UTAH MARBLES AND MARS BLUEBERRIES: TERRESTRIAL ANALOGS FOR HEMATITE CONCRETIONS ON MARS. Marjorie A. Chan[1], Brenda Beitler[1], W. T. Parry[1], Jens Ormö[2] and Goro Komatsu[3] [1]Department 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), [2]Centro de Astrobiología (INTA/CSIC), Instituto Nacional de Técnica Aeroespacial (Ctra de Torrejón a Ajalvir, km 4, 28850 Torrejón de Ardoz, Madrid, Spain), [3]International 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" (<0.5 cm) from the Mars Exploration Rover 'Opportunity' landing site at Meridiani Planum[1,2] bear a striking resemblance to diagenetic (post-depositional), iron oxide-cemented "marbles" that are common in southern Utah. The Jurassic Navajo Sandstone in Utah contains a great variety of well-exposed iron oxide concretionary forms. We present a conceptual groundwater flow model for the production of these concretions, and suggest the implications for analogous hematite concretions on Mars. Although host rock compositions as well as iron sources and mobilization mechanisms may differ, the morphology, character and distribution of Navajo hematite concretions allow us to infer host-rock properties, and subsurface fluid processes necessary for similar features to develop on Mars.

Hematite is one of few minerals found on Mars that can be linked directly to water-related processes. The potential role of biomediation in the precipitation of some terrestrial hematite concretions can hold important clues in the search for extraterrestrial life. The study of the terrestrial analogs will increase our insight to understanding fluid flow history and the possibilities of life on Mars.

Terrestrial hematite nodules: Hematite (Fe_2O_3) 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 (Fig. 1A), oolitic (Fig. 1B), and concretionary (Fig. 1C-E). The hematite spherules at Meridiani Planum show geometries, physical spacing, and weathered accumulations most consistent with concretions[3].

Concretions consist of a minor mineral component (e.g., iron oxide) that builds up a localized mass and precipitates as a pore filling cement, sometimes around a nucleus. Concretions differ in chemical composition from the matrix of their host rocks. On the Colorado Plateau, iron-oxide concretions occur in PreCambrian through Mesozoic units. However, the Navajo Sandstone examples bear a strong resemblance to the Mars concretions, and the existing studies of the Navajo diagenesis[4,5,6] provide a valuable framework for terrestrial comparisons.

Utah model and concretions: Navajo sandstone color variations and zones of iron mineralization indicate a diagenetic history of groundwater

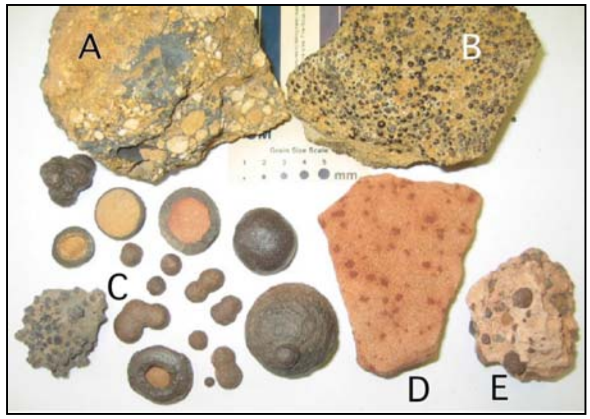

Figure 1. Iron-oxide nodules: A. Pedogenic - Miocene from Mali; B. Oolitic – Miocene from Puerto Rico; C. Concretionary (well-developed) of spherical and bulbous shapes (some show cross sections and shell/rinds) - Jurassic from Utah; D. Concretionary (moderately-developed, and more homogeneous lacking shell/rinds)- Jurassic from Arizona; and E. Concretionary (reworked Jurassic nodules enveloped in a later/modern caliche) – from Utah.

flow[3,4,5,6]. Near surface, meteoric waters and processes of weathering commonly 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 and remove the thin hematite films and mobilize the iron, leaving the sandstone "bleached" white. When these reducing fluids carrying the iron mix with oxidizing groundwater, concentrated hematite precipitates as a concretionary cement.

Field observations of numerous Navajo Sandstone concretion sites indicate abundant spherical forms, and different population sizes (mm to cm) (Figs.1-3). Many different shapes such as bulbous nodules, pipes, sheets, and banding are also common[3]. The spherical geometry is the minimum free-energy shape that forms in where the host rock is relatively homogeneous and lacks strong anisotropy[7] (e.g., joints, fracture, faults, or other concretions). Concretion growth appears to be concentric, and typical concretions display an outer cementation rind (Fig. 1) that may range from a thin 'egg shell' (< few mms), to a thicker rind (> few mms), to a series of nearly coalescing 'onion-skin' layers. Some concretions appear homogeneous or solid without any apparent rind (Fig. 1D). Fe_2O_3 comprises up to ~35% in whole-rock analysis and x-ray diffraction analyses indicate hematite and/or other metastable iron oxides (e.g., goethite) are the mineral cement.

