TRAVERSABILITY STUDY OF JEZERO CRATER USING COMPARATIVE ORBITAL AND GROUND-BASED IMAGE ANALYSIS OF MER AND MSL ROVER TRAVERSES

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1 Introduction

Jezero crater (18°N, 77°E) is the future landing site of NASA's Mars2020 rover [1] initiating the globally collaborative Mars Sample Return.

The western edge of Jezero has been confirmed as the landing site due to the presence of an alluvial fan (Fig 1.) indicating ancient water flow.

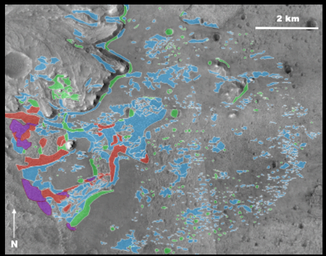

Fig. 1 - A HiRISE image of the proposed landing ellipse within Jezero crater annotated **with** sand ripple terrains.

The European Space Agency's Sample Fetch Rover (SFR) (Fig. 2) will collect sample tubes deposited by NASA's Mars2020 rover.

A traversability analysis was completed in 2019 at the beginning of the SFR Phase B in order to determine hazards SFR may encounter. The study utilized 16 terrain classifications from [2]. Since this study SFR has evolved and will continue to evolve further.

This study highlights the variability of terrains concluded from orbital analysis. The physical properties of duricrust – thin, cemented layer of regolith that behaves in a brittle manner and can easily be destroyed by low surface pressures [5] - appears to contribute the most variability.

2 Smooth terrain

- Safest terrain type
- Found throughout the study area
- Appears benign from HiRISE images
- Closer inspection reveals fractures within terrain classified as smooth
- Smooth regolith is deemed safer to traverse than smooth outcrop due to wheel grip

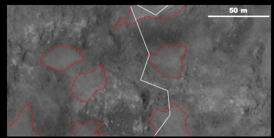

Fig. 3 – HiRISE image, annotated with MER Spirit's traverse and areas of smooth regolith.

Fig. 4 – Spirit traversing smooth regolith. NASA/JPL.

Figs. 3 and 4 display orbital and ground-based MER Spirit rover data. The traverse over smooth regolith here was safe.

Smooth terrain, especially smooth regolith, is likely to be the least hazardous terrain type for the rover to traverse.

3 Rough regolith

- Dispersed rough features within Jezero landing ellipse
- Rough outcrop can be easier defined from orbit by its lighter appearance than rough regolith
- The appearance of rough terrain from orbit suggests it is too large to traverse so traverse paths must be made around the features

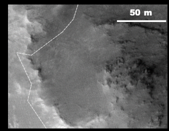

Fig. 5 – Oppy traverse at Endeavour crater rim, as seen from a HiRISE image.

Fig. 6 – Ground image of Oppy at Endeavour crater rim. NASA/JPL.

Fig. 7 – Ground image of Spirit over possibly damaging terrain. NASA/JPL.

Fig. 5 shows rough regolith from orbit, but some areas could be concluded as smooth. Correlated ground images (Fig. 6) displayed large outcrops that must be traversed around. Fig. 7 shows a rocky area of rough regolith that could cause damage to rover wheels if traversed for too many sols.

4 Fractured terrain

- There are a range of fracture sizes (Fig. 8, 9)
- The largest fracture has a depth of ~20 cm, as profiled in GIS software
- Some radial fracturing can be seen the south-western edge of the landing ellipse
- Depth and physical properties of the regolith at least partially infilling the fractures is unknown

Fig. 10 – HiRISE images of Vera Rubin Ridge fractures, traversed by MSL Curiosity.

Fig. 11– MSL Curiosity facing ~south on fractured terrain shown in Fig. 7. NASA/JPL.

Fig. 10 shows fractures that appear potentially and deep and hazardous from orbit, but Fig. 11 shows that the fractures are easily traversed. The contrast of dark regolith and light bedrock makes this terrain type seem more hazardous than it is.

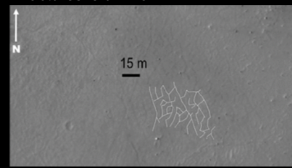

Fig. 8 – small fractures within smooth terrain at Jezero crater annotated onto HiRISE images.

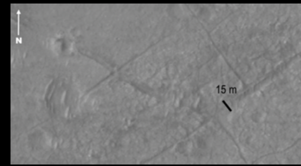

Fig. 9 – potentially hazardous fractures within smooth terrain at Jezero crater annotated onto HiRISE images.

5 Sand ripple terrain

- Ripples are dispersed across the landing site (Fig. 1)
- Sparse ripples on a firm substrate are deemed the safest (Fig. 1, light blue)
- Dense linear and polygonal ripples should be avoided and are locally confined to the south of the alluvial fan (Fig. 1, red and purple)
- Varying success of previous rover traverse over ripple terrains
- Ripples on a slope may pose a threat (Fig. 12)

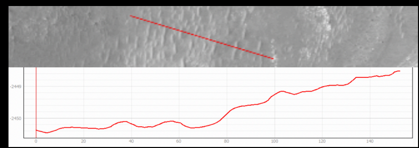

Fig. 12 – Vertical terrain profile using HiRISE images in GIS software. Sparse ripples are traversable here, the slope is more of a threat to traversability.

