MAGMA GENERATION ON MARS: ESTIMATED VOLUMES THROUGH TIME

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Images of volcanoes and lava flows (1), chemical analyses by the Viking landers (2), and studies of the SNC meteorites (3) show that volcanism has played an important role in the evolution of Mars. Photogeologic mapping (4-8) suggests that half of Mars' surface is covered with volcanic materials. A previous estimate for the volume of volcanic materials (9) assumed a uniform thickness of 1 km for plains and plateau units, and did not consider plutonic materials. Here we present results from new mapping, including estimates of volcanic deposit thicknesses based on partly buried and buried impact craters using the technique of DeHon (10), infer the volumes of possible associated plutonic rocks, and derive the volumes of magmas on Mars, generated in its post-crustal formation history. We also consider the amount of juvenile water that might have exsolved from the magma through time.

1:2,000,000 photomosaics served as the bases for mapping volcanic materials, following the conventions from the 1:15 M photogeologic maps of Mars (5-6). Our higher resolution mapping enabled better distinction of volcanic materials and ages. We estimate the total exposed volcanic materials to be 66.98 x 10^6 km^3, or about 46.5% of the martian surface. Not included are possible igneous rocks of the "original" crust, for which no diagnostic volcanic signatures are visible. Thus, Early Noachian materials are excluded and this is a conservative estimate. The outline of each volcanic area was digitized into a computer data base and "tagged" as to geologic age. The method of DeHon (10) was used to derive thicknesses of volcanic plains units. Thicknesses were entered into the digital data base and contoured to derive total volumes of exposed units by age. The volumes for volcanic deposits having significant relief, such as the shield volcanoes, were derived from paleostratigraphic (11) and topographic maps. The method outlined above accounts for only the materials exposed on the surface. The total areal extent, including buried surfaces, for each geological epoch followed the estimates of Tanaka et al. (8, Table 4), assuming that the ratio of volcanic to non-volcanic buried materials is the same as the ratio of exposed materials, to derive the total volume of volcanic materials by age (Table 1).

Table 1. Estimated Volumes of Volcanic and Plutonic Materials on Mars, and Inferred Associated Water Released, Expressed as a Layer on the Planet

Epoch	Age① 10^9 yr	Volcanic 10^6 km^3	Plutonic 10^6 km^3	Total Magma 10^6 km^3	H_2O, m
L. Amazonian	0.1	2.06	1.44	3.50	.81
M. Amazonian	0.5	9.73	13.29	23.01	5.32
E. Amazonian	1.3	16.72	36.39	53.29	12.31
L. Hesperian	2.5	18.52	74.25	92.86	21.46
E. Hesperian	3.3	17.45	106.33	123.79	28.60
L. Noachian	3.6	9.36	58.93	68.29	15.78
M. Noachian	4.0	1.77	17.71	19.48	4.50
E. Noachian	4.6	—	—	—	—
Totals		75.6	308.34	384.22	88.78

① Approximate age at start of epoch

We next consider the total magma produced on Mars through time. Crisp (12) surveyed the ratios of intrusive and extrusive rocks on Earth and found a range of ratios of ~ 5:1 for oceanic localities to 10:1 for continental localities. We used a ratio of 10:1 for martian ages of Late Hesperian and older on the assumption that the early crust of Mars consisted of megaregolith which might be comparable to terrestrial continental crust. We used a ratio of 5:1 for Middle Amazonian and younger materials on the assumption that the Tharsis province and younger volcanic areas might have crusts somewhat similar to oceanic areas on Earth. A ratio of 8:1 was used for Early Amazonian as an intermediate value. Based on these assumptions, the total magma produced on Mars is estimated at ~384 x 10^6 km^3 with peak production in the Early Hesperian epoch. If the Middle Noachian is taken as the time when the surface record is first preserved, and it is assumed that ~ 4.0 ae is the start of this epoch, then the rate of magma production on Mars is less than 0.1 km^3/year, substantially less than the 26 to 34 km^3/year estimated for Earth over the last 180 x 10^6 years (12). If we assume that juvenile water was released in association with martian magmas, and if we take a value of 1% by weight for exsolved juvenile water, then the total volume of water outgassed from the magma would form a layer of water 88.8 m deep on Mars.

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