Landed missions to the surface of Mars have long sought to determine the material properties of rocks and soils encountered during the course of surface exploration. Increasingly, emphasis is placed on the study of materials formed or altered in the presence of liquid water. Placed in the context of their geological environment, these materials are then used to help evaluate ancient habitability. The Mars Science Laboratory mission—with its Curiosity rover—seeks to establish the availability of elements that may have fueled microbial metabolism, including carbon, hydrogen, sulfur, nitrogen, phosphorus, and a host of others at the trace element level. These measurements are most valuable when placed in a geological framework of ancient environments as interpreted from mapping, combined with an understanding of the petrogenesis of the igneous rocks and derived sedimentary materials. In turn, the analysis of solid materials and the reconstruction of ancient environments provide the basis to assess past habitability.

ANDERSON & KRAMER, 2009; BISCHOF, 2010; CRISP & ATREYA, 2007; DARTNALL et al., 2011; DEKENS et al., 2011; GROTZINGER et al., 2012; KANE et al., 2006; KICHER et al., 2007; MACDONALD et al., 2011; MANN & FLEMMI, 2011; MILLER et al., 2006; MING et al., 2014; VANIMAN et al., 2014). During its nominal one-Mars-year mission (23 Earth months), Curiosity drilled or scooped five samples, made over twenty mineralogical and isotopic measurements and hundreds to thousands of compositional measurements, took hundreds of thousands of images that provided geological context for samples, and acquired millions of observations of the modern environment. Curiosity is the most advanced mobile geochemistry laboratory to have ever roved another planet, and it has been very productive.

Curiosity’s science payload (FIG. 1) includes a gas chromatograph–mass spectrometer and tunable laser spectrometer (SAM) that can measure isotopic compositions, volatile abundances, and organic carbon content in soils; rocks, and the atmosphere; an X-ray diffractometer (CheMin) that determines the mineralogical diversity of rocks and soils; an alpha particle X-ray spectrometer (APXS) for the in situ determination of rock and soil compositions; a laser-induced breakdown spectrometer (LIBS) to remotely sense the composition of rocks and minerals with high-resolution point imaging (ChemCam); cameras (MAHLI, MARDI, Mastcam) that can image landscapes and rock/soil textures in natural color; an active neutron spectrometer (DAN) designed to search for water in rocks/soil; a weather station (REMS) to measure modern-day environmental variables; and a sensor (RAD) designed for continuous monitoring of background solar and cosmic radiation. The various payload instruments work together to establish the geological and paleoenvironmental framework for the mineralogical and geochemical measurements. Potential targets for eventual drilling (or scooping) and sample delivery to the onboard analytical instruments (SAM, CheMin) are first studied with remote sensing instruments (Mastcam, ChemCam) and then by direct-contact...
measurements (MAHLI, APXS). The atmosphere and environment around the rover are also studied to provide further context (RAD, REMS, DAN). The analytical instruments obtain samples via a sample acquisition, processing, and handling subsystem that acquires soil samples by scooping and rock samples by drilling. Details about instrument and sampling-system design and function and about mission planning can be found in Grotzinger et al. (2012).

**GALE CRATER EXPLORATION SITE**

The 154 km diameter Gale Crater (Fig. 2) was chosen as Curiosity’s field site based on several attributes: (1) the crater contains an interior mountain of ancient flat-lying strata extending over 5 km above the elevation of the landing site; (2) the lower few hundred meters of the mountain show an age progression in which phyllosilicate-bearing and sulfate-bearing strata are separated by an unconformity from overlying, likely anhydrous strata; (3) the 20 × 7 km landing ellipse is characterized by a mixture of alluvial fan and high-thermal-inertia/high-albedo stratified deposits; and (4) the site contains a number of stratigraphically/geomorphically distinct fluvial features (Grotzinger et al. 2012). Gale has a well-defined regional context and shows strong evidence for a succession of multiple ancient aqueous environments, one of which has been shown to have been habitable (Grotzinger et al. 2014) and to have preserved trace amounts of organic carbon (Freissinet et al. 2014). These environments are represented by a stratigraphic record of extraordinary extent exposed along the flank of Gale’s internal mountain, Aeolis Mons. This mountain is informally known as Mt. Sharp, after pioneering planetary geologist Robert Sharp. Mt. Sharp was judged to preserve a rich record of the environmental history of early Mars. In essence, by choosing to explore Gale Crater, the Mars Science Laboratory (MSL) team was employing a tried and true exploration strategy used by resource exploration companies on Earth: to select a target with not just one but multiple objectives, as a way of reducing the risk of failure. That strategy succeeded.

