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

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GMAP Winter School 2023

03/02/2023

Rosalind Franklin Oxia Planum landing site

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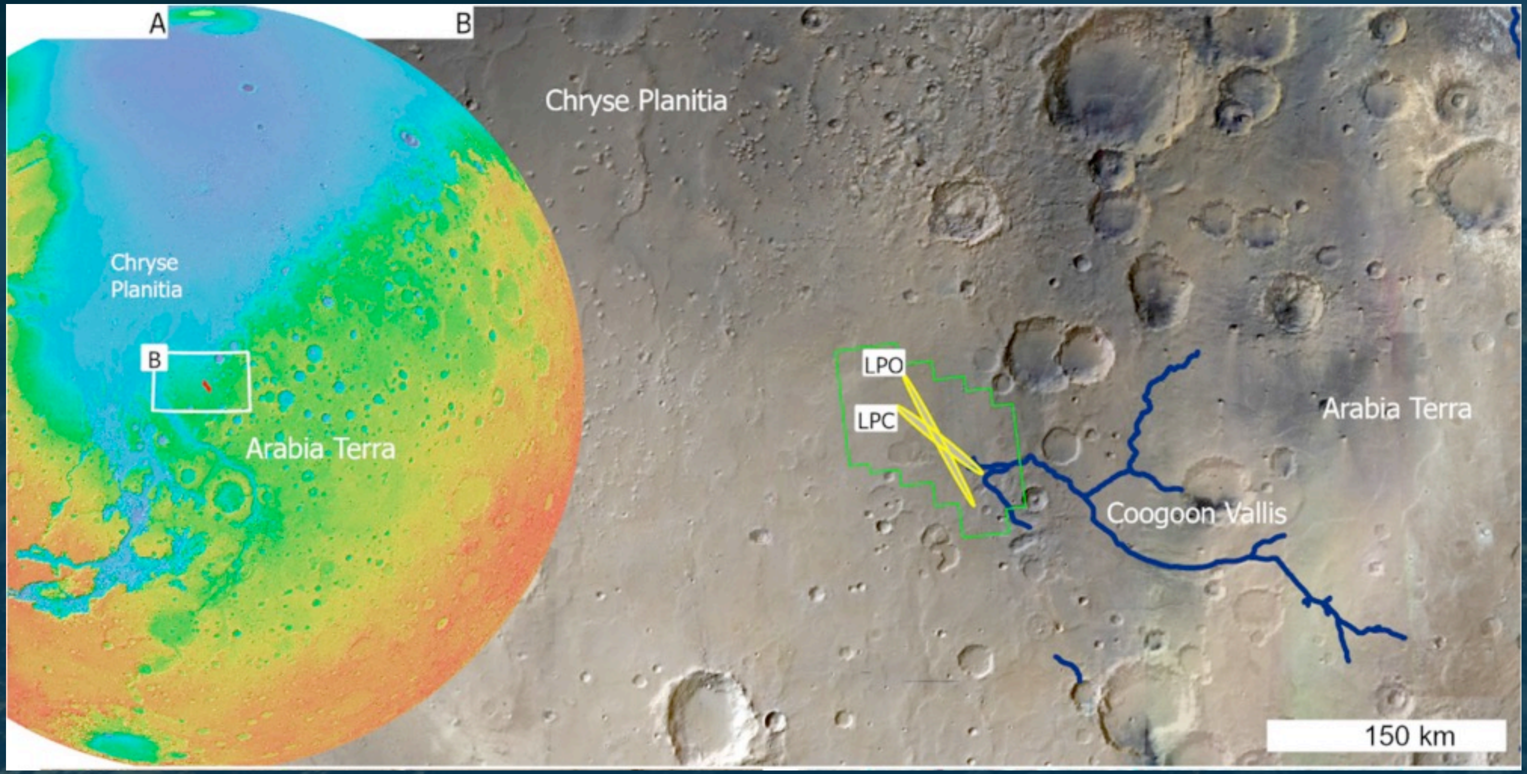
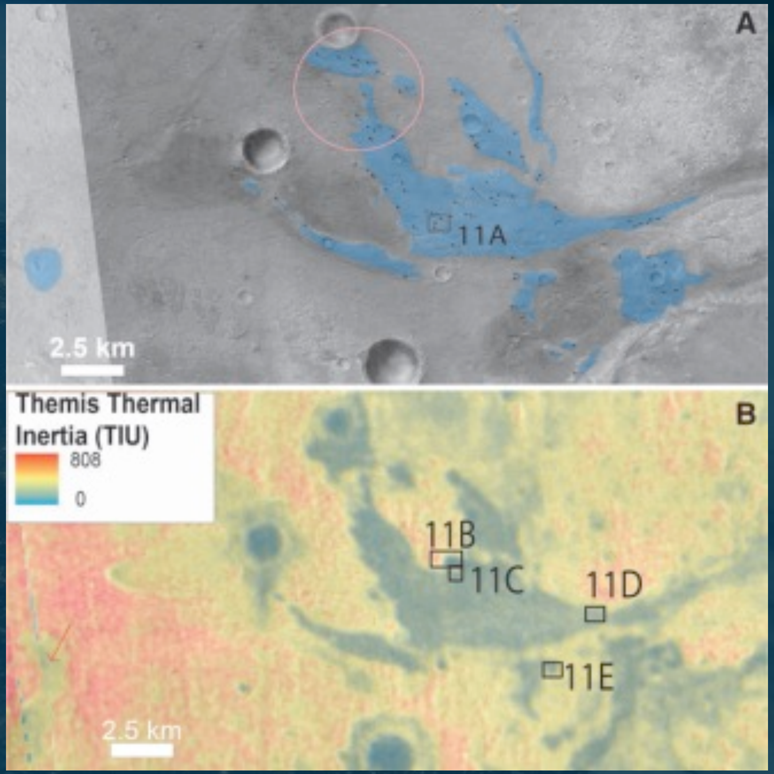


