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Planetologcial considerations on the geologic intermediate stage of Mars between Moon and Earth and observations on the Jovian satellites

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Geologia. — *Planetological considerations on the geologic intermediate stage of Mars between Moon and Earth and observations on the Jovian satellites.* Nota (*) del Socio PIERO LEONARDI.

RIASSUNTO. — È diffuso il concetto che Marte si trovi in uno stadio di evoluzione geologica intermedio tra quello della Luna e quello della Terra. L'Autore nel complesso aderisce a questa opinione, ma ritiene che sia opportuno precisare il significato del termine « intermedio ». Inoltre l'Autore non è molto favorevole all'uso – parlando della Luna e di Marte – del termine « oceanizzazione » non essendoci a suo parere una convincente analogia fra i fenomeni che vengono indicati con questo termine sui due corpi celesti indicati e sulla Terra. Vengono date infine notizie preliminari sulla Geomorfologia dei satelliti di Giove acquisite mediante la sonda spaziale USA « Voyager 1 ».

I agree with some planetologists (for instance, cf. H. Masursky, Rome, 1976, p. 426) in considering Mars—within the sphere of comparative planetology—to be in an intermediate stage of geologic evolution, located between the Earth, on the one hand, and the Moon, on the other.

The problem is to determine in what sense this is so. Should the Moon, that is, be considered more primitive or more advanced than the Earth? It is more " primitive " since—as its volume is less than the Earth's and as it consequently underwent a more rapid process of cooling and consolidation—it has been " fossilized " at a more primitive stage; and in the absence of atmosphere a very old morphology has been kept intact, or nearly so (the lunar soil has undergone in the course of time considerable weathering; cf. P. Leonardi 1976, pp. 44–49; 73, Figs. 2.57–2.60).

On the other hand, from a structural point of view, the Moon has long since reached its final stage, or almost (the volcanic phenomena still in progress observed by various Soviet and American astronomers show that our satellite is not yet completely " dead "). It has emerged in fact that there has been no tectonic activity on the Moon in the past two and a half billion years (T. A. Mutch *et al.*, 1976, p. 225), and in this sense, then, it can be considered more " advanced " than the Earth.

Similar considerations may be made for Mercury, given the close morphologic and probably genetic affinities between these two celestial bodies. It must be noted, however, that our knowledge regarding the details of the Mercurian surface is far less than that of the Moon. Therefore, one cannot

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exclude the possibility that, as in the case of the Moon, there may stile be volcanic phenomena in course on Mercury.

As for Mars, I agree, as I said, with some colleagues that it is indeed in an intermediate stage between the Moon and the Earth, from a structural point of view. According to a recent study by H. Masursky (Rome, 1976, p. 427), the division of Mars' surface into a more or less depressed and only slightly craterized region (the boreal hemisphere), probably corresponding to lava effusions, and a higher, very old, and highly craterized " continental " region (the austral hemisphere), probably of anorthositic or noritic composition, like the lunar " highlands " (1), recalls the situation of the Earth prior to the fracturization of the " Pangea " and the resulting drift of the continental plates (Pl. I, Fig. 1).

On Mars, however, there do not seem to be unquestionable indications of continental fragmentation suggesting a plate tectonics comparable to the Earth's (T. A. Mutch *et al.*, 1976, pp. 191, 200, 233, 319).

Nevertheless, T. A. Mutch himself (1976, p. 228) mentions some analogies between the structural group of the Valles Marineris, which is unquestionably of tectonic origin, even though the canyons certainly have been enlarged by erosion, and that of the East African rift valleys. He also mentions the possibility, envisaged by W. K. Hartmann (1973), that horizontal plate movements on Mars are just beginning.

Now, if Masursky's and Mutch's suggestions should be true—and I myself would not deny that they are possible—then Mars, from a structural point of view, and also as regards the crustal thickness and depth of melting, would thus be at an intermediate stage of crustal evolution between the Moon's primitive " fossilized " stage and the Earth's advanced stage, still fully active from both the structural and the magmatic viewpoints.

