Widespread Weathered Glass on the Surface of Mars

Briony Horgan and Jim Bell

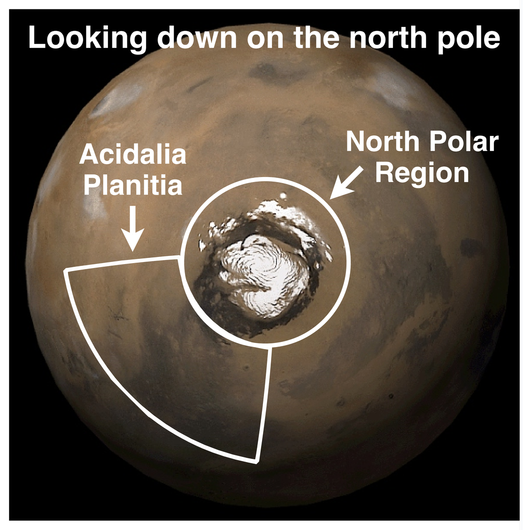
School of Earth and Space Exploration
Arizona State University

0 Introduction

Motivation

What are the low albedo units in the northern lowlands of Mars?

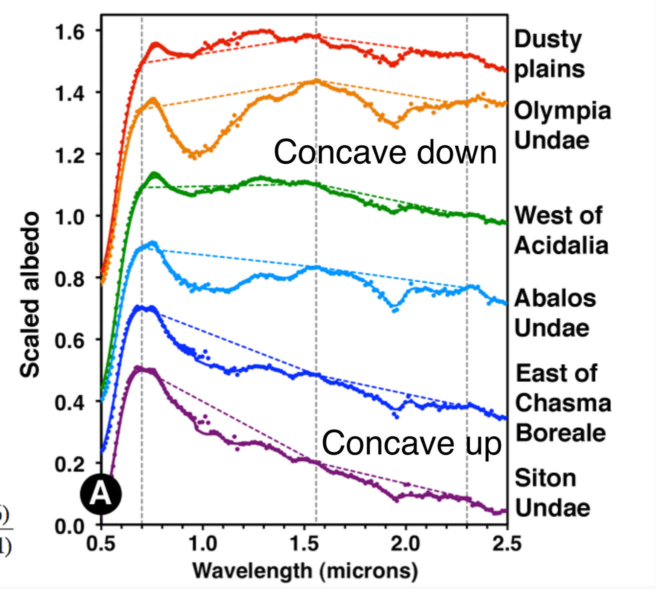
In the near-infrared, the surface is nearly spectrally featureless [2]. In the thermal-infrared, these regions exhibit the highest concentration of high-silica phases on the planet [3-6]. How do we reconcile these observations?



Near-infrared spectral characteristics

Some regions in the northern lowlands do exhibit broad and shallow absorptions at 1 micron, as well as a unique concave up continuum slope. **We can parameterize the concavity using ratios:**

$$\text{Concavity} = \frac{A(0.71)+A(0.73)+A(0.75)}{A(1.53)+A(1.54)+A(1.56)} - \frac{A(1.53)+A(1.54)+A(1.56)}{A(2.29)+A(2.30)+A(2.31)}$$



