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The Canals of Mars: An Assessment after Mariner 9

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The Lowellian canal network has been compared with the results of Mariner 9 photography of Mars. A small number of canals may correspond to rift valleys, ridge systems, crater chains, and linear surface albedo markings. But the vast bulk of classical canals correspond neither to topographic nor to albedo features, and appear to have no relation to the real Martian surface.

The canals of Mars have been something of an embarrassment to planetary astronomers since attention was called to their existence by Schiaparelli in 1877. The reality of most of the canals, much less the processes producing them, has been the subject of heated controversy; and the initial hypothesis by Lowell that they were the constructs of intelligent beings on Mars has led to their general classification somewhere in the no-man's land between science and fiction. Since a variety of independent observers—including some, such as Trumpler, intensely skeptical of the hypothesis that the canals are artificial—have produced canal maps of tolerable mutual consistency, it cannot be claimed that there is no phenomenon to explain. On the other hand, by no means all of the canals displayed on the classical maps are seen by all or even most observers, and the observational problems in detecting features of intrinsically low contrast and small angular size under poor seeing conditions are severe. Also the term canal has been used to describe a variety of quite different features. For example, Agathodaemon, Cerberus, and Thoth-Nepenthes are dark markings of considerable extent which have been repeatedly photographed and about whose reality there can be no question. But they are hardly fine dark lines following great circles for thousands of kilometers; instead they are irregular, broad quasilinear features. On the other hand, the great bulk of very regular Lowellian canals have never been photographed, have not been seen by all or in some cases even by most observers, and are probably of dubious reality. There are no more than 10 or 20 so-called canals whose reality is likely; and no more than half a dozen whose reality is beyond question.

Probably no Martian observable has elicited so many varied and mutually exclusive hypotheses as the canals. A very incomplete list of these hypotheses follows.

(1) Canals are the waterways, or the vegetation along the banks of waterways, constructed by an advanced civilization on Mars (Lowell, 1906).

(2) Canals are natural valleys or surface cracks produced by a range of geological processes. (Wallace, 1907; Pickering, 1921; Tombaugh, 1950). The idea that the canals are ridges has also been suggested (Joly, 1898) and a variety of authors have proposed some combination of rifts or faults with ridges, dikes, or escarpments (Schiaparelli, 1893; Arrhenius, 1918; Wasiutyński, 1946; Katterfel'd, 1959; Hope, 1966). In detail many of these suggestions are physically naive or based upon now-outmoded geophysical models—for example the idea that the canals are ridges produced by tidal interaction with asteroids on near-grazing collisions, cracks produced during contraction from an initially molten state, etc.

(3) Canals are accidental alignments of disconnected fine surface detail (Maunder, 1894; Antoniadi, 1930). A specific version of this hypothesis attri-

butes some canals to chains of large craters (Sagan, 1966).

(4) The canals are crater rays as on the lunar surface (Plassman, 1901; Oncley and Fulmer, 1966). Why lunar rays are bright and Martian canals dark is not readily apparent in this explanation.

(5) The canals are rectilinear sand dunes (Gifford, 1964).

(6) A new hypothesis which might be suggested by the discovery of long linear windblown streaks on Mars (Sagan *et al.*, 1972, 1973): the canals are albedo features produced by a covering or uncovering of surface material by windblown particulates.

No topographic feature on Mars has large enough dimensions to cast a shadow detectable from Earth, as has been stressed to us by W. A. Baum. It follows that features reported by ground-based observers must, if real, arise from regional albedo or roughness differences, these can, however, be topography-associated (Sagan *et al.*, 1972, 1973).

Mariner 9 has achieved a complete mapping of the surface of Mars down to 1km resolution (A-frames) and spot photography of a few percent of the surface down to 100m resolution (B-frames). The best photographic resolution of Mars obtained before spacecraft reconnaissance was several hundred kilometers and the best imaginable visual resolution perhaps slightly better than 100km. The Mariner 9 photography has now been mosaicked, and it should therefore be possible to make some definitive conclusions about the nature of the Martian canals. In the following figures we have employed mosaics of Mariner 9 A-frame photography.

Since Mariner 9 was in orbit about Mars for more than half a Martian year, it is unlikely that the planet was viewed at a time when canals were not to be seen. While the early part of the mission was marked by the waning phases of a great dust storm, the later stages of the mission were remarkably clear. Variable-features information obtained during the mission seems to correlate well with other ground-based information (Sagan *et al.*, 1972, 1973). The mosaics are chiefly useful for their topographic information. Albedo information is contained within each Mariner 9 A-frame but no attempt has been made to preserve albedo information from frame to frame within the mosaic. In some of the mosaics "gores" between adjacent A-frames can be seen.

