season on a cloud-free day, but also, it is important that the angle of insolation and the angle of view be reproduced in successive photographs. Because vegetation has a highly nonuniform and rough structure, the reflectivity may depend significantly on the relative angles of the Sun and the spacecraft. Since even approximate reproduction of these conditions occurs only rarely, the search for seasonal variations was not pursued in any detail. A photograph of the Texas Gulf coast near the beginning of the cotton planting season is seen in Fig. 1. The bright streak to the left is a cloud pattern; the large, dark feature near the middle of the picture is the Gulf of Mexico; and the slightly brighter area in the upper right-hand half of the picture is the Texas Gulf coast. Note the relative lack of contrast in the land area. This is a feature which is very common in photographs of the Earth, and suggests that seasonal variations in deciduous forests or cultivated crops may be very difficult to detect.

In attempting a preliminary evaluation of the detectability of intelligent life on Earth at kilometer resolution, it seemed apparent to us that the features of greatest interest were straight lines and arrays of straight lines. In the construction of communications networks and in his expressions of territoriality, considerations of economy and geometry together encourage man towards linear constructions. When the scale of construction is so large that Euclidean geometry is inapplicable, great and small circles are expected; but generally speaking, the scale of reworking the Earth's surface has not yet reached non-Euclidean proportions. Straight lines have the additional feature that they are not commonly produced in large scale by geological processes. Such natural rectilinear features as faults, rays of impact and volcanic craters, and rivers each have distinctive geometrical aspects which should lead to their recognition in photography of the Earth. On some other planet, where unfamiliar geological processes may operate, such recognition may be more difficult.

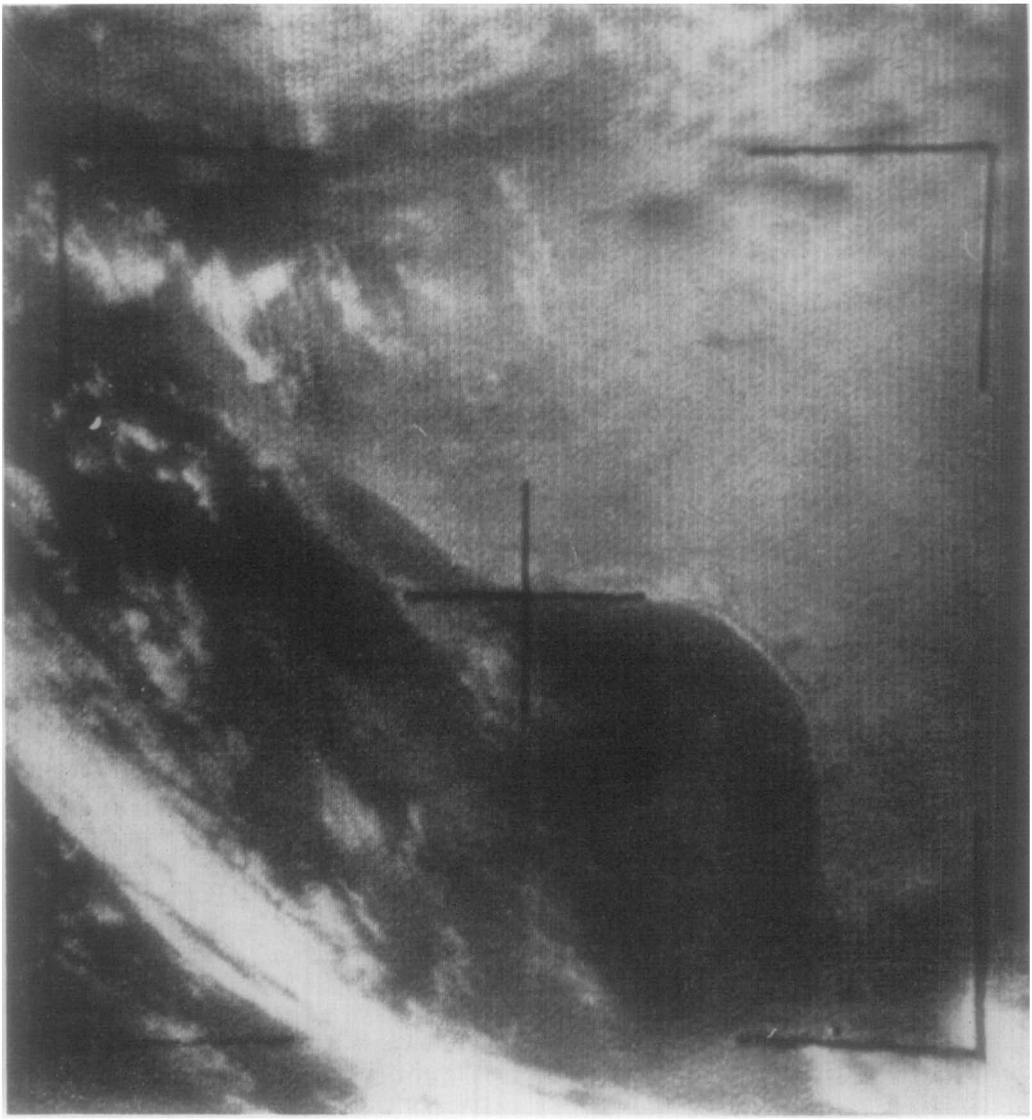

FIG. 1. Tiros 7 photograph of the Texas Gulf coast, orbit 4057, 19 March 1964.

The most obvious large-scale linear constructions of man are roads, railways, bridges, breakwaters, dikes, and great walls. Connected with transportation are two other features contemporary in nature: the condensation trails of jet aircraft, and the wakes of ships.

There are some criteria which can be used to distinguish rivers and roads. Rivers generally join each other at acute angles, forming the characteristic dendritic patterns of tributary systems. Road junctions are much more nearly at right angles. In addition, rivers rarely flow parallel to the shore or to each other for long distances. On the other hand, roads often parallel the coast, and not uncommonly, each other.

While the width of even large superhighways is smaller than the best ground resolution discussed here, this does not exclude the possibility of detecting roads and similar linear features with the Tiros and Nimbus systems. It is well known that, provided such features have high contrast with their surroundings, they are fairly easily visible even if their widths are well below the theoretical resolving power. Such rectilinear features must, however, be at least several resolution elements long.

The Great Wall of China is the only great wall with much chance of being observed. It is much larger than any other wall, averaging 8 meters in height and 5 to 10 meters' thickness at the base, sloping to 4 meters at its top (Columbia Encyclopedia, 1963). However, it is not a very straight feature, and its contrast with the surroundings is low. The Great Wall is therefore not an ideal rectilinear object for satellite photography.

Roads are longest, straightest, and widest in the United States, where transportation by automobiles is most common. Due to the relative paucity of superhighways elsewhere, the search for roads would best be carried out on photographs of the United States. A divided highway of six or eight lanes has a width between 30 and 40 meters, and this is much wider than railroad tracks. Both roads and railroads are sometimes cut through forests and other vegetation, and the resulting high-contrast swath might be visible even if the railroad or highway were not. The areas chosen for our first investigation contain certain sections of the Interstate and Defense Highways 5, 10, 35, 40, 90, and 95, and the Garden State Parkway in the Eastern United States (Portland Cement Assn., 1964).

The second class of linear objects is comprised of linear features in the water—dikes, breakwaters, and bridges. For example, the sea wall forming the boundary of the Zuider Zee, in the Netherlands, is perfectly straight for more than 25 km, and is $\sim$0.1 km wide. Bridges are usually too short to be visible—they are never very many resolution elements long, if the resolution is about 1 km—but for those which are long enough, their straightness and functional locations (connecting two peninsulas, or crossing a river or bay) are good indicators of intelligence. The widest and longest are again in the United States. They have widths of up to six lanes (about 30 meters), and lengths near 2 km. Suspension bridges might sometimes be more readily seen, because their shadows on the water would render their apparent width greater. Putting a premium on rectilinearity, we selected among the largest bridges the George Washington, the Golden Gate, the Mackinac Straits, the Verrazano Narrows, and the Lake Washington Floating Bridge (Seattle), all in the United States.

The last class of linear features includes transient indications of transportation. The largest such features are jet aircraft condensation trails and the wakes of large ships, both in water and in breaking ice. Icebreakers, however, generally follow the path of least resistance in the ice, and this is very rarely straight. In contrast, contrails and water wakes are almost always rectilinear. Especially in the case of water wakes, the angle of insolation is important, since the rectilinear feature is to be contrasted against surroundings of the same material. Both contrails and water wakes would point to intelligence, especially because they could be seen to dissipate and reappear in the same region at a later time, due to the fact that the routes of commercial shippers and airlines are fairly well fixed, and are traversed regularly.