1 Evidence for glass

briony.horgan@asu.edu

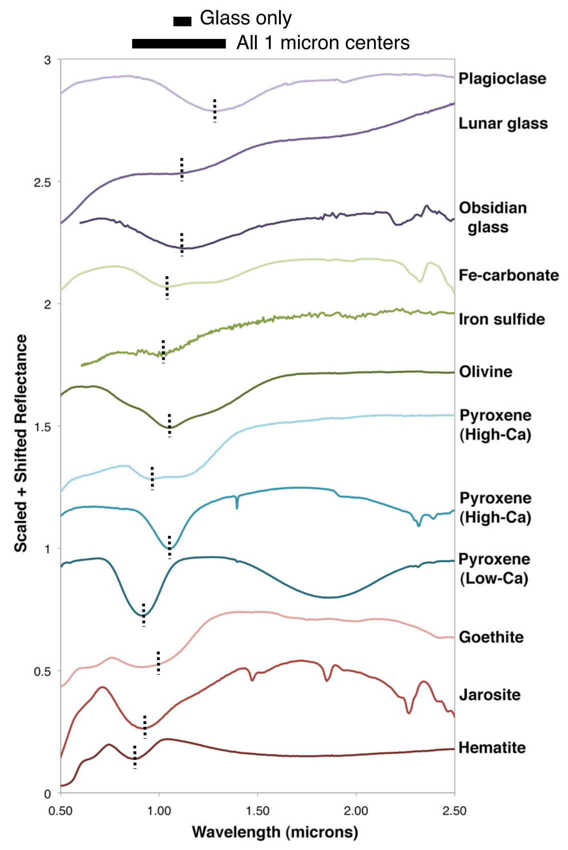
Detecting glass

Iron-bearing minerals exhibit broad absorptions near 1 micron due to ferrous iron in a crystal lattice.

For most ferrous minerals, this band is centered between 0.9-1.1 microns [7].

For iron-bearing glass, the band is centered between 1.1-1.2 microns [8].

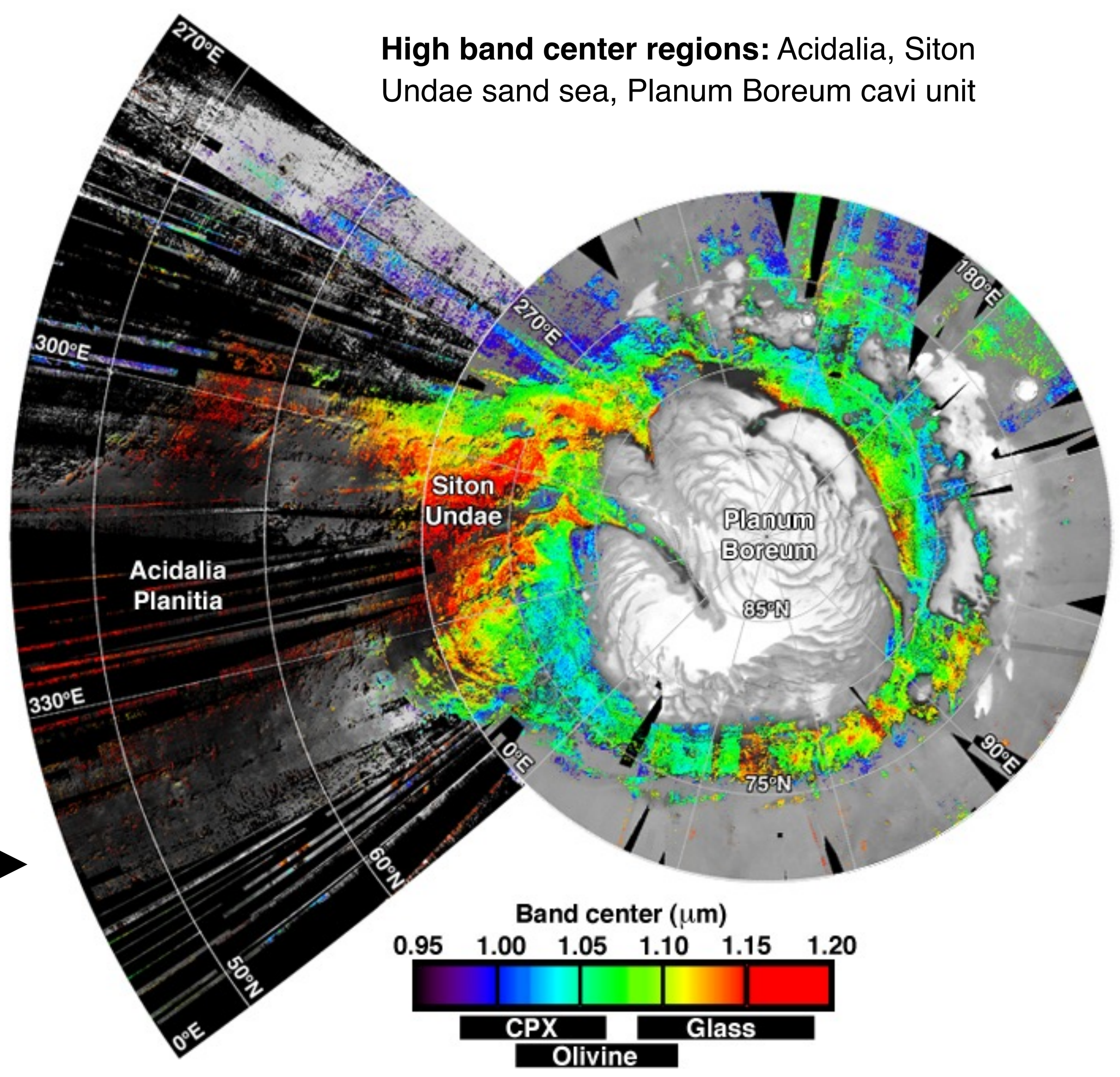
Thus, the 1 micron band center can be used to uniquely identify glass.