Fawdon et al. (2021)



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?

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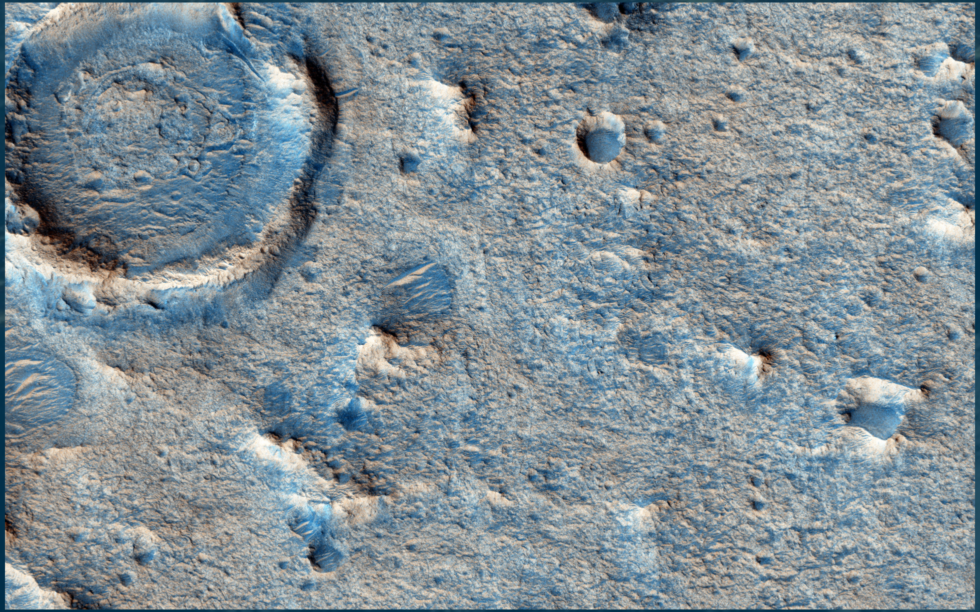
- Prepare for ESA ExoMas Rosalind Franklin rover mission operations
  - Locate landing site hazards
  - Forecast safe routes
  - Identify regions of interest for scientific study during the mission
- Meanwhile, they could be scientifically useful products
  - Understand landing site geology



NASA/JPL/University of Arizona

ESA/ATG medialab

Why use machine learning?