In Fig. 1 are displayed four representations of the same region of Mars in the region between Elysium Planitia and Hesperia Planum. The representations are Fig. 1a, Schiaparelli, 19th Century; Fig. 1b, Antoniadi, 1929; Fig. 1c, Mariner 9, photography, 1971–72; Fig. 1d, cartography based on Mariner 9 photography and Earth-based photography. The network of single and double canals of Schiaparelli is found by Antoniadi, under superior seeing conditions, to resolve into an array of disconnected fine detail (Hypothesis 3). Mariner 9 shows no evidence of any "canals" in this region. The vertical sequence of spots in the middle of Fig. 1b might possibly be an array of craters, just barely too small to have been given names, which may be seen in Fig. 1c. The largest distinct crater near the center of Fig. 1c is Gale about 150km across. To its southwest is the more subdued but larger crater, Herschel. It is barely possible that one of these craters corresponds to the dark semicircular outline toward the lower left of Fig. 1b, at the edge of Mare Cimmerium. But these are very dubious correlations.

In the remaining figures we have chosen to compare the Mariner 9 results with the canal cartography of Slipher (1962), the most recent representative of the Lowellian Canal School. In Slipher's as in Lowell's maps, cartographic errors of 5° in latitude and longitude are not uncommon and errors up to 10° or 15° exist. For example Hellas Planitia is shown by Slipher centered at 300° W rather than 290° W. Where common albedo features such as this exist we have distorted Slipher's cartography to bring it into agreement with ground-based or space-borne photographic data sources. A somewhat subjective interpolation was utilized to position features adjacent to displaced features.