Distribution of 1 micron band centers

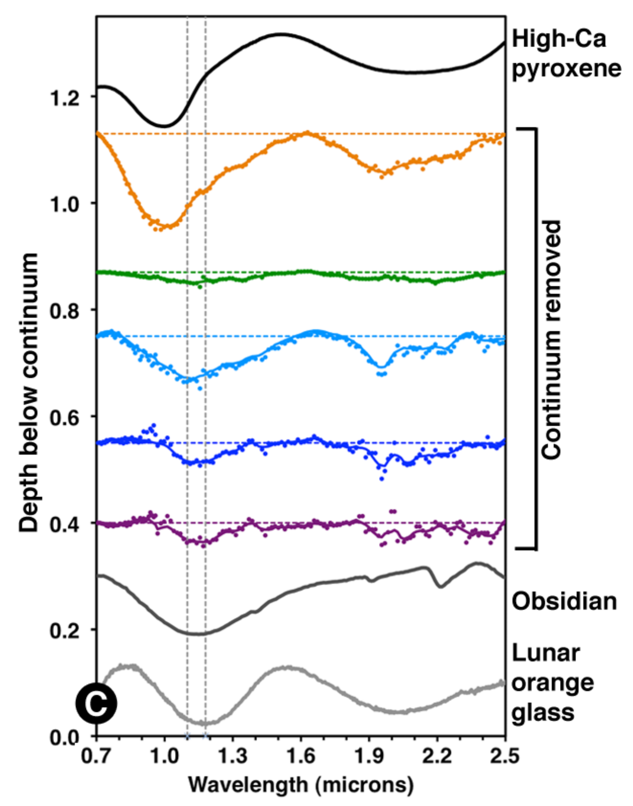
While many spectra in the north polar region and Acidalia Planitia have 1 micron band centers between 0.9-1.1 microns that are consistent with pyroxene or olivine (blue and green), large regions exhibit band centers between 1.1-1.2 microns that are consistent with glass (red and yellow) [1].

High band center regions: Acidalia, Siton Undae sand sea, Planum Boreum cavi unit



Comparison to lab spectra

After continuum removal, spectra with high 1 micron band centers exhibit broad bands consistent with glass.

