UNIVERSITY OF COPENHAGEN
DEPARTMENT OF GEOSCIENCES AND NATURAL RESOURCE MANAGEMENT

M.Sc. Project in Geology-Geoscience

NASAs Mars 2020 Mission to Jezero Crater from landing to Sol 130 – A Mastcam-Z geology student collaborators experiences and work on the M2020 Mission

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Cover picture representing *Perseverance* & *Ingenuity* from April 7th, 2021:
https://mars.nasa.gov/resources/25790/perseverances-selfie-with-ingenuity/

Name of department:	Department of Geosciences and Natural Resource Management
Author(s):	Stephanie Zielke Fleron, dhr266
Title and subtitle:	NASAs Mars 2020 Mission to Jezero Crater from landing to Sol 130 – A Mastcam-Z geology student collaborators experiences and work on the M2020 Mission.
Topic description:	NASA's new Mars Rover, Perseverance, landed on Mars on the 18th of February. Mastcam-Z is a multispectral zoom camera on Mars and the first camera with zoom on Mars. RIMFAX is the first Ground Penetrating Radar (GPR) on a Mars rover. I am a student collaborator on the Mars 2020 Rover mission and therefore I also participated in the workings of the mission after the rover landed. I also contributed a small part to the geological remapping effort of Jezero Crater as well as looking at a combination of Mastcam-Z mosaics and RIMFAX radargrams to gain an understanding of surface to near-surface reflections and their correlation to surface expressions in the mosaics in the rovers driving path in order to gain an understanding of the geological history of Jezero Crater.
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Abstract

The purpose of this thesis is to present the experiences and the work contributed as a Mastcam-Z student collaborator on the Mars 2020 Mission, focusing on participating in the workings of the mission after the landing, as well as adding to the geological remapping effort and correlating Mastcam-Z mosaics and RIMFAX radargrams in order to gain an understanding of the geological history of Jezero Crater. This thesis does not contain any major research questions but offers a collection of my experiences as a Mastcam-Z student collaborator on the Mars 2020 Mission. The M2020 Mission with its *Perseverance* rover landed in Jezero Crater on the 18th of February 2021 with its goal to find evidence of extinct microbial life. Jezero Crater was chosen as a landing site due to showing promise of containing habitable environments from a time period prior to ~3.5 Ga (billions of years ago), in which liquid water existed on the surface. The role as a student collaborator on the Mastcam-Z camera team included developing the following skill, such as geological interpretations based on images taken through a range of filters with the purpose of producing spectral plots for multispectral analysis of the different rocks found in Jezero Crater. Furthermore, a geological remapping effort was established in the early Sols of the mission in order to produce a map to put observations into context and to create a framework for samples, as well as enabling investigation of the relationship between the delta and the crater floor later in the mission. Correlations between Mastcam-Z mosaics and RIMFAX radargrams would enable an investigation into whether an integrated understanding of the rocks in Jezero Crater could establish a connection between the rock classifications that have been put forth. The discussion is based upon a consensus of the M2020 science team, that the one of the main geological units in Jezero Crater (CF-Fr) is of a mafic igneous origin. Furthermore, the geological remapping effort alongside pre-landing studies present an event scenario that involves coverage of CF-Fr by the western delta fan. Expanding upon the proposed event scenario and my own observations, it can be theorized that CF-Fr originates from an edifice of potentially volcanic nature on the southeast rim of Jezero Crater. Future research into the aforementioned edifice would depend on higher resolution orbital images from MRO as well as CRISM data of the area containing the edifice and the south-eastern part of Jezero Crater. Finally, it can be concluded, that identifying CF-Fr’s origin is crucial to understand the complex geological history of Jezero Crater.

Keywords: Mars · Mars 2020 Mission · Perseverance rover · Mastcam-Z · Downlink Shift · sPDL · Geological Mapping · RIMFAX · Radargram

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1 Introduction

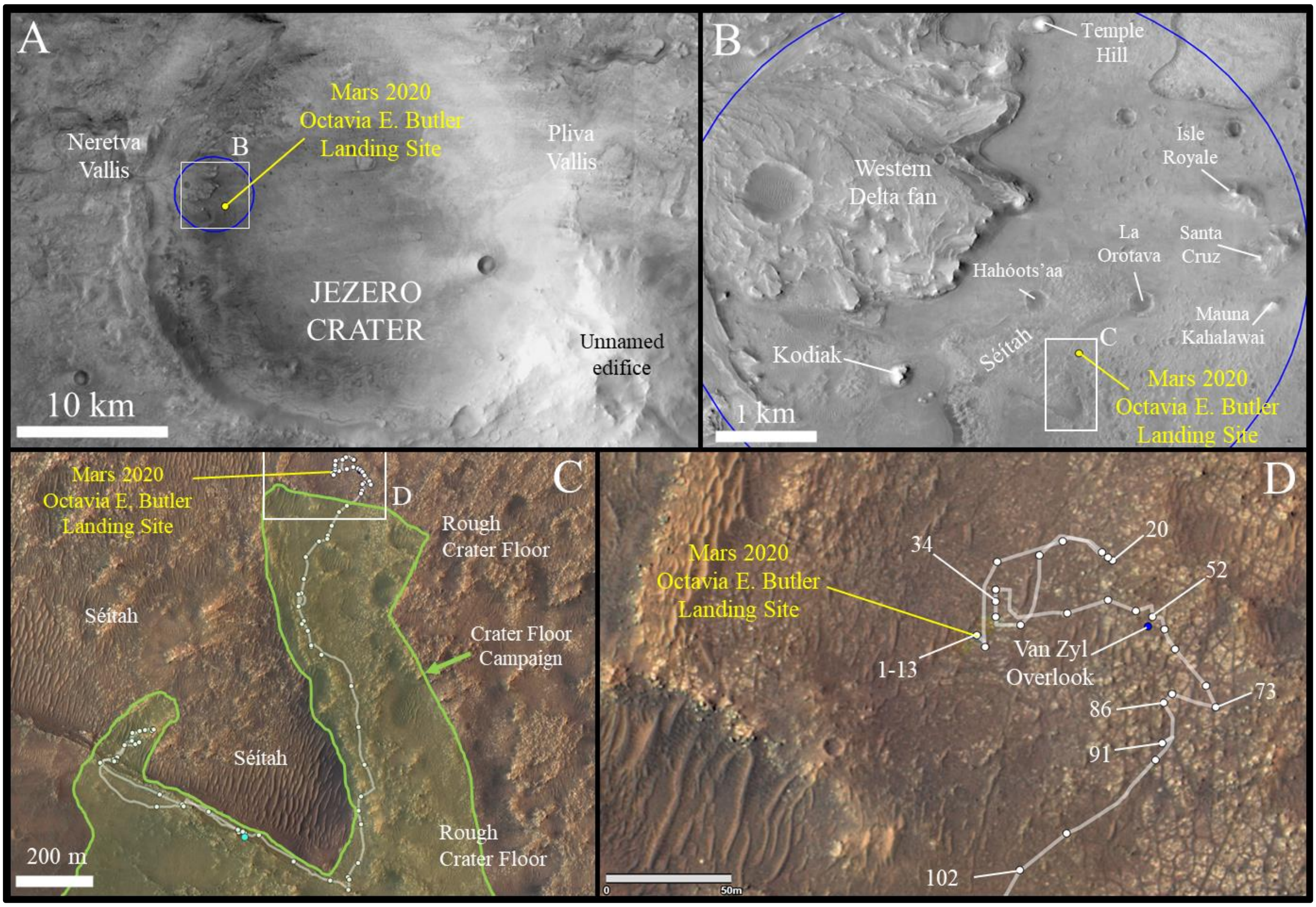


Figure 1. A) Regional view of Jezero Crater and the Mars 2020 *Perseverance* rover's landing ellipse (dark blue oval). B) Close-up of the western delta fan in Jezero Crater with major features highlighted. C) Crater Floor Campaign shown in green with the rover traverse from landing to the rover's current location as of Sol 343 (aquamarine dot). D) Detailed map of the rover traverse from Sol 1 to 102 with the parking spots marked in with white dots. Some are labelled to give an idea of rover progression throughout the Sols. North is up on all images.

The Mars 2020 Mission is the first mission of a multi-mission campaign known as the Mars Sample Return. While searching for evidence of ancient microbial life on Mars, the rover will take samples for future return to Earth for analysis. The mission will also characterize the geology of Jezero Crater and provide context for the samples it will take along the way (Figure 1). The rover will journey through the crater towards the eastern delta, driving up onto it and then out through the Neretva Vallis inlet channel to Nili Fossae region (not shown in Figure 1), east of Jezero Crater. The mission is set to run for at least one Mars year, which is equivalent to about 687 Earth days.

As stated previously, the M2020 Mission and its rover, *Perseverance*, builds upon years of previous missions to Mars. As such, the rover itself and its major components were modified from its precursor mission, MSL and its rover, *Curiosity*.

I was fortunate to be able to be a part of the Mars 2020 Mission as a student collaborator on the Mastcam-Z team in the few months before the rover landed in February 2021 and throughout the year. As a student collaborator on the Mastcam-Z team, I participated in surface operations on the downlink side throughout the early Sols of the mission (landing to around Sol 130). On these shifts I assessed the imagery sent back from Mars taken with the ZCAM instrument and applying my geological knowledge to them. I thus contributed with data products for the rest of the M2020 Science Team as well as for any future work and/or publications (Farley *et al.*, 2022 - To be published; Bell *et al.*, 2022 - To be published; Mangold *et al.*, 2021).

Below is an overview of the different sections that this thesis will include:

- Overview of the geological history of Mars, followed by a subsection briefly introducing the geology of Jezero Crater as well as the established pre-landing geological units from Stack *et al.*, 2020.
- A small intro to the Mars Exploration Program (MEP) and its Science Goals
- A brief run-through of previous Mars missions (inspired by Farley *et al.*, 2020), which lead up to the Mars 2020 Mission. Followed by an overview of the M2020 Mission and the rover itself, *Perseverance*, alongside high-level information on its different payloads – engineering and science alike, albeit there will be slightly more in-depth information on both Mastcam-Z and RIMFAX.
- A rundown of the tools and methods that I utilized during my time with the Mars 2020 Mission, followed by a high-level run-through of my Sol 80 Mastcam-Z shift.
- A small overview of products plucked from my array of work during my shifts from Sol 1-130 and sorted into categories: Focus, Multispectral, Geology, followed by my contribution to the geological remapping effort alongside geological unit examples from my chosen area.
- An overview of near-surface & surface features found on the Sol 47-102 rover traverse RIMFAX radargrams alongside Mastcam-Z mosaics and NAVCAM/HAZCAM images highlighting the same features.

- Discussion section that will draw upon my own work in regard to mapping and the RIMFAX radargrams and Mastcam-Z mosaics. It will also include some of the other geological conclusions and theories from team members from across mission chat channels and the Science Discussions.
- Preliminary conclusion ~what we knew before *Perseverance* landed and what we know now (# Sols into the mission).

The following is a disclaimer:

The discussion section of this thesis draws upon theories from both pre-landing articles and the various science discussions, Mattermost chat channels, and private discussions during my time on the M2020 Mission.

2 Geological Background

Present day Mars is an inhospitable planet compared to Earth – below-freezing annual temperatures of -58° Celsius near the equator, a thin atmosphere providing no protection from ionizing solar and cosmic radiation and global dust storms. Although surface features tell a much different story of planets past. Mars' past, most notably a time period prior to 3.5 Ga, indicate that an abundance of liquid water existed on the planet's surface over a long period of time, carving out valley networks and open system lakes.

These Martian surface features have been divided into three age groups on the basis of intersection relations and the numbers of superimposed impact craters (Carr and Head, 2010) and are as follows from oldest to youngest: Pre-Noachian, Noachian, Hesperian and Amazonian (Figure 2).

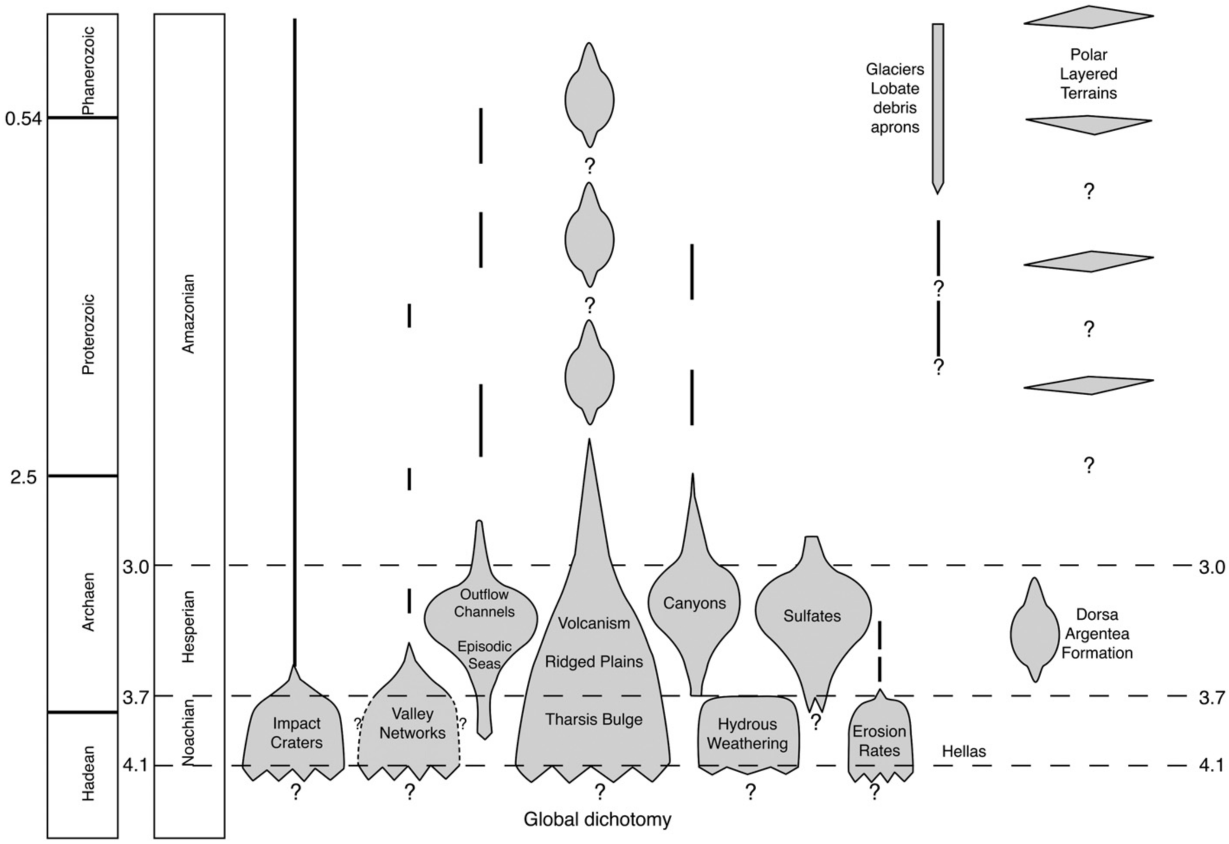


Figure 2. Geological activity as a function of time on Mars. Shown are the relative importance of different processes (impact cratering, volcanism), the time and relative rates of formation of various features and units (valley networks, Dorse Argentea Formation), and types of and rates of weathering, as a function of time. The approximate boundaries of the major time periods of Mars history are shown and are compared to similar major time subdivisions of Earth history. Figure and figure text from Carr and Head, 2010.

I will be covering these periods as well some of Jezero Craters geology in this section.
Much of the information pertaining to Mars' geological history is from Carr and Head, 2010 and they state that large errors in the end estimates for the Noachian period is improbable, due to the sizeable quantity of older, larger impact craters. Whereas the Hesperian-Amazonian boundary contains significant uncertainties from using younger, smaller craters due to the non-uniform distribution of secondary craters and a possible long-term decrease in impact crater events.

2.1 Mars' geological history

From the formation of the planet to the formation of the Hellas impact basin, the Pre-Noachian period stretches from 4.5 Ga to between 4.1-3.8 Ga. The span of 3.0 Gyr is based on whether a steady decline in basin formation or a late spike is assumed, as it was an era, riddled with large, episodic, basin forming impact events. It is also in this era, that the global dichotomy is thought to have formed. This dichotomy is expressed as differences in crater densities, a difference in elevation of 5.5 km between the north and south hemisphere, and a difference in crustal thickness: estimated to average 30 km to the north and 60 km to the south. The cause behind the formation of the dichotomy is still uncertain but is theorized to have been a result of one or more large impact events. It is also hypothesized that Early Mars had a magnetic field, as large magnetic anomalies have been found in the southern highlands but are absent around the large impact basins. Some of these anomalies are also striped, thus sharing similarities to the magnetic anomalies found near spreading ridges on the ocean floor of Earth (Carr and Head, 2010).

The Noachian uses the formation of the Hellas impact basin as the base, 4.1/3.8 Ga, and ends around 3.7 Ga. It is a period showing mineralogic and geomorphic evidence for warm conditions, though the means through this was achieved is unclear. Some of the distinguishing features of this period are as follows: high rates of cratering, erosion and valley formation. The formation of Tharsis also occurred in this period, with much of the volcanism of this period being centred around it (Carr and Head, 2010).

Another defining feature is that the surface conditions of this period allowed for widespread production of phyllosilicates, such as nontronite, saponite, montmorillonite and Fe-rich chlorites, which form from aqueous alteration of basalts (Carr and Head, 2010). Most of the Noachian terrain is also dissected by extensive valley networks, with fluvial erosion of crater rims and partial infilling of lows such as craters (Figure 2).

Following the Noachian period is the Hesperian period, which covers 3.7 to 3.0 Ga. Volcanism continued into this period and formed vast lava plains compared to the Noachian (Figure 2**)**. It is also theorized that Olympus Mons started accumulating in this period, as part of the large Tharsis shield volcanoes. The volcanic activity is also proposed to be the cause of increase sulphur activity, which caused an increase in sulphate-rich deposits that the Hesperian is known for (Carr and Head, 2010). A steep decline in the other features, namely erosion and rock alteration, indicate that the conditions that enabled the formation of the Noachians defining features, are missing in the Hesperian. Even with the decline in valley formations, there is evidence for formation of canyons and the largest outflow terminals are of a fluvial origin and was likely caused by the rapid release of large volumes of stored water, possibly from extensive aquifers trapped underneath a thick cryosphere (Carr and Head, 2010).

The last age is the Amazonian, stretching from 3.0 Ga up to the present day and has been subdivided into the Early (3.0-1.4 Gyr), Middle (1.4-0.3 Gyr) and Late (0.3 Gyr to Present) Amazonian. This period is most known for the presence, accumulation and movement of ice as well as the features they formed (Figure 2**)** – particularly at mid to high latitudes. Although deposition of ice at lower latitudes may also have been common during higher obliquity epochs of the planet (Carr and Head, 2010). Even with the period stretching over such a long time period, only modest geomorphical changes occurred during those 3 billion years and the rate of volcanism continued to decrease throughout. Erosion and weathering also continued to be very low just like in the Hesperian (Carr and Head, 2010).

2.2 Jezero Crater geology

Jezero Crater is a Noachian-aged impact crater with a ~45 km diameter (Figure 1). It is located at the northwestern edge of the Isidis Basin, in the Nili Fossae region of Mars at 18.4°N, 77.5°E (Fassett and Head, 2005; Schon, Head and Fassett, 2012; Goudge *et al.*, 2015; Stack *et al.*, 2020; Holm-Alwmark *et al.*, 2021).

Nili Fossae is a series of approx. concentric graben and is thought to be a tectonic response to the impact that formed the Isidis Basin (Goudge *et al.*, 2015). The Nili Fossae region consists of the units that were deposited prior to the Isidis Basin formation but also eject and brecciated units from the formation of Isidis. Fluvial activity, surface runoff and volcanism from the Syrtis Major volcanic complex have all influenced the Nili Fossae region following the formation of the Isidis Basin.

Jezero Crater contains two fan-shaped deposits, one in the northern and one in the western part of the crater. Both of these fans are connected to their own inlet valleys that fed the paleolake, which was contained in Jezero Crater. Phyllosilicate clays and carbonates have been detected in both the fan-shaped deposits. There is an outlet channel on the eastern part of the Jezero Crater, which helped drain the lake. This outlet channel was made from overtopping of the crater rim and erosion of the breach, until there was a topographic difference within a few tens of meters between the delta and outlet (Schon, Head and Fassett, 2012).

Many pre-landing articles such as Goudge *et al.*, 2017, 2018; Brown, Viviano and Goudge, 2020; Scheller, 2020, contain more information and different hypotheses on geology, stratigraphy, mineralogy and/or paleohydrology of Jezero Crater and its western delta fan deposit but they will not be covered here.

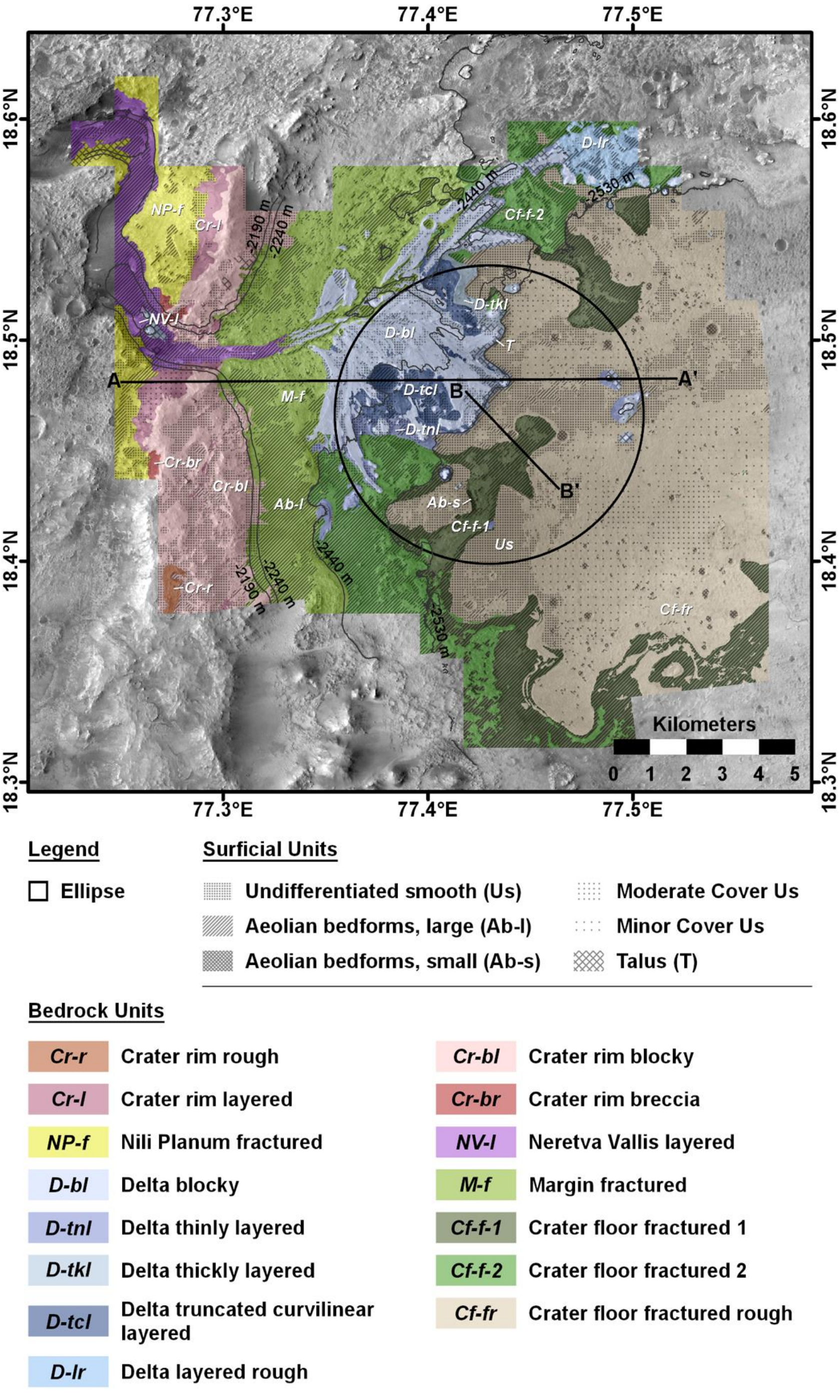


Figure 3. Photogeologic map emphasizing bedrocks units within the mapped area. From Stack *et al.*, 2020.

For the Mars 2020 Mission prior to landing, Stack *et al.*, 2020 produced a photogeological map (Figure 3) based on satellite imaging from Mars Reconnaissance Orbiter High Resolution Imaging Science Experiment (MRO-HiRISE) to identify and map geological units of Jezero Crater and the surrounding areas. The map formed the base for scientific hypothesis development and strategic planning for the upcoming M2020 mission in Jezero Crater.

The mapping work was performed at a scale of 1:5000, and it was the most detailed and comprehensive mapping effort prior to landing. A grid of 1.2 km by 1.2 km quads was overlain on the region of available orbital data. The 166 quads were divided by geographic setting: crater floor, basin fill, delta, marginal deposits, crater rim, and inlet valley. Within the mapping area and based on the geographical settings, Stack *et al.*, 2020 distinguished four surficial units and fifteen distinct bedrock units in the map area. The fifteen bedrock units were further categorized into the following groups: Jezero Crater Floor (3), Jezero Crater Inner Margin (1), Jezero Crater Delta (5), and Jezero Crater Rim and Beyond (6). These are all shown on map visible on Figure 3.

Most relevant to the early stages (Pre-Sol 300) of the M2020 mission as well as the Remapping Effort section [4.2 and 5.2] of my thesis are the surficial units: Ab-l, Ab-s, and Us and the crater floor bedrock units: Cf-f-1, Cf-f-2 and Cf-fr.
If interested, then please see Stack *et al.*, 2020 for detailed explanations of all the units not mentioned here.

Out of the surficial units, the first is the **Aeolian Bedforms, Large (Ab-l) unit**. It covers approximately 70% or more of the surface area. These bedforms vary in length from ~10s to several ~100s of meters. They are light-toned and have symmetrical bedforms. Whereas the second surficial unit, **Aeolian Bedforms, Small (Ab-s)**, are dark-toned and straight-crested bedforms. They are up to a few ~10s of meters in length. The **Undifferentiated Smooth (Us)** unit is the last of the 3 surficial units and was given to any deposits within the map area that has a medium to dark uniform tone and generally lack resolvable texture at map scale. This unit appears to conform to topography, often occurring within impact craters and on slopes.
Stack *et al.*, 2020 states that the Jezero Crater Floor bedrock units all share textural and tonal similarities. As such, Stack *et al.*, 2020 had to define the units of the Jezero crater floor and inner crater margin primarily by elevation contours, which coincided with the distinct geographic settings.
Crater Floor Fractured 1 unit (Cf-f-1) occurs below the -2530 meter elevation contour. It has a mottled tone, which is a result of a linear mixture of dark and intermediate-toned sand, which fills crevices and fractures within the light-toned bedrock. This unit form SW-NE trending ridges and is exposed primarily in the northern part of the Jezero delta and in the southern extent of the delta.
Crater Floor Fractured 2 unit (Cf-f-2) crops out between the -2530m and -2440m elevation contours in the western portion of the Jezero crater. It resembles Cf-f-1 in both tone and texture but has a rougher surface texture and has no indication of internal stratification. It also shares similarities to the crater floor fractured rough (Cf-fr) unit detailed just below. The difference is that Cf-f-2 retains fewer craters and does not have any distinctive resistant curved margins compared to Cf-fr.
Crater Floor Fractured Rough Unit (Cf-fr) is the most crater-retaining and boulder-producing unit within Jezero Crater. The unit is light- to medium-toned and rough on the meter-scale. It contains small fractures up to a few meters across, as well as large fractures up to several hundreds of meters in length. In some areas Cf-fr is overlain by the Us unit, and in these areas, there are fewer fractures and craters observed.

Relative age relationship model from Holm-Alwmark *et al.,* 2021

Stack *et al.*, 2020 proposes four different scenarios to explain the relative age relationships of their established units within the map area. Holm-Alwmark *et al.*, 2021 draws similarities between scenario two and four to their own scenario (Figure 5a).

Holm-Alwmark *et al.,* 2021's scenario describes that the western delta is deposited on top of at least the Cf-fr unit, and possible the Us unit alongside it as well. This is then followed by erosion of all the units, including delta deposits and formation of the delta remnants seen in Jezero Crater at present.
Through analysis of topographic profiles and Digital Elevation Models (DEM), Holm-Alwmark *et al.*, 2021 further reveals that the youngest crater floor units (Cf-fr + Us) slopes away from the delta, in a radial pattern rather than uniform. As well as stating that their observations of the fractures in the Cf-fr and Us units end abruptly at the edge of the delta scarp, indicating the fracture forming event happened before the western delta was deposited.
Horgan *et al.,* 2020 uses CRISM data to characterize the geological units, which Holm-Alwmark *et al.*, 2021 uses to further support her scenario (Figure 5b). In CRISM imagery, the Cf-fr and Us units are defined by a high-calcium pyroxene (HCP) signal, which contrast with the low-calcium pyroxene (LCP) signal with the western delta, and the olivine-enriched sediment extending across the Cf-f units. It should be noted that the Us unit has a LCP signal prominent closer to the delta fan. There is also a clear topographical difference at the boundary between Cf-fr and Cf-f-1 (Holm-Alwmark *et al.*, 2021).

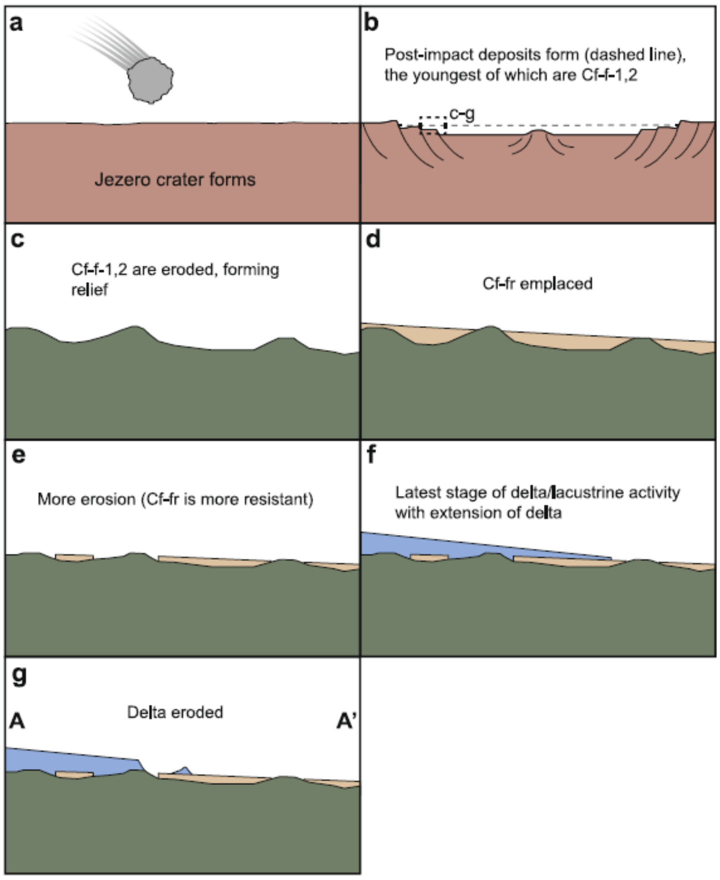


Figure 5a. Overview sketch for a sequence of events in Jezero Crater from Holm-Alwmark *et al.*, 2021: (a) Jezero Crater is formed from impact. (b) Post-impact deposits form as the youngest, which are cf-f-1, 2. (c) Cf-f-1 and 2 are eroded and form relief. (d) Cf-fr unit is deposited. (e) Cf-fr and Cf-f-1, 2 are eroded with Cf-fr being the more weathering resistant unit. (f) Later stages of fluvial lacustrine activity and lastly, (g) erosion of the units and delta, which creates the delta remnants.

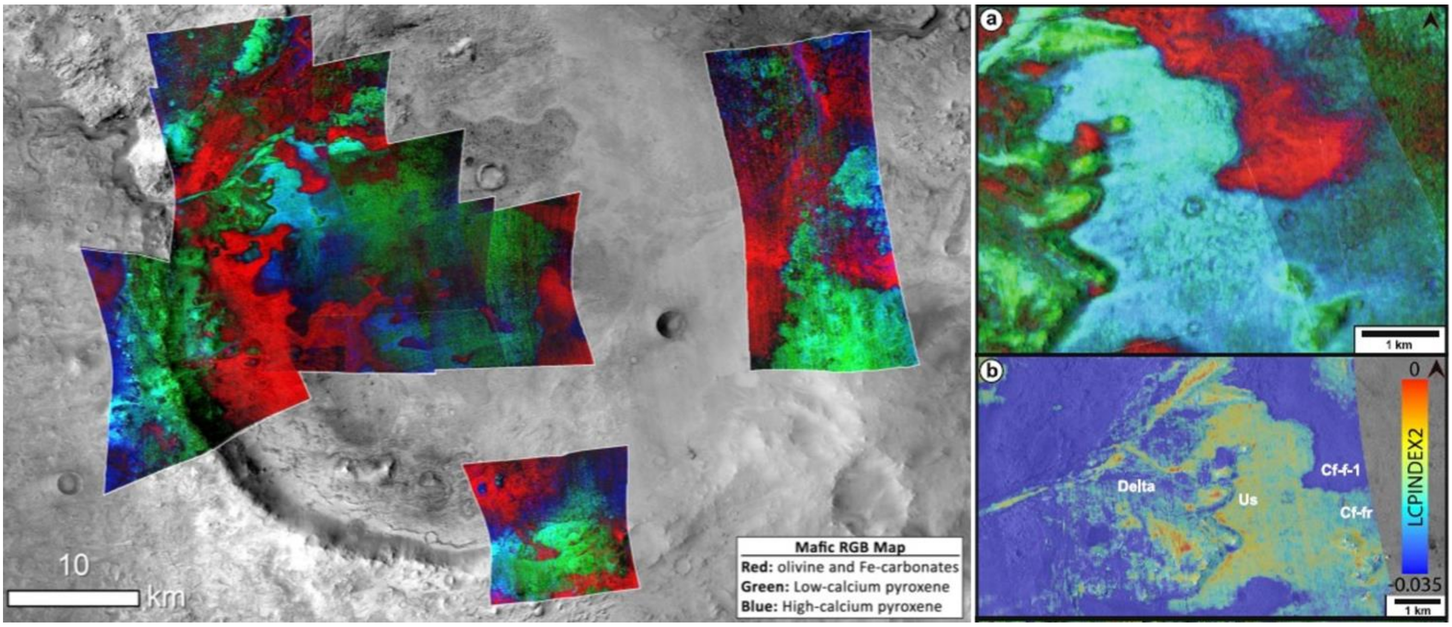


Figure 5b. Left image is a cropped image from Horgan *et al.*, 2020 showing mafic signatures from primary minerals in the surface sediments and bedrock units in Jezero Crater. Red denotes olivine and Fe-carbonates, green: low-calcium pyroxene (LCP) and blue: high-calcium pyroxene (HCP). Right image is cropped from Holm-Alwmark *et al.*, 2021 displaying (a) same image as on the left but zoomed-in from Horgan *et al.*, 2020 and (b) distribution of spectral signals consistent with LCP with blue being low and red being high.

3 Mars Exploration Program

The Mars 2020 Mission, as well as many of the missions to Mars – whether they are flyby's, orbiters, landers, or rovers, stretching all the way back to Mariner 3 & 4 from 1964 – are all a part of NASA's Mars Exploration Program (MEP). Some of these missions I will mention by name further down in this section, as it is them that the Mars 2020 Mission builds upon – both figuratively and literally.

This program, as the name suggests, is to explore Mars and understand whether Mars was, is, or can be, a habitable world. The Mars Exploration Program Analysis Group (MEPAG) is a part of MEP, and this group maintains the MEPAG Mars Science Goals, Objective, Investigations, and Priorities document, with the first version of it being released back in 2001. This document is regularly updated, as our knowledge of Mars continues to grow. The 2020 version of the mentioned document is arranged into a four-tiered hierarchy: Goals, Objectives, Sub-Objectives, and Investigations. The goals contain the major areas of scientific knowledge and are as follows (MEPAG 2020):

- Goal I	Determine if life ever existed, or exists, on Mars
- Goal II	Characterize Mars climate – the process and history
- Goal III	Characterize Mars geology – origin and evolution
- Goal IV	Prepare for human exploration

Each goal has objectives that incorporate the strategies, knowledge, and milestones that are required to achieve set goals. The sub-objectives concern the broader scope of the objectives and includes more details, whereas the individual investigations contribute to the completion of said sub-objectives.

Expanded statements on the goals, objectives, sub-objectives, and priorities can be found in MEPAG (2020).

Previous Mars Missions

The NASA Viking Mission to Mars consisted of two spacecraft, Viking 1 and Viking 2, which each consisted of an orbiter and a lander. They were both launched back in 1975 and were the first spacecraft ever to successfully land and operate on Mars. Both orbiters and landers operated between a span 2-6 years with their goal to seek out evidence of Martian life (NASA (1)). The results yielded by landers' experiments shed no further light on this goal and as such, no conclusions were reached concerning extant life on Mars (Soffen, 1976). Since the Viking mission, several missions have been sent to Mars, which build upon the same goal of the Viking landers albeit expanded. Though the particular goal of finding life on Mars has evolved over time to look for life in Mars' past, and not in what is known as a very cold and very dry, inhospitable environment, which is present day Mars. Many missions followed in Viking's footsteps, one of them especially paved the way for the way we explore Mars in present day. Pathfinder with its mini-rover *Sojourner*, which arrived at Mars in 1997 and operated for almost 10 months. This mission found evidence in the surrounding area of the landing site that large flooding had occurred in the past (Smith *et al.*, 1997, NASA (2))), once more solidifying that we had to look to the past. The Pathfinder mission, specifically it's micro rover, was also a successful demonstration of the utility of surface mobility, which lead up to the next Mars mission and its rovers – Mars Exploration Rover's (MER) *Spirit* & *Opportunity*. These rovers goal were to find rocks and soils that pertained to the extent of past water activity on Mars, which they found in the form of aqueous alteration products and water-precipitated minerals (Squyres and Knoll, 2005). Both rovers landed in 2004 and both long surpassed their planned operation time, with *Spirit* being active until 2010 and *Opportunity* being active until 2018 (NASA (3)). Mars Science Laboratory (MSL) with its *Curiosity* rover was the next step and its task was to seek out and characterize habitable paleoenvironments. It landed on Mars in 2013 and shortly after it found just such an environment, which were sediments deposited in a shallow lake at the end of a river channel. *Curiosity* has since then also discovered organic molecules in ancient fluvio-deltaic rocks (Eigenbrode *et al.*, 2018, NASA (4)) but has so far found no solid evidence of past or present life on Mars, although it continues to march on in its search up to this day (NASA (4)).

The most recent addition to this long line of missions is the Mars 2020 Mission with its rover, *Perseverance*.

3.1 Mars 2020 Mission

The Mars 2020 Mission is the first mission of a multi-mission campaign known as the Mars Sample Return and is set to run for at least one Mars year, which is equivalent to about 687 Earth days.

The Mars 2020 Mission will search for evidence of ancient microbial life on Mars and take samples for future return to Earth for analysis. This means that the landing site was required to include habitable environments from a time period prior to ~3.5 Ga (billions of years ago). A time when liquid water existed on the Martian surface and to have lithologic diversity for the sampling process (Farley *et al.*, 2020).

NASA chose Jezero Crater as the landing site out of 28 potential sites, as Jezero Crater fulfilled the previous mentioned standard and other engineering criteria (NASA (5)). Jezero Crater is ~45 km in diameter and is located at the north western edge of the Isidis basin, in the Nili Fossae region of Mars (Stack *et al.*, 2020).

The *Perseverance* rover as well as other major components were modified from its precursor mission MSL, which provided a great advantage as it reduced developmental risk as well as saving money and time (Farley *et al.*, 2020). The Mars 2020 Rover launched from Cape Canaveral, Florida, on July 30th, 2020, and landed in Jezero Crater on Feb. 18, 2021, after its 7-month long journey to Mars (Figure 1).

3.1.1 Mars 2020 Mission Objectives

The Mars 2020 mission objectives contribute to the MEPAG Science Goals through the following four mission objectives as stated in Farley *et al.*, 2020 and on the Mars 2020 Mission Science Objectives website (NASA (6)):

A. Develop a scientific understanding of the geology of its landing site.
B. Identify ancient habitable environments, locate rocks with high probability of preserving biosignatures, and use the rovers’ instruments to look for potential biosignatures based on the geological understanding.
C. Collect and document an assembly of scientifically compelling samples for a possible future return mission back to Earth for further study.
D. Enable future Mars exploration by humans by demonstrating new technologies as well as making progress filling in strategic knowledge gaps.

As Farley *et al.*, 2020 states, a key consideration in these objectives is the directive that Mars 2020 should seek signs of ancient life and not extant life. Hence Mars 2020 will be seeking biosignatures that might be present in rocks hailing from the earlier and wetter period of Mars’ history and collect at least twenty samples in the prime mission of one Mars year whilst providing sample context through in situ science investigations.

3.2 *Perseverance* Rover and Payloads

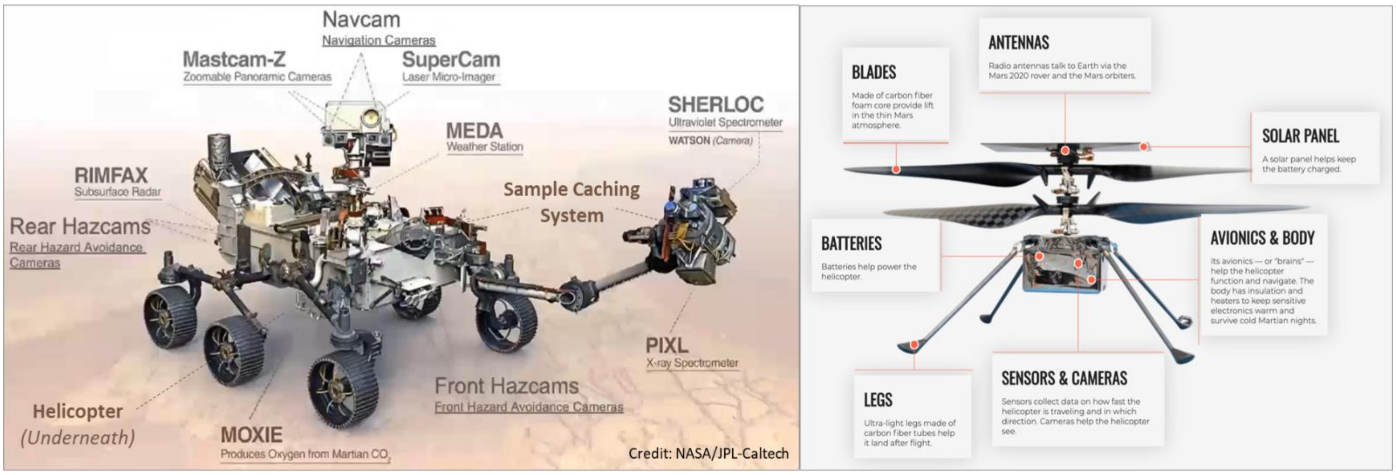


Figure 6. The *Perseverance* Rover, with Front + Rear HAZCAMs, NAVCAMs, the 7 scientific instruments and their main components, Heli and SCS highlighted (left), as well as an image of the *Ingenuity* Helicopter and its components in its deployed, flight-ready state (right). Images from NASA/JPL-Caltech (modified by me to include Heli and SCS location) & NASA (7), respectively.

As previously mentioned, the Mars 202 Missions builds on the success of the MSL spacecraft from 2012 and such, *Perseverance* strongly resembles *Curiosity* in appearance (Figure 6). See Grotzinger *et al.*, 2012 for further descriptions of the MSL mission, as well as the architecture and performance of the heritage components on which Mars 2020 builds upon.

The main changes from MSL to M2020 include: two new scientific and technology-demonstration payloads (*Ingenuity* Heli and MOXIE), enhanced engineering cameras for surface operations [253.2.3] and a collection of cameras for EDL for improved accuracy in landing and in rough terrain as well as a sophisticated new subsystem for preparing, sampling and caching of rock and regolith samples (SCS) for possible future return to Earth (Farley *et al.*, 2020).
Alongside these changes, the *Perseverance* rover hosts a scientific instrument payload consisting of seven instruments (Figure 6) – some are for proximity science, performing observations very close to, but not in contact with, the surface under study. These are mounted on the robotic arm of the rover and consists of PIXL and SHERLOC. Others are for remote science, either mounted on the rover mast such as Mastcam-Z [3.2.1] and SuperCam, and others are located on various parts of the rover body, like RIMFAX [3.2.2], which is on the aft underside of the rover. MOXIE is situated on the inside of the rover, while MEDA is located in different locations on the exterior of the rover.

Due to being a student collaborator on Mastcam-Z and my work involving RIMFAX, this thesis will therefore include detailed descriptions of these two instruments and some information on the engineering cameras, NAVCAM and HAZCAM. Only very brief, high-level descriptions of the other five instruments and their functions are presented here, as well as an intro to the helicopter technology-demonstration and the complex sample and caching system. As such, I will be referring to the main articles pertaining to more in-depth explanations and details for each of the seven instruments under their respective sections for the reader to peruse.

3.2.1 Mast Camera Zoom (Mastcam-Z / ZCAM)

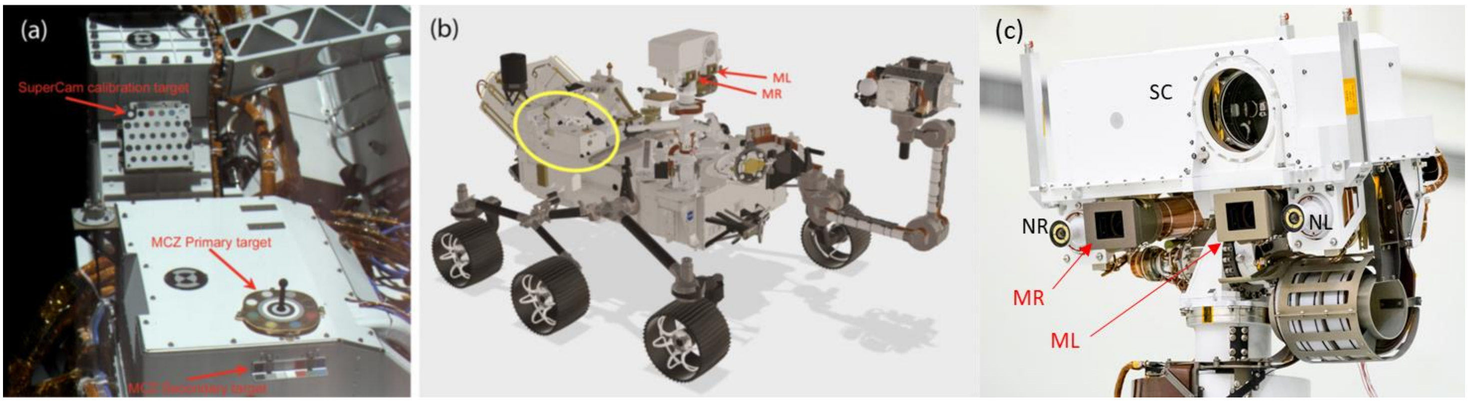
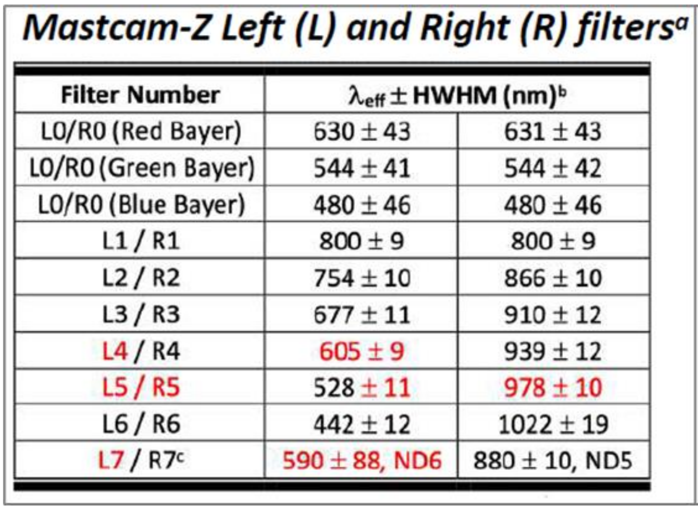


Figure 7. (a) Scene showing flight Mastcam-Z calibration targets mounted on the rover and imaged using flight cameras. The SuperCam calibration target is also visible. (b) shows a technical drawing with both Mastcam-Z eyes pointed out with red arrows and the scene shown in (a) is highlighted with a yellow circle. Whereas (c) shows the Flight RSM with ZCAM (red arrows), NAVCAM and SuperCam locations. (Fig. 3 from Kinch *et al.*, 2020 – Modified by me to include image of the RSM).

