Hydrous silicates in terrestrial impactites: Implications for the formation of phyllosilicates on Mars

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CTX of fresh 7 km D crater in Hesperia Planum
Hydrated silicate phases on Mars: What do they tell us?

- OMEGA and CRISM-detected phyllosilicates and hydrous glass (silica) occur in the ancient heavily-cratered and dissected Noachian terrains
  - Suggestion: Early Mars had a thicker atmosphere, was warmer / wetter and more habitable
  - Do phyllosilicates = abundant long term water?

- Mars may have been cold/dry throughout much of its history w/ water only sporadically (intensely) occurring at or near the surface [e.g., Segura et al., 2002, 2008 in press - JGR ]

- Is it possible to form such hydrous phases under transient water conditions? … YES.

- Clays (particularly Fe-Mg smectites) are very common:
  - In IDPs and carbonaceous chondrites [e.g., Nouguchi et al., 2002; McSween, 1999; Tomeoka, 1990]
  - In impactites recovered from terrestrial impact structures [e.g., Naumov, 2005; Osinski, 2005]
    - Causal relationship - Heavy bombardment and Noachian clays?

- Multiple geologic setting/mechanisms for phyllo-bearing sites need to considered to truly address water availability / habitability issues

Megabreccia, Holden Crater
Hydrous silicates in terrestrial impact structures

- A study of 62 impact structures (D ~1.8 -250 km) and a detailed petrographic/SEM analysis of impactites indicate [Naumov, 2005; Osinski, 2005]:
  - Phyllosilicates are abundant in terrestrial impactites (up to 70 vol% of groundmass in Ries impactites)
    - Especially within melt-bearing impactites (interior and exterior)
  - Hydrous silica melt/glasses (volatile-rich target)
    - Typically rich in other common elements (e.g., Fe, Al, Mg, Na, K) and w/ up to 24 wt% H₂O [Osinski et al., 2004, Harris et al., 2007 LPSC]
  - Terrestrial impactite phyllosilicates formed predominately by:
    - Hydrothermal
      - Post-impact fluids and heat (impact + melt + geotherm) circulating and interacting with impactites or surrounding country rocks
    - Devitrification (and autometamorphism)
      - Direct, solid-state transformation unstable hydrous melt/glasses transformed by their composition and water content (autometamorphism) [Osinski et al., 2004; McPhie et al., 1993]
  - Does not require post-impact water rock interactions to form clays

Figure 2. from Osinski, 2005
**Hydrous silicates on Mars and in Terrestrial impact structures**

[Mustard et al., 2008 - Nature, and Ehlmann et al., 2008 - LPSC]

- **Common phyllosilicates on Mars include:** Smectites
  - Fe-Mg-rich (most ubiquitous on Mars)
    - Probably nontronite/saponite - dispersed in heavily cratered S. Highlands - All MSL sites
  - Al-rich
    - Probably montmorillonite - S. Meridiani, Mawrth
  - Hydrous silica/glasses - ubiquitous in S. Highlands - Most MSL sites?
  - Chlorites - Nili, Tyrhenna, Vallis Marineris
  - Zeolites (analcime?) - Nili
  - Iilitie/Muscovite (mixed-layer?) - Nili

[Naumov, 2005 and Osinski, 2005]

- **Common phyllosilicates in terrestrial craters: Smectites**
  - Fe-Mg-rich (most common)
    - Saponite/notronite
  - Al-rich
    - Montmorillonite
  - Hydrous melt/glasses (very common throughout structures)
  - Chlorites (commonly in perph. of central uplift)
  - Various zeolites associated with some calcite and pyrite
    - Na-rich and Ca-rich (e.g., analcime, laumontite, chabazite)
  - Some Illite and mixed-layer clays (typically smectite-chlorite)
Devitrification of melt-bearing breccias

- SEM studies of the groundmass of melt-bearing impactites from Ries:
  - Groundmass comprised of a series of impact melts/glasses varying in composition and H$_2$O content
  - Devitrified melts = mostly smectite clays
    - Intricate flow-banding, melt-bleb/globules & immiscibility textures
    - Quench crystallites present (Plagioclase, garnet and pyroxene)
    - Vesicles

SEM of Ries impact-melt bearing breccia - Osinski et al., 2004
Impact structure hydrothermal alteration

