CONSTRUCTION OF A VOLATILE-RICH MARTIAN UPPER CRUST DURING THE IMPACT CATACLYSM. J.A.P. Rodriguez[1], J.S. Kargel[2], K.L. Tanaka[3], and D.C. Berman[1]. [1]Planetary Science Institute, Tucson, AZ, 85719 (alexis@psi.edu), [2]Univ. of Arizona, Tucson, AZ 85721, [3]USGS, Flagstaff, AZ.

Introduction: The early hydrologic history of Mars comprises a long-standing, fundamental mystery regarding the geologic history of the planet. Unresolved issues include *(1)* the timing and mechanisms involved in the formation of a volatile-rich upper crust, and *(2)* the nature of the transition from a period of accelerated erosion and sedimentary deposition early in its history, seemingly coeval or overlapping with the late heavy impact bombardment, to a subsequent period dominated by dry and frigid surface conditions. It has been proposed that the migration of outer planets' orbits may have caused severe depletion of asteroids due to orbital instabilities as strong gravitational resonances swept across the asteroid belt, thereby producing the objects responsible for the late heavy bombardment [1,2,3]. Strom [4] suggested that this period occurred as a cataclysmic bombardment of the Moon and all terrestrial planets and lasted only about 10^7 to 10^8 years between ~4.0 and ~3.85Ga.

The highlands and lowlands of Mars contain large populations of quasi-circular depressions (QCD's), generally interpreted to represent depressions formed due to differential compaction of sediments over buried impact craters [5, 6]. The thickness of the geologic materials that allegedly bury the impact craters has been estimated to range between 1 km and 6 km [7]. Rodriguez et al. [8, 9] characterized the morphology and morphometry of chaotic terrains and zones of plateau subsidence in south Chryse and concluded that buried impact craters may have formed significant regional aquifers and may have promoted long-range groundwater migration through the fractured crust. They proposed that the upper crust of Mars contains extensive sedimentary deposits, in which buried impact craters are likely to have formed aquifers. In their hypothesis, lakes would have frequently formed within impact craters, so that their burial would have led to heterogeneous distribution of volatiles within the upper crust of Mars. The absence of globally distributed chaotic terrains implies that most of these aquifers remain untapped, or that they have lost their volatiles slowly over billions of years.

Concurrent aggradation of the Martian upper crust and heavy bombardment must have taken place during climatic periods that allowed for widespread hydrologic activity on the Martian surface [9]. Kargel et al. [10] proposed that impact crater/basin forming events may have led to the formation of transient atmospheres during the cataclysm, capable of sustaining active hydrologic environments and accelerated water- and ice-driven geomorphic activity.

Chronology of crustal accretion in southern circum-Chryse: The plateau materials of southern circum-Chryse contain dense populations of *(1)* QCD's (interpreted as buried craters), *(2)* impact craters that have been infilled almost to their rims, and (3) degraded and pristine impact craters (Fig. 1). The combined population of pristine, degraded, infilled, and buried craters > ~16 km diameter (Fig. 2) is consistent with an overall age of 3.85 ±0.1 Ga according to the crater density/age calibration model of [11]; if there had been no crustal aggradation but simply a clean surface produced at 3.85 ±0.1 Ga, that surface would have a crater density equal to this combined crater density. However, looking only at pristine craters >16 km in diameter, the apparent age is ~3.7 Ga; we interpret this to mean that vigorous crustal aggradation occurred simultaneously with intense impact cratering from 3.85 to 3.7 Ga, and then slowed dramatically. The pronounced rollover of all types of craters, including pristine ones, at diameters <16 km, especially approaching 4 km diameter, indicates that some significant resurfacing and erosion of many small craters and QCD's occurred, with little crustal aggradation, until at least 3 Ga. Any such chronology depends on the impact flux history, which is strictly known only for the Moon.

Thus, we propose that between ~3.8 and 3.0 Ga, there were three distinct resurfacing stages; *(I)* 3.85-3.7 Ga, during which the region of the south Chryse basin accumulated extensive sedimentary deposits, which buried large populations of impact craters formed while the rock record accumulated, *(II)* roughly 3.7-3.4 Ga during which large impact craters were infilled but not buried, and *(III)* a subsequent stage during which hydrologic and other surficial activity were significant enough as to degrade crater rims of large craters and wipe out many craters <4 km in diameter, but not significant enough as to lead to extensive burial/ infilling of craters >16 km.

Within the outflow channel and chaos areas, a long-recognized dearth of fresh impact craters (which Figure 1 shows extends to infilled craters and QCD's) indicates that deep-level erosion and disaggregation of the terrain occurred well after late heavy bombardment ended. Within the outflow channel boundaries there are plateau outliers resembling the more heavily cratered terrains that indicate that the plateau areas once extended across this whole region. Thus the threephase history above was followed by, or perhaps stage III above was concurrent with, a prolonged period of intense but strongly localized crustal disintegration to form chaos and outflow channels.