Mastcam-Z is a multispectral, stereoscopic camera with zoom capacity on the Mars 2020 Missions *Perseverance* rover. Mastcam-Z comprises of a pair of focusable cameras with zoom capabilities, mounted 1.98 meters above the ground on the Remote Sensing Mast of the *Perseverance* rover. Alongside these cameras follows two passive calibration targets, one primary and one secondary located on the rover deck (Figure 7).

The cameras have seven standard Zoom positions at 26mm, 34mm, 48mm, 63mm, 79mm, 100mm and 110mm. Mastcam-Z contains 11 narrow-band filters covering 400-1000 as well as a standard set of red/green/blue broadband Bayer filters (Figure 8) (Bell *et al.*, 2022 - To be published; Kinch *et al.*, 2020; Bell *et al.*, 2021; Hayes *et al.*, 2021).

Bell *et al.*, 2021 states that Mastcam-Z will support all the science objectives of A through D of the Mars 2020 Mission by providing multispectral, stereo, and panoramic images in which detailed morphology and geological context will be determined. Mastcam-Z images will also be used alongside the engineering cameras for rover navigation as well as document the rover's sample and caching locations.



Mastcam-Z Left (L) and Right (R) filters[a]

Filter Number	$\lambda_{eff} \pm$ HWHM (nm)[b]	
L0/R0 (Red Bayer)	630 ± 43	631 ± 43
L0/R0 (Green Bayer)	544 ± 41	544 ± 42
L0/R0 (Blue Bayer)	480 ± 46	480 ± 46
L1 / R1	800 ± 9	800 ± 9
L2 / R2	754 ± 10	866 ± 10
L3 / R3	677 ± 11	910 ± 12
L4 / R4	605 ± 9	939 ± 12
L5 / R5	528 ± 11	978 ± 10
L6 / R6	442 ± 12	1022 ± 19
L7 / R7[c]	590 ± 88, ND6	880 ± 10, ND5

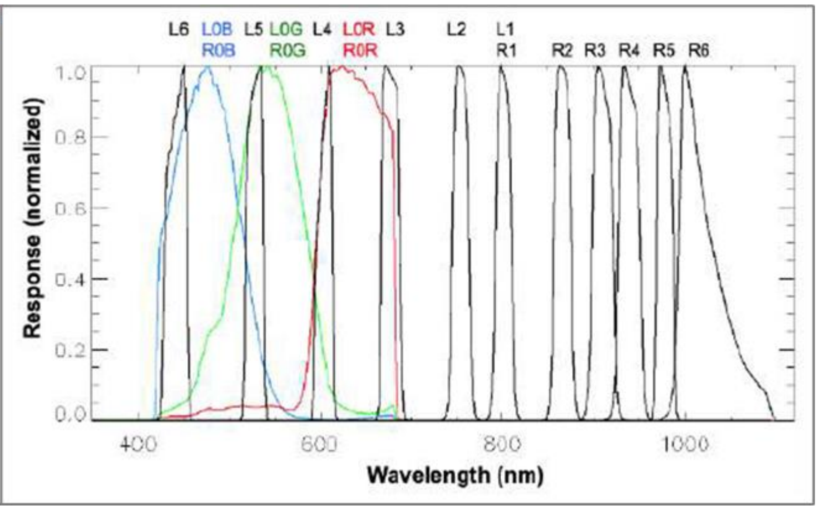


Figure 8. Left image is an overview table that shows the left and right eye narrowband filters. The red text highlights new performance compared to MSL. Right image shows the Mastcam-Z filter transmission profiles as measured during calibration. Images are the Multispectral Imaging Guidelines .pdf, made as a sort-of cheat sheet for the Mastcam-Z but the details on either image can be found in Hayes *et al.*, 2021.

IOF Calibration and Multispectral

The two calibration targets combine designs from previous Mars missions and is composed of one primary and one secondary. The primary calibration target will be used to verify and validate preflight calibration after the instruments have arrived on Mars and assist in tactical conversion of images of the Martian surface from units of radiance to units of reflectance. It will also help estimate the ratio of irradiance in the direct solar beam to diffuse sky irradiance reaching the surface via atmospheric scatterings and monitor the stability of the calibration throughout the duration of the mission.

The secondary calibration target will act as a cross-check with the main calibration target at a location that is more likely to be shielded from dust deposition during landing and surface operations. It will also function as a dust deposition monitor of the calibration target without the effects of magnets as are present in the primary target (Kinch *et al.*, 2020).

Raw images taken by Mastcam-Z is sent through Mastcam-Z radiometric calibration pipeline (Hayes *et al.*, 2021) and are converted to radiance images through conversions and corrections that I will not go into detail here. After these first steps, the radiance images are then converted to radiance factor values (also known as incidence-over-reflectance, IOF or I/F) by using the closest available image of the calibration target. Although if the incidence angle of illumination on the surface is known or assumed, then one can convert IOF to a reflectance factor (R*) by R* = IOF/cos(i) (Bell *et al.*, 2022 - To be published).

Spectra in up to 14 specific wavelengths can then be extracted from the multispectral images taken by ZCAM by selecting Regions of Interest (ROIs). Error bars are shown in the produced spectra plot to specify the standard deviation of pixels within each ROI. This uncertainty is generally much larger than the uncertainty in the instrument itself (Bell *et al.*, 2022 - To be published).
Section 4.1.3 contains a walkthrough of this ROI spectra extraction procedure done during a sPDL shift.

As such, Mastcam-Z is capable of acquiring 14-point spectra of rock and soil reflectance from the near-UV to the near-IR through the use of a filter wheel. This provides the science team with compositional information at low spectral resolution but extremely high spatial resolution, allowing us to identify interesting targets for follow-up investigation by the other rover instruments and extrapolate the measurements by these other instruments to a broader landscape context.

I refer to Bell *et al.*, 2021 as the main Mastcam-Z instrument overview paper, alongside its two companion papers. The first companion paper focuses on the design, pre-flight characterization, and intended uses of the Mastcam-Z Primary and Secondary calibration targets and is Kinch *et al.*, 2020. Whereas the second companion paper supplies information on the performance and pre-flight calibration of the Mastcam-Z cameras and is Hayes *et al.,* 2021.

3.2.2 Radar Imager for Mars' Subsurface Experiment (RIMFAX / RFAX)

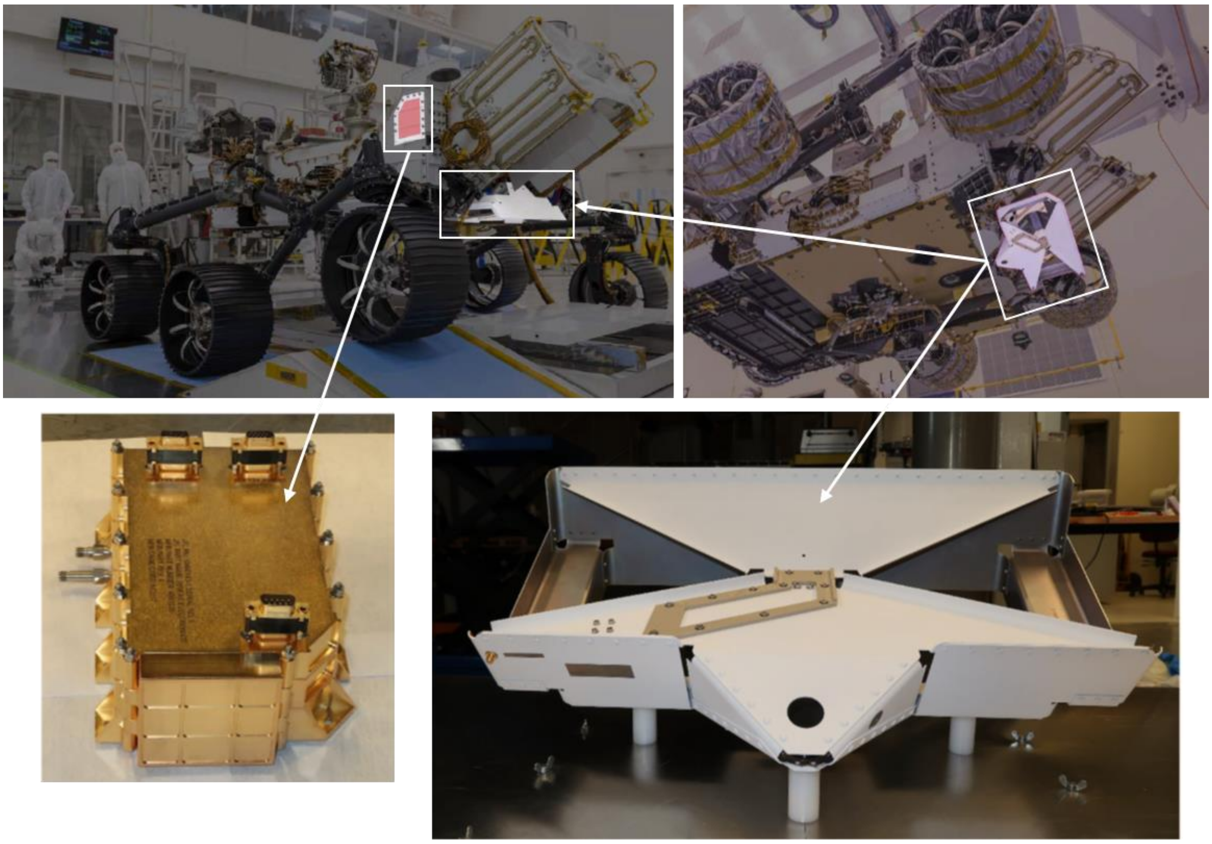


Figure 9. Location of the RIMFAX electronics box inside (red highlight) the *Perseverance* rover and the electronics box itself approximately to scale (left bottom image). The location of the RIMFAX bowtie antenna underneath the MMRTG on the *Perseverance* rover and the antenna itself approximately to scale (right bottom image). (Top two images from Hamran *et al*., 2020 and bottom two images from Farley *et al*., 2020 – Modified by me to include arrows and boxes).

RIMFAX is a Ground Penetrating Radar (GPR) on the *Perseverance* rover and first ever GPR on the surface of Mars. The instrument is comprised of a bowtie antenna mounted underneath the rear of the rover, around 60 cm above the ground and an internally mounted electronics box (Figure 9). RIMFAX utilizes a Frequency Modulated Continuous Waveform (FMCW) in which the baseband signal is low-pass filtered before being sampled and transmits electromagnetic waves of 150-1000 MHz into the subsurface, travelling downwards until they are reflected by subsurface interfaces in the geologic materials (Hamran *et al.*, 2020).

The measurements done by RIMFAX are called soundings and will be collected every time the rover moves for either a short or a long drive, a full sol traversal or even while turning in place or being stationary. Hamran *et al.*, 2020 states that RIMFAX should have the capability to penetrate atleast 10 meters into the Martian subsurface.

Because RIMFAX only has a single antenna, then the antenna itself acts as both a transmitter and a receiver through the use of a gating technique. The gating technique effectively increases the dynamic range coverage of the radar system (Hamran *et al.*, 2020; Russell and Sullivan, 2021).
RIMFAX has three modes of operation: (1) Surface mode in which the surface reflection and very upper subsurface is measured and the antenna reflection is captured in the receiver window; (2) Shallow mode measures the surface reflection and the shallow subsurface, while removing the antenna reflection from the receiver window; and (3) Deep mode in which the antenna and surface reflections are both removed from the receiver window and the reflections from the upper subsurface (~1 m depth) through the instrumented range is measured (Hamran *et al.*, 2020; Russell and Sullivan, 2021).

Data Processing

Below is a short overview of the general calibration process from Russell and Sullivan, 2021.
The raw sounding data from RIMFAX undergoes six steps of data processing. Some of these are done in the frequency domain, before being converted to the time domain to undergo further processing and ending up as the final product in the time domain. There are six steps in total, although I will not be going into detail as it is not relevant for my thesis:
The first step is the amplitude and phase correction, the second is radiometric correction, third is shift to time-zero (t=0) at antenna delay, fourth is multiply with window function, before lastly performing IFFT with 16x interpolation, followed by correcting the amplitude for gating function.

Please see Hamran *et al.*, 2020 for more in-depth explanations of the instrument hardware and its field tests. The calibration process briefly mentioned here is detailed in the Russell and Sullivan, 2021 alongside the publicly released RIMFAX data on the PDS website.

3.2.3 Engineering Cameras (ECAM)

The *Perseverance* rover has a total of 23 cameras – 19 of those 23 cameras are rover-mounted with the remaining 4 cameras mounted on the entry vehicle for use during EDL. Out of the 19 cameras mounted on the rover, 16 of them are to use during everyday surface operations. Two of the remaining 3, out of the 19 total, are controllable after landing but have not been designed to endure the surface environment, whereas the remaining one is not controllable after landing (Maki *et al.*, 2020).

Maki *et al.*, 2020 describes the 16 engineering cameras and has compiled them into three separate groups based on the separate development teams that designed, built, and delivered the hardware. The first group comprises of NAVCAM (2), HAZCAM (4 in the Front and 2 in the Rear) and CACHECAM (1). The second and third group comprises the remaining seven cameras – 6 of them used for EDL documentation and 1 was used for providing critical image data to the Lander Vision System (LVS) during the parachute phase of EDL.

I will only briefly mention NAVCAM and HAZCAM in detail out of all these cameras, as their images played a small part in some of my thesis work in Section 5.3.

The two NAVCAMs (Left and Right) are mounted to the underside of the camera plate on the Remote Sensing Mast (RSM), with the HAZCAMs located on the underside in both the front and rear of the rover (Figure 10).

Figure 10. ***Perseverance*** **Left/Right NAVCAMs and Front L/R HAZCAMs (left image). Rear Left/Right HAZCAMs underneath either side of the Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) (right image). (Modified Fig. 14 & 15 from Maki** ***et al.*****, 2020)**

The design of the NAVCAM and HAZCAMs on the Mars 2020 Mission are a modernization of the MER and MSL camera designs, brought on by significant advancements in electronics hardware since the time the MER rovers were flown to Mars (Maki *et al.*, 2020).

The Mars 2020 NAVCAMs and HAZCAMs offer three primary improvements (Farley *et al.*, 2020; Maki *et al.*, 2020): (1) An upgrade to a detector with 3-channel, red/green/blue (RGB) colour capability as the previous engineering cameras only had black/white capability; (2) A wider field of view on the NAVCAMs, improving the quality of the mosaics and able to simultaneously image both near and far field terrain and on the HAZCAMs to allow for better coverage of the rover wheels; (3) Finer pixel scale (µrad/pixel), to permit better drive planning and hardware inspection capabilities.

More in-depth explanations and information on all the engineering cameras hardware as well as associated flight and ground software can be found in Maki et al. (2020).

All the descriptions of the remaining five science payloads as, well as *Ingenuity* and the Sample and Caching System, can be found below. Although the instruments themselves do not tie directly into this thesis, they have been included because the Mars 2020 Mission theories that will be covered in the discussion could only be achieved through a combination of all these instruments.

- ***Ingenuity* Helicopter**

Ingenuity is a 1,8 kg, 1.2 m diameter helicopter (Figure 6). This helicopter is a technology-demonstration payload of the Mars 2020 Mission and will be deployed from the rover for a 30-Sol experimental campaign. The aim of this campaign is to demonstrate autonomous, controlled flight of an aircraft in the Mars environment for the first time and perform a planned set of five flights during this period. This will benefit the development of new Mars rotorcraft designs, which could help broaden the range of exploration and science capabilities for future missions (Balaram *et al.*, 2019; Farley *et al.*, 2020; Balaram, Aung and Golombek, 2021).
For more detailed explanations on the helicopter subsystems and operations, please refer to Balaram, Aung and Golombek, 2021.

The *Ingenuity* helicopter made history with its first successful flight on the 19th of April 2021 (Sol 58) after being deployed on the 3rd of April 2021 (Sol 42). Mastcam-Z captured footage of this historical flight as well as flights nr. 2, 3, 4, 5 and 13 (Bell *et al.*, 2022 - To be published). I also helped process some of the first images of *Ingenuity* by Mastcam-Z after its deployment from the rover [Section 5.1.1].
Even though no flights were originally planned to follow the 30-Sol demonstration window (Balaram, Aung and Golombek, 2021), *Ingenuity* has since transitioned to a new operations demonstration phase and continues to operate. In this new phase *Ingenuity* has subsequently performed 18 flights as of Sol 292 (NASA (7)) - travelling more than 3.592 meters and accumulating a total flight time of over 30 mins across all of its flights (NASA (8)). *Ingenuity* continues to explore how aerial scouting and other functions could benefit future exploration of Mars while also providing this type of support to *Perseverance* (NASA (9)).

- **Sampling and Caching System (SCS)**

In order to fulfil the third mission objective: "Collect and document an assembly of scientifically compelling samples for a possible future return mission back to Earth for further study.", *Perseverance* carries a specific system for that, known as the Sample and Caching System (SCS). This system consists a few parts. First is a turret that forms the abrading and coring drill (nicknamed "Corer"), which is integrated with the SHERLOC and PIXL instruments, and a gas dust removal tool (gDRT). The second part is an external robotic arm (RA) for positioning said turret. With the third and last part is a complex internal mechanism named the Adaptive Caching Assembly (ACA) is used to handle the sample tubes within the rover body and also contains a bit carousel for exchanging bits and samples tubes between the ACA and "Corer". *Perseverance* carries a total of 43 samples tubes, with 5 of them relegated to monitoring the potentially evolving contamination state of the rover, with respect to organic molecules (Farley *et al.,* 2020).

Farley *et al.*, 2020 contains more in-depth descriptions of coring depth, a walkthrough of how a sample is taken and other technical details.

- **Mars Environmental Dynamics Analyzer (MEDA)**

MEDA is an ensemble of sensors and are used to measure environmental variables and as such, characterize the local micrometeorology and microclimatology near the surface of Mars, as well as constrain the bulk aerosol properties from changes in atmospheric radiation (Rodriguez-Manfredi *et al.*, 2021).
According to Rodriguez-Manfredi *et al.*, 2021 MEDA will contribute to the M2020 Science Objective D, specifically characterizing the dust environment during and between activity of the MOXIE instrument in order to understand its effects on its operation as well as providing surface weather measurements that will help validate global atmospheric models. In addition, MEDA will also help support the M2020 Science Objective C, as atmospheric conditions form a vital part of the context in which the samples were acquired (Rodriguez-Manfredi *et al.*, 2021).

More detailed information on the MEDA sensors and their specifics can be found in Rodriguez-Manfredi *et al.*, 2021.

- **Mars Oxygen *In-Situ Resource Utilization* (ISRU) Experiment (MOXIE)**

MOXIE is one of the two technology demonstrations on the *Perseverance* rover. MOXIE will produce oxygen by collecting the Martian atmosphere, filtering and compressing it before injecting it into a **S**olid **Ox**ide **E**lectrolysis reactor (SOXE) that will convert CO_2 into Oxygen and CO through the $2CO_2 \rightarrow 2CO + O_2$ reaction. This will support the M2020 Science Mission Objective D by demonstrating a way that will enable future explorers to produce oxygen from the Martian atmosphere for propellant and also for breathing (Hecht *et al.*, 2021).
The instrument has three top-level requirements it needs to fulfil: The first involves having the capability of producing at least 6 g/hr of O_2 in the context of the M2020 Mission, while the second is it needs to produce oxygen of >98% purity. And lastly, it needs to fulfil the two previous requirements for at least 10 operational cycles, while also being expected to operate in all seasons and at all times of day and night on Mars, as well as during a dust storm, if the opportunity presents itself (Farley *et al.*, 2020; Hecht *et al.*, 2021).

MOXIE had its first test run, and it took place on April 20th, which equates to Sol 60 on Mars. Although in this test MOXIE produced a total of 5.37 grams of oxygen, MOXIE is designed to generate up to 10 g/hr of oxygen. The 5.4 grams of oxygen produced in this first test is equivalent to 10 minutes of breathable oxygen for an astronaut (NASA (10)).

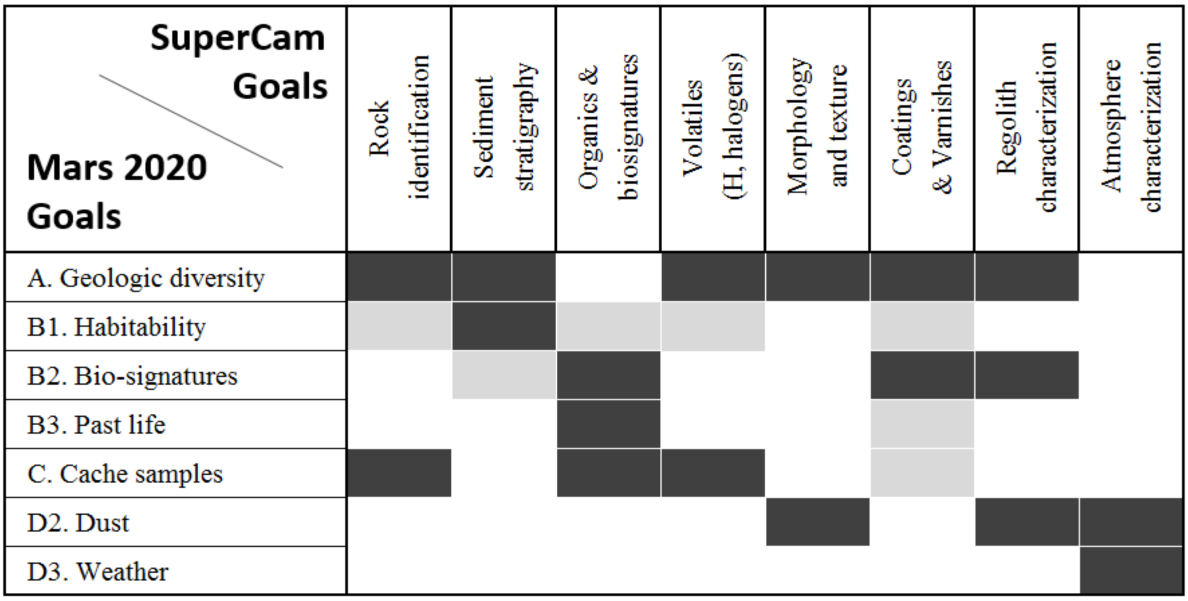
For more detailed information on the intricacies of MOXIE, please see Hecht *et al.*, 2021**.**

- **SuperCam**

SuperCam operates at a remote distance of 2-7 meters, while providing data on the diversity in composition of any rock at sub-millimetre to millimetre scales and therefore complimenting the proximity instruments, PIXL and SHERLOC (Maurice *et al.*, 2021).

Due to SuperCam being such a versatile instrument, it therefore also covers a majority of the M2020 Science Objectives with ease. Maurice *et al.*, 2021 has compiled this into a nice qualitative form in the shape of a table in his paper, which is shown on Table 1.

Table 1. Relation between SuperCam Science Objectives and the M2020 Science Objectives. Dark indicates a major contribution, whereas light grey indicates a minor contribution from SuperCam. (Table 1 from Maurice *et al.*, 2021)



SuperCam Goals / Mars 2020 Goals	Rock identification	Sediment stratigraphy	Organics & biosignatures	Volatiles (H, halogens)	Morphology and texture	Coatings & Varnishes	Regolith characterization	Atmosphere characterization
A. Geologic diversity	■	■		■	■	■	■	
B1. Habitability	▒	■	▒	▒		▒		
B2. Bio-signatures		▒	■			■	■	
B3. Past life			■			▒		
C. Cache samples	■		■	■		▒		
D2. Dust					■		■	■
D3. Weather								■

Please see Maurice *et al.*, 2021 for the details of the physics behind the spectroscopy techniques listed here and the fine points of the SuperCam instrument.

- **Scanning Habitable Environments with Raman and Luminescence for Organics and Chemicals (SHERLOC)**

SHERLOC is an arm-mounted, deep UV (DUV) resonance Raman and fluorescence spectrometer. It has two imagers it utilizes: One for spectroscopy combined with microscopic imagery. The other is the Wide-Angle Topographic Sensor for Operations and eNgineering (WATSON), which is a copy of the MSL MAHLI instrument. This boresight procures color images from microscopic scales to infinity and is also used to perform engineering tasks such as document rover health and the likes (Bhartia *et al.*, 2021). It was WATSON imager, which took the *Perseverance* & *Ingenuity* selfie – the image which is used on the front page of this thesis.

SHERLOC uses a DUV laser in order to obtain the native fluorescence emissions from aromatic organic species and Raman scattered photons, which allow for identification of groups of organics, chemicals and minerals (Bhartia *et al.*, 2021).

SHERLOC will contribute to the M2020 Science Objective B of searching for Martian biosignatures by producing micron-to-millimetre scale microscopy in combination with mineral and organic detection and characterization, and as such placing any potential Martian biosignatures in the proper geological context. SHERLOC will also play a role in providing organic and mineral analysis for selected samples for later sample return to Earth (Bhartia *et al.*, 2021).

For details on Raman and fluorescence spectroscopy and SHERLOC itself, I recommend delving into Bhartia *et al.*, 2021.

- **Planetary Instrument for X-Ray Lithochemistry (PIXL)**

PIXL is a microscopic X-Ray fluorescence (XRF) spectrometer. It is controlled by software that allows for it to autonomously locate and point to a specified area of interest and adjusting the distance to the target. During its autonomous work that stretches over a span of several hours, it generates a chemical map involving X-ray spectral collection and motor movements. Through the use of the hexapod, it can correct for minor lateral and vertical drift during these scans, which are caused by miniscule thermal contraction and expansion of the rover itself (Allwood *et al.*, 2020).

Allwood *et al.*, 2020 states that PIXL will provide the capability to detect potential chemical biosignatures by detecting micro-scale variations in the major and trace element abundances, which can be preserved through time. PIXL can also facilitate detailed geochemical characterization of other types of potential biosignatures, such as stromatolites. And thus, PIXL helps fulfil the M2020 Science Objective B.

Alongside many of the previous instruments, PIXL also contributes to the M2020 Science Objective C, as PIXL enables well-informed sample selection alongside the data produced from the other instruments.

Allwood *et al.*, 2020 contains more details on the hardware that makes up the PIXL instrument as well as examples of micro-XRF analogues found on Earth.

4 Tools and Methods

In this section I will cover the Mars 2020 Science Operation as well as some of the tools used during the downlink Tactical side of the Mars 2020 Science Operations. In that relation, I will therefore also be covering what it means to be part of the Mastcam-Z Science Support Downlink team. What it means to be on a shift, the roles on the team, what tools we use, and the procedures we follow on a shift. A run-through of my Sol 80 shift is also located in this section.

The tools and methods used during my time in the remapping effort as well as my own work on correlating ZCAM mosaics and RFAX radargrams is also shown in this section.

4.1 Mars 2020 Science Operations

Mars 2020 Science Operations (SOPS) has 4 processes: Strategic, Campaign Planning, Campaign Implementation and Tactical (Figure 11).

Keep in mind, that there is an abundance of different roles (science, engineering & robotics alike) that make up these processes and all play an integral part in the complexity that is the Mars 2020 Mission. Below is a very high-level walkthrough of these previously stated processes, in which the mission is built upon.

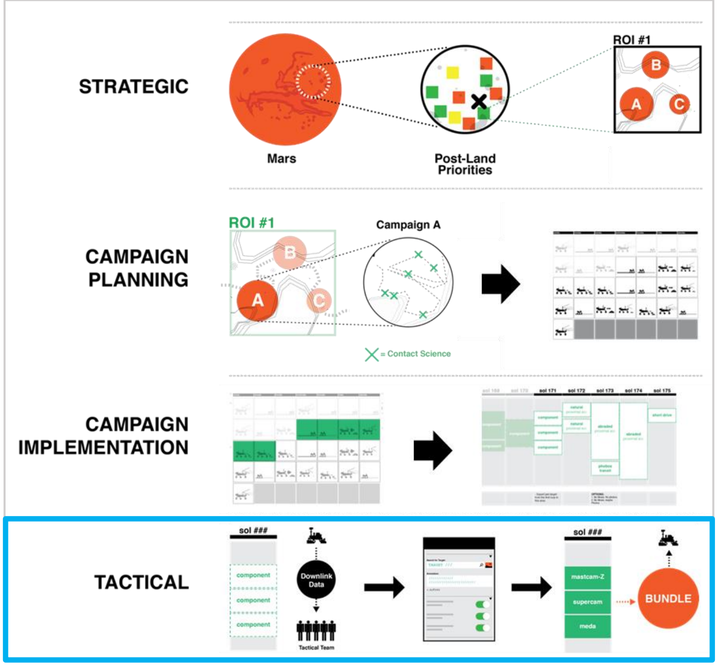


Figure 11. Overview of the 4 Mars 2020 Operation processes: Strategic (top), Campaign Planning (second to the top), Campaign Implementation (second to the bottom) and Tactical (bottom). The blue box encompasses the Tactical process, which is the process I was a part of when attending sPDL shifts on the Mastcam-Z downlink side. (From "Introduction to Science Operations" presentation by Sarah Milkovich, 2-11-2020)

The first process, Strategic, encompasses the mission as a whole and covers decisions that revolve around sampling strategies, which regions of interest to explore, the what's and why's of campaigns as well as their durations. The following three processes further support the Strategic process, going further and further into detail on the different science decisions.

With the second process, Campaign Planning, unfolding over the course of several months. The science decisions in this process focuses on the different campaign science objectives and investigation strategies, e.g., estimating a drive path for the rover when moving between strategical targets as well as a high-level activity schedule.

The third process is the Campaign Implementation (CI), which focuses on a short time range of 2 to 7 days. This process includes the more detailed science decisions such as, what are we seeing in the data, and what do we think about it? Where are we going based on the different campaign science objectives? Do we have several sol options here? E.g., do we do just a drive sol, a targeted remote imaging science sol or an arm contact science sol?

The last process is Tactical and focuses on the day-to-day science decisions and as such, decides what sol option is the most optimal based on most recent Downlink (DL). Other deciding decisions are also: what final set of instrument observations and their order do we want in the plan for Uplink (UL)? As well as a final selection of strategic targets and data reprioritization, if any, before command sequences were uplinked to the rover.

As a student collaborator on the Mastcam-Z team, I attended Tactical Downlink (DL) shifts as a sPDL on the Mastcam-Z Science Operations **Downlink** Team, during SOPS – a more detailed explanation of how the sPDL team is setup, their tasks, as well as the tools at our disposal (alongside the large repertoire that is the Mars 2020 Tools), has been written out in Section 4.1.2.

Below is a brief description of some of the roles I encountered during my shifts, followed by a brief rundown of what a Tactical shift involves:

Mastcam-Z Payload Downlink Leads (PDLs) worked on the DL side of a shift and were assisted by the sPDLs. The ZCAM PDLs job is to fill out the current Sols PDL reports on both the Mastcam-Z wiki and on CACHER, as well as making sure the downlinked science data and the Mastcam-Z instrument health data are satisfactory. If everything was in order, then the PDLs would mark Mastcam-Z as nominal and go for planning next Sol.

Mastcam-Z Payload Uplink Leads (PULs) is an engineering role, and their job was to write the actual command sequences for the rover, which would include where the camera should point to, the exact exposure time as well as taking the suns position into account. The Mastcam-Z Science Payload Uplink Leads (sPULs) job were to advise the engineering PULs from a science perspective and provide the scientific argumentation behind choice of targets and pointings. There are therefore three sub-roles of sPULs: sPULgeology (sPULgeo), sPULmultispectral (sPULmspec), and sPULatmosphere (sPULatm), which all cover their specific scientific areas.

The Campaign Implementation – Long Term Planner (CI-LTP) and Campaign Implementation – Documentarian (CI-Doc) are part of the CI process. A few of the responsibilities of the CI-LTP are as follows: maintain strategic science vision and science intent in the Campaign Implementation; facilitate the Implementation Discussion conversations and lead the team in evaluating progress towards Campaign Goals and Tasks, as well as identifying upcoming decision points. CI-Doc is in charge of following the CI planning process and work with the CI-LTP to prepare the Implementation Discussion as well as documenting key decisions and thoughts from said discussion.

A shift is setup as such, that when DL is assessing the most recently completed Sol, the UL team will be planning the following Sol and the CI team will be planning 2 Sols ahead. So, for instance, when DL would be assessing Sol 21, UL would be planning Sol 22 and CI would be planning Sol 23+.

Therefore, a Tactical Downlink shift would always start before the Tactical Uplink shift. This is because DL was the first set of eyes on the most recent downlinked data and therefore passed on relevant observations for UL and CI planning. Downlink time was constantly in flux, because we were dependent on orbiter overflights to relay back data from the rover as well as general drift of a Mars Sol (24 hours and 40 mins) compared to an Earth day. During the first 90 Sols of the mission, we were on Mars time and the shift start time was therefore pinned to a decisional downlink time, which always coincided with night-time on Mars, regardless of the time on Earth. This was to ensure that while the rover recharged throughout the night, all tactical relevant decisions based on its downlinked data could be sorted through and new sequences uplinked to the rover, so it would be ready to perform science at the start of the next Mars Sol.

Following Sol 90, shift time was moved in order to fit within the 6 am to 10 pm Pacific window on Earth. Due to the aforementioned drift, this meant that there were Sols in which this window would overlap with day on Mars instead of night. These Sols were listed as a “Restricted Sol”. In short, it means that UL had to plan without knowing the outcome of the most recently uplinked plan, as the downlink data had yet to come down.

Quite a few voice meetings between different disciplines and processes would occur during a shift but the most important, was the teamwide Science/Implementation Discussion, led by the CI-LTP and documented by the CI-Doc on the current Sols CI CACHER report. This 2-to-2,5-hour long meeting was the main platform where new observations, results or theories from the different instrument teams could be presented and discussed. This is where the overlap between the Campaign Implementation and Tactical process would happen.

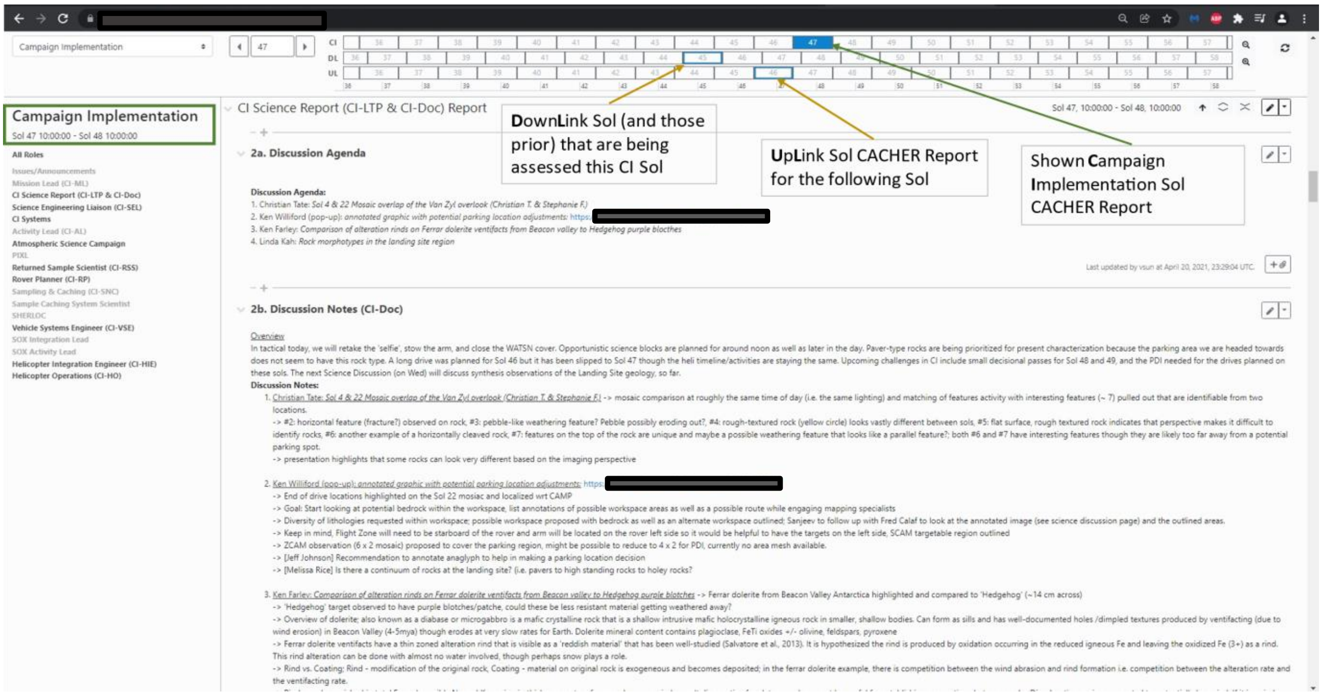
The Mars 2020 Mission is a conglomerate of different instrument science teams, engineering teams, and robotics groups. In order to facilitate everything and have it all run smoothly 24/7, the tools at our disposal have to be of the topmost quality and able to perform a variety of tasks. I was allowed to use some of these tools during my shifts and I will go into more detail on them in the following section.

4.1.1 Mars 2020 Mission Tools

The tools mentioned in this section are continuously being improved throughout the duration of the mission as well as new tools are being developed and added every once in a while. For instance, the ASDF program for ZCAM was developed later in the mission. This program automates the process of plotting spectra and archiving the spectra for ease of accessibility. The sPDL staff and I made a large contribution to how this program carries out that specific task.

In order to gain access to Starting Line, which was a JPL/NASA website with the tools available for the Mars 2020 Surface Operations, I had been provided with a JPL login, the PulseSecure VPN on my PC, and the DUO authentication app on my phone. I only used a small fraction of the starting line tools for my Mastcam-Z downlink support shifts and other thesis work. The tools that I used are as follows:

<u>CACHER (**C**urrent **A**ctivities, **C**oncerns, **H**andovers, and **E**vents **R**eports)</u>: A tool for reading and entering operational reports from Campaign Implementation (CI), Uplink (UL), and Downlink (DL) for every instrument (science-related and non-science) on every Sol. These reports are documents on main issues or discussions from that planning day. These reports therefore capture the narrative of the Tactical or CI planning day and present the most detailed context for past plans and decisions.



Campaign Implementation
Sol 47 10:00:00 - Sol 48 10:00:00

All Roles
Issues/Announcements
Mission Lead (CI-ML)
CI Science Report (CI-LTP & CI-Doc)
Science Engineering Liaison (CI-SEL)
CI Systems
Activity Lead (CI-AL)
Atmospheric Science Campaign
PIXL
Returned Sample Scientist (CI-RSS)
Rover Planner (CI-RP)
Sampling & Caching (CI-SNC)
Sample Caching System Scientist
SHERLOC
Vehicle Systems Engineer (CI-VSE)
SOX Integration Lead
SOX Activity Lead
Helicopter Integration Engineer (CI-HIE)
Helicopter Operations (CI-HO)

CI Science Report (CI-LTP & CI-Doc) Report

Sol 47, 10:00:00 - Sol 48, 10:00:00

2a. Discussion Agenda

Discussion Agenda:
1. Christian Tate: *Sol 4 & 22 Mosaic overlap of the Van Zyl overlook (Christian T. & Stephanie F.)*
2. Ken Williford (pop-up): *annotated graphic with potential parking location adjustments:* https:[redacted]
3. Ken Farley: *Comparison of alteration rinds on Ferrar dolerite ventifacts from Beacon valley to Hedgehog purple blocthes*
4. Linda Kah: *Rock morphotypes in the landing site region*

Last updated by vsun at April 20, 2021, 23:29:04 UTC.

2b. Discussion Notes (CI-Doc)

<u>Overview</u>
In tactical today, we will retake the 'selfie', stow the arm, and close the WATSN cover. Opportunistic science blocks are planned for around noon as well as later in the day. Paver-type rocks are being prioritized for present characterization because the parking area we are headed towards does not seem to have this rock type. A long drive was planned for Sol 46 but it has been slipped to Sol 47 though the heli timeline/activities are staying the same. Upcoming challenges in CI include small decisional passes for Sol 48 and 49, and the PDI needed for the drives planned on these sols. The next Science Discussion (on Wed) will discuss synthesis observations of the Landing Site geology, so far.
Discussion Notes:
1. <u>Christian Tate: *Sol 4 & 22 Mosaic overlap of the Van Zyl overlook (Christian T. & Stephanie F.)*</u> -> mosaic comparison at roughly the same time of day (i.e. the same lighting) and matching of features activity with interesting features (~ 7) pulled out that are identifiable from two locations.
   -> #2: horizontal feature (fracture?) observed on rock, #3: pebble-like weathering feature? Pebble possibly eroding out?, #4: rough-textured rock (yellow circle) looks vastly different between sols, #5: flat surface, rough textured rock indicates that perspective makes it difficult to identify rocks, #6: another example of a horizontally cleaved rock, #7: features on the top of the rock are unique and maybe a possible weathering feature that looks like a parallel feature?; both #6 and #7 have interesting features though they are likely too far away from a potential parking spot.
   -> presentation highlights that some rocks can look very different based on the imaging perspective

2. <u>Ken Williford (pop-up): *annotated graphic with potential parking location adjustments:*</u> https:[redacted]
   -> End of drive locations highlighted on the Sol 22 mosiac and localized wrt CAMP
   -> Goal: Start looking at potential bedrock within the workspace, list annotations of possible workspace areas as well as a possible route while engaging mapping specialists
   -> Diversity of lithologies requested within workspace; possible workspace proposed with bedrock as well as an alternate workspace outlined; Sanjeev to follow up with Fred Calaf to look at the annotated image (see science discussion page) and the outlined areas.
   -> Keep in mind, Flight Zone will need to be starboard of the rover and arm will be located on the rover left side so it would be helpful to have the targets on the left side, SCAM targetable region outlined
   -> ZCAM observation (6 x 2 mosaic) proposed to cover the parking region, might be possible to reduce to 4 x 2 for PDI, currently no area mesh available.
   -> [Jeff Johnson] Recommendation to annotate anaglyph to help in making a parking location decision
   -> [Melissa Rice] Is there a continuum of rocks at the landing site? (i.e. pavers to high standing rocks to holey rocks?

3. <u>Ken Farley: *Comparison of alteration rinds on Ferrar dolerite ventifacts from Beacon valley to Hedgehog purple blotches*</u> -> Ferrar dolerite from Beacon Valley Antarctica highlighted and compared to 'Hedgehog' (~14 cm across)
   -> 'Hedgehog' target observed to have purple blotches/patche, could these be less resistant material getting weathered away?
   -> Overview of dolerite; also known as a diabase or microgabbro is a mafic crystalline rock that is a shallow intrusive mafic holocrystalline igneous rock in smaller, shallow bodies. Can form as sills and has well-documented holes /dimpled textures produced by ventifacting (due to wind erosion) in Beacon Valley (4-5mya) though erodes at very slow rates for Earth. Dolerite mineral content contains plagioclase, FeTi oxides +/- olivine, feldspars, pyroxene
   -> Ferrar dolerite ventifacts have a thin zoned alteration rind that is visible as a 'reddish material' that has been well-studied (Salvatore et al., 2013). It is hypothesized the rind is produced by oxidation occurring in the reduced igneous Fe and leaving the oxidized Fe (3+) as a rind. This rind alteration can be done with almost no water involved, though perhaps snow plays a role.
   -> Rind vs. Coating; Rind - modification of the original rock, Coating - material on original rock is exogeneous and becomes deposited; in the ferrar dolerite example, there is competition between the wind abrasion and rind formation i.e. competition between the alteration rate and the ventifacting rate.

Figure 12. Screencap of Discussion Agenda and Notes from the Science Discussion on CI Sol 47 in the CI CACHER Report, with the green arrow showing CI Sol 47 on the navigation track at the top and the two yellow arrows pointing out the DL & UL Sols relevant for the shown CI report. On the left is the list of roles and their reports contained in this CI report, where the dark colour names highlight existing reports and that grey names highlight no currently existing reports (Part of the URLs have been covered with black bars as a precaution).

A screencap covering a small part of the CI Sol 47 CACHER report can be seen on Figure 12, with the navigation track in the top for moving between CI, DL, and UL reports.

CI CACHER reports were divided into segments, with some of them listed here: Context Summary, which included information on what campaign we were in, what Sols that were being assessed on a given Sol, as well as what upcoming Sols that were being pre-planned. This context summary also included a geological map overview of the rover's location and traverse, campaign goals and decisions points, highlights, and recent activities. The report also included a segment for the CI discussion notes and attached presentations from the Science/Implementation Discussions of the Sol (as shown on Figure 12), and other segments such as, High-Level Sol Path, Look Ahead Plan, etc.

A ZCAM Downlink report contains contact info for which PDLs and sPDL Lead were on shift, an instrument summary on any anomalies and instrument health graphs. One of the segments of the DL report also contained a data accounting part, which included the expected and received observations and their respective sequence IDs. The report is finished off with a handover note segment for the next DL shift.

A ZCAM Uplink report contained the contact info on the PULs and sPULs on shift. A detailed summary of targets as well as activity notes. A part of the report also contained the different activities, intent, and requestor from the three different sPUL roles. A portion of the report was filled out with notes from CI regarding ZCAM activities as well as footprints (images that show the pointing of the camera) of the uplinked image sequences. The UL report itself was rounded off with handover notes for the next UL shift.

CAMP (**C**ampaign **A**nalysis **M**apping & **P**lanning): Tool for viewing and working with orbital datasets. Different geological and topographical maps as well as strategic targets could be applied as layers for different scientific purposes. Other functions were also available such as the Viewshed tool, measuring tool and drawing tool. A screencap of it is shown on Figure 14a, which shows the landing site in Jezero Crater and the Rover traversal path.

Marsviewer: Image browsing tool for the Mars 2020 Mission. This tool enables viewing, measuring, sharing, searching, uploading, and downloading of image files as well as derived image data for the whole of the Mars 2020 team. A screencap of Marsviewer, displaying a ZCAM left-eye Sol 102 image is shown on Figure 14b. There was also a direct connection from Marsviewer to DataDrive.

DataDrive (DD) is the interface through which you can navigate the Operational Cloud Storage (OCS), which contains almost all files from the Mars 2020 Mission – ranging from science data from the different instruments, science planning materials, engineering data, etc.

Meeting Tracker: As the name suggests, it is a tool for seeing the Tactical and CI meeting timeline and tracking meetings for a given Sol or Earth date, whilst also providing passwords and link to the WebEx meetings.

The Mars 2020 Raw Image Website, which is a website freely available to the public, was also a tool that I used alongside all the aforementioned tools for my thesis work - primarily for my work with the ZCAM Mosaics & RFAX Radargrams.

