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ChemCam investigation of the John Klein and Cumberland drill holes and tailings, Gale crater, Mars

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ABSTRACT

The ChemCam instrument on the Mars Science Laboratory rover analyzed the rock surface, drill hole walls, tailings, and unprocessed and sieved dump piles to investigate chemical variations with depth in the first two martian drill holes and possible fractionation or segregation effects of the drilling and sample processing. The drill sites are both in Sheepbed Mudstone, the lowest exposed member of the Yellowknife Bay formation. Yellowknife Bay is composed of detrital basaltic materials in addition to clay minerals and an amorphous component. The drill tailings are a mixture of basaltic sediments and diagenetic material like calcium sulfate veins, while the shots on the drill site surface and walls of the drill holes are closer to those pure end members. The sediment dumped from the sample acquisition, processing, and handling subsystem is of similar composition to the tailings; however, due to the specifics of the drilling process the tailings and dump piles come from different depths within the hole. This allows the ChemCam instrument to analyze samples representing the bulk composition from different depths. On the pre-drill surfaces, the Cumberland site has a greater amount of CaO and evidence for calcium sulfate veins, than the John Klein site. However, John Klein has a greater amount of calcium sulfate veins below the surface, as seen in mapping, drill hole wall analysis, and observations in the drill tailings and dump pile. In addition, the Cumberland site does not have any evidence of variations in bulk composition with depth down the drill hole, while the John Klein site has evidence for a greater amount of CaO (calcium sulfates) in the top portion of the hole compared to the middle section of the hole, where the drill sample was collected.

1. Introduction

The ChemCam instrument on the Mars Science Laboratory (MSL) rover, also called *Curiosity*, consists of a Laser Induced Breakdown Spectroscopy (LIBS) instrument which allows for ~400 μm diameter chemical analyses from 1.5 m to 7.0 m away, as well as a panchromatic Remote Micro Imager (RMI) for context. These analyses provide geochemical context for the mineralogical analysis of drill samples by the internal instruments, Chemistry and Mineralogy (CheMin) and Sample Analysis at Mars (SAM); furthermore, the fine spatial resolution of ChemCam, as applied to veins and other fine-scale diagenetic features, provides an important complement to the bulk composition from the internal instruments or the Alpha Particle X-Ray Spectrometer (APXS), e.g., McLennan et al. (2014); Mangold et al. (2015).

After landing on Mars, the Curiosity rover briefly drove away from its main science objective of Mount Sharp and towards a secondary science objective at Yellowknife Bay. The objective in this detour was to sample a local region of higher thermal inertia observed from orbit, which turned out to be exposed sandstone and mudstone, in contrast to the gravelly surface of the Bradbury Rise on which the rover landed (Grotzinger et al., 2014).

Yellowknife Bay was topographically the lowest point on the rover traverse. This campaign included drilling into two locations

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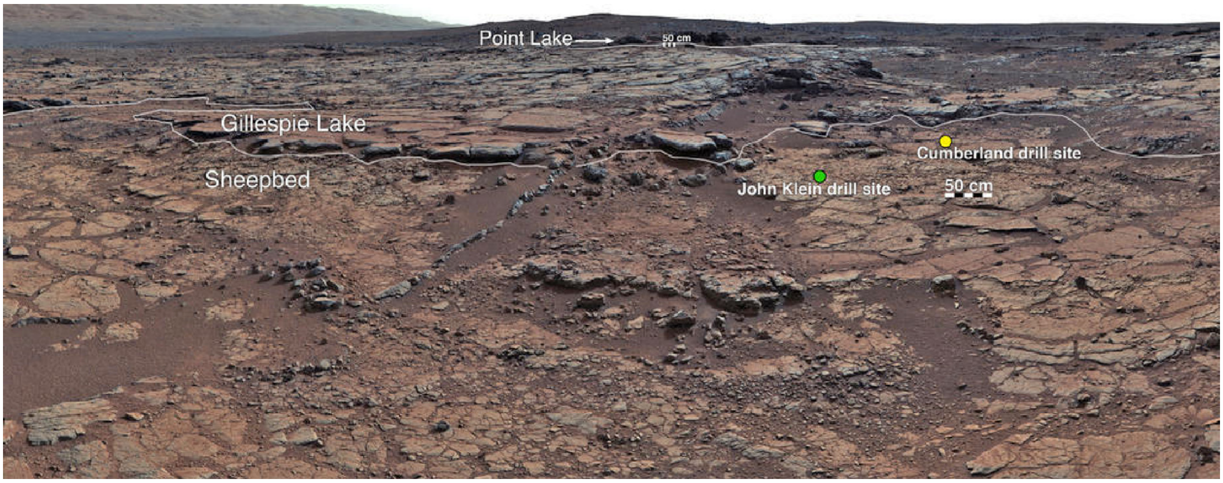

Fig. 1. MastCam mosaic of the Yellowknife Bay formation with the two drill sites marked with the colored circles.

