Ground-based stratigraphic correlation of the Jura and Knockfarril Hill members of the Murray formation, Gale crater: bridging the Vera Rubin ridge – Glen Torridon divide

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Introduction: Lithostratigraphic correlation represents a fundamental tool for interpreting the depositional history and stratal architecture in sedimentary rock successions. On Earth, this is accomplished by measuring the thickness and lithologies through a stratigraphic unit at multiple places along and across strike, then linking similar rock types. Across kilometer-scale distances, such correlations have the potential to not only connect lithologies, but also identify units that were deposited at or near the same time as a single body of sediment. Prior to the exploration of Gale crater by *Curiosity*, this type of correlation had not been possible on Mars because of the requirement for making ground-based observations of the same unit in multiple locations. This paper reports on stratigraphic correlation of the Jura and Knockfarril Hill members of the Murray formation across the Vera Rubin ridge (VRR) and Glen Torridon (GT) areas, which are separated by topographic, mineralogic, and spectral boundaries.

Stratigraphic context: Prior to *Curiosity* landing in Gale crater, the area intended study area had been mapped using orbiter-based cameras and spectrometers, which characterized distinct "orbitally defined units." Two such examples included a hematite-bearing ridge (now VRR) and a clay-bearing unit (CBU) exposed in GT. Data collected by *Curiosity* have greatly expanded our ability to resolve the rock types and compositions, sedimentary structures, and stratal orientations. Furthermore, orbiter-instrument and rover-based observations provide the foundation for correlation. For nearly 2000 sols and 300 m of elevation ascent, *Curiosity* has been used to document eight members of the Murray formation, which record deposition in lake and lake-margin environments. Within a few degrees, stratigraphic units comprising the Murray formation are flat, so that elevation gain approximates stratal thickness. With this approach, the *Curiosity* science team has generated a time-ordered stratigraphic column of rock type encountered along the rover traverse as a function of elevation (Fig. 1). One important caveat is that the overall stratigraphic column contains kilometers of lateral observations.

Jura member (Jm): Strata comprising VRR have been divided into two members dominated by laminated mudstone (Pettegrove Point member overlain by Jura member). On the north side of VRR, the base of the Jura is identified by a ~6-meter-thick, distinct, resistant/recessive weathering unit (e.g. targets "Foula" and "Galloway") expressed as a small topographic ridge relative to the underlying Pettegrove Point member. This occurs at about -4155 m elevation at the eastern extent of the traverse across the top of the ridge is in about 6 m thick. Subsequently, *Curiosity* descended into a valley below, parallel to, and south of VRR. Based on topographic changes, outcrop expression and spectral signatures that are very different from VRR, GT (and the CBU) was mapped as a distinct geologic region. Based on macrotextures and morphologies observed from orbit, the CBU was subdivided into the smooth-ridged and fractured parts. Prior to investigation, it was unclear whether Jura member strata on the north side of VRR projected into GT or represent an entirely different lithologic assemblage. At about -4155 m elevation and through a similar thickness in the Glen Torridon trough, we identified the same distinct resistant/recessive weathering unit (e.g., targets "Flodigarry" and "Woodland Bay") as previously encountered. Consequently, we correlate the Jura member from VRR into GT using this distinct lithofacies that defines its base, making rocks of the smooth-ridged CBU stratigraphically equivalent to those comprising the upper part of VRR.

Knockfarril Hill member (KHm): As *Curiosity* began descending into Glen Torridon at the western end of VRR, we encountered a distinct, meters-thick cross-bedded sandstone (Knockfarril Hill). Initially this was thought to represent a sandstone interlayer at the top of the Jura member. From the lowest explored elevation in GT, *Curiosity* resumed gaining elevation and encountered cross-bedded sandstone at Teal Ridge and Harlaw at about the same elevation (-4140 m) as Knockfarril Hill, but hundreds of meters away. Cross-bedded sandstone (recognized as fractured CBU) occurs above this elevation along the traverse through an area informally called the "visionarium," indicating that sandstone is likely to be widespread in the basin. Consequently, we correlate all the localities showing cross-bedded sandstone at this elevation as a continuous stratigraphic package (and named Knockfarril Hill member) that again connects strata observed on VRR with strata exposed in GT, and which overlies the Jura member.

Implications: Stratigraphic correlations presented here carry a number of important local and broader-scale implications. That the same strata occur in two regions that have distinctly different outcrop/topographic patterns (i.e., ridge versus valley), and spectral signatures demonstrates the importance of in-situ rover observations in building models of stratigraphy and geologic history. Based on orbiter data alone, this correlations would not have been possible. Furthermore, such a conclusion indicates that geologic units defined from orbiter-based platforms do not necessarily provide guidance about recognizing time-ordered depositional successions.

Identification of the Knockfarril Hill member as a widespread cross-bedded sandstone indicates a significant change in the depositional environment in Murray formation stratigraphy, which has been dominated by nearly continuous lacustrine deposition for more than 200 m of compacted stratigraphic thickness. Although the depositional environment of the KHm is at this time of this writing still actively under investigation, the sedimentology and sedimentary structures represent an important change in depositional processes and environment, and potentially paleoclimate.

On Earth, stratigraphic correlation is a critical tool for helping to define sedimentary architecture, potentially define time-equivalent sedimentary packages, and provides needed datum constraints for interpreting depositional environments and their areal extent. On Mars, this has not been really possible to accomplish in this detail until the exploration Gale crater stratigraphy by *Curiosity*, which has permitted observations at the same elevation, and thus, stratigraphic units from multiple locations. Building the correlations as demonstrated here shows how using approaches learned on Earth for understanding the geologic record remain potent for helping to understand the assembly and evolution of the martian sedimentary record.

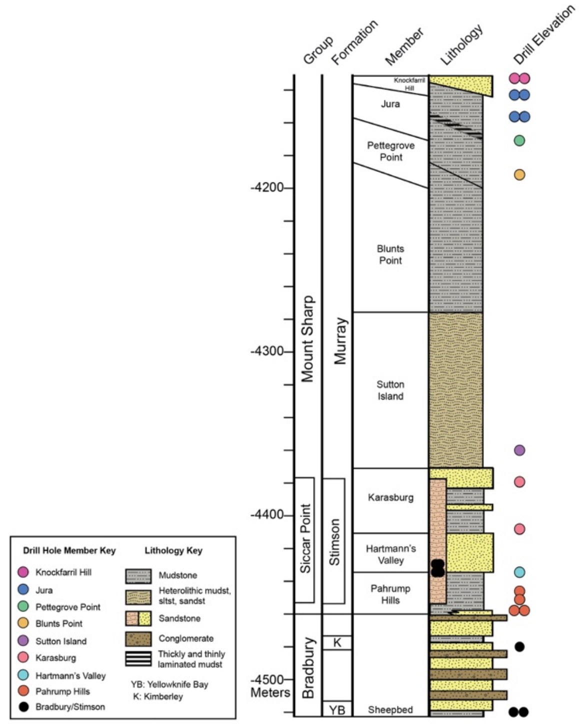

Figure 1. Stratigraphic column showing lithology versus elevation. Also shown are drill locations with unit designation.