STRATEGY OF INVESTIGATING IGNEOUS ROCKS WITH THE PLANETARY INSTRUMENT FOR X-RAY LITHOCHEMISTRY (PIXL) IN THE MARS 2020 MISSION.

Yang Liu[1,*], Abigail Allwood[1], Joel A. Hurowitz[2], Christopher M. Heirwegh[1], William T. Elam[3]. [1]Jet Propulsion Laboratory, California Institute of Technology (Caltech), Pasadena, CA 91109, USA; [2]Division of Geological and Planetary Sciences, Caltech, Pasadena, CA 91125, USA. Stony Brook University, Department of Geosciences, Stony Brook, NY, 11794. 3 Applied Physics Laboratory, University of Washington, Seattle, WA 98195. *yang.liu@jpl.nasa.gov.

Introduction: The Mars 2020 mission contributes to the NASA's Mars Exploration Program science strategy of seeking signs of life by exploring an ancient lake delta in Jezero crater that likely has been habitable. The Mars 2020 rover will also select and cache a set of compiling rock and soil samples to be returned by future missions.

Investigation of igneous rocks is important to the science goals and objectives of the Mars 2020 mission. The lake delta in Jezero crater provides an excellent repository of diverse igneous rocks that have been delivered from the surrounding, ancient Martian crust. Some, if not all, of these igneous rocks are likely not present in our current meteorite collections (e.g., [1]). Therefore, *in situ* investigation of igneous rocks with the Mars 2020 science instruments will provide chemical and mineralogical information that enables selection of key samples to be cached and returned. Moreover, understanding the mafic floor unit is also an important part of the contextual constraint of astrobiology investigations. Here, we discuss the role of PIXL in such endeavor.

PIXL: The Planetary Instrument for X-Ray Lithochemistry (PIXL) is a microfocus X-ray fluorescence spectrometer that consists of a sensor assembly (SA, Fig. 1) and a body unit. The SA will be mounted in the turret of the Mars 2020 rover arm. The key components of the PIXL SA are an X-ray source, two energy-dispersive silicon drift X-ray detectors, an optical fiducial system, and a hexapod system. The optical fiducial system contains a micro-context camera, structure-light illuminators, and a flood light illuminator. The flood light illuminator provides illumination for images for the context camera. It is made of RGB and UV LEDs. The structure-light illuminators project 3x5 and 7x7 laser spots onto the surface of the target, which are used to gauge instrument-to-target distance. The X-ray source consists of a Rh-target X-ray tube attached to a silica polycapillary optic. Nominal operation of the tube at 28 kV and 20 µA produces X-rays that are focused by the polycapillary optic to a 100-150 µm diameter beam spot at the target rock surface, when the front of the PIXL SA is 25 mm away from the rock. The energies and intensities of emitted fluorescent X-rays are counted using a pair of energy-dispersive silicon drift X-ray detectors. The hexapod system moves PIXL in X-Y-Z dimensions, scanning the X-ray beam across the surface of rocks at adjustable step sizes of >30 µm.

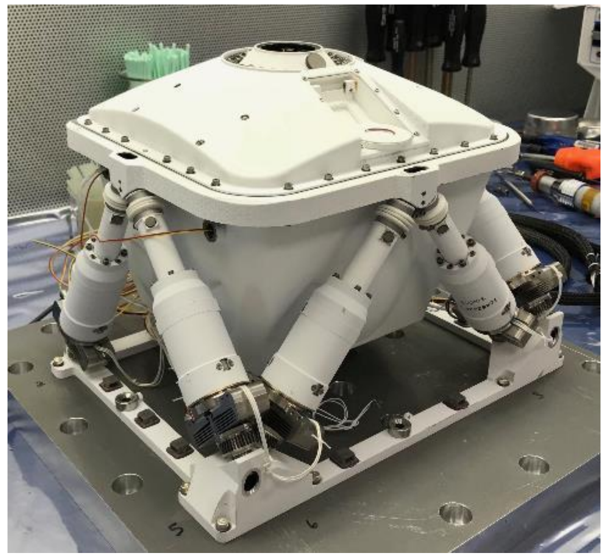

Fig. 1. *Engineering model (EM) of the PIXL sensor assembly.*

The design of PIXL enables its versatile application to petrology and astrobiology [2]. PIXL is capable of detecting major, minor, and several trace elements of key interests to geology and astrobiology, and has sensitivity to detect some trace elements at very low concentrations. The small spot size of PIXL X-ray beam allows the characterization of elemental chemistry of small features in Martian rocks, such as single mineral grains and veinlet. The small beam size and the ability to scan the rock surface offer texturally correlated elemental information, such as discerning different minerals or determining the compositional zoning of minerals. PIXL's high degree of spatial resolution and capacity to yield the textural-correlated chemistry distinguish it from previous XRF instruments on Mars, which were focused on bulk lithochemistry rather than small-scale chemical variations [2].

