BLAST BEDS AND OTHER SEDIMENTARY ROCKS DEPOSITED BY MASS MOVEMENTS IN GALE CRATER: EVIDENCE OF IMPACTS. 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: Terrestrial alluvial fan deposits typically contain a high proportion of coalescing deposits formed by mass movements (e.g., slumps, rock falls, debris flows, mud flows, and so on). This is especially true of deposits found near their sources (typically a zone of faulting) or formed in the early stages of deposition. The rest consists of a superposed, radiating pattern of short-lived, distributary small channel deposits, so that going laterally many channels are crossed and their presence should be obvious. Muds are deposited as water ceases flowing in or adjacent to a given channel.

The Curiosity Rover (Mars Science Laboratory or MSL) on Mars has for the past two Earth years (single Martian year) been traversing what is interpreted to be the surface of a distal alluvial fan near the bottom of Gale Crater on Mars, and all sedimentary rocks studied to date have been interpreted as alluvial, lacustrine, or aeolian in origin - that is, as formed by flowing or standing water and wind. In other words, they have been interpreted as Earth-analog. Curiously, evidence of Earth-analog or other mass movements seems not to have been recognized, nor have any former channels or gradations to mud been recognized.

Mass-movement deposition on Mars, in addition to that caused by Earth-analog mass wasting in areas of high elevation contrast, probably also included deposition caused by nearby (proximal) and distal impact cratering. On Mars, with its formerly thicker atmosphere and abundant subsurface volatiles (mainly as water ice), such deposits might include, in addition to the expected ballistic ejecta and glassy impact breccias, abundant more distal deposits formed by concentrated to dilute accumulations of clastic fragments in turbulent vapor [1]. By analogy with well-studied pyroclastic density currents related to volcanic blasts, such blast deposits should range from massive coarse breccias to finely cross-bedded sands greatly resembling those deposited by wind or flowing water.

Deposits of this latter type ("blast beds") appear to occur at many sites visited by the MSL in Gale Crater; they were initially seen at a small outcrop called "Shaler". They had previously been seen by the two Mars Exploration Rovers, Spirit and Opportunity, initially throughout Meridani Planum [2], where they were named the Burns Formation and ascribed (probably erroneously) to wind, flowing, and standing water, and later at an outcrop named "Home Plate" in Gusev Crater [3], where they were ascribed to a volcanic blast, despite the lack any evidence of a near-by volcano [4].

Blast Beds in Gale Crater: The outcrop informally called Shaler is only 0.7 m thick and about 20 m across, yet seven distinct depositional facies have been claimed for it as part of an alleged fluvial-lacustrine complex called Yellowknife Bay [5]. The described facies range from fluvial sinuous to channel to bar to fan lobes to intermittent drying to aeolian reworked, depending on bed erodability, grain size, the nature of cross-bedding, bedding deformation, and features possibly indicating shrinkage cracks. No actual channels are exposed, sorting appears relatively poor throughtout, and no gradations to shale beds (i.e., mud) are apparent. These features are surprising for what is described as a distal alluvial fan sequence. Except for ubiquitous Ca-sulfate in veinlets, the sandstones appear fairly uniformly basaltic in composition [6] (i.e., made up of easily altered but completely unaltered igneous minerals).

After leaving Yellowknife Bay, the MSL moved southeast more than 3.6 km to a site known as The Kimberly. It imaged shallowly cross-bedded sands ("blast beds" to us) resembling Shaler almost continously along its traverse, with similar features including poor sorting, notable pebbly beds but a lack of any exposed channels, and no gradations to shale. These light-toned beds, some of which are visible from orbit (as "striated beds") were similarly interpreted as dominantly subaqueous fluvial (where relatively coarse-grained), and subordinately aeolian (if fine-grained) [7]. That simple interpretation implies an extensive, deep river system with truly wide (if invisible) channels. Furthermore, the river system appears to have flowed uphill, gaining at least 40 m, according to southeasterly flow directions interpreted from major cross beds [8]. Note that poor sorting, uphill flow across topography, uniform scouring (lack of obvious channels), and broad lateral distribution are not problems for blast beds.

