DISTINCTIVE FEATURES OF IMPACTOCLASTIC LAYERED ROCKS ON MARS.

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Introduction: Based on orbital observations and terrestrial analogs, the cross-bedded clastic rocks on Mars studied by the initial 3 rovers were interpreted to have been deposited by flowing or standing liquid water or by wind, implying that early Mars must have been Earth-like and habitable [1]. From the beginning (owing mainly to prior field work in volcanic rocks), my co-workers and I reinterpreted the spherule-bearing cross-bedded rocks at the two MER landing sites (Meridiani Planum and Gusev Crater) and later the concretion- and clay-bearing cross-bedded rocks at Gale Crater as probably being deposited by large-scale impactoclastic density currents (IDCs) or surges, analogous to the smaller-scale pyroclastic density currents (PDCs) associated with terrestrial volcanoes and nuclear blasts [2,3]. Unlike on the Moon, these were possible during bombardment because early Mars had a relatively thick atmosphere and abundant water (possibly ice). Supporting this idea, the Martian atmosphere appears to have been both colder and much thinner than Earth's, especially after about 3.5 Ga [4]. This feature helped preserve older (Late Noachian) rocks from erosion.

Confusing interpretations somewhat, variable later diagenesis was caused both by neutral groundwater (in Gale Crater only, forming primitive clays and typical concretions [5]), and by surficial acid condensates (acid frost or mist, forming both acid and neutral sulfates near the surface [6]). Such diagenetic features can be confused with those caused by primary deposition. Similarly, polygonal joints in Gale were confused with mud cracks [7] and erosion patterns, viewed from above, were mistaken for both festoon current bedding (Meridiani) and a volcanic bomb sag (Gusev).

Observations: A problem with testing the impactoclastic hypothesis is that recognized examples of impactoclastic rocks are rare to absent on Earth, except for ancient marine layers of impact spherules, and occasional remnant basal breccias, and these are poor analogs for Mars. Mars itself appears to have had relatively rapid (in multi-million-year terms) wind erosion of finer-grained distal impact sediments, including most of those resulting from young rampart (layered ejecta) cratering. The preserved ramparts represent the coarse, dense fractions. Unlike the terrestrial continental crust, the Martian crust (including sediments) is almost entirely basaltic, and the basalt (based on meteorite samples) is much more Fe-rich than on Earth. Mars also is richer in Cl and S, implying acidic and Fe-rich impact devolatilization and condensation (as of fumarolic specularite accreting into Meridiani spherules).

Terrestrial PDC (volcanic) deposits could be considered analogous, but the related volcanic (and also nuclear base surge) blasts were less energetic and different in composition, plus their finer fractions have also been eroded over short time periods. Nevertheless, they provide useful textural analogs in terms of low-angle cross-bedding, spherical accretionary lapilli, and other features.

Note that the rover landing sites are near the boundary between the Martian highlands and lowlands, and thus are at the focus for density current flow generated by impacts anywhere in the highlands.

Discussion: So what are the diagnostic features of impactoclastic density current (IDC) deposits (blast beds), such as might be seen on Mars? The lack of known terrestrial examples means none have been recognized. By using analogous features resulting from explosive volcanism and nuclear blasts [8,9], an attempt can be made to say what they should be. We can also examine the diagnostic features of water deposits on Earth and see how those compare with Mars deposits.

My tentative results for such a comparison are summarized below in Table 1 (for general features) and Table 2 (for spheroid features). Features of the Martian sediments that suggest they were **not** deposited by liquid water include their primitive basaltic composition, their abundance of amorphous material, their variable content of acid salts, such as jarosite, their ubiquitous low-angle cross-bedding, their planar unconformities (lack of paleochannels), their friable, low-density (porous) nature [10], and their abundance of tiny spherules (including larger accretionary lapilli). Stated differently, the exposed sediments have all the characteristics that would be expected of impactoclastic deposits and none that would be diagnostic of water deposits (except for limited later aqueous diagenesis). Aeolian dune sandstones are less ambiguous, except for having been misinterpreted at Meridiani Planum. Spherules there also were misinterpreted as diagenetic concretions.

