

Does machine learning mean the end of geological mapping? Well, no actually...

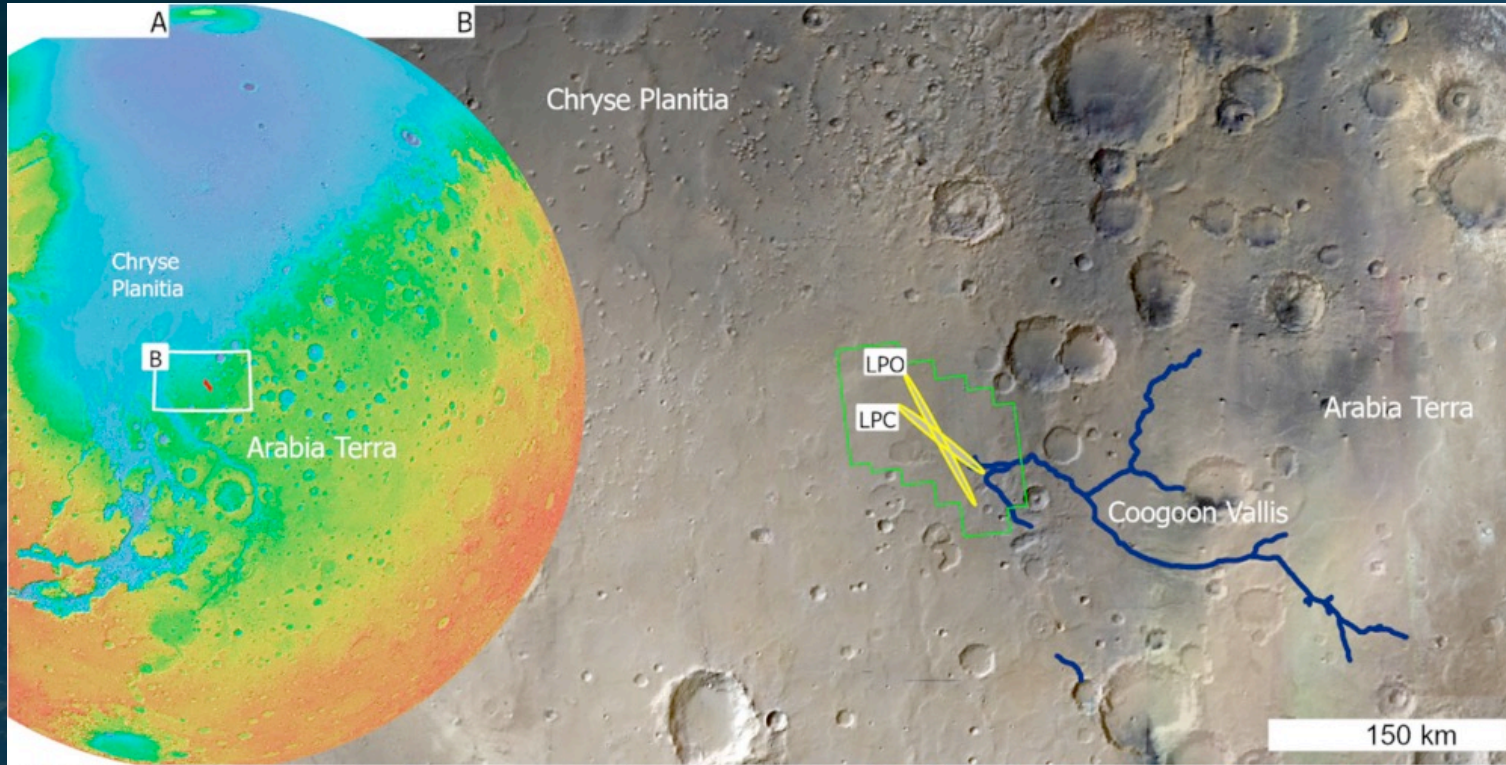
Jack Wright¹ – ESA Research Fellow

With thanks to:
Alexander M. Barrett²
Peter Fawdon²
Elena A. Favaro²
Matthew R. Balme²
Mark J. Woods³
Spyros Karachalios⁴
Levin Gerdes⁵

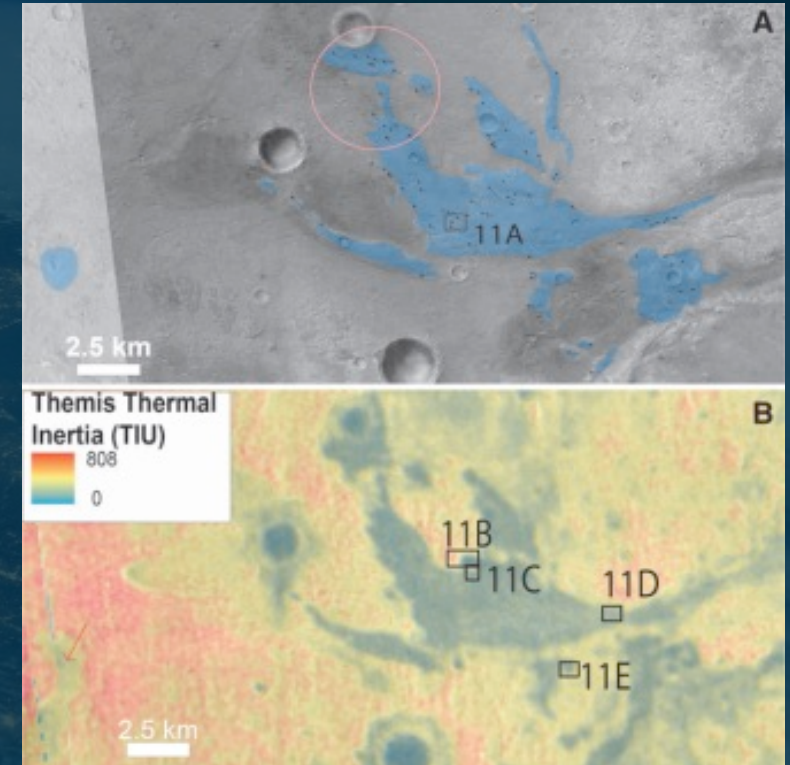
¹European Space Agency, ESAC, Spain
²The Open University, UK
³Centre for Modelling and Simulation, UK
⁴DeGould, UK
⁵European Space Agency, ESTEC, The Netherlands

GMAP Winter School 2023
03/02/2023

Rosalind Franklin Oxia Planum landing site



Fawdon et al. (2021)

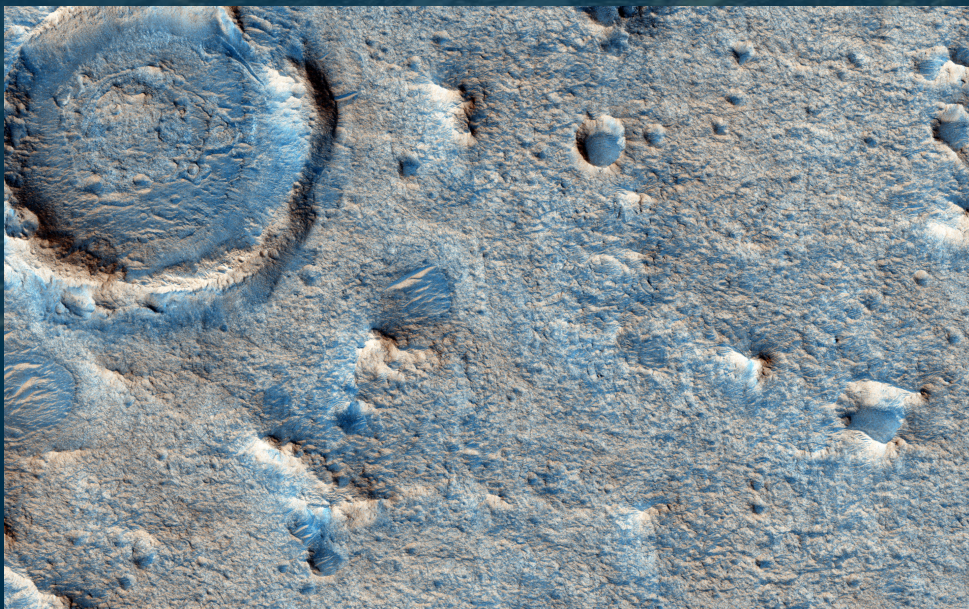


Quantin-Nataf et al. (2020)

- Meets landing site science and engineering constraints: Noachian (4.1–3.7 Ga), low latitude, low altitude
- Widespread clay-bearing rocks, indicative of rock alteration by water, a prerequisite for life
- Clays are good at preserving biosignatures, evidence of past life

Why make terrain classifications?

- Prepare for ESA ExoMas Rosalind Franklin rover mission operations
 - Locate landing site hazards
 - Forecast safe routes
 - Identify regions of interest for scientific study during the mission
- Meanwhile, they could be scientifically useful products
 - Understand landing site geology



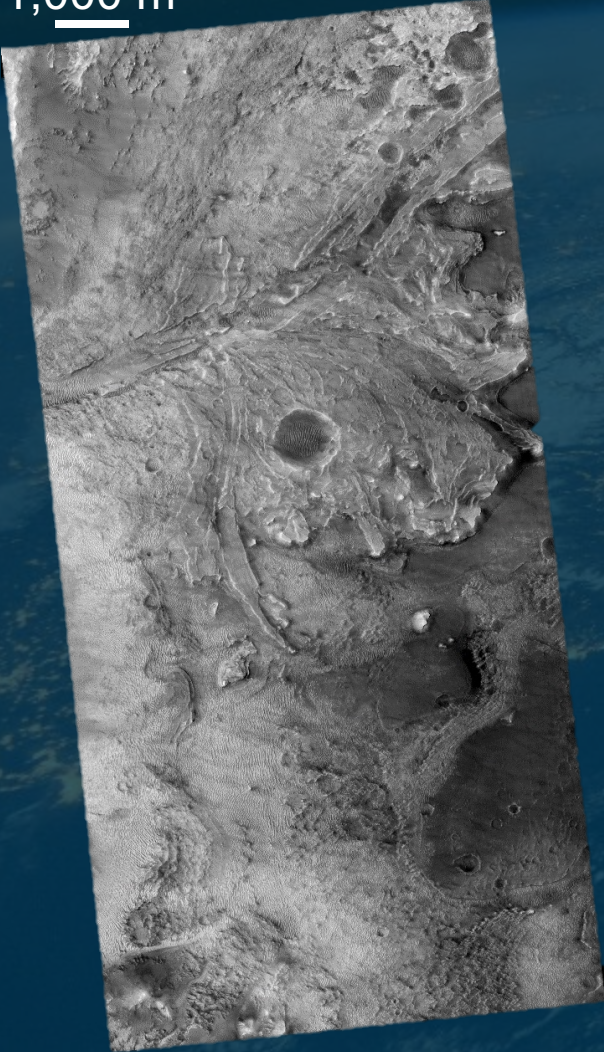
NASA/JPL/University of Arizona



ESA/ATG medialab

Why use machine learning?

