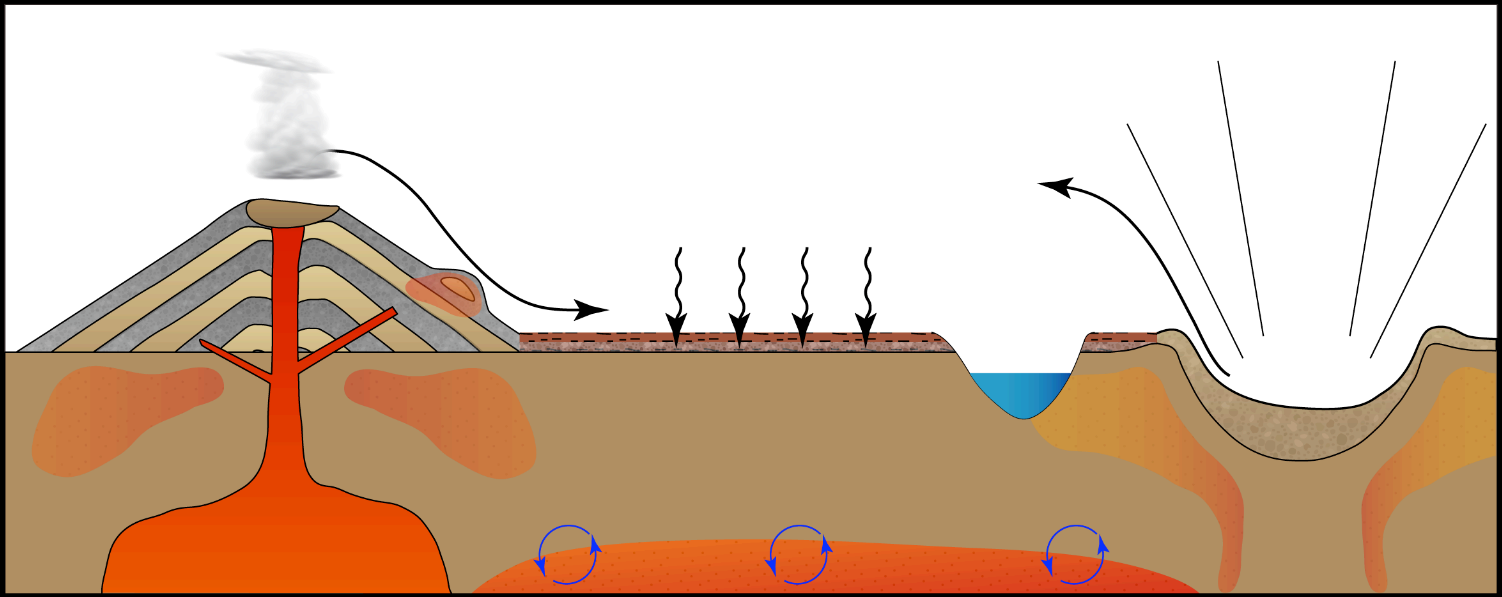
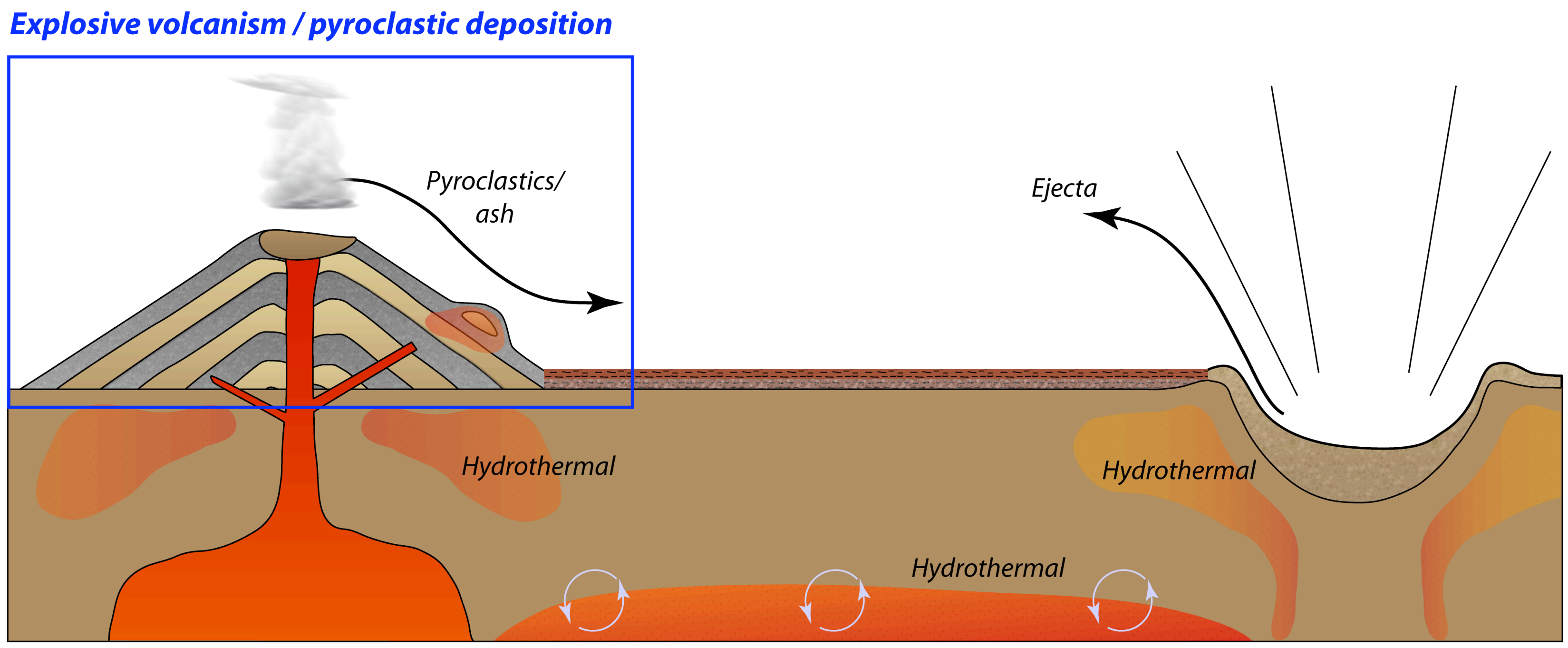
The early supracrustal rocks of Mars



