Jet Propulsion Laboratory
California Institute of Technology

# Mars 2020

## Landing Site Traversability

## Project Briefing
Docushare Collection 14961

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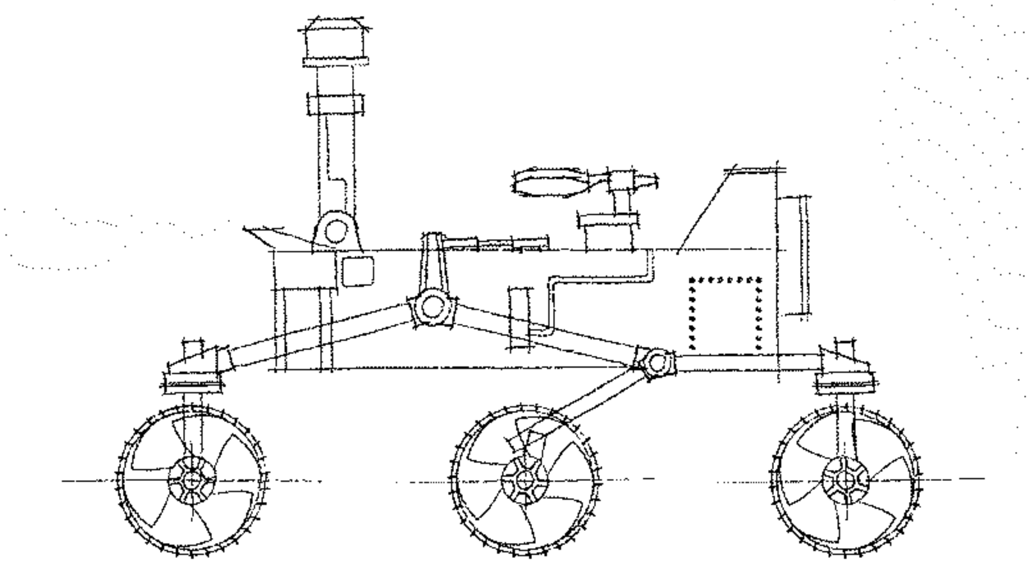
Jan 18, 2017

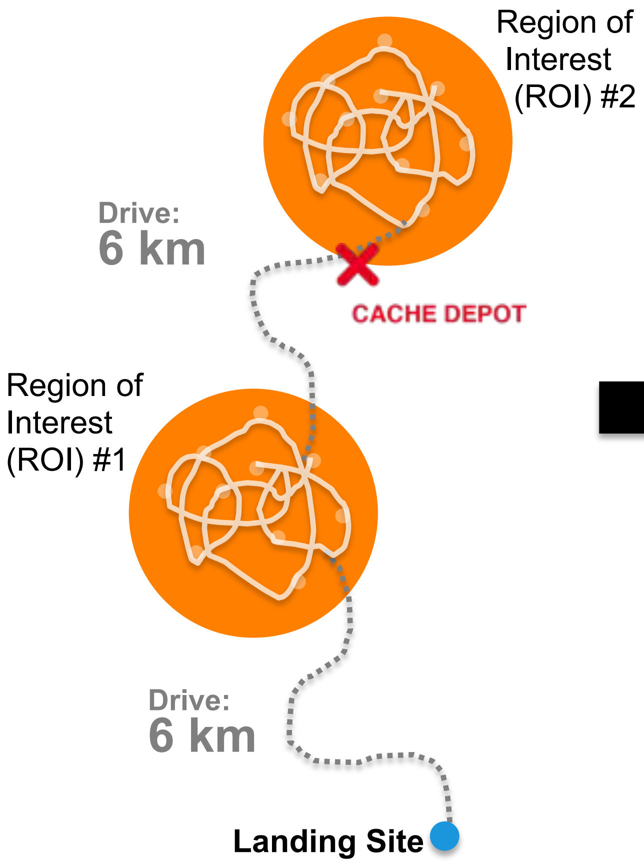


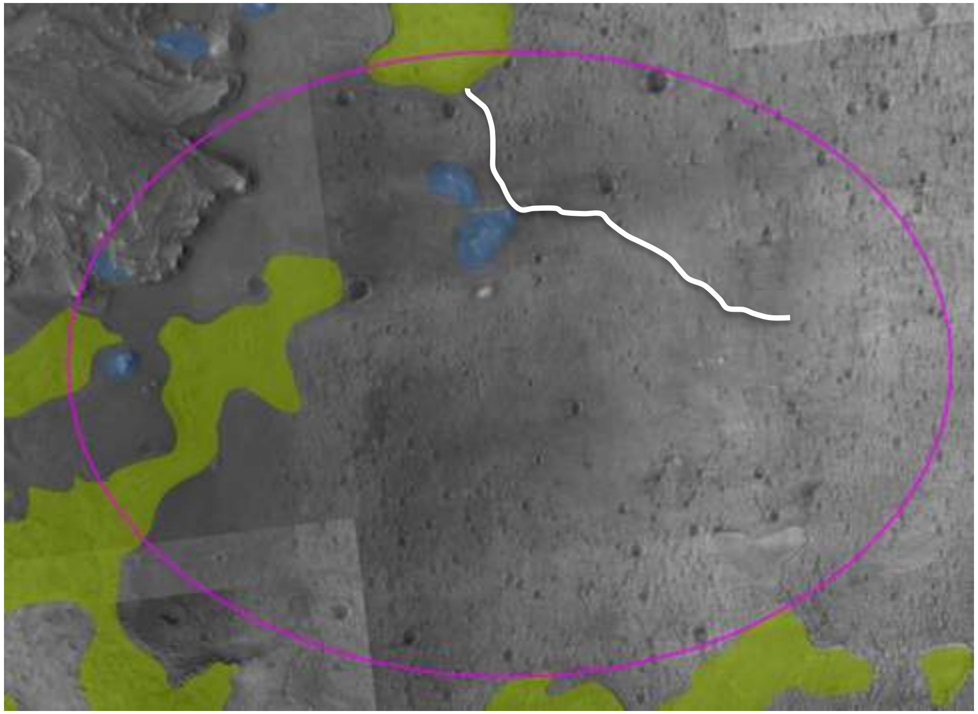
**Mars 2020** Project

# Objective



Attempting to move from a generic Baseline Reference Scenario (BRS) to a quantitative analysis with specific mission objectives at each landing site



Example scenario at Jezero Crater

# Acknowledgements


## JPL

- Hiro Ono
- Brandon Rothrock
- Eduardo Almeida
- Hallie Gengle
- Fred Calef
- Tariq Soliman
- Richard Otero
- Ken Williford
- Matt Golombek
- Rob Lange
- Sarah Milkovich
- Nathan Williams
- Takuto Ishimatsu
- Kyohei Otsu

## Site Proposers

- Steve Ruff (CLH)
- Jim Rice (CLH)
- Alex Longo (CLH)
- Melissa Rice (EBW)
- Sanjeev Gupta (EBW)
- Nick Warner (EBW)
- Ross Irwin (HOL)
- James Wray (HOL)
- John Grant (HOL)
- Jack Mustard (JEZ, NES, NIL)
- Bethany Ehlmann (JEZ, NES)
- Tim Goudge (JEZ)
- Jim Head (JEZ)
- Briony Horgan (MAW)
- Damien Loizeau (MAW)
- Francois Poulet (MAW)
- Michael Bramble (NES)
- Kevin Cannon (NIL)
- Becky Williams (SWM)

# Objectives of This Package



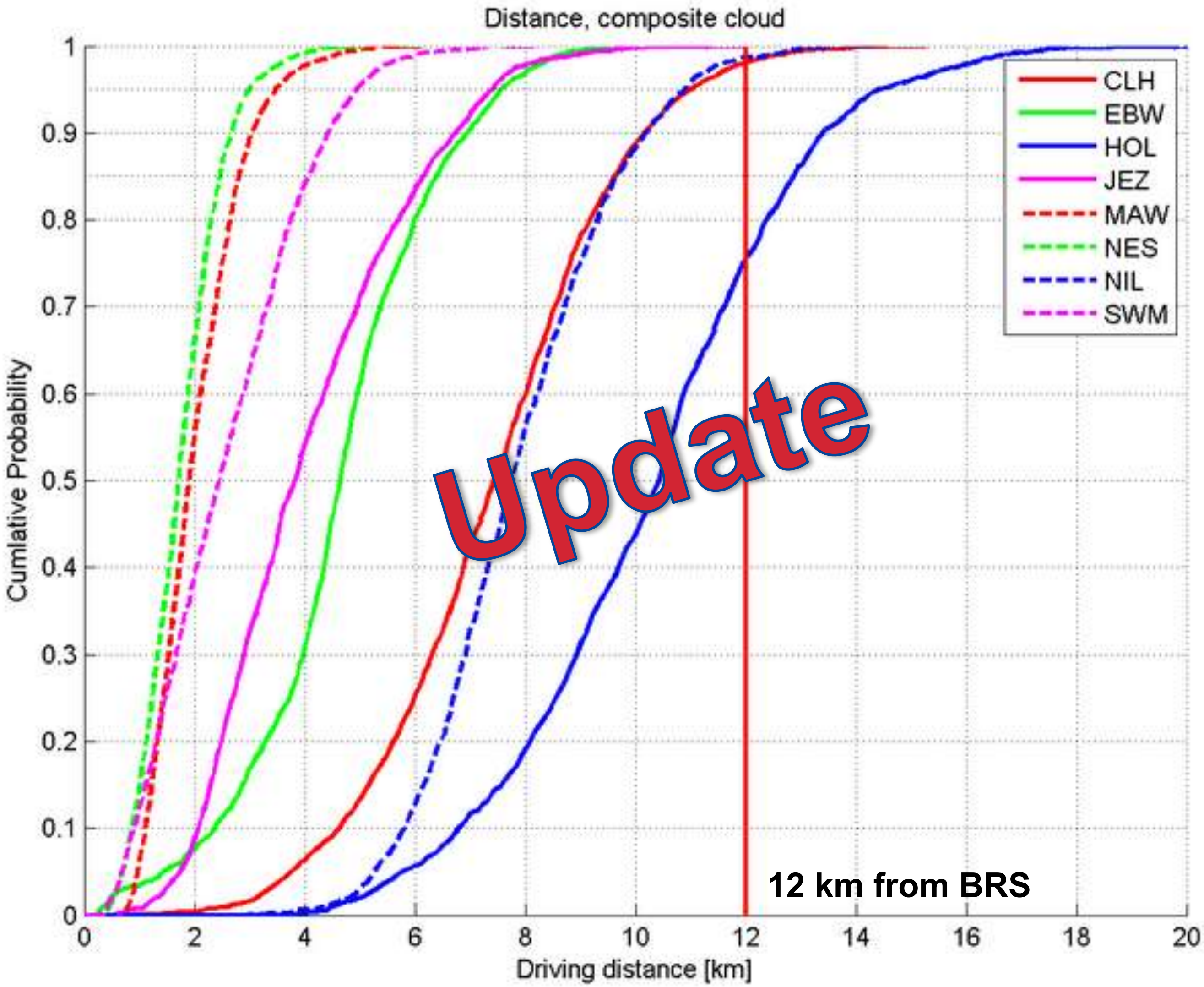
- Inform those who may not have been involved in the site specific discussion about the landing sites
- Ensure that we have the right criteria for the analysis we will present at Landing Site Workshop #3
- Ensure that we have appropriate consistency across the sites since the process evolved as we explored each site

Note that this is an ongoing evaluation and what is captured here is simply a snapshot in time. We will continue to refine our analysis, mature the techniques, and fold in more data as it becomes available.

# Outline

- Traversability analysis process
- Site specific analysis summary for each site
- Results of traversability analysis

# Punchline




Note that these numbers will evolve as more data is added

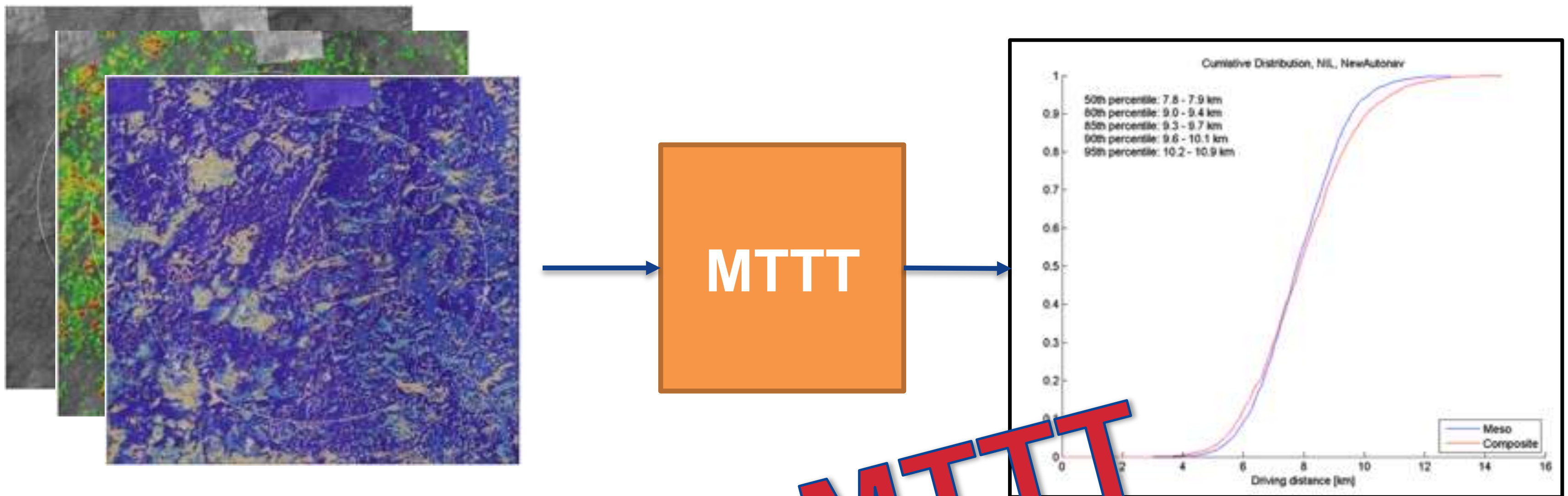
# Punchline


Note that these numbers will evolve as more data is added

# Traversability Analysis Process

# Data-driven Traversability Analysis

**Inputs: slope, CFA, terrain type** | **Output: CDF of time/distance**



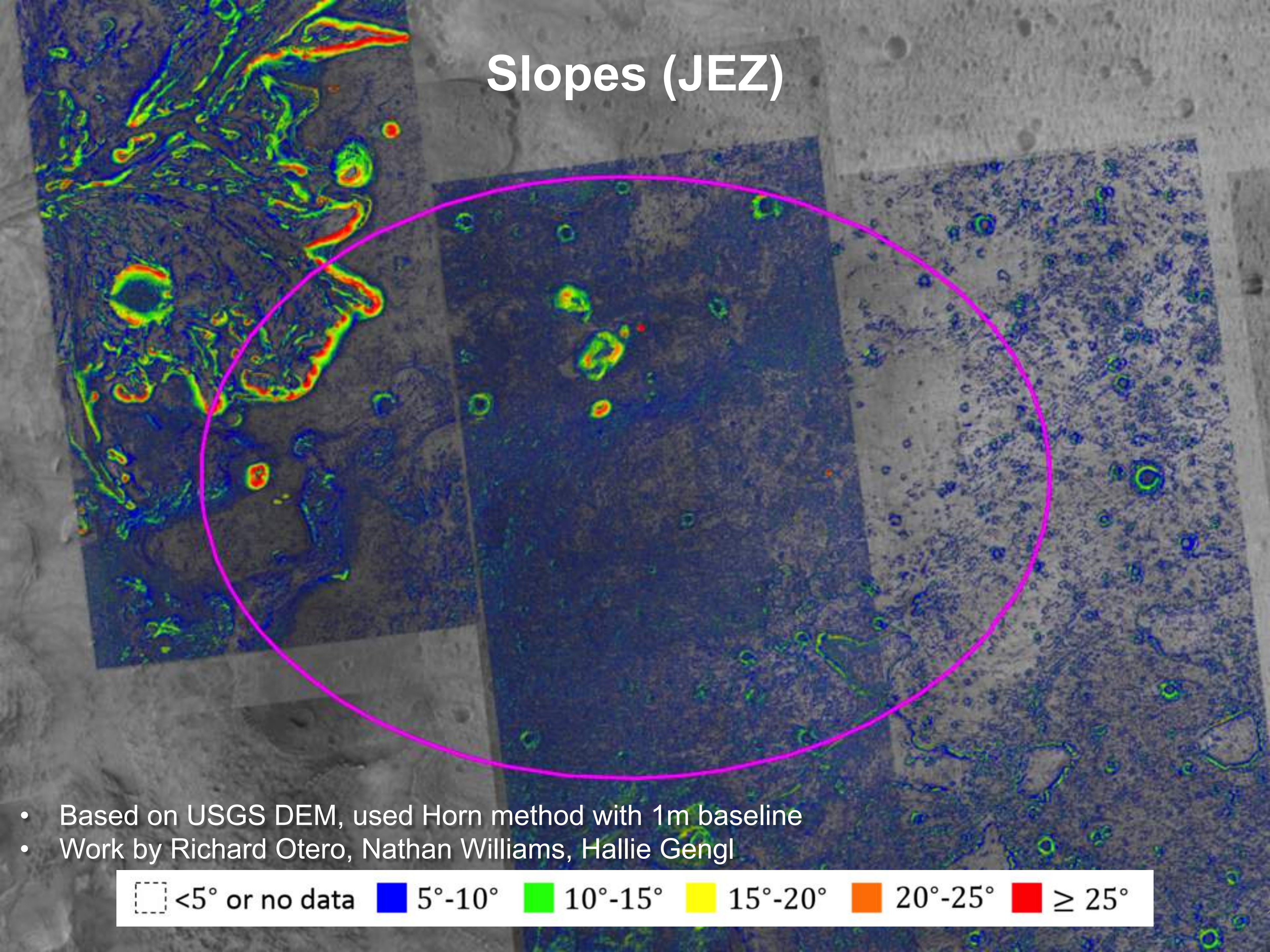

**Define MTTT**

- Uses slope, CFA, and terrain type to assess traversability (MSL did not use terrain classification)
- Outputs statistical distribution of driving time and distance to visit required ROIs
- Avoids subjectivity by algorithmic evaluation of terrain type and rock abundance
- Solves traveling salesman problem to find the minimum-time path to visit multiple ROIs (MSL had only one ROI)

# Assumptions

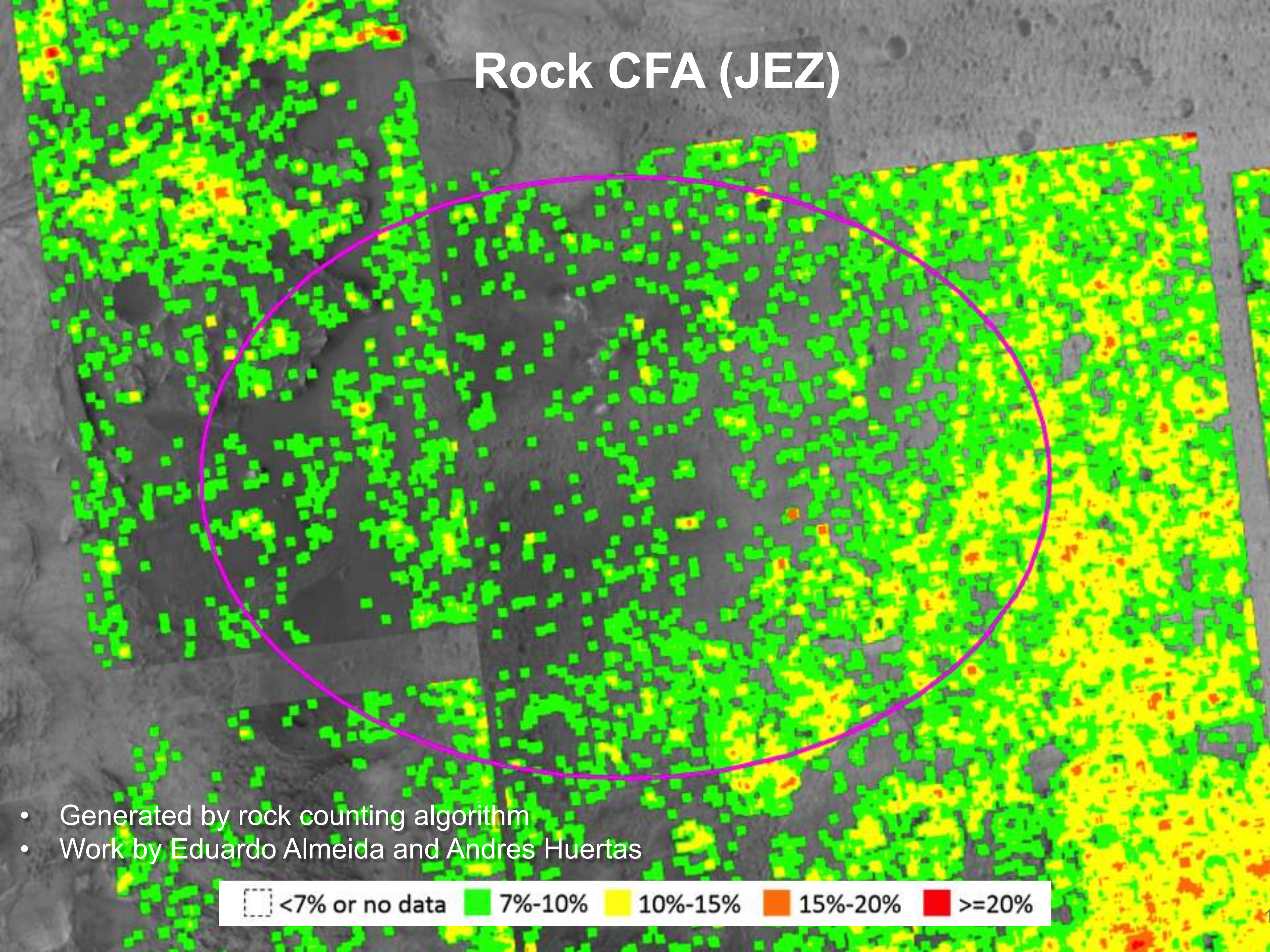
- Terrain Relative Navigation (TRN) can land us in a safe location
- Inescapable hazards are evaluated separately and are incorporated in to the Entry Descent and Landing (EDL) analysis
- Not an evaluation of driving within the Regions Of Interest (ROI), only between ROIs

# Slopes (JEZ)



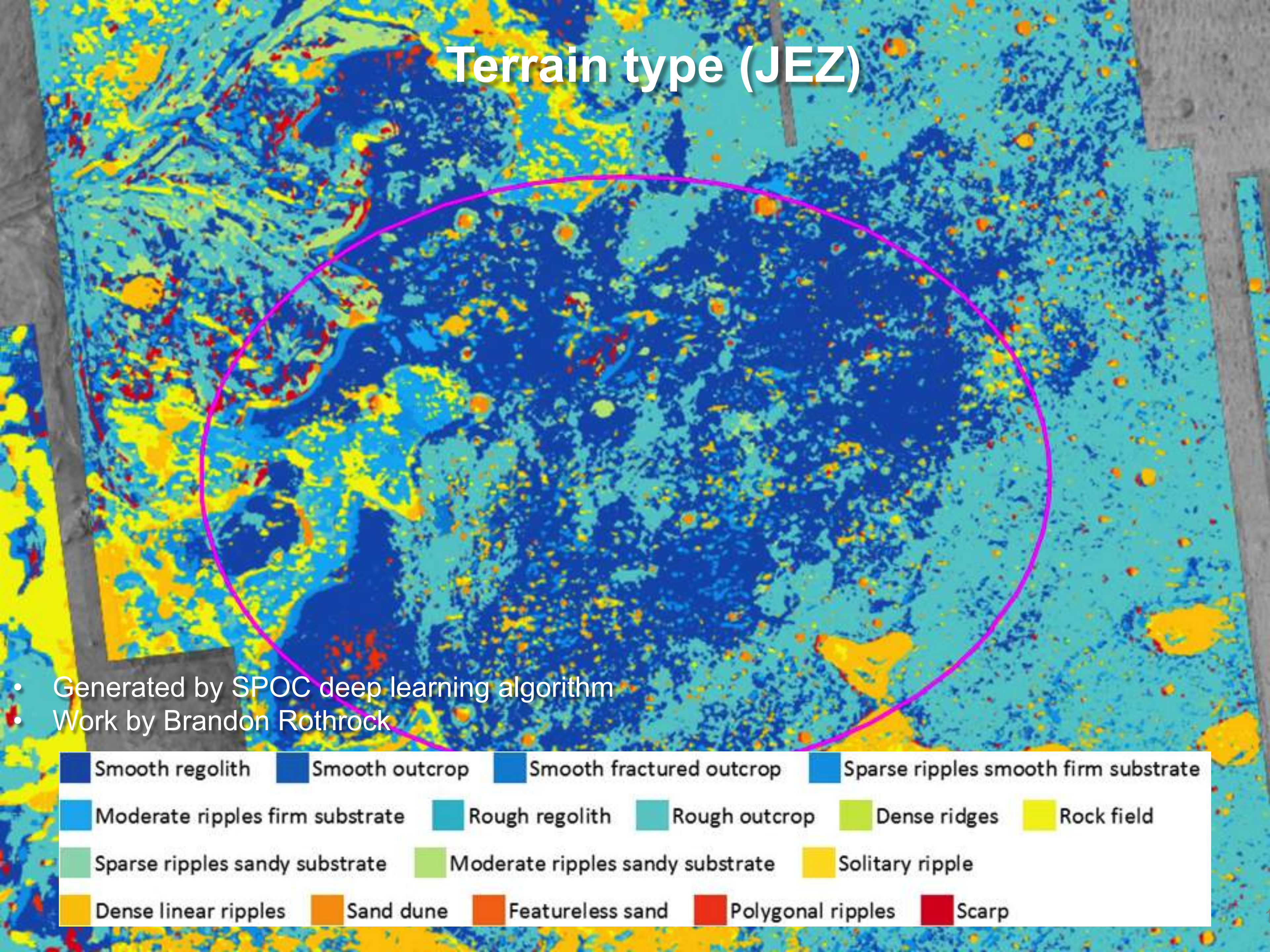

- Based on USGS DEM, used Horn method with 1m baseline
- Work by Richard Otero, Nathan Williams, Hallie Gengl

# Rock CFA (JEZ)




- Generated by rock counting algorithm
- Work by Eduardo Almeida and Andres Huertas

# Terrain type (JEZ)

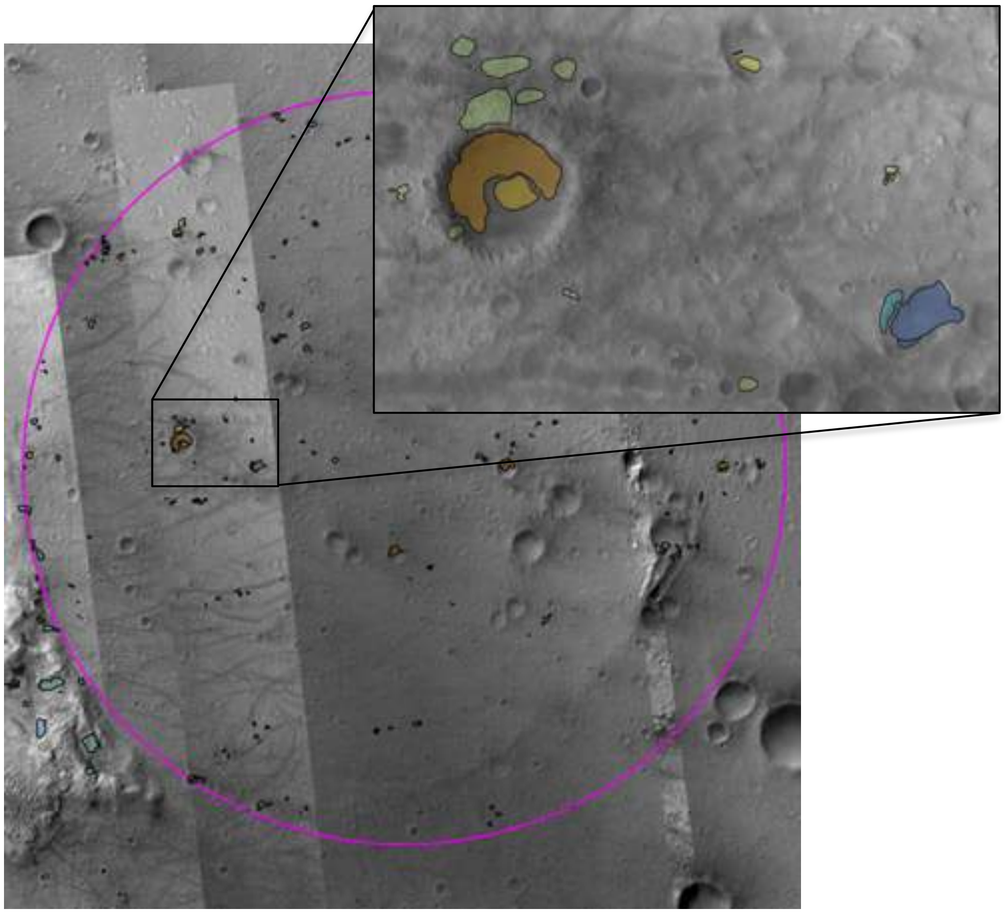


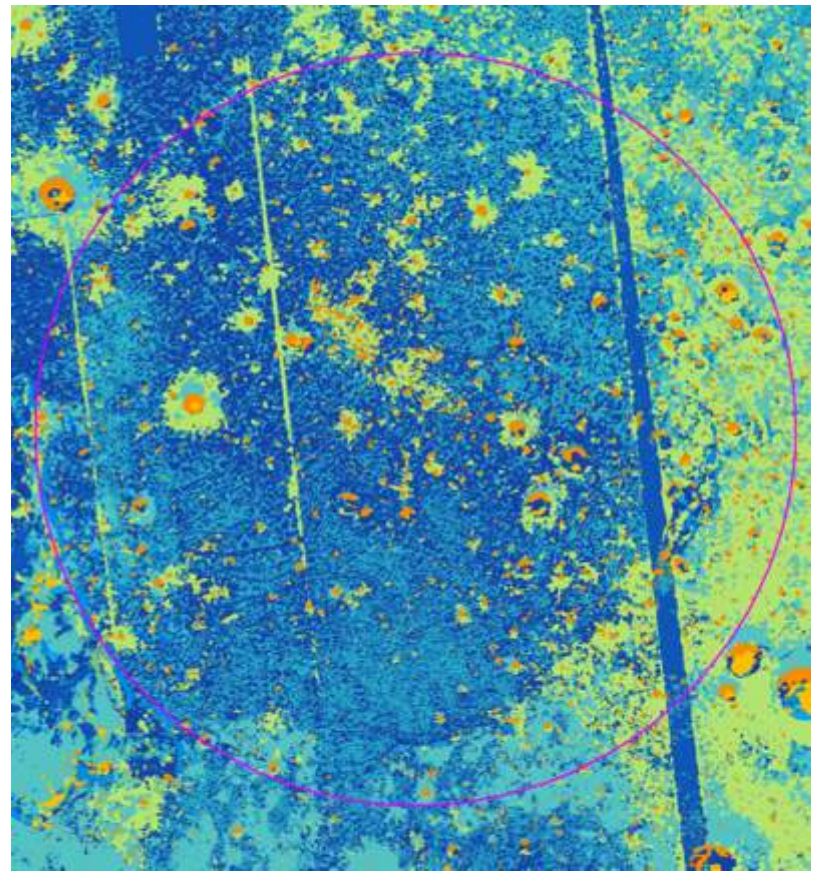

- Generated by SPOC deep learning algorithm
- Work by Brandon Rothrock

# Terrain Classification



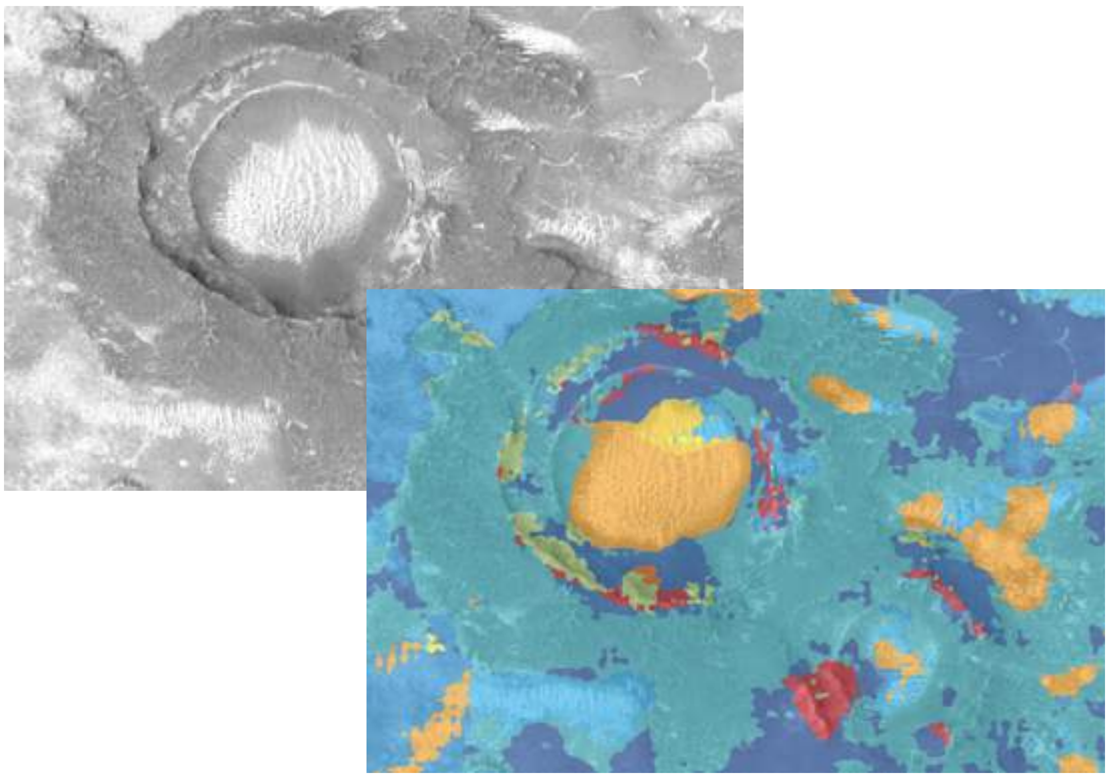
- Machine learning algorithm is used to take a small sample of terrain classification training data and apply it to the entire landing site





# Terrain Classification

- Each pixel in the landing site mosaic assigned one of 17 terrain classes
- These terrain classes can then be used for traversability analysis



Smooth Regolith
Smooth Outcrop
Fractured Outcrop
Sparse Ripples Firm Substrate
Moderate Ripples Firm Substrate
Rough Regolith
Rough Outcrop
Sparse Ripples Sandy Substrate
Moderate Ripples Sandy Substrate
Dense Ridges
Rock Field
Solitary Ripple
Dense Linear Ripples
Sand Dune
Featureless Sand
Polygonal Ripples
Scarp

# Drive rate estimates (Effective rate)



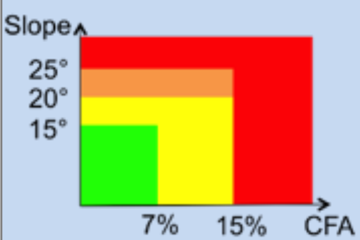
- 17 terrain types are categorized into 5 classes
- Optimistic and conservative estimates are assigned based on slope, CFA for each class
- Drive rates are “taxed” by path inefficiency and slip
- Assumed 2.5 hr/sol drive (Blind drive speed averaged over 2.5 hr)

## Class 1
**Benign Terrains**

Smooth regolith

Smooth outcrop

Fractured outcrop

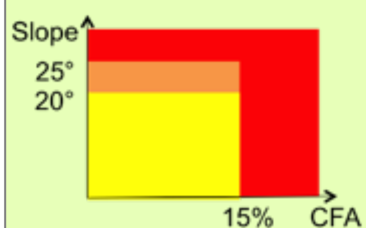



- 64.8 m/hr
- 52.5 m/hr
- 10.9 m/hr
- Avoid

## Class 2
**Rough terrains**

Rough regolith

Routh outcrop

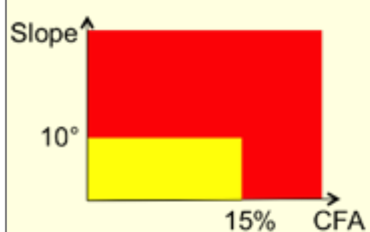



- 24.2 – 48.5 m/hr
- 10.9 m/hr
- Avoid

## Class 3
**Sandy terrains**

Sparse ripples firm/sandy substrate

Moderate ripples firm/sandy substrate



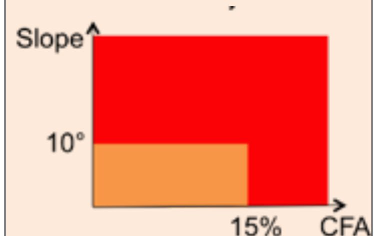

- 10.9 – 40.8 m/hr
- Avoid

## Class 4
**No-autonav terrains**

Dense ridges

Rock field

Featureless sand




- 8.7 m/hr
- Avoid

## Class 5
**Untraversable**

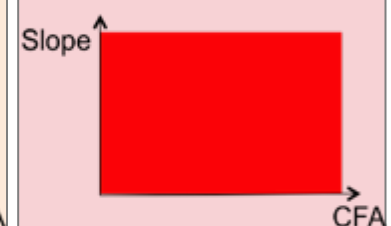
Solitary ripple

Dense linear ripples

Sand dune

Polygonal ripples

Scarp

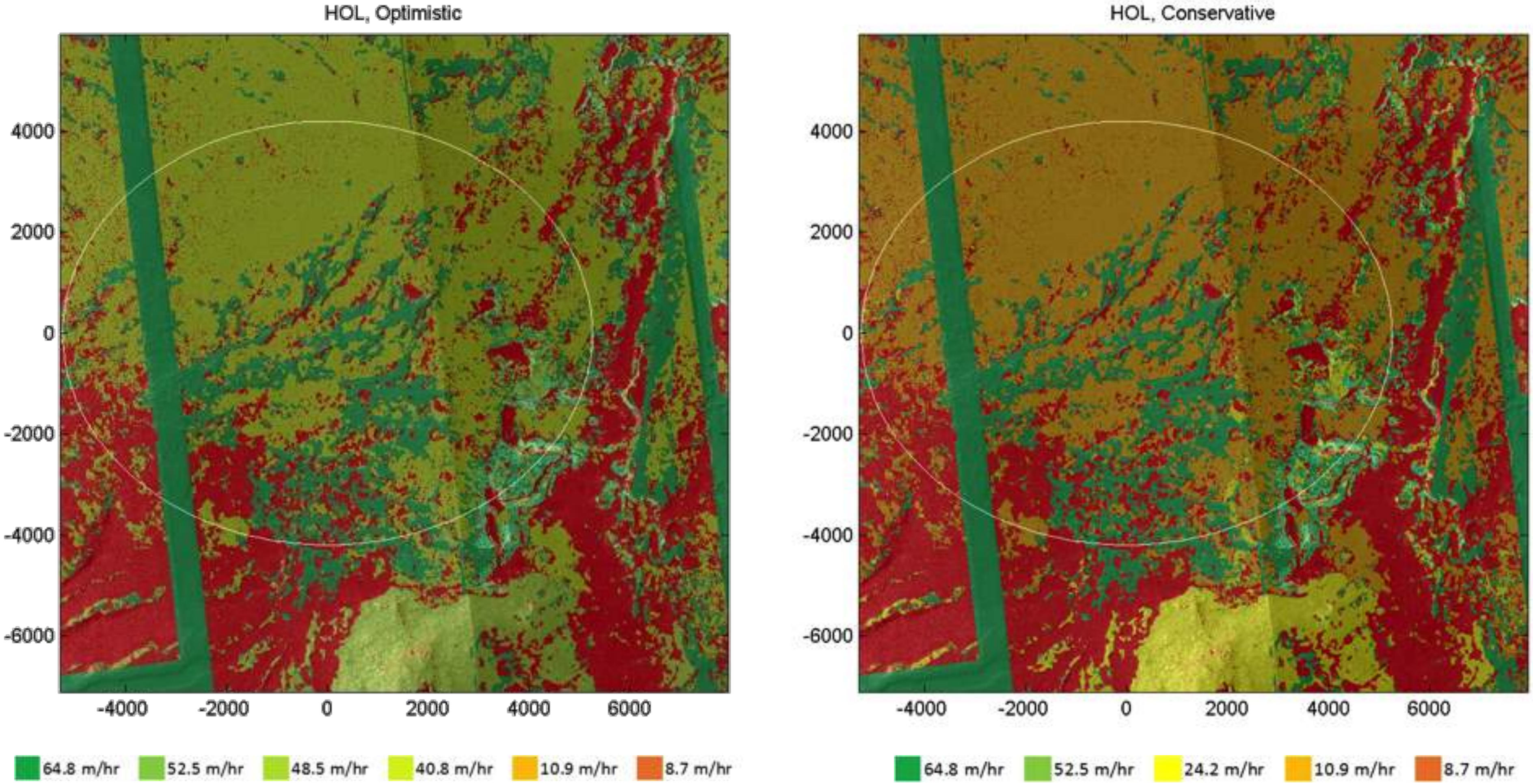



- Avoid

# Traversability Maps

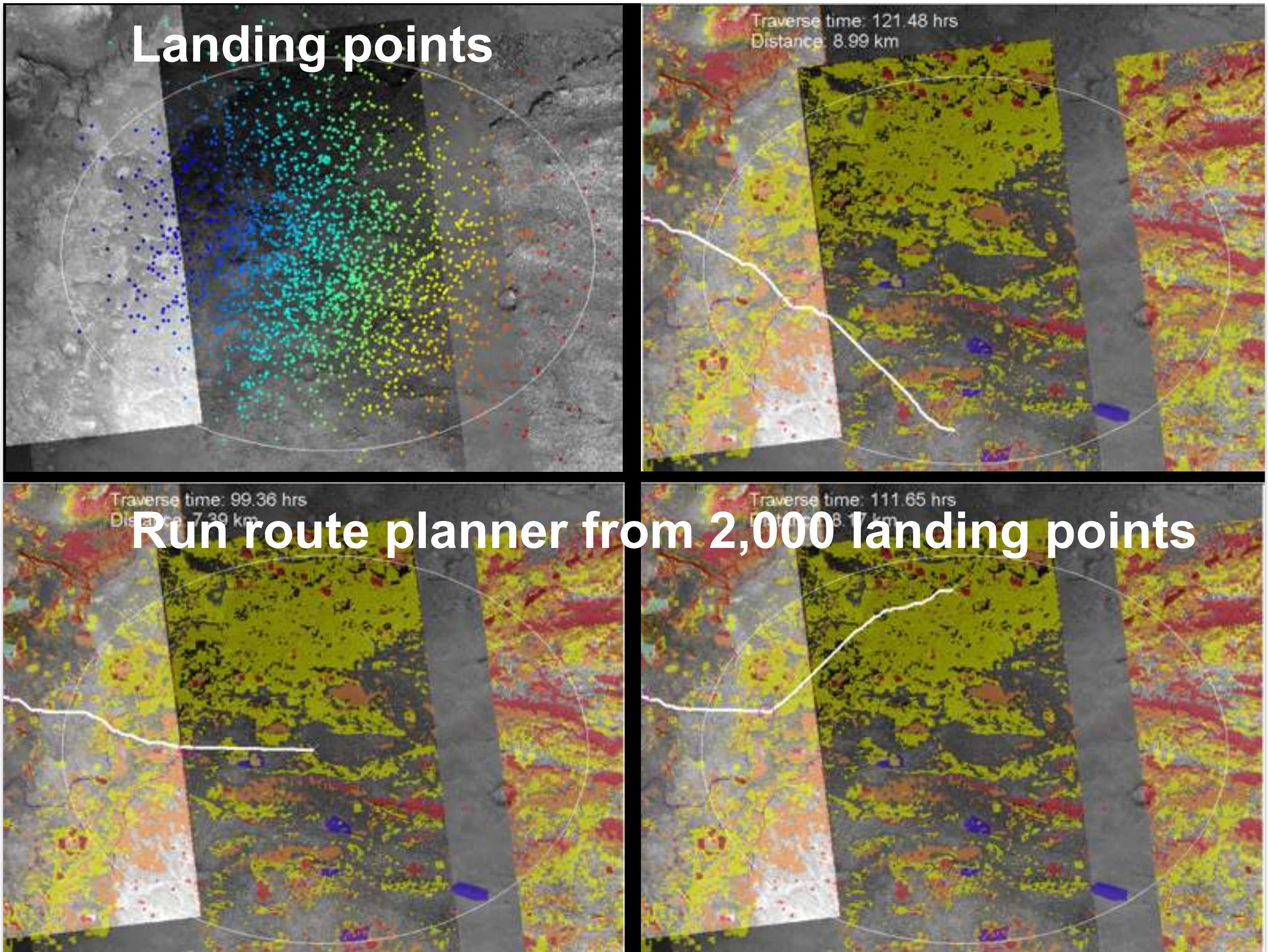


- Plan fastest route from a landing point to two ROIs
- Monte-Carlo simulation with 2,000 landing points sampled from landing probability distribution



# Monte Carlo w/ Optimal Route Planning

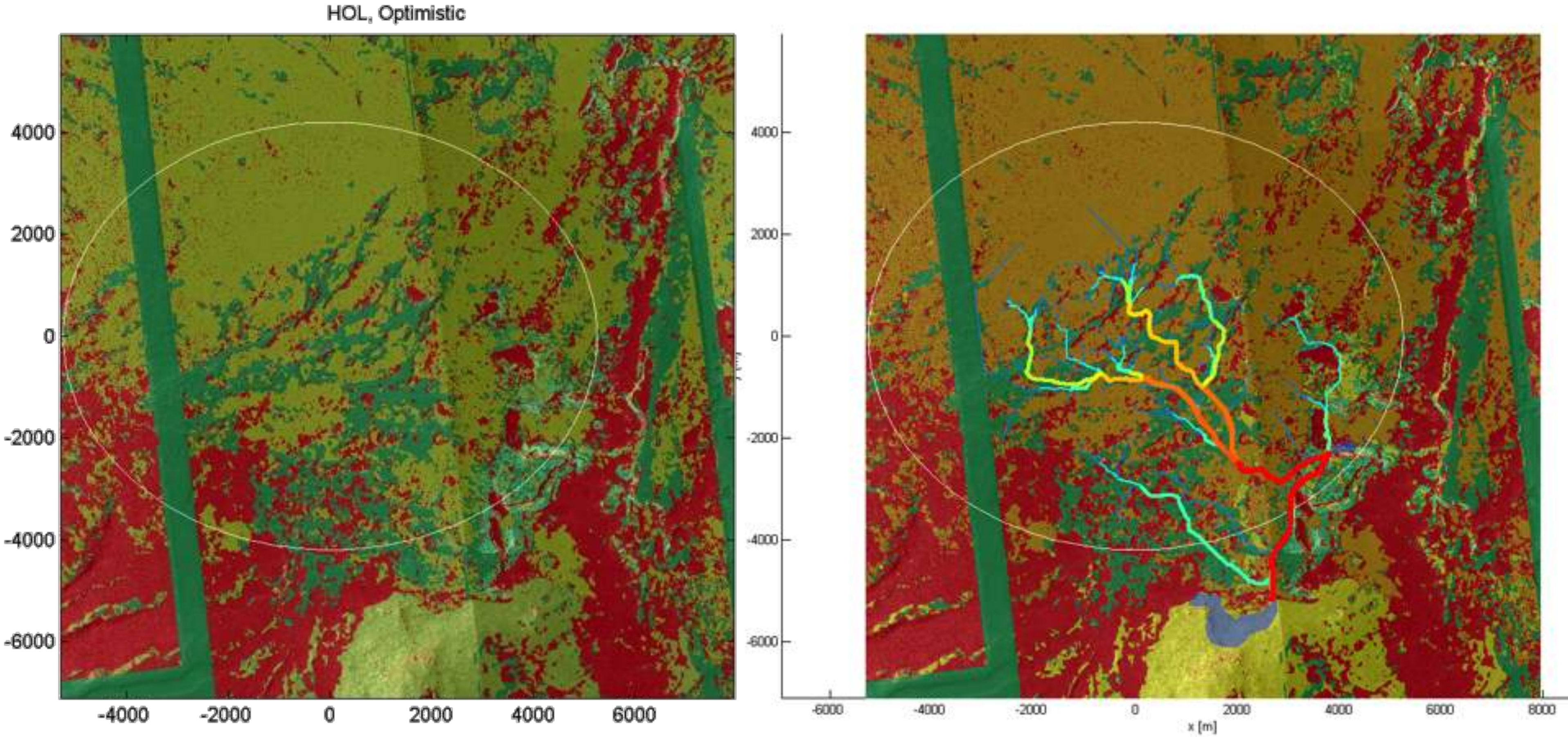




# Fastest Route Planning/Monte-Carlo



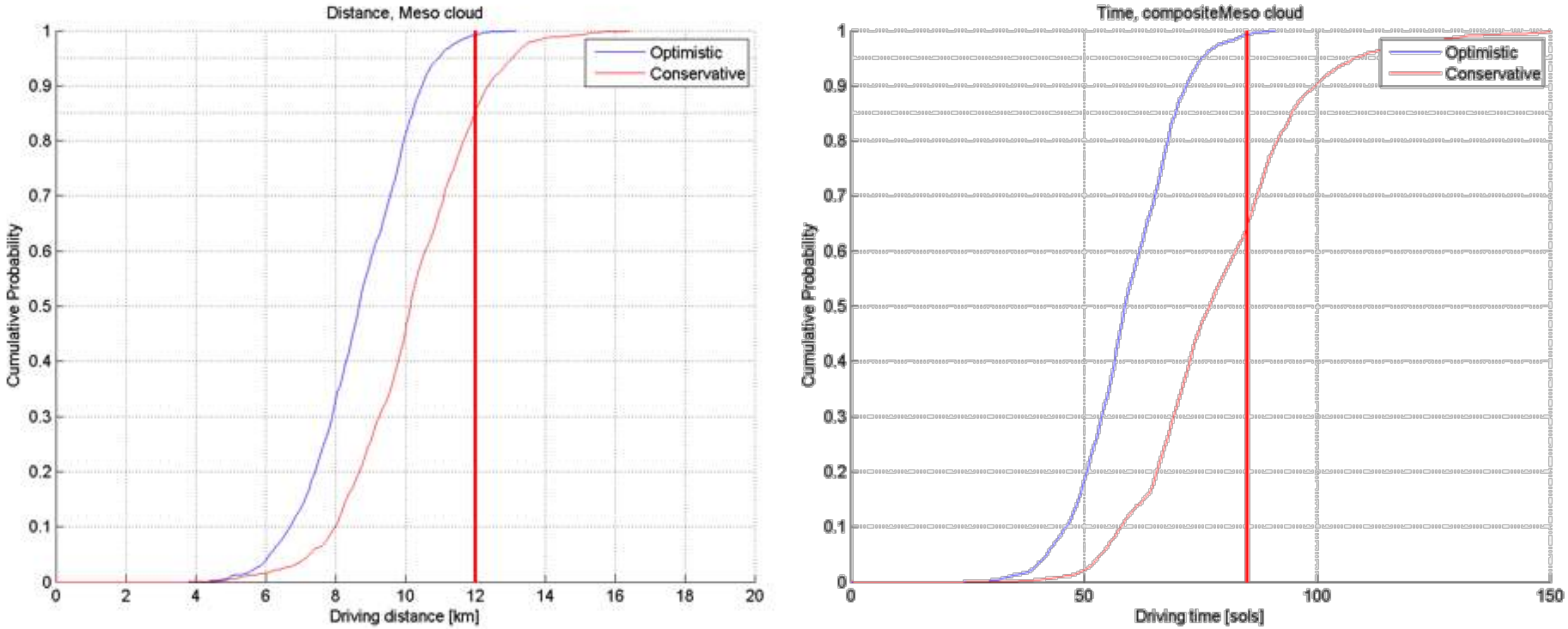
- Use optimal route planner to plan fastest route from a landing point to two ROIs
- Monte-Carlo simulation with 2,000 landing points sampled from landing probability distribution




"Highway chart" – width and color represent the probability that the route is traversed

# Cumulative Distribution Functions

## HOL (high uncertainty)

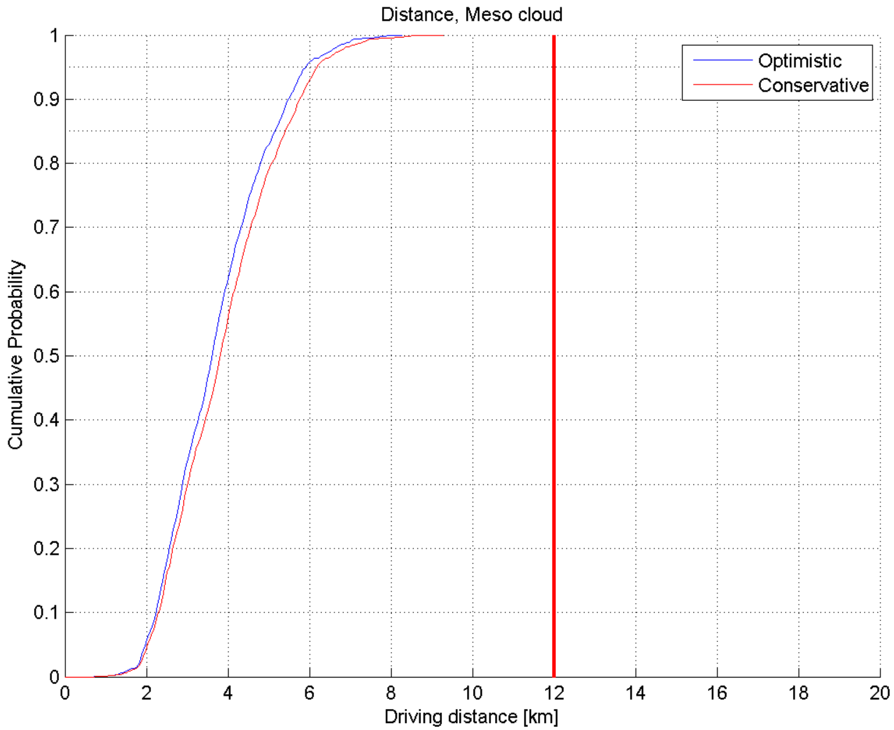


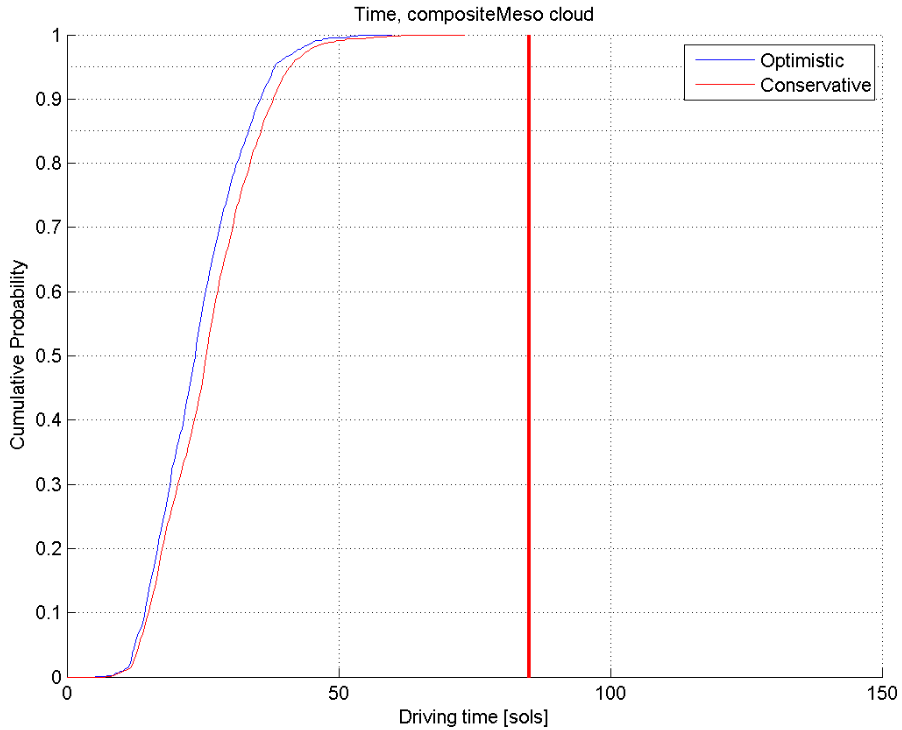

- Distance is a map distance with no added distance for slip or path inefficacy
- Slip/path inefficiency added to time

# Cumulative Distribution Functions



## JEZ (low uncertainty)



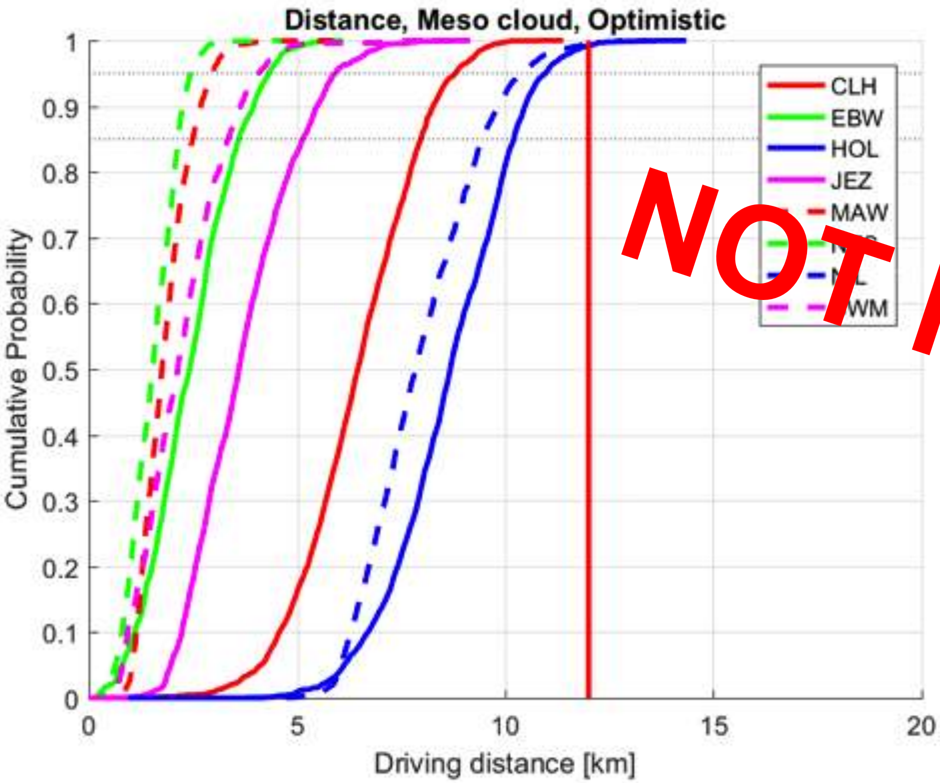




- Distance is a map distance with no added distance for slip or path inefficacy
- Slip/path inefficiency added to time

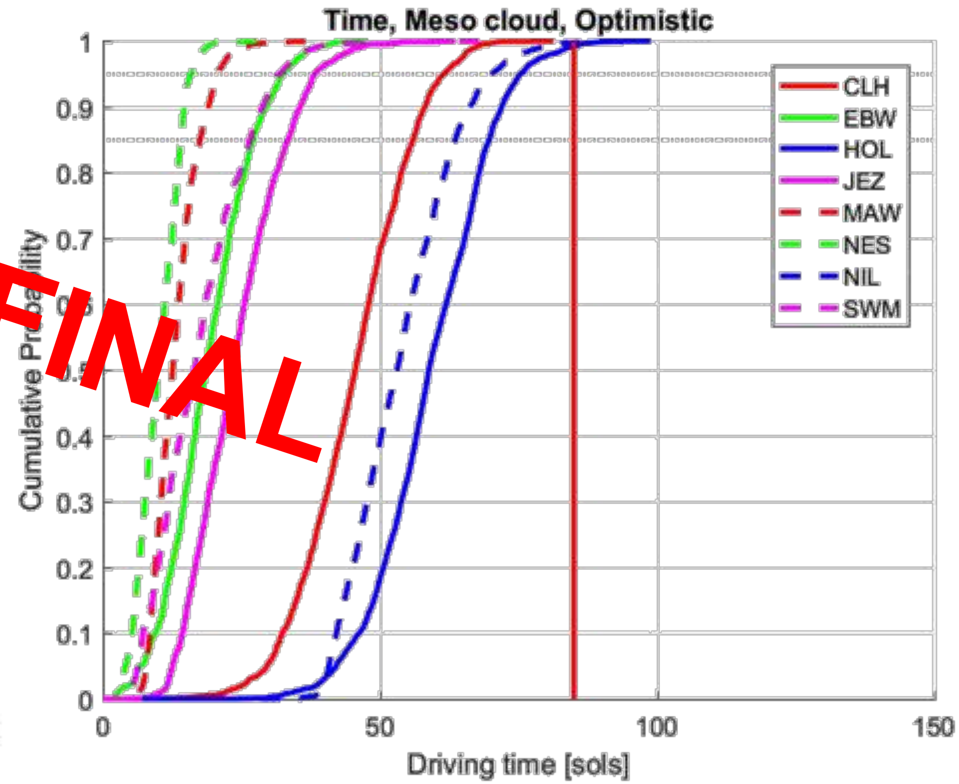
# CDF for All Sites (Optimistic)



## Distance




## Time

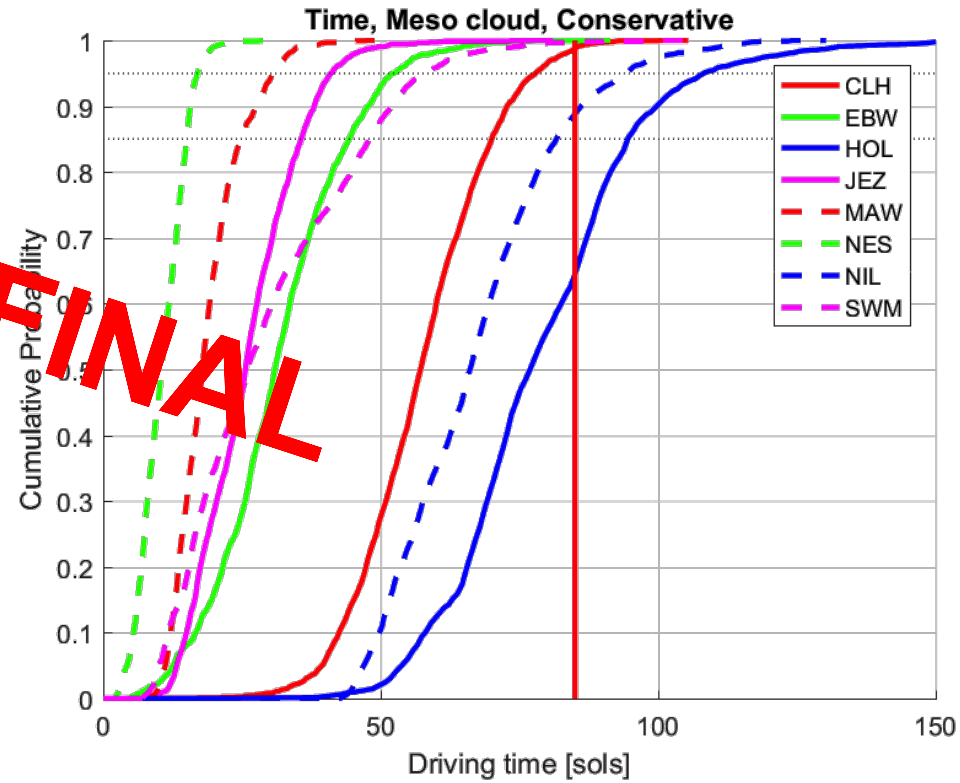


# CDF for All Sites (Conservative)



## Distance


## Time



# Terrain Class Distribution (Optimistic)

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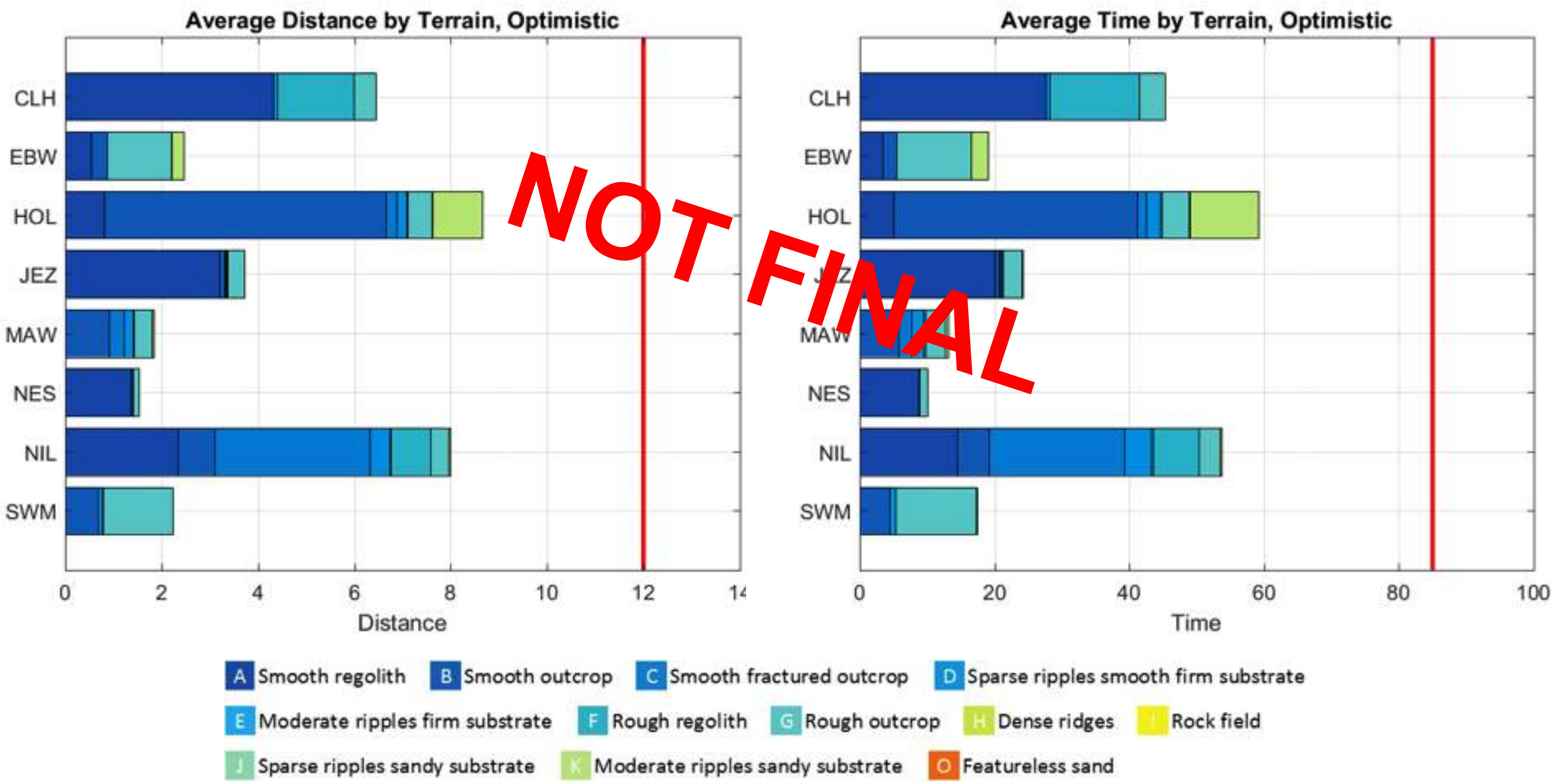
Distance | Time



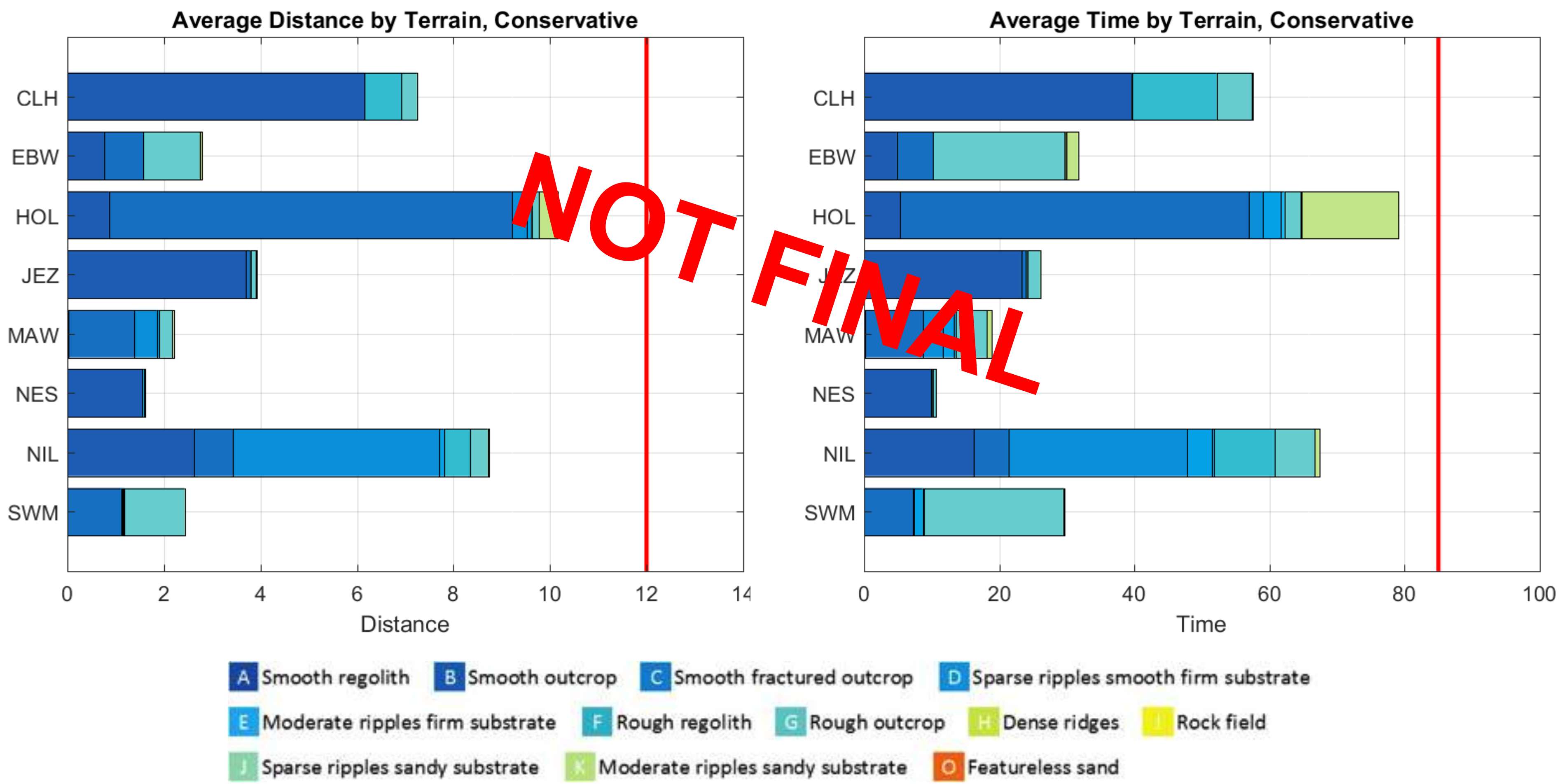
# Terrain Class Distribution (Conservative)

Jet Propulsion Laboratory
California Institute of Technology

**Mars 2020** Project

## Distance

## Time



# Site Specific Analysis

# Site Specific Analysis

A series of meetings with the site proposers, project science, EDL, and mission system representatives in an attempt to build consensus on the following

- **Region Of Interest (ROI) definition**: Do we all agree on what constitutes an ROI and that all the areas labeled as an ROI would be sufficient for the science of the mission?
- **What ROIs to visit**: Do we agree on the set of ROIs we need to visit to get the science we want in the prime mission?
- **Scenario modeling**: What would we do for exploration at the ROIs to achieve the mission objectives? Where do we sample? How much time do we spend at the various ROIs?
- **Ellipse placement**: Do we have the ellipse in the right location to minimize risk and maximize science return?
- **Seasonal dependencies**: How do the seasonal variations impact the mission scenario?

