"BLUEBERRIES", "NEWBERRIES" AND ACCRETIONARY LAPILLI; LESSONS FROM THE ANTARCTIC PREBBLE FORMATION ON DIAGNOSING THE ORIGINS OF DARK LUSTROUS SPHERICAL THINGIES.

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Introduction: The spherical concretions known informally as "blueberries" discovered by the MER rover Opportunity are an omnipresent feature on the surface of Meridiani Planum on Mars [1] Most authors have interpreted "blueberries" as hematite-rich concretions from within (and weathering out of) local eolian sandstones of eolian origin. [2,3]. More recently a second type of spherule dubbed "Newberries" has been described, again encountered by the Opportunity Rover (but this time at the Kirkwood outcrop in the Cape York segment of the rim of Endeavor Crater) [4]. The "newberries" are distinct from "blueberries" in terms of concentration, composition, structure and distribution.

During recent fieldwork at Mt. Darwin in the Transantarctic Mountains we were presented with our own "Opportunity" to examine an outcrop rich in spherules. The Prebble Formation is an extrusive endmember of the Jurassic Ferrar Large Igneous Province (FLIP), extending for 3500 miles along the Transantarctic Mountains and into Australasia. Prior work has examined intrusive components of the FLIP as analogs for Martian surface lithologies based on mineralogical similarities to Martian meteorites and rover-based soil and rock compositions [5,6]. In this work we examine samples of accretionary lapilli produced during phreatic eruptions within early sequences of the FLIP for comparison to the various spherule types identified on Mars and proposed phreatomagmatic activity on early Mars.

The Prebble Formation and lapilli: The extrusive components of the FLIP include a wide variety of eruptive styles, with explosive pyroclastic magmatism dominating early sequences (formally the Prebble, Mawson and Exposure Hill formations) and quieter but voluminous flows most prominent in later phases (the Kirkpatrick Basalt) [7]. Interbedding and stratigraphic relationships between these extrusives and with the intrusive Ferrar Dolerite strongly suggest all were associated with FLIP emplacement over a fairly short interval 182 million years ago [7] Most of the pyroclastic eruptives show evidence for significant magma-water interaction during eruption. Tuffs and tuff-breccias are common as well as basal-surge and clast-supported debris flows [8]. Accretionary lapilli beds make up a large proportion of some tuffs and can be found reworked within explosive breccias.

Accretionary lapilli are considered diagnostic of phreatomagmatism, and are thought to form by accretion of pyroclastic debris within steam-rich volcanic ash clouds. Typically they are spherical or ellipsoidal and 5-10 mm in longest dimension. However, their size, shape and composition are naturally dependent on the composition of the parent magma, the amount of water involved, scale of the eruption, and the amount of reworking during and after deposition.

The lapilli examined here come from planar beds within a thick (several 100 m) sequence of lahar deposits and tuff-breccias exposed throughout the Upper Beardmore Glacier region (Fig 1). Localized fluvial and lacustrine deposits, extensive palagonitization of the tuffs and included blocks of

Figure 1, Lapilli bed within pyroclastic sequence of the Kirkpatrick Basalt, Mount Darwin, Antarctica. The sequence here dips strongly to the left with strike running directly away from the point of view. Picture courtesy Karen Hilton, US Ant. Program.

Fig 2. "Newberries" and Prebble Formation Lapilli at hand-sample and microscopic scale. Left: the "Newberries" of Kirkwood outcrop, Endeavour Crater, Meridiani Planum, Mars. Image from [4] taken by MER rover Opportunity's Microscopic Imager. Scale was not indicated. Center: Hand sample of Prebble Formation lapilli bed, showing mm-scale dark grey lapilli standing out in relief against red pyroclastic matrix. Right: Plane-polarized light thin section view of a compound lapilli from the Prebble Formation. Orange outline shows approximate surface of lapilli, approx 7 mm in

underlying sediments throughout local exposures support the picture of interactions between erupting pyroclastics and wet local crust.

In hand sample the Prebble lapilli bear a strong resemblance to the "berry"-bearing rocks observed on the surface of Mars (Fig. 2). The lapilli are dark grey with a smooth, wind-polished semi-metallic luster and stand out in relief against the soft, granular red matrix. The lapilli are highly concentrated throughout most of the, touching in many cases. In thin section the lapilli consist of a dense glassy rim with occasional variolitic pyroxene fans surrounding a more granular interior consisting primarily of quartz. They are strongly intergrown with the matrix; needles of quartz permeate the thin section inside and outside lapilli.

Comparisons to Mars: FLIP volcanics on average are basaltic andesites or andesites, with more Mg-rich and Si-poor intrusive and plutonic endmembers and more Fe-, Si- and alkaline-rich pyroclastics. This range of compositions is attributed to fractional crystallization and a small amount of crustal assimilation. The FLIP thus serves as a broad analog for Martian volcanism, including rocks similar to those seen by the MER rovers including explosive phreato-magmatic episodes [1]. Formation of lapilli is thus expected on early Mars [9].

Distinguishing lapilli from other types of spherules is problematic given the wide variety of natural mechanisms that form them (e.g. [10-16]). The Prebble lapilli serve as a good example concerning what ISN'T diagnostic. As siliceous ash and hot acidic steam agglomerate into spheres, mobilization of Si encourages quartz recrystallization in lapilli interiors. Fe excluded from growing quartz crystals diffuses outwards, concentrating in the glassy exterior layer that chills more quickly. As a result, relatively homogenous volcanic glass is turned into quartz-rich lapilli with an Fe-rich exterior, masquerading compositionally as a hematitic concretion.

Structural clues to the origin of spherules are similarly non-diagnostic. The host units for lapilli are airfall deposits whose layering can mimic eolian or fluvial bedding, while actual eolian or fluvial reworking of the pyroclastics can further complicate the picture. The structure of individual lapilli, like concretions and nodules produced by other mechanisms, may or may not show multiple concentric layers depending on their time and cycling within the volcanic column. Lapilli can be tightly sintered into their host rock when significant post-fall subsolidus recrystallization has occurred (as in the Prebble samples) or as loose deposits of "berries" where immediate cooling and reworking has occurred. The moral of the story is that interpretation of "berry"-like objects is strongly dependent on the full context of their geological setting, so caution in describing their origin is warranted.

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