IMPACT SURGE ON MARS. L.P. Knauth[1], S. Bryan[2], D.M. Burt[1], and K.H.Wohletz[3]. [1]Arizona State Univ., Box 871404, Tempe, AZ 85287-1404 (Knauth@asu.edu; dmburt@asu.edu), [2]Kingston Univ., Kingston Upon Thames, KT1 2EE, U.K. (S.Bryan@kingston.ac.uk), [3]Los Alamos National Laboratory, Los Alamos, NM 87545 (wohletz@lanl.gov).

Introduction Finely bedded strata have been observed at both MER landing sites, and layered sequences difficult to explain in terms of aqueous or eolian deposition are being imaged from orbit in numerous craters and over vast areas of the martian surface. Strata at the Opportunity site have been singularly interpreted by the MER team as *in situ* wind-reworked playa deposits [1]. A finely-layered cross-stratified deposit at the Spirit Site, "Homeplate", has been interpreted as a hydromagmatic explosion vent [2]. At both sites, highly acid ground waters have been invoked to explain the chemistry and mineralogy of bedrock phases and light-colored material stirred up by the rover wheels. While possible, these interpretations are not unique, have questionable plausibility, and rely on features and geochemical processes rarely observed in the cited terrestrial analogues. An alternative impact surge hypothesis [3] readily accounts for *all* sedimentary structures observed and points the way to a possible comprehensive understanding of the geochemistry, mineralogy, and distribution of many layered rocks on Mars.

Sedimentary layering High angle cross-bedding is the typical layering in known terrestrial eolian deposits, but flat beds and low angle crossbeds have been the *dominant* sedimentary structures observed throughout the traverse area of the Opportunity Rover. Whereas minor in eolian deposits, such bedding is widespread in known base surge deposits, suggesting that base surge rather than eolian reworking is a simpler explanation for bedding at Meridiani. Sedimentary layering in base surge deposits shows superficial similarities to that of aqueous and eolian deposits such that base surge deposits have frequently been misindentified [4].

Impact surge deposition at Meridiani has been dismissed because of possible occurrences of small-scale cross-stratification that are claimed to be uniquely formed by surface flow of water [5]. However, "festoons" are best seen in cross-section in the direction of flow where they cannot be confused with curvature arising from oblique views of low-angle cross-beds eroding out on sloping surfaces. Oblique views of dipping surfaces upon which the claims for water flow are based are thus ambiguous. In any case, the claim that cm-scale "festoons" do not occur in base surge deposits [5] is incorrect, as demonstrated by Fig. 1. Trough cross-stratification occurs in base surges at all scales.

Fig 1. Cm-scale trough cross-stratification ("festoons") in Quaternary base surge deposit of the El Rio Member [6], Tenerife, Canary Islands. Pen is 15 cm.

Low-angle cross bedding at "Home Plate" is very similar to that at Meridiani and to that commonly found in terrestrial base surges. The coarse-grained layers at the base of the section and a possible bomb sag suggest a more proximal facies than the possible surge deposits at Meridiani. Layering identical to that commonly observed in base surges has thus been encountered at both landing sites on opposite sides of the planet. Although Meridiani has been interpreted as an aqueous/eolian deposit and Home Plate as a volcanic deposit, both can be alternatively interpreted as layered impacto-clastic deposits created by impact surge. Small outcrops of coarsely stratified layers have been imaged at various points along the Spirit traverse, such as on sols 676, 695, 698, 776, 777, 778, 783, 781, 800, 802, 807, 809, 811, 819, 820, 823, 827, 831, 833, 835, 843, 844, 862, 867, 869, 872, 877, and 879. These layers may be further examples of impact surge on Mars.

Cracks observed by Opportunity near Erebus Crater have been interpreted as intermittent drying during oscillation of a water table in bedded sulfates [5]. We note that desiccation cracks frequently develop after implacement of terrestrial base surge deposits [7]. The polygonal cracks on base surge surfaces strongly resemble those formed in the interdune areas invoked as Mars analogies. The impact surge hypothesis invokes impact into megaregolith storing ices, hydrous salts, and eutectic brines [3], so desiccation after emplacement is expected. Oscillating aquifers on Mars are not required.