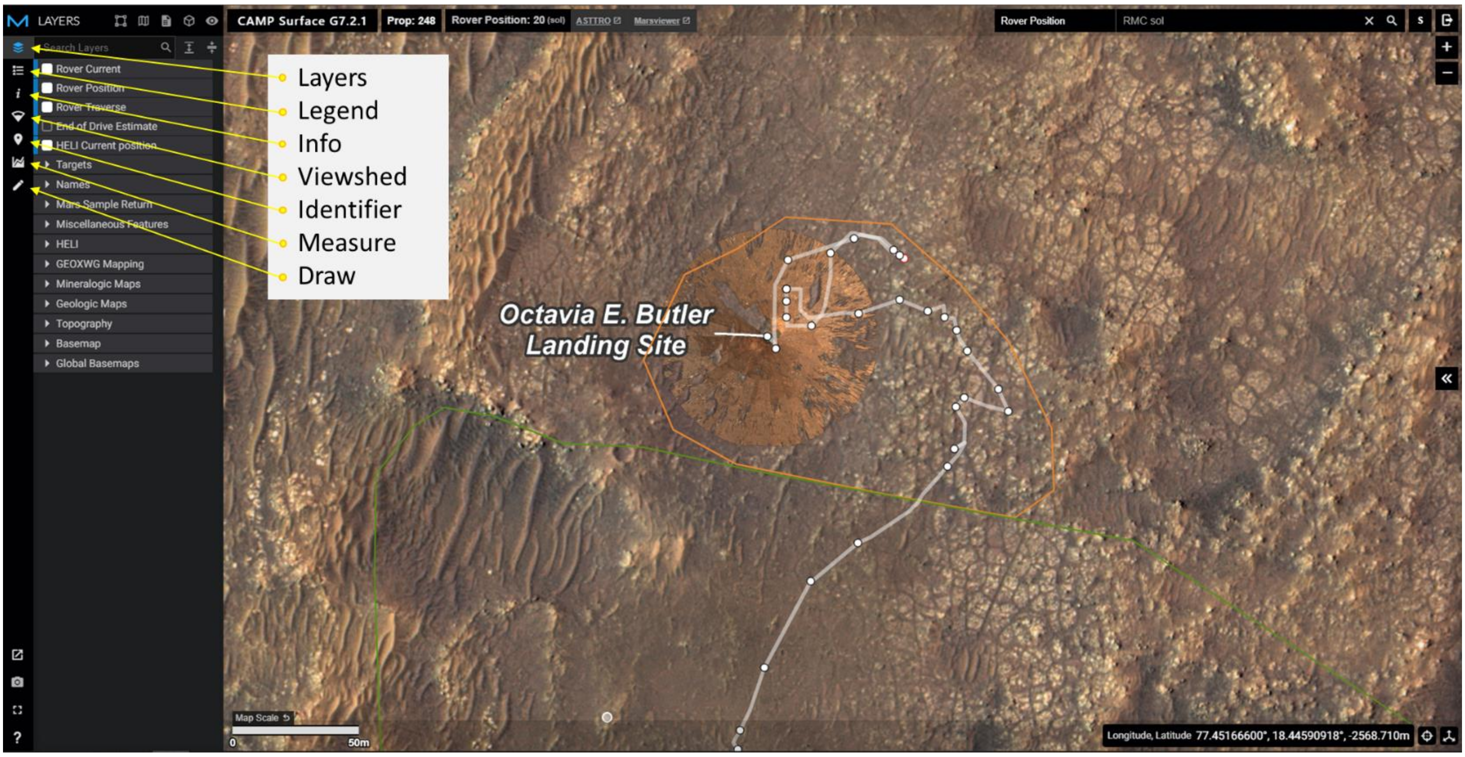
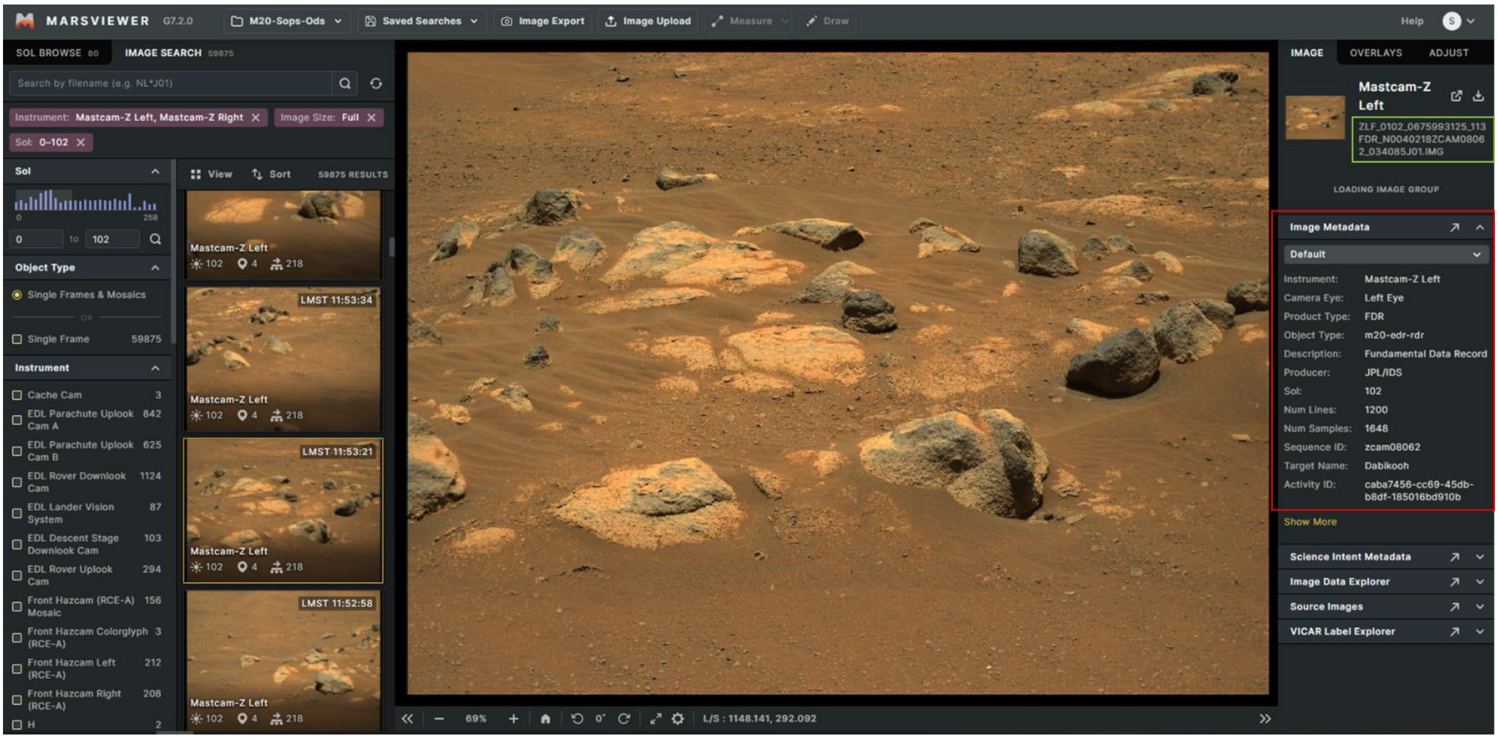


Figure 14a. Screencap of the CAMP tool showing a map of the landing site and Layers sidebar on the left. All the functions and their names are indicated with yellow arrows.



Mastcam-Z Left
ZLF_0102_0675993125_113FDR_N0040218ZCAM08062_034085J01.IMG

Image Metadata
Default
Instrument: Mastcam-Z Left
Camera Eye: Left Eye
Product Type: FDR
Object Type: m20-edr-rdr
Description: Fundamental Data Record
Producer: JPL/IDS
Sol: 102
Num Lines: 1200
Num Samples: 1648
Sequence ID: zcam08062
Target Name: Dabikooh
Activity ID: caba7456-cc69-45db-b8df-185016bd910b

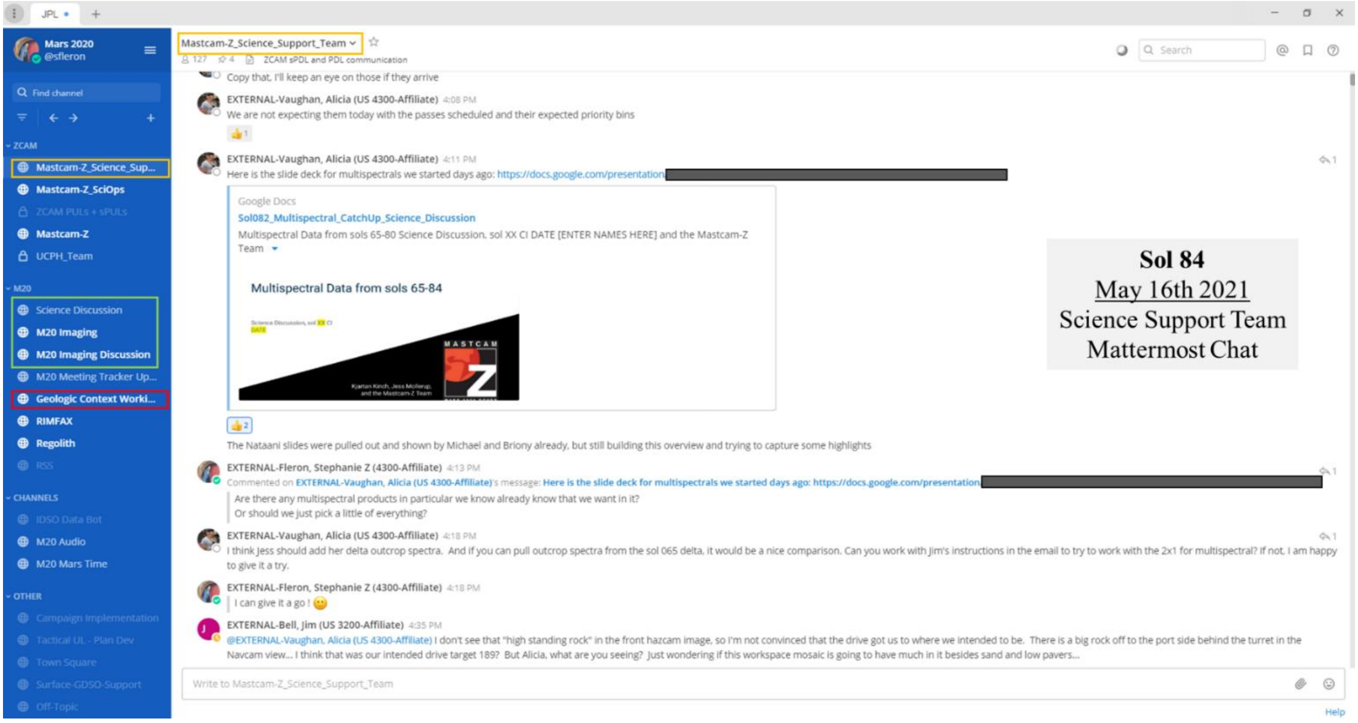
Figure 14b. Screencap of Marsviewer showing a ZCAM left eye full frame image from Sol 102, seq. 08062 with the green box highlighting the file name of the selected image, and the red box highlighting the Image Metadata for the selected image. It is possible to search for images and data through many different types of search parameters.

Due to the COVID-19 Global Pandemic, all shift work was done remotely. Therefore, the main way to keep contact with the rest of the team both on and off shift was through the Mattermost chat program. Mattermost is a chat tool that allows instant message communications between individuals and small/large groups. For the different tag-ups and discussions we would utilize the standard JPL WebEx, which is a commercial teleconferencing tool sort of like Zoom. Regular email updates were also sent out after each Sol in order to keep us up to date on plans and developments in the mission.

Going back to Mattermost, the main chat channels that I used throughout my time with the Mars 2020 Mission were the following:

- Science Discussion: The main channel to post one's theories and work for everybody to see and talk about. All WebEx chats also got copy pasted from the different Science Discussion telecons into here during and/or after a telecon.
- M20 Imaging: The channel dedicated to posting exciting M20 imagery, links, and related products for everybody to see without cluttering the Science Discussion text channel.
- M20 Imaging Discussion: The companion to the M20 Imaging channel and made for discussing posted images as well as image processing, image tips, image viewing etc for all instruments.
- Geologic Context Working Group: The text channel for the Geologic Context Working Group, which during Sol 0 to around Sol 113 focused on the remapping effort and was used for discussions regarding units and their defining features alongside the biweekly telecons.
- Mastcam-Z_Science_Support_Team: Primary communication tool for ZCAM sPDL and PDL during shifts. Here we posted our shift work for feedback before posting it to the relevant PDL report on the ZCAM wiki and showing it to the rest of the M20 team.

A screenshot of how Mattermost chat program with a channel chat visible (specifically the Mastcam-Z_Science_Support_Team chat) is shown on Figure 15.



Copy that. I'll keep an eye on those if they arrive

EXTERNAL-Vaughan, Alicia (US 4300-Affiliate) 4:08 PM
We are not expecting them today with the passes scheduled and their expected priority bins

EXTERNAL-Vaughan, Alicia (US 4300-Affiliate) 4:11 PM
Here is the slide deck for multispectrals we started days ago: https://docs.google.com/presentation[redacted]

Google Docs
Sol082_Multispectral_CatchUp_Science_Discussion
Multispectral Data from sols 65-80 Science Discussion, sol XX CI DATE [ENTER NAMES HERE] and the Mastcam-Z Team

Multispectral Data from sols 65-84

The Nataani slides were pulled out and shown by Michael and Briony already, but still building this overview and trying to capture some highlights

EXTERNAL-Fleron, Stephanie Z (4300-Affiliate) 4:13 PM
Commented on EXTERNAL-Vaughan, Alicia (US 4300-Affiliate)'s message: Here is the slide deck for multispectrals we started days ago: https://docs.google.com/presentation[redacted]
Are there any multispectral products in particular we know already know that we want in it?
Or should we just pick a little of everything?

EXTERNAL-Vaughan, Alicia (US 4300-Affiliate) 4:18 PM
I think Jess should add her delta outcrop spectra. And if you can pull outcrop spectra from the sol 065 delta, it would be a nice comparison. Can you work with Jim's instructions in the email to try to work with the 2x1 for multispectral? If not, I am happy to give it a try.

EXTERNAL-Fleron, Stephanie Z (4300-Affiliate) 4:18 PM
I can give it a go ! 😊

EXTERNAL-Bell, Jim (US 3200-Affiliate) 4:35 PM
@EXTERNAL-Vaughan, Alicia (US 4300-Affiliate) I don't see that "high standing rock" in the front hazcam image, so I'm not convinced that the drive got us to where we intended to be. There is a big rock off to the port side behind the turret in the Navcam view... I think that was our intended drive target 189? But Alicia, what are you seeing? Just wondering if this workspace mosaic is going to have much in it besides sand and low pavers...

Write to Mastcam-Z_Science_Support_Team

Sol 84
May 16th 2021
Science Support Team
Mattermost Chat

Figure 15. Screencap of the Mattermost chat program - specifically the Mastcam-Z_Science_Support_Team chat (orange box highlight) from Sol 84. The green boxes highlight the 3 most relevant text channels for the Mars 2020 Mission and the red box highlights the Geological Context Working Group channel. (Part of the URLs have been covered with black bars as a precaution.)

4.1.2 Mastcam-Z Science Operations Downlink Team: sPDLs

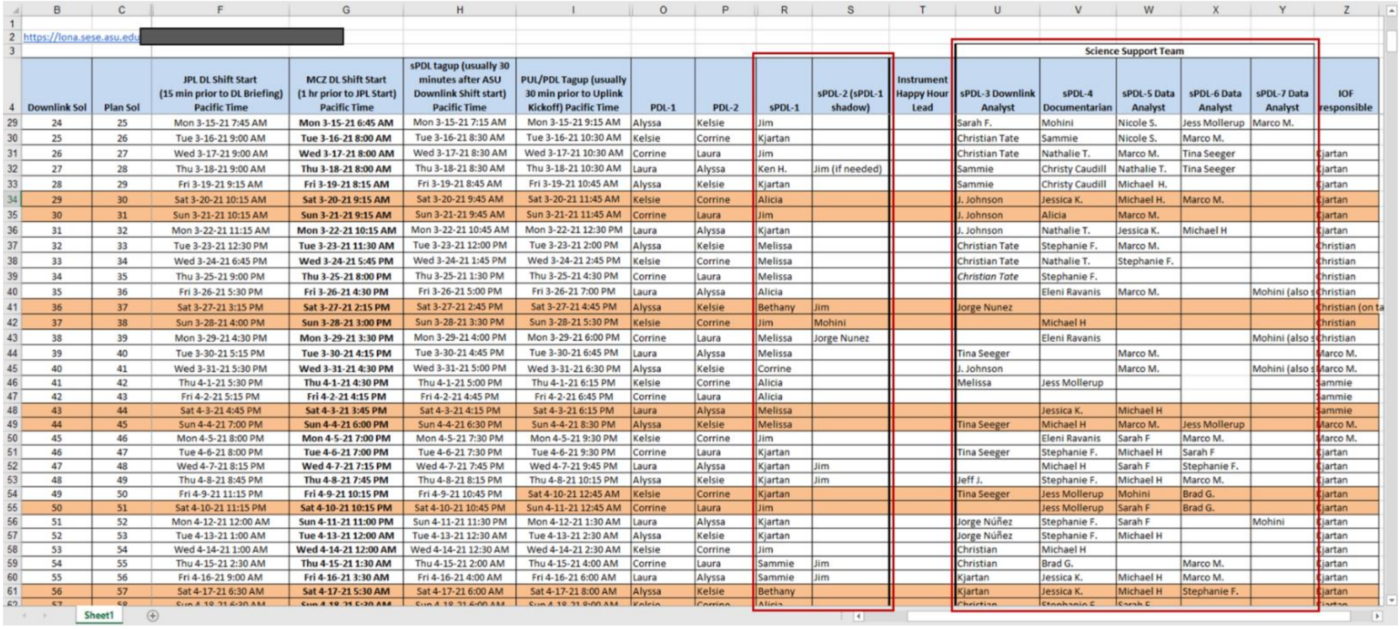
The Mastcam-Z Science Operations Downlink Team consists of the sPDL-1 and a team of support sPDLs (sPDL-2+). This team is tasked with reviewing the downlink from a scientific perspective and followed the tactical downlink side of the operational process all the while supporting the Mastcam-Z Payload Downlink Leads (PDLs). Hence the nature of this team allowed less-experienced Mastcam-Z Co-I's and collaborators (including students) the chance at participating in rover operations by contributing to scientific data analysis, documentation, communication, and outreach during the tactical timeline[1].

In order to sign-up for a Mastcam-Z Payload Downlink Science Support (sPDL) shift, you needed to access the Google Spreadsheet "ZCAM Downlink Staffing Spreadsheet" (Figure 16) and input your

---

[1] Surface_Science_Support_procedures.v.3.1-word document available on the Mastcam-Z wiki for the team.

name under one of the mentioned roles for a given shift. It was not a requirement for the sPDL team to be fully staffed for every shift.



	B	C	F	G	H	I	O	P	R	S	T	U	V	W	X	Y	Z
1																	
2	https://lona.sese.asu.edu [redacted]																
3												Science Support Team					
4	Downlink Sol	Plan Sol	JPL DL Shift Start (15 min prior to DL Briefing) Pacific Time	MCZ DL Shift Start (1 hr prior to JPL Start) Pacific Time	sPDL tagup (usually 30 minutes after ASU Downlink Shift start) Pacific Time	PUL/PDL Tagup (usually 30 min prior to Uplink Kickoff) Pacific Time	PDL-1	PDL-2	sPDL-1	sPDL-2 (sPDL-1 shadow)	Instrument Happy Hour Lead	sPDL-3 Downlink Analyst	sPDL-4 Documentarian	sPDL-5 Data Analyst	sPDL-6 Data Analyst	sPDL-7 Data Analyst	IOF responsible
29	24	25	Mon 3-15-21 7:45 AM	**Mon 3-15-21 6:45 AM**	Mon 3-15-21 7:15 AM	Mon 3-15-21 9:15 AM	Alyssa	Kelsie	Jim			Sarah F.	Mohini	Nicole S.	Jess Mollerup	Marco M.	
30	25	26	Tue 3-16-21 9:00 AM	**Tue 3-16-21 8:00 AM**	Tue 3-16-21 8:30 AM	Tue 3-16-21 10:30 AM	Kelsie	Corrine	Kjartan			Christian Tate	Sammie	Nicole S.	Marco M.		
31	26	27	Wed 3-17-21 9:00 AM	**Wed 3-17-21 8:00 AM**	Wed 3-17-21 8:30 AM	Wed 3-17-21 10:30 AM	Corrine	Laura	Jim			Christian Tate	Nathalie T.	Marco M.	Tina Seeger		Kjartan
32	27	28	Thu 3-18-21 9:00 AM	**Thu 3-18-21 8:00 AM**	Thu 3-18-21 8:30 AM	Thu 3-18-21 10:30 AM	Laura	Alyssa	Ken H.	Jim (if needed)		Sammie	Christy Caudill	Nathalie T.	Tina Seeger		Kjartan
33	28	29	Fri 3-19-21 9:15 AM	**Fri 3-19-21 8:15 AM**	Fri 3-19-21 8:45 AM	Fri 3-19-21 10:45 AM	Alyssa	Kelsie	Kjartan			Sammie	Christy Caudill	Michael H.			Kjartan
34	29	30	Sat 3-20-21 10:15 AM	**Sat 3-20-21 9:15 AM**	Sat 3-20-21 9:45 AM	Sat 3-20-21 11:45 AM	Kelsie	Corrine	Alicia			J. Johnson	Jessica K.	Michael H.	Marco M.		Kjartan
35	30	31	Sun 3-21-21 10:15 AM	**Sun 3-21-21 9:15 AM**	Sun 3-21-21 9:45 AM	Sun 3-21-21 11:45 AM	Corrine	Laura	Jim			J. Johnson	Alicia	Marco M.			Kjartan
36	31	32	Mon 3-22-21 11:15 AM	**Mon 3-22-21 10:15 AM**	Mon 3-22-21 10:45 AM	Mon 3-22-21 12:30 PM	Laura	Alyssa	Kjartan			J. Johnson	Nathalie T.	Jessica K.	Michael H		Kjartan
37	32	33	Tue 3-23-21 12:30 PM	**Tue 3-23-21 11:30 AM**	Tue 3-23-21 12:00 PM	Tue 3-23-21 2:00 PM	Alyssa	Kelsie	Melissa			Christian Tate	Stephanie F.	Marco M.			Christian
38	33	34	Wed 3-24-21 6:45 PM	**Wed 3-24-21 5:45 PM**	Wed 3-24-21 1:45 PM	Wed 3-24-21 2:45 PM	Kelsie	Corrine	Melissa			Christian Tate	Nathalie T.	Stephanie F.			Christian
39	34	35	Thu 3-25-21 9:00 PM	**Thu 3-25-21 8:00 PM**	Thu 3-25-21 1:30 PM	Thu 3-25-21 4:30 PM	Corrine	Laura	Melissa			*Christian Tate*	Stephanie F.				Christian
40	35	36	Fri 3-26-21 5:30 PM	**Fri 3-26-21 4:30 PM**	Fri 3-26-21 5:00 PM	Fri 3-26-21 7:00 PM	Laura	Alyssa	Alicia				Eleni Ravanis	Marco M.		Mohini (also s	Christian
41	36	37	Sat 3-27-21 3:15 PM	**Sat 3-27-21 2:15 PM**	Sat 3-27-21 2:45 PM	Sat 3-27-21 4:45 PM	Alyssa	Kelsie	Bethany	Jim		Jorge Nunez					Christian (on ta
42	37	38	Sun 3-28-21 4:00 PM	**Sun 3-28-21 3:00 PM**	Sun 3-28-21 3:30 PM	Sun 3-28-21 5:30 PM	Kelsie	Corrine	Jim	Mohini			Michael H				Christian
43	38	39	Mon 3-29-21 4:30 PM	**Mon 3-29-21 3:30 PM**	Mon 3-29-21 4:00 PM	Mon 3-29-21 6:00 PM	Corrine	Laura	Melissa	Jorge Nunez			Eleni Ravanis			Mohini (also s	Christian
44	39	40	Tue 3-30-21 5:15 PM	**Tue 3-30-21 4:15 PM**	Tue 3-30-21 4:45 PM	Tue 3-30-21 6:45 PM	Laura	Alyssa	Melissa			Tina Seeger		Marco M.			Marco M.
45	40	41	Wed 3-31-21 5:30 PM	**Wed 3-31-21 4:30 PM**	Wed 3-31-21 5:00 PM	Wed 3-31-21 6:30 PM	Alyssa	Kelsie	Corrine			J. Johnson		Marco M.		Mohini (also s	Marco M.
46	41	42	Thu 4-1-21 5:30 PM	**Thu 4-1-21 4:30 PM**	Thu 4-1-21 5:00 PM	Thu 4-1-21 6:15 PM	Kelsie	Corrine	Alicia			Melissa	Jess Mollerup				Sammie
47	42	43	Fri 4-2-21 5:15 PM	**Fri 4-2-21 4:15 PM**	Fri 4-2-21 4:45 PM	Fri 4-2-21 6:45 PM	Corrine	Laura	Alicia								Sammie
48	43	44	Sat 4-3-21 4:45 PM	**Sat 4-3-21 3:45 PM**	Sat 4-3-21 4:15 PM	Sat 4-3-21 6:15 PM	Laura	Alyssa	Melissa				Jessica K.	Michael H			Sammie
49	44	45	Sun 4-4-21 7:00 PM	**Sun 4-4-21 6:00 PM**	Sun 4-4-21 6:30 PM	Sun 4-4-21 8:30 PM	Alyssa	Kelsie	Melissa			Tina Seeger	Michael H	Marco M.	Jess Mollerup		Marco M.
50	45	46	Mon 4-5-21 8:00 PM	**Mon 4-5-21 7:00 PM**	Mon 4-5-21 7:30 PM	Mon 4-5-21 9:30 PM	Kelsie	Corrine	Jim				Eleni Ravanis	Sarah F	Marco M.		Marco M.
51	46	47	Tue 4-6-21 8:00 PM	**Tue 4-6-21 7:00 PM**	Tue 4-6-21 7:30 PM	Tue 4-6-21 9:30 PM	Corrine	Laura	Kjartan			Tina Seeger	Stephanie F.	Michael H	Sarah F		Kjartan
52	47	48	Wed 4-7-21 8:15 PM	**Wed 4-7-21 7:15 PM**	Wed 4-7-21 7:45 PM	Wed 4-7-21 9:45 PM	Laura	Alyssa	Kjartan	Jim			Michael H	Sarah F	Stephanie F.		Kjartan
53	48	49	Thu 4-8-21 8:45 PM	**Thu 4-8-21 7:45 PM**	Thu 4-8-21 8:15 PM	Thu 4-8-21 10:15 PM	Alyssa	Kelsie	Kjartan	Jim		Jeff J.	Stephanie F.	Michael H	Marco M.		Kjartan
54	49	50	Fri 4-9-21 11:15 PM	**Fri 4-9-21 10:15 PM**	Fri 4-9-21 10:45 PM	Sat 4-10-21 12:45 AM	Kelsie	Corrine	Kjartan			Tina Seeger	Jess Mollerup	Mohini	Brad G.		Kjartan
55	50	51	Sat 4-10-21 11:15 PM	**Sat 4-10-21 10:15 PM**	Sat 4-10-21 10:45 PM	Sun 4-11-21 12:45 AM	Corrine	Laura	Jim				Jess Mollerup	Sarah F	Brad G.		Kjartan
56	51	52	Mon 4-12-21 12:00 AM	**Sun 4-11-21 11:00 PM**	Sun 4-11-21 11:30 PM	Mon 4-12-21 1:30 AM	Laura	Alyssa	Kjartan			Jorge Núñez	Stephanie F.	Sarah F		Mohini	Kjartan
57	52	53	Tue 4-13-21 1:00 AM	**Tue 4-13-21 12:00 AM**	Tue 4-13-21 12:30 AM	Tue 4-13-21 2:30 AM	Alyssa	Kelsie	Kjartan			Jorge Núñez	Stephanie F.	Michael H			Kjartan
58	53	54	Wed 4-14-21 1:00 AM	**Wed 4-14-21 12:00 AM**	Wed 4-14-21 12:30 AM	Wed 4-14-21 2:30 AM	Kelsie	Corrine	Jim			Christian	Michael H				Kjartan
59	54	55	Thu 4-15-21 2:30 AM	**Thu 4-15-21 1:30 AM**	Thu 4-15-21 2:00 AM	Thu 4-15-21 4:00 AM	Corrine	Laura	Sammie	Jim		Christian	Brad G.		Marco M.		Kjartan
60	55	56	Fri 4-16-21 9:00 AM	**Fri 4-16-21 3:30 AM**	Fri 4-16-21 4:00 AM	Fri 4-16-21 6:00 AM	Laura	Alyssa	Sammie	Jim		Kjartan	Jessica K.	Michael H	Marco M.		Kjartan
61	56	57	Sat 4-17-21 6:30 AM	**Sat 4-17-21 5:30 AM**	Sat 4-17-21 6:00 AM	Sat 4-17-21 8:00 AM	Alyssa	Kelsie	Bethany			Kjartan	Jessica K.	Michael H	Stephanie F.		Kjartan

Figure 16. Overview of the ZCAM Downlink Staffing Spreadsheet, shown here as a screenshotted excel version with two red boxes highlighting the sPDL roles.

The sPDL roles and their definitions are as such[2]:

- sPDL-1 and sPDL-2 (shadow) was the primary connection between the ASU professional PDL staff (Kristen, Alyssa, Kelsie, Laura, and Corrine) and the rest of the sPDL-n staff on shift as well as the rest of the ZCAM science team. The sPDL-1 was the leader of the science support team.
- sPDL-3 (Lead) was the mentoring role for a Co-I or other relatively experienced person, who is responsible for checking in with the other sPDL roles and provide assistance where needed.
- sPDL-4 (Doc) was responsible for producing a summary report of the downlink events of the current sol from the scientific perspective of Mastcam-Z.
- sPDL-5, 6 + 7 (Analysts) assisted in producing second-order data products to be passed by the Lead to the sPDL-1 for potential incorporation into the PDL report.

---

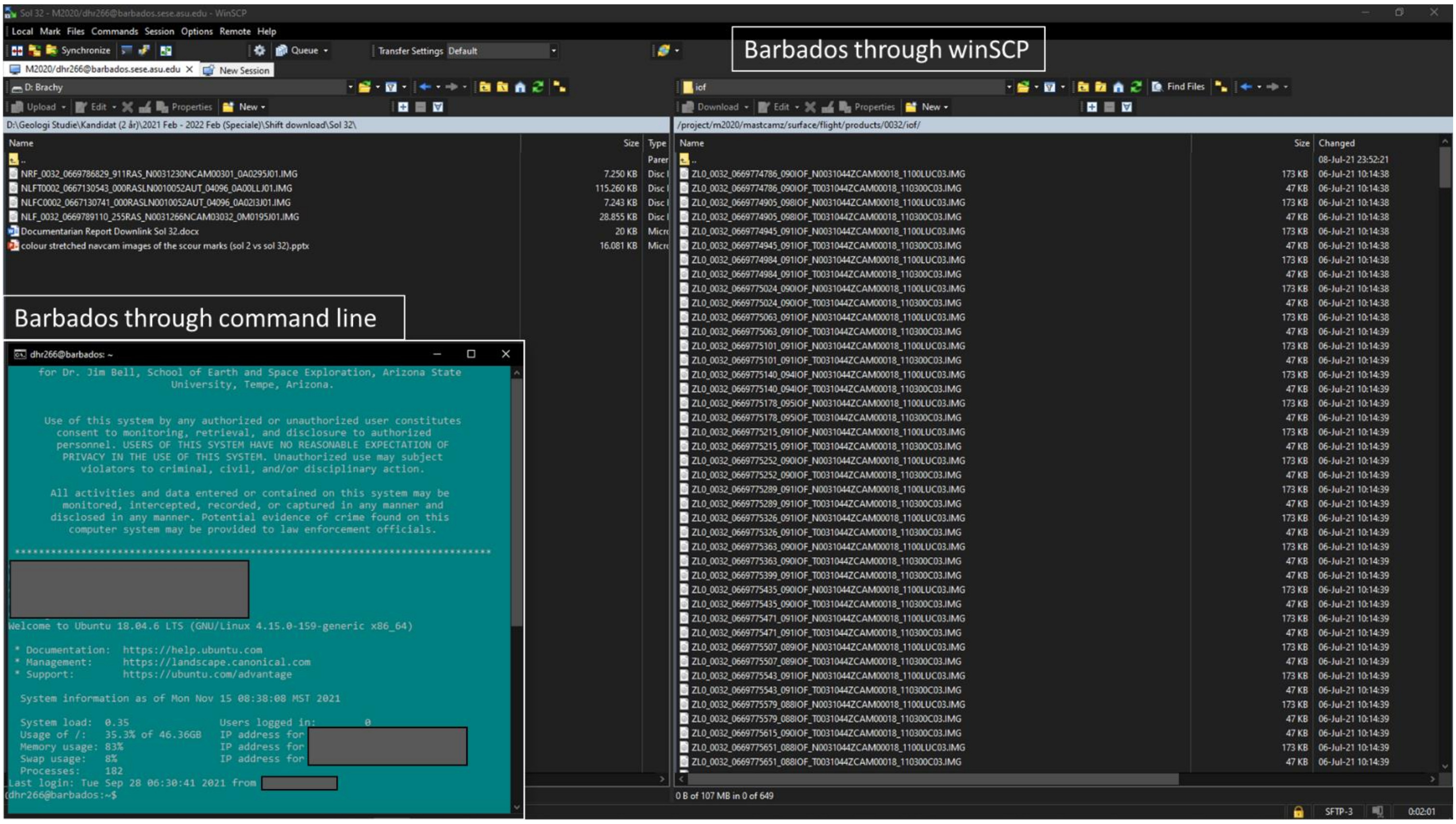
[2] Surface_Science_Support_procedures.v.3.1-word document available on the Mastcam-Z wiki for the team.

Note that prior to Oct. 4th, 2021, the sPDL team consisted of the above listed roles, with the sPDL-3 & sPDL-4 roles having been removed following this date due to not having enough people to staff the roles and people becoming more experienced with the tools and procedure.

The Mastcam-Z sPDL tools are as follows:

Barbados (& Islamorada)

Barbados was the ASU server in which the downlinked Mastcam-Z data is stored. In order to access Barbados, you needed a Bell Research Group LDAP account as well as know your way around the command line or use a graphical interface, e.g., winSCP for Microsoft Windows. Both instances are shown on Figure 17 just below. There was also a high-speed server named Islamorada that had the same content and file structure like Barbados but was dedicated specifically to science data processing.



D:\Geologi Studie\Kandidat (2 år)\2021 Feb - 2022 Feb (Speciale)\Shift download\Sol 32\

Name	Size	Type
..		Parer
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NLFT0002_0667130543_000RASLN0010052AUT_04096_0A00LLJ01.IMG	115.260 KB	Disc I
NLFC0002_0667130741_000RASLN0010052AUT_04096_0A02I3J01.IMG	7.243 KB	Disc I
NLF_0032_0669789110_255RAS_N0031266NCAM03032_0M0195J01.IMG	28.855 KB	Disc I
Documentarian Report Downlink Sol 32.docx	20 KB	Micr
colour stretched navcam images of the scour marks (sol 2 vs sol 32).pptx	16.081 KB	Micr

/project/m2020/mastcamz/surface/flight/products/0032/iof/

Name	Size	Changed
..		08-Jul-21 23:52:21
ZL0_0032_0669774786_090IOF_N0031044ZCAM00018_1100LUC03.IMG	173 KB	06-Jul-21 10:14:38
ZL0_0032_0669774786_090IOF_T0031044ZCAM00018_110300C03.IMG	47 KB	06-Jul-21 10:14:38
ZL0_0032_0669774905_098IOF_N0031044ZCAM00018_1100LUC03.IMG	173 KB	06-Jul-21 10:14:38
ZL0_0032_0669774905_098IOF_T0031044ZCAM00018_110300C03.IMG	47 KB	06-Jul-21 10:14:38
ZL0_0032_0669774945_091IOF_N0031044ZCAM00018_1100LUC03.IMG	173 KB	06-Jul-21 10:14:38
ZL0_0032_0669774945_091IOF_T0031044ZCAM00018_110300C03.IMG	47 KB	06-Jul-21 10:14:38
ZL0_0032_0669774984_091IOF_N0031044ZCAM00018_1100LUC03.IMG	173 KB	06-Jul-21 10:14:38
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ZL0_0032_0669775024_090IOF_N0031044ZCAM00018_1100LUC03.IMG	173 KB	06-Jul-21 10:14:38
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ZL0_0032_0669775101_091IOF_T0031044ZCAM00018_110300C03.IMG	47 KB	06-Jul-21 10:14:39
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ZL0_0032_0669775178_095IOF_T0031044ZCAM00018_110300C03.IMG	47 KB	06-Jul-21 10:14:39
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ZL0_0032_0669775363_090IOF_T0031044ZCAM00018_110300C03.IMG	47 KB	06-Jul-21 10:14:39
ZL0_0032_0669775399_091IOF_T0031044ZCAM00018_110300C03.IMG	47 KB	06-Jul-21 10:14:39
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ZL0_0032_0669775435_090IOF_T0031044ZCAM00018_110300C03.IMG	47 KB	06-Jul-21 10:14:39
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ZL0_0032_0669775471_091IOF_T0031044ZCAM00018_110300C03.IMG	47 KB	06-Jul-21 10:14:39
ZL0_0032_0669775507_089IOF_N0031044ZCAM00018_1100LUC03.IMG	173 KB	06-Jul-21 10:14:39
ZL0_0032_0669775507_089IOF_T0031044ZCAM00018_110300C03.IMG	47 KB	06-Jul-21 10:14:39
ZL0_0032_0669775543_091IOF_N0031044ZCAM00018_1100LUC03.IMG	173 KB	06-Jul-21 10:14:39
ZL0_0032_0669775543_091IOF_T0031044ZCAM00018_110300C03.IMG	47 KB	06-Jul-21 10:14:39
ZL0_0032_0669775579_088IOF_N0031044ZCAM00018_1100LUC03.IMG	173 KB	06-Jul-21 10:14:39
ZL0_0032_0669775579_088IOF_T0031044ZCAM00018_110300C03.IMG	47 KB	06-Jul-21 10:14:39
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ZL0_0032_0669775651_088IOF_T0031044ZCAM00018_110300C03.IMG	47 KB	06-Jul-21 10:14:39

0 B of 107 MB in 0 of 649

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     for Dr. Jim Bell, School of Earth and Space Exploration, Arizona State
                          University, Tempe, Arizona.


      Use of this system by any authorized or unauthorized user constitutes
        consent to monitoring, retrieval, and disclosure to authorized
        personnel. USERS OF THIS SYSTEM HAVE NO REASONABLE EXPECTATION OF
         PRIVACY IN THE USE OF THIS SYSTEM. Unauthorized use may subject
            violators to criminal, civil, and/or disciplinary action.

       All activities and data entered or contained on this system may be
         monitored, intercepted, recorded, or captured in any manner and
       disclosed in any manner. Potential evidence of crime found on this
          computer system may be provided to law enforcement officials.

 ********************************************************************************
[redacted]
Welcome to Ubuntu 18.04.6 LTS (GNU/Linux 4.15.0-159-generic x86_64)

 * Documentation:  https://help.ubuntu.com
 * Management:     https://landscape.canonical.com
 * Support:        https://ubuntu.com/advantage