1,000 m



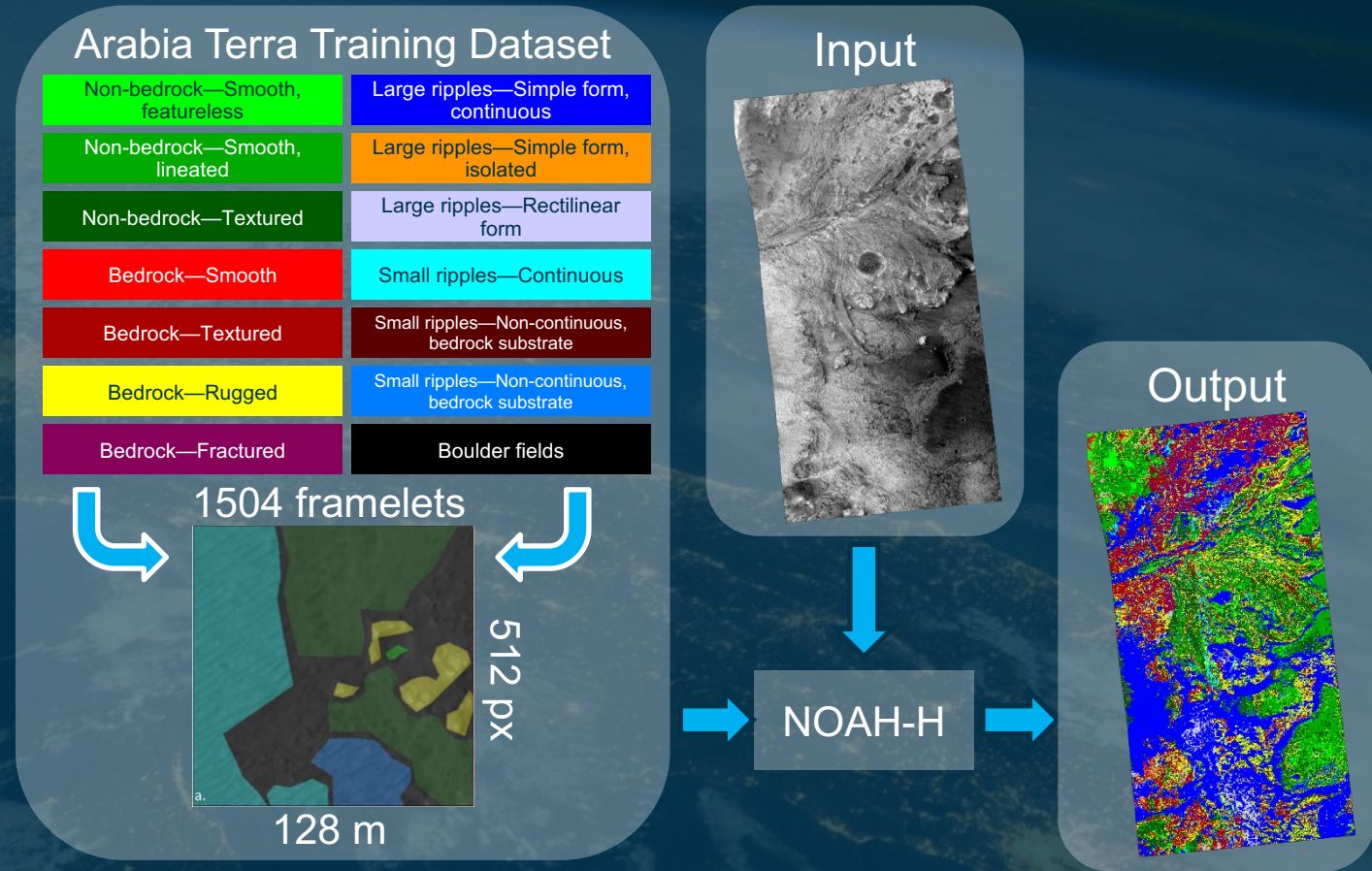
NASA/JPL/University of Arizona MRO/HiRISE



Getty Images/iStockphoto

NOAH-H: Mars Terrain Classifier

- Novelty or Anomaly Hunter—HiRISE
- Deep Learning Convolutional Neural Network
 - Neural network—model learns terrain classification based on examples
 - Deep learning—model contains many layers allowing it to generalise and learn hierarchical classification systems
 - Convolutional—convolution filters are used to detect features within images, progressing from edge detection, to complex shapes, to set of shapes



Barrett et al. (2021)

What are the terrain classes?

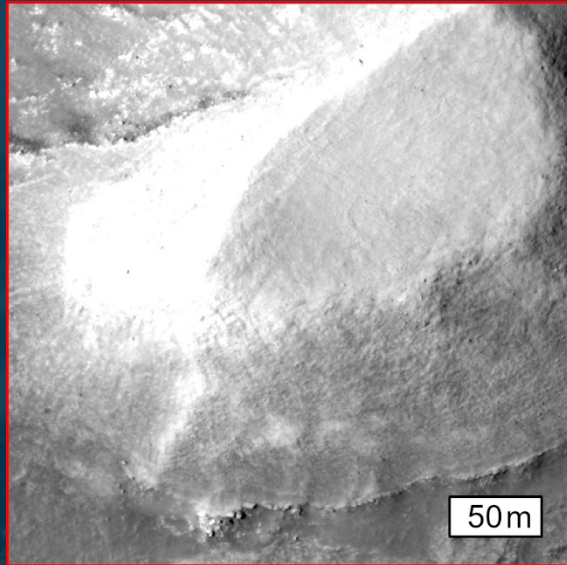
Bedrock

Non-bedrock

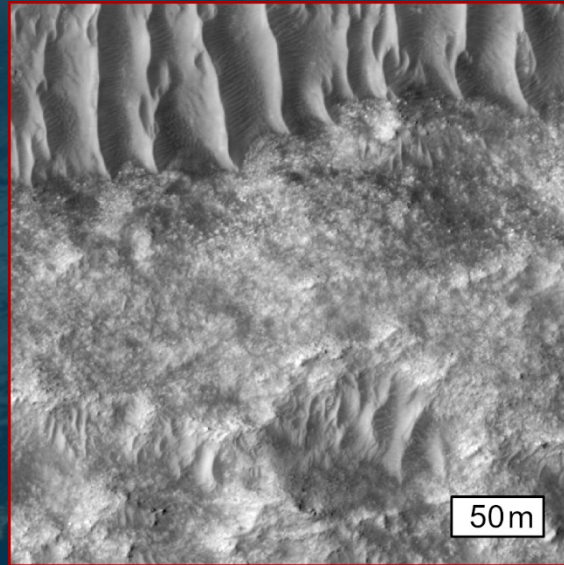
Large ripples

Small ripples

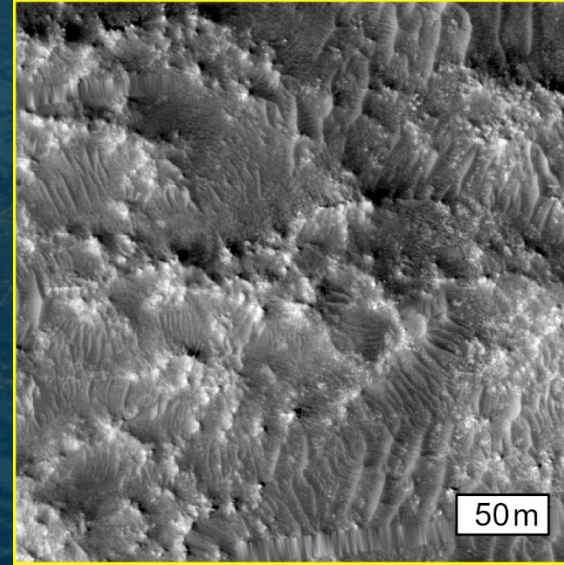
Boulder fields



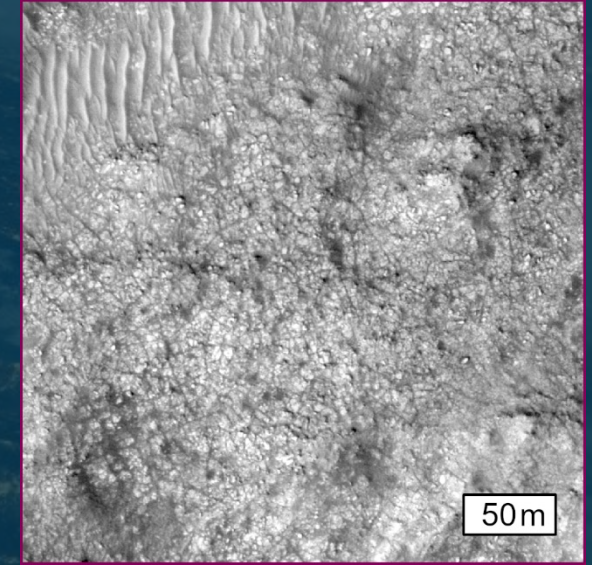
Bedrock—Smooth



Bedrock—Textured



Bedrock—Rugged



Bedrock—Fractured

What are the terrain classes?