N. Tosca[1,2], J. Hurowitz[3], D. Sumner[4], R. Milliken[5]

[1]Dept. of Earth Sciences, Univ. of Cambridge, UK
[2]Planetary Science Institute, USA
[3]JPL/Caltech, USA
[4]UC Davis, USA
[5]Univ. Notre Dame, USA

Surface processes on Early (Noachian) Mars



In the absence of geomorphic evidence for abundant surface water pre- 3.7 Ga
we assume three processes dominate the earliest martian surface:

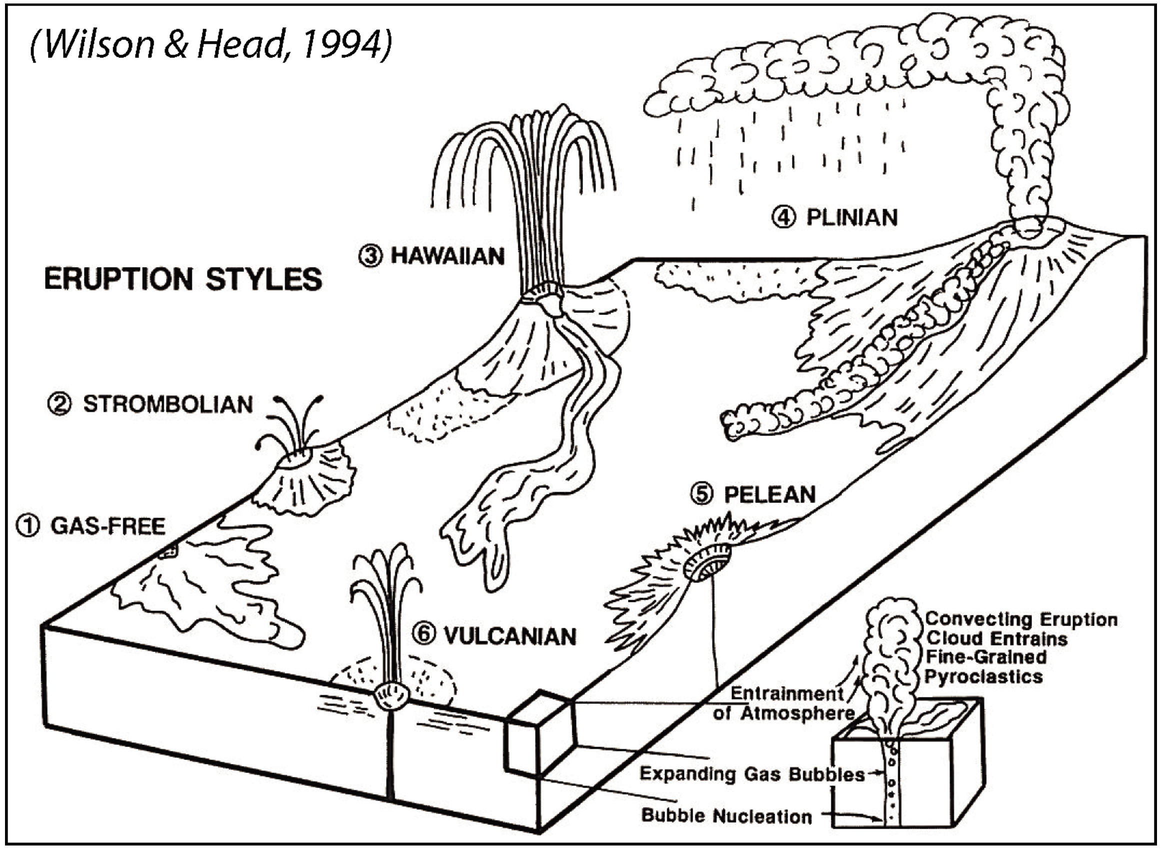
1. *Impacts*
2. *Volcanism*
3. *Eolian reworking*

Here, we explore rock accumulation and mineralogical predictions in this context

Finally, we compare this model to observations at Mawrth Vallis

Explosive volcanism: An dominant contributor to the martian surface

- **Explosive volcanism on Mars common:**
  - Lower atm pressure
  - Greater gas exsolution
  - Enhanced magma disruption
  - Higher volatile content