By most measures the Gale Crater exploration site has been richly rewarding. The locations of analyses performed by ChemCam, by APXS, and during drilling are shown on Figure 3. Within a few months of landing, a Mars soil sample (dubbed “Rocknest”) had been scooped and analyzed, providing a wealth of information on a “typical” material that has been observed in all previous missions; this material is now understood in terms of its complete mineral composition (including amorphous materials) and volatile content. Following that, Curiosity drove a short distance away from Mt. Sharp, based on a hunch that thinly stratified bedrock observed in orbiter and rover image data may provide samples of an ancient lacustrine...
and arrived at the Pahrump Hills in September 2014. This drive of roughly 8.5 km took just over one year, allowing for several stops along the way for science campaigns aimed at understanding the composition and geological context of key rock units. These waypoints (called Darwin, Cooperstown, and Kimberley) were important in that they allowed the science team to test hypotheses about the origin(s) of the Aeolis Palus (Gale Crater plains) rocks and their relationship to rocks that form the lowermost strata of Mt. Sharp. At one stop, located within the Kimberley map quadrangle, Curiosity drilled another sample (Windjana) for analysis by CheMin and SAM. In addition to the work at these waypoints, Curiosity routinely analyzed whatever rocks and soils she stopped on with both APXS and ChemCam. This protocol assured that no major compositional changes or terrain boundaries were missed that might not correlate with rock properties reflected in rover and orbiter image data.

Thus, on September 17, 2014 (sol 753), Curiosity finally crossed the geologic boundary separating the rocks of Aeolis Palus, on which she landed, from those that define the base of Mt. Sharp (Fig. 3). Initial data suggest the geological boundary relates to differences in sedimentary facies, which in turn reflect differences in grain size and/or the extent of cementation.

**ROCK TYPES OF GALE CRATER PLAINS (AEOLIS PALUS)**

Gale Crater has an age of 3.6 to 3.8 billion years, and it is inferred that Mt. Sharp developed shortly after crater formation. The mountain was perhaps the result of crater filling, followed by erosion and the creation of a “moat.” This hypothesis is supported by initial observations from the Pahrump Hills, where the Murray formation is composed of a complex assemblage of fluvial, deltaic, lacustrine, and eolian deposits. In contrast, upper Mt. Sharp strata may have originated from directed wind patterns and sediment accretion, forming a mound in the middle. In either case, sedimentation and denudation were complete by 3.2–3.4 billion years ago (Newsom et al. 2014). Curiosity landed in the plains, or lowlands, between Gale Crater’s rim and Mt. Sharp.
Gale’s larger-scale stratigraphy, mineralogy, and landforms have been well studied (Milliken et al. 2010; Grotzinger et al. 2014; Newsom et al. 2014), and Gale’s relevance to MSL’s goals has been established (Grotzinger 2009; Grotzinger et al. 2012). To fulfill the primary mission objective, Curiosity is exploring the lower foothills of Mt. Sharp, where strata containing hematite, hydrated clays, and sulfate (Milliken et al. 2010) are accessible (Fig. 2). At the time of this writing, Curiosity is analyzing the first hematite-bearing outcrops along the drive between the landing site and the base of Mt. Sharp. Geological mapping (Fig. 3) reveals several units, including the Peace Valls alluvial fan (not shown in Fig. 3, but is north of the map area displayed); an immediately adjacent and downslope bedded, fractured unit; surfaces with higher crater densities; tonally smooth but hummocky plains; light-toned, topographically variable, or rugged terrain; and light-toned striated rocks. The Murray formation is composed of rocks on the south side of the Aeolis Palus / Mt. Sharp boundary; from orbit these rocks appear to be massive, with hints of stratification, and show spectroscopic evidence for hematite, sulfate, and hydrated clay minerals. At the Pahrump Hills, the Murray formation consists of finely laminated mudstones, with interstratified cross-bedded sandstones of basaltic composition. The rocks contain abundant hematite, providing a link to orbiter-based observations and predictions. Finally, minor units of eolian fill/bedforms and ejecta blankets adjacent to larger craters are present. These diverse units represent a range of bedrock lithologies and looses, poorly consolidated mantling materials. All units except for the “alluvial fan” have now been examined by Curiosity. Nevertheless, all of the bedrock examined by Curiosity consists of alluvial deposits, with minor lacustrine and rare eolian deposits. These bedrock deposits are either down-gradient time equivalents of the Peace Valls alluvial fan or older facies equivalents that have experienced a greater degree of diagenesis and lithification.