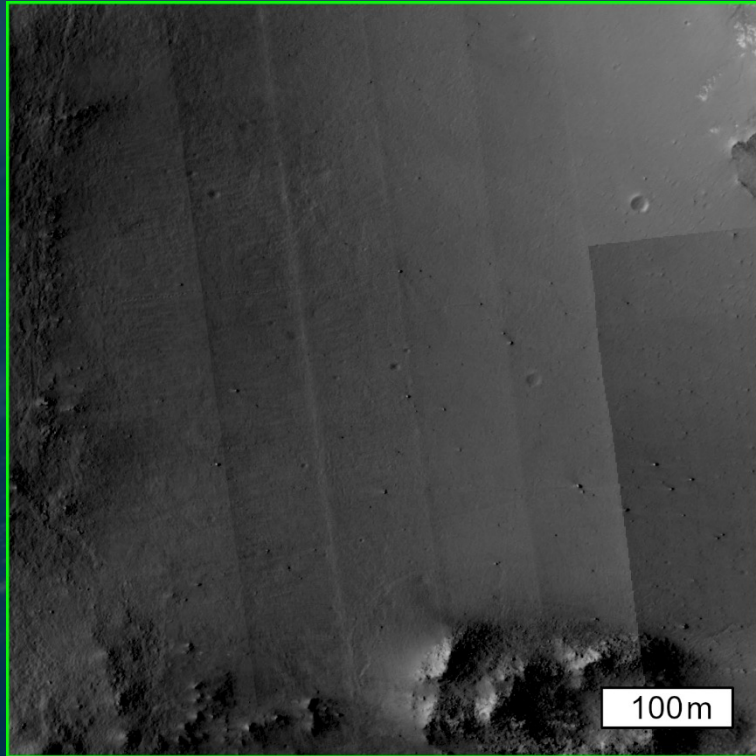
Bedrock

Non-bedrock

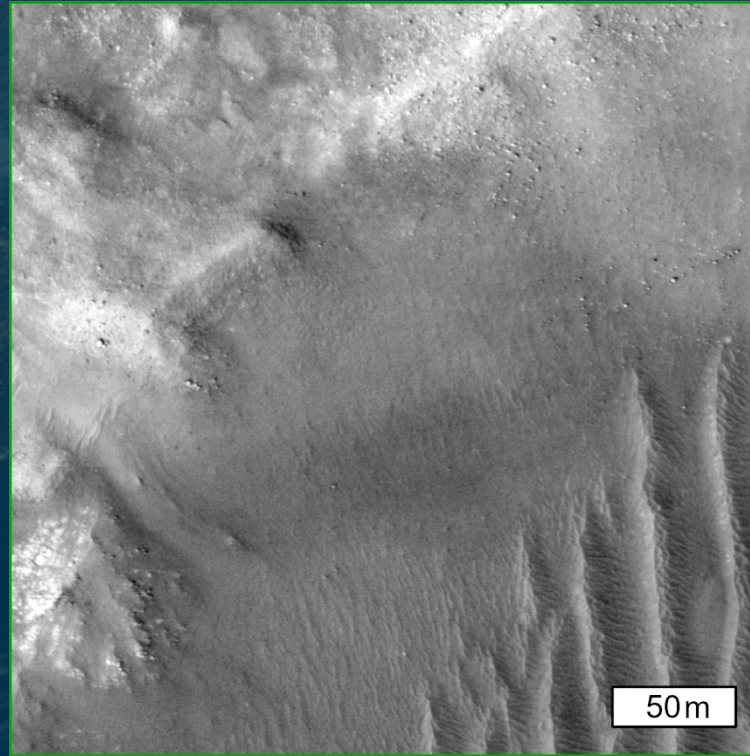
Large ripples

Small ripples

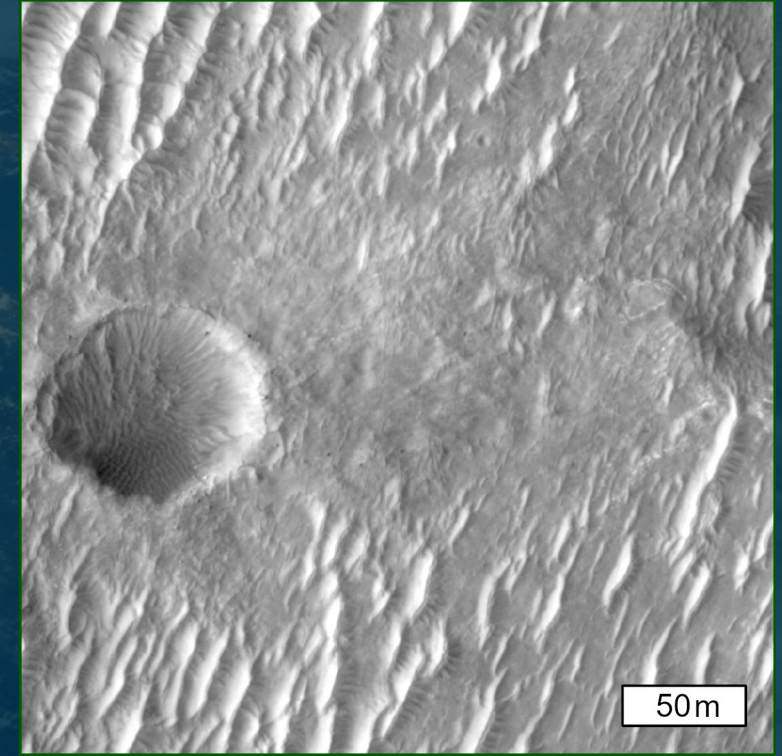
Boulder fields



Non-bedrock—Smooth,
featureless



Non-bedrock—Smooth,
lineated



Non-bedrock—Smooth,
textured

What are the terrain classes?

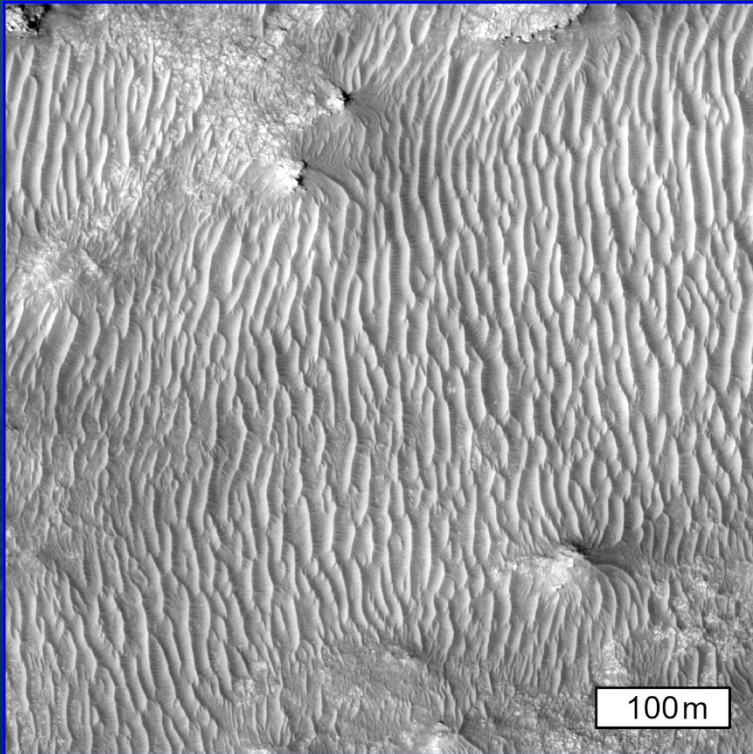
Bedrock

Non-bedrock

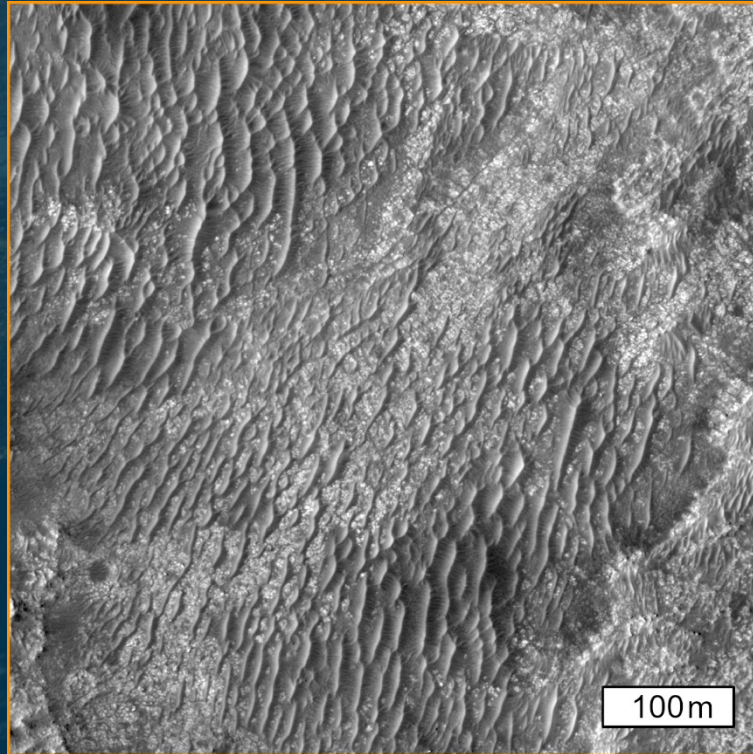
Large ripples

Small ripples

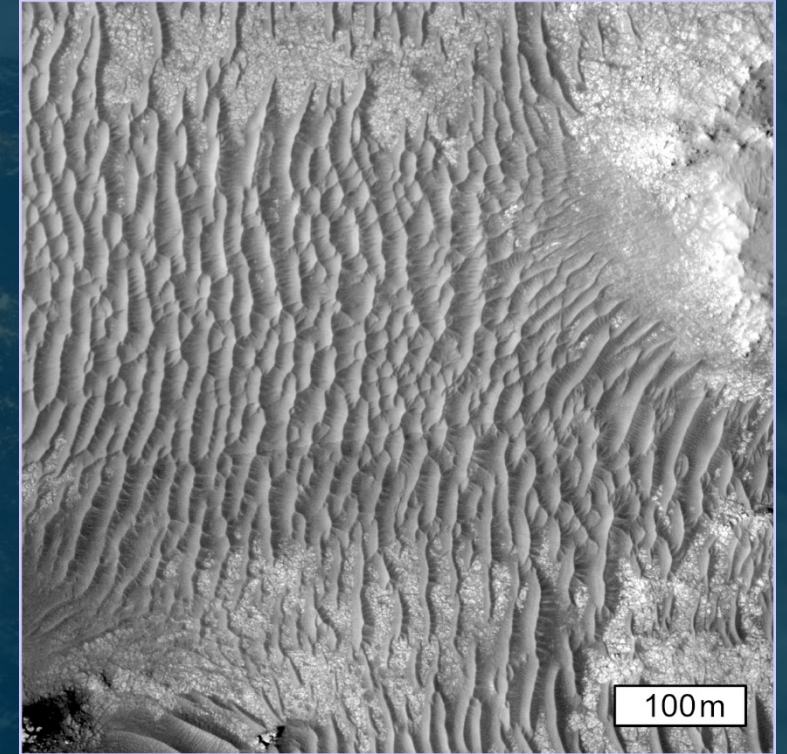
Boulder fields



Large ripples—continuous



Large ripples—isolated



Large ripples—rectilinear

What are the terrain classes?