  System information as of Mon Nov 15 08:38:08 MST 2021

  System load:  0.35               Users logged in:        0
  Usage of /:   35.3% of 46.36GB   IP address for [redacted]
  Memory usage: 83%                IP address for
  Swap usage:   8%                 IP address for
  Processes:    182
Last login: Tue Sep 28 06:30:41 2021 from [redacted]
(dhr266@barbados:~$
```

Figure 17. Barbados as seen through cmd line (bottom left corner) showing the welcome screen and winSCP (background) showing the Sol 32 shift folder on both my own pc and the Sol 32 IOF files on ASU server. (IPs covered with black boxes as a precaution.)

MERTools

The standard software for basic analysis and product generation used during a ZCAM sPDL shift was MERTools, which was a set of team-internal graphical user interface tools coded in the Interactive Data Language (IDL). I downloaded IDL Virtual Machine in order to load and open MERTools. MERTools had a total of 8 functions but I only used 4 of them, specifically: MERstamp, MERview, MERspect, and MERmap.

MERstamp was an image browser for the .img files and was used to highlighting the relevant images in a chosen sequence and excluding caltargets. The highlighted image could then be opened in either MERview or MERspect. MERspect was the function in which all the other mentioned second-order data products were produced: natural colour, enhanced colour, decorrelation stretches (DCS), band depths, slopes as well as picking Regions of Interest (ROIs), and producing spectra plots from these points, with MERmap being used for mosaic creation. Although one can choose to make the enhanced colour image of a target in either MERview or MERspect, it was much more consistent to do in MERview compared to MERspect.

The MERTools menu with MERstamp and MERspect is displayed on Figure 18 with the "Delta Scarp" target from Sol 54 as an example.

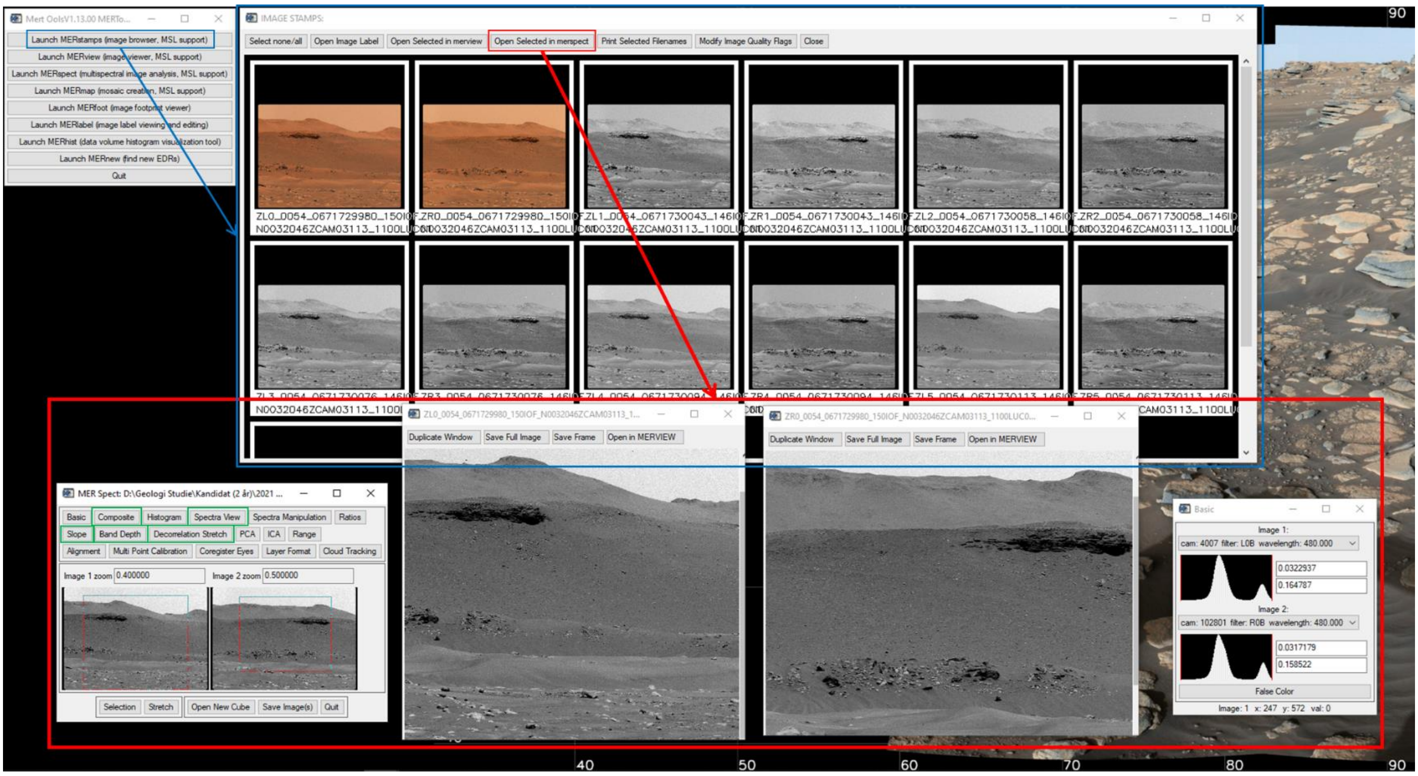


Figure 18. Screencap of the MERTools menu (upper left), MERstamp with the Sol 54, seq. ID 03113 .img files opened in it and then MERspect windows with the selected .img files from MERstamp. The green boxes on the MERspect menu highlight the functions we used primarily during shifts. "Selection" in the bottom left was used in correlation with "Spectra View" to pick out ROIs.

4.1.3 Multispectral Data Visualization

The point of the sPDL shift was to quickly evaluate the downlinked data (full frames and thumbnails alike) for any errors. As well as making any relevant scientific observations and then make the second-order products in a short amount of time. If there was any relevant scientific observations, it could quickly be sent to tactical uplink or perhaps shown during the current shifts' Science Discussion for the rest of the team. These products and observations would then be archived for later use in the mission as well as future publications. These products have a very specific file naming convention and is as follows[3]:

QZCAM_SOL<sol>_<seqid>_<filter>_Z<zoom>_<target>_<producttype><version>.<extension>

An example of this would be:

QZCAM_SOL0149_ZCAM08160_L0_Z110_KODIAK_TH_E01.jpg

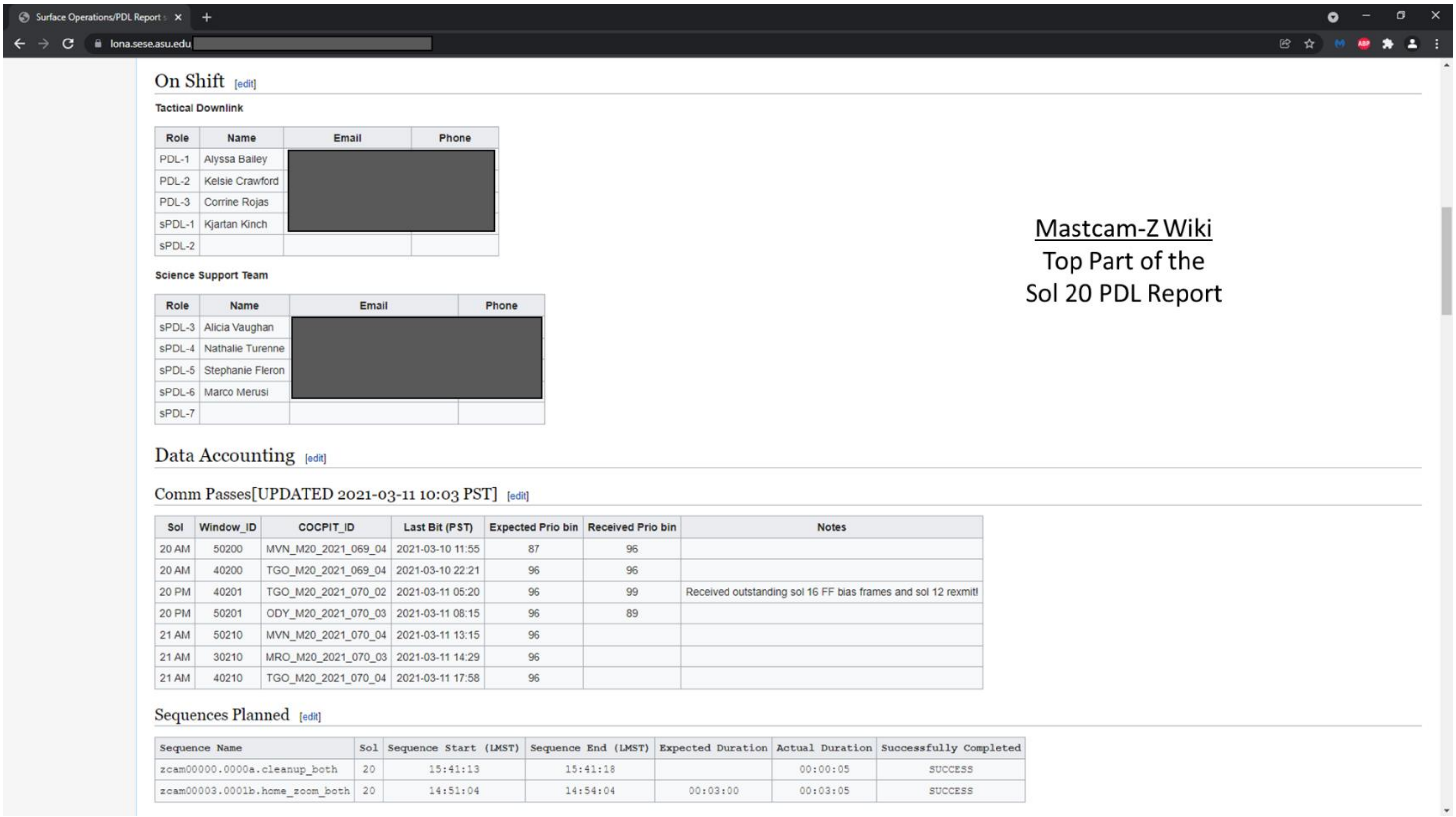
This tells us that this is the first version of an enhanced color thumbnail image taken by the Mastcam-Z camera on Sol 149 with seq. id 08160, in the Left 0 filter and at 110 mm zoom of the Kodiak target.

---

[3] Surface_Science_Support_procedures.v.3.1-word document available on the Mastcam-Z wiki for the team

sPDL Shift

Right at the start of the shift, which started together with the Mastcam-Z PDLs an hour before start of the JPL Downlink shift, I would go to the Mastcam-Z wiki and find the current Sols PDL report and type in my contact details (e-mail & phone nr.), as shown on Figure 19 with Sol 20 as an example. Following the start of the shift, we would have a 30-min window before having to attend the kick-off meeting on the ASU zoom. In this 30-min window, I would do 3 things: Notify the lead in the Mastcam-Z Science Support Team chat channel on Mattermost that I was present, check-up on the previous Sols PDL report on the Mastcam-Z wiki and lastly, have a look at the CACHER reports for both the CI and Mastcam-Z UL and DL.



On Shift [edit]

Tactical Downlink

Role	Name	Email	Phone
PDL-1	Alyssa Bailey	[redacted]	[redacted]
PDL-2	Kelsie Crawford	[redacted]	[redacted]
PDL-3	Corrine Rojas	[redacted]	[redacted]
sPDL-1	Kjartan Kinch	[redacted]	[redacted]
sPDL-2			

Science Support Team

Role	Name	Email	Phone
sPDL-3	Alicia Vaughan	[redacted]	[redacted]
sPDL-4	Nathalie Turenne	[redacted]	[redacted]
sPDL-5	Stephanie Fleron	[redacted]	[redacted]
sPDL-6	Marco Merusi	[redacted]	[redacted]
sPDL-7			

Mastcam-Z Wiki
Top Part of the
Sol 20 PDL Report

Data Accounting [edit]

Comm Passes[UPDATED 2021-03-11 10:03 PST] [edit]

Sol	Window_ID	COCPIT_ID	Last Bit (PST)	Expected Prio bin	Received Prio bin	Notes
20 AM	50200	MVN_M20_2021_069_04	2021-03-10 11:55	87	96	
20 AM	40200	TGO_M20_2021_069_04	2021-03-10 22:21	96	96	
20 PM	40201	TGO_M20_2021_070_02	2021-03-11 05:20	96	99	Received outstanding sol 16 FF bias frames and sol 12 rexmit!
20 PM	50201	ODY_M20_2021_070_03	2021-03-11 08:15	96	89	
21 AM	50210	MVN_M20_2021_070_04	2021-03-11 13:15	96		
21 AM	30210	MRO_M20_2021_070_03	2021-03-11 14:29	96		
21 AM	40210	TGO_M20_2021_070_04	2021-03-11 17:58	96		

Sequences Planned [edit]

Sequence Name	Sol	Sequence Start (LMST)	Sequence End (LMST)	Expected Duration	Actual Duration	Successfully Completed
zcam00000.0000a.cleanup_both	20	15:41:13	15:41:18		00:00:05	SUCCESS
zcam00003.0001b.home_zoom_both	20	14:51:04	14:54:04	00:03:00	00:03:05	SUCCESS

Figure 19. Example of the top half of a PDL report on the Mastcam-Z wiki– specifically the Sol 20 PDL report showing who's on shift as well as Comm Passes & the Planned sequences from UL. (Black boxes used to cover e-mails and phone numbers as a precaution.)

During my time as a student collaborator, I attended 20 shifts in total on the sPDL team in the roles as both sPDL-4 (Doc) a total of 13 times and sPDL-5+6 (Analysts) a total of 7 times.

The tasks varied from shift to shift – sometimes we had new image data from which we could produce second-order products from and perhaps present them on the Sols Science Discussion meeting. Whereas other times we did not receive any new data and we could then catch-up on housekeeping tasks or, if needed, remake products from previous shifts. The aim of the shift would always be to complete the tasks set out for current Sol before the start of the Science Discussion in case we had to setup a presentation for said discussion. The shift itself would then be slowly winding down during the Science/Implementation Discussion and after that, the sPDL lead and those on shift would have a quick catch-up on the ASU zoom. Here we would wrap up the documentarian report and sort out any handover notes for the following shift. Everybody on shift would then send a quick sign-off message in the Mastcam-Z_Science_Support_Team channel on Mattermost, indicating the end of the shift.

Below is an example of the workflow from my Sol 80 shift and relevant to the multispectral shift work results presented in Section 5.1:

For this shift the sPDL-1 & 2 roles were occupied whereas sPDL-3, 4, 5 & 7 were vacant with me as sPDL-6, and therefore I stood in as documentarian and filled out the report that Sol (appendix 4.1.3a contains the Documentarian Report for this particular Sol). I was tasked with producing full frame multispectral products of the Sol 79 Tsetah target (Frame 2) with the sPDL-1 producing multispectral products of the same target (Frame 1). A natural colour image of Frame 1 can be seen in appendix 4.1.3b and a natural colour mosaic combining Frame 1 & 2 in appendix 4.1.3c.

I connected to Barbados through the WinSCP graphical interface in order to find the IOF calibrated .img files, I browsed for the server folder with the following label: project/m2020/mastcamz/surface/flight/products/0079/iof/ and downloaded the full frames to my own computer in order to work on them with MERTools.

Opening up all the .img files for Tsetah (Frame 1 & 2) in MERstamps and then selecting all the images for both the Left and Right eye of Frame 2 before proceeding to opening up the selected frames in MERview. Here I chose to exclude values less than “n” sigma from median with n = 4 and then applying it to all the channels (Red, Green & Blue) in order to make an enhanced colour image of Tsetah as both an .img and .jpeg file for later use.

Going one step back I opened up the selected .img files into MERspect and produced the essential second-order products, starting with the natural colour image with the 0R, 0G & 0B filters in each eye, respectively. Examples of the spectral parameters and their corresponding products can be seen on Table 2 and Figure 20. These were all saved as .jpeg files to be uploaded onto the Mastcam-Z wiki Shared Space page for the Sol 80 shift using the file naming convention mentioned earlier. The different filters and their corresponding wavelengths that were used to make these products can be seen on Table 2 with the specific parameters highlighted in separate colours between the table and figure caption text.

Using the enhanced colour, DCS, slope and band depth images I picked out ROIs in both eyes and then proceeded to pull spectra from them through Spectra View in MERspect. The ROIs and spectra plot of Tsetah that I made is shown on Figure 21. During this process, I averaged the eyes at overlapping wavelengths for a visually more pleasing plot and also scaled the right eye to the left eye at 800 nm to counteract for general offsets as well as temperature differences between the cameras.

Table 2. Spectral Parameters table modified from the Multispectral Imaging Guidelines .pdf made as a sort-of cheat sheet for the Mastcam-Z

Product (abbv.)	Wavelength	Filters	Comments
BD529	529, shoulders at 441, 605	L5, shoulders at L6 and L4	Band depth at 529 nm: ferric absorption
BD866	866, shoulders at 801, 940	R2, shoulders at R1, R4	Band depth at 866 nm: hematite
BD678	678, 605, 754	L3, shoulders at L4, L2	Band depth at 678 nm: ferrous clays?
RGB	754, 529, 441	L256	Enhanced RGB colour
DCS	754, 529, 441	L256	Decorrelation stretch of RGB colour
S56	979, 1012	R5, R6	Slope of near-IR bands: hydration
S16	801, 1012	R1, R6	Overall slope in infrared

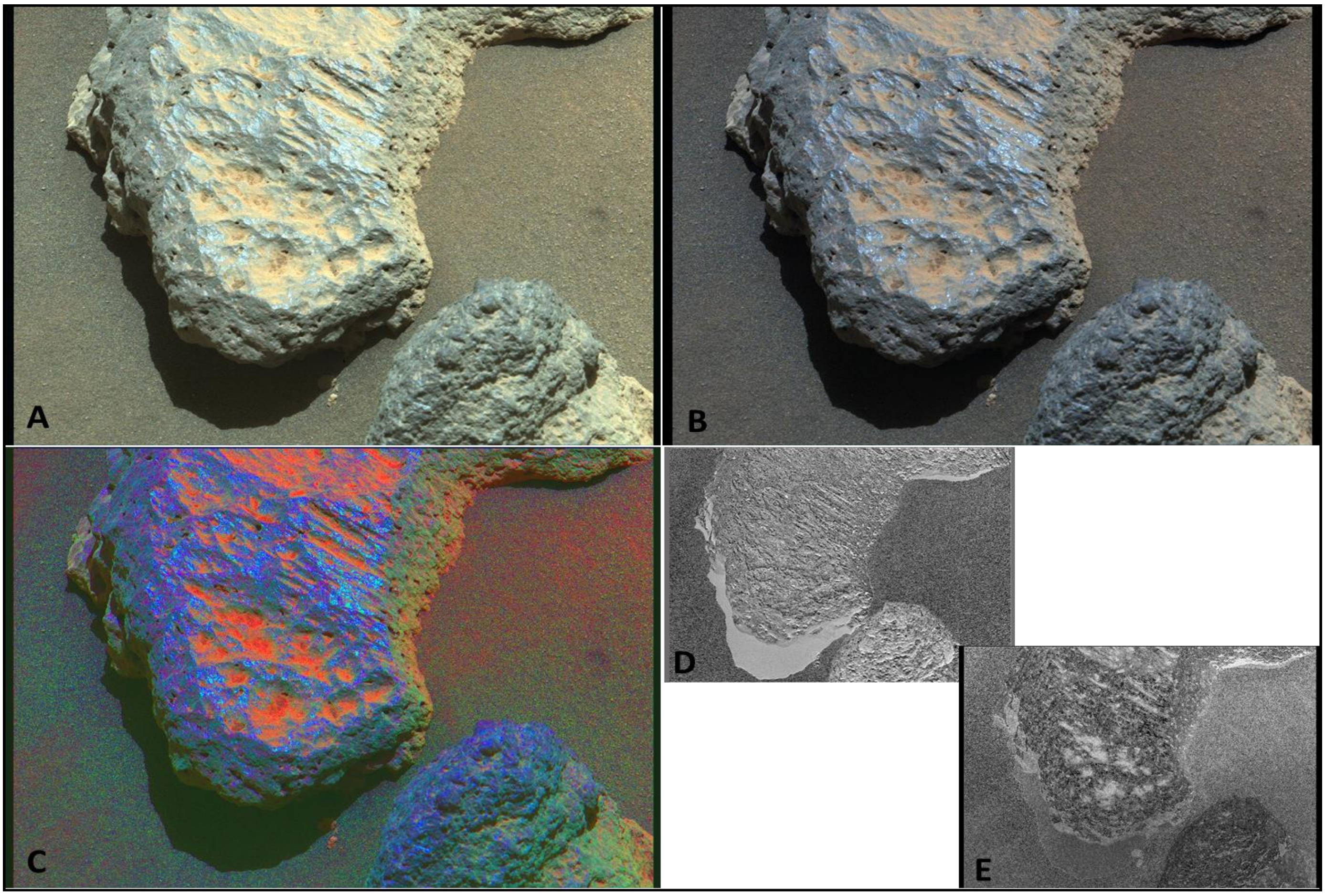


Figure 20. Example of standard second-order products of Left-eye Sol 79 Tsetah (Frame 2) made on Sol 80 sPDL shift. The examples ordered in the way they are made: (A) Natural Colour; (B) L256 Enhanced Colour; (C) L256 Decorrelation Stretch; (D) S16 Infrared Slope & (E) BD529 Band Depth.

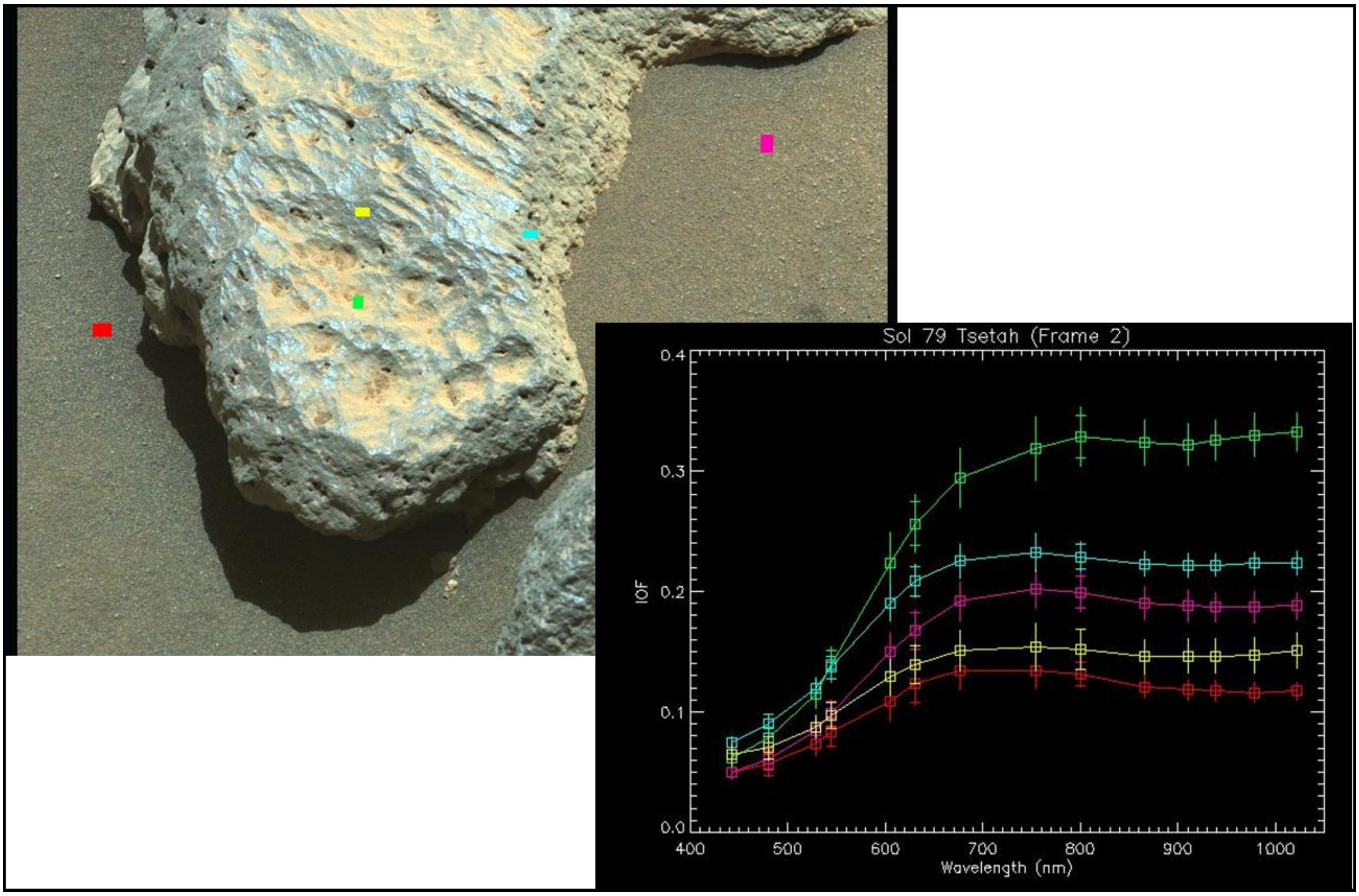


Figure 21. ROI selections overlain the natural colour image of Tsetah (left top corner) and the plot showing the spectra of these selected areas (bottom right corner). Each ROI point on the image has its own colour that matches their own graph on the plot.

On some shifts, only thumbnails would be downlinked during a satellite pass, and we would then work with those the same way as if they were full frames. The downside of the thumbnails is that the resolution is quite low compared to the full frames, but they worked just fine while waiting for the full frames to be downlinked. An example of an enhanced colour thumbnail product based on the previous aforementioned target and frame can be seen in appendix 4.1.3d.

Although a lot of the processes that were carried out by the Science Support Team have been automated now (Sol 300+) compared to when I was last on shift (Pre-Sol 150), the sPDL team is still continuously being staffed through the mission. This is because a human pair of eyes on the autogenerated products is still very much needed in case of any errors made in the process due to incorrect inputs, as well as archiving these products for future use and making them available to the broader team.

4.2 Remapping Effort

The Geologic Context Working Group's purpose was "To provide a forum for the discussion and organization of team efforts related to documenting and analysing the spatial and stratigraphic record of rock units at the M2020 Perseverance field site in Jezero Crater and beyond". The specific tasks set forth for this group included[4]:

- **Updating, maintaining, and expanding the team's "orbital" photogeologic map of the Perseverance field site**.
- Updating, maintaining, and expanding a geologic context map based on in-situ rover observations for the Perseverance field site.
- Provide a forum for the discussion and initial proposal of geologic/stratigraphic unit and feature nomenclature, both "from orbit" and on the ground.
- Updating and maintaining a team stratigraphic column.

The bolded task was what came to be called the Remapping Effort and was the first task that the working group tackled and that I was a part of. This effort was meant to expand on the photogeological map that had been produced prior to landing and published in Stack *et al.*, 2020 (Figure 3). This updated map would be important to putting other observations into context and also be critical for establishing a framework for samples and investigate the relationship between the delta and crater floor later in the mission.

All of the remapping work itself was done through CAMP and the two following layers out of many others were the ones used by me during the remapping process: The grayscale Mission Basemap, which is the highest resolution data (25 cm/pixel) available of Jezero from the Mars Reconnaissance Orbiter High Resolution Imaging Science Experiment (MRO-HiRISE), and the Enhanced Slope layer.

By changing the contrast bar setting on the grayscale Mission Basemap I was able to better make out polygonal patterns and crumbly features. While the Enhanced Slope layer allowed me to properly see very small topographic differences because it has a 5-degree increment from 0-15, with everything above 15° being shown as red.

---

[4] Taken from the 3rd of Feb 2021 E-mail from Kathryn M. Stack "Kickoff of the Mars 2020 Geologic Context Working Group" sent to users on the m2020-science email list.

A total of 56 quads were mapped during the Remapping Effort with the quads being separated into connecting pairs of a total of 28 pairs. A map overview of all the quads can be seen on Figure 22:

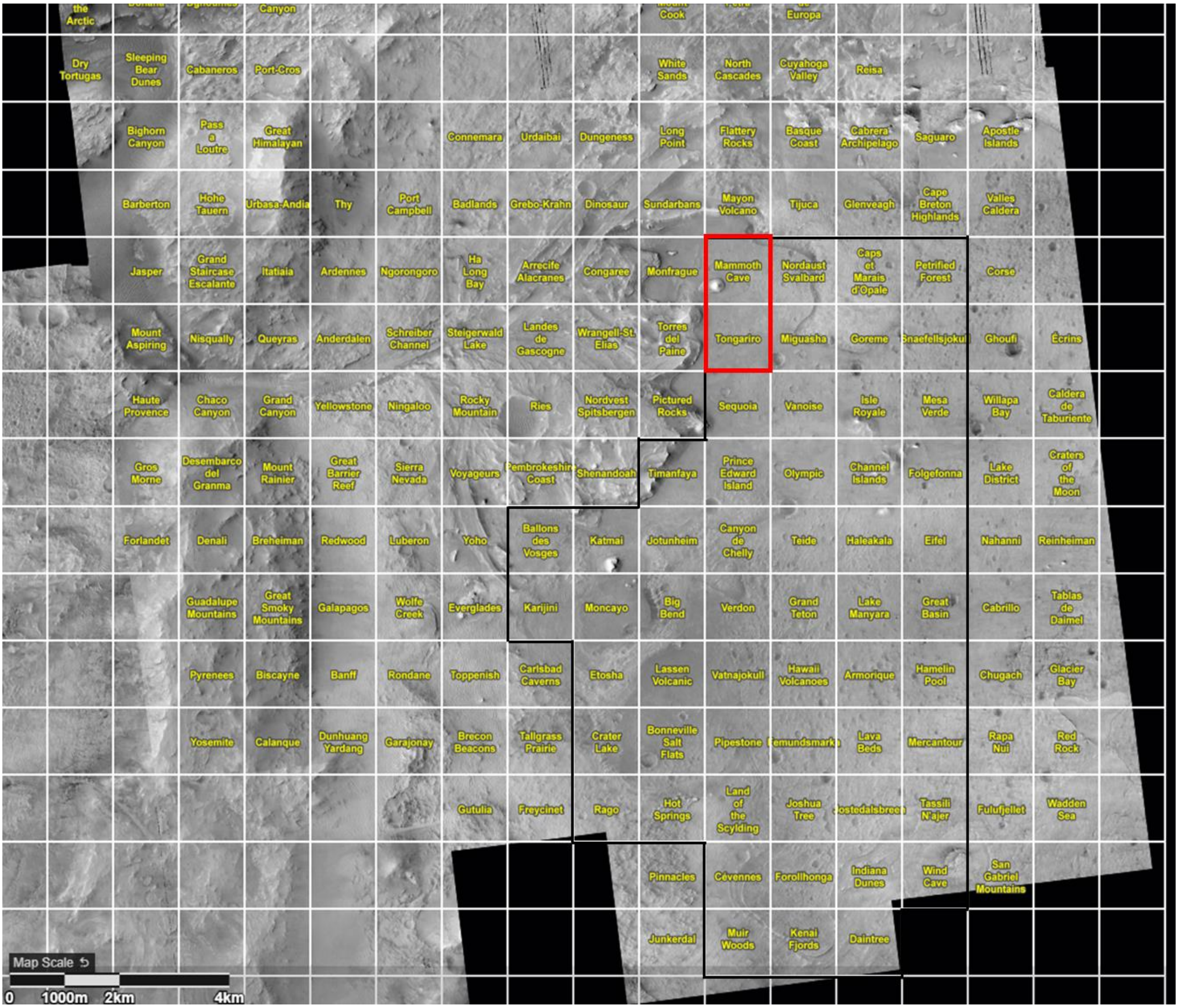


Figure 22. Map taken from CAMP with the grayscale mission basemap as the bottom layer with all the quads and their corresponding names displayed on top. The 56 mapped quads used in the remapping effort are outlined with black and my chosen quad pair: Mammoth Cave and Tongariro are shown here in red.

The remapping effort was started back in late February with the formation of the Geological Context Working Group. All the practical information such as mapping scale, tools, and layers available in CAMP etc. were discussed at the biweekly group meetings and the first step was that everybody on the remapping team picked out their own quad pairs. I picked the Mammoth Cave and Tongariro quad pair near the top left of the proposed mapping area. We mapped around ~50 m beyond our quad's boundaries to reconcile the quads between different mappers and to make the map stitching process of the final map smoother. The quads were mapped at a scale of 1:2500, with the smallest mappable polygon size in one's quads being roughly 25m^2.

The map units were continuously revised throughout the process, and our first draft maps were due on May 17th. Although the final units, their defining features as well as their mapping colours were first really settled on the 1st of June with the finished quad map deadline being two weeks later - on the 14th of June. The map units, their suggested mapping colours, as well as unit descriptors are listed below, and general examples of the units for the team can be seen on Figure 23:

- Crater Floor Units
  - CF – Rough/Highstanding (**DARK PURPLE**)

    Descriptors: Rubbly, rough texture and boulder-forming in some places. It has some distinct edges and looks high-standing.

  - CF/Us – Crumbly/Fractured (YELLOW)

    Descriptors: Typically, crosscut by large fractures with 90-degree intersections and is often mantled with dark cover. It consists of light toned small irregular low relief boulders.

  - CF – Smooth Polygonal (PINK)

    Descriptors: It looks smooth and has a low relief to slightly rough with medium relief. It is polygonally fractured and is noted as "pavers".

  - Us - Undifferentiated Smooth (CYAN)

    Descriptors: It is dark and very smooth compared to the other units as well as ranging between extensive and patchy. It retains small fractures and contains very few aeolian bedforms.

- Inlier Units
  - Seitah Rubbly/Highstanding (**DARK BLUE**)

    Descriptors: It is contained within the Seitah unit and is characterized by apparent high-standing boulders. It is a topographically-variable 'rubbly' unit.

  - Seitah Flagstone (**MAGENTA**)

    Descriptors: Another unit that is contained within the Seitah unit and is characterized by light-toned, low-relief and looks like potential polygonal fractures.

- Aeolian Bedforms – Crater floor and inlier (**GREEN**)

  Descriptors: The bedforms are sand ripples/dunes and had to fill or surpass a 25m^2 scale box in order to be mapped. These bedforms often overlaps the other units and were also mapped as crater infill.

- Crater Rim (**RED**)

  Descriptors: Smallest crater mapped is around ~30m in diameter and the area of the crater rim is subjective to the viewer but quite easy to distinguish when bordering Us.

- Delta Units (**GREY**)

  Descriptors: The name explains itself. Delta units were not addressed in much detailed as it complicated the mission to understand the crater floor. Notable remnants inside the various quads were mapped with an outline.

The finished map has since been incorporated as a layer in CAMP and labelled "CF Remap v1". This geological map layer with the "Surficial Geology" overlaying it, has been used in the Context section of the CI CACHER reports on later Sols for planning.

Since I stopped joining the biweekly meetings after finishing my part on the remapping effort, the Geological Context Working Group has gone through different stratigraphic models trying to explain the CF-Fr-Séítah transition. As well as having already produced preliminary stratigraphic columns of different stratigraphic members we have encountered throughout the mission.

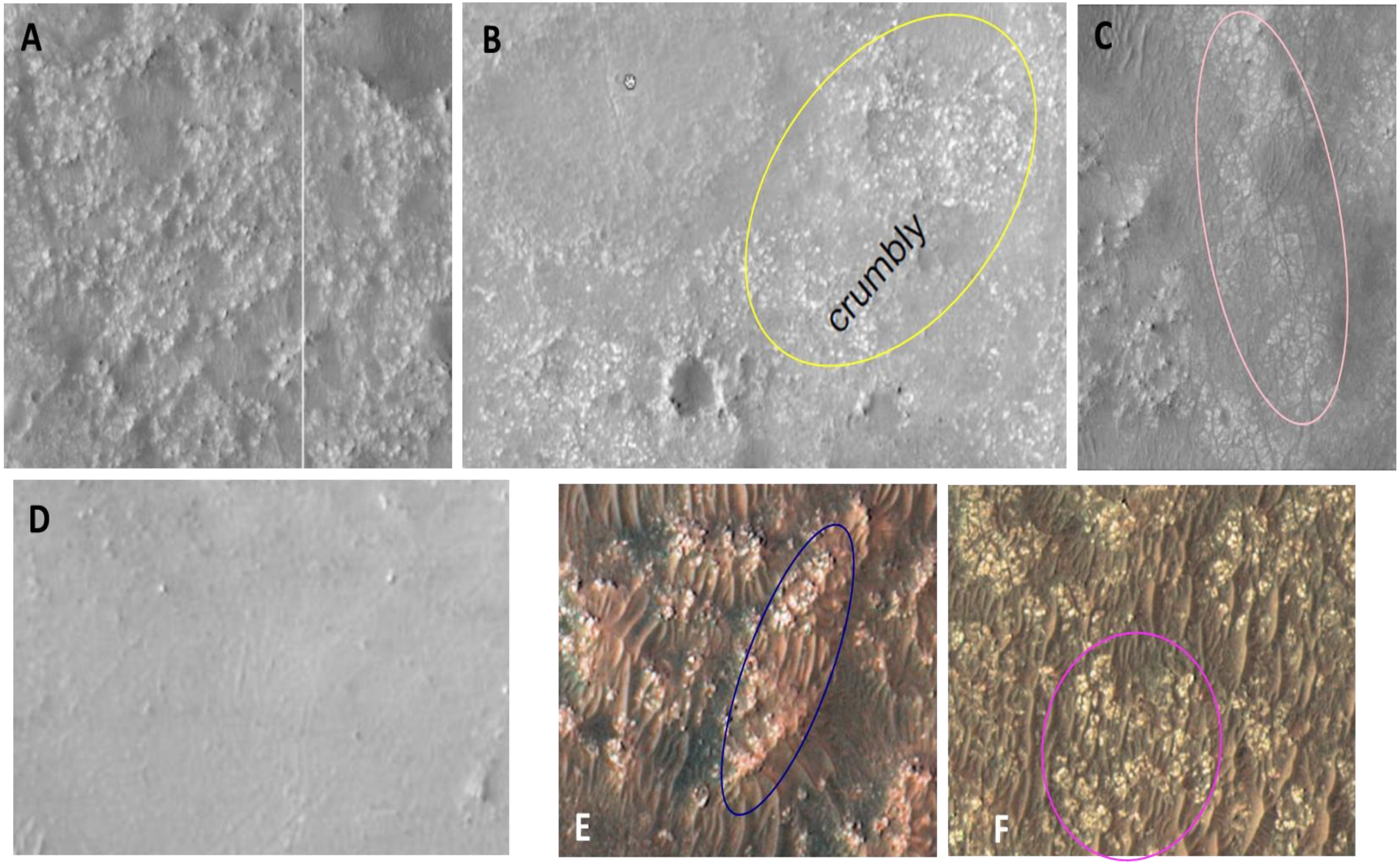


Figure 23. General examples of the defining features of each unit for the mapping team (excluding Aeolian bedforms, Crater Rim & Delta Units) taken from a presentation by Briony Horgan. Starting top left: (A) CF- Rough/Highstanding; (B) CF/Us- Crumbly/Fractured; (C) CF- Smooth /Polygonal; (D) Us; (E) Séítah Rubbly/Highstanding and (F) Séítah Flagstone with circles highlighting some of the features. In Section 5.2, Figure 23 examples from my own two quads of these self same units can be seen. CF - Smooth/Polygonal and Séítah Flagstone are not represented in my quads and are therefore excluded in that figure.

4.3 Mosaics & Radargrams

My initial idea for my thesis included combining Mastcam-Z imagery and RIMFAX radargrams to correlate subsurface features to structures found on the surface or in outcrops in order to gain an understanding of the stratigraphy in Jezero Crater. Alongside my supervisor, Kjartan Kinch who is a Co-Investigator on ZCAM, we tried contacting Svein-Erik Hamran on RIMFAX a few times in order to get access to their preliminary radargrams a few Sols into the mission without much luck. This led to me privately contacting Hans Amundsen from RIMFAX over Mattermost months later into the mission, where I explained my situation and he so graciously provided me with two pre-processed radargrams that combined only two of the three modes – surface and shallow. One radargram covers Sol 47-84 and one covers Sol 86-102. The radargrams can be seen in their fullest in appendix 4.3a.

Note that I was not a part of the processing and so do not know the extent of the changes (be it filters and such) that these radargrams have gone through. I only found a general explanation of the process, which I have mentioned in Section 3.2.2.

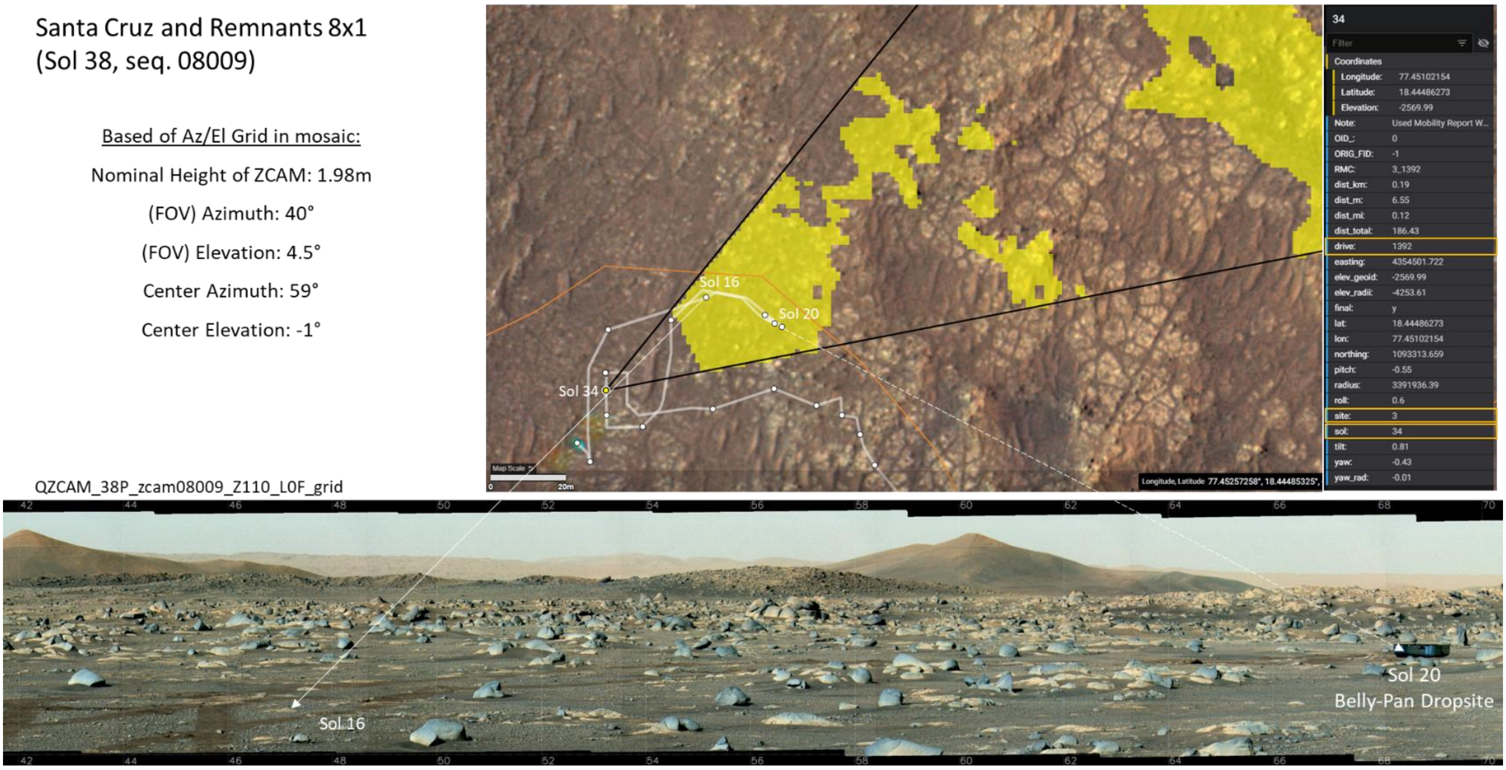
The depth in meters that is shown on the right side of both radargrams is calculated based on a travel time of 0,123 m/ns, which is a value established by the engineers of RIMFAX. Hans Amundsen did not provide any explanation in my short exchanges with him as to why the depth is displayed in -25XX meters on the radargrams. I surmised by myself that it is due to the elevation of the rover's location in Jezero Crater, which is between the -2500 and -2600 contour lines. Contour lines can be seen on Figure 3.

With these radargrams in hand, I then changed my focus to correlating surface and near-surface reflections in the radargrams to surface expressions visible on the mosaics in the rovers driving path.

