Icarus 319 (2019) 1–13

Contents lists available at ScienceDirect

Icarus

journal homepage: www.elsevier.com/locate/icarus

A look back: The drilling campaign of the curiosity rover during the Mars science Laboratory's Prime Mission

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ARTICLE INFO

Keywords:
Mars
Surface
Instrumentation
Prebiotic environments

ABSTRACT

The Mars Science Laboratory (MSL) rover, Curiosity, completed its first Martian year, 669 sols (687 Earth days), of operation on June 24, 2014. During that time the rover successfully drilled three full depth drill holes into the Martian surface and analyzed the recovered material using onboard instruments, giving us new insights into the potential habitability of ancient Mars. These drill targets are known as 'John Klein' (Sol 182) and 'Cumberland' (Sol 279), which lie in the mudstones of the Yellowknife Bay formation, and 'Windjana' (Sol 621), which lies in the sandstones of the Kimberley formation. In this paper we will discuss what was necessary to procure these samples, including: 1) an overview of the sampling hardware; 2) the steps taken to ensure sampling hardware is safe when drilling into a target (i.e., evaluation of rock type, rover stability, prior testbed experience, etc.); and 3) the drilling parameters used to acquire these samples. We will also describe each target individually and discuss why each sample was desired, the triage steps taken to ensure it could be safely acquired, and the telemetry obtained for each. Finally, we will present scientific highlights obtained from each site utilizing MSL's onboard instrumentation (SAM & CheMin), results enabled by the drills ability to excavate sample at depth and transfer it to these instruments.

1. Introduction

On August 6, 2012, the Mars Science Laboratory mission's rover, Curiosity, landed in Gale Crater on Mars. The overarching science goal of its mission is to better understand the past habitability of the Red Planet by investigating the layered strata associated with the crater's central mound, Aeolis Mons ("Mount Sharp") (Grotzinger et al., 2012). To assist the mission in achieving this goal, the MSL rover is equipped with a drill, the first extraterrestrial autonomous drill designed by NASA capable of penetrating into solid rock (Fig. 1). This is also the first autonomous drill used on another planetary body since the Soviet Union landed the historic Venera missions on Venus in the early 1980s (Surkov et al., 1984). The only other notable attempt in the intervening years was ESA's ill-fated Beagle 2 Mars lander, which was equipped with a rock grinder capable of collecting cores up to 1 cm deep (Richter et al., 2002). The Mars Exploration Rovers (Spirit & Opportunity) were equipped with Rock Abrasion Tools (RATs), but these were only designed to grind away the upper 5 mm of a rock's surface (Gorevan et al., 2003). On June 24, 2014, after 687 Earth days, Curiosity completed its Prime Mission, 669 sols, or one Martian year, on Mars. During this time Curiosity successfully drilled three full depth drill holes on the planet's surface.

The reliable and robust collection of samples from a mobile robotic platform on rough terrain under highly variable conditions on the surface of Mars can create unique science and engineering challenges. The Science Team and Rover Planners had to work closely together to ensure successful drilling operations during the Prime Mission, as many associated activities had never before been attempted outside of an Earth-based testbed. Fortunately, this effort was complemented by the wide array of tools and instruments available to the team on the rover itself, as summarized by Grotzinger et al. (2012) (Fig. 2). These tools include mast-mounted cameras (Mastcams) and a Laser Induced Breakdown Spectroscopy (LIBS)-based instrument (ChemCam) that can gather elemental composition from a standoff distance of up to 7 m.

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https://doi.org/10.1016/j.icarus.2018.09.004
Received 14 June 2018; Received in revised form 11 August 2018; Accepted 5 September 2018
Available online 06 September 2018

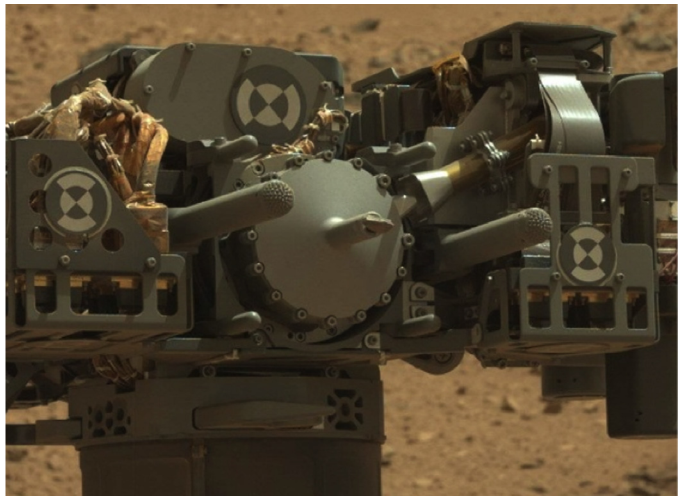

Fig. 1. Mastcam image of NASA's first extraterrestrial autonomous drill taken shortly after Curiosity's arrival on Mars and prior to commencement of first drilling campaign on Sol 65 (0065ML0334000000E2). Note that the Drill Stabilizers, on either side of the drill bit, are ~15 cm apart. *Image Credit:* NASA/JPL-Caltech/MSSS.