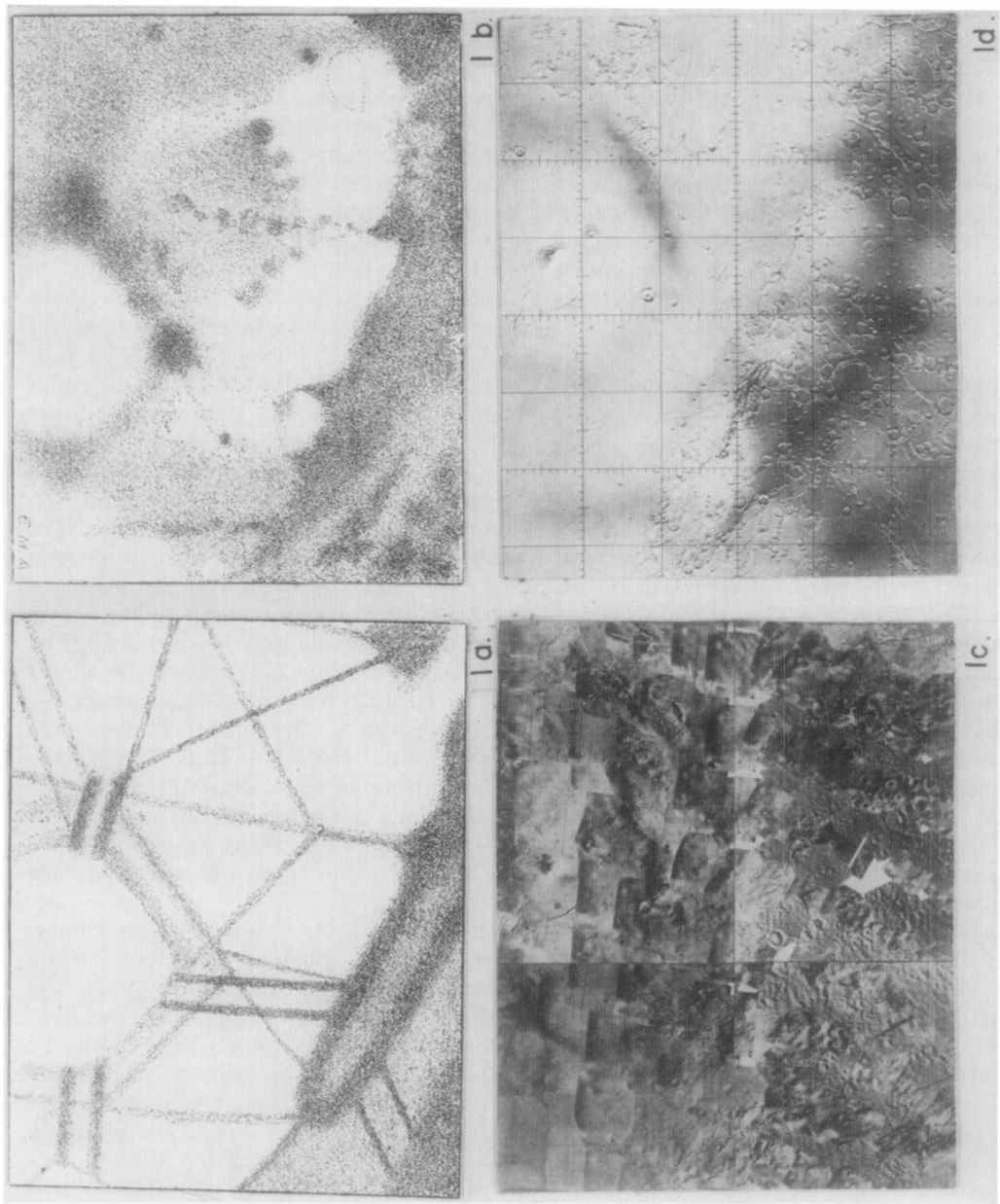

FIG. 1. The region between Elysium Planitia and Hesperia Planum according to Schiaparelli (1a), Antoniadi (1b), Mariner 9 photography (1c), and cartography based on Mariner 9 and Earth-based photography (1d). Figure (1c) is not corrected for the albedo and shading of adjacent constituent frames, and is useful only for topographic features.

In making comparisons between ~100 straight lines and a surface which requires $\sim 10^{10}$ bits to characterize it, it is clear that there will be occasional correlations which are due merely to chance. Therefore the following conclusions represent an upper limit to any real correlation between true Martian surface features and classical canals. The subsequent figures were prepared by laying down the canals as opaque tape on a transparent overlay placed over the Mariner 9 results. Occasionally a faint shadow of the overlay can be discerned following one side of the "canal"; of course, these are not true surface albedo features. As mentioned above, the Mariner 9 imagery was not well controlled photometrically, and it is possible that faint albedo features which may cross many adjacent A-frames exist on Mars but are indetectable in these figures. But features with contrast $\gtrsim 5\%$ should be discernible. In many classical descriptions the canals are reported to have high contrast.

Figures 2, 3, and 4 display typical comparisons. Canals are shown as straight or straightish white thick lines; dark areas as drawn by Slipher are shown as broad pin-striped overlays. In Fig. 2 we see a striking connection between the canal Agathodaemon and the great rift valley, Valles Marineris. But this is a low-albedo feature, 5000km long, easily resolvable and of high contrast to ground-based observers. Elsewhere in Figs 2, 3, and 4, no correlations are apparent. Indeed there are many major topographic or albedo features which show no hint of having been observed by Slipher despite the fact that they have much larger two-dimensional angular extent than many of the linear features which were drawn by Lowell and his followers.

Figure 5 is our best effort at a superposition of Slipher's global canal map with the Mariner 9 cartography. The baseline map here used was prepared by J. Inge and the Lowell Observatory on the basis of Mariner 9 topographic data and photographable ground-based albedo data. In addition to Elysium and Hellas, a number of control points were employed, including Dawes' forked bay (5° S, 0° W), Aurorae Sinus (12° S, 49° W), Ascraeus Mons (11° N, 104° W), and Lunae Planum (15° N, 65° W). The canal Thoth-Nepenthes is drawn in the position given by Slipher and is obviously 5° displaced from the albedo feature of the same name. The correlation of canals with other topographic or albedo features is again seen to be extremely poor. For example, the large shield volcanoes Pavonis Mons, Arsia Mons, and Olympus Mons have not been noted at all, while Ascraeus Mons is shown as the nexus of seven canals. It is a discernible albedo feature—as, however, was Olympus Mons. It is possible that the convergence of three canals at coordinates (13° N, 124° W) is intended to correspond to the position of Olympus Mons.

In the light of these results, we now discuss each of the six canal hypotheses in turn.

(1) Mariner 9 photographed the surface of Mars with a resolution and surface coverage which would have detected a civilization of our own extent and level of development had it been there (Sagan and Wallace, 1971). No such civilization was uncovered. No features which strongly suggest intelligent life were discerned. The data counterindicate Hypothesis 1.

(2) There is at least one correspondence between a classical canal and a valley or ridge. By far the most striking case is the connection between Agathodaemon and Valles Marineris, whose width (~100km) corresponds well to the resolution limits of Earth-based photography and visual observations. It should have been seen and it was. It is approximately but not compulsively linear. A possible second case is Ceraunius, which had been deduced from preliminary doppler radar spectroscopy to be a ridge system (Sagan *et al.*, 1967; Sagan and Pollack, 1966). The feature is near Ceraunius Fossae and may join with Mareotis Fossae, producing a system which is 25° in latitude or about 1500km long. It is in many places hundreds of kilometers wide. Like Valles Marineris it may be a region where bright or dark material is temporarily trapped. It is just possible that similar cases include correlation of the canal Styx with the Phlegra Montes. On the other hand there are a great many other Martian features designated Valles, Fossae,

