GEOLOGIC MAP AND STRATIGRAPHY OF THE YGGDRASIL QUADRANGLE FROM THE 2015 CANMARS MSR ANALOGUE MISSION.
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Introduction: The 2015 CanMars MSR analogue mission was a Mars Sample Return Analogue Mission carried out in partnership between the Canadian Space Agency (CSA), MacDonald, Dettwiler and Associates Ltd. (MDA), and the Centre for Planetary Science and Exploration (CPSX) at the University of Western Ontario, as part of the NSERC CREATE project “Technologies and Techniques for Earth and Space Exploration” [1]. The 2015 CanMars mission took place in an undisclosed location in Utah, USA over the course of ~2 weeks during November using the Mars Exploration Science Rover (MESR) rover, built by MDA. Mission goals included evaluating hardware and software capabilities along with exploration strategies, workflow, and logistics associated with a Mars Sample Return mission. The mission payload instrumentation used by the rover included: a hand-held XRF stand-in for Laser Induced Breakdown Spectroscopy (LIBS) [2], portable XRD, a hand-held Raman spectrometer, the Three Dimensional Exploration Multispectral Microscope Imager (TEMMI) [3, 4], a MastCam [5], a push tube solid sampler, and a portable field core drill as a stand-in for a rock core sampler.

Following the Mars Exploration Program Analysis Group (MEPAG) science goals, one of the primary objectives of the mission, was to characterize and understand the geologic history and paleoenvironment of the landing site. To this end, a geologic map and stratigraphic section were created using rover and orbital observations of the area around the landing site. This was coupled with orbital observations from the larger landing ellipse [6], and used to examine the geologic history and paleoenvironment of the area.

Methods: Prior to the beginning of the mission, the science team was provided with a series of remote data products – Landsat8 OLI, ASTER, and Quickbird imagery – to evaluate the ~5km by ~2.5km landing ellipse as a whole (Fig. 1C) and to begin to develop multiple working hypotheses regarding the regional geology, geologic history, and landscape evolution [6]. After the rover was localized on Sol 0, these data products were cropped to the specific quadrangle (Yggdrasil) containing the landing site (Fig. 1A). This, in addition to mapping based on remote sensing data of the landing ellipse [6], was used as a starting point for the creation of a geologic map of the quadrangle. Over the course of the mission, ground-based geochemical measurements [2, 4] and imagery data [5] were integrated with orbital datasets [6] to characterize the stratigraphy and lithologies within the Yggdrasil quadrangle. The integration of these data sets allowed for the creation of a finer scale bedrock geologic map, and a stratigraphic column of the quadrangle.

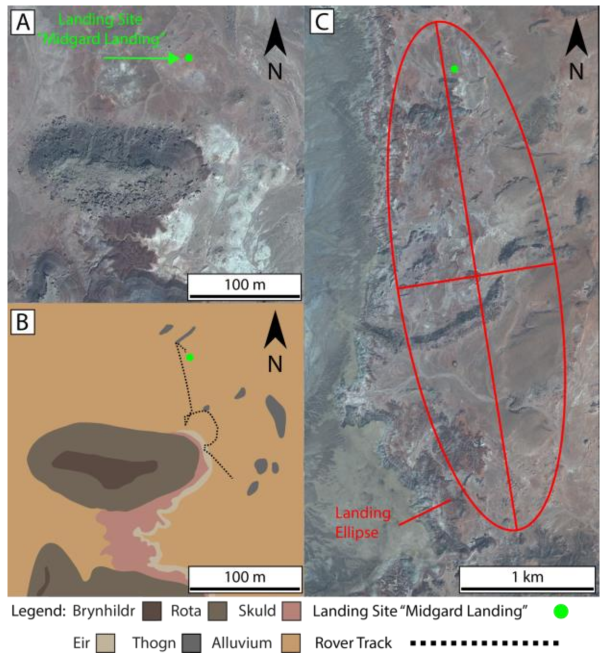

Figure 1: *A) Portion of a Quickbird image of the Yggdrasil Quadrangle, located 2.1km north-by-west of the center of the landing ellipse. B) Bedrock geologic map of the Yggdrasil Quadrangle. C) Quickbird image depicting the landing ellipse and landing site.*

Mission Naming Convention: The convention of naming of geologic features (i.e. outcrops, lithologic units, landforms, and etc.) observed during the mission was used to organize points of interest and science targets. This facilitated efficient communication between the science and tactical teams [7], and within each team. It was decided to base the nomenclature off of a single culture’s mythology for better organization. Norse mythology was chosen to serve as the theme and basis for the place names used during the mission. A basic naming convention hierarchy was developed, which used the names of locations within Norse mythology as the names of locations within the quadrangle. For example, the names of the nine Norse homeworlds were chosen as the second level of the hierarchy used to describe regions within the landing area

(Fig. 1). This was subdivided further with the usage of places found in each of the nine worlds, and then Giants, Gods, and/or Goddesses who inhabited these realms beneath that in the hierarchy.