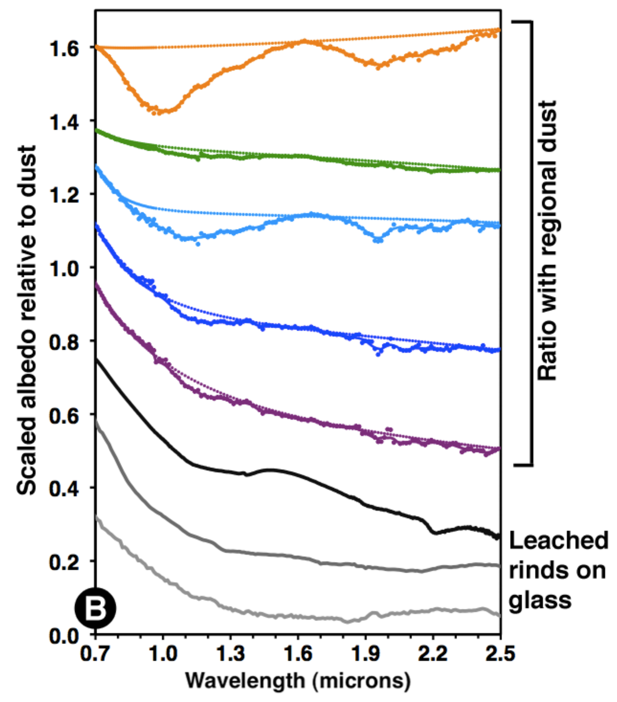


Because glass is a weak absorber, these clear glass bands imply that the abundance of other ferrous phases is <10-20%. **Thus, these must be glass-rich deposits.**

2 Evidence for weathering under moderately acidic conditions

Comparison to leached glass rinds

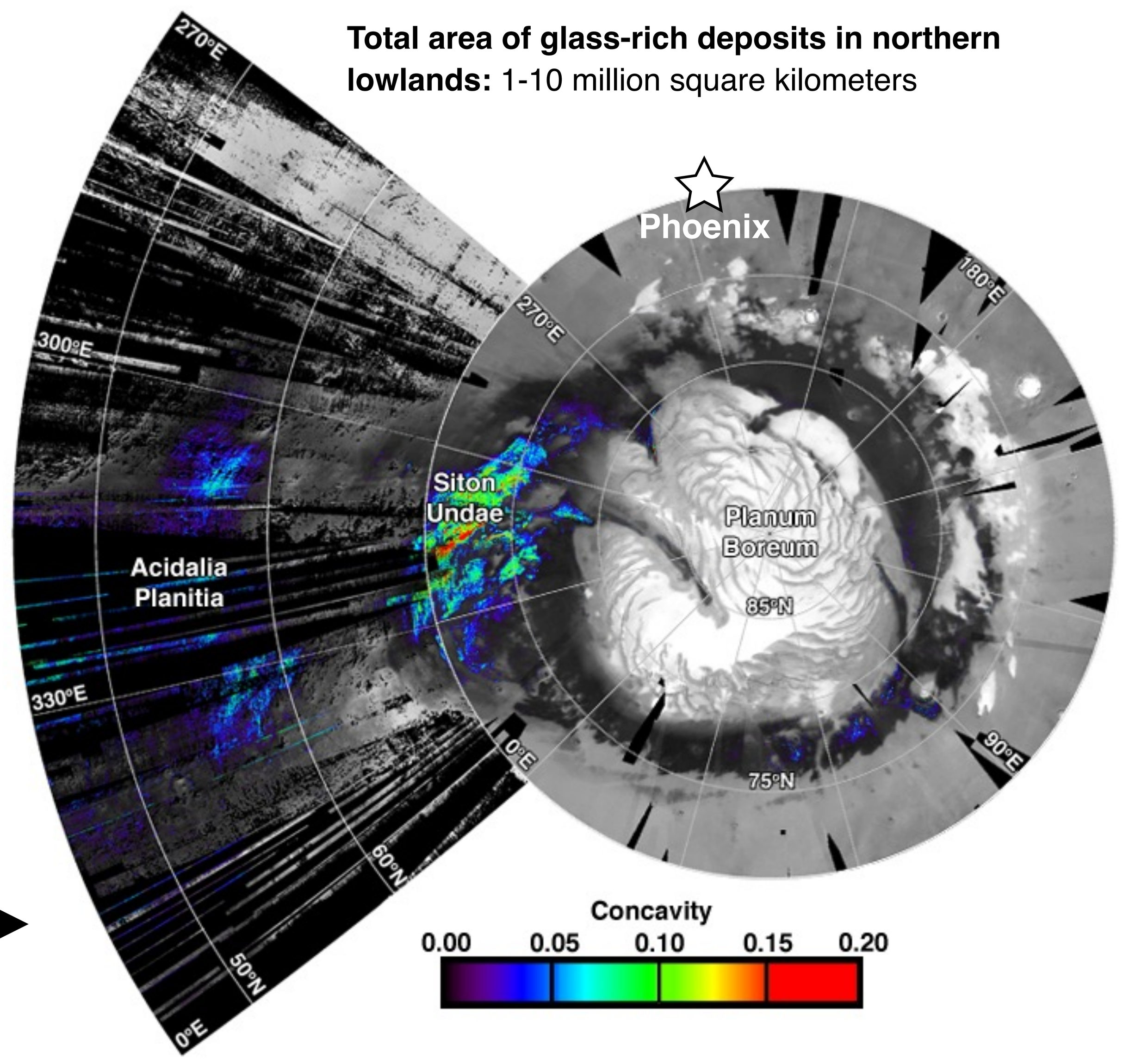
After suppressing dust and instrumental artifacts, the concave shape of the spectra becomes more apparent, and is consistent with lab spectra of 2-10 micron leached rinds on glass, formed when glass is leached by acidic fluids [9].