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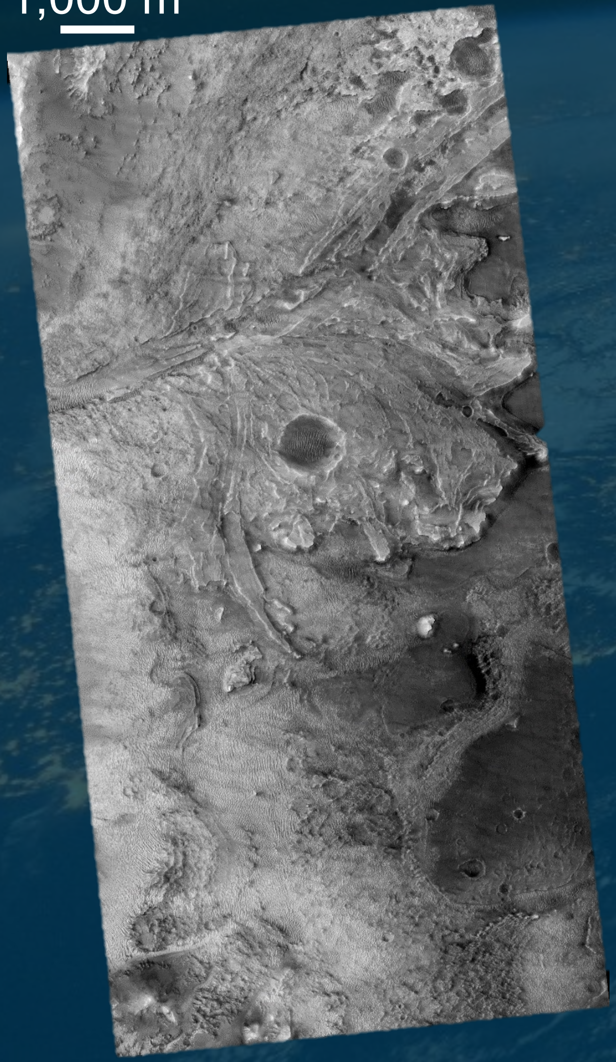
1,000 m



NASA/JPL/University of Arizona MRO/HiRISE

Getty Images/iStockphoto

NOAH-H: Mars Terrain Classifier

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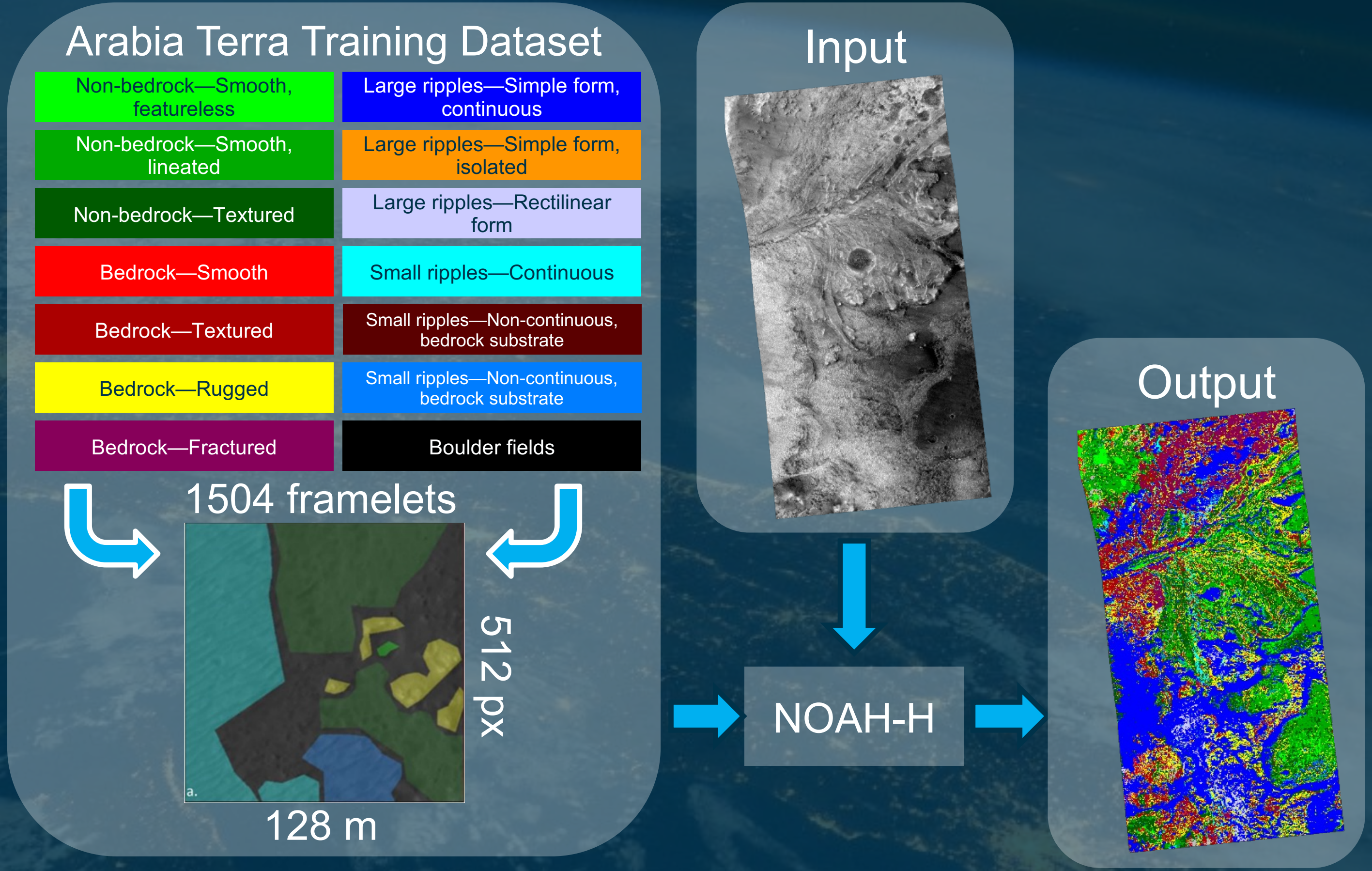
- Novelty or Anomaly Hunter—HiRISE
- Deep Learning Convolutional Neural Network
  - Neural network—model learns terrain classification based on examples
  - Deep learning—model contains many layers allowing it to generalise and learn hierarchical classification systems
  - Convolutional—convolution filters 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?

