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Building Blocks on the Red Planet: The New Hunt for Martian Biosignatures in Jezero Crater

Biology * Space * DNA

The Bright Angel Outcrop and the Cheyava Falls Mudstone

More than 3.5 billion years ago, during the Noachian-Hesperian transition on Mars, a braided river network carved the Neretva Vallis inlet channel through the western rim of Jezero Crater and emptied into a standing crater lake[1]. That fluvial system transported weathered phyllosilicates, detrital silicates, and dissolved ions across an alluvial delta fan, depositing fine-grained lacustrine mudstones capable of trapping and preserving molecular traces of ancient environments[1]. As NASA's Perseverance rover ascended the northern margin of Neretva Vallis into a light-toned, stratified outcrop designated the Bright Angel formation, its micro-analytical payload encountered the most diagnostically compelling suite of candidate biosignatures yet documented on the Red Planet[2][3].

Centered on an arrowhead-shaped, ferric-oxide-bearing mudstone target christened "Cheyava Falls" -- from which Perseverance extracted its 25th sample overall (its 22nd rock core), "Sapphire Canyon," on July 21, 2024, with peer-reviewed analytical synthesis published in September 2025 -- the investigation unites three independent lines of astrobiological evidence within a single sedimentary horizon[2][3]. Specifically, the rock hosts macromolecular carbon compounds, cross-cutting aqueous calcium sulfate veins, and millimeter-scale redox reaction fronts ("leopard spots") rimmed by ferrous iron-phosphorus and iron-sulfur mineral assemblages[3][4]. Evaluating whether these coupled organo-mineral textures represent fossilized microbial metabolism or low-temperature abiotic synthesis has become the central analytical question of Mars exploration.

Multi-Instrument Spectroscopic Detection of Organics and "Leopard Spots"

To characterize the Cheyava Falls mudstone without destroying micro-scale spatial context, the Mars 2020 science team coordinated non-contact optical, vibrational, and X-ray spectroscopies across an abraded patch of the outcrop[2][3]. Using the Scanning Habitable Environments with Raman and Luminescence for Organics and Chemicals (SHERLOC) deep-ultraviolet (248.6 nm) resonance Raman and fluorescence spectrometer, researchers identified prominent G-band (~1600 cm 1) and D-band (~1350 cm 1) vibrational peaks characteristic of aromatic and aliphatic macromolecular organic carbon distributed across the fine-grained clay and silt matrix[3][4]. Unlike sporadic organic detections in igneous floor units lower in Jezero Crater, where Raman shifts were frequently confounded by cerium-bearing phosphate luminescence, the Bright Angel organic signature exhibits unambiguous carbon-ring stretching modes localized within a low-energy sedimentary facies[3][4].

Crucially, these organic detections co-occur spatially with two distinct diagenetic

textures embedded in the reddish, hematite-pigmented host rock: sub-millimeter dark-toned nodules termed "poppy seeds" and millimeter-scale, light-centered reaction halos with dark outer rings nicknamed "leopard spots"[2][3]. High-resolution micro-focus X-ray fluorescence (XRF) elemental maps acquired by the Planetary Instrument for X-ray Lithochemistry (PIXL) at 120-micrometer spot resolution demonstrated that the dark reaction rims are strongly enriched in ferrous iron and phosphorus -- stoichiometrically consistent with hydrated iron phosphate such as vivianite, Fe3(PO4)2 * 8H2O -- while the bleached cores contain iron-sulfide phases compatible with greigite (Fe3S4) or mackinawite (FeS)[3][5]. Simultaneously, SuperCam Laser-Induced Breakdown Spectroscopy (LIBS) and visible/near-infrared (VISIR) reflectance confirmed that millimeter-wide white veins of hydrated calcium sulfate (bassanite and anhydrite, CaSO4 * nH2O) transect the bedding planes, proving that low-salinity liquid water percolated through the lithified mudstone during post-depositional diagenesis[2][3].

| Instrument | | Analytical Technique | | Bright Angel / Cheyava Falls Finding | | Astrobiological Significance |

| SHERLOC | | Deep-UV (248.6 nm) Resonance Raman & Fluorescence | | Macromolecular organic carbon G-band (~1600 cm 1) peaks | | Preserved Reduced carbon compounds within low-porosity mudstone matrix |

| PIXL | | Micro-focus X-ray Fluorescence (XRF, 120 m spot) | | Fe-P (vivianite) rims & Fe-S (greigite) reaction cores | | Spatial zoning of reduced Fe2+ and S2 phases around bleached halos |

| SuperCam | | LIBS, VISIR & Time-Resolved Luminescence/Raman | | Ferric hematite matrix cut by hydrated CaSO4 veins | | Confirms sustained, circumneutral low-temperature aqueous fluid flow |

| Mastcam-Z & WATSON | | Multispectral Stereoscopic & Microscopic Imaging | | Sub-millimeter lamination, "leopard spots," and olivine-rich layers | | Resolves in-situ diagenetic reaction fronts vs. detrital grain transport |

