

UTAH MARBLES AND MARS BLUEBERRIES: COMPARATIVE TERRESTRIAL ANALOGS FOR HEMATITE CONCRETIONS ON MARS. Marjorie A. Chan¹, Brenda Beitler¹, W. T. Parry¹, Jens Ormö² and Goro Komatsu³ ¹Department of Geology & Geophysics, University of Utah (135 S 1460 E, Salt Lake City, Utah 84112-0111, USA. machan@mines.utah.edu, bbeitler@mines.utah.edu), ²Centro de Astrobiología (INTA/CSIC), Instituto Nacional de Técnica Aeroespacial (Ctra de Torrejón a Ajalvir, km 4, 28850 Torrejón de Ardoz, Madrid, Spain), ³International Research School of Planetary Sciences, Università d'Annunzio (Viale Pindaro 42, 65127 Pescara, Italy).

Introduction: Images of *in situ* and loose accumulations of abundant, hematite-rich spherical “blueberries” from the Mars Exploration Rover ‘Opportunity’ landing site at Meridiani Planum [1] bear a striking resemblance to diagenetic iron oxide-cemented “marbles” that are common in southern Utah [2]. The Jurassic Navajo Sandstone in Utah contains a great variety of well-exposed iron oxide concretionary forms that are the result of geochemical redox fronts from groundwater mixing [2-6]. This terrestrial model of diagenetic groundwater flow for the production of iron oxide concretions has important implications for understanding analogous hematite concretions on Mars [2,3].

Although host rock compositions, iron sources, and mobilization mechanisms may differ between Utah and Mars, the process for concretion formation is analogous. The morphology, character and distribution of Navajo hematite concretions (Fig. 1) allow us to infer host-rock properties, and subsurface fluid processes necessary for similar features to develop on Mars. Fe₂O₃ comprises ~30% in whole-rock analysis in both the Utah and the Mars concretions [2,7].

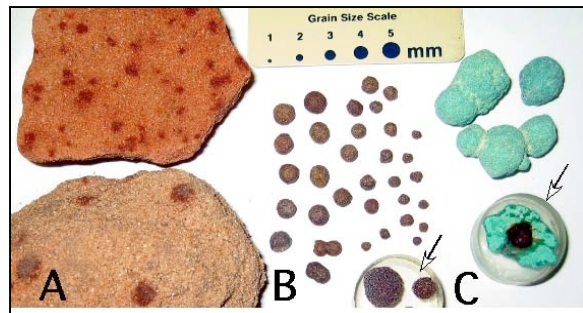


Figure 1. Spherical iron-oxide nodules in quartz arenites: A. Moderately cemented *in situ* “popcorn” concretions (Navajo Sandstone); B. Small, hard solid interior concretions with joined doublets at lower right, all from one population chemical reaction front (Navajo Sandstone) – similar in size and form to Meridiani Planum, and C. “Batter ball” concretions with green malachite-cemented exterior rind, and some interior goethite- plus hematite-cemented cores (Cretaceous Dakota Sandstone). Arrows = polished cross section plugs through middle of concretions.

Terrestrial hematite examples: Hematite (Fe₂O₃) and other iron-oxide (e.g., goethite- FeOOH)

nodules occur in a variety of geological settings and have a wide range of expressions including pedogenic, oolitic, and lakebed or seafloor nodules. Although a number of mechanisms can generate spherical shapes and iron-oxide rich nodules, the Utah concretions are consistent with more of the Mars blueberry characteristics and currently comprise a good analog for Mars blueberries for the following reasons:

- 1) Comparable and similar distribution of iron oxides (nodules and host) on an outcrop scale.
- 2) Comparable loose spherules in weathered accumulations collected in topographic lows.
- 3) Comparable *in situ* and spaced, self-organized distribution of spherules with consistent and constrained size population.
- 4) Comparable geometric forms from abundant spherules to joined forms (doublets and triplets).
- 5) Comparable iron-oxide mineralogy of hematite as well as goethite.
- 6) Comparable near-massively solid interior forms, particularly in small blueberry sizes.
- 7) Comparable associated iron-oxide joint and/or fracture fills.
- 8) Comparable variations in cementation that create less-cemented “popcorn” forms as well as embedded “batterball” forms with a hematite interior core.

Utah concretions: Concretions consist of a minor mineral component with a different chemical composition than the host rock. The minor mineral builds up a localized mass and precipitates as a pore-filling cement. Concretions commonly precipitate around a nucleus, but the Utah hematite examples do not have an identifiable macronucleus. Although numerous iron-oxide concretions occur worldwide, Navajo Sandstone examples bear a strong resemblance to the Mars concretions, and the existing studies of the Navajo diagenesis [2-6] provide a valuable framework for terrestrial comparisons. The potential role of biomediation in the precipitation of some terrestrial hematite concretions can hold important clues in the search for extraterrestrial life.