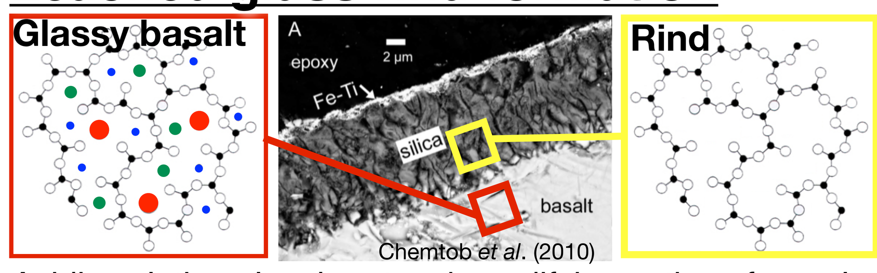
Distribution of concave spectra

Much like glass, concave spectra are concentrated in Acidalia, Siton Undae, and at outcrops of the Cavi unit. Indeed, 77% of concave spectra have band centers beyond 1.1 microns, supporting that the concave slope is related to the glass [1].

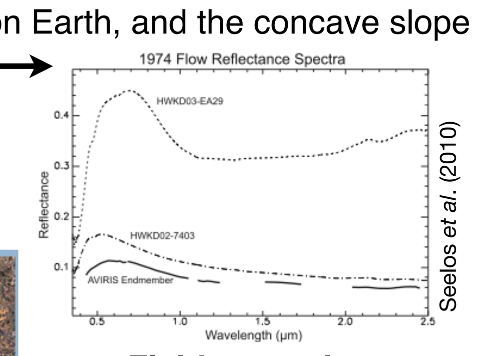
Total area of glass-rich deposits in northern lowlands: 1-10 million square kilometers



