Introduction: Since sol ~2300 (January 2019), the Curiosity rover has been traversing through Glen Torridon (GT), a trough on the northern slopes of Aeolis Mons (informally known as Mt. Sharp) in Gale crater, Mars (Fig. 1). Curiosity descended into GT from the Vera Rubin ridge (VRR), a linear topographic feature that defines the northern edge of the trough (Fig. 1). From orbital data, the rocks in GT have been interpreted to exhibit a high spectral clay signature, which is distinct from the strong hematite signature of VRR rocks and sulfate signatures in stratigraphically higher rocks [e.g., 1, 2]. Because these strata may record a period of depositional and climatic change on early Mars [e.g., 2], characterizing the depositional history preserved in them has been a key priority for the Mars Science Laboratory mission.

In this study, grain size estimates determined using ChemCam Laser Induced Breakdown Spectroscopy (LIBS) data and the Gini Index Mean Score (GIMS) [3, 4] were coupled with textural information observed in images to characterize grain size and facies changes in GT strata. This information was then used to make preliminary interpretations of the depositional environments preserved in GT.

Methods: Visual inspection of grain-size is rarely available for rocks investigated at field sites on Mars due to limited image coverage and resolution. Grain sizes can also be estimated using the GIMS, a composition-based grain-size proxy that uses ChemCam LIBS data [3]. The GIMS quantifies the compositional variability between ChemCam LIBS observation points on a rock target. The diameter of each point vaporized by the ChemCam laser ranges between 0.4-0.6 mm (medium to coarse sand in size) [5, 6]. Rocks with grains considerably smaller than the LIBS observation points (e.g., mudstone) yield bulk rock compositions and low point to point variability [7-11] resulting in low GIMS values [3]. In contrast, if the rocks have variable grain composition, those with grains about the size of or larger than the LIBS observation points (e.g., sandstone) may have compositional contributions from individual grains and have higher point to point variability [7-11] resulting in higher GIMS values [3]. The presence of sand can be inferred for coarse rocks with non-uniform grain compositions and diameters smaller than ~2 mm in size [very fine gravel; 4]. Because other factors can cause compositional variability between LIBS points (e.g., diagenetic features), the ChemCam LIBS data was filtered using the methods outlined in [3] before the GIMS analysis.

GIMS grain size results: GIMS results for 134 GT rocks (sols 2300-2480), suggest that 84% of GT rocks have mud-sized grains and are likely mudstones. Sand was also detected in GT rocks at specific stratigraphic intervals (Fig. 2a), suggesting the presence of medium to coarse sandstones. Compared to the VRR, GT has a higher proportion of mudstones and coarser sandstones (Fig. 2b). In contrast, the VRR has a higher proportion of siltstones and possibly very fine sandstones (Fig. 2b).

Image based facies correlations to GIMS grain size estimates: For GT rocks, GIMS grain sizes were coupled with textural observations made using images taken by the Mars Hand Lens Imager (MAHLI) and Mastcams to group the rocks by sedimentary facies.

Glen Torridon facies with mud-sized grains: Five facies were identified that are interpreted to have mud-
sand-sized grains. Two of these facies have planar lamination and are red and light-toned in color. One of these facies has a rubbly outcrop texture and the other is more coherent. The third facies consists of planar-laminated rocks with a darker red color and a blocky texture due to polygonal cracks. The fourth facies consist of rocks that have alternating thin (~150-450 µm) and thick laminations (~500 µm-1 mm) and are red and light-toned in color. Sometimes the thinner laminae in the fourth facies appear to be cross-stratified. These four facies correspond to rocks from the Jura member [13]. The fifth facies consists of rocks in the Knockfarril Hill member [13] that appear to be cross-laminated and are red and light-toned in color.

The possible presence of cross-lamination in the fourth and fifth facies suggests that the grains may have been transported as bedload, which is typically associated with sand-sized grains. If these rocks are indeed cross-stratified, it is possible that the sand-sized grains are mud aggregates (for terrestrial examples see [14]) or that the rocks have a high ratio of mud to sand sized grains. Further detailed analyses are needed to reconcile the cross-lamination with the mud-size interpretation.

Glen Torridon facies with sand-sized grains: Three facies were identified that are interpreted to have sand-sized grains for rocks from the Knockfarril Hill member. Two of these facies are characterized by cross-laminated rocks. One facies is dominated by rocks that are grey-toned and the other by those that are red and light-toned. The third facies consists of layered rocks that are red and dark-toned in color.

Sand grains were confirmed in MAHLLI images for some of the inferred sandstones (e.g., Fig. 3). The grains vary from white to black in color. The color differences likely correspond to varying grain compositions. Co-investigation of grains using images and compositional data from the ChemCam and APXS instruments will help constrain stratigraphic and textural relationships between grain color and composition.

Interpretations and Discussion: Stratigraphic grain size transitions from mud to very fine sand are important for reconstructing past depositional environments, because they usually reflect changes in flow regime from suspension to traction transport. These grain sizes are challenging to resolve in images but provide the best GIMS grain size estimates [3]. Thus, the GIMS analysis of GT documents systematic variations in grain size that were not captured from image-based analyses. However, when possible GIMS grain size estimates are confirmed using MAHLLI images.

The GIMS grain size distributions in GT record variations in depositional environment through time. Overall, there does not appear to be a significant change in the dominant rock lithology between GT and the rest of the Murray formation. This continuity in mudstone facies suggests that the GT rocks are also part of the Murray formation and that the mud was deposited in a low energy lake environment. However, the GIMS analysis shows that there are specific stratigraphic intervals with rocks are interpreted as fine to medium grained sandstones (Fig. 2a), suggesting deposition in a fast flow, either an aeolian or fluvial environment.