# Coordinating with Site Proposers

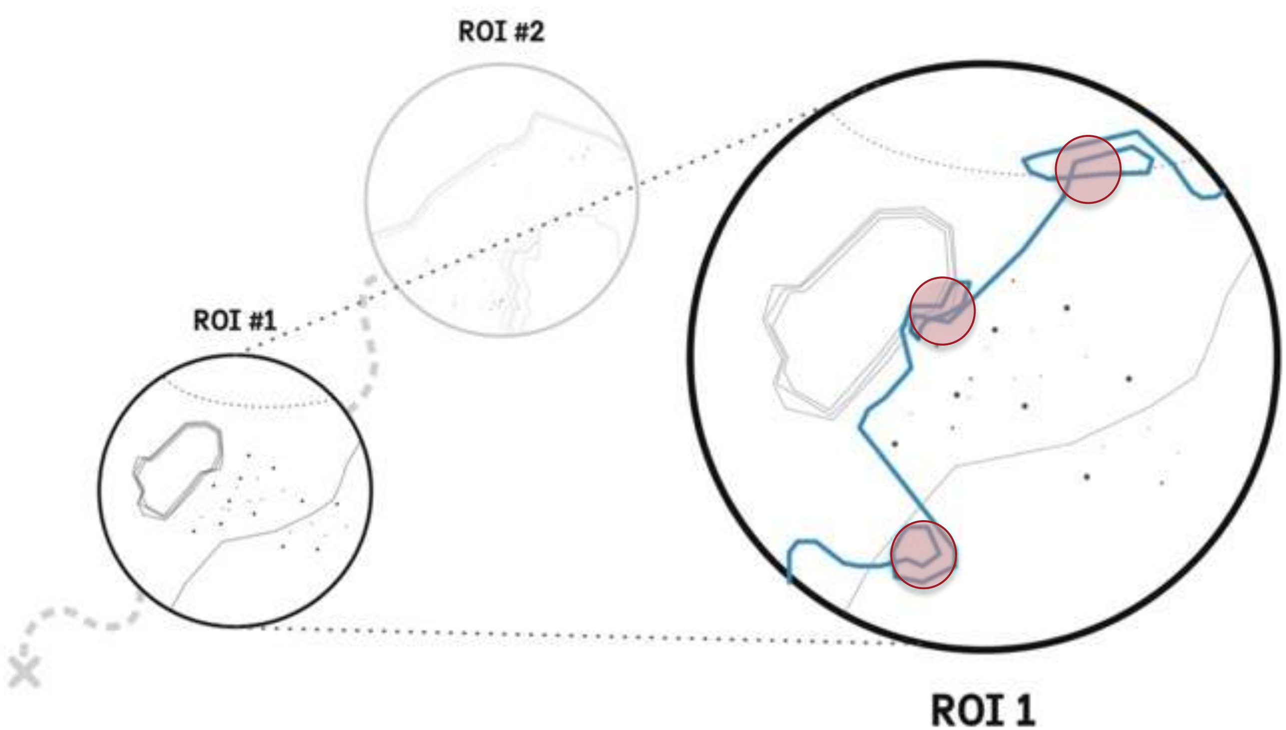


- Resulted in a collaborative relationship with the proposers where we can balance landing and traversability constraints with science objectives
- We head in to Landing Site Workshop #3 with everyone in agreement on the objectives of the mission at each site and the criteria of the traversability analysis

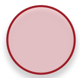
# ROIs and Campaigns



- Region of Interest (ROI) is an area, identified from orbit, that contains geological features and units aligned with mission objectives
  - Contains many discrete areas that we would want to study in further detail
- A campaign is a focused area of detailed study over ~100 m diameter area within an ROI
- The complexity of the campaign is a function of the number of geological units we would explore*




*A geological unit is a volume of rock that is mappable and distinct from another volume of rock



# Waypoints

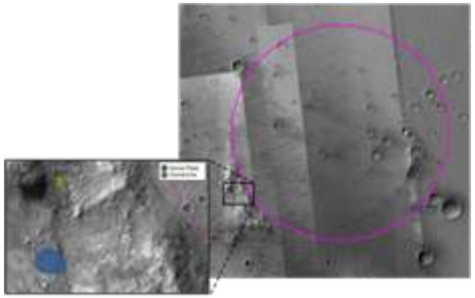


- A Waypoint is abbreviated campaign where we collect a single sample with limited supporting science observations
  - Rock Waypoint
  - Regolith Waypoint
- Many waypoints are for the collection of samples that are ubiquitous throughout the ellipse. These types of waypoints will be done opportunistically and will not be used as input to the design of the strategic traverse route
- Some waypoints are at specific predefined locations and these are factored in to the design of the traverse route

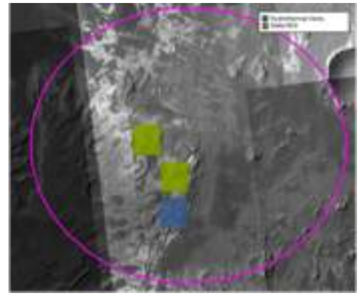
# Site-Specific ROI Locations

**https://wiki.jpl.nasa.gov/display/MSMFS/Landing+Site+Traversability**

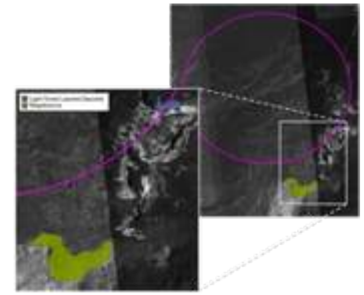
Columbia Hills



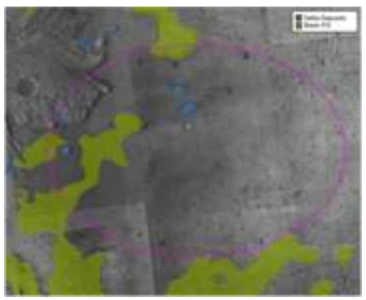
Eberswalde



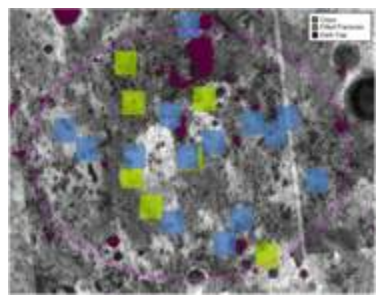
Holden



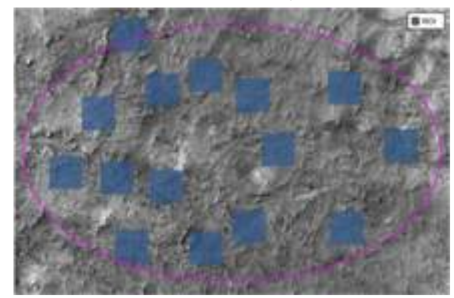
Jezero



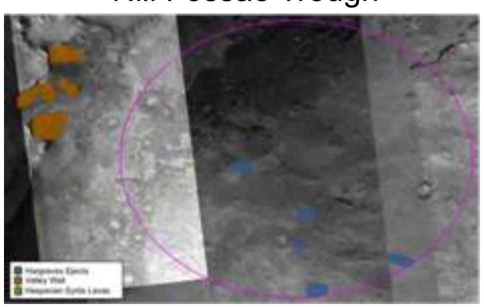
Mawrth



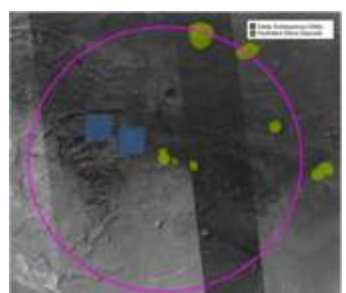
Northeast Syrtis



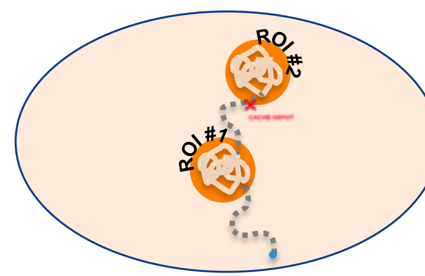
Nili Fossae Trough



Southwest Melas

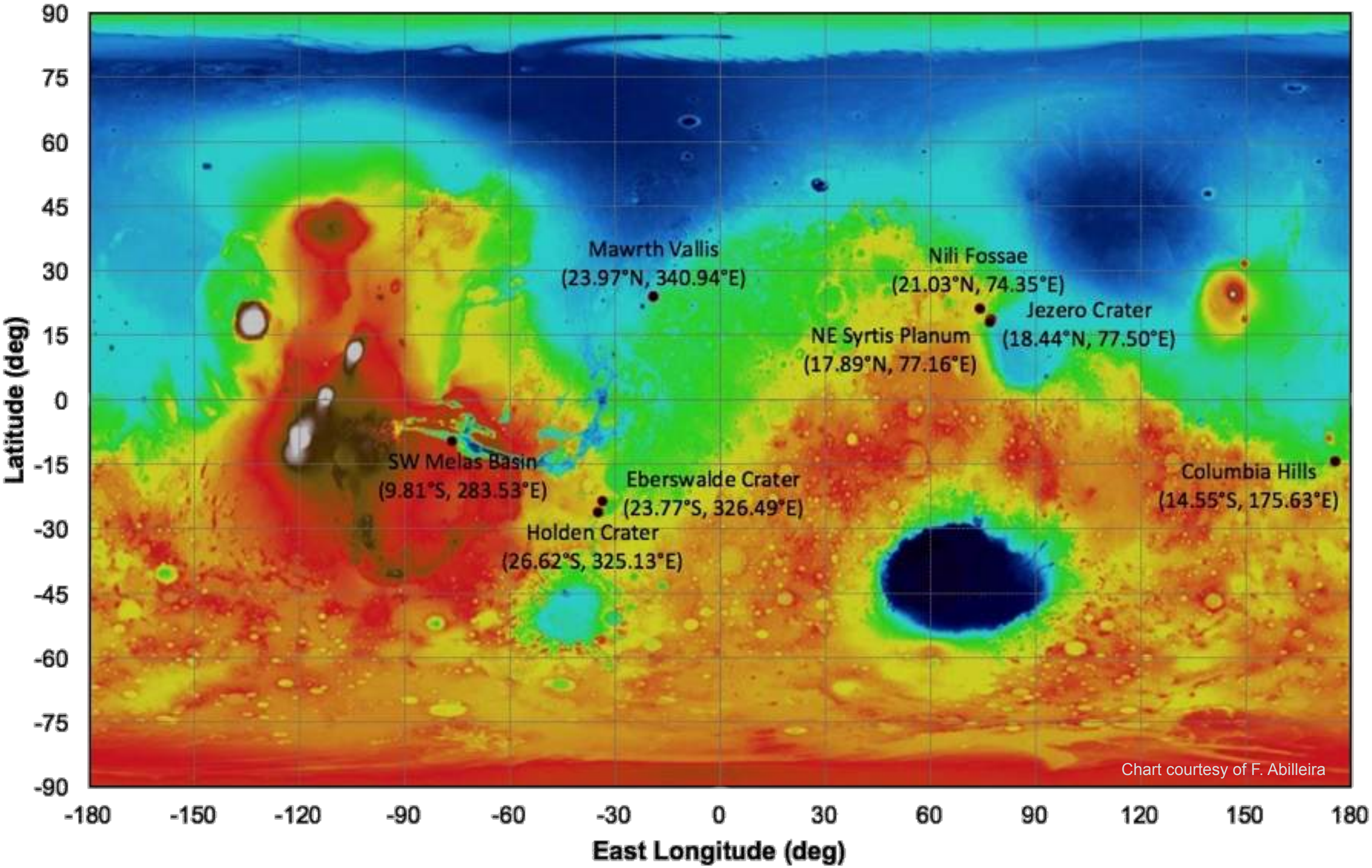


Baseline Reference Scenario



# Landing Site Tour





# Scientific Rationale for CLH ROIs

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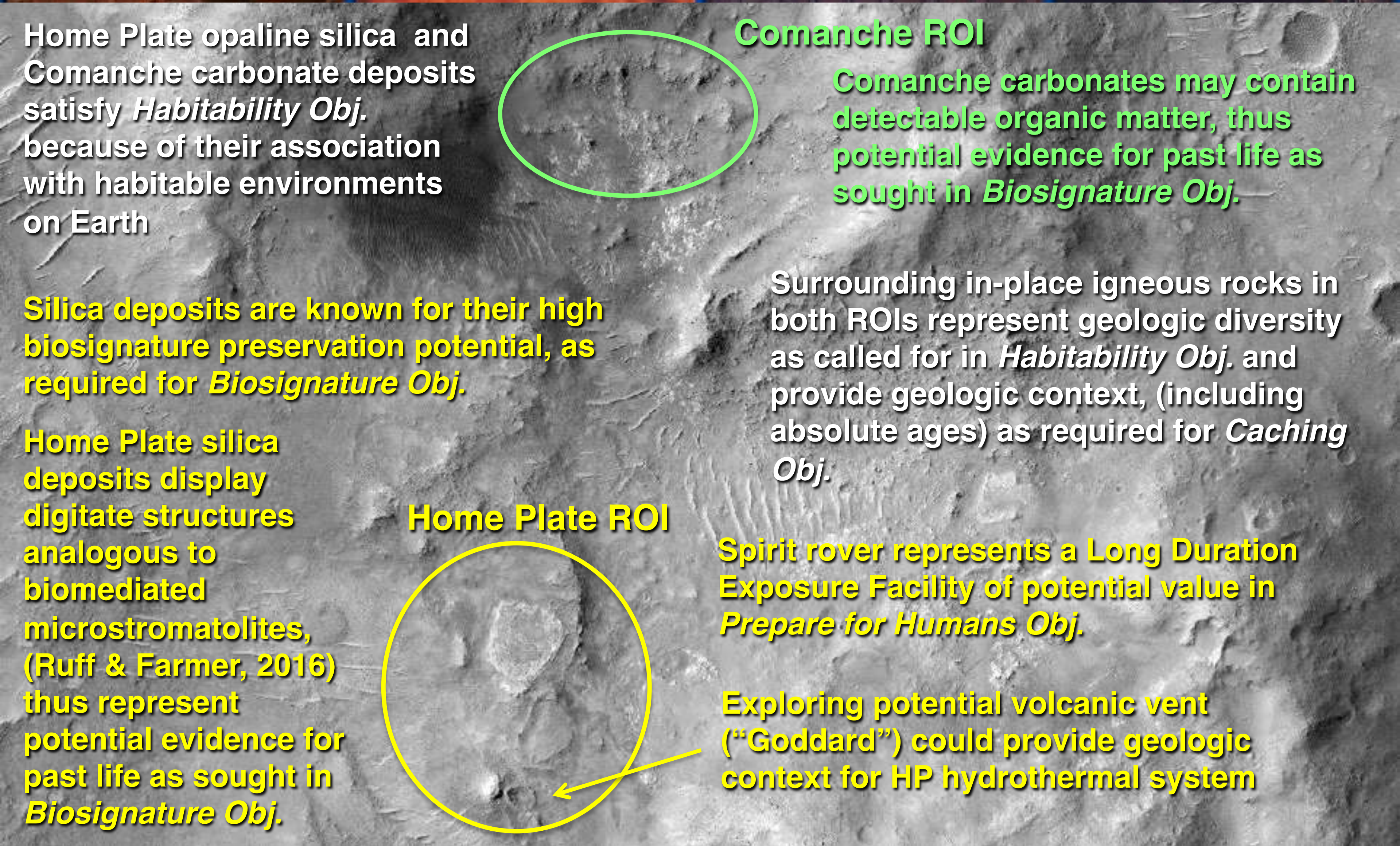
Science Objective A: **HABITABILITY** | Science Objective B: **BIOSIGNATURES** | Science Objective C: **SAMPLE CACHING** | Science Objective D: **PREPARE FOR HUMANS**




**Home Plate opaline silica and Comanche carbonate deposits satisfy *Habitability Obj.* because of their association with habitable environments on Earth**

**Comanche carbonates may contain detectable organic matter, thus potential evidence for past life as sought in *Biosignature Obj.***

**Silica deposits are known for their high biosignature preservation potential, as required for *Biosignature Obj.***

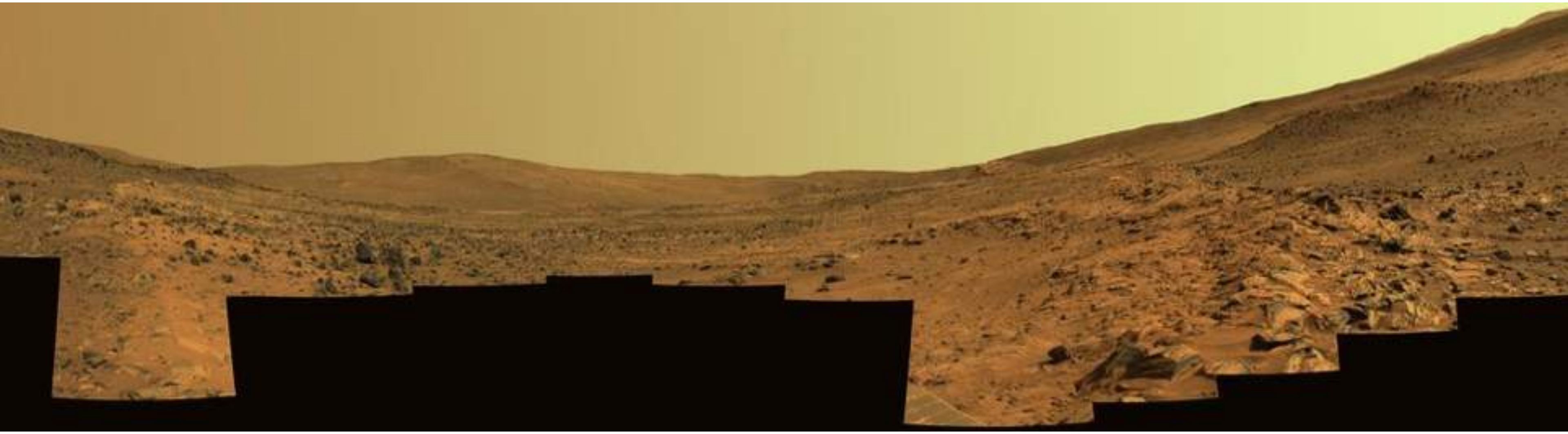
**Surrounding in-place igneous rocks in both ROIs represent geologic diversity as called for in *Habitability Obj.* and provide geologic context, (including absolute ages) as required for *Caching Obj.***

**Home Plate silica deposits display digitate structures analogous to biomediated microstromatolites, (Ruff & Farmer, 2016) thus represent potential evidence for past life as sought in *Biosignature Obj.***

**Spirit rover represents a Long Duration Exposure Facility of potential value in *Prepare for Humans Obj.***

**Exploring potential volcanic vent ("Goddard") could provide geologic context for HP hydrothermal system**

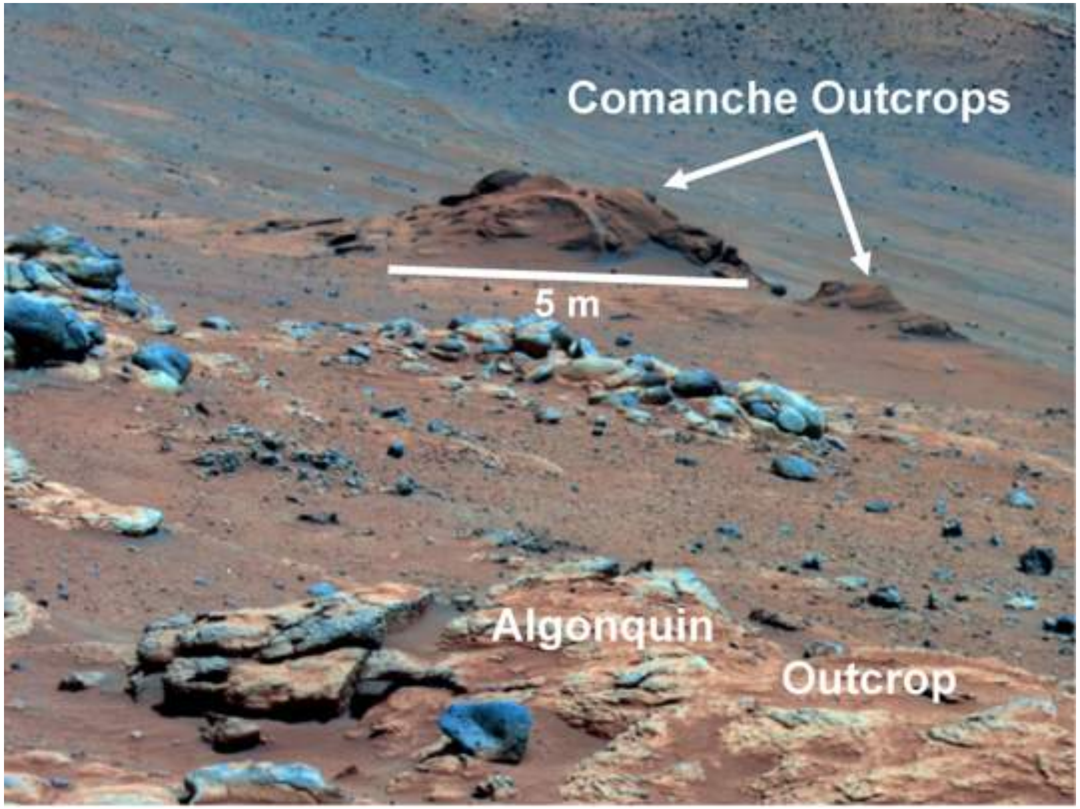
# Home Plate



Spirit panorama from the top of Home Plate taken on sol 758.
http://mars.nasa.gov/mer/gallery/press/spirit/20060306a.html

The small outcrops of opaline silica known to be concentrated on the east site of the Home Plate feature are a “must visit” target given their astrobiological significance. Other candidates occur to the west and south of Home Plate, but these were not visited by Spirit so are speculative at this point.

# Comanche



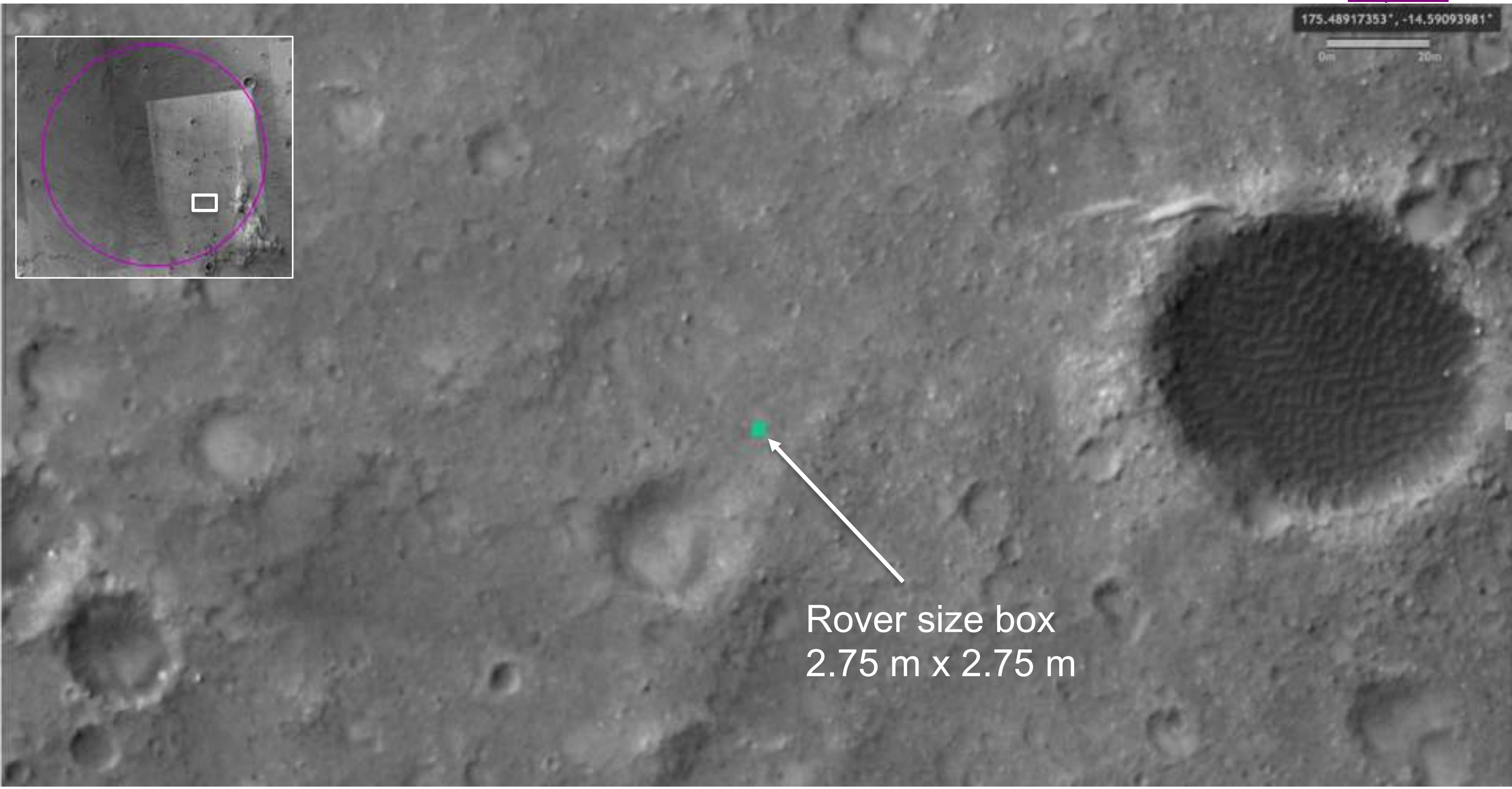

Spirit rover view of the Comanche outcrop from sol 689
http://mars.nasa.gov/mer/gallery/press/spirit/20100603a.html

Comanche carbonate outcrops: These also are "must visit" targets because the carbonate minerals preserve evidence of the ancient aqueous environment in which they formed.

# Key Characteristics

Overall the site is smooth regolith with many impact craters and ejecta.
Some sand filled craters, but they are identifiable from orbit and avoidable.

Map link



# Key Challenges

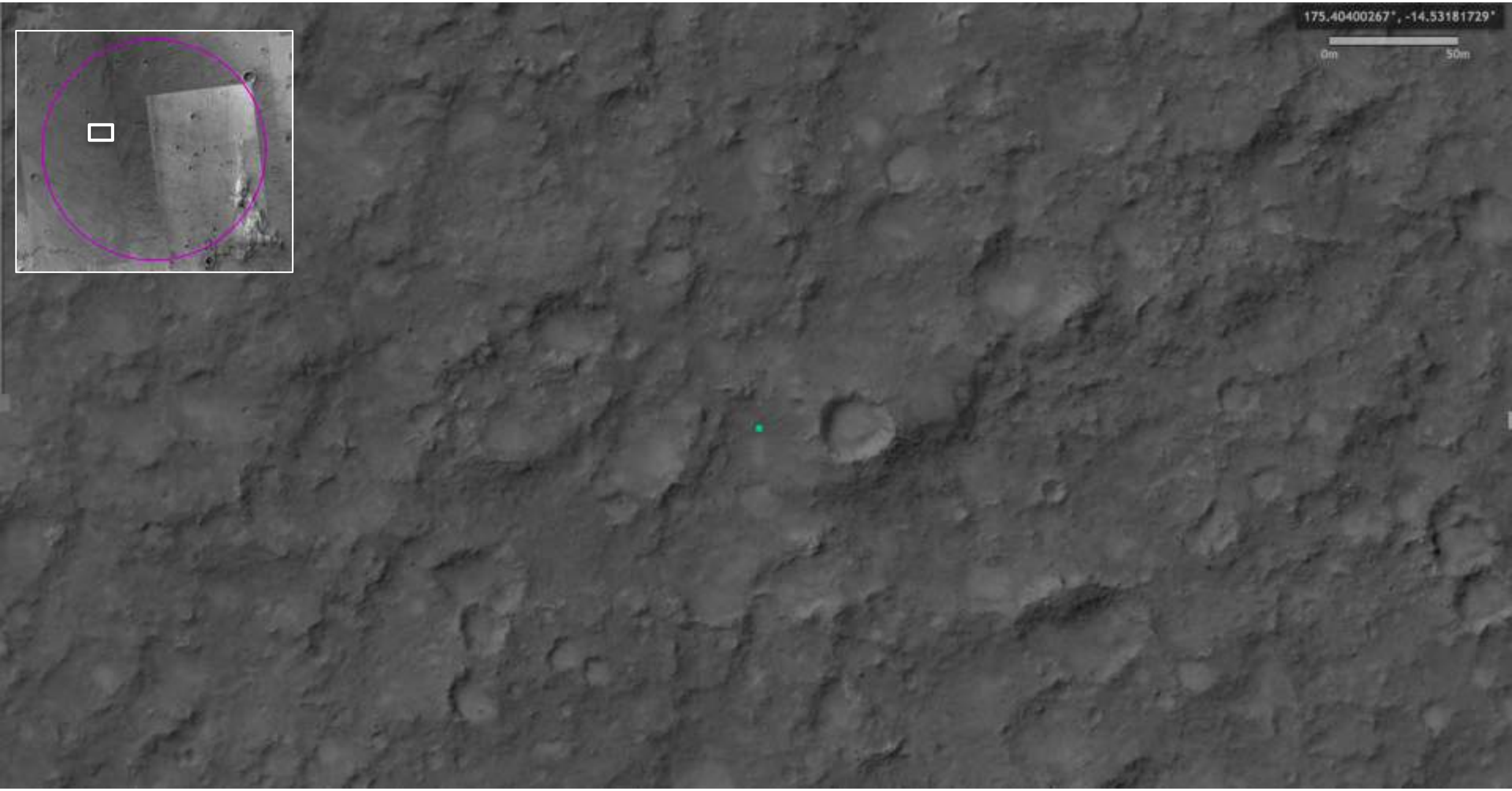






Many areas with undulating terrain that may affect viewshed and may require longer traverse routes.

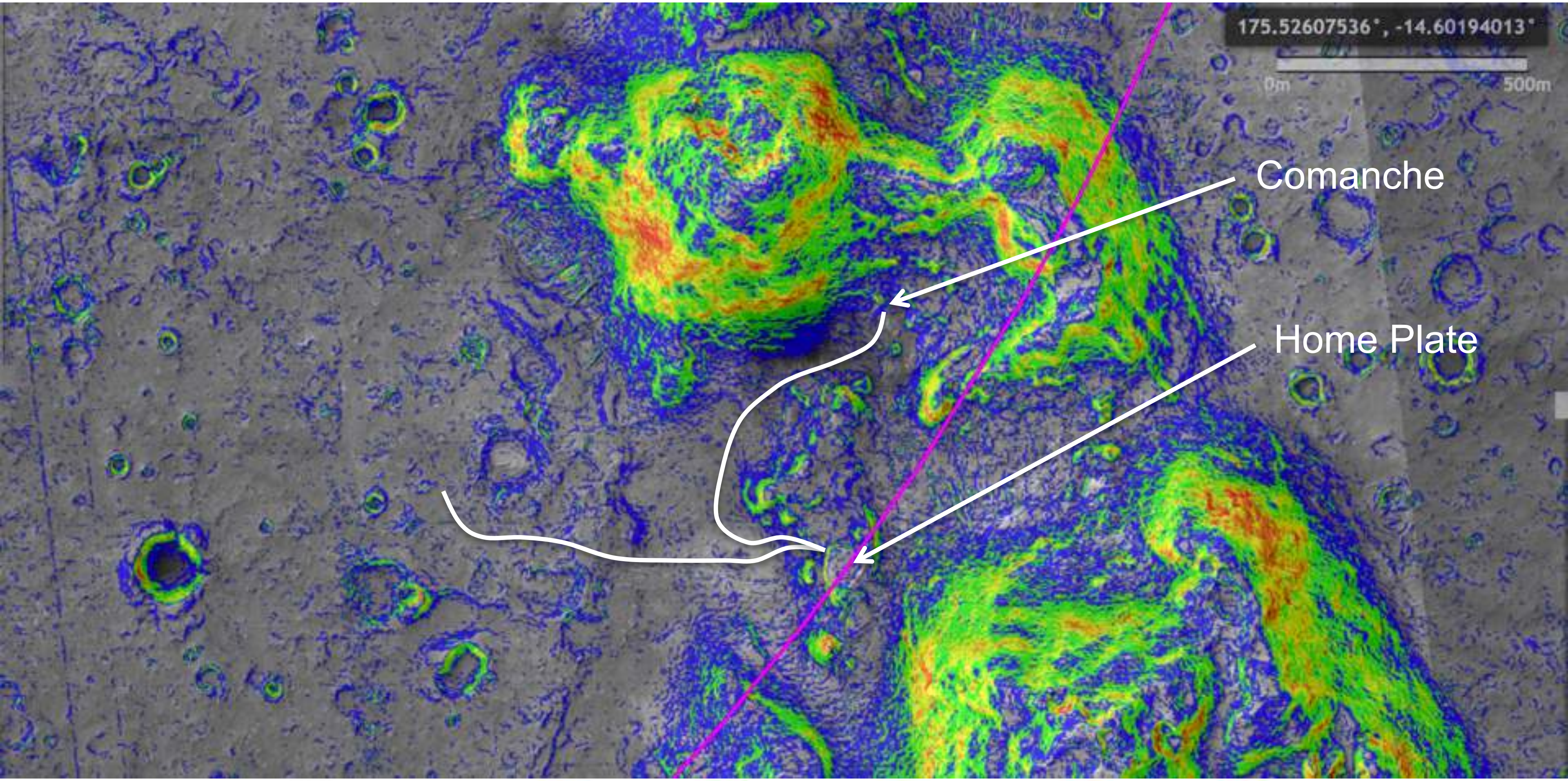
Map link



# Through the Columbia Hills



ROIs are easily reachable without the need to traverse over significant slopes at the Columbia Hills




<5° or no data | 5°-10° | 10°-15° | 15°-20° | 20°-25° | ≥ 25°

Example routes shown for illustrative purposes only

# Through the Columbia Hills

CLH

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California Institute of Technology

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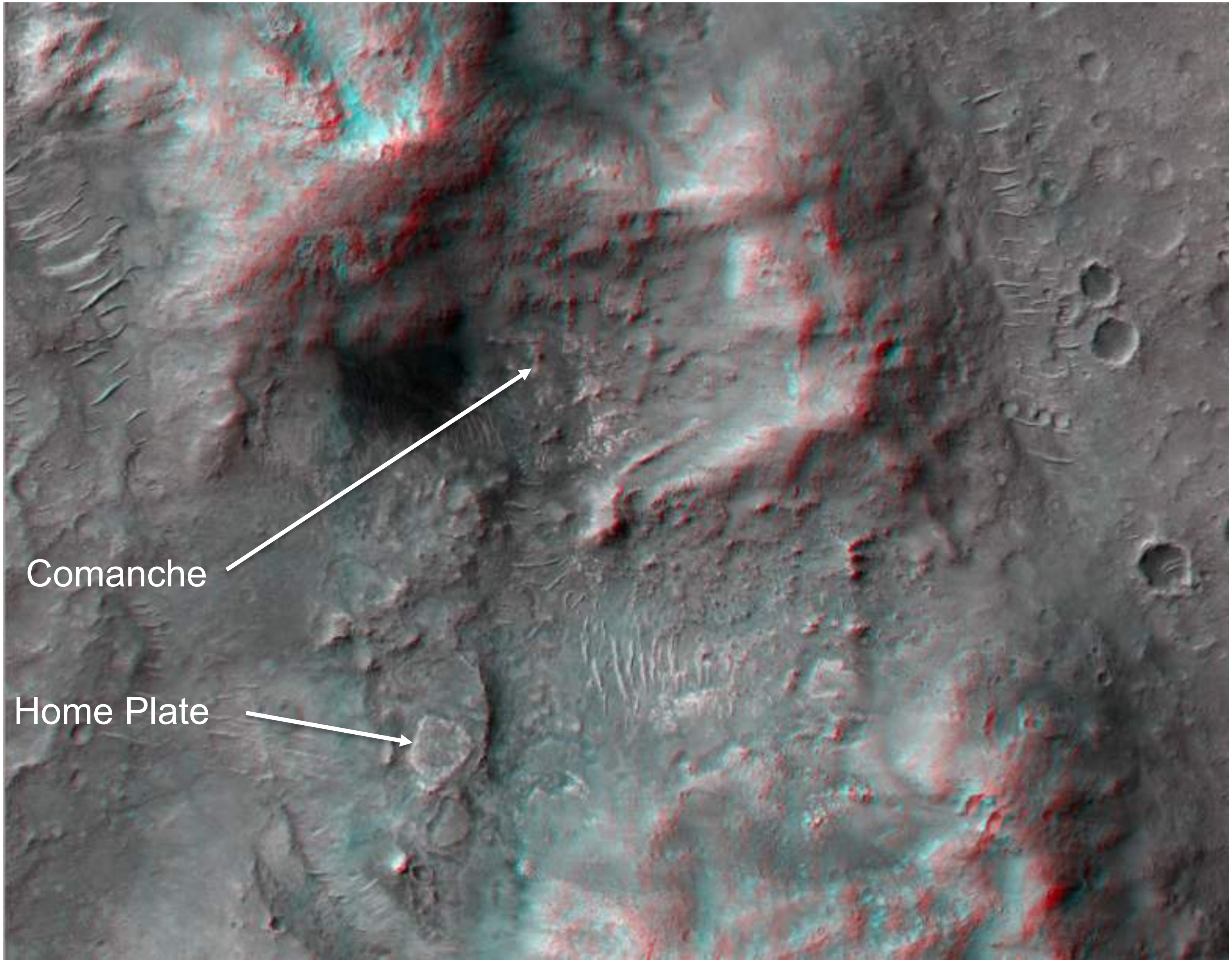


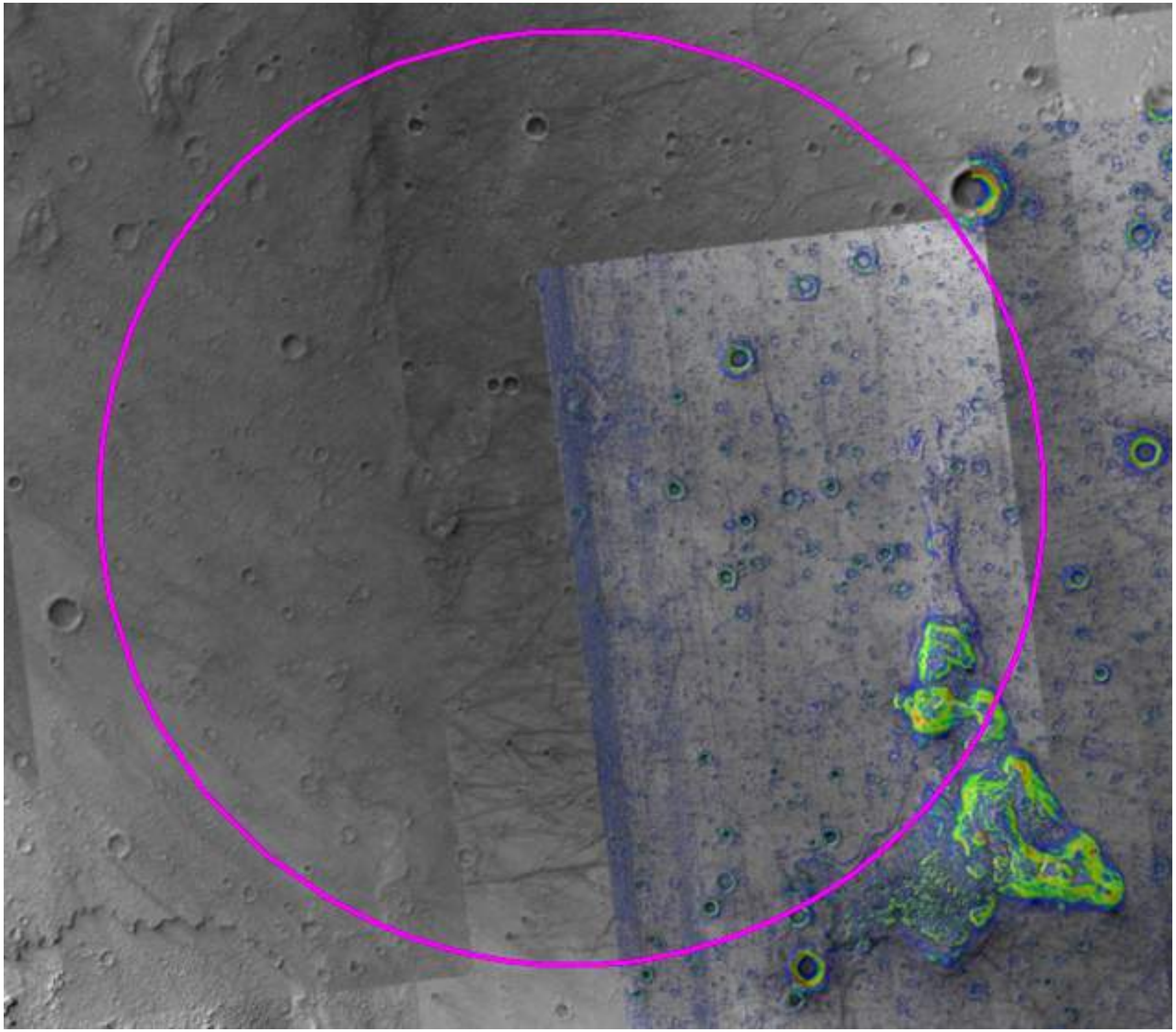
# Slope Map



Sparse slope coverage

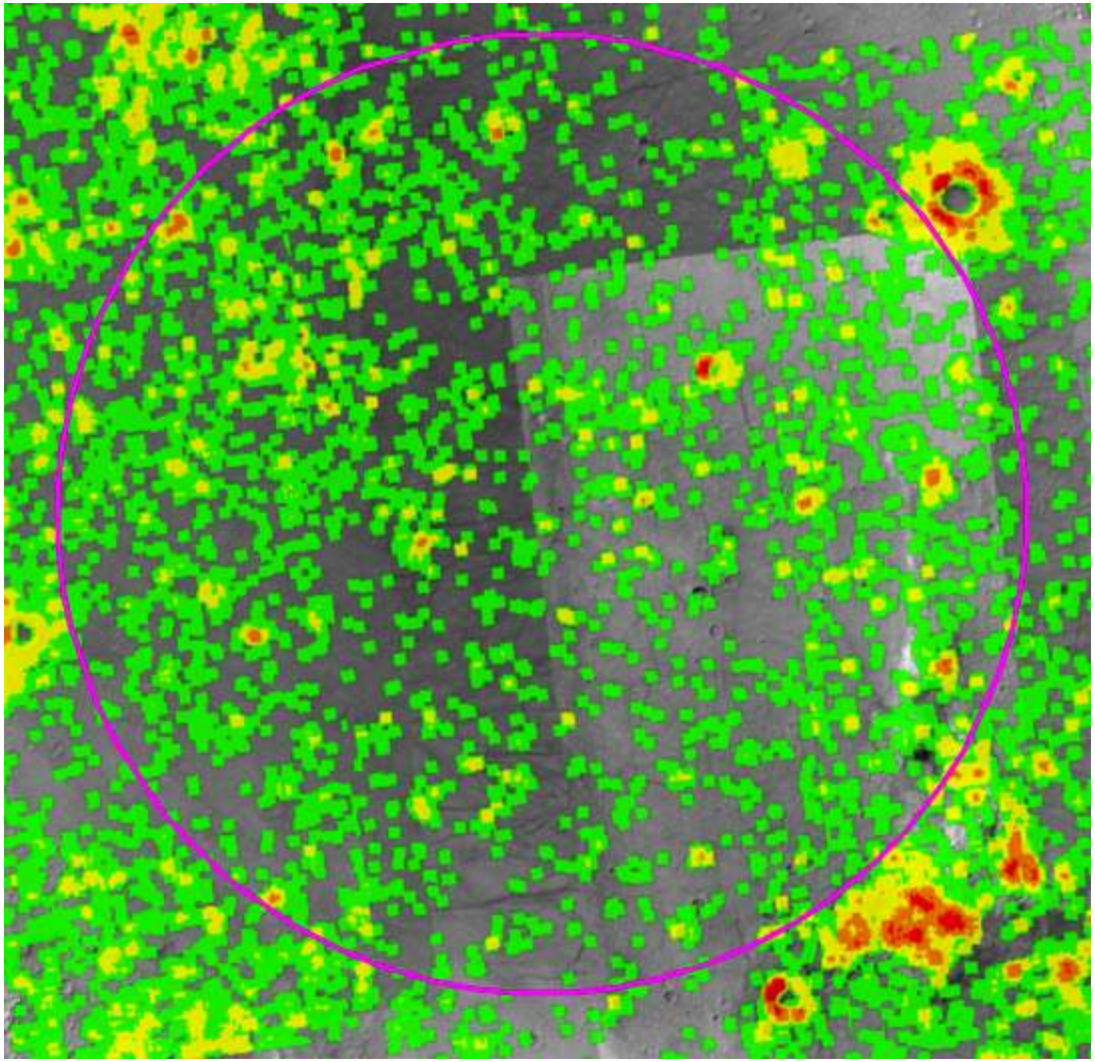
HiRISE images are in the queue for acquisition & processing if this site moves to the next round

No significant slope concerns



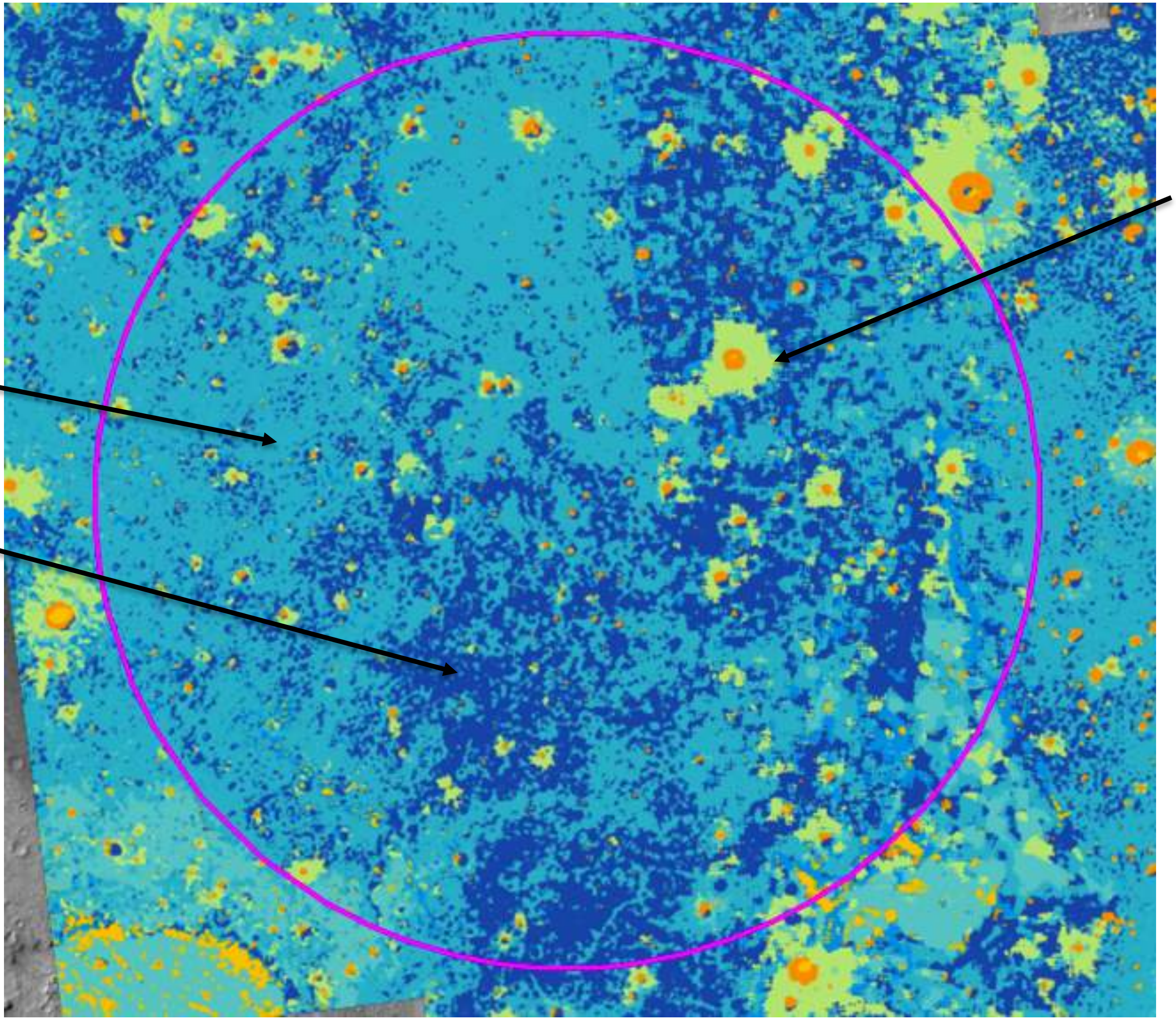
# Rock Map

No significant rock concerns



<7% or no data | 7%-10% | 10%-15% | 15%-20% | >=20%

# Terrain Classification



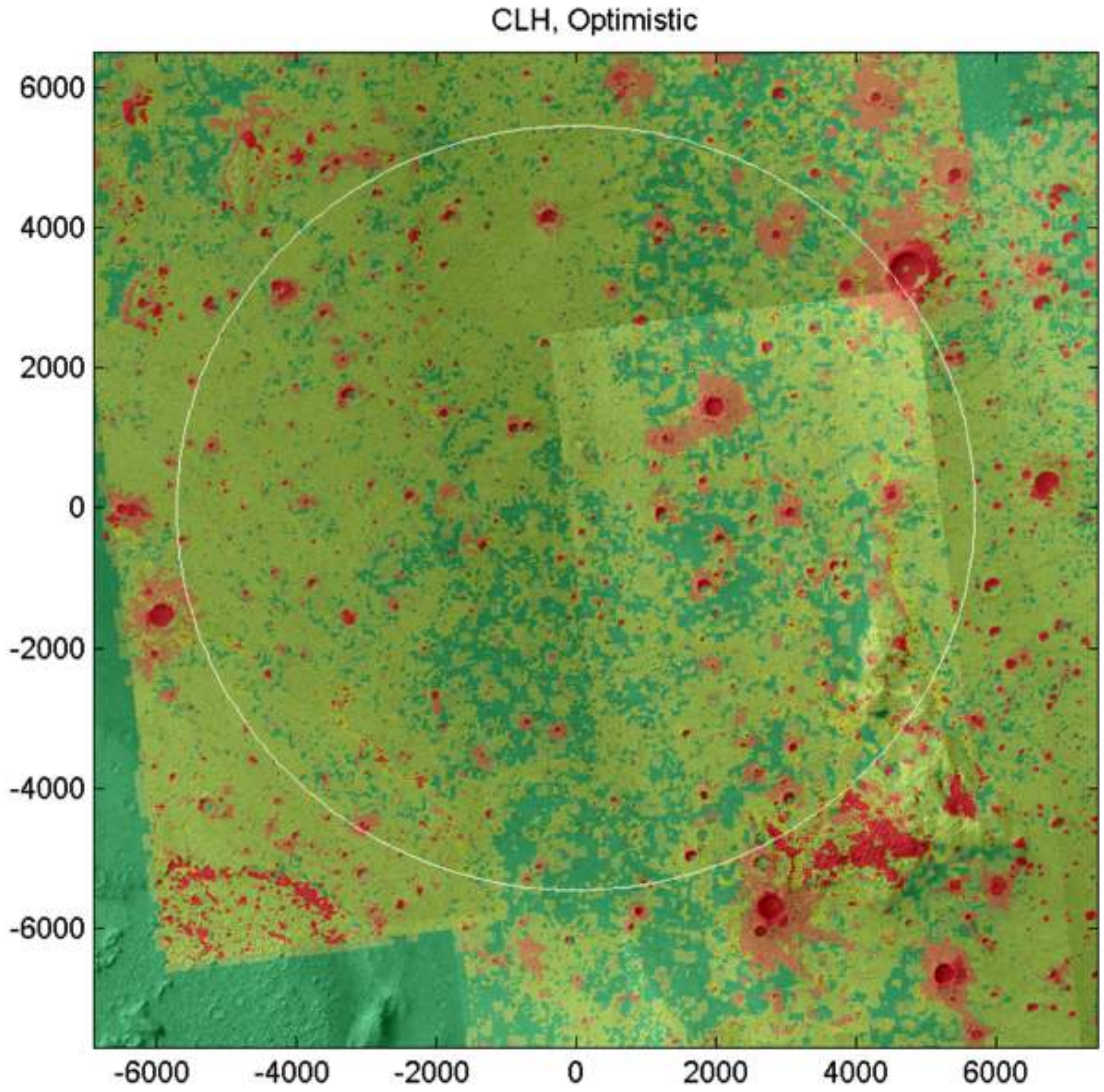
Rock fields

Rough regolith

Smooth regolith

# Traversability Map






Benign

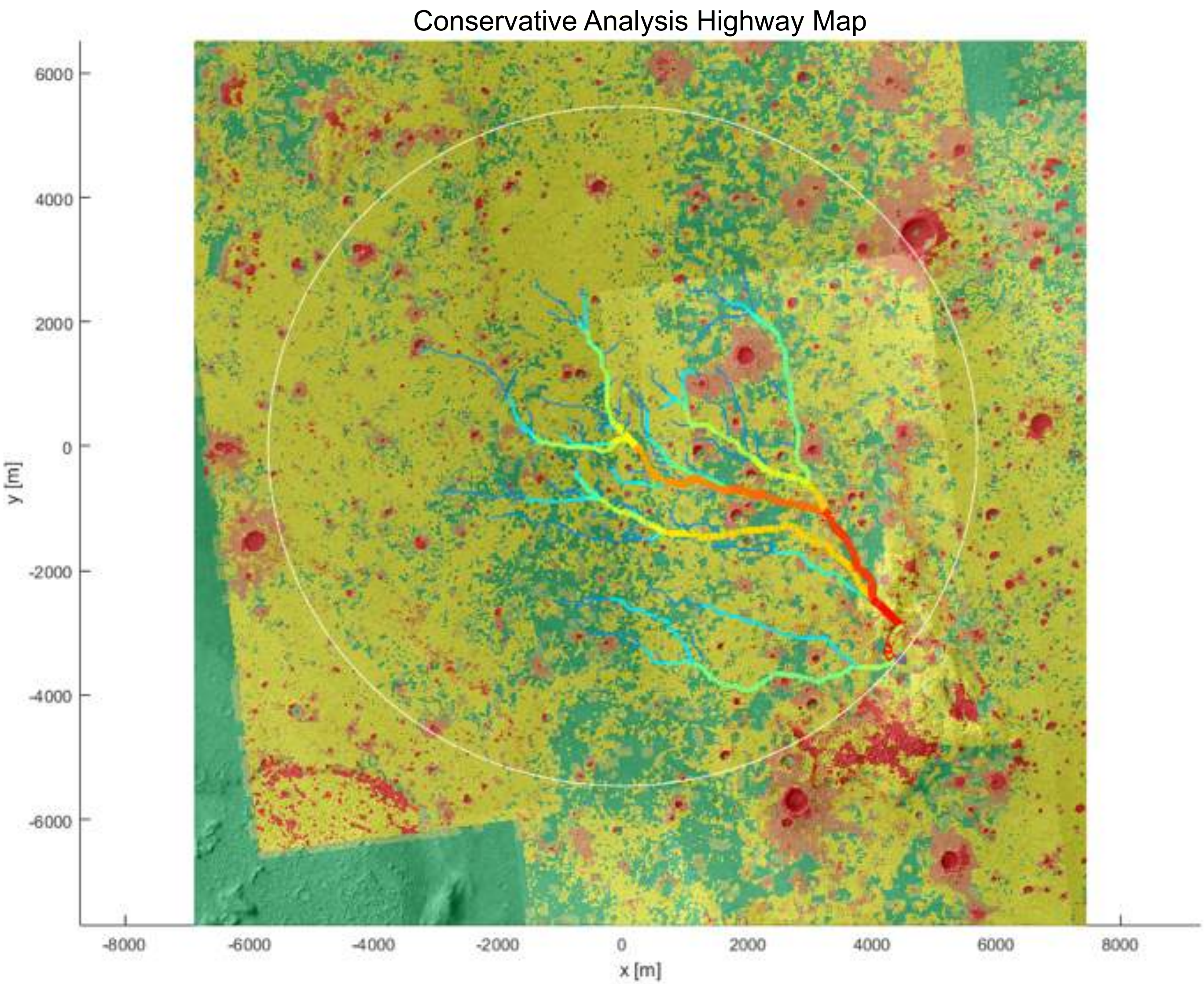
Complex

Blind drive only

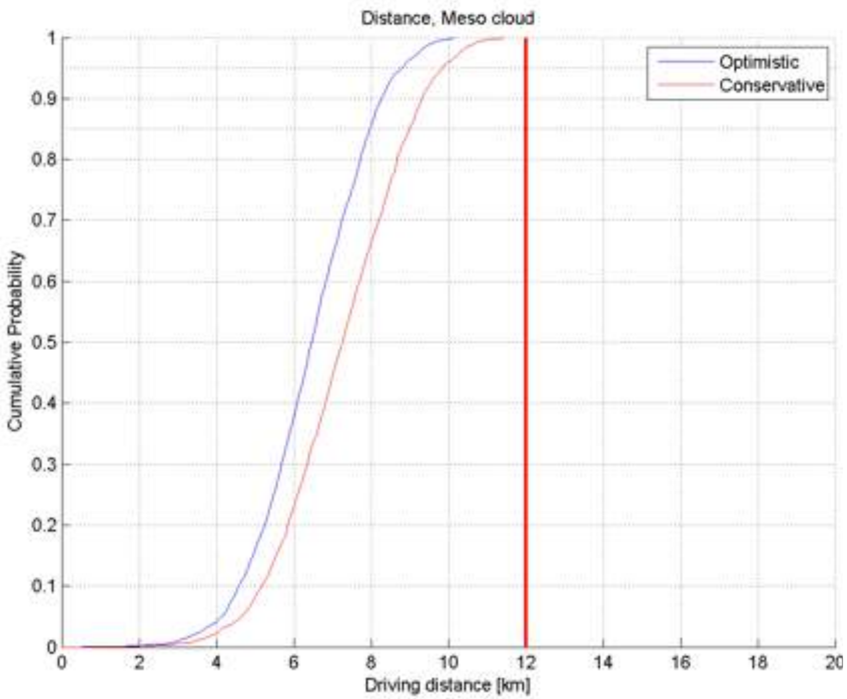
Untraversable

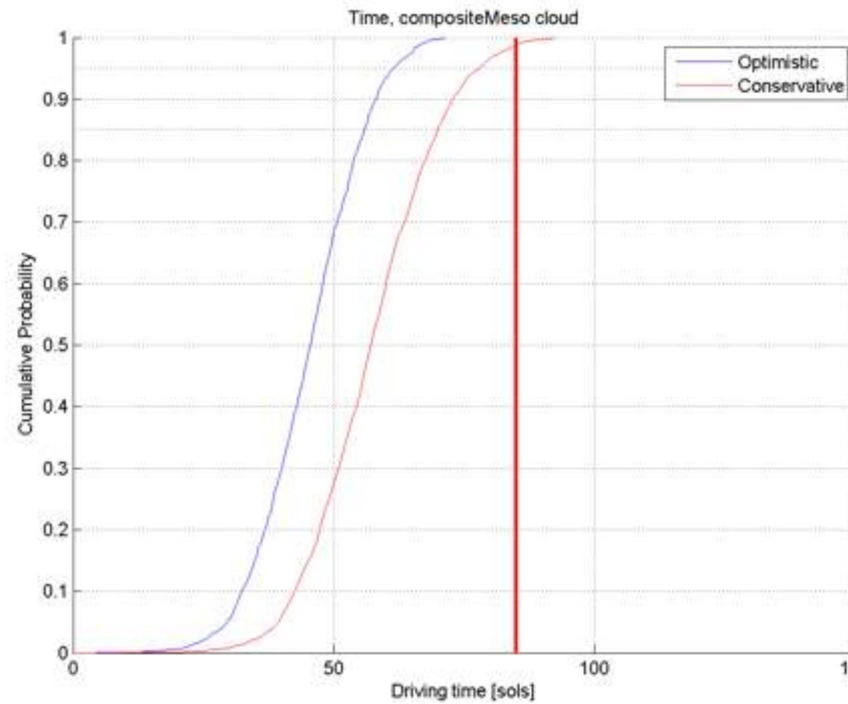
# Highway Map




Conservative Analysis Highway Map
6000
4000
2000
0
-2000
-4000
-6000
y [m]
-8000
-6000
-4000
-2000
0
2000
4000
6000
8000
x [m]