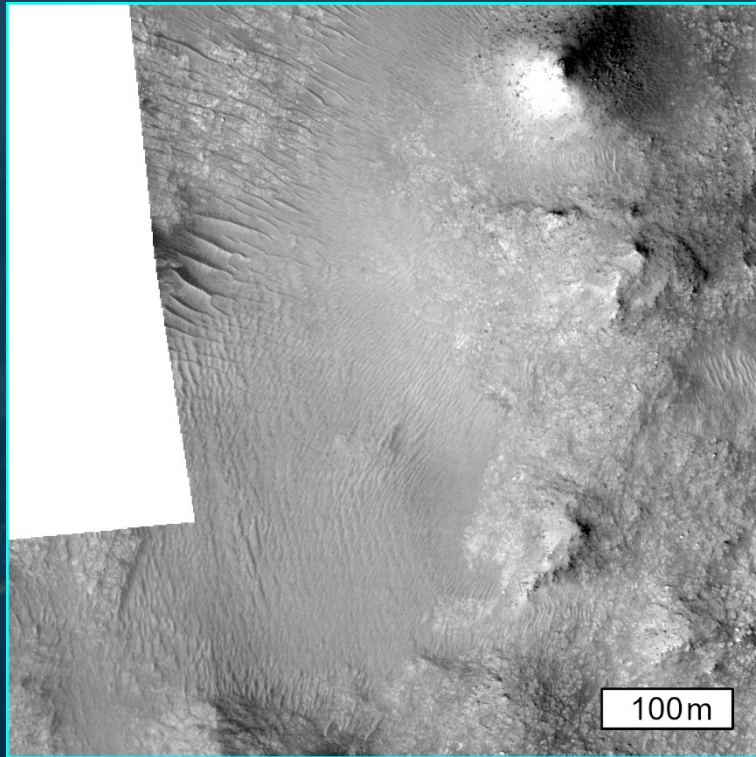
Bedrock

Non-bedrock

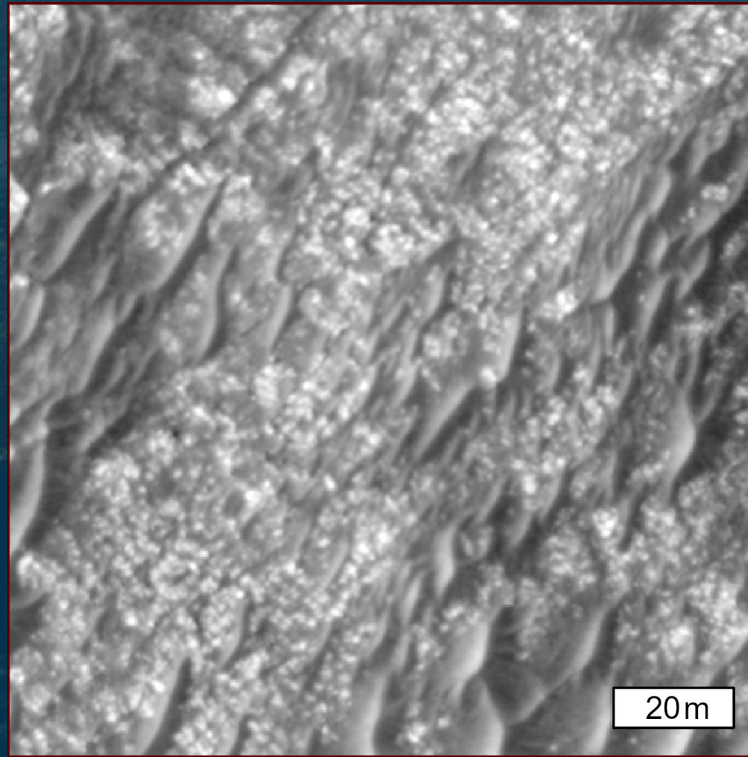
Large ripples

Small ripples

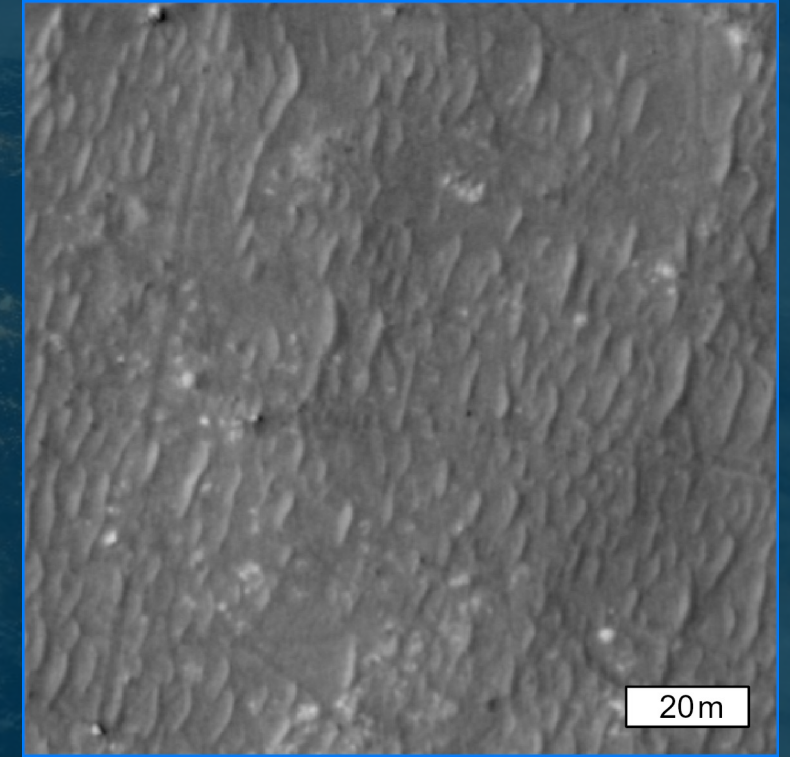
Boulder fields



Small ripples—continuous



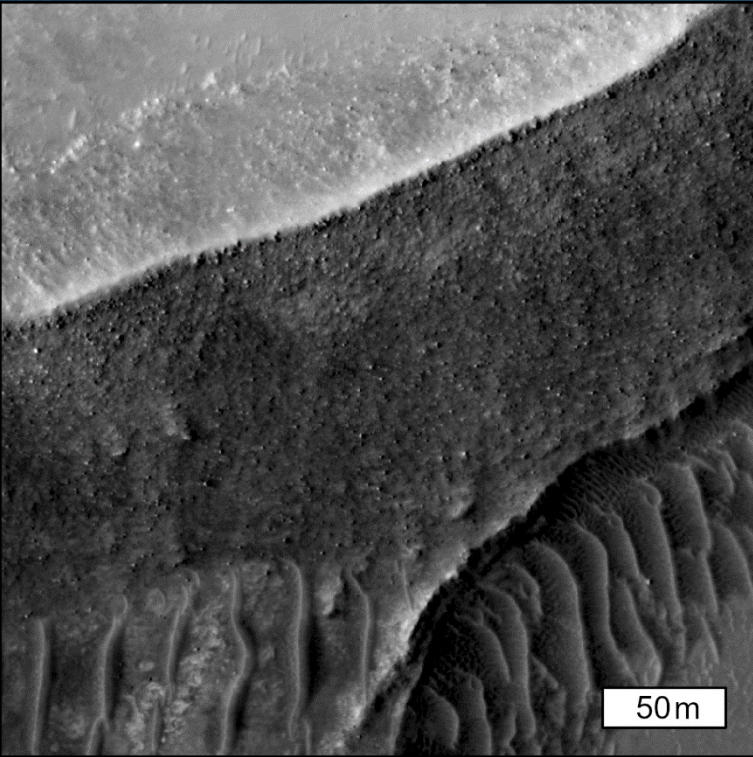
Small ripples—non-continuous,
bedrock substrate



Small ripples—non-continuous,
non-bedrock substrate

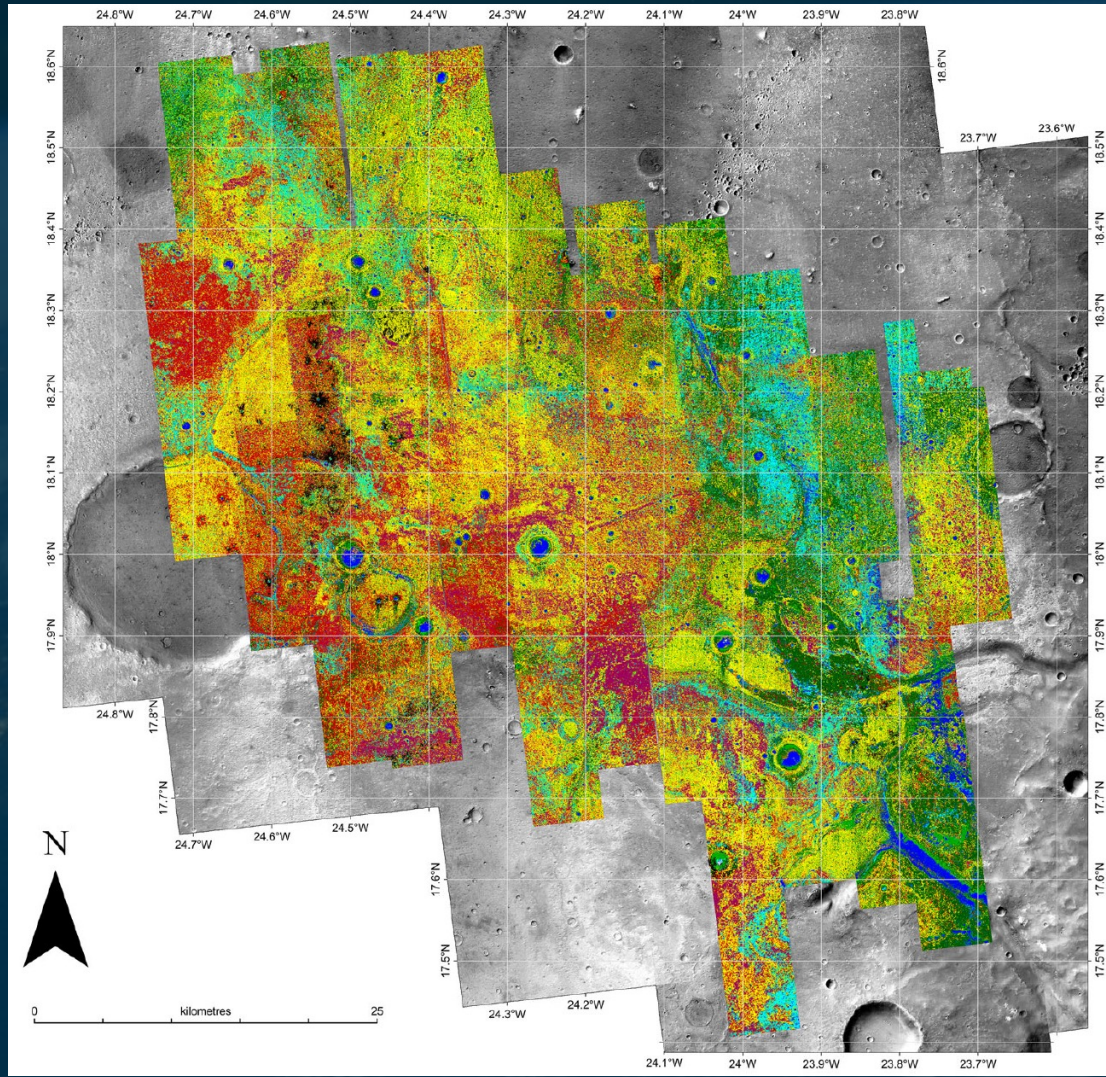
What are the terrain classes?