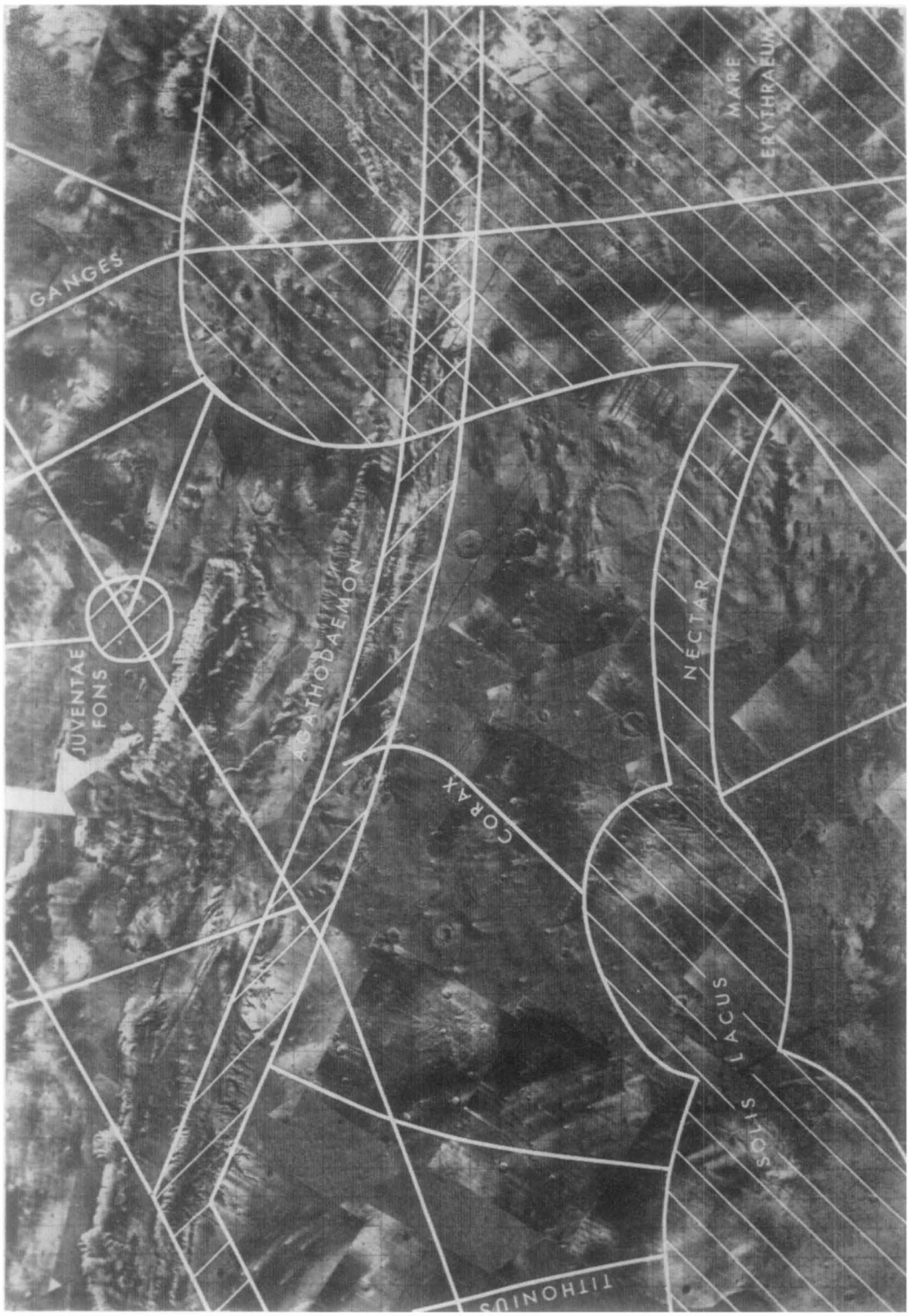

FIG. 2. Connection of Slipher's canal cartography with Mariner 9 imagery near Solis Lacus. Dark areas are shown by pinstripes, canals by straight lines. The mosaic is from Mars chart 18. Only topographic information can be extracted from this Mariner 9 mosaic.