# Traverse Analysis Results




**Distance**

| Drive rate assumption | 50% | 80% | 85% | 90% | 95% |
|---|---|---|---|---|---|
| Optimistic | 6.5 km | 7.8 km | 8.0 km | 8.3 km | 8.8 km |
| Conservative | 7.3 km | 8.7 km | 9.0 km | 9.3 km | 9.9 km |

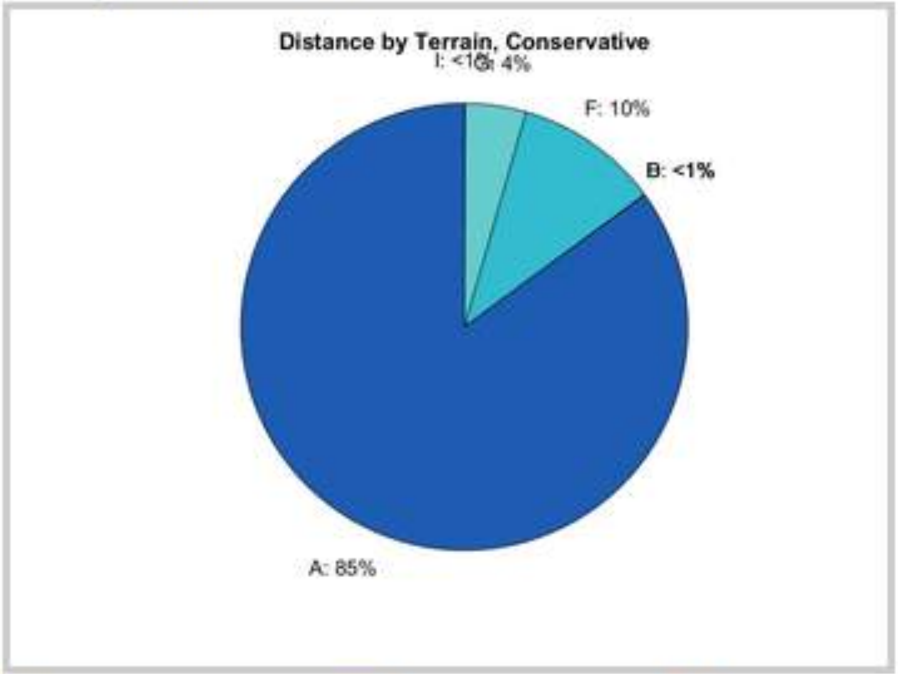
**Time**

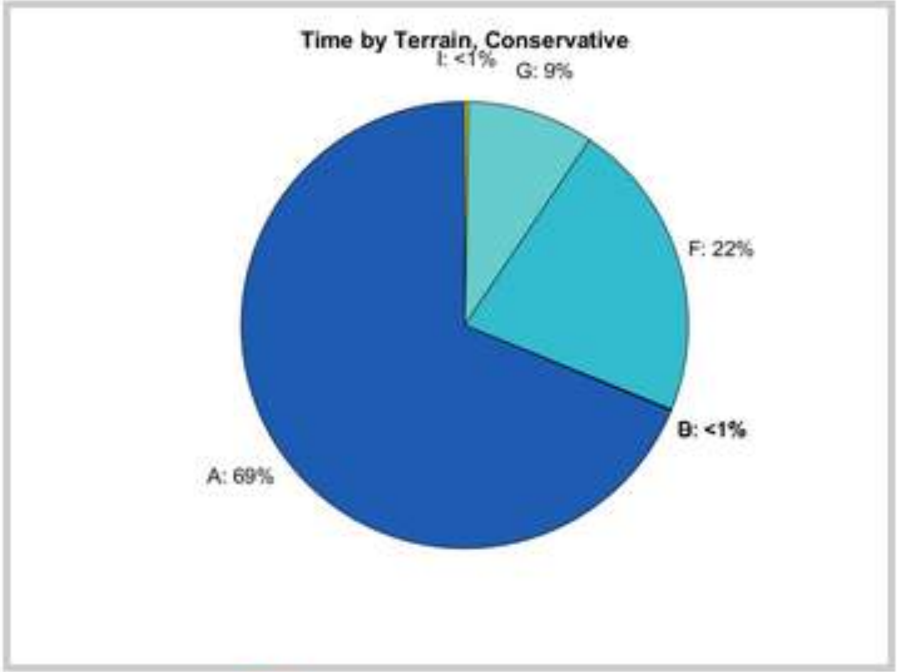
| Drive rate assumption | 50% | 80% | 85% | 90% | 95% |
|---|---|---|---|---|---|
| Optimistic | 45.7 sols | 54.2 sols | 56.1 sols | 58.4 sols | 61.9 sols |
| Conservative | 57.2 sols | 67.8 sols | 70.3 sols | 72.8 sols | 78.3 sols |

Assumes 2.5 hours of dedicated drive time per sol
85 sols is the portion of the mission allocated to traversing between ROIs

# Terrain Type Breakdown

**Conservative**
Average Distance: 7.2 km
Average Time: 57.6 sols



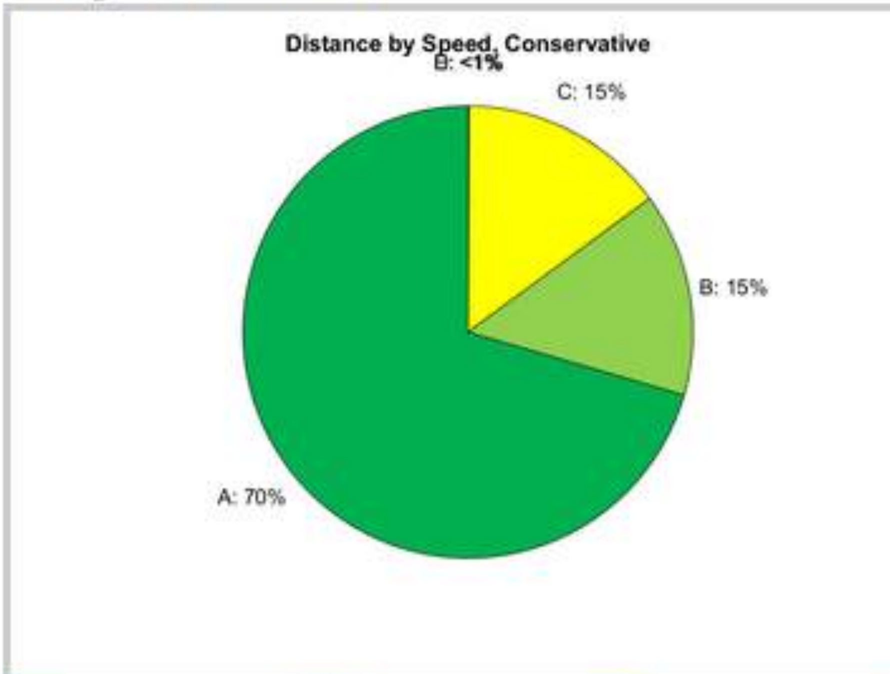

A Smooth regolith | B Smooth outcrop | C Smooth fractured outcrop | D Sparse ripples smooth firm substrate
E Moderate ripples firm substrate | F Rough regolith | G Rough outcrop | H Dense ridges | I Rock field
J Sparse ripples sandy substrate | K Moderate ripples sandy substrate | O Featureless sand

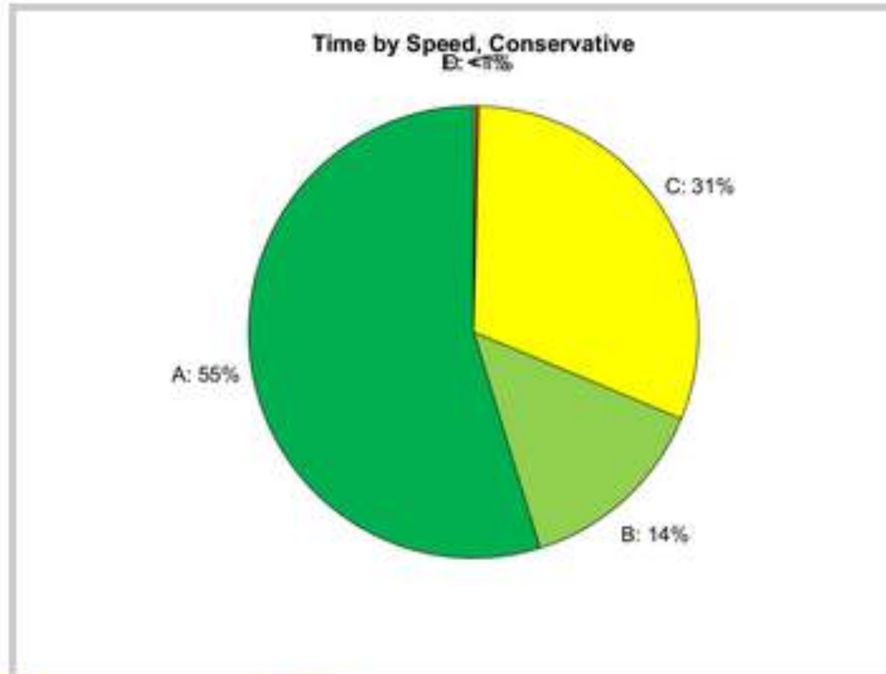
# Drive Rate Breakdown

**Conservative**

Average Distance: 7.2 km

Average Time: 57.6 sols




A 64.8 m/hr B 52.5 m/hr C 24.2 m/hr D 10.9 m/hr E 8.7 m/hr

# Environmental Conditions



- Columbia Hills, located at Lat=14.6 S, experiences significant variability between hot and cold environments that exercise the range of expected rover design limits.
  - While the rover is designed to be capable of safely operating at bounding environments, there are consequences to overall surface performance when operating near bounding environment conditions.

- Columbia Hills summer and winter environments are nearly bounding. (Holden has the most extreme environment):
  - Hot summers, maximum ground temperature = 27.2 deg-C
  - very cold winters, minimum ground temperature = -105 deg-C
    - Absolute temperature is the coldest of all sites, but overall environment (daily max/min) is less extreme.

- **Survival heating and mechanism heat-to-use energy** needed during Columbia Hills cold winter season will negatively impact mission productivity.

- **Hardware overheat conditions** may exist during hot summer season, which could limit operations timing.

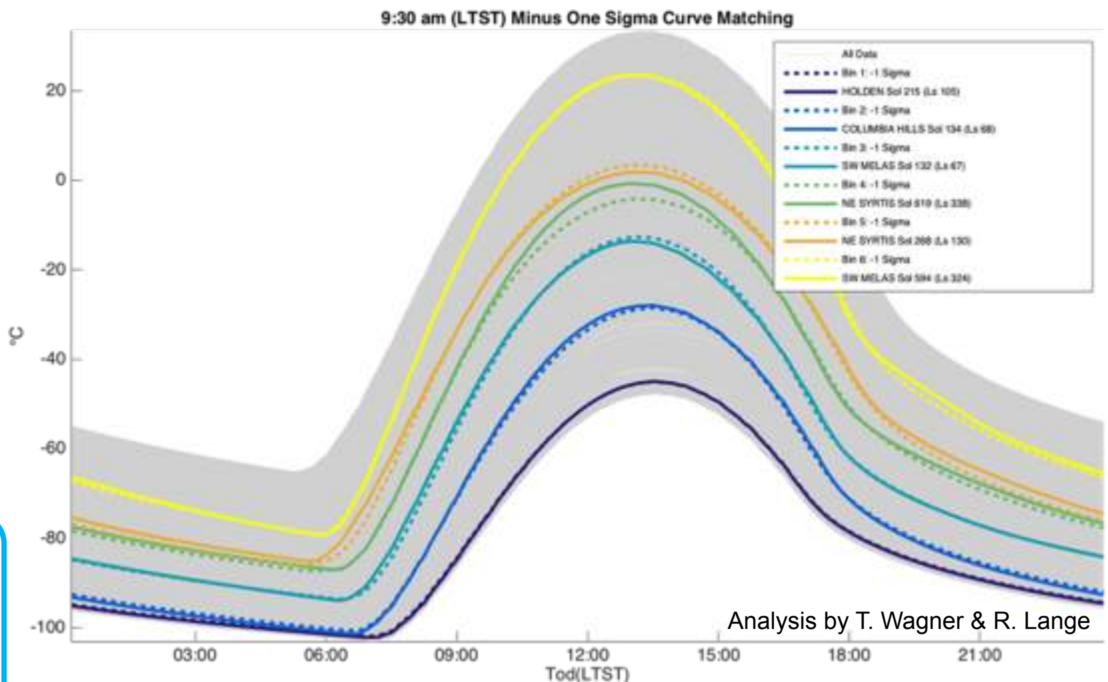
- More detailed analyses of the seasonal effects to operability and mission performance is in-progress…

# Environments & Thermal

- (opposite) 6 diurnal temperature profiles, optimized for 9:30 LTST, to use for modeling all sites throughout Mars year.
- (lower-right) Percentage of environment bin usage over 1-MY for each landing site, based on Sol ranges defined by curve-fit optimization.

**6 environments have been provided to Payload and Thermal teams for analysis on survival heating, mechanism heat to use, instrument warm-up and ops TOD info.**

- Results from thermal analysis of 6 environments will be ready by early October

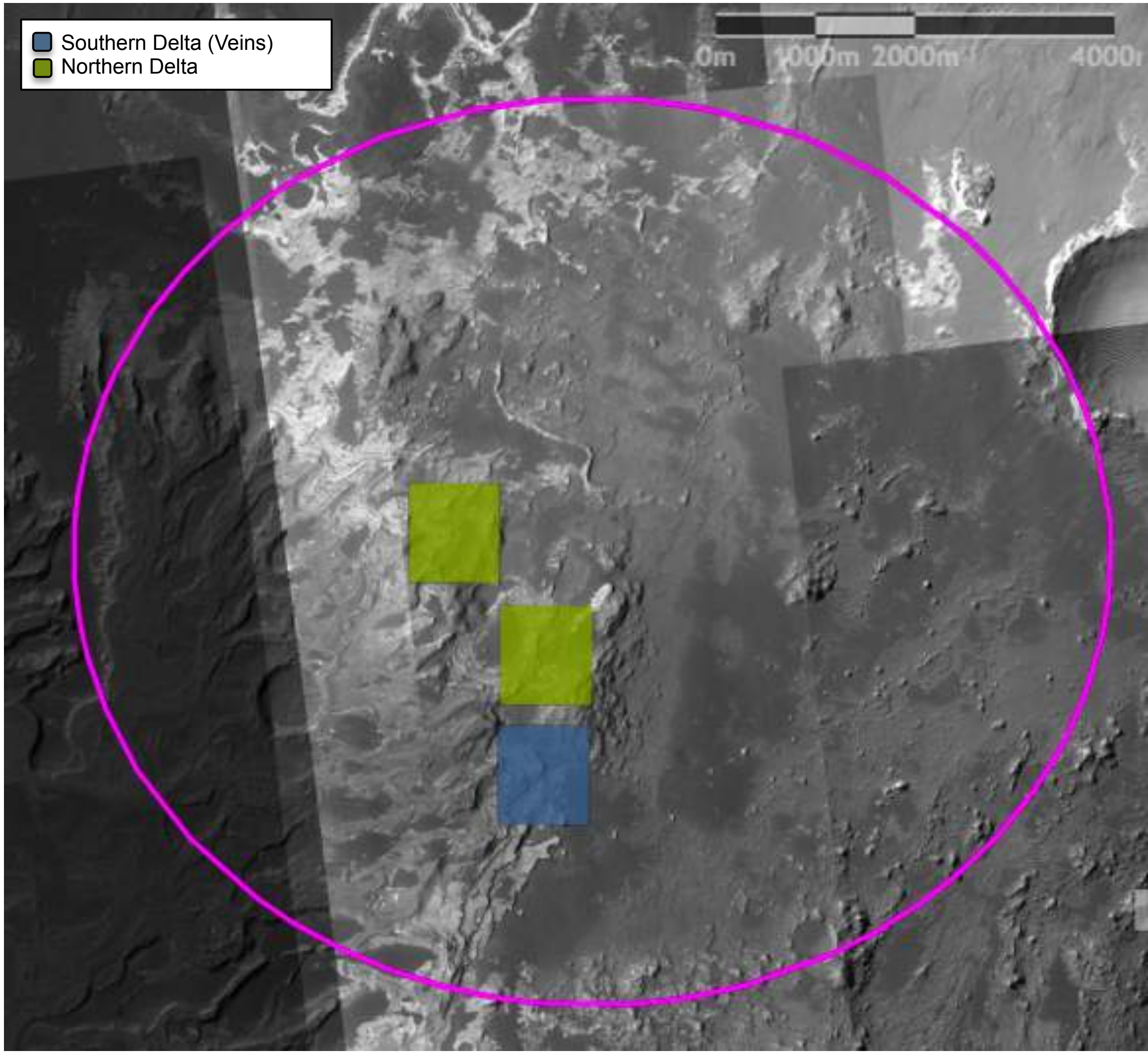



| | Bin: | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| 1 | Eberswalde | 24% | 16% | 13% | 8% | 12% | 28% |
| 2 | Columbia Hills | 0% | 33% | 16% | 11% | 18% | 21% |
| 3 | Holden | 29% | 14% | 11% | 8% | 11% | 27% |
| 4 | Jezero | 0% | 0% | 29% | 64% | 8% | 0% |
| 5 | Mawrth | 0% | 11% | 19% | 42% | 27% | 0% |
| 6 | NE Syrtis | 0% | 0% | 21% | 62% | 16% | 0% |
| 7 | Nili | 0% | 0% | 24% | 52% | 24% | 0% |
| 8 | SW Melas | 0% | 0% | 32% | 14% | 17% | 36% |

# Eberswalde

## Mission Scenario

- ROIs
  - Southern Delta (Veins)
    - **7 samples**
    - 2 Campaigns in the delta bottom set with 1 units each separated by 200 m
      - 5 delta bottom set samples
    - 1 Campaign in the vein / breccia area
      - 2 vein / breccia samples
  - Northern Delta
    - **7 samples**
    - 2 Campaigns in the delta bottom set with 1 units each separated by 200 m
      - 5 delta bottom set samples
    - 1 Campaign in the vein / breccia area
      - 2 vein / breccia samples
- Waypoints
  - Rock Waypoint (throughout ellipse)
    - **1 sample**
    - 1 rock waypoint on a knob or in the mantling unit
  - Regolith Waypoint (throughout ellipse)
    - **1 sample**
    - 1 regolith waypoint wherever a suitable sample is found along the traverse
- Procedural Blanks
    - **4 samples**



# Eberswalde ROI Science

To be provided by site proposers

# ROIs


Map link

ROIs are roughly 1 km x 1 km boxes that contain all of the following geological units

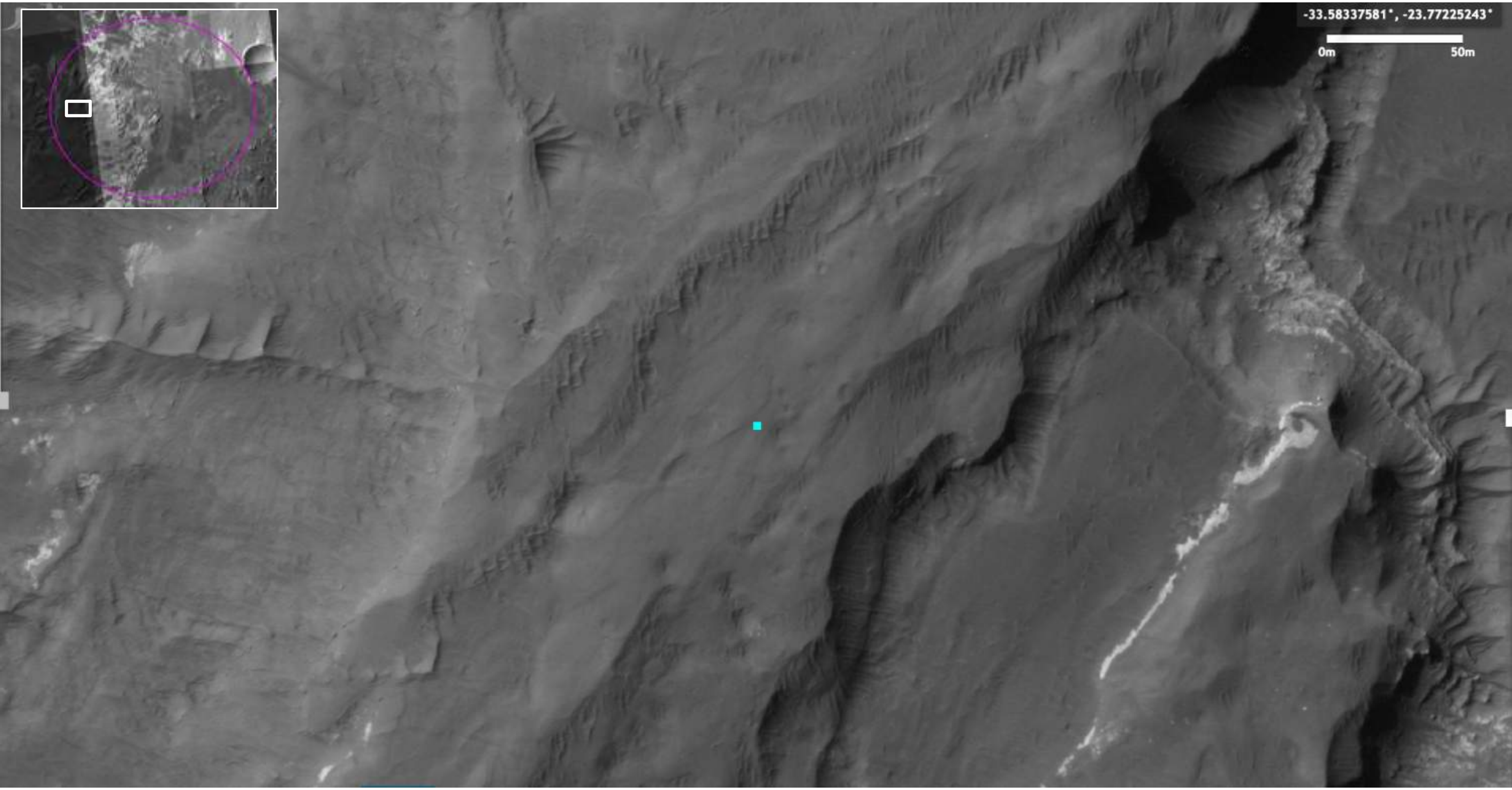
- Delta deposits
- Veins
- Breccia Outcrop
- Mantling Unit

# Key Characteristics



Relatively smooth outcrop on the delta. Credible paths connecting the delta with the valley floor

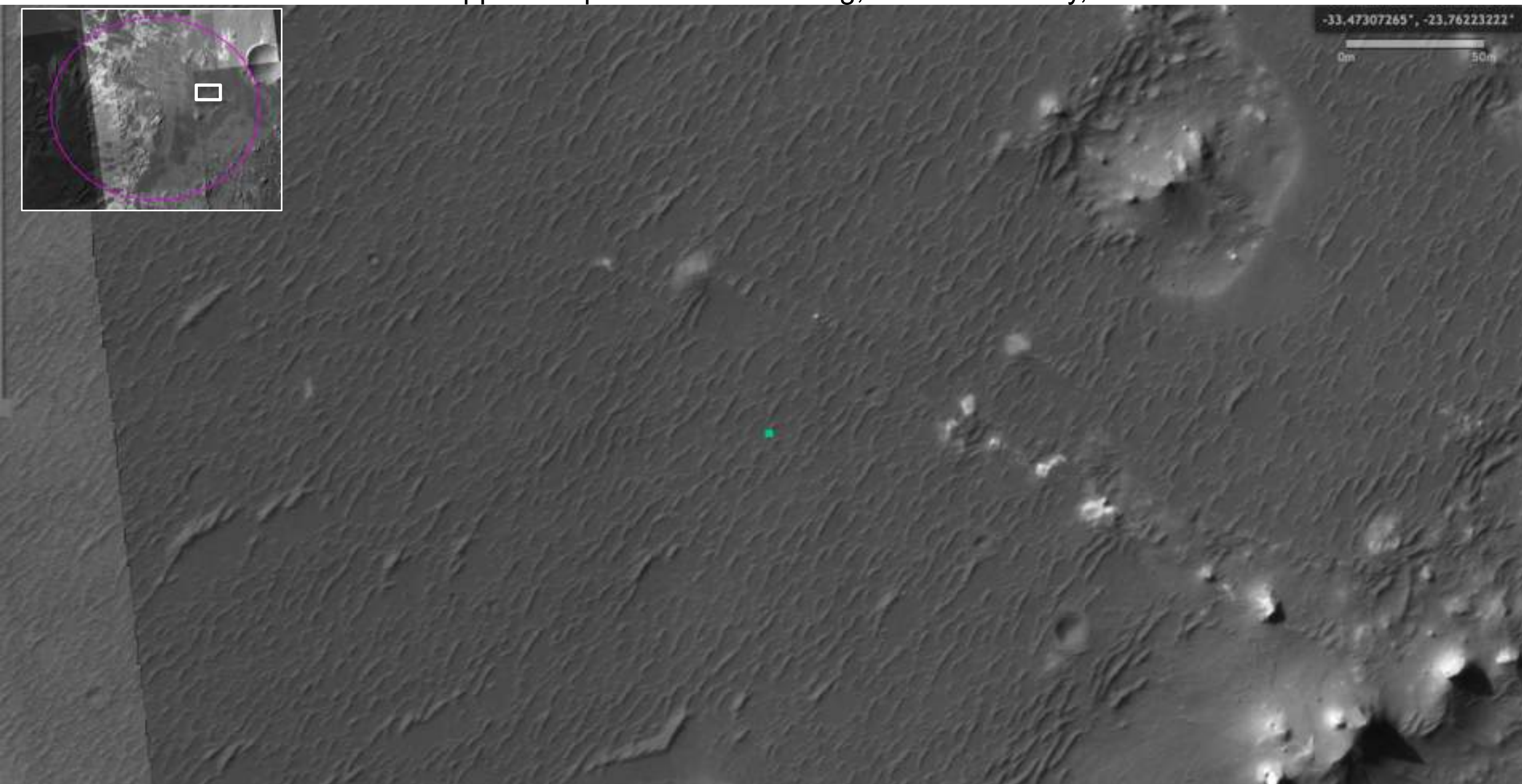
Map link



# Key Challenges



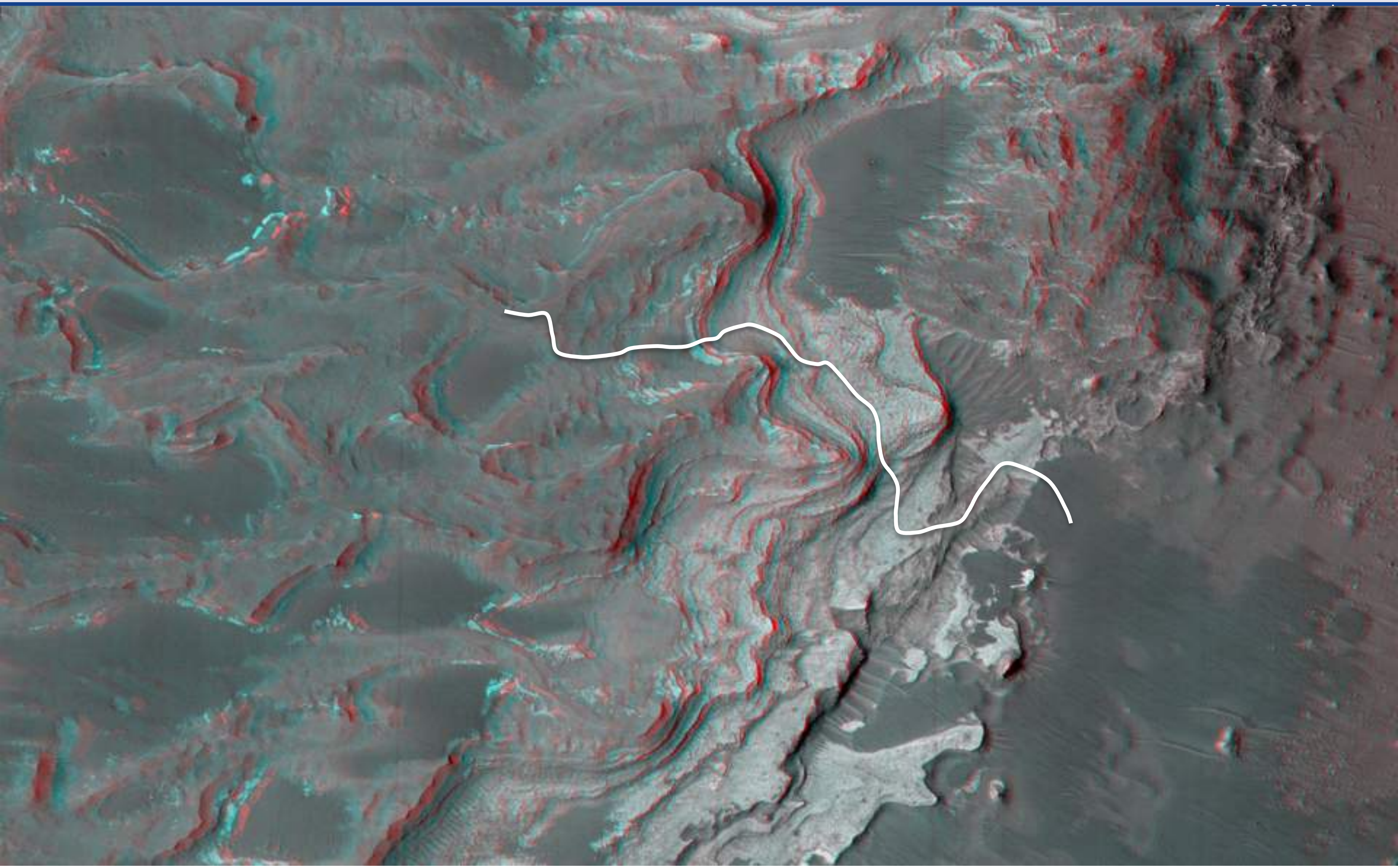
“Mantling unit” which is found throughout the terrain is flat and rock free, but it is covered with sand and small ripples. Appears traversable, but uncertain about the rate of progress due to lack of texture for stereo in sand and occlusions due to ripples. Impacts to blind driving, visual odometry, and AutoNav. Map link



# Driving on and off the Delta

EBW

Jet Propulsion Laboratory
California Institute of Technology

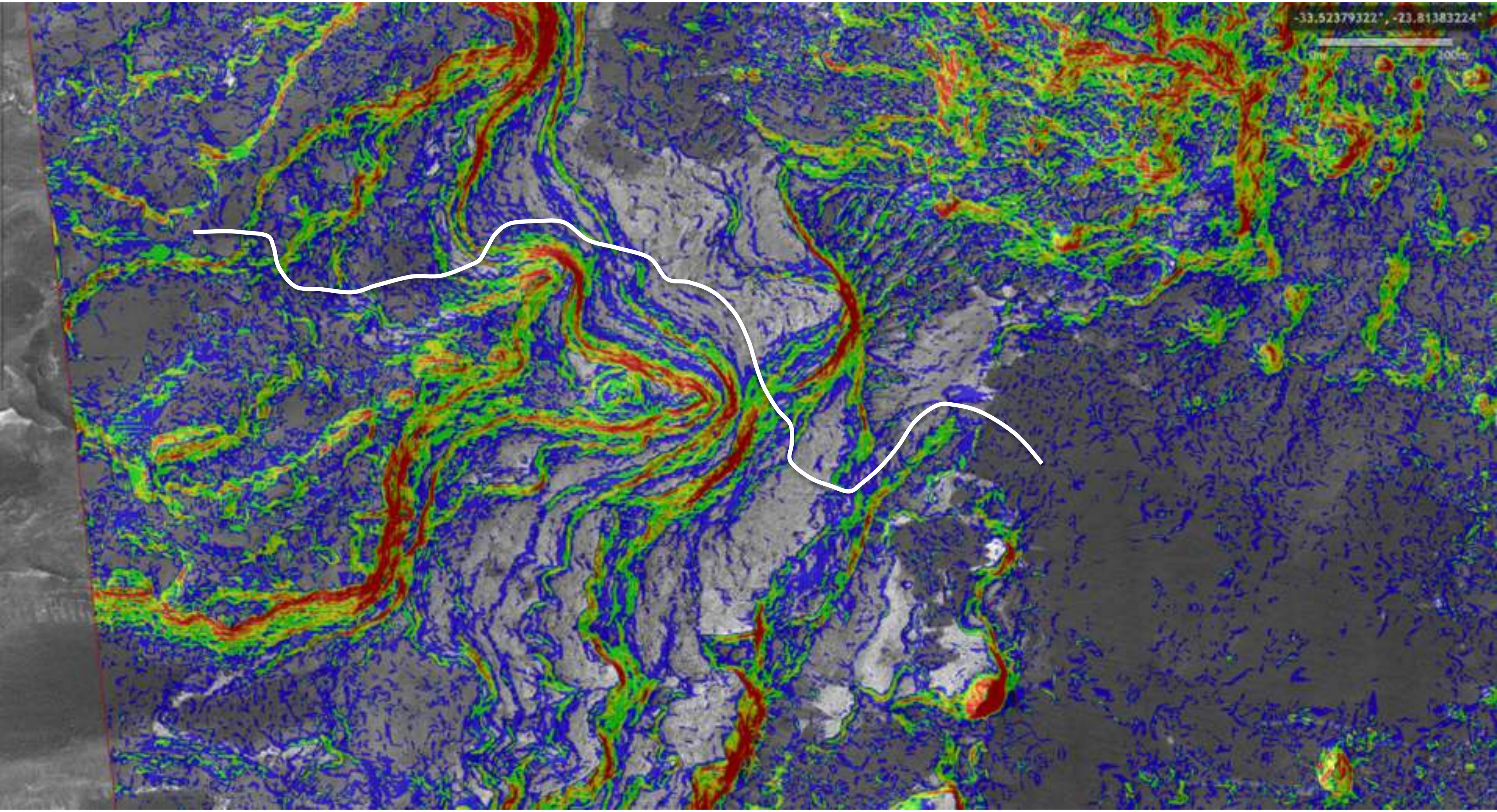


Source image PSP_004000_1560

# Driving on and off the Delta



Map link

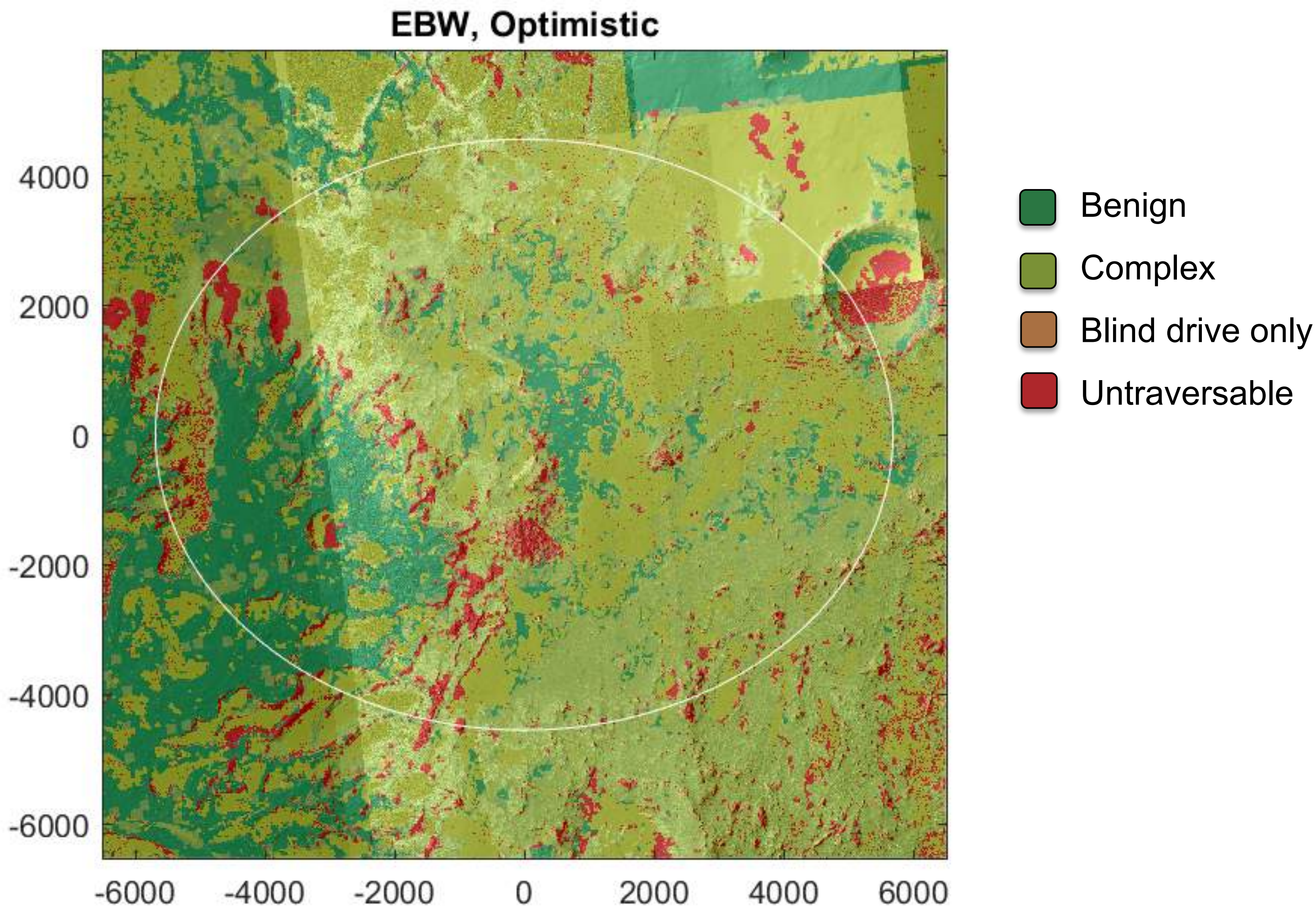



<5° or no data | 5°-10° | 10°-15° | 15°-20° | 20°-25° | ≥ 25°

# Traversability Map

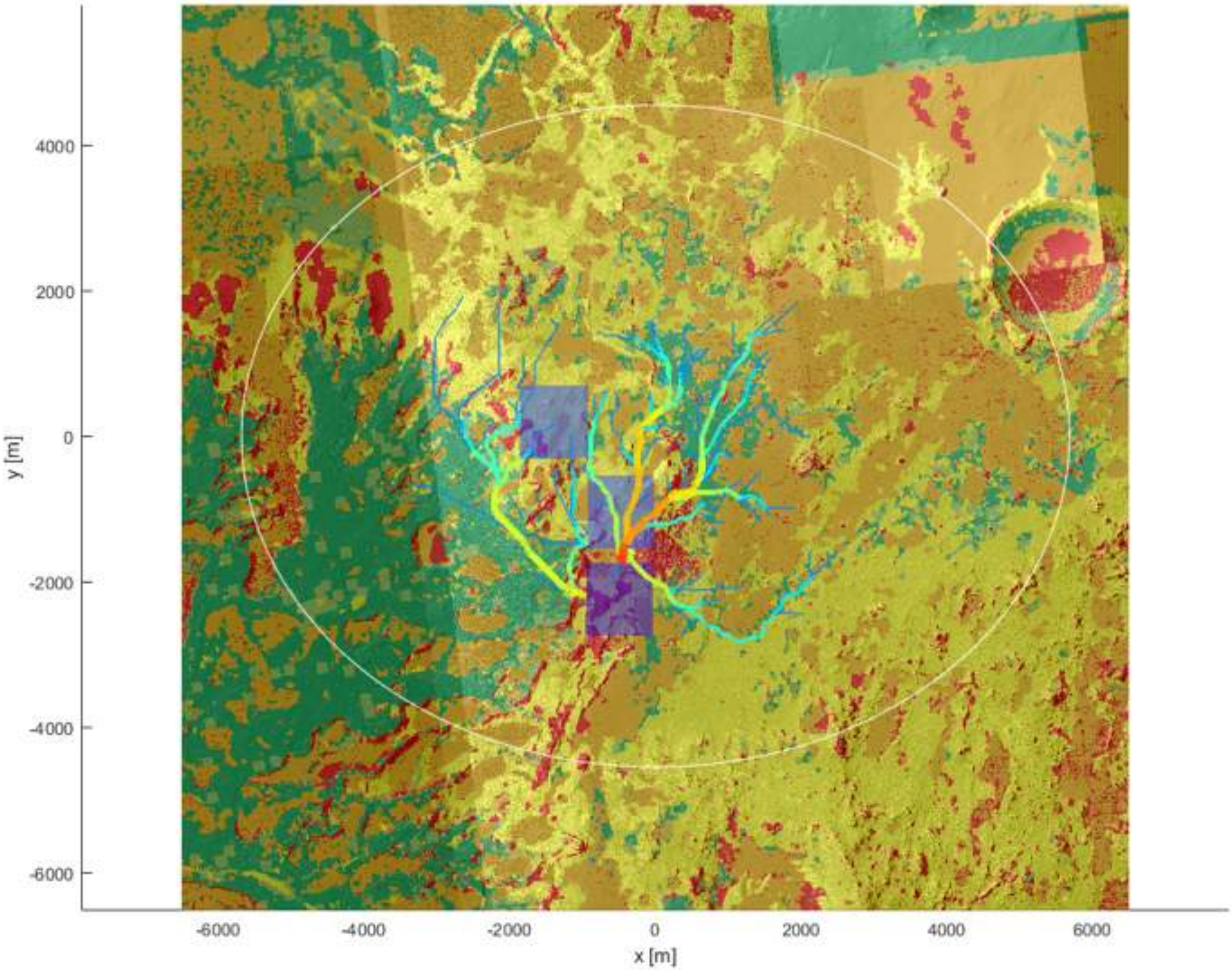




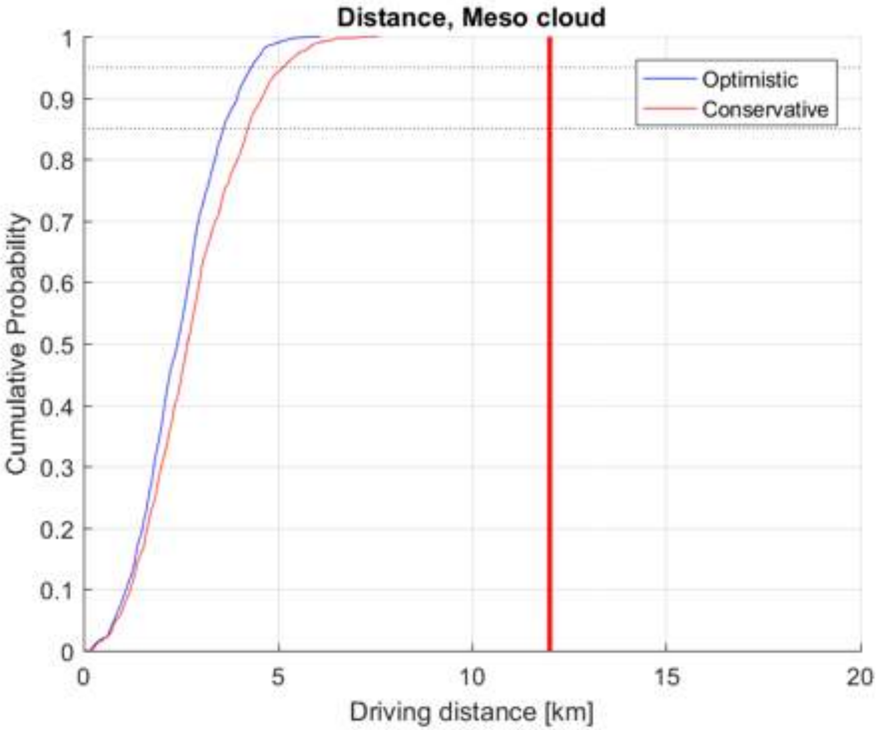


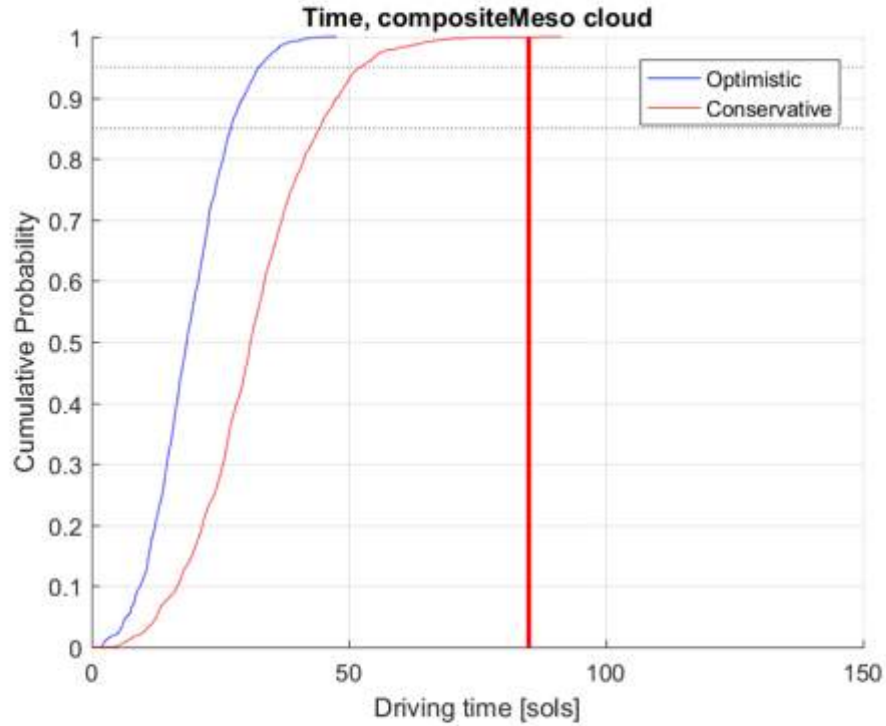
# Highway Map

Conservative Analysis Highway Map



# Traverse Analysis Results




**Distance**

| Drive rate assumption | 50% | 80% | 85% | 90% | 95% |
|---|---|---|---|---|---|
| Optimistic | 2.4 km | 3.4 km | 3.6 km | 4.0 km | 4.3 km |
| Conservative | 2.7 km | 4.0 km | 4.2 km | 4.6 km | 5.2 km |

**Time**

| Drive rate assumption | 50% | 80% | 85% | 90% | 95% |
|---|---|---|---|---|---|
| Optimistic | 18.6 sols | 25.7 sols | 27.3 sols | 29.5 sols | 32.7 sols |
| Conservative | 31.3 sols | 41.3 sols | 44.4 sols | 47.9 sols | 52.6 sols |

Assumes 2.5 hours of dedicated drive time per sol
85 sols is the portion of the mission allocated to traversing between ROIs

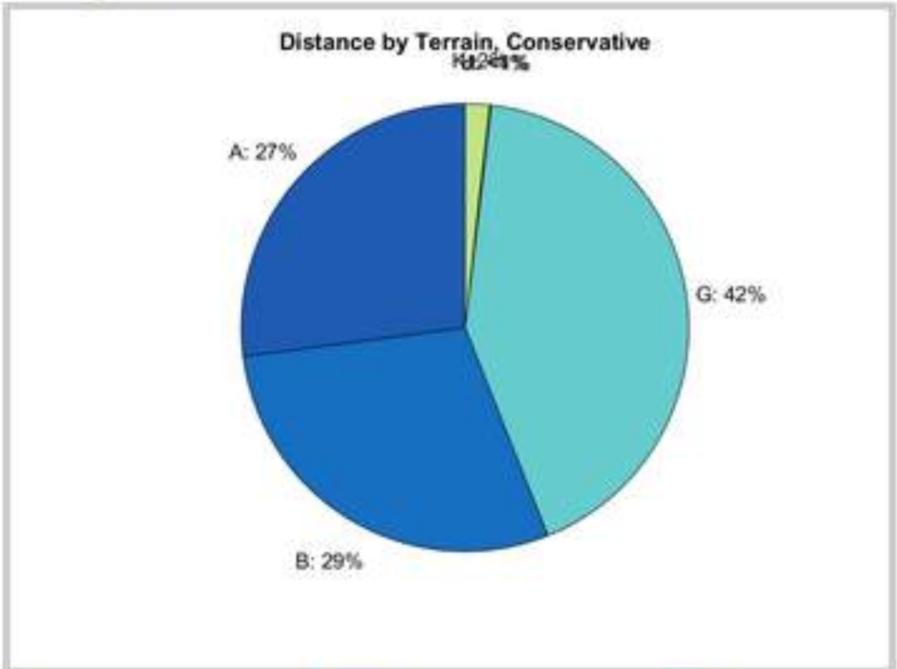
# Terrain Type Breakdown

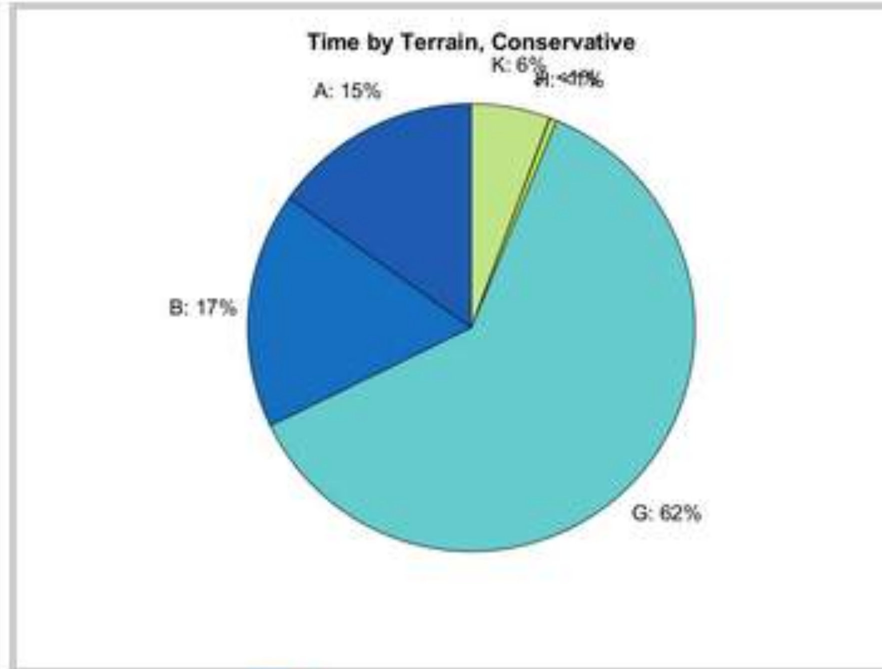


## Conservative

Average Distance: 2.8 km

Average Time: 31.7 sols



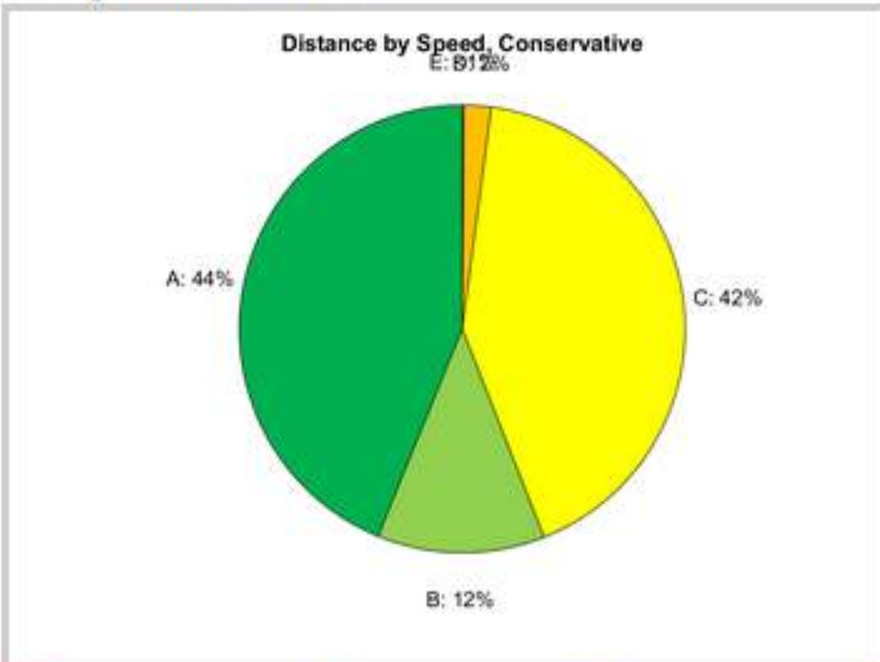

A Smooth regolith
B Smooth outcrop
C Smooth fractured outcrop
D Sparse ripples smooth firm substrate
E Moderate ripples firm substrate
F Rough regolith
G Rough outcrop
H Dense ridges
I Rock field
J Sparse ripples sandy substrate
K Moderate ripples sandy substrate
O Featureless sand

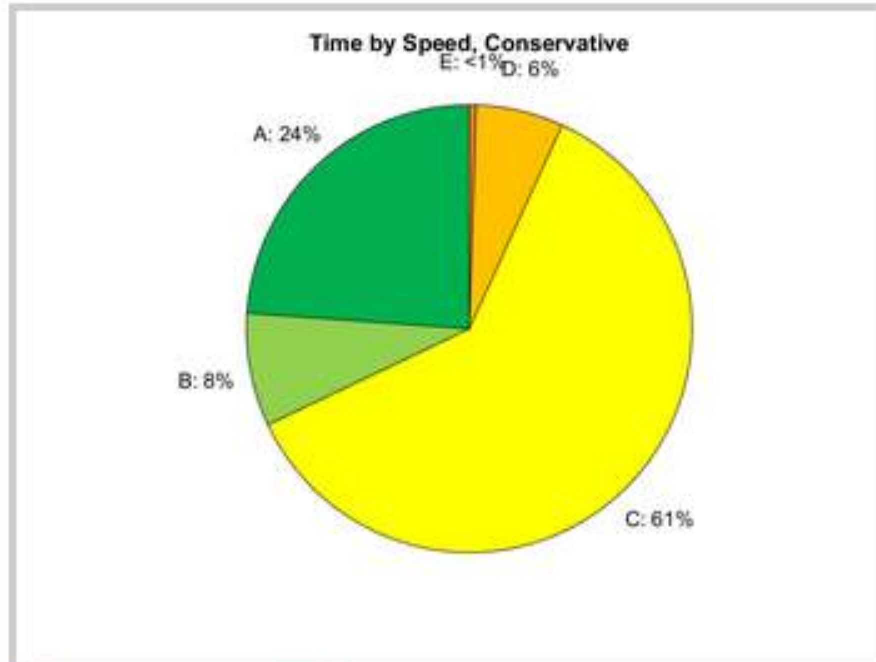
# Drive Rate Breakdown

**Conservative**

Average Distance: 2.8 km

Average Time: 31.7 sols




A 64.8 m/hr  B 52.5 m/hr  C 24.2 m/hr  D 10.9 m/hr  E 8.7 m/hr

# Environmental Conditions



- Eberswalde, located at Lat=23.4 S, experiences **extreme environmental conditions,** both hot and cold, across the range of bounding, rover design limits.
  - While the rover is designed to be capable of safely operating at bounding environments, there are consequences to overall surface performance when operating at bounding conditions.

- Extreme environmental conditions:
  - hottest summer of all landing sites (maximum ground temperature = 33 deg-C)
  - very cold winter conditions (minimum ground temperature = -101 deg-C)

- **Survival heating and mechanism heat-to-use energy** needed during Eberswalde cold winter season will negatively impact mission productivity.

- **Hardware overheat conditions** may exist during hot summer season, which could limit operations timing.

