Drilling on Mars: What We Have Learned from the Mars Science Laboratory Powder Acquisition Drill System (PADS), Robert. C. Anderson, Luther Beegle, and William Abbey, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA, Robert.C.Anderson@jpl.nasa.gov

Introduction: The collection of Martian samples from a mobile robotic platform on rough terrain creates unique engineering challenges to ensure not only reliability and robustness in a highly indeterminate Martian environment, but also the cleanliness of the samples ingested by onboard instruments, such as MSL CheMin and SAM. In the Sample Acquisition/Sampling Processing and Handling System (SA/SPaH), the Powder Acquisition Drill System (PADS) is the system responsible for acquiring powdered samples from the interiors of rocks [1]. In this presentation, we will summarize what we have learned from the first five drill holes on Mars and compare the results to the prelaunch MSL testing.

For MSL, PADS was designed to perform two main functions [2]; the first is to penetrate into the interior of rocks (Figure 1), the second is to collect the powdered sample in a size fraction appropriate for use by the onboard analytical instruments (< 1 mm or < 150 µm for SAM; < 150 µm for CheMin). The diameter of the drilled hole is 1.6 cm and the drill can collect interior samples to a depth of 5 cm, depending on the surface topography of the rock (sample depth capability is reduced for surfaces that are considerably concave). It should be noted that due to the design of the Drill and collection method, material from the upper ~1.5 cm of the drilled hole is not collected, but is deposited on top of the rock surrounding the drill hole (Figure 1). Once the Drill bit is lower than 1.5 cm depth, the sample is acquired up the collection tube and stored in chambers within the Drill Bit Assembly. After the sampling operation is complete, the Drill is stowed and then the sample is transferred to the CHIMRA subsystem for sieving and portioning (*see Anderson et al.,* 2012 *for complete detail of this subsystem*). The sample transfer is achieved through a series of turret poses with respect to gravity, provided by the robotic arm, combined with a dynamic environment generated by both the Drill's percussion and CHIMRA's vibration mechanisms.

Brief Summary of Samples Drilled: To date we have successfully drilled into 4 different rock samples and unsuccessfully attempted a fifth. Successful samples were John Klein (sol 182), Cumberland (sol 279), Windjana (sol 621) and Confidence Hills (sol 759) (Figure 1). There was a fifth sample that we were unable to drill, known as Bonanza King, attempted on sol 724 (Figure 2).

Target Assessment: As we have learned how the MSL rover operates, drilling operations have become more streamlined. Because there are single point failures within the PADS and CHIMRA systems, before each use of the Drill we perform a target assessment analysis of each new sample before authorizing the drilling, processing and delivery of samples. This process includes studying the geology of the site to understand the nature of the sample, if there are target reachability issues (i.e. rover arm placement, rover slip risks, etc.) and to determine if we have experience drilling into that type of material in terms of morphology of the target, likely physical parameters of the rock and likely mineralogy of the sample. For example, we use APXS and ChemCam data to characterize the target, Hazcams to understand the physical state of the rover, and a mini-drill hole to understand physical properties of the material. At the target called Bonanza King (Figure 2), the target assessment indicated a target of high scientific value that posed little risk to the rover hardware but would most likely be very difficult to acquire. During the mini-drilling activity, the rock moved enough to cause a drill fault. The hardware acted exactly as it should have, resulting in a "successful failure". As we have gained more experience drilling on Mars, the target assessment has become more streamlined.

John Klein **(Fig. 1a):** The first rock the MSL rover drilled into was a Martian rock called John Klein. It is part of the Sheepbed mudstone deposit in the Yellowknife Bay area of Gale Crater and is interpreted to represent an ancient lake environment. The MAHLI image in Fig. 1a reveals the presence of gray colored drill tailings and a good view of the interior wall. John Klein appears to be a fine-grained, homogeneous mudstone, crosscut by a network of sulfate-filled hairline fractures. The vertical array of pits which, can be seen inside of the borehole, resulted from use of the laser-shooting ChemCam instrument on this target.

Cumberland **(Fig. 1b):** Cumberland was the second rock drilled by the MSL PADS system. Powder derived from Cumberland resembles the material collected at John Klein and lies about nine feet (2.75 meters) farther west of John Klein. Both samples are within a shallow depression called Yellowknife Bay. One of the most significant finds from the Cumberland drilled sample was the detection of organic molecules, the first definitive detection of organics in surface materials on Mars.

Windjana **(Fig. 1c):** The sandstone target's informal name comes from Windjana Gorge in Western Australia. The drill tailings from this rock are darker-toned and less red than we saw at the two previous drill sites.

Confidence Hills **(Fig. 1d):** This target was the first rock drilled by PADS after Curiosity reached the official base of Mount Sharp. CheMin analysis of the powder found evidence for the iron-oxide mineral hematite in this rock. This is different from the rocks examined at Yellowknife Bay that contained other iron oxides, predominantly magnetite. A much higher ratio of hematite to magnetite at Confidence Hills indicates that the ancient environmental conditions recorded in this rock were more oxidative than conditions recorded in the Yellowknife Bay rocks.

REFERENCES: [1] R. C. Anderson et al., *Space Sci. Rev.*, (2012) DOI 10.10077/s11214-012-9898-9. [2] L. Jandura, in *Proc. 40th AMS*. [3] A. Okon, in *Proc. 40th AMS*.

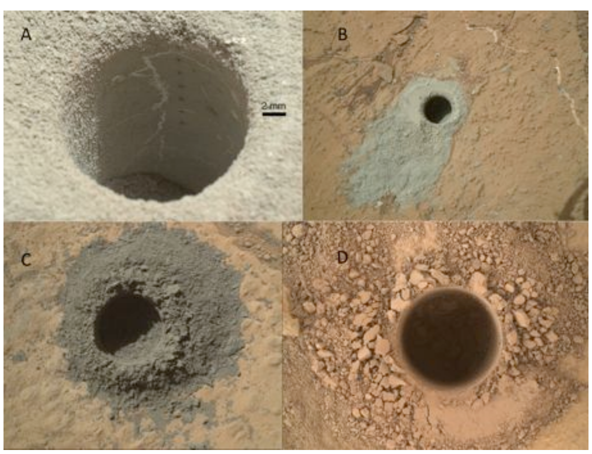

Fig. 1: **(a)** John Klein; **(b)** Cumberland; **(c)** Windjana; **(d)** Confidence Hills. The diameter of hole is about 0.6 inch (1.6 centimeters).

Fig. 2: The Bonanza King site after DRT-ing the rock (left), and after the failed mini-drill hole (right). Notice how the slab has shifted during the mini-drill attempt and appears to be partially depressed into the subsurface material. This resulted in a 'successful' drill failure when rover hardware detected the shift and halted activity before damage could be done to the PADS system. Dirt Removal Tool ellipse is roughly 40 x 60 mm.