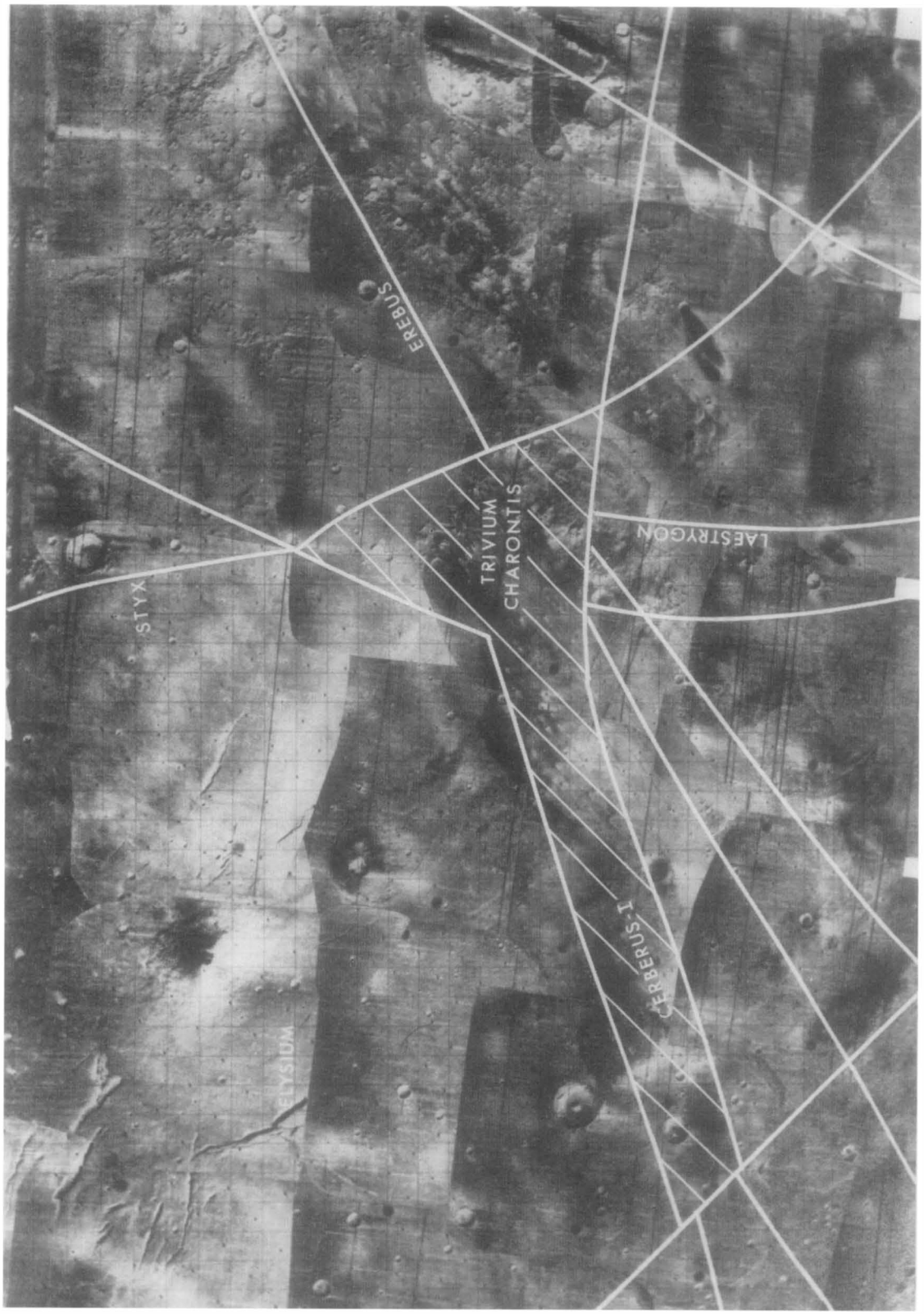

FIG. 3. Connection of Slipher's canal cartography with Mariner 9 imagery near Trivium Charontis. Dark areas are shown by pinstripes, canals by straight lines. The mosaic is from Mars chart 15. Only topographic information can be extracted from this Mariner 9 mosaic.

