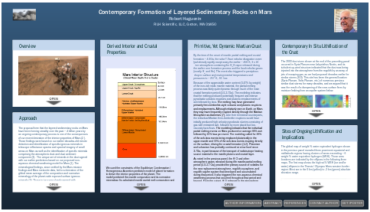
Contemporary Formation of Layered Sedimentary Rocks on Mars



Contemporary Formation of Layered Sedimentary Rocks on Mars
Robert Huguenin
RLH Scientific, LLC, Groton, MA 01450

Overview

OPEN

Approach

OPEN

Derived Interior and Crustal Properties

Mars Interior Structure

OPEN

Primitive, Yet Dynamic Martian Crust

OPEN

Contemporary In Situ Lithification of the Crust

OPEN

Sites of Ongoing Lithification and Implications

OPEN

AUTHOR INFORMATION ABSTRACT REFERENCES CONTACT AUTHOR GET POSTER

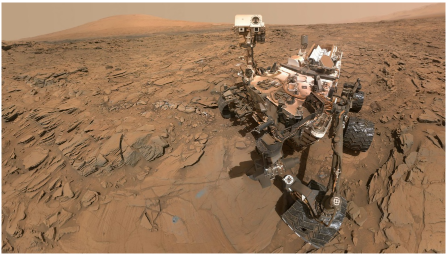
Robert Huguenin

RLH Scientific, LLC, Groton, MA 01450

PRESENTED AT:

AGU FALL MEETING
New Orleans, LA & Online Everywhere
13–17 December 2021
Poster Gallery
brought to you by
WILEY

OVERVIEW



A generally accepted assumption made by the various recent and ongoing Mars orbiter, lander and rover mission scientists is that the layered sedimentary rocks exposed on the cold and dry Martian surface are relics of an early Earth-like epoch when Mars had a warmer and wetter surface environment that could support standing water and potentially an ancient population of microbial life. The present work makes the case that the layered sedimentary rocks instead likely formed in situ by an ongoing process whereby water that episodically and/or periodically leaks from a massive global sub-permafrost aquifer system in the crust below (analogous to oilfield macro seepage leaks) dampens the crustal fines material at locations subjected to the macro-seepage.

The fines material contains an atmospherically deposited dust sediment component that has been steadily forming and accumulating over the past ~ 4 billion years by non-aqueous chemical weathering of exposed surface igneous ferrosilicate minerals, primarily olivine and pyroxene (1). The dust sediment component contains nano-scale magnesium-silicate hydrate (M-S-H) minerals that, when dampened by the macro seepage, chemically react like their calcium counterparts (C-S-H) in commercial Portland cement, binding with other fines components to rapidly (within hours to days) turn the fines sediment layers into concrete-like sedimentary rock formations.

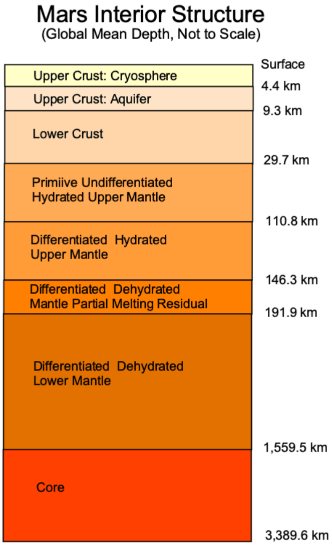
The sedimentary rocks in their terrain settings on Mars appear deceptively similar to traditional lakebed layered depositional sedimentary rocks on Earth. Their different proposed mode of formation, however, means that, unlike their Earth counterparts, the age of a Martian sedimentary rock layer reflects when the fines in that layer were exposed to the macro-seepage. Ages are predicted to range from ~ 4 billion years at the base of the crust (29.7 km depth) to < 10^5 years within the upper meter. Consequently, organic material and other materials carried by the micro-seepage to form the surface sedimentary rock are likely not ancient but were relatively recently emplaced in the rock. This has important implications for re-examining and interpreting the organic material reported in 2018 by the Curiosity mission. This also has implications, including planetary protection considerations, for the ongoing Perseverance mission search for biologically relevant rock samples for future retrieval and return to Earth.

APPROACH

The proposal here that the layered sedimentary rocks on Mars have been forming steadily over the past ~ 4 billion years by an ongoing contemporary process is one of the consequences of our recent derivation of the interior properties of Mars (2). Those findings were based on our earlier decades-old remote detection and identification of specific igneous minerals in telescope reflectance spectra and spectral imagery of small areas on Mars as well as the identification of specific minerals comprising the atmospheric dust and dust sediment component (3). The unique set of minerals in the dust agreed with our earlier predictions based on our proposed non-aqueous chemical weathering model for Mars (1). The mineralogical findings, since verified by the Mars mission findings and Mars meteorite data, led to a derivation of the global mean average of the composition and normative mineralogy of the planet-wide exposed surface igneous minerals (4). Those in turn very closely agreed with independently modeled predictions of the composition and normative mineralogy of the Martian primary mantle partial melt (5).