- More detailed analyses of the seasonal effects to operability and mission performance is in-progress…

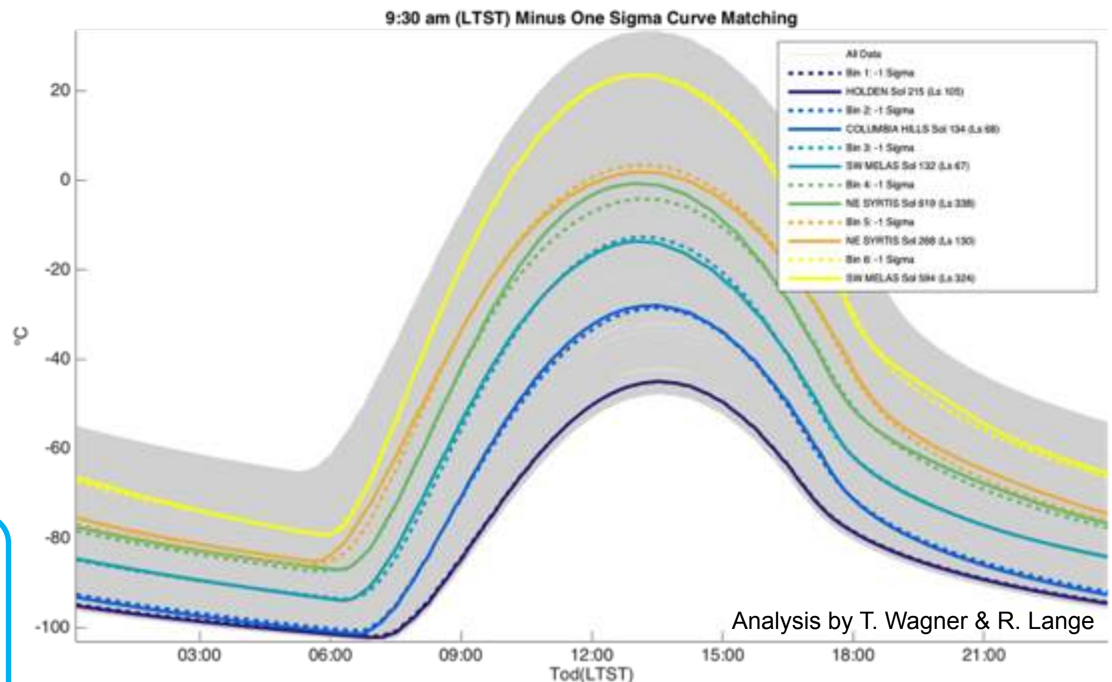
# Environments & Thermal



- (opposite) 6 diurnal temperature profiles, optimized for 9:30 LTST, to use for modeling all sites throughout Mars year.
- (lower-right) Percentage of environment bin usage over 1-MY for each landing site, based on Sol ranges defined by curve-fit optimization.

6 environments have been provided to Payload and Thermal teams for analysis on **survival heating, mechanism heat to use, instrument warm-up and ops TOD info.**

- Results from thermal analysis of 6 environments will be ready by early October

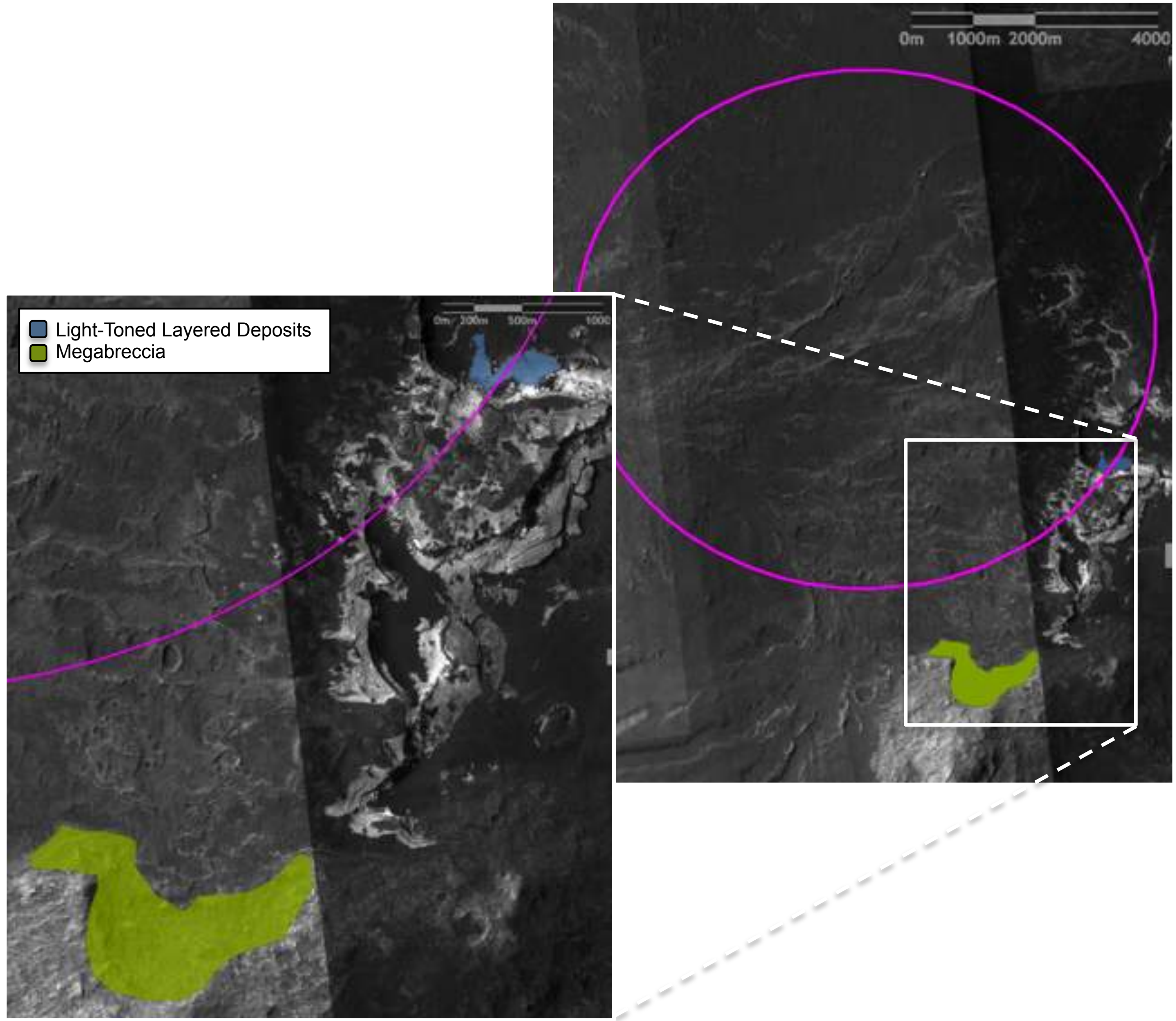



| | Bin: | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| 1 | Eberswalde | 24% | 16% | 13% | 8% | 12% | 28% |
| 2 | Columbia Hills | 0% | 33% | 16% | 11% | 18% | 21% |
| 3 | Holden | 29% | 14% | 11% | 8% | 11% | 27% |
| 4 | Jezero | 0% | 0% | 29% | 64% | 8% | 0% |
| 5 | Mawrth | 0% | 11% | 19% | 42% | 27% | 0% |
| 6 | NE Syrtis | 0% | 0% | 21% | 62% | 16% | 0% |
| 7 | Nili | 0% | 0% | 24% | 52% | 24% | 0% |
| 8 | SW Melas | 0% | 0% | 32% | 14% | 17% | 36% |

# Holden

## Mission Scenario

- ROIs
  - Light-Toned Layered Deposits
    - **8 samples**
    - 2 Campaigns with 3 unit each separated by 100 m (upper layers and then lower layers)
  - Megabreccia
    - **6 samples**
    - 2 Campaigns with 2 unit each separated by 1000 m
- Waypoints
  - Alluvial Fan (throughout ellipse)
    - **1 sample**
    - 1 rock waypoints
  - Regolith
    - **1 sample**
    - 1 regolith waypoint
- Procedural Blanks
    - **4 samples**



# Holden ROI Science

**Alluvial fans** (Objective A + minimal sampling)

- Stream discharge and runoff required to transport observed sediment load
- Mineralogy, diagenesis, and weathering processes: Alluvial gravel/cobbles sample top 1-2 km of highland crust, up to 800 Myr of the Noachian Period

**Light-toned, layered materials with phyllosilicates** (Objectives A, B, C)

- Stratigraphy, sedimentology, and geochemistry of 100-m-thick medium to fine-grained section reflects depositional environment and change over time
- Ideal site to search for organics and effects of biological processes
- Contemporary modification processes as constraints on paleoclimate

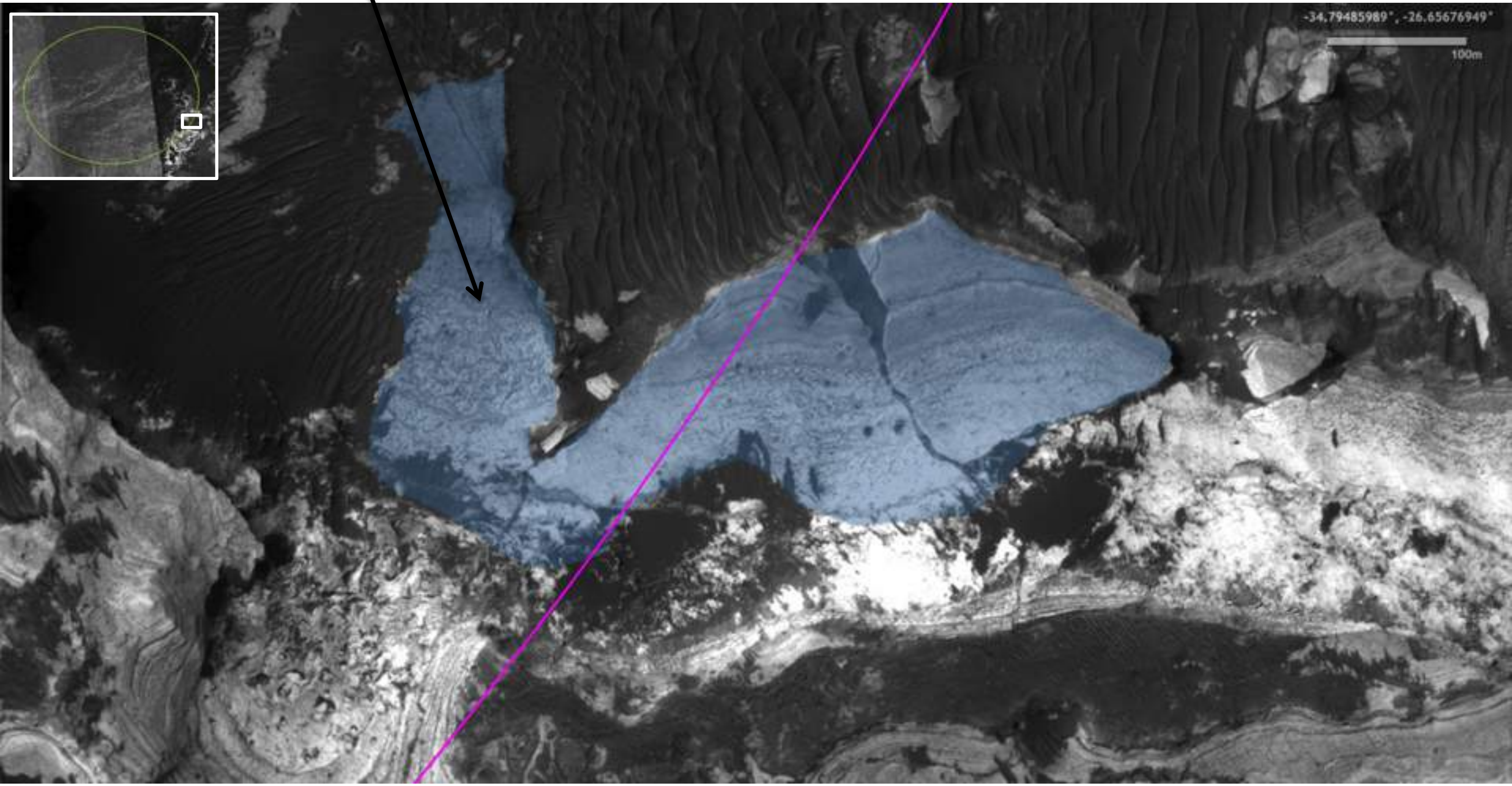
**Megabreccia** (Objectives A, B, C)

- Ancient bedrock uplifted during impact, veins, possible hydrothermal system

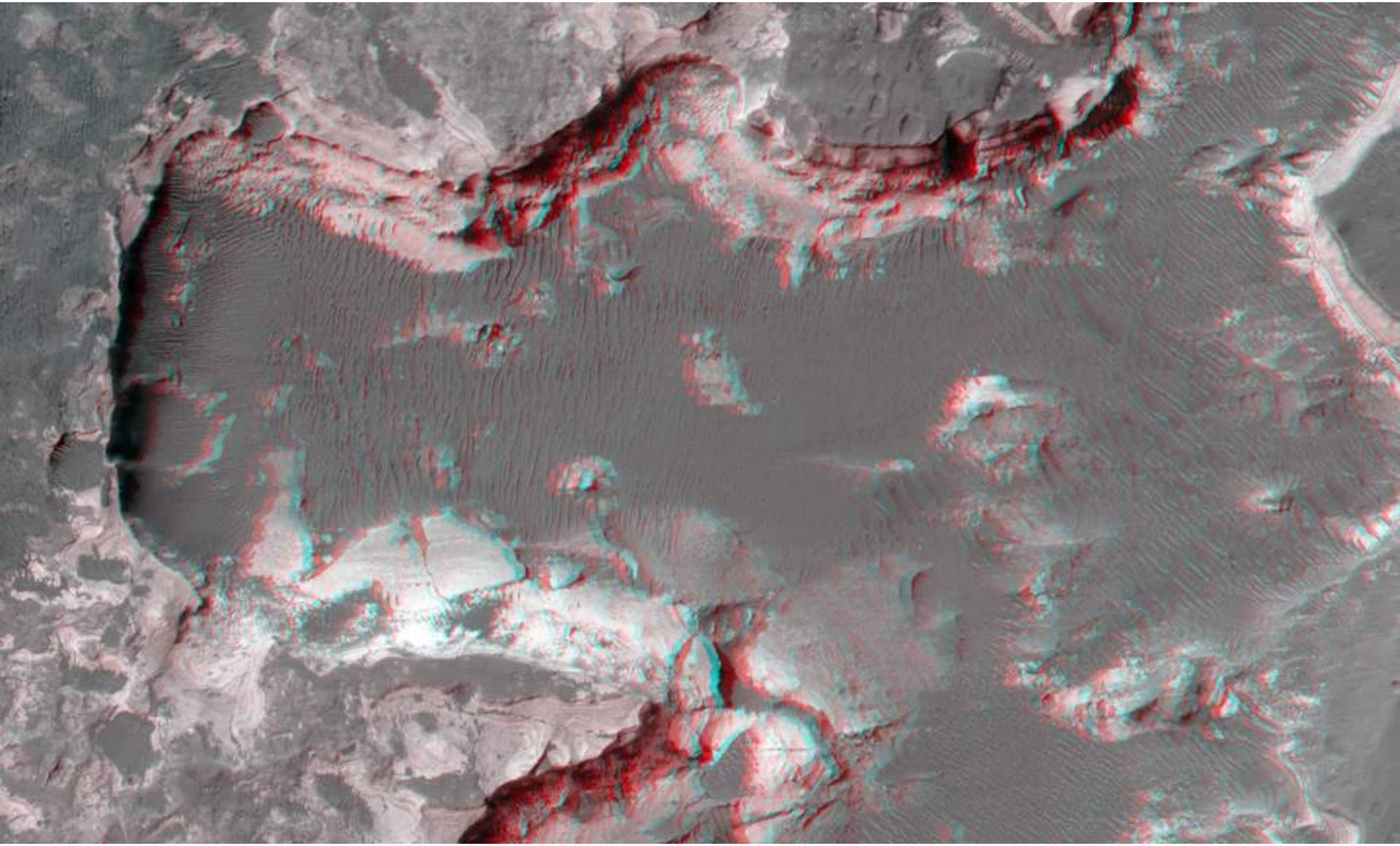
# Light Toned Layered Deposits

ROI

Map link

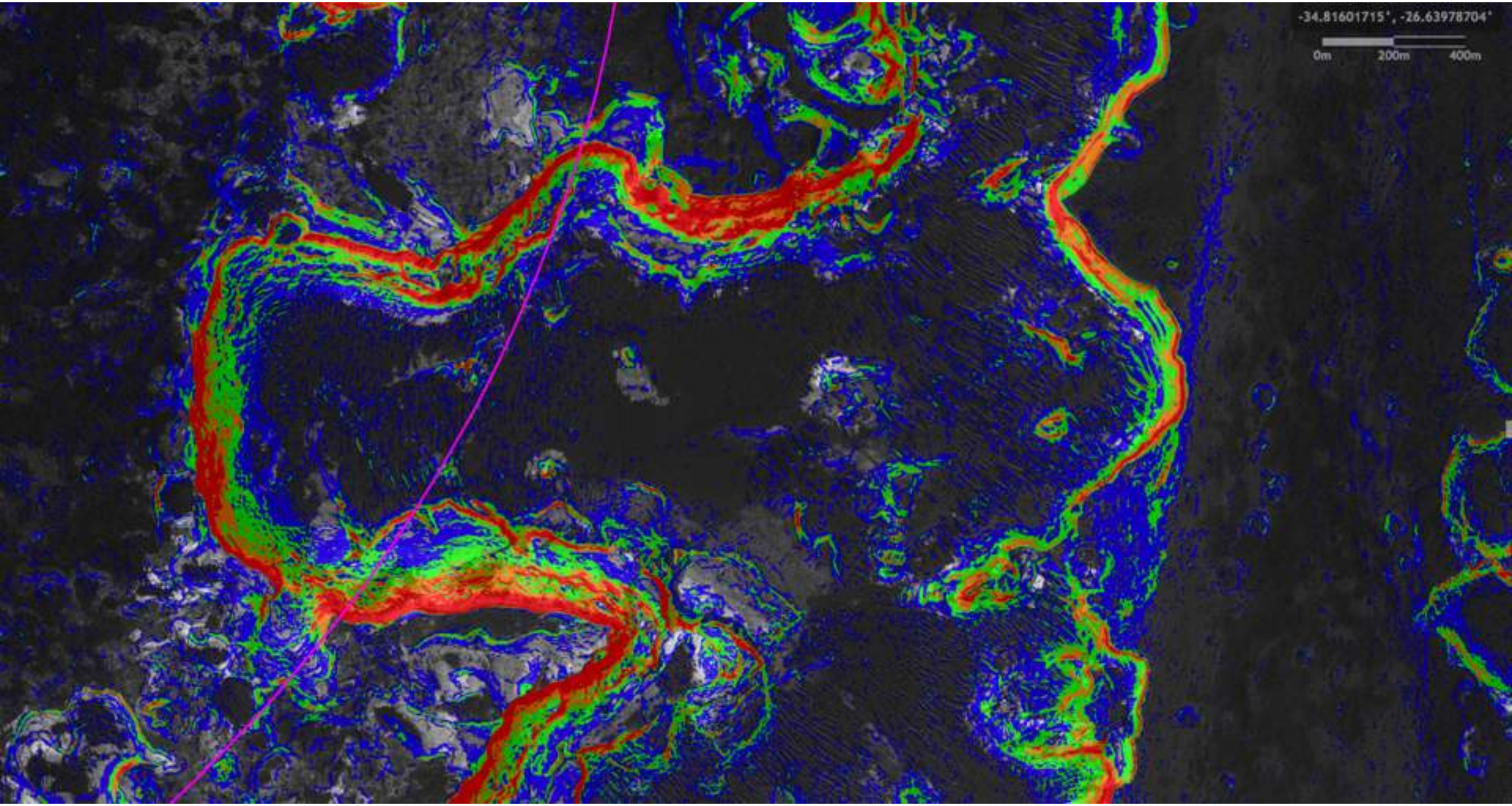


# Light Toned Layered Deposits



Source image PSP_002154_1530

# Light Toned Layered Deposits




<5° or no data 5°-10° 10°-15° 15°-20° 20°-25° ≥ 25°

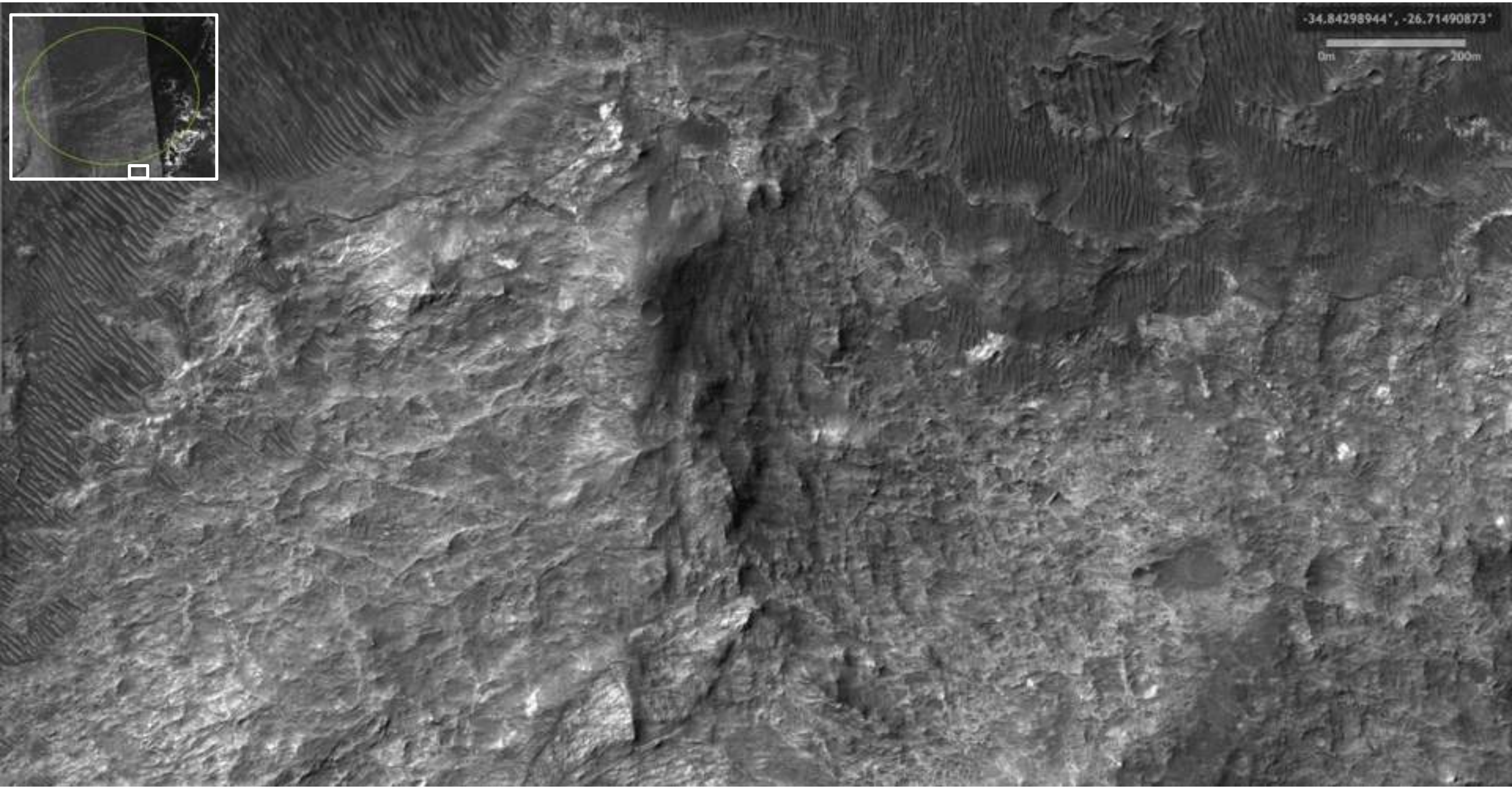
# Megabreccia







Map link

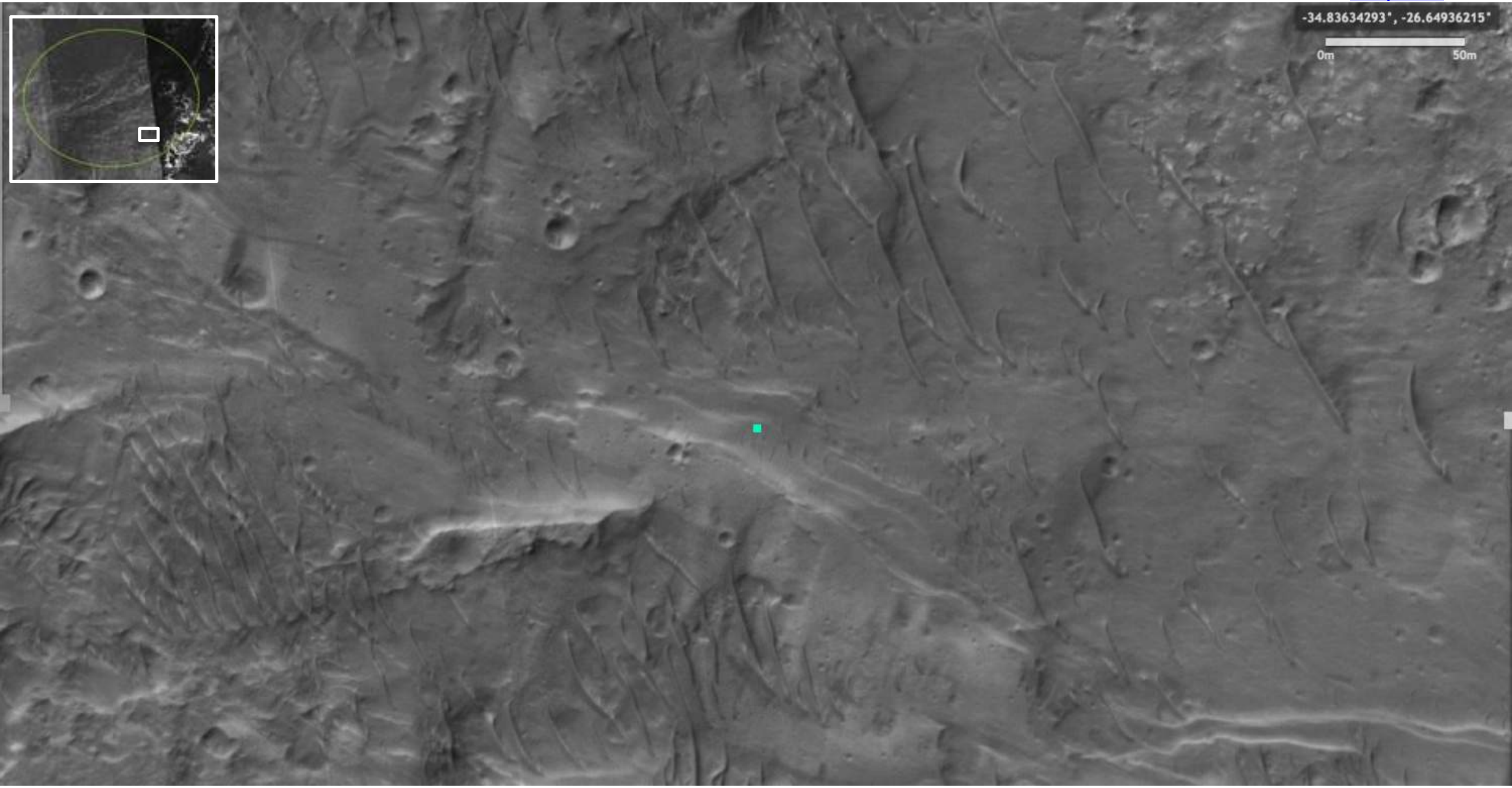


# HOL Key Characteristics



The southeast part of the ellipse (close to the ROIs) is smooth outcrop with overlaid sparse sand ripples

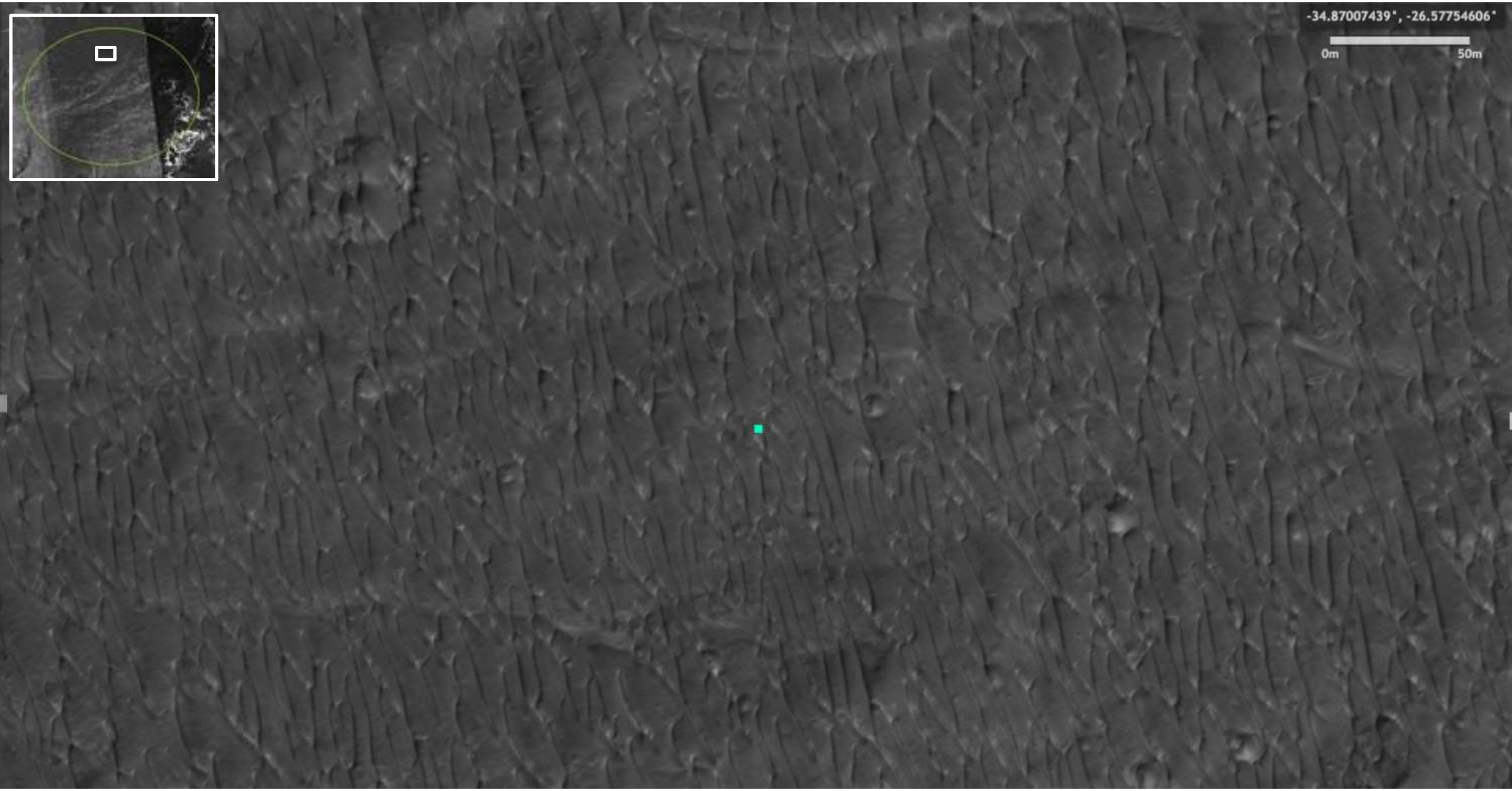
Map link



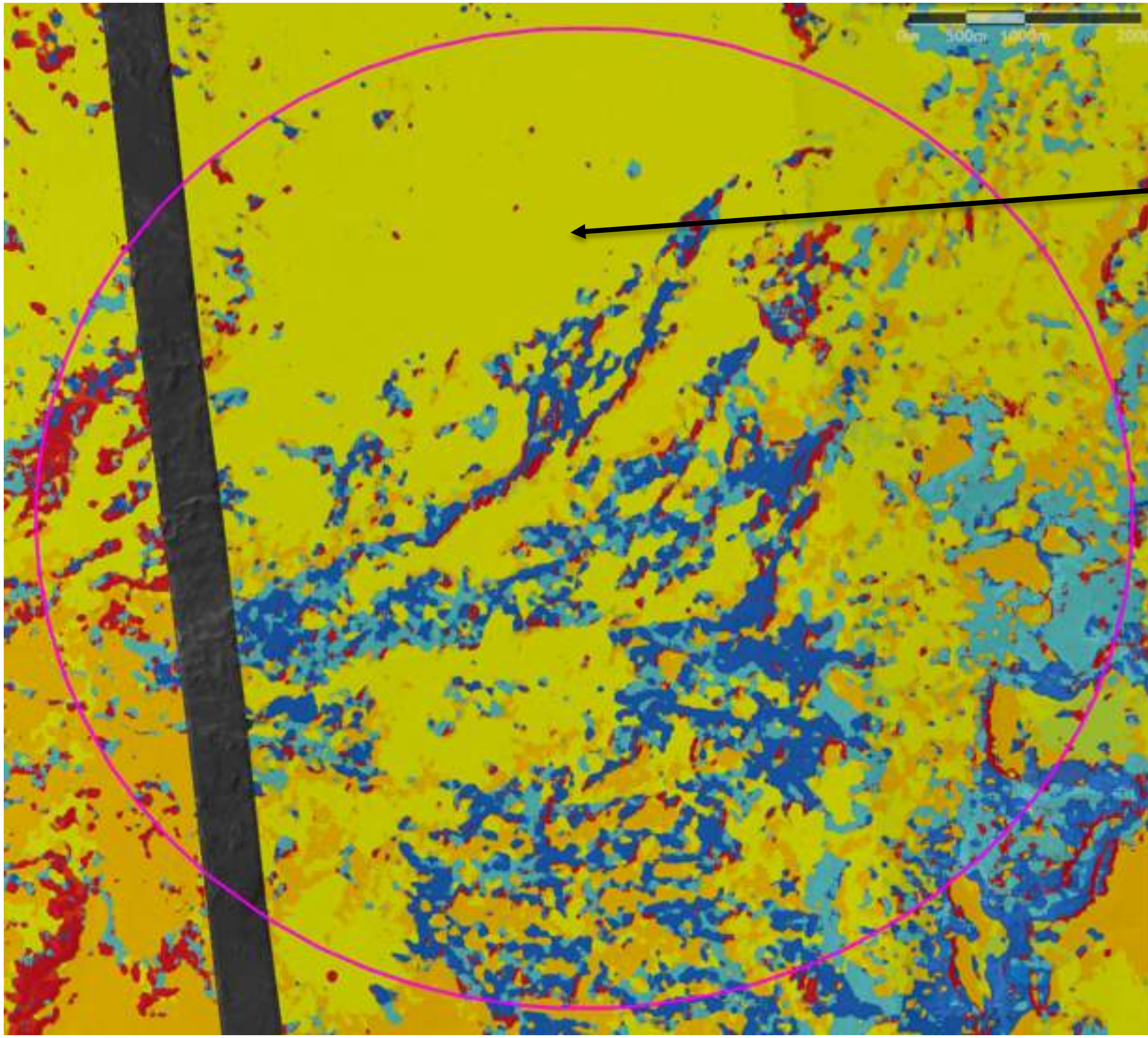
# HOL Key Challenges

Much of the northern portion of the ellipse appears to be bedrock covered with a layer of sand with superimposed ripples. Uncertain about the rate of traverse through the ripple fields. Lack of texture for stereo in sand and occlusions due to ripples may result in slow drive rates. Impacts to blind driving, visual odometry, and AutoNav.

Map link



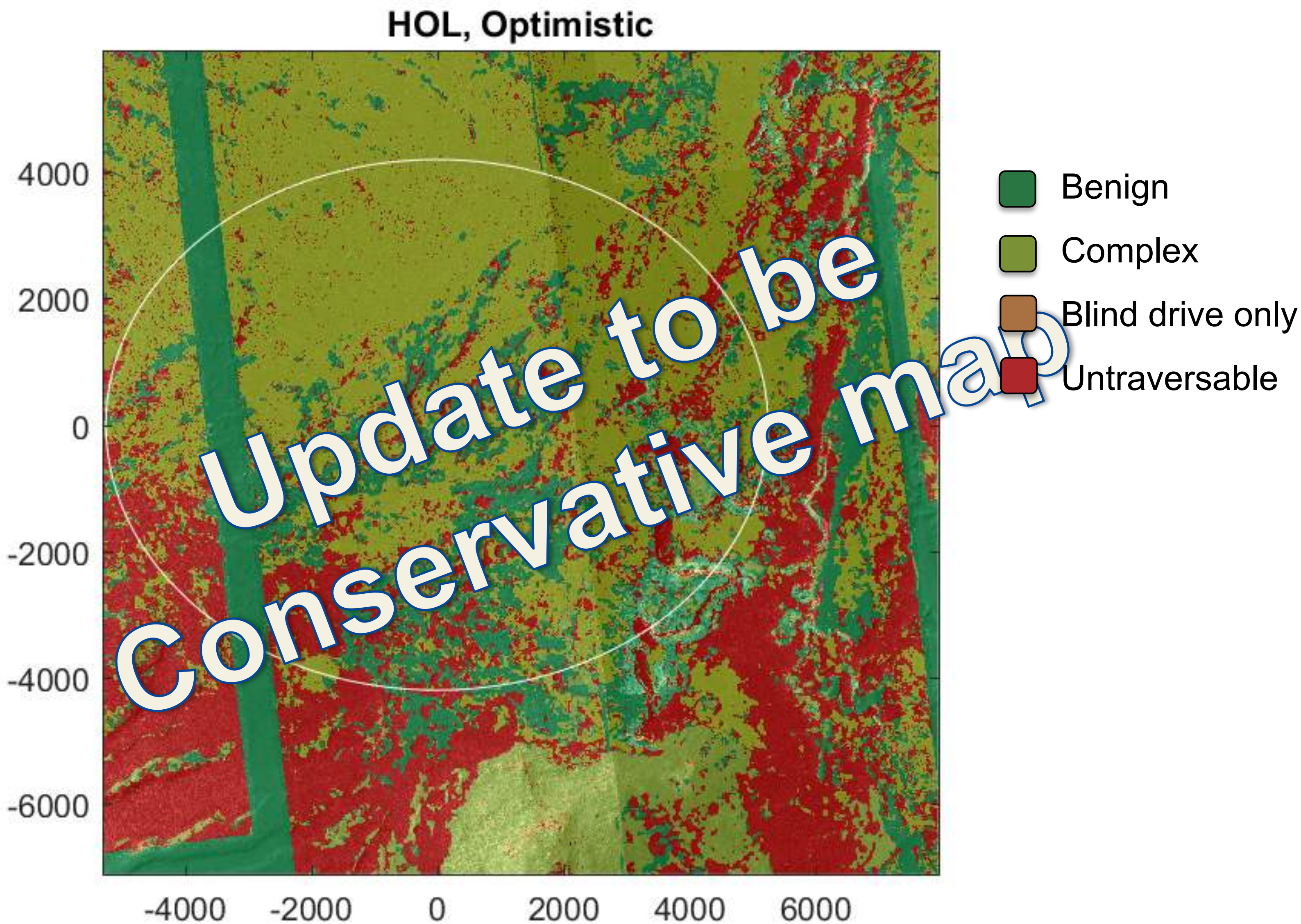
# Terrain Classification



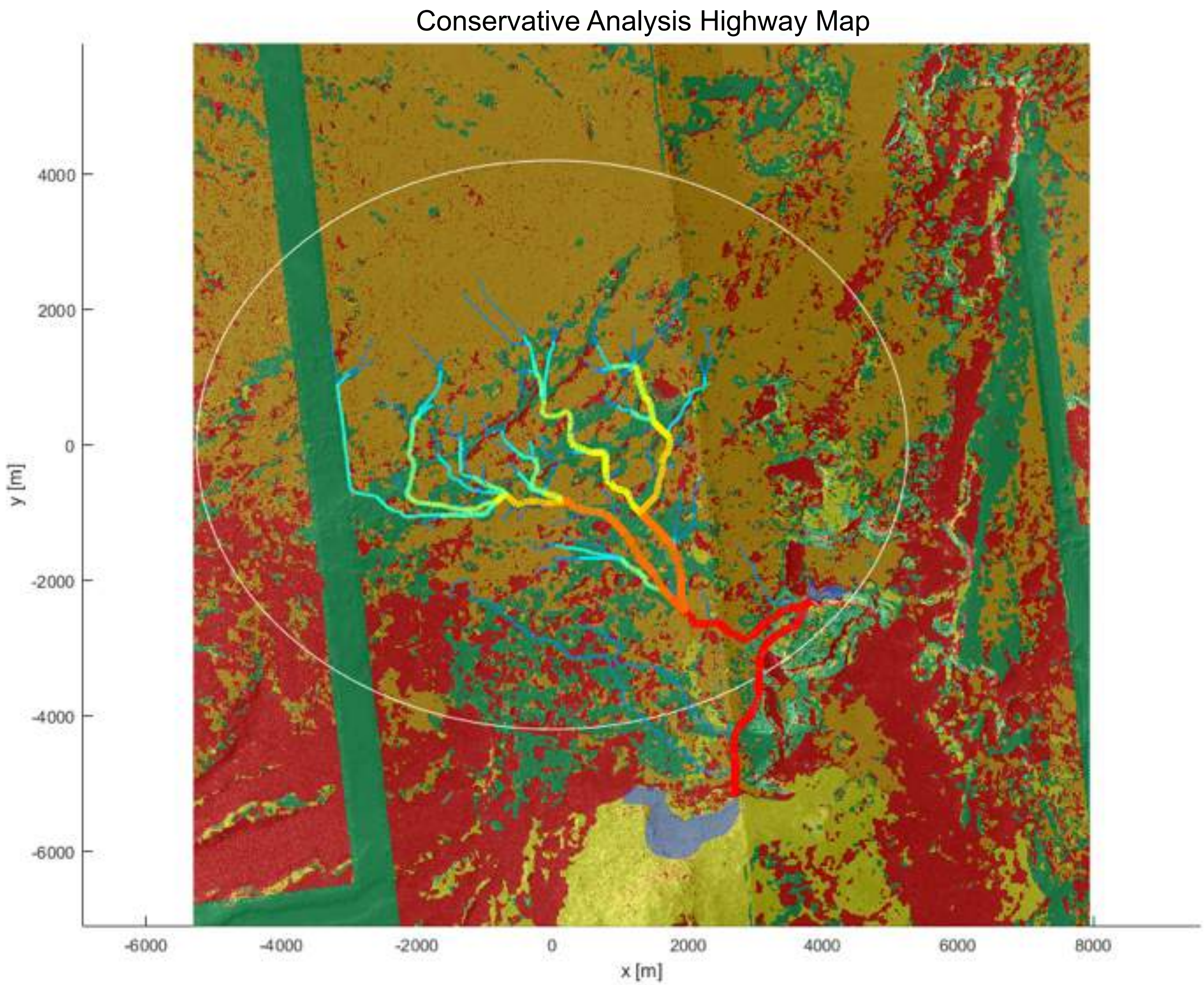
Moderate ripples with a sandy substrate

The northern portion of the ellipse is believed to be cemented granule ripples. There is not widespread concern about the vehicle's ability to traverse these ripple fields, but the rate of traverse for AutoNav is uncertain and could be slow.

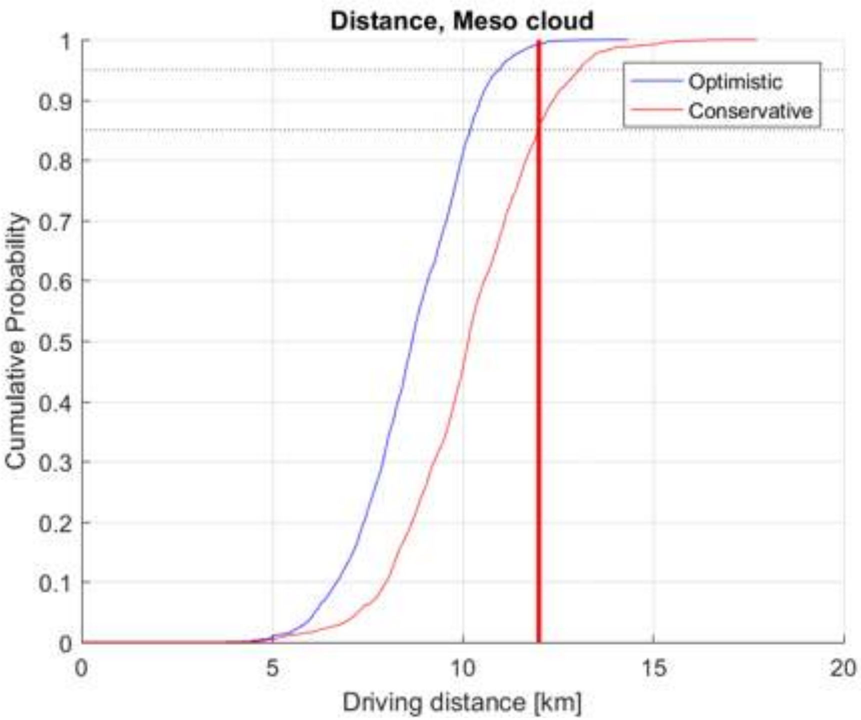
# Traversability Map

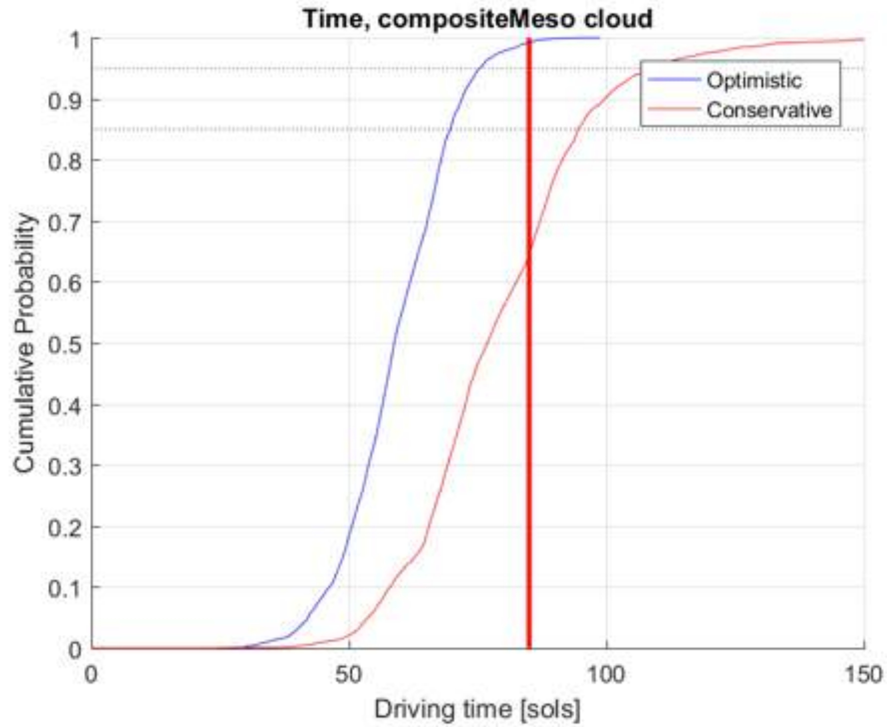


# Highway Map


Conservative Analysis Highway Map
4000
2000
0
-2000
-4000
-6000
y [m]
-6000
-4000
-2000
0
2000
4000
6000
8000
x [m]

# Traverse Analysis Results




**Distance**

| Drive rate assumption | 50% | 80% | 85% | 90% | 95% |
|---|---|---|---|---|---|
| Optimistic | 8.7 km | 10.0 km | 10.2 km | 10.5 km | 11.0 km |
| Conservative | 10.2 km | 11.7 km | 12.0 km | 12.4 km | 13.1 km |

**Time**

| Drive rate assumption | 50% | 80% | 85% | 90% | 95% |
|---|---|---|---|---|---|
| Optimistic | 58.8 sols | 68.2 sols | 70.1 sols | 72.0 sols | 75.8 sols |
| Conservative | 77.6 sols | 92.2 sols | 94.6 sols | 100.3 sols | 108.3 sols |

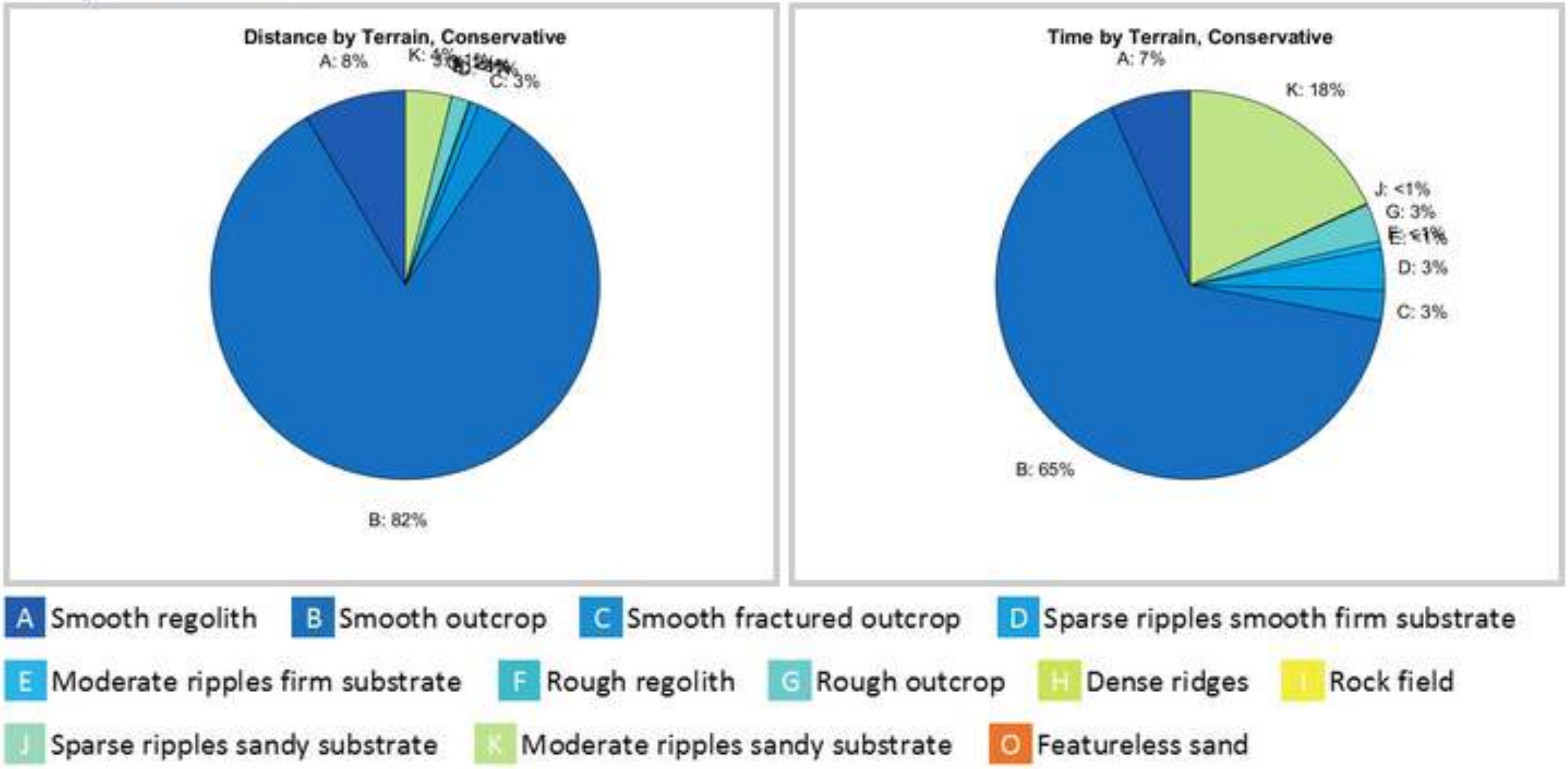
Assumes 2.5 hours of dedicated drive time per sol
85 sols is the portion of the mission allocated to traversing between ROIs

# Terrain Type Breakdown

**Conservative**

Average Distance: 10.2 km

Average Time: 79.1 sols

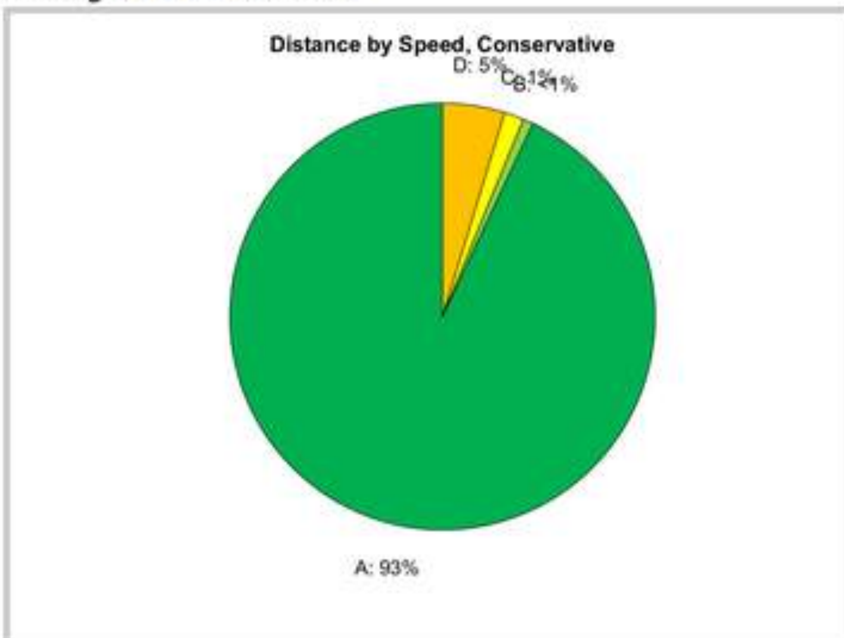


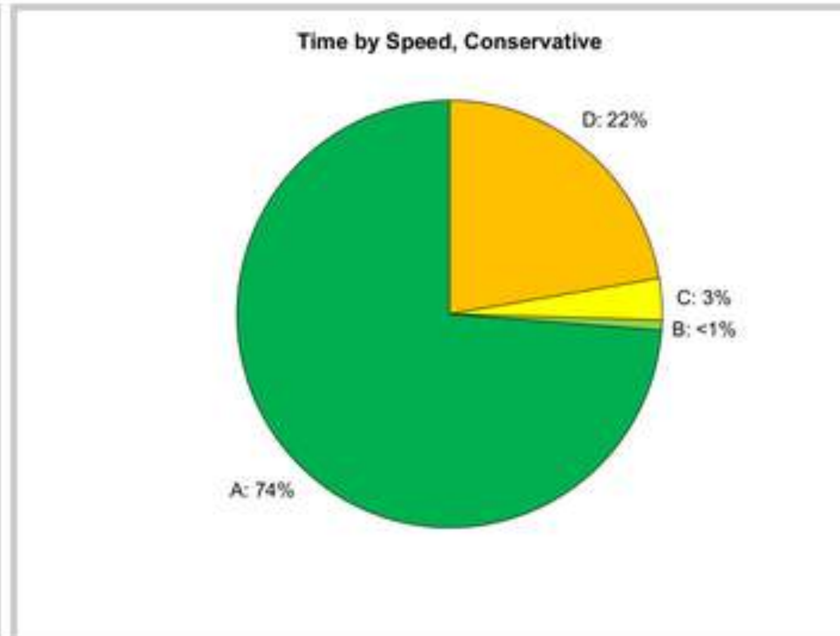
# Drive Rate Breakdown

**Conservative**

Average Distance: 10.2 km

Average Time: 79.1 sols




A 64.8 m/hr | B 52.5 m/hr | C 24.2 m/hr | D 10.9 m/hr | E 8.7 m/hr

# Environmental Conditions

- Holden Crater experiences the **most extreme environmental conditions** of all landing sites. While the rover is designed to be capable of safely operating at such extremes, there are consequences to overall mission performance when trying to operate at bounding conditions.

- Extreme environmental conditions:
  - hottest summer of all landing sites (maximum ground temperature=32 deg-C)
  - coldest winter of all landing sites (minimum ground temperature=-103 deg-C)

- **Mechanism heat-to-use energy** needed during Holden cold winter season will negatively impact mission productivity.

- **Unheated hardware components** may further limit time-of-day operation windows during *both* hot summer and cold winter. Thermal analyses are in-progress.
- For example, initial results for Mobility subsystem show:
  - Holden cold case, some mobility components do not reach minimum op AFT until late in the normal ops window. (see slide 5)
  - Holden hot case, some mobility components
- Robotic Arm, SCS, cable harness, and RAMP temperature are all additional areas that will be evaluated by FS Thermal in the coming year.

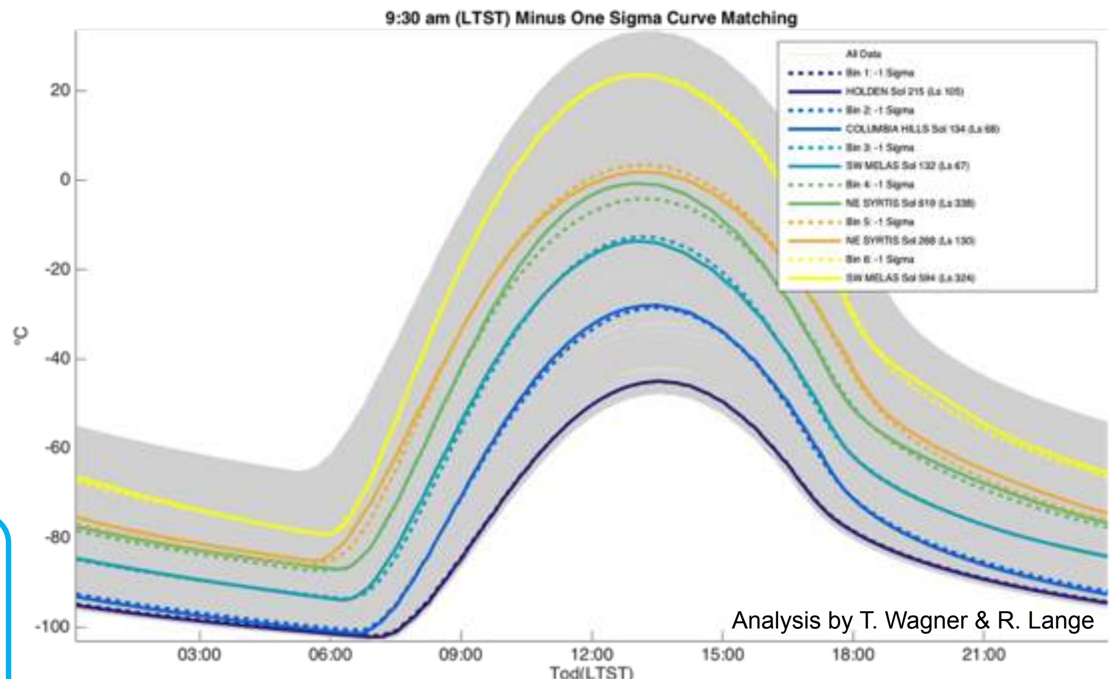
# Environments & Thermal



- (opposite) 6 diurnal temperature profiles, optimized for 9:30 LTST, to use for modeling all sites throughout Mars year.
- (lower-right) Percentage of environment bin usage over 1-MY for each landing site, based on Sol ranges defined by curve-fit optimization.

6 environments have been provided to Payload and Thermal teams for analysis on **survival heating, mechanism heat to use, instrument warm-up and ops TOD info.**

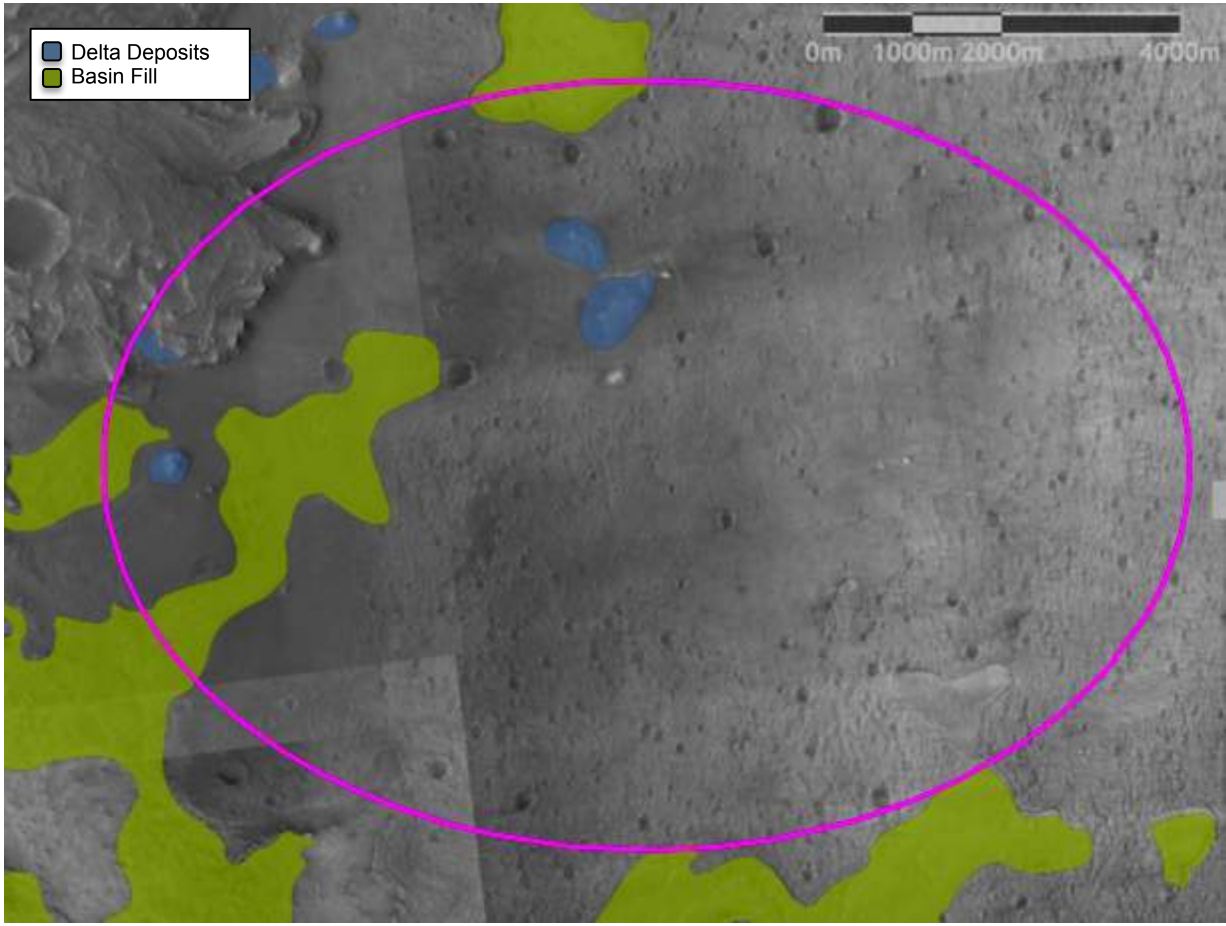
- Results from thermal analysis of 6 environments will be ready by early October




| | Bin: | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| 1 | Eberswalde | 24% | 16% | 13% | 8% | 12% | 28% |
| 2 | Columbia Hills | 0% | 33% | 16% | 11% | 18% | 21% |
| 3 | Holden | 29% | 14% | 11% | 8% | 11% | 27% |
| 4 | Jezero | 0% | 0% | 29% | 64% | 8% | 0% |
| 5 | Mawrth | 0% | 11% | 19% | 42% | 27% | 0% |
| 6 | NE Syrtis | 0% | 0% | 21% | 62% | 16% | 0% |
| 7 | Nili | 0% | 0% | 24% | 52% | 24% | 0% |
| 8 | SW Melas | 0% | 0% | 32% | 14% | 17% | 36% |

## Mission Scenario

- ROIs
  - Delta Deposits
    - **10 samples**
    - 1 campaign with 6 units (notionally the southern delta remnant)
    - 1 campaign with 4 units (notionally the northern delta remnant)
  - Basin Fill
    - **3 samples**
    - 2 Campaigns with 1 unit each separated by 200 m
- Waypoints
  - Volcanic Floor (throughout the ellipse)
    - **2 samples**
    - 2 Rock waypoints separated by 500 m (First sample shortly after landing, second sample after first ROI)
  - Regolith (throughout the ellipse)
    - **1 sample**
    - 1 Regolith waypoint wherever we find sand
- Procedural Blanks
    - **4 samples**



# Jezero ROI Science

- Delta Deposit
  - Carbonate- and smectite-rich deltaic sediment deposited in a circumneutral pH, hydrologically open, likely habitable lake (Fassett and Head, 2005; Ehlmann et al., 2008a,b; Goudge et al., 2015, 2016). **[A,B,C]**
  - Deltaic sediment is an ideal site for (formation), concentration, and preservation of organic matter (Summons et al., 2011). **[A,B,C]**
- Basin Fill
  - Mg-carbonate-bearing basin fill formed from alteration of an olivine unit prior to and/or during lacustrine activity. Example of regional carbonate unit (Ehlmann et al., 2008b; Goudge et al., 2015). **[A,C]**
  - In situ/returned sample analyses provide unique opportunity to study: martian carbon reservoirs; atmospheric chemistry; and temperature of carbonate precipitation (e.g., Halevy et al., 2011). **[A,C]**
- Volcanic Floor
  - Volcanic unit with a Hesperian ridged plains spectral signature and a crater retention age of ~3.5 Gyr (Goudge et al., 2012). [A,C]
  - Absolute age from returned samples would help constrain martian crater production functions. [A,C]

M2020 Objectives (Farley and Williford, 2nd M2020 Landing Site Workshop, 2015):
A. Characterize geologic history of astrobiologically relevant site/units.
B. Assess habitability/past life in units with high biosignature preservation potential.
C. Cache scientifically compelling samples.

