

FLOOD BASALT VOLCANISM ON THE MOON AND MARS¹KONRAD BENEŠ²

ABSTRACT

Beneš, K. 1979 Flood basalt volcanism on the Moon and Mars. *In*: W. J. M. van der Linden (ed.): Fixism, mobilism, or relativism: Van Bemmelen's search for harmony – Geol. Mijnbouw 58: 209-212.

Comparative studies of the surfaces of the terrestrial planets reveal that processes of flood basalt volcanism were common to all of them, irrespective of their stages of evolution either primitive, intermediate or progressive. On the Moon manifestations of flood basalt volcanism have been recognized in basins (*maria*); on the planet Mars both in basins (*planitiae*) and in higher topographic (continental) levels. The mare-epoch of the less developed planets led to significant changes in their relief and in the crustal structure. Examples of volcanic flows from the lunar and martian surface are introduced. Some crustal uplifts on Mars can be interpreted in terms of Van Bemmelen's undations.

INTRODUCTION

Systematic investigations of volcanic landforms on the Moon and Mars brought evidence of various kinds of extrusive mechanisms. In the following lines the form known as areal fissure or flood basalt volcanism will be discussed in more detail on selected examples from lunar lowlands, traditionally called *maria*, as well as from martian plains, termed *planitiae*. The more or less extensive areas occupied by lunar *maria* and martian *planitiae* are believed to have been sites of the origin of a new type of crust, mostly of basaltic composition.

In the eyes of comparative planetology the Earth, Moon and Mars represent planets in different stages of geologic evolution: advanced (the Earth), primitive (the Moon) and intermediate (Mars). Processes resulting in flood basalt volcanism, however, were common to all of them.

EVIDENCE OF FLOOD BASALT VOLCANISM ON THE MOON

Recent samplings of lunar flatlands confirmed marial rocks to be of basaltic nature and not the same age. Most authors now share the opinion that the marial complexes did not originate by a sudden catastrophic process, as presumed by the theory of impact-induced melting, but rather by a sequence of volcanic outpourings. As a matter of fact, VON WOLFF (1914) already believed that the floors of lunar *maria* were the result of linear and areal extrusions, which overflowed the earlier surface. Some thirty years later SPURR (1945) began to distinguish between the older and younger extrusions (*imbase*, *lunabase*, *novabase*) stressing the periodic character of volcanic events.

Recent orbital photography as well as the direct survey of the marial surfaces confirmed the existence of basaltic flows in several areas of the Moon. At present there is a fair evidence of:

- (1) flow units buried under the lunar regolith;
- (2) flows strongly degraded by processes of meteoritic erosion;
- (3) relatively young areal extrusions, whose flow termini are still distinctly observable on the present surface

¹Contribution No. 15/78/IRGTCP.

²Member of the International Research Group on Terrestrial and Cosmic Physics; Institute of Geology, Mining and Metallurgy, Míchálovická 72, 71000 OSTRAVA, Czechoslovakia.

(‘flow upon older regolith’ and/or ‘flow upon flow’).

(1) The first type of basaltic flow was discovered during the Apollo 15 mission along the wall slopes of the narrow V-shaped rille, called Rima Hadley, in the eastern marginal parts of Mare Imbrium. At this place horizontal to subhorizontal bedrock layers covered by a blocky regolith crop out along the slopes. Multiple buried flow units, some of them up to 10 m thick, are well visible in the upper section of the slope. The Lunokhod 2 photography revealed bedrock protuberances (probably disintegrated flows) in a linear rille located in the eastern part of Mare Serenitatis, as recently described by BASILEVSKY ET AL. (1977). It is thus likely that the numerous V-shaped or U-shaped troughs occurring in lunar maria may be sites of similar bedrock exposures. Their verification, however, would need the same kind of survey as accomplished by the Apollo 15 astronauts or by vehicles of the Lunokhod type.

(2) Some of the Orbiter photographs taken at low angle solar illumination show strongly degraded flows the frontal parts of which form moderate ‘steps’ or rather ‘waves’ on the cratered mare surface. These presumably subdued flow termini represent the original ‘flow upon flow’ structure, which would be entirely invisible at a higher sun. At the time of the sunset or sunrise on the Moon various morphologic details, such as flat domes, faults, ridges, valleys and the like can be resolved even on photographs gained by telescopes.