The hummocky plains are different in that they represent mostly a surface mantle of debris, with frequent windows through which sedimentary bedrock is observed. In the vicinity of the landing site, the hummocky plains are composed dominantly of loose materials, including clasts of rock interpreted to be impact ejecta, but these plains are dominated by erosional remnants of underlying bedrock of sedimentary origin. Analyzed clasts have basaltic compositions (occasionally alkaline), and some clasts have porphyritic textures. Windows through this material in the vicinity of Bradbury Landing, including the excavations produced by Curiosity’s descent rockets, expose conglomerate bedrock of fluvial origin (Williams et al. 2013; Kah and the MSL Science Team 2015 this issue).

PETROLOGY

As Curiosity drove across and sampled the terrain of Aeolis Palus, it became clear that all bedrock is sedimentary and dominantly of fluvial origin (Williams et al. 2013; Grotzinger et al. 2014). Igneous rocks may occur as impact ejecta, likely derived from outside the crater, but the clearest examples we have seen are present as rounded clasts within the sedimentary conglomerates. These clasts reveal porphyritic textures (see Kah and the MSL Science Team 2015, Fig. 6d), and the phenocrysts are very likely feldspars, based on ChemCam LIBS data (Sutter et al. 2014; Wiens et al. 2015). Given that sediment transport directions for these fluvial rocks are southward (Grotzinger et al. 2014), we infer that the source area for these igneous rocks is the northern rim of Gale Crater.

Other igneous rocks of basaltic composition may also be present, but their fine-grained textures make their origins ambiguous—they could be sedimentary as well. As the mission evolved, we learned that all the sedimentary rocks are of basaltic composition, and in some cases they are indistinguishable from definitive igneous rocks observed previously on Mars (Gellert et al. 2015). These sedimentary rocks have compositions very close to the average crustal composition of Mars, indicating that they experienced little chemical weathering in their source region (Fig. 4). This similarity implies that the disintegration of primary igneous rocks to form sedimentary materials may have occurred largely by physical processes, as interpreted for the sandstones and mudstones of the Yellowknife Bay formation (McLennan et al. 2014). However, despite the absence of major element mobility (Fig. 4), mineralogical data for these rocks suggest a model of alteration in which primary mafic minerals, especially olivine, were converted into secondary Fe–Mg-smectite clay minerals (Vaniman et al. 2014). This alteration can be observed in Figure 5 by comparing mineral-abundance data from the Rocknest soil with those from the John Klein and Cumberland drill holes in the Sheepbed mudstone. The combined mineralogical and chemical data indicate that the rocks were altered and their mineralogy changed, but this occurred during diagenesis of the water-saturated sediment rather than in the sediment source region during weathering. Such isochemical diagenesis was a significant discovery by Curiosity, and the discovery was surprising because most models predicted clay mineral formation on Mars during weathering or hydrothermal fluid circulation, but not during diagenesis in sedimentary basins. This process may be a significant factor elsewhere on Mars.
**The Alkaline Igneous Province of Gale Crater’s Northern Rim**