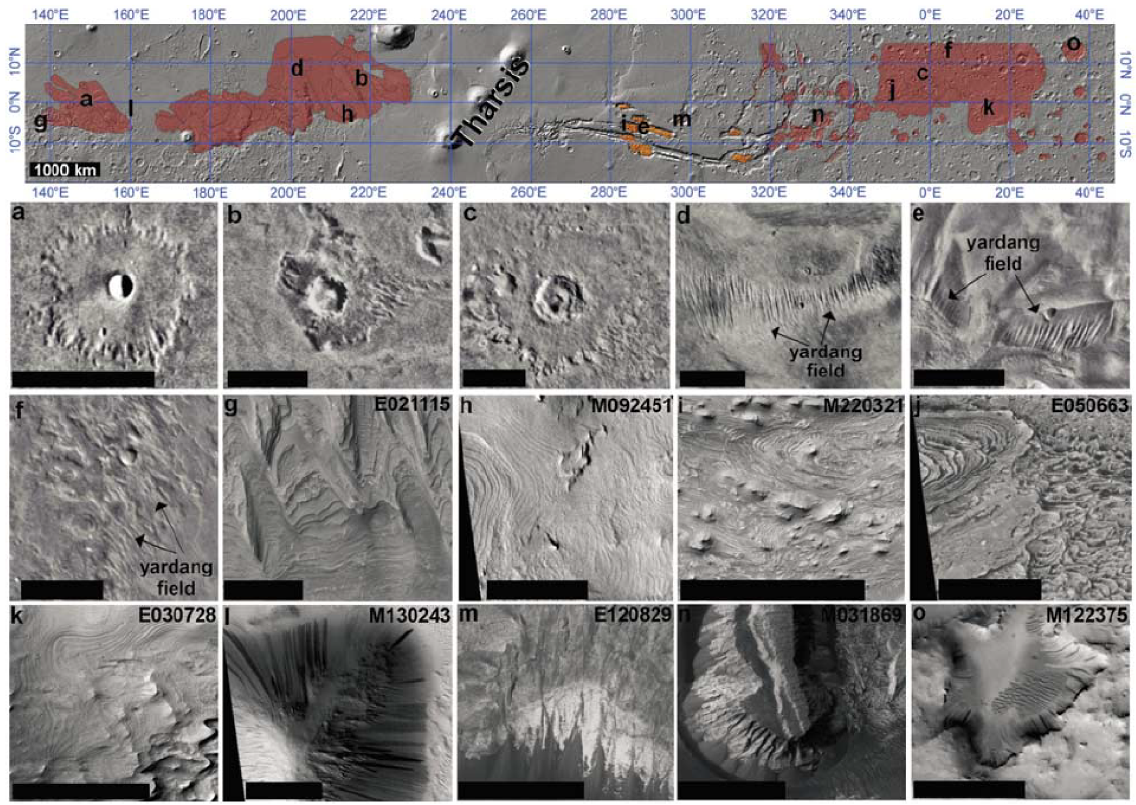
- **Pyroclastic deposits**
  - 100x finer grained
  - Greater distances
  - Clouds rise 5x higher

- **Virtually every eruption (regardless of composition) of volatile-bearing magma accompanied by fine-grained pyroclastic deposit**

- **The Earth's sedimentary budget contains a minimum of 30% volcaniclastic contributions (Garrels & Mackenzie, 1971)**

Explosive volcanism on Mars: Observational support

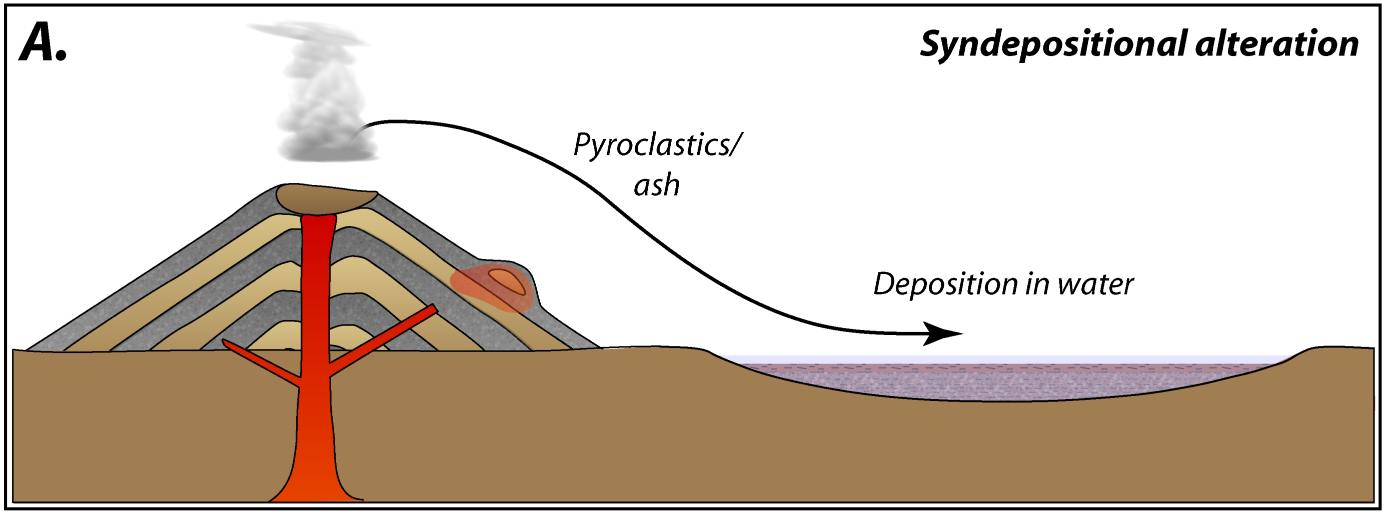
- **Volcanic ash deposition important in forming Friable layered deposits (FLDs)**
  - Mapped by *Schultz & Lutz* (1988) & Hynek et al. (2003) across equatorial regions 1000s km apart
- **FLDs fine-grained & thinly layered**
  - Distributed over 10^5 to 10^6 km^2
  - Mostly post-Noachian