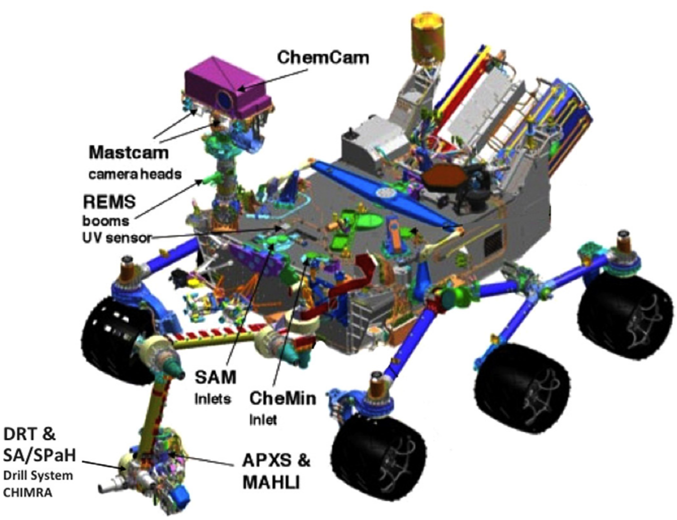

Fig. 2. Schematic image of the rover showing location of tools and instruments referenced in this paper, including mast-mounted Mastcams and ChemCam and turret-mounted APXS, MAHLI, DRT and SA/SPaH systems. SAM and CheMin are onboard instruments housed within the body of the rover. The Rover Environmental Monitoring Station (REMS) is also shown. See Fig. 3 for close up of turret configuration. Rover is 2.9 m long by 2.7 m wide by 2.2 m in height.

They also include a suite of tools and instruments at the end of the rover arm designed to both analyze samples in situ and to acquire samples for further analysis onboard the rover. The two contact science instruments on the rover arm include the Alpha-Particle X-ray Spectrometer (APXS), to determine elemental chemistry of a sample, and the Mars Hand Lens Imager (MAHLI), a high resolution, focusable color camera. The rover arm is also equipped with a Dust Removal Tool (DRT) and the Sample Acquisition/Sample Processing and Handling (SA/SPaH) subsystem. The SA/SPaH subsystem is responsible for both acquiring powdered samples from rock interiors via rotary percussive drilling and delivering these samples to the two analytical instruments on board the rover, SAM (Sample Analysis at Mars) (Mahaffy et al., 2012) and CheMin (Chemistry & Mineralogy) (Blake et al., 2012). These two instruments are the primary reason for the existence of the drill as they both require powdered sample for analysis. The SAM instrument combines a mass spectrometer, gas chromatograph, and tunable laser spectrometer to detect organic compounds and other (light) elements and compounds relevant to life. CheMin identifies and quantifies minerals using X-ray diffraction. Together the MSL payload, specifically SAM and CheMin, offers our best chance to understand the past habitability of Mars.

2. Overview of SA/SPaH hardware

The SA/SPaH subsystem is responsible for both acquiring powdered samples from rock interiors and delivering these samples to SAM and CheMin (Anderson et al., 2012; Jandura, 2010). It is comprised of two major components situated on the turret at the end of the rover arm, the Powder Acquisition Drill System and the sample processing unit CHIMRA (Collection and Handling for Interior Martian Rock Analysis) (Fig. 3). The Drill System is designed to collect powdered rock samples from inside the rover arm workspace volume, which consists of an upright cylinder 80 cm in diameter and 100 cm high positioned 105 cm in front of the body of the rover and extending 20 cm below the surface plane when the rover is on smooth flat terrain. Samples can be collected on slopes up to 20° from horizontal, though this was limited to 7° during the first few months of operation to minimize risk. It should be noted that the powdering bit design came at a cost to science: losing the ability to view intact drill cores. However, it simplified the overall system by removing the need for a rock crusher to pulverize the cores after collection (an early design consideration).

The business end of the Powder Acquisition Drill System is the Drill Bit Assembly (DBA), consisting of a commercial 5/8 inch (~1.6 cm) diameter hammer bit that cuts into rock targets using rotary percussion, a combination of hammering and rotation (Okon, 2010). To remove and collect cuttings from the hole, deep flutes machined into the bit shank allow powdered material to be augered up the flutes and into the sample chamber, confined by a steel collection tube surrounding the bit shank. Powdered material is held in the chamber until ready for transfer