Size of heavy mineral grains from PIXL datasets for characterization of sedimentary environments. L. P. O'Neil[1], M. Tice[1], T. Kizovski[2], M. J. Zawaski[1], A. J. Brown[3]. [1]Texas A&M University, Texas, USA, (oneil@tamu.edu) [2]Brock University, Ontario, Canada. [3]Plancius Research, Maryland, USA

Introduction: The *Perseverance* rover landed on Mars in February 2021 in Jezero crater. It started on the crater floor and traveled up section into a delta, observing a variety of igneous and then sedimentary outcrops. It uses a suite of science instruments for analysis, and here we focus on data collected by the Planetary Instrument for X-ray Lithochemistry (PIXL), because it provides high-resolution geochemical information [1]. PIXL collects elemental data with high spatial resolution, with a spot size of ~120 microns in diameter. Over several hours, it collects numerous spectra to generate a map of elemental abundances across several millimeters of a rock's surface. It has been used on both natural, weathered surfaces as well as fresh surfaces with the top 5-10 millimeters abraded away. It uses x-ray fluorescence (XRF) to quantify elemental abundances in each spot in a map [2].

Heterogeneities in rock composition are difficult or impossible to detect on a scale below PIXL's resolution. In a single analytical spot, the PIXL software assumes a heterogeneous sample. Absent other information, PIXL must make this assumption because it is incapable of resolving heterogeneities with a single beam spot. The micro-context camera has only slightly better resolution, and it therefore cannot significantly improve our knowledge of small grain geometries. Images taken by other instruments are often not collected at the same angle, and it can be very difficult to correlate PIXL data with pixels on these images. This means that component grains smaller than about 120 microns appear to be mixed with the surrounding grains in the PIXL data, and are unresolvable.

On Earth, minerals can be considered heavy when they exceed a density of 2.9 g/cm^3. On Mars, mafic minerals typically found on the surface (e.g., olivine and pyroxene) are heavier, and the heavy mineral cutoff should be higher for the purposes of analyzing sedimentary deposits. We suggest that minerals having density greater than 4 g/cm^3 be considered heavy minerals in Martian sediments and sedimentary rocks. During sediment transport, less abundant, smaller, denser grains are deposited along with larger, lighter grains, and all can be included in the resulting sedimentary rock. Because they have a distinct composition, we can observe the heavy minerals with PIXL.

Methods: We seek here to detect detrital mineral grains and infer grain size from the measured fluorescence intensity of a characteristic element. The characteristic element (e.g., Zr, S, Ti, or Cr) is selected to have as great a contrast as possible between concentrations in the host rock and in the mineral of interest. For example, Zr is found in high concentration in zircon and baddeleyite but in trace concentrations in olivine, so we use Zr to observe zircon and baddeleyite grains. We assume that these heavy minerals are in very low abundance and are well mixed in the sedimentary rock, so if such a grain is detected in two adjacent PIXL measurement spots, we conclude that there is one grain straddling the measurements and combine them accordingly.

The depth distribution of heavy mineral grains affects their observed size. Heavy elements often make good characteristic elements for heavy minerals. The characteristic fluorescence energies of these elements are at higher energies than the fluorescence for more common, lighter elements such as silicon. These high-energy x-rays penetrate further through the rock before being re-absorbed, so we can detect these elements deeper in the rock than lighter elements. However, fluorescence from deep in the rock gets attenuated on

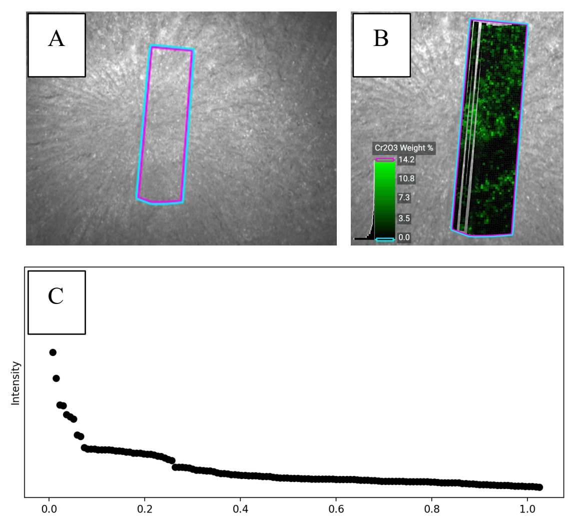

Figure 1: Chromite in Novarupta. Panel A shows an image of the area scanned by PIXL taken by the micro-context camera. It is in the Novarupta abrasion patch on a fine sandstone. Panel B shows the concentration map of Cr as measured by PIXL. Panel C shows the calculated depth of each chromite grain relative to intensity. We expect this to follow an exponential curve, and deviations from this suggest that the grains are not distributed evenly with depth. The y-intercept indicates the observed size of a grain sitting on the surface, and this value is used to calculate the grain size.

the way out to the detector, so a grain below the surface appears smaller. This effect leads to an exponential distribution of observed sizes if the grains are evenly distributed with depth, and we can fit the data to calculate the average size of a grain as it would appear sitting at the surface. An example of chromite grains is shown in Figure 1.

Discussion: Grain size in sedimentary rocks reveals the conditions of the sedimentary environment in which the sediment accumulated. Density and size are related to flow speeds, and variations in size and sorting can also reveal environmental conditions [3]. The process presented here is meant to characterize the grain size, but the results may misrepresent the overall rock in a few ways.

There are often systematic differences between the behavior of heavier minerals and the behavior of lighter, surrounding grains because of the difference in density. However, heavy minerals can be the only option for measuring grain size. In some cases, partial grain dissolution or cement growth can obscure original grain boundaries, making paleocurrent estimates from grain size distributions difficult or impossible. In such cases, however, many detrital heavy minerals preserve their original boundaries and compositions. Their diameters can then be used to estimate the average grain sizes of co-transported light mineral grains after accounting for density differences.

This estimation method makes several assumptions. First, we assume that heavy minerals are evenly distributed in the rock. This is not always the case, as in sedimentary lag deposits we would expect heavy minerals to be concentrated in discrete layers or stringers. Second, we assume that heavy minerals are only rarely in contact, which would cause multiple grains to appear as one large grain. This is particularly likely when the method is applied to igneous rocks, where minerals such as spinels occur in clusters or to sedimentary lags, where heavy minerals are hydraulically concentrated. Future work will examine how relaxing these assumptions affects size estimates and explore ways to compensate for common situations in which they do not apply.

Conclusion: Here we have developed a method for determining the grain size of sedimentary rocks on Mars using PIXL data. In the case of chromite shown in Figure 1, we have inferred a grain size a factor of 5 smaller than the PIXL spot size, which greatly extends our analytical capabilities.

References: [1] Allwood, A. C. et al. (2020) *Space Science Reviews,* 216(8), 1-132. [2] Heirwegh, C. M. et al. (2022) *Spectrochim. Acta B.,* **196** 106520. [3] Slingerland, R. and Smith, N. D. (1986) *Annu. Rev. Earth Planet. Sci.* 14, 113-147.