THERMAL HISTORY AND CLIMATIC IMPLICATIONS OF EARLY HESPERIAN AGES FOR PRESUMED NOACHIAN AGE VOLCANIC FLOWS ON MARS  
H. V. Frey, Geodynamics Branch, Goddard Space Flight Center, Greenbelt MD 20771

Introduction

Volcanic resurfacing has apparently dominated all other forms throughout martian history [1-7]. A major (apparently volcanic) resurfacing at the Early Hesperian (EH) time of ridged plains (unit Hr) formation in Lunae Planum occurred in the highland/lowland boundary in eastern Mars [8] and elsewhere [9-12]. In this paper we consider the possibility that several units mapped as Middle and Late Noachian (MN, LN) were actually resurfaced in the EH, and the implications of this for the thermal and climate history of Mars.

The stratigraphic position of Nplr ridged plains (frequently gradational with EH Hr units) is Middle Noachian (MN); their high density of impact craters would certainly suggest a Noachian age. But total crater counts can be misleading: inefficient resurfacing events allow older surfaces to show through and give old total crater retention ages, which may not be the age of the resurfacing unit. We have shown [13] that Nplr ridged plains in Memnonia and Argyre are the same age as - but significantly thinner than - Hr in Lunae Planum [9,11,14].

The Late Noachian (LN) plateau unit Npl2 has a strong EH resurfacing branch in the cumulative frequency curves in Xanthe Terra, in Noachis southeast of the Valles Marineris, and south of the highland/lowland boundary [8,10,12]. An older MN surface shows through the EH resurfacing, leading to the old total crater age. Likewise, the undivided HNu unit, where it occurs as knobby terrain along the highland/lowland boundary and north and east of the Elysium volcanic complex, has MN and especially EH resurfacing ages [8,12].

Volcanic Resurfacing and Resurfacing Rates at Different Epochs

Figure 1 shows how the fraction of Mars resurfaced by volcanism at different epochs depends on the assumed resurfacing age of Nplr, Npl2 and HNu. If Noachian (Figure 1a), volcanic resurfacing greatest but similar in the MN and EH, and 50% less in the LN and LH [7]. If any of these were resurfaced in the EH, that epoch was the dominant volcanic period, mostly at the expense of the LN. If all three units were resurfaced in the EH, LN volcanism was < 5% and EH volcanism > 60% the Mars surface, twice that of MN volcanic resurfacing (Figure 1d).

The average rate of volcanic resurfacing is strongly dependent on poorly known absolute ages of the different martian epochs. Both the Neukum and Wise (N&W) [15] and Hartmann (HRT) [16] timescales, as modified by Tanaka et al. [7], produce two peaks in the average rate of volcanic resurfacing, and a significantly lower rate in the LN. For both chronologies, this quiet interval was similar; 350-400 my long. In HRT's chronology, the brief (70 my) MN always had the highest rate of volcanic resurfacing. In the N&W chronology, if any of the three units were resurfaced in the EH, this period was dominate in terms of average resurfacing rate (excluding the unknown Early Noachian). If all three were resurfaced in the EH, the average rate was 1.7 times that in the MN and 60 times greater than that in the LN.

Discussion

(1) Thermal history models of Mars may have to explain a late "pulse" of volcanic activity in the EH following a 350-400 my Late Noachian "lull" during which such activity nearly vanished. The timing of the LN "lull" and the relative importance of the peaks on either side differ between the chronologies and may provide different constraints for thermal history models. Regardless of the chronology, the "lull and pulse" scenario of volcanism is at variance with most current thermal evolution models [17-19] which do not have delayed core formation [20]. Figure 2 compares the amount and rate of volcanic resurfacing (from Figure 1c), for a compromise average chronology, with conventional secular cooling. The variations in volcanism shown are consistent with the suggestion [21] that volcanism may stabilize or even temporarily shut off early convection [22], causing the interior to heat up, leading to episodes of volcanism.

(2) The climatic implications are related to volcanic outgassing. Assuming an average thickness of 250 m for the volcanic resurfacing and 1 wt% H2O, a 3-5 m "planet-wide
Early Hesperian Ages for Volcanic Flows on Mars: Frey, H.

An equivalent layer of juvenile water would have been outgassed by EH extrusive volcanism. This minimum amount is 1/10th that needed to carve the Chryse outflow channels [23] but would have filled the entire northern lowlands to a depth of 11-18 m. Far larger amounts were likely recycled from the regolith by volcanic heating of ice. The 0.1-0.2 bars of outgassed EH juvenile regolith as carbonates LN when atmospheric loss through carbonate formation have filled the entire northern lowlands to a depth of 11-18 m. Far larger amounts were likely. Noachian valley networks have produced the post-EH features which suggest conditions more clement than at present. The EH climate may have moderated following a cold 400 my ln when atmospheric loss through carbonate formation [24-26] was not offset by volcanism.

Concluding Thoughts
(a) The amount of EH volcanic resurfacing has probably been significantly underestimated. The EH may have been the major period of volcanism on Mars.
(b) The Late Noachian may have been a time of volcanic quiescence, a 350-400 my long "lull" in activity. This would be important for thermal history (and climate) models.
(c) The rate of EH volcanic resurfacing may have been very high, with large amounts of CO2 and H2O rapidly outgassed. These important greenhouse contributions may help explain the subsequent development of outflow channels.
(d) The juvenile CO2 and H2O contributed by EH volcanism cannot, by themselves, produce a "warm, wet" interval on Mars, nor account for the Chryse outflow channels or the proposed Borealis Ocean on Mars. Water (and CO2) released from the regolith is still needed to produce the post-EH features which suggest conditions more clement than at present. The EH volcanism likely contributed to this release and subsequent moderation of the climate.

FIGURE 1 RESURFACING OF MARS

FIGURE 2 RESURFACING OVER TIME (AVERAGED CHRONOLOGY)

References: