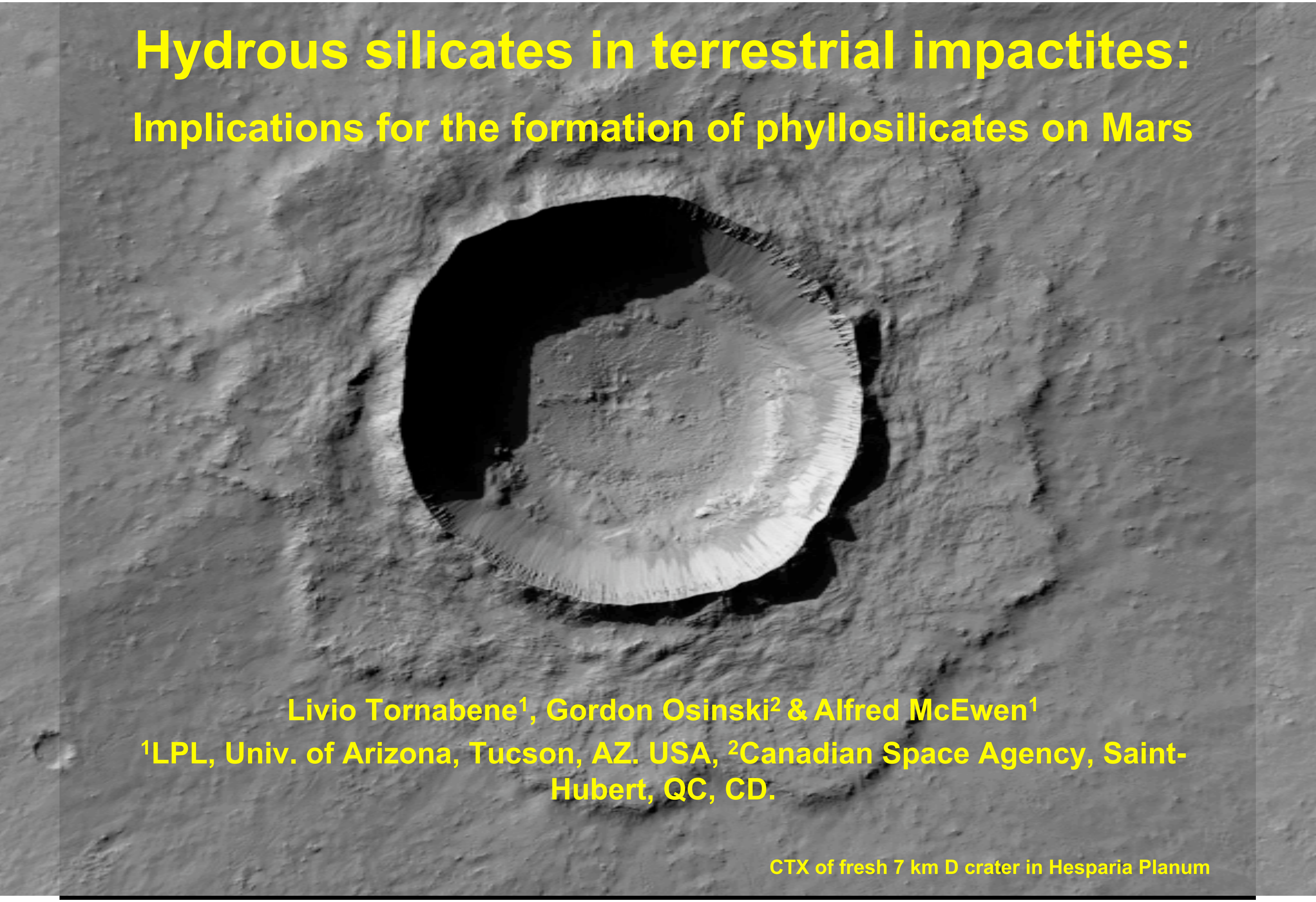
Hydrous silicates in terrestrial impactites:

Implications for the formation of phyllosilicates on Mars



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CTX of fresh 7 km D crater in Hesparia 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 <u>long term</u> 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]**
    - **<u>In impactites recovered from terrestrial impact structures [e.g., Naumov, 2005; Osinski, 2005]</u>**
      - **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 petrogrphic/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% H_2O [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

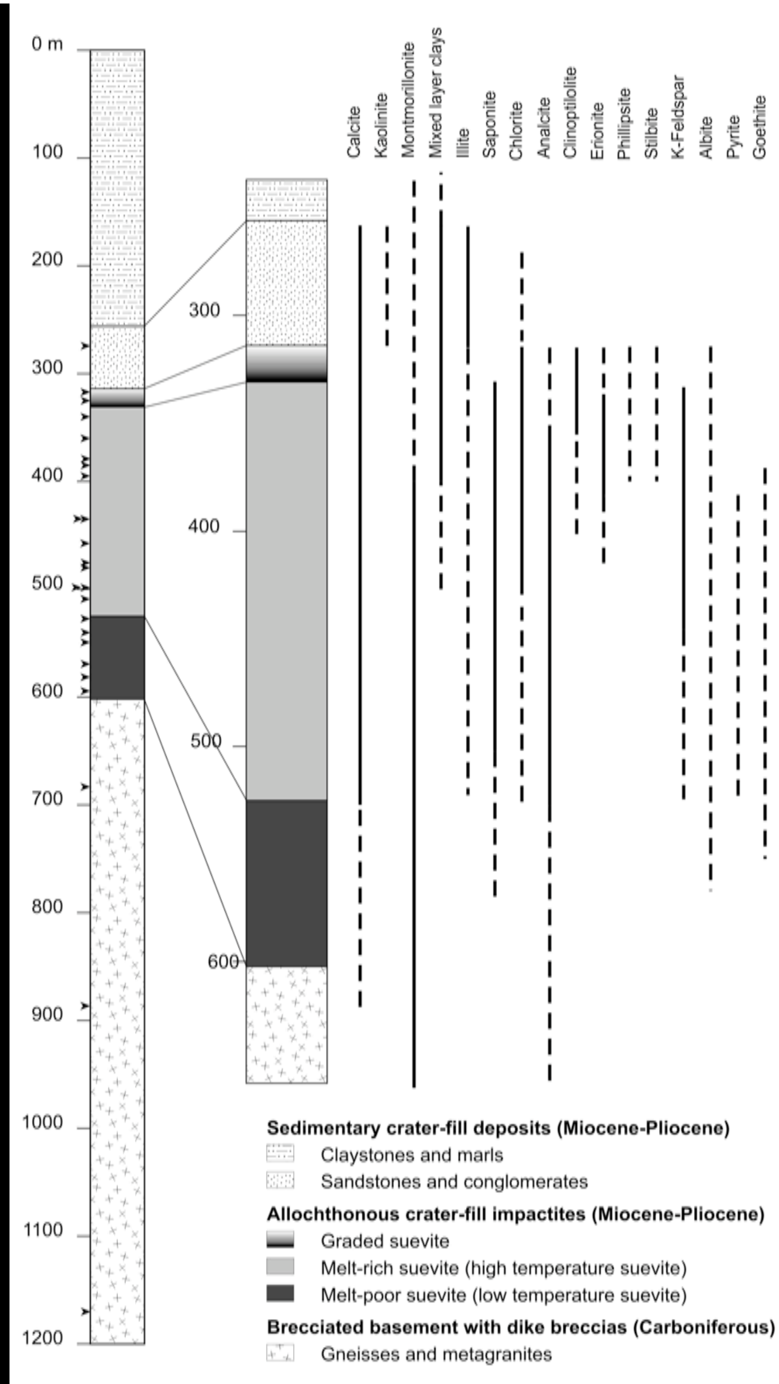


Figure 2. from Osinski, 2005

Hydrous silicates on Mars and in Terrestrial impact structures

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

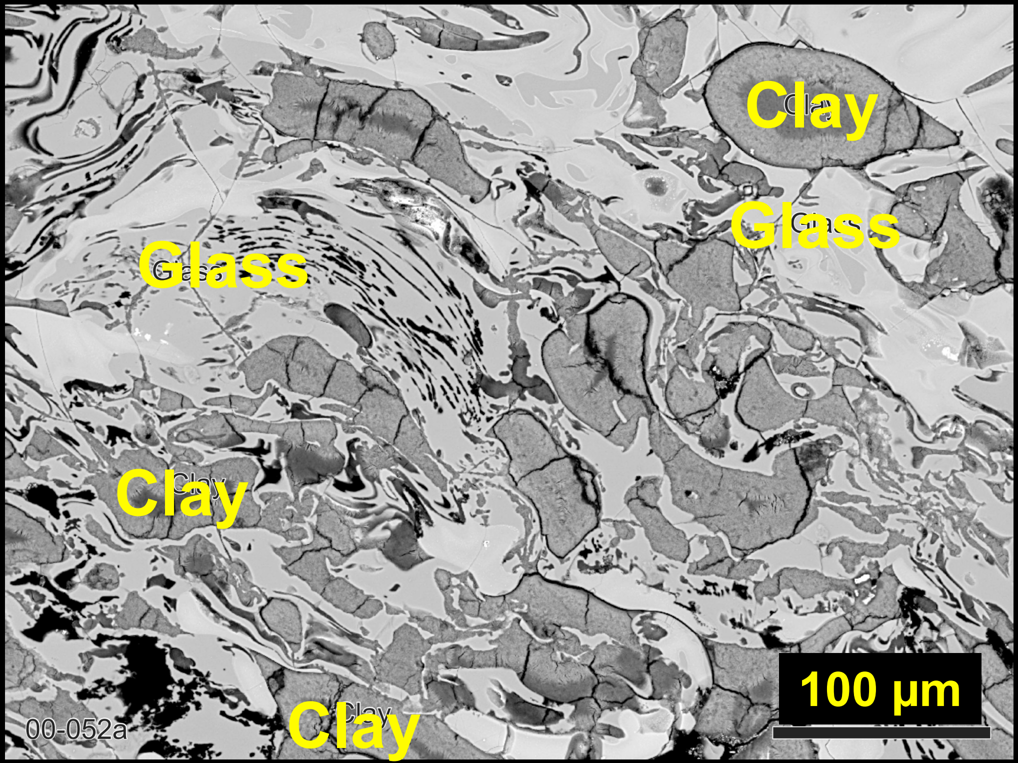
- Common phyllosilicates on Mars include: Smectites
  - Fe-Mg-rich (most ubiquitous on Mars)
    - Probably nontronite/saponite - dispersed in heavily cratered S. Highlands - All MSL sites
  - Al-rich
    - Probably montmorillonite - S. Meridiani, Mawrth
  - Hydrous silica/glasses - ubiquitous in S.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

