HIGH-RESOLUTION PLANETARY PHOTOGRAPHY AND THE DETECTION OF LIFE

Carl Sagan

Harvard University
and Smithsonian Astrophysical Observatory
Cambridge, Massachusetts

The brilliant success of the *Mariner IV* photographic mission has lent increased interest in the possibility of detection of extraterrestrial life by high-resolution photography from planetary flyby or orbiter spacecraft. The following discussion is primarily a brief summary of the conclusions of two recent studies of this problem (Refs. 1 and 2) to which reference may be made for further details.

For organisms or the artifacts of organisms to be detected from high altitude, they must, under most circumstances, have dimensions greater than the ground resolution of the photographic system; and they also must have a detectable contrast difference with their surroundings. The principal exception is in the case of a rectilinear feature, which, if it has high contrast with its surroundings, may be detected even if its width is significantly below the limiting ground resolution. It must, of course, be at least several resolution elements long. Such rectilinear features are, in principle, of possible significance in the detection of extraterrestrial life, because, as terrestrial experience indicates, the combined factors of geometry and economy lead a technical civilization to construct rectilinear artifacts.

The *Mariner IV* spacecraft was designed to obtain a maximum of 22 photographs of the planet Mars, each of 64 shades of gray and with a ground resolution of a few kilometers. This performance is comparable with that of the *Tiros* and *Nimbus* series of meteorological satellites, where there are 16 to 32 shades of gray and where the ground resolution ranges from about 2 km to about 0.2 km. The best *Tiros* and *Nimbus* photographs of the Earth, therefore, can detect contrast variations only half to a quarter as well as *Mariner IV*; at the same time, the ground resolution may be an order of magnitude better.

A typical *Tiros* photograph of a relatively cloud-free region of the Earth's surface is contained in Fig. 47, a photograph in slightly unusual perspective of the eastern seaboard of the United States. The cross and right-angle markings are fiducial standards. No sign of life on Earth, intelligent or otherwise, is detectable in this picture. Similar conclusions apply to photographs taken of the major populated regions of the Earth. Almost without exception, no sign of the vast highway networks, bridges, dams, contour farming, dikes, breakwaters, and great

