On the formation of Martian blueberries

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ABSTRACT

The Martian blueberries, first discovered by NASA's Opportunity rover, are concretions likely formed in sediments from hydrothermal solutions resulting from bolide impact into groundwater or permafrost. Evidence for this conclusion comes from the shapes of particle size distributions measured from Opportunity photos by Royer et al. (2006, 2008). These distributions, which exhibit a unique negative skew and lognormal positive skews, fit theoretical and experimental shapes determined for minerals precipitated from solution at higher and lower levels of supersaturation, respectively. The authors of these particle size measurements suggested that the blueberries were formed by aggregation or vapor condensation from a large meteoritic impact cloud. This origin is unlikely because such an event would not have created both negative and positive skews that closely fit distribution shapes expected for mineral crystallization from solution.

Keywords: Martian blueberries, crystal growth, Ostwald ripening, Mars, concretions

METHODS AND DISCUSSION

The particle size distributions (PSD) of ubiquitous, granule-sized, hematite spherules, nicknamed blueberries, discovered and photographed at Meridiani Planum by the Opportunity rover, were measured semiautomatically from Pancam images by Royer et al. (2006, 2008). These and other authors (Burt et al. 2005; Misra et al. 2014; Burt 2021) favored an origin for these spherules by aggregation, vapor condensation, or meteoritic melting from a large meteoritic impact cloud. Other investigators have suggested an origin by fluid-driven concretion formation (Chan et al. 2004; Grotzinger et al. 2005; McLennan et al. 2005), and, most recently, by the growth of mushrooms (Joseph et al. 2021). Based on the shapes of PSD data, the present contribution favors concretion formation by nucleation and growth from solutions supersaturated with respect to hematite.

Figure 1 shows a typical Pancam photo from which blueberry sizes and PSD shapes were carefully determined. Figures 2 and 3 show PSD shapes measured from near Endurance Crater rim, and from ~5 km to the south near Victoria Crater rim. The sol number indicates the number of Martian days that the rover was on Mars, and therefore approximately marks the progress of the rover's traverse around and between these craters. Rover traverse maps are available at https://mars.nasa.gov/mer/mission/traverse-maps/opportunity/, and https://en.wikipedia.org/wiki/Opportunity_(rover).

The PSDs exhibit a regular change in shape, from left-skewed west and south of Endurance Crater rim (Fig. 2, upper), to right-skewed north of Victoria Crater rim (Fig. 3), with shapes transitional between the two end-members west of Victoria Crater rim (Fig. 2, lower). The different PSD shapes indicate origins by different growth mechanisms that appear to apply to the blueberries as well as to crystals in general. PSD shapes for blueberries and for crystals are nearly identical, and therefore it is reasonable to assume that the same equations (LSW and LPE, discussed below) apply.

The left-skewed PSDs from sols 110, 188, and 202 mimic the universal steady-state PSD shape expected for Ostwald ripening in solution according to LSW theory, an equation that was derived independently by Lifshitz and Slyozov (1961) and by Wagner (1961). Experiments (Kile et al. 2000) have shown that this unique distribution shape reflects initial, very high levels of supersaturation, where abundant and extremely fine nuclei precipitate. A large contrast in specific surface areas among these particles leads to growth of the larger nuclei at the expense of dissolution of the smaller, less stable nuclei according to the Ostwald ripening mechanism. According to LSW theory, the PSD for any mineral that has undergone sufficient ripening will have the identical negatively skewed distribution when the data are plotted on reduced axes (size/mean size vs. frequency/maximum frequency), a shape

Figure 1. Pancam image of Martian blueberries (from Royer et al. 2006). The average particle diameter is 3.73 mm.