We used the composition and mineralogy of our derived mantle primary partial melt as a test probe to identify which, if any, of the extant published models of planet formation predicted a mantle composition that was most closely compatible with our partial melt composition (2). Of the 22 models assessed, the Equilibrium Condensation / Homogeneous Accretion model of planet formation clearly emerged as the best candidate (2,6). Using the constraints of that predictive model as proposed (7), we derived the formation history and interior characteristics of the planet over its 4.56-billion-year history.

DERIVED INTERIOR AND CRUSTAL PROPERTIES


Mars Interior Structure
(Global Mean Depth, Not to Scale)
Surface
Upper Crust: Cryosphere
4.4 km
Upper Crust: Aquifer
9.3 km
Lower Crust
29.7 km
Primiive Undifferentiated Hydrated Upper Mantle
110.8 km
Differentiated Hydrated Upper Mantle
146.3 km
Differentiated Dehydrated Mantle Partial Melting Residual
191.9 km
Differentiated Dehydrated Lower Mantle
1,559.5 km
Core
3,389.6 km

We used the constraints of the Equilibrium Condensation / Homogeneous Accretion predictive model of planet formation to derive the interior properties of the planet. The model predicted the mantle composition and its normative mineralogy. Its calculated mantle partial melt composition and mineralogy closely agreed with our earlier reported remotely identified surface mineralogy and derived global average parent magma composition and normative mineralogy. This tightly constrained our derivation of the interior properties using the Equilibrium Condensation / Homogeneous Accretion model.

Our derivation revealed that Mars is apparently a primitive embryo planet that accreted much more slowly than the Earth and Venus, resulting in premature termination of accretion ~3.7 Ga. Because of the slow accretion rate, the derived thermal history led to incomplete core formation, starting ~4.3 Ga at the center of the embryo and stopping within 110.8 km of the current surface prior to the solar T-Tauri nebular dissipation event ~4.0 Ga. This led to a small 1830.1 km derived core radius having the composition $\{(Fe_{0.9},Ni_{0.1})S + 0.05(Fe_{0.9},Ni_{0.1})\}$. It also yielded an 81.6 km-hick upper layer of the upper mantle that retained the primitive hydrated undifferentiated material properties of the original accretion material. That layer contained 26% of the $\{(Fe_{0.9},Ni_{0.1})S + 0.05(Fe_{0.9},Ni_{0.1})\}$, the bulk of the material that didn't melt and contribute to the core. Core formation involved transport of 0.7ppm K as K_2S into the core, representing 0.075% of the total accreted planetary abundance of K (881ppm) and an ongoing heat source for the core.

Mars accreted substantial (0.35% by weight) H_2O in the form of ferrosilicate hydrates, which was released at depths below 191.9 km prior to the solar T-Tauri nebular dissipation event ~4.0 Ga. The H_2O was released as vapor to the hot ~450K, 3×10^{-4} bar atmosphere. The T-Tauri nebular dissipation event swept away the H_2O and other gases (primarily nebular H_2 and He), and the surface and environmental temperature dropped precipitously to ~217K by ~4.0 Ga

Shortly after the T-Tauri dissipation event, mantle partial melting occurred (4.0-3.7 Ga) in a 45.6 km thick layer of the mantle between 191.6 - 146.3 km depth. The volcanism and plutonic activity initiated the formation of the crust and new replacement atmosphere (4.0-3.7 Ga). The H_2O and other atmospheric gases volcanically released during the mantle partial melting period (4.0-3.7 Ga) provided the primary source for the new replacement atmosphere, which initiated the non-aqueous chemical weathering process. The released H_2O was also cold-trapped and stored on the surface (diurnal frost) and in the polar caps, as well as in the upper 9.3 km (global average) of the derived 29.7 km-thick crust.

In that upper 9.3 km layer the released H_2O is stored as permafrost in the upper 4.4 km (cryosphere), and as a 4.9 km-thick global liquid H_2O aquifer system below the cryosphere. The cryosphere and aquifer system occupy a globally inter-connected network of fractures and pore spaces that comprise a globally averaged minimum 1.1×10^8 km^3 in the upper 9.3 km crustal layer volume (based on derived 27% average surface porosity dropping to 1-4% porosity at the 9.3 km self-compaction depth).

The crust overall is comprised of 31.3 vol % mantle partial melt ash (85%) and lava (15%); 34.2 vol % primitive nebular accretion material; 17.5 vol % atmospherically deposited dust sediment formed by non-aqueous chemical weathering; 4.1 vol % non-aqueous chemical weathering residual (lag) material; 8.3 vol % (0.35×10^8km^3) H_2O permafrost, excluding polar caps; and 4.6 vol % (0.19×10^8km^3) sub-permafrost water. The latter represents a 0.38 km-thick equivalent global ocean surface layer of ice and water concealed within the upper 9.3 km layer of the regolith.