One remarkable attribute of Aeolis Palus stratigraphy is the abundance of rocks with high alkali content (Fig. 6). Beginning with the Jake_M rock, the first rock measured on the mission with APXS, rocks with an alkaline composition as revealed by both the APXS and ChemCam instruments have been observed intermittently between the landing site and the Pahrump Hills (Gellert et al. 2015; Wiens et al. 2015).

As first described by Stolper et al. (2013), Jake_M is a float rock with a dark, macroscopically homogeneous, fine-grained texture. Although initially interpreted as igneous in origin, the subsequent discovery of ubiquitous sedimentary rocks (sandstones and siltstones) with similar composition and texture suggests that Jake_M may be sedimentary. Because the rock is out of place and does not have any diagnostically unique igneous textures (e.g. porphyritic, as observed in some conglomerate clasts), it is difficult to make this fundamental distinction. Nevertheless, even as a first-cycle sandstone, its composition may reasonably reflect that of its provenance, which is regarded as belonging to an alkaline igneous province. The composition of Jake_M and other similar rocks suggests this province is composed of rocks that represent a previously unknown Martian magma type (Stolper et al. 2013). In contrast to the moderately fractionated Fe-rich and Al-poor tholeiitic basalts typical of Martian igneous rocks, this province is highly alkaline and fractionated; no other known suite of Martian rocks is as compositionally similar to terrestrial igneous rocks. Some of the most alkaline compositions observed so far, other than Jake_M, were encountered within the Kimberley area, where the Windjana drill sample was studied by CheMin. It is noteworthy that the Windjana rock is composed of a significant quantity of potassium feldspar (Fig. 5), which is consistent with derivation from an evolved magma, such as represented by rocks of Gale Crater’s northern rim.

The Aeolis Palus sedimentary rocks of alkaline composition compare closely with an uncommon terrestrial rock type known as a mugearite, which is typically found on ocean islands and in rift zones (Fig. 6; Stolper et al. 2013). The igneous province from which these sedimentary rocks with alkaline composition were derived is likely the northern part of the Gale Crater’s rim, based on the sediment transport directions indicated by cross-bedding in fluvial sandstones (Grotzinger et al. 2014). This conclusion is also consistent with the morphologic expression of the Peace Vallis fan, which indicates sediment transport from the crater’s northern rim. The igneous province probably originated from magmas generated by low degrees of partial melting at high pressure of relatively water-rich, chemically altered Martian mantle; such a mantle is different from the sources of other known Martian basalts (Stolper et al. 2013).

**Cementation of Sedimentary Rocks**

It was a surprise to discover an extensive deposit of well-lithified, siliciclastic sedimentary rocks within the rover’s landing region. Before landing, the occurrence of broad expanses of “cratered surfaces” suggested that at least some of these rocks were hard, like lava flows; the preservation of impact craters is favored by hard target rocks, often inferred to be of igneous origin. At this point in the mission, all bedrock has been shown to be sedimentary, and the unexpected hardness of the rocks results from pervasive cementation. This bedrock is composed entirely of detrital sedimentary rocks of fluvial, lacustrine, and possibly eolian origin (Williams et al. 2013; Grotzinger et al. 2014). The rocks drilled and sampled at Yellowknife Bay (John Klein, Cumberland) and Kimberley (Windjana) were also formed by these depositional processes. The composition of these rocks indicates basaltic precursors, though substantial variations in the alkali, iron, and magnesium contents also occur (Blaney et al. 2014; McLennan et al. 2014). This variation could be due to variations in the compositions of the primary grains in the precursor rocks, which in turn might dominantly reflect the composition of their mantle source; however, it might also reflect the compositions of cementing materials, as these could comprise up to 20–30% of the rock by volume, assuming minimal compaction under the reduced gravity of Mars.