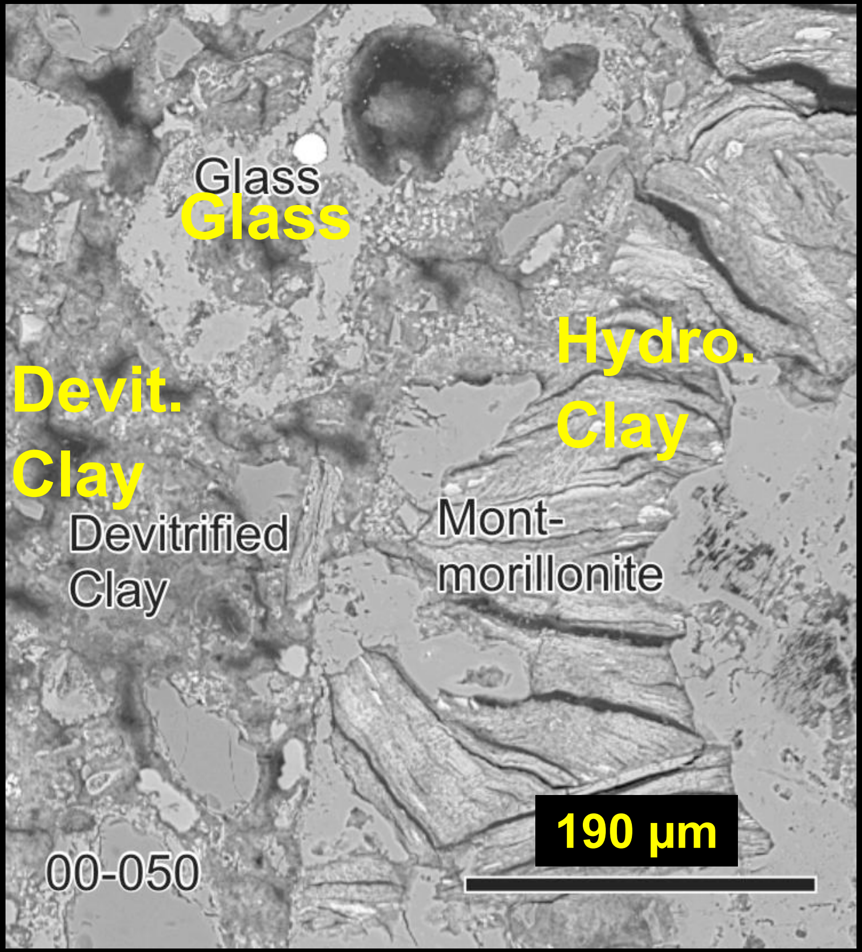
- SEM studies of the groundmass of melt-bearing impactites from Ries:
  - Groundmass comprised of a series of impact melts/glasses varying in composition and H_2O content
  - Devitrified melts = mostly smectite clays
    - Intricate flow-banding, melt-bleb/globules & immiscibility textures
    - Quench 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 ~50-350ºC; pH ~6-8; low P_{CO_2} [Naumov, 2005]
  - Most long lived and deep-seated (kms) alteration stage of hydro thermal 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



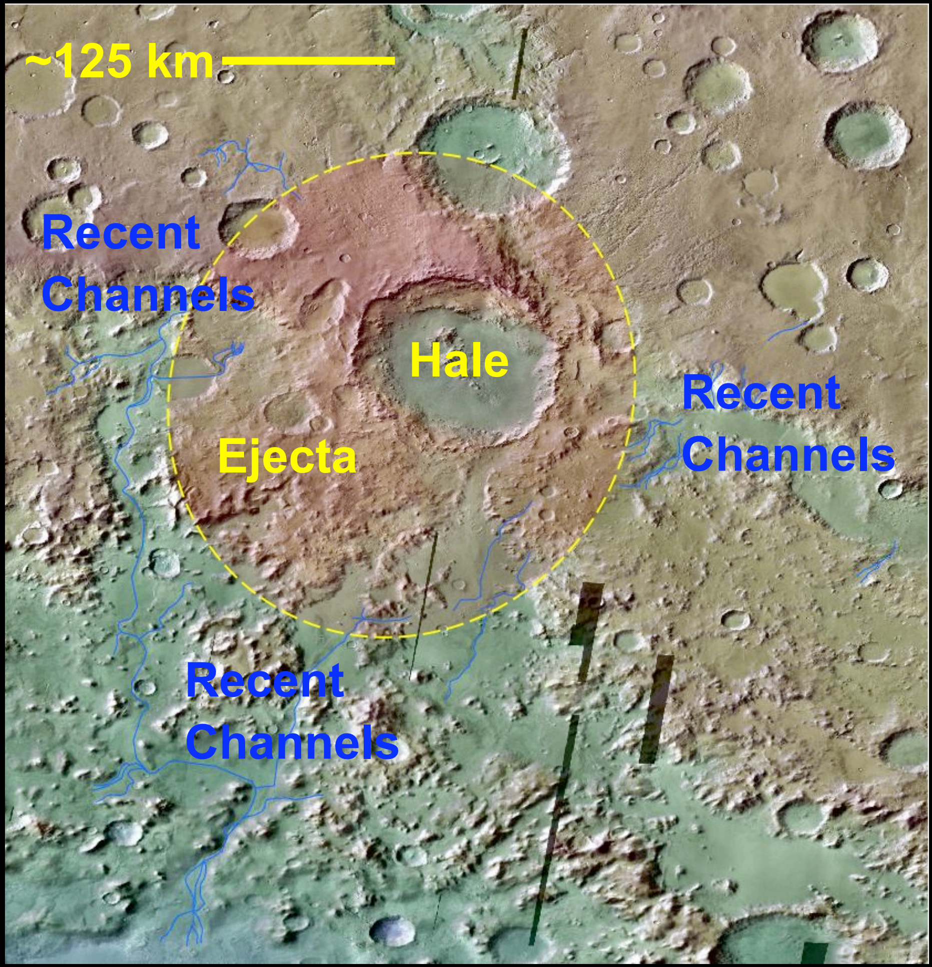
SEM of Ries impact-melt bearing breccia - [Osinski, 2005]

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]