Of the total 19.57 km thick layer of mantle partial melt generated, 26% was deposited in the undifferentiated upper mantle as intrusive masses and 74% provided source material for the crust. The ash and magma generated by the mantle partial melt was enriched in K_2O by a factor of 1.6807 to 0.100% relative to the 0.0595% K_2O in the undifferentiated mantle material prior to removal of the partial melt. The partial melt also contained the principal alkaline host minerals for the U and Th. In the aqueous melting environment, the U and Th concentrations were estimated to have increased by a comparable factor (1.6807) to 0.029 ppm U and 0.100 ppm Th, relative to the 0.017 ppm U and 0.060 ppm Th in the mantle material prior to the partial melting. This provided an extra source of radioisotopes for heating within the volcanic and plutonic deposits. A comparable enhancement would be expected in impact melts as well.

PRIMITIVE, YET DYNAMIC MARTIAN CRUST

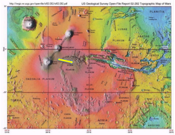
By the time of the onset of mantle partial melting and crustal formation ~ 4.0Ga, the solar T-Tauri nebular dissipation event had already rapidly swept away the earlier ~ 450°K, 3×10^{-4} torr atmosphere containing the H_2O vapor released during the earlier core formation process and the local nebular gases (mostly H_2 and He). The event also triggered a precipitous drop in surface and environmental temperatures and pressures to ~ 217°K,. 10^{-7}bar.

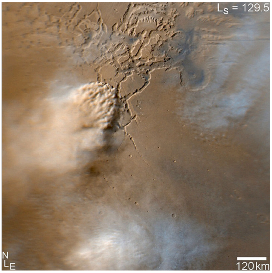
Because of the appreciable water content (0.47% by weight) of the iron-rich mafic mantle material, the partial melting process was likely quite dynamic through much of the main crustal formation period (4.0-3.7Ga). The modeling indicates that the melting produced potentially frequent and intense pyroclastic volcanic eruptions and plutonic emplacements of ash followed by lava. The melting may have generated primarily ferro-kimberlite-style volcanic and plutonic eruptions and emplacements. Although relatively rare on Earth, on Mars they may have frequently erupted directly through the Martian lithosphere as diatremes (7). Like their terrestrial counterparts, the individual Martian ferro-kimberlite eruptions would have initially produced high velocity pyroclastic slurries consisting of gas with entrained ash, followed by more placid but low-viscosity lava flows. The modeling indicates that the individual partial melting events on Mars produced on average 85% ash followed by 15% lava per event. The modeling called for 26% of the ash-lava events being emplaced plutonically in the upper mantle and 74% of the ash-lava events erupting directly on the surface, driving the crustal formation (1,2). Plutonism and volcanism has probably continued at a low level since 3.7Ga, in part because of the transport of radioisotope heating source material to the mantle plutons and crustal layer.

As noted in the previous panel, the H_2O and other atmospheric gases released during the mantle partial melting period (4.0-3.7 Ga) provided the primary source of volatiles for the new replacement atmosphere, regolith cryosphere, and regolith aquifer system that developed and accumulated during that period. It also triggered the non-aqueous chemical weathering process that occurred throughout that period and beyond. From the outset, H_2O released to the atmosphere would have formed surface frosts (especially during diurnal radiational cooling cycles), which initiated the two-component non-aqueous chemical weathering process (9). During the Chemical Frost Weathering phase of that two-component process, frost-induced hydrolysis of exposed surface igneous ferrosilicate minerals (primarily olivine and pyroxene) induces migration of Fe^{2+} cations from within the crystal substrate to surface sites and replacement of the removed cations by $2H^+$ and $2e^-$. This is followed by oxidation and entrapment of the surface Fe^{2+} to surface Fe_2O_3 during the second Photostimulated Oxidation Weathering phase of the diurnal cycle. The hydrolysis and separation of the iron transforms the source silicate into the iron-depleted and chemically reduced acid silicates $Mg_2HSiO_4(OH)$ (from olivine) and $Mg(HSiO_3)(OH)$ (from pyroxene). The enhanced chemically reduced state of the acid silicate substrate drives the restoration of an estimated ~25% of the photooxidized surface Fe^{3+} back to surface Fe^{2+}. This converts a fraction of the surface Fe_2O_3 to the stable and structurally separable Fe_3O_4 phase. The return of adsorbed H_2O during the subsequent diurnal Chemical Frost Weathering phase of the cycle hydrates the Fe_2O_3 to $Fe_2O_3 \cdot H_2O$. Also formed by the non-aqueous chemical weathering process are $CaSO_4$, $MgSO_4$, $CaCO_3$, and SiO_2. The existence of each in the Martian dust and fines has been subsequently supported spectroscopically and by Mars mission ground sample data (e.g., Viking lander duricrust vs. deep fines sample analysis). The non-ferrosilicate minerals in the exposed surface igneous ash and lava source material remain as a non-aqueous chemical weathering residual (lag) component of the regolith. The model estimates that from 4.0Ga to the present day the 29.7 km-thick crust contains 17.5 vol % atmospherically deposited dust sediment formed by non-aqueous chemical weathering and 4.1 vol % non-aqueous chemical weathering residual (lag) material.