Long, straight jet contrails should be common anywhere on the Earth, because of the world-wide air transportation system, but they would best be seen against the dark background of an ocean. The heavily traveled North Atlantic seems to provide the best opportunity for contrail detection; but the ocean is large, and the chance of spotting such a contrail on a given photograph is small. Some concentration of contrails near cities might be expected.

The wakes of ships are most concentrated near straits and channels of importance. The obvious points of concentration include such locales as New York Harbor, the Straits of Gibraltar, the Suez and Panama Canals, the Red Sea, the English Channel, the Straits of Malacca, and the Tokyo-Yokohama coastal waters.

### The Observations

With the foregoing as *a priori* background, a selection was made from available Tiros and Nimbus photographs.

In the Tiros film library of the Goddard Space Flight Center, there are several hundred thousand Tiros photographs, of which only a few thousand portray with high quality land areas fairly clear of clouds. From this file, we selected photographs of areas chosen above as likely prospects for the detection of life on Earth. No clear sign of seasonal vegetation changes was detected on the selected photographs. Nimbus 1, being in operation only 26 days, produced roughly $10^4$ pictures. Because of the short operational duration of this flight, no significant analysis of seasonal variations in vegetation could be attempted.

Of the Nimbus 1 photographs, a few hundred showing cloud-free areas and fine detail were selected in a random extraction of high-quality pictures made independently of any search for life on Earth. These photographs were enlarged and each examined in detail. The vast majority of the selected Tiros and Nimbus 1 photographs showed no features which seemed indicative of life on Earth. One high-resolution photograph of Tiros 2 and seven high-resolution photographs from Nimbus 1 were of interest, and are displayed and described below.

The lines of white and black dots, and the right-angle cross and T-shaped black features, are fiducial markings superposed on the camera system for orientation of the photographs. In all of these photographs, the direction of video scan is horizontal. One should therefore be wary about inter-

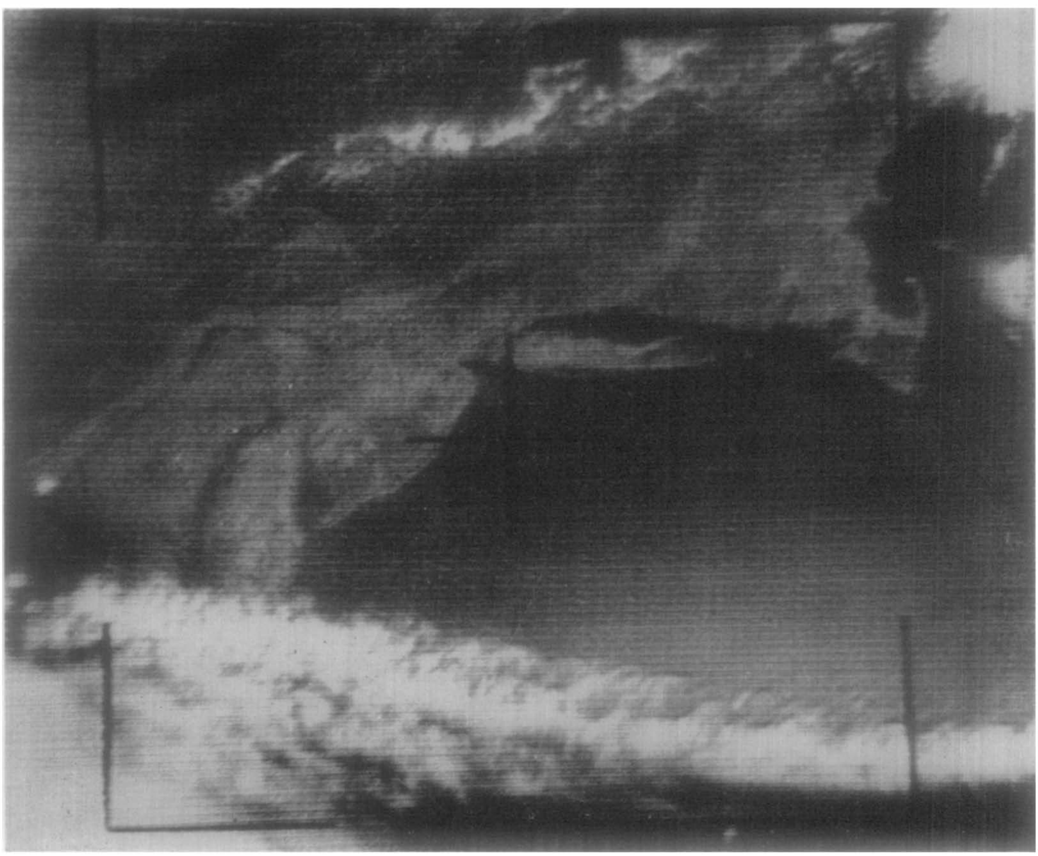

Fig. 2. Tiros 7 photograph of the eastern seaboard of the United States, orbit 0063, 23 June 1963.

preting any rectilinear horizontal markings as a sign of life, because system noise has a tendency to align itself horizontally. The width of the scanning lines on the scale of the enlarged photographs is 0.25 mm per line. Any feature appearing smaller than this should not be considered significant.

Figure 2 is a typical Tiros photograph of a relatively cloud-free region of the Earth. It displays the Eastern seaboard of the United States from Cape Cod to Chesapeake Bay at a resolution of a few kilometers. This is one of the most heavily populated and industrialized areas in the world. It is covered with an elaborate system of railroads and superhighways, all of which are entirely invisible. A careful search was made for the bridges across, for example, Chesapeake Bay, but with negative results. There was no sign of New York City, the world's largest metropolis. At a resolution of a few kilometers and at optical frequencies, there is no sign of life near the Eastern seaboard of the United States. Similar conclusions were obtained from photographs of the regions of London, Paris, Los Angeles, Chicago, Tokyo, Calcutta, and Cairo. Figure 3 is a photograph of the Florida peninsula. The causeway to Key West, a long and isolated feature, is entirely invisible.

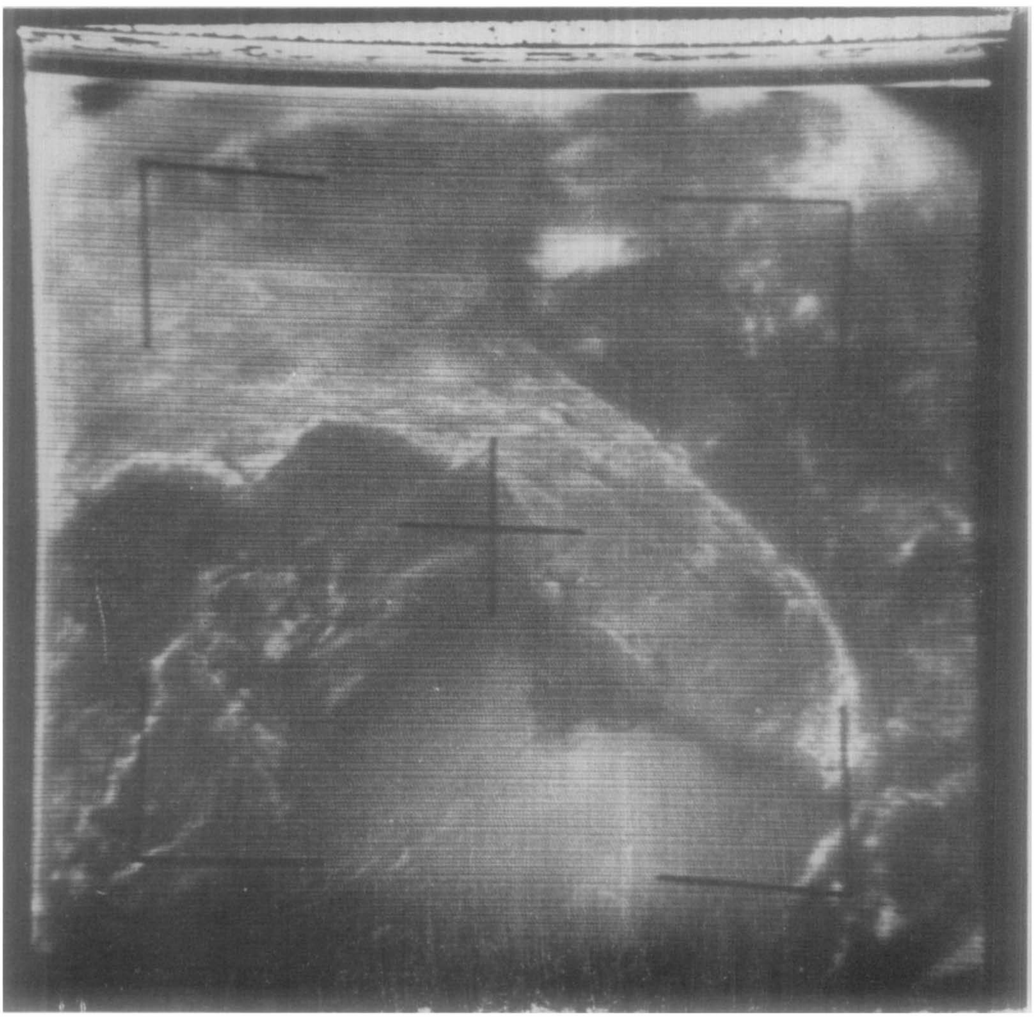

FIG. 3. Tiros photograph of the Florida peninsula.

