

direction of jarosite and melanterite stability [17], thus creating a potential mechanism for abruptly shutting down the concretion-forming process. Formation of concretions by such reactions is very likely to be a major porosity-forming process. The molar volumes of jarosite and melanterite are approximately seven times that of goethite and five times that of hematite. Accordingly, depending on the exact reaction and assuming sulfate ion remains in solution, between approximately 2 and 10 cm³ of porosity is produced for every cm³ of goethite/hematite that is formed.

The time it takes for concretions to grow has been studied in some detail [55–58]. For the example where hematite (or a hematite precursor such as goethite) forms by breakdown of jarosite with no additional introduced material [17] the concretions would likely grow by transport-controlled replacement/precipitation [56,58]. The rate of growth would depend on concretion size, molar volume of dissolving and precipitating minerals, concentration gradients of solute in precipitating fluid around growing concretions, volume fraction of the sediment in which the concretion forms and molecular diffusion coefficients. For 4 mm concretions of goethite or hematite, that form at the expense of jarosite in a sediment with 20% porosity, ~3 ppm Fe concentration gradients (consistent with modeling of Tosca et al. [17]) and molecular diffusion rates of 10⁻⁵ cm/s, timescales of significantly less than 10³ martian years are calculated, indicating very rapid formation.

In summary, diagenetic hematitic concretions embedded within the outcrops appear to have formed very rapidly under near isotropic fluid flow conditions (stagnant to very slow fluid movement). Formation of hematite by breakdown of jarosite during basin recharge by relatively dilute groundwater [17] or oxidation of ferrous sulfates, such as melanterite, are plausible mechanisms for their formation. There is no need to call on the introduction of any exotic fluid composition or any mineral that is not inferred for this geochemical system [17,25].

5.3. Secondary Porosity

Throughout much of the outcrops, void spaces of various sizes and shapes were observed. These voids typically are significantly larger than the size of framework sand grains and accordingly are interpreted to represent secondary porosity related to dissolution processes. The pores can be divided into two basic types:

1. Crystal-shaped molds. These features are equivalent to the “vugs” described in Squyres et al. [1]. For this

work, the porosity nomenclature of Choquette and Pray [59] is applied and the term “vug” is restricted to non-fabric selective features.

2. Elongate to sheet-like vugs. The length to width ratios of these pores are variable but in places are greater than 10, which would indicate that this pore type grades into “channel pores” [59].

Scattered throughout the outcrops are domains containing millimeter scale crystal-shaped pores (Fig. 11). The pores typically are on the order of 0.5–1.5 mm wide and 2–8 mm long and, where present, constitute as much as 5% of the outcrop by area (Fig. 11a). Length/width ratios vary by about a factor of 3–4 (Fig. 11a,b). In many places they are lozenge or tabular shaped with sharp well-defined straight edges. In others, the edges appear corroded and the pore enlarged. In places the pores appear to preferentially align at high angles to bedding but in other places there is no clear preferred orientation. Accordingly, the pores are interpreted to represent molds of an earlier formed mineral (see below). Although no independent constraints are available on the mineral, the shapes of the pores suggest a monoclinic crystal habit. There is no evidence that the original crystal mold-filling mineral, which is significantly larger and less spherical and rounded than typical grains, significantly disrupts primary laminations.

In many places, these pores are filled with fine-grained dark material, likely fine basaltic sand. There is no textural evidence to suggest that this sandy material is derived from the outcrop itself and so it is likely that this fine-grained debris results from relatively recent accumulation by aeolian processes.

On Earth, the timing of randomly oriented euhedral evaporitic mineral growth (i.e., syndepositional vs. post-depositional) is generally considered to be ambiguous. However, for the sedimentary environments that have been proposed for these rocks (dune–sand sheet–interdune), very early diagenetic, syndepositional formation of evaporitic minerals is a common phenomenon [32,44,60–62]. Accordingly, we interpret the original crystal mold-filling mineral to be an early diagenetic mineral that formed within the sediment shortly after deposition by evaporation of pore-filling brines derived from the underlying water table or capillary fringe.

We further interpret the pores themselves to represent secondary moldic porosity [59] rather than a surficial feature caused by relatively recent wind or chemical abrasion. In places, the size of pores increases rather than decreases with depth on surfaces that have