Also, the modeling indicates that the planet accreted the final ~1% of its mass from the primitive solar nebula during the crustal formation stage. Significantly this material contains 26% by weight of $\{(Fe_{0.9},Ni_{0.1})S + 0.05(Fe_{0.9},Ni_{0.1})\}$, a possible diagenetic source of the sulfate salts and for possible eventual creation of crustal magnetic anomalies. It is uncertain whether the primitive accretion material was added steadily and is uniformly mixed with the steadily accumulating ash, lava, and non-aqueous chemical weathering sediment deposits, or whether it is primarily shallow or deep within the accumulated crustal mass. The modeling indicates that 34.2 % by volume of the crust is comprised of this primitive component.

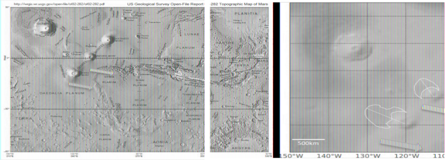
Central to the ongoing dynamic nature of the otherwise primitive Martian crust has been the presence of the massive permafrost and aquifer system embedded within it. The crust contains materials that progressively accumulated and/or formed in a cold and dry (non-aqueous) surface environment. The H_2O that was progressively released with the ash and magma was cold-trapped as frost on the cold surface and as permafrost in the uppermost portions of the accumulating regolith. The other accumulating materials are out of equilibrium with liquid H_2O, and later exposure to liquid H_2O can produce dynamic chemical reactions (c.f., the Viking Biology Experiment activity) and large-scale planetary surface activity, such as seasonal dust storms (xx). An illustration of the latter contemporary activity is shown in the following image of a dust storm that occurred in 2001 at the location shown in the accompanying map (yellow arrow). As discussed in the next panel, that and other dust storms were likely triggered by exposure of the near-surface fines material to liquid H_2O. Other dynamic crustal activity, including seismic, can potentially be attributed to the circulation and movement of the aquifer H_2O as well.


http://wrgis.wr.usgs.gov/open-file/of02-282/of02-282.pdf
US Geological Survey Open-File Report 02-282 Topographic Map of Mars
PLANITIA
LUNAE
PLANUM
XANTHE
TERRA
DAEDALIA PLANUM
TERRA
AONIA
ARGYRE



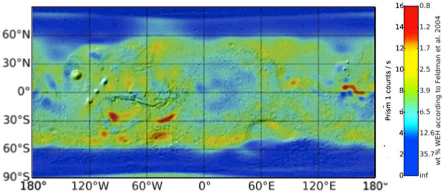
CONTEMPORARY IN SITU LITHIFICATION OF THE CRUST

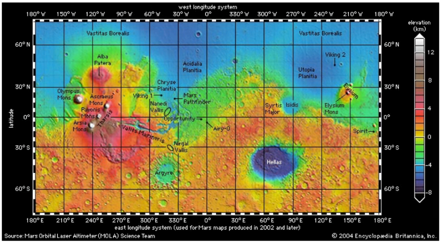
The 2003 dust storm shown at the end of the preceding panel occurred in Syria Planum near Labyrinthus Noctis, and its turbulent up-wind structure indicated that the dust was being injected into the atmosphere from the regolith by an array of jets of escaping gas, as we had proposed decades earlier for similar storms (8,9). This site has been the general location (Syria Planum, Solis Planum, etc.) of numerous previous similar dust storms for many decades, and we argued that it was the result of a dampening of the near-surface fines by moisture leaking from an aquifer system below.


http://wrgis.wr.usgs.gov/open-file/of02-282/of02-282.pdf
US Geological Survey Open-File Report
282 Topographic Map of Mars
PLANITIA
LUNAE
PLANUM
XANTHE
DAEDALIA PLANUM
TERRA
AONIA
ARGYRE
500km
150°W
140°W
130°W
120°W

On the left half of the figure the location of a second dust storm during the same May 2003 time frame is shown by the orange arrow. It occurred on the opposite boundary of Syria Planum in Claritas Fossae. Also shown in that figure on the right is a map of the area revealing the detected ~ 6 weight percent of water equivalent Hydrogen (WEH) at those two specific locations during 2003 by the NASA 2001 Mars Odyssey Neutron Spectrometer (MONS) (10). The MONS data revealed local areas of macro-seepage from the aquifer below that we proposed triggered the injection of dust into the atmosphere (11). Other prominent areas of enhanced near-surface H_2O can be seen in the western and northeastern portions of the map on the right, discussed further below and in the next panel.

