WHERE IMPACT-CAUSED DENSITY CURRENTS CAME TO DIE: GALE CRATER?

D. M. Burt[1] and L. P. Knauth[2], [1,2]ASU School of Earth and Space Exploration, P.O. Box 871404, Tempe, AZ 85287-1404, [1]dmburt@asu.edu; [2]Knauth@asu.edu.

Introduction: Since its successful landing in Gale Crater on August 8, 2012 (five years ago), the Curiosity Rover (Mars Science Laboratory or MSL) has, according to published reports, basically discovered what it was expected (and tasked) to find based on orbital data, and has discovered little else of real significance. That is, its images and measurements have been interpreted as evidence of a long-lived (up to tens of millions of years) past habitable environment consisting of streams emptying into a large, deep crater lake. In detail, MSL traversed what had been interpreted [1] to be the distal end of a basin-filling alluvial fan, and then a thick sequence of underlying lake beds [2]. Consistent with this prior expectation, rocks observed directly have been classified [3][4] as aeolian sandstone (if fine-grained and cross-bedded), alluvial conglomerate (if coarser grained, whether well-rounded and sorted or not), or lacustrine mudstone (if extremely fine-grained, however bedded).

Numerous features that appear inconsistent with these narrow Earth-based interpretations appear to have been ignored or discounted, as were alternative depositional processes that might seem particularly appropriate for early Mars, such as deposition by mass wasting of crater walls (e.g., long run-out debris or mud flows, possibly triggered by impacts) or direct deposition (sedimentation) by impact cratering at various scales, times, and distances. A partial exception is a short paper by Newsom et al. [5] that cautiously considers ambiguous evidence for conventional indicators of cratering related to the first Gale observations, but does not consider sedimentation by turbulent density currents (impact blast processes) [6] [7]. In this regard, [8] proposes that a similar density current process could have generated relatively young LARLE (low aspect-ratio layered ejecta) deposits related to some recent Martian craters, and [9] notes evidence for blast wind scouring more than 500 km (in one case, up to nearly 2000 km) from some fresh impact craters, but omits discussing sedimentation of what was scoured.

Problems with Existing Interpretations: The outstanding odd feature of the Gale rocks that seems to contradict the conventional depositional story is their geochemistry (and mineralogy). All Gale rocks analyzed apparently have about the same primary geochemistry, corresponding to typical Martian basalt (and alkaline differentiates) [10]. Primary compositional differences can be interpreted as resulting primarily from differential physical sorting of grains of different mineral types [10]. Mineralogical and geochemical features involving water (mainly formation of salts and clay minerals) apparently originated post-depositionally, that is, diagenetically. These post-depositional aqueous processes were, for the most part, limited in effect and extent, and were in many cases obviously controlled by fractures. Some produced apparent concretions. Pervasive post-depositional surficial alteration also appears to have occurred, possibly caused by descending acid surficial fluids [11].

In other words, the basaltic sedimentary rocks in Gale Crater appear to be a puzzling heterogeneous mineralogical mixture of various high temperature igneous minerals and low temperature aqueous-alteration minerals (primitive clays and salts, including acid salts such as jarosite). Evidence for formation of clay minerals by initial weathering, prior to erosion, transport, and deposition, such as would be typical of a habitable environment on Earth, appears to be completely lacking.

Basalts on Mars should react extremely rapidly with naturally acidic waters to form clay minerals, far more rapidly than rocks that are richer in Si and Al. On Mars the ancient atmosphere is believed to have consisted mainly of acid-generating CO_2 with variable SO_2, so that ancient Martian waters should have been even more acidic and reactive than terrestrial waters. Why were there no aqueous chemical reactions to clays until, apparently, well after sediment deposition?

A reasonable hypothesis might be that the climate was too cold, as suggested by virtually all climate modeling for Mars [12]. If so, the climate wouldn't have been habitable. In fact, the authors of [4] specifically exclude cold or periglacial climates as having contributed significantly to Gale sedimentary features (in that there are no observed traces of moraines, ice wedges, or lacustrine dropstones).

