MÖSSBAUER SPECTROSCOPY ON THE MARTIAN SURFACE: PREDICTIONS. M. W. Schaefer[1] and M. D. Dyar[2], [1]Center for Space Research, The University of Texas at Austin, 3925 W. Braker Lane, Suite 200, Austin, TX 78795; mschaefer@csr.utexas.edu. [2]Department of Astronomy, Kendade Hall, Mount Holyoke College, 50 College St., South Hadley, MA 01075; mdyar@mtholyoke.edu.

Introduction: Mössbauer spectrometers will be used on the upcoming MER/Athena and Mars Express/Beagle 2 landers to identify and quantify relative amounts of iron-bearing minerals and determine Fe^{3+}/Fe^{2+} ratios, allowing more realistic modeling of Martian mineralogy and geochemistry. To properly interpret the spectra acquired by these instruments, we must understand the Mössbauer parameters of minerals that we might expect to find on Mars. We present here a summary of predicted Fe-bearing minerals that might be observed by the MER Mössbauer spectrometers, based upon previous and our own on-going work.

Predictions: Many minerals have been predicted or observed to exist on Mars. Predictions have been based on theoretical considerations, Mars-analogs, and existence in SNC meteorites. A listing of proposed phases is given in Table 1.

Mineralogy based on SNC meteorites. In a conservative estimation, one can predict that at least the minerals found in SNC meteorites will exist on Mars. Fe-bearing minerals found in more than trace abundance in SNC meteorites include:

1. Oxides: magnetite, ilmenite, chromite.
2. Sulfides: pyrrhotite, pyrite, chalcopyrite.
3. Silicates: olivine, pyroxene.
4. Others: whitlockite, carbonates, iddingsite.

Although all SNC meteorites discovered have been igneous, this bias in sampling does not preclude the existence of other rock types on the surface of Mars.

Mineralogy based on spectroscopic observations. The list of minerals actually observed on Mars itself is much shorter than is found in SNCs. Whereas several iron-bearing minerals have been *possibly* detected on Mars from ground-based observations, recent spacecraft observations have only seen a few [1], primarily pyroxene, a material described as being either sheet silicate or high-Si glass, and some hematite and olivine. [Plagioclase feldspar, also detected in large quantities, is not generally detectable by Mössbauer spectroscopy, due to its low iron content.]

Caveats on mineralogies observed remotely. It is important to remember that spectroscopic techniques may provide a good mineralogical characterization of the surface, but they do not offer a direct measurement of what rock types might be present unless they can determine mineral modes. For the case of Mössbauer spectroscopy, this means that the technique can determine what percentage of the total Fe is present in which phases (under ideal circumstances). However, it cannot determine how much of each of those mineral or glass phases is present, because it cannot measure wt% FeO, or the amount of Fe relative to the other elements that are present.

Other minerals or rocks that might be present. The samples that Mössbauer spectrometers on the surface of Mars will have to study will not be single-phase minerals, however, but rocks and particulates. Some types of rocks expected to exist on Mars include basalt [1, 2], andesite [1] (although there is some controversy about their detection [3]), and palagonite [2, 4]. It is unlikely that the surface of Mars is composed entirely of one rock type, even though remote spectroscopic observations may be interpreted as indicating either basalt+andesite, or basalt+weathered basalt. Since spectroscopy only samples the uppermost layers of the surface, a thin layer of dust on the surface or even in the atmosphere can severely influence what the spectrometer sees. Mössbauer spectroscopy on Mars is similar to other spectroscopic techniques in that it only measures the uppermost few hundred microns of the sample surface, and therefore is most sensitive to any weathering products that may be present, not to the bulk composition of the rocks.

Table 1. Possible Fe-Bearing Minerals on Mars

Mineral Species	Mineral Group	References
hematite (nanophase)	oxide	[5, 7]
hematite and titanohematite	oxide	[5, 6, 8, 9]
ferrihydrite	oxide	[10, 11]
perovskite	oxide	this work
magnetite	spinel	[6]
maghemite	spinel	[6, 12, 13, 14]
magnesioferrite	spinel	this work
hercynite	spinel	this work
goethite	hydroxide	[6, 15]
lepidocrocite	hydroxide	[6, 15]
akaganéite	hydroxide	[15]
schwertmannite	hydroxide	[16]
feroxyhyte	hydroxide	[15, 17]
pentlandite	sulfide	[18, 19]
pyrite	sulfide	[20, 21]
pyrrhotite	sulfide	[22, 23]
hydronium jarosite, natrojarosite	sulfate	[24, 25]
rhomboclase	sulfate	this work
melanterite	sulfate	this work

