

LATE-STAGE WEATHERING AND CHLORAPATITE DISSOLUTION AS A POSSIBLE SOURCE FOR CHLORIDES ON THE MARTIAN SURFACE

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Chloride-bearing deposits occur widely on Mars [1]. Where did the components to form them come from? We use geochemical models, geomorphological evidence and mass balance calculations to place constraints on their origin.

Why study chlorides? Their presence can be used to quantify past aqueous activity. Salts could potentially preserve biosignatures [e.g. 2], and they remain important targets for current and future biosignature detection missions [e.g. 3].

Possible sources of chlorine

- 1) Weathering of primary igneous minerals in basalts — namely chlorapatite ($\text{Ca}_5(\text{PO}_4)_3\text{Cl}$) [e.g. 4].
- 2) A reworked, ancient evaporite deposit [e.g. 5].
- 3) Cl-bearing components (e.g. HCl and perchlorates) in the soil and atmosphere resulting from volcanic degassing [e.g. 6].

Weathering of near-surface basalts

We used a 1D reaction-transport thermodynamic geochemical model (CHIM-XPT [7]) to weather basalts (Fig. 1) and compute:

- chemical equilibria
- precipitated minerals
- ion activities

Assumptions:

- $p\text{CO}_2 = 60$ mbar
- $T = 273.15$ K
- Host rock composition based on the basaltic clasts of martian meteorite NWA 7034 (Fig. 2) adjusted for the incongruent dissolution behavior of different minerals (Fig 3).

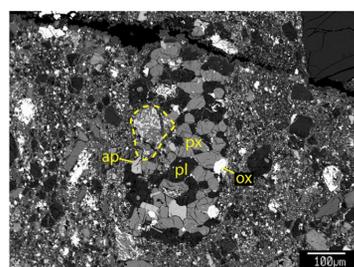


Fig. 2. BSE of basalt clast in NWA 7034, from [8]. ap = apatite, pl = plagioclase, px = pyroxene, ox = Fe-oxide.

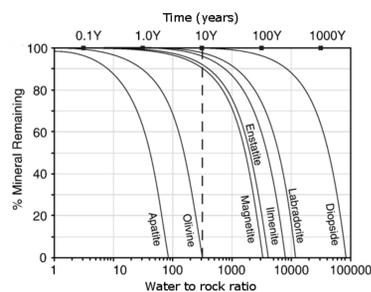


Fig. 3. Lifetime of minerals vs. water-to-rock ratio, from [9].

Weathering model results:

See Figs. 4 and 5.

- A secondary mineral assemblage (fluorite, calcite, chlorite, nontronite, etc.) precipitates along the reaction path (Fig. 4).
- With increased rock fraction (i.e., higher to lower water-to-rock ratio; W/R), the fluid is increasingly saline (Fig. 5).

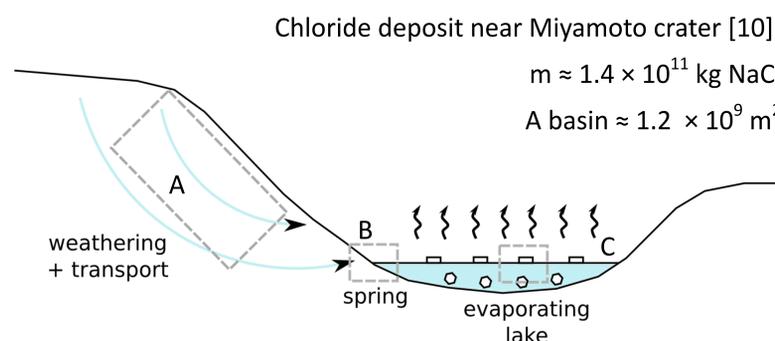


Fig. 1. Schematic of the geological context of the possible chloride-bearing lake. Fluids flow from left to right, permeating the basin rocks (A) and discharging at a local topographic low (B), ultimately concentrating and precipitating salts as water evaporates (C).

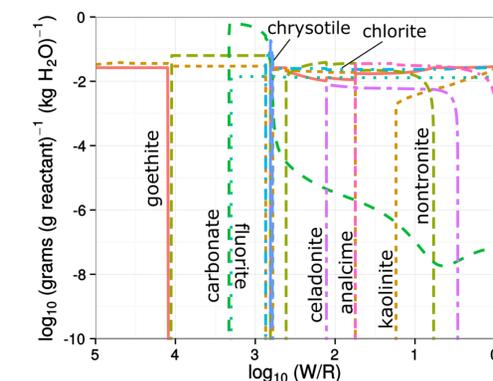


Fig. 4. Secondary minerals precipitated along the 1D reaction-transport path. Host rock = 90 wt. % apatite.