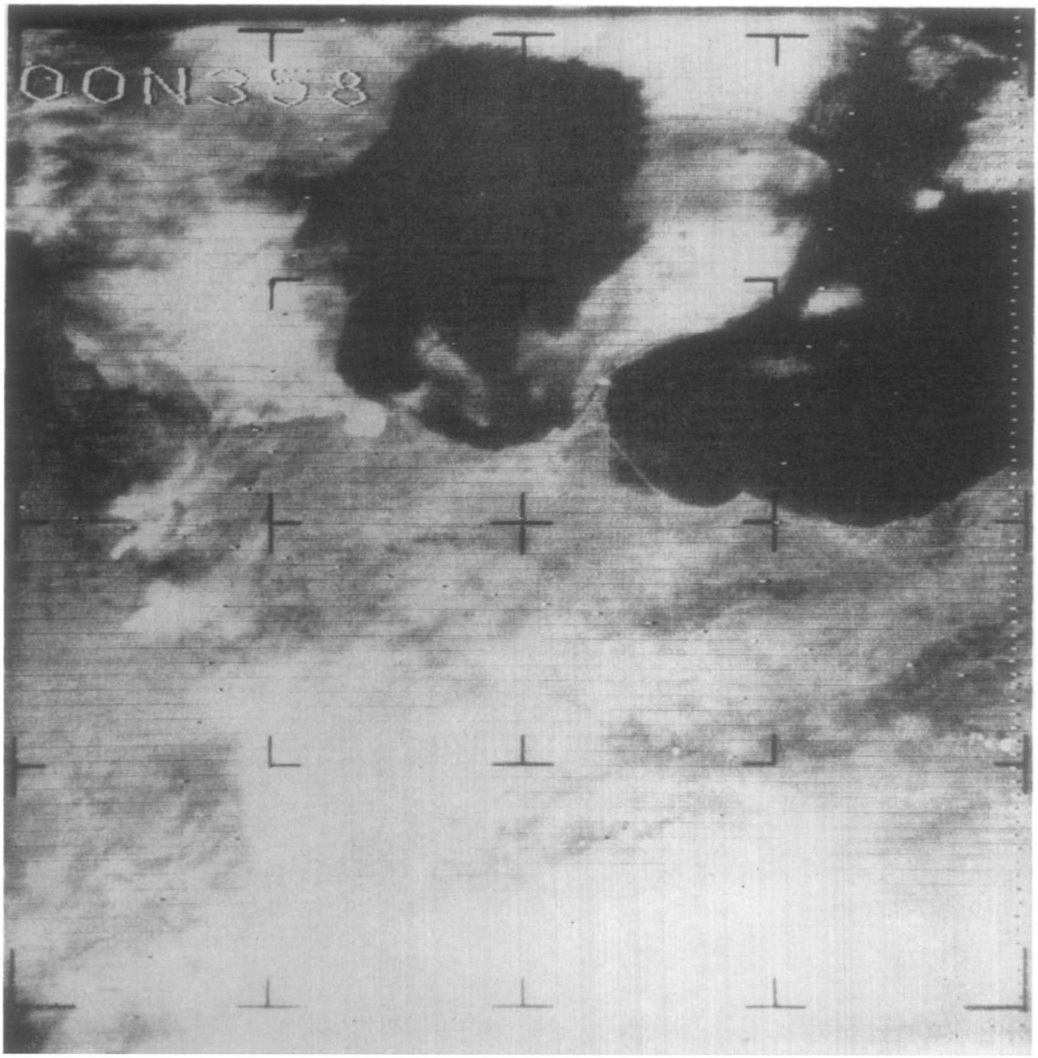


FIG. 4. Nimbus 1 photograph of the northern coast of Morocco, orbit 295, September 1964.

Figure 4 is a Nimbus 1 photograph of the northern coast of Morocco. The bright features north of the coast are clouds. The Mediterranean appears very dark. An apparently perfectly straight bright line can be seen extending across an expanse of water and connecting two land areas. This rectilinear feature is 25 km long and in some places 1.5 km wide. It corresponds closely to the kind of feature which we would tend to associate with intelligent life.

However, almost certainly, this feature is not a breakwater but a natural peninsula. From Fig. 4 there seems no reason to question the connectedness of this linear feature with the western peninsula. In the upper half of Fig. 5 is a drawing of the region we are here describing, taken from the Nimbus 1 print. In the lower half of the same figure is a drawing taken from a map in Mercator projection of the same area (U. S. Army Map Service, 1955). The Nimbus 1 projection is of course somewhat different from the Mercator. It is clear that the apparent rectilinear feature is not exactly rectilinear, nor is it connected with the peninsula at

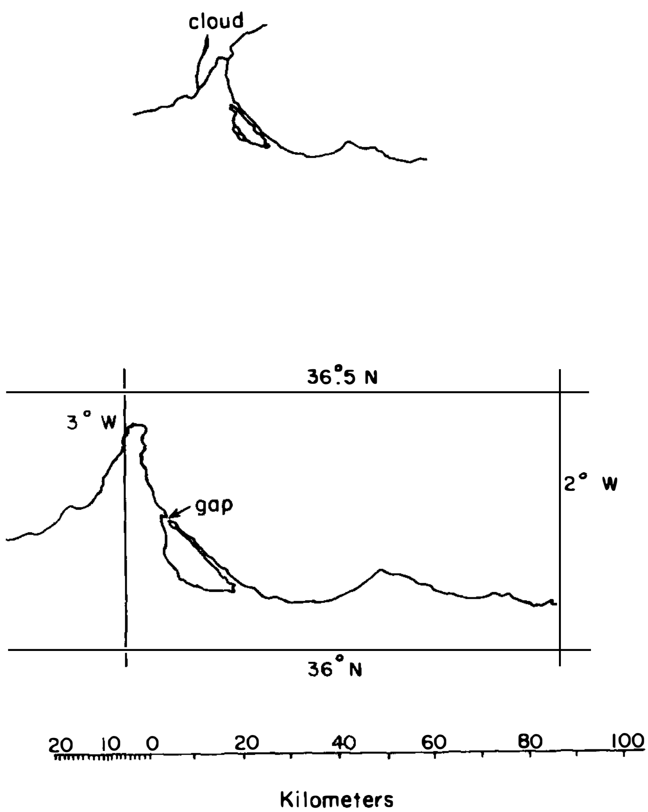


FIG. 5. Upper: Drawing of the appearance of a section of the northern coast of Morocco, from the Nimbus 1 photograph of Figure 4. Lower: Mercator projection cartography of the same region, taken from U. S. Army Map Service maps.

3° W. It is separated from the peninsula by 1.5 km of water. The discrepancy may be due to one or two bits of false data, or to the rectilinear feature actually extending to the peninsula at 3° W, but being covered over by water at the position of the gap. There is, however, a tendency, long known to students of the Martian canal problem (Antoniadi, 1930), for the human eye to connect disconnected features into rectilinear ones. This rectilinear feature in Morocco was found purely by accident from the randomly selected Nimbus photographs, and illustrates the danger of deducing the existence of intelligent life from rectilinear features on a planetary surface.

Other examples of linear features found on the Earth, but not due to intelligent activity, can be found in Fig. 6, where wave clouds over the Appalachians are shown, and in the discussion by Gifford (1964) on the seif sand dunes of the Arabian Peninsula.

Figure 7 is a Nimbus 1 photograph of the Tennessee area of the United States. Figure 8 is drawn from a tracing which attempts to reproduce all important linear details in Fig. 7. The Mississippi River, seen meandering towards the lower left corner, provides an excellent reference feature for comparison with existing maps. A map of the same area has been prepared in Fig. 9. In making tracings from such photographs, the decision as to what constitutes a continuous rectilinear feature is rather subjective; we decided not to try to depict details whose continuity might be illusory. With this constraint, the details observed were still sufficiently plentiful for some conclusions to be drawn.