(Hynek et al., 2003)

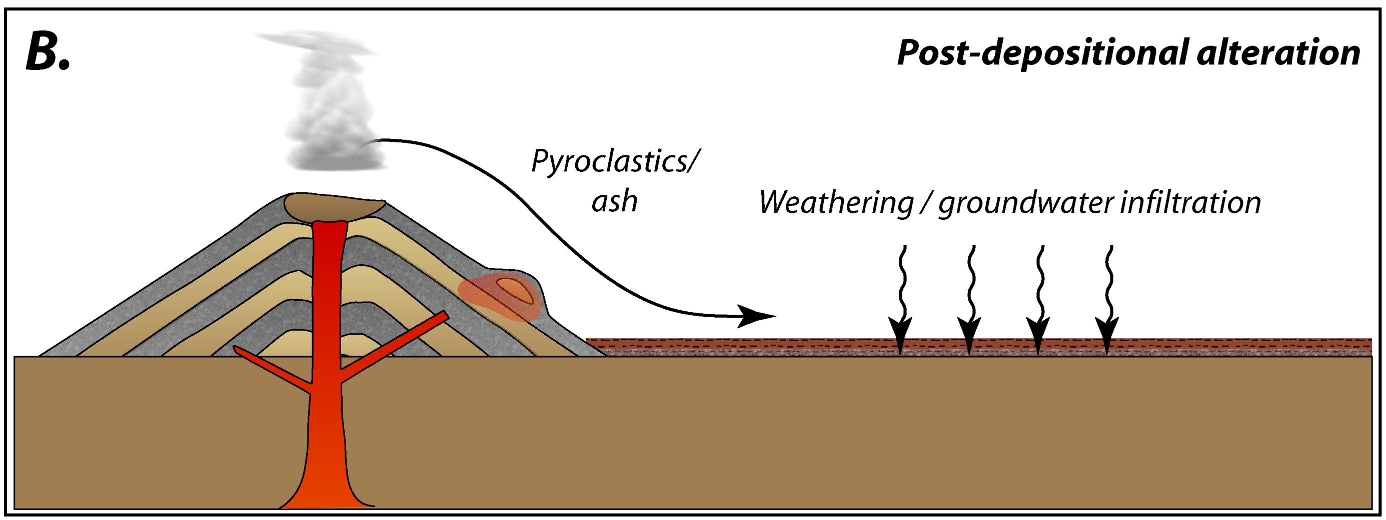
- **Additional support for pyroclastic activity from Home Plate in Gusev Crater**
- **Many additional reports** **(Mouginis-Mark, 1982, 2002; Edgett, 1997; Greeley & Crown, 1990, etc.)**
- **Robbins et al. (2010) identify transition from explosive to effusive volcanism at about 3.5 Ga from survey of major calderas**

Usually, we associate the products of explosive volcanism with either:



Requirements:

- *Nearly pure smectite deposits (e.g., bentonites)*
- *Pre-existing water body must be spatially and temporally persistent*
- *Additional detrital pulses/signals?*



Requirements:

- *Dominated by halloysite, kaolinite, opaline SiO_2, imogolite*
- *Smectite rare; when present is Al-rich*

The origin of smectite in pyroclastic deposits

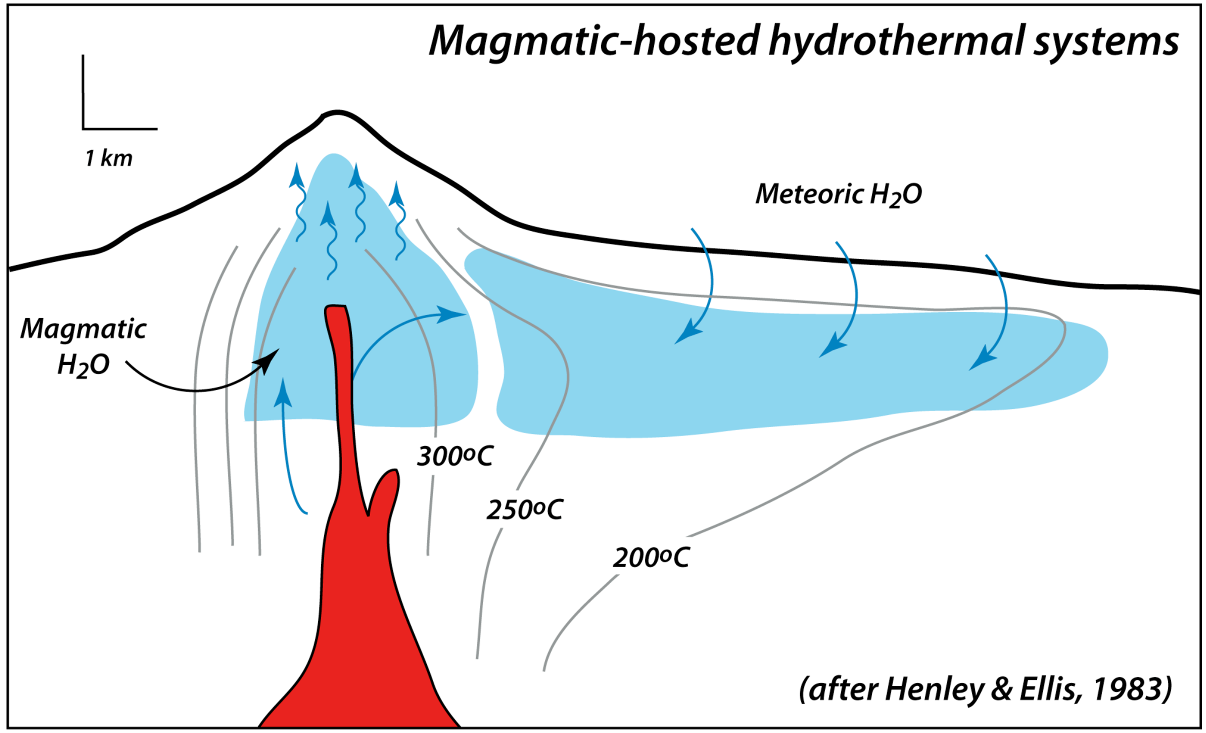
- ***Most smectite in pyroclastic deposits & soils is hydrothermally formed within volcanic vents and entrained upon eruption***
  - Mineralogy, geochemistry, $\delta^{18}O$ & δD show elevated formation temperatures
  - Smectite is Fe/Mg-rich; including saponite & nontronite
  - Occurs with minor/trace chlorite, biotite, vermiculite, and C/S, etc.
  - Hydrothermal smectite deposited w/ash in localities across globe

