Highlights and Breakthroughs *based on Farrand et al.: VNIR Multispectral Observations of Aqueous Alteration Materials by the Pancams on the Spirit and Opportunity Mars Exploration Rovers*

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Abstract

Earth-based and Earth-orbiting telescopic observations, and Mars orbital and landed missions all contribute to our understanding of how the planet has been shaped by water. Recent results from Mars missions indicate an ever more complex history of water-surface interactions. Landed missions provide detailed views of diverse types of aqueous alteration at various places on Mars. Integration of data from different instruments and novel data acquisition and analysis techniques are extending our understanding of the geological history of the Martian surface, indicating that aqueous processes are more diverse in space and time than initially expected.

Keywords: Mars, weathering, hydrous minerals, phyllosilicates, sulfates, optical spectroscopy

Introduction

Water and/or hydroxyl (OH)-bearing minerals are valuable petrologic indicators of past conditions on Mars. In addition to indicating the presence of some form of water on Mars in the past, many of them form only under restricted conditions. Similarly, a number of them are unstable or metastable under current Mars surface conditions. Thus, identifying specific types of water-bearing minerals that are present on Mars can provide insights into past conditions.

While phyllosilicates were the first water-bearing minerals inferred to be present on Mars from analysis of Earth-based telescopic spectra (McCord et al. 1982), it took recent spacecraft missions to enable mapping the global distribution and determining the types of specific species that are present on the surface and their geological context.

Even at coarse spatial scales of a few km, a number of regions on Mars whose surfaces were spectrally dominated by water-bearing minerals were identified by their spectral reflectance signatures (Observatoire pour la Minéralogie, l'Eau, les Glaces, et l'Activité (OMEGA) aboard the European Space Agency Mars Express mission – Bibring et al. (2005)), and it was found that two mineral groups were dominant – sulfates and phyllosilicates. Subsequent higher spatial resolution spectroscopic observations made by the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) instrument aboard the Mars Reconnaissance Orbiter found a wider array of outcrops and greater variety of phyllosilicates (e.g., Viviano-Beck et al. 2014).

Our interest in water-bearing minerals, and in particular phyllosilicates, stems from the kinds of information they can provide concerning Mars history and evolution: (1) the requirement of a source of water to enable their formation; (2) most phyllosilicate outcrops are associated with ancient, Noachian age (4.1-3.7 Gya), consistent with models of ancient Mars that postulate more Earth-like surface conditions in the past, and with ages roughly equal to those associated with the evolution of life on the Earth (Altermann and Kazmierczak 2003). This era has been termed the phyllocian and appears to be more conducive to life than later eras where more acidic conditions prevailed (theiikian), and even later, when slow oxidation conditions prevailed (termed the siderikian – Bibring et al. 2006); (3) The possibility that clays can provide templates for the self-organization of complex organic molecules that are precursors to life (Ferris 2005); (4) The likelihood that phyllosilicate-dominated terrains may preserve evidence of early life on Mars (Ehlmann et al., 2008).

The paper by Farrand et al. (2016) is a first detailed ground-level look at the variety of aqueous alteration materials present at the two sites on Mars visited by the Spirit and Opportunity Mars Exploration Rovers; Meridiani Planum and Gusev crater, both of which were selected as landing sites largely on the basis of geomorphological evidence of the presence of surficial water at some time in the past.

Farrand et al. (2016) based their identification of diverse materials subjected to a variety of aqueous processes largely on multispectral observations made by the rovers' Pancam instruments, supplemented by data from the rovers' other instruments, and orbital observations. They found that the data acquired along the rovers' traverses are consistent with a number of minerals: hematite, gypsum, manganese oxides, hydrated Mg-sulfates, Fe-smectites, Al-smectites, hydrated silica, ferric sulfates, and possibly free water contained in voids or absorbed into the silica. This study demonstrates how even "coarse" spectral resolution observations can be used to identify or at least severely constrain the nature of aqueously altered materials on Mars. Farrand et al. (2016) extended their spectral analysis results to the logical next step – placing the detections of various minerals associated with aqueous processes within a petrogenetic/diagenetic context.

In a similar vein, integration of data from the various instruments aboard the Mars Science Laboratory Curiosity rover enables a more detailed analysis and interpretation of how different terrains in Gale Crater may have formed (e.g., Grotzinger et al. 2015). Mars researchers are also finding new and novel ways to utilize instruments and interpret data from the rover's various instruments to gain new insights into Mars surface geology, such as constraining exhumation ages of sedimentary layers (Farley et al. 2014) and determining the mineralogy of distal targets (Johnson et al., 2015). Laboratory experiments are also providing information on the stability of water-bearing minerals (Cloutis et al., 2007, 2008), and how exposure of such materials could lead to measurable changes in their spectral reflectance properties (Figure 1). Such experiments could be applied to constraining the nature of materials that may be exposed by surface operations.

Such innovative data analysis techniques and data integration are enabling us to gain an ever more nuanced and informative picture of aqueous alteration processes that have operated on Mars, and the planet's astrobiological potential (and which may continue to be operating – Ojha et al. 2015). New and existing data from current missions and data from future missions (such as the ExoMars and NASA Mars 2020 rovers) will continue to clarify and refine our understanding of the role of water on Mars.

References cited

Altermann, W., and Kazmierczak, J. (2003) Archean microfossils: a reappraisal of early life on Earth. Research in Microbiology, 154, 611-617.

Bibring, J.-P., Langevin, Y., Gendrin, A., Gondet, B., Poulet, F., Berthé, M., Soufflot, A., Arvidson, R., Mangold, N., Mustard, J., Drossart, P., and the OMEGA Team (2005) Science, 307, 1576-1581.