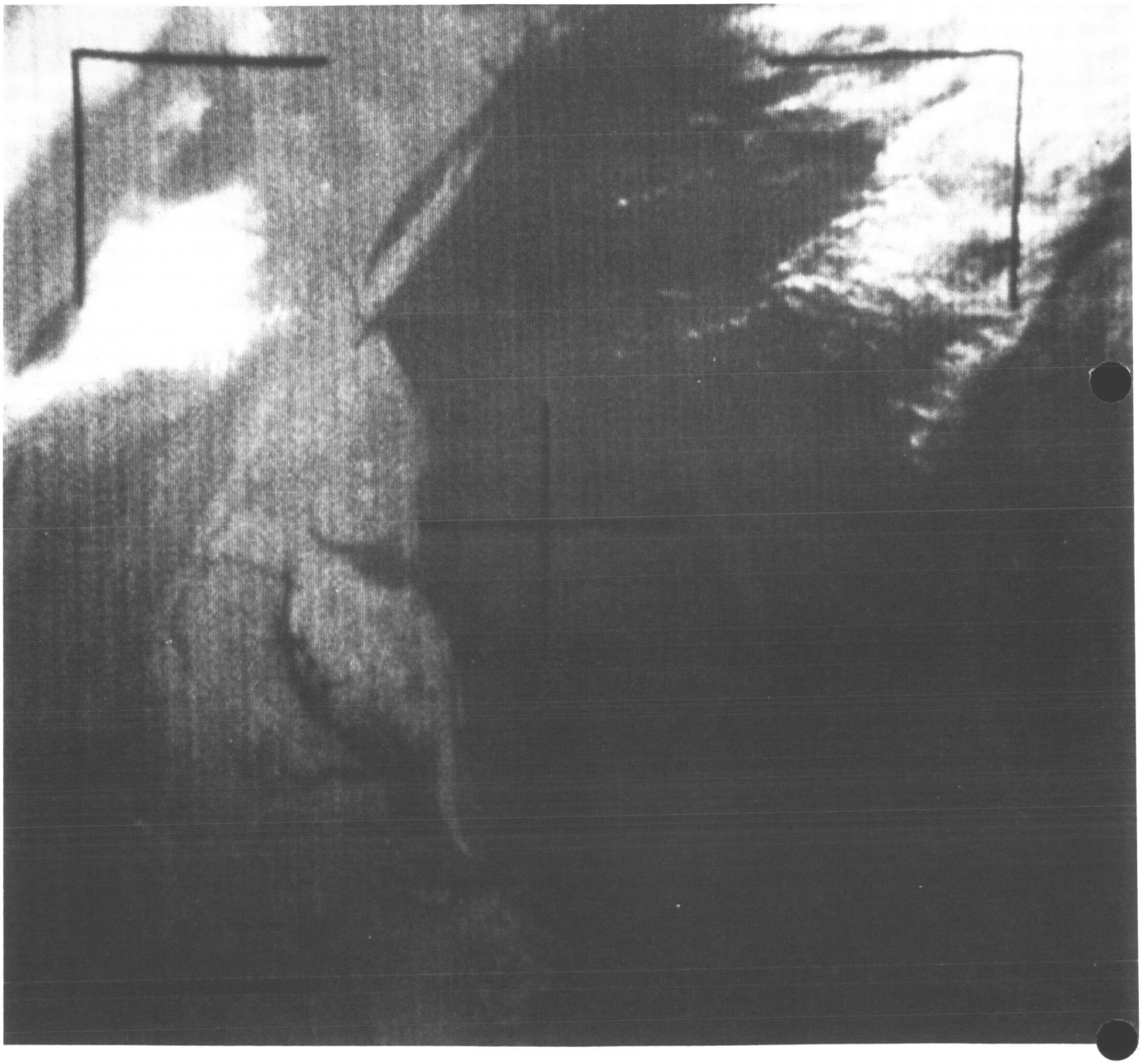

Fig. 47. A typical *Tiros* photograph of the Earth's surface. The Atlantic Ocean is the dark region in the right half of the picture; the eastern seaboard of the United States is the brighter region towards the left. The very bright features at the left and upper left are clouds. Cape Cod is just off the top of the picture. In this unusual projection, Long Island can be seen stretching upwards and to the right. Chesapeake Bay is towards the lower end of the figure. Courtesy of Goddard Space Flight Center, National Aeronautics and Space Administration.

walls can be found on the Earth with a ground resolution $\sim$ 1 km. Similarly, seasonal contrast changes in such high-contrast crops as cotton and in deciduous forests are difficult to detect, because of the small absolute contrast changes sometimes involved, problems of intercalibration of widely spaced photographs, and the difficulties in properly correcting for changing angles of insolation and view.

Very rarely an apparent rectilinear marking such as that seen in Fig. 48 can be detected. This particular rectilinear feature, about 25 km long, and in some places 1.5 km wide, despite its apparent artificiality, turns out to be most likely a natural peninsula, and not a breakwater. In Fig. 49, a comparison is made between the feature as it appears in the *Nimbus* photograph and as it is represented in Mercator projection by the U. S. Army