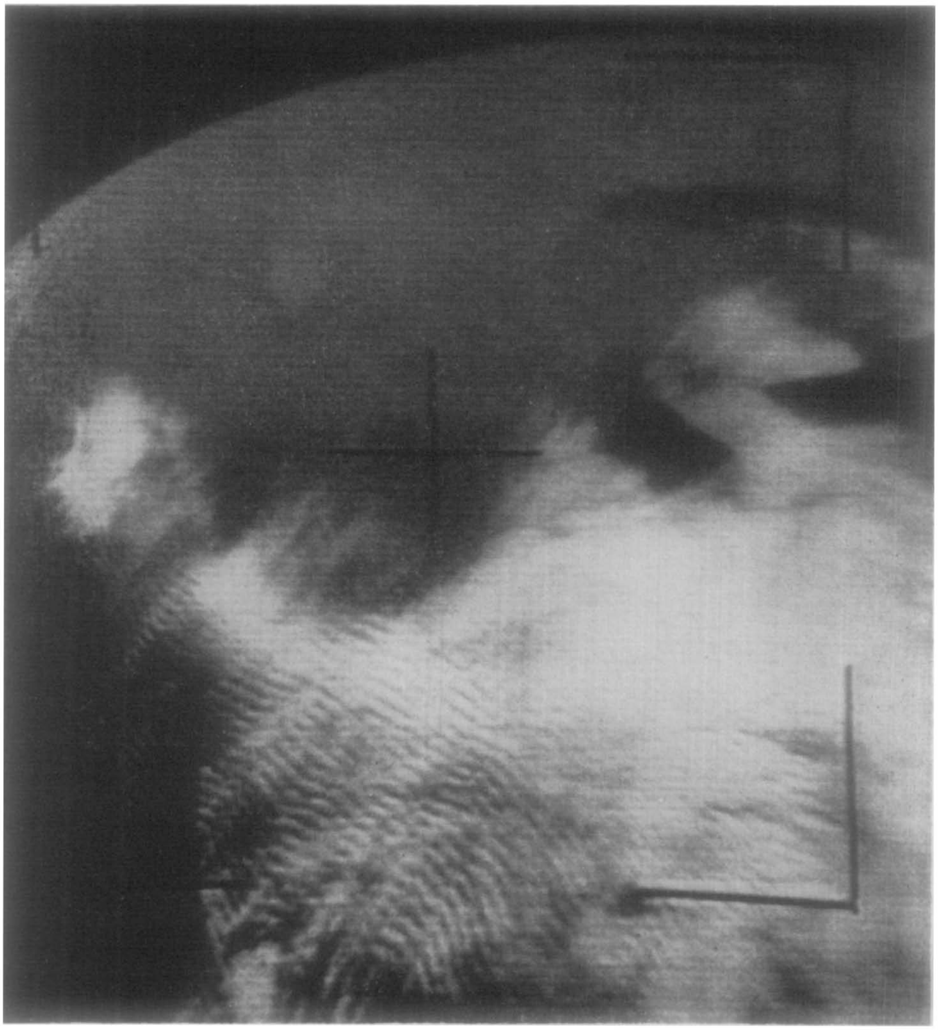

FIG. 6. Tiros 7 photograph of wave clouds over the Appalachians, orbit 4363, 9 April 1964.

Figures 8 and 9 were not drawn to the same scale; even if they were, the distortions introduced by the projection effects would preclude any detailed superposition of the features of the entire region. Nevertheless, the best technique for comparison was found to be superposition of small areas. The kinks, discontinuities, and linear features were especially helpful in performing the comparisons.

Both bright and dark lines appear in this photograph, the bright lines appearing almost exclusively in the lower center and lower right regions of the photograph. Examining either the photograph or the tracing, one sees significant differences between the characteristics of the bright and those of the dark lines. Some of the bright lines are connected with the Mississippi River and Kentucky Lake on the Tennessee River (center of Fig. 7) and can be attributed to sun glint on the water surfaces. Some of the dark tributaries along the Mississippi Basin are probably not large enough to exhibit sun glint; their presence is indicated by the dark vegetation of varying widths along the banks and beds. The dark lines all appear to join the Mississippi and its tributaries at acute angles, and are clearly part of the river system. In contrast, the bright lines cross each other and are less clearly connected with the Mississippi system.

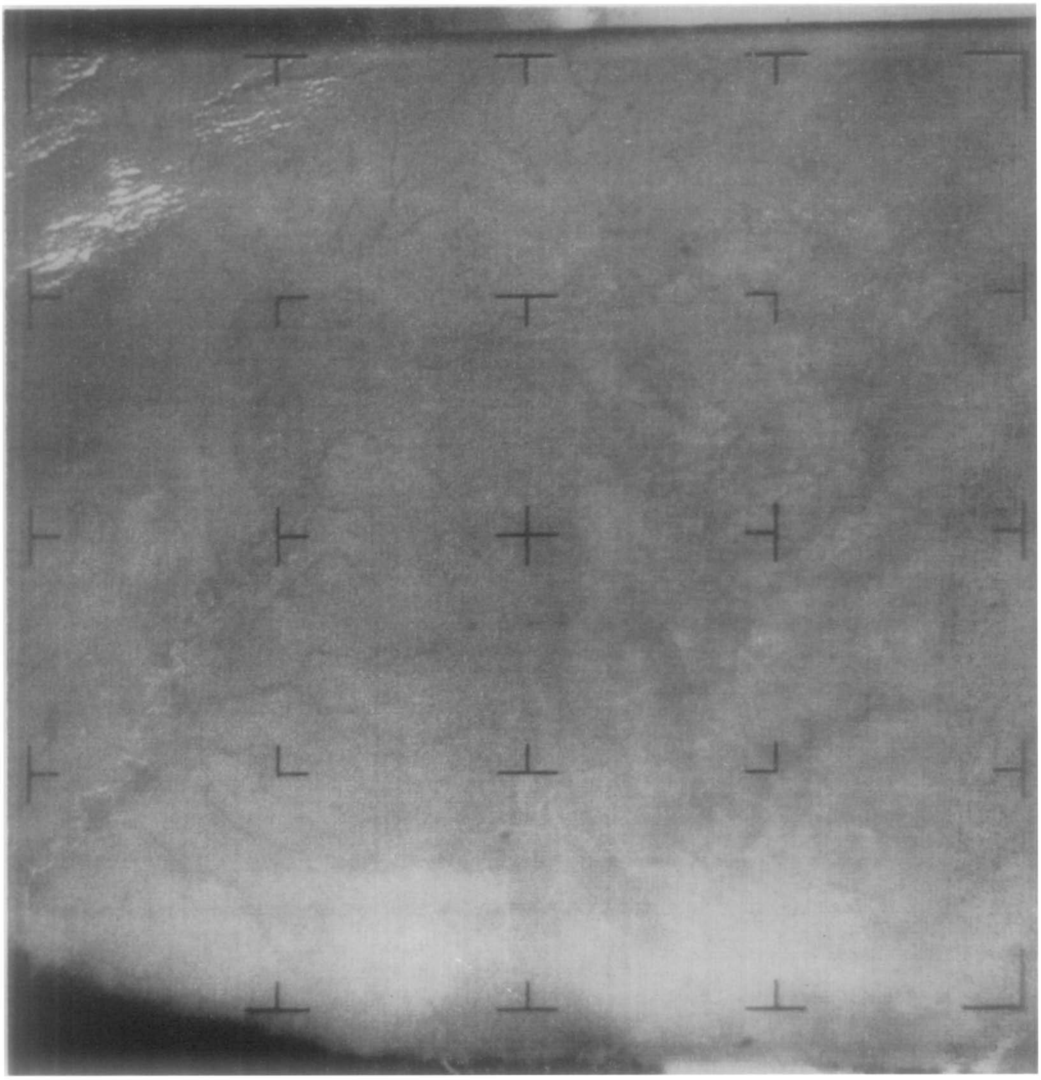

FIG. 7. Nimbus 1 photograph of Tennessee, orbit 196, 10 September 1964.

They are therefore the features of primary interest in the present context.

Since natural linear features are not expected both to be straight for extensive distances and to cross each other, at least one of the thin unbroken lines in Fig. 8 should represent a road. The line so designated is the only one which is fairly straight and which crosses more than one other linear feature.