Based on superposition, these are the youngest beds in the sequence, and their relative age is therefore unconstrained. Crater counting suggests an age of 3.2-3.3 Ga for this area, called the lower Peace Vallis Fan and its former burial to less than 20-40 m [9], implying very little later exhumation (less than 0-5 m for 80% of the area) [9]. Whether more typical alluvial fan beds underlie these unusual surficial rocks is unknown

Other Mass-Movement Beds: So-called conglomerates (although many are more accurately described as breccias) are widely distributed in the rocks traversed to date. All have been interpreted to be ultimately fluvial, despite their obvious lack of sorting (most appear matrix-supported), lack of restriction to channels, and highly inconsistent degree of clast rounding. They contain multiple clast types, including porphyritic alkaline basaltic igneous rocks [10]. Some larger clasts have been interpreted as derived from an impact breccia [11]. Note that clast rounding simply implies prolonged abrasion (e.g., via long runout inside a large crater), not necessarily a liquid water medium, and could therefore happen in various types of mass movements, including density currents caused by impacts. Therefore a mass movement of some sort would seem to provide a more plausible origin.

So-called mudstones or lake beds that underlie the cross-bedded strata (e.g., at initially described at Yellowknife Bay) are poorly sorted, also basaltic in composition (like average Martian soil without salt [10]), and clay-poor (about 20%, described as probably authigenic [10]). What clay is present is described as probably saponite (a primitive trioctahedral smectite) which could also form by low temperature hydrothermal processes [12]. The highly heterogenous aspect, primitive chemical nature, massive bedding style (resembling vesicular lava in some instances) [13], and other features again suggest to us these masses are mud flows or other mass movements rather than lake beds. Some could just represent mobilization, accumulation, and slight alteration of ordinary Martian dust. Whether they might be underlain by easily recognizable lake beds is again unknown.

Obviously Impact-Related Features: Recently, Newsom et al. [14] summarized evidence that they regard as unambiguous for impact-related processes in Gale Crater. This evidence, in addition to impact craters themselves, includes abundant millimetric or smaller shiny spherules, present both in sedimentary rocks and loose surface sediment, possible impact-related breccias (that could also have a different origin), possible shatter cones, shocked rocks, and ropy-textured melt fragments, plus loose angular blocks and impact-caused disruptions to layering. Obvious fragments of metallic meteorites, including quite large ones, also occur on the surface, as they do at the other two rover landing sites. Impact-related spherules (including larger accretionary lapilli), seemingly occur at the other two rover landing sites, although they haven't been widely recognized as impact-related at the other two sites.

Summary: The heterogenous, primitive, unsorted nature of virtually all the relatively young sedimentary rocks imaged and measured by the MSL on the surface near the bottom of Gale Crater suggests that they have, to date, largely been misinterpreted as to origin. They seem to represent various types of mass movements, with at least some (i.e., the rather characteristic "blast beds") probably caused by impact cratering in the immediately surrounding regions, and others possibly caused by mass wasting involving the crater walls themselves.

The implied change in geological interpretation need not affect interpretations regarding former habitability (heterogenous wet sediments being even more likely, on an energy basis, to be habitable than homogeneous ones), nor does it imply that older fluvial or lacustrine sediments might not underlie a surface veneer of observed younger rocks deposited by 3.2 Ga of impacts and mass wasting.

References (many older ones omitted)**:** [1] Burt, D.M. et al. (2011) *2nd PCC*, Abstr. #1108. [2] Knauth L.P. et al. (2005) *Nature, 438*, 1123. [3] Burt D.M. et al. (2008) *JVGR*, *177*, 755. [4] Burt D.M. et al. (2013) *4th PCC*, Abstr #1313. [5] Edgar L.A. et al. (2014) *LPS 45*, Abstr. #1648. [6] Anderson R. et al. (2014) *Icarus* (accepted). [7] Edgar L.A. et al. (2014) *4th Int. Conf. Mars*, Abstr. #1389. [8] Lewis K.W. et al. (2014) *4th Int. Conf. Mars*, Abstr. #1485. [9] Newsom H.E. et al. (2014), *4th Int. Conf. Mars*, Abstr. #1304. [10] Wiens R.C. et al. (2014) *4th Int. Conf. Mars*, Abstr. #1170. [11] Yingst R.A. et al. (2014) *LPS 45*, Abstr. #1295. [12] Morris R.V. et al. (2014) *4th Int. Conf. Mars*, Abstr. #1370. [13] Yingst R.A. et al. (2014) *4th Int. Conf. Mars*, Abstr. #1168. [14] Newsome H.E. et al. (2014) Icarus (submitted).