The diagene of these sedimentary rocks has turned out to be as interesting as their primary composition. Understanding the nature and history of cementation has become a major mission focus in an attempt to decipher the evolution of pore fluid composition. Currently, we are exploring several hypotheses for the origin of these cements. One possible cement is clay minerals, which are abundant in the Windjana sandstone (~8%; see Downs and the MSL Science Team 2015) and very abundant in the Sheepbed mudstone (~20%; see Vaniman et al. 2014). Magnetite is also sufficiently abundant to serve, at least in part, as a possible cementing material. ChemCam data point to high total FeO, which is not easily related to a primary igneous composition and therefore suggests the possibility of iron oxide cement (Blaney et al. 2014). These data are important given that the ChemCam laser works as a type of microprobe providing ~0.5–1 mm spot size for the elemental analysis of grains and cement. By analyzing the fine-grained sandstone at Kimberley (Windjana). Minerals in gray italics are at or near detection limits. Opx = orthopyroxene.
On a planet made of basalt and altered under neutral pH conditions, this outcome is perhaps not surprising. This type of alteration strongly contrasts with the alteration of the Burns formation at Meridiani Planum, where primary basaltic rocks were altered under acidic conditions, leading to extensive deposition of sulfate-rich sedimentary rocks (McLennan et al. 2005). Paradoxically, the X-ray-amorphous component of Gale Crater sedimentary rocks is substantial, despite the near elimination of olivine and a significant reduction in the amounts of other igneous minerals during the alteration to authigenic Fe–Mg-smectite and magnetite. These X-ray-amorphous materials are revealed in CheMin diffraction patterns by an elevated background at low 2-theta angles, that is, between approximately 15 and 40 degrees (Blake et al. 2013; Vaniman et al. 2014).

One possibility is that at least some of the large fraction of amorphous materials in the Sheepbed and Windjana samples (Fig. 5) could have also formed authigenically, perhaps as a silica-rich cementing material, supplementing the possible iron oxide cements discussed above. However, if such an amorphous cement did form, it is not pure silica given the abundance of other elements; instead, the composition may be a mixture of some of these components: volcanic glass, hisingerite (or silica + ferrihydrite), amorphous sulfates, and nanophase ferric oxides (Dehouck et al. 2014). It seems more likely that amorphous materials of this composition are detrital in origin and that somehow their kinetics of dissolution were less favorable than those for olivine. Alternatively, the amorphous materials might consist of multiple components that might represent distinct and separate geologic processes of formation.

VOLATILES

Volatile components that are adsorbed on and chemically bound within solid materials at Gale have been detected by several instruments. These occur in the ubiquitous dust that coats nearly every surface observed by Curiosity so far, in the soil that fills depressions and creates eolian bedforms, as well as in rock-forming particles and in the cement that binds them together. Some volatiles have been recognized within ChemCam’s plasmas, others via the structures revealed by X-ray diffraction, but most have been detected during pyrolysis of solid samples. The volatiles released during pyrolysis include H2O, SO2, CO2, O2, H2, NO, H2S, HCl, and trace hydrocarbons. Most of these are not discussed further here, and the reader is referred to Mahaffy et al. (2015) and papers referenced therein for further information. A few examples representing a range of interesting geological materials discovered by Curiosity are presented here.

