Mineral chemistry and crystallography are both necessary for the full determination and characterization of minerals and for thorough understanding of their origin, genesis, and occurrence. Planetary remote sensing and surface-mission instruments routinely return data about the chemical compositions of distant solar system materials, but not crystallographic data. Only recently did the first intentionally crystallographic instrument deployed anywhere in the solar system other than Earth—the CheMin X-ray diffractometer (XRD) on Mars Science Laboratory (MSL) rover Curiosity—begin operations on the surface of Mars. Morrison et al. (2018a, this issue) refine previously acquired CheMin data for rock-forming silicate and oxide minerals, and some alteration products, in unconsolidated wind-blown (dune) sediments and environmentally diverse clastic sedimentary rocks encountered along Curiosity’s traverse through Gale Crater, Mars. These refined unit-cell parameters constitute a much-strengthened foundation for the next generation of geologic and petrologic interpretation of Mars’ surface minerals.

Minerals are defined by crystalline structure and composition or compositional range. Structure and composition are related. The smallest structural constituents (for example, cations, silica tetrahedra, or carbonate or sulfate anionic groups), and their linkages with one another, have geometric attributes that are consequences of bonding between specific pairs of atoms. Each member of the bonded pair is commonly visualized as having a size (e.g., an atomic or ionic radius) and a charge (valence). Different combinations of elements commonly result in different bond attributes and different structures. However, pairs of structures with similar symmetry but different unit-cell dimensions (isomorphs) are common, as are variations of unit-cell dimensions caused by substitutions for one another of ions with similar valence and bond characteristics but slightly different size (solid solution). For many mineral groups, correlations between chemical composition and unit-cell parameters permit each to be estimated from the other.

Where samples, including meteorites known to originate from Mars, are available in sufficient abundance for examination in terrestrial laboratories, the full range of crystallographic and compositional methods permits thorough identification and characterization of the minerals in the samples. Many minerals have been well characterized in meteorites from Mars, but specific source areas on Mars are not known for any individual Mars meteorites, so meteoritic mineral data cannot be linked to specific source regions on Mars.

Mars orbiters acquire images and spectra from large areas, but planetary remote sensing and surface-mission instruments routinely return data about the chemical compositions of distant solar system materials, but not crystallographic data. Only recently did the first intentionally crystallographic instrument deployed anywhere in the solar system other than Earth—the CheMin X-ray diffractometer (XRD) on Mars Science Laboratory (MSL) rover Curiosity—begin operations on the surface of Mars. Morrison et al. (2018a, this issue) refine previously acquired CheMin data for rock-forming silicate and oxide minerals, and some alteration products, in unconsolidated wind-blown (dune) sediments and environmentally diverse clastic sedimentary rocks encountered along Curiosity’s traverse through Gale Crater, Mars. These refined unit-cell parameters constitute a much-strengthened foundation for the next generation of geologic and petrologic interpretation of Mars’ surface minerals.

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Mars orbiters acquire images and spectra from large areas, but at spatial resolutions much coarser than individual samples. Robotic surface landers and rovers acquire data at sample (centimeter) scale. However, constrained as they are by cost, payload mass, volume, power, and data transfer rates, the ensembles of instruments on individual landers and rovers include only a subset of the analytical capabilities of terrestrial laboratories. One consequence of the hard choices that must be made in selecting instruments is that crystallographic data are almost entirely lacking. Planetary geology continues to advance with remote mineral characterization data that are incomplete by the standards of terrestrial mineralogy.

As was the case in the progress of terrestrial mineralogy, scientific understanding of Mars’ surface materials was supported by morphological crystallography (along with chemical data) before X-ray crystallography. Eight years before Curiosity landed on Mars (2012), each of the twin Mars Exploration Rovers (MERs) Spirit and Opportunity (2004) carried a Microscopic Imager (MI; ~30 μm/pixel, yielding images with ~100 μm spatial resolution) (Arvidson et al. 2006). A few MER MI images show euhehedral features.

Mars Exploration Rover Opportunity encountered weathered outcrops of hematite-rich basaltic sandstones in the Burns Formation at Meridiani Planum (Herkenhoff et al. 2004; Squyres et al. 2004). Some outcrop surfaces displayed randomly oriented euhehadral (blade-shaped) or discoid to lozenge-shaped cavities (collectively called vugs in the earliest papers) transecting sedimentary laminations (Squyres et al. 2004; Herkenhoff et al. 2004). The euhehadral cavities were interpreted as mdiolic secondary porosity after euhehadral crystals of a water-soluble early diagenetic mineral (Herkenhoff et al. 2004; McLennan et al. 2005). Their parallelogram outlines are consistent with a tabular (pinacoidal) habit of a mineral that is either monoclinic (Herkenhoff et al. 2004; McLennan et al. 2005) or triclinic (Peterson and Wang 2006; Peterson et al. 2007).

Chemical data from Opportunity’s Alpha Particle X-ray Spectrometer (APXS) and deconvolution of thermal-emission spectroscope (TES) data from Opportunity’s Mini-TES suggest that magnesium, calcium, or iron sulfate minerals are present in abundances of 15–40 ± 5 modal vol% (Christensen et al. 2004; McLennan et al. 2005). Several sulfate minerals consistent with compositional data for these and related sedimentary rocks at Meridiani Planum are monoclinic (gypsum, kieserite, hexahydrate; Herkenhoff et al. 2004; Squyres et al. 2004; Arvidson et al. 2005; melanterite, McLennan et al. 2005; starkeyite, Peterson et al. 2007) or triclinic (pentahydrate, meridianiite; Peterson and Wang 2006).

Meridianiite (MgSO₄·11H₂O) was experimentally synthesized and recognized from natural samples found at terrestrial locales with environmental conditions consistent with the solid’s phase diagram (Peterson and Wang 2006; Peterson et al. 2007). The crystallographic parameters of natural terrestrial meridianiite (a = 6.7459, b = 6.8173, c = 17.280 Å, α = 88.137°, β = 89.481°, γ
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unit-cell parameters corresponding to Fo_{67.5} (Morrison et al. 2018a). The mineral abundances and compositions determined from MSL Curiosity CheMin data are the most complete mineralogical data set for Mars surface materials until a Mars Sample Return mission (MSR), which is still at least a decade away. The XRD data, acquired with Curiosity’s unique CheMin instrument and corrected for small sample-stage offsets by Morrison et al. (2018a), enabled a major expansion from and improvement upon all previous identifications of rock-forming minerals from Mars mission data, all of which were based on observations that did not include crystallography. The refined unit-cell parameters and the updated mineral compositions derived from them by Morrison et al. (2018a) provide a firm new foundation for future interpretations of igneous-mineral and igneous-rock formation conditions, sediment provenance, pre-depositional and diagenetic chemical alteration, and habitability assessment on Mars.

References cited


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