In this regard, fissile shale, made up predominantly of fine clay minerals resulting from weathering, is the expected lake or distal alluvial plain sediment on Earth. For some reason, this distinctive, extremely common terrestrial rock seems to be completely lacking in the fine-grained so-called lacustrine mudstones of Gale Crater, which, by primary mineralogy and geochemistry, could have been deposited nearly anhydrously (i.e., as dust). Shale also seems to be lacking anywhere else in Gale Crater. If so, how could it have been habitable for so long?

Multiple other problems exist. Why are virtually all the ancient sediments, whatever their presumed depositional environment, characterized by the same low-angle cross-beds? Is such cross-bedding typical of lake beds? Why did the postulated streams never produce, at any scale, diagnostic lateral and vertical sedimentary facies variations, such as exposed flow channels containing coarse gravels? (The so-called conglomerates seem to occur as layers.) Why did the putative standing lake waters that were interpreted as having dried up multiple times never leave distinctive mud cracks, ripple marks, or discrete evaporitic salt layers, not to mention paleo-shorelines?

Why is there absolutely no evidence of dewatering textures (soft-sediment deformation resulting from uneven dewatering during sediment compression) in any of the sediments that were interpreted has having been under water when deposited and as having undergone compressive dewatering afterwards? Such obvious features would be present in almost any sequence of terrestrial sediments deposited and compressed under the postulated water-saturated conditions.

Impact-Derived Density Currents as an Alternative Explanation: Is there another reasonable way to derive these distinctively low-angle cross-bedded, basaltic, heterogeneous sediments that mysteriously failed to react with water until after they were deposited? How about impact cratering? Even on the airless Moon, impacts and secondary impacts generated ground hugging debris flows that pushed outward for up to 600 km [13]. Induced seismic waves generated long-runout landslides within older craters. Impacts (blasts) on planets with a significant atmosphere, such early Mars, or significant subsurface volatiles (including ices and hydrous phases), also produce what have been called base surges (a far-travelling type of density current that resembles a desert dust storm or haboob) that can generate the extremely pervasive low-angle crossbedding observed now by all three rovers [6][7]. The full range of basaltic grain sizes, glassy tektites and glass fragments, shattered and shatter-coned rocks, metallic meteorite fragments, and a variety of melt spherules and accretionary lapilli that resemble concretions are also produced by impacts, and most have already been reported from inside Gale Crater [5]. Note that the water-rich and salt-rich nature of the Martian subsurface should favor a tendency for impacts on Mars to generate glass, because these components are natural fluxes (that is, they favor melting). Furthermore, metastable basaltic class generated by impacts should be easier to alter to clay minerals than any individual mineral or mineral assemblage.

Everything observed during the first five years in Gale Crater is consistent with known impact and other blast processes (plus wind) followed by limited amounts of surface and subsurface aqueous alteration (including highly local acid alteration and leaching, itself possibly generated by condensation of impact-generated S-rich vapors). None of the compositional and other problems mentioned above apply if impact sedimentation (with limited aeolian activity) is responsible for the sequence of beds.

Impact-derived deposition (the blast bed hypothesis [7]) can also account for numerous other features seen in these beds, even including local horizons with polygonal shrinkage cracks that superficially resemble mud cracks, and clast rounding in “conglomerates” that can be caused by simple abrasion, not river deposition. The considerable thickness of fine-grained (and commonly cross-bedded) sediments called “lake beds” can be simply explained by hypothesizing that dusty distal density currents “came to die” in Gale.

Conclusions: If the above interpretations are correct, the thick sequence of beds so far traversed in Gale Crater would an ideal place to study details of an impact-dominated stratigraphic succession virtually unhindered by the plate tectonic, weathering, and diagenetic processes that have erased or obscured such ancient sections from early Earth. The deep depression formed by Gale Crater could have acted as a natural trap for density currents generated by impacts over the latter history of Mars, although the record of the latest ones may have been scoured away. Gale Crater could even preserve a record of impact sedimentation that occurred as Mars was losing most of its atmosphere.

As noted by others [1], there may be an aeolian-dominant succession of strata higher in the stratigraphic section in Gale. If there is an aqueously-deposited (rather than altered) part of the section, it probably hasn’t yet been encountered. If do occur, aqueous deposits may underlie the section that the Curiosity Rover has been able to examine, and deep drilling might be needed to explore them.

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