At some point during the early stages of the Mars 2020 Mission, Mastcam-Z Principal Investigator Jim Bell, created a google spreadsheet for the ZCAM team containing a comprehensive list of all the mosaics with azimuth and elevation gridlines made during the mission. The spreadsheet contains information such as Sol, Sequence ID, Site + Drive number, Zoom used, LMST (Local Mean Solar Time) as well as links to Marsviewer and DataDrive for each specific mosaic and is continuously being updated over the duration of the mission.

I used the previously mentioned google spreadsheet and proceeded to locate and download all the mosaics that showed horizon and/or rover tracks in the Sol 1-102 timeframe while excluding mosaics that only showed close-ups of different rock targets, keeping Sol numbers and sequence IDs of the chosen mosaics in mind. There were 11 mosaics in total, although not all of them ended up being used due to certain reasons as will be explained in Section 5.3.

The next step was to open CAMP and make use of the Viewshed function, where I picked a point on the map, allowing me to produce a map overview of what I should be able to see in the mosaic taken from that exact spot. I was able to produce viewsheds for 8 different mosaics by deducing the FOV and the center Az/El based on the grid lines in the generated mosaics and being aware that the nominal height of ZCAM is 1.98 meters. An example of one of these viewsheds alongside its corresponding mosaic can be seen on Figure 24. An abundance of large, upright rocks can be seen spread out in the near/mid-field of the mosaic between the rover and the delta remnants.



Santa Cruz and Remnants 8x1
(Sol 38, seq. 08009)

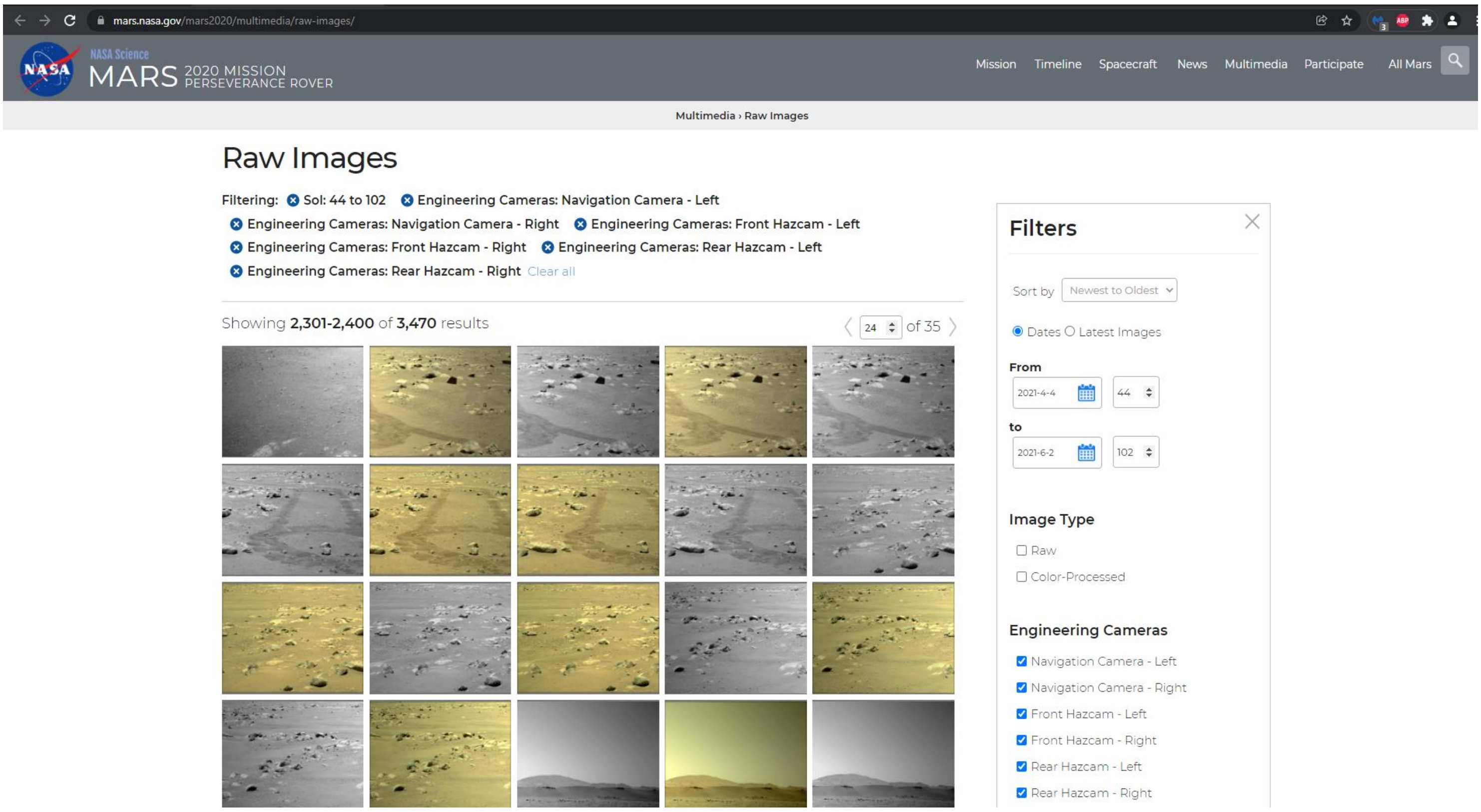
Based of Az/El Grid in mosaic:
Nominal Height of ZCAM: 1.98m
(FOV) Azimuth: 40°
(FOV) Elevation: 4.5°
Center Azimuth: 59°
Center Elevation: -1°

QZCAM_38P_zcam08009_Z110_L0F_grid

34
Coordinates
Longitude: 77.45102154
Latitude: 18.44486273
Elevation: -2569.99
Note: Used Mobility Report W...
OID_: 0
ORIG_FID: -1
RMC: 3_1392
dist_km: 0.19
dist_m: 6.55
dist_mi: 0.12
dist_total: 186.43
drive: 1392
easting: 4354501.722
elev_geoid: -2569.99
elev_radii: -4253.61
final: y
lat: 18.44486273
lon: 77.45102154
northing: 1093313.659
pitch: -0.55
radius: 3391936.39
roll: 0.6
site: 3
sol: 34
tilt: 0.81
yaw: -0.43
yaw_rad: -0.01

Figure 24. Example of the Sol 38 Santa Cruz and Remnants mosaic (bottom) and its estimated Az/El parameters followed by the viewshed itself (left & middle). The Sol 38 parking spot info taken from CAMP indicating Drive, Site and Sol number with orange can be seen on the right. The white arrows point to estimated locations of where in the mosaic the different Sol parking spots are located.

The Sol parking spots location were estimated from NAVZAM and HAZCAM images found on the Raw Image Website for the Perseverance rover (Figure 26a), as it was much faster at loading compared to Marsviewer and was therefore the most efficient tool when establishing an overview of said images for this process. I sifted through all of the images stretching from Sol 44 to Sol 102 and tried correlating rocks (and/or rover tracks, if visible) found in both the mosaics and images in order to establish an approximate location for the rover parking spots as well as the rover traversal path – both behind and in front of the rover. An example of this can be seen on Figure 26b.



mars.nasa.gov/mars2020/multimedia/raw-images/

Multimedia › Raw Images

Raw Images

Filtering: ☒ Sol: 44 to 102 ☒ Engineering Cameras: Navigation Camera - Left ☒ Engineering Cameras: Navigation Camera - Right ☒ Engineering Cameras: Front Hazcam - Left ☒ Engineering Cameras: Front Hazcam - Right ☒ Engineering Cameras: Rear Hazcam - Left ☒ Engineering Cameras: Rear Hazcam - Right Clear all

Showing **2,301-2,400** of **3,470** results 〈 24 of 35 〉

Filters

Sort by: Newest to Oldest

● Dates ○ Latest Images

From: 2021-4-4 44

to: 2021-6-2 102

Image Type

☐ Raw

☐ Color-Processed

Engineering Cameras

☑ Navigation Camera - Left

☑ Navigation Camera - Right

☑ Front Hazcam - Left

☑ Front Hazcam - Right

☑ Rear Hazcam - Left

☑ Rear Hazcam - Right

Figure 26a. Screencap of the Mars 2020 Raw Images website with Sol 44 to 102 and L & R NAVCAM as well as Front/Rear L & R HAZCAM filters added. (URL: https://mars.nasa.gov/mars2020/multimedia/raw-images/)

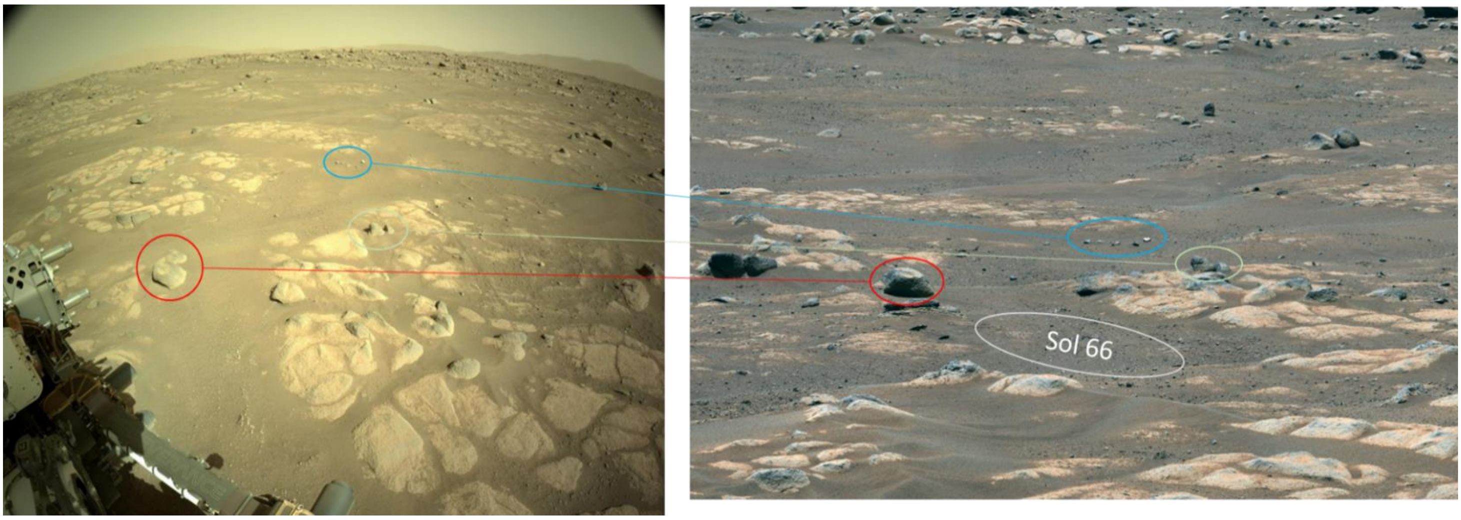
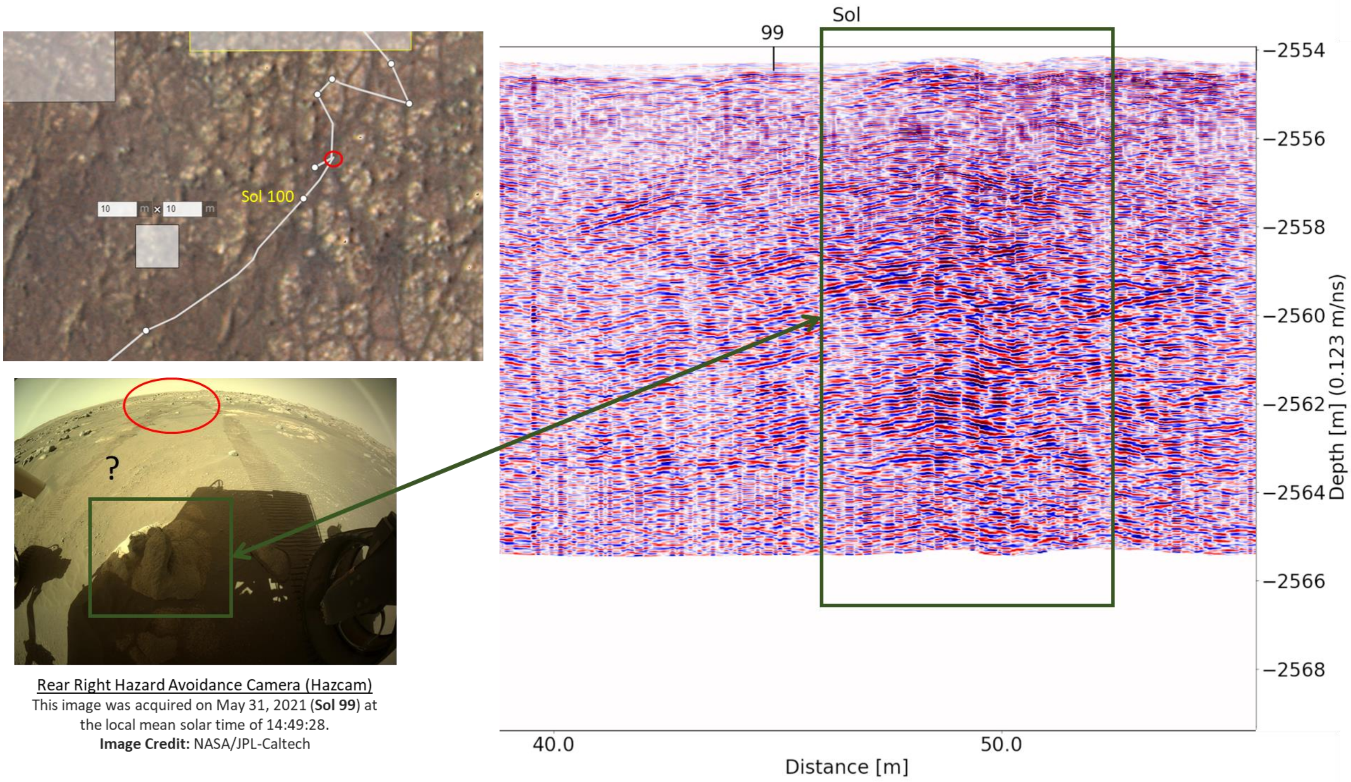


Figure 26b. Sol 66 parking spot identification on Sol 62 mosaic example, with the Sol 66 NAVCAM image in the left and Sol 62 Van Zyl Mosaic on the right. Note the different rocks use for correlation are highlighted with their own colour as well as a line between them. The NAVCAM image is taken from: https://mars.nasa.gov/mars2020-raw-images/pub/ods/surface/sol/00066/ids/edr/browse/ncam/NRF_0066_0672809614_074ECM_N0032208NCAM02066_01_295J01_1200.jpg and the mosaic image is cropped from QZCAM_SOL0062_ZCAM08106_L0_Van_Zyl_part7a_Z110_E01.

As previously mentioned, Hans Amundsen from the RIMFAX team was so kind to provide me with two separate radargrams – one from Sol 47-84 and one from Sol 86-102. I focused on interesting features at the surface/near-surface of these profiles in order to correlate it to the NAVCAM & HAZCAM images and the ZCAM mosaics. These interesting features were mostly high amplitude permittivity events (brightly coloured) as well as internal structures or layering in the radargrams.

Finding rocks in the rover's path that I could correlate to the features seen on the radargram was sometimes quite tricky, due to lack of images facing behind the rover and therefore a lot of my work is conjecture.

Below on Figure 27 is an example of this problem, where there are no mosaics pointed in this direction and only very few NAVCAM & HAZCAM images in this timeframe between Sol 91 and Sol 102. Hence the correlation between the feature on the radargram and the HAZCAM image is pure speculation (indicated with a question mark on said figure).



Rear Right Hazard Avoidance Camera (Hazcam)
This image was acquired on May 31, 2021 (**Sol 99**) at the local mean solar time of 14:49:28.
Image Credit: NASA/JPL-Caltech

Figure 27. Example showing a cropped map from CAMP covering parking spots Sol 91, 100 & 102 in the top left and a rear right HAZCAM image from Sol 99 in the bottom left. The red circle on both the map and HAZCAM image was my attempt at pointing out the rovers turn to and from the Sol 91 parking spot, in order to correlate the image's location to the highlighted feature on the radargram. A cropped section of the Sol 86-102 Radargram is on the right with an arrow between the HAZCAM image and a large, pinpointed feature, spreading from the surface and down, in this section of the radargram, although the connection is vague due to the lack of images in the vicinity.

5 Results

This following segment will include a small selection of some of the work I did on my sPDL shifts [5.1]. It will also include the final map and the differences between it and my draft map from the remapping effort [5.2]. And lastly, it will include the correlations I have made between the chosen ZCAM mosaics from Sol 1-102 and the provided RFAX radargrams [5.3].

5.1 Operational Work

All the science support downlink shifts that I attended, which are 20 in total, have been set up in a quick overview table on the following page (Table 3) and is arranged into columns containing Campaign, Sol number, sPDL role (the roles and definitions are outlined in Section 4.1.2), and a quick note on the work I did on a particular shift.

Note that only a small selection of the work done on these shifts have been written into further detail in this thesis and I have arranged the work into the following 3 categories: Focus (Red), Multispectral (Green) & Geology (Blue). The multispectral work detailed in this section is based on the same procedure described in Section 4.1.3.

Each shift was unique in the form of work as well as the data available and such it was almost guaranteed you would learn something new every time – whether it was software-related or more theoretical in nature.

Table 3. Overview of all my sPDL shifts during the mission alongside the different campaigns, which Sols as well as my role and what work I did during the shift. Blue highlight indicates Geology-relevant shifts, Red indicates Focus-relevant shifts and Green indicates Multispectral-relevant shifts. Note that the Sol #'s in BOLD will be touched upon in more detail during this section. The asterix on Sol 80 indicates the work example that was shown in Section 4.1.3: sPDL-shift.

Attended ZCAM sPDL Shifts			
Campaign	**Sol**	**Role**	**Work**
SOX1B (Sol 9-15)	**9**	sPDL-4	Pointed out Features of Interest in the Sol 4 Z110 Panorama
	10	sPDL-4	Redid Panorama setup and added more Interesting Features
	11	sPDL-4	Assessed Focus of retaken Sol 11 images compared to Sol 3
SOX2A (Sol 16-31)	18	sPDL-4	Continued Focus Pair Evaluation
	20	sPDL-5	Last Focus Assessments
SOX2A: HELI (Sol 32-74)	32	sPDL-4	Colour stretched NAVCAM images from Sol 32 vs. Sol 2 that include Scour Marks
	33	sPDL-5	Sol 4 & Sol 22 Overlap Presentation work + Natural & Enhanced Colour mosaics from Sol 3 North-east Scour Marks.
	34	sPDL-4	Multispectral Products of Sol 33 Ahyééh Thumbnails
	46	sPDL-4	Multispectral Products of Sol 46 Peppermint Thumbnails
	47	sPDL-6	3x3 Mosaic of Ingenuity with Best Found Focus frames from Z-stack
	48	sPDL-4	Regolith Analysis of Iiná alongside new quicklook products
	51	sPDL-4	Continued Iiná regolith analysis + ROIs and Spectra taken from Soil, Pavers Light & Dark Pebbles in Sol 46 Peppermint
	56	sPDL-6	Multispectral Products of long-distance delta sequence 03113
	57	sPDL-4	Finished up regolith analysis of Iiná and filled in missing metadata in the multispectral dossier
SOX2B (Sol 75-99)	80*	sPDL-6	Multispectral Products of Sol 79 Tsetah, Frame 2 of 2
	81	sPDL-4	ROIs and spectra of Sol 65 Delta Scarp, Frame 1 of 2
	83	sPDL-4	Natural & Enhanced Colour Mosaics of Sol 82 Nizhoni 5x1
	84	sPDL-5	ROIs and spectra of 4 different areas on the Sol 65 Delta Scarp 2x1 Mosaic
Crater Floor (Sol 100+)	115	sPDL-5	Picked out features on Sol 113 PDI Drive Direction Mosaic and presented the finds at the Science Discussion
	127	sPDL-4	ROIs + Natural & Enhanced 6x1 Mosaic of Séítah Sol 123, seq. ID 03167

5.1.1 Focus

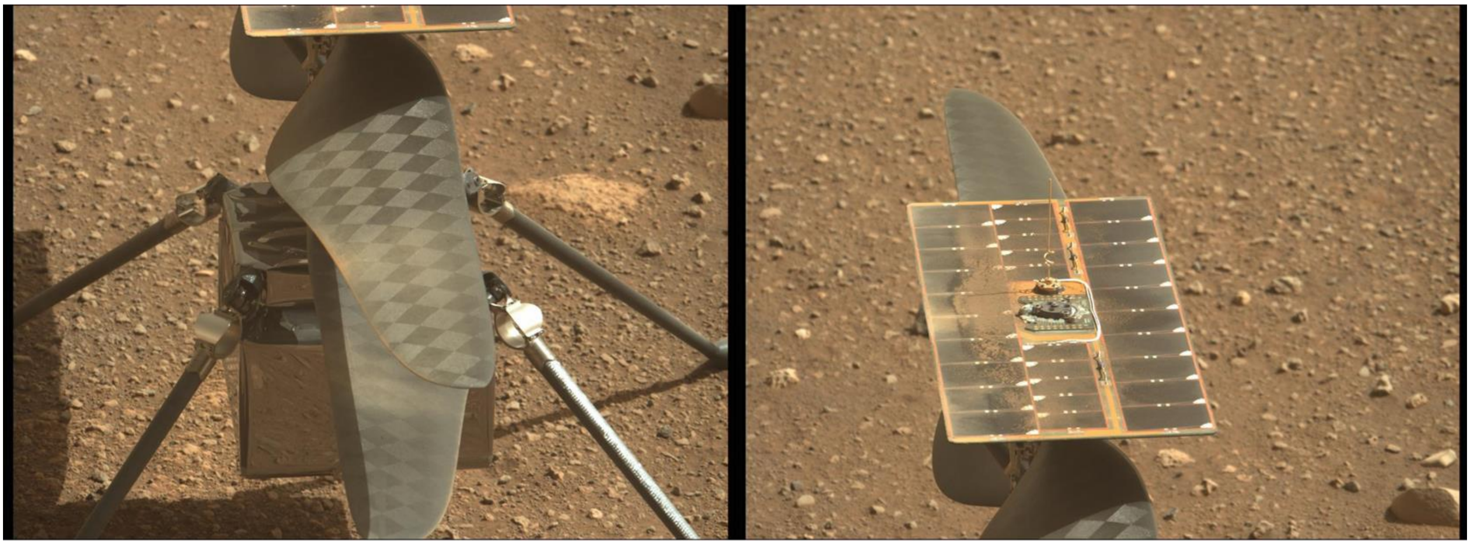
Sol 47 – 3x3 Z110 mosaic of Ingenuity with best found focus frames from Z-stack

The following Mastcam-Z images were taken after *Ingenuity* was deployed from *Perseverance* on Sol 43. The purpose of these images was to check the helicopters health and that it was ready for flight. But also, to document that Mastcam-Z had its pointing and focus correct for later flight documentation.

A series of images were taken with differing focus (a Z-stack) and later focus merged in order to create a mosaic with the best overall focus possible. This is because frames that included helicopter hardware would always be in much better focus than the ground surrounding the hardware. Frame 3349 on Figure 29a shows this difference in focus between the ground and helicopter quite well.

During the Sol 47 shift we received almost all the images from the Sol 45, seq. id 05003, except one partial right-eye image, though this had no influence on my work done this shift. The centre image and centre top image were the Z-stacked images with differing focus frames and so I manually went through these and picked out the best ones, which were Frame 3567 & 3349 (Figure 29a) and used MERmap in order to make a 3x3 mosaic with these two frames and the remaining 7 images, which were not Z-stacked.

I ran into several problems with MERmap and struggled to produce an image with proper seams and lighting (see appendix 5.1.1a for my attempts). Michael Hansen, another student from Univ. of Copenhagen, was also on shift that Sol and replicated the procedure after my failings, having much better luck and produced the following mosaic that can be seen on Figure 29b. This mosaic as well as two of my failed attempts were archived on the Mastcam-Z wiki Sol 47 Shared Space by the end of the shift for future uses. It was also noted that there is slight varying in the focus on the regolith on Michael Hansen’s mosaic product, but it was concluded, that it was to be expected due to the differing focus values on all six frames.



ZL0_0045_067094**3567**_350EBY_N0031416ZCAM05003_1100LUJ ZL0_0045_067094**3349**_350EBY_N0031416ZCAM05003_1100LUJ

Figure 29a. Frame 3567 comprises the centre of the 3x3 mosaic with focus on the middle of the Heli (left image) and frame 3349 comprises the top middle of the 3x3 mosaic with focus on the Heli's solar panel (right image). The file names are stated below their respective images and frame numbers are highlighted in bold.

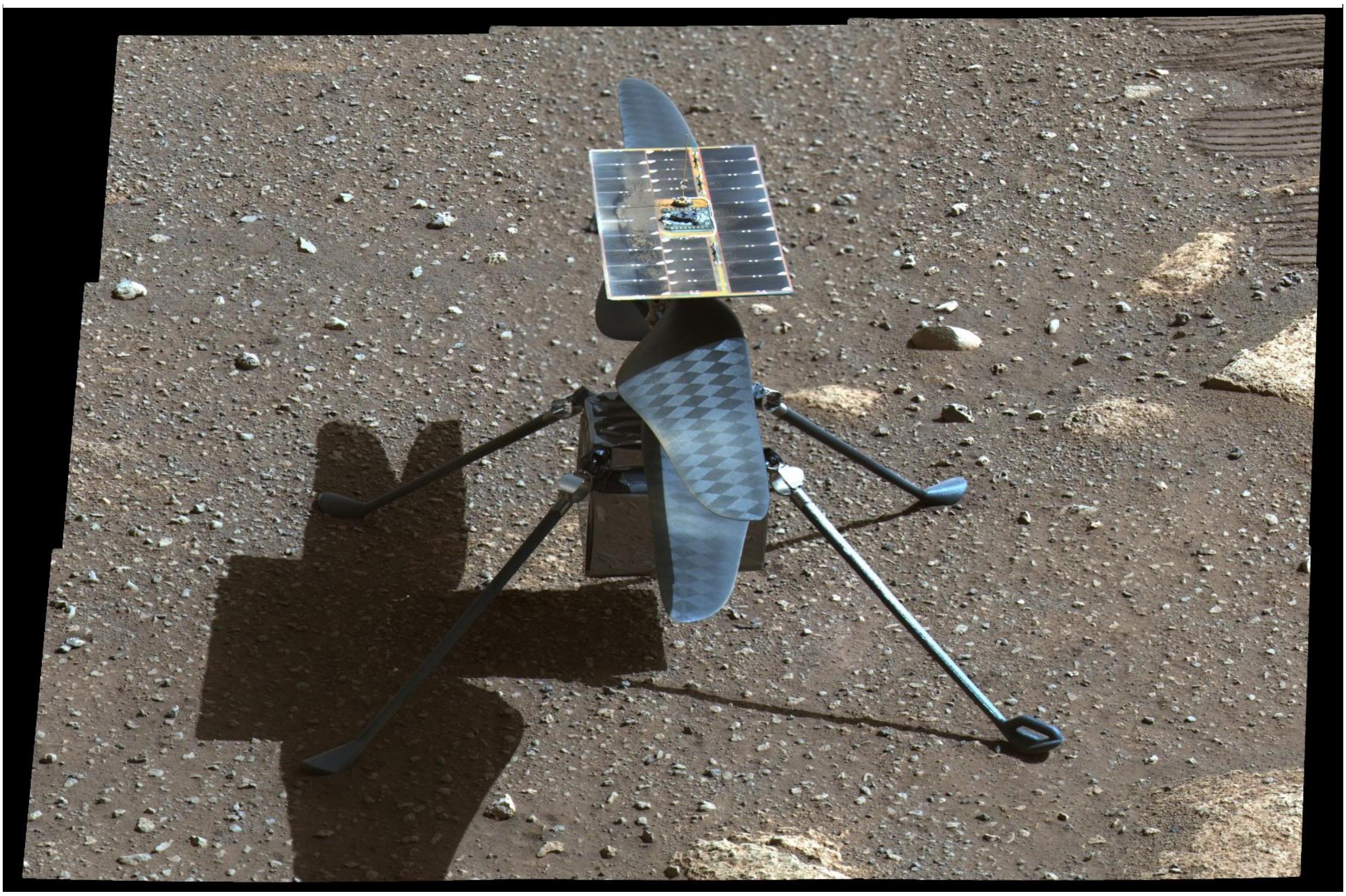


Figure 29b. Sol 45, seq. id 05003 IOF L0 enhanced colour 3x3 mosaic with plane set to ground based on Heli frames 3349 and 3567. [NASA/JPL/MSSS/Univ. of Copenhagen/M. Hansen]

5.1.2 Multispectral

Sol 84 – ROIs and spectra of 4 different areas on Sol 65, Delta Scarp 2x1 mosaic

Mastcam-Z took long distance images of the delta scarp for remote science, and it was these images that I worked on during my shift.

The work done on the Sol 65, seq. id 03119, Delta Scarp (Z110) was originally started on Sol 81, where Jorge Núñez (sPDL-1) and I divided the two frames between us, with me focusing on Frame 1 and Jorge focusing on frame 2 – both of us producing ROIs and spectra for each of these. The reason for this was that MERTools kept crashing when trying to load in the 2x1 mosaic .IMG file into MERspect.

A workaround for this problem was found by Jim Bell the following Sol and it included renaming the .IMG mosaic file produced by MERmap in a specific way, which then made it possible to open the mosaic file in MERspect and make multispectral products of the mosaic. This workaround was used during the Sol 84 shift and led to my work for this shift, where I picked ROIs in 4 different areas of the 2x1 Sol 65 Delta Scarp mosaic as well as making spectra based on these ROIs and colour-coding them. The 2x1 mosaic and an overview of the four chosen areas can be seen on Figure 30, followed by a close-up of each areas ROIs and spectra plots (Figure 31).

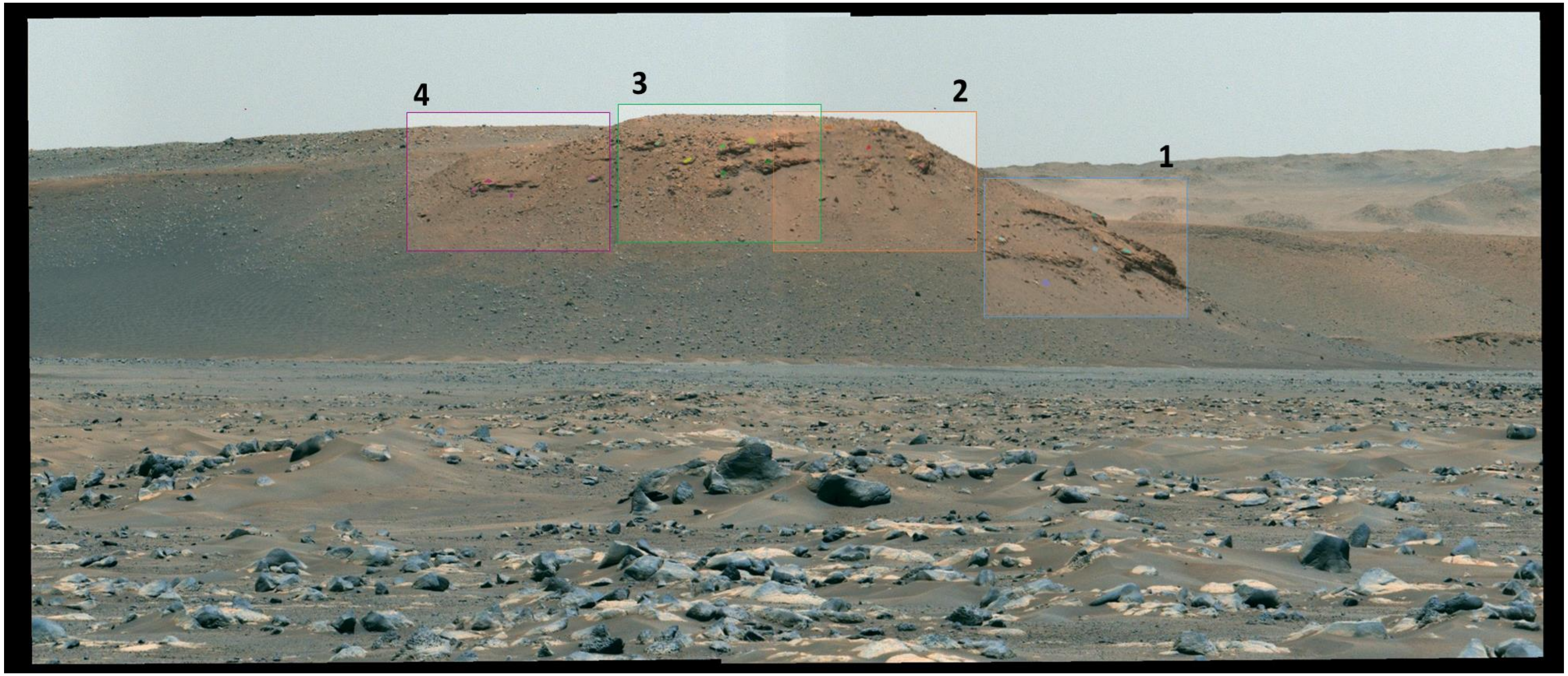


Figure 30. Sol 65 Delta Scarp 2x1 mosaic with the four different areas containing ROIs and colour-coded for convenience. From right to left: Area 1 is marked with a blue square and contains 5 ROIs, Area 2 is marked with orange and contains 7 ROIs, Area 3 is marked with green and contains 6 ROIs and lastly, Area 4 is marked with purple and contains 4 ROIs.

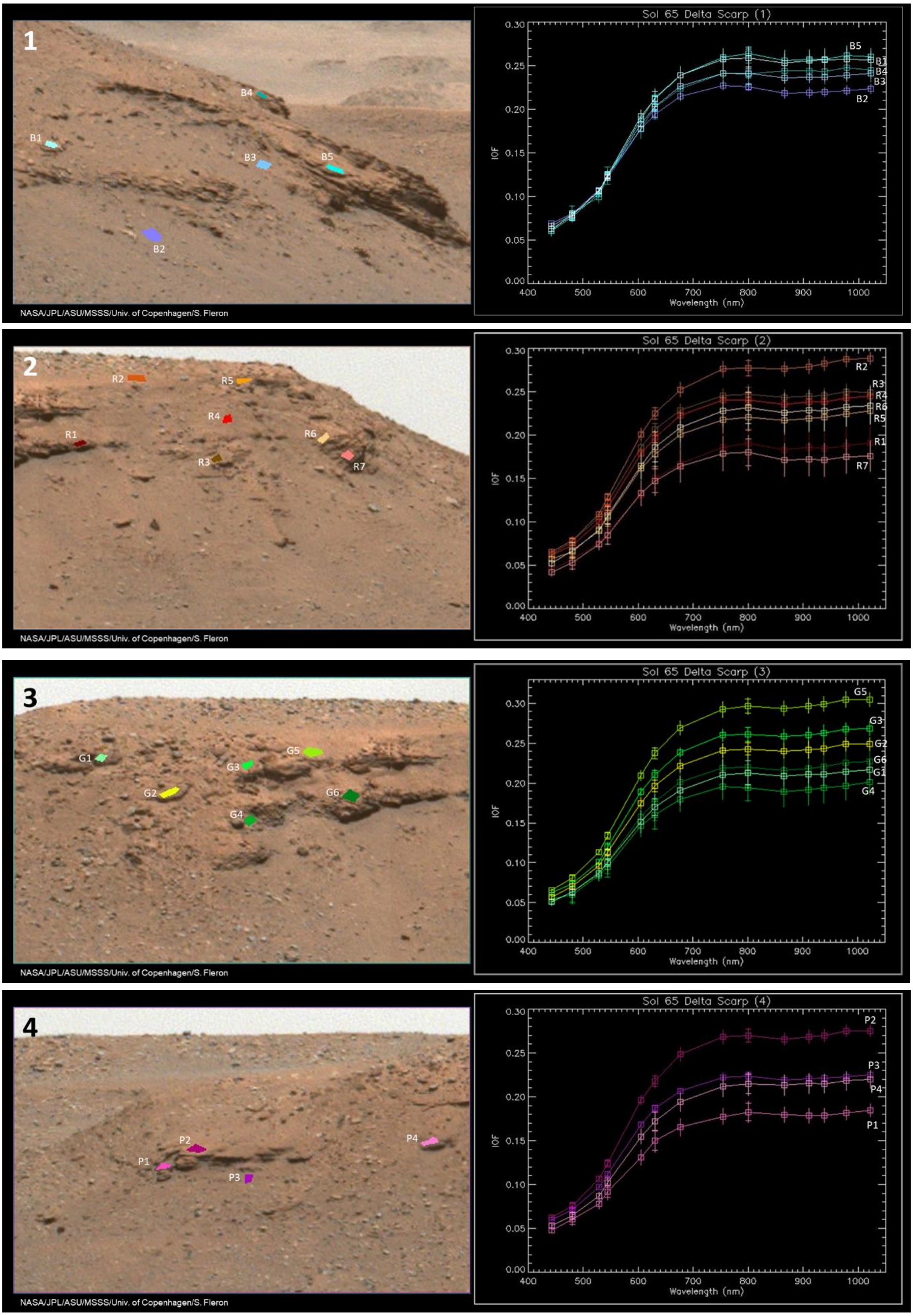


Figure 31. Close-ups of Sol 65 Delta Scarp areas with their ROIs and spectra plot. Each ROI and their respective graph are labelled with the initial letter of their colour, followed by an ascending number going left to right when looking at the natural colour image. Area 1 (top image and plot) is the northern most outcrop on the delta on this mosaic, Area 2 is the second most northern part in this mosaic, followed by Area 3, which is part of the same outcrop of the delta as Area 2 and Area 4 (bottom image and plot) is the southern-most part of the delta in this mosaic.

The ROIs have been chosen with the purpose in mind to try and encompass both the surrounding regolith and outcrops on the delta scarp. Some of the ROI placements do not quite follow the best-practice method that was produced by Jess Mollerup following this shift, as some of the ROIs are either on slightly shadowed surfaces or on non-flattened surfaces, causing large error bars. The error bars are the standard deviation in pixel value, which is not as precise, but are more accurate way is being worked on.

The spectra extracted from the four areas all show a strong positive slope in the long wavelengths between 445 and 677 nm with only slightly weaker variations found in Area 2's R1 and R7; Area 3's G1, G4, and G6; and lastly Area 4's P1.

Area 1: B1 dips after 800 nm but flattens out between 866 and 1022 nm. B2 and B3 dips after 800 nm before increasing, ending in the upturn at 1022. B4 dips after 800 nm before slowly increasing between 866 and 1022 nm with an upturn at the end. B5 also dips after 800 nm but spikes around 978 nm before ending in a downturn at 1022 nm.

Area 2: All the spectra dip around 800 nm before increasing at 866 nm, ending in an upturn at 1022 nm, with R3 being the exception and ending in a downturn.

Area 3: All of the spectra also dip around 800 nm, before increasing after 866 nm. G2 and G5 have neither an upturn or downturn at 1022 nm, whereas G1, G3, G4, and G6 all have a slight upturn at 1022 nm, albeit the upturn on G3 and G6 is very weak compared to G1 and G4.

Area 4: P1, P2 & P3 dip around 800 nm, before increasing after 866 nm, whereas P4 is almost flat with almost no increase between 866 and 1022 nm. P2 is flat near 1022 nm, compared to P1, P3, and P4 which all have a slight upturn at the end of the longer wavelengths.

One would have expected more variation in the spectra of the layers due to being in the exposed front of the delta and have thus experienced more weathering throughout time.

5.1.3 Geology

Sol 9 & 10 – Pointed out features of interest in the Sol 4 Z110 Panorama

On Sol 4 a 110 mm zoom, 360° horizon-only panorama was taken with the seq. id 00024. This mosaic was taken to help the team quickly orient themselves after landing.

The panorama wasn't downlinked fully until on Sol 9, due to the rover moving from the SOX1A campaign at the end of Sol 4 into the Surface Flight Software Transition between Sols 5-8 and then into SOX1B on Sol 9. This was the first high-resolution 360° Mastcam-Z panorama taken by the Perseverance rover after landing on Mars and was released in the NASA/JPL photo journal on 2/3-2021.

I was on shift as sPDL-4 on both Sol 9 & 10 alongside the same team of people on both Sols. The shift work was made in collaboration with Christian Tate and Nicole Schmitz, and it comprised of us pointing out features of interest in the panorama, making close-ups of said features and indicating where these features were located in a 4-frame version of the panorama image. The 4-frame version of the panorama is displayed on Figure 32, followed by two figures that show the close-ups of the chosen features: Figure 33 showing the smaller close-ups and Figure 34 showing the bigger features. A satellite image overview of the estimated locations of these features can also be seen in appendix 5.1.3a.

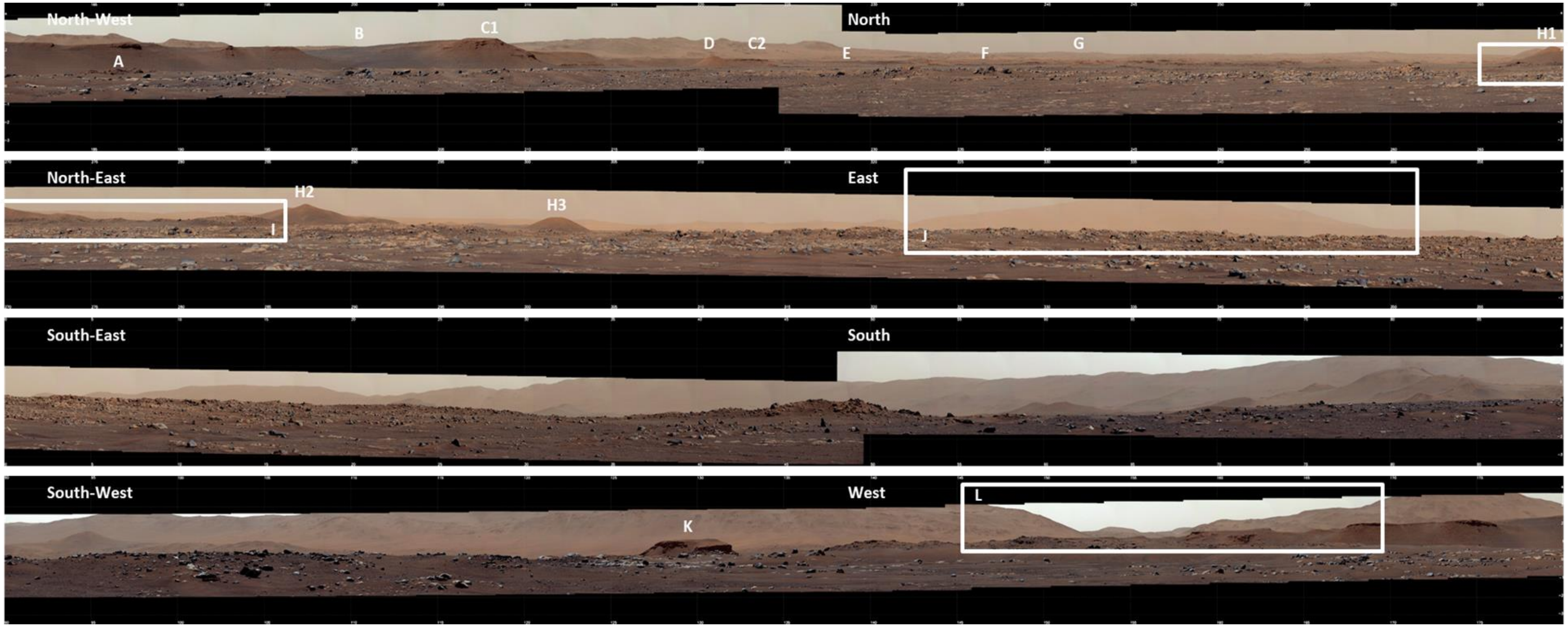


Figure 32. The right-eye Sol 4 360° panorama divided into 4-pieces, each one facing a different cardinal direction with North at the top, East as the 2nd from the top, South being the 2nd from the bottom and West at the bottom. Each of the four sections have interesting features annotated with A through L and some of the bigger features are also highlighted with boxes. A through H are displayed on Figure 33, with I, J & L shown on Figure 34.

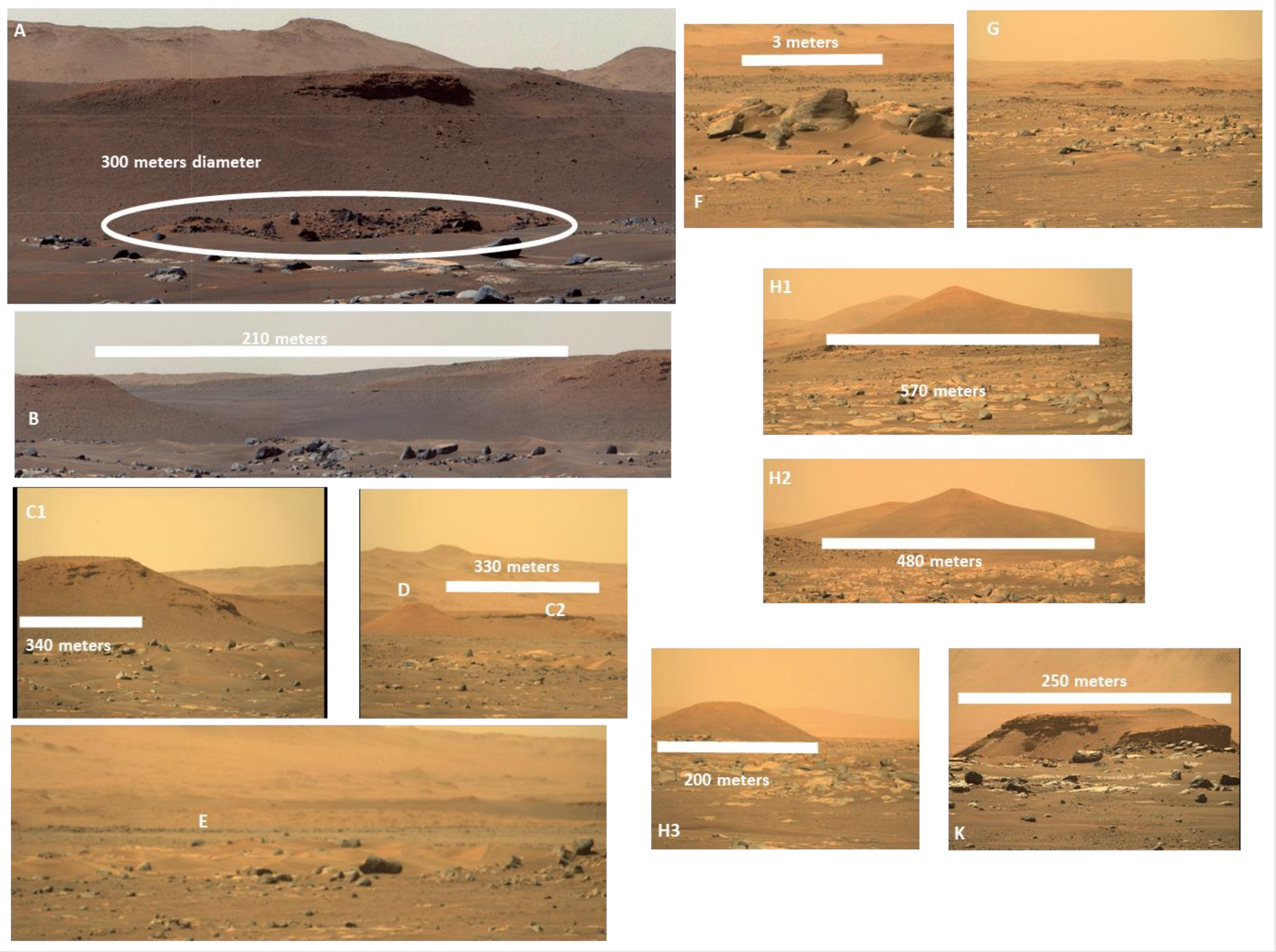


Figure 33. Close-ups of the interesting features that were highlighted on the Sol 4 360-panorama containing A, B, C1 & C2, D, E, F, G, H1 & H2 & H3 and K. Some of the more notable features are: C1 & C2 which highlight the layering on the Jezero Crater delta; G shows the northern delta in Jezero Crater at a distance of ~7 km from the rover; H1, H2 and H3 are the 3 delta remnants located to the north-east, relative to the rover's position at that time and their names are respectively: Isle Royale, Santa Cruz and Mauna Kahalawai; with feature K showing off the Kodiak delta remnant to the south of the delta itself. The crater shown on A was not named back when we first made these highlights but has later in the mission been dubbed Hahóót'sa.

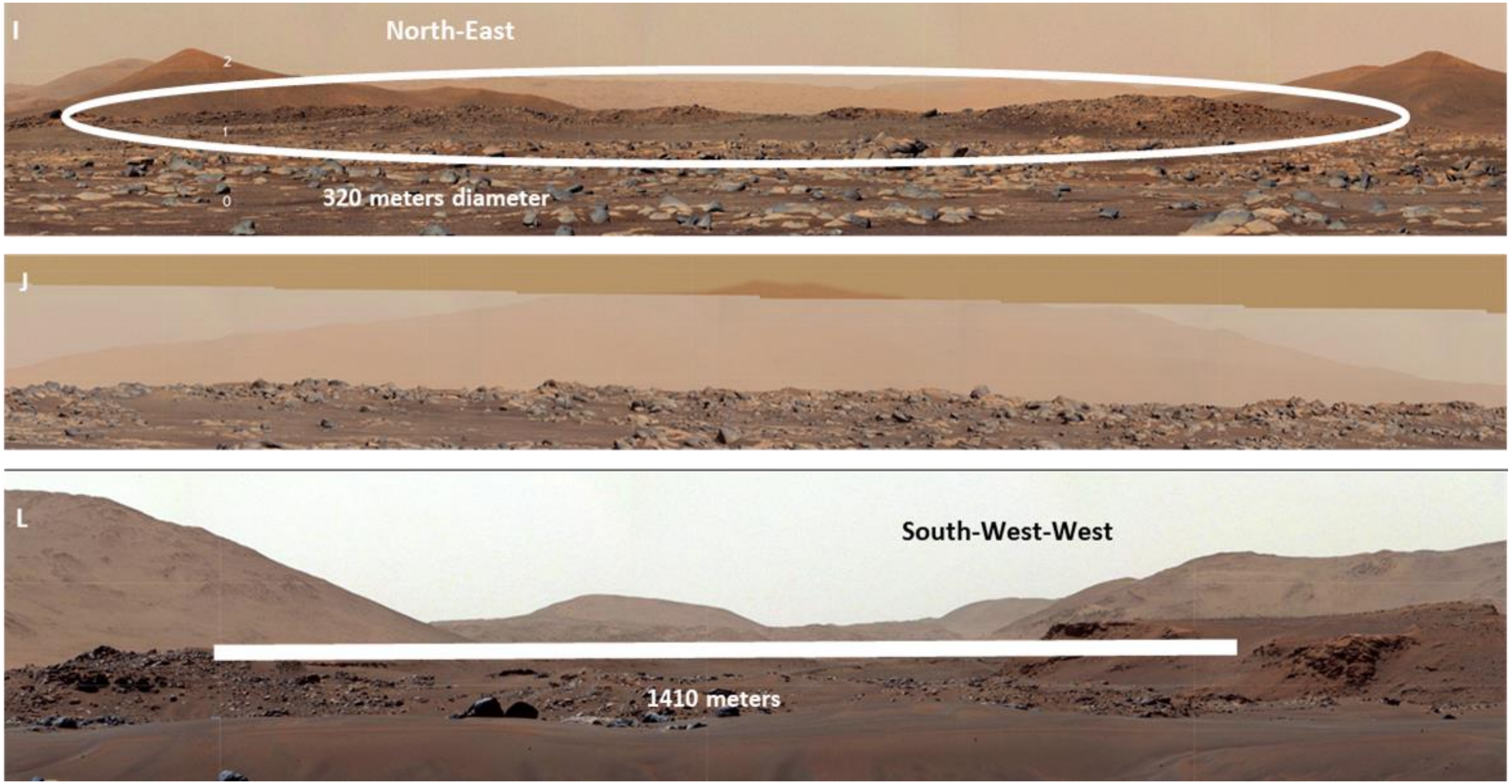


Figure 34. Close-ups of the interesting features that were highlighted on the Sol 4 360-panorama containing I, J and L. Feature I is the rim of an impact crater, which is located between the north-eastern delta remnants and the rover's position at that time. This crater has later been named La Orotava. Both feature J and L are located on Jezero Craters rim, with J being a huge mountain to the south-east on the crater rim with feature L being the Neretva Vallis. Note that the frame for J is the Sol 4 Z110 mosaic overlain on the Sol 3 Z34 mosaic in order to capture the whole mountain.

Feature A shows a rim from an impact crater (Hahóót'sa) about 900 meters towards the north-west, between the rover and the delta. It is about 300 m's in diameter and is somewhat hidden behind the topography of the crater floor. Feature B is a channel that has cut into the Jezero Delta and has dark coloured sediments compared to the regolith on the steep slopes underneath the outcrops on the delta itself. Both feature C1 and C2 shows fine layering on the delta scarps with D being a delta remnant with a near perfect cone-shaped with no layering or bedding visible very close to the delta itself. Feature E shows a large ripple field, which looks to be a part of Séítah.