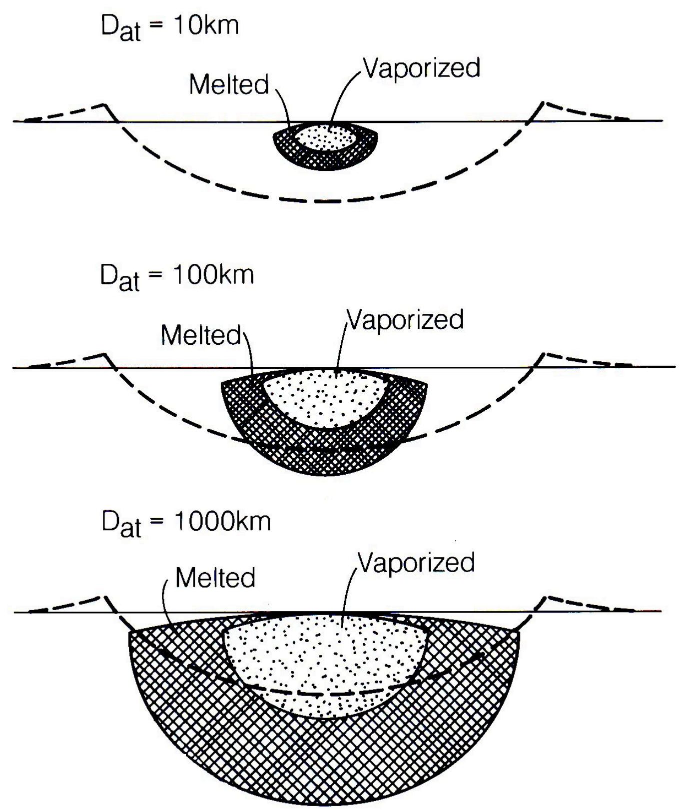


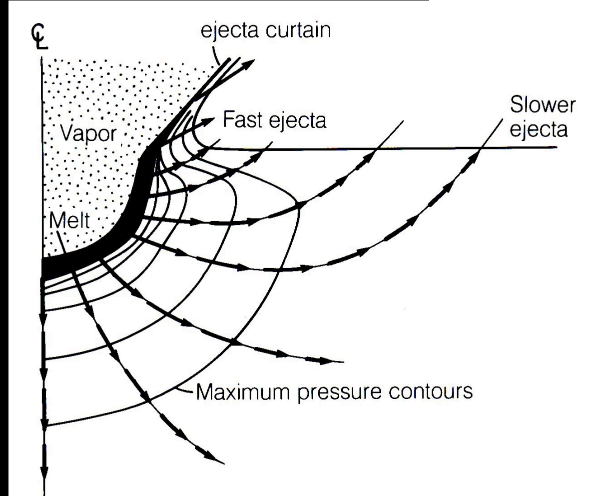
Channels asscoaiated with Hale ejecta [Tornabene et al., 2008 LPSC]

