MARS SAMPLE RETURN "THREE FORKS" LANDING AND DEPOT SITE SELECTIONS.
N. R. Williams[1], M. P. Golombek[1], S. Do[1], F. Calef[1], H. Lethcoe[1], M. Cameron[1], A. Trussell[1,2], C. Brooks[1,3], F. Russo[1,4], M. Deahn[1,5], M. Morris[1,6], S. Hibbard[1], M. Heverly[1], D. Spencer[1], E. Fosse[1], J. Maki[1], [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, 91109, Nathan.R.Williams@jpl.nasa.gov, [2]School of Earth and Space Exploration, Arizona State University, [3]Kansas State University, [4]University of Pittsburgh, [5]Wesleyan University, [6]Stony Brook University.

Introduction: Since landing on Feb. 18, 2021, NASA's Mars 2020 Perseverance rover has collected rock, regolith, atmosphere, and witness samples [1] for potential future return to Earth through the NASA-ESA Mars Sample Return (MSR) campaign. Each sample is sealed within a Returnable Sample Tube Assembly (RSTA) and attached glove assembly (RGA). As the rover approaches completion of its prime mission, an initial subset of 10 samples is being deposited onto the surface within Jezero crater. These 10 samples serve as a backup set to be placed on a benign surface for possible retrieval if the rover is unable to deliver its primary collection directly to MSR's Sample Retrieval Lander (SRL) in the extended mission. In this backup scenario, two Sample Recovery Helicopters (SRH) would be employed to retrieve RGAs from the surface (collectively, the "depot") to SRL.

SRL and SRH must land safely and interact with the surface to collect the RGAs, prompting requirements for acceptable landing site and depot terrain properties. Previous Mars landings and surface operations have relied upon analyses of images and other data acquired from orbit, as well as extrapolating ground data from other previous landing sites [e.g., 2-4]. Orbital data's resolution (>0.25 m/pixel [5]) limits assessments of terrain features at ~1 m length scales, and extrapolated comparisons to other landing sites don't capture the inherent variability and uncertainty for geologic surface properties across a planet.

The Perseverance rover presents the first ever use of *in situ* reconnaissance to collect surface data for a future Mars mission at its planned landing and operations site. MSR's Council of Terrains has leveraged this data to select safe locations for SRL and SRH to land and operate, as well as to feed back into system design and testing. This abstract presents a summary of the requirements, surface evaluation and site selection for the landing site and depot.

Requirements: The SRL landing ellipse is a circle 60 m in radius, enabled by terrain relative navigation and sufficient fuel to divert and fly out other errors during descent. Landing circle slopes must be <10° measured at the length scale of the vehicle landing gear (~2 m). SRL landing gear can tolerate rocks up to 0.19 m in height and the cumulative fractional area of rocks must be <4%. RGAs must be deposited at a distance of 200-700 m away from the landing site to prevent interactions between the lander plume and the RGAs, yet still be within the range of an SRH flight.

RGAs would be deposited by the Perseverance rover spaced ≥4.9 m apart. The 0.70-0.95 m radius circular drop zones must have no rocks >0.02 m in height. Surrounding an RGA drop zone, an SRH approach annulus out to an additional 0.9 m must have at most one rock between 0.03-0.05 m in height. Also bordering each RGA drop zone, we define an SRH helipad extending 4.9 m beyond the drop zone, containing no rocks >0.05 m in height. RGA's must be approached by the SRH along one axis for pick up, so the percent area around the RGA drop zone where potential helipads meet the rock/relief requirement should be maximized and be at least >90%. Similar to the landing site, SRH-scale (0.6 m baseline) slopes must be <10° within each of the RGA drop zones, SRH approach annuli, and helipads. RGAs are also desired to be visible from anywhere within a helipad.

Data and Methods: An initial suite of candidate sites was preliminarily mapped using orbital data [6]. On sols 408 and 409 of Perseverance's mission, the rover drove through a candidate landing site, subsequently named "Three Forks." The rover made two stops in this region and acquired two high-resolution stereo Navcam [7] panoramas plus low-resolution stereo images every 7 m, from which 0.01 m/pixel orthoimage mosaics (ORRs) and digital elevation models (DEMs) were derived and then co-registered to orbital maps in a global coordinate system. Similarly for the depot, on sols 413, 414, 432, 433, and 434 the rover stopped 13 times to take a mixture of high- and medium-resolution panoramas of candidate drop zones. A high-zoom (110 mm focal length) Mastcam-Z [8] panorama containing the entire landing site was also taken on sol 470 from ~30 m higher in elevation on the Jezero delta.

Preliminary rock reliefs were estimated as the max-min DEM pixel differences within a 0.1 m or 0.02 m radius moving window. These fixed-size windows include non-rock relief contributions, such as from slopes or image artifacts, so individual rocks >0.03 m in diameter were then manually mapped in a geographical information system (GIS) to derive diameter and re-evaluated for total relief within the mapped rock boundary plus a 0.03 m buffer of background terrain.