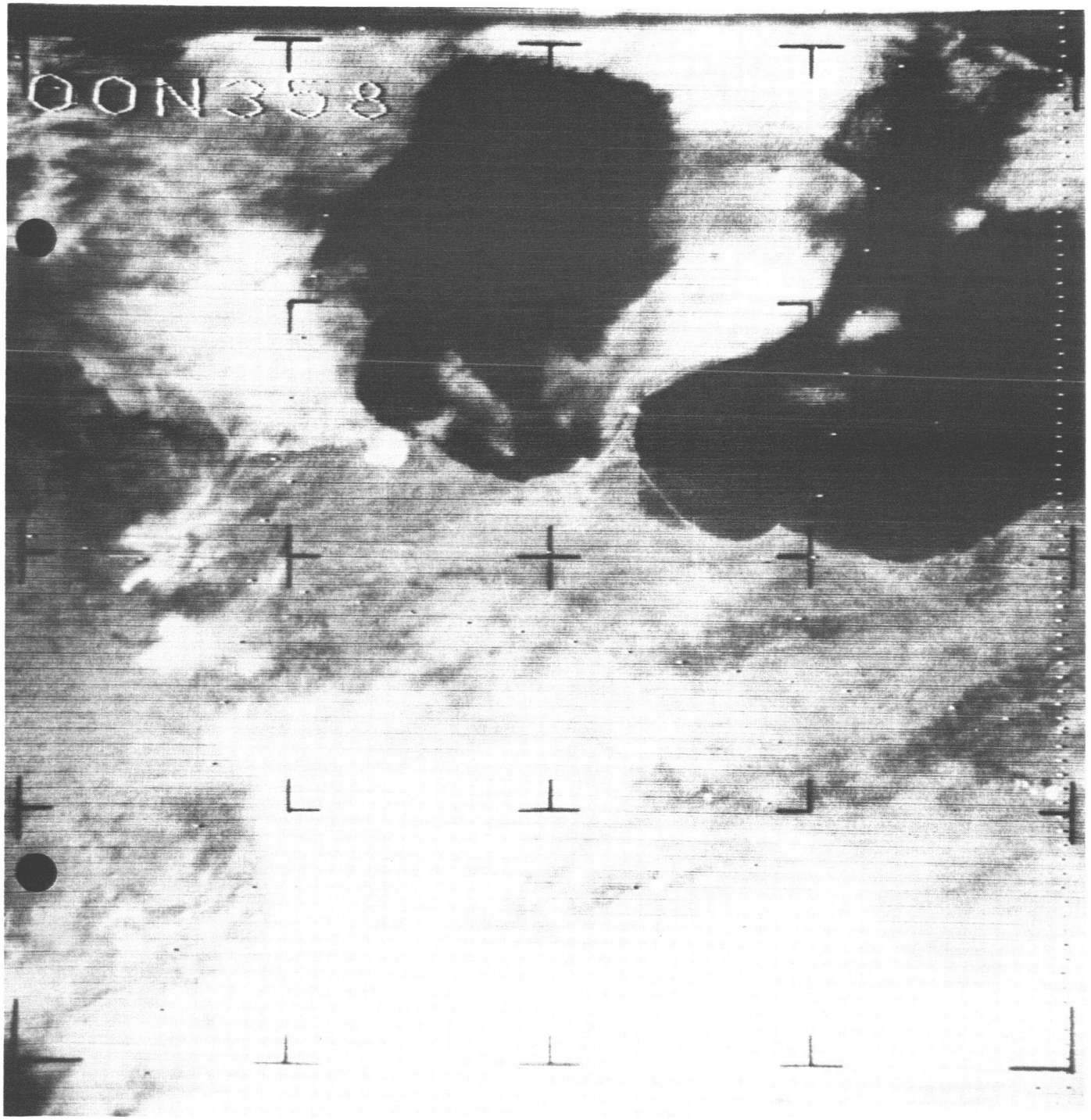

Fig. 48. A *Nimbus I* photograph of the northern coast of Morocco, orbit 295, September 1964. Courtesy of Goddard Space Flight Center, National Aeronautics and Space Administration.