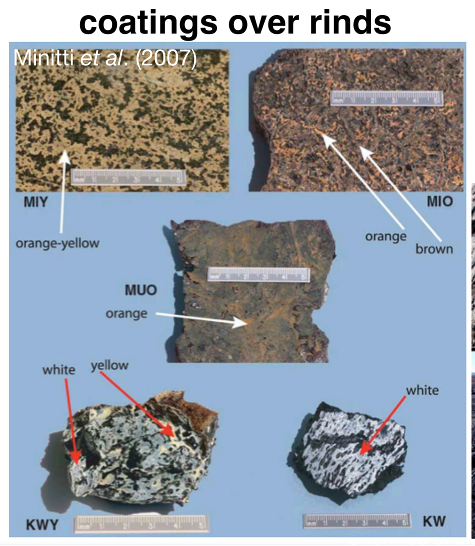
Leached glass rind formation



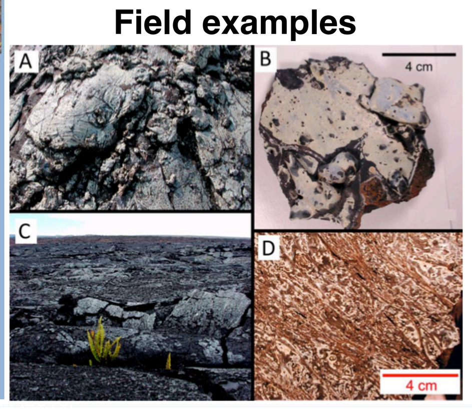
Acidic solutions leach network modifying cations from glass surface, leaving behind the silica network, which therefore appears silica-enriched. This produces a dark, dull rind that underlies depositional coatings. This is a common process in arid volcanic environments, on Earth, and the concave slope is apparent in aerial spectra → [10,11]



Hand samples with coatings over rinds

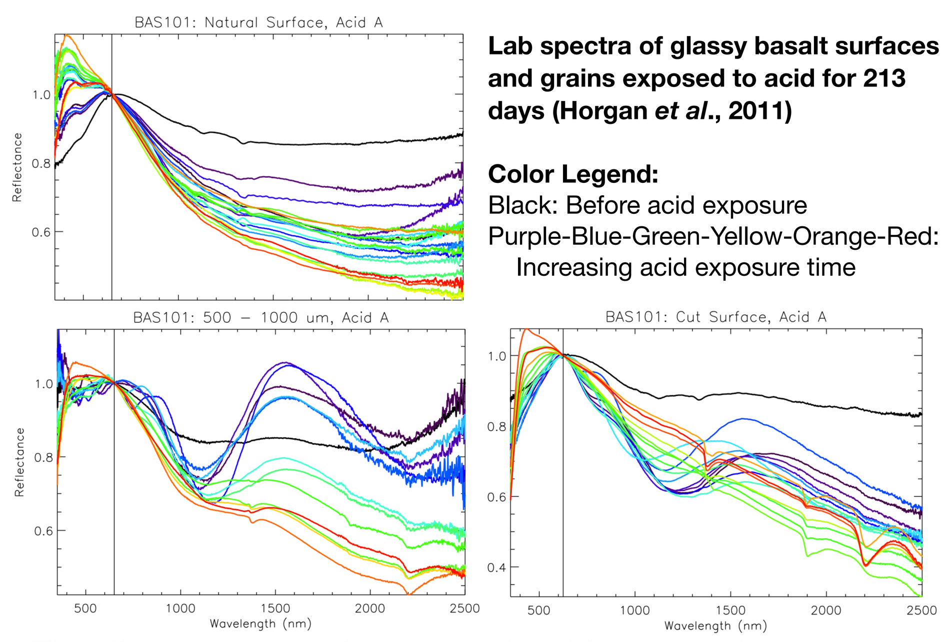


Field examples



A glassy basalt takes an acid bath

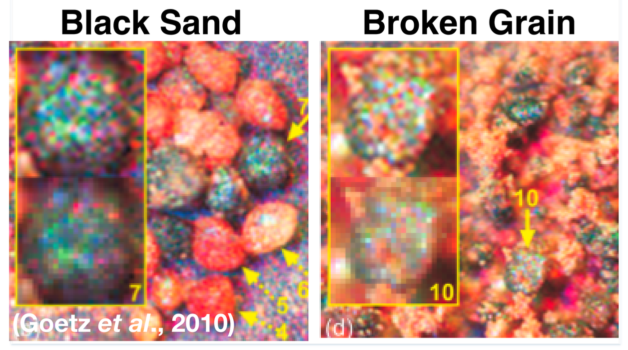
To understand how the spectral effects of acid leaching on glass develop over time, glassy basalts were exposed to periodically renewed acidic (pH~1) solutions over a period of 213 days. Sand size grains, natural surfaces, and cut surfaces all exhibited different spectral behavior [12].