Geochemical Mechanisms: Dissimilatory Redox Couples vs. Abiotic Catalysis

The astrobiological significance of the Cheyava Falls leopard spots stems from their striking mineralogical and morphological homology to reduction spheroids preserved in terrestrial Proterozoic and Phanerozoic continental red beds[5][6]. On Earth, such millimeter-scale bleached halos form when subsurface chemotrophic microorganisms catalyze the oxidation of refractory organic matter or molecular hydrogen while coupling that electron flux through a membrane electron transport chain to the dissimilatory reduction of ferric iron (Fe3+) and dissolved sulfate (SO42)[5][6]. In this thermodynamic sequence, governed by negative changes in Gibbs free energy (G < 0), insoluble crimson hematite (Fe2O3) is reduced to mobile ferrous iron (Fe2+), bleaching the sediment immediately surrounding an organic reaction nucleus[5][6]. As diffusing Fe2+ encounters pore-water orthophosphate (PO43) and biogenic bisulfide (HS), it precipitates concentric reaction fronts of vivianite and greigite.

Under the Confidence of Life Detection (CoLD) framework, however, establishing a

definitive biosignature requires falsifying all plausible abiotic geochemical pathways capable of producing identical mineral assemblages[7]. In purely abiotic systems, the kinetic activation energy barrier defined by the Arrhenius equation strongly inhibits thermochemical sulfate reduction (TSR) by organic carbon at habitable surface temperatures (<100 deg C); uncatalyzed TSR typically requires hydrothermal regimes exceeding 150-200 deg C[7]. Because the Bright Angel clay minerals and hydrated calcium sulfates show no petrographic evidence of high-temperature thermal metamorphism or greenschist-facies recrystallization, planetary geochemists are actively testing three non-biological hypotheses:

* Magmatic or Impact-Driven Olivine Intrusion: Immediately adjacent to the laminated Cheyava Falls mudstone lies a darker, coarse-grained unit containing millimeter-sized olivine ((Mg,Fe)2SiO4) crystals[2][3]. If those olivine grains crystallized from a localized magmatic sill or impact melt sheet -- rather than being detrital grains washed into Neretva Vallis -- transient conductive heating or serpentinization fluids could have driven abiotic iron and sulfate reduction.

* Photochemical and Radiolytic Redox Cycling: Ultraviolet irradiation of iron-bearing brines on ancient Martian mudflats, or long-term alpha/gamma radiolysis of pore water, can generate reactive intermediate sulfur species (such as sulfite and thiosulfate) that disproportionate and reduce Fe3+ at ambient temperatures without enzymatic catalysis or DNA-directed cellular machinery[7].

* Meteoritic Organic Delivery: Carbonaceous chondrite infall continuously supplies polycyclic aromatic hydrocarbons and carboxylic acids to the Martian regolith, providing an exogenous reduced-carbon reservoir capable of participating in diagenetic reactions.

The Imperative for Terrestrial Laboratory Analysis

By sealing the Sapphire Canyon core inside an ultra-clean titanium sample tube, Perseverance has secured one of the highest-priority astrobiological specimens ever collected beyond Earth[2][3]. While rover-mounted spectrometers can resolve elemental distributions at the 100-micrometer scale, they lack the mass resolution required to measure diagnostic stable isotope fractionations -- specifically 13C depletion in macromolecular carbon, 34S fractionation exceeding 20-40 in greigite cores, and clumped iron isotopes (56Fe) across vivianite rims[7]. Resolving whether the Jezero Crater mudstones preserve the metabolic footprints of an ancient Martian biosphere or a sophisticated prebiotic geochemical reactor will ultimately depend on returning the Sapphire Canyon core to terrestrial laboratories equipped with nanoscale secondary-ion mass spectrometry (NanoSIMS), synchrotron X-ray absorption near-edge structure (XANES) spectroscopy, and high-resolution transmission electron microscopy -- even as the legacy Mars Sample Return architecture was canceled in 2026 and replaced by a fresh Perseverance Sample Retrieval Architecture (PSRA) study team convening in January 2027[7][8].

Updates (Nov 15, 2026): Clarified that Sapphire Canyon is Perseverance's 25th sample overall (22nd rock core), added the peer-reviewed Bright Angel potential biosignature synthesis by Hurowitz et al. (2025) in Nature (https://doi.org/10.1038/s41586-025-09413-0), noted NASA's 2026 transition from the canceled legacy Mars Sample Return architecture to the Perseverance Sample Retrieval

Architecture (PSRA) planning team, and replaced a misattributed terrestrial red-bed citation with verified reduction-spot literature by Spinks et al. (2010) and Hofmann (1990).

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