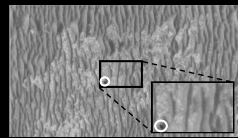

Fig. 13 – MSL Opportunity traversing moderate ripples HiRISE image.

MER Opportunity (Oppy) traversed moderate ripples on a firm substrate with ease (Fig. 13) but became stuck in a polygonal ripple field known as Purgatory (Fig. 14).

MSL Curiosity was able to traverse Dingo Gap solitary ripple (~7 m wavelength, ~1 m amplitude) with skid (>intended distance travelled) coming down the ripple but with minimal wheel sink [3].

Fig. 14 – Oppy stuck in polygonal ripples. NASA/JPL.

6 Deep sand

- Potential for deep sand to be filling craters
- Should be easy to avoid by traverse planning
- Smooth regolith and deep sand can be confused using orbital images alone

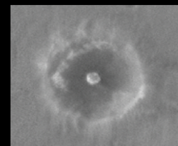

Fig. 15 – Oppy's lander in Eagle Crater shown from orbit captured in a HiRISE image.

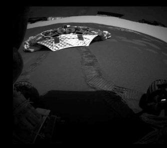

Fig. 16 – Oppy's tracks in Eagle Crater. NASA/JPL.

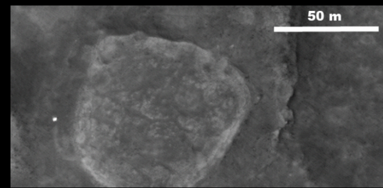

Fig. 17 – Oppy stuck in deep sand at Troy as shown from a HiRISE image.

Fig. 15 shows a HiRISE image of Oppy's lander in what appears to be deep sand. Upon traverse (Fig. 16) it was found to be smooth regolith. 100% slip occurred when traversing 17° slopes out of Eagle Crater [4].

Fig. 17 shows Oppy at its final resting place, Troy, near Homeplate. This terrain was deemed smooth from orbit but was found to be deep sand when traverse occurred.

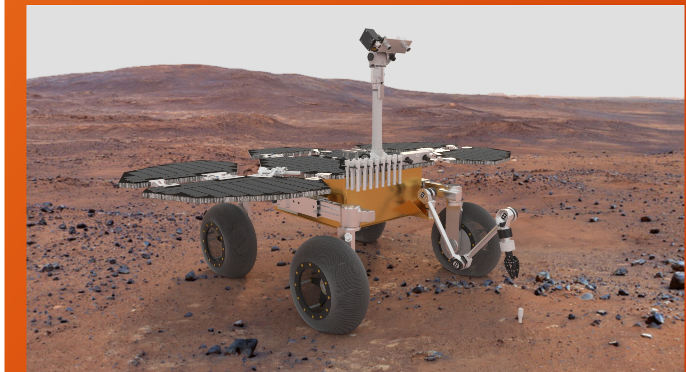

Fig. 2 – artist's interpretation of Sample Fetch Rover (SFR) – courtesy of ESA

7 Conclusion

Terrain can be classified and grouped into hazardous and non-hazardous using orbital images. However, ground-based images can conclude or contradict these estimates and thus should be used to define rover traverses. This study has highlighted the traversability ranges seen within one terrain type using MER and MSL ground-based images and rover data.

Smooth terrain is deemed the safest with the only hazard likely to be fractures, the largest of which found in this study is likely to be a small depth hazard. Although ground images should be used to conclude these statements. Ground data should also be used when attempting to traverse a crater or other feature where regolith could have built up over time. MER Spirit has shown the danger of deep sand. Previously traversed fractured terrain has been shown to appear hazardous from orbit but safe during traverse. The depth of fractures, especially small fractures, is hard to determine from orbital data alone.

The lack of data on Martian duricrust increases the difficulty of classifying hazardous terrains from orbit and terrestrial analogs should be used to plan traverses over varying depths of duricrust.

Further research

Future research should focus on the creation of terrestrial analogues to test rovers prior to missions. Autonomous rover driving capabilities are key to the future of Mars rover missions and will vary due to the level of hazard posed by each terrain type. Adding a higher level of description to terrains, perhaps including terrestrial or previously traversed Martian terrain, would allow geologists and engineers alike to base traversability on rover capabilities for differing terrain types.

References: [1] NASA (2019) https://www.nasa.gov/image- feature/jezero-crater-mars-2020s-landing-site. [2] Rothrock *et al.,* (2016) *American Institute of Aeronautics and Astronautics*. [3] Arvidson *et al.,* (2016) *Journal of Field Robotics*. 1–24 [4] Arvidson *et al.,* (2004) *Science Mag*. Vol. 306. [5] Lewinger *et al.,* (2018) *Acta Astronautica.* 152. 567-579.