There are three corresponding features on both the tracing of Fig. 8 and the map of Fig. 9; they are designated a, b, and c. Their correspondence leads to the conclusion that the line in question is indeed a road, namely Interstate Highway 40. The reason Interstate 40 is visible, while many other roads of comparable linearity and width are not (cf. Fig. 2) is due to the fact that this highway was, at the time it was photographed, a new one. A relatively highly reflecting surface had been made visible by cutting a swath through a forested region. The width of the swath ranged from 15 to about 50 meters, typical values for the interstate highway system. Thus, a major road has been observed, even though its width could be no more than

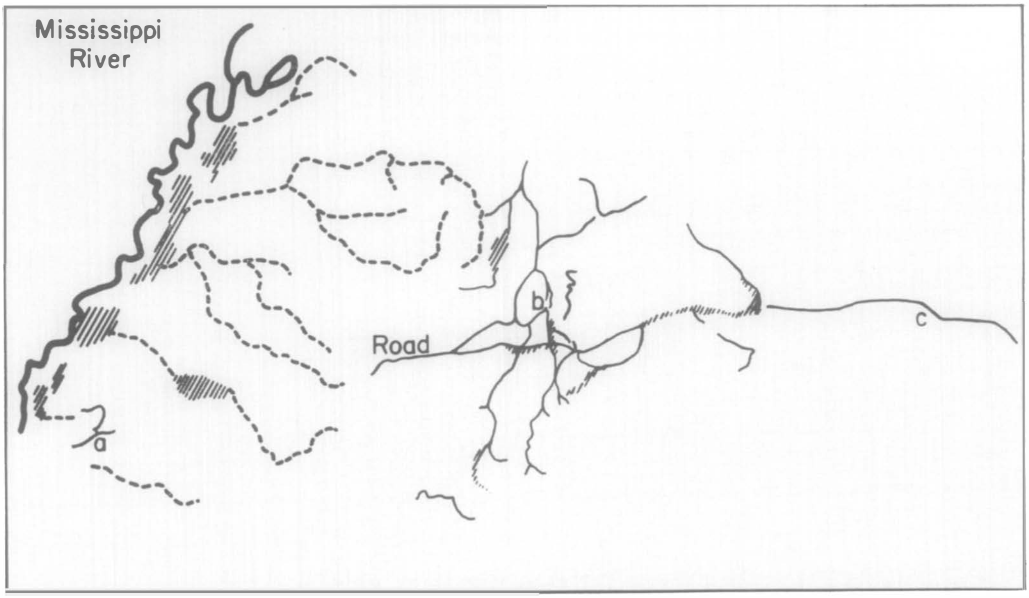


FIG. 8. A tracing of fine detail which reliably appears on the original of Fig. 7. The thick line corresponds to the Mississippi River. The dashed lines correspond to dark, approximately rectilinear features on the photograph. The thin line corresponds to bright rectilinear features on the photograph other than the Mississippi River. (The shallow sinusoid extending upwards and to the right above the feature marked b, until it ends abruptly, is a railroad.)

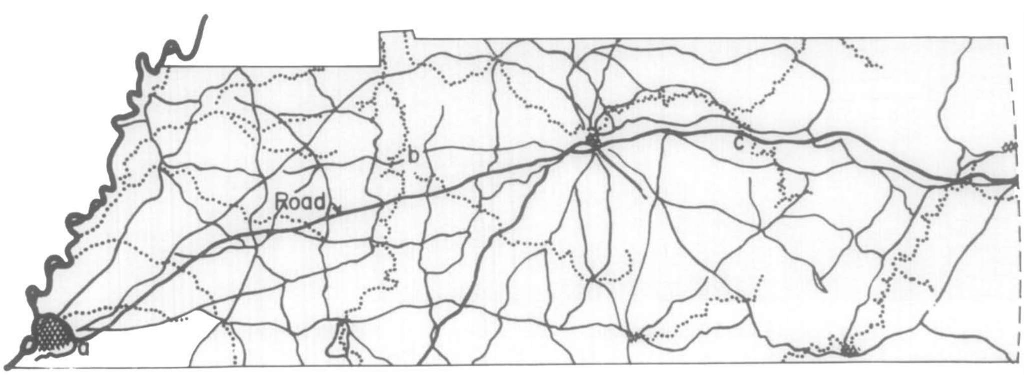


FIG. 9. Map of the area of Figs. 7 and 8. The thick line corresponds to the Mississippi River; the dotted lines, to rivers and lakes; the thin lines, to roads; and the shaded areas, to cities (Esso Oil Company, 1961; National Geographic Society, 1963; Portland Cement Assn., 1964).

10% of the 0.5-km ground resolution of Nimbus 1. The observation was possible only because of the high contrast between this rectilinear feature and its background. With Interstate Highway 40 detected, it then becomes clear that the feature to the left of the bifurcation marked a is the city of Memphis.

Figure 10 is an exception to the collection of photographs shown in the present paper, in that it represents a region that is almost entirely cloud-covered. The break in the clouds at the center of the picture is located in the Davis Straits, about midway between Godhavn, Greenland and Baffin Island, Canada. To the left of the break in the clouds, a rectilinear feature over 200 km long may be viewed. The length and recti-

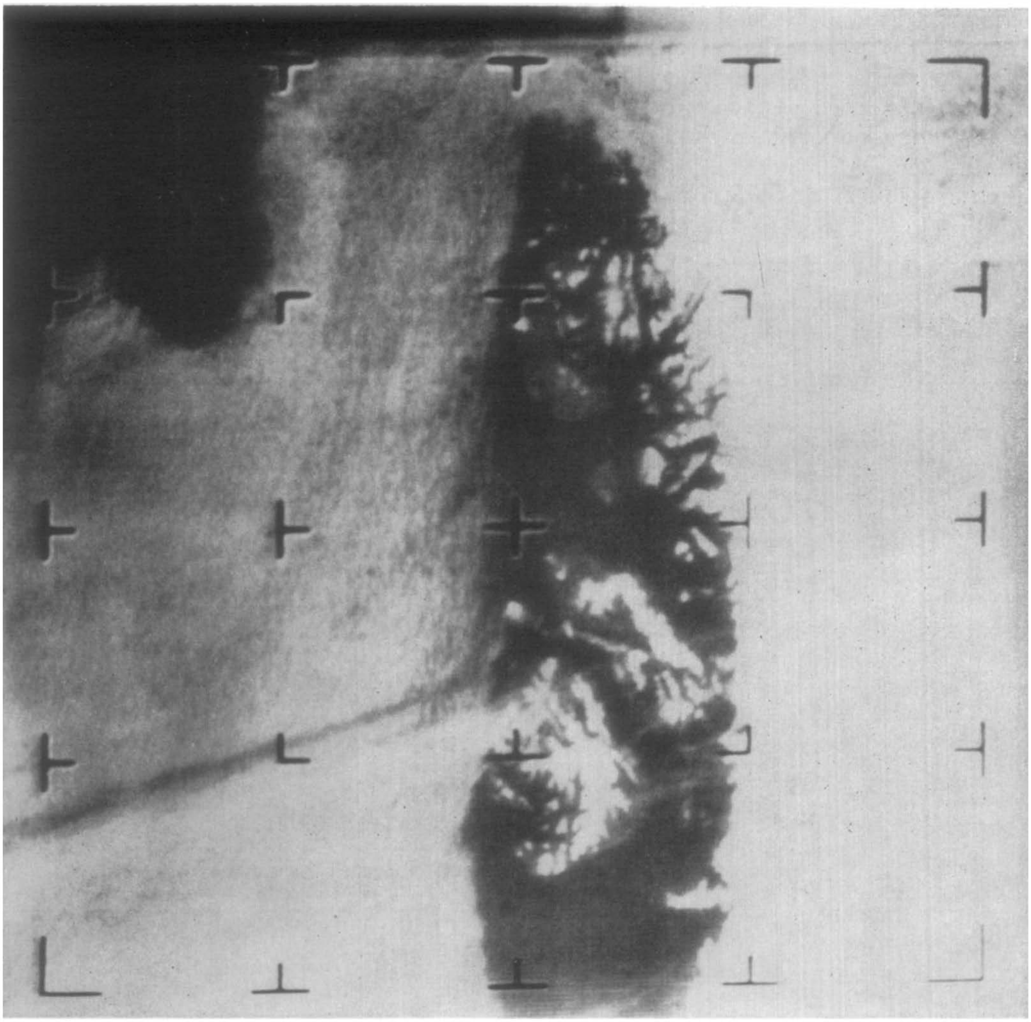

FIG. 10. Nimbus 1 photograph of a primarily cloud-covered area near the Davis Straits, orbit 49, September 1964.

linearity of this feature provides a strong suggestion of intelligent origin. Closer examination shows that there are two rectilinear features, one bright and the other dark, both superposed on the cloud layer. We are looking at a bright rectilinear feature and the shadow it casts upon the cloud bank: perhaps an aircraft contrail. The photograph was taken at about local noon near 70°N latitude at approximately the autumnal equinox. With this information and the apparent distance between the feature and its shadow, it is easy to compute that the height of the feature is approximately 6 km above the cloud bank, a reasonable altitude for jet aircraft. Plotting this rectilinear feature on a globe suggests that it falls approximately on a great circle connecting California and Northern Europe. It may represent the jet contrail of a commercial over-the-pole flight. Alternatively, this feature may represent a natural jet stream cloud (White, 1965).