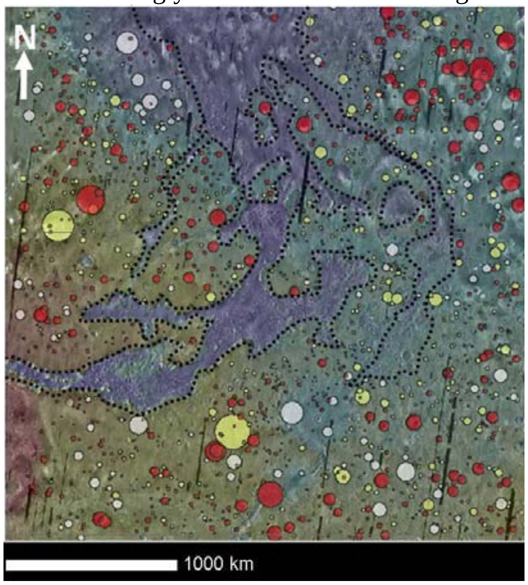

Figure 1. *Color shaded relief view of south Chryse. Shown are the populations of pristine and degraded impact craters (red circles), infilled impact craters (yellow circles), and QCD's (white circles) in the plateau surfaces that form the peripheries of the chasmata, chaotic terrains, and outflow channels (margins outlined by black dots). Composite of MOLA based DEM (128 pixels/degree) and THEMIS IR mosaic (256 pixels/degree).*

Multi-volatile-driven resurfacing during the cataclysm: The decrease in hydrologic activity presumably occurred in association with a trend in global cooling. Thus, we expect a zonation of volatiles in the upper crust in which volatiles with lower freezing points are preferentially located in areas of colder crust. Impact-related epochs of globally widespread erosion and deposition of sedimentary rocks would be interspersed with volcanic and impact deposits. Impact crater basins would have accumulated sedimentary deposits and refrozen lake and groundwaters, which would be overlain by, or interlayered, with aeolian, volcanic, and impact ejecta materials. The impact blitz also would have released other volatiles, besides H_2O, including SO_2, CO_2, CO, H_2SO_4, HCl, elemental sulfur, O_2, alkali metals, and other highly and slightly volatile materials due to impact heating of metal sulfides, sulfate and other salts, and silicates. For example, pyrite, upon heating, would yield elemental sulfur liquid (or vapor at low confining pressures); gypsum would dehydrate (yielding H_2O) and, at higher temperatures, give off SO_2 and O_2. In an oxygenic system, sulfuric acid would be produced. With sudden transient disturbances to the planet's radiative balance and climate caused by atmospheric injection of multiple volatiles, global episodes of acid rain and acid chemical weathering, reformation of sulfates, and oxidation of iron in ferrous silicates would have been widespread. Rapidly evolving climatic excursions would attend draw-down of transient atmospheric species. With each large im-pact, a transient episode of rainfall, fluvial erosion, and lacustrine deposition [e.g., 12] would have been followed by an epoch dominated by snowfall and glaci-ations, and finally increasingly severe periglacial environments.

The larger and longer lived climatic excursions could have been modulated by obliquity variations and other astronomical forcings as well as by massive volcanism [13], even while trends were toward a geologically rapid drying and cooling of the planet. In summary, the late heavy bombardment also appears to have been a period of cataclysmic crust formation and hydrogeologically driven resurfacing.

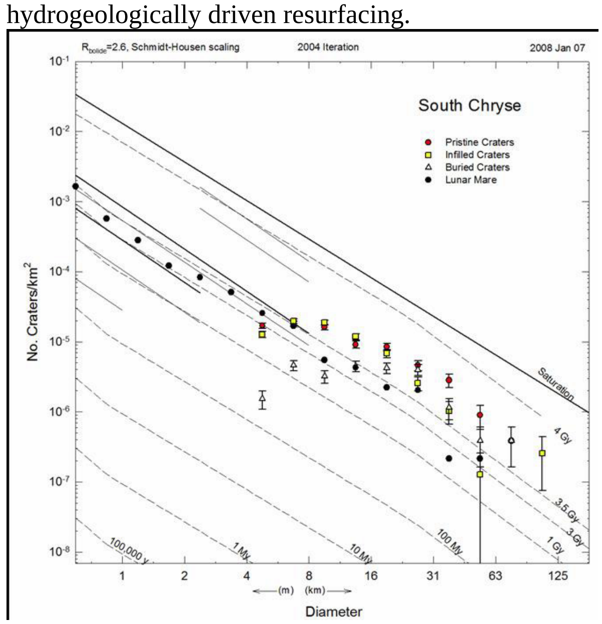

Figure 2. *Plot showing the relative ages obtained from impact crater populations displayed in Fig. 1 versus impact crater populations in the lunar mare.*

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