Bedrock Non-bedrock Large ripples Small ripples **Boulder fields**



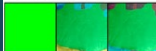
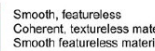
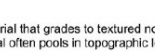

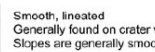
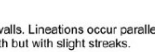

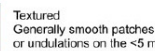
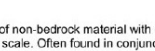

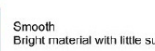
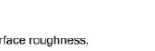
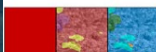

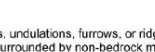


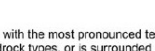

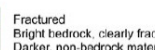
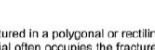
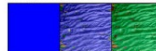
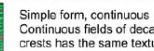
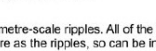

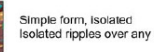


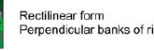
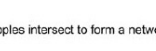
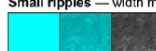
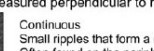
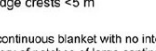
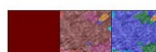
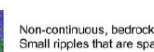


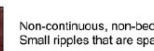


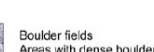
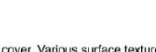
Boulder fields

Oxia Planum terrain classification map



Barrett et al. (2022)

Descriptive classes Each descriptive class is shown in the legend three ways. Left: Solid colour symbol. Centre: 60% transparent colour symbol overlaying High Resolution Imaging Science Experiment (HiRISE) Image (similar to Main Map). Right: HiRISE Image.

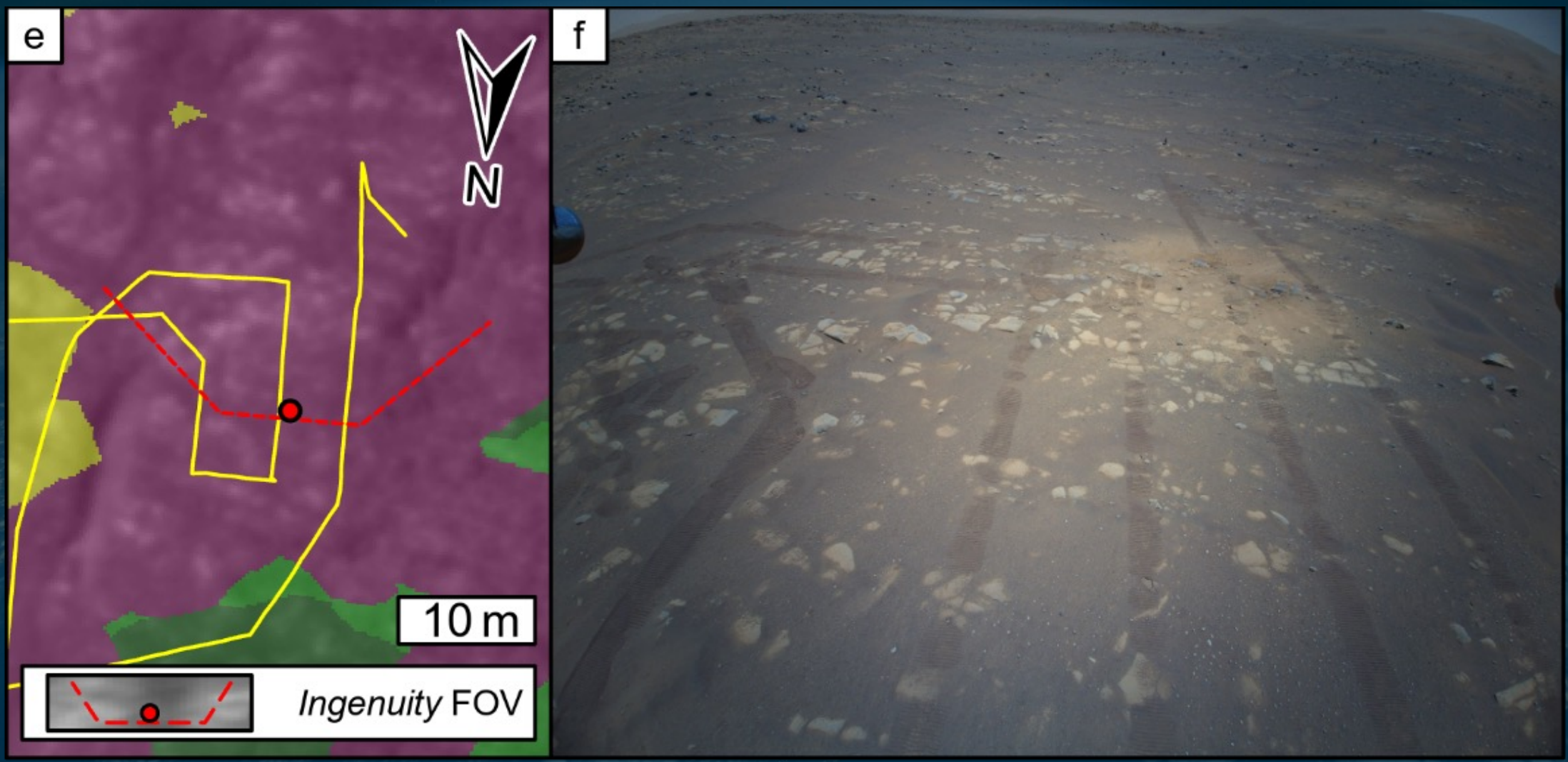
Non-bedrock		
		
<p>Smooth, featureless Coherent, textureless material that grades to textured non-bedrock at its edges. Smooth featureless material often pools in topographic lows, such as small impact craters.</p>		
		
<p>Smooth, lineated Generally found on crater walls. Lineations occur parallel to the direction of slopes. Slopes are generally smooth but with slight streaks.</p>		
		
<p>Textured Generally smooth patches of non-bedrock material with clear pits or undulations on the <5 m scale. Often found in conjunction with featureless material.</p>		
Bedrock		
		
<p>Smooth Bright material with little surface roughness.</p>		
		
<p>Textured Bedrock textured by craters, undulations, furrows, or ridges on a 5–20 m scale. Often forms blocks surrounded by non-bedrock material.</p>		
		
<p>Rugged Roughest bedrock surface, with the most pronounced texture and highest relief. Often grades into other bedrock types, or is surrounded by non-bedrock material.</p>		
		
<p>Fractured Bright bedrock, clearly fractured in a polygonal or rectilinear pattern. Darker, non-bedrock material often occupies the fractures in the bright bedrock.</p>		
Large ripples — width measured perpendicular to ridge crests >5 m		
		
<p>Simple form, continuous Continuous fields of decametre-scale ripples. All of the material between the ridge crests has the same texture as the ripples, so can be interpreted as an aeolian deposit.</p>		
		
<p>Simple form, isolated Isolated ripples over any substrate.</p>		
		
<p>Rectilinear form Perpendicular banks of ripples intersect to form a network of rectangular cells.</p>		
Small ripples — width measured perpendicular to ridge crests <5 m		
		
<p>Continuous Small ripples that form a continuous blanket with no intervening material. Often found on the periphery of patches of large continuous ripples.</p>		
		
<p>Non-continuous, bedrock substrate Small ripples that are sparsely distributed over bedrock substrates.</p>		
		
<p>Non-continuous, non-bedrock Small ripples that are sparsely distributed over non-bedrock substrates.</p>		
Boulder fields		
		
<p>Boulder fields Areas with dense boulder cover. Various surface textures can exist between clasts. Clast sizes vary.</p>		

Barrett et al. (2022)

- 25 cm/pixel machine learning terrain map
- How do we know if it is fit for purpose?
- Can we ground truth this product before *Rosalind Franklin* arrives?
 - NASA Mars 2020 landing site – Jezero crater

Comparison with *Ingenuity* helicopter images

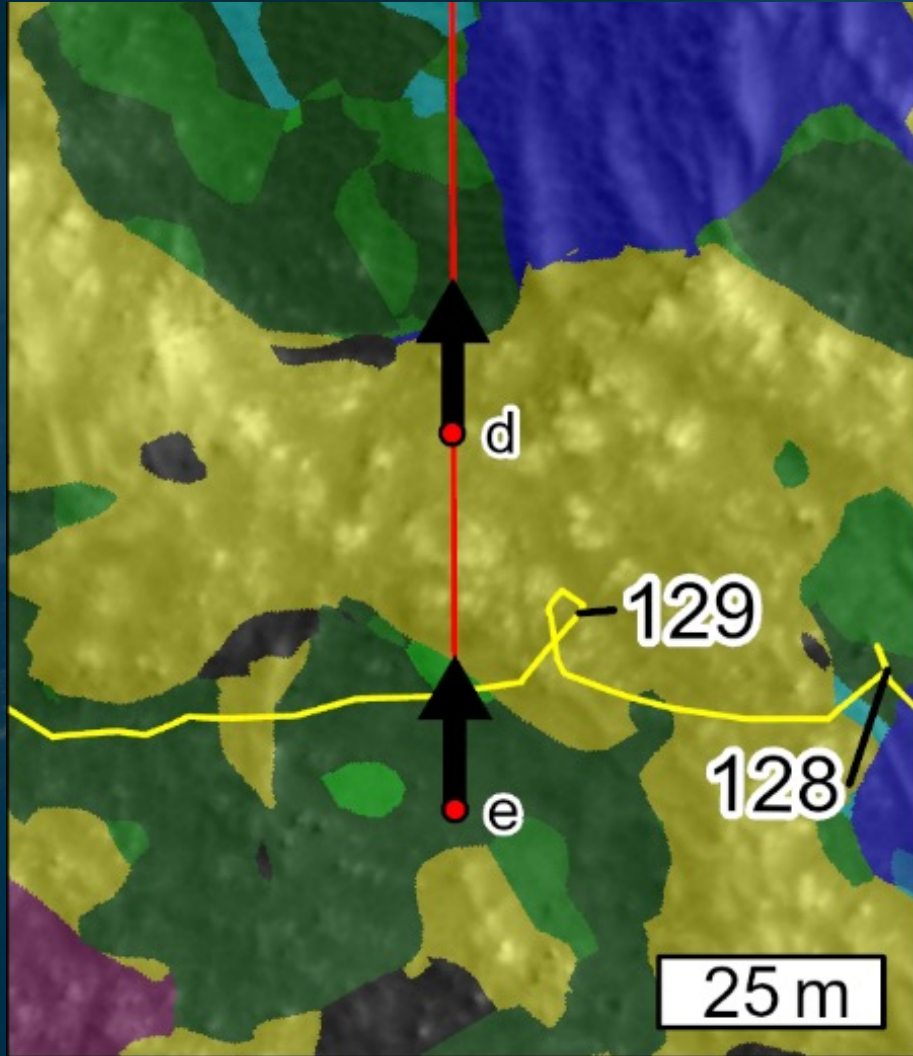
 @wrightplanet



Wright et al. (2022)