(3) The most convincing examples of areal flows extending over surprisingly long distances were brought by Apollo 15 photography. On the picture labelled AS 15-1557 the sharpness of flow contours enhanced by low-sun illumination makes it possible to estimate the length, width and height of individual flow tongues. SCHABER (1973), presuming extremely high extrusion rates, estimated the extent of the Eratosthenian flows in the Mare Imbrium to be around 200,000 km². This is approximately as much as the area occupied by the Columbia and Snake River flood basalts in the north-western part of the United States.

Evidence of buried, degraded and distinctly developed areal flows in the lunar maria speaks in favour of two fundamental facts: the historic existence of areal fissure volcanism and of its episodic character.

On the lunar globe the maria are distributed in an asymmetric way. The reverse side of the Moon is predominantly continental with basaltisation confined to a lesser number of basins such as Mare Moscoviense, Mare Ingenii, the parathalassoids Korolev, Hertzprung, double ring Schrödinger and some others. The near side displays large areas of basaltisation either of circular or irregular shape. The circular ones show distinctly different degrees of inundation: an initial, a transitive and an advanced one. The evidently non-impact Mare Australe represents the first stage, Mare Nectaris or

Table I
Geologic interpretations of some of the morphologic units on Mars.
Scale of maps 1 : 5,000,000.

Authors	Mapped units and their interpretation	Areographic position
Scott & Allingham, 1976	Rolling plains material (pr): Mostly lava flows thinly covered by aeolian deposits	Elysium Quadrangle
Potter, 1976	A: Ridged plains material (prg): flood basalts with widely spaced wrinkle ridges marking sites of feeder fissures; lavas have almost completely buried the rough mountain (highland) surface. B: Peripheral plains material (pp): volcanic field of flood lavas mantled with sediments burying rough mountain land form	Hellas Quadrangle
Schaber, 1977	A: Ridged plains material (pr): basaltic lava flow materials covered by a thin mantle of aeolian deposits. B: Hummocky plains material (ph): basaltic lava flows in various stages of erosion and mantling by aeolian and sedimentary materials. C: Cratered plains material (pc): basaltic lava flows overlying the hilly and cratered material intertongued with sedimentary deposits	Iapygia Quadrangle

Moscoviense the second, Mare Crisium, Serenitatis or Imbrium the third one. Possible reasons predetermining the asymmetric distribution of maria may be seen in the spatial differences in the thickness of the premarial lithosphere along with its differentiated grade of tectonic disturbance. It is perhaps significant that the reverse continental hemisphere lacks not only irregular maria, but also those of the circular ones, representing advanced stages of inundation.

FLOOD BASALT VOLCANISM ON MARS

Similarly to the Moon large expanses of Mars are characterized by low relief energy. Areas of this morphologic type were termed planitiae (see the TOPOGRAPHIC MAP OF MARS, 1976). The shape of planitiae is either irregular or roughly circular, thus reminiscent of the lunar or mercurian lowlands.

Closer photogeologic investigations of the surface features occurring within the martian planitiae strengthen the opinion that they are near genetic analogues of lunar maria. The idea is based on the following observations. Planitiae are sites of

extensive extrusions of areal and central type. Areal extrusions are represented by basaltic flows and sheets recently discovered in various parts of the planet. Evidence of these features has been brought by excellent Mariner 9 and Viking Orbiter photography in the following provinces: Memnonia, Tharsis, Amazonis and several others. The Memnonia flows, occurring in a region centered at 146°N and 19°S, show a distinct 'flow upon flow' structure, well known from the terrestrial plateaubasalt areas in Deccan or along the shores of the Columbia River in Oregon. Multiple overlapping flow termini illuminated by the sun appear as distinct, bright, steep walls. The partial inundation of this area is manifested by the occurrence of 'islands' of older crust. Similar remnants of the premarial crust may be seen in some flooded (epicontinental) areas on the Moon as exemplified by Montes Teneriffe and other hills in the northern marginal parts of Mare Imbrium. On the surface of planitiae several other morphologic features typical of lunar maria have been identified (wrinkle ridges, domes, lava channels and the like).