On the other hand, seen from other points of view—namely, magmatic, hydric and atmospheric—Mars seems to be in a more advanced stage than the Earth, and its overall position between the Earth and the Moon is thus a bit ambiguous.

I am fully in agreement with the opinion that the lunar " oceanisation " has not been a sudden catastrophic process, as presumed by the theory of impact–induced melting, but rather a sequential one, and also that the floors of lunar " *maria* " were the result of linear and areal extrusions, which overflowed earlier surfaces (F. Wolff, 1914) with processes analogous to the ones which produced the greatest continental flood basalts on the Earth (Deccan, Paranà, Columbia River Plateau).

This is all the more true for Mars, where the phenomenon which some planetologists call " oceanisation " is articulated into various episodes at different times and places. I agree with the opinion that the lava formations of Mars produced by basaltic floods correspond to extrusions which occurred in

(1) HARTMANN W. K. and RAPER O., 1974, pp. 56, 57.

separate, successive epochs and which underwent volcano-tectonic and tectonic *sensu stricto* actions much more pronounced and articulated than on the Moon, during and after the above-mentioned process of " oceanisation " (cf. F. A. Mutch *et al.*, 1976, p. 317, Fig. 9.1).

It should also be pointed out that while on the Moon the lava-flooded plains are generally depressions, on Mars the plains (" *planitiae* ") comparable to the lunar ones (" *maria* ") also correspond to plateaux, such as *Tharsis*, raised above the depressions. I am therefore not sure whether in the case of these plateaux it is appropriate to speak of the " oceanic " type of crust, unless they were originally on the same level as the *planitiae* and genetically analogous, and then subsequently raised by tectonic phenomena. I do not feel our present state of knowledge is adequate to clear up this point, except partially, as regards the *Tharsis* uplift (T. A. Mutch, *et al.*, 1976, pp. 225–226), on which there were distinct volcanic floods, before and after the uplift (T. A. Mutch *et al.*, pp. 225, 226; 317, Fig. 9.1).

On the other hand, I am not personally much in favour of the term " oceanisation ", since I do not feel that a comparison between the lava-flood areas of the Moon and Mars and the oceanic areas of the Earth is genetically orthodox, especially in the case of Mars, where, as was noted above, these areas correspond not only to depressions, like the lunar " *maria* ", but also to plateaux, which at least in some cases, such as *Tharsis*, do not seem to be structurally comparable to these " *maria* " and even less so to the terrestrial ocean floors, but rather to the above-mentioned great continental flood basalts on the Earth (Deccan, Paranà, Columbia River Plateau, etc.). I would thus prefer to speak not of " oceanisation " but of volcanic infilling of ancient basins or plains.

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The photographs of several of Jupiter's satellites as transmitted by the space probe " Voyager 1 " (USA) are extremely interesting from a morphological viewpoint.

The images of the surface of the satellite *Io* (which is only slightly larger than our Moon) are particularly remarkable because they show evidence of intense volcanic activity in action (Pl. II, Fig. 1).

In fact, numerous volcanic vents with differing morphology were discovered. Some cases seem to present characteristics typical of calderas with lava lakes. Several are surrounded by extensive deposits of volcanic ashes; others show characteristic fresh radial lava flows. The photos demonstrate the existence of at least 8–10 active vents.

The volcanic features seem to be concentrated in the equatorial belt.

The eruptive manifestations which were verified during the four days when *Io* was in view of Voyager's cameras seem to denote a prevalence of explosive volcanic activity.

The exceptional photograph taken of the rim of the satellite shows an enormous volcanic plume that rises about 161 km above the airless surface (Pl. I, Fig. 2). Several bright areas seem related to materials created by geyser-like phenomena.

The volcanic activity on *Io* is even greater than that on the Earth. Therefore, the surface of this satellite is the most active in our solar system, going by present knowledge.

There are, instead, no clear indications of impact craters on *Io*. In this aspect the satellite differs from the earth's Moon and from other planets which have been explored by space probes up to the present.

This type of crater, with the characteristic bright rays of debris ejected by impact, abounds on Jupiter's largest satellite, Ganymede, where great amounts of ice are believed to cover the surface. One of these ray systems extends 1000 km. Other craters without rays may be discerned on Ganymede, but their origin is not so clear.