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

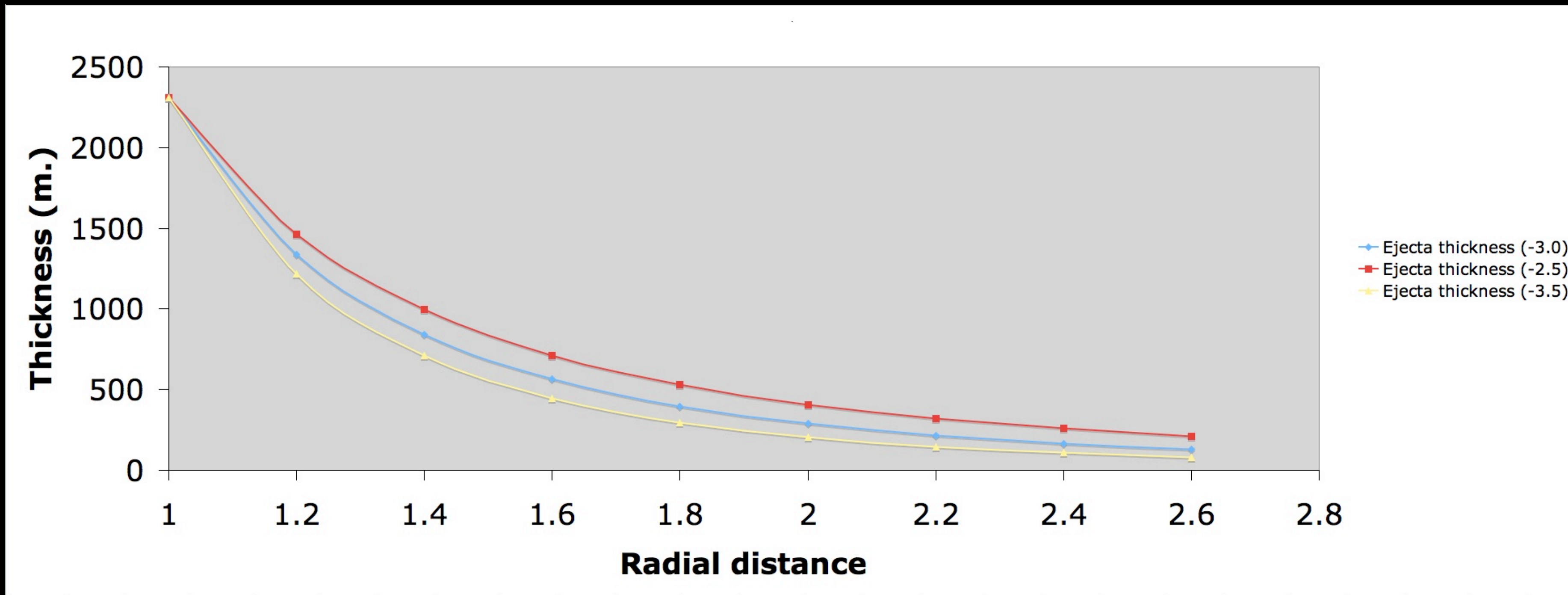
Impact Melting

- 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



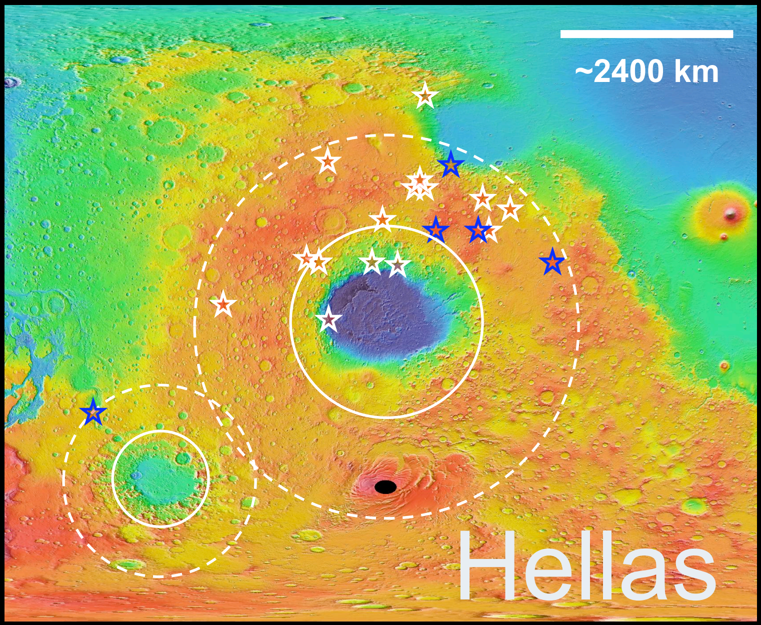


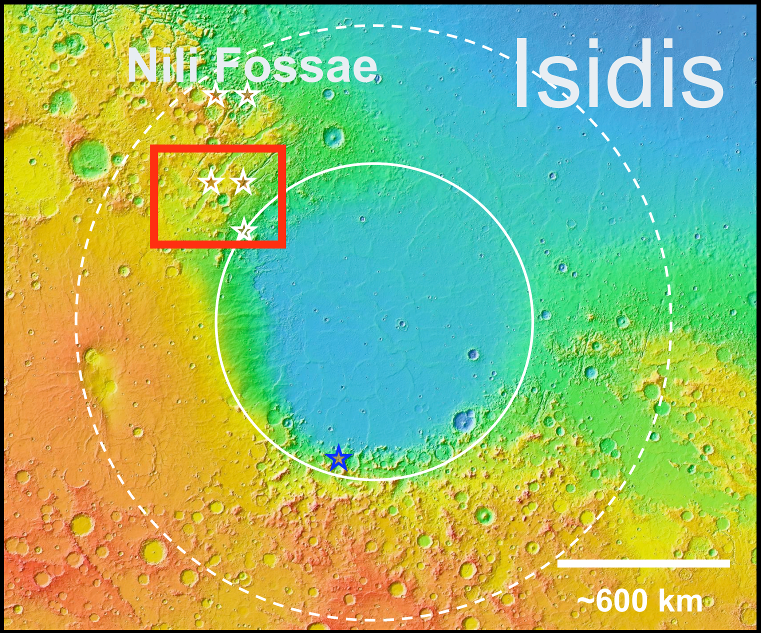
An approximation for Basin ejecta thickness vs. radial distance for a 1000-km sized basin