In the photograph of Fig. 10, the trail can be seen to have dissipated more at left than at right, indicating that the source was traveling from west to east. From an extraterrestrial vantage point, the detection of a moving rectilinear feature of approximately constant length, generated at one end and dissipated at the other, casting a shadow and traveling large distances, would provide a strong case for the existence of intelligent life on Earth.

Figures 11, 12, and 13 are Nimbus 1 photographs of, respectively, Southern California; the Fergana Basin in the Kirghiz Soviet Socialist Republic and in western Sinkiang Province; and the Island of Öland, off the southern coast of Sweden. All three figures illustrate situations where linear features were suspected, but could not be convincingly demonstrated.

The photograph of Southern California shows the region of Santa Barbara. Several roughly rectilinear features can be detected. All, however, correspond to rivers. There are no highways visible, including the very wide and straight Interstate Highway 5, and there is no trace, in a heavily cultivated area, of rectilinear fields. In the top center of Fig. 11 is a feature with somewhat regular outlines lying in the same area as the Central Valley Project of the San

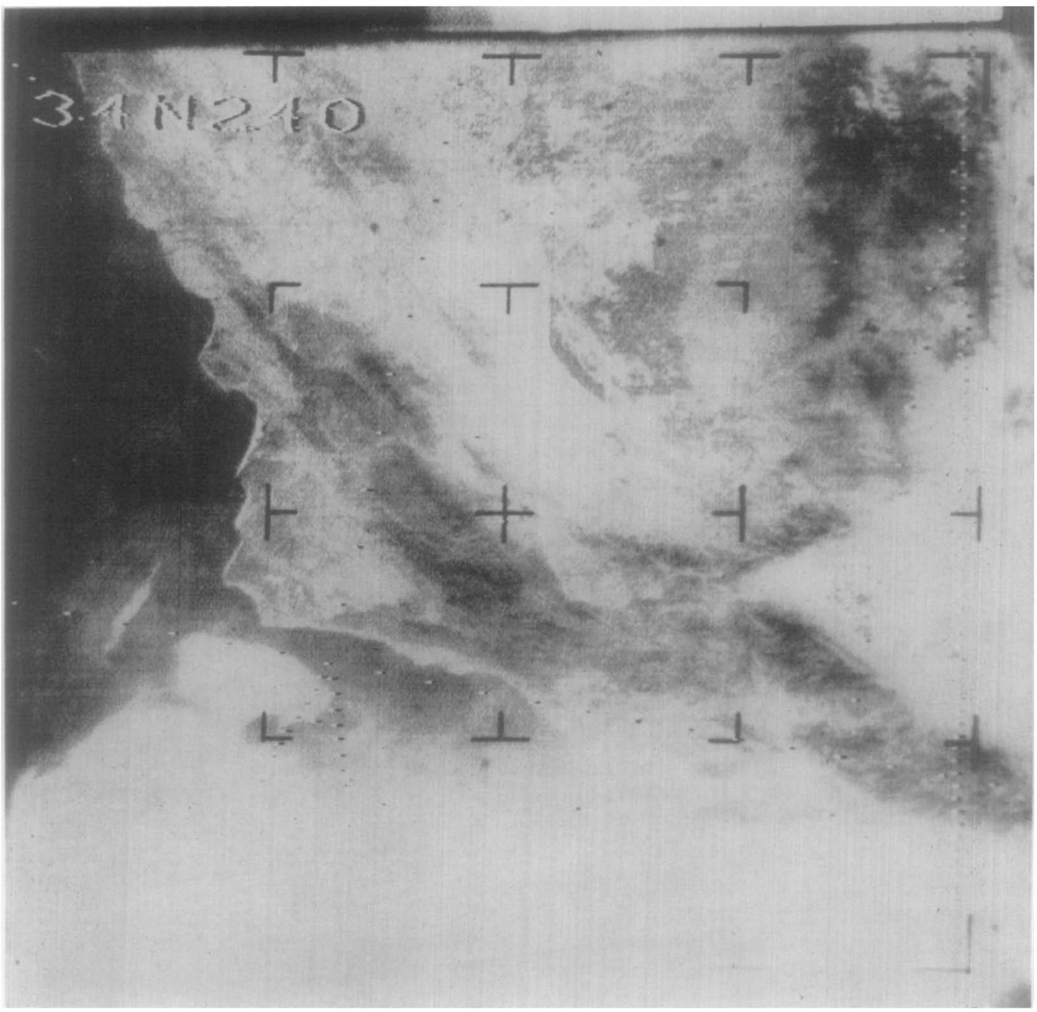


FIG. 11. Nimbus 1 photograph of southern California, orbit 329, 19 September 1964.

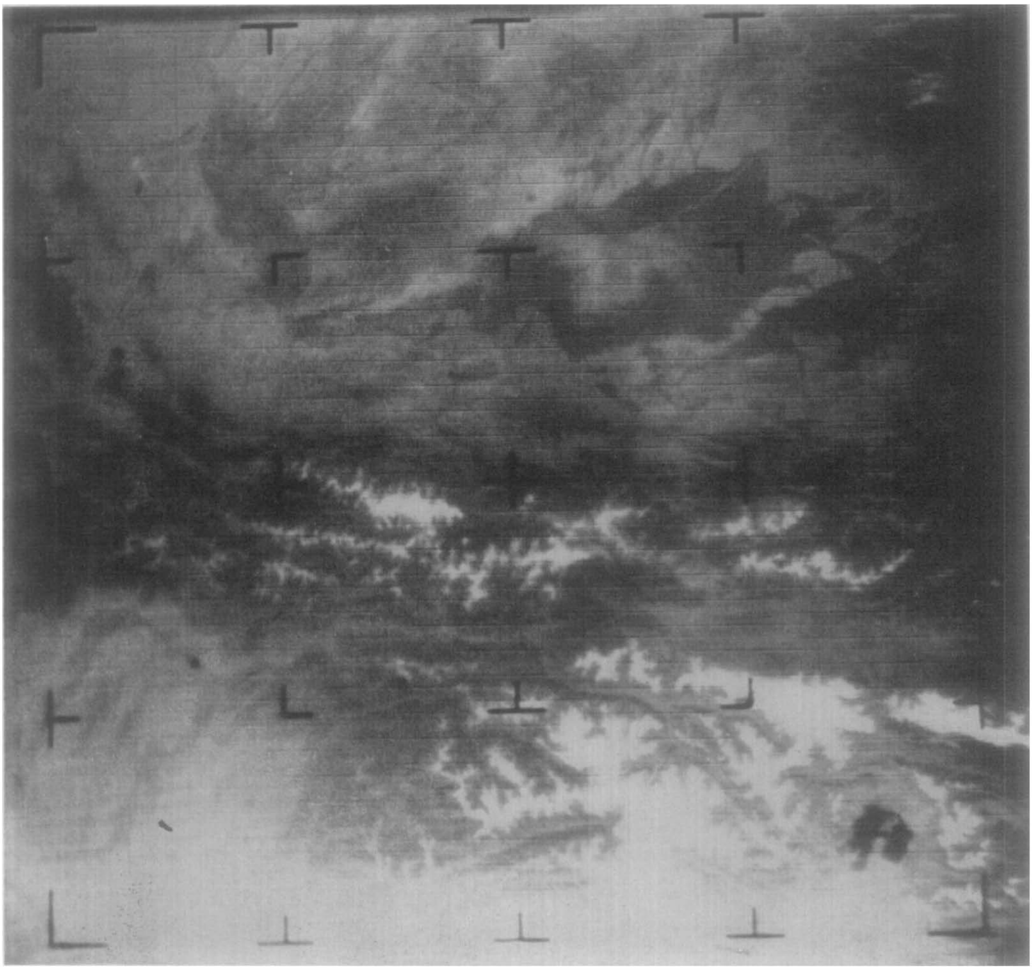

FIG. 12. Nimbus 1 photograph of the Fergana Basin, in the Kirghiz Soviet Socialist Republic and Western Sinkiang Province, China, orbit 321R, September 1964.