The satellite *Europa*, somewhat smaller than our Moon, shows particular characteristics. Its surface is criss-crossed by linear features, which in all probability correspond to fractures of considerable size in the crust of the satellite. A comparison may be useful—keeping the different scale in mind—between the surface of *Europa* and an aerial photograph of the Sahara (near Sinkat, Sudan) where the absence of vegetation permits the clear observation of intersecting fractures and dikes which also correspond to fracture lines (2). An even better comparison may be made with several photographs of the surface of Mars (3) showing marked analogies with the images of this Jovian moon.

A particular, concentric, bull's-eye type structure, which is quite extensive, represents the most important feature of *Callisto*, the outermost of the Jovian moons. It may be interpreted as the effect of the collision of a relatively large celestial body with the surface of this satellite.

And finally, the innermost and smallest Jovian satellite, *Amalthea*, with its irregular shape shows considerable similarity to the Martian satellites Deimos and Phobos. It may be interpreted, as are the Martian satellites, in all probability as an asteroid captured by the planet.

It is interesting to note, in concluding this brief report on Jupiter's satellites, that they present characteristics that are very different from each other. Furthermore, they correspond to distinct stages of geological evolution, and they may even have, as in the case of *Amalthea*, entirely particular genetic origins.

(2) *National Geographic*, vol. 133, N. 6, 1967, p. 830.

(3) W. K. HARTMANN and O. RAPER, 1974, pp. 86, 93; H. MASURSKY *et al.*, 1974, pp. 37, 62, 63, 64.

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Fig. 1. – Global mosaic of Mars made of more than 1500 computer corrected television pictures taken by U. S. "Mariner 9" in 1971 and 1972, prepared by Caltech's Jet Propulsion Laboratory. Between the northern polar cap (top) and the southern hemisphere, vast flat surfaces (*Planitiae*) are visible. These areas contrast with the rugged morphology of the southern hemisphere (See Text p. 2, 3). Near the center of the photograph, one can see the huge shield volcano *Mons Olympus*, the largest volcanic structure known at the present: 600 km wide and 25 km high. (*Original photo*, courtesy of NASA).

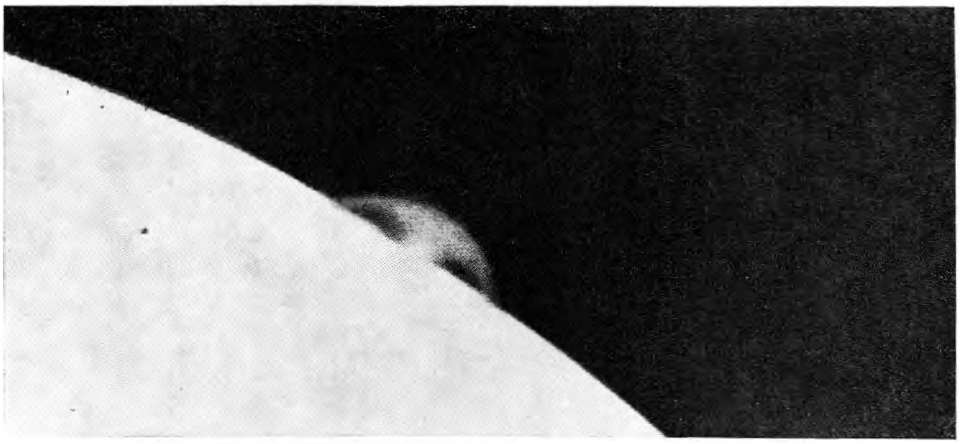

Fig. 2. – Volcanic plume on the limb of Jupiter's satellite *Io* as recorded by the U. S. space probe "Voyager 1". The cloud rises more than 60 miles above the surface. (NASA *photo*).