- **Mt. St Helens 1980 deposits (*Pevear et al., 1982*)**
  - Largely andesitic/basaltic composition
  - Saponite in the unaltered ash reaches 10 vol. % of bulk, increasing with distance from vent
  - Total deposits >25% lithic material (i.e., entrained vent rocks)

- **Mt. Usu, Japan (*Mizota & Faure, 1998*)**
  - Nontronite present at >10 vol. % in unaltered ash
  - *Water-saturated zone under vents driving hydrothermal activity*

Hydrous magmatism & hydrothermalism: Hand in hand

- **Every group of meteorites preserves evidence for magmatic hydrothermalism**
- **Abundant geochemical evidence for early hydrous volcanism**
- **When magmatic volatiles were high, degassing & hydrothermalism results**



- **Petrogenetic studies infer the earliest magmas were also the most volatile rich**
- **Thus, magmatic hydrothermal activity can be inferred to be directly proportional to volcanism**
- **Meteoric water may also contribute, but constraints are less clear pre-3.5 Ga**

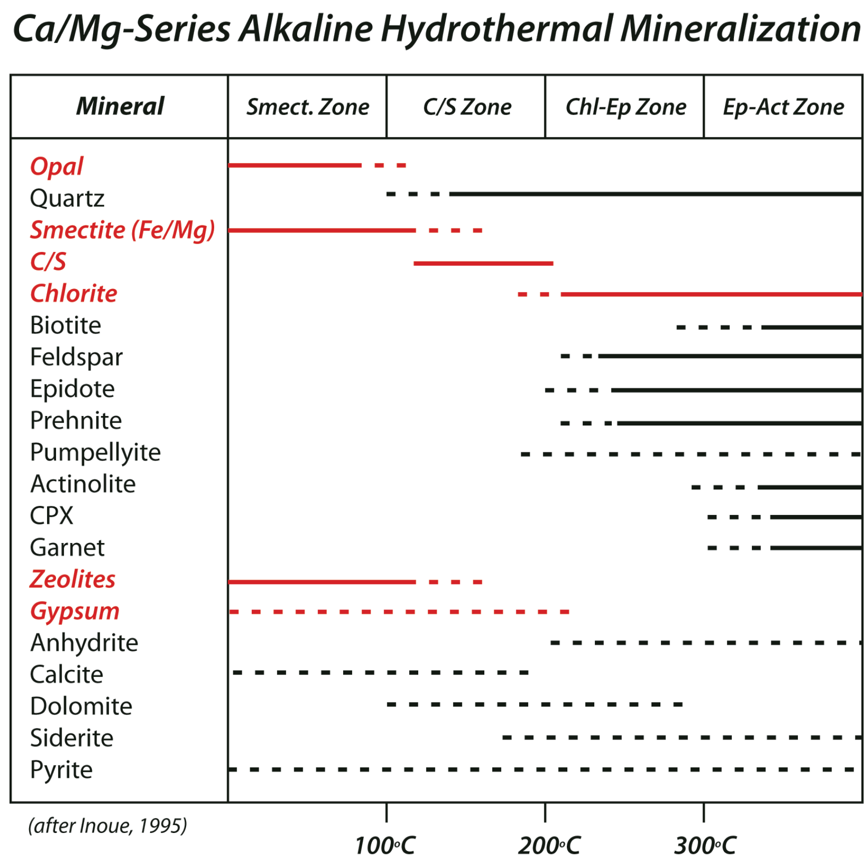
The pyroclastic contribution to early martian sedimentary budget

- **Significant volcanism in pre-/mid-/late-Noachian (e.g., Tharsis)**

- **Magma-water/ice interactions would have produced:**

  Hydrothermal systems
  - Dependent on nature of interaction, volatile content, crustal H_2O reservoir
  - Generate significant Fe/Mg-smectite & lesser chlorite, C/S, biotite, etc.
  - Clays would be transported & concentrated in air fall deposits