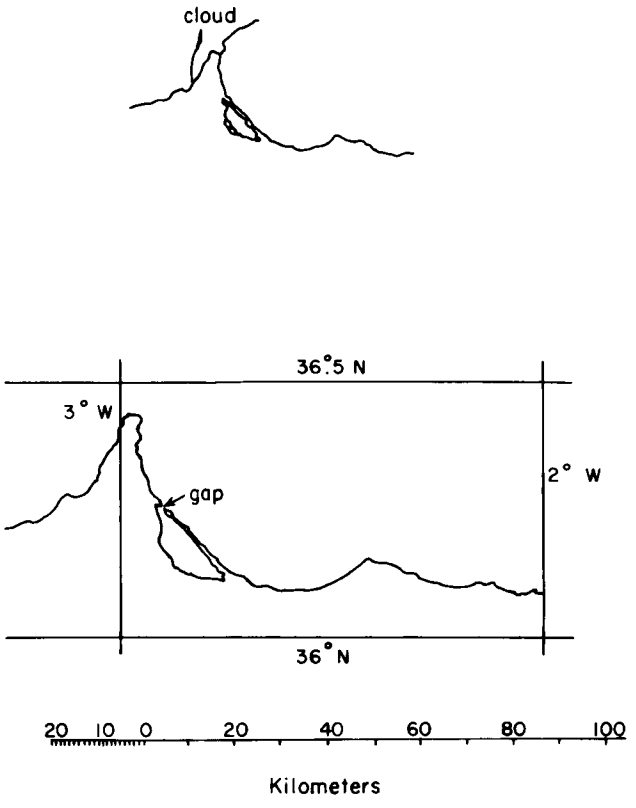

Fig. 49. Upper: drawing of the appearance of a section of the northern coast of Morocco from the *Nimbus I* photograph of Fig. 48. Lower: Mercator projection cartography of the same region taken from U. S. Army Map Service Maps, Series 1301, Sheets NJ29, NJ30, NI29, NI30 (1955).

Map Service. The lesson that all apparent rectilinear features are not artifacts of intelligent life is useful to bear in mind in interpreting photographs of other planets.

A successful detection of life on Earth is shown in Fig. 50, which displays a bright orthogonal array on a dark background towards the upper left corner. The width of the rectilinear features is $\sim$ ½ km. The photograph is of an area near Cochrane, Ontario, Canada, a lumber region. The grid pattern is the result of a lumbering operation in which parallel swaths were cut through the forest, with wide avenues of trees left standing to insure later reforestation. Then similar cuts were made at right angles. When the logging operation was completed, snows fell, heightening the contrast. But were a similar orthogonal array to found in *Mariner IV* photographs of the Martian surface, we would be hasty in concluding that it was *prima facie* evidence for an advanced technical civilization on that planet. We would first want to be very sure that the grid was not an artifact of the photographic reduction, or was not a feature that could be attributed to geological causes. There is, for example, a lunar grid system that is attributed to fracture patterns on the surface of the Moon.

Rectilinear features have, of course, been reported on the Martian surface; these are the so-called "canals," whose apparent straightness seemed explicable to Percival Lowell only if they were the artifacts of an indigenous and advanced technical civilization. The classical representation of the canals can be seen in the left-hand portion of Fig. 51, a drawing of single and double rectilinear markings as observed by Schiaparelli. On the right-hand portion of this same figure is seen the identical area of Mars as drawn by Antoniadi (Ref. 3) under conditions of superb seeing. The canals have been resolved into a disconnected sequence of fine mottling, which, when the atmosphere grows slightly less steady, the eye tends to string up in linear order. It is much easier to recall a few straight lines from the moment of superb seeing than it is to remember a more or less disordered array of disconnected detail.