Joaquin Valley; but while suggestive of intelligent origin, this feature is not entirely convincing. The photograph of Fergana Basin shows, among other rectilinear features, a set of faint bright lines penetrating mountain passes in the eastern half of the photograph. However, because of the absence of convenient road maps of this region, no further investigation of these features was made.

On the island of Öland, there are some approximately rectilinear features seen which are in fact the boundaries of regions of differing contrast. There seems to be some correlation with the positions of roads and railroads on standard maps of Öland

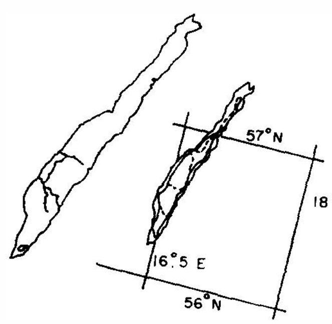


FIG. 14. At left, a tracing of faint rectilinear features in the Nimbus 1 photograph of Öland, Fig. 13. At right, a drawing of Öland redrawn after the Times *Atlas of the World,* showing roads as straight lines, and railroads as dashed lines.

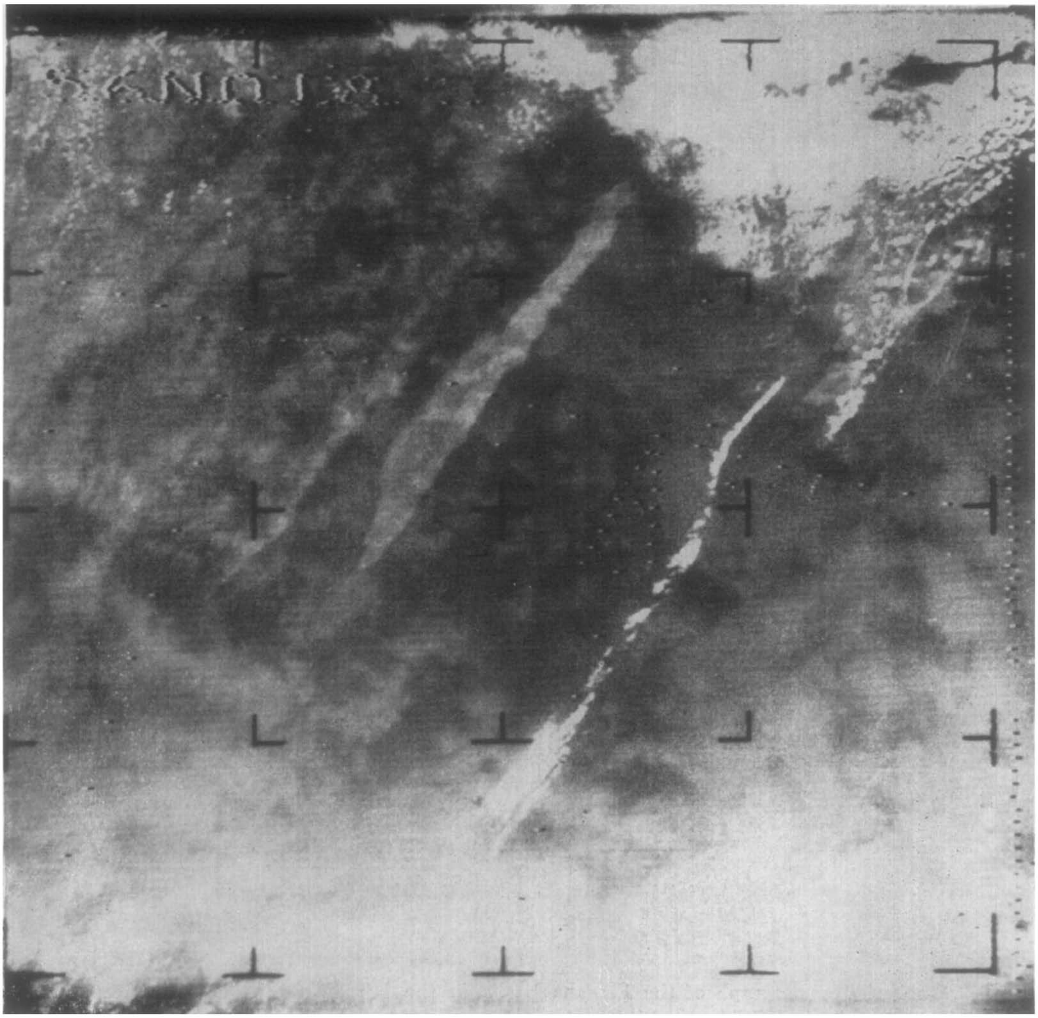

FIG. 13. Nimbus 1 photograph of the Island of Öland, off southern Sweden, orbit 367, September 1964.

(cf. Fig. 14), but while suggestive, the detection of these features can at best be considered marginal.

A striking array of rectilinear markings may be seen in Fig. 15, a Tiros 2 photograph of the region near Cochrane, Ontario, Canada, obtained on April 4, 1961. This photograph, taken with the narrow-angle Tiros camera, has a ground resolution of about 0.2 km. The width of the rectilinear features is $\sim$0.5 km. Cochrane is a lumber region, and the rectangular array represents an orthogonal grid of logging swaths. The swaths appear especially bright in this photograph because snow had recently fallen. The grid pattern is designed to allow for reforestation of the logged regions. This is surely a case where ground truth is the whole story. If we were to detect a similar rectangular array on Mars, it would certainly be premature to conclude that there are trees on Mars, that it had recently snowed, and that the trees were felled by a race of intelligent beings concerned for future reforestation. All that could be concluded would be that this is an area of unusual interest deserving further study.