We had proposed earlier that this and several other prominent locations of repeated seasonal dust storm activity are locations on the planet where water from the sub-permafrost aquifer system episodically leak (macro-seepage) and expose the near surface (upper meter) regolith material to liquid H_2O (8,9). They are located near Syria Planum /Solis Lacus, Hellas/Helespontus, Syrtis Major border regions, and Elysium. This is supported in the figure below, which provides a global map of the near-surface H_2O concentrations detected by MONS (integrated over the n 2003-2010 interval) (10). Locations in the vicinity of the Tharsis / Olympus Mons (180-120W), Syrtis Major (0-60E), and Elysium (120E-180) volcanic complexes reveal concentrations > 6 wt. % WEH, which is consistent with macro-seepage from the aquifer there.





Source: Mars Orbital Laser Altimeter (MOLA) Science Team

© 2004 Encyclopædia Britannica, Inc.

The presence of near-surface moisture in contact with the surface fines in these regions can result in their rapid contemporary lithification into sedimentary rock. The exposure to H_2O causes the silicate components, nano-scale $Mg_2HSiO_4(OH)$ (from olivine) and $Mg(HSiO_3)(OH)$ (from pyroxene), of the dampened dust sediment material to behave as hydraulic M-S-H cement, analogous to their Portland cement (C-S-H) counterparts. The dampened M-S-H cement binds with the other regolith components to transform the fines sediment into concrete-like sedimentary rock. The layering of the dust deposits produces layered sedimentary formations. While these sedimentary rock formations in many ways mimic traditional sedimentary rock formations found on Earth, they differ in two significant ways: they form over very rapid relative time scales, analogous to poured concrete at construction sites, and they are tolerant to the suspected low pH conditions of the Martian materials and water.

The water migrates from below the surface as capillary films where water and ice are thermodynamically stable. Individual macro-seepage events need only be short-term in duration (e.g., ~ 6 hours to set and begin hardening). Compressive strength rapidly grow with cumulative/repeated exposures to more than 8 MPa (1 MPa = 145.03 psi) within only 24h to > 45 MPa within one week and > 75 MPa within a month for water-to solid ratios of 0.4 or less (consistent with capillary films). Strengths continue to increase with continued repeated / cumulative exposure to water, reaching strengths that can exceed those of sedimentary (e.g, sandstone) rocks on Earth within a few months. Furthermore, unlike the Portland cement-based concrete, the M-S-H -based rocks on Mars are compatible with the suspected low-pH conditions of the macro-seepage capillary films.

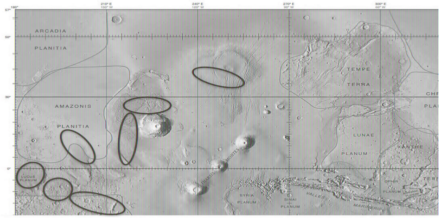
Another impact of the micro-seepage is the likely rapid transformation of the other nano-scale non-aqueous chemical weathering products in the dust sediment component (silica, carbonate, sulfates, and magnetite) into pseudo-aqueous weathering products, leading to some of the unusual materials and “contradictory” assemblages of materials reported by the Spirit mission team (e,g., sedimentary rocks having olivine-rich basaltic composition, opaline silica, hematite, carbonates, etc.).

It is likely that most of the crust below 4.4 km depth has been progressively lithified over the formation history of the crust. As the ash, lava, dust sediment, and primitive crustal components accumulated, the H_2O released by partial melting was cold-trapped as frost on the surface and as permafrost in the porous layer above the compaction depth. As more material was added, the trapped H_2O migrated upward to the colder newly added available surface and regolith pore space. Eventually a depth (~4-5 km) was reached, below which the trapped regolith H_2O remained above the melting point and exposed the crustal material to liquid H_2O, lithifying it.

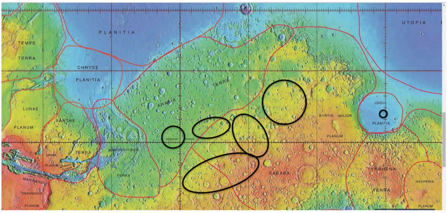
As the layers of crustal material continued to accumulate,the modeling predicts that this zone (~5-10km depth) containing trapped liquid H_2O migrated upward, progressively exposing the crustal material within that “sliding” depth zone to water and lithifying it. With most of the accretion cratering terminated, the layers of material were largely undisturbed and preserved in the order of deposition throughout all but the lower portions of the 29.7 km crustal layer, so that their ages should generally follow the uniformitarianism principle with the oldest layers at the bottom and the most recent at the top. The modeling predicts that the ages of the layered sedimentary rocks in the upper 4.4km of the present-day regolith generally range from 600 million years (at ~4.4 km depth) to < 10^5 yr within the upper meter of soil, with the local depths generally mirroring the local topography.