hydromagnesite	carbonate	[26, 27]
siderite	carbonate	[28]
ankerite	carbonate	this work
fayalite	olivine	[29, 30]
laihunite	olivine	[31]
garnet	almandine	this work
garnet	andradite	this work
enstatite/ferrosilite	orthopyroxene	[32]
augite	orthopyroxene	[32]
pigeonite	clinopyroxene	[32]
hedenbergite	clinopyroxene	this work
actinolite	amphibole	[33, 34, 35]
anthophyllite	amphibole	[33, 34, 35]
kaersutite	amphibole	this work
annite	mica	this work
biotite	mica	[36]
muscovite	mica	[27]
glauconite	mica	this work
"illite"	mica-clay	[38, 39]
"smectite"	mica-clay	this work
chamosite	chlorite	[40, 41]
montmorillonite	smectite	[9, 42]
nontronite	smectite	[43, 44, 45]
antigorite, chrysotile, and lizardite	kaolinite-serpentine	[33, 34, 35, 40]

It would not be surprising to find other rock types on the surface of Mars, such as sedimentary (various types of chemical precipitates or mudstones, for example), metamorphic (perhaps associated with tectonic features), or samples of the mantle excavated by larger impacts.

In all of these cases it will be desirable to be able to distinguish between the component silicate and oxide phases, and to be able to determine the relative abundances of each component. As explained in our companion abstract [41], there are disturbing limitations on the ability of Mössbauer spectroscopy, acting alone, to adequately characterize the materials we might expect to find on the surface of Mars.

Acknowledgments: NASA grant NAG5-12687.