Conclusions: The sediments exposed at the three rover sites appear to have no features diagnostic of primary liquid water deposition, and abundant features suggestive of sedimentation by impactoclastic density currents. Variable aqueous diagnesis later occurred, however, as did wind deposition inside Gale Crater. Past habitability is not restricted by these inferences. Unlike Earth or the Moon, Mars would appear to be an excellent place to study the diagnostic features of ancient impactoclastic density current (IDC) deposits.

TABLE 1. WATER-DEPOSITED vs. IMPACT-DEPOSITED LAYERED SEDIMENTS (Burt)

Deposit Features:	**Liquid Water Deposits**	**Impact Deposits (Blast Beds)**
Mars climate restrictions:	Severe: Warm and wet	None: Can be cold and icy
Compositions and clays:	Evolved; depend on slope, distance, grain size; shale and mature clays should be abundant	Primitive, basaltic; smectites only after diagenesis or via impact reworking; no shale
Amorphous material:	Rare to absent (crystallizes in water)	Expected, abundant, glassy
Salts:	Neutral only, in evaporite beds	Acid sulfates persist, acid salts mixed in with basic basalt
Cross-bedding:	Rare, small-scale, usually steep; from bars and ripples in channels or near shore	Very common, extensive, usually low-angle with planar scouring of substrate
Distinct channels:	Typical at all scales, filled with coarser sediment; cut unconformities	Rare, formed by scouring by turbulent vortices (not water) or basal fragments
Friction-caused rounding of clasts:	Depends on distance from source; conglomerates usually confined to stream channels or shorelines	Depends on distance from source; gravels not restricted (e.g., to channels or shorelines)
Dewatering features and mud cracks:	Soft-sediment deformation, relatively low permeability, and diagnostic sediment-filled mud cracks typical	Typically lacking; rocks friable (weak) and porous; polygonal shrinkage cracks possible

TABLE 2. SEDIMENTARY CONCRETIONS vs. SPHERICAL ACCRETIONARY LAPILLI (Burt)

Spheroid Features:	**Diagenetic Concretions**	**Spherules (Accretionary Lapilli)**
Shape	Any; directly related to permeability (e.g., flattened along bedding planes)	Rounded spherules, unless broken in half. Other spherule types mostly smaller.
Size/Mass	Any maximum size (supported by strength of sediment, controlled by kinetics and diffusion)	Severely restricted maximum size (must be supported only by turbulent gas cloud, as are hailstones). Narrow size range at a given site.
Clumping	Clumps of any number of equant spheroids growing together, up to huge masses in fluid mixing zones; feature is diagnostic	Sticky: clumping possible but rare; if doublets, spherules typically about 1/2 size; if triplets, about 1/3 size or smaller
Mineralogy	Low T only, as cement; host rock grains are dominant component	High T gas-phase (fumarolic) minerals such as spinel and specular hematite may be common
Bedding passes through	Common; feature is diagnostic (along with flattening)	Absent; concentric growth only (possibly around an older clast)
Concentric color banding	Possible, if nature of diagenetic fluids changed during growth	Universal but visible only if make-up of turbulent cloud changed during growth

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References: [1] McLennan, S.M. et al. (2019) *AnnRevEarPlanetSci 47*, 91. [2] Knauth L.P. et al. (2005) *Nature, 438*, 1123. [3] Burt D.M. et al. (2008) *JVGR, 177*, 755. [4] Head, J.W. et al. (2020) *LPS LI,* Abstract #2967. [5] Sun, V.Z. et al. (2018) *Icarus 321*, 866. [6] Zolotov, M.Y. and Mironenko, M.V. (2007), *JGR 112,* E07006. [7] Stein N. et al., (2018) *Geology 46*, 515. [8] Wohletz (1998) *in* Freundt, A. and Rosi, A. *From Magma to Tephra*, Elsevier, Ch. 7, 247. [9] Branney, M.J. and Kokelaar, P. (2002) *GeolSocMemoir 27*. [10] Lewis, K.W. et al. (2019) *Science 363*, 535.