Utah model of iron mobility: Navajo sandstone color variations and zones of iron mineralization indicate a diagenetic history of groundwater flow [2-6]. Near surface, meteoric waters and processes of

weathering distribute thin disseminated iron films that impart a pink to orange-red color to the quartz sandstone early in the depositional or burial history. During burial, reducing fluids moving through the sandstone reservoir remove the thin hematite films and mobilize the iron, leaving the sandstone “bleached” white. Later, these reducing fluids carrying the iron, mix with oxidizing groundwater to precipitate concentrated hematite concretion cement. Some concretions may have originally precipitated as iron sulfide and later oxidized to goethite.

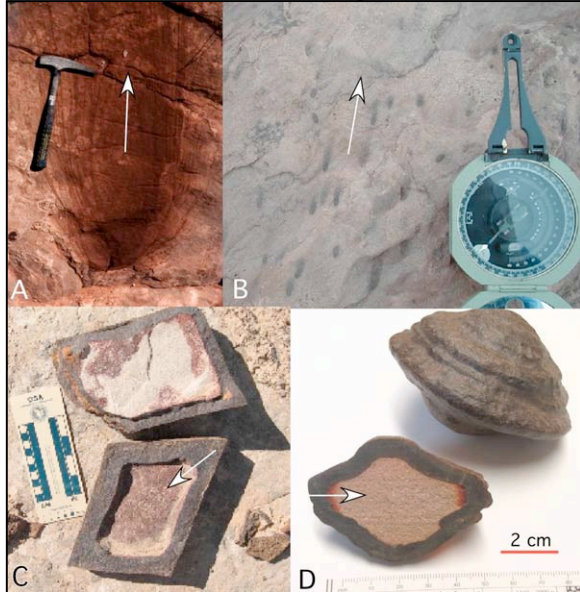


Figure 2. Flow patterns (arrows) indicated by preferential geometries in Navajo concretions: A-B. Advective flow indicated by strong unidirectional patterns; and C-D. diffusive flow indicated by inward directed patterns (left, along conjugate joints becoming less angular inward; and right, “bleeding” along more permeable laminae).

Physical relationships of concretion size and spacing reflect host-rock characteristics, fluid chemistry, Eh (oxidation potential), pH, flow paths, and growth timing. The spherical geometry is the minimum free-energy shape that forms where the host rock is relatively homogeneous and lacks strong anisotropy (e.g., joints, fracture, faults, or other concretions). Larger concretions (Fig.2) typically have an outer rind or ‘onion-skin’ layers, but small ones are typically homogeneous without any apparent rind (Fig.1B). Regular spacing and the lack of macro-nuclei suggest a self-organized distribution for the spherical concretions, at an optimal nearest-neighbor spacing in zones along reaction fronts [2]. Anisotropy of individual lamina can affect the fluid flow and create a ridge-like feature around the periphery (Fig. 2D). Concretion formation involves 1) advective flow that is necessary to supply the required amounts of reactant iron or oxidant (indicated by oriented

concretionary flow forms), and 2) diffusive fluid flow and mass transport (indicated by gradational inward growth and color change) (Fig.2).

Comparisons: There are clearly differences between Utah and Mars concretions. The hematite in the Mars spherules is reportedly pure and crystalline [1], and the iron may be mobilized by acidic conditions [3]. These acid conditions at Meridiani Planum [1] may cause differences in the characteristics (e.g., crystal size, purity, texture) of Martian hematite in contrast to the mild terrestrial solutions that are unable to affect the resistant, abundant host quartz grains. At present, it is not clear exactly how or if the adjacent sulfate minerals [1] relate to the concretions.

Concretions in the Navajo Sandstone span tens of kilometers with variable conditions, expressions, multiple waters and chemical reaction fronts, and likely more geologic time or episodes in a very porous media. These factors, in addition to an active plate tectonic regime, contribute to the diversity of Utah forms. However, within a given chemical reaction front akin to the Meridiani Planum sites, the terrestrial concretions are typically small and comprise a consistent size population for a given bed, unit, or lithologic type.

Diagenetic Implications: The presence of spherical hematite concretions implies pore volumes of moving subsurface fluids through porous rock. The abundant uniform spheres suggests groundwater flow in a homogeneous media. Based on the Utah model, we predicted other concretion geometries to be present on Mars as well [2], and we now see this borne out in the recent NASA discoveries of apparent joint/fracture fills, and “batterballs” at Meridiani Planum [1]. The different “popcorn” and “batter ball” forms (Fig.1) suggest a variable diagenetic history with perhaps two stages of cementation that produced both denser hematite cores and rougher textured, less cemented outer rinds.

Similarities of Utah marbles and Mars blueberries are striking and compelling. Terrestrial examples such as this Utah analogue, offer very useful comparative and predictive models for interpreting the fascinating history of fluid flow in the hematite region of Mars.

References: [1] Squyres, S.W. et al. (2004) *Science* 306, 1709-1714. [2] Chan et al. (2004) *Nature* 429, 731-734 [3] Ormo et al. (2004) *Icarus* 171, 295-316. [4] Chan, M.A. and Parry, W.T., (2002), *Utah Geol. Surv. Public Info. Ser.* 77, 19 p. [5] Beitler, B. et al. (2003) *Geology*, 31. [6] Chan, M.A et al. (2000) *AAPG Bull.* 84, 1281-1310. [7] Sodderblom, L.A. et al., (2004) *Science* 306, 1723-1726.