SITES OF ONGOING LITHIFICATION AND IMPLICATIONS

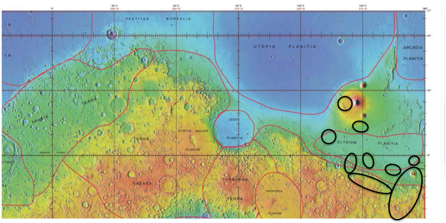
The global map of weight % water equivalent hydrogen shown in the previous panel revealed three prominent equatorial and midlatitude regions having clusters of areas exceeding ~ 6 weight % water equivalent hydrogen (WEH). Those area locations are indicated by the ellipses in the following three maps. The first map shows the high wt.% WEH (ice and/or water) ellipses in the Tharsis / Olympus Mons western border region. Most are in the 0 km (yellow) to -2 km (green) absolute elevation range.



The next figure reveals the locations of the high wt.% WEH (ice and/or water) ellipses in the western border region of the Syrtis Major volcanic complex. Like the areas in the western border region of the Tharsis/Olympus Mons volcanic complex, they occurred in the 0 km to -2 km absolute elevation range on the boundary between the southern uplands and northern lowlands. The westernmost ellipse included the Meridiani Planum / Columbia Hills location of the of NASA MER-2 rover "Opportunity." The NASA "Perseverance" rover is located to the northeast of the easternmost ellipse in Jesro Crater (18.44486°N, 77.45102°E) along the eastern upland/lowland border in the large green embayment just southeast of the northern tip (yellow) of the greater Syrtis Major uplands region.



The third region below shares many of the characteristics of the other two regions in the preceding two figures. The locations of the macro-seepage areas are again generally along the upland/lowland border predominantly in the 0 km to -2 km absolute elevation range. The two northernmost ellipses appear to be associated with the Elysium Mons volcanic complex, while the cluster of six to the south appear to be associated with the southern highlands that border on Elysium Planitia between them. The southern cluster of six includes the Gusev Crater location of the NASA MER-1 rover "Spirit" in the easternmost large ellipse. The western edge of that same cluster of six also came very close to the Gale Crater location of the NASA Mars Science Laboratory Curiosity rover, which falls on the north/south transition boundary.



It is notable that the absolute elevations of the macro-seepage areas and their locations along the upland/lowland boundary are common to each of the above three figures. It is also notable that they are generally in the vicinity of major volcanic complexes. With the three main volcanic features sitting on terrain having a surrounding absolute elevation of ~ 2km (yellow orange), the wetness is appearing at absolute elevations equivalent to ~2–4 km depths below the upland surface. This suggests that the aquifer water may be breaching the cryosphere ice barrier (4.4 km depth) at the ellipse locations along the upland/lowland border. The cryosphere/aquifer system depth generally mirrors the terrain surface topographic elevation. The terrain absolute elevation and hence the cryosphere/aquifer depth both make a ~ 4 km depth transition at the border between the southern uplands and northern lowlands, and the cryosphere thickness is reduced and most susceptible to breaching at the depth transition point. Their occurrence in the vicinity of the major volcanic complexes suggests that the breaches may have occurred as a result contemporary thermal waters in the aquifer that were able to melt the ice and breach the cryosphere at those locations.

The thermal waters may originate from submerged, likely dormant or inactive, volcanic vents, analogous to the lower-temperature dormant seafloor vents on Earth referred to as deep-sea smokers. Other thermal sources could be plutonic or volcanic ash/lavs deposits that have elevated temperatures due to their ~1.6 times higher concentrations of dissolved K, U and Th radioisotopes, discussed earlier in Panel 3.

The leaking waters contain dissolved and suspended matter from the aquifer, which become trapped in the actively forming contemporary sedimentary rocks in the macro-seepage areas. It is notable in this context, that the presence of lower temperature heat sources in the aquifer has potential biological significance. On Earth, the lower-temperature smokers are the ones that are most reliably associated with underwater populations of living organisms that depend on the associated organic material (black "smoke") and other disequilibrium thermal water reactions at non-lethal temperatures (< 200°C) for their survival and growth. The higher temperature active seafloor vents on Earth are super-heated and destroy critical organic molecules and interfere with important disequilibrium reactions that would otherwise occur at the warm water / cold water interface in the vicinity of the vent or heated rock.