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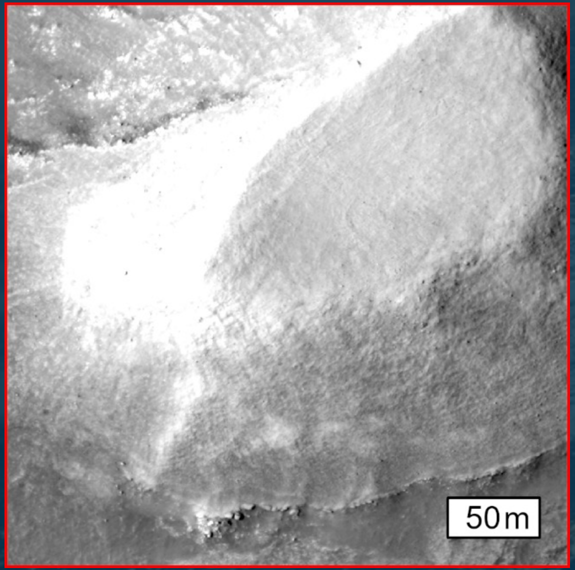
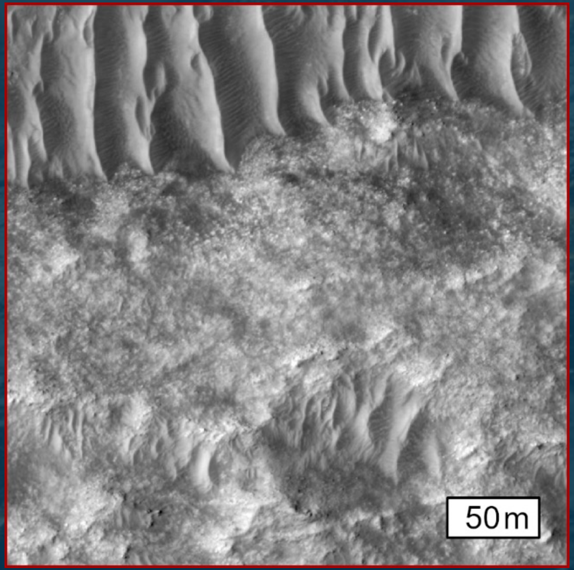
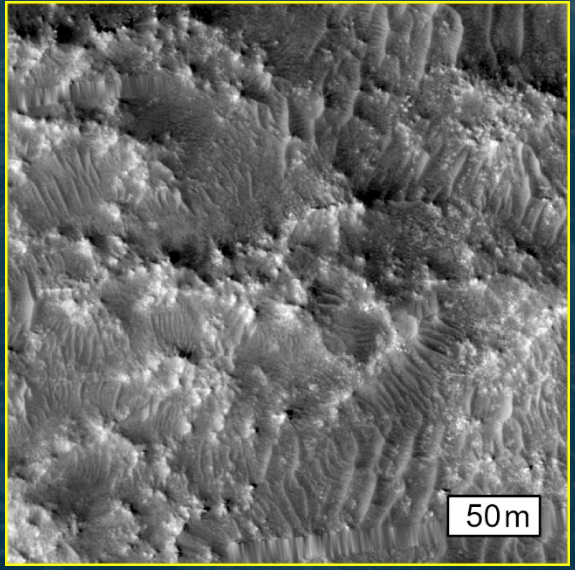
Bedrock Non-bedrock Large ripples Small ripples Boulder fields