Water in Dust and Soil

In the course of obtaining thousands of LIBS analyses of Gale Crater’s surface, the ChemCam instrument has had to penetrate at least some dust on every sample. A standard ChemCam analytical sequence involves 25–30 consecutive shots at the same target, resulting in ablation of the surface and penetration to a depth of about 1 mm (Wiens et al. 2015). When the laser was used for the first time on sol 19, it was recognized that the first five or so shot points were measuring the composition of the dust coating the rock or soil surface (Meslin et al. 2013); such analyses must be discarded if an uncompromised rock or soil composition is desired. These first few shot points indicated the presence of hydrogen in the dust and, in many soils, the hydrogen in the sedimentary rock samples due to alteration to clay minerals and minor amounts of other authigenic phases (Blake et al. 2013; Vaniman et al. 2014; Downs and the MSL Science Team 2015).

One of Curiosity’s most important capabilities arises from its being equipped for X-ray diffraction analysis, the historical tool of choice for mineralogical investigation of terrestrial geological materials. The CheMin instrument (Blake et al. 2012; Downs and the MSL Science Team 2015) has been able to analyze samples from one Martian soil deposit and four drilled rocks, providing a wealth of information on their mineral compositions. These samples all share major mineral compositions that reflect the basaltic igneous protoliths from which they were derived. The abundances of the major igneous minerals are much lower than those expected on Earth, given the much smaller force of gravity on Mars.

Amorphous Materials

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a number of rocks, ChemCam was able to differentiate between these components, suggesting that in places iron oxides may be important in cementation (Blaney et al. 2014; Wiens et al. 2015).

A combination of chemical (APXS, ChemCam) and mineralogical (CheMin) data indicates that the clay minerals and magnetite in the Sheepbed mudstone are authigenic, and possibly this interpretation also applies to the Windjana magnetite in the Sheepbed mudstone are authigenic, and logically (CheMin) data indicates that the clay minerals and oxides may be important in cementation (Blaney et al. 2014; Wiens et al. 2015).

FIGURE 6

Alkali–silica diagram. Compositional boundaries and rock names are from Stolper et al. (2013); the mugearite field is shown in blue. The dashed curve is the alkali–subalkaline boundary. The solid-red symbols represent the three Jake_M analyses, normalized to 100 wt% without SO3, Cl, and trace elements. The small gray circles are APXS data for bedrock and loose float rocks on Aeolis Palus, which were sampled on the mission up to and including the Windjana drill hole at Kimberley. Other rocks are shown for comparison, including those from the Mars Exploration Rover mission (MER), the Pathfinder rover mission, and Mars meteorites (shergottites, breccias).
was inferred to have originated from the hydration of amorphous phases (Meslin et al. 2013; Wiens et al. 2015). This signal has been seen throughout the course of the mission, indicating the ubiquitious nature of this hydration. Independently, pyrolysis of the Rocknest soil sample and analysis by the SAM quadrupole mass spectrometer and tunable laser spectrometer have shown that the X-ray-amorphous component of soil, including dust, is hydrated and is estimated to contain 1.5–3 wt% H₂O (Leshin et al. 2013). This water is thought to be “recent,” given that its D/H isotopic value (Leshin et al. 2013) is close to that measured in the modern Martian atmosphere (Webster et al. 2013); the water is perhaps the result of adsorption onto materials such as allophane and iron (oxy)hydroxides (Meslin et al. 2013). This finding implies soil–atmosphere exchange.

**Water in Ancient Clays**

The Fe–Mg-smectite clay minerals detected by CheMin in the Sheepbed mudstone at Yellowknife Bay were studied by SAM pyrolysis. Water was released over a range of temperatures, and at low temperatures represents adsorbed water, hydrated compounds within amorphous materials, and interlayer water in the Fe–Mg-smectites (Ming et al. 2014). However, release of water in the upper range of temperatures likely represents structurally bound OH, whose origin dates back to the time of clay mineral formation in the Yellowknife Bay lake sediments. The D/H measured in this high-temperature water is ~3 times the D/H ratio in standard mean ocean water (VSMOW), in contrast to the present Martian atmosphere whose D/H ratio is ~6 times VSMOW (Mahaffy et al. 2014, 2015) and a primordial value close to 1 times VSMOW. This result shows that at the time of clay formation substantial loss of the Martian atmosphere had already occurred. However, these values allow for an approximate Global Equivalent Layer thickness of 100–150 m or more for a Martian water reservoir that allowed pooling in local topographic depressions, such as occurred at Yellowknife Bay (Mahaffy et al. 2014).