Methodology for *in situ* analysis: PIXL is designed to conduct line, grid, and map scans of rock targets with hundreds of X-ray analyses at pre-defined spatial intervals. The step size between each X-ray analysis is adjustable. The XRF data collected will be plotted on the micro-context image of the rock target. All X-ray analyses can be added together to generate a sum spectrum of the target rock, which can be then quantified to generate an estimate of the bulk composition for the target rock. Individual X-ray analysis, if collected with sufficient integration time, will provide elemental compositions of the analytical spot.

Distinction between extrusive and intrusive rocks. Extrusive rocks are quenched relatively rapid in comparison to the intrusive rocks. We will be able to discern extrusive from intrusive igneous rocks using a finely-spaced map scan. The resulted elemental maps will be analogous to those generated by electron microprobe, which allow delineation of minerals, estimation of their sizes and petrographic relationships. The size distribution of the major minerals, such as pyroxene, can further provide insights on the cooling history of the rock.

Classification of igneous rocks. Distinction between mafic and silicic rocks can be achieved through several approaches. First, a bulk rock composition can be obtained of a given scan by calculating the sum of all X-ray analysis spots. These data can be then plotted in the total alkali versus silica diagram. If a map scan was used, we can further assess if the rock is volcanic or intrusive as discussed above. Second, for a map scan, we will use the mineral modal percentages inferred from elemental maps to constrain the rock type.

Petrogenesis. Mineral chemistry and the petrography of the rock are needed to assess the formation of the igneous rocks. Such information is readily obtained from a map scan. The bulk rock composition derived from the scan will be compared to the mineral chemistry to examine open versus closed system evolution of the rock. Moreover, the bulk rock composition can be casted into the CIPW norm. Comparison between the normative mineralogy with the observed mineralogy also offers insight into processes that affect the rock as a system.

Application of PIXL to the investigation of igneous rocks in the Mars 2020 mission:

The *in situ* investigation of igneous rocks by PIXL is important for deciding which igneous samples should be selected for return to Earth, where high resolution laboratory studies will provide important insights on the formation, differentiation, and evolution of Mars. Because a limited number of samples can be cached, it is important to select interesting igneous rocks that can advance the understanding of Mars as geological system.

Questions for this endeavor include. 1) Is a fine-grain mafic rock, e.g., Jake_M, igneous [6]? If we see a rock like Jake_M, what approach do we use to answer this question? PIXL's ability to observe grain shapes, sorting, boundaries, and compositional variations within grains is important to assess whether it is igneous, metamorphic or sedimentary, and examine the diagenetic history if proven to be a sedimentary rock. 2) If diverse crustal rocks as observed in Gale crater [1, 6] are present in Jezero crater, what are the nature of large crystals? How are they affected by transporting mechanisms (impact or fluid flow)? PIXL will be able to assess the nature of the light-toned crystals and the dark matrix via either a small map analysis placed on these phases, respectively, or processing chemical groups obtained by a larger map. Alteration rim or impact glasses, if present, in the PIXL analysis will provide insights on the secondary processes occurred in the rock. 3) For a mafic rock, how do we assess if it differs from those already in our meteorite collection? It is desirable to return a new type of mafic rock as it will give us complementary information on the evolution and differentiation of Martian crust and mantle. A map scan with sufficient integration time by PIXL will generate major and trace element compositions for assessing the similarity to Martian meteorites. Moreover, the study of shergottites (mafic meteorites) shows that these mafic samples divide into geochemical groups [3-5]: enriched, intermediate and depleted groups. Enriched group contains higher abundances of incompatible elements (e.g., Rb, Nd, REE), and is more enriched in light REE (La, Ce) than heavy ones (Yb, Lu). It will be interesting to evaluate if igneous crustal rocks at Jezero crater display similar groupings. However, the abundances of La, Nd, Yb, and Lu (<~1 ppm) are below the detection limits for PIXL, where Rb and Ce in enriched group reaches ~10 ppm (e.g., [5]). With the abundant geochemical data in the literature, we will explore the proxies that *can* be detected by PIXL for distinguishing these geochemical groups.

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