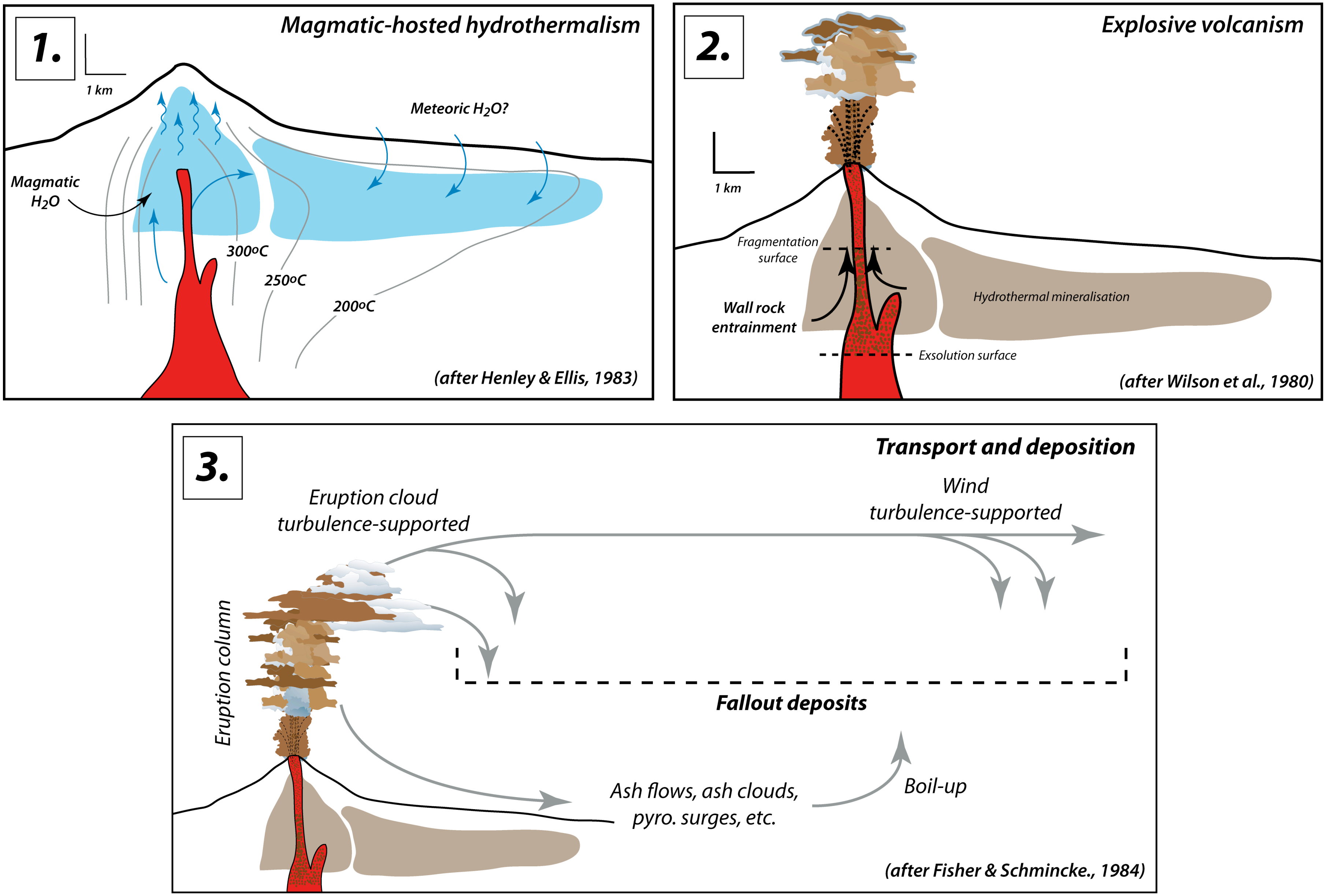
  Fine-grained pyroclastics
  - *Entrainment of atmosphere could alter syn-eruptive ash*
  - *Distinct post-eruptive Al-rich weathering signal*



- **The total amount of pyroclastic clay delivery to surface is a function of:**
  - Frequency & extent of magmatic-hydrothermal & syn-eruptive alteration (dependent on volatiles)
  - Efficiency of explosive delivery & transport