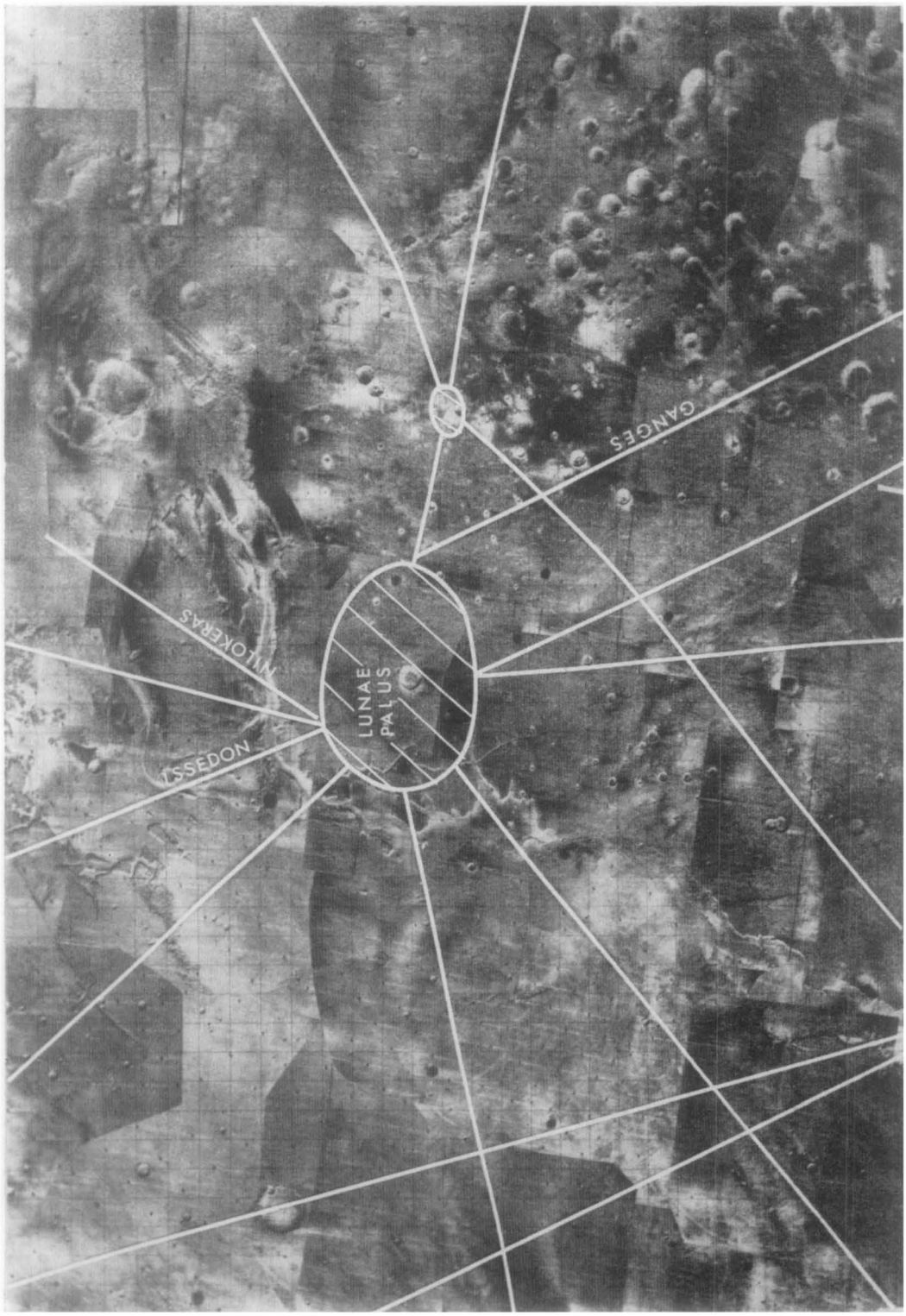

FIG. 4. Connection of Slipher's canal cartography with Mariner 9 imagery near Lunae Palus. Dark areas are shown by pinstripes, canals by straight lines. The mosaic is from Mars chart 10. Only topographic information can be extracted from this Mariner 9 mosaic.

and Montes which correspond closely to none of the classical canals. Most of these cases are either smaller in linear or lateral extent or are at higher latitudes than the features just mentioned.

(3) Sagan and Pollack (1966) asked why, if some subset of Martian canals is due to the psychophysiological alignment of disconnected fine detail, there are not similar psychophysiological linearities seen on other astronomical objects. It is possible that Mars is the only planet where there are a multitude of features of low contrast and marginal resolution which can be so strung up. In any case only a few examples of the Maunder/Antoniadi Hypothesis 3 could be found. The most striking is the chain of large craters proceeding from the northern tip of Margaritifer Sinus, and which includes the craters Trouvelot, Rutherford, Becquerel, Curie, and Sklodowska. It is possible that this was drawn as Oxia (Fig. 5) or as the unnamed canal immediately west of Oxia. Likewise striking is the crater chain which proceeds northeast from Argyre Planitia and includes the craters Galle, Wirtz, Helmholtz, and Lohse. Lohse may just possibly be a feature detectable from the Earth. It is apparently shown by Slipher as the conjunction of seven canals (Fig. 5). The canal proceeding through these craters (Fig. 5) is unnamed. The craters Lowell (52°S, 82°W) and Schiaparelli (2°S, 343°W) do not seem to be parts of any canal system, a deep but inadvertent irony visited on them by the International Astronomical Union's Committee on Martian Nomenclature. As in the case of other Martian craters observed directly by Mariner 9 (Sagan *et al.*, 1972) the floors of these craters may darken seasonally, due to the removal of windblown dust, and both the existence and seasonal variations of some canals can be understood in this way. A similar remark applies to linear topographic features discussed in the paragraph above.