Comparison with *Ingenuity* helicopter images

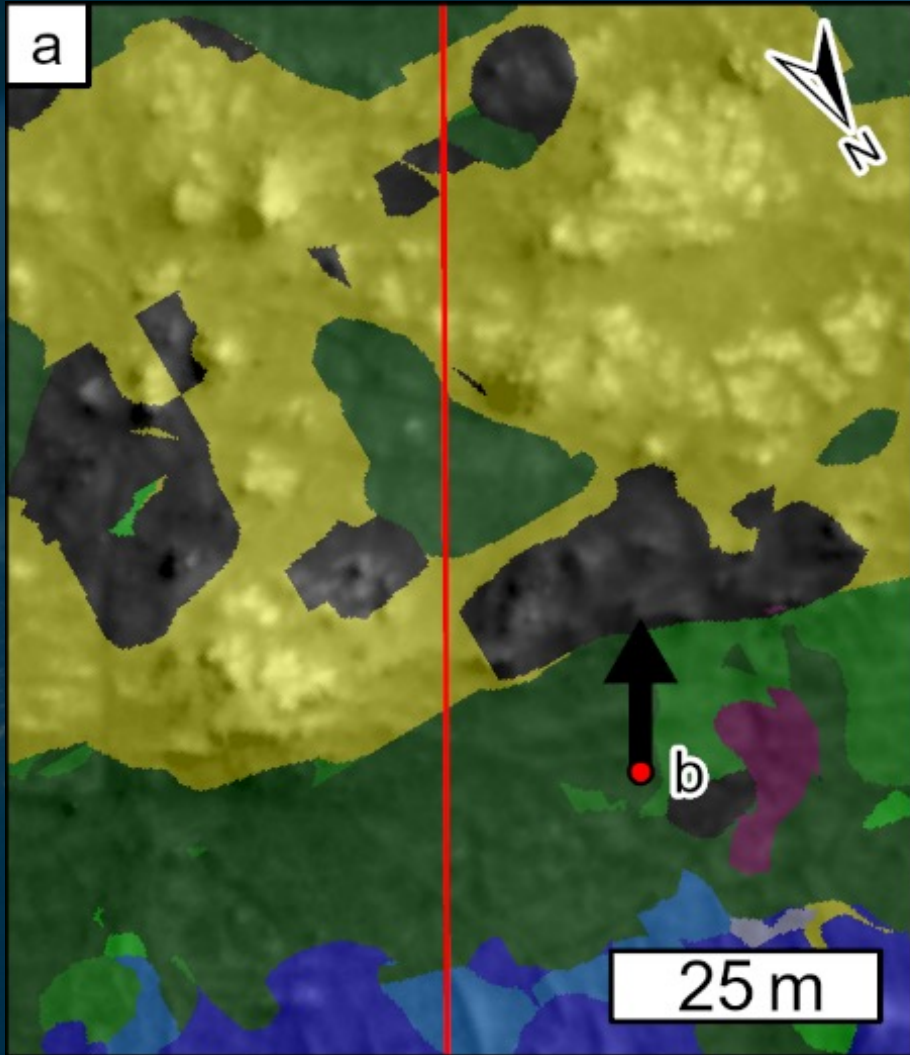


Wright et al. (2022)



Wright et al. (2022)

Comparison with *Ingenuity* helicopter images

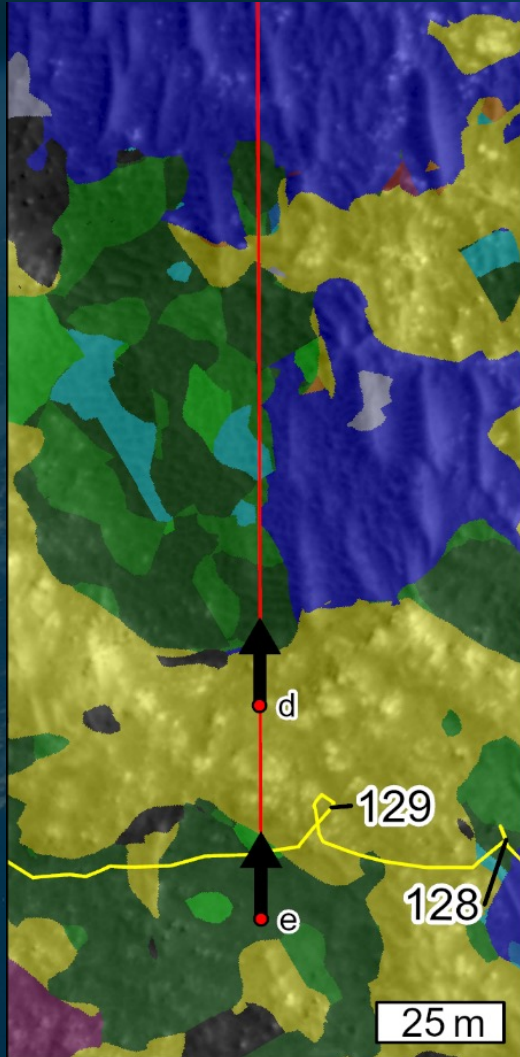


Wright et al. (2022)



Wright et al. (2022)

Comparison with *Ingenuity* helicopter images

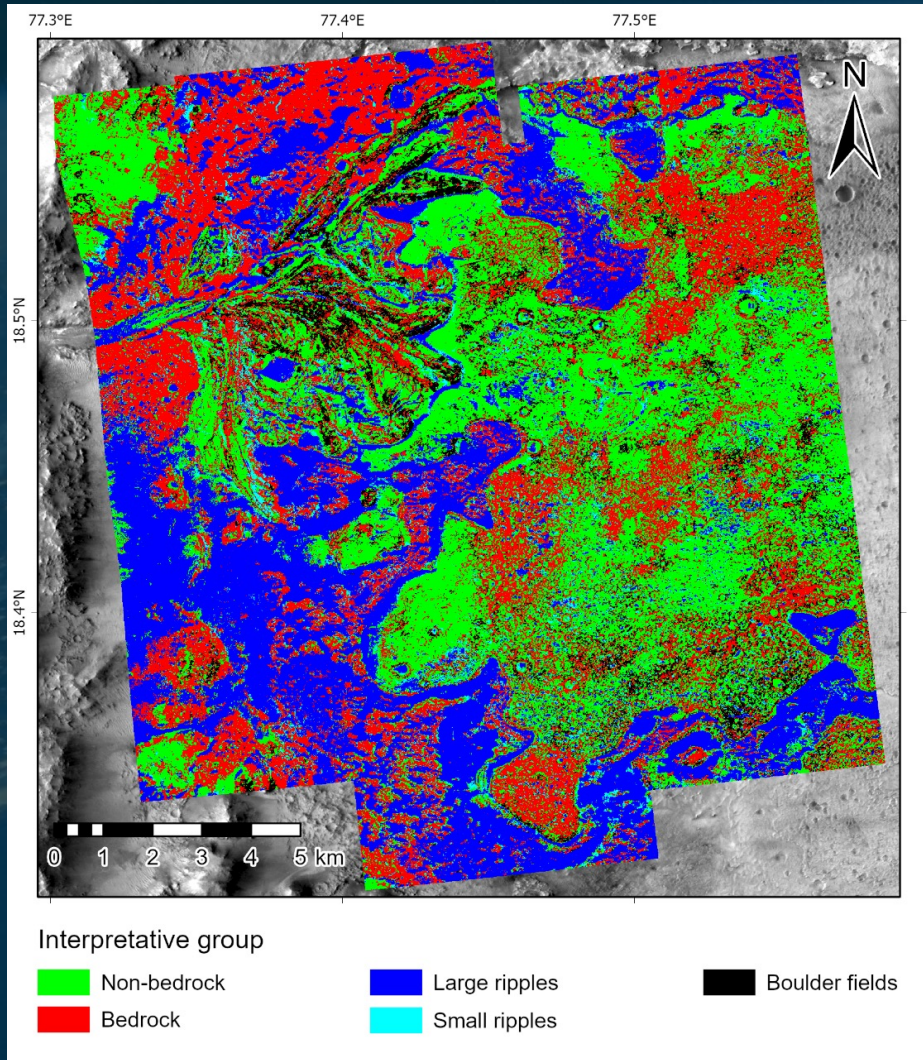


Wright et al. (2022)

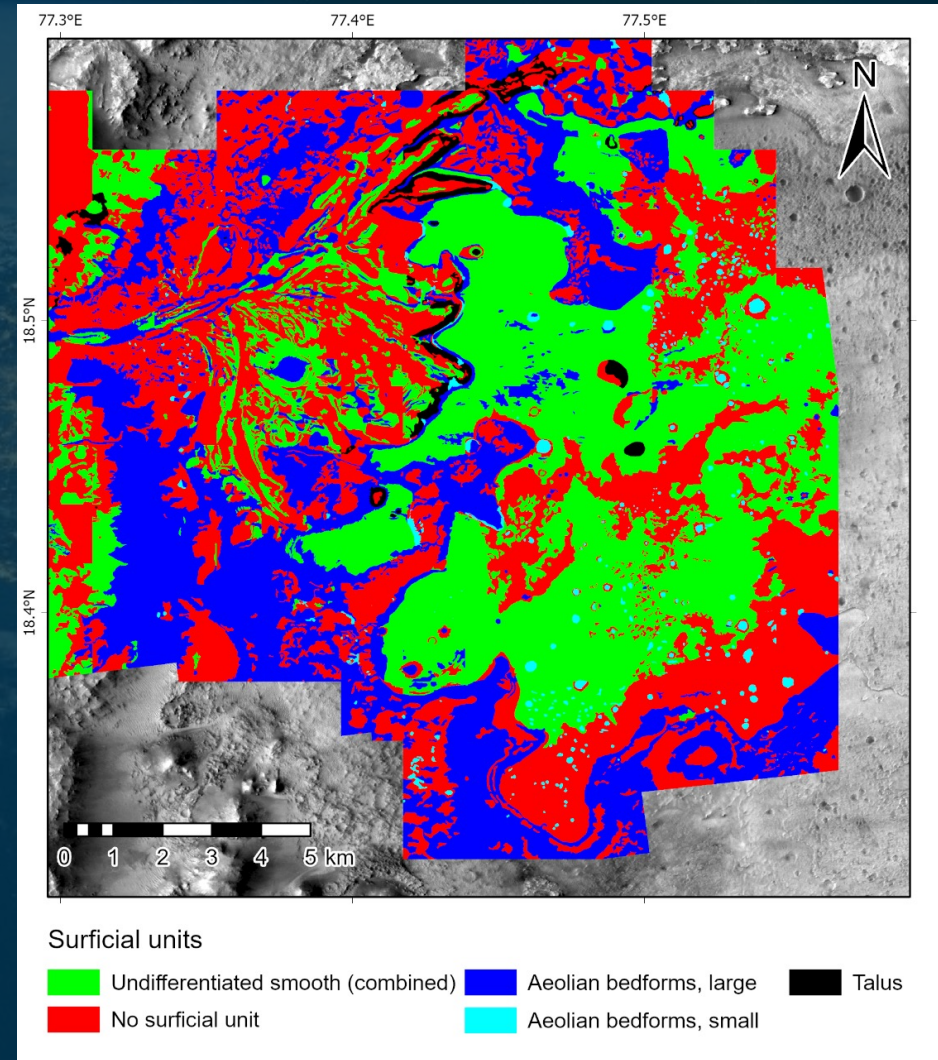


Wright et al. (2022)

Comparison with human-made map



Wright et al. (2022)



Stack et al. (2020)

A literal “confusion matrix”!