As a last example of satellite photogra-

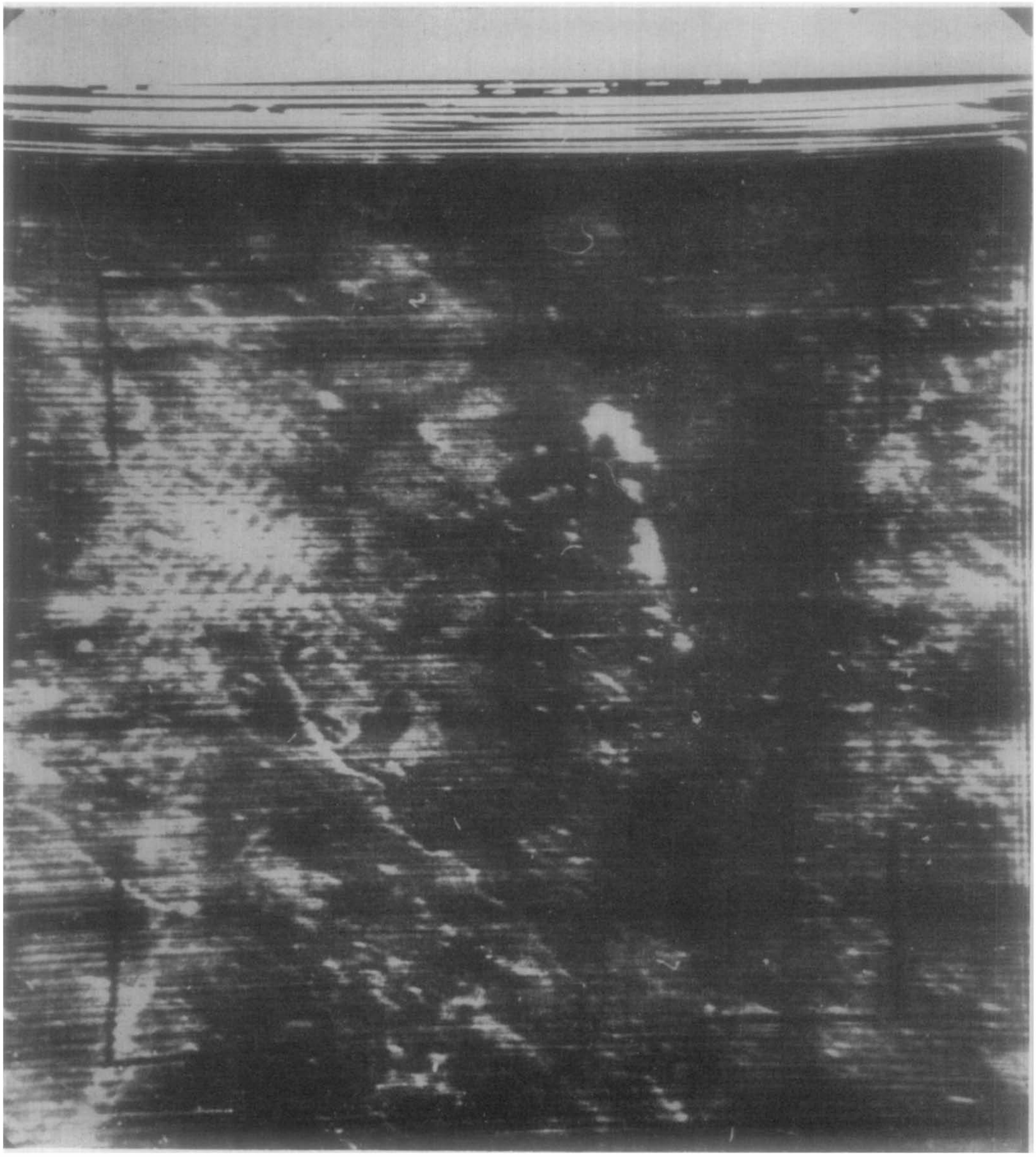

FIG. 15. Tiros 2 photograph with the narrow-angle camera, of the region of Cochrane, Ontario, Canada, taken on 4 April 1961.

phy of the Earth, consider Fig. 16, a Nimbus 1 photograph of central France, initially selected in the hope of finding the characteristic checkerboard pattern of cultivated fields. None of these was found. Paris, which lies in the left center of the picture, on the Seine River, is entirely invisible. There is, however, one striking feature: the bright region immediately to the right of center. Examination of vegetation maps in the *Atlas de la France* shows that this feature corresponds to the only large conifer forest in France, occupying much of the province of Champagne. The spectral acceptance passband of the Nimbus 1 photometer extended into the near infrared, where the preferential reflectivity of conifers and other green plants is well

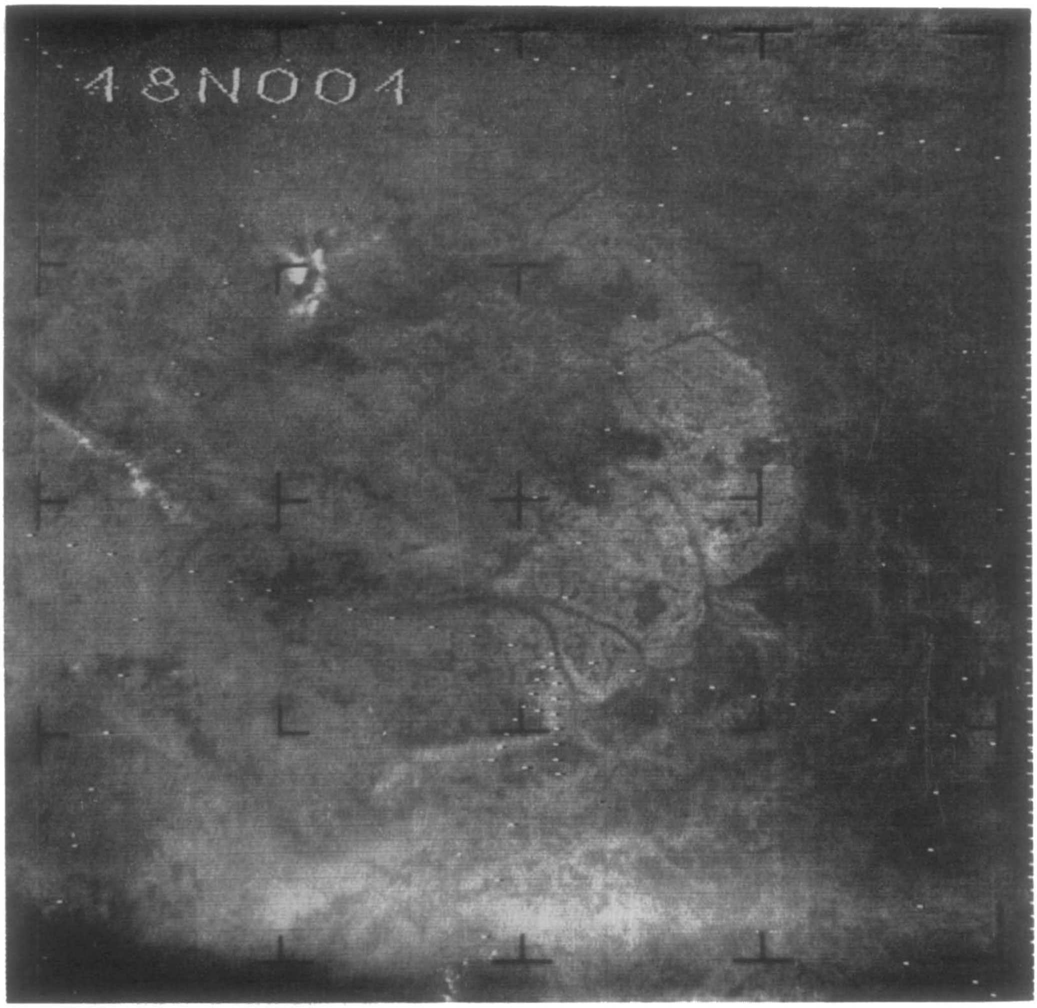


FIG. 16. Nimbus 1 photograph of central France, orbit 236, 13 September 1964.

known. However, there are many inorganic materials which have a high near-infrared reflectance, and the mere existence of a patch of high reflectivity is far from a demonstration of the existence of vegetation. In fact this same area also corresponds to the exposed Upper Cretaceous chalk formations of the Barren Champagne (Goddard Space Flight Center, 1965). The chalk formations and the conifer forest seem to be occupying the same region and a decision between these two possible sources of high reflectivity requires further study. (For further discussion of the problem of remote detection of vegetation, see Sagan, 1965b).

## CONCLUSIONS

The remote detection of seasonal variations in the reflectivity of vegetation is difficult to perform because of the general low contrast between the vegetation and the underlying terrain. The detection of rectilinear features due to the constructions of an intelligent civilization on Earth is possible with the narrow-angle systems of the Tiros and Nimbus satellites, but such features are not evident in photographs taken with the wide-angle system of the Tiros series. The transition to detectability seems to lie somewhere around 1-km ground resolution.

If the rectilinear features have high contrast with their surroundings, they have a certain probability of detection from satellite altitudes with resolution of $\sim$1 km. Four of the photographs seem to show strong evidence for rectilinear features of intelligent origin. These are Interstate Highway 40, in Tennessee (Fig. 7); the jet "contrail" over the Davis Straits (Fig. 10); the logging swaths near Cochrane, Canada (Fig. 15); and the "breakwater" in Northern Morocco (Fig. 4). In this small sample, the reliability of the conclusion that rectilinear markings betoken intelligence is seen to be 50% to 75%. The data is difficult to treat statistically, since the detection of even one long rectilinear feature, preferably crossing others, might be in itself convincing.

However, it is possible to make some estimate of the probability of intelligence being detected on the Earth by a given number of random observations of a quality similar to that obtained by Nimbus 1. The 200 Nimbus photographs which we examined in detail were selected from a larger group of photographs of approximately cloud-free areas, containing approximately 10 times as many photographs. Thus, out of several thousand photographs of the Earth's surface, two highly indicative objects—the "contrail" and Interstate Highway 40—were found. Also, one deceptive feature—the Moroccan "breakwater"—was identified. Thus, very crudely, we may conclude that several thousand photographs of the Earth, with a resolution of a few tenths of a kilometer, are required before any sign of intelligent life can be found with some reasonable reliability. As the resolving power improved, the number of photographs randomly distributed of the surface of the Earth required would probably decrease somewhat (Sagan, 1965*b*).

It is clear then, that an equivalent Mariner 4 system—taking 22 photographs of the Earth with a resolution of several kilometers—would not detect any sign of life on Earth, intelligent or otherwise. We do not expect intelligent life on Mars (Sagan, 1965*a*), but if there were intelligent life on Mars, comparable to that on Earth, a photographic system considerably more sophisticated than Mariner 4 would be required to detect it. Photographic reconnaissance of Mars from an orbiting spacecraft is in principle capable of providing some very significant information relevant to life on Mars providing very high resolution were obtained (Sagan, 1965*b*,*c*). The Mariner 4 photographic system can be considered the forerunner of future photographic reconnaissance experiments from spacecraft in the vicinity of Mars, experiments which might conceivably have some bearing on the question of life on Mars.

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