Physical relationships of concretion size and spacing reflect host-rock characteristics as well as fluid chemistry, Eh (oxidation potential), pH, flow paths, and timing[3]. Regular spacing and the lack of macro-nuclei suggest a self-organized distribution for

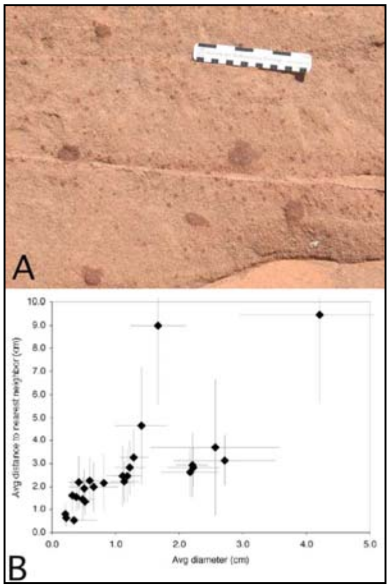

Figure 2. Different size populations of iron-oxide concretions with smaller sizes at closer spacing than larger sizes. A. Two size populations, Jurassic Navajo Sandstone, near Highway 89 and the Utah-Arizona border. Scale=15 cm) B. Different measured "marble" size and spacing populations from southern Utah areas (N=545).

the spherical concretions, at an optimal nearest-neighbor spacing in zones along reaction fronts[7]. Small spherical concretion populations (mm-size) are typically more closely spaced, and larger concretion populations (cm-size) are more widely spaced (Fig 2). The concretion size, shape and spacing may also vary depending on the amount of fluids available and the growth time. Anisotropy of individual lamina can affect the fluid flow, and thus the spherical concretions may have a ridge-like feature around the periphery (Fig. 3D). There are likely a combination of processes at work in forming the concretions that range from advective flow (indicated by oriented concretionary flow forms) as well as diffusive flow (e.g., gradational inward change) (Fig. 3).

The conditions for formation of Utah concretions is interpreted to be diagenetic (<100 °C) based on Navajo Sandstone burial estimates[3] and lack of other high-temperature mineral assemblages. However, more work is needed to fully understand the role of temperature regimes in the terrestrial example.

Comparisons: The Utah analogue is similar to the Mars concretions in: iron-rich fluids and oxidizing groundwater for precipitation of hematite mineralogy, *in situ* and accumulated distributions,

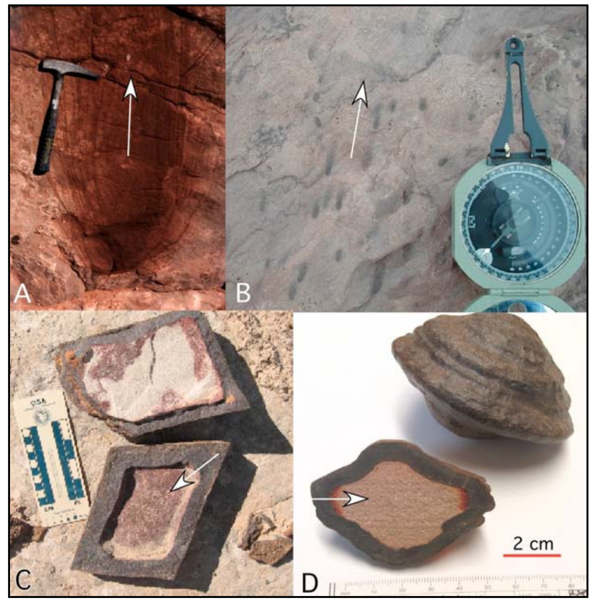

Figure 3. Flow patterns (arrows) indicated by preferential geometries in Navajo concretions: A-B. Advective flow indicated by strong unidirectional patterns; and C-D. diffusive flow indicated by inward directed patterns (left, along conjugate joints becoming more less angular inward; and right, "bleeding" along more permeable laminae).

and the small spherule geometry. There are clearly differences between Utah and Mars concretions. The hematite in the Mars spherules is reportedly pure and crystalline[2], and the iron mobilization may utilize acidic conditions (vs. reducing mechanisms in the Utah case). Concretions in the Navajo Sandstone span tens of kilometers with variable conditions, expressions, and chemical reaction fronts, which all contribute to the diversity of forms. However, within a limited or local area akin to the 22-m diameter scale of the Meridiani Planum Eagle crater[1,2], the spheres are typically a consistent size population for a given bed, unit, or lithologic type. Based on the Utah model, we expect other geometries of hematite concretions to be present on Mars as well.

The presence of spherical hematite concretions implies significant pore volumes of moving subsurface fluids through porous rock. Terrestrial examples such as this Utah analogue, offer useful comparative models for interpreting the fascinating history of fluid flow in the hematite region of Mars.

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