# Delta Deposits



Jet Propulsion Laboratory
California Institute of Technology
Mars 2020 Project

All are in agreement that this delta remnant inside the ellipse should be the primary delta ROI.

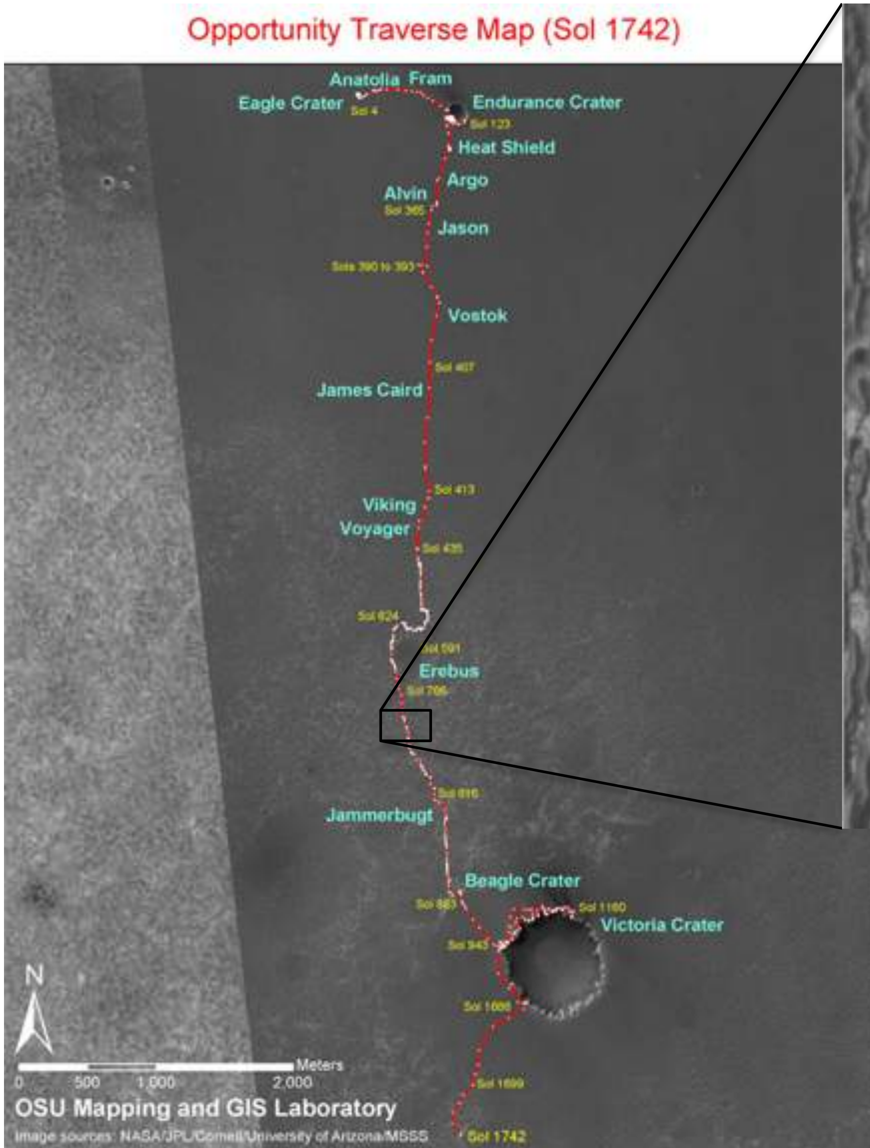
Map link

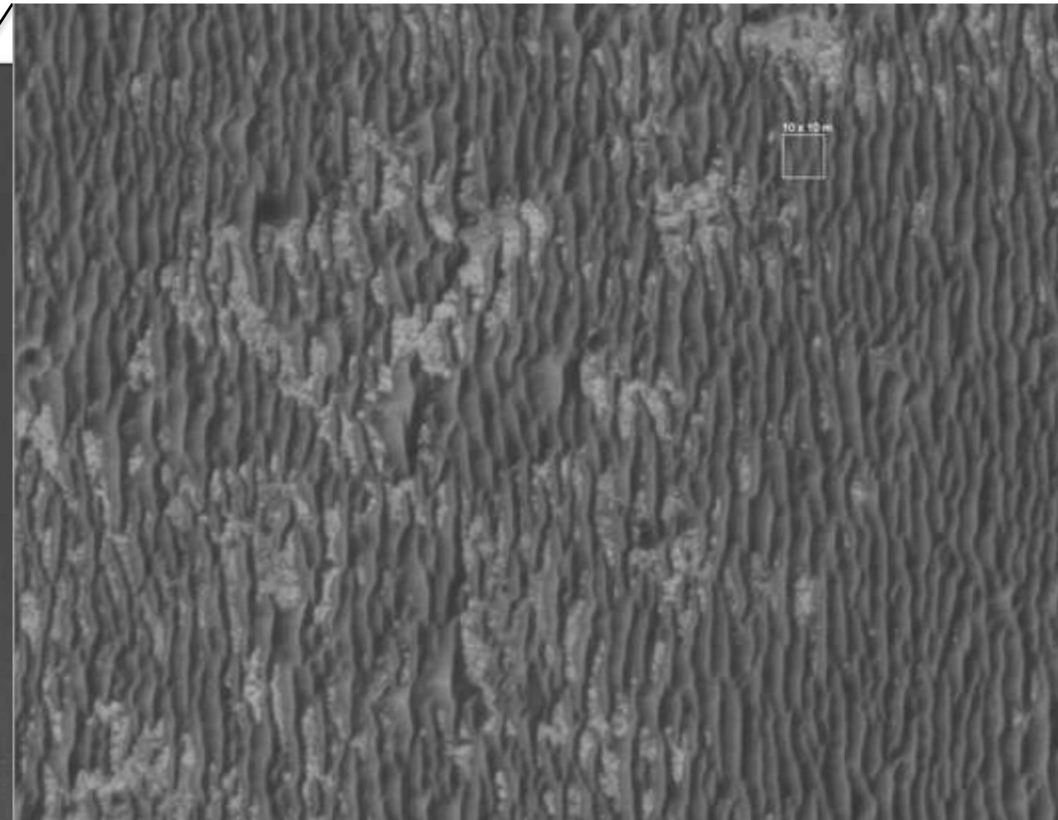
# Basin Fill

Map link

# Similar to Terrain Seen by Opportunity





Sparse linear ripple field

Firm terrain between ripples

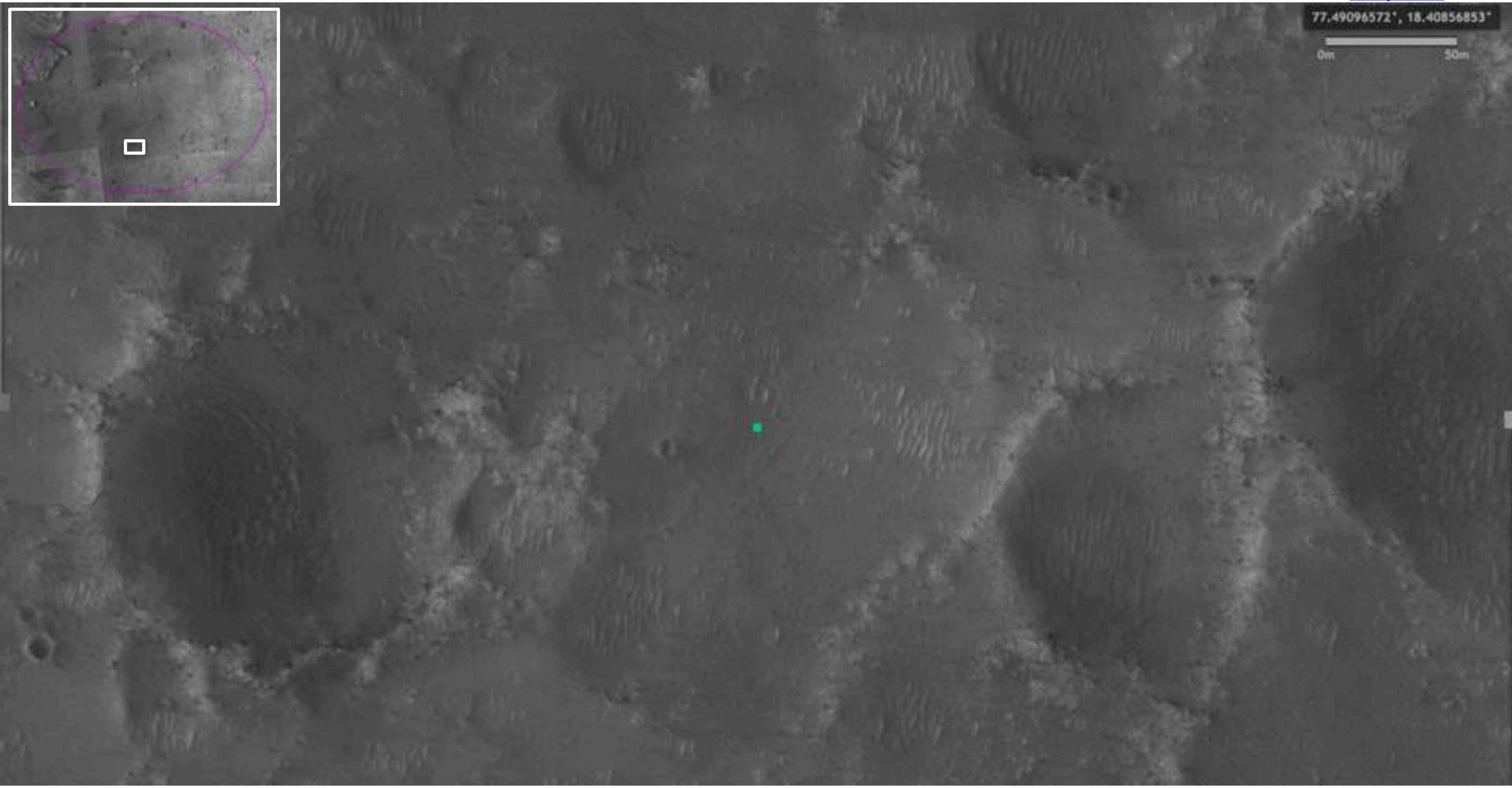
# Opportunity Ripples

Opportunity sol 795

Not the easiest of driving, but no danger to the vehicle

# JEZ Key Characteristics

The majority of the landing ellipse is regolith with degraded craters and sparse to moderate sand coverage. Credible ingress and egress routes from the delta. Map link



# JEZ Key Challenges

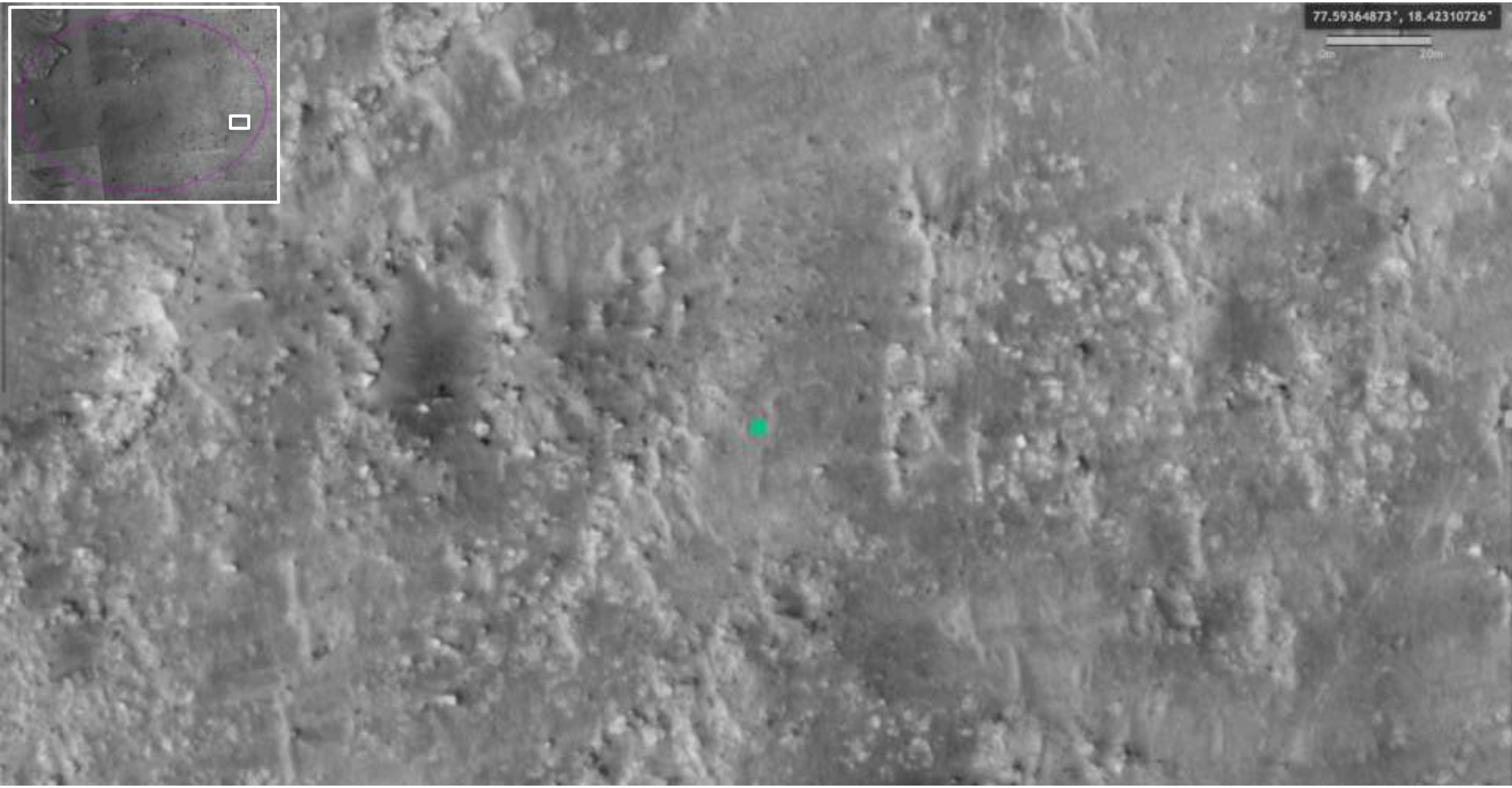


Jet Propulsion Laboratory
California Institute of Technology



The eastern portion of the ellipse has a high abundance of rocks

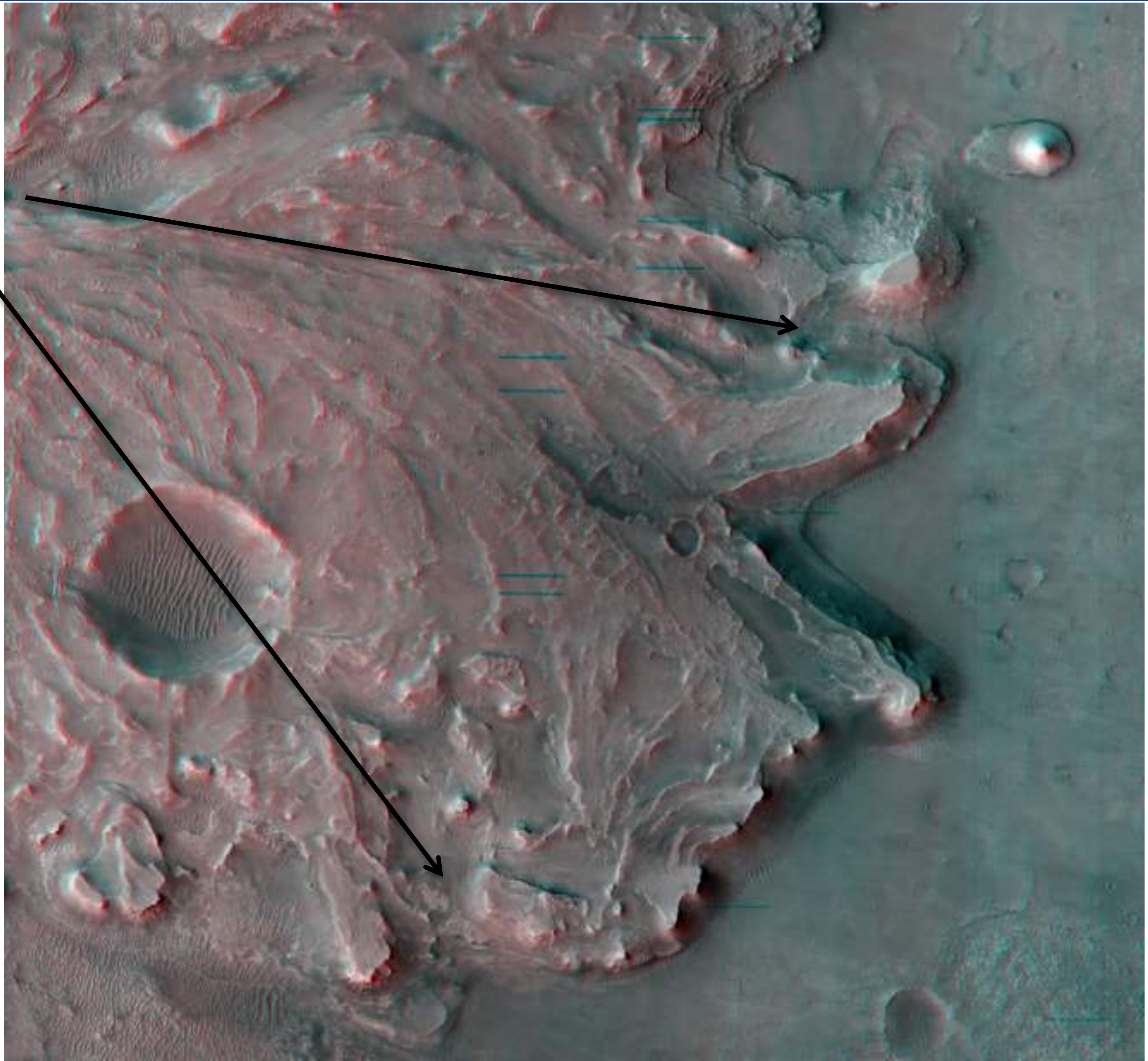
Map link



# Routes Up the Delta



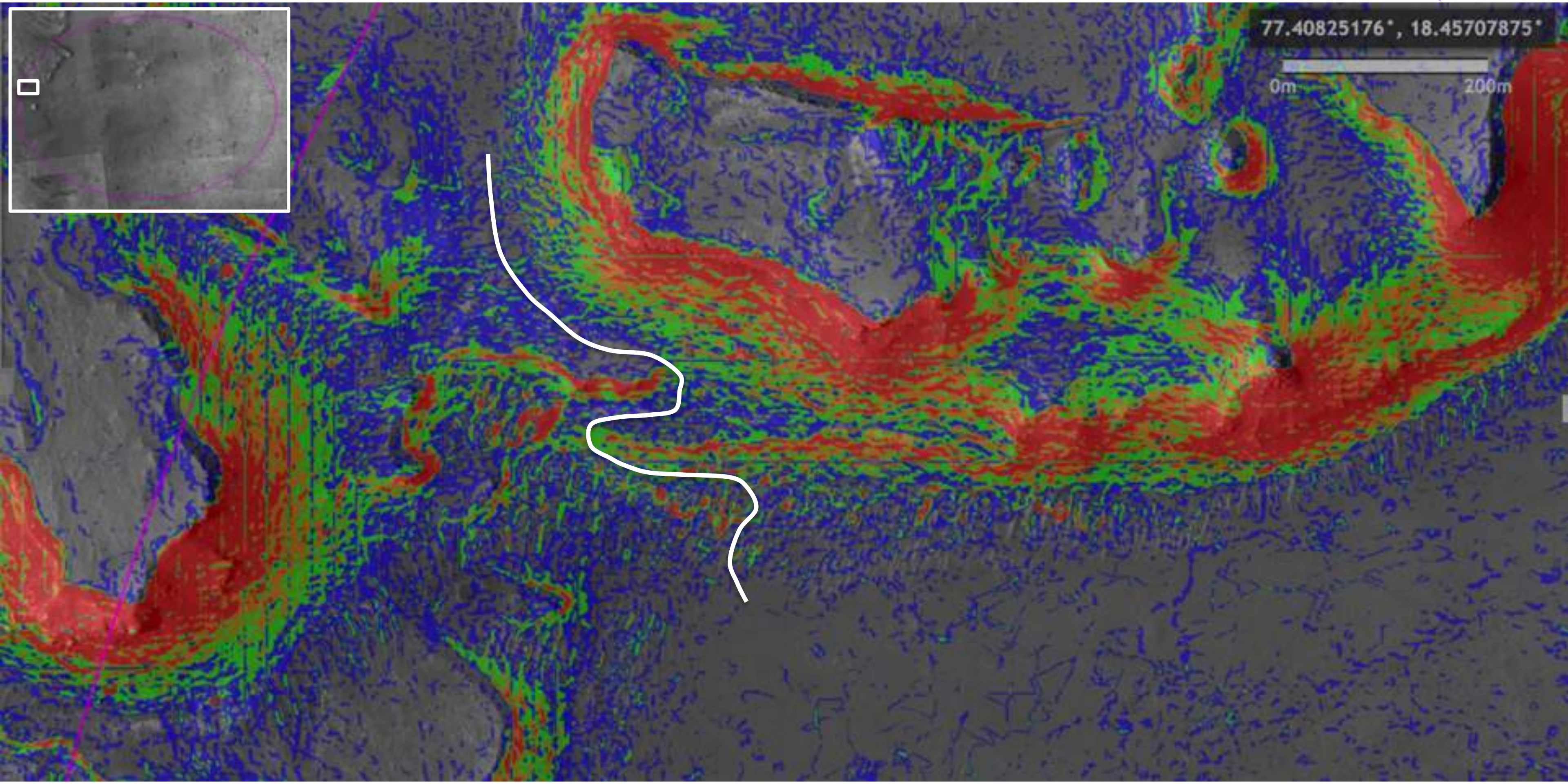
Access
Routes



# Routes up the Delta

Sand skirt around the base of the delta is a significant challenge to climbing the delta, but viable routes do seem to exist.

Map link

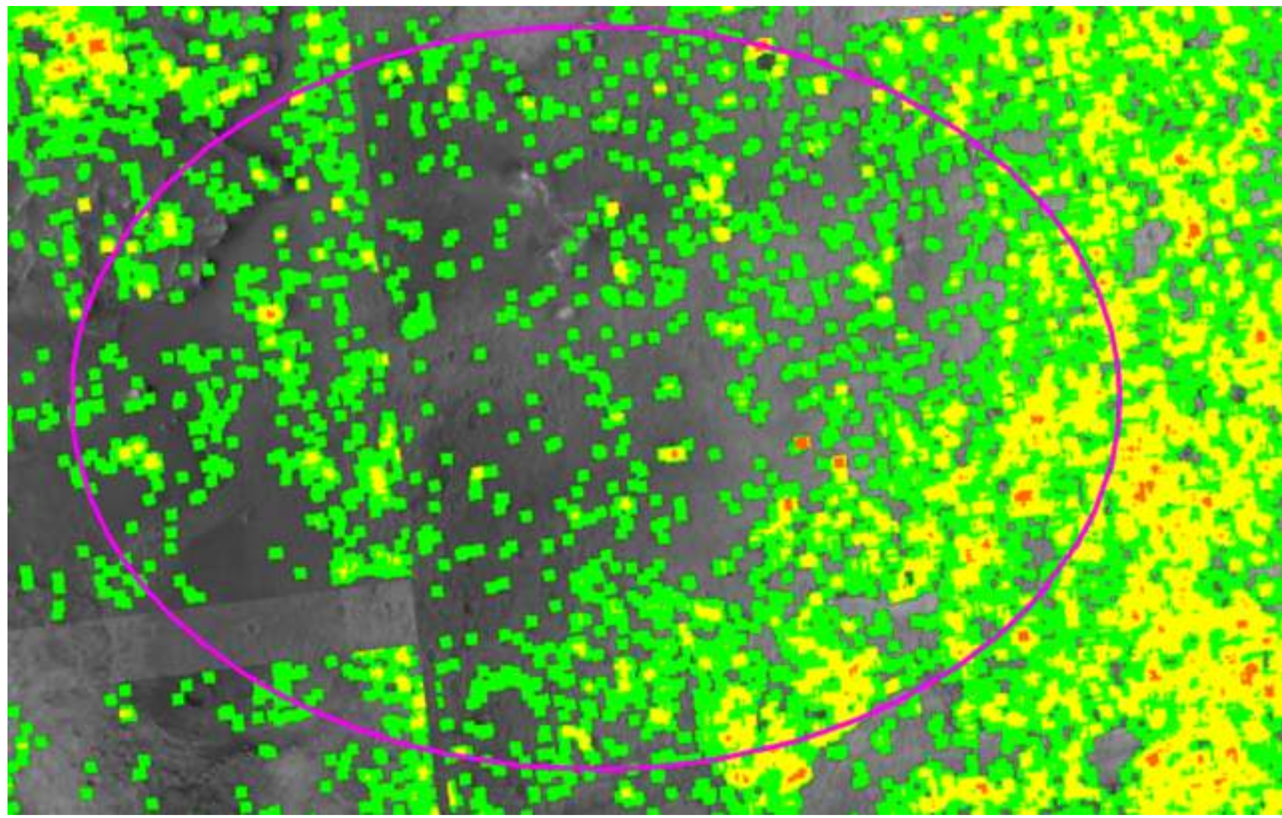



<5° or no data | 5°-10° | 10°-15° | 15°-20° | 20°-25° | ≥ 25°

# Rock Map

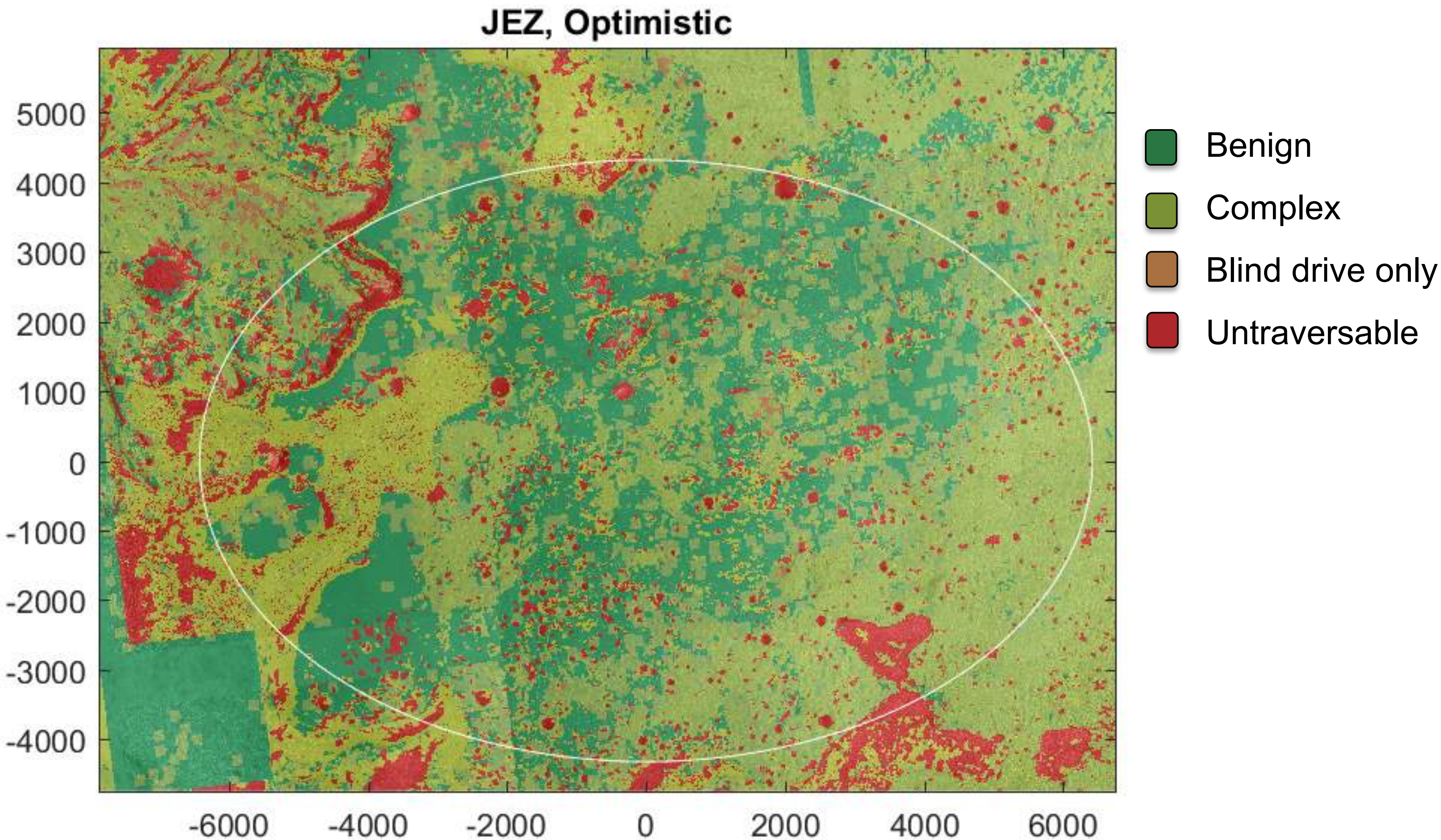
Much less concerned then previously due to smaller ellipse

AutoNav traverse rates
- < 7% CFA at 75 m/hr
- CFA between 7% – 15% at 70 m/hr
- Cannot traverse > 15% CFA

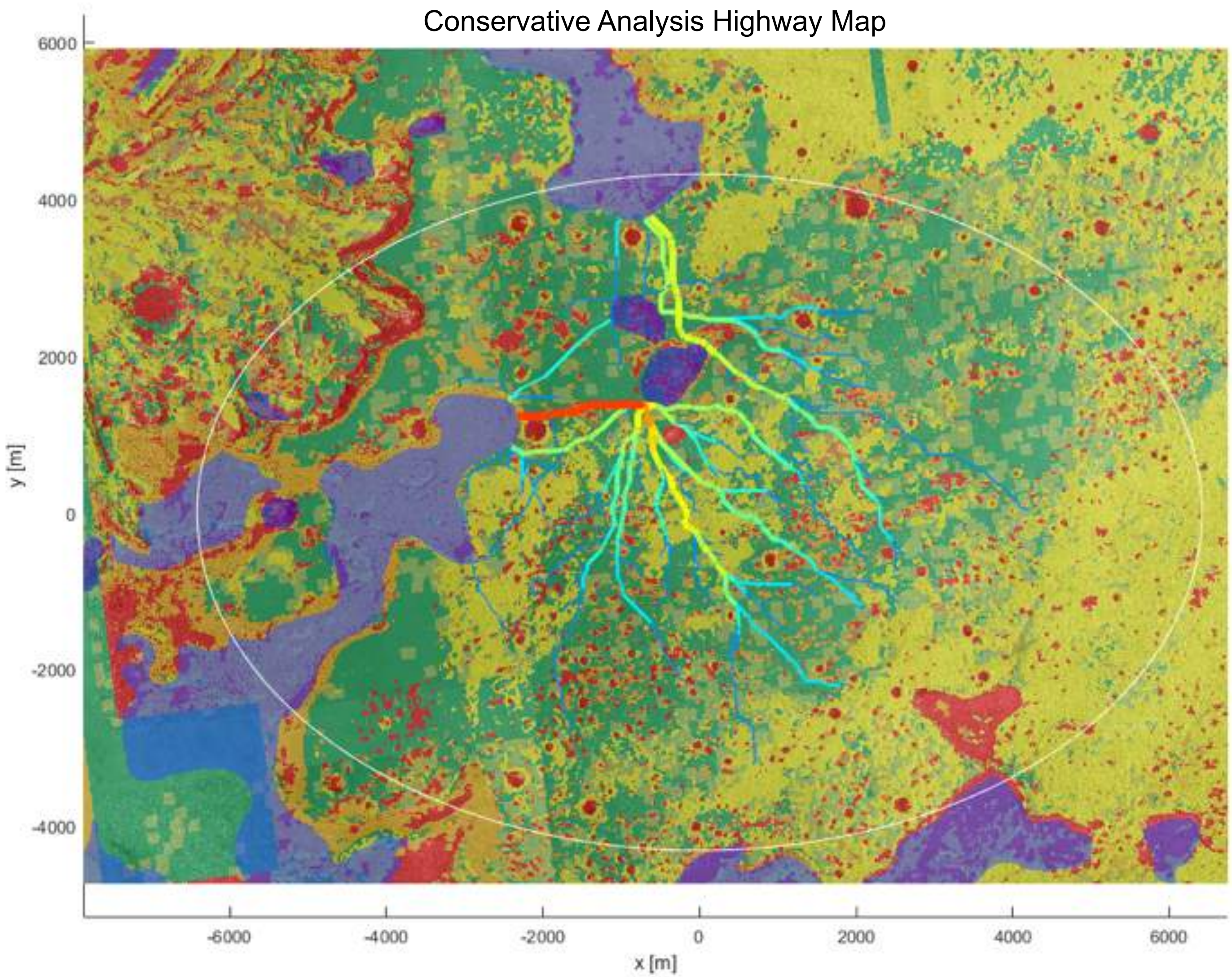


<7% or no data | 7%-10% | 10%-15% | 15%-20% | >=20%

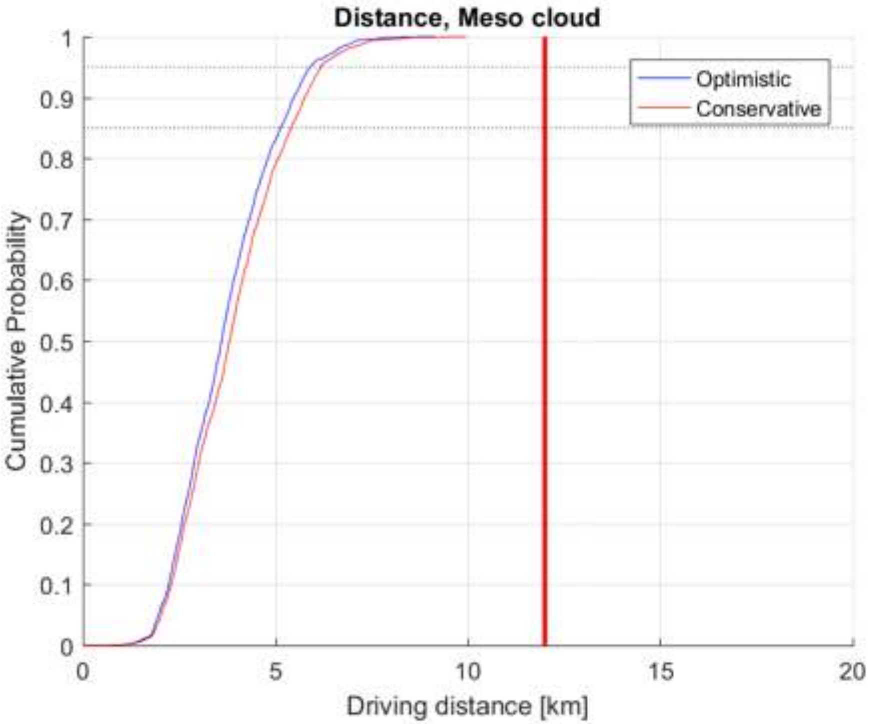
# Traversability Map

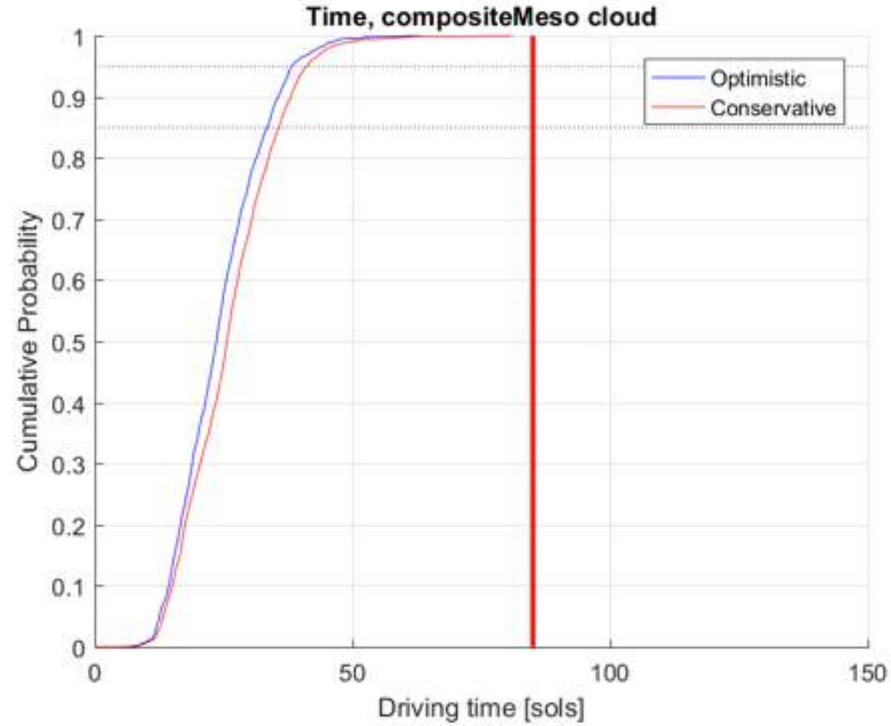


# Highway Map


Conservative Analysis Highway Map
6000
4000
2000
0
-2000
-4000
y [m]
-6000
-4000
-2000
0
2000
4000
6000
x [m]

# Traverse Analysis Results




**Distance**

| Drive rate assumption | 50% | 80% | 85% | 90% | 95% |
|---|---|---|---|---|---|
| Optimistic | 3.6 km | 4.8 km | 5.1 km | 5.5 km | 5.9 km |
| Conservative | 3.8 km | 5.1 km | 5.5 km | 5.8 km | 6.2 km |

**Time**

| Drive rate assumption | 50% | 80% | 85% | 90% | 95% |
|---|---|---|---|---|---|
| Optimistic | 23.9 sols | 31.4 sols | 33.5 sols | 35.7 sols | 38.4 sols |
| Conservative | 25.9 sols | 34.0 sols | 35.9 sols | 38.2 sols | 41.3 sols |

Assumes 2.5 hours of dedicated drive time per sol
85 sols is the portion of the mission allocated to traversing between ROIs

# Terrain Type Breakdown

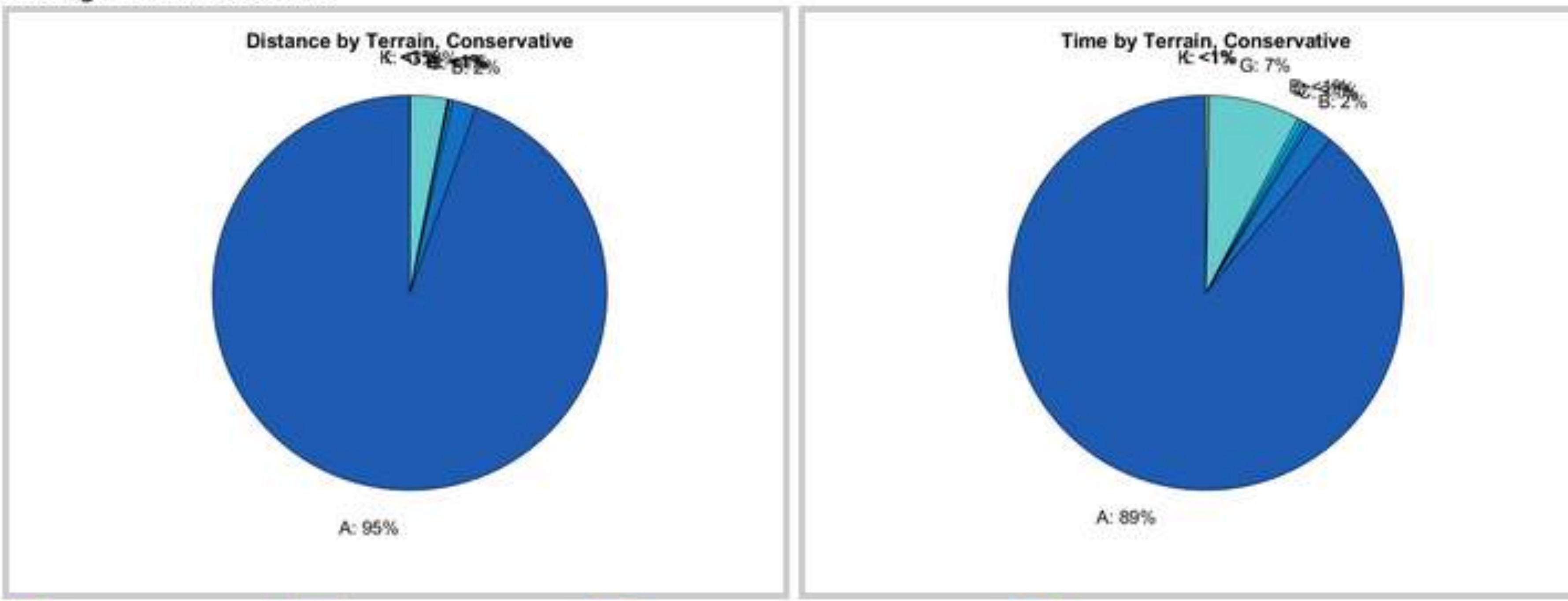
Jet Propulsion Laboratory
California Institute of Technology



**Conservative**

Average Distance: 3.9 km

Average Time: 26.1 sols




A Smooth regolith · B Smooth outcrop · C Smooth fractured outcrop · D Sparse ripples smooth firm substrate · E Moderate ripples firm substrate · F Rough regolith · G Rough outcrop · H Dense ridges · I Rock field · J Sparse ripples sandy substrate · K Moderate ripples sandy substrate · O Featureless sand

# Drive Rate Breakdown



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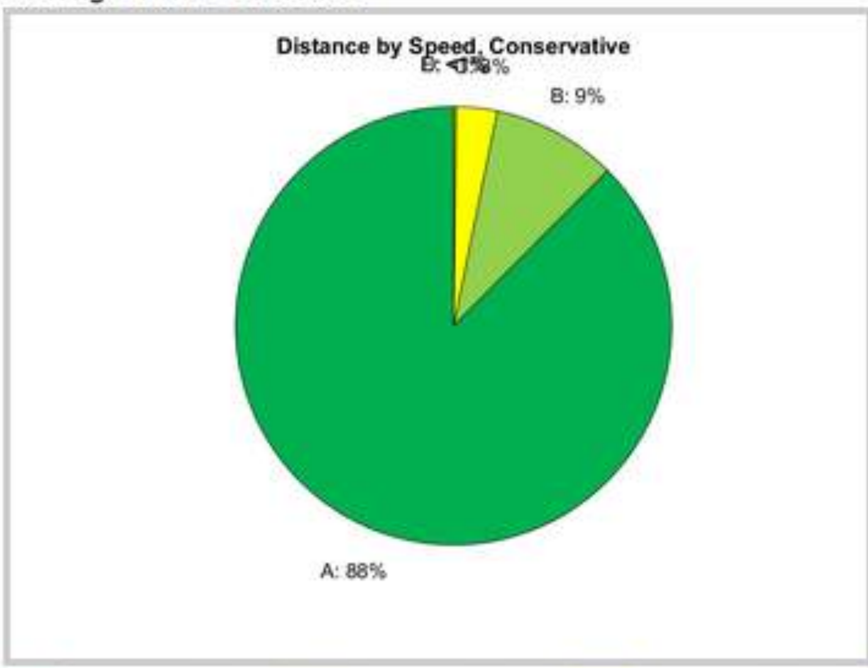


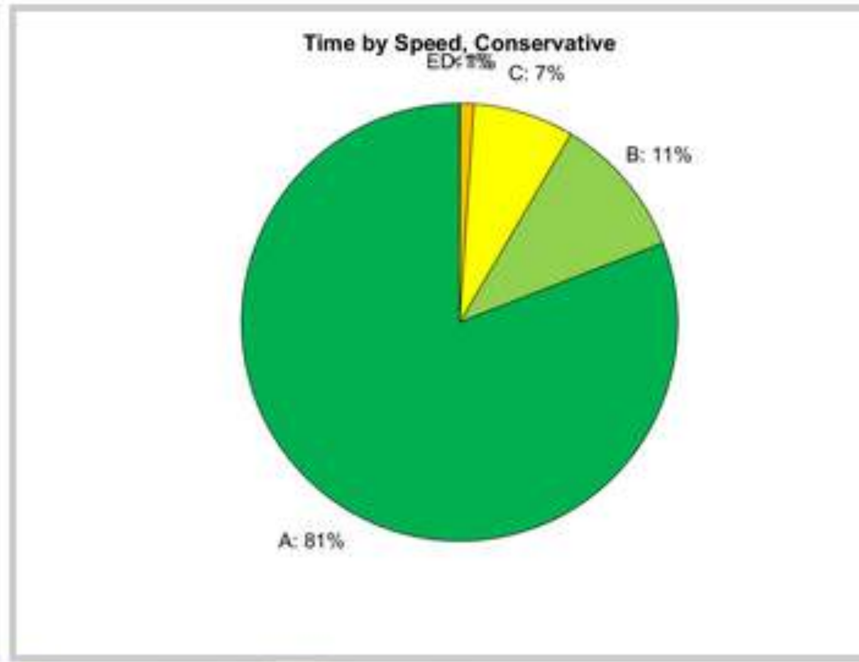


A 64.8 m/hr  B 52.5 m/hr  C 24.2 m/hr  D 10.9 m/hr  E 8.7 m/hr

# Environmental Conditions

- Jezero, located at Lat=18.5 N, has a mild environment and does not experience the temperature extremes in summer or winter as compared to southern latitude sites.

- There are no known operational or hardware constraints due to environmental conditions at Jezero.

- More detailed analysis of the seasonal effects to operability and mission performance is in-progress…

# Environments & Thermal

- (opposite) 6 diurnal temperature profiles, optimized for 9:30 LTST, to use for modeling all sites throughout Mars year.
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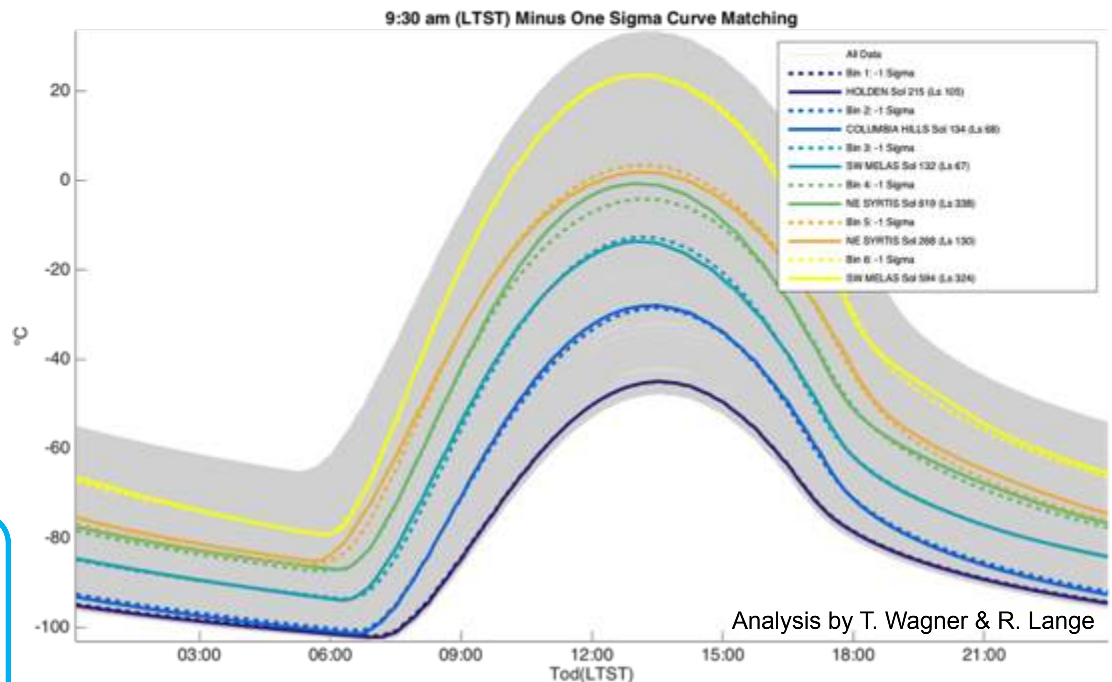
- Results from thermal analysis of 6 environments will be ready by early October

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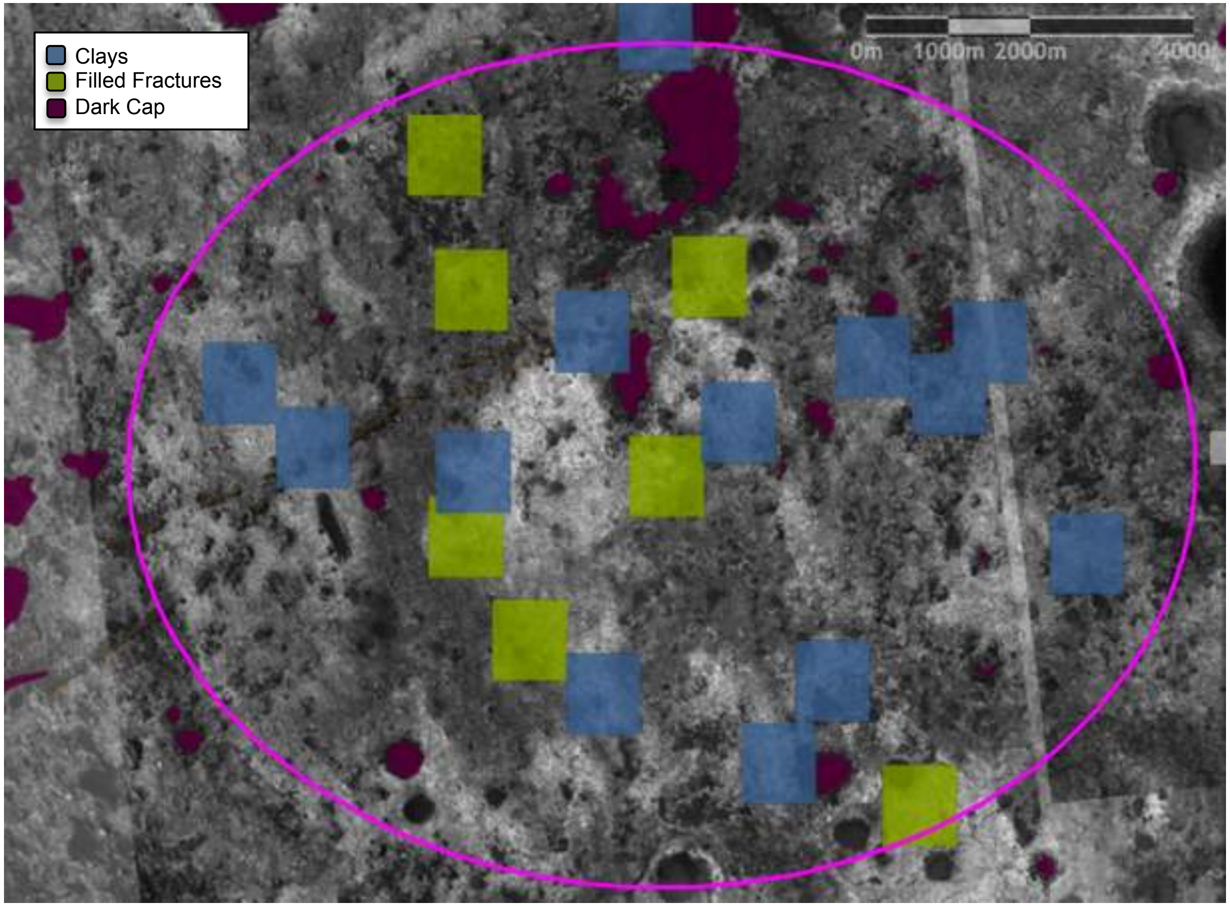
| 7 | Nili | 0% | 0% | 24% | 52% | 24% | 0% |
| 8 | SW Melas | 0% | 0% | 32% | 14% | 17% | 36% |

# Mawrth

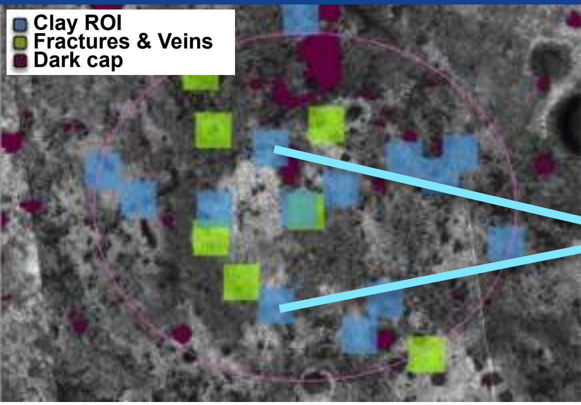
## Mission Scenario

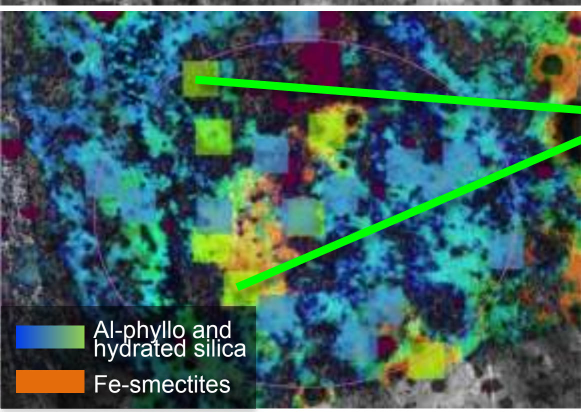
- ROIs
  - Clays
    - **9 samples**
    - 3 Campaigns with 2 units each separated by 50 – 300 meters
  - Filled Fractures
    - **4 samples**
    - 1 campaign with 2 units
- Waypoints
  - Dark Cap
    - **2 samples**
    - 2 Rock waypoints separated by at least 100 meters
    - Note that these rock waypoints are at specific locations and from a traverse analysis perspective are equivalent to an ROI, but from a mission scenario perspective we will spend much less time here compared to the other ROIs
  - Regolith (throughout ellipse)
    - **1 sample**
    - 1 Regolith waypoint which can come from anywhere we find accessible material
- Procedural Blanks
    - **4 samples**



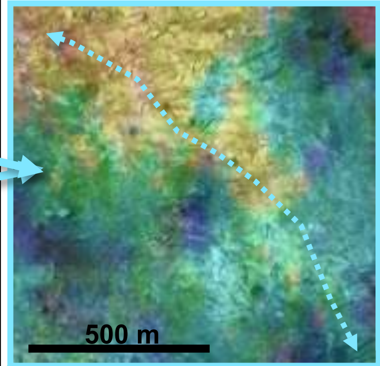
# Mawrth ROI Science





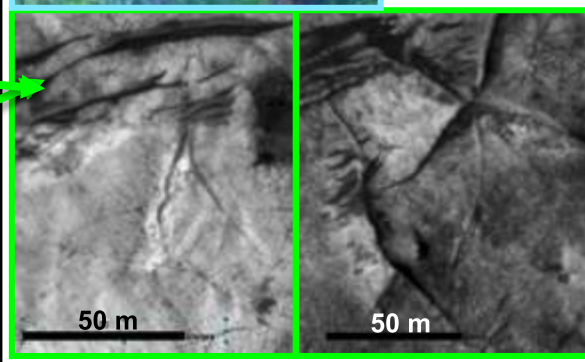

## MAIN CAMPAIGNS




**THE CLAY UNIT: Astrobiology in Noachian *surface* environments**

Very diverse mineralogy resulting from different fluid and redox conditions at the surface and in the subsurface, well preserved:

- **two main clay-rich units** and their stratigraphy: Al-clays/hydrated silica and Fe-clays, over 300m thick, spanning the Early to Late Noachian
- **contact between these two units**, through a reduced ferrous iron layer.
- **reducing environment**: Areas particularly rich in kaolinite, and showing the presence of ferrous iron, outside of the main ferrous iron layer, **possible ancient wetlands-like ponds**
- **1O+ ROIs within the ellipse**



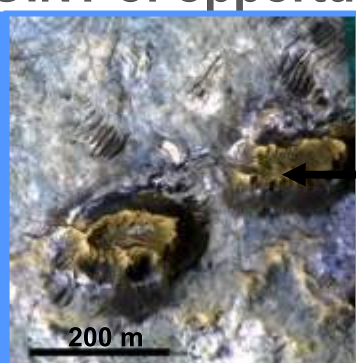

**HALO-BOUNDED FRACTURES AND VEINS: Astrobiology in Noachian *subsurface* environments**

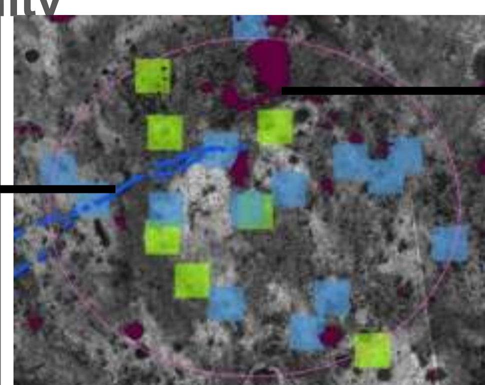
- **Large halo-bounded fractures**, and **veins** where erosion is stronger, likely deposited by fluid circulation in ancient fractures, possibly linked to **impact–generated hydrothermal activity**
- Main concentrations are within the green boxes but other isolated halos are found in the ellipse
- **10+ ROIs within the ellipse**

## ROCK WAYPOINT of opportunity

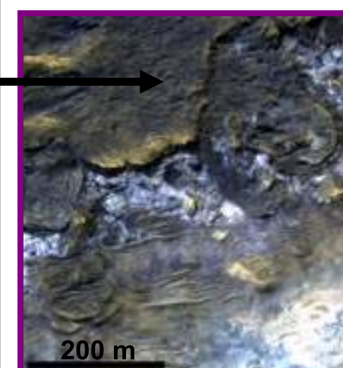
**INVERTED VALLEY: Habitability and biosignatures**

Suites of elongated mesas that likely represent a very **eroded inverted valley**, target: base of the inverted valley, at the base of the remnant buttes



## ROCK WAYPOINT

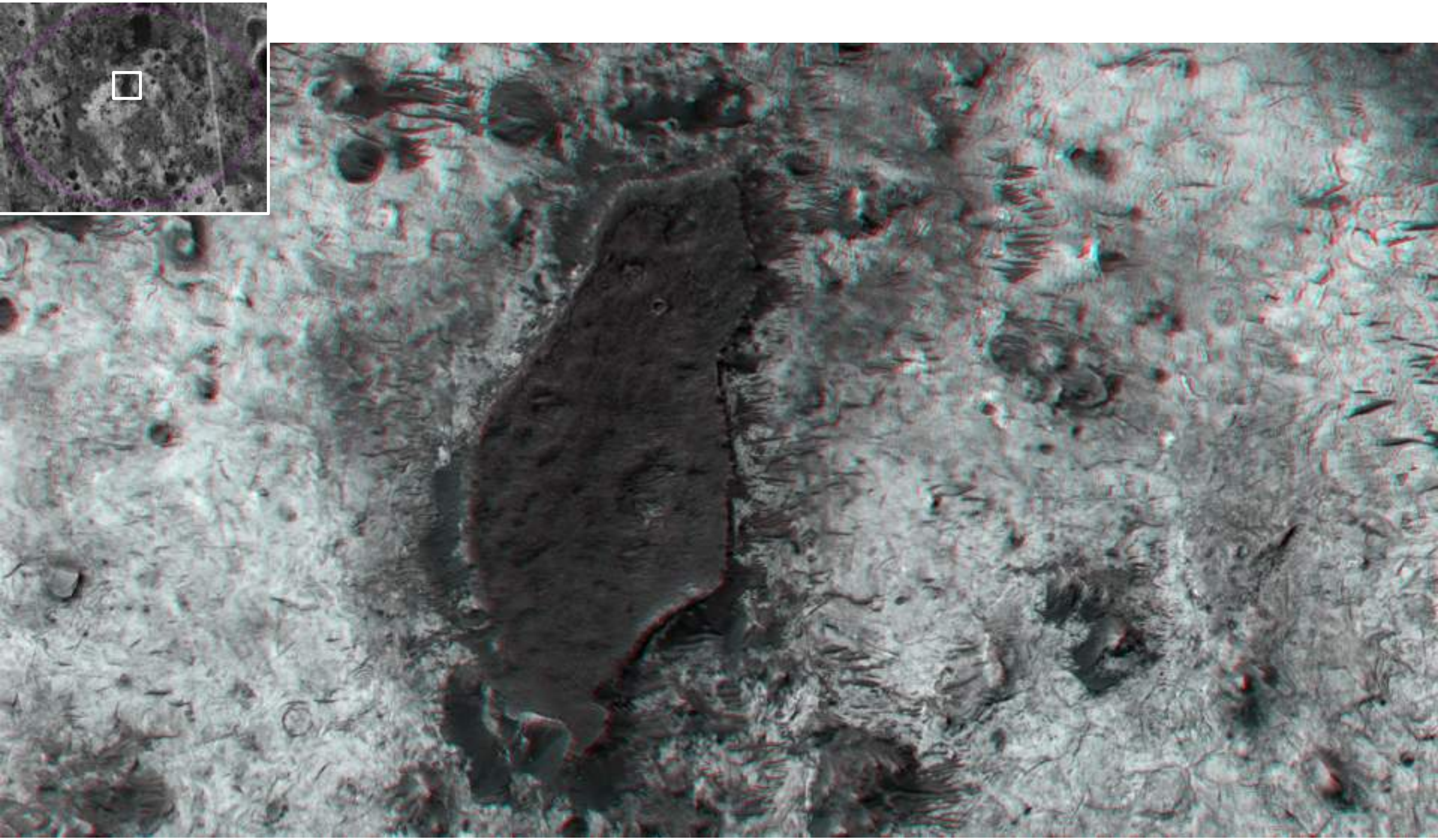



**DARK CAP: sample caching**

Dark mesas, remnant of the regional mafic cap, likely made of pyroclastics; for which an early Hesperian crater retention age has been determined (3.6-3.7 Ga)

# Dark Cap Waypoint



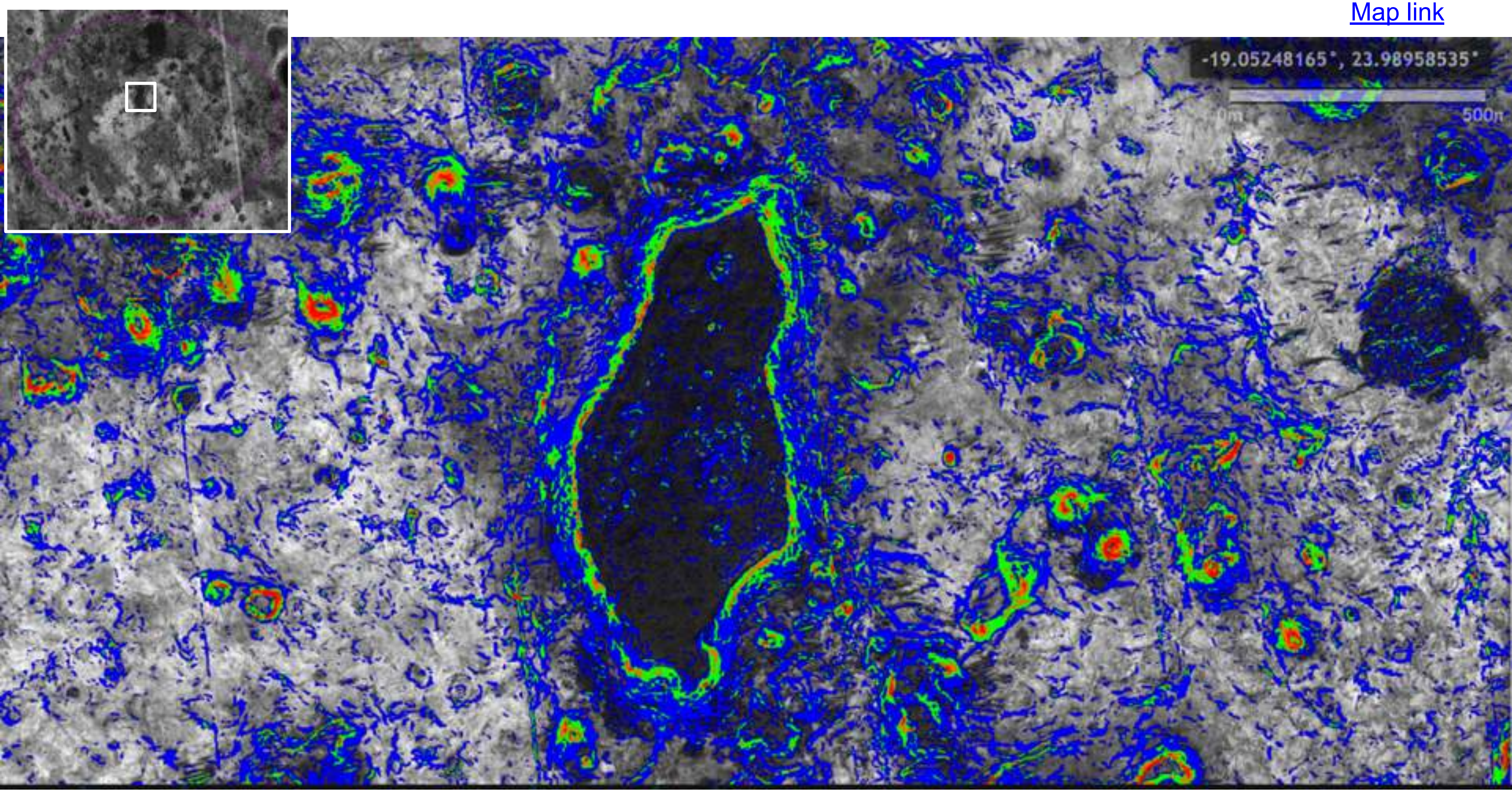


Source image PSP_008825_2040

# Dark Cap Waypoint

Slopes are low enough that the top of the mesa is likely accessible

Map link

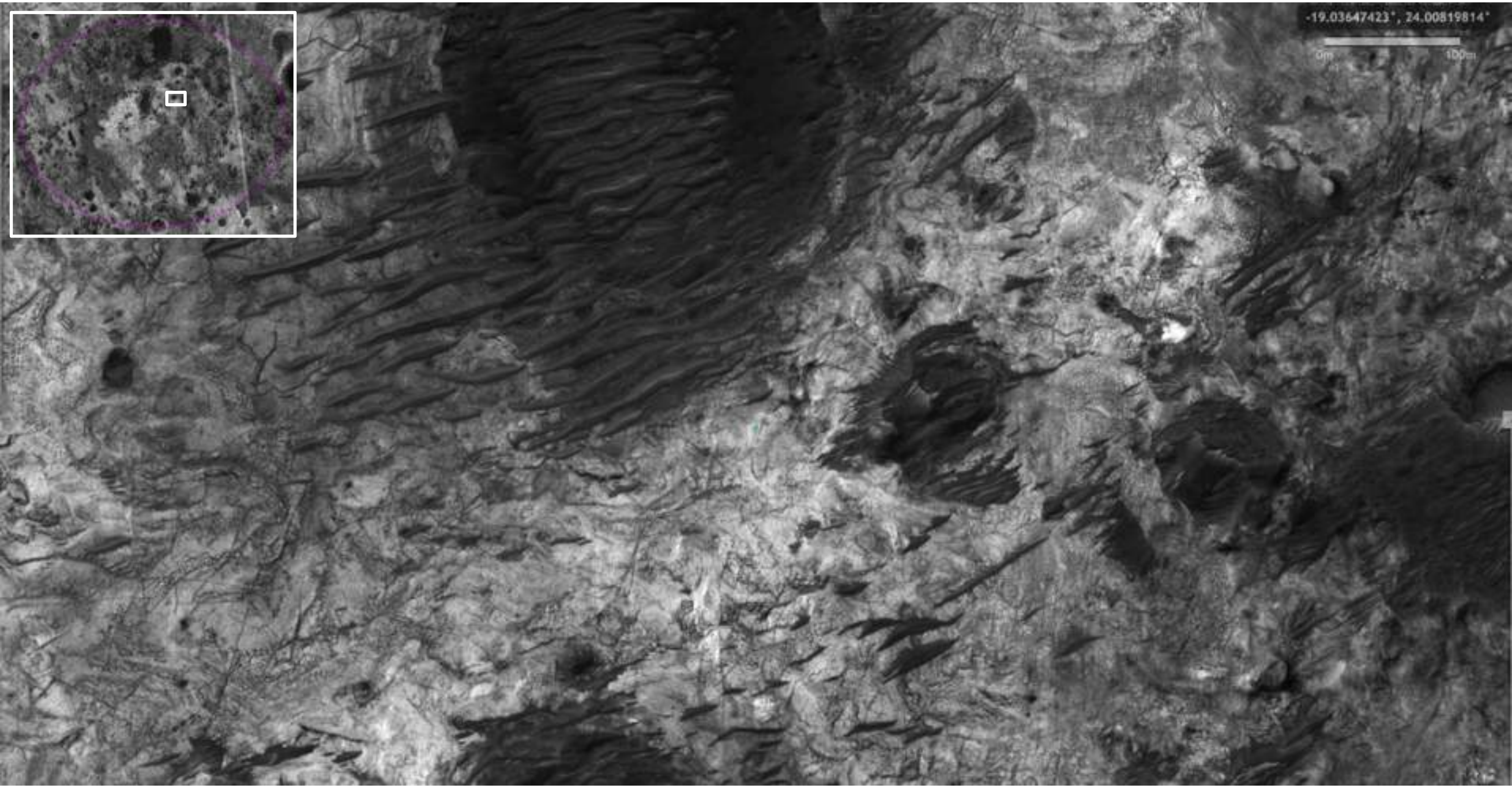



<5° or no data | 5°-10° | 10°-15° | 15°-20° | 20°-25° | ≥ 25°

# Key Characteristics

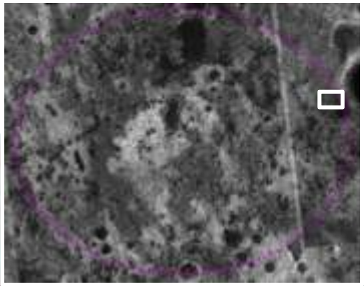
Much of the site is smooth outcrop with sparse sand coverage and dense sand accumulations in craters.