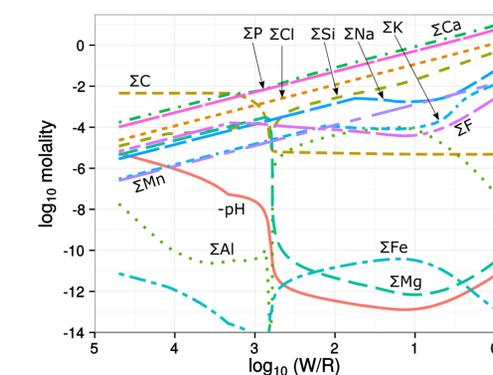


Fig. 5. Fluid composition evolution in the 1D reaction-transport model. Host rock = 90 wt. % apatite.

Case study: salt deposit near Miyamoto crater

Chloride deposit mass $\approx 1.4 \times 10^{11}$ kg [10]

Surface area of the basin $\approx 1.2 \times 10^9$ m² [10]

Assumptions: a) chlorides are NaCl. b) 45 % porosity. c) thermal diffusivity host rock = 7×10^{-7} m² s⁻¹.

We calculate: $\sim 2.5 \times 10^4$ kg rock/m² (~ 14.9 m depth) of rock needed to be weathered across the basin to produce the deposit. A thermal wave would require ~ 1 Mars year to penetrate 15 m, i.e., minimum time scale for the wet event > 1 season. Fig. 6 shows the H₂O required to leach sufficient Cl to form the deposit.

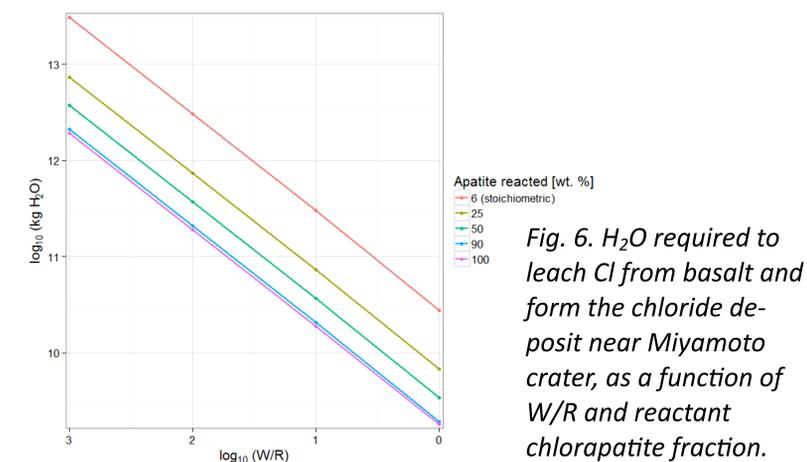


Fig. 6. H₂O required to leach Cl from basalt and form the chloride deposit near Miyamoto crater, as a function of W/R and reactant chlorapatite fraction.

Volcanic degassing as a source of Cl?

- Volcanic degassing rate of Cl estimated at: 1.1×10^{-7} kg m⁻² year⁻¹ to 1.1×10^{-9} kg m⁻² year⁻¹ on Mars over time [6].
- Concentrating Cl on the surface to the same order as the basalt clasts of NWA 7034 (~ 0.3 wt. %; [8]) would require > 400 Ma of degassing at the highest degassing rate.
- $p\text{HCl} \approx 1.2 \times 10^{-4}$ bar at its height, in the early Hesperian atmosphere (from volumes of volcanic extrusions [11]).
- Liquid water in equilibrium with this atmosphere would contain $\sim 4 \times 10^{-3}$ g Cl L⁻¹, i.e. lower than the Cl concentration in NWA 7034 basalt clasts (~ 3 g kg⁻¹), and the Cl concentration in basalt leachates at W/R < 5000 (Fig. 5).

Conclusions

Dissolution of igneous chlorapatite could have leached sufficient Cl to form the chlorides. Volcanic degassing of Cl compounds occurred too slowly to account for the observed masses of chlorides, and reworking of ancient evaporite deposits is an unlikely origin based on geomorphology. Seasonal melting cannot explain the observed mass of chlorides at the deposit near Miyamoto crater.

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References

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