American Mineralogist, Volume 101, pages 1499–1500, 2016

HIGHLIGHTS AND BREAKTHROUGHS

Alunite on Mars

KATHLEEN C. BENISON[1,*]

[1]Department of Geology and Geography, West Virginia University, Morgantown, West Virginia 26506, U.S.A.

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 vs. 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 × 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 compositions. Mars' hydrologic and mineral history is different from, but as complex as, that of Earth.

REFERENCES CITED

Amils, R., Gonzalez-Toril, E., Fernandez-Remolar, D., Gomez, F., Aquilera, A., Rodriguez, N., Malki, M., Garcia-Moyano, A., Fairen, A.G., de la Fuente, V., and Sanz, J.L. (2007) Extreme environments as Mars terrestrial analogs: the Rio Tinto case. Planetary and Space Science, 55, 370–381.

Benison, K.C., and Bowen, K.C. (2006) Acid saline lake systems give clues about past environments and the search for life on Mars. Icarus, 183, 225–229.

Benison, K.C., and Gonzalez, M.M. (2007) Sedimentology of two acid saline lakes in the high Andes of northern Chile. Abstracts with Programs, Geological Society of America Annual Meeting, Denver, Colorado, 39, 433.

Benison, K.C., Bowen, B.B., Oboh-Ikuenobe, F.E, Jagniecki, E.A., LaClair, D.A., Story, S.L., Mormile, M.R., and Hong, B.Y. (2007) Sedimentology of acid saline lakes in southern Western Australia: Newly described processes and products of an extreme environment. Journal of Sedimentary Research, 77, 366–388.

* E-mail: kcbenison@mail.wvu.edu

0003-004X/16/0007–1499$05.00/DOI: http://dx.doi.org/10.2138/am-2016-5802

Benison, K.C., LaClair, D., and Walker, J. (2008) Physical sedimentology experiments with sulfuric acid solutions: Implications for Mars? Earth and Planetary Science Letters, 270, 330–337.
Bishop, J.L., and Murad, E. (2005) The visible and infrared spectral properties of jarosite and alunite. American Mineralogist, 90, 1100–1107.
Bowen, B.B, Benison, K.C., and Story, S. (2012) Early diagenesis by modern acid brines in Western Australia and implications for the history of sedimentary modification on Mars. In J. Grotzinger and R. Milliken, Eds., SEPM Special Publication 102. Sedimentary Geology of Mars, 229–252.
Burns, R.G. (1987) Gossans on Mars: spectral features attributed to jarosite: Lunar and Planetary Science Conference XVIII, Houston, Texas, 141–142.
——— (1994) Schwertmannite on Mars: deposition of this ferric oxyhydroxysulfate mineral in acid saline meltwaters: Lunar and Planetary Science Conference XXV, Houston, Texas, 203–204.
Carr, M.H. (1996) Water on Mars, 229 p. Oxford University Press, New York.
Clark, B.C. (1979) Chemical and physical microenvironments at the Viking landing sites. Journal of Molecular Evolution, 14, 13–31.
——— (1999) On the non-observability of carbonates on Mars. Fifth Conference on Mars, Pasadena, California, 6214.
Ehlmann, B.L., Swayze, G.A., Milliken, R.E., Wray, J.J., Mustard, J.F., Breit, G.N., Clark, R.N., Gondet, B., Poulet, F., Carter, J., and others. (2016) Discovery of alunite in Cross Crater, Terra Sirenum, Mars: Evidence for precipitation from acidic, sulfurous groundwaters on the margin of a paleolake. American Mineralogist, 101, 1527–1542.
Farrand, W.H., Glotch, T.D., Rice, J.W. Jr., Hurowitz, J.A., and Swayze, G.A. (2009) Discovery of jarosite within the Mawrth Hills region of Mars: Implications for the geologic history of the region. Icarus, 204, 478–488.
Klingelhofer, G., Morris, R.V., Bernhardt, B., Schröder, C., Rodionov, D.S., de Souza, P.A. Jr., Yen, A., Gellert, R, Evlanov, E.N., Zubkov, B., and others. (2004) Jarosite and hematite at Meridiani Planum from Opportunity's Mossbauer Spectrometer. Sciecne, 306, 1740–1745.
Long, D.T., Fegan, N.E., McKee, J.D., Lyons, W.B., Hines, M.E., and Macumber, P.G. (1992) Formation of alunite, jarosite and hydrous iron oxides in a hypersaline system: Lake Tyrrell, Victoria, Australia. Chemical Geology, 96, 183–202.
Miller, J.L., Elwood Madden, A.S., Phillips-Lander, C.M., Pritchett, B.N., and Elwood Madden, M.E. (2016) Alunite dissolution rates: Dissolution mechanisms and implications for Mars. Geochimica et Cosmochimica Acta, 172, 93–106.
Scott, K.M. (1990) Origin of alunite- and jarosite-group minerals in the Mt. Leyshon epithermal gold deposit, northeast Queensland, Australia. American Mineralogist, 75, 1176–1181.
Sqyures, S.W., Grotzinger, J.P., Arvidson, R.E., Bell, J.F. III, Calvin, W., Christensen, P.R., Clark, B.C., Crisp, J.A., Farrand, W.H., Herkenhoff, K.E., and others. (2004) In situ evidence for an ancient aqueous environment at Meridiani Planum, Mars. Science, 306, 1709–1714.

Manuscript received April 9, 2016
Manuscript accepted April 21, 2016
Manuscript handled by Keith Putirka