		NOAH-H classifications					
	# Pixels	Non-bedrock	Bedrock	Large ripples	Small ripples	Boulder fields	% Precision
Stack et al. (2020) surficial units	Non-bedrock	718,129,789	148,558,964	65,659,831	48,752,390	76,522,140	68
	Bedrock	268,334,690	635,849,178	102,517,664	54,311,191	122,579,714	54
	Large ripples	59,695,987	70,075,017	653,703,061	5,363,385	1,156,385	79
	Small ripples	22,758,727	4,831,135	6,656,076	5,363,385	1,156,385	13
	Talus	18,561,816	4,657,489	2,263,904	820,065	15,846,249	38
	% Recall	66	74	79	4	7	
	% IoU	50	45	65	3	6	

Wright et al. (2022)

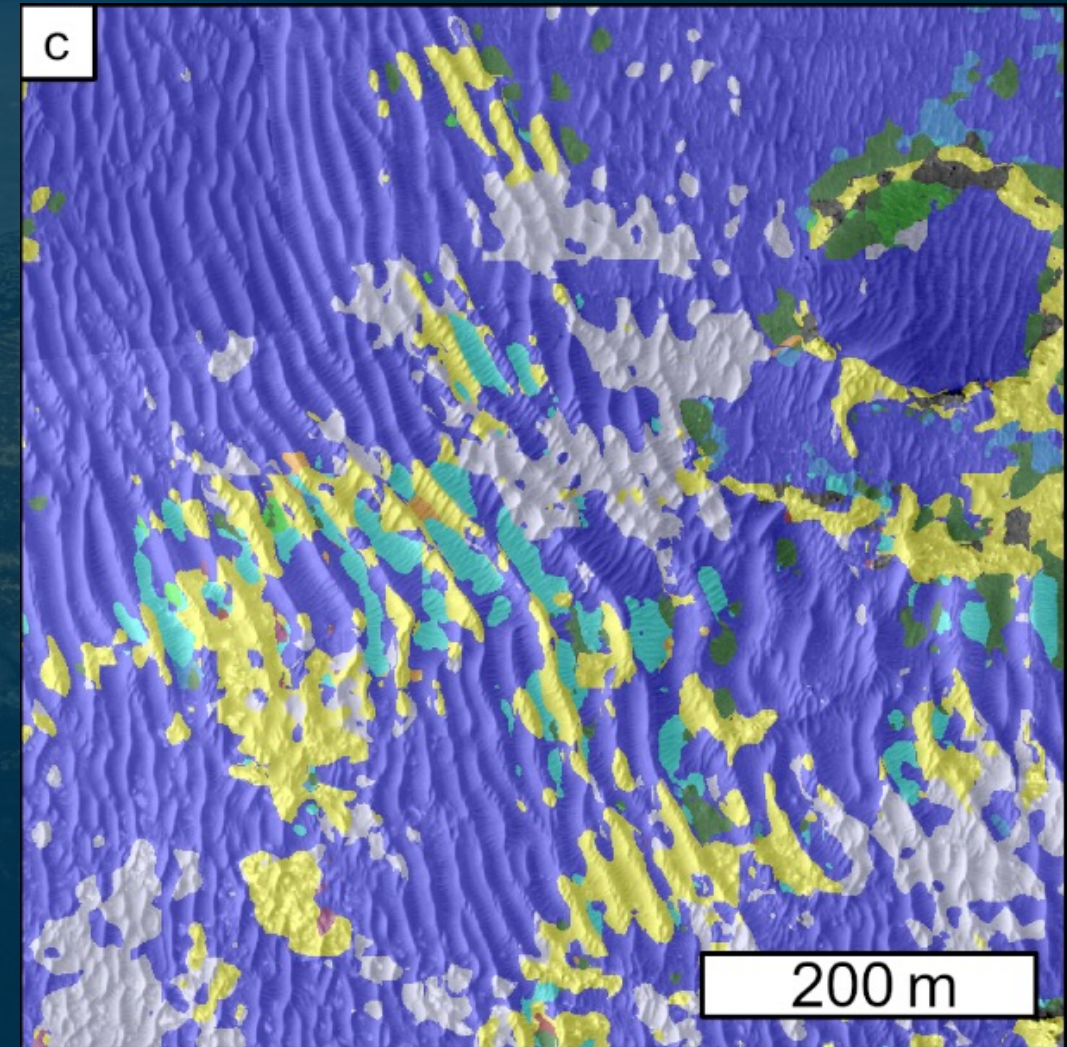
- Precision: If NOAH-H has found a class in a given pixel, has it got it right?
- Recall: How much of a given class does NOAH-H find?
- IoU (Intersection over Union): A measure of whether both Precision and Recall are both good

Has the machine defeated the humans? No.

- Purely descriptive, incapable of interpretation from context
 - No concept of origin of rocks/textures

Large ripples—continuous

Bedrock—Rugged



Wright et al. (2022)

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Has the machine defeated the humans? No.

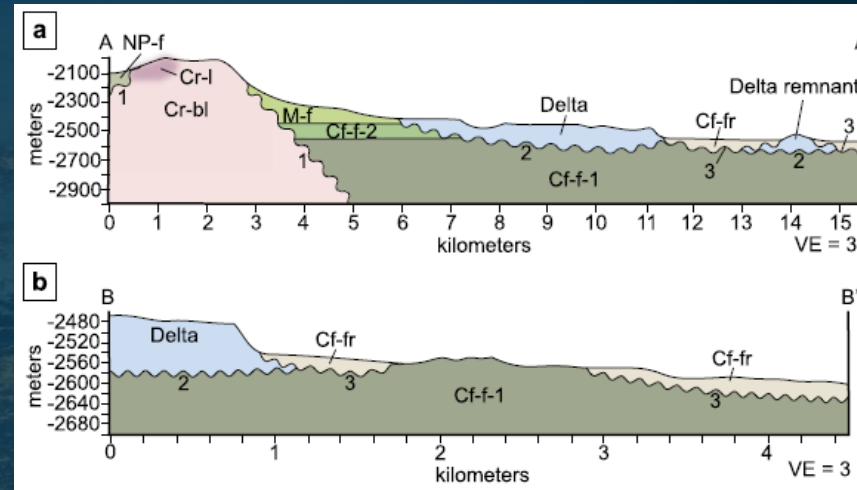


@wrightplanet

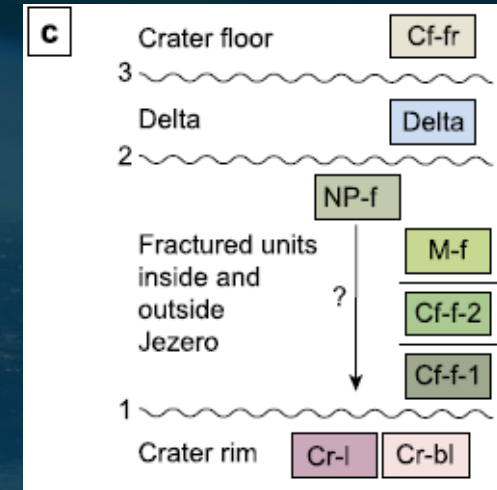


- Purely descriptive, incapable of interpretation from context
 - No concept of origin of rocks/textures
 - No concept of rocks as 3D volumes
 - Cannot produce cross sections
 - Cannot correlate map units
 - No concept of sequence of geological events

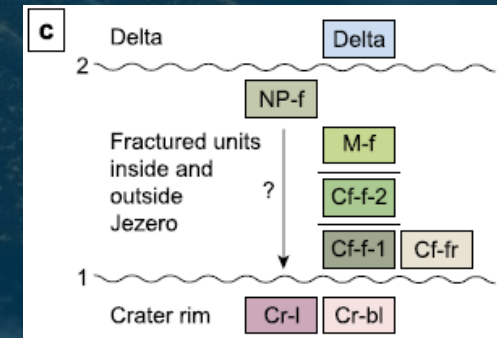
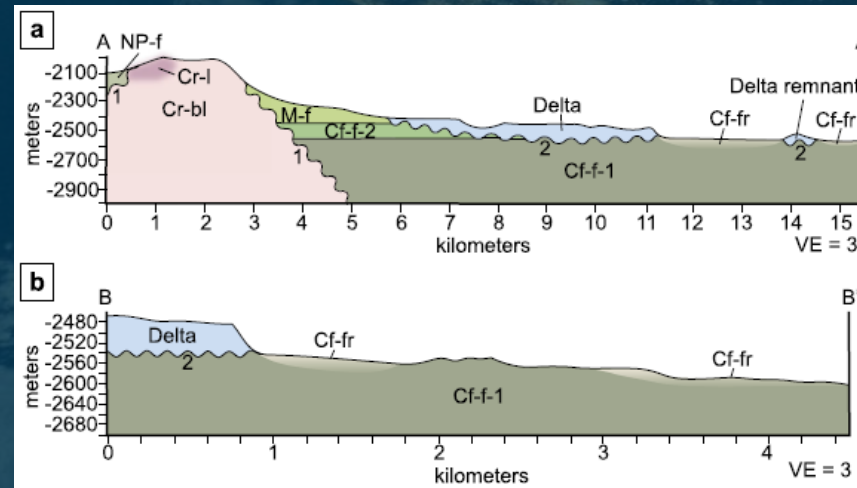
Scenario 1