(4) Only a handful of cases of crater rays were uncovered by Mariner 9. All cases are of such small contrast and angular extent as not possibly to be detectable from the Earth. On a planet with extensive windblown dust, impact crater rays should have very short lifetimes, and should not be expected to contribute to features visible from the Earth (cf. Sagan and Pollack, 1966).

(5) Dune fields have been discovered on Mars (Cutts and Smith 1973; Sagan *et al.*, 1972). But there are no cases of individual dunes of sufficiently extensive size to be seen from the Earth. Also, in all cases where linear dunes are found, they are found collectively, which does not correspond to the classical canal description.

(6) A few Martian "canals," notably Cerberus and perhaps Thoth-Nepenthes, are real surface albedo features which are not strongly connected to topography. They may represent locales where, for meteorological reasons, fine bright dust is unlikely to be deposited; or where, for reason of geochemistry or surface roughness, there is a preferential abundance of lower albedo material. The longest dark-crater-associated streak uncovered by Mariner 9 is in the Gaea region of Mars, and is seen in Fig. 3 extending at right angles to the nearest canals. It is not impossible that some canals reported in the past are connected with time-variable features of this sort.

We conclude that while a small subset of the classical Lowellian canals corresponds to topographic or albedo features on Mars, the bulk of the canals do not. Indeed there are many canals where there are no real surface features, and there are many real surface features where there are no canals. Although we have not pursued the relevant statistical study, we have the impression that there exists an anticorrelation between the cartographic accuracy of a map and the number of canals it displays. The vast majority of the canals appear to be largely self-generated by the visual observers of the canal school, and stand as monuments to the imprecision of the human eye–brain–hand system under difficult observing conditions.