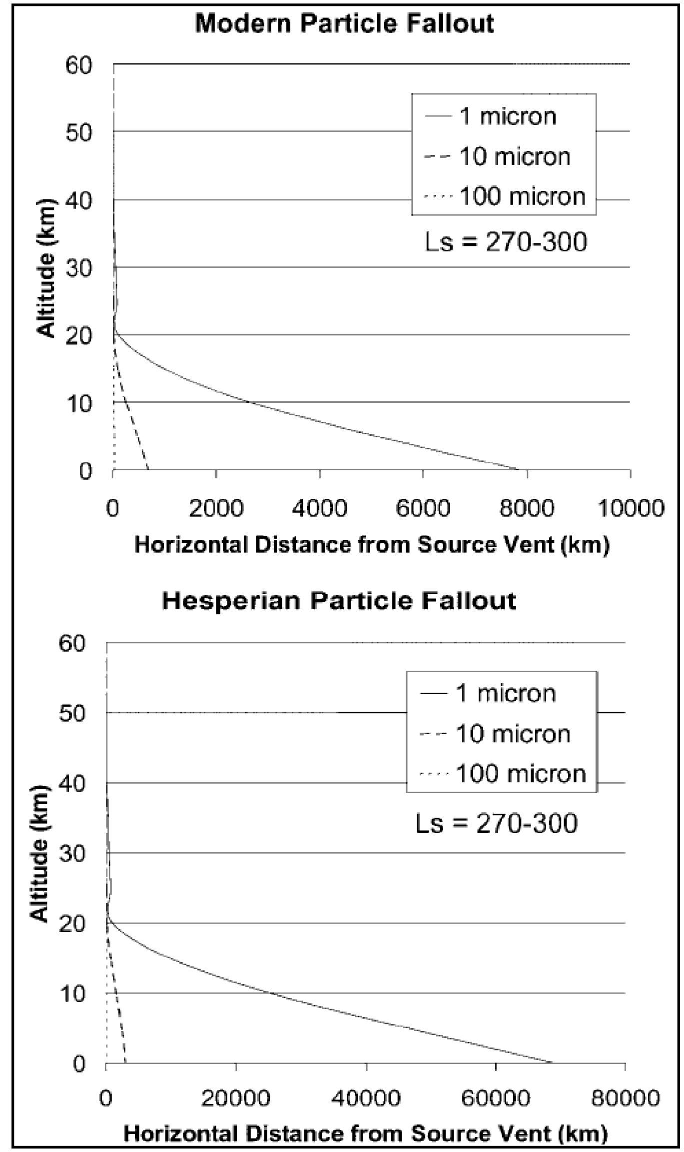
- **Volumetrically significant flux of newly formed clay available for impact/physical reworking**

A model for pyroclastic contributions to surface mineralogy



How much & how far? Ash transport and particle size segregation

- **Atmospheric winds could carry <10μm particles several 1000 km**
- **Ordovician ash beds in E. US distributed over 5 x 10^6 km^2**
- **Significant atmospheric residence time (up to 4 years on Earth)**
- **Smectite & other clays present in ash concentrated in the <2μm fraction w/ increasing transport distance**
  - e.g., Mt. St. Helens ash deposits as a function of distance from source

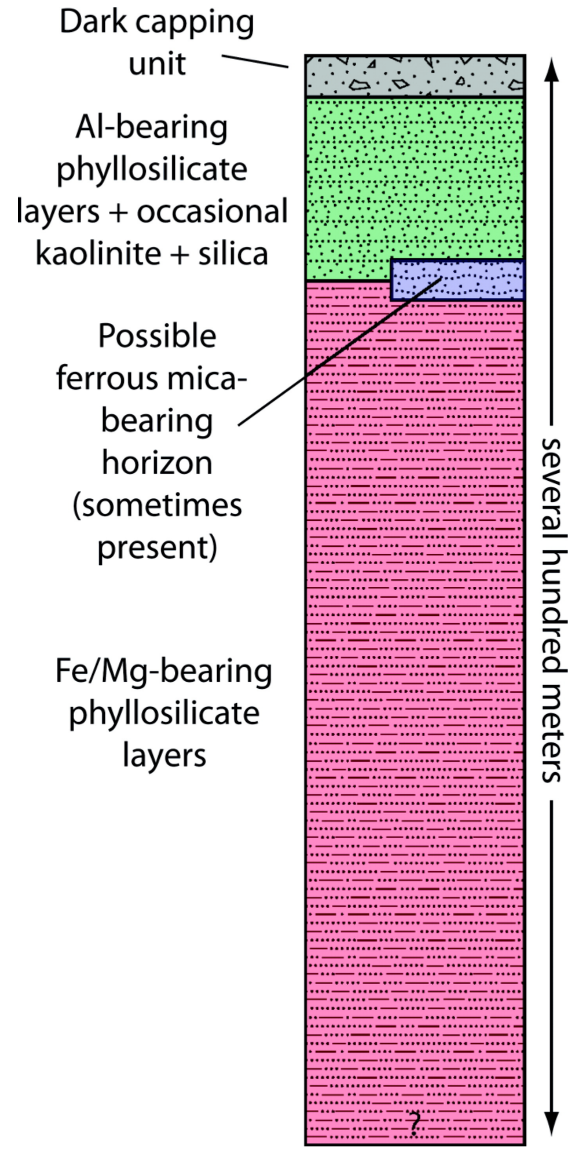


(Hynek et al., 2003)

Implications for "layered" phyllosilicates (e.g., Mawrth Vallis)

- **Mawrth Vallis:**
  - Aerially extensive (>10^6 km^2)
  - Mineralogy consistent within stratigraphic units
  - Temporally significant
    - Buried impact craters
  - Compositional stratigraphy observed elsewhere
    - Eridania, Noachis, Valles Marineris

- **A significant pyroclastic contribution is capable of explaining:**
  - Persistent & extensive distribution
  - Disparity between TES & OMEGA/CRISM
  - Fe/Mg assemblage: Largely derived from volcanic/impact hydrothermal sources
  - Al assemblage: Largely derived from weathering pre-deposited fine-grained glassy tephra