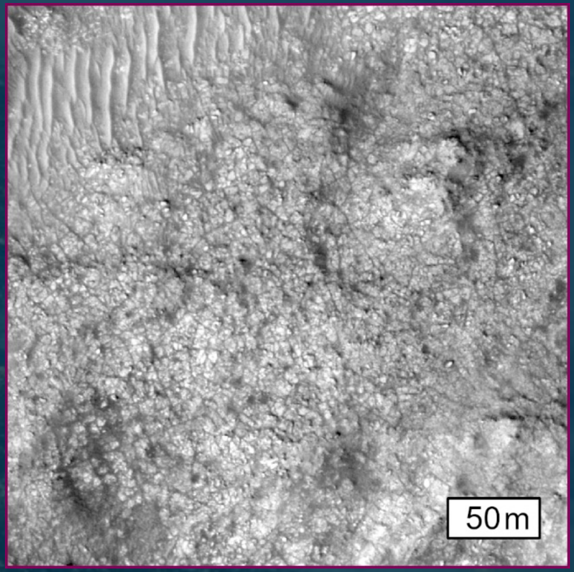
Bedrock—Smooth



Bedrock—Textured



Bedrock—Rugged



Bedrock—Fractured

What are the terrain classes?

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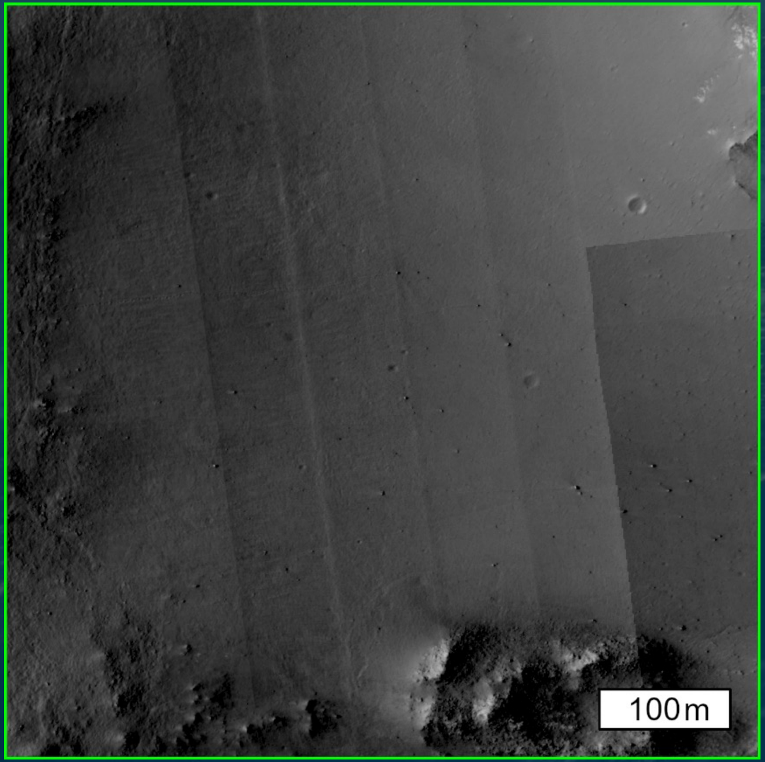