Yet one might still ask how it is that some of this disconnected fine detail seems to be ordered in approximately a linear array. Now that we know, from the *Mariner IV* photographs, that the Martian surface is covered with craters, it is possible to suggest that such ordered spots as those in the right-hand portion of Fig. 51 are actually chains of dark craters. While a more or less straight chain of six or eight craters, each about 100 km in diameter, is not common on the Moon, there are a few examples, most notably the chain Ptolemaeus, Alphonsus, Arzachel, Purbach, Walter, and Stöfler; and vast numbers of smaller crater chains exist. Alternative explanations of the canals have been offered —e.g., Gifford (Ref. 4) has suggested that they may be similar to the seif sand dunes of terrestrial desert regions. This explanation, however, does not explain the high-resolution appearance of the canals (again, cf. the right-hand side of Fig. 51). At any rate, there is no reason to attribute the reported Martian canals to biological activity on that planet.

It appears that several thousand photographs of the Earth, with approximately 0.1-km resolution, are required before any convincing signs of intelligent life on the Earth can be detected (Ref. 1). Had the *Mariner IV* vehicle passed the same distance from the Earth that it did from Mars, and obtained 22 comparable photographs of the Earth, no sign of life on our planet would have

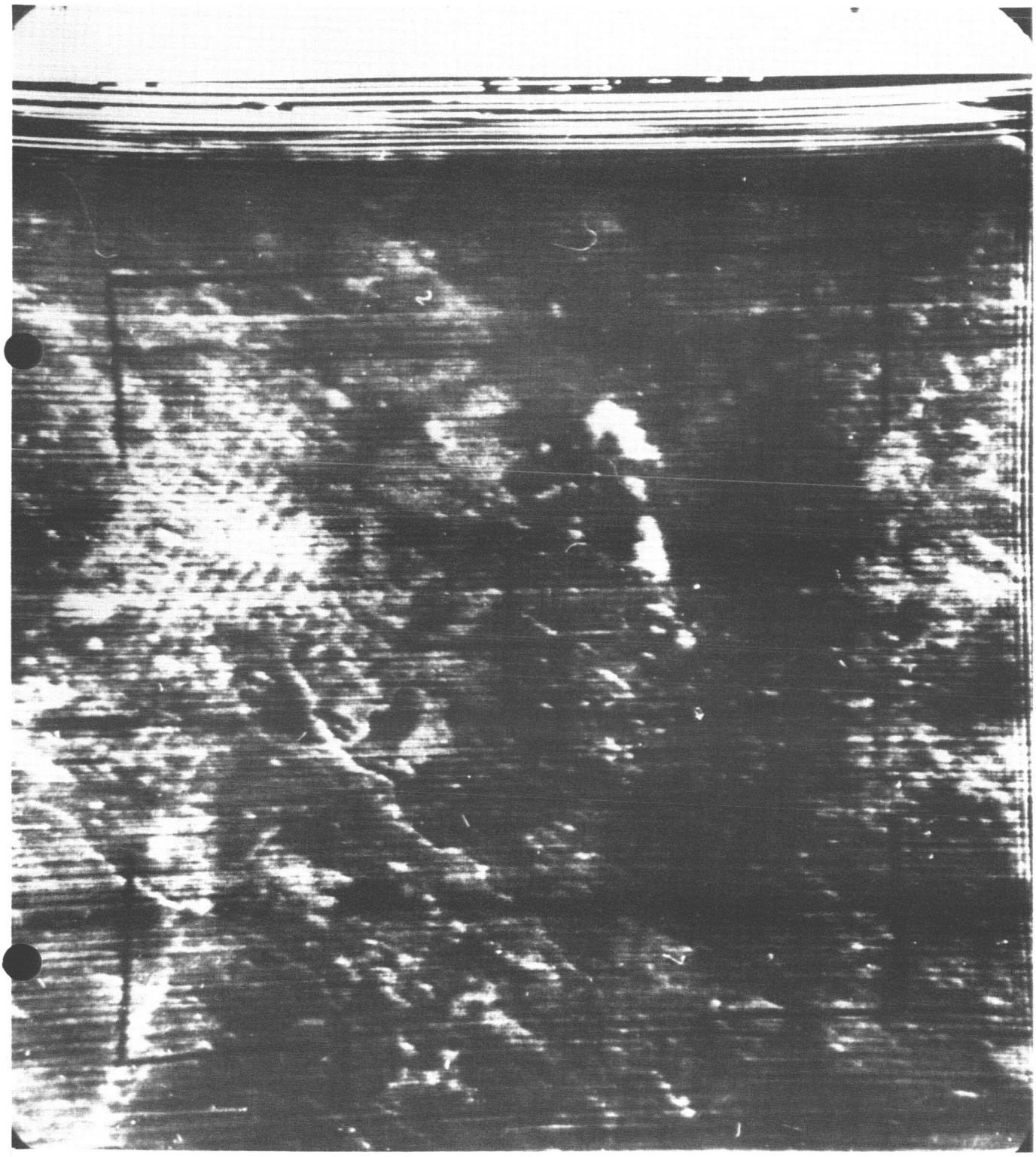

Fig. 50. *Tiros* 2 photograph with the narrow-angle camera, of the region of Cochrane, Ontario, Canada, taken on April 4, 1961. Courtesy of Goddard Space Flight Center, National Aeronautics and Space Administration.

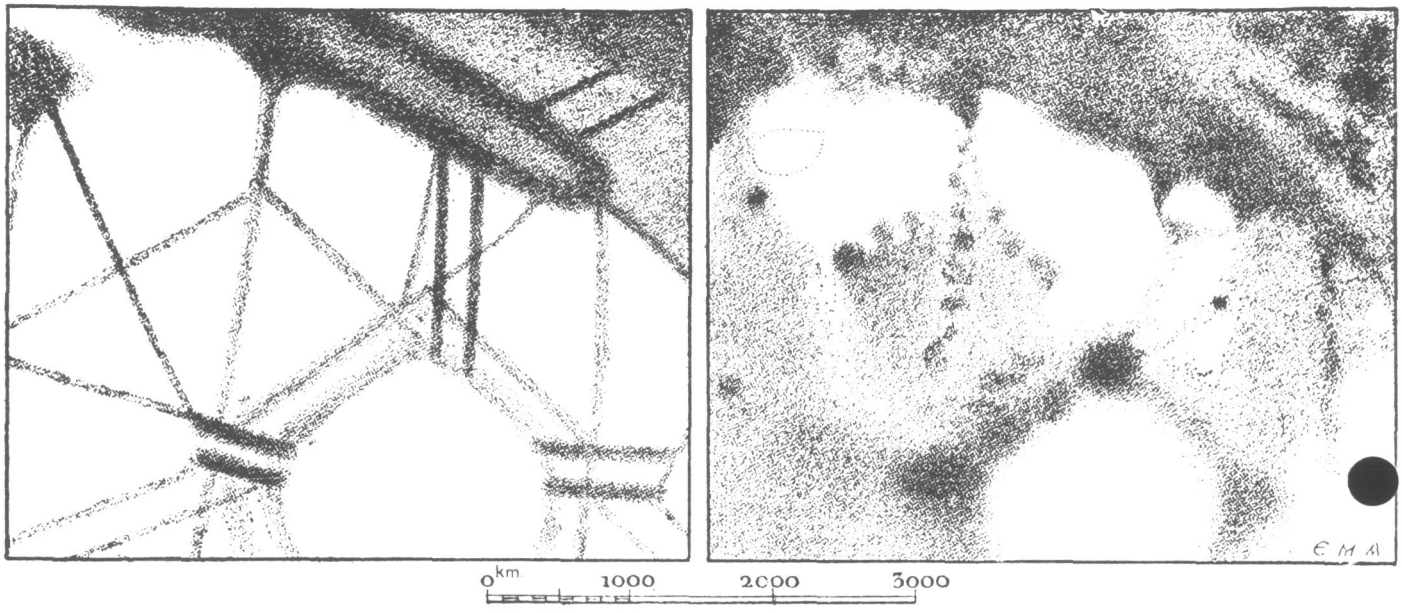

Fig. 51. Comparison of views of the same region of the Martian surface; at left as seen by Schiaparelli; at *right, as seen under superior seeing conditions* by Antoniadi (1930). (Reproduced from *La Planète Mars*. E. M. Antoniadi, Hermann et C^ie^, 1930.)