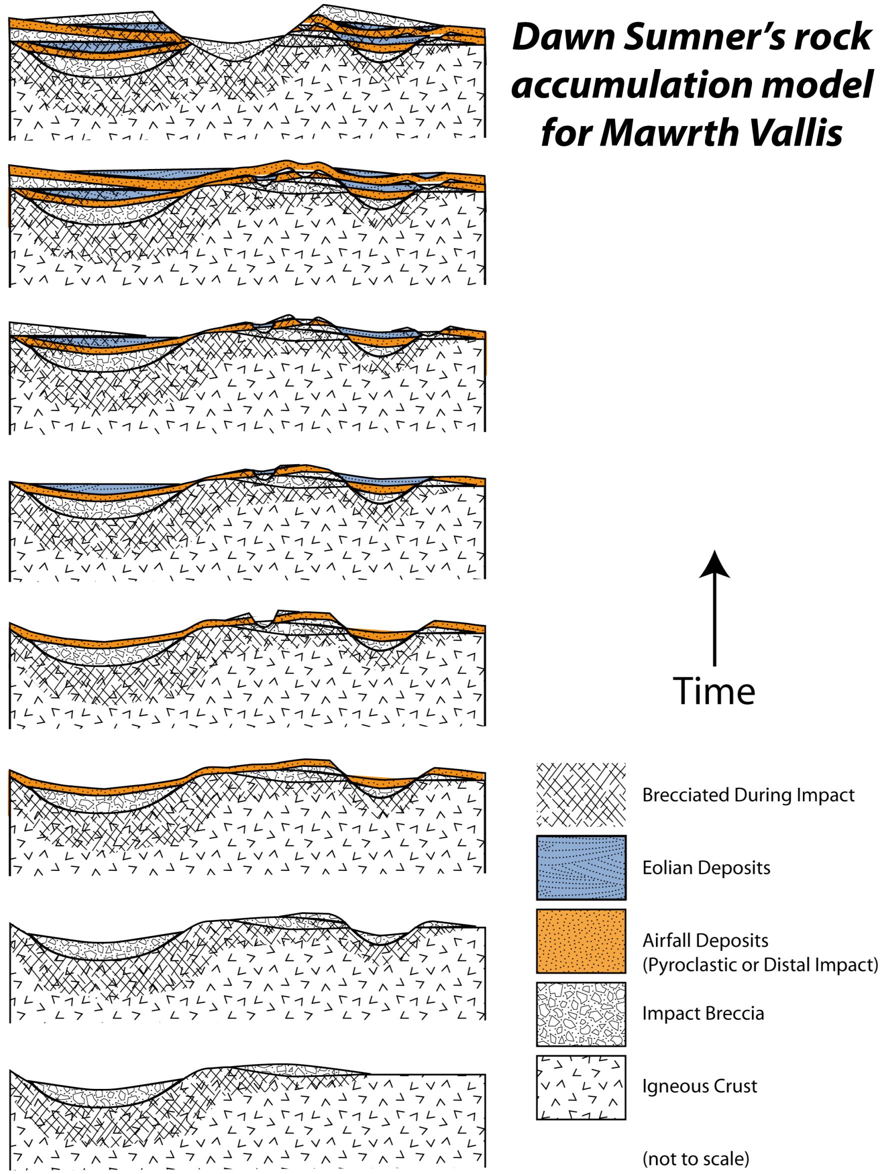


(Michalski et al., 2010)

A model for rock accumulation on early Mars (esp. at Mawrth)

- **Heterogeneous physical processing; consistent mineralogy**
  - Rock accumulation primarily driven by impact processes, eolian reworking
  - Predicts heterogeneous mineralogical distribution
  - *Continuous pyroclastic delivery & eolian reworking homogenizes mineralogy in time & space*

- **Caveats:**
  - Does not exclude other modes of neoformation, but may well be dominant
  - *Abundances*: do we understand clay production in hydrothermal & magma-volatile interaction on Mars? We may be lacking suitable analogs.



Conclusions (1)

- **Weathering of pyroclastic material produces a distinct Al-rich assemblage dominated by: halloysite, imogolite, opaline SiO_2, kaolinite and lesser Al-smectite (e.g., beidellite)**

- **Pyroclastic delivery of clay-bearing material is a common source of Fe/Mg-smectite (and other Fe/Mg 2:1 phases) in ash fall tephra deposits on Earth**

- **Volcanic-hosted hydrothermal systems on Mars, or syn-eruptive alteration of volatile-rich pyroclastics could represent a significant flux of Fe/Mg clay to the early surface of Mars**

- **Ash transport is an effective mechanism for Fe/Mg clay contribution to the early martian sedimentary record:**
  - Provide significant mineralogical overprint to complex processes

- **If true, a large portion of clay mineralogy on Mars may record the spatial and temporal history of volatile-magma interaction during the earliest portion of martian history**

Conclusions (2)

- **This model does not *require* a significant role for surface water on early (Noachian) Mars. Later alteration of upper stratigraphy (presuming an Fe/Mg-rich protolith) could date to any post-depositional period.**

- **We view magmatic hydrothermalism (& explosive volcanism) as waning in response to decreasing magmatic volatile load and perhaps decreasing subsurface water/ice**

- **We view the earliest supracrustal rocks on Mars as receiving two dominant contributions to mineralogy:**

1. Impacts

- Require pre-existing water to drive hydrothermalism
- May suffer from low-temperature overprinting as system "dies out"

2. Pyroclastic volcanism

- Records conditions of magmatic hydrothermalism
- Mineralogical contributions & delivery will correlate with high volatile load

- **Eolian mixing will act to homogenise these two components**