The idea of martian plains being genetic counterparts of lunar maria seems to find further support from the project of the systematic geologic mapping of the planet. Genetic interpretations of certain mapped units are strikingly similar although originating from various authors (Table I). Volcanic complexes of martian planitiae as well as those of lunar maria are probably the result of a similar kind of process leading to the significant rebuilding of the primary crust.

TECTONO-VOLCANIC CONSEQUENCES OF LARGE REGIONAL UPLIFTS ON MARS

The historical evolution of Mars seems to have been of a more complex nature than that of the Moon. After the mare-epoch the Moon entered the descendant line in active crustal development. Not so Mars. Its surface testifies volcano-tectonic events which seem to be of post-mare age. In this respect two provinces are of particular interest: the Tharsis-Syria and the Elysium province.

According to the Topographic map of Mars, the Tharsis-Syria elevation (sometimes called the Tharsis bulge, dome or plateau) is of roughly elliptical shape some 3000 and 4000 km across. The whole area obviously went through extensive fracturing and rifting accompanied by a multistage volcanic activity in the planet's not too distant history. The Tharsis-Syria uplift is characterised by its roughly radial peripheral pattern of rift structures. The rifts, usually 2 to 8 km wide and tens to hundred kilometres long, form parallel to subparallel systems in some areas. Rift floors are either smooth or cratered. Small craters also occur on rift intersections. Some areas, however, show extremely complex patterns of rifts and fractures (area of Labyrinthus Noctis, area to the SE of Olympus Mons etc.), so that several periods of structural deformation must be assumed.

On the Tharsis-Syria elevation relatively young shield and

Table II
Approximative widths of rifts on small and larger terrestrial planets.

Planet – relative radius	Approximative width of rifts	Examples
Earth- 1.000	continental: 30-70 km rarely more (Red Sea)	Rhine Valley (35-45km) Lake Tanganyika (40-50km) Lake Baikal (30-70km)
	oceanic: 25-50 km	Mid-Atlantic (25-50km)
Venus- 0.813	unknown	Malin-Saunders (Rift?) Valley: 100 to 150 km
Mars – 0.530	strongly rifted western hemisphere: 2 to 8 km	Tempe Fossae Ceraunius Fossae Memnonia Fossae
Moon – 0.273	few hundreds of metres to few kilometres	Fossa Hypatia Fossa Hyginus Vallis Alpina

tholoid volcanoes are superimposed. Colossal dimensions of the Tharsis-Syria uplift, extensive tectonism, occurrence of fresh looking rifts and volcanic constructions have led to various considerations on the origin, history and age of these features. CARR (1976), discussing the creation of the Tharsis-Syria Rise, mentioned 'a concentrated upwelling of material from deep in the mantle. The effects of the plume' in his opinion 'may have been amplified by their sustained action on a stabilized crust, that was much thicker than the crust of the Earth'. Indeed, the uniform appearance and the small width of rifts could plausibly be explained by the latter assumption. On average the rudimentary rifts of the less developed planets seem to be much narrower than the terrestrial ones (Table II).

In the view of Van Bemmelen (pers. comm., 1978) the Tharsis or Elysium bulge on Mars can be regarded as a kind of undation comparable with the terrestrial ones. Such undations, according to the same author, came into being by buoyant magmatic matter underneath, which resulted in tensional rifting of the crust and the occurrence of volcanism of areal and later of central type. In the course of time the mean density of the buoyant magmablisters and the strength of its matter rose by cooling, so that the cycle of volcano-tectonic evolution came to a halt without any gravitative horizontal movements having taken place. Actually, on the whole surface of Mars no direct evidence of any larger movements of crustal plates is found, if minor tectonic offsets are ignored. Mobilistic conceptions with regard to the small and less developed planets (Moon, Mercury and Mars) are hard to apply. Van Bemmelen is correct in stressing the fact that differences in the magnitude of various physical parameters on

Mars and Earth cause the endogenic structural evolution of the crust on Earth to be much more varied than on the much smaller Mars.