- Synthesis of 62 impact sites: Bulk alteration occurs ~50-350°C; pH ~6-8; low $P_{\text{CO}_2}$ [Naumov, 2005]
  - Most long lived and deep-seated (kms) alteration stage of hydrothermal alt. (e.g., Siljan)
  - Clays-zeolite-calcite-pyrite assemblage predominates & overprints most higher T alteration phases

- Hydrothermal clays can be distinguished from devitrification/autometamorphic clays:
  - In veins and has open space-filling textures
    - Cross-cutting groundmass / devitrified clays
    - Coarse xrys. platy habit
  - Clays more homogenous in composition (devitrified clays very heterogeneous) [Osinski et al., 2004; Dence et al., 1974]

- Example: Ries (D ~24 km; ~14.5 Ma) melt-bearing impactites [Osinski et al., 2004]
  - ~10-15% Hydrothermal
  - up to 50% Devitrified melt/glass

**Devitrification/autometamorphism could be more prevalent then hydrothermal as a clay-forming mechanism with respect to large impacts into volatile-rich targets!**
Hydrous silicate impact melts on Mars?

• D/H ratio suggests more water in the past [Carr, 2007]

• Presence of a global-scale cryosphere [Clifford, 1993; Boyton et al., 2002]

• >90% of ejecta-bearing Martian craters (>5 km) possess layered ejecta [Barlow, 2007]
  – Impact into a volatile-rich target (Amazonian - Noachian?) [e.g., Carr et al., 1977]

• Recent H and X work on fresh and well-preserved craters
  – Possible impact-melt bearing bodies
  – Volatiles have played an important role during impact process [McEwen et al., 2007; Tornabene et al., 2007, 2008]

Large & numerous impacts+volatile-rich crust = hydrated silicates
Impact Melting

- $E$ from hypervelocity impacts (impacting bodies are slower for Mars, but...)

- Consequence of high $E$ - shock: Fracturing, pulverization, **melting** and vaporization of target

- Peak shock, hence melting, is dependant on total energy yield

- Whereas, size of a crater becomes dependant on gravity-scaling

- Excavation flow crosses pressure contours
  - Large craters: prodigious ejected melt volumes
  - Melt-scaling may explain phyllosilicate bias to Noachian
  - Small craters: less melt minimal ejected

![Diagram showing impact melting and crater formation](image)
An approximation for Basin ejecta thickness vs. radial distance for a 1000-km sized basin

- Basins can create meters - kilometers thick ejecta deposits

Melosh, 1989
- Large-scale phyllosilicate bedrock and outcrops near basins make sense
- Exposure and redistribution by smaller impacts important locally
- Impact-melt distribution from largest impacts could be global (e.g., Chicxulub) [Alvarez, 1997]
Megabreccias in the Nili Fossae

Suggests basin ejecta (melt-rich) from nearby Isidis Basin

Correlates w/ Fe-Mg smectite-rich units - suggests a possible impact-origin for some Nili Fossae hydrated silicates is likely

See Poster by McEwen et al. - this conference
Habitability and preservation - Good News!

- Hydrothermal oasis - up to $10^5$ yrs for large craters, but longer for basins (up to $10^7$) [Abramov and Kring, 2004]
  - Longer lived than paleolakes?

- Impacts also increase rock porosity and fracturing for cryptoendolithic habitats [Cockell et al., 2005]

- Studies of melt-bearing impactites
  - Suggest high survivability of organics in “cold” clasts within melt-bearing breccias [Lindgren et al., 2006 LPSC]
  - Preservation and transfer of “organic signatures” to impactite-derived seds [Parnell et al., 2005]
    - Both lacustrine and wind-blown deposits

Haughton melt-bearing “breccia”
MSL site summary - Likelihood of some impact-generated hydrated silicates

- Eroded, transported and deposited impact-generated hydrated silicates formed during the Noachian (i.e., a terrain dominated by altered crater/basin ejecta) probably important
- Nili Fossae - megabreccia + Fe-Mg smectites, proximity to Isidis Basin
- S. Meridiani - Hydrated silicates possibly outcropping in eroded Miyamoto ejecta?
- Miyamoto - multiple channels suggesting eroded and transported materials from Noachian highlands
- Holden - Uzboi Valles - same as above; also near Argyre Basin
- Eberswalde - same as above
- Mawrth -?
- Gale -?

- Take home: Martian hydrated silicates do not necessarily require long-term water
  - Large & numerous impacts+volatile-rich crust = hydrated silicates

- Final thought: If we land in a Noachian terrain - impactites will certainly be likely surface components - warrants further consideration and study of them as analogs