Feature F is a rock containing apparent layering that rises above the sand ripples in the near area about 120 meters for the rover. Feature G marks the northern delta in Jezero Crater, which stands at a distance of ~7 km from the rover. It is theorized that the northern delta is a separate and older than the current western delta or even an older part of the western delta. Features H1, H2, and H3 are the delta remnants to the east of the rover, with Isle Royale being the northernmost, Santa Cruz the middle one, and Mauna Kahalawai is the southernmost one of the three. These remnants just like the near-perfect cone shaped remnant near the delta have no clear bedding or layering visible.
Feature K is another delta remnant named Kodiak and is to the south-west. This remnant, compared to the others that have been highlighted, has very distinct layering as well as foresets and truncation, which is often found in delta stratigraphy.

Feature I shows another impact crater about 1 km distance towards the north-east with a diameter of 320 m, in front of the Isle Royale and Santa Cruz eastern delta remnants relative to the rover's position. The large feature J is a 20 km wide edifice located about 35 km to the south-east on the rim of Jezero Crater. Others have theorized the edifice is of volcanic origin, which erupted after the impact event that formed Jezero Crater. This edifice will be mentioned in the discussion section as I believe it plays an important role to the sequence of events that formed the geological units of Jezero Crater.
Feature L is the prominent valley of Neretva Vallis, that was formed by an ancient river channel that fed the Jezero delta.

Sol 33 – Sol 4 & Sol 22 mosaic overlap presentation work

Christian Tate was the first to start this small project and asked me if I wanted to do it with him after being a second set of eyes on the first connections, he had made between the two mosaics. He started this work because he wanted to contribute to mapping out interesting targets to investigate near the Van Zyl Overlook, where the rover would be parked while *Ingenuity* would perform its first flight test.

The two mosaics used for this work are the following:

- Sol 22, seq. id 07000, Z110 12x2 mosaic: This mosaic faces south-east with the centre azimuth of 150°, centre elevation of -4°, a FOV azimuth of 60°, and FOV elevation of 8°.
- Sol 4, seq. id 00024, Z110 360° panorama: This panorama has been cropped facing east with the centre azimuth of 110°, centre elevation of -0.5°, a FOV azimuth of 65°, and FOV elevation of 4.5°.

The mosaics and their respective viewsheds alongside a correlation example between the two can be seen on the following Figure 35.

The correlations found between the two mosaics were done both on and off shifts. It required a lot of deliberation and quite a bit of double-checking chosen markers between the mosaics in order to make sure the associations were 100% correct. A total of 23 correlations across the two mosaics were done in the near, mid, and far field and around the Van Zyl overlook and a map showing an overview of their locations can be seen in appendix 5.1.3b. I was also the one that presented this work in the Sol 46 Science Discussion on April 5th-6th 2021 and really put an emphasize on perspective and the benefits of viewing rocks from different angles.

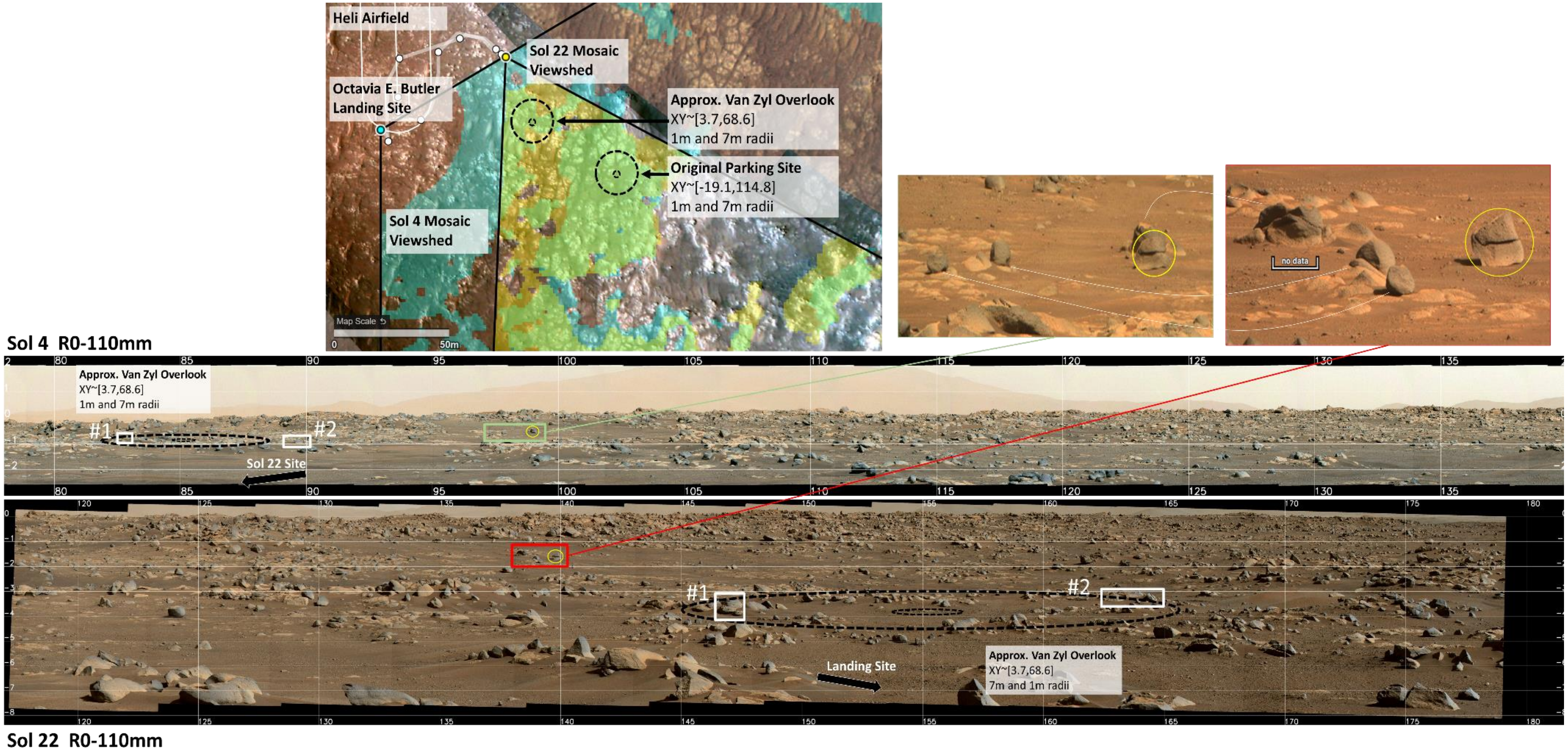
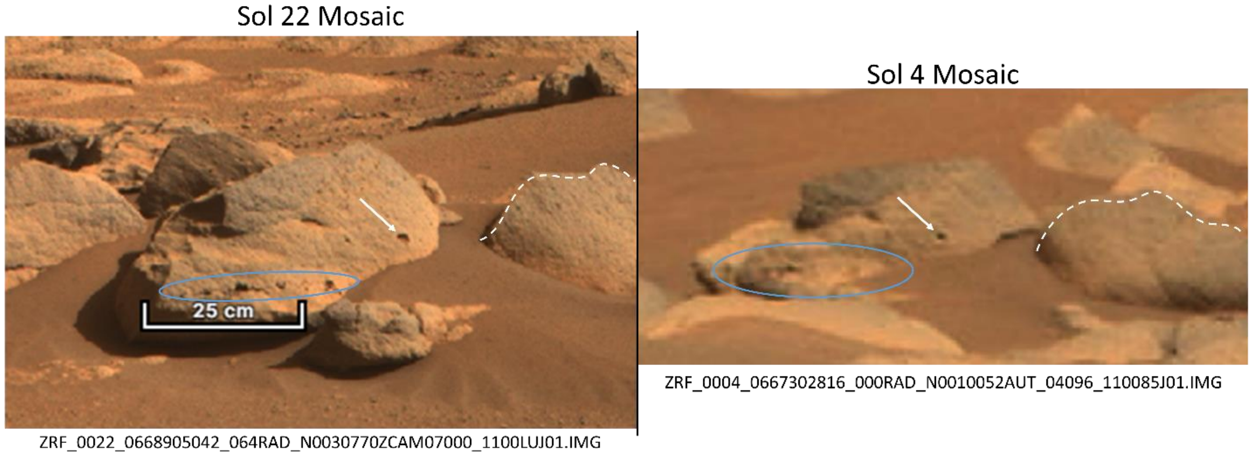


Figure 35. Sol 4 (top) & Sol 22 (bottom) Natural Colour Mosaics and their respective viewsheds on a map showing the Sol 0-34 Rover Traverse (top left corner). Sol 4 is the blue viewshed and Sol 22 is the yellow viewshed with the green indicating overlap between the two viewsheds. An example of the perspective change between the two mosaics (top right corner. The perspective change here is quite clear in that the big boulder is almost hidden behind the yellow-circled rock in the Sol 4 mosaic but is visible in the Sol 22 mosaic. The white curved lines between the other rocks are there to show the correlation between the rocks on the two mosaics. The two images used here are both right-eye images from their respective Sols. The white numbered boxes show the location of two more correlation examples. Also note that the approximate location of the Van Zyl Overlook has been marked on both the map and mosaics, though the original planned parking site which was swapped for Van Zyl Overlook has only been marked on the map.

Two examples of comparison between the mosaics can be seen below on Figure 36.
The square #1 example shows a rock with a horizontal pebble-like weathering feature highlighted with a blue circle as well as a single isolated hole (indicated with a white arrow). The dotted line on the rock to the right was used alongside the two aforementioned features for correlation.

Example square #2 shows a rock with a rough/weathering texture, its outline indicated with the dotted line. A small rock in the foreground (highlighted here with a blue circle) was used alongside a supposed cracked rock (white arrow pointing to the “crack” in the rock) in the right-side of the image in order to pinpoint the previously mentioned rough textured rock.

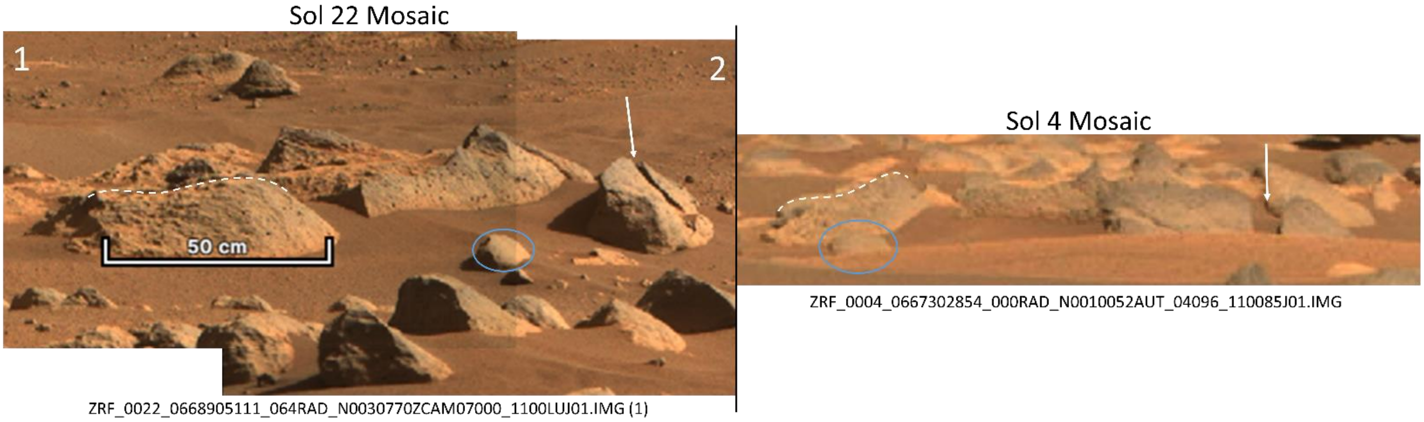
Square #1, near Van Zyl overlook



ZRF_0004_0667302816_000RAD_N0010052AUT_04096_110085J01.IMG

ZRF_0022_0668905042_064RAD_N0030770ZCAM07000_1100LUJ01.IMG

Square #2, near Van Zyl overlook



ZRF_0004_0667302854_000RAD_N0010052AUT_04096_110085J01.IMG

ZRF_0022_0668905111_064RAD_N0030770ZCAM07000_1100LUJ01.IMG (1)
ZRF_0022_0668905146_064RAD_N0030770ZCAM07000_1100LUJ01.IMG (2)

Figure 36. The top two images show the square #1 correlation example between the mosaics. The bottom two images show the square #2 correlation example between the mosaics.File names are listed underneath their respective images. Both examples are taken from near the Van Zyl Overlook.

Sol 33 – Natural & colour enhanced mosaics of the Sol 3 NE Scour Marks

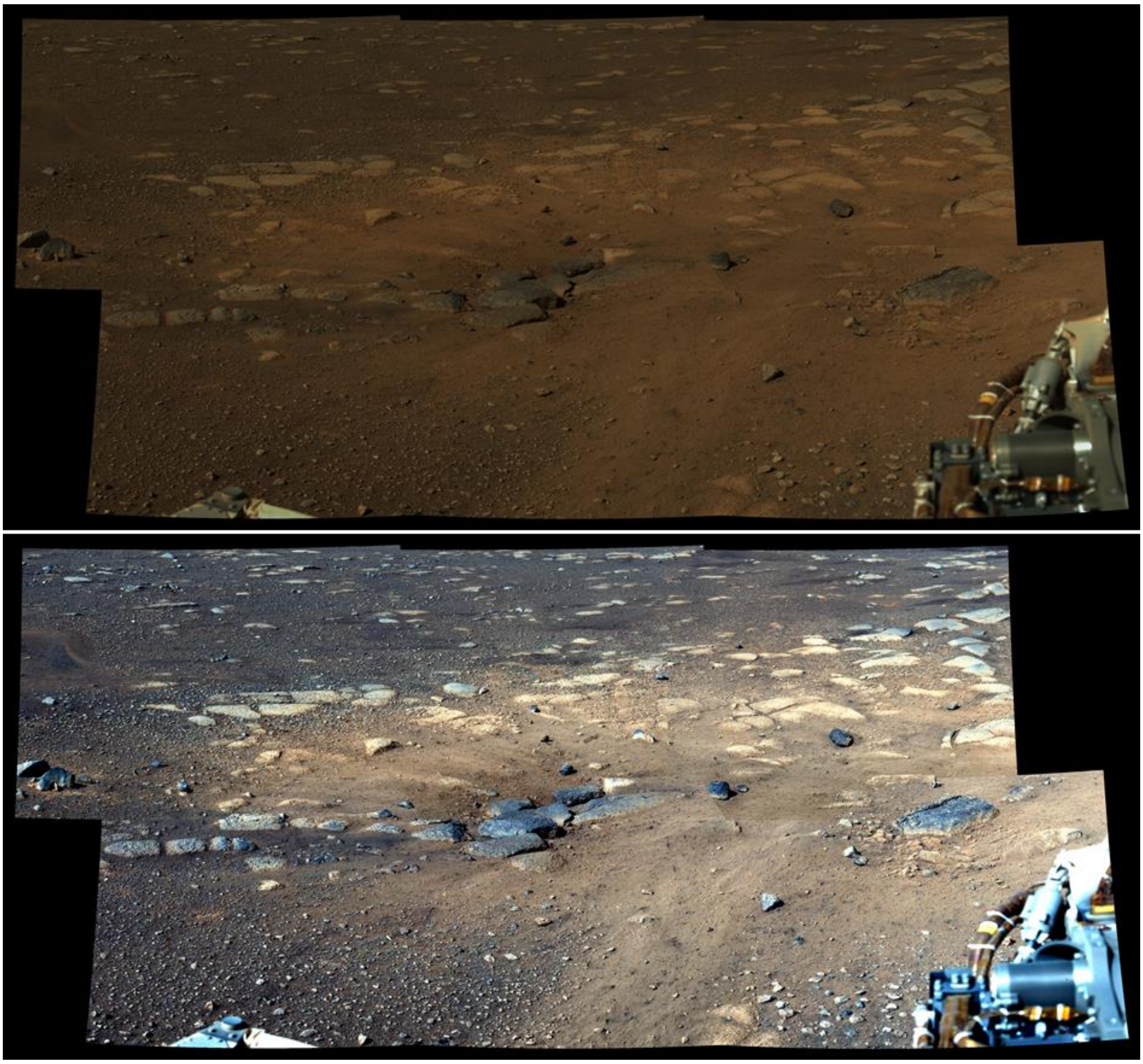


Figure 37. Natural (top) & Enhanced Colour (bottom) 3x2 mosaic of Sol 3 North-East Scour Marks from the Rover landing site with some rover hardware in the bottom right corner. Note that the pavers inside the scour marks are decidedly darker compared to the pavers outside of the scour zone.

Most of the shift on Sol 33 was used on the Sol 4 & 22 overlap work and so I only managed to make natural, and colour enhanced 3x2 mosaics of the Sol 3 NE scour marks for that shifts Science Discussion. The other multispectral products were made by another person on one of the following downlink shifts.

The area in the vicinity of where the rover touched down has been scoured by the very powerful brake thrusters during the landing and has literally sandblasted the rocks in the near vicinity. This provides a unique situation, where we can perform multispectral imaging on a much larger surface of the bared rocks, compared to just the small, abraded patches the rover itself makes on target rocks.

On Figure 37 above, it is clear that the rocks that have been excavated are much darker in colour and this is especially visible on the colour-enhanced image. The enhanced colour image really helps bring out the details one would otherwise not see in the natural colour images. It is also apparent, that some of the rocks just outside of the scour zone have a much thicker coating of dust, and this excess dust is probably the dust that has been blown off of the scoured rocks by the thrusters.

As one can see, the shift work as sPDL has its challenges but allows us to produce a variety of different products for the benefit of the Mars 2020 Team as a whole. Also, I want to note that the work and results, which are highlighted here, is only a small snippet of the tremendous number of products that have, since I have been on shift, been produced and is still being produced by the sPDL and PDL crew up to this day.

5.2 Remapping Effort

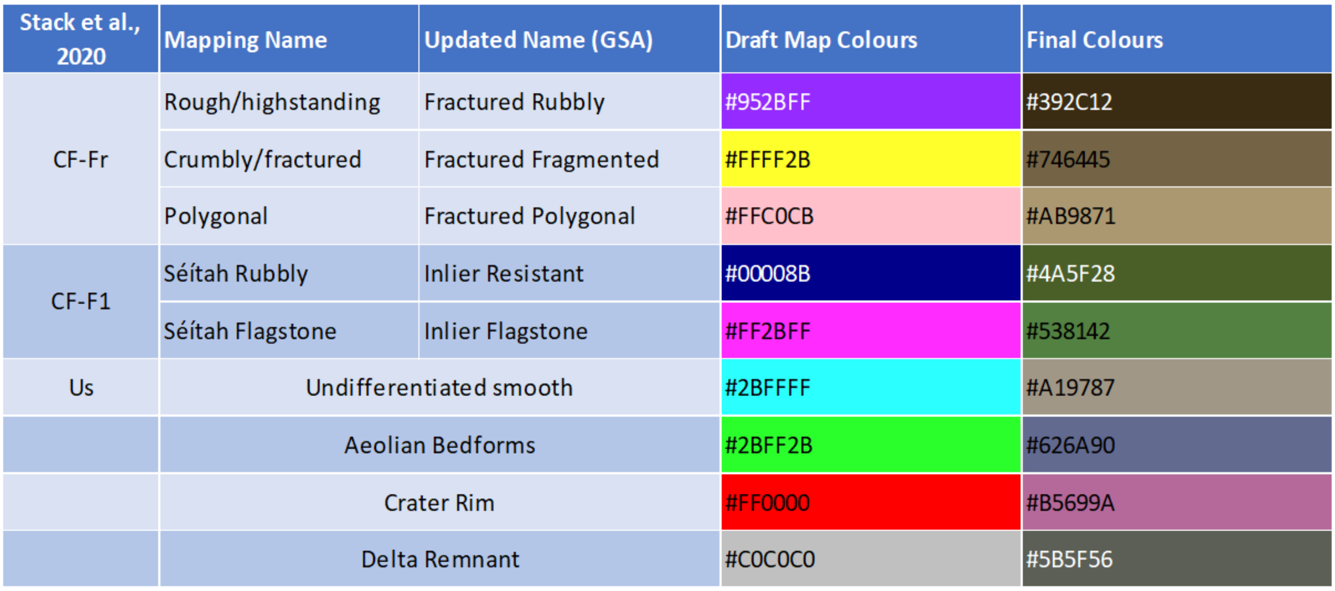
This segment includes the finished map from the Remapping Effort, which was stitched together from the draft maps made based on the method shown in Section 4.2. This effort was meant to expand upon the photogeological map and units that had been produced prior to landing and is shown in Section 2.2, Figure 3 from Stack *et al.*, 2020. The newly updated map would be important to putting other observations into context and be critical for establishing a framework for samples and investigate the relationship between the delta and crater floor later in the mission.

After finishing our draft maps, the final map was stitched together. Brittan Wogsland presented this finished map alongside revised geological unit names at the 2021 GSA convention (Geological Society of America).

Table 4 was originally made by Brittan Wogsland for the 2021 GSA presentation and it contains a list of said geological units with their labels from Stack *et al.*, 2020; the draft unit labels and colours from the remapping effort, as well as the revised labels and colours from GSA. This table was modified by me to include the remapping effort draft unit colours for ease of comparison between the draft map and the finished geological map.

Mapped unit examples from my own quads can be seen on Figure 38, with the exception of Crater Rim as there are only a few examples present. A Delta Unit in the form of one large delta remnant, also designated Temple Hill, is present alongside the western edge of Mammoth Cave. The units CF – Smooth Polygonal and Séítah Rubbly/Highstanding are also not shown among the examples because they were not present in my quads, but they are shown in the general unit example figure alongside their individual definitions in Section 4.2.

Table 4. Overview table containing the units and labels from the Stack et al., 2020 article; the Remapping Effort process as well as the updated names and colours used for GSA. Made and presented at GSA 2021 by Brittan Wogsland from University of Tennessee, Knoxville, TN. Modified by me to include draft map colours for comparison.



Stack et al., 2020	Mapping Name	Updated Name (GSA)	Draft Map Colours	Final Colours
CF-Fr	Rough/highstanding	Fractured Rubbly	#952BFF	#392C12
	Crumbly/fractured	Fractured Fragmented	#FFFF2B	#746445
	Polygonal	Fractured Polygonal	#FFC0CB	#AB9871
CF-F1	Séítah Rubbly	Inlier Resistant	#00008B	#4A5F28
	Séítah Flagstone	Inlier Flagstone	#FF2BFF	#538142
Us	Undifferentiated smooth		#2BFFFF	#A19787
	Aeolian Bedforms		#2BFF2B	#626A90
	Crater Rim		#FF0000	#B5699A
	Delta Remnant		#C0C0C0	#5B5F56

From here on out, I will be referring to the updated names of the units from GSA.

Jezero Crater in the mapping effort was divided into two primary geologic regions: Crater Floor and Séítah Inlier. These two regions were then further divided into their own separate units based on what we observed from orbit. The Crater Floor contains 3 distinct units: Fractured Rubbly, Fractured Fragmented, and Fractured Polygonal while Séítah Inlier contains two units: Inlier Resistant and Inlier Flagstone.

My quad pair consists mainly of the units Undifferentiated Smooth, Fractured Fragmented, and Fractured Rubbly, with some Aeolian Bedform’s and Crater Rim’s scattered in between. The Fractured Rubbly unit is only found in the Mammoth Cave quad, with an area in the southern part of the Mammoth Cave quad, where a gradual transition between Fractured Rubbly and Fractured Fragmented occurs. It was therefore hard to make a clear-cut border between them in some of those overlapping places, but I did it based on the definitions, that the Fractured Rubbly is more highstanding and therefore pops out more from the ground. Whereas Fractured Fragmented is a low-relief unit and therefore lies, closer to the ground. This boundary between units is visible on both the maps in Figure 39 and a close-up can be seen in appendix 5.2a. The Fractured Fragmented unit is, as stated previously, found in that southern part of the Mammoth Cave quad and spreads into the Tongariro quad and all way to the bottom of said quad. Although it is mostly condensed near the northern and middle part of Tongariro.

The Undifferentiated Smooth unit is spread throughout both of my quads in equal measure. It covers portions of the Crater Floor on its own as well as in between the Fractured Rubbly and Fractured Fragmented units. There are also quite a few large (>200m) criss-crossing linear fracture features interspersed in both of my chosen quads and intersecting all the different units in some way – some are high-ridged and stand-out, while some are lower and less prominent. An example of the lower, less-prominent fractures is highlighted with orange arrows on Figure 38 on the (B) Undifferentiated Smooth unit.

The top right corner of Mammoth Cave covers a bit of Gaspé, which looks a lot like Séítah that lies to the south and has such been interpreted as having Inlier units. It is a very small area (325 m x 150 m) that covers the edge between the Crater Floor and Gaspé and therefore only encompasses some Aeolian Bedforms and Inlier Flagstone units.

There are only very minor changes from my final draft map to the updated map. These are corrections made by the working group leads after I handed over my map for stitching. These changes included some added Crater Rims (A1 and A2) in the bottom of the Mammoth Cave Quad. More details in the Fractured Fragmented and Undifferentiated Smooth units (B1 and B2) of the Tongariro quad. Some changes to the interior of the large crater on the right edge of the Tongariro Quad, with the whole of it marked as Aeolian Bedforms (east side of C1 and C2), followed by changing some of the Fractured Fragmented to Aeolian Bedforms (west side of C1 and C2).

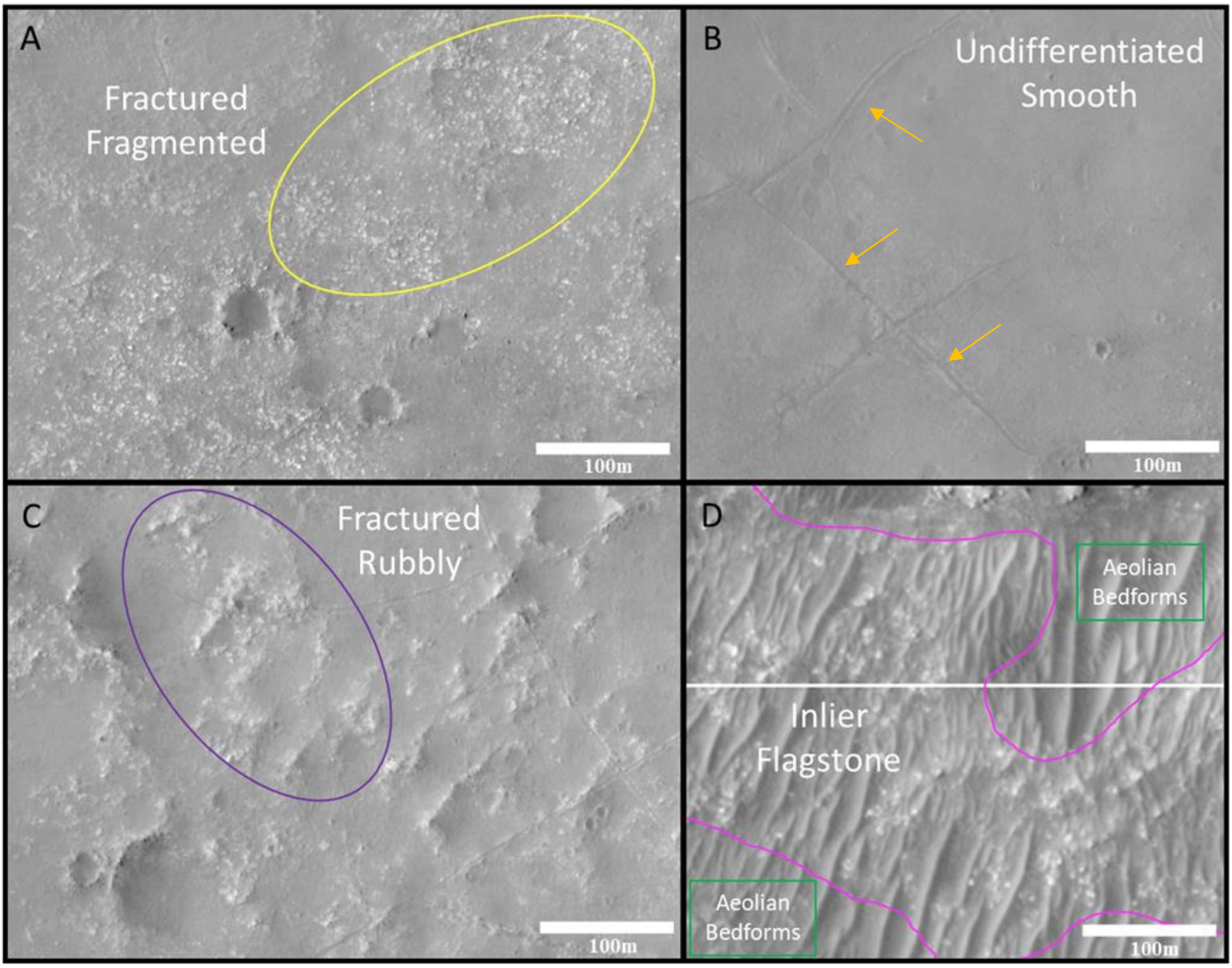


Figure 38. Examples of some of the mapped units that are present in my two quads, with the draft colours and updated names for clarity of correlation between draft and updated maps. From the top left corner: (A) shows the Fractured Fragmented unit; (B) is the Undifferentiated Smooth unit; (C) displays the Fractured Rubbly unit and lastly, (D) shows both the Inlier Flagstone encompassed by the magenta lines and some Aeolian Bedforms on each side. The orange arrows on example (B) highlights the intercutting fractures that are visible in the undifferentiated smooth unit.

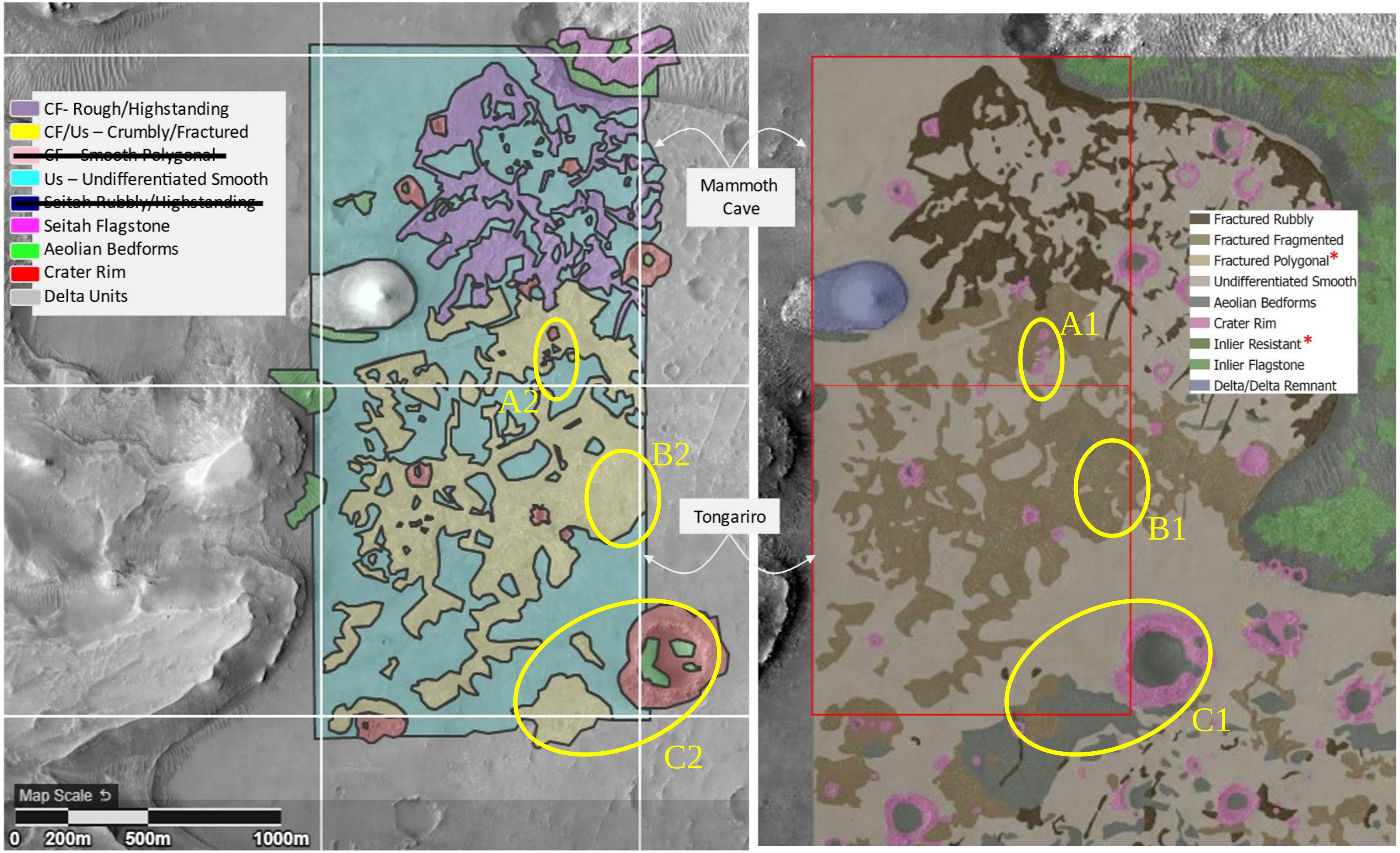


Figure 39. Finished draft map (left) and the updated geological map shown at GSA (right) zoomed in on my chosen quads: Mammoth Cave and Tongariro. Note that CF-Smooth Polygonal/Fractured Polygonal and Seitah Rubbly/Inlier Resistant are not present within my quads and have therefore been crossed out on the draft map legend but have only been marked with a red asterix on the final map legend. The scale is viable for both maps.

Table 5. Overview of 11 mosaics, containing rover tracks and horizon from Sol 0 to 102, with the mosaic name, respective Sol #_Seq. ID as well as Drive, Site and Sol number information taken from the CAMP parking spots. The mosaics marked in bold will be touched upon in further detail in this section. The green asterix (*) highlights the mosaic example used in Section 4.3, which also faces away from the part of the rover path that has a radargram. While the orange asterix (*) highlights the mosaics used in Section 5.1.3. The red asterix' indicate the following reasons for why these specific mosaics have not been used in my work: *The mosaics face away from the Rover Traverse lines; **The mosaic is weirdly stitched together; ***The mosaic is too far away to make out the Rover Traverse.

Mosaic	**Sol & Seq. ID**	**CAMP (Parking Spot)**
Full 360-degree horizon only panorama*	0004_00024	Drive 0, Site 3, Sol 13
12x2 mosaic of the rover heli-phase parking area*	0022_07000	Drive 770, Site 3, Sol 20
Santa Cruz & Remnants 8x1*	0038P_08009	Drive 1392, Site 3, Sol 34
Van Zyl Mosaic, Part 4	**0057_08103**	**Drive 2046, Site 3, Sol 52**
Santa Cruz, Part 5*	0059_08104	Drive 2046, Site 3, Sol 52
Van Zyl, Adziilii, part 7a	**0062_08106**	**Drive 2046, Site 3, Sol 52**
Delta, Part 9*	0063_08108	Drive 2046, Site 3, Sol 52
Butler Landing	**0078P_08038**	**Drive 2430, Site 3, Sol 73**
Dibahi-Nataani**	0078P_08039	Drive 2430, Site 3, Sol 73
Delta, Santa Cruz merged**	0087_08046 & 0090_08051	Drive 48, Site 4, Sol 86
Seitah region***	0096_08054	Drive 136, Site 4, Sol 91

5.3 Mosaics & Radargrams

The results shown in this following segment are based on the method shown in Section 4.3. The purpose for this work was to try and combine imagery from Mastcam-Z with the RIMFAX radargrams in order to gain an integrated understanding of rocks on the surface and their expression in the shallow subsurface.

A total of 11 mosaics from Sol 1 to 102 were found in the comprehensive Mastcam-Z mosaic google spreadsheet. Their names, Sol_Seq. ID as well as information pertaining their CAMP Parking Spot (Drive, Site & Sol) can be seen in Table 5. The location of all 11 mosaics on their respective parking spots, annotated with Sol_Seq. ID is shown on a map in Figure 40.

In Table 5 itself I have marked the mosaics with different coloured asterix’. These asterix’ all have their own meaning, which is mentioned in the caption text to the table.
The green marked asterix indicates the mosaic that was used for Figure 24 in Section 4.3, since it wasn’t pointed towards a part of the traverse that contained any radargrams. The orange asterix highlights the two mosaics that were used in Section 5.1.3 of the Sol 4 vs. Sol 22 overlap presentation work but were not used in this section. This is due to the Sol 4 mosaic being too far and thus making estimations of the rover path and parking spots highly unreliable. The Sol 22 mosaic was closer but there was hardly anything of interest to correlate from that view on the Sol 47-84 radargram compared to the other mosaic (0087P_08038) I have chosen, which covers the areas with Sol Parking Spots 48, 52, 65, and 66, just from the opposite side.
The red asterix’ (single, double, and triple) all have their reasons for not being included in this work and these have been noted in the tables caption text. The single and triple red asterixed mosaics all have simple explanations as either facing away or being too far away to make out the rover traversal path. The double red asterixed mosaics however are a bit different. These highlight mosaics that somewhat cover a small section of the rover traversal path but have large FOVs (>300°) and scattered image coverage. Both of the two mosaics marked with this type of double red asterix can be seen in appendix 5.3a.

Out of the 11 mosaics, only three mosaics (names highlighted in **bold** on Table 5) will be shown in further detail. Alongside these mosaics, I have used both Rear HAZCAM & NAVCAM images in order to correlate between rocks found near the Sol Parking Spots and near-surface features on the radargrams.

As previously stated, I had been provided with two different radargrams, Sol 47-84 and Sol 86-102 – a map pertaining to their coverage can be seen in appendix 5.3b. Both radargrams stretch over several Sols, but I only managed to tie-in the mosaics and single images to the Sol 47-84 radargram in some places along the traverse. This is simply due to the images not covering every meter of the traverse. The one and only example of a correlation between an image and the Sol 86-102 radargram can be seen on Figure 27 from Section 4.3. Though this example is based on a great deal of uncertainty, due to a simple reason – a lack of imagery from Mastcam-Z, HAZCAM, and NAVCAM in that area covering the rover's traversal path. Only two images: one from Left and one from Right Rear HAZCAM), with the Right Rear image shown in the aforementioned figure, display a good portion of rover tracks. But the precise location on the traversal path and the connection to the feature observed in the radargram is pure speculation. Therefore, this figure has been used as an example in the methods section to give an indication of how the following correlation examples will be presented.

As previously mentioned, only three mosaics will be detailed further as they were the ones that covered features found in the Sol 47-84 radargram and they are the following mosaics: Van Zyl Mosaic, Part 4; Van Zyl, Adziilii, Part 7a, and Butler Landing.

The Van Zyl Mosaic, Part 4 from Sol 57, and the Van Zyl, Adziilii, Part 7a from Sol 62 were both taken from the Sol 52 parking spot near Van Zyl Overlook (Figure 40), hence the naming of these mosaics. These two mosaics are a part of a series of mosaics, that together form a 360°, 110mm zoom panorama of the Van Zyl Overlook. This series of mosaics were all taken from Sol 53 to 64 and covers the sequence IDs from 08100 to 08109. The 360° panorama has also been published in the NASA/JPL photo journal on 9/6-2021.

The Van Zyl, Part 4, and Butler Landing mosaics both contain rover tracks (Figure 41 and Figure 45). Whereas the Van Zyl, Adziilii, Part 7a mosaic did not contain rover tracks. This meant that I had to manually try to locate and plot out the traversal path based on parking spot imagery taken from HAZCAM and NAVCAM, in order to draw it in on the Sol 62, Van Zyl, Adziilii, Part 7a mosaic itself (Figure 43).