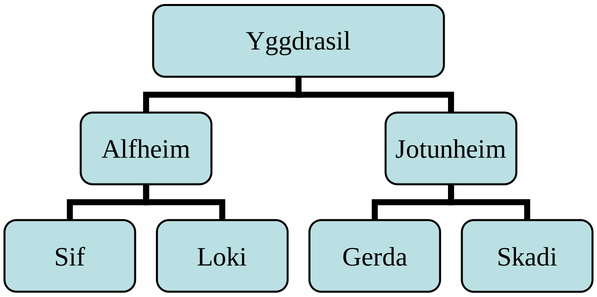

Figure 2: *Example of the naming hierarchy used during the 2015 CanMars MSR analogue mission.*

Geologic Map and Stratigraphic section: Using XRF, Raman, and TEMMI data the chemical composition of target lithologies was classified [2, 4]. Coupled with physical characteristics from TEMMI and MastCam visual data, the observed lithologies were grouped into units and named [4, 5]. The resulting stratigraphic column is divided into five units: Brynhildr, Skuld, Rota, Eir, and Thogn (Fig. 3). Brynhildr and Thogn consist of a hardened well indurated unit. In contrast, Rota, Skuld, and Eir consist of poorly consolidated loose silts and clays. This data was then used as ground truth and applied to the orbital imagery data sets to create a geologic map of the quadrangle (Fig. 1B). It was observed that the well indurated units such as Brynhildr were commonly found on the high topography of the quadrangle.

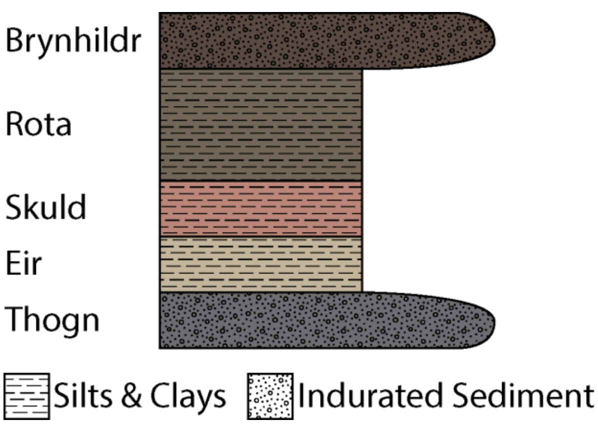

Figure 3: *Stratigraphic column of the Yggdrasil quadrangle depicting the five units analyzed by MESR.*

Discussion: The creation of a bedrock geologic map and stratigraphic section of the Yggdrasil Quadrangle was critical to the evaluation of the geologic history, and paleo environment of the area.

Geologic bedrock map and stratigraphic column. The main geologic structure identified over the course of the mission was a set of sinuous ridges interpreted to be inverted channel deposits formed within a sedimentary basin. These deposits are thought to have been created by the deposition and subsequent differential erosion of resistant materials atop fine-grained materials, which were not as resistant to weathering and erosion (Fig. 3).

Based on this interpretation, the paleo environment for the Yggdrasil Quadrangle is best characterized by the repeated transgression and regression of a large water body. During highstands, the area remained covered by this water body, resulting in the deposition of fine-grained materials (e.g., mudstones and claystones). While during lowstands, the region was likely dissected by channels, a higher-energy environment, which deposited coarser materials. These deposits of coarse grained materials, once cemented and induration, then formed a capping unit of the stratigraphic section (i.e. the Brynhildr unit).

Mission Operations lessons learned. The creation a bedrock geologic map and stratigraphic column of the Yggdrasil Quadrangle was a critical step to evaluating the geologic history and paleo environment of the area [8]. The placement of lithological units and associated data in a spatial context allows for the interpretation of large scale geologic structures. It is therefore critical to begin the creation of a geologic map and stratigraphic column as soon as possible during a mission's lifetime, optimally done pre-mission.

Another lesson learned is the importance of integrating orbital and ground data. Combining orbital data with rover "ground truth" allowed the mapping team to expand mapped units beyond rover line-of-sight.

References: **[1]** Osinski et al. (2016) *LPSC XLVII*. This conf. **[2]** Caudill C. M., et al. (2016) *LPSC XLVII*, (This conf.) **[3]** Coulter et al. (2012) *LPSC XLIII*. **[4]** Ryan C. H., Haid T., et al. (2016) *LPSC XLVII*, (This conf.) **[5]** Harrison T., et al. (2016) *LPSC XLVII*, (This conf.) **[6]** Morse et al. (2016) *LPSC XLVII*. (This conf.) **[7]** Moores J. et al. (2012) *Adv. Space Rsrch* 50 pp 1666-1686 **[8]** Pontefract et al. (2016) *LPS XLVII*. (This conf.)

Acknowledgements: This work was funded by the Natural Sciences and Engineering Research Council of Canada's CREATE program and the Canadian Space Agency. We would like to acknowledge Hans van 't Woud of Blackshore and its partners, including European Space imaging and EuroMoonMars research for the use of the colour Quickbird image that covers the analogue mission site.