Melosh, 1989

- Basins can create meters - kilometers thick ejecta deposits





- 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]

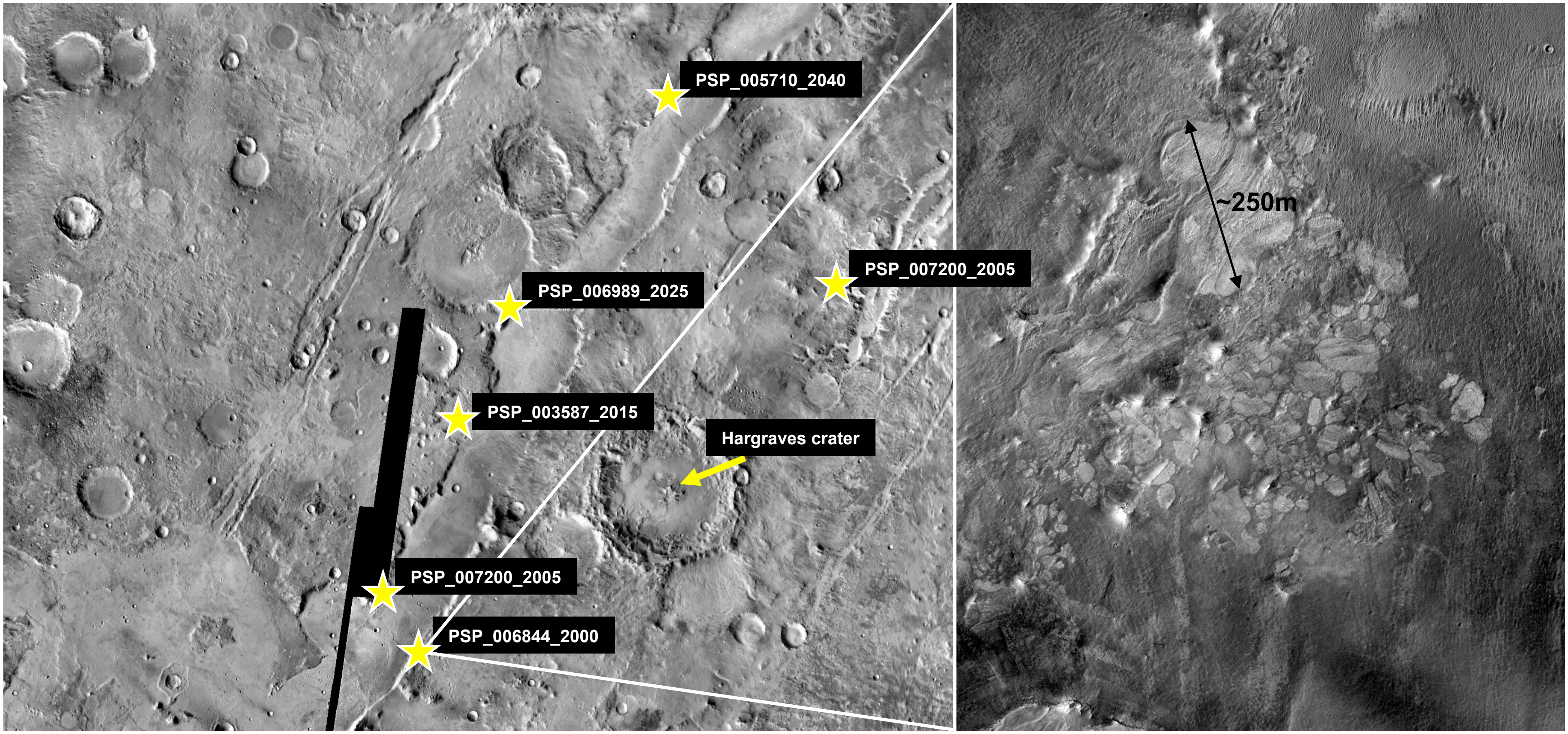
☆ After Bibring et al. 2006

★ Reported in LPSC 2007 abstracts by Grant et al., Pelkey et al. and Bishop et al.

—— Basin outer topographic ring

– – 2r - possible extent of ejecta deposits

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 depoists

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

HiRISE Mojave crater megabreccia