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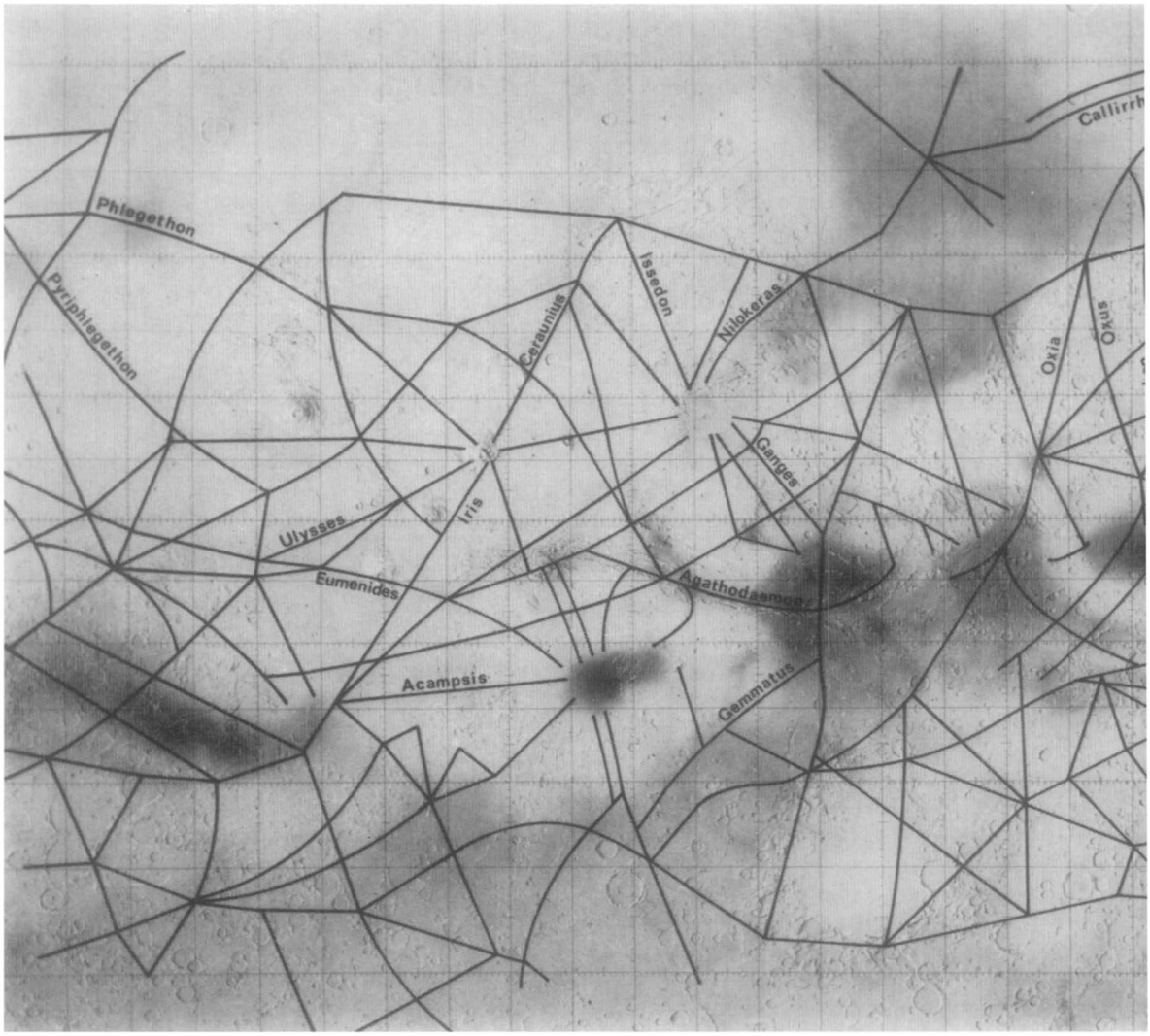
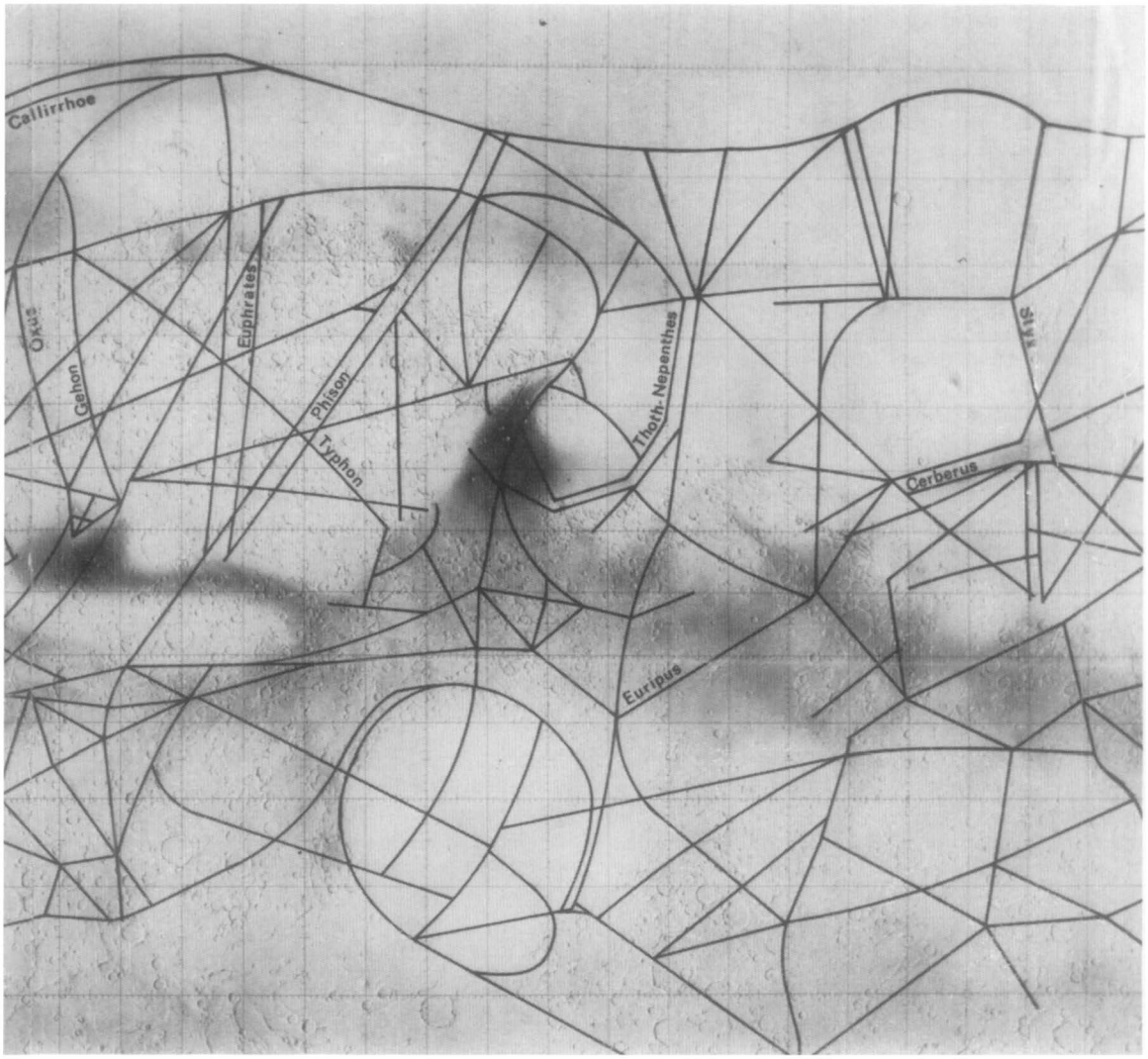


FIG. 5. The Lowellian canal network superposed on the



Mariner 9 Mars cartography and Earth-based albedo.

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