Map link

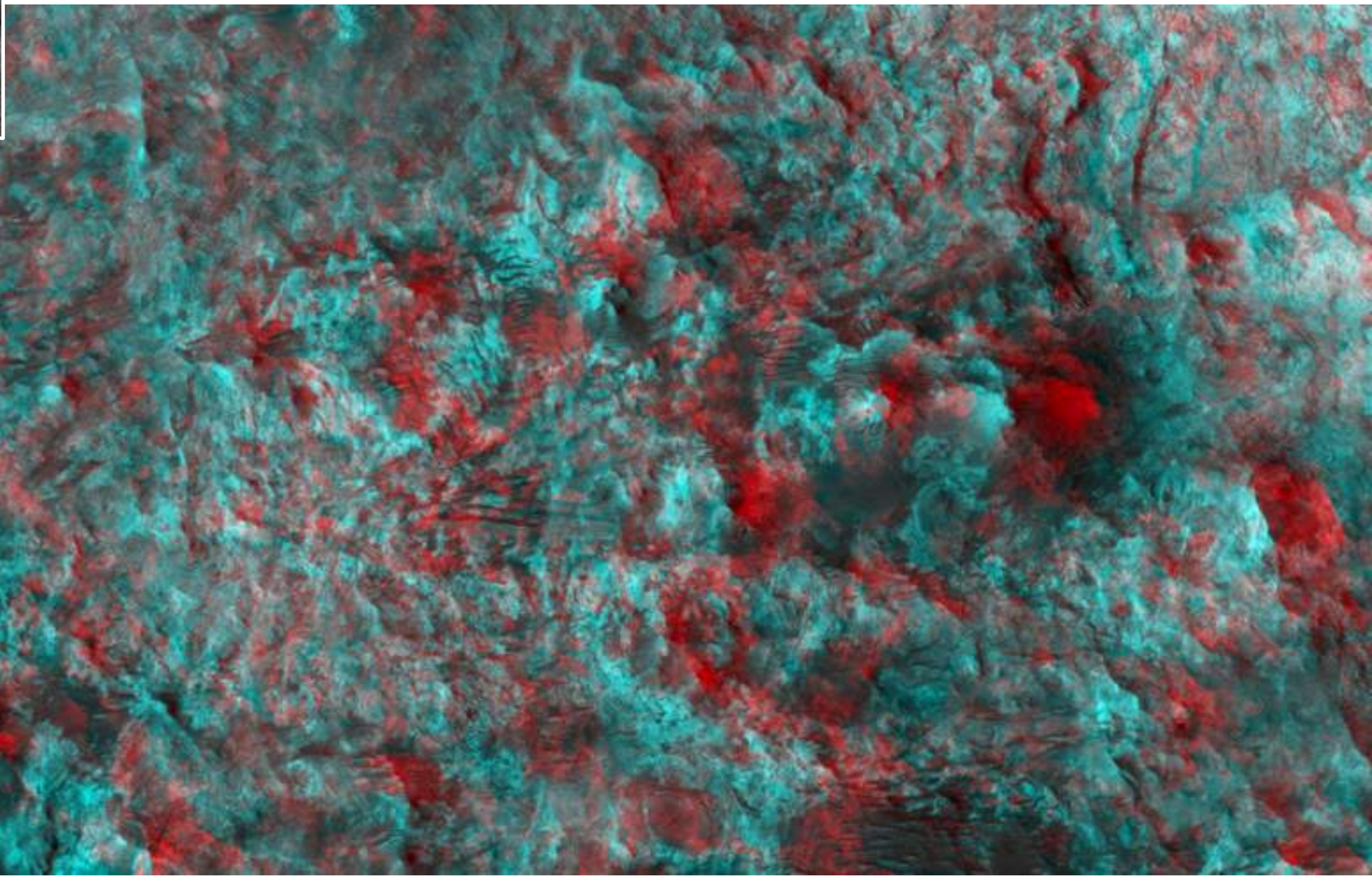


# Key Challenges



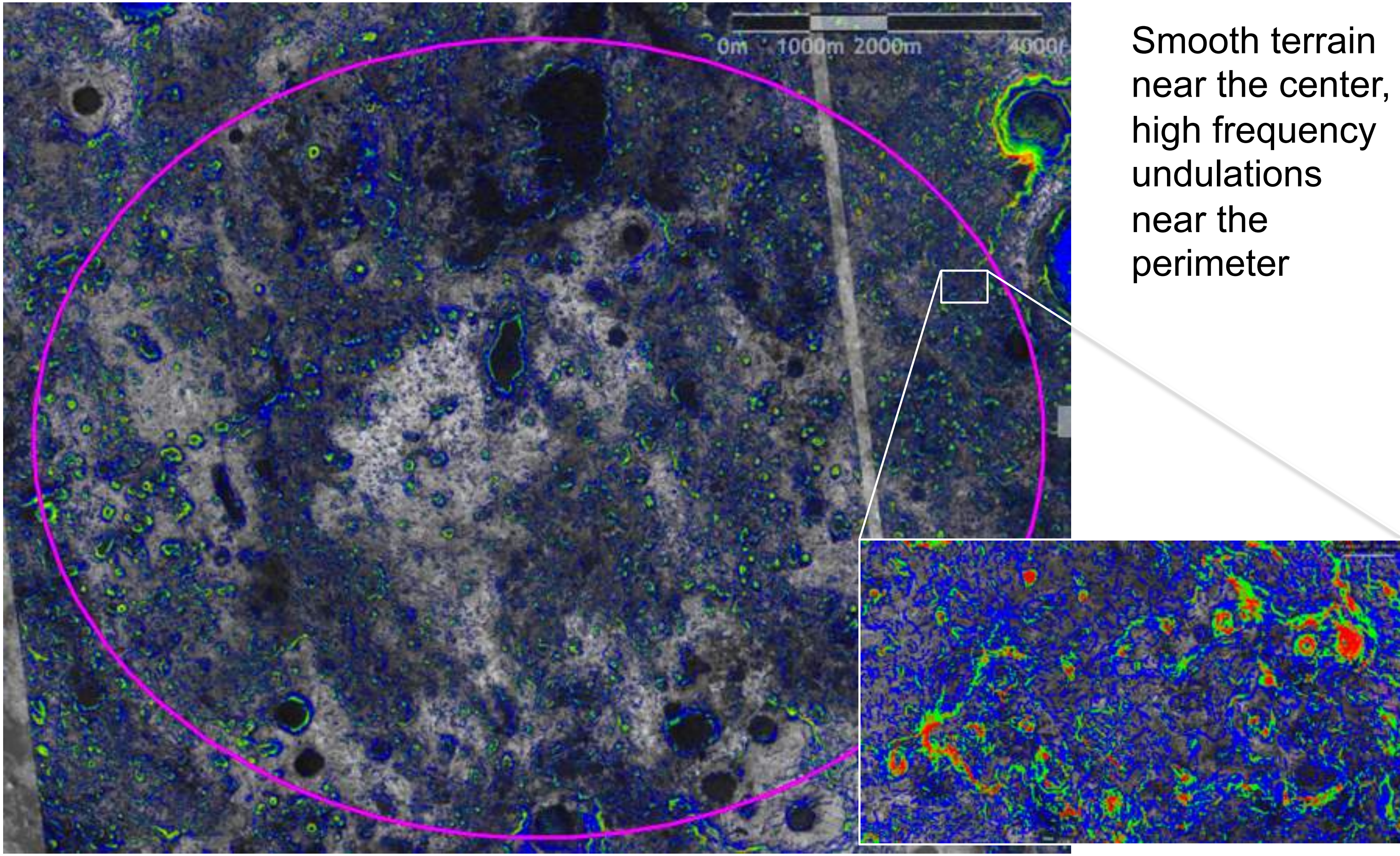


Rougher terrain, which means slower driving and more challenging for AutoNav, near the perimeter of the ellipse.



Source image PSP_005964_2045

# Slopes




Smooth terrain near the center, high frequency undulations near the perimeter

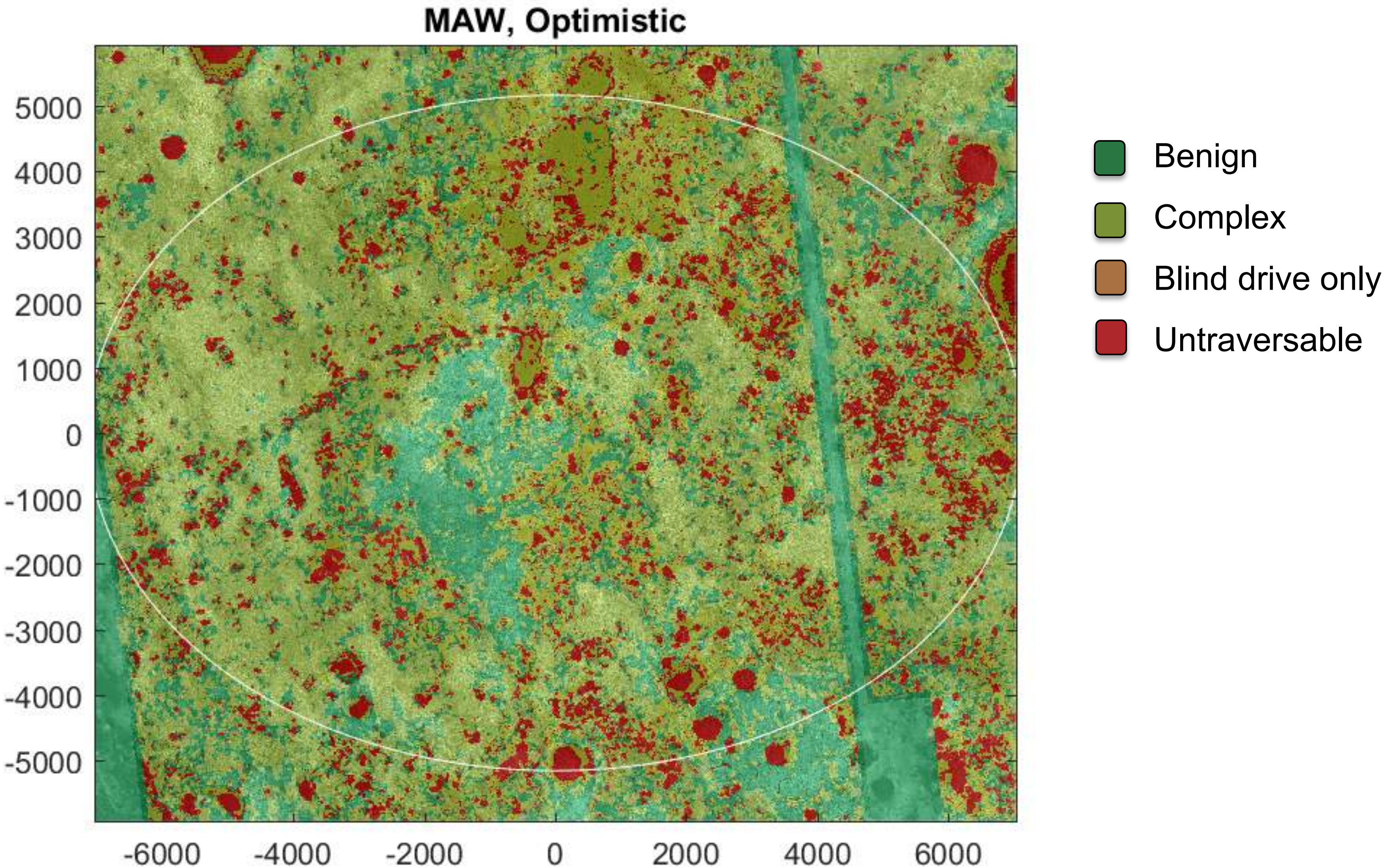
<5° or no data | 5°-10° | 10°-15° | 15°-20° | 20°-25° | ≥ 25°

# Traversability Map

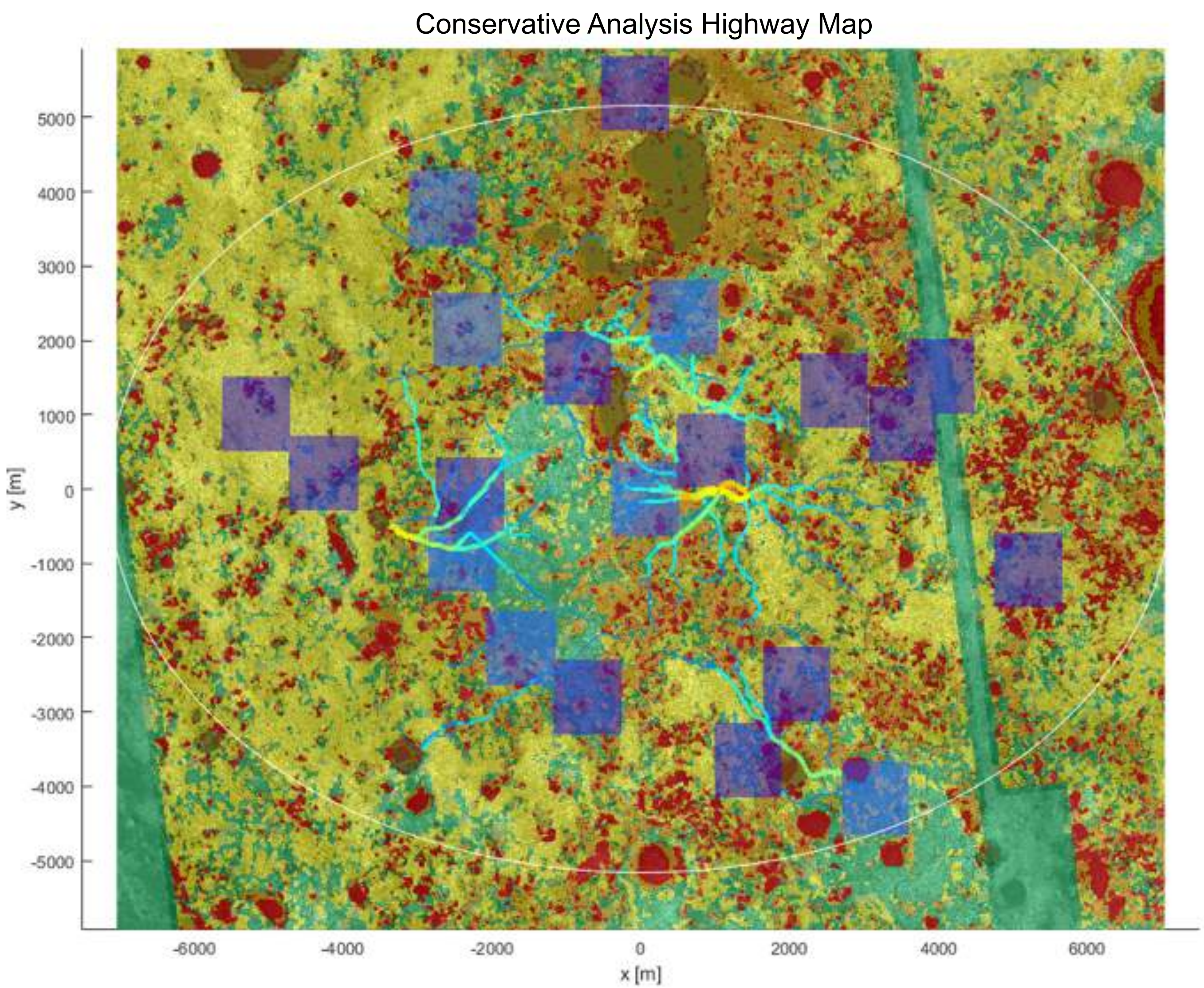




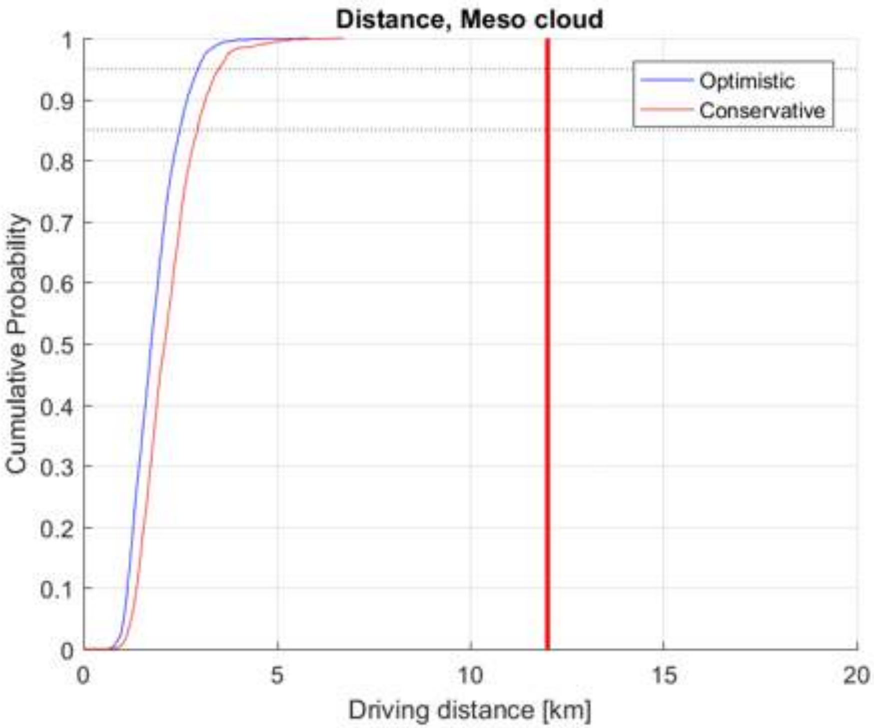


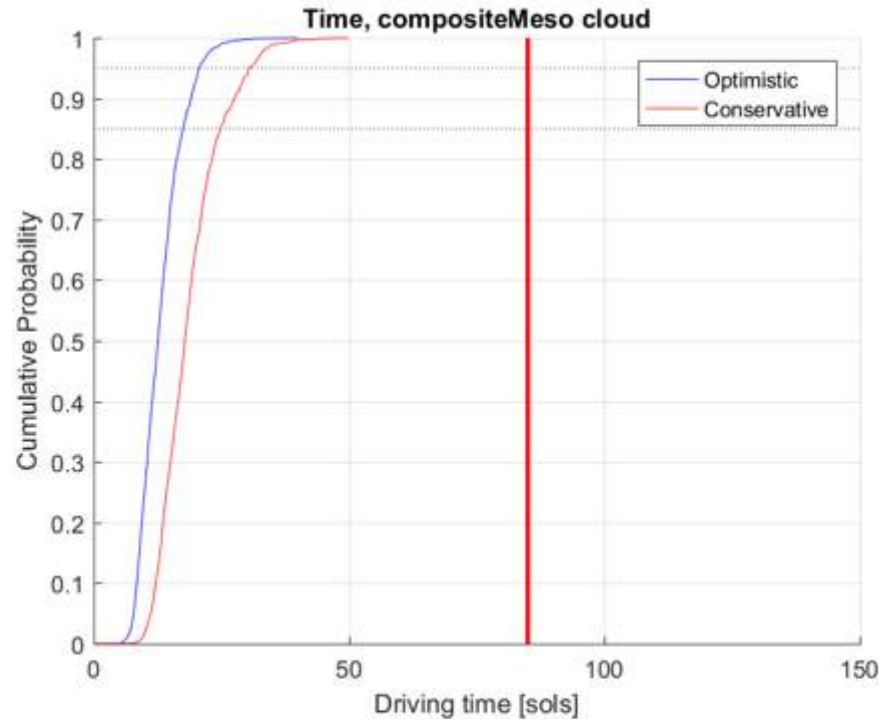


# Highway Map


Conservative Analysis Highway Map
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000
-5000
y [m]
-6000
-4000
-2000
0
2000
4000
6000
x [m]

# Traverse Analysis Results




**Distance**

| Drive rate assumption | 50% | 80% | 85% | 90% | 95% |
|---|---|---|---|---|---|
| Optimistic | 1.8 km | 2.3 km | 2.5 km | 2.7 km | 3.0 km |
| Conservative | 2.1 km | 2.8 km | 3.0 km | 3.2 km | 3.5 km |

**Time**

| Drive rate assumption | 50% | 80% | 85% | 90% | 95% |
|---|---|---|---|---|---|
| Optimistic | 12.6 sols | 16.4 sols | 17.5 sols | 19.2 sols | 20.8 sols |
| Conservative | 18.0 sols | 23.2 sols | 24.9 sols | 27.8 sols | 30.6 sols |

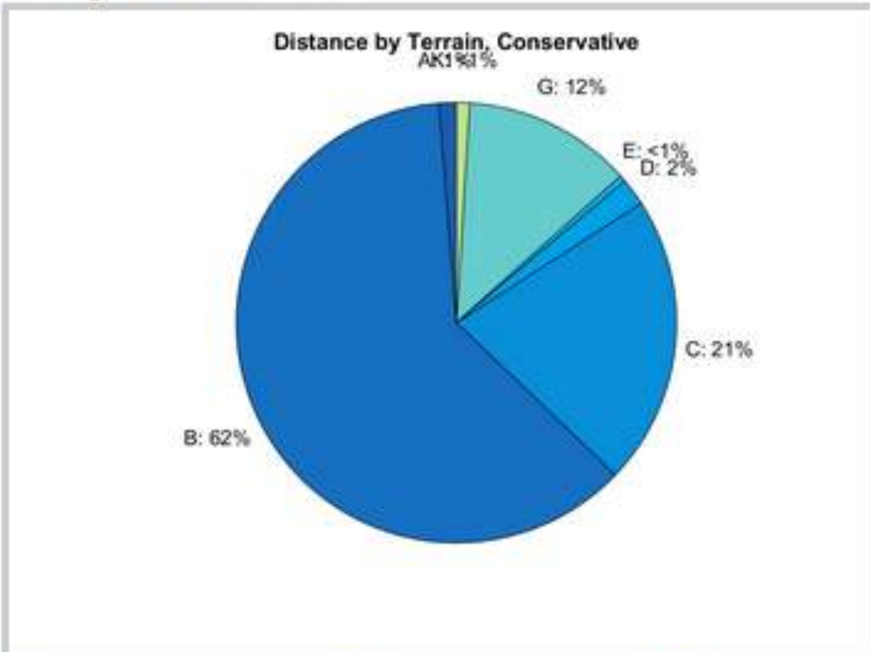
Assumes 2.5 hours of dedicated drive time per sol
85 sols is the portion of the mission allocated to traversing between ROIs

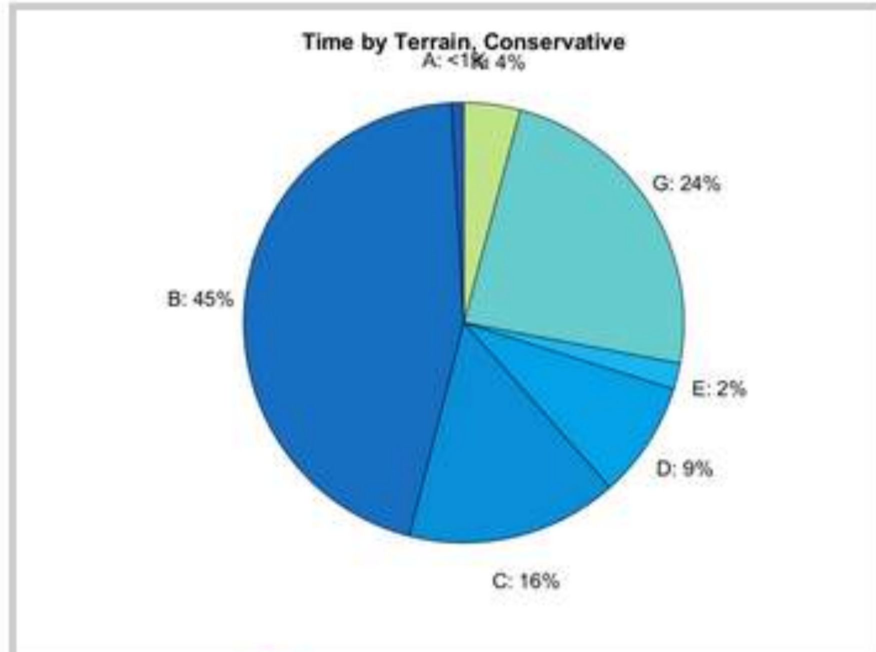
# Terrain Type Breakdown

**Conservative**

Average Distance: 2.2 km

Average Time: 18.9 sols




A Smooth regolith · B Smooth outcrop · C Smooth fractured outcrop · D Sparse ripples smooth firm substrate

E Moderate ripples firm substrate · F Rough regolith · G Rough outcrop · H Dense ridges · I Rock field

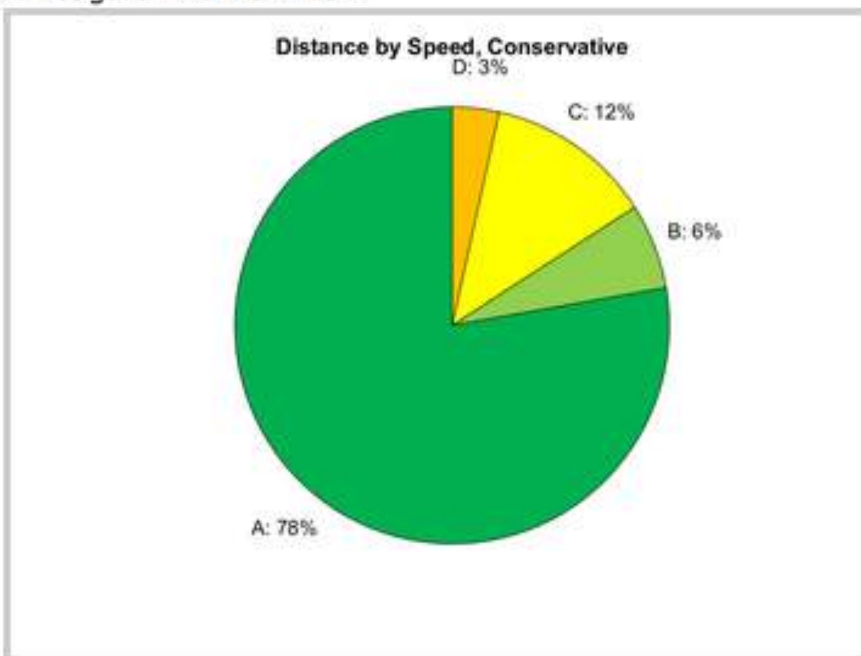
J Sparse ripples sandy substrate · K Moderate ripples sandy substrate · O Featureless sand

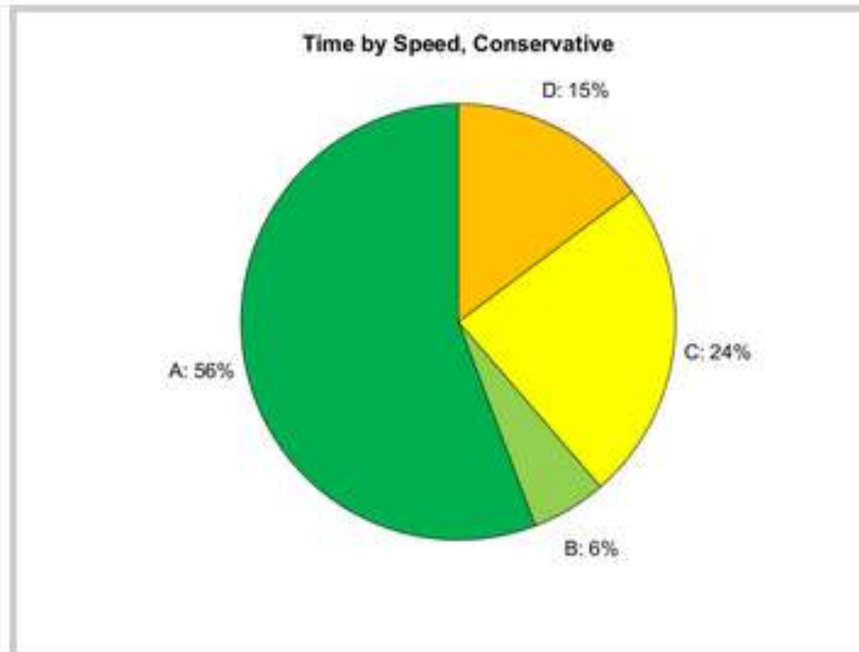
# Drive Rate Breakdown

**Conservative**

Average Distance: 2.2 km

Average Time: 18.9 sols




A 64.8 m/hr   B 52.5 m/hr   C 24.2 m/hr   D 10.9 m/hr   E 8.7 m/hr

# Environmental Conditions

- Mawrth, located at Lat=24 N, has a temperate environment and does not experience the temperature extremes in summer or winter as compared to southern latitude sites.

- Of the 4 northern candidate landing sites, Mawrth has the coldest winter temperatures. Spring/summer/fall seasons are more similar to the other northern sites.

- There are no known operational or hardware constraints due to environmental conditions at Mawrth.

- More detailed analysis of the seasonal effects to operability and mission performance is in-progress…

# Environments & Thermal



- (opposite) 6 diurnal temperature profiles, optimized for 9:30 LTST, to use for modeling all sites throughout Mars year.
- (lower-right) Percentage of environment bin usage over 1-MY for each landing site, based on Sol ranges defined by curve-fit optimization.

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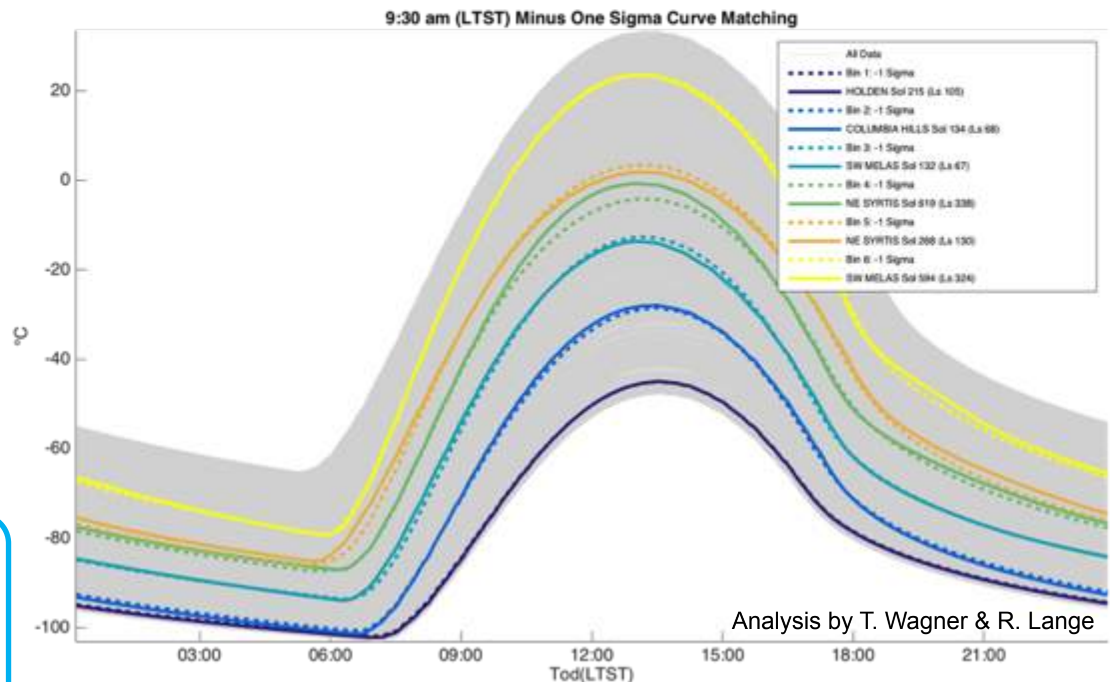
- Results from thermal analysis of 6 environments will be ready by early October



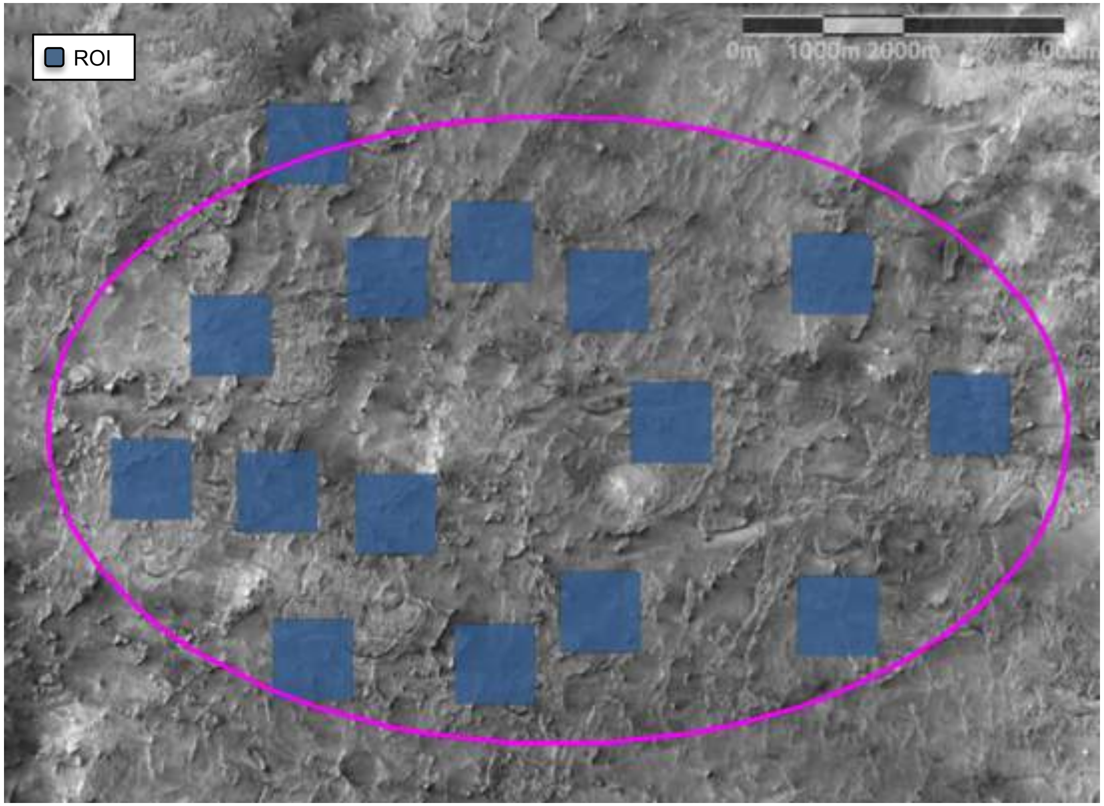

| | Bin: | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| 1 | Eberswalde | 24% | 16% | 13% | 8% | 12% | 28% |
| 2 | Columbia Hills | 0% | 33% | 16% | 11% | 18% | 21% |
| 3 | Holden | 29% | 14% | 11% | 8% | 11% | 27% |
| 4 | Jezero | 0% | 0% | 29% | 64% | 8% | 0% |
| 5 | Mawrth | 0% | 11% | 19% | 42% | 27% | 0% |
| 6 | NE Syrtis | 0% | 0% | 21% | 62% | 16% | 0% |
| 7 | Nili | 0% | 0% | 24% | 52% | 24% | 0% |
| 8 | SW Melas | 0% | 0% | 32% | 14% | 17% | 36% |

# Northeast Syrtis

## Mission Scenario

- ROIs
  - ROI #1 (any ROI box)
    - **6 samples** (from 3 units)
    - 2 campaigns with 2 units each, separated by 200 meters
  - ROI #2 (any ROI box)
    - **6 samples** (from 3 units)
    - ROI 2 will be separated by at least 1 km from ROI 1
    - 2 campaigns with 2 units each, separated by 200 meters
- Waypoints
  - Early/Mid-Noachian Clay-rich Basement (throughout ellipse)
    - **3 samples**
    - 3 waypoints along the strategic route between ROIs separated by at least 500 meters
  - Regolith (throughout ellipse)
    - **1 sample**
    - 1 Regolith waypoint wherever we find sand
- Procedural Blanks
    - **4 samples**

It should be noted that there is no preference for any of the 1 km x 1 km box ROIs. The mission can be accomplished by visiting any two ROIs.




Each box is an ROI with good exposure of all the key geologic units

- Crater-Retaining Mafic Capping Rock
- Olivine-Carbonate Variably Banded Formation
- Early/Mid-Noachian Low-Calcium Pyroxene-Bearing Mounds
- Early/Mid Noachian Clay-rich Basement

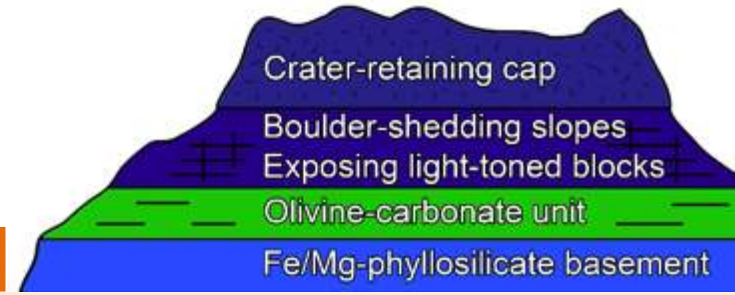
# Northeast Syrtis ROI Science

NES

Jet Propulsion Laboratory
California Institute of Technology

Mars 2020 Project

Northeast Syrtis Major mesas are spatially concentrated time capsules that record the majority of geological processes active on Mars during the Noachian and Hesperian and are special because of the large carbonate deposit.




## Characterize geologic history of astrobiologically relevant site/units

- **3 distinct, time-ordered formations** (mafic cap, carbonate, basement); one with 3 subunits (megabreccia basement, massive basement, Al-phyllosilicate weathering horizon) are **mappable from orbit for easy rover direction**
- **~250 Myr early Noachian to Hesperian historical record is the earliest accessible and well-understood in the context of Mars history**, bounded by the Isidis impact event and Syrtis Major volcanism (with still older

## Assess habitability/past life in units with high biosignature preservation potential

- **Regionally extensive carbonates** represent either near-subsurface mineralization of host rock or travertine-like mineral springs precipitation – either has **high biosignature preservation potential**
- The **Noachian clay basement and breccia blocks within preserve rocks from the time Mars had a magnetic field and thicker atmosphere.** Cross-crossing veins point to **available water in a continuously habitable environment** – the NE Syrtis paleo-aquifer is a good place to search for mineralized life

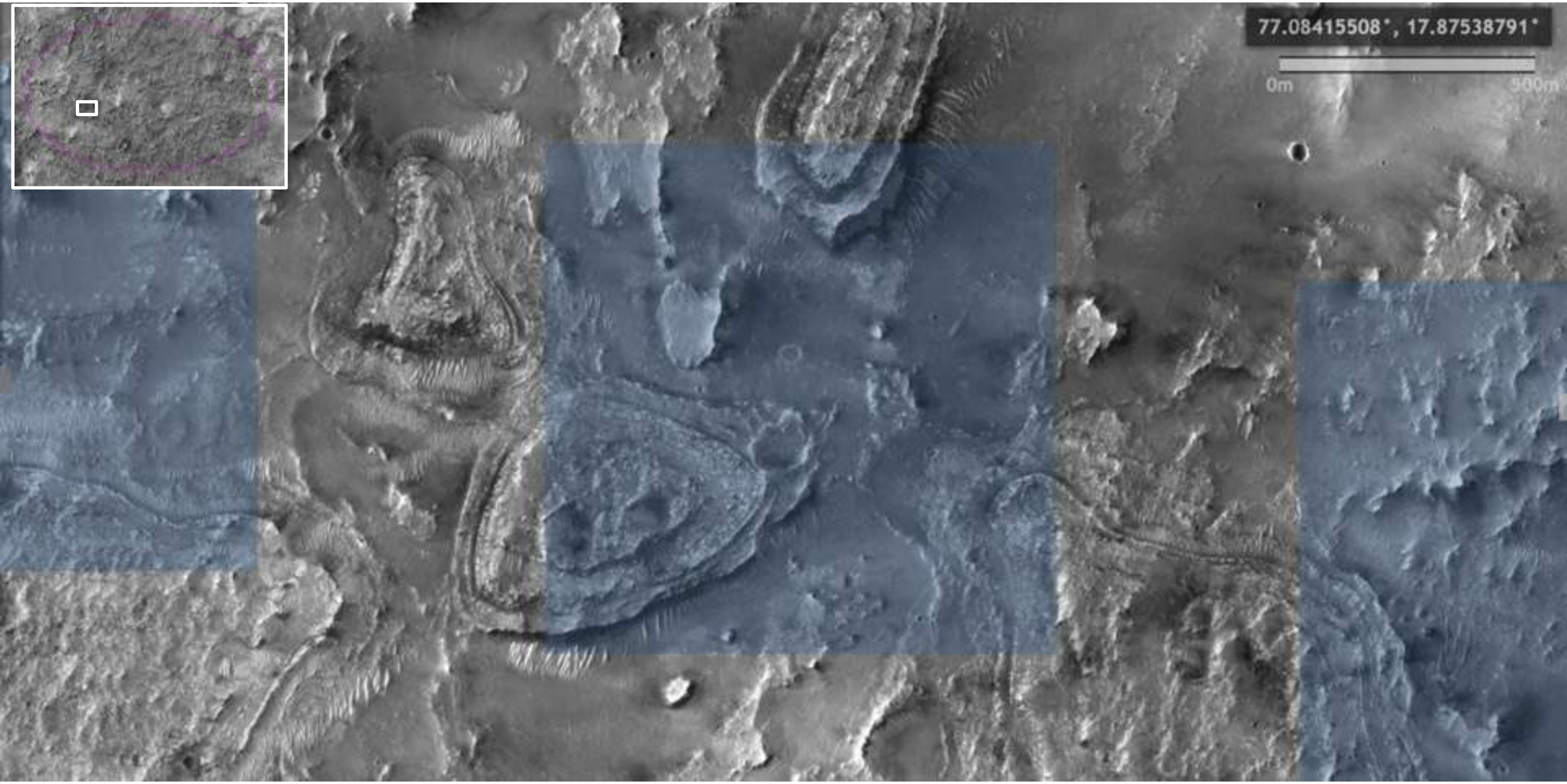
## Cache scientifically compelling samples

- **4 aqueous environments** (early clays, early carbonates, weathering horizons, *go-to sulfate sediments*) have distinct astrobio. potential, record of atm. evolution, volatile sequestration for traditional, clumped isotopes
- **4 age-date pins** for Martian chronology (1) Isidis-formed melt within Noachian basement, (2) regional olivine-rich unit, (3) dark-toned mafic cap rock, *(4) Syrtis lava front (go-to)*
- **Igneous evolutionary history from Pre-Noachian to Early Hesperian**, with distinct low-Ca pyroxene, olivine enriched (komatiite-type hot lava or mantle xenolith), high-Ca pyroxene lavas

# Typical ROI

ROIs are well distributed throughout the ellipse

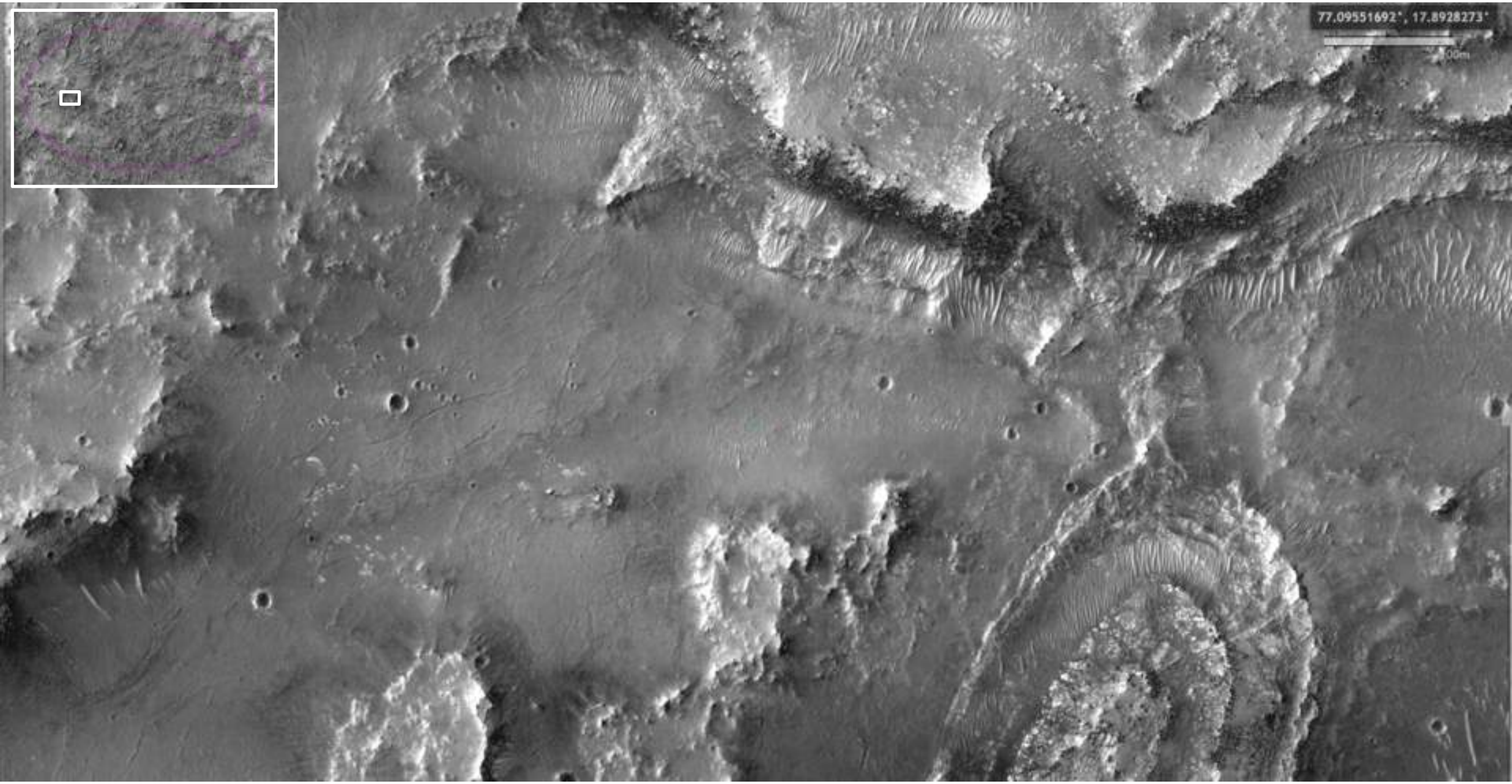
Map link



# Key Characteristics

Majority of the site is a network of smooth and traversable terrain on the valley floor between buttes and mesas.  Some deposits of dense sand which are identifiable and avoidable.