Slopes were calculated over 2 and 0.6 m length scales using Horn's method [9] on resampled Navcam DEMs. Maximum SRH tilts were also calculated at 0.01 m/pixel from DEM values at the corners of a square 0.6 m on a side (representing the 4 SRH wheel contact points), and rotating the square footprint through all possible clock angles. Geometric viewsheds for each depot helipad range were calculated and merged from each of 8 observer points in cardinal and ordinal directions around the outer helipad range to assess visibility of the RGAs from these extremities.

Results: The Three Forks landing site is defined as a 60 m radius circle centered at 18.45369687°N latitude, 77.41359752°E longitude, and -2548.673 m elevation (relative to the controlled HiRISE basemap [5,10] and MOLA geoid [11]). No rocks exceed 0.19 m in height within the landing circle (tallest measured is 0.16 m), and lander-scale slopes are <10°. The cumulative fractional area of rocks in the landing site is measured to be 0.6-0.8%, the lowest of any Mars landing site assessed to date [12]. The landing site is 216 m from the closest RGA drop zone and 395 m from the farthest (see Figure 1 and sections below).

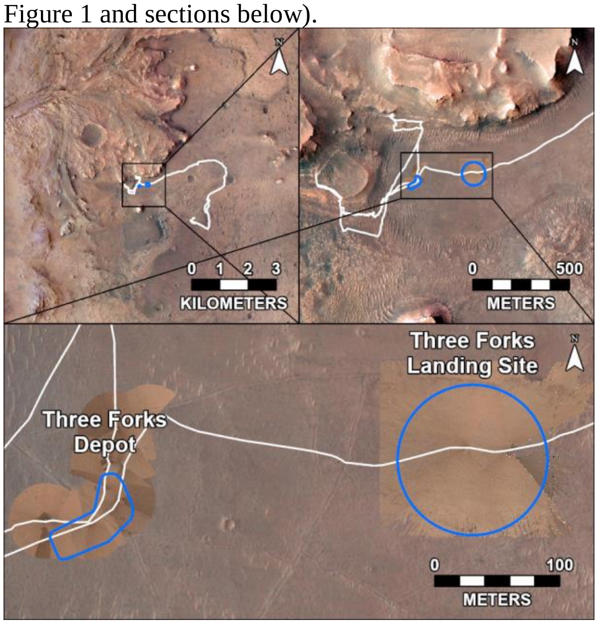

Figure 1: Map of the Three Forks Landing Site and Depot. For a detailed map of the depot, see Figure 2.

Eleven RGA drop zones were certified to meet all rock and slope requirements for the selected RGA drop zones and SRH approach annuli (Fig. 2, Table 1). All helipads satisfy approach azimuths for >95% of their full annuli, with the exception of drop zone #15 (>90% area due to two rocks), which is being retained as a contingency location. Slopes are ~1-2° towards the southeast. Viewsheds show any RGA would be visible from anywhere within any defined helipad.

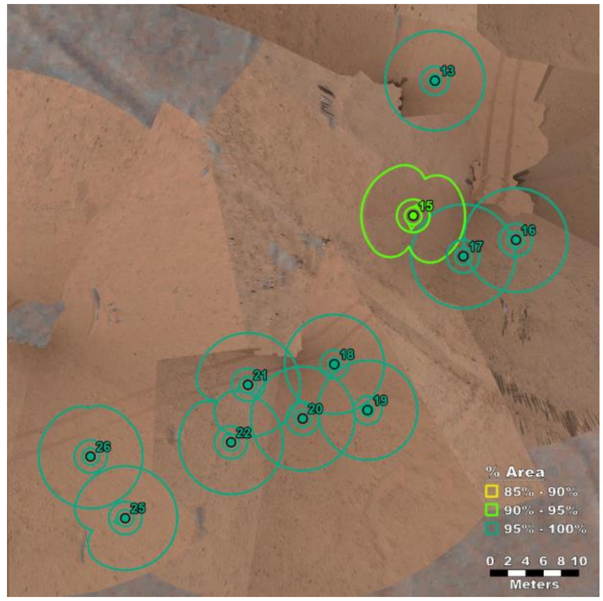

Figure 2: Map of Three Forks Depot, with RGA drop zones, SRH Approach Annuli, and Helipad Ranges.

Table 1: Locations and sizes of Depot RGA drop zones.

Drop Zone #	Latitude (°)	Longitude (°)	Elevation (m)	Drop Zone Radius (m)
13	18.45335876°	77.40845187°	-2545.06 m	0.7
15	18.45310211°	77.40840831°	-2545.13 m	0.95
16	18.45305613°	77.40861382°	-2545.23 m	0.95
17	18.45302517°	77.40850874°	-2545.16 m	0.95
18	18.45282019°	77.40825046°	-2545.28 m	0.7
19	18.45273305°	77.40831719°	-2545.36 m	0.7
20	18.4527171°	77.40818728°	-2545.36 m	0.95
21	18.45278117°	77.40807742°	-2545.28 m	0.95
22	18.45267194°	77.40804345°	-2545.36 m	0.95
25	18.45252828°	77.40783165°	-2545.42 m	0.95
26	18.45264516°	77.40776224°	-2545.28 m	0.95

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