Bibring, J.-P., Langevin, Y., Mustard, J.F., Poulet, F., Arvidson, R., Gendrin, A., Gondet, B., Mangold, N. Pinet, P., Forget, F., and the OMEGA team (2006) Global mineralogical and aqueous Mars history derived from OMEGA/Mars Express data. Science, 312, 400-404.

Cloutis, E.A., Craig, M.A., Mustard, J.F., Kruzelecky, R.V., Jamroz, W.R., Scott, A., Bish, D.L., Poulet, F., Bibring, J.-P., and King, P.L. (2007) Stability of hydrated minerals on Mars. Geophysical Research Letters, 34, L20202; doi:10.1029/2007GL031267.

Cloutis, E.A., Craig, M.A., Kruzelecky, R.V., Jamroz, W.R., Scott, A., Hawthorne, F.C., and Mertzman, S.A. (2008) Spectral reflectance properties of minerals exposed to simulated Mars surface conditions. Icarus, 195, 140-168; doi: 10.1016/j.icarus.2007.10.028.

Ehlmann, B.L., Mustard, J.F., Fassett, C.I., Schon, S.C., Head III, J.W., Des Marais, D.J., Grant, J.A., and Murchie, S.L. (2008) Clay minerals in delta deposits and organic preservation potential on Mars. Nature Geoscience, 1, 355-358.

Farley, K.A., Melspin, C., Mahaffy, P., Grotzinger, J.P., Vasconcelos, P.M., Milliken, R.E., Malin, M., Edgett, K.S., Pavlov, A.A., Hurowitz, J.A., Grant, J.A., Miller, H.B., Arvidson, R., Beegle, L., Calef, F., Conrad, P.G., Dietrich, W.E., Eigenbrode, J., Gellert, R., Gupta, S., Hamilton, V., Hassler, D.M., Lewis, K.W., McLennan, S.M., Ming, D., Navarro-González, R., Schwenzer, S.P., Steele, A., Stolper, E.M., Sumner, D.Y., Vaniman, D., Vasavada, A., Williford, K., Wimmer-Schweingruber, F., and the MSL Science Team (2014) In situ radiometric and exposure age dating of the Martian surface. Science, 3443, doi:10.1126/science.1247166.

Farrand, W.H., Johnson, J.R., Rice, M.S., Wang, A., and Bell III, J.F. (2016) VNIR multispectral observations of aqueous alteration materials by the Pancams on the Spirit and Opportunity Mars Exploration Rovers. American Mineralogist, this volume.

Ferris, J.P. (2005) Mineral catalysis and prebiotic synthesis: Montmorillonite-catalyzed formation of RNA. Elements, 1 (3), 145-149.

Grotzinger, J.P., Gupta, S., Malin, M.C., Rubin, D.M., Schieber, J., Siebach, K., Sumner, D.Y., Stack, K.M., Vasavada, A.R., Arvidson, R.E., Calef III, F., Edgar, L., Fischer, W.F., Grant, J.A., Griffes, J., Kah, L.C., Lamb, M.P., Lewis, K.W., Mangold, N., Minitti, M.E., Palucis, M., Rice, M., Williams, R.M.E., Yingst, R.A., Blake, D., Blaney, D., Conrad, P., Crisp, J., Dietrich, W.E., Dromart, G., Edgett, K.S., Ewing, R.C., Gellert, R., Hurowitz, J.A., Kocurek, G., Mahaffy, P., McBride, M.J., McLennan, S.M., Mischna, M., Ming, D., Milliken, R., Newsom, H., Oehler, D., Parker, T.J., Vaniman, D., Wiens, R.C., and Wilson, S.A. (2015) Deposition, exhumation, and paleoclimate of an ancient make deposit, Gale crater, Mars. Science, 250, doi:10.1126/science.aac7575.

Johnson, J.R., Bell III, J.F., Bender, S., Blaney, D., Cloutis, E., DeFlores, L., Ehlmann, B., Gasnault, O., Gondet, B., Kinch, K., Lemmon, M., Le Mouélic, S., Maurice, S., Rice, M., Wiens, R.C., and the MSL Science Team (2015) ChemCam passive reflectance spectroscopy of surface materials at the Curiosity landing site, Mars. Icarus, 249, 74-92.

McCord, T.B., Clark, R.N., and Singer, R.B. (1982) Mars: Near-infrared spectral reflectance of surface regions and compositional implications. Journal of Geophysical Research, 87, 3021-3032.

Ojha, L., Wilhelm, M.B., Murchie, S.L., McEwen, A.S., Wray, J.J., Hanley, J., Massé, M., and Chojnacki, M. (2015) Spectral evidence for hydrated salts in recurring slope lineae on Mars. Nature Geoscience, 8, 829-832.

Viviano-Beck, C.E., Seelos, F.P., Murchie, S.L., Kahn, E.G., Seelos, K.D., Taylor, H.W., Taylor, K., Ehlmann, B.L., Wiseman, S.M., Mustard, J.F., and Morgan, M.F. (2014) Revised CRISM spectral parameters and summary products based on the currently detected mineral diversity on Mars. Journal of Geophysical Research, 119, 1403-1431.

Figure 1. Reflectance spectra of fibroferrite, a ferric iron-, hydroxide-, and water-bearing sulfate showing how exposure to Mars surface conditions (21 days) can change its spectral reflectance properties, likely due to compositional and structural changes accompanying exposure. (Color online).