It is further notable that the massive central peak of Gale Crater (Aeolis Mons) rises ~ 5.5 km above the crater floor at the landing site of Curiosity, the latter at an absolute depth of 4.4 km. As noted in a previous panel the depths to the cryosphere and aquifer locally mirror the surface topography, so it is likely that the ice and water levels are at higher absolute elevation inside Aeolis Mons than under the crater floor. Thermal waters could potentially breach the cryosphere from inside Aeolis Mons or from the surrounding terrain along the upland / lowland depth transition boundary. The discovery by Curiosity in 2018 of biologically significant organic molecules in near surface “rock” samples from the base of Aeolis Mons and the releases of methane gas there support the possibility that their findings represent organic debris from contemporary aquifer macro-seepage rather than from an ancient lakebed deposit.

Another significant implication is the likely rapid transformation by the micro-seepage of the other nano-scale non-aqueous chemical weathering products in the dust sediment component (silica, carbonate,sulfates, and magnetite) into pseudo-aqueous weathering products, leading to some of the unusual materials and “contradictory” assemblages of materials reported by the Spirit mission team (e,g., sedimentary rocks having olivine-rich basaltic composition, opaline silica, hematite, carbonates, etc.).

Furthermore, the component of primitive solar nebula material added during the crustal formation stage contains 26% by weight of $\{(Fe_{0.9},Ni_{0.1})S + 0.05(Fe_{0.9},Ni_{0.1})\}$, a possible diagenetic source of the sulfate salts and potentially the creation of crustal magnetic anomalies resulting from macro-seepage exposures.

Finally, although the Perseverance rover was not explicitly included in one of the ellipses of current macro-seepage, it was located along the northern upland / southern lowland boundary relatively close to the ellipses associated with the Syrtis Major and Elysium volcanic complexes. The search for relevant samples for future return to Earth, including planetary protection considerations, should consider the possibility that the samples may be of contemporary age despite their possibly deceptive ancient age.

References:

1) R.L. Huguenin, J. Geophys Res.,79, 3895-3905, 1974; R.L. Huguenin, J. Geophys. Res., 87(B12), 10,069-10,082, 1982; R.L. Huguenin et al., J. Mol. Evol., 14, 103-132,1979; **2)** R.L. Huguenin, “New Constraints on the Interior Properties of Mars” , Presentation DI024-0007, AGU 2020 Annual Fall Meeting, 15 December 2020; manuscript in preparation; **3)** R.L. Huguenin, J.B. Adams and T.B. McCord, LPSC, 8, 478-480, 1977; 4. R.L. Huguenin, Icarus, 70, 162-188, 1987; **4)** M. Maderazzo and R.L. Huguenin, Bull. AAS, 9, 527-528, 1977; **5)** T.R. McGetchin and J.R. Smyth, Icarus 34, 512-536, 1978; **6)** J.S. Lewis, Earth & Plan. Sci. Letters, 15, 286-290, 1972; S.S. Barshay and J.S. Lewis, Ann. Rev. Astronomy & Astrophysics, 14, 81-94,1976; S.J. Weidenschilling, Aspects of Planetary Formation, PhD Dissertation, Massachusetts Institute of Technology, Cambridge, MA, 1976; **7)** T.R. McGetchin and J.R. Smyth, Icarus 34, 512-536, 1978; **8)** R.L. Huguenin and S.M. Clifford, J. Geophys. Res., 87 (B12), 10,227-10,251, 1982; S. M. Clifford, J. Geophys. Res., 98 (E6), 10,973-11,016, 1993; **9)** R.L. Huguenin, S.L. Harris, and R. Carter, Icarus, 68, 99-119, 1986; **10)** J.T. Wilson, et al., Icarus 299, 148-160, 2018

AUTHOR INFORMATION

Author / Presenter: Robert L. Huguenin

Current Affiliation: RLH Scientific, LLC

Email Address: rhuguenin@alum.mit.edu; rhuguenin@rlhscientific.com

Web address: www.rlhscientific.com/web

Postal address: R. Huguenin, PO Box 19, Groton, MA 01450-0019 USA

Education: MIT ScD 1972; MIT MSc.1972; U Pittsburgh BSc 1969

Prior academic appointments: MIT, Brown U and U Massachusetts/Amherst

Prior Corporate appointments: Aerodyne Research Inc., Applied Analysis Inc.

R&D background: Earth, atmospheric and planetary scientist specializing in 1) Martian surface chemistry (non-aqueous chemical weathering and dust formation, formation of surface oxidants), surface mineralogy (remote identification of igneous and dust mineralogy), and hydrologic cycle; and 2) Remote Situational Awareness Technology R&D (environmental water quality, environmental incident response, National Defense Intelligence, Reconnaissance and Surveillance (ISR), buried hazard identification). Methods and techniques are based on automated remote material identification using UV/VIS/IR spectroscopy and spectral imaging.