been uncovered. The *Mariner IV* photographic system was designed for geological exploration of Mars; in this it succeeded admirably. The absence of obvious extensive water erosion features suggests that the planet did not have open bodies of liquid water in its immediate past; this was, in any case, expected from the absence of open bodies of liquid water at the present time. The most recent estimate of the age of the oldest features revealed on the *Mariner IV* photographs is $\sim$ several hundred million years (Ref. 5). Thus, in the early history of the planet, open bodies of water are still possible. Significant quantities of subsurface water are, in any case, likely, and the origin of life on the planet Mars seems as likely now, after the *Mariner IV* mission, as it did before. Thus, as the experimenters themselves have stressed, the *Mariner IV* photographic reconnaissance neither demonstrated nor precluded the possibility of life on Mars.

The existence of military reconnaissance satellites demonstrates that the detection of life on Earth at orbital altitudes is feasible. Figures 52 and 53 are aerial photographs of the planet Earth in the San Francisco–Sacramento region, with a ground resolution some 30 times better than that of the best *Tiros* and *Nimbus* photographs displayed earlier in this discussion. It is easy to calculate that similar ground resolutions are possible from characteristic orbital altitudes. We see that, with this ground resolution, contour farming, urban developments, railways, and airports are all easily discernible. Even if we had no previous acquaintance with any of these manifestations of intelligent life on Earth, we would have little doubt that these features are of intelligent origin.

Were our resolving power to improve by another factor of 30 it would be possible to detect—especially when the Sun is at large zenith angles—individual large organisms such as trees, horses, or cows. The fact that these organisms tend to be found near others of their kind would enhance the probability of successful interpretation.

Only a few hundred randomly situated photographs of the Earth's surface with a resolution of that of Figs. 52 and 53 would give unambiguous evidence of the existence of intelligent life on our planet. A similar number of photographs with a resolution $\sim$ 1 [redacted] especially taken at low sun—would probably give unambiguous evidence of forms of life other than Man. If we are interested in pursuing biological exploration of Mars by flyby or orbital photography, our strategy should be to photograph a small fraction of the planet's surface at the highest possible resolution, rather than to photograph the entire surface at low resolution. With the orbital altitudes and spacecraft payloads now envisioned for the *Voyager* exploration of Mars, ground resolution in the 1- to 10-m range seems quite feasible. Whether or not Mars is a life-bearing planet, high-resolution photography of its surface is of the greatest scientific interest.

Fig. 52. Reproduction, made at the Smithsonian Astrophysical Obs., of a section of a photo montage of the San Francisco–Sacramento, California, area. Prepared by Aero Service, Inc., Philadelphia. Courtesy of Dr. Robert N. Colwell.

Fig. 53. Reproduction, made at the Smithsonian Astrophysical Obs., of a section of a photo montage of the San Francisco–Sacramento, California, area. Prepared by Aero Service, Inc., Philadelphia. Courtesy of Dr. Robert N. Colwell.

REFERENCES

1. Kilston, S. D., Drummond, R. R., and Sagan, C., 1966, *Icarus*, Vol. 5, pp. 79–98.
2. Sagan, C., et al., 1966, "Remote Reconnaissance of the Earth," *Biology and the Exploration of Mars*, U.S. National Academy of Sciences, Washington, in press.
3. Antoniadi, E. M., 1930, *La Planète Mars*, Librairie Scientifique, Hermann et Cie, Paris.
4. Gifford, F., 1964, *Icarus*, Vol. 3, No. 2, pp. 130–135.
5. Anders, E., and Arnold, J., 1965, *Science*, Vol. 149, No. 3691, pp. 1494–96.