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Highlights and Breakthroughs:

Alunite on Mars

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Abstract: Identification of minerals on the surface of Mars is critical to understanding the geological history of our neighbor planet. In this issue of *American Mineralogist*, Ehlmann et al. report their discovery of alunite ($KAl_3(SO_4)_2(OH)_6$) in Cross Crater on Mars. Because terrestrial alunite forms from Al-rich acid sulfate waters, these results strongly suggest the past presence of Al-rich acid saline martian waters. **Keywords:** alunite, Mars, acid, brines, CRISM.

The idea of past water on Mars has intrigued humans for several centuries, since martian canals were first spied through early telescopes. But only in the past few decades has more diagnostic evidence of martian waters been documented (e.g., Carr, 1996). Currently, planetary scientists are gathering sedimentological and mineralogical data to trace types of waters (surface waters versus groundwaters) as well as water composition. Ehlmann et al. (2016), featured in this issue, document their discovery of alunite ($KAl_3(SO_4)_2(OH)_6$), contributing significant evidence that Mars once hosted Al-rich acid sulfate waters.

A case has been building for past, and perhaps even modern, acid solutions on Mars. Clark (1979, 1999) used martian surface conditions, as well as sediment and atmospheric composition, to hypothesize that a sulfuric acid solution would be the most likely stable liquid on the martian surface. Some of the first remotely sensed spectral features from Mars were attributed to acid sulfate minerals jarosite ($KFe^{3+}_3(OH)_6(SO_4)_2$) and schwertmannite ($Fe_8O_8(OH)_6SO_4$; Burns, 1987, 1994). Physical sedimentology experiments showed that sulfuric acid solutions make channels and fans morphologically similar to those on Mars (Benison et al., 2008). Abundant recent studies have demonstrated the likelihood of acid saline waters on Mars through: (1) detailed observations of martian surface mineralogy and sedimentology from rovers, landers, and satellites (e.g., Farrand et al., 2009; Sqyures et al., 2004); (2) laboratory experiments involving mineral precipitation, alteration, and dissolution by acid waters (e.g., Bishop and Murad, 2005; Miller et al., 2016); and (3) field and laboratory analyses of potential terrestrial analogs (e.g., Amils et al., 2007; Benison and Bowen, 2006; Bishop and Murad, 2005).

Ehlmann et al. (2016) analyzed images and visible/shortwave infrared spectra of Cross Crater in the Terra Sirenum region of Mars. Spectral data were obtained by CRISM (Compact Reconnaissance Imaging Spectrometer for Mars) on the Mars Reconnaissance Orbiter. Mineralogical results were placed in a topographic and stratigraphic context. Their study discovered a large (10 km x 5 km) sedimentary deposit of alunite, as well as mixed layered alunite and kaolinite ($Al_2Si_2O_5(OH)_4$) deposits (Ehlmann et al., 2016). Alunite-rich and mixed alunite-kaolinite units have been identified over a wide elevation range along the inner crater walls and floor, suggesting that alunite-bearing strata are hundreds of meters thick. The alunite and kaolinite are spatially restricted within Cross

Crater; strata outside of the crater contain a different mineral assemblage with no Al-sulfates or Al-phyllosilicates.

Alunite is commonly known as a hydrothermal mineral (e.g., Scott, 1990) or as a weathering product of sulfides (e.g., Amils et al., 2007). However, it also has been documented as a syndepositional mineral precipitated from shallow, Al-rich acid saline groundwaters associated with ephemeral acid saline lakes in Chile, Western Australia, and southeastern Australia (Benison and Gonzalez, 2007; Bowen et al., 2012; Benison et al., 2007; Long et al., 1992). In Chile and Australia, alunite typically forms alongside kaolinite. The spatial characteristics of the alunite documented by Ehlmann et al. (2016), as well as association with kaolinite, strongly suggests that alunite on Mars was formed by long-lived lake waters and/or associated shallow groundwaters.

Alunite is rare on Earth because acid waters rich in Al are needed for its formation. The pH of alunite-producing brines ranges from ~ 2 to ~ 4 (e.g., Benison et al., 2007; Miller et al., 2016). Although acid, sulfurous waters have been documented elsewhere on Mars previously by identification of jarosite (e.g., Klingelhofer et al., 2004), those were Fe-rich acid brines. This study by Ehlmann et al. (2016) is the first to confirm that the past presence of Al-rich, sulfurous acid brines on Mars.

Ehlmann et al.'s discovery of alunite on Mars is a significant contribution to the "follow the water" objective of the planetary geology community. The diverse mineral assemblages in sedimentary strata in different geographic regions on Mars tells us that Mars has had a rich aqueous history that involved

surface waters and groundwaters of various water compositions. Mars' hydrologic and mineral history is different from, but as complex as, that of Earth.

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