Spherules Hematite-rich spherules are present at both MER landing sites. Although interpreted as concretions at the Meridiani site, the spherules in outcrop are more uniform in size in a given area than those of nearly all known occurences of terrestrial concretions. Concentrations of spherules occur in rocks at both landing sites (Fig. 2) but spherules are apparently mostly dispersed when they occur in outcrops at Meridiani. They are similar in size, shape, and abundance to accretionary lapilli and cored lapilli that occur commonly, voluminously, and over vast areas in terrestrial base surge and ash-fall deposits. Regional sheets mixed with impact spherules occur in the Archean of South Africa and Australia and may be an appropriate Mars analogy with regard to size, shape, and immense areal distribution. The uniform size of accretionary lapilli results from physical sorting during growth in a surge cloud, similar to hail stones. The change in size on the traverse to Victoria crater is thus easily understood in terms of variations during physical sorting and fall-out during surge events.

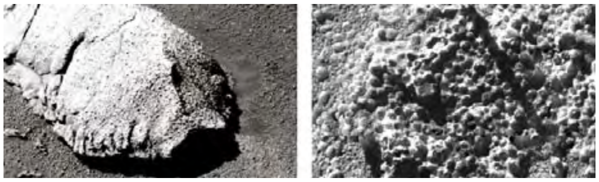

Fig. 2 Spherule concentrations observed by Opportunity (left, PanCam, sol 881) and by Spirit, (right, MI, sol 1031).

Chemistry The chemistry of impact surge deposits should be that of ejected target material plus a contribution from the impactor. Highly oxidized phases are expected because impact energies are sufficient to break even Si-O bonds [8]. The unique chemistry of Meridiani could represent impact(s) into an area unusually rich in iron sulfide deposits, as almost certainly occur on Mars [9]. In this scenario, the hematite and sulfate are largely condensation products from the impact, with hematite concentrating in the spherules as has been documented to a lesser degree in smaller terrestrial base surges [10]. Although plausible that the condensation products would be rich in iron oxides and sulfates, the process cannot presently be demonstrated. Future modeling and experimentation are needed to test this aspect of the impact surge hypothesis. However, the Ni enhancement in the spherules [11] is compatible with Ni from iron sulfide rich deposits or from an iron impactor. It is not compatible with the alternative concretion hypothesis because Ni^{+2} cannot substitute for Fe^{+3} or other incompatible sites or be preferentially adsorbed while surrounded by abundant Mg^{+2} sites in the $MgSO_4$-rich host rock. The apparent basaltic chemistry of Home Plate implies that the target rocks there were largely basaltic.

The abundant sulfate on Mars is easily understood in terms of the analogy between Mars and terrestrial mine dumps [12]. Finely comminuted grains derived from impact into abundant martian sulfide cumulates [9] are dispersed planet-wide in ballistic ejecta and surge deposits, which are themselves repeatedly impacted and scattered. Oxidation to sulfate occurs during impact volatilization and subsequent weathering in water vapor. Acid fogs, mists, aquifers, or surface pools are not required. As on mine dumps, sulfate in the regolith probably wicks up and concentrates toward the surface as efflorescences. The red color of Mars is probably due to oxidation of the associated iron, as occurs on terrestrial mine dumps [12]. The "fresh" water recharge event invoked to produce the hematite spherules at Meridiani could not have occurred as proposed [13] because fresh waters cannot physically displace a saline aquifer at low water rock ratios [14] and would have removed the highly soluble Br and Cl. Br and Cl are expected in the impact surge scenario [3] and require only small, localized films of water to account for the diagenetic features observed.

Global Mars Layered rocks of problematic origin are ubiquitous in high-resolution orbital images of Mars. Many fill craters, drape slopes, and display post-depositional topographic deflation. Previously considered only in terms of aqueous and/or wind deposition, we suggest that many may be the distal products of innumerable impact surges that deposit fine layers within older craters and over the surrounding landscape. Impact explosions can also be erosional agents that redistribute previously deposited material. In nuclear explosions, shock waves propagating along the ground surface can entrain large amounts of fine dust which eventually settles and blankets surrounding topography to distances of many crater radii [15]. Considering that impacts are the most common geologic process on Mars, their potential role in the deposition and removal of surficial layers should not be underestimated.

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