The different spectral effects of leaching on grains vs. surfaces may explain why dune fields exhibit strong glass detections *and* high concavities, while central Acidalia exhibits high concavities or flat, steep spectra but no or very weak glass detections. This difference may also be due to mechanical abrasion during saltation in dune fields, which could partially remove rinds, revealing underlying glass.

3 Ground truth

Phoenix Optical Microscope observations of soils at the landing site (star in map above) revealed a population of black sand grains with a possible thin rind below the resolution limit (< 8 microns thick) [13].



4 Periglacial leaching?

The weathered glass deposits are in young, Amazonian terrains, so they probably weathered under climatic conditions not all that different from today. The modern martian environment is oxidizing, so acidic solutions are easily created at the surface in limited volumes of water [14]

Possible water sources:

(1) Periglacial: Melt from regional ice sheets or snow packs
(2) Atmospheric: Dew or frost

Phoenix results: Soils with neutral-alkaline pH form under interactions with the atmosphere, **so dew and frost do not acidify soil** [15].

The concavity distribution implies areally heterogeneous alteration, **consistent with an ice sheet or snow pack.**

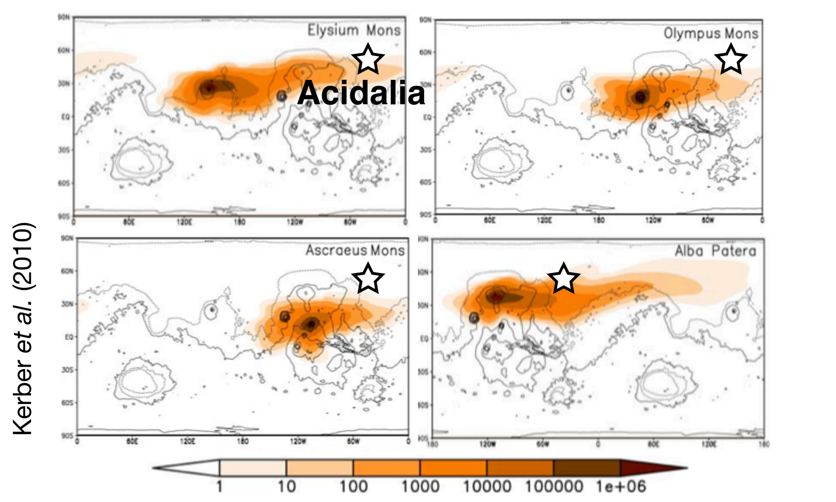
5 Possible glass sources

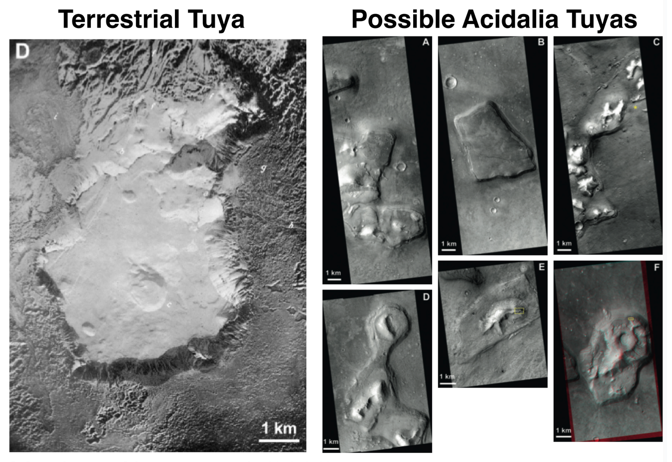
Both impacts and explosive volcanism can produce glass [16], but only **explosive volcanism** can produce concentrated glass-rich deposits.