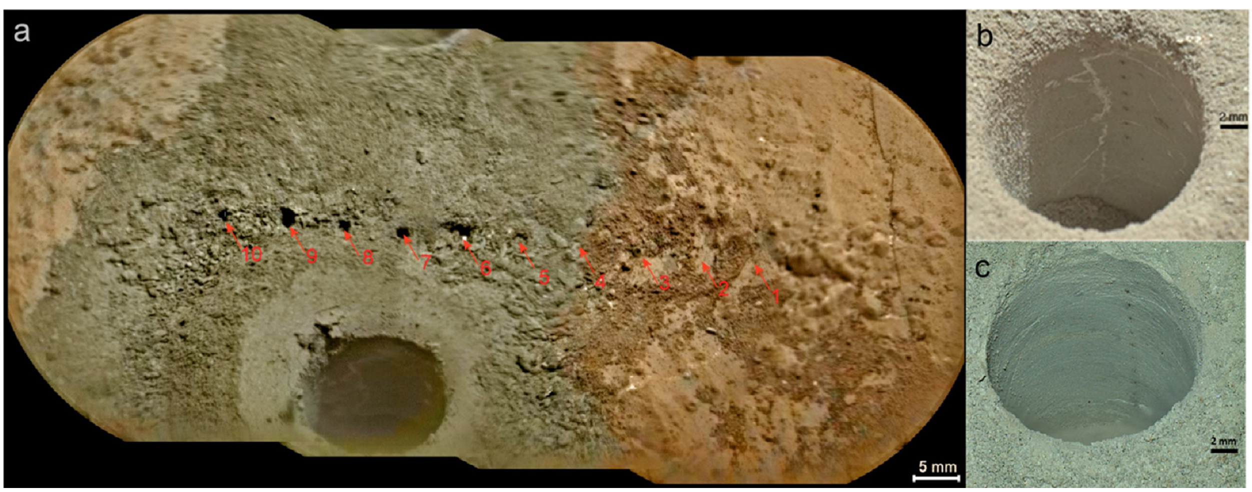

Fig. 2. (a) Merged RMI and MastCam mosaic of the John Klein drill hole and tailings. The tailings are grey on top of the red surficial dust. (b) MaHLI image of the John Klein Drill hole, veins and pits from the ChemCam laser. (c) MaHLI image of the Cumberland Drill hole, veins and divots from the ChemCam laser. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).

in the Sheepbed Mudstone, termed John Klein and Cumberland; ChemCam was used to characterize the surface of the drill target, the walls of drill holes, and drill tailings. Fig. 1 displays a MastCam mosaic of Yellowknife Bay with the drill sites marked, and Fig. 2 is a RMI mosaic (Le Mouelic et al., 2015) of the John Klein drill hole and tailings, as well as MaHLI images of the drill hole walls. The results of this first use of the drill sampling system, including the nearby Cumberland drill hole, confirmed that the Sheepbed unit represented an ancient lacustrine environment (e.g., Grotzinger et al., 2014). The Sheepbed unit in the areas around the rover traverse, including the vicinity of the drill holes contains veins, nodules, and Mg-rich ridges (Stack et al., 2014; Léveillé et al., 2014; Nachon et al., 2014). The veins are fracture-fill material within the Sheepbed Mudstone; they have calcium sulfate composition and consist of the minerals anhydrite and bassanite (Nachon et al., 2014; Vaniman et al., 2014). The nodules are roughly spherical diagenetic features likely to be concretions with Fe-rich cement (likely magnetite), formed from aqueous alteration of the mudstone by diagenetic pore fluids, and having a composition not greatly dissimilar to the mudstone (Stack et al., 2014). The Mg-rich ridges are diagenetic features in the mudstone that are more resistant to erosion than the rock; the ridges have a composition similar to smectite clays with cement layers and are enriched in Mg (Léveillé et al., 2014; Siebach et al., 2014).

Because the sample provided to the rover's internal instruments at each site is a small amount of material from a specific portion of the drill hole (the lower portion), an important question is whether this sample has the same composition as the materials analyzed by ChemCam and APXS at the surface near the drill sites, and by ChemCam down the upper portion of the drill holes, especially given the presence of the diagenetic features. The elemental composition of rock sampled near the hole is used to infer the composition of the x-ray amorphous phase (e.g., Morris et al., 2015), assuming that the nearby chemistry is the same as that of the lower portion of the drill hole. If they in fact differ, the inferred amorphous composition will be incorrect. ChemCam has the unique capability of understanding compositional differences within the drill hole as well as the tailings and dump pile. This paper presents a detailed examination of the ChemCam analyses of the drill target, thereby providing an important chemical context for the analysis of the drill samples by the CheMin and SAM experiments (Vaniman et al., 2014; Ming et al., 2014).