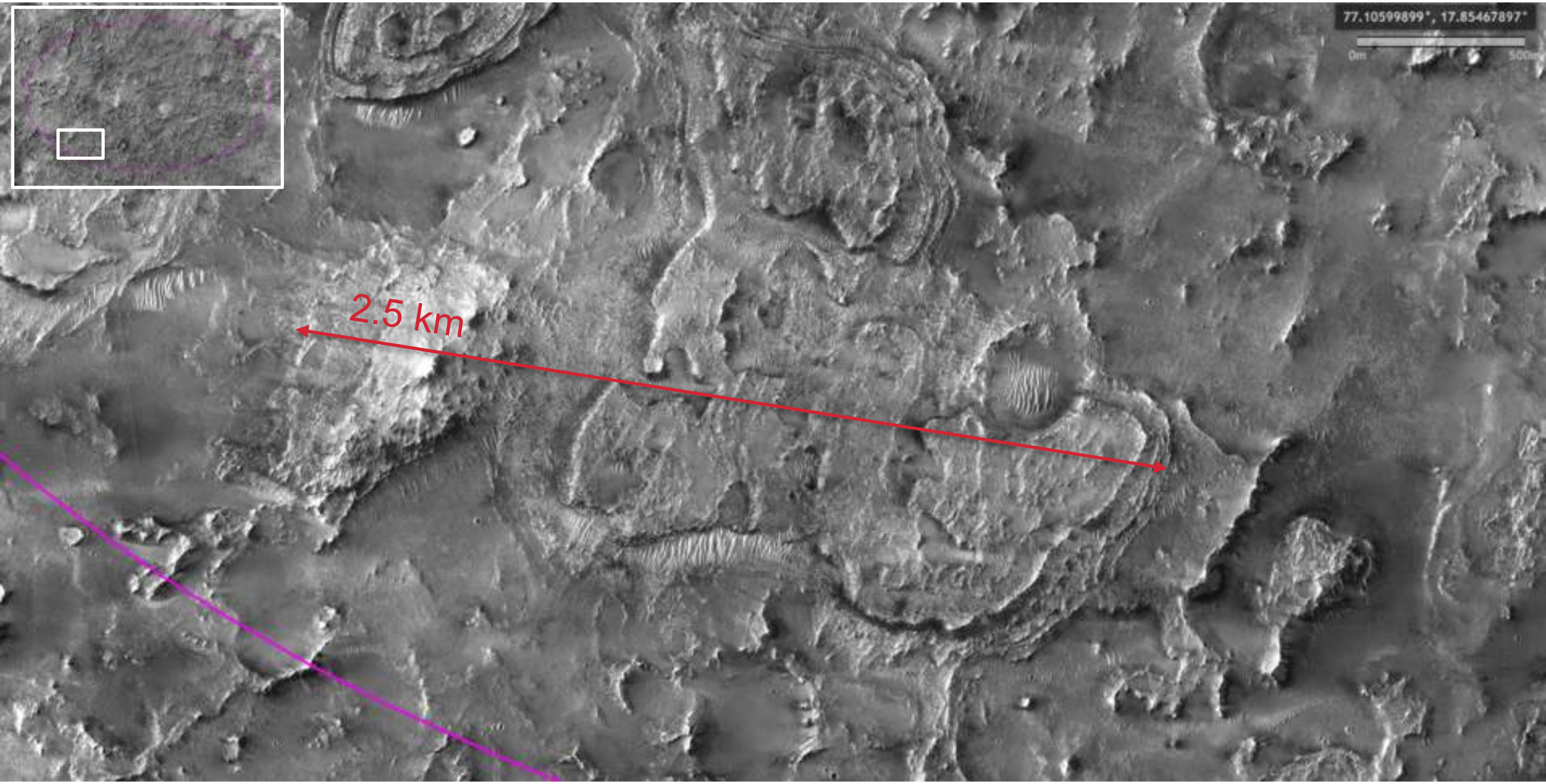
Map link



# Key Challenges

Some large scale challenging terrain features that would require many kilometers to avoid. These areas are often categorized as ROIs

Map link

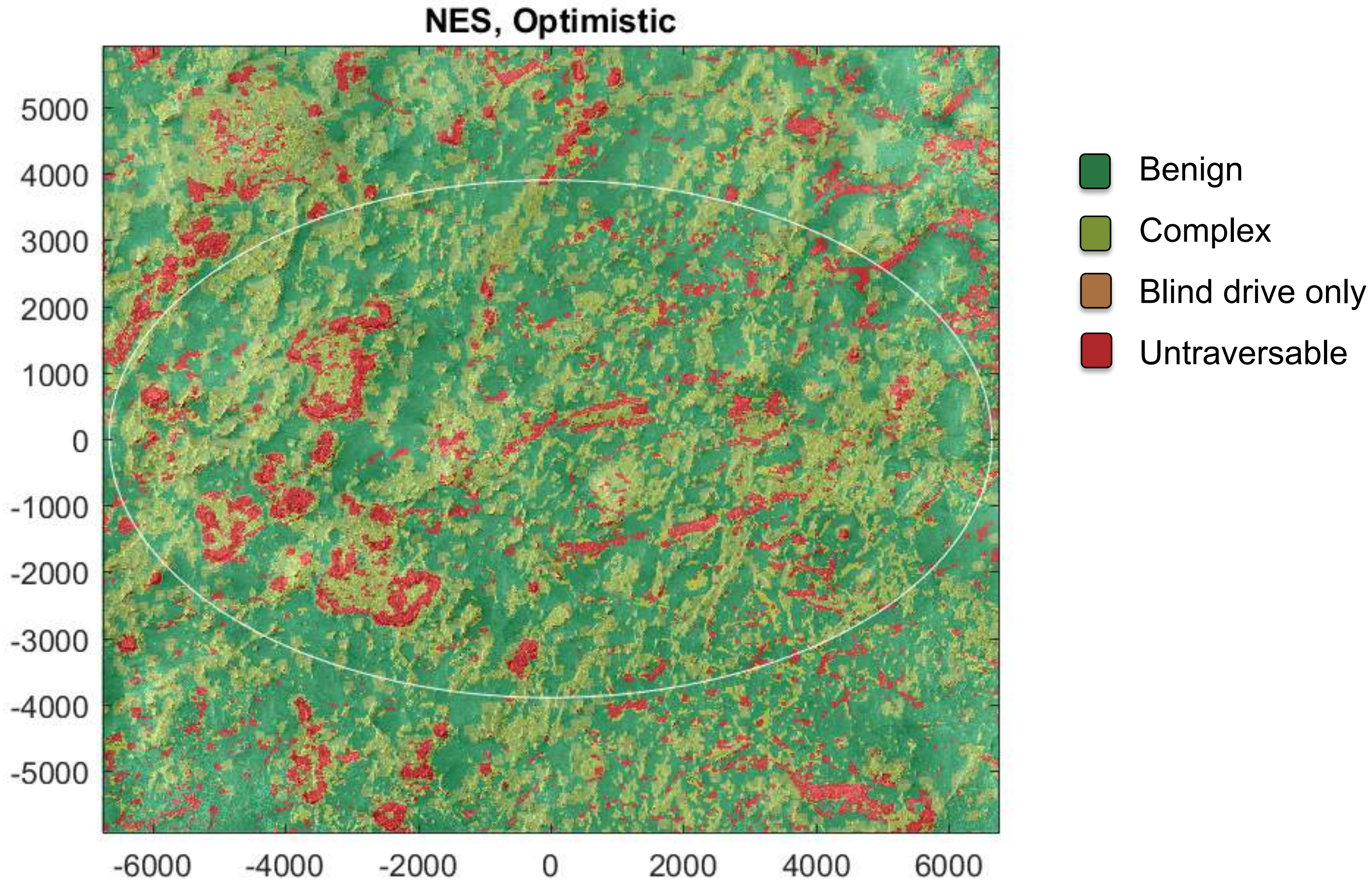


# Traversability Map

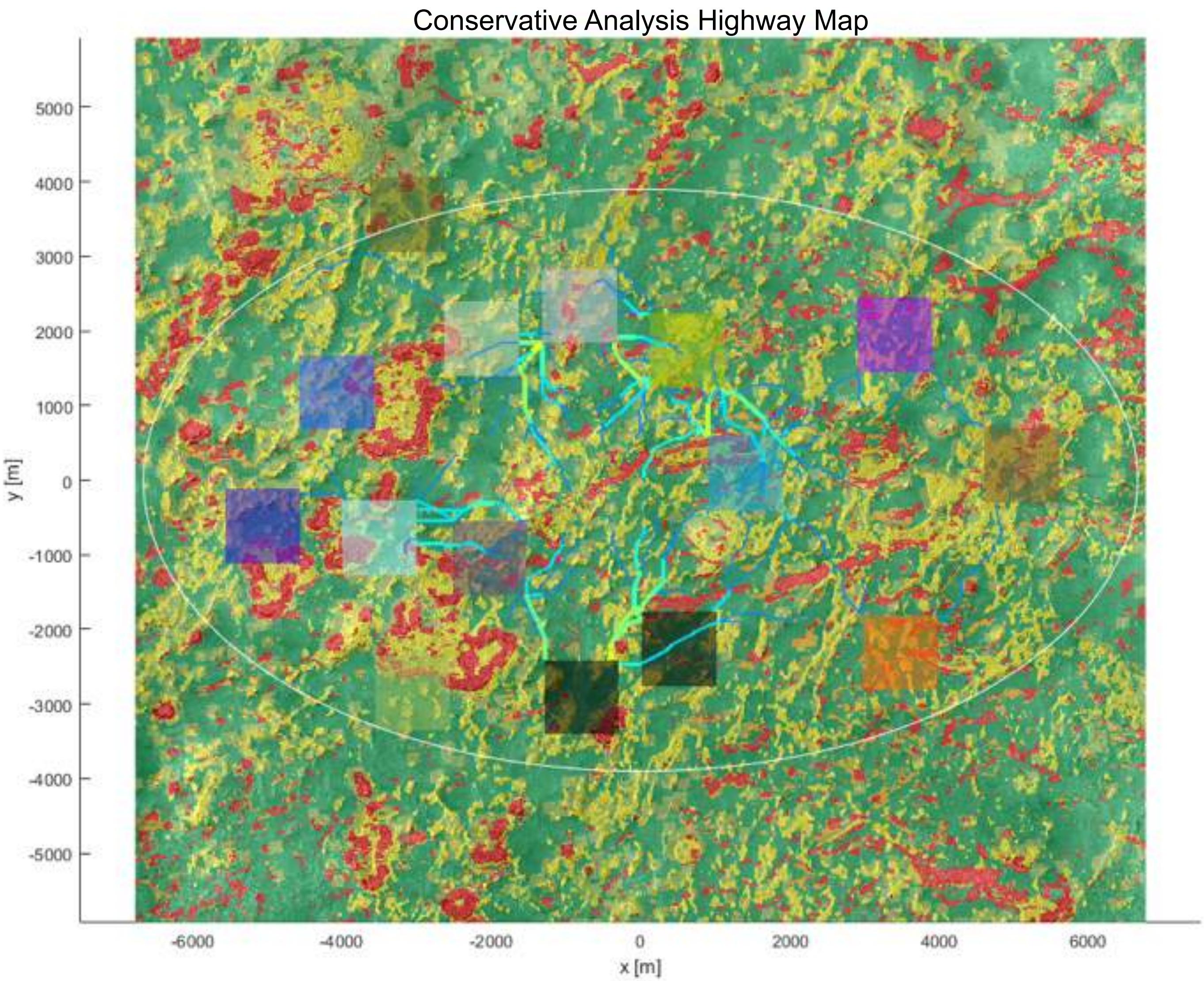
NES

Jet Propulsion Laboratory
California Institute of Technology

**Mars 2020** Project



# Highway Map


Conservative Analysis Highway Map
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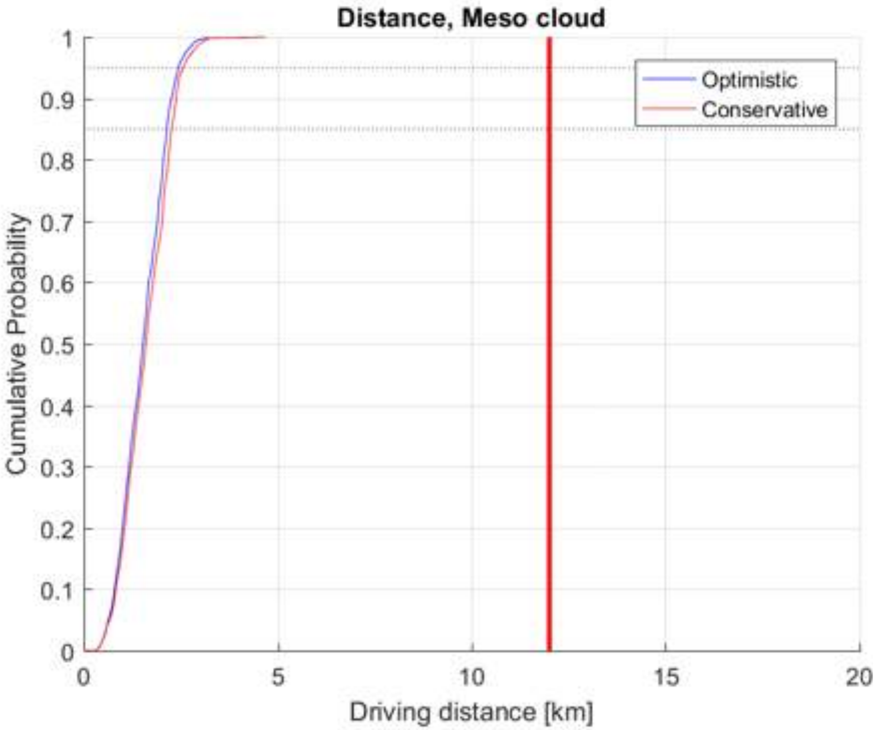
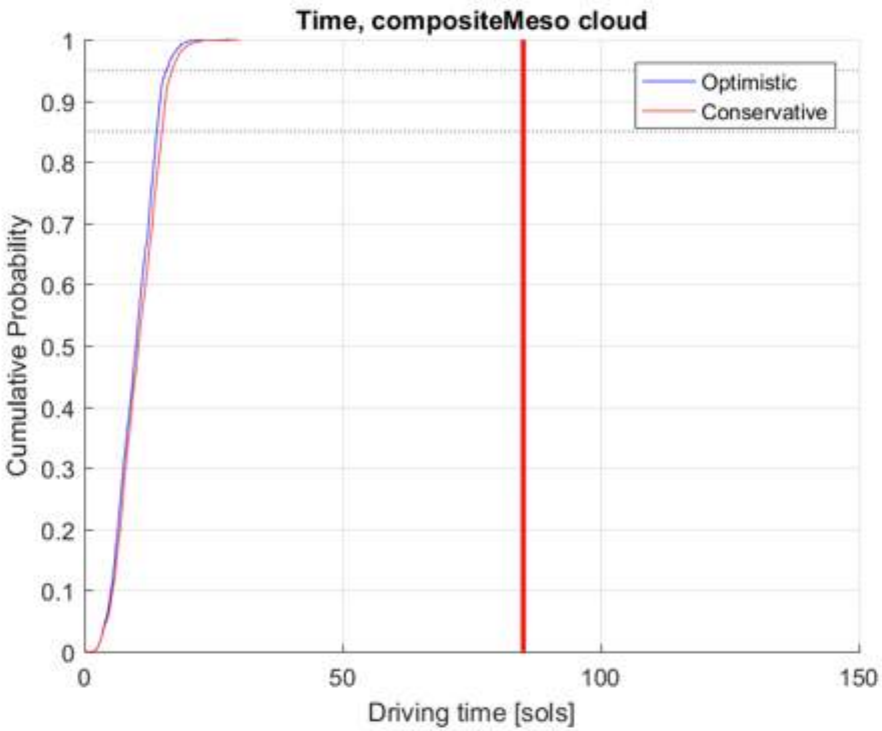
# Traverse Analysis Results




**Distance**

| Drive rate assumption | 50% | 80% | 85% | 90% | 95% |
|---|---|---|---|---|---|
| Optimistic | 1.5 km | 2.1 km | 2.2 km | 2.3 km | 2.4 km |
| Conservative | 1.6 km | 2.2 km | 2.3 km | 2.4 km | 2.6 km |

**Time**

| Drive rate assumption | 50% | 80% | 85% | 90% | 95% |
|---|---|---|---|---|---|
| Optimistic | 10.0 sols | 13.6 sols | 14.2 sols | 14.7 sols | 16.1 sols |
| Conservative | 10.5 sols | 14.4 sols | 15.1 sols | 15.8 sols | 17.1 sols |

Assumes 2.5 hours of dedicated drive time per sol
85 sols is the portion of the mission allocated to traversing between ROIs

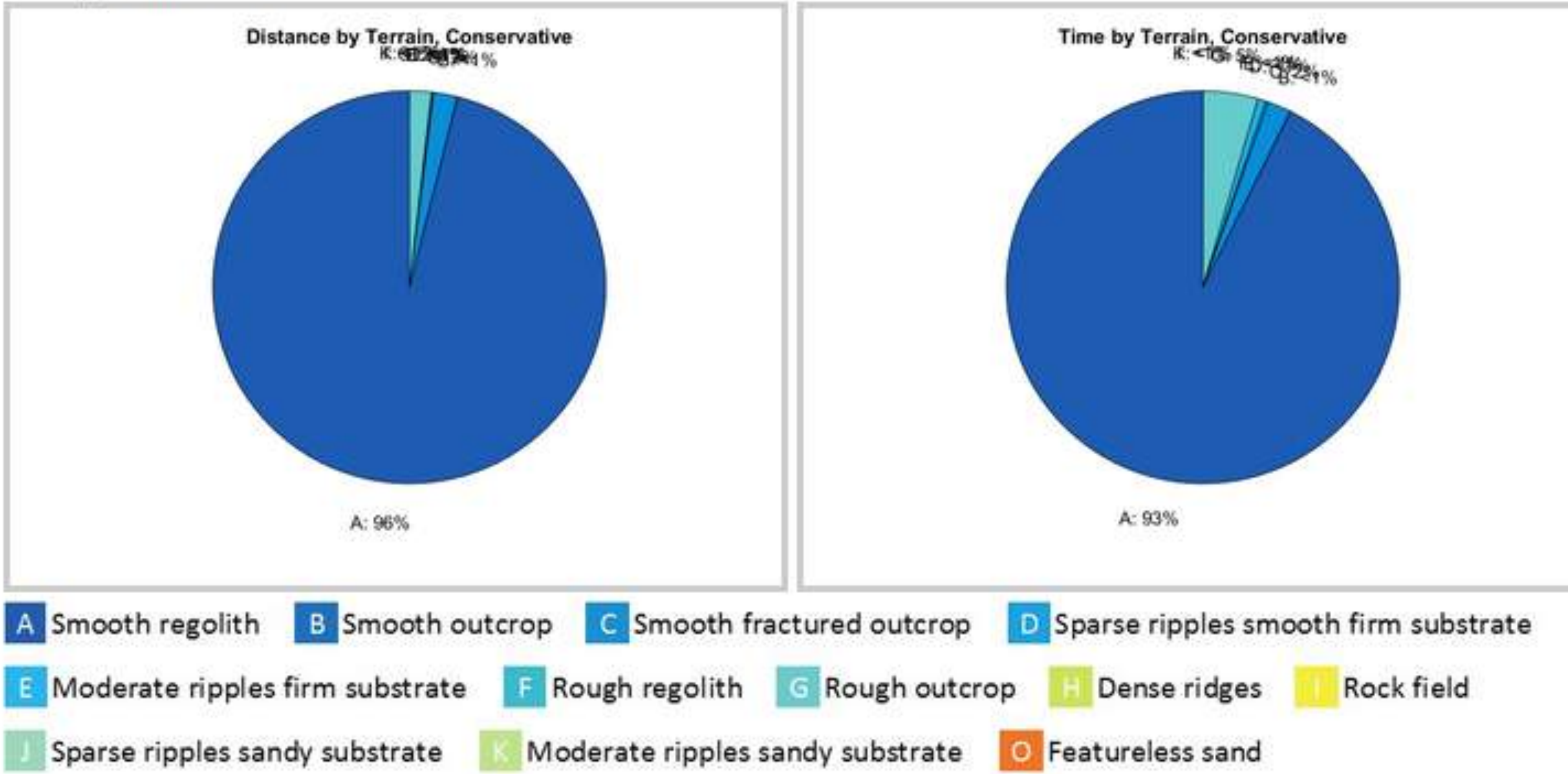
# Terrain Type Breakdown



**Conservative**

Average Distance: 1.6 km

Average Time: 10.6 sols

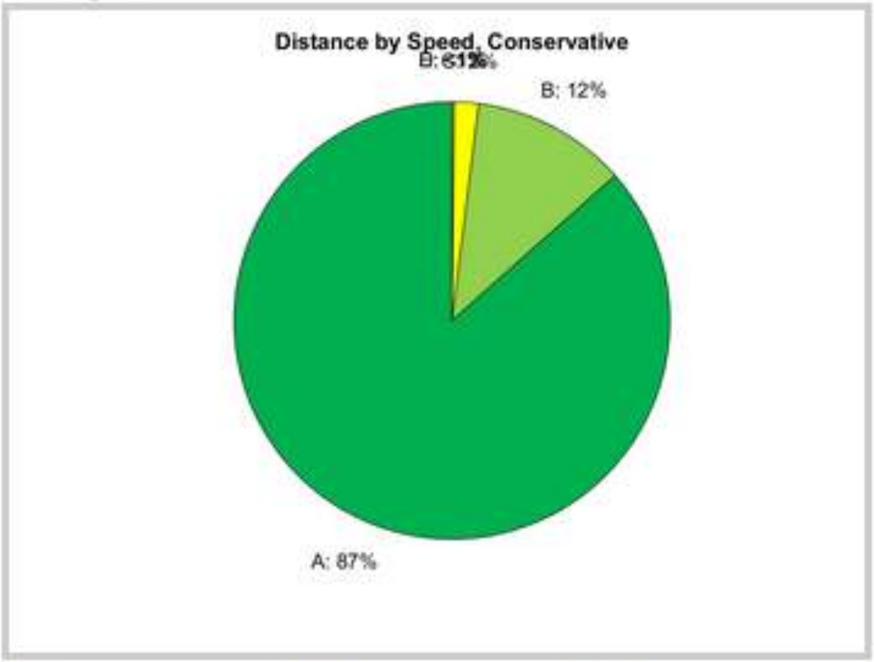


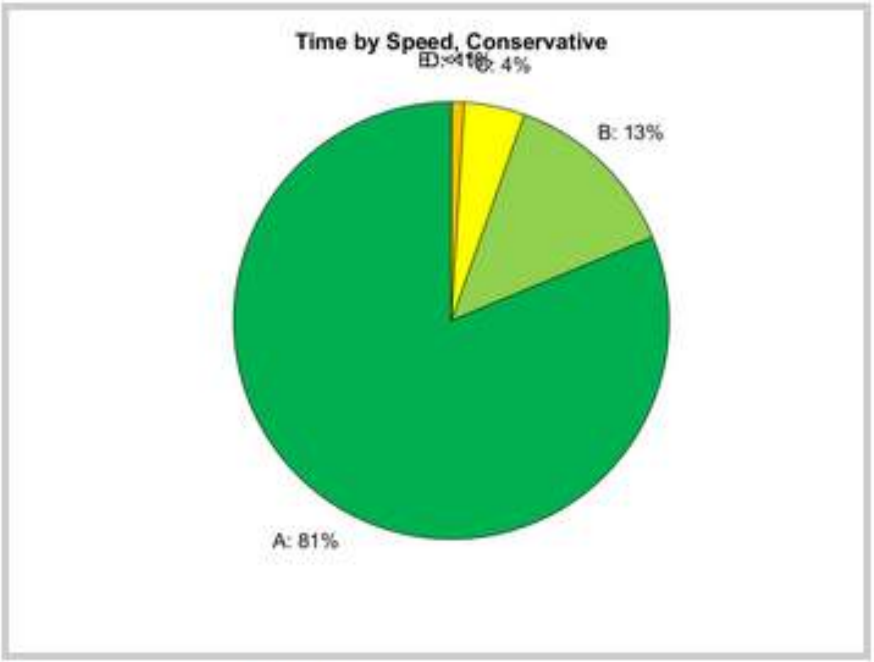
# Drive Rate Breakdown

**Conservative**

Average Distance: 1.6 km

Average Time: 10.6 sols




A 64.8 m/hr B 52.5 m/hr C 24.2 m/hr D 10.9 m/hr E 8.7 m/hr

# Environmental Conditions

- NE Syrtis, located at Lat=17.8 N, has a mild environment and does not experience temperature extremes in summer or winter when compared to southern latitudes.
- There are no significant operational or hardware constraints due to seasonal environment variability at NE Syrtis.
- More detailed analysis of the seasonal effects to operability and mission performance is in-progress…

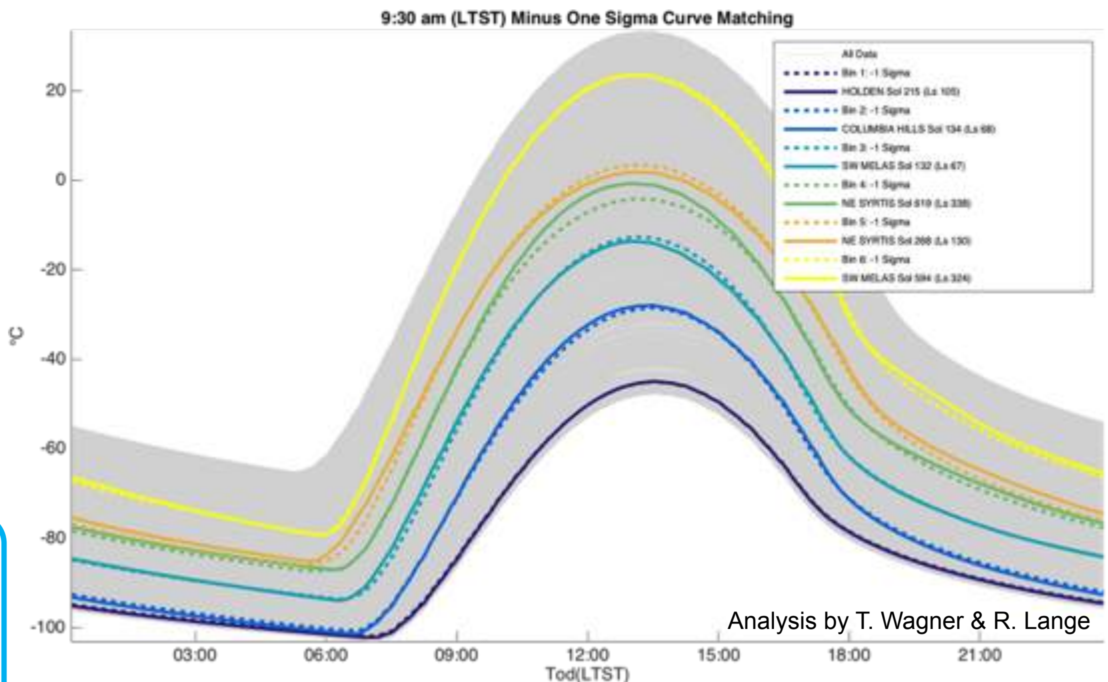
# Environments & Thermal

- (opposite) 6 diurnal temperature profiles, optimized for 9:30 LTST, to use for modeling all sites throughout Mars year.

- (lower-right) Percentage of environment bin usage over 1-MY for each landing site, based on Sol ranges defined by curve-fit optimization.

6 environments have been provided to Payload and Thermal teams for analysis on **survival heating, mechanism heat to use, instrument warm-up and ops TOD info.**

- Results from thermal analysis of 6 environments will be ready by early October




| | Bin: | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| 1 | Eberswalde | 24% | 16% | 13% | 8% | 12% | 28% |
| 2 | Columbia Hills | 0% | 33% | 16% | 11% | 18% | 21% |
| 3 | Holden | 29% | 14% | 11% | 8% | 11% | 27% |
| 4 | Jezero | 0% | 0% | 29% | 64% | 8% | 0% |
| 5 | Mawrth | 0% | 11% | 19% | 42% | 27% | 0% |
| 6 | NE Syrtis | 0% | 0% | 21% | 62% | 16% | 0% |
| 7 | Nili | 0% | 0% | 24% | 52% | 24% | 0% |
| 8 | SW Melas | 0% | 0% | 32% | 14% | 17% | 36% |

# Nili Fossae

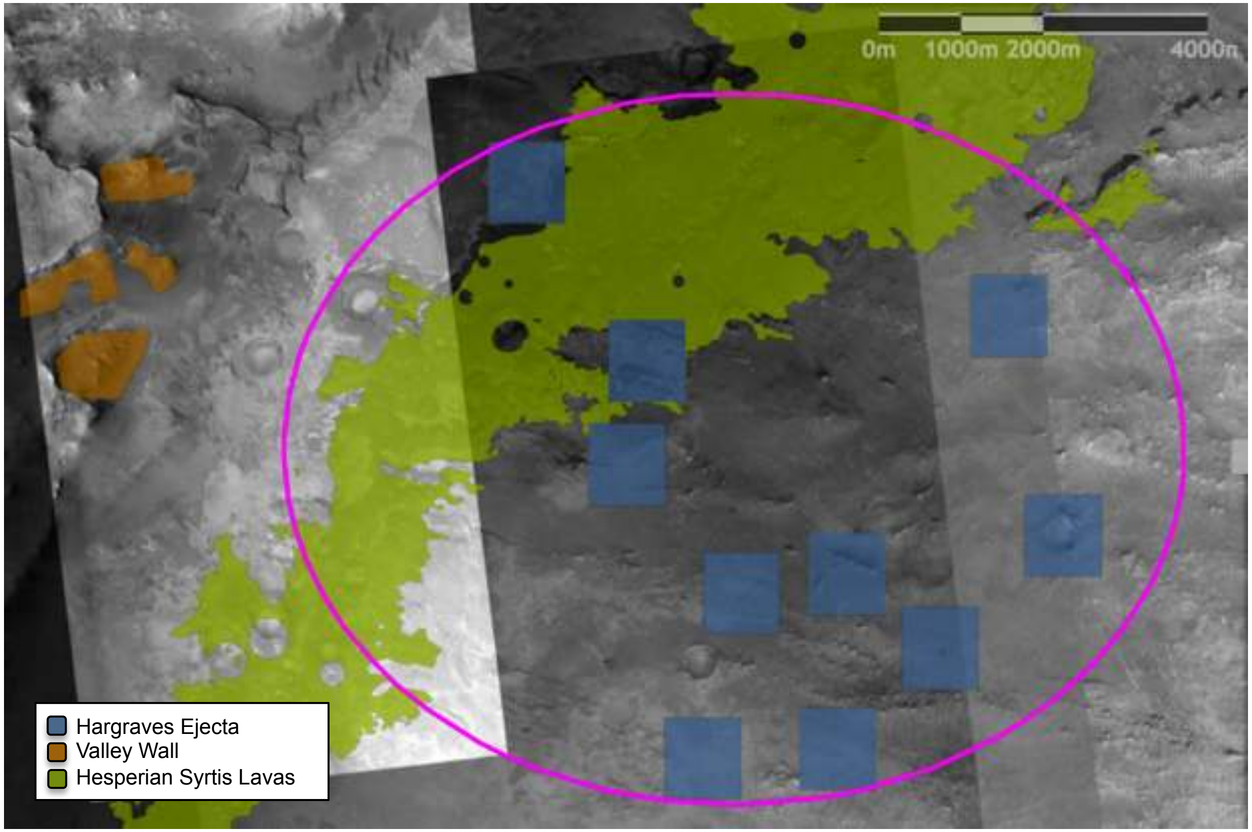
NIL

Jet Propulsion Laboratory
California Institute of Technology

Mars 2020 Project

## Mission Scenario

- ROIs
  - Hargraves Ejecta (blue)
    - **6 samples**
    - 2 Campaigns with 2 units
  - Valley Wall (brown)
    - **6 samples**
    - 2 Campaigns with 3 units.
    - Note that the Valley Wall ROI is more complex of an exploration campaign to find the right samples compared to the Hargraves Ejecta ROI
- Waypoints
  - Hesperian Syrtis Lavas (green)
    - **3 samples**
    - 3 rock waypoints as we cross the boundaries at of the ROI. Likely at least one sample on the eastern contact and at least one sample on the western contact
    - We will not alter our traverse path significantly for the Hesperian Syrtis Lavas waypoint, but we will sample where our strategic route between ROIs intersects the waypoint
  - Regolith (throughout the ellipse)
    - **1 sample**
    - 1 regolith waypoint wherever suitable samples are found along the traverse
- Procedural Blanks
    - **4 samples**



# Nili Fossae ROI Science

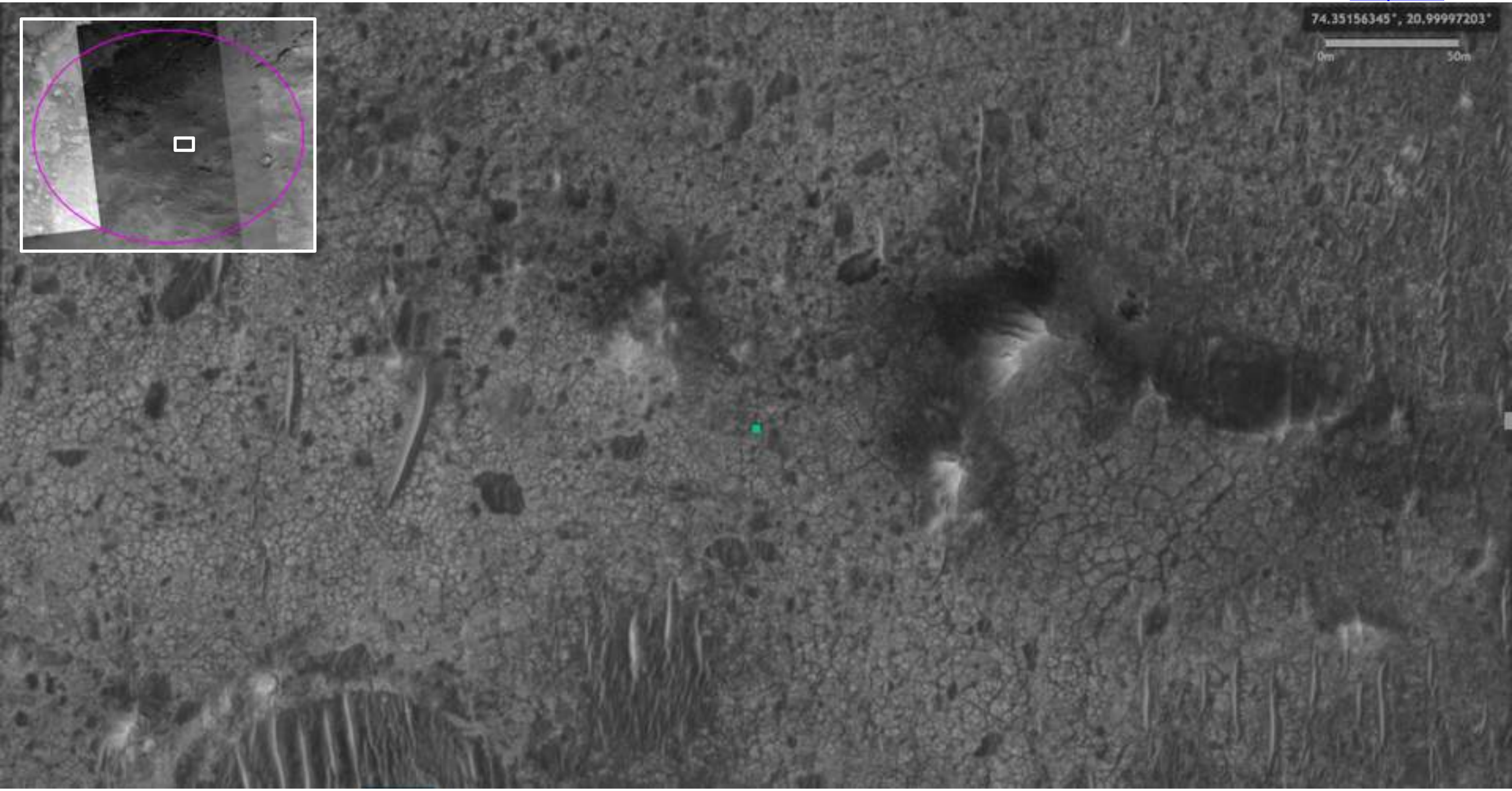
- ROI #1: Hargraves ejecta
  - Excavates into mid-Noachian crust, providing unique access to potential **subsurface biosphere** (seek signs of past life); impacts generate their own **habitable environments** through hydrothermal systems and generation of porous rocks

- Waypoint: Syrtis Major Lavas
  - Compelling cache samples: Use to **tie together crater-counting chronology** for Martian history, petrogenesis of Hesperian lavas

- ROI #2: Noachian crustal stratigraphy
  - Unit contains phyllosilicates, carbonates and possible serpentine. Could represent **a habitable serpentinizing system** that provides an **energy source for microbes** (seek signs of past life)

# Hargraves Ejecta ROI

Map link

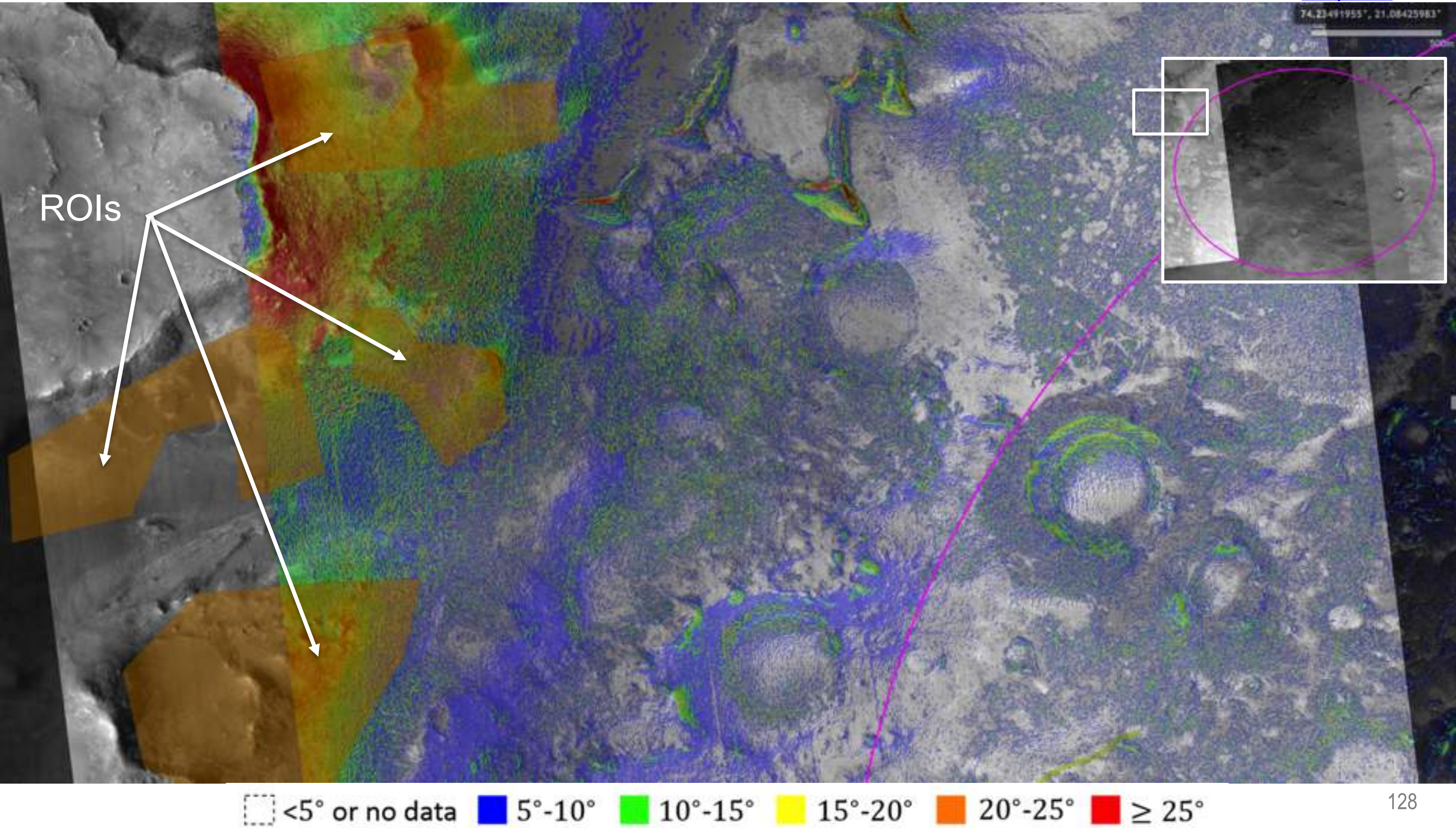


# Valley Wall ROI

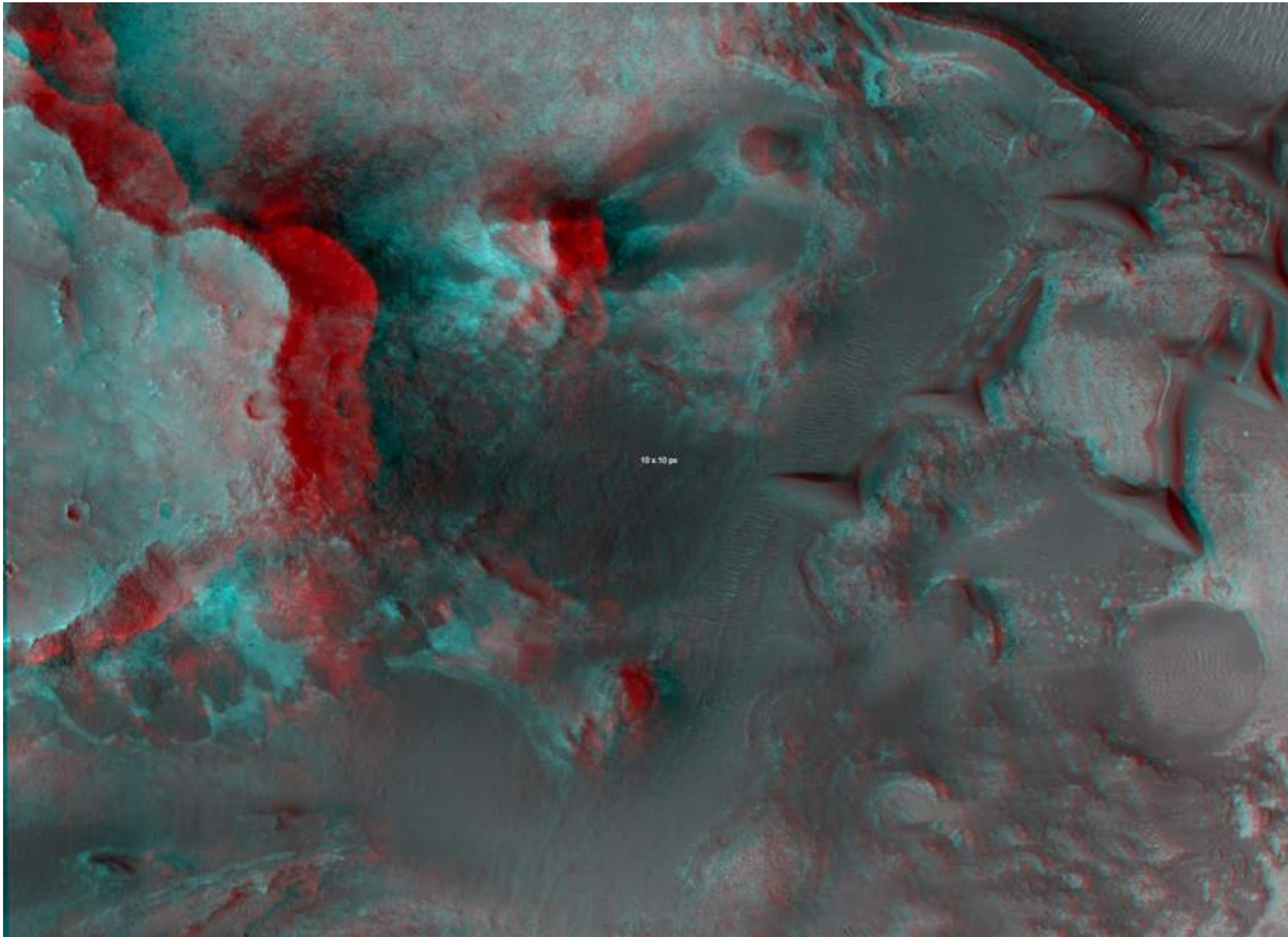


Expect to be able to access the areas of interest at the base of the slopes

Map link



# Valley Wall ROI



# Key Characteristics

NIL

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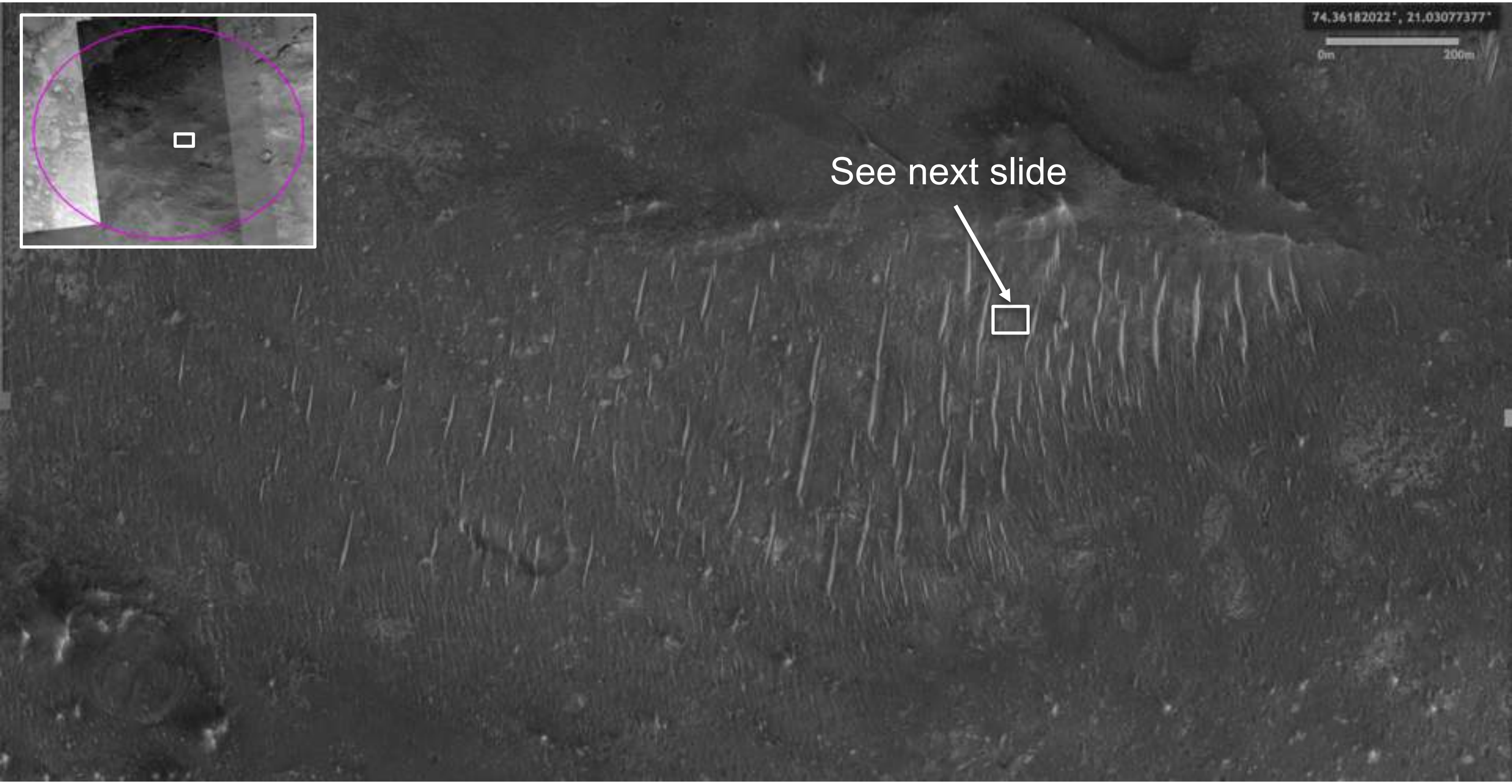
Mars 2020 Project

The majority of the ellipse is relatively flat bedrock or regolith covered with large but widely spaced sand ripples.

Map link

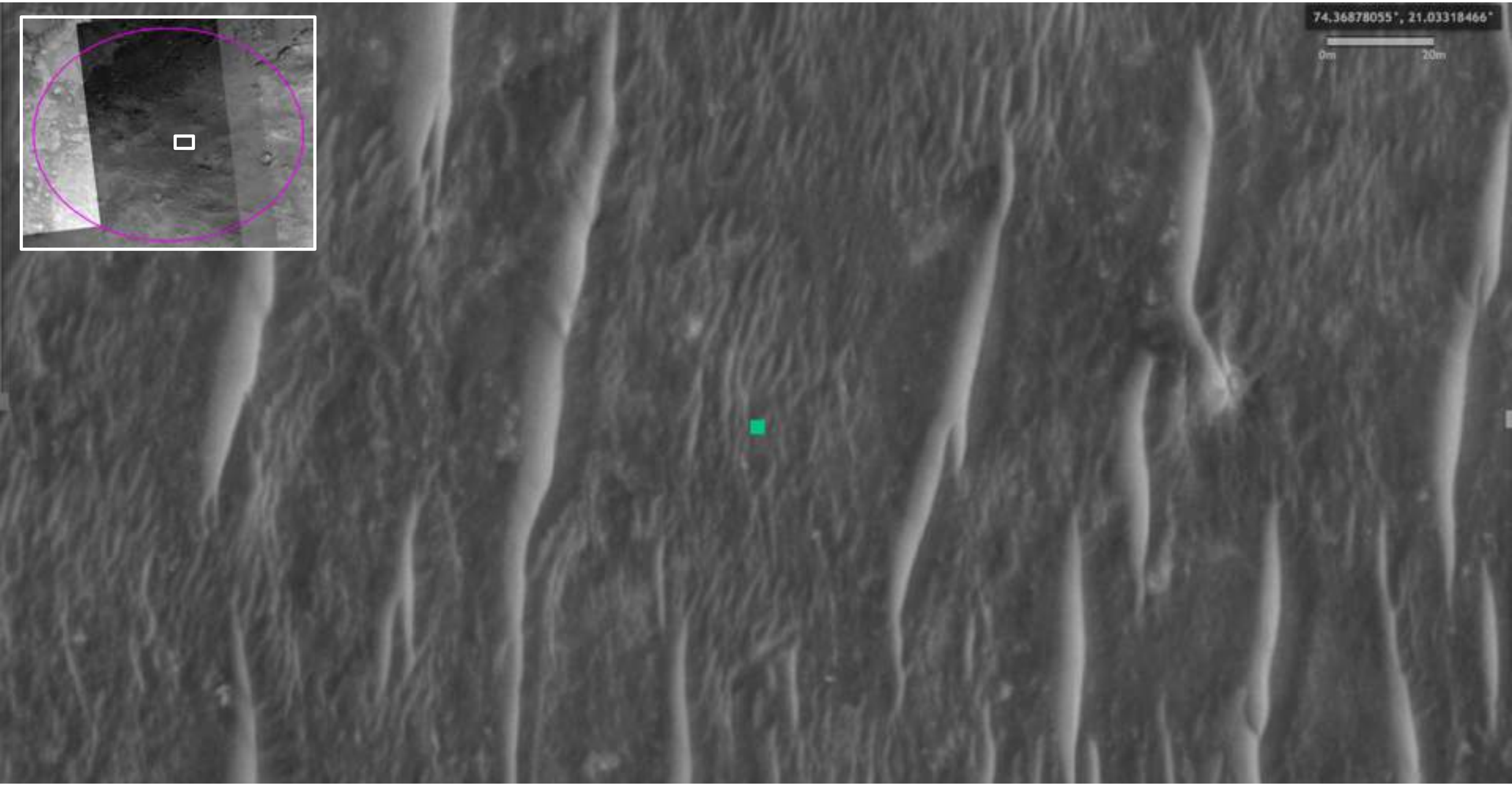


# Key Challenges

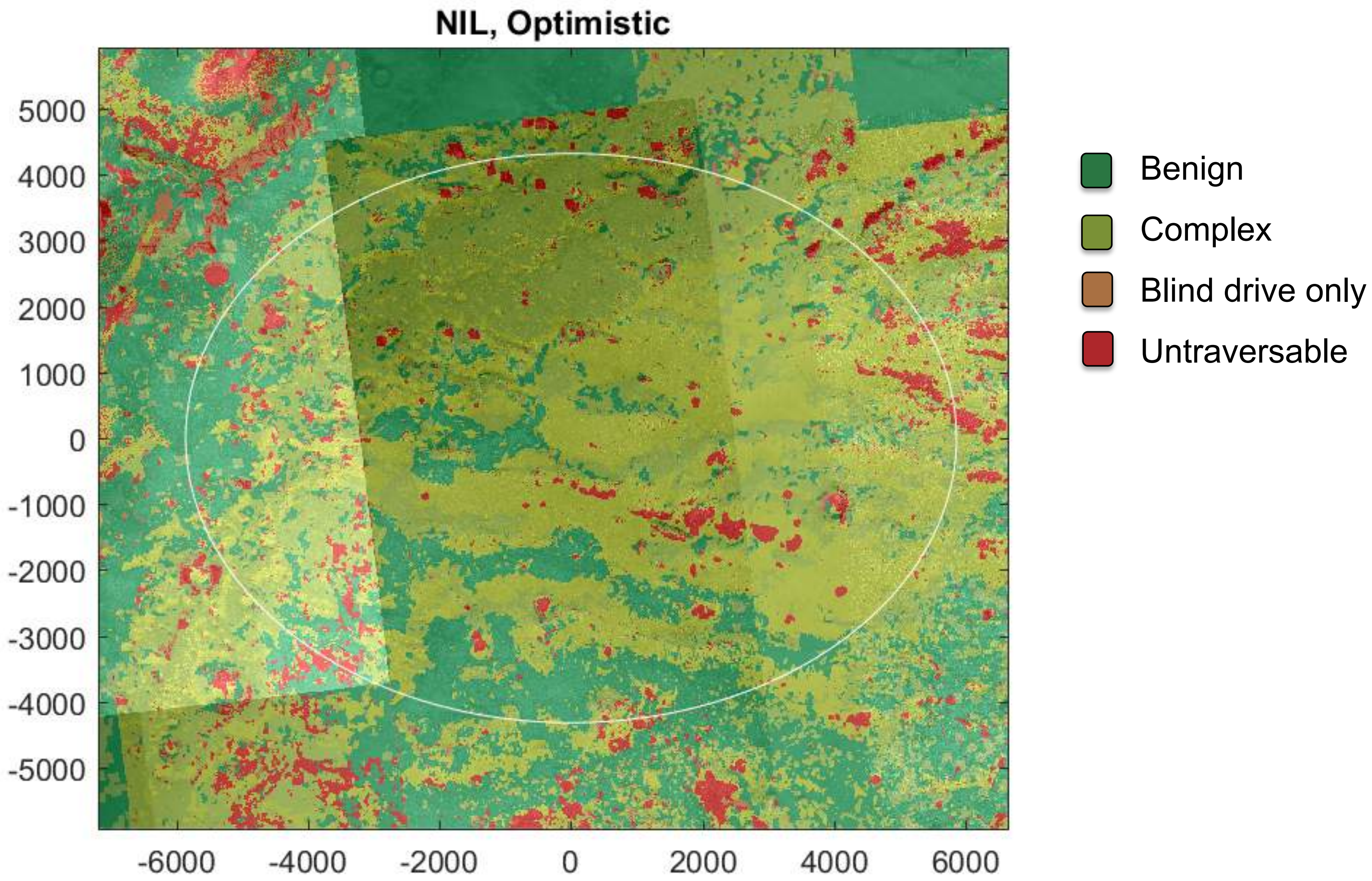


Often between the larger ripples there are smaller ripples which may cause traversability challenges.  Not necessarily embedding hazards, but may cause high slip or cause trouble for AutoNav due to lack of texture

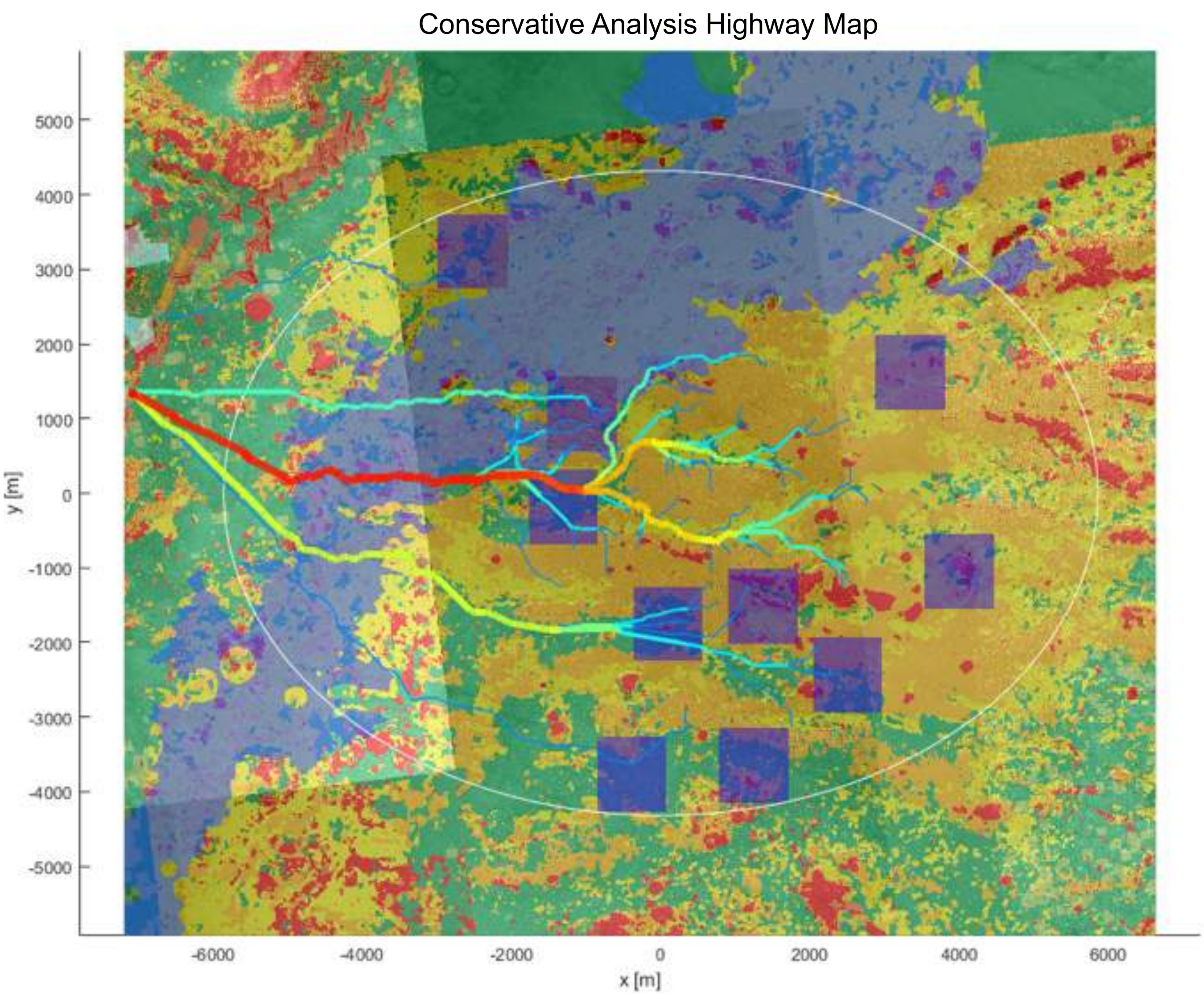
Map link



# Traversability Map



# Highway Map


Conservative Analysis Highway Map
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y [m]
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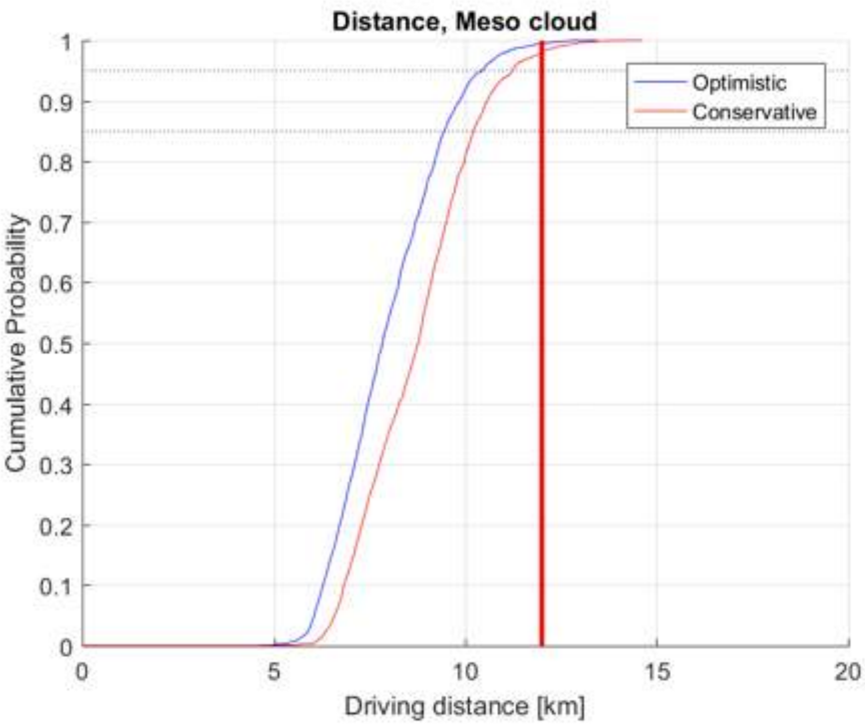
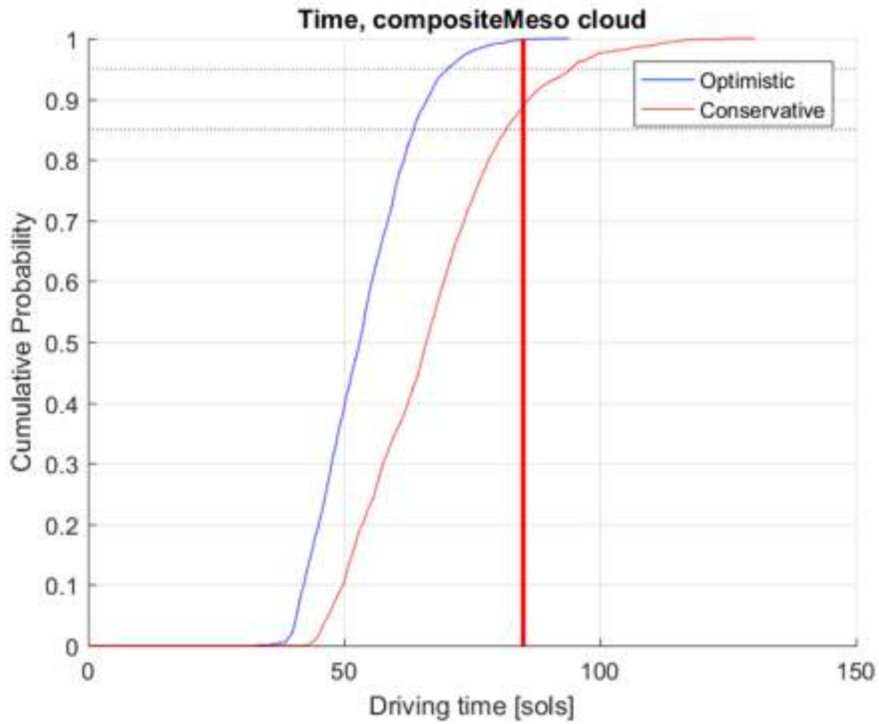
# Traverse Analysis Results




**Distance**

| Drive rate assumption | 50% | 80% | 85% | 90% | 95% |
|---|---|---|---|---|---|
| Optimistic | 7.9 km | 9.2 km | 9.5 km | 9.9 km | 10.5 km |
| Conservative | 8.8 km | 10.0 km | 10.2 km | 10.6 km | 11.3 km |

**Time**

| Drive rate assumption | 50% | 80% | 85% | 90% | 95% |
|---|---|---|---|---|---|
| Optimistic | 53.3 sols | 61.8 sols | 64.0 sols | 66.3 sols | 70.3 sols |
| Conservative | 66.4 sols | 78.8 sols | 81.9 sols | 86.2 sols | 94.9 sols |

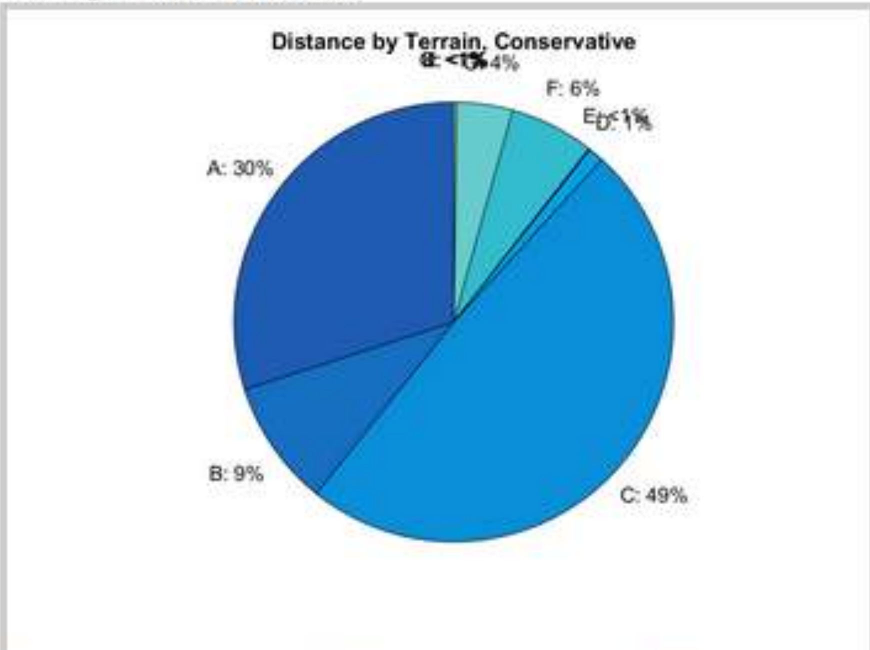
Assumes 2.5 hours of dedicated drive time per sol
85 sols is the portion of the mission allocated to traversing between ROIs

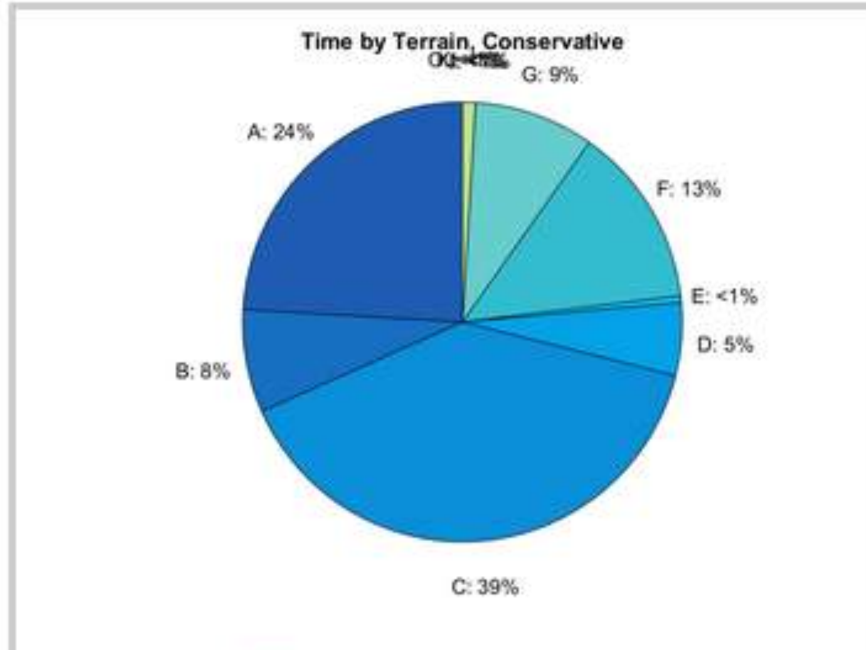
# Terrain Type Breakdown

**Conservative**

Average Distance: 8.7 km

Average Time: 67.3 sols



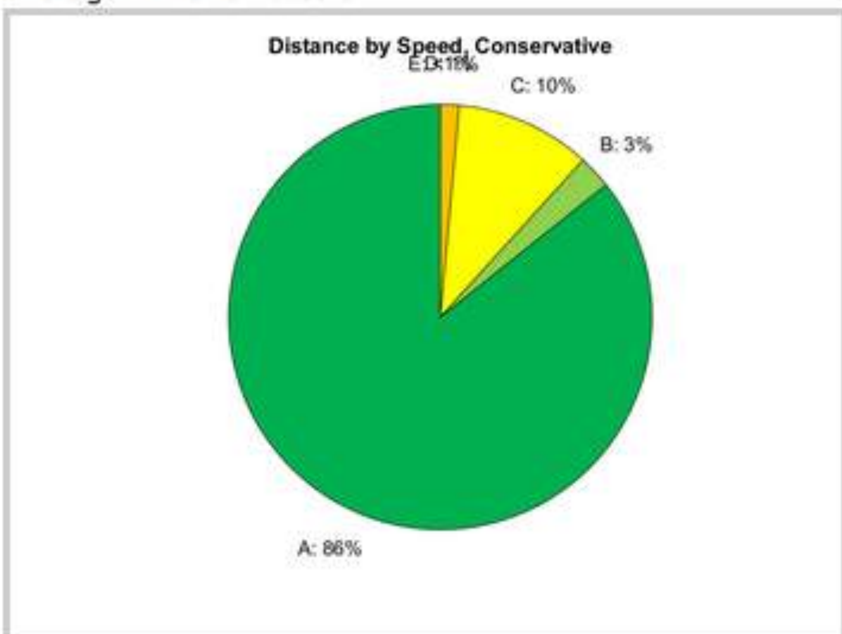

- A Smooth regolith
- B Smooth outcrop
- C Smooth fractured outcrop
- D Sparse ripples smooth firm substrate
- E Moderate ripples firm substrate
- F Rough regolith
- G Rough outcrop
- H Dense ridges
- I Rock field
- J Sparse ripples sandy substrate
- K Moderate ripples sandy substrate
- O Featureless sand

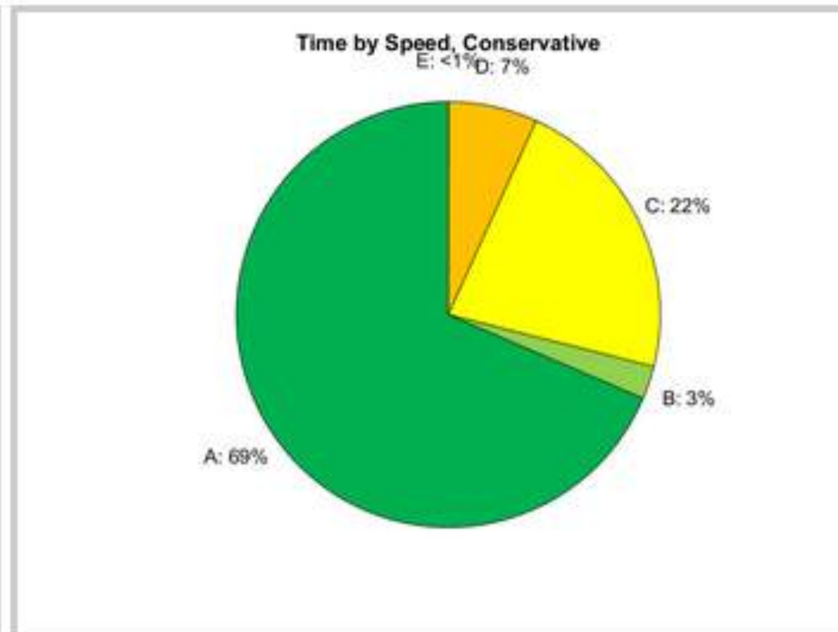
# Drive Rate Breakdown

**Conservative**

Average Distance: 8.7 km

Average Time: 67.3 sols




A 64.8 m/hr   B 52.5 m/hr   C 24.2 m/hr   D 10.9 m/hr   E 8.7 m/hr

# Environmental Conditions

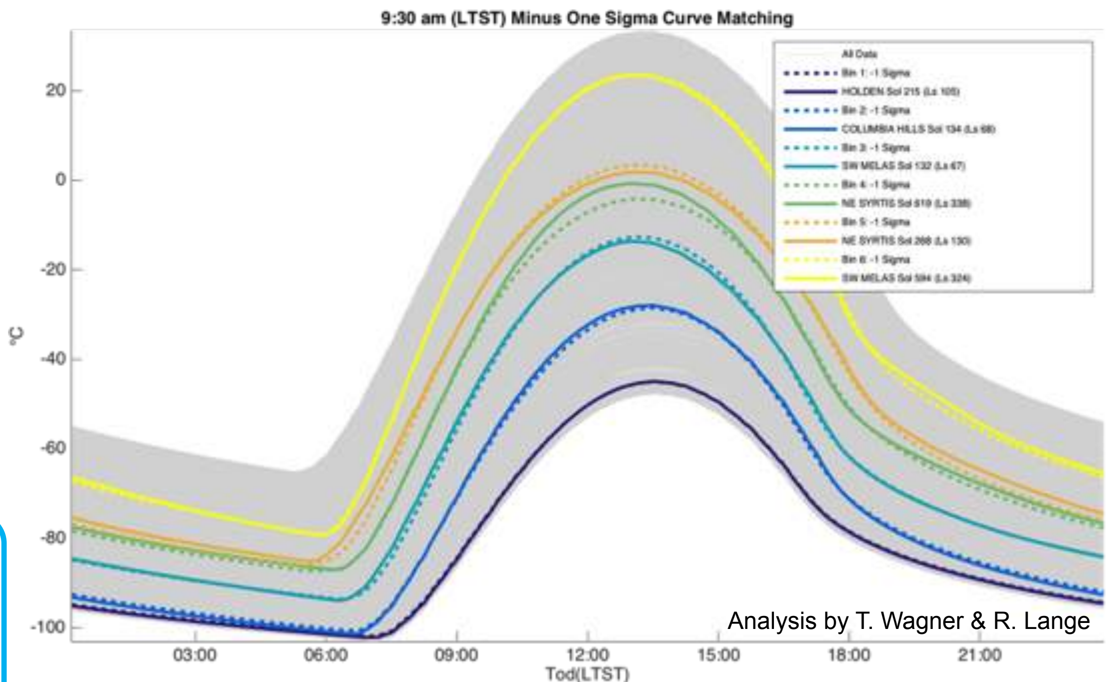
- **Nili Fosse**, located at Lat=21 N, experiences relatively **benign environmental conditions** compared to bounding design-to rover environments.
  - While the rover is designed to be capable of safely operating at bounding environments, there are consequences to overall surface performance when operating near bounding environment conditions.
  - Nili Fosse is not an environmental/thermal stressing landing site
- **Survival heating and mechanism heat-to-use energy** needed during Nili Fosse winter season will likely not be drastically different than summer season.
- **Hardware overheat conditions** may exist during hot summer season, which could limit operations timing.
- More detailed analyses of the seasonal effects to operability and mission performance is in-progress…

- (opposite) 6 diurnal temperature profiles, optimized for 9:30 LTST, to use for modeling all sites throughout Mars year.