Ice-volcano interactions produce extremely glass rich deposits dominated by sand size grains, as demonstrated in Iceland. Possible sub-glacial volcanic features have been identified in Acidalia and Chryse Planitiae [17].

Alternatively, **volcanic eruption into a thin atmosphere is inherently explosive** [18], and GCM's predict ash in Acidalia from several of the large volcanoes [19]:


Icelandic glass-rich sand dune field





Martinez-Alonso et al. (2011)

6 Conclusions

Summary: Iron-bearing glass covers several million sq. km in the northern lowlands of Mars and may be due to explosive volcanism during the Amazonian.The glass exhibits spectral signatures consistent with leaching under moderately acidic conditions, potentially due to periglacial processes [1].

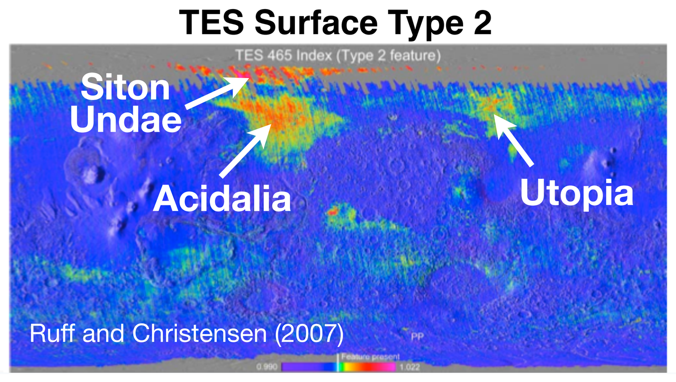
Implications:

(1) Explosive volcanism may be a major source of sediments and aeolian materials on Mars. Further work may demonstrate the presence of glass in aeolian deposits elsewhere on Mars.

(2) Limited liquid water has been present on Mars even under long-term hyper-arid conditions.

(3) The leached rinds may be the high silica phase in TES Surface Type 2, but this needs to be verified at other locations.

TES Surface Type 2



References:

[1] Horgan, B. and Bell, J.F. III (2012) Geology, in press, doi:10.1130/G32755.1. [2] Mustard, J.F. et al. (2005) Science, 307, 1594-1597. [3] Bandfield, J.L. et al. (2000) Science, 287, 1626-1630. [4] Michalski, J.R. et al. (2005) Icarus, 174, 161-177. [5] Rogers, A.D. and Christensen, P.R. (2007) JGR, 112, E01003. [6] Ruff, S.W. and Christensen, P.R. (2007) GRL, 34, L10204. [7] Cloutis, E.A. and Gaffey, M.J. (1991) Earth Moon and Planets, 53, 11-53. [8] Adams, J.B. et al. (1974), Proc. 5th Lunar Conf., 1, 171-186. [9] Minitti, M.E. et al. (2007) JGR, 112, E05015. [10] Chemtob, S.M. et al. (2010) JGR, 115, E04001. [11] Seelos, K.D. et al. (2010) JGR, 115, E00D15. [12] Horgan, B. et al. (2011) LPSC XLII, #2415. [13] Goetz, W. et al. (2010) JGR, 115, E00E22. [14] Hurowitz, J.A. et al. (2010) Nat. Geo., 3, 323-326. [15] Hecht, M.H. et al. (2009) Science, 325, 64-67. [16] Schultz, P.H. and Mustard, J.F. (2004) JGR, 109, E01001. [17] Martínez-Alonso, S. et al. (2011) Icarus, 212, 597-621. [18] Wilson, L. and Head, J.W. (2007) J. Vol. Geotherm. Res., 163, 83-97. [19] Kerber, L. et al. (2010), LPSC XLI, #1006.