EVALUATION OF CONCRETION FORMATION MODELS AGAINST NEW EVIDENCE AND IMPLICATIONS FOR HABITABILITY OF MARTIAN ENVIRONMENTS. S. L. Potter-McIntyre, Southern Illinois University, School of Earth Systems and Sustainability, Parkinson Lab Mailcode 4324, Carbondale, IL 62901, pottermcintyre@siu.edu

Introduction: Concretions have been observed by the rover Opportunity, and by the rover, Curiosity, throughout the long history of sedimentary geology research on Mars [e.g., 1, 2]. These diagenetic features record the history of fluid/rock interactions in the subsurface, and therefore also record the history of habitability and potentially interaction with biota. Although concretions form in many different sedimentary substrates, from many different mineralogies, and in many different morphologies, this paper will focus on spheroidal iron (oxyhydr)oxide concretions, as those are the most common type observed in the sedimentary strata on Mars to date.

Concretion Formation Models: Three primary models have been proposed for formation of iron (oxyhydr)oxide concretions—predominately the Navajo Sandstone in Spencer Flat, southern Utah, USA—but these models should be applicable to any formations that host these common diagenetic features, which would give them value as analogs for martian concretion formation.

Model #1 [3]: This model is tripartite. The first step is the early diagenetic breakdown of ferromagnesian minerals resulting in hematite grain coatings. Then, dissolution of hematite grain coatings occurs when a reducing fluid infiltrates the reservoir. Iron is mobilized as Fe^{2+}, and is later precipitated as Fe^{3+} when the reducing fluid meets and mixes with an infiltrating oxidizing fluid. This model proposes a burial diagenetic origin for the concretions.

Model #2 [4]: This model proposes a late-stage diagenetic origin (<5Ma) as a CO_2 fluid flowed down a hydraulic gradient during uplift of the region. This advecting fluid precipitated spheroidal siderite concretions with solid interiors. Subsequently, microbes oxidized the iron from the interiors of the concretions outward, dissolving the concretions that are then reprecipitated as iron oxide in rinds around the center.

Model #3 [5]: This model takes into account the long history of burial diagenesis recorded in the Navajo Sandstone and states that concretions were originally precipitated as calcium carbonate. These carbonate concretions were then transformed to hematite by an iron-bearing acidic fluid. The fluid was acidic because of CO_2 content.

New Evidence and Application of Models to Other Examples: Directly west of the San Rafael Swell on the Colorado Plateau in the western U.S., the Jurassic Entrada Sandstone is intruded by a ~2 km long mafic dike. The dike is Miocene; however, the area is also crosscut by Laramide (~50Ma) clusters of deformation bands that are up 500 m long and up to ~3 m wide. The mafic intrusions infused the area with fluids that bleached the red sandstone surrounding the dike. On one side of the dike, the bleached area terminates at an adjacent deformation band set ~475 m south of the dike. Field observations suggest that the dike acted as a baffle preventing fluids from migrating further into the sandstone. Spheroidal calcite and iron (oxyhydr)oxide concretions are present in the bleached host rock, although calcite concretions (1-3 cm diameter) are present throughout the area on both sides of the deformation bands and in both red and white host rock. Iron (oxyhydr)oxide concretions (1-5 cm diameter) are limited to the uppermost bleached section between the dike and the deformation band set. Some iron concretions have solid interiors, and some have well-cemented rinds with interiors depleted of cement. Additionally, some iron concretions are nucleated on individual deformation bands that are ~2 mm wide and iron (oxyhydr)oxide cemented joint faces are also present. Thermochemical modeling shows the infiltrating Miocene fluids were CO_2-bearing, but near neutral pH.

Evaluation of the Models: Although all of these models have parts that could work and may be possible, only the first model fits the new evidence and is discussed in the final section.

Model #2 is possible for the Spencer Flat study area, as there is a modern CO_2 reservoir in the Navajo Sandstone upgradient from the Colorado River, so it is possible that a CO_2-bearing fluid flowed down gradient from this reservoir through to the Colorado River during downcutting (as suggested by [6]). However, many reasons demonstrate the unfeasibility of this model. 1. The fluid that emanates from this reservoir in springs downgradient from the study area for [4] contains hydrocarbons, and this evidence actually supports Model #1. 2. Abundant evidence shows that these concretions were precipitated prior to the downcutting of the Colorado River during burial diagenesis [7]. 3. Pseudomorphs or remnant siderite minerals would be present either in the concretions or in the host rock and none to very few are observed. 4. Advecting fluids precipitate elongate, not spheroidal concretions [8]

Model #3 is a recently proposed model for Spencer Flat concretions; however, similar to Model #2, it is expected that there would be other acidic minerals present, such as jarosite or at least kaolinite, and although some kaolinite is present, the main clay mineral is illite [9]. Additionally, this model would produce hematite; however, multiple iron phases are present sch as goethite, ferrihydrite, lepidocrocite, and manganese oxide [9].

This model, however, fails to explain the Entrada Sandstone occurrence because both calcite and iron (oxyhdr)oxide concretions co-occur in the same host rock. Additionally, no partially transformed concretions are observed, as would be expected if this was a ubiquitous process.

Conclusions and Application to Mars: Model #1 can explain the Entrada Sandstone example. The host rock is originally red, and the fluid infiltrates the when the dike is intruded, mobilizing the iron into solution. However, the restricted location of the iron (oxyhydr)oxide concretions and relation to the calcite concretions suggest that stagnation of fluid is needed for spheroidal iron oxyhydroxide concretion formation. Calcite concretion nucleation and growth may be quicker resulting in more widespread occurrences, and/or may have preceded the Miocene fluids that infiltrated the unit.

This has implications for habitability as it has been demonstrated that biomass increases by two orders of magnitude at redox boundaries [10]. Therefore, when spheroidal iron oxide concretions are present, it suggests a stagnant to near-stagnant water table with active redox reactions taking place, providing an excellent habitat for life to exploit.

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