CONCLUSIONS

The opinion that volcanic complexes of variable thickness of lunar maria and martian planitiae are the result of extrusions of areal and central type has been strongly endorsed by recent investigations. The primary crust on both these planets underwent processes of rebuilding on a regional scale and in an asymmetric way. On the Moon such processes predominantly affected its near (Earthside) hemisphere, on Mars its northern one.

It is believed that at the origin of the new type of crust the major role is to be attributed to flood basalt volcanism. Extrusive events within the lunar maria are manifested by the existence of buried, strongly eroded and distinctly observable basaltic flows of variable age, thickness and extent. Closer examinations of the seemingly structureless surface of the martian planitiae show the existence of morphologic features similar to those found in lunar maria: single flows, mutually overlapping areal flows, sometimes disclosing the 'flow upon flow' structure, protruding remnants of basement rocks in incompletely flooded areas, elongate, sometimes *en échelon* arranged mare ridges, volcanic domes and similar features. The similarity of volcanic features leads to the conclusion that the complexes of martian planitiae are near genetic analogues of volcanic complexes filling the lunar maria.

On Mars, contrary to the Moon, still younger periods of the volcano-tectonic activity can be observed in areas of large crustal uplifts. Formerly inundated provinces have been extensively faulted, rifted and superimposed by fresh looking shield and tholoid volcanoes. Mars is believed to have a special kind of undations, not known from the more primitive Moon and Mercury.

ACKNOWLEDGEMENTS

The author greatly appreciates the stimulating remarks of Prof. Dr. Piero Leonardo and Dr. Péter Hédervári, who kindly reviewed the manuscript.

BIBLIOGRAPHY

- Basilevsky A. T., C. P. Florensky & L. B. Ronca 1977 A possible lunar outcrop: a study of Lunokhod 2 data – *The Moon* 17: 19-28.
- Beneš, K., I. V. Galibina & G. N. Katterfeld 1975 The trends in the evolution of the terrestrial planets – *Proc. USSR Acad. Sci. Geol. Ser.* 5 (in Russian).
- Carr, M. H. 1975 Geologic map of the Tharsis Quadrangle of Mars – *U.S. Geol. Surv., Miscell. Invest. Series.*
- 1976 The volcanoes of Mars – *Scient. Amer.* 236 (1): 33-43.
- Hédervári, P. 1968 Similar tectonic patterns of Earth and Moon – *Ann. Geof.* 21: 73-90.
- Leonardi, P. 1976 Volcanoes and impact craters on the Moon and Mars – Elsevier Publ. Co. (Amsterdam).
- Malin, C. M. & S. R. Saunders 1977 Surface of Venus. Evidence of diverse landforms from radar observations – *Science* 196: 987-990.
- Masursky, H. 1973 An overview of geological results from Mariner 9 – *J. Geoph. Res.* 78: 4009-4030.
- Potter, D. B. 1976 Geologic map of the Hellas Quadrangle of Mars – *U.S. Geol. Surv., Miscell. Invest. Series.*
- Schaber, G. G. 1973 Lava flows in Mare Imbrium. Geologic evidence from Apollo orbital photography – *Geochim. Cosmochim. Acta* 1: 73-92.
- 1977 Geologic map of the Iapygia Quadrangle of Mars – *U.S. Geol. Surv., Miscell. Invest. Series.*
- Scott, D. H. & J. W. Allingham 1976 Geologic map of the Elysium Quadrangle of Mars – *U.S. Geol. Surv. Miscell. Invest. Series.*
- Spurr, J. E. 1945 *Geology applied to Selenology. Vol. 2: The features of the Moon.*
- Topographic map of Mars. Atlas of Mars – *U.S. Geol. Surv. Miscell. Invest. Series.*
- Van Bemmelen, R. W. 1978-a The present formulation of the undulatory theory – *Berita Direct. Geol.* 10 (3): 28-36.
- 1978-b In: P. Hédervári (ed.): Report of the Intern. Res. Group on Terrest. and Cosmic Phys. II 2 – Budapest.
- Wolff, F. 1914 *Der Vulkanismus. Vol. I* – Stuttgart.