COMU 1



Scenario 2

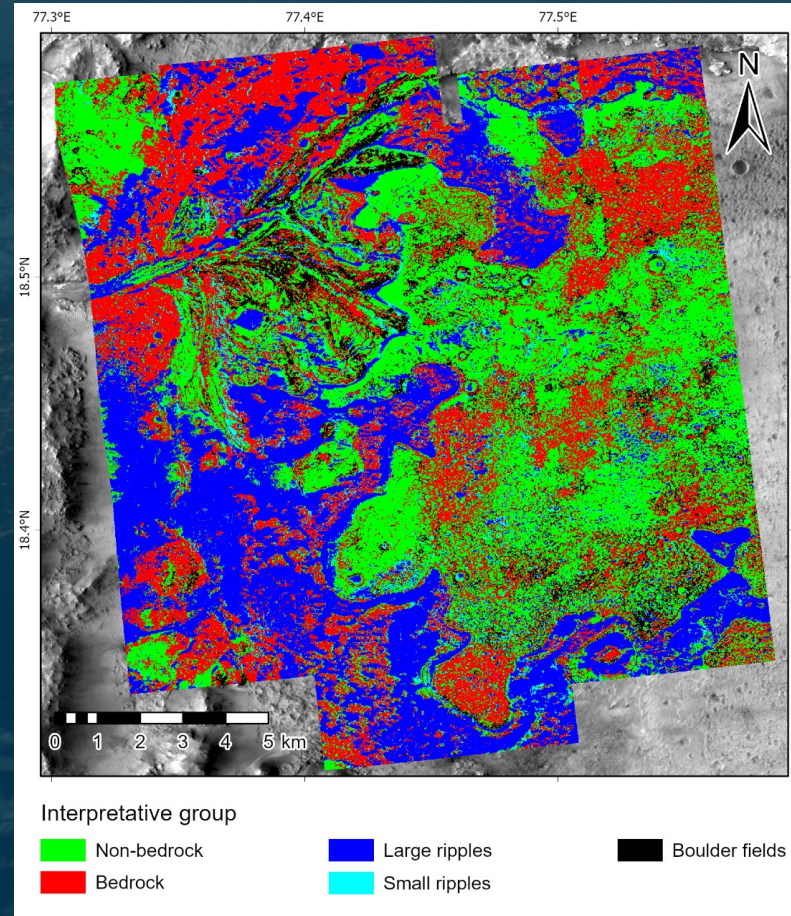


Stack et al. (2020)

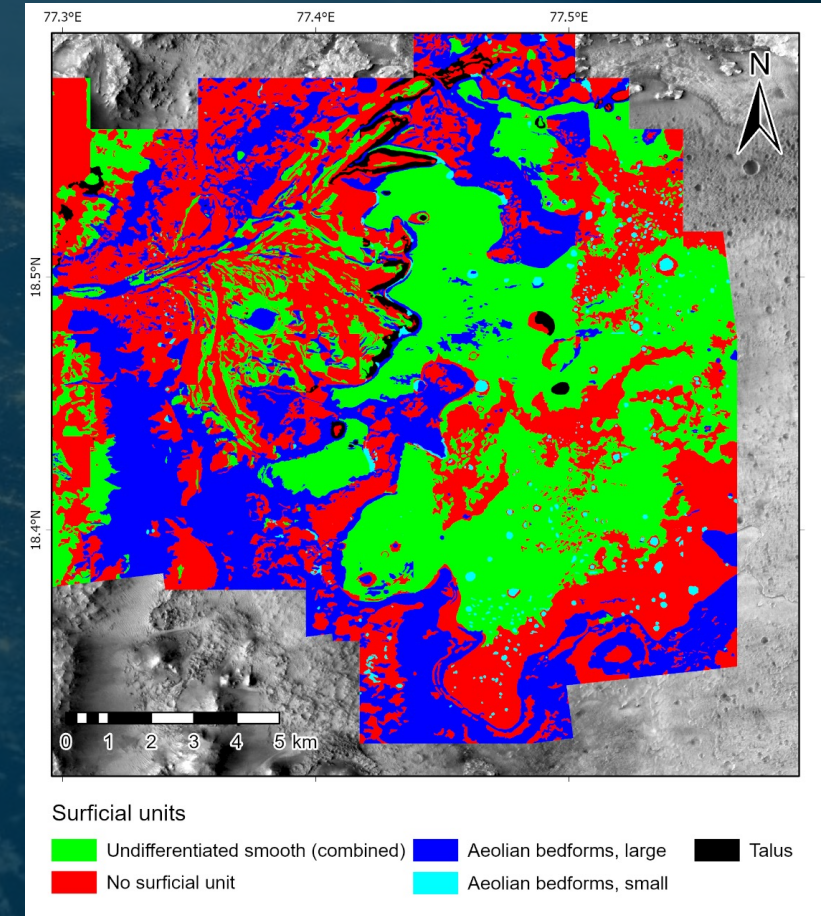


Has the machine defeated the humans? No.

- Purely descriptive, incapable of interpretation from context
 - No concept of origin of rocks/textures
 - No concept of rocks as 3D volumes
 - Cannot produce cross sections
 - Cannot correlate map units
 - No concept of sequence of geological events
- Does not summarise information to be ingestible by humans



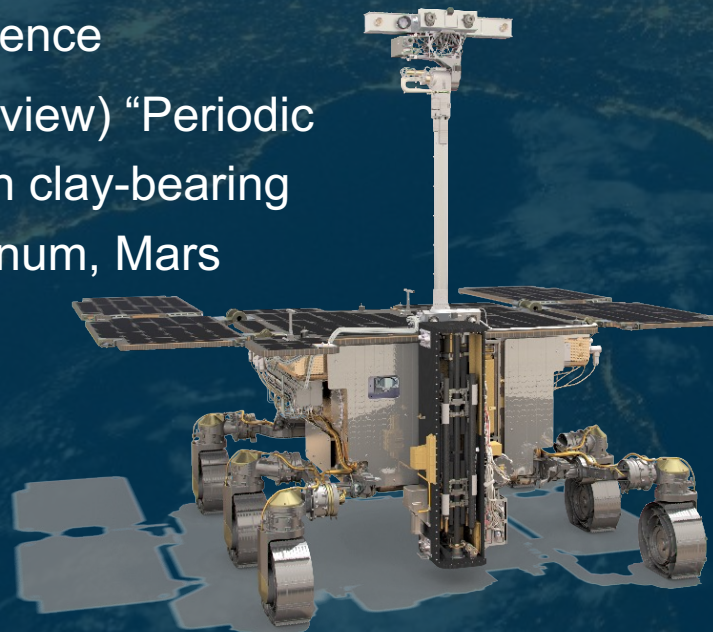
Wright et al. (2022)



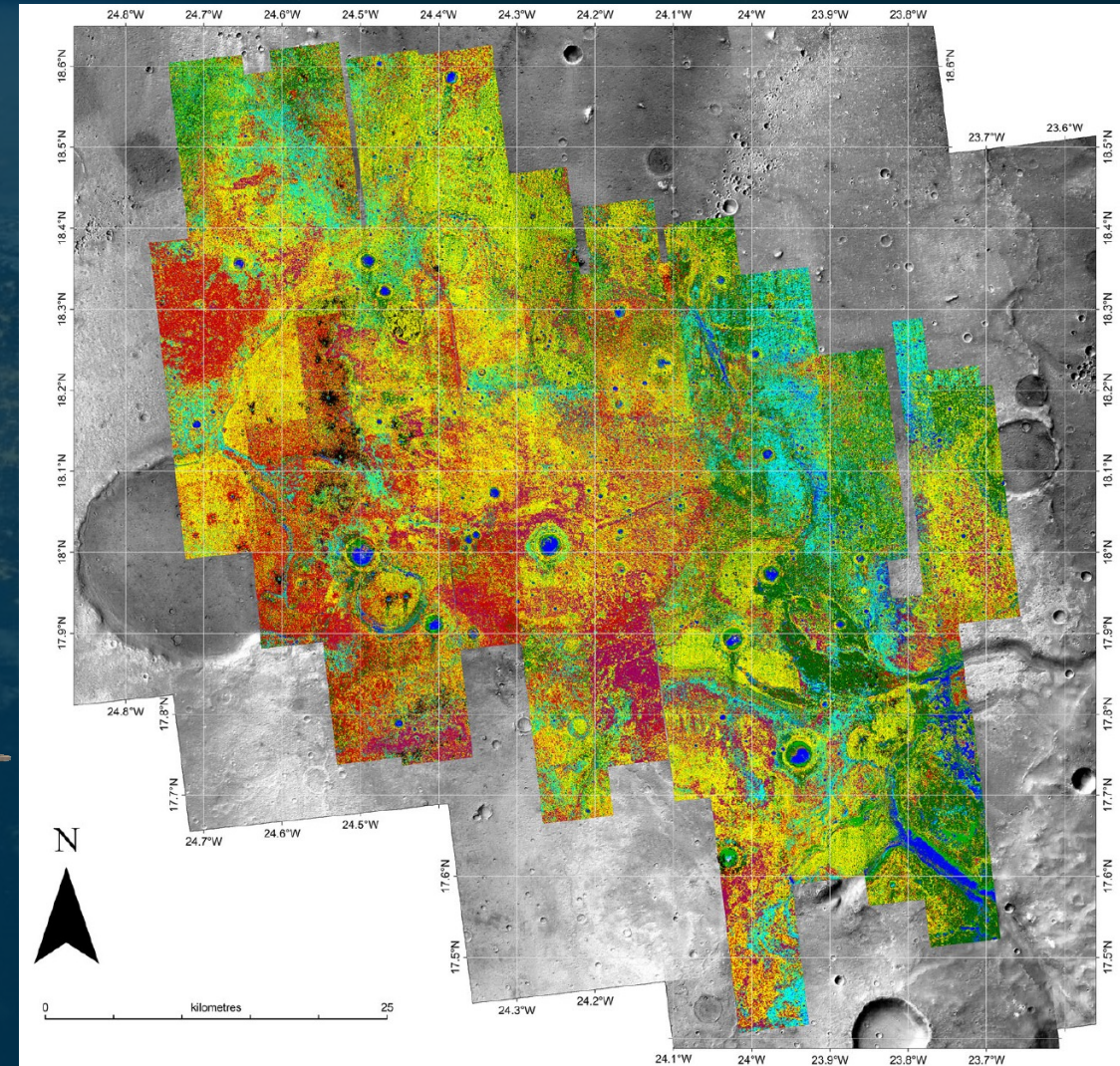
Stack et al. (2020)

Conclusions

- Can use ML to map Mars terrain
 - Rover traversability/trafficability
 - Aid to geological mapping?
- “Ground truthing” can be possible
- Input for ExoMars Rosalind Franklin rover mission
- Already being used for science
 - Favaro et al. (in review) “Periodic Bedrock Ridges on clay-bearing terrain at Oxia Planum, Mars”



ESA/ATG medialab



Barrett et al. (2022)

Barrett, A. M., Balme, M. R., Woods, M., Karachalios, S., Petrocelli, D., Joudrier, L., & Sefton-Nash, E. (2022). NOAH-H, a deep-learning, terrain classification system for Mars: Results for the ExoMars Rover candidate landing sites. *Icarus*, 371, 114701.

<https://doi.org/10.1016/j.icarus.2021.114701>

Barrett, A. M., Wright, J., Favaro, E., Fawdon, P., Balme, M. R., Woods, M. J., ... & Joudrier, L. (2022). Oxia Planum, Mars, classified using the NOAH-H deep-learning terrain classification system. *Journal of Maps*, 1–14. <https://doi.org/10.1080/17445647.2022.2112777>

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