ABSTRACT

Abstract

It is proposed that the exposed layered sedimentary rocks on Mars were recently formed rather than being ancient relics from a past warmer and wetter period. Crustal sedimentary rocks have been forming steadily over the past ~ 4 billion years to the present day by an ongoing and contemporary process. This finding is one of the consequences of our recent derivation of the interior properties of Mars, based on a mineralogically constrained identification of the “best” of 22 extant planetary formation compositional model predictions (Equilibrium Condensation/Homogeneous Accretion model). Using that predictive formation model, our derivation successfully predicted the recent seismic-based interior structure and properties of Mars reported by the InSight mission, and it led to a formation and thermal history that is incompatible with an ancient epoch of warmer and wetter Earth-like surface conditions. Mars instead is a primitive embryonic planet that accreted very slowly and incompletely due to early nebular accretion termination. The planet accreted substantial H_2O. Some was lost early during incomplete core formation and hot (~450 K) surface/atmospheric temperatures prior to 4Ga, but a substantial amount was cold-trapped on the surface and in the developing crust as a cryosphere and global aquifer system during the later mantle partial melting and crustal deposition period (4.0-3.7 Ga) and very cold (217 K) surface conditions. Martian dust, which likely formed by non-aqueous chemical

weathering throughout the crustal formation period to the present day is susceptible to rapid diagenesis when exposed to macro-seepage from the sub-permafrost aqueous aquifer system on Mars. The silicate components of the dust, derived from the non-aqueous weathering of primarily olivine and pyroxene, are $Mg_2HSiO_4(OH)$ and $Mg(HSiO_3)(OH)$. These Magnesium Silicate Hydrate (M-S-H) compounds react chemically like their calcium-based (C-H-S) counterpart compounds that form the commercial Portland cement binder in concrete. The M-S-H compounds form an $Mg_3Si_2O_5(OH)_4$ counterpart binder on Mars upon exposure to liquid H_2O macro-seepage from the aquifer below. The macro-seepage rapidly cements layers of dust and regolith fines into layers of M-S-H concrete on timescales and with strengths comparable to terrestrial construction site concrete. Contemporary macro-seepage was mapped during 2010-2017 by the Mars Odyssey Neutron Spectrometer (MONS), apparently triggered by modest geothermally heated water near three major volcanic complexes along the southern upland/northern lowland border. Surface rocks (upper meter) have formed within the most recent $< 10^5$ years. Deeper rock formations are progressively older, following uniformitarianism order to 4.0 Ga at the derived 29.7 km deep base of the crust. Water from the aquifer in the surface rocks can carry suspended inorganic and organic debris and dissolved substances that may have been incorporated in the rocks as recently as a few months to years ago. Each of the Mars rovers (MER 1 and 2, Curiosity and Perseverance) were located along this boundary, potentially explaining some key “unexpected” findings in their sample analyses. The discovery by the Curiosity rover team in 2018 of biologically relevant organic matter in surface rocks should be re-examined and analyzed in the context of its possible contemporary origin in the aquifer, analogous to their association with low-temperature (<200ºC) deep sea smokers on Earth. It also has implications for the ongoing Perseverance mission search for relevant rock samples, including in situ analysis and planetary protection considerations

REFERENCES

References:

1) R.L. Huguenin, J. Geophys Res.,79, 3895-3905, 1974; R.L. Huguenin, J. Geophys. Res., 87(B12), 10,069-10,082, 1982; R.L. Huguenin et al., J. Mol. Evol., 14, 103-132,1979; **2)** R.L. Huguenin, “New Constraints on the Interior Properties of Mars” , Presentation DI024-0007, AGU 2020 Annual Fall Meeting, 15 December 2020; manuscript in preparation; **3)** R.L. Huguenin, J.B. Adams and T.B. McCord, LPSC, 8, 478-480, 1977; 4. R.L. Huguenin, Icarus, 70, 162-188, 1987; **4)** M. Maderazzo and R.L. Huguenin, Bull. AAS, 9, 527-528, 1977; **5)** T.R. McGetchin and J.R. Smyth, Icarus 34, 512-536, 1978; **6)** J.S. Lewis, Earth & Plan. Sci. Letters, 15, 286-290, 1972; S.S. Barshay and J.S. Lewis, Ann. Rev. Astronomy & Astrophysics, 14, 81-94,1976; S.J. Weidenschilling, Aspects of Planetary Formation, PhD Dissertation, Massachusetts Institute of Technology, Cambridge, MA, 1976; **7)** T.R. McGetchin and J.R. Smyth, Icarus 34, 512-536, 1978; **8)** R.L. Huguenin and S.M. Clifford, J. Geophys. Res., 87 (B12), 10,227-10,251, 1982; S. M. Clifford, J. Geophys. Res., 98 (E6), 10,973-11,016, 1993; **9)** R.L. Huguenin, S.L. Harris, and R. Carter, Icarus, 68, 99-119, 1986; **10)** J.T. Wilson, et al., Icarus 299, 148-160, 2018