References: [1] Bandfield, J. L. (2002) *JGR*, *10*(E6), 5042, doi: 10.1029/2001JE001510. [2] Soderblom, L. A. (1992) Ch. 17 in *Mars*, ed. Kieffer, H. H., B. M. Jakosky, C. W. Snyder, M. S. Matthews, U. of Ariz. Press, pp. 557-593. [3] Wyatt, M. B., and H.Y. McSween, Jr. (2002) *LPS XXXIII*, Abs. # 1702. [4] Banin, A., B. C. Clark, H. Wänke (1992) Ch. 18 in *Mars*, ed. Kieffer, H. H., B. M. Jakosky, C. W. Snyder, M. S. Matthews, U. of Ariz. Press, pp. 594-625. [5] Morris, R. V., D. G. Agresti, H. V. Lauer, Jr., J. A. Newcomb, T. D. Shelfer, A. V. Murali, (1989) *J. Geophys. Res.*, *94*, 2760-2778. [6] Morris, R. V., H. V. Lauer, Jr., C. A. Lawson, E. K. Gibson, Jr., G. A. Nace, C. Stewart (1985) *J. Geophys. Res.*, *90*, 3126-3144. [7] Morris, R. V., H. V. Lauer, Jr. (1990) *J. Geophys. Res.*, *95*, 5101-5109. [8] Morris, R. V., D. C. Golden, J. F. Bell, III., H. V. Lauer, Jr. (1995) *J. Geophys. Res.*, *100*, 5319-5328. [9] Singer, R. B. (1982) *J. Geophys. Res.*, *87*, 10159-10168. [10] Bishop, J. L., C. M. Pieters, R. G. Burns, (1993) *LPI Tech. rept., 1993*, 6-8. [11] Agresti, D. G., M. L. Wade, T. J. Wdowiak, L. P. Armendarez, J. D. Farmer. (1999) *LPSC XXX*, Abs. #1840. [12] R. B. Hargraves, D. W. Collinson, R. E. Arvidson, C. R. Spitzer (1977) *J. Geophys. Res.*, *82*, 4547-4558. [13] Sherman, D. M., R. G. Burns, V. M. Burns (1982) *J. Geophys. Res.*, *87*, 10169-10180. [14] Coey, J. M. D., S. Morup, M. B. Madsen, J. M. Knudsen (1990) *J. Geophys. Res.*, *95*, 14423-14425. [15] Murad, R., and J. H. Johnston (1987) In *Mössbauer Spectroscopy Applied to Inorganic Chemistry*, ed. G. J. Long, Plenum Pub. v. 2, pp. 507-582. [16] Bishop, J. L., E. Murad (1996) In *Mineral Spectroscopy: A Tribute to Roger G. Burns*, ed. Dyar, M. D., C. A. McCammon, M. W. Schaefer, *Geochemical Society Special Pub. 5*, pp. 337-358. [17] Burns, R.G. (1980) *Nature*, *185*, 647. [18] Burns, R. G. (1988) *Reports of Planetary Geological and Geophysics Program, 1987, NASA Technical Memo.*, 127-129. [19] Burns, R. G., D. S. Fisher (1989) *Reports of Planetary Geological and Geophysics Program, 1988, NASA Technical Memo.*, 217-219. [20] Greenwood, J. P., L. R. Riciputi, H. Y. McSween, Jr. (1997) *Geochim. Cosmochim. Acta*, *61*, 4449-4453. [21] Greenwood, J. P., S. J. Mojzsis, S. D. Coath (2000) *Earth Planet. Sci. Letts.*, *184*, 23-35. [22] Rochette, P., J.-P. Lorand, G. Fillion, V. Sautter (2001) *Earth Planet. Sci. Letts.*, 190, 1-12. [23] Kletetschka, G., P. J. Wasilewski, P. T. Taylor (2000) *Meteoritics and Planet. Sci.*, *35*, 895-899. [24] Murchie, S., J. Mustard, J. Bishop, J. Head, C. Pieters (1993) *Icarus*, *105*, 454-468. [25] Morris, R. V., D. W. Ming, D. C. Golden, J. F. Bell, III (1996) In *Mineral Spectroscopy: A Tribute to Roger G. Burns*, eds. Dyar, M. D., C. A. McCammon, M. W. Schaefer, *Geochemical Society Special Pub. 5*, pp. 327-336. [26] Calvin, W. M., T. V. V. King, R. N. Clark (1994) *J. Geophys. Res.*, *99*, 14659-14676. [27] Farquhar, J., M. H. Thiemens, T. L. Jackson (1999) *LPSC XXX*, Abs. #1675. [28] Schaefer, M. W. (1996) In *Mineral Spectroscopy: A Tribute to Roger G. Burns*, eds. Dyar, M. D., C. A. McCammon, M. W. Schaefer, *Geochemical Society Special Pub. 5*, pp. 381-393. [29] King, T. V. V., W. I. Ridley (1987) *J. Geophys. Res.*, *92*, 11457-11469. [30] Sunshine, J. M. (1994) *Inferring the composition of mafic lithologies from multi- and hyper-spectral data sets: Implications for remote sensing of terrestrial bodies.* Ph.D. dissertation, Brown University. [31] Mikouchi, T., I. Yamada, M. Miyamoto (2000) *Meteoritics Planet. Sci.*, *35*, 937-942. [32] Mustard, J. F., J. M. Sunshine (1995) *Science*, 267, 1623-1626. [33] McCord, T. B., R. N. Clark, R. L. Huguenin (1978) *J. Geophys. Res.*, *83*, 5433-5441. [34] McCord, T. B., R. N. Clark, R. B. Singer (1982) *J. Geophys. Res.*, *87*, 3021-3032. [35] Singer, R. B., T. B. McCord, R. N. Clark, J. B. Adams, R. L. Huguenin (1979) *J. Geophys. Res.*, *84*, 8415-8426. [36] Watson, L. L., I. D. Hutcheon, S. Epstein, E. M. Stolper (1994) *Science*, *265*, 86-90. [37] Roush, T. L., R. B., Singer, T. B. McCord (1987) *LPSC XVIII*, 856-857. [38] Gooding, J. L. (1992) *Icarus*, *99*, 28-41. [39] Bridges, J. C., M. M. Grady (2000) *Earth Planet. Sci. Letts.*, *176*, 267-279. [40] Calvin, W. M. (1998) *LPSC XXIX*, Abs. #1162. [41] Griffith, L. L., E. L. Shock (1997) *GSA Abstracts*, *29*, 214. [42] Hunt, G. R., L. M. Logan, J. W. Salisbury (1973) *Icarus*, *18*, 459-469. [43] Moskowitz, B. M., R. B. Hargraves (1982) *J. Geophys. Res.*, *87*, 10115-10128. [44] Burns, R. G. (1993) *Geochim. Cosmochim. Acta*, *57*, 4555-4574. [45] Banin, A., J. Rishpon (1979) *J. Molecular Evolution*, *14*, 133-152. [41] Dyar and Schaefer (2003) *LPSC XXXIV*, #1329.