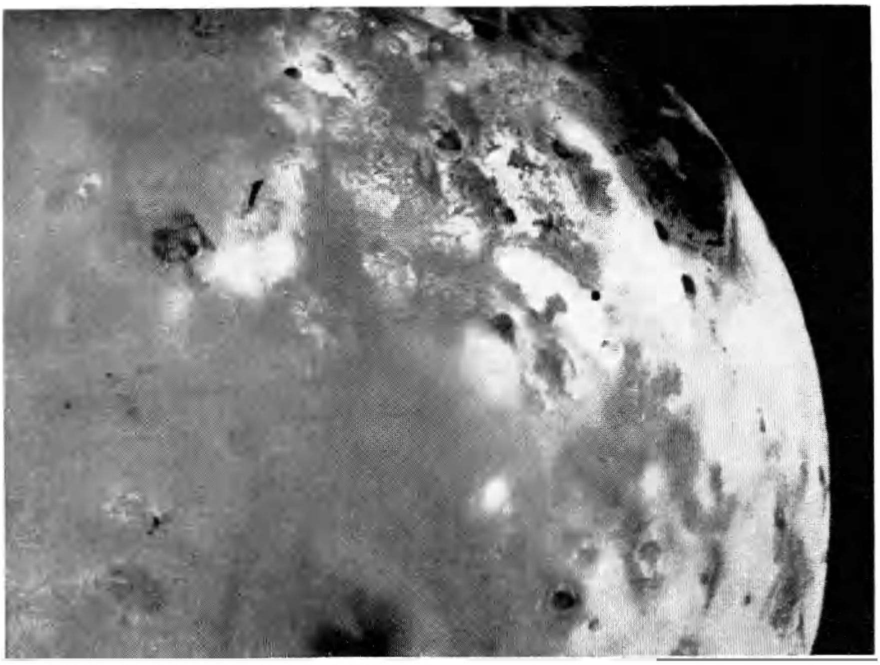

Fig. 1. – Part of the surface of the Jovian satellite *Io*, photographed form a distance of 377.000 km by "Voyager 1". Various active volcanic vents are evident. The large spots—especially the dark ones—correspond in all probability to superficial deposits of volcanic origin. (*Original* NASA *photo*, courtesy of Dr. Sergio Era).

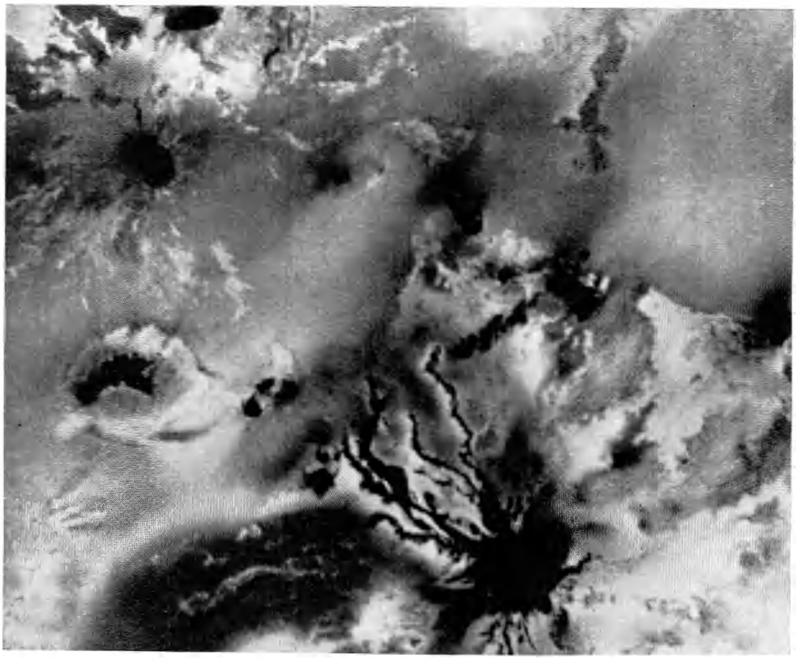

Fig. 2. – Another part of the surface of the Jovian satellite *Io*, photographed by "Voyager 1" at a range of 128.500 km. The dark spots correspond in all probability to various volcanic vents. The spot with an irregular radiating pattern near the bottom appears be a crater with lava flows. The diffuse colorations are probably surface deposits of sulfur compounds, salts and possibly other volcanic sublimates. (*Original NASA photo*, courtesy of Dr. Karin T. Stephen).