- (lower-right) Percentage of environment bin usage over 1-MY for each landing site, based on Sol ranges defined by curve-fit optimization.

> 6 environments have been provided to Payload and Thermal teams for analysis on **survival heating, mechanism heat to use, instrument warm-up and ops TOD info.**

- Results from thermal analysis of 6 environments will be ready by early October




| | Bin: | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| 1 | Eberswalde | 24% | 16% | 13% | 8% | 12% | 28% |
| 2 | Columbia Hills | 0% | 33% | 16% | 11% | 18% | 21% |
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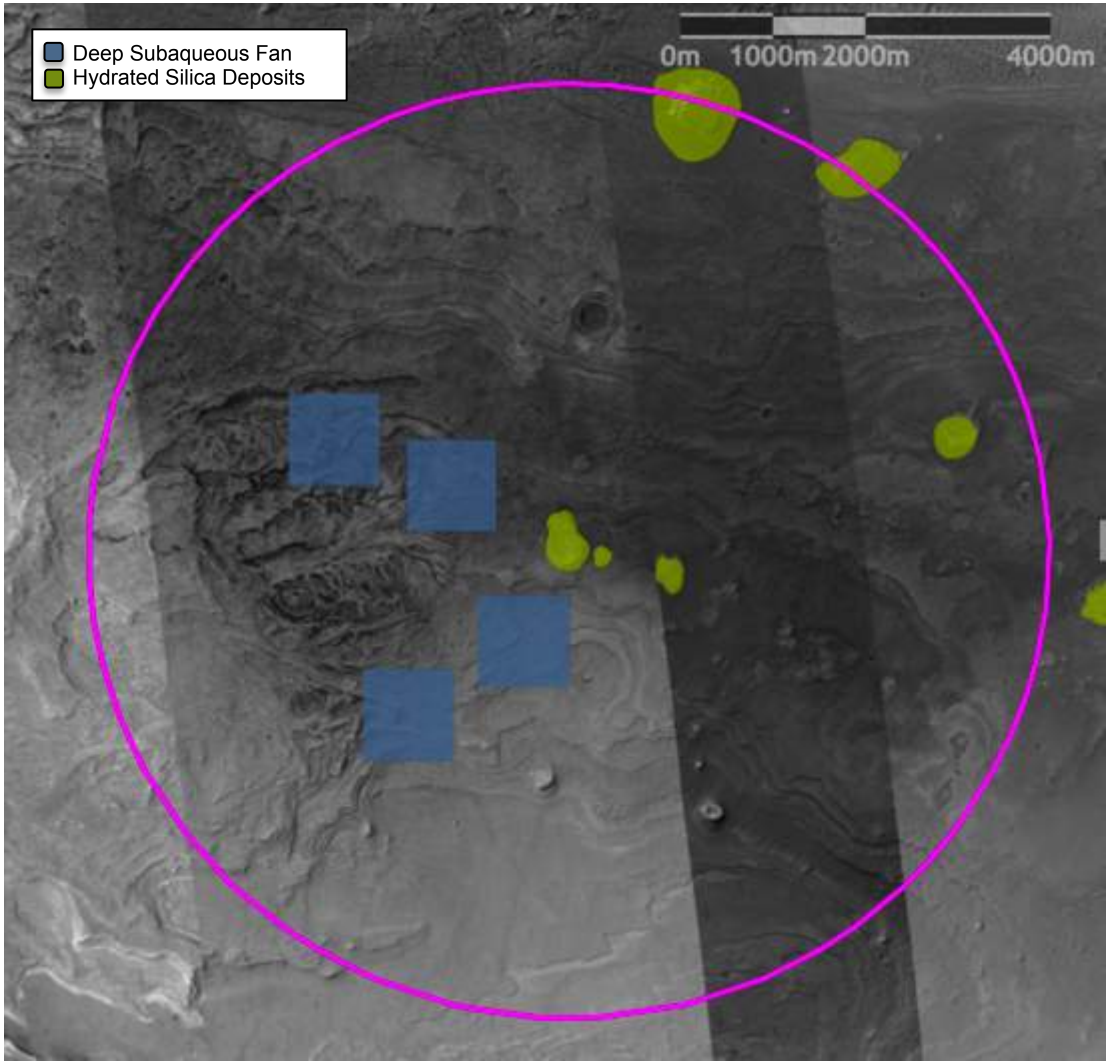
| 4 | Jezero | 0% | 0% | 29% | 64% | 8% | 0% |
| 5 | Mawrth | 0% | 11% | 19% | 42% | 27% | 0% |
| 6 | NE Syrtis | 0% | 0% | 21% | 62% | 16% | 0% |
| 7 | Nili | 0% | 0% | 24% | 52% | 24% | 0% |
| 8 | SW Melas | 0% | 0% | 32% | 14% | 17% | 36% |

# Southwest Melas



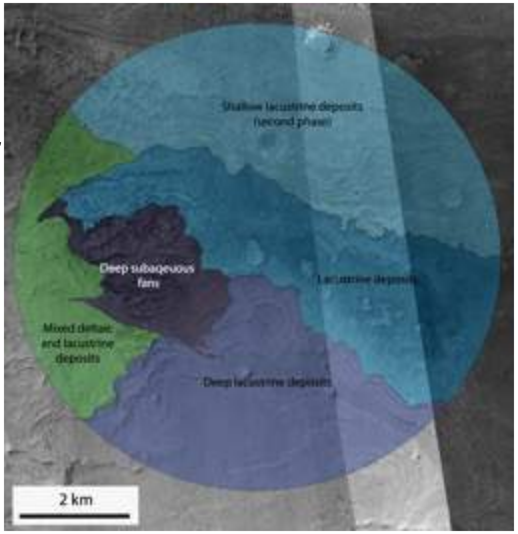
## Mission Scenario

- ROIs
  - Deep Subaqueous Fan
    - **8 samples**
    - 2 campaigns with 3 units each
    - ROIs are 1 km x 1 km boxes that contain good exposures of the delta as well as good exposure of the adjacent layered deposits
  - Hydrated Silica Deposits
    - **6 samples**
    - 2 campaigns with 2 units separated by at least 100 meters
- Waypoints
  - Layered Deposits (throughout ellipse)
    - **1 sample**
    - 1 rock waypoint
  - Regolith (throughout ellipse)
    - **1 sample**
    - 1 regolith waypoint
- Procedural Blanks
    - **4 samples**



# Southwest Melas Science
## SWM






*To "Seek Signs of Life", we must a select landing site with*

- ✔ *sedimentary deposits associated with long-lived, habitable environment,*
- ✔ *shielding from irradiation (e.g., protection of deposits via burial >1 m), &*
- ✔ *abundant sample sites to maximize chance of finding the needle in the haystack.*

Highest biosignature preservation potential (BPP) associated with
low-energy, prolonged, water-rich environment.

**SWM fits this criteria with lacustrine deposits covering >90% ellipse**

- Long-lived lake: over periods of at least several centuries
- At least two basin-filling highstands
- >50 m stratigraphic section to explore
- Driving over deposits of interest regardless of traverse
  (Quantin et al., 2005; Metz et al., 2009; Williams and Weitz, 2014)

**ROI #1 Lacustrine Deposits: Deep Subaqueous Fan and Layered Deposits**

In situ investigation: seeking signs of life with 2020 payload

- Opportunity to sample deposits emplaced in deep water conditions
- Recent exhumation of formerly buried fan deposits enhances BPP

**ROI #2: Hydrated Silica (Opal)**

In situ investigation: sedimentary context of opal deposits

- Test formation hypotheses via occurrence, sedimentary textures, & chemistry
  - ➢ hydrothermal process? primary precipitate from solution? diagenetic alteration product? replacement mineral?
- Insight into late-stage (post-exhumation) aqueous processes

Additional Science Objectives

- Insight into sedimentary & tectonic processes in Valles Marineris system
- Basalt wall rock transported into basin via landslides & debris flows: potential dateable rock
- Airfall deposits, likely including volcanic ash (Weitz et al., 2015)
- Craters with exposed layering
- Sulfates (outside ellipse) (Dromart et al., 2007)

# Deep Subaqueous Delta ROIs

Exposure of the fan as well as the adjacent layered deposits

Map link

# Hydrated Silica ROIs

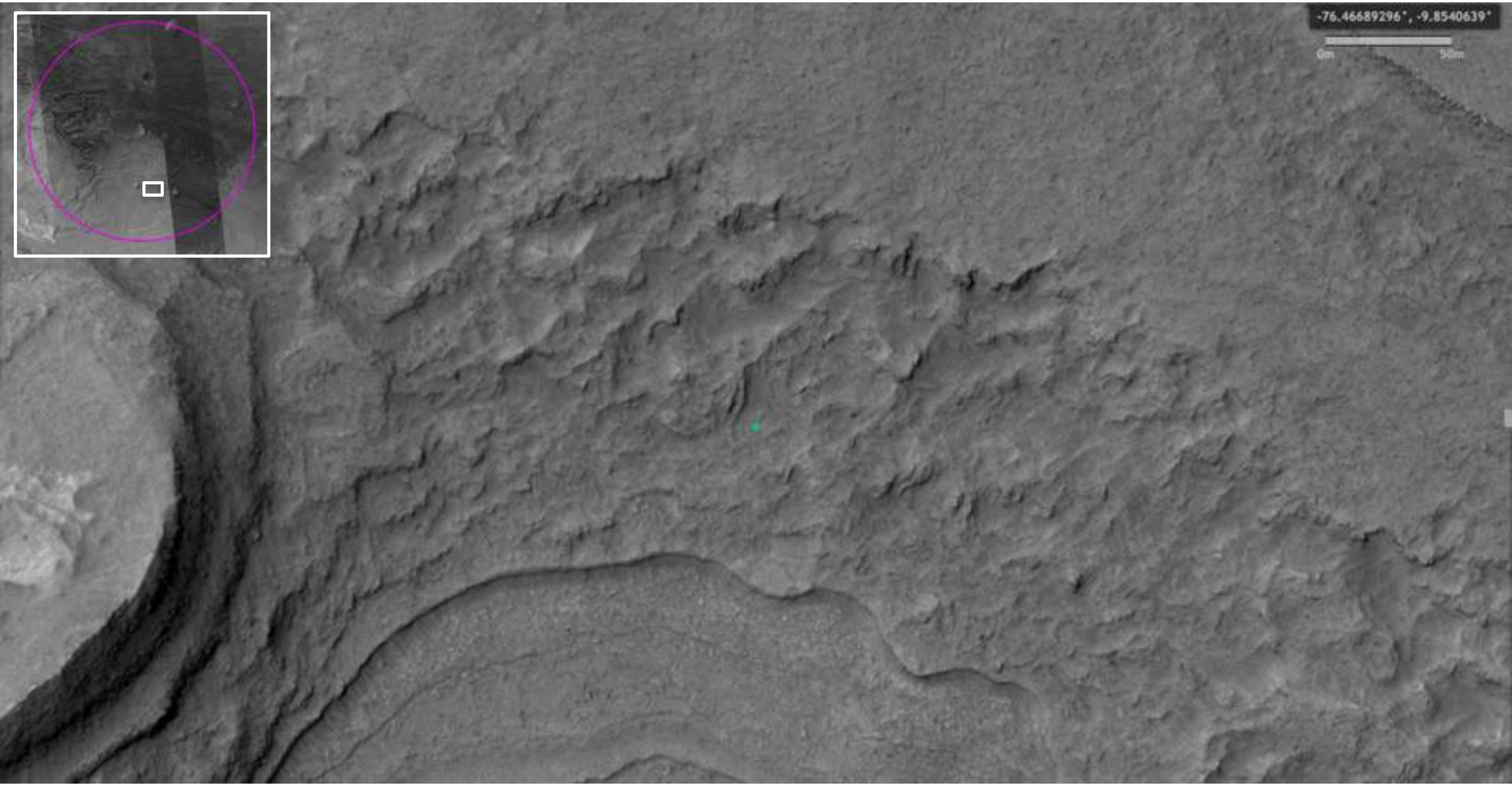
Mesas that we believe to be accessible

Map link

# Key Characteristics

Predominantly rough outcrop with some smoother outcrop exposures

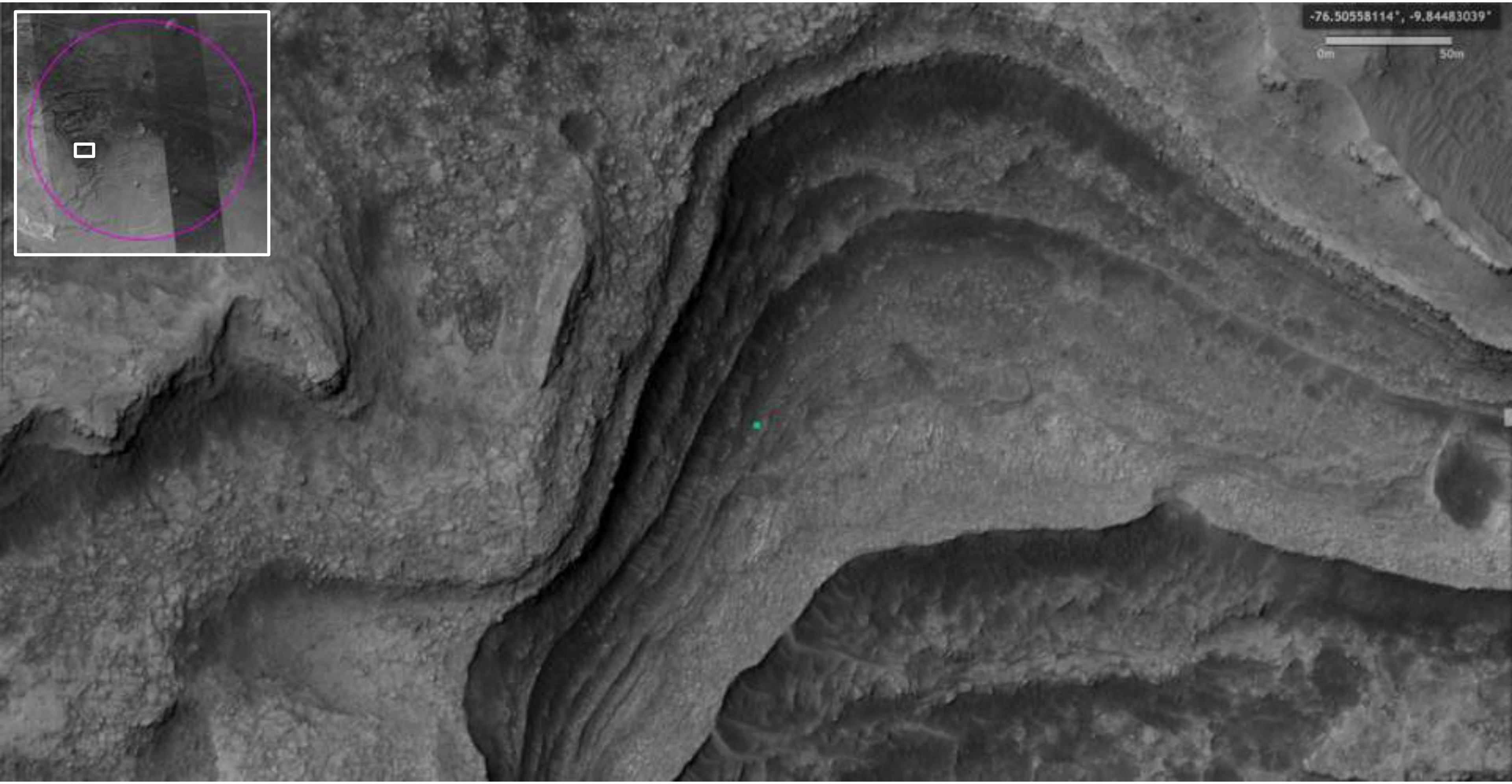
Map link



# Key Challenges

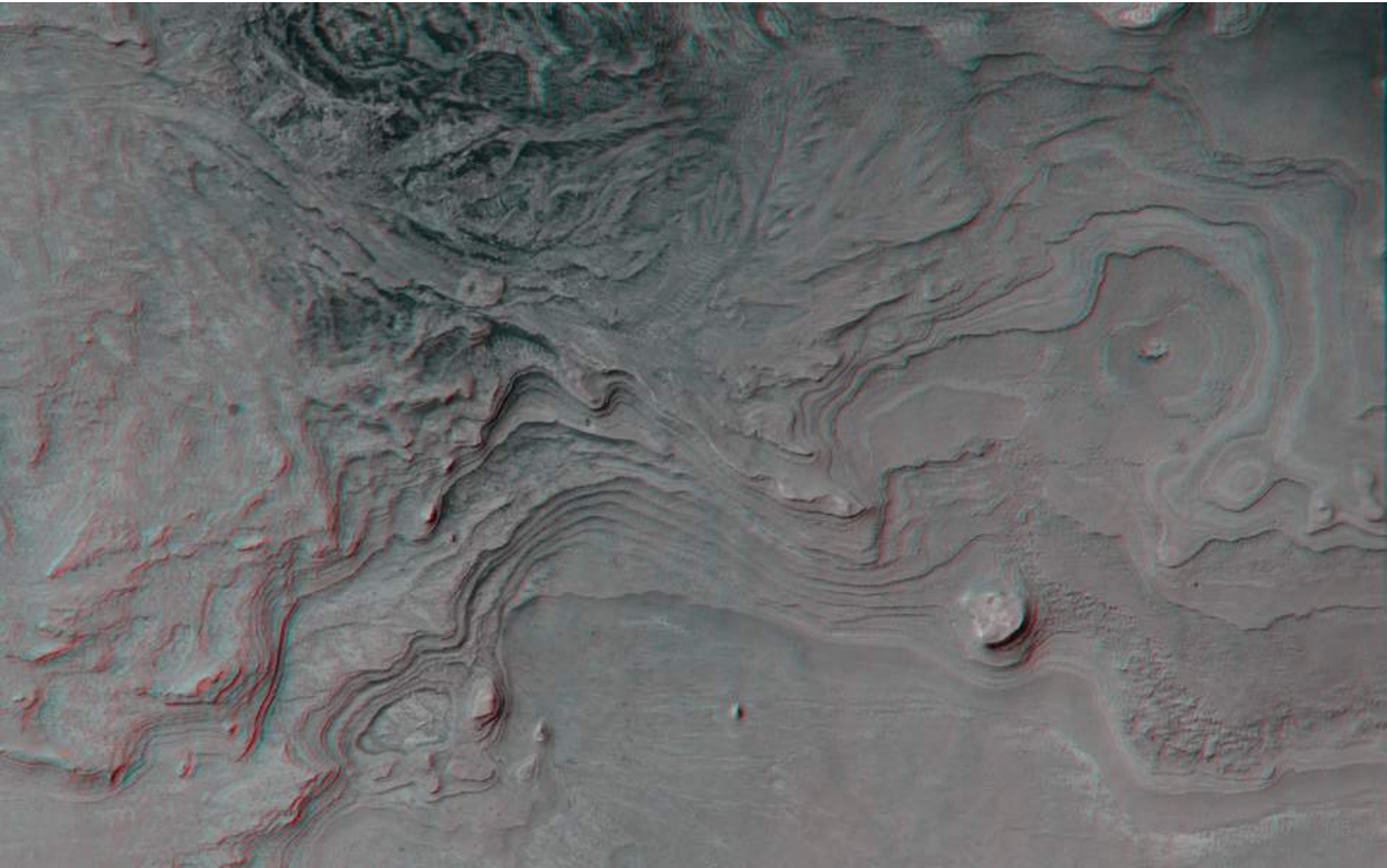
Many steep scarps and lots of rough outcrop which makes for slow and challenging driving.

Map link

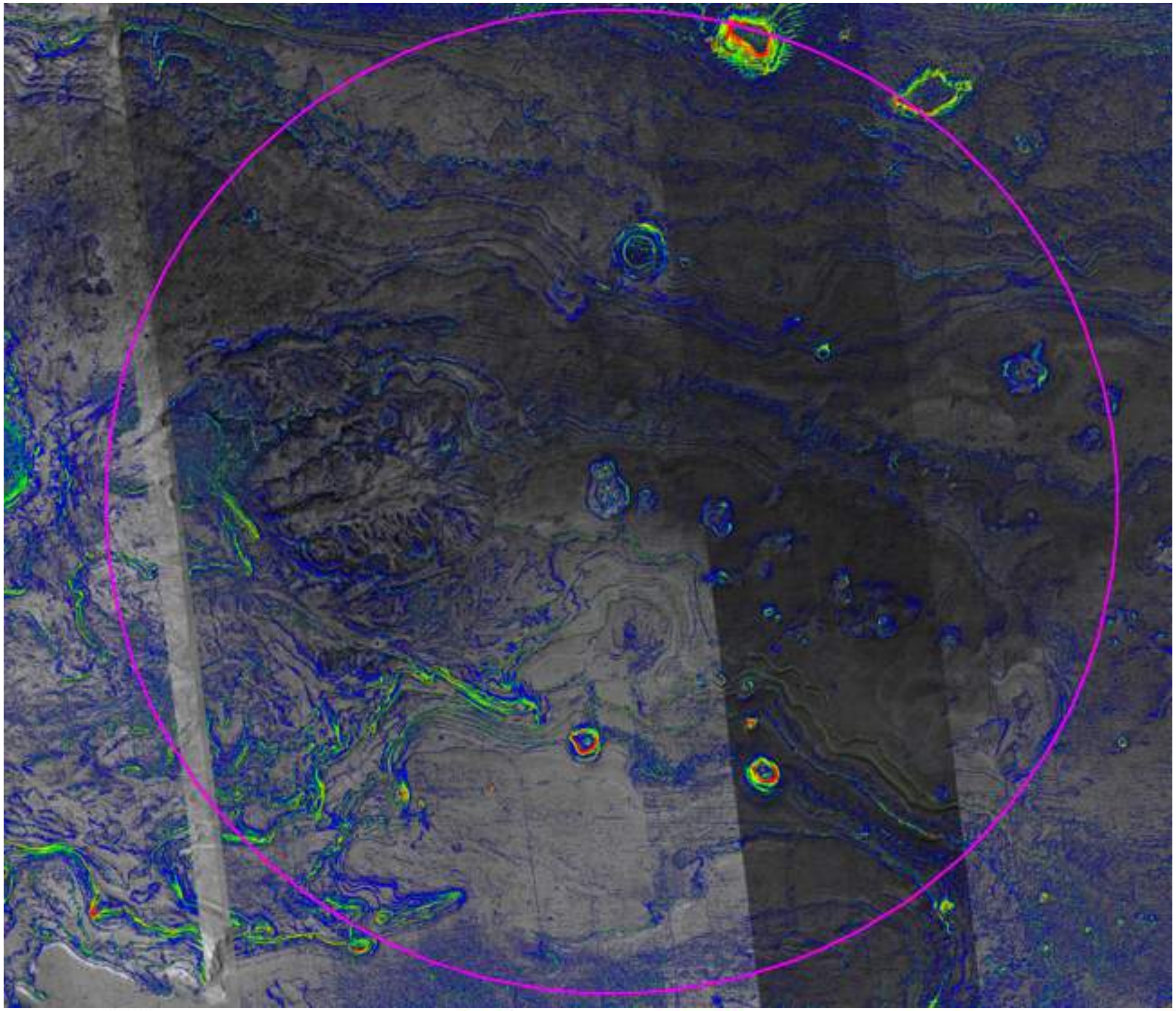


# Key Challenge





# Slopes

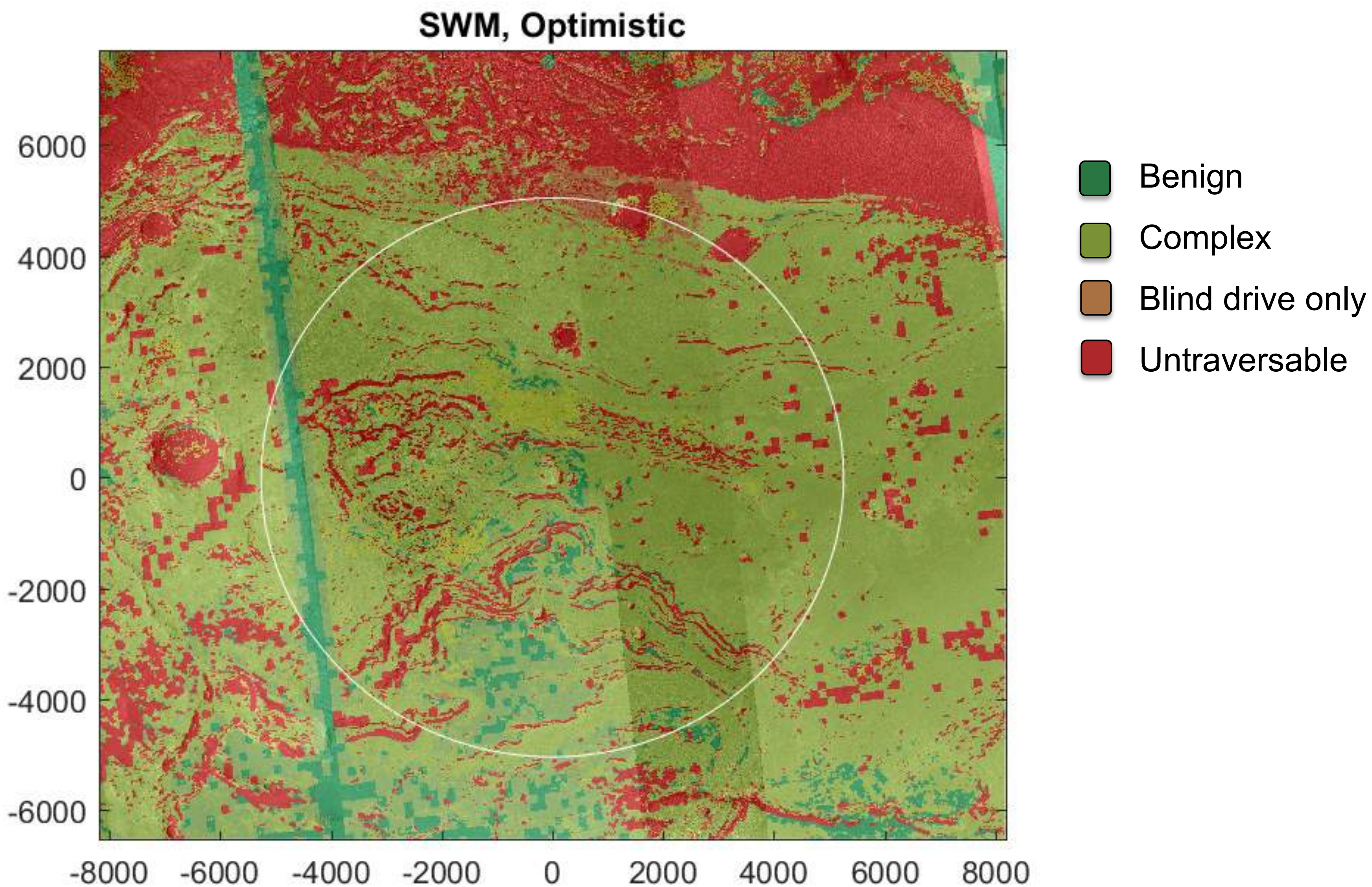


Slope calculation algorithm may not accurately capture the traversability of wheel diameter sized scarps, which may be challenging for ascent.

Qualitative analysis makes us believe that there are viable routes up the ledges, but the traverse distance analysis may not accurately reflect the circuitous route likely needed to find a viable ascent path.

<5° or no data | 5°-10° | 10°-15° | 15°-20° | 20°-25° | ≥ 25°

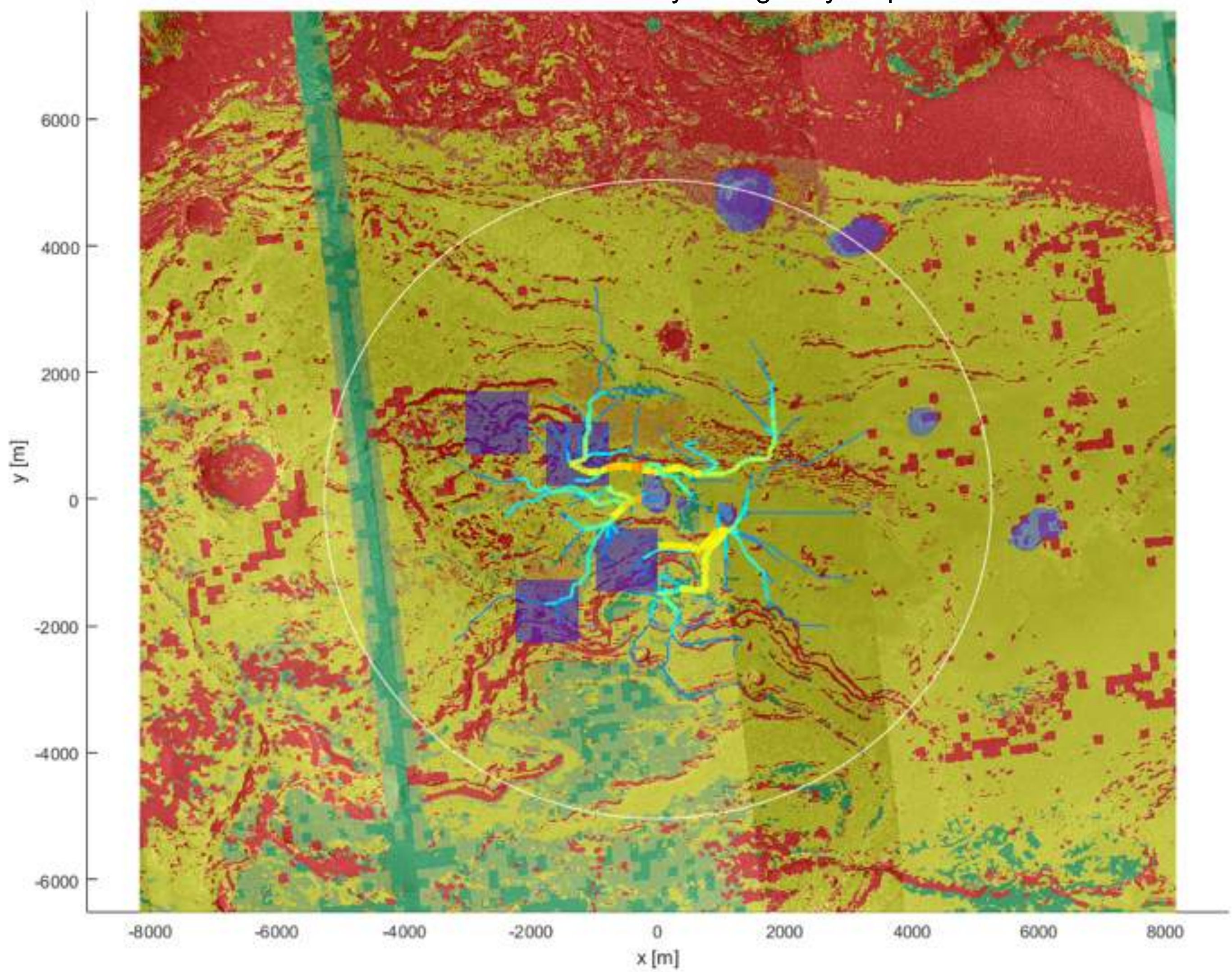
# Traversability Map



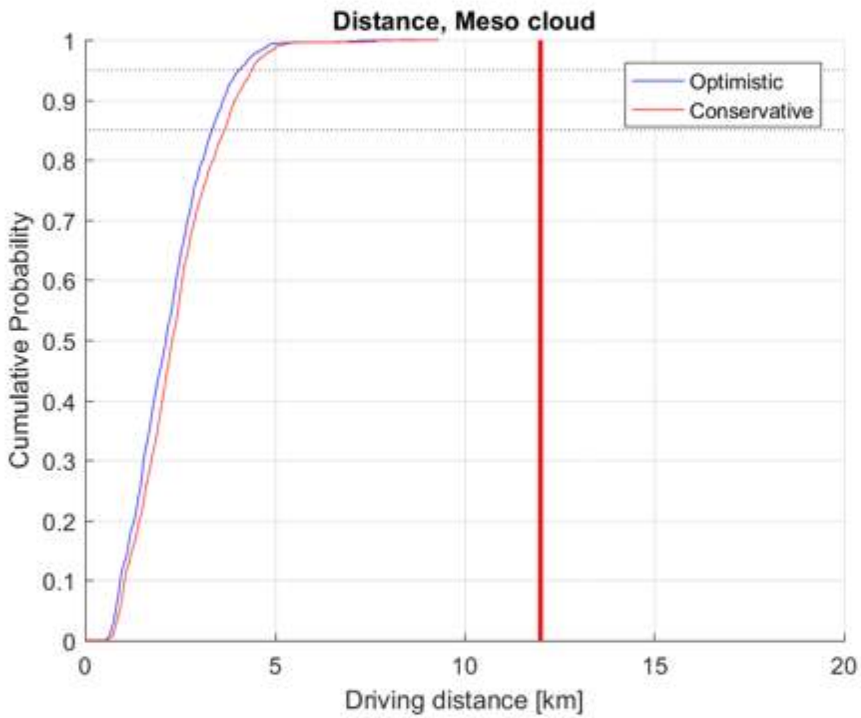
# Highway Map

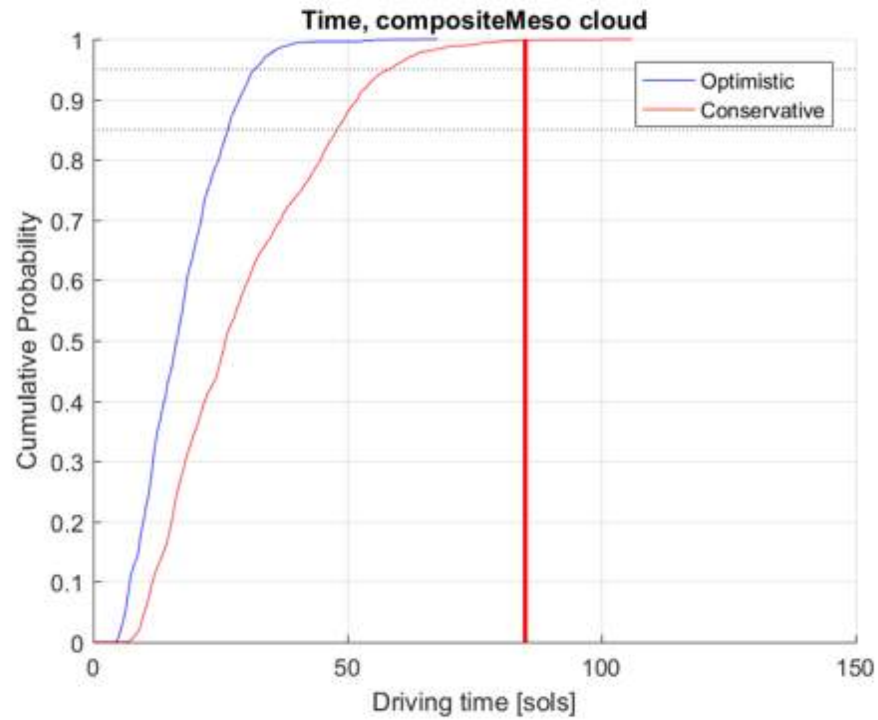


Conservative Analysis Highway Map



# Traverse Analysis Results




**Distance**

| Drive rate assumption | 50% | 80% | 85% | 90% | 95% |
|---|---|---|---|---|---|
| Optimistic | 2.2 km | 3.1 km | 3.4 km | 3.7 km | 4.1 km |
| Conservative | 2.3 km | 3.4 km | 3.7 km | 4.0 km | 4.4 km |

**Time**

| Drive rate assumption | 50% | 80% | 85% | 90% | 95% |
|---|---|---|---|---|---|
| Optimistic | 16.5 sols | 24.9 sols | 26.8 sols | 28.7 sols | 32.0 sols |
| Conservative | 26.2 sols | 44.9 sols | 48.4 sols | 52.0 sols | 58.5 sols |

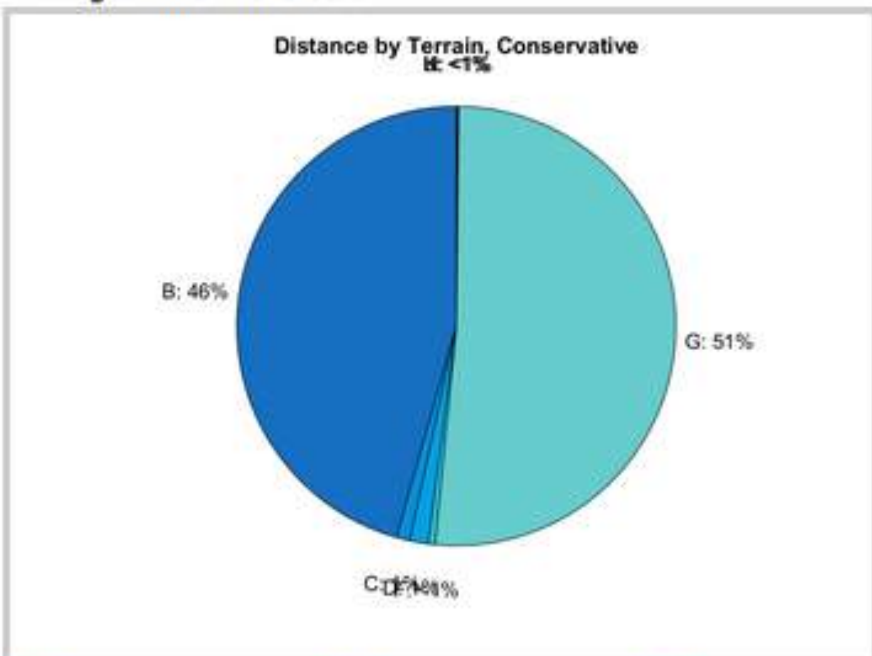
Assumes 2.5 hours of dedicated drive time per sol
85 sols is the portion of the mission allocated to traversing between ROIs

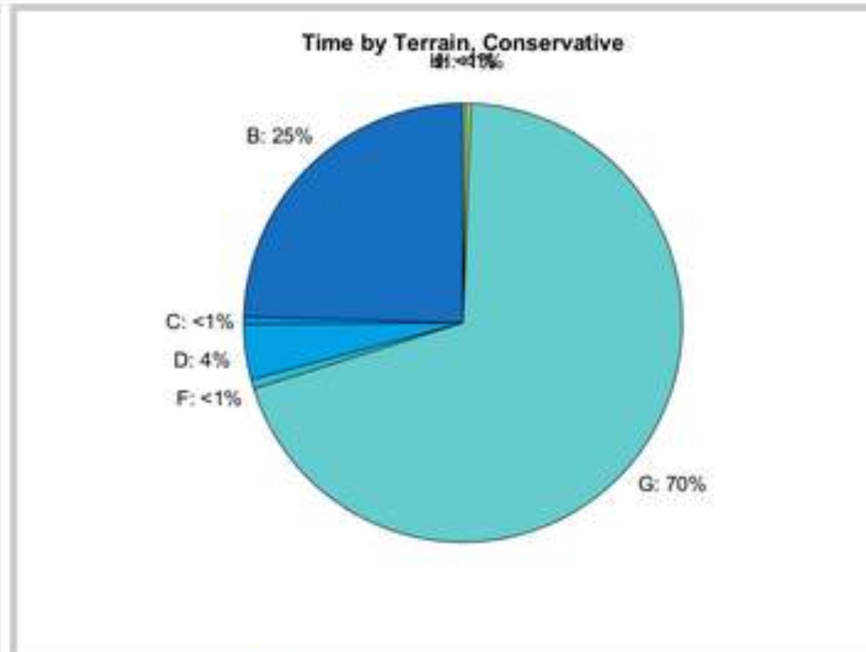
# Terrain Type Breakdown

**Conservative**

Average Distance: 2.4 km

Average Time: 29.6 sols



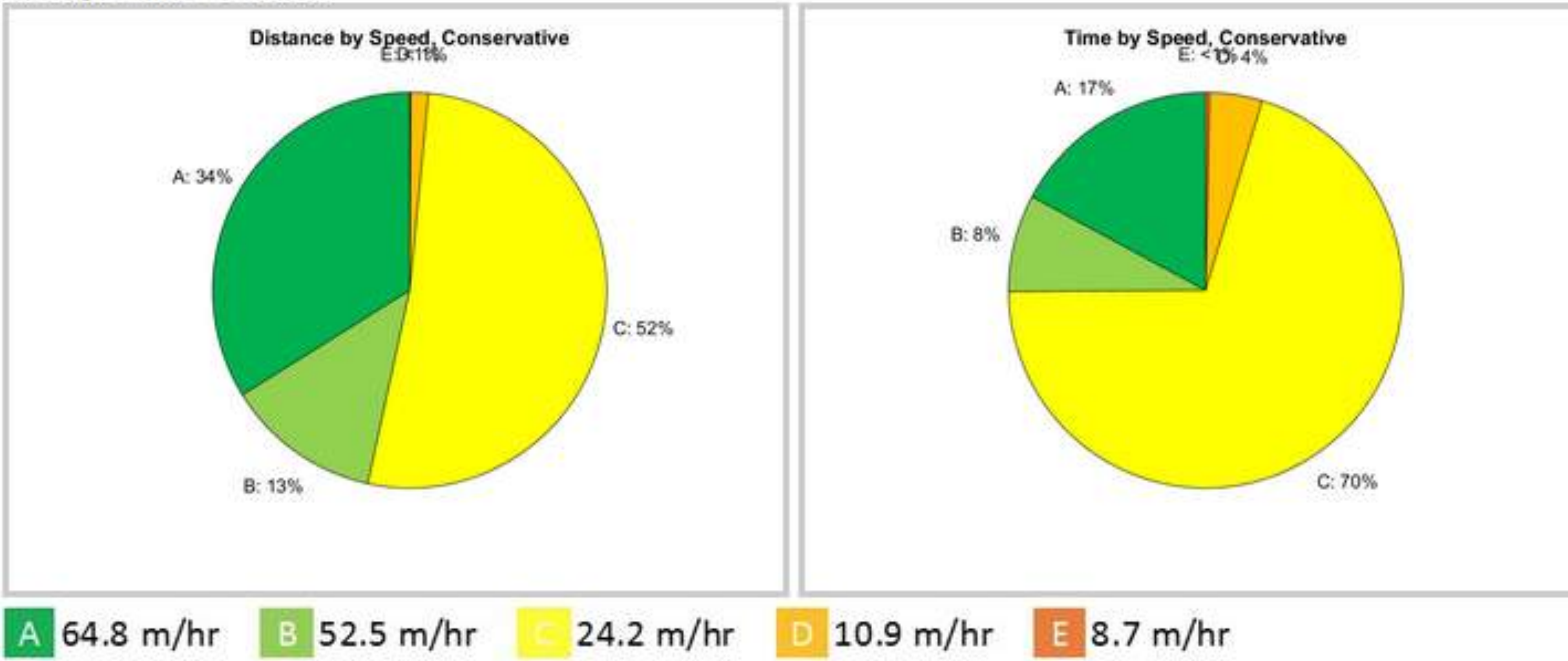

A Smooth regolith
B Smooth outcrop
C Smooth fractured outcrop
D Sparse ripples smooth firm substrate
E Moderate ripples firm substrate
F Rough regolith
G Rough outcrop
H Dense ridges
I Rock field
J Sparse ripples sandy substrate
K Moderate ripples sandy substrate
O Featureless sand

# Drive Rate Breakdown

**Conservative**

Average Distance: 2.4 km

Average Time: 29.6 sols



# Environmental Conditions

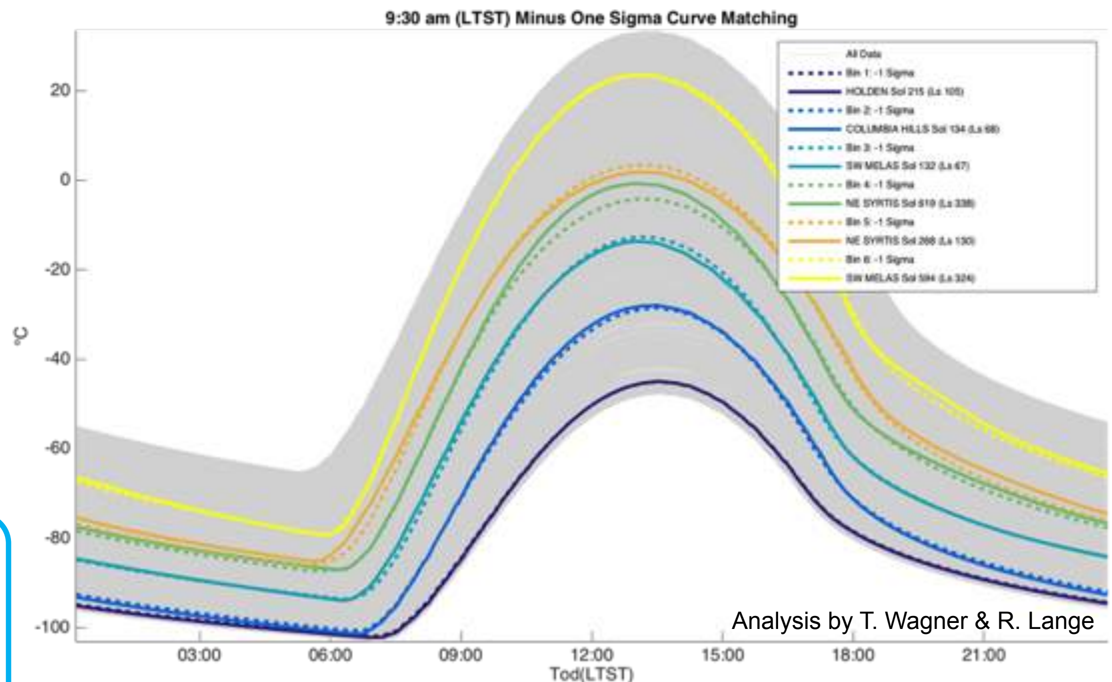
- There are no known significant operational or hardware constraints due to seasonal variations at SW Melas (-9.8° north)

# Environments & Thermal

- (opposite) 6 diurnal temperature profiles, optimized for 9:30 LTST, to use for modeling all sites throughout Mars year.
- (lower-right) Percentage of environment bin usage over 1-MY for each landing site, based on Sol ranges defined by curve-fit optimization.

**6 environments have been provided to Payload and Thermal teams for analysis on survival heating, mechanism heat to use, instrument warm-up and ops TOD info.**

- Results from thermal analysis of 6 environments will be ready by early October

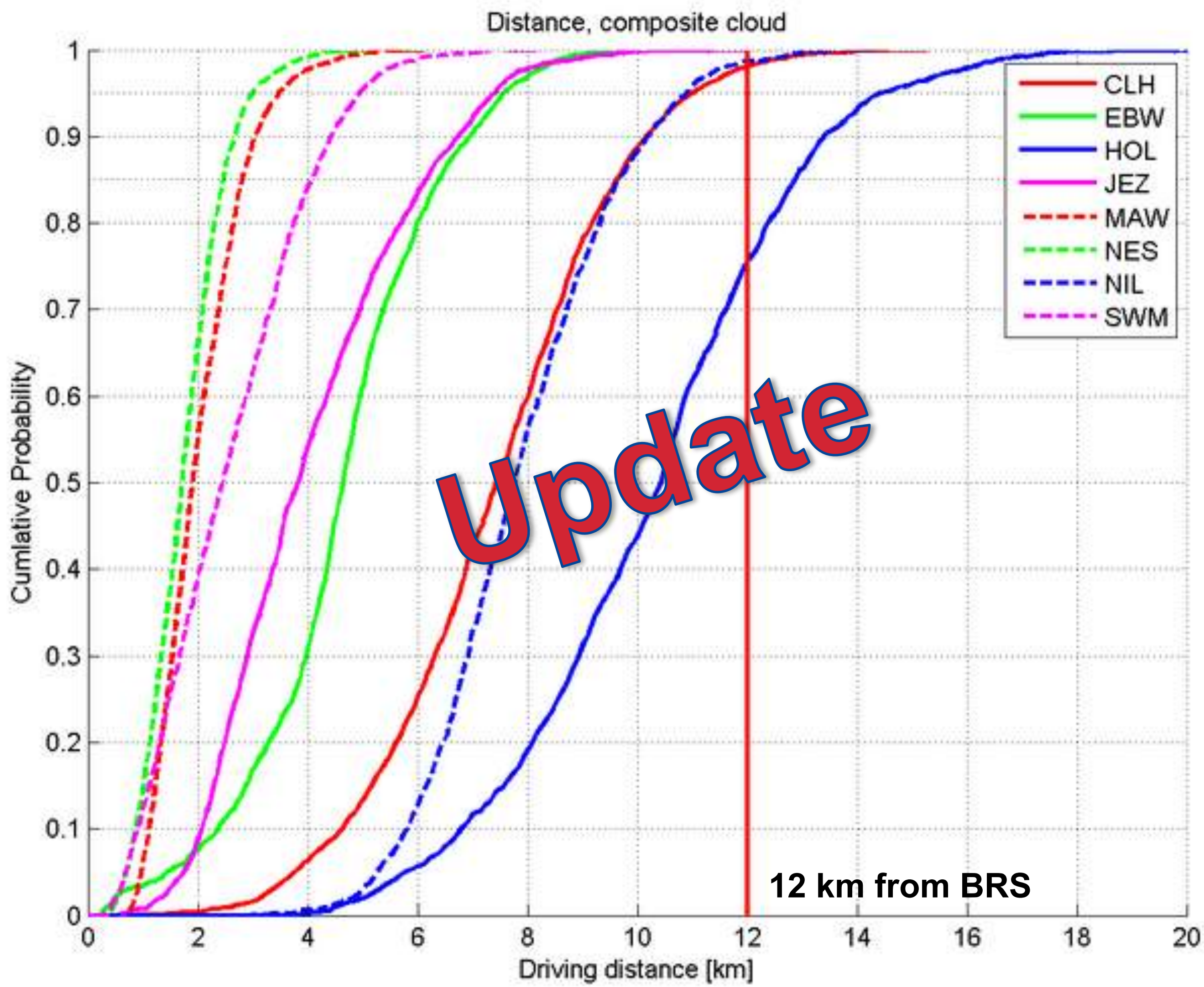



| | Bin: | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| 1 | Eberswalde | 24% | 16% | 13% | 8% | 12% | 28% |
| 2 | Columbia Hills | 0% | 33% | 16% | 11% | 18% | 21% |
| 3 | Holden | 29% | 14% | 11% | 8% | 11% | 27% |
| 4 | Jezero | 0% | 0% | 29% | 64% | 8% | 0% |
| 5 | Mawrth | 0% | 11% | 19% | 42% | 27% | 0% |
| 6 | NE Syrtis | 0% | 0% | 21% | 62% | 16% | 0% |
| 7 | Nili | 0% | 0% | 24% | 52% | 24% | 0% |
| 8 | SW Melas | 0% | 0% | 32% | 14% | 17% | 36% |

# Summary For All Sites

# Traverse Distance for All Sites






Note that these numbers will evolve as more data is added

# Traverse Time for All Sites




Note that these numbers will evolve as more data is added

# Summary of Status & Results



As of Jan 13, 2017

| | 90% Time [Sol] | 90% Distance [km] | Traversability challenges |
|---|---|---|---|
| BRS | 85 | 12 | Baseline |
| CLH | 58.4 – 72.8 | 8.3 – 9.3 | Go-to site |
| EBW | 28.5 – 47.9 | 4.0 – 4.6 | Mantling unit with ripples<br>Scarps on delta |
| HOL | 72.0 - 100.3 | 10.5 – 12.4 | Go-to site; >60% covered by potentially no-Autonav ripples; highways exist but in unfavorable directions<br>Access to ROI (layered deposit) challenging due to high slope/sand |
| JEZ | 35.7 – 38.2 | 5.5 – 5.8 | High CFA on SE of ellipse but ROIs are on NW |
| MAW | 19.2 – 27.8 | 2.7 – 3.2 | Surface roughness could limit the range of Autonav, but can achieve mission with conservative estimate |
| NES | 15.1 – 15.8 | 2.3 – 2.4 | Buttes and sand deposits, but localized and easy to go around |
| NIL | 66.7 – 86.2 | 9.9 – 10.6 | Go-to site<br>Ripples but mitigated by highway in the favorable direction |
| SWM | 24.2 – 52.0 | 3.1 - 4.0 | Scarps, but traversable routes seem to exist across |

# Backups

# Landing Points

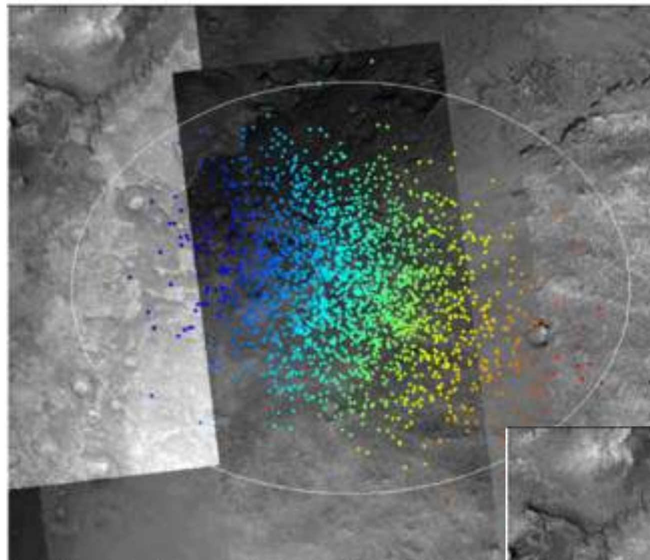


2000 landing points are distributed across the landing site according to the Monte Carlo EDL simulation.

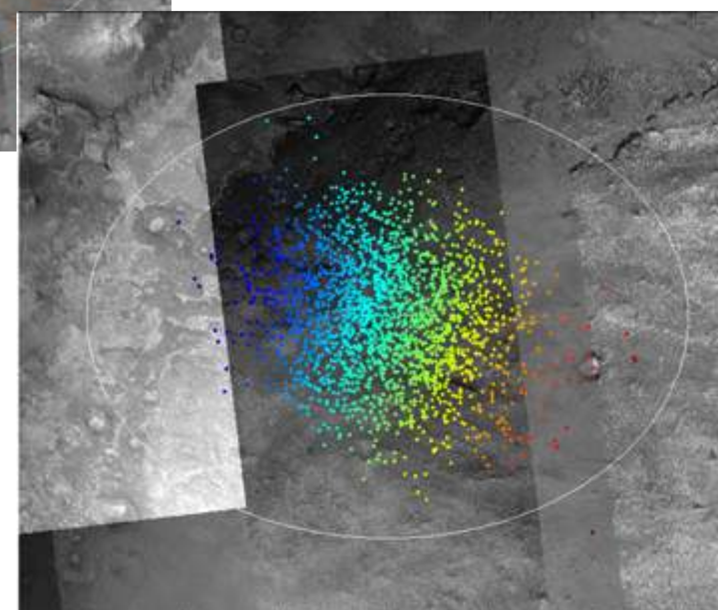
The Composite distribution is a buffered version of the mesoscale distribution

A traverse to reach the requisite ROIs is planned for each landing point. The traverse avoids hazards and minimizes traverse time given traverse rates based on terrain type, slope and rock density.

Composite Distribution



Mesoscale Distribution



# Accuracy of Terrain Clasification



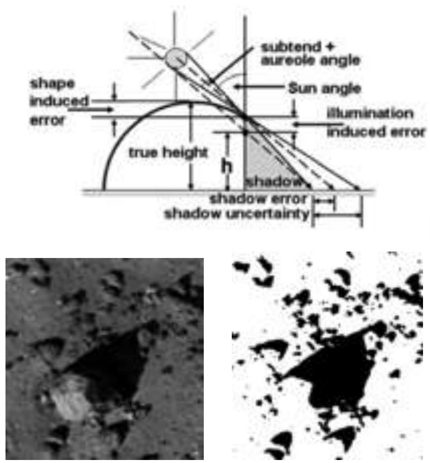
- Accuracy evaluated by cross validation
- Overall >90% accuracy
- Iteratively trained for further improvement in accuracy

**Table 2. Confusion matrix of classified terrain on Columbia Hills**

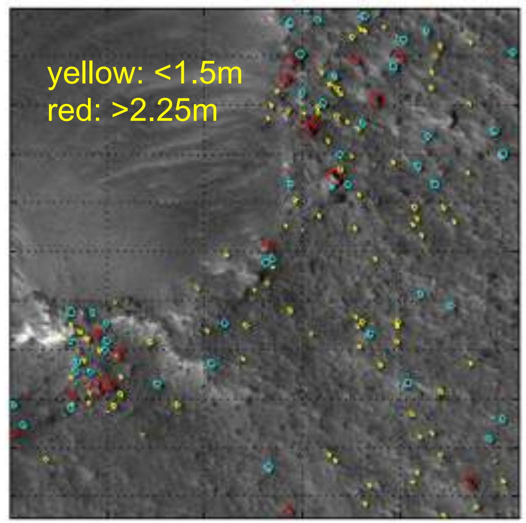
| Ground Truth | Prediction: SR | SO | SRF | RR | RO | SRS | DLR | PR | % of data |
|---|---|---|---|---|---|---|---|---|---|
| Smooth regolith | 81.2% | 1.0% | 0.0% | 13.3% | 0.0% | 0.2% | 0.0% | 0.0% | 19.8% |
| Smooth outcrop | 0.0% | 93.5% | 0.0% | 0.0% | 0.4% | 0.0% | 0.0% | 0.0% | 5.4% |
| Sparse ripples firm | 0.6% | 0.0% | 99.6% | 0.0% | 0.0% | 0.6% | 0.0% | 0.0% | 2.5% |
| Rough regolith | 12.1% | 4.7% | 0.0% | 83.6% | 6.2% | 1.1% | 0.0% | 0.2% | 11.8% |
| Rough outcrop | 0.0% | 0.0% | 0.0% | 0.6% | 71.6% | 0.3% | 0.0% | 0.0% | 9.6% |
| Sparse ripples sandy | 5.7% | 0.9% | 0.2% | 1.5% | 21.8% | 97.6% | 0.0% | 0.0% | 20.8% |
| Dense linear ripples | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 97.2% | 1.9% | 6.0% |
| Polygonal ripples | 0.4% | 0.0% | 0.1% | 1.0% | 0.0% | 0.3% | 2.8% | 97.8% | 24.1% |

# Rock Detection

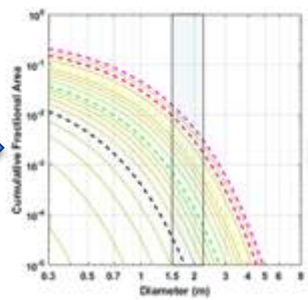
- Shadows are used to identify rocks' location and sizes independent of scarps and other terrain features §,‡.
- Rocks with estimated diameters between **1.5m and 2.25 meters** to estimate a Cumulative Fractional Area (CFA) of **all** rocks in a 150m x 150m area.
- With the CFA estimate we can model the size and spatial distribution of rocks of all sizes based on theoretical distributions.




(a) Shadow detections.




(b) Rocks locations + sizes.




(c) Fitting model.

CFA:
fraction of surface covered by rocks
(of all sizes)

(d) Model size and frequency of all rock diameters.

# Not Final as of 1/13



- NES
- SWM