**Ancient Organic Compounds**

Measurements of the Rocknest soil, the Sheepbed mudstone, and Confidence Hills mudstone (the first sample drilled at the Pahrump Hills outcrop) indicate that, under specific conditions, organics may be preserved in ancient rocks on Mars. Simple alkanes of chlorinated hydrocarbons have been detected in all samples analyzed to date, and while greater abundances in samples relative to abundances in blanks suggest that some carbon may be indigenous to Mars, it is difficult to rule out contamination by terrestrial sources (Leshin et al. 2013; Glavin et al. 2013; Ming et al. 2014). However, C₂ to C₄ dichloralkanes were studied in further detail by Freissinet et al. (2014) and their abundances may be above the detection limit. In contrast, the abundances of more complex chlorobenzene compounds suggest a more convincing case for the presence of ancient organics preserved in rocks (Freissinet et al. 2014). FIGURE 7 shows samples analyzed from the Rocknest soil, the John Klein and Cumberland samples from the Sheepbed mudstone, and a sample from the Confidence Hills part of the Pahrump Hills outcrop. This last sample is a fine-grained sedimentary rock and possibly of lacustrine origin. A fourth sample of sedimentary bedrock was obtained at the Kimberley outcrop (Windjana sample), but this sample was processed in a manner to isolate heavier organic compounds and without the use of the hydrocarbon trap; thus the analysis may have missed lower-molecular-weight organic compounds if these were present.

The four samples presented in FIGURE 7 show that the Cumberland sample has significant quantities of chlorobenzene, above blank levels. Furthermore, samples analyzed at other drill and scoop sites show chlorobenzene levels comparable to those of the blanks (Freissinet et al. 2014). This important result underscores the value of analyzing multiple samples, including those collected after an initial detection, as a way of building confidence in earlier results. Unfortunately, it is hard to establish the source of the organics preserved at the Cumberland location in the Sheepbed mudstone. It may be that pyrolysis leads to breakdown of those initial compounds and to synthesis of new molecules that contain chlorine in their structure; this chlorine would likely be due to the presence of oxychlorine compounds in the rocks and soils. Alternatively, the cosmic radiation striking the Martian surface may facilitate reactions with inorganic chlorine, to form chlorine-containing organic compounds.

The unexpected abundance of these oxidizing compounds in ancient rocks provides a challenge for Curiosity as the mission goes forward. Nevertheless, the demonstration that
organics are likely preserved in ancient rocks on Mars represents a step forward in our understanding of how such molecules are preserved in the Martian rock record. In turn, this finding allows development of a strategy for the deliberate search for ancient biomarkers—assuming of course that life evolved on Mars. With one rover mission to Mars every decade, it’s important to have a strategy.

Here’s why. On Earth, a planet teeming with microbial life, it’s difficult to identify hydrocarbons in rocks that are billions of years old. The discovery of organics depends on three processes: (1) enrichment in the primary environment, usually by reduction of background sediment, which allows any organics to preferentially accumulate; (2) minimization of the effects of oxidative diagenesis during the conversion of sediment to rock (lithification); and (3) minimization of the thermal decomposition of organic molecules during burial. On a planet without plate tectonics and with a lithosphere that is thicker than Earth’s, thus reducing geothermal gradients, Mars is a better planet for retaining the risk of diagenetic diagenesis during burial. However, with its much thinner atmosphere, Mars poses a far greater risk of degradation by radiolysis once rocks are exposed at the surface (Farley et al. 2014; Mahaffy et al. 2015). Nevertheless, the point is that just as explorers of carbon in ancient rocks on Earth must optimize their chances of success, so must our robots on Mars.

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