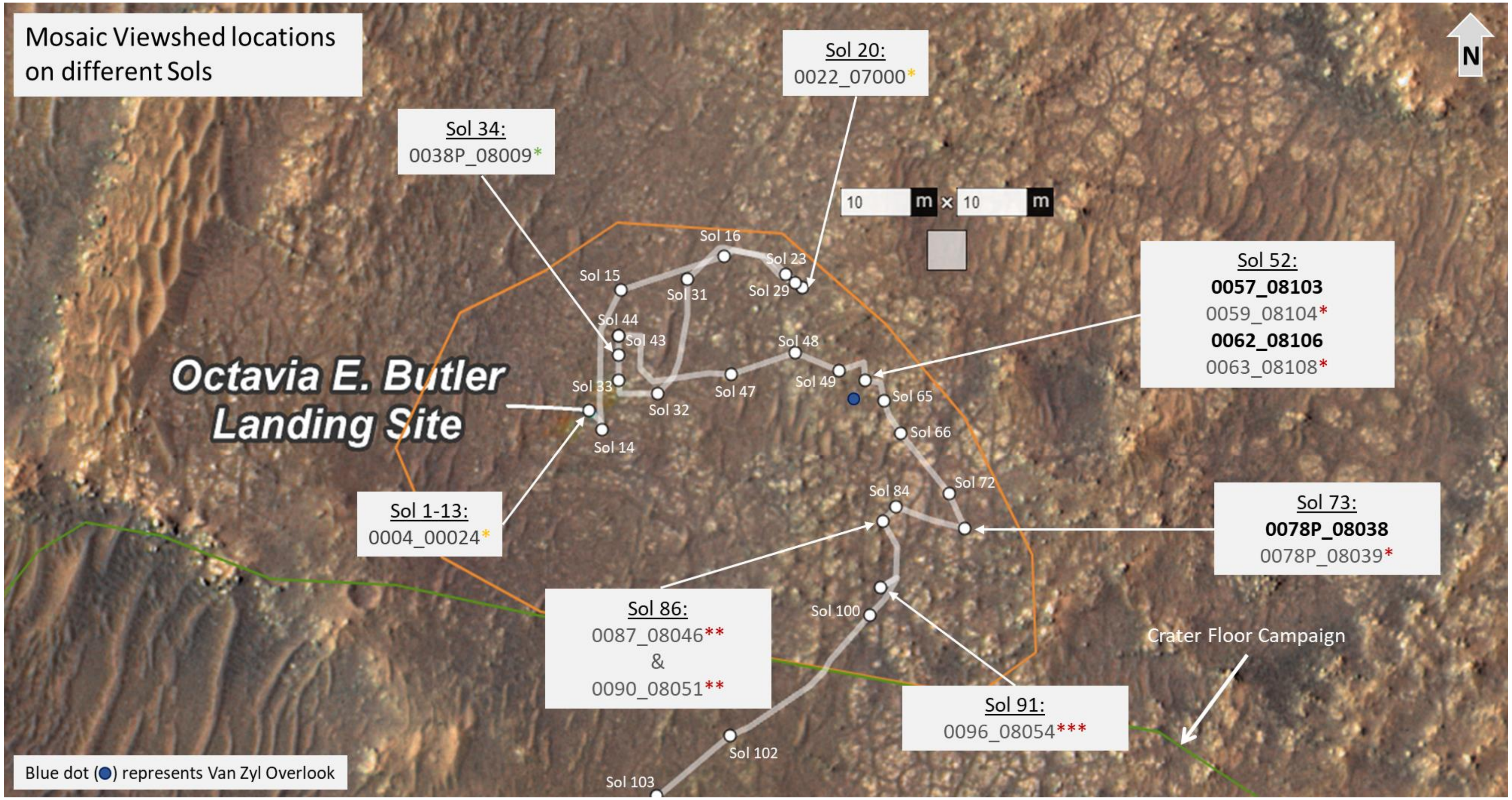
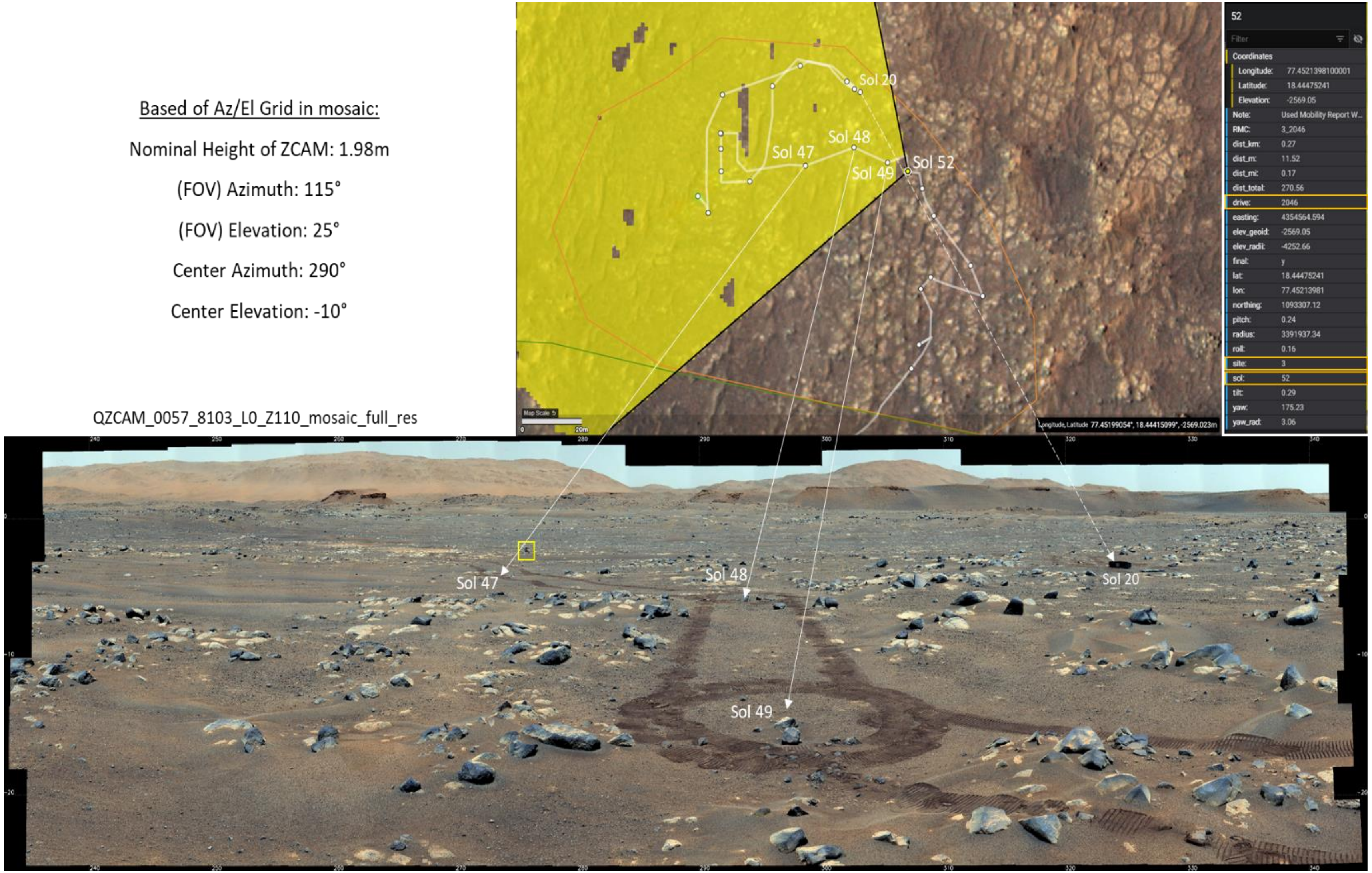


Figure 40. **A map overview of all the 11 mosaics and their respective viewshed locations for visual clarity within Sol 1-102. Note that the Crater Floor Campaign starts between Sol 100 and Sol 102 and that all mosaics after Sol 78 Butler Landing mosaic are not in use due to either being (**) weirdly stitched together or (***) simply too far away to make out the Rover Traverse path.**

Van Zyl Mosaic, Part 4 (Sol 57, Seq. ID 08103)

The mosaic itself as well as its viewshed is shown on Figure 41. The viewshed shows that the mosaic itself covers the rover traverse all the way from Sol 1 to just past Sol 49 and should be visible on the mosaic. I was however only able to ascertain the locations of the Sol 47, 48, and 49 parking spots the mosaic with confidence, as well as Sol 20 due to the bellypan. One of the only notable features in the Sol 47-84 is a 6 m long, high-density bulge at the surface, reaching from the surface and down to just above the -2556 m mark. It is located between the Sol 49 parking spot and Sol 52 parking spot. This feature is also clearly visible on the mosaic – it looks like a small mound in the middle of the drive path. It has been highlighted in the radargram as well as the mosaic itself and a left-eye NAVCAM image from Sol 52 (Figure 42). There also seems to be some more pronounced layering/structure further below it, between -2559 m and -2564 m.



Coordinates
Longitude: 77.4521398100001
Latitude: 18.44475241
Elevation: -2569.05
Note: Used Mobility Report W...
RMC: 3_2046
dist_km: 0.27
dist_m: 11.52
dist_mi: 0.17
dist_total: 270.56
drive: 2046
easting: 4354564.594
elev_geoid: -2569.05
elev_radii: -4252.66
final: y
lat: 18.44475241
lon: 77.45213981
northing: 1093307.12
pitch: 0.24
radius: 3391937.34
roll: 0.16
site: 3
sol: 52
tilt: 0.29
yaw: 175.23
yaw_rad: 3.06

<u>Based of Az/El Grid in mosaic:</u>

Nominal Height of ZCAM: 1.98m

(FOV) Azimuth: 115°

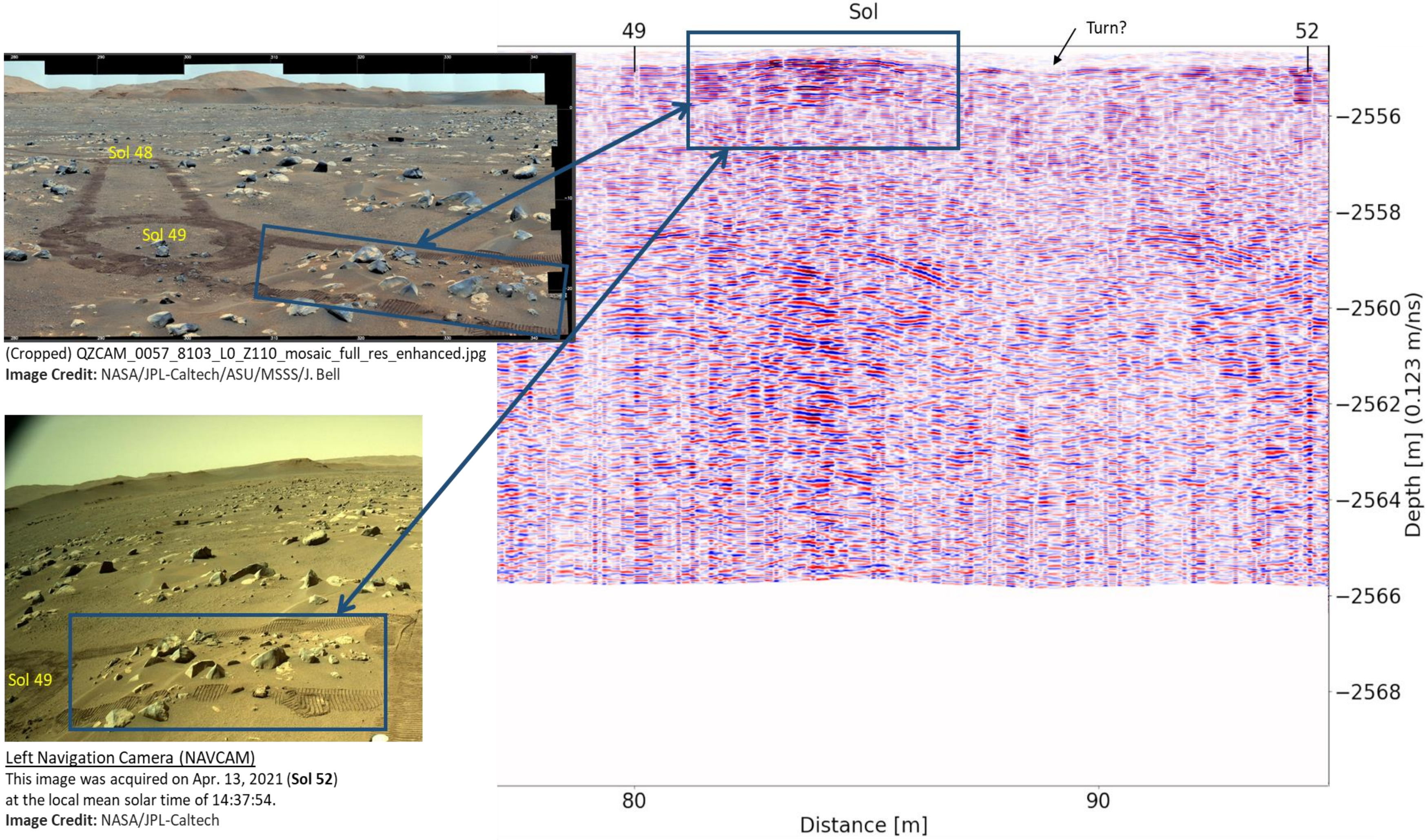
(FOV) Elevation: 25°

Center Azimuth: 290°

Center Elevation: -10°

QZCAM_0057_8103_L0_Z110_mosaic_full_res

Figure 41. Sol 57, Van Zyl Part 4 mosaic (bottom) and its estimated Az/El parameters followed by the viewshed itself (left & middle). The Sol 52 parking spot info from CAMP is on the right side of the viewshed. The white arrows point to the estimated Sol parking spots. The belly pan drop site from Sol 20 (dashed line) and Ingenuity itself (yellow box) has also been marked out for fun.



(Cropped) QZCAM_0057_8103_L0_Z110_mosaic_full_res_enhanced.jpg
Image Credit: NASA/JPL-Caltech/ASU/MSSS/J. Bell

Left Navigation Camera (NAVCAM)
This image was acquired on Apr. 13, 2021 (**Sol 52**)
at the local mean solar time of 14:37:54.
Image Credit: NASA/JPL-Caltech

Figure 42. Cropped part of the Sol 47-84 radargram showing a large high-density feature at the surface of the rover traverse. This has been correlated to a small hill along the rover traverse between Sol 49 and 52. This small is indicated with blue arrows between the rectangles on both the radargram, the cropped Sol 57 mosaic and a left NAVCAM image from Sol 52.

Van Zyl, Adziilii, Part 7a (Sol 62, Seq. ID 08106)

The mosaic and its viewshed is shown on Figure 43. The viewshed indicates that the future parking spots of Sol 66, 72, 73, 84, 88, 91, 100, and 102 spots should be visible. By browsing the catalogue of HAZCAM and NAVCAM images, I was able to pinpoint the following parking spots on the mosaic: Sol 66, 72, 73, and 84. I was unable to accurately pinpoint the parking spots following Sol 84, due to the distance from Sol 62. My parking spot identification attempts are shown in appendix 5.3c, where I correlated at least three rocks between the Van Zyl, Adziilii, Part 7a mosaic and NAVCAM images from their respective Sol parking spots.

On the Sol 47-84 radargram, there is a 0.5-meter thick, high-density feature, stretching 4.7 meters at right at the surface on the Sol 66 parking spot (Figure 44). A rear HAZCAM image shows what looks to be pavers covered with a light layer of sand (red circle) between some exposed pavers further behind the rover and one singular isolated rock (red arrows), which I have interpreted to be a sort of exposed paver as well. This isolated rock was also found the Sol 62 mosaic and is shown here with a blue arrow between the rock on the rear HAZCAM image and a cropped image of Sol 62 mosaic.

<u>Based of Az/El Grid in mosaic:</u>

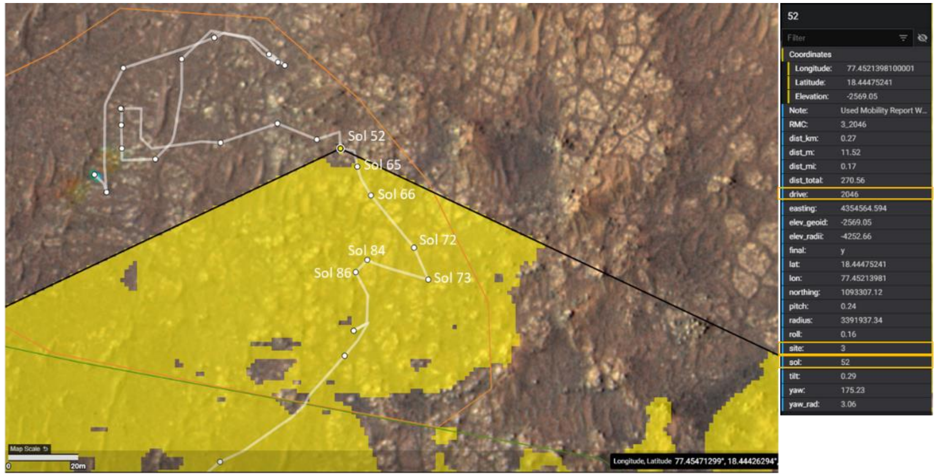
Nominal Height of ZCAM: 1.98m

(FOV) Azimuth: 130°

(FOV) Elevation: 24°

Center Azimuth: 180°

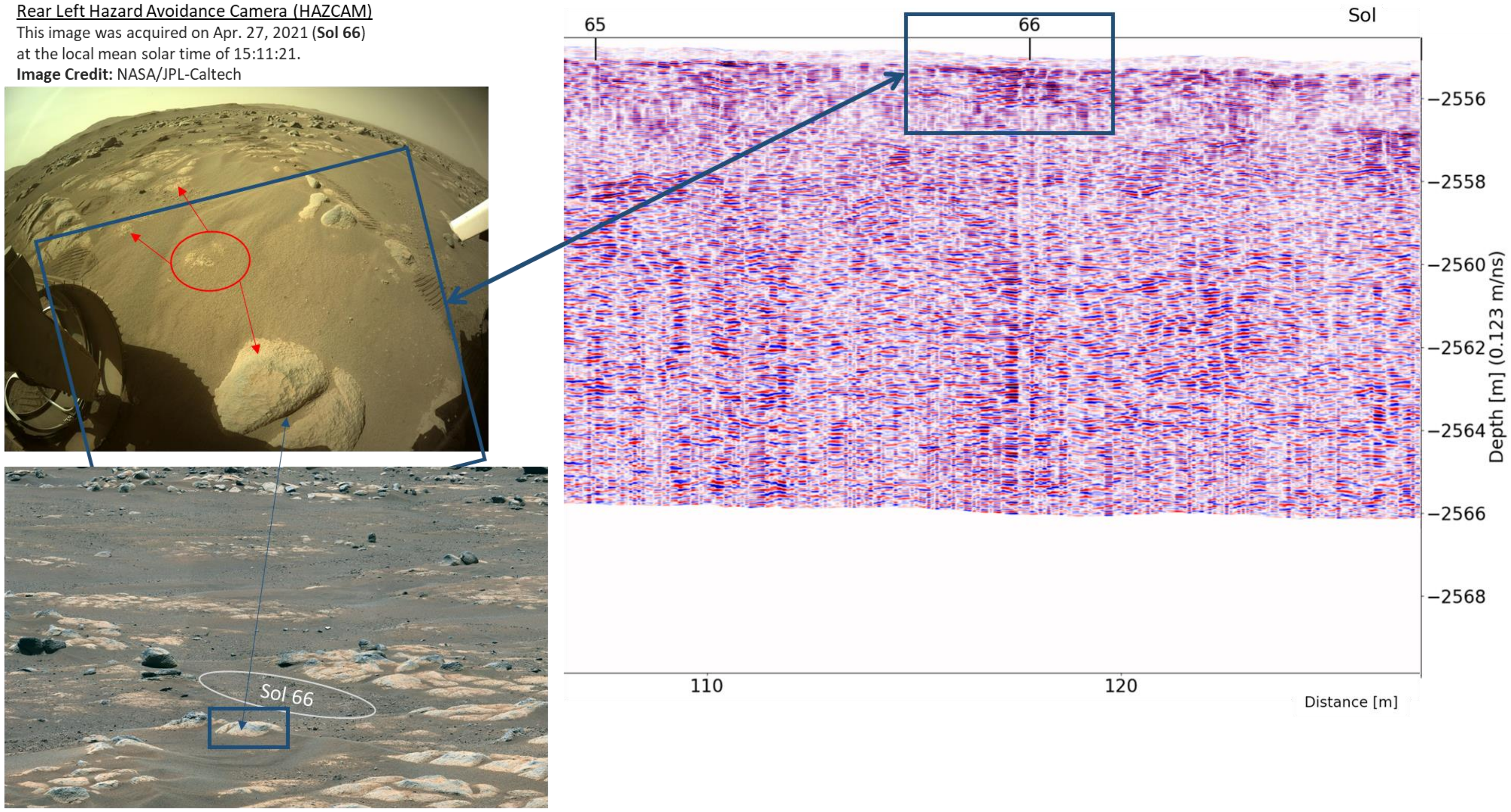
Center Elevation: -7°



Coordinates
Longitude: 77.4521398100001
Latitude: 18.44475241
Elevation: -2569.05
Note: Used Mobility Report W...
RMC: 3_2046
dist_km: 0.27
dist_m: 11.52
dist_mi: 0.17
dist_total: 270.56
drive: 2046
easting: 4354564.594
elev_geoid: -2569.05
elev_radii: -4252.66
final: y
lat: 18.44475241
lon: 77.45213981
northing: 1093307.12
pitch: 0.24
radius: 3391937.34
roll: 0.16
site: 3
sol: 52
tilt: 0.29
yaw: 175.23
yaw_rad: 3.06

QZCAM_SOL0062_ZCAM08106_L0_Van_Zyl_part7a_Z110_E01

Figure 43. The Sol 62, Adziilii, Part 7a mosaic is shown on the bottom with a rough estimation of the rover traversal path from Sol 62 and onwards to Sol 84. This was estimated and plotted by me through the use of various HAZCAM and NAVCAM images from the parking spots Sol 66, 72, 73 and 84 and correlating to the Sol 62 mosaic itself. The parking spot info for Sol 62, alongside the mosaics viewshed and viewshed parameters based on the Az/El gridlines is also seen here (right to left).



Rear Left Hazard Avoidance Camera (HAZCAM)
This image was acquired on Apr. 27, 2021 (**Sol 66**)
at the local mean solar time of 15:11:21.
Image Credit: NASA/JPL-Caltech

QZCAM_SOL**0062**_ZCAM08106_L0_Van_Zyl_part7a_Z110_E01

Figure 44. Cropped part of the Sol 47-84 radargram (right) and the Sol 66 rear left HAZCAM image (left) with a higher-density feature near the surface highlighted here with a blue rectangle. This feature has been interpreted as correlating with the area marked on the HAZCAM image (indicated with the blue arrow between the radargram and image) and the Sol 62, Adziilii, mosaic. The red circled rock on the HAZCAM image is assumed to be a paver that is covered with a thin layer of sand that is an extension of the exposed pavers in the mid-left of the image as well as the isolated rock in the bottom of the self-same image (highlighted here with red arrows from the circle to the rocks). The isolated rock in the bottom of the HAZCAM image has also been located in the Sol 62, Adziilii mosaic, which is shown here with the small blue arrow between the said rock on both the images.

25-pointing Butler Landing Mosaic (Sol 78, Seq. ID 08038)

The mosaic and its viewshed is show on Figure 45. All the parking spots from Sol 1 to 66 are supposedly visible on this mosaic according to its viewshed, but I was only able to determine Sol parking spots 20, 47, 49, and 66 with a certain accuracy. The Sol 20 parking spot is easy to distinguish due to it being the belly pan drop site.

On this specific rover traverse I tried pinpointing what amounted to pavers on the mosaic in the radargram. Two clear paver areas can be seen between the Sol 66 and Sol 72 parking spot and has been correlated to the Sol 47-84 radargram (Figure 46). No NAVCAM or HAZCAM image has been found to correlate to this area and such these pavers have only been marked onto the mosaic with their own blue box and arrows pointing to them from the radargram. The pavers closest to the Sol 66 parking spots covers around 5 meters of the rover traverse, with the following pavers covering 4-4.5 meters of the traverse. The paver expressions in the radargram are not as prominent compared to the likes found on the Sol 62 mosaic as is seen on Figure 44.

Despite only having been provided with 2 preliminary radargrams containing only surface and shallow modes, a lot of different density features were visible – both near the surface as well as deeper. I have tried covering a few of these in the mosaics that I had available.

Although the lack of localization imaging (both ZCAM and ECAM alike) made the task of correlating, at least the surface features, very difficult.

An observation of note is that the pavers seem to have varying expressions in the radargrams – some are quite pronounced (Figure 44) and others much less (Figure 46). An explanation for this could be erosion and/or weathering influencing the density (e.g., an increase in pore space). This in turn reduces the density and permittivity of the rock, making the expression of the rock less pronounced on the radargrams.

Based of Az/El Grid in mosaic:

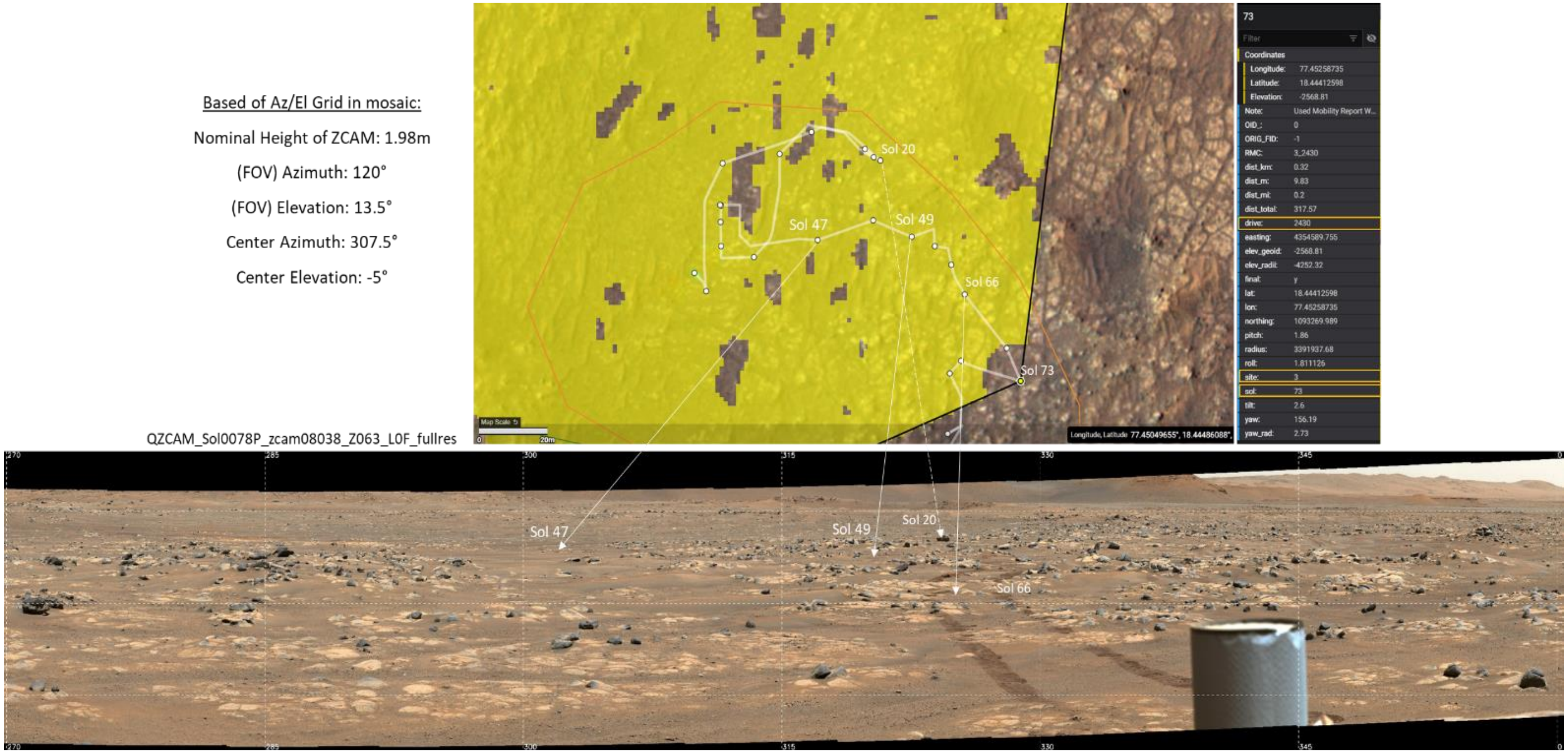
Nominal Height of ZCAM: 1.98m

(FOV) Azimuth: 120°

(FOV) Elevation: 13.5°

Center Azimuth: 307.5°

Center Elevation: -5°



73

Coordinates	
Longitude:	77.45258735
Latitude:	18.44412598
Elevation:	-2568.81
Note:	Used Mobility Report W...
OID_:	0
ORIG_FID:	-1
RMC:	3_2430
dist_km:	0.32
dist_m:	9.83
dist_mi:	0.2
dist_total:	317.57
drive:	2430
easting:	4354589.755
elev_geoid:	-2568.81
elev_radii:	-4252.32
final:	y
lat:	18.44412598
lon:	77.45258735
northing:	1093269.989
pitch:	1.86
radius:	3391937.68
roll:	1.811126
site:	3
sol:	73
tilt:	2.6
yaw:	156.19
yaw_rad:	2.73

Figure 45. Sol 78 Butler Landing mosaic (bottom) alongside it's viewshed and Az/El parameters (middle & left). The parking spot info for Sol 73 from CAMP is also shown on the right. Estimated locations of the rover parking spots are highlighted with white arrows. Note that this mosaic has been cut about ~25 degrees Az of the grid lines on the left side of the mosaic and about ~5 degrees on the right side. This is because that part of the mosaic doesn't include anything relevant to my work, as well as making this figure's size proportions more balanced.

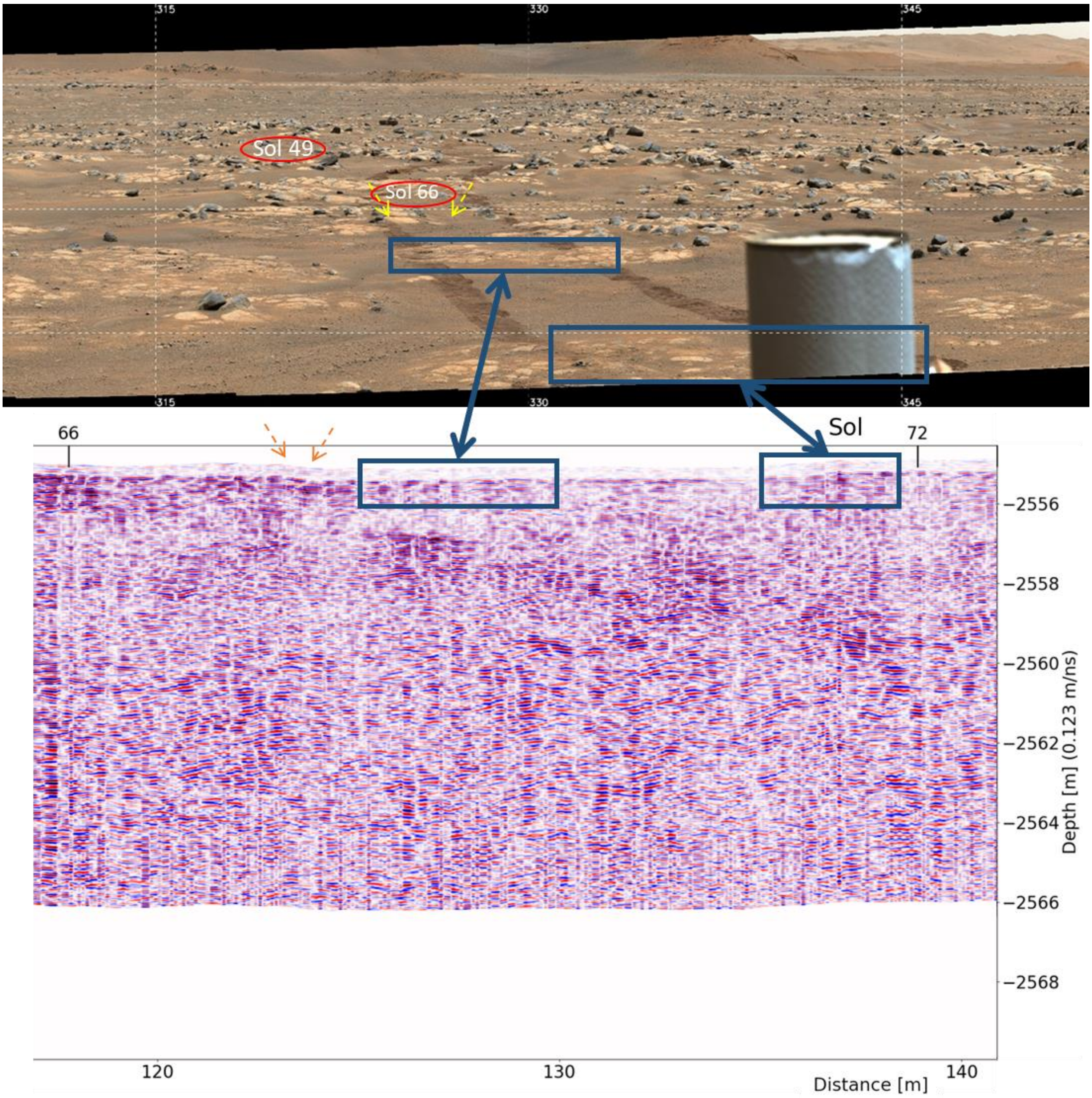


Figure 46. Cropped part of the Sol 78 Butler Landing mosaic and Sol 47-84 radargram with Sol Parking Spots 49 & 66 marked in with a red circle. The two yellow arrows on the mosaic are connected to the two orange arrows on the radargram and highlight a small downwards dip on the rover traversal path. The two blue boxes highlight features on the radargram that each have been interpreted as two sets of pavers. Both of these paver sets are visible on mosaic.

6 Discussion

In this section, I will cover some of my results from my shift work alongside the mosaic and radargram correlations that I have made in order to supplement my work done in the remapping effort. I will then tie in some of these results into the general observations and theories from the science team and from pre-landing articles.

At landing, the science team decided on some general classifications of the observed rocks near the landing area. They are as follows: “Pavers” are light-toned rocks with a low relief and skyward facing surfaces (Figure 44 from Section 5.3). “Massive” rocks are large, upright standing, dark-toned rocks, which display no clear internal structuring (Figure 24 from Section 4.3). “Pitted” rocks are dark-toned rocks and vary in size from small to large, mostly characterized by pockmarks in the rocks surface (Figure 36, Square #2 from Section 5.1.3). Great close-up examples of a “Massive” and a “Pitted” rock are shown in appendix 6a as there are not any such examples of these specific rock types in my own results. There is one more classification, which was added later – so called “Layered” rocks but they are only found in Séítah.

These were found close to the boundary between CF-Fr and Séítah, and, as the name suggests, show clear evidence of layering in the rock itself. One should note though that many of these rocks are actually transitional between the set rock classifications. With these in mind, I will look at the work done in the remapping effort and try to correlate these rock classifications with the units we have established.

It is quite clear, that the “Paver” rocks are equivalent to the unit titled Fractured Polygonal. “Massive” rocks could be correlated to the Fractured Rubbly unit, based on the distribution of said rocks, where a large, packed collection of “Massive” rocks would provide very recognisable relief from orbit. “Pitted” rocks do not really seem to fit into any of the established geological units from the remapping effort, and they sometime show up as transitional between both “Pavers” and the “Massive” rocks. Isolated incidents of both “Massive” and “Pitted” rocks are also found interspersed and/or embayed in the Undifferentiated Smooth and Fractured Polygonal units.

Figure 47 shows a close-up of the rover traversal from landing to Sol 102 and is from the final draft map found in appendix 6b. Here we can see that the traversal from Sol 48 to just past Sol 91 is on the Fractured Polygonal unit. This is consistent with what we see on the mosaics and radargrams covering that area. Figure 43 and Figure 45 shows clear “Pavers” in both mosaic and radargram from Section

5.3 with "Massive" and "Pitted" rocks spread throughout the landscape. Confirming that the Fractured Polygonal unit is very distinct in both satellite imagery (Figure 23, example C from Section 4.2) and also in surface images.

The Undifferentiated Smooth (Us) unit is the flat and tough regolith that is spread in between "Pavers" and "Massive" rocks. It has no clear characteristics, either in the radargrams or the mosaics. On orbital imagery the unit is characterized by its smooth, expansive coverage, and intermittent occurrences between the other established units at the 1:2500 scale (Figure 38, example B from Section 5.2), and its HCP signature (Figure 5b). In Stack *et al.*, 2020's work, the Undifferentiated Smooth unit has been mapped as the closest unit in the Octavia E. Butler landing site to Séítah, which is the same as the remapping effort (Figure 47). The mapped extent of the Us unit is the same between Stack *et al.*, 2020's map and the final map from the remapping effort.

The Séítah unit is quite distinguishable from orbit. It appears much more low lying compared to CF-Fr and contains an abundance of aeolian bedforms of all shapes and sizes (Figure 1, B and C). In the remapping effort it has been characterized as containing two inlier units: Inlier Resistant and Inlier Flagstone, to further detail the geological differences in the unit. In Stack *et al.*, 2020 the area is simply noted as Cf-f-1 in the lower lying parts of the crater and as Cf-f-2 in the higher elevation parts that are closer to the crater rim. Aeolian bedforms are also noted as prevalent in the area. The Séítah unit displays a very strong olivine signature in the CRISM orbital imagery (Figure 5b), which strongly indicates an igneous origin of some kind.

The delta units are much more detailed in Stack *et al.*, 2020 compared to the work done in the remapping effort, as our focus was on the crater floor itself for the first part of the M2020 Mission. The delta units (both the western delta fan and eastern delta remnants) themselves exhibit a strong LCP signature on the CRISM orbital imagery and are easy to discern in surface images (Figure 33, features H1, H2, H3") from Section 5.1.3 and normal satellite images (appendix 5.1.3a).

The only major difference is that the remapping effort has divided the Cf-fr unit from Stack *et al.*, 2020 into three different subdivisions: Fractured Rubbly, Fractured Polygonal, and Fractured Fragmented. Since Stack *et al.*, 2020 hasn't subdivided Cf-fr, it makes sense that they have mapped the area just to the east of the landing site as mostly just Cf-fr (Figure 47), whereas the remapping effort has mapped both Fractured Polygonal and Fractured Rubbly with some Aeolian Bedforms interspersed between them. One should keep in mind, that these subdivisions may just be different erosional expressions of the same rock or different sedimentary facies with intrinsic erosional properties, which could support the theory of a long history of aqueous alteration in Jezero Crater.

It seems that the Fractured Rubbly unit is almost non-existent in the area between the western delta fan and eastern delta remnants (appendix 6a). It only shows up in the south-eastern parts of our mapping area and has a slight LCP signature on orbital CRISM imagery (Figure 5b). This may indicate that this specific expression has some sort of connection to the western delta fans extent, showing up only in areas that are presumed to not have been covered by the delta in the past.

It has also been noted that rocks found in what is characterized as CF-Fr exhibit flow textures, pits and pit chains which is consistent with a lava flow/igneous origin (Farley *et al.*, 2022 - To be published; Bell *et al.*, 2022 - To be published).

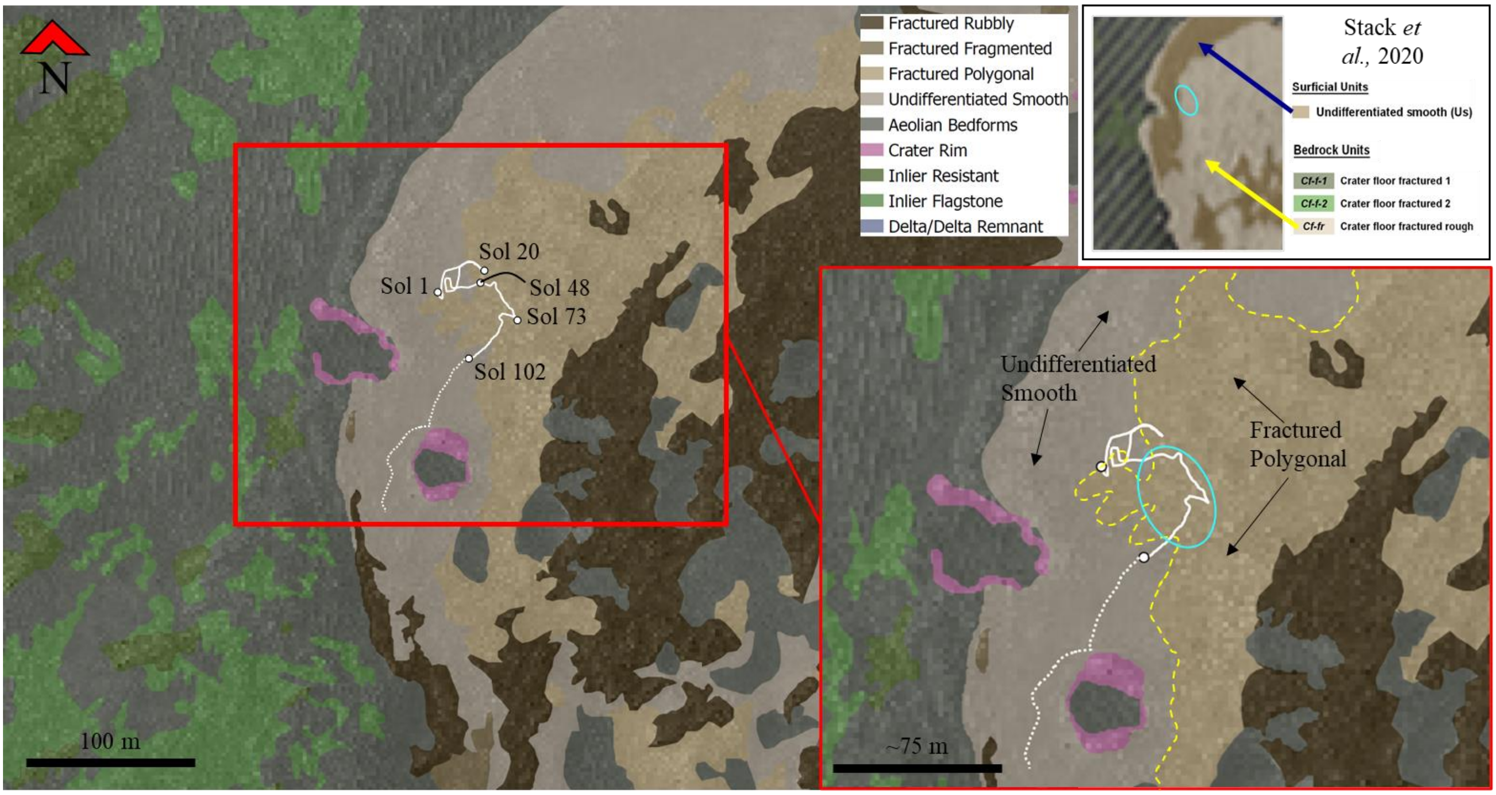


Figure 47. Rover traversal path from Sol 1 to 102 overlain the finished geological map from the remapping effort. The red box shows the boundary (yellow dotted line) between the Undifferentiated Smooth and Fractured Polygonal units. Note that the majority of the traversal path from Sol 48 to just past Sol 91 is on the Fractured Polygonal unit (marked with an aquamarine ring). A small snippet of Stack et al., 2020 photogeological map is also seen in the top right corner, pointing out what has been mapped as Cf-fr (brown) and Us (light grey) in their work. The aquamarine ring is there to show the approx. location of the area marked on the zoomed image just below. The grey colour here represents Aeolian Bedforms.

CF-Fr's composition and origin, whether sedimentary or igneous, was heavily debated in pre-landing papers and even through most of the early discussions among the science team of the Mars 2020 Mission. The science team has finally come to somewhat of a consensus that based on mineralogy, texture, and bulk composition, that CF-Fr is most consistent with a primary igneous (Farley *et al.*, 2022 - To be published; Bell *et al.*, 2022 - To be published). With Séítah displaying an olivine and

Fe-carbonate multispectral signature and CF-Fr exhibits HCP signatures – these signatures are seen in both orbital imagery and surface observations across multiple instruments. With Séítah being slated as possibly the deepest and oldest geological unit exposed in Jezero Crater. Séítah is topographical low and highly eroded, which aligns with the presence of olivine as olivine is less resistant to erosion in low pressure environments. Albeit the origin of Séítah could be everything from a lava flow, a lava lake, impact melt sheet, or a sill. While the CF-Fr unit displays high-calcium pyroxene (HCP) signatures, the Us unit does as well. An explanation for this is that the Us unit could be interpreted as erosional lag derived from CF-Fr and acts as a regolith layer mantling CF-Fr and most of the crater floor besides Séítah. This would also explain why the Us unit also exhibits LCP signatures when near delta deposits, as mixture of erosional delta regolith and Us would produce a reduce response of HCP.

Figure 5b also shows a clear area between the western delta fan and eastern delta remnants, which show high response of HCP, while beyond the eastern delta remnants a LCP response can be seen. The area between the delta deposits is interpreted from the remapping effort as composed mostly of the Us unit, with Aeolian Bedforms and small clusters of Fractured Polygonal units. This could correlate back quite well with what is seen in the scenario (Figure 5a) described by Holm-Alwmark *et al.*, 2021. This scenario explains that the western delta fan extended far out into the crater and covered the CF-Fr unit, possibly alongside Us and perhaps preserved the HCP signature of the units. The exact origin point of CF-Fr is still under debate, although some have pointed to an unnamed possibly volcanic edifice that is visible to the SE rim of Jezero Crater. It can be seen from orbit on Figure 1 (A) from the Section 1 but is also visible from the ground in the Sol 4 360° panorama as the large shape on the horizon, titled feature (J) in Figure 34. I believe it has similarities to Mt. Saint Helens, which erupted back in 1980 and formed a horseshoe crater. The edifice on the crater rim has a similar shape, facing towards the south, although erosion has reduced the expression since time of last activity. The debris avalanche and later lava flow could have flowed out from there and propagated west and flowed into the crater due to topographical differences. Therefore, I believe this edifice might be the igneous origin point of CF-Fr or at least could have played a major part in contributing to the CF-Fr lava flow.

Below I describe my own theory as to the origins of CF-Fr. It is heavily inspired by the scenario proposed by Holm-Alwmark *et al.*, 2021 shown in Figure 5a as well as based on the observations made in the discussion section:

CF-Fr is lava from the unnamed, potentially volcanic edifice located on the SE rim of the Jezero Crater. This volcano erupted sometime before the deposition of the western delta fan far into the crater, in a period of no water in the crater and deposited CF-Fr as an extensive lava plain on the crater floor. CF-Fr overlays the remains of the older olivine-enriched geological unit of Séítah. Séítah is exposed over time by the gradual erosion of the overlaying weathering resistant CF-Fr. Us is a possible erosional regolith lag from the resistant CF-Fr and mantles the CF-Fr unit. Us exhibits HCP signatures further away from the delta fan and delta remnants but an increased LCP signature closer to the delta deposits, which is probably caused by mixing of the delta regolith and Us regolith.

The delta deposits are the youngest in this series and covers CF-Fr and Us. At some point in time the delta fan extended far into the crater – as far as, or even further beyond the eastern delta remnants. The clear HCP signature of Us between the western delta fan and eastern delta remnants further supports the coverage theory.

However, this is a very simple explanation to what seems like a very complex geological area and more investigations are needed by the *Perseverance* rover in order to reach a more solid explanation.

7 Conclusion

As stated in the introduction, my thesis will cover the mission from landing to Sol 130. As it is in this period, that I attended sPDL shifts and contributed to the geological remapping effort. Also, the two RFAX radargrams that I was provided only cover the traverse from Sol 47 to 102 and I therefore only looked at ZCAM imagery from these Sols.

This means, that due to the ever-evolving nature of this mission, much of the terminology presented here is already partial outdated, whereas the hypotheses are constantly being developed and refined. For example, more detailed stratigraphic relationships have since been developed. CF-Fr (now dubbed Máaz Fm) has been divided into several members based on the lithostratigraphic classifications and the Séítah Fm has been divided into two members. All the members are named after targets encountered throughout the course of the M2020 Mission. Several samples have also been taken for the planned future Sample Return Mission by the end of this decade alongside investigated abraded patches of the sampled rocks for context to these samples.

In this thesis I presented some of the work I have done during the Mars 2020 Mission as a student collaborator on the Mastcam-Z team. As a student collaborator, I attended Mastcam-Z sPDL shifts on tactical downlink, where I manually produced multispectral products and mosaics. I also made a large contribution to how a program, named ASDF, automates the process that I performed during my shifts. It was also normal to present some of the work done during these shifts for the broader science team, as such I helped setup presentations and even presented by myself on some shifts.

My contribution to the geological remapping effort, that builds upon the work of Stack *et al.*, 2020, is also shown here. This geological map is now the reference map that the science team refers to when planning and picking out regions of interest that the rover should drive to. My contribution are two quads to the very north of the mapping area, which covers parts of a crater floor that is in between the western delta fan, a delta remnant (Temple Hill), and a region that shares many similarities to Séítah but is named Gaspé. This is not an area where the rover will drive to but many of the geological units present here such as Undifferentiated Smooth, Fractured Rubbly, Fractured Fragmented (Crater Floor units), as well as Inlier Resistant and Inlier Flagstone (Gaspé/Séítah units), are also seen near the Octavia E. Butler landing site. Another crater floor unit that is not present in my mapping area but is widely distributed near the landing site is the Fractured Polygonal unit. This unit has been linked together with the rock classified as “Pavers”, which is seen in surface imagery as light-toned and low relief, whereas the “Massive” rock classification fits under the Fractured Rubbly unit based on the bulk distribution of said rocks in an area.

The work I have done on correlating surface and subsurface structures in the Jezero Crater floor based on Mastcam-Z mosaic imagery and RIMFAX radargrams is also presented here in this thesis. It was only shallow subsurface observations that could be done, as I was provided with radargrams that only combined the Surface and Shallow modes of RIMFAX. Lack of imagery covering the rover traverse path also made this a challenging process. An observation of note is that the pavers seem to have varying expressions in the radargrams, with some being quite distinct (strong expression) and others much less pronounced (weak expression). Erosion and/or weathering could be the cause of this, as it would influence the density (e.g., an increase in pore space) of the rock. Thus, reducing the overall density and therefore permittivity of the rock, which would produce a weak expression on the radargrams. One interpretation is that the pavers could have a varying degree of “pittedness” and as such, correlate to the “Pitted” rocks (and perhaps even the “Massive” rocks) of the landing site in a way that indicates that the rock classifications are transitional between each other.

A preliminary conclusion based on the findings presented in the discussion section is that the most dominating geological units of Jezero Crater are Séítah and CF-Fr (Máaz Fm). Both of these units have an igneous origin, albeit from different compositional melts – Séítah being more olivine-rich and CF-Fr being more high-calcium pyroxene (HCP) rich. CF-Fr is lava that was erupted from the unnamed, potentially volcanic edifice located on the SE rim of the Jezero Crater in a period where no water was present in the crater. CF-Fr was therefore deposited as an extensive lava plain on the crater floor, overlaying the remains of the older olivine-enriched geological unit of Séítah. Séítah is exposed over time by the gradual erosion of the overlaying weathering resistant CF-Fr. Us is a possible erosional regolith lag from the resistant CF-Fr and mantles the CF-Fr unit. Us exhibits HCP signatures further away from the delta fan and delta remnants but an increased LCP signature closer to the delta deposits, which is probably caused by mixing of the delta regolith and Us. And therefore, the origin of CF-Fr provides the first step in gaining an understanding of the complex geological history of Jezero Crater.

Perseverance has been on Mars for a total of 350 Sols (as of 13/2-2022) and it still has around 319 more Sols left of its prime mission. As previously mentioned, *Perseverance* shares many of its major components with MSLs *Curiosity*. MSLs prime mission was set to last one Mars year and the *Curiosity* rover continues to operate on Mars to this day even after 3385 Sols (equivalent to 9.5 Earth years, or 5 Mars years). Therefore, we can expect, if nothing goes majorly wrong, that the *Perseverance* rover will carry on for just as long and continue to add to our knowledge of Jezero Crater on Mars in the years to come.

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NASA (3) – Mars Exploration Rover Mission Page by Mars Exploration Program and the Jet Propulsion Laboratory for NASA's Science Mission Directorate (Last updated --; Date viewed 9 July 2021): [https://mars.nasa.gov/mer/]

NASA (4) – Mars Curiosity Rover Mission Page by Mars Exploration Program and the Jet Propulsion Laboratory for NASA's Science Mission Directorate (Last updated --; Date viewed 9 July 2021): [https://mars.nasa.gov/msl/mission/overview/]

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NASA (6) - Mars 2020 Mission Science Objectives by Mars Exploration Program and the Jet Propulsion Laboratory for NASA's Science Mission Directorate (Last updated --; Date viewed 8 September 2021): [https://mars.nasa.gov/mars2020/mission/science/objectives/]

NASA (7) – Mars Helicopter Tech Demo by Mars Exploration Program and the Jet Propulsion Laboratory for NASA's Science Mission Directorate (Last updated --; Date viewed 1 February 2022): [https://mars.nasa.gov/technology/helicopter/]

NASA (8) – Public news Article: NASA's *Ingenuity* total flight time by Mars Exploration Program and the Jet Propulsion Laboratory for NASA's Science Mission Directorate (Last updated 15 December 2021; Date viewed 28 January 2022): [https://mars.nasa.gov/news/9099/nasas-ingenuity-mars-helicopter-reaches-a-total-of-30-minutes-aloft/]

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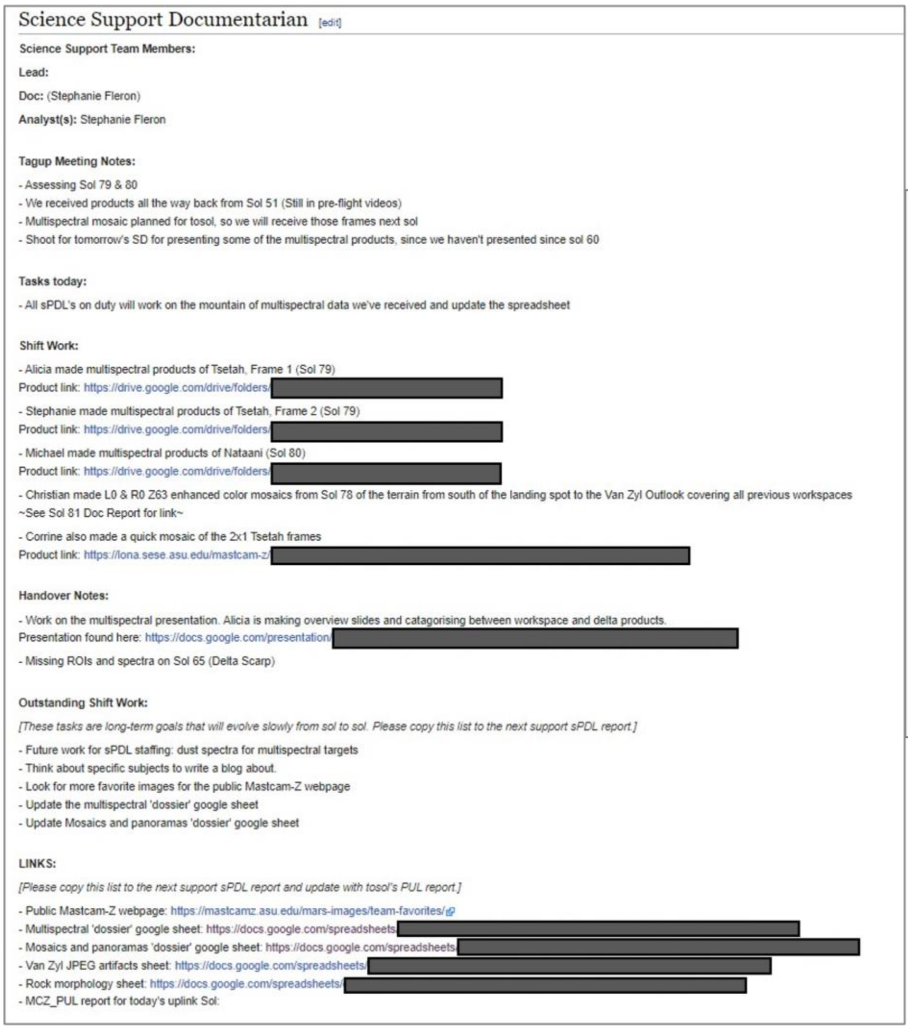
NASA (10) – Public news article: NASA's *Perseverance* Mars Rover Extractis First Oxygen From Red Planet by Mars Exploration Program and the Jet Propulsion Laboratory for NASA's Science Mission Directorate (Last updated 21 April 2021; Date viewed 5 February 2022): [https://mars.nasa.gov/news/8926/nasas-perseverance-mars-rover-extracts-first-oxygen-from-red-planet/]

Appendix

4.1.3a Science Support Document from Sol 80 PDL Report



Science Support Documentarian [edit]

Science Support Team Members:

Lead:

Doc: (Stephanie Fleron)

Analyst(s): Stephanie Fleron

Tagup Meeting Notes:

- Assessing Sol 79 & 80
- We received products all the way back from Sol 51 (Still in pre-flight videos)
- Multispectral mosaic planned for tosol, so we will receive those frames next sol
- Shoot for tomorrow's SD for presenting some of the multispectral products, since we haven't presented since sol 60

Tasks today:

- All sPDL's on duty will work on the mountain of multispectral data we've received and update the spreadsheet

Shift Work:

- Alicia made multispectral products of Tsetah, Frame 1 (Sol 79)
Product link: https://drive.google.com/drive/folders/[redacted]

- Stephanie made multispectral products of Tsetah, Frame 2 (Sol 79)
Product link: https://drive.google.com/drive/folders/[redacted]

- Michael made multispectral products of Nataani (Sol 80)
Product link: https://drive.google.com/drive/folders/[redacted]

- Christian made L0 & R0 Z63 enhanced color mosaics from Sol 78 of the terrain from south of the landing spot to the Van Zyl Outlook covering all previous workspaces
~See Sol 81 Doc Report for link~

- Corrine also made a quick mosaic of the 2x1 Tsetah frames
Product link: https://lona.sese.asu.edu/mastcam-z/[redacted]

Handover Notes:

- Work on the multispectral presentation. Alicia is making overview slides and catagorising between workspace and delta products.
Presentation found here: https://docs.google.com/presentation/[redacted]

- Missing ROIs and spectra on Sol 65 (Delta Scarp)

Outstanding Shift Work:

[These tasks are long-term goals that will evolve slowly from sol to sol. Please copy this list to the next support sPDL report.]

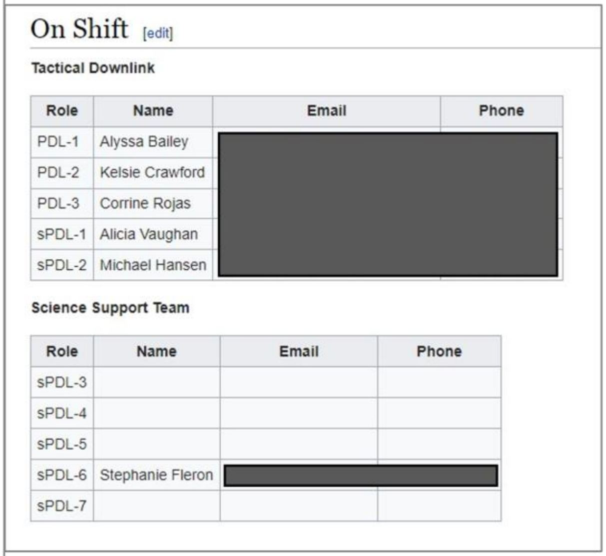
- Future work for sPDL staffing: dust spectra for multispectral targets
- Think about specific subjects to write a blog about.
- Look for more favorite images for the public Mastcam-Z webpage
- Update the multispectral 'dossier' google sheet
- Update Mosaics and panoramas 'dossier' google sheet

LINKS:

[Please copy this list to the next support sPDL report and update with tosol's PUL report.]

- Public Mastcam-Z webpage: https://mastcamz.asu.edu/mars-images/team-favorites/
- Multispectral 'dossier' google sheet: https://docs.google.com/spreadsheets[redacted]
- Mosaics and panoramas 'dossier' google sheet: https://docs.google.com/spreadsheets[redacted]
- Van Zyl JPEG artifacts sheet: https://docs.google.com/spreadsheets/[redacted]
- Rock morphology sheet: https://docs.google.com/spreadsheets/[redacted]
- MCZ_PUL report for today's uplink Sol:

Mastcam-Z Wiki
Science Support Document for
the Sol 80 PDL Report



On Shift [edit]

Tactical Downlink

Role	Name	Email	Phone
PDL-1	Alyssa Bailey	[redacted]	[redacted]
PDL-2	Kelsie Crawford	[redacted]	[redacted]
PDL-3	Corrine Rojas	[redacted]	[redacted]
sPDL-1	Alicia Vaughan	[redacted]	[redacted]
sPDL-2	Michael Hansen	[redacted]	[redacted]

Science Support Team

Role	Name	Email	Phone
sPDL-3			
sPDL-4			
sPDL-5			
sPDL-6	Stephanie Fleron	[redacted]	[redacted]
sPDL-7			

Figure 48. Screen dump of the Sol 80 Science Support Document in the PDL Report that I filled out during the shift, as well as two tables showing who was on shift for Sol 80. It lists any important details from the tag-up meeting at shift start as well as tasks to be done tosol and the actual shift work that was carried out. There are also two sections for handing over any unfinished work – both for the following Sols support team and for outstanding work in general. (Black boxes used to cover e-mails and phone numbers as a precaution.)

4.1.3b Natural Colour (L0) image of Tsetah, Sol 79 (Frame 1)

Figure 49. Left-eye natural colour image of Tsetah Sol 79 (Frame 1). Regenerated by me through MERspect for this thesis.

4.1.3c Natural Colour (L0) Mosaic of Tsetah, Sol 79 (Frame 1 & 2)

Figure 50. Left-eye natural colour mosaic image of Tsetah Sol 79 (Frame 1 & 2). Regenerated by me through MERmap for this thesis.

4.1.3d Enhanced Colour Thumbnail product (L0) of Tsetah, Sol 79 (Frame 2)

Figure 51. Left-eye enhanced colour thumbnail product example of Tsetah, Sol 79 (Frame 2) generated by me for this thesis to demonstrate the large variation in resolution quality between the full frames and thumbnails.

4.3a Sol 47-84 & Sol 86-102 radargrams as provided by Hans Amundsen (RIMFAX)

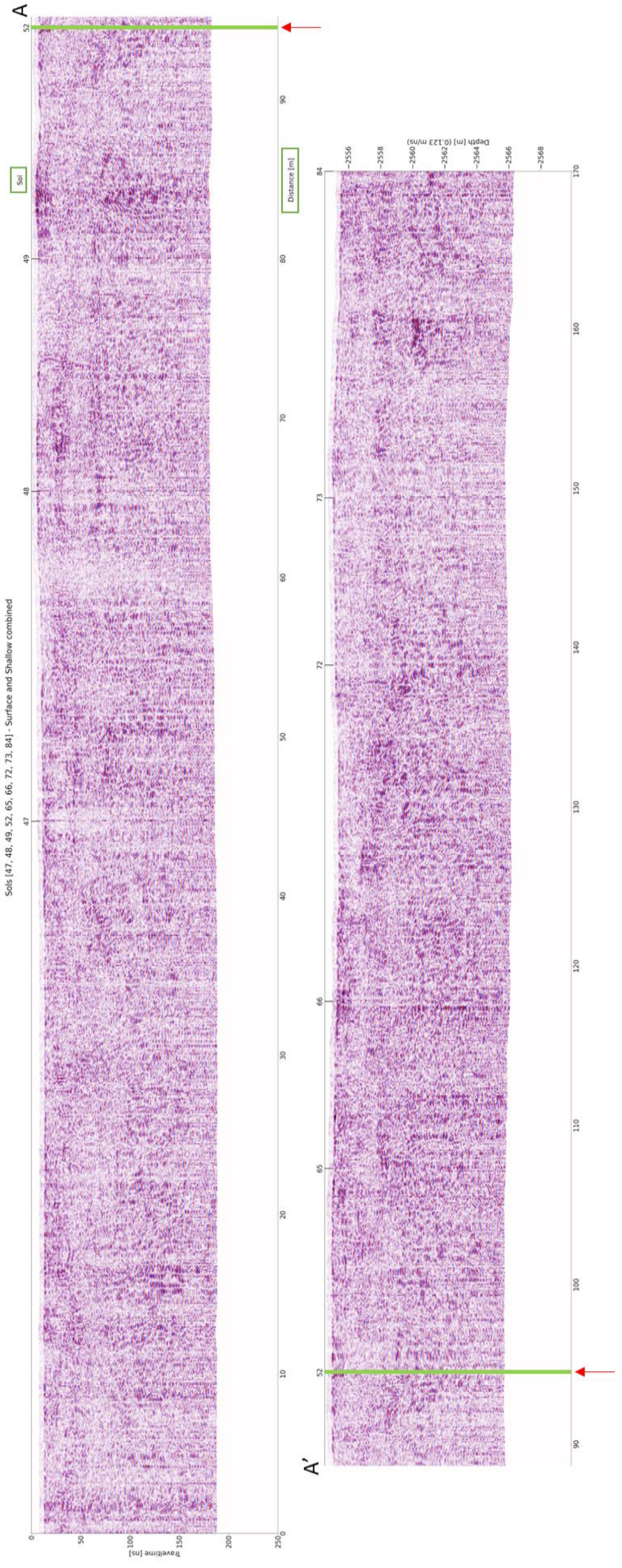


Figure 52. The Sol 47-84 Surface & Shallow combined radargram as provided by Hans Amundsen from RIMFAX. It has been divided into two segments in order to fit onto a normal A4 page. Only modified by me to include the green lines and red arrows on both sections to indicate the overlap between the two sections on Sol 52. Alongside the annotated A and A’, each marking the part of the two sections that go together.

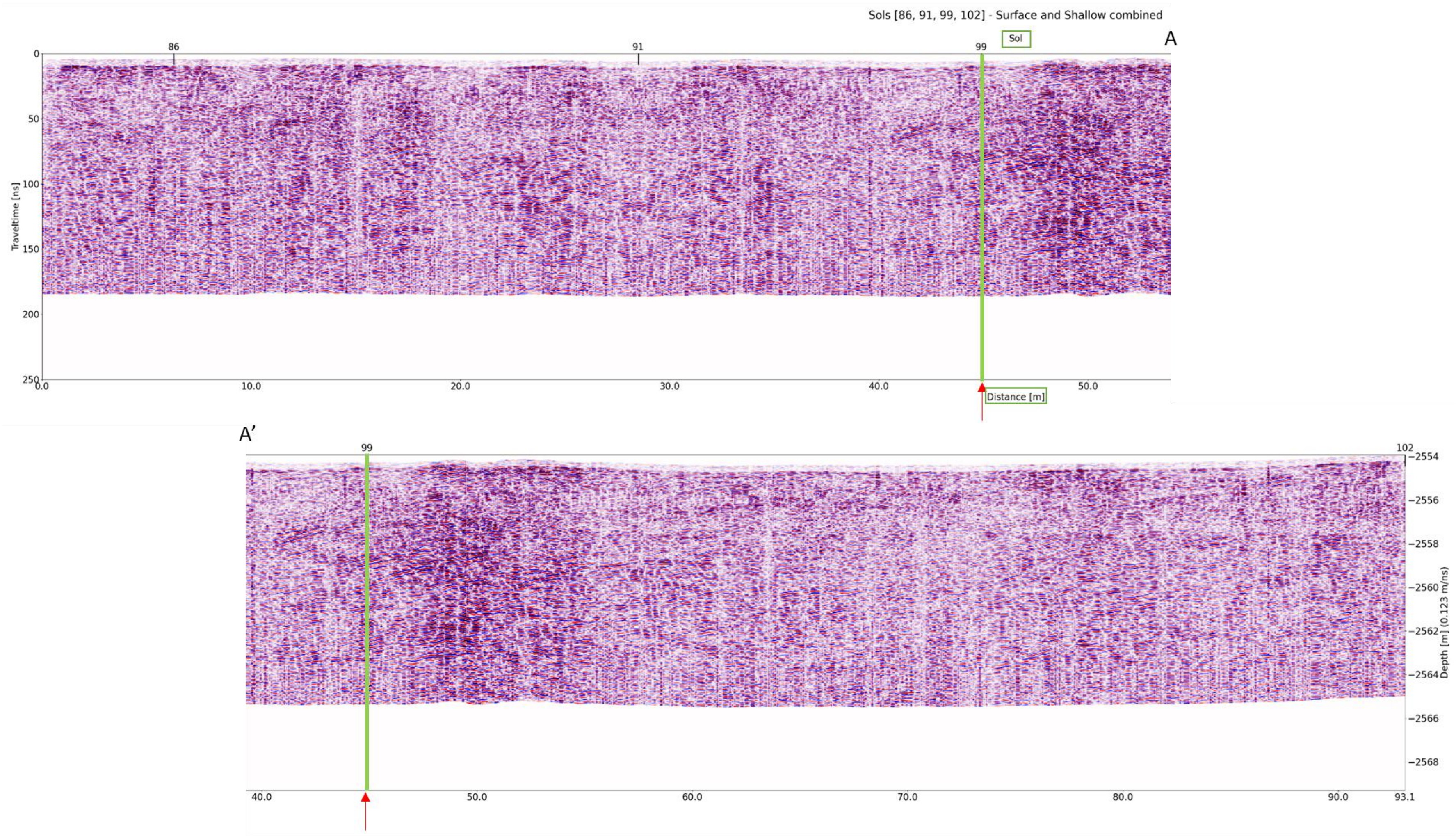


Figure 53. The Sol 86-102 Surface & Shallow combined radargram as provided by Hans Amundsen from RIMFAX. It has been divided into two pieces in order to fit onto a normal A4 page. Only modified by me to include the green lines and red arrows on both sections to indicate the overlap between the two sections on Sol 99. Alongside the annotated A and A’, each marking the part of the two sections that goes together.

5.1.1a My attempts at the 3x3 Heli mosaic

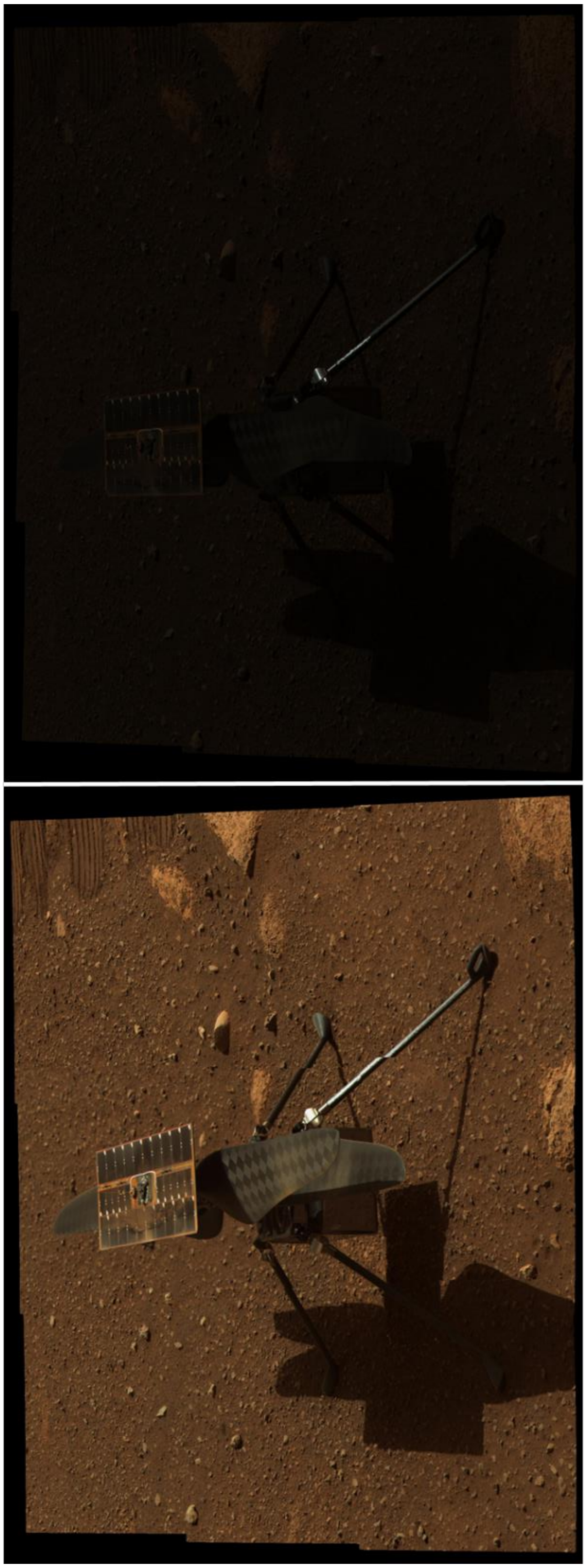


Figure 54. Left image was my first attempt at the 3x3 Heli mosaic and the seams are off near the bottom middle and bottom right frames, as well as the brightness of the image is slightly dimmer than Michael's attempt. The right image is a second attempt after fiddling with the settings with the seams being a lot better, but the brightness is even worse compared to the first attempt.

5.1.3a Satellite image of pinpointed feature locations from the Sol 4 panorama

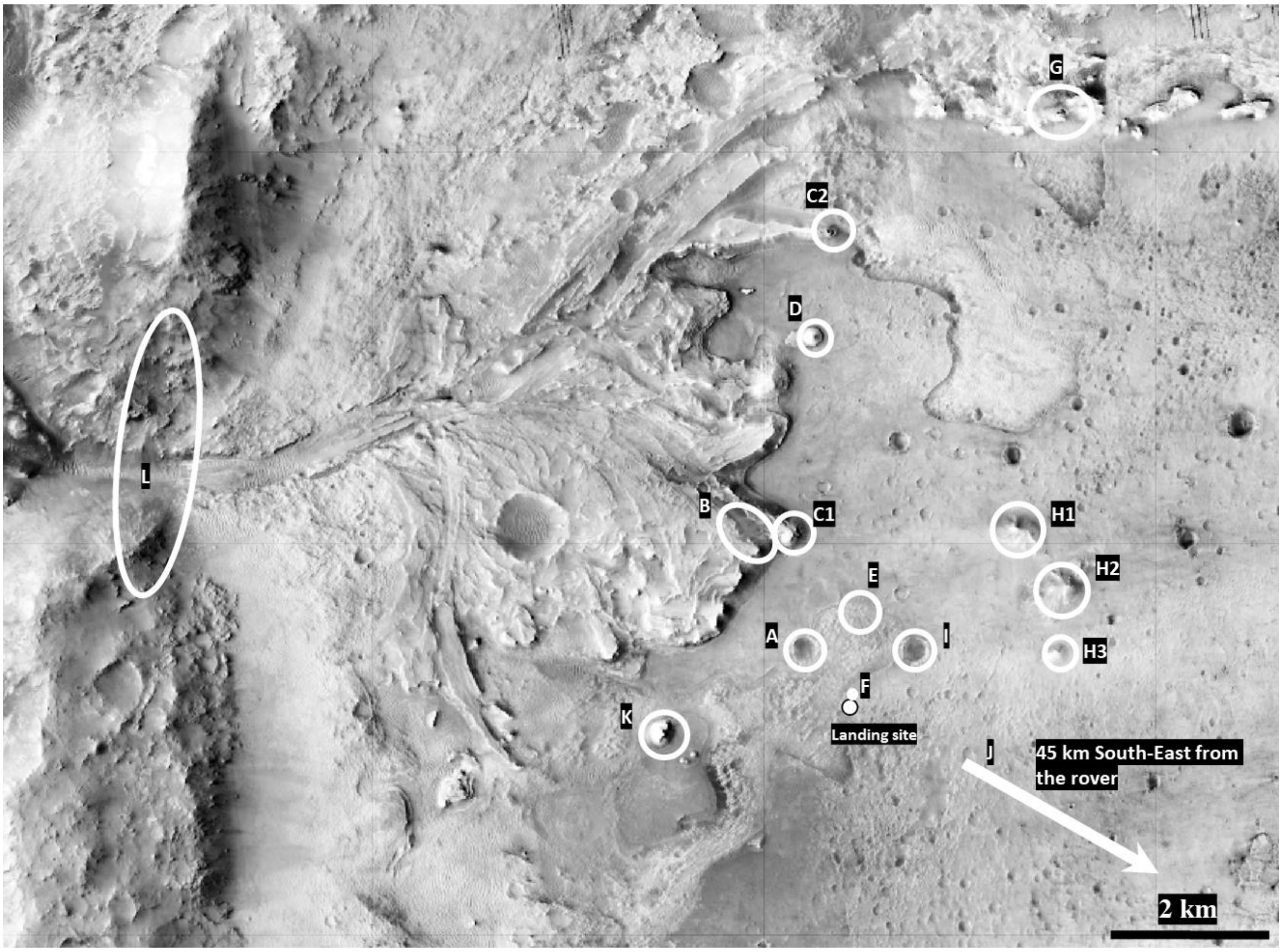


Figure 55. Satellite image showing the locations of features of interest with same annotation from the Sol 4 Z110 360° panorama. Note that feature J is highlighted with the white arrow, pointing to the south-eastern (bottom-right corner) part of the Jezero Crater rim.

5.1.3b Overview of all the Sol 4 & Sol 22 mosaic correlations

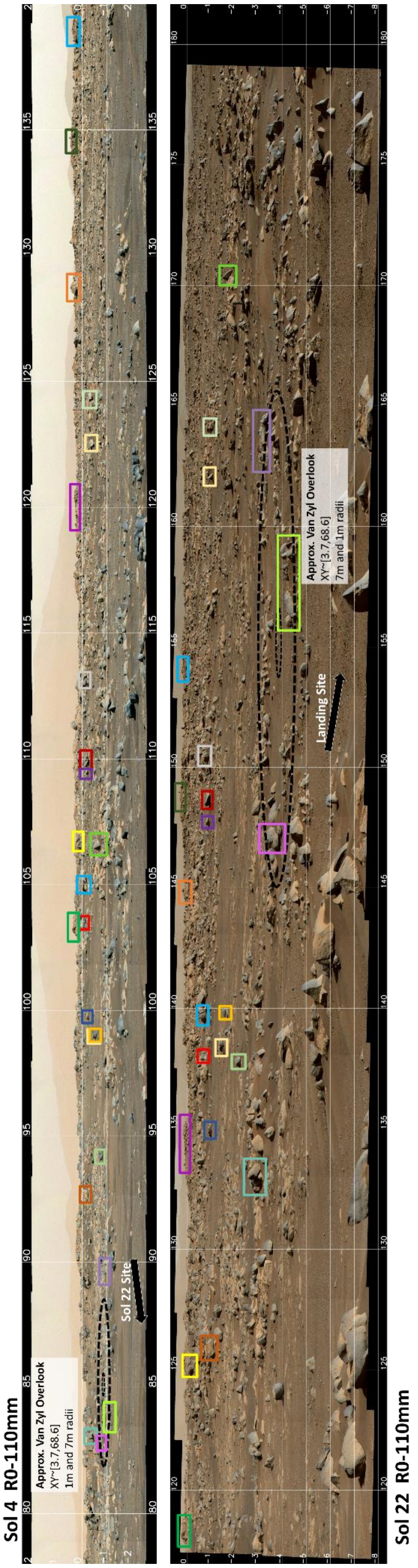


Figure 56. Sol 4 mosaic (top) and Sol 22 mosaic (bottom) with all 23 correlations as well as the approximate location of the Van Zyl overlook. All the correlations each have their own square and colour.

5.2a Fractured Rubbly and Fractured Fragmented boundary in Mammoth Cave quad

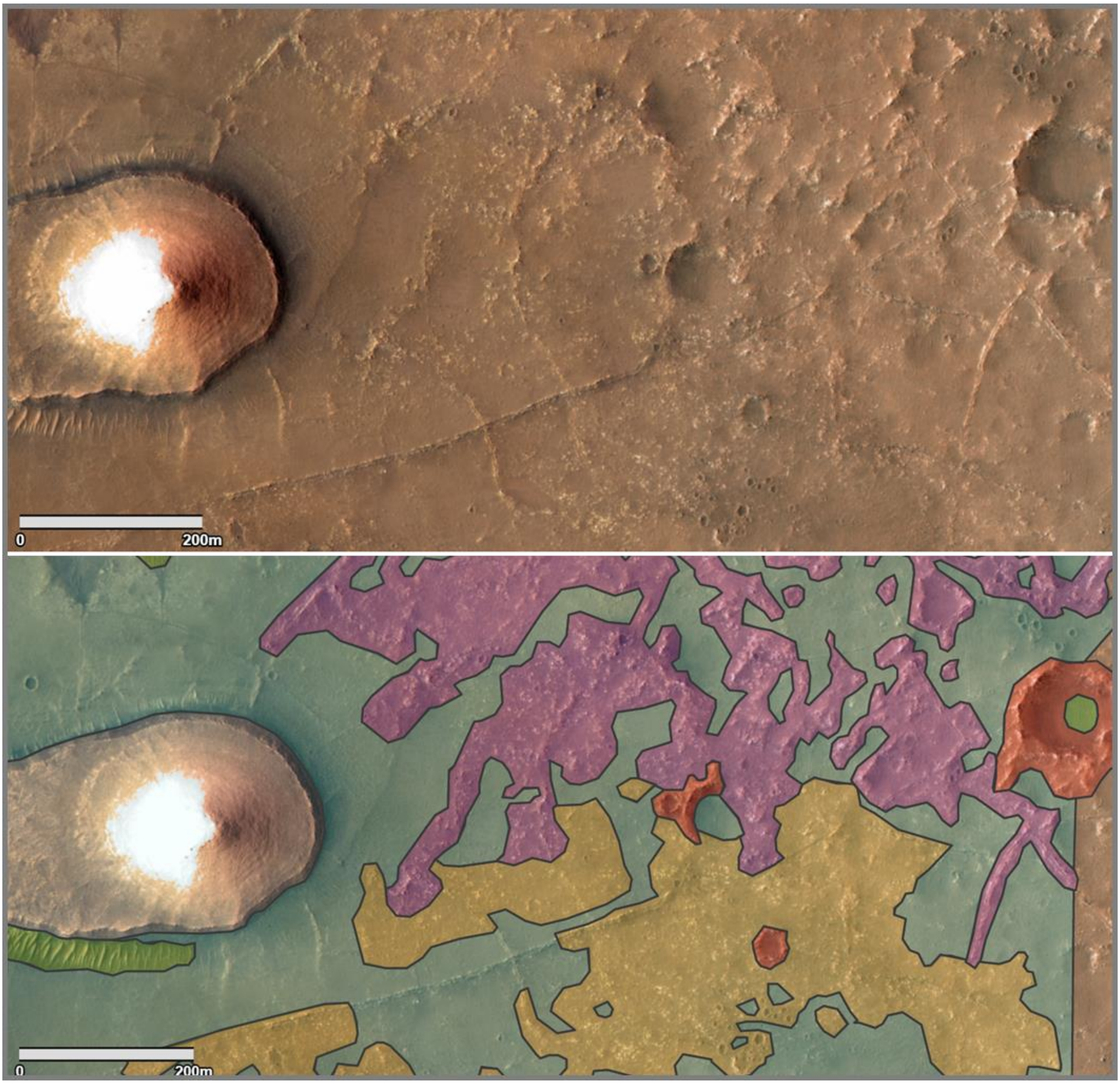
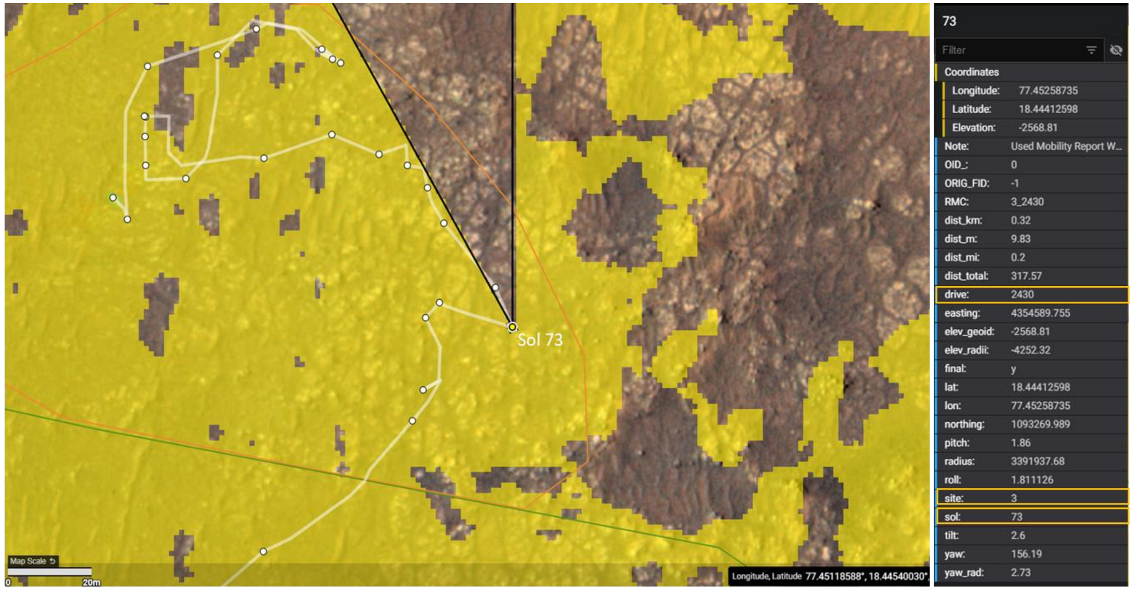


Figure 57. Close-up of the Fractured Rubbly (Purple) and Fractured Fragmented (Yellow) units in the bottom of the Mammoth Cave quad. Note the higher-standing Fractured Rubbly, which rises from the crater floor, whereas Fractured Fragmented is low-lying and light-toned.

5.3a Weirdly stitched together mosaics and their viewsheds



73

Coordinates

Longitude:	77.45258735
Latitude:	18.44412598
Elevation:	-2568.81
Note:	Used Mobility Report W...
OID_:	0
ORIG_FID:	-1
RMC:	3_2430
dist_km:	0.32
dist_m:	9.83
dist_mi:	0.2
dist_total:	317.57
drive:	2430
easting:	4354589.755
elev_geoid:	-2568.81
elev_radii:	-4252.32
final:	y
lat:	18.44412598
lon:	77.45258735
northing:	1093269.989
pitch:	1.86
radius:	3391937.68
roll:	1.811126
site:	3
sol:	73
tilt:	2.6
yaw:	156.19
yaw_rad:	2.73

Based of Az/El Grid in mosaic:

Nominal Height of ZCAM: 1.98m

(FOV) Azimuth: 330°

(FOV) Elevation: 60°

Center Azimuth: 165°

Center Elevation: -30°

QZCAM_Sol0078P_zcam08039_Z034_L0F_fullres

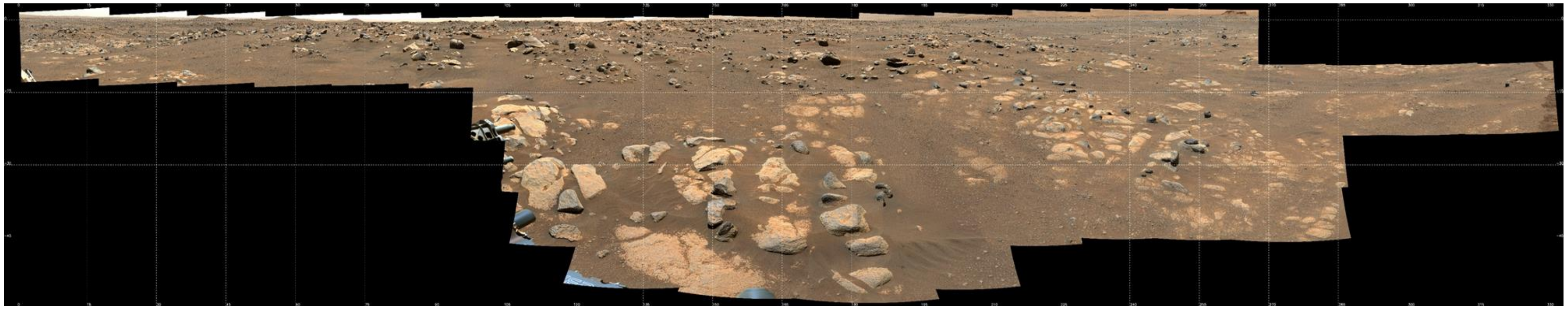


Figure 58. First double red asterixed example: 53-pointing Dibahi-Nataani Mosaic (Sol 78, seq. 08039) with its viewshed and viewshed parameters as well as parking spot information from CAMP. Notice the 330° FOV and scattered image coverage, which makes connecting between the mosaic and the map of the Sol Parking Spots near impossible.

<u>Based of Az/El Grid in mosaic:</u>

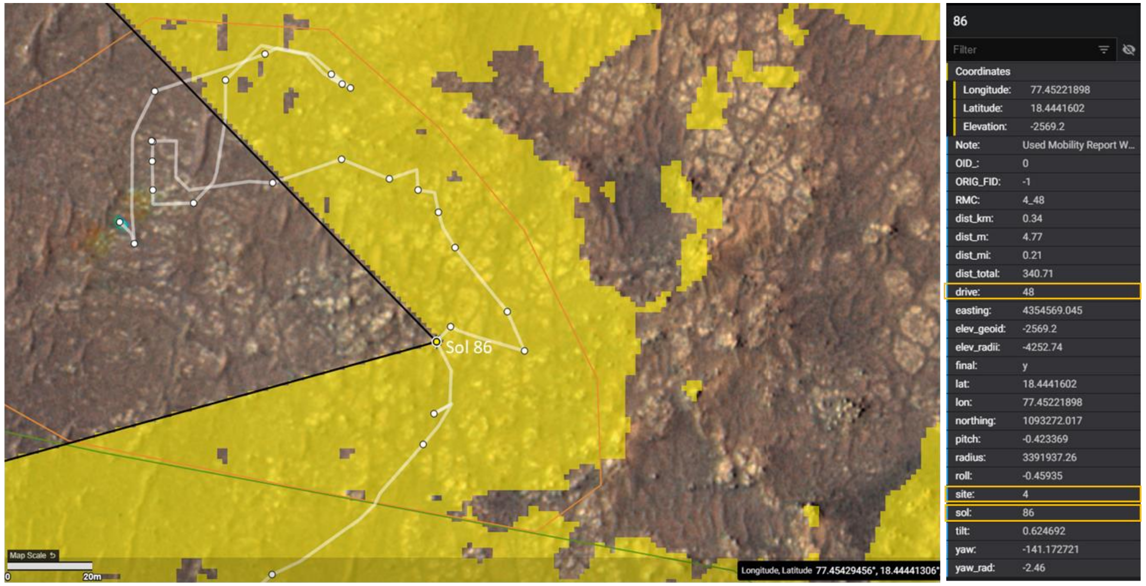
Nominal Height of ZCAM: 1.98m

(FOV) Azimuth: 300°

(FOV) Elevation: 60°

Center Azimuth: 105°

Center Elevation: -30°



Coordinates	
Longitude:	77.45221898
Latitude:	18.4441602
Elevation:	-2569.2
Note:	Used Mobility Report W...
OID_:	0
ORIG_FID:	-1
RMC:	4_48
dist_km:	0.34
dist_m:	4.77
dist_mi:	0.21
dist_total:	340.71
drive:	48
easting:	4354569.045
elev_geoid:	-2569.2
elev_radii:	-4252.74
final:	y
lat:	18.4441602
lon:	77.45221898
northing:	1093272.017
pitch:	-0.423369
radius:	3391937.26
roll:	-0.45935
site:	4
sol:	86
tilt:	0.624692
yaw:	-141.172721
yaw_rad:	-2.46

QZCAM_sol0087_sol0090_zcam08046-zcam05081_L0_34-110_workspace_E01

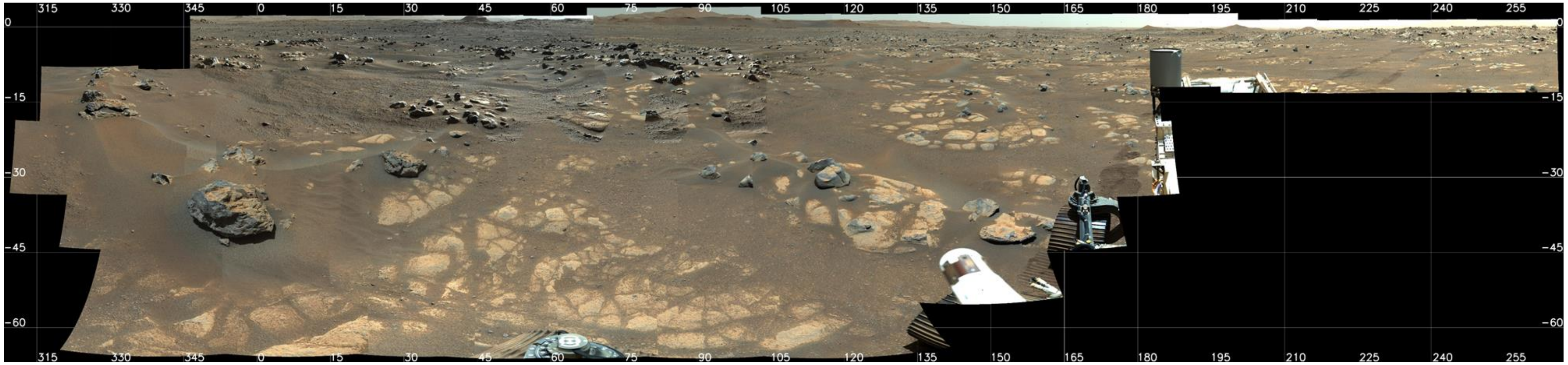


Figure 59. Second double red asterixed example: Delta, Santa Cruz merged mosaic (Sol 87 & 90, seq. 08046 & 08051) alongside its viewshed & parameters as well as the CAMP Parking Spot info. This mosaic also has a FOV of 300°. A problem I had with this mosaic is that the backside of the rover is visible on the right side of the mosaic. This does not correspond with how the viewshed is setup. It should be visible on the left side of the mosaic since it has driven from north to south. Another reason to not use this viewshed is that the only interesting part is between Sol 84 and 86 on the Sol 86-102, which is obscured by the RTG and rover hardware.

5.3b Map overview of radargram coverage

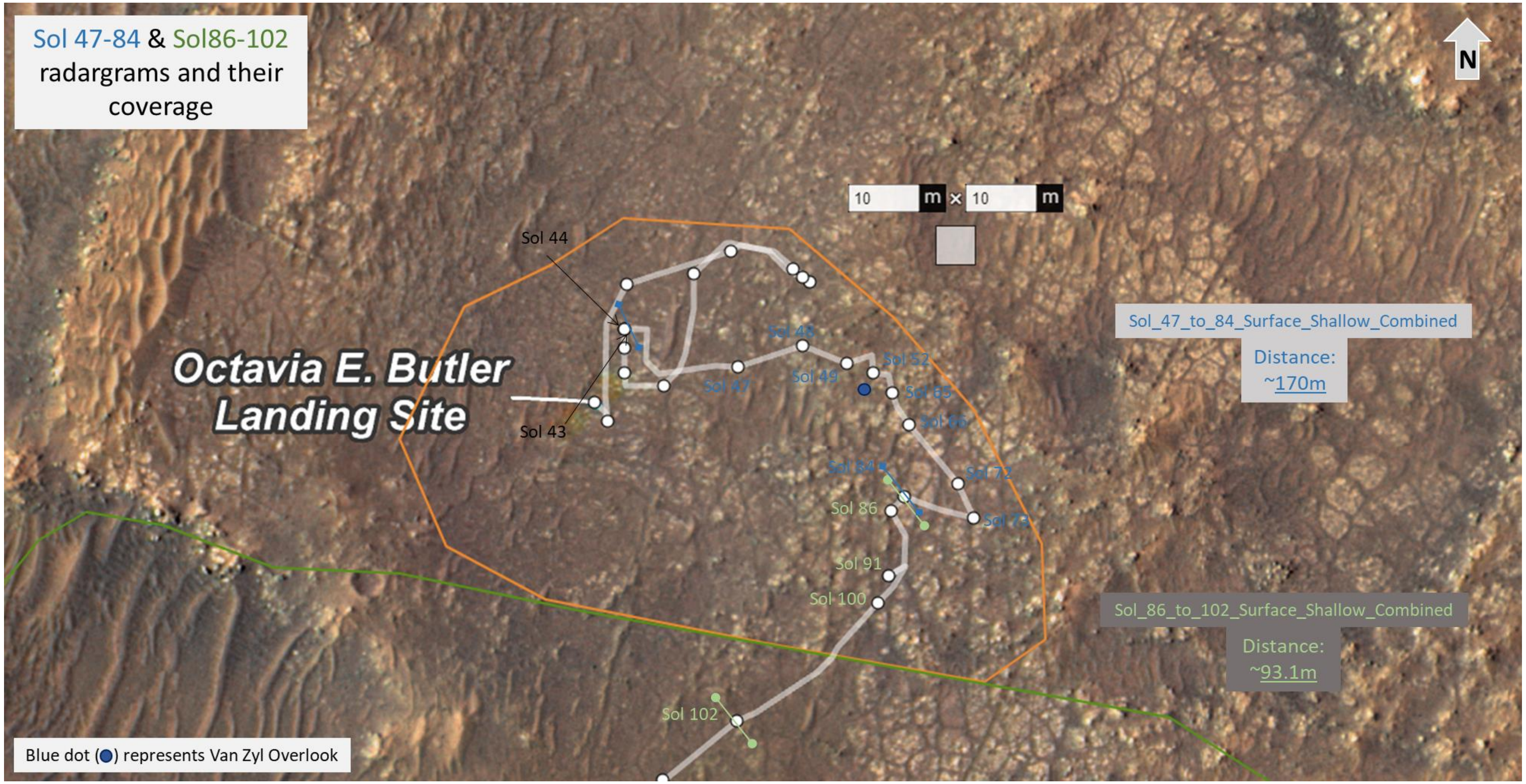
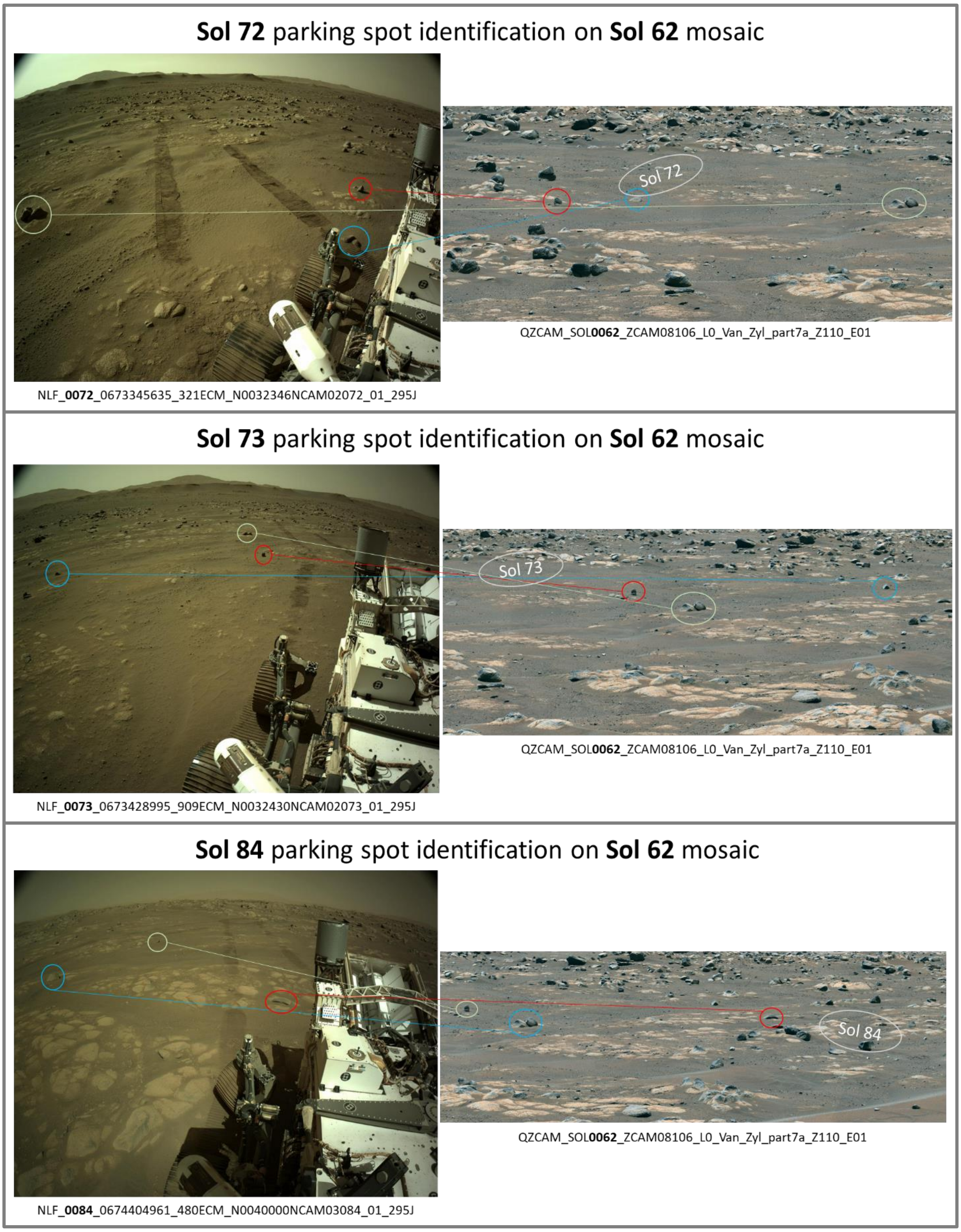


Figure 60. Map overview for a visual representation of the Sol 47-84 & Sol 86-102 radargrams coverage as well as their distance in meters. The Sol 47-84 radargram is represented here in a dark blue colour and each Sol parking spot it covers is noted here in the same colour. The Sol 86-102 radargram is shown here in dark green and each Sol parking spot it covers is marked in the identical colour. The start and end of both radargrams are indicated with lines with dots at the ends for both colours, with the change from the Sol47-84 radargram to Sol 86-102 occurring at the Sol 84 parking spot. Note that around Sol 100 we transitioned from the Landing Site campaign (orange coloured boundary) into the Crater Floor campaign (formerly known as Green Zone campaign, hence the green coloured boundary).

5.3c Parking spot identifications based on NAVCAM images for the Sol 62 mosaic



Sol 72 parking spot identification on **Sol 62** mosaic

NLF_**0072**_0673345635_321ECM_N0032346NCAM02072_01_295J

QZCAM_SOL**0062**_ZCAM08106_L0_Van_Zyl_part7a_Z110_E01

Sol 73 parking spot identification on **Sol 62** mosaic

NLF_**0073**_0673428995_909ECM_N0032430NCAM02073_01_295J

QZCAM_SOL**0062**_ZCAM08106_L0_Van_Zyl_part7a_Z110_E01

Sol 84 parking spot identification on **Sol 62** mosaic

NLF_**0084**_0674404961_480ECM_N0040000NCAM03084_01_295J

QZCAM_SOL**0062**_ZCAM08106_L0_Van_Zyl_part7a_Z110_E01

Figure 61. Sol 72, Sol 73, and Sol 84 parking spot estimations done by me in the Sol 62, Adziilii mosaic based on correlations between the mosaic itself and rocks found in NAVCAM images from each parking spot. Each image has 3 rock correlations (shown with red, green, and blue circles and lines between the NAVCAM image and cropped mosaic) and the parking spot itself has been highlighted with a white circle and parking spot Sol # inside said circle.

6a Close-up examples of a “Massive” and a “Pitted” rock from Mastcam-Z images

Figure 62. Both images are Mastcam-Z left eye, enhanced colour.

The top image of a massive rock, dubbed Ch’ał, from Sol 78.

The bottom image is of a pitted rock, dubbed Hedgehog from Sol 37.

6b Final Map from the Remapping Effort

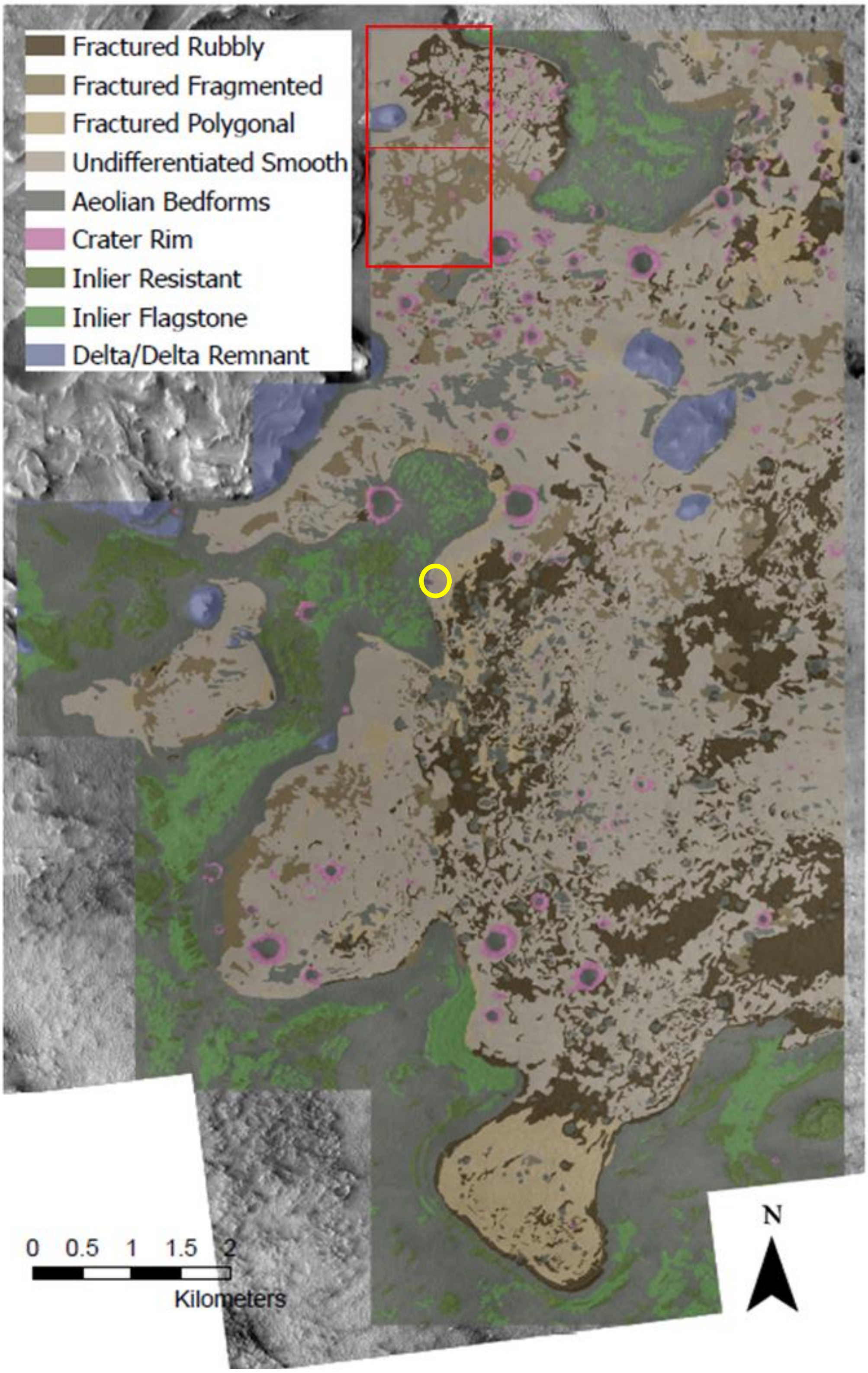


Figure 63. Final draft map from the Remapping Effort, stitched together from all 28 quad pairs. Legend is in the top left, scale bar in the bottom left and north arrow in the bottom right. My quad pair has been marked in with red squares. Mammoth Cave is the top. Yellow circle: Octavia E. Butler Landing Site.