

CONSTRAINTS ON THE AGE, COMPOSITION AND SIZE OF THE MARTIAN SEDIMENTARY MASS.

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Introduction: Quantitative understanding of the physical, chemical, mineralogical and temporal nature of the sedimentary mass on Earth provides fundamental constraints for understanding how the terrestrial sedimentary record forms and evolves, and how that record relates to the origin and evolution of the upper crustal igneous sources [1-4]. Over the past decade, remarkable progress has been made in understanding the nature, extent and origin of the Martian sedimentary record [5], however, the scientific community is just beginning to take an inventory of the sedimentary materials that are present. Accordingly, anything approaching a quantitative understanding of the overall Martian sedimentary record is many years away.

In this paper, an attempt is made to place some basic constraints on the age, average chemical and mineralogical composition and overall size of the Martian sedimentary mass and its various lithological reservoirs.

Age of the Martian Sedimentary Mass: The terrestrial continental crust, which is the ultimate source of the vast proportion of sedimentary rocks on Earth, is relatively young, having grown episodically since about 4 Gyr and with a mean age of about 2.5 Gyr [2,4]. Stratigraphically, the terrestrial sedimentary record is very much younger and with a fundamentally different (exponential) age distribution than the ultimate upper crustal igneous sources (Fig. 1) due to various well understood cannibalistic sedimentary recycling processes [3,6].

Although volcanic activity on Mars has likely continued through to the present-day, the Martian crust on average is very old with most of it likely being in place by ~4.5-4.4 Gyr, and related largely to solidification of a very ancient primary crust that formed from an early magma ocean. The mean age of the Martian crust is certainly >4 Gyr and thus much older than the terrestrial continental and oceanic crusts (Fig. 1). Although there are inadequate constraints on the age of the Martian sedimentary mass, it also appears to be old, possibly suggesting that sedimentary recycling processes have been less important on Mars than on Earth.

Composition of the Martian Sedimentary Mass:

The chemical and mineralogical compositions of sediments and sedimentary rocks on any planet are controlled by the chemical and lithological composition of the exposed crust that erodes to produce sediments and sedimentary rocks and by the nature of volatiles (e.g., CO₂, SO₄, Cl, H₂O) that may be added to sediments

during weathering and other alteration processes (e.g., diagenesis), and during various depositional processes (e.g., evaporation and other direct precipitation from seawater).

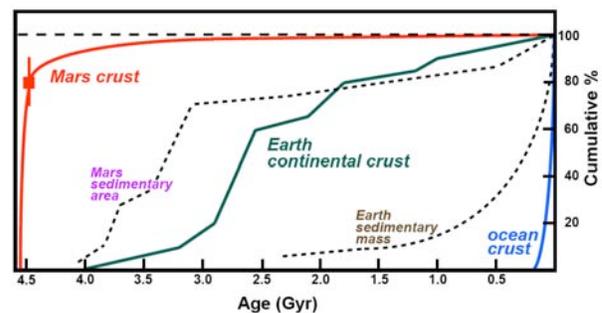


Figure 1. Comparison of models for the growth histories for the crusts and sedimentary masses on Mars and Earth [adapted from refs. 4, 6 & 7]. Note that for Mars, only Viking-era estimates of global sedimentary cover are available and these are considered a lower age boundary for the age distribution of the overall Martian sedimentary mass.

Mars is characterized by a basaltic exposed crust, which differs fundamentally in terms of major and trace element geochemistry and mineralogy from the more felsic “granodioritic” upper continental crust that is the ultimate source of most terrestrial sediment [4]. The overall effect of this is that mafic primary minerals (olivine, pyroxene, plagioclase, Fe-Ti-oxides, mafic rock fragments) and secondary (sedimentary) minerals that are Fe-Mg-rich and Na-K-poor compared to the terrestrial record (quartz, K-feldspar, felsic-intermediate rock fragments, K-Na-rich and Fe-Mg-poor secondary minerals) dominate Martian sedimentary mineralogy [8].

There is also growing consensus that Martian surficial processes, over significant periods of geological time, were controlled by some form of a S-cycle rather than the well-known C-cycle that dominates terrestrial weathering [8,9]. A sedimentary system dominated by the S-cycle likely leads to widespread low pH conditions and, among other things, such a difference would likely influence:

- (1) the record of chemical sedimentary rocks such that sulfates dominate over carbonates;
- (2) the composition of the Martian hydrosphere, that would be Mg-Fe-Al-rich and Na-K-poor compared to terrestrial seawater;

(3) the order of precipitation of evaporite minerals during brine evolution such that halite would precipitate after Mg-sulfates (and at much lower water activity) rather than before as is the case for terrestrial seawater [10].

Size of the Martian Sedimentary Mass: It may be possible to place some quantitative, but model-dependent, constraints on the overall size of the Martian sedimentary mass. Assuming that plate tectonics have not operated on Mars, it is reasonable to assume that any degassed S remained in the near-surface environment. Conservative estimates of sulfur degassing rates, combined with the most recent estimates of post-magma ocean volcanism, suggest $\sim 10^{21}$ g of total S has been degassed [11, 12]. Another approach is to assume that Mars has outgassed S proportionately the same as the Earth. A recent estimate of total terrestrial S degassing is $\sim 11\%$ of the Earth's primitive mantle complement [13]. This is also considered a conservative assumption since S is an incompatible element and Mars has differentiated more of its other incompatible elements into the crust than has the Earth [4]. When corrected for the higher concentration of S in the Martian primitive mantle compared to the Earth [4], this equates to about 2.3×10^{22} g degassed S on Mars. Accordingly, for this analysis, a range of $10^{21} - 10^{22}$ g of degassed S is adopted.

Assuming that degassed S reacted in the near-surface to form sulfate-bearing sediment and adopting a reasonable average sulfate mineralogy ($\text{Fe}_{0.4}\text{Mg}_{0.4}\text{Ca}_{0.2}\text{SO}_4 \cdot 2\text{H}_2\text{O}$) lead to a sulfate mineral reservoir of 5.5×10^{21} to 5.5×10^{22} g. The total mass of chemical sediment can then be derived by adding the amount of chlorides (estimated using soil S/Cl ratios) and the amount of amorphous silica estimated from basalt weathering models (carbonates are assumed to be negligible). The mass of chemical sediment is thus estimated at 8×10^{21} to 8×10^{22} g.

The ratio of siliciclastic/chemical sediments on Earth has been estimated by several workers and values fall in the range of 3:1 and 6.5:1. The average terrestrial value probably represents a minimum for Mars since pyroclastic activity, that produces large amounts of particulate debris, has been more active on Mars than on Earth [14]. Accordingly, if a ratio of 5:1 is adopted, an overall mass of the Martian sedimentary rock record of 5×10^{22} to 5×10^{23} g is derived. For comparison, this represents between about 2 and 20% of the size of the terrestrial sedimentary mass. Given that the surface area of Mars is only one-third of the Earth's and that sedimentary recycling and preservation associated with plate tectonics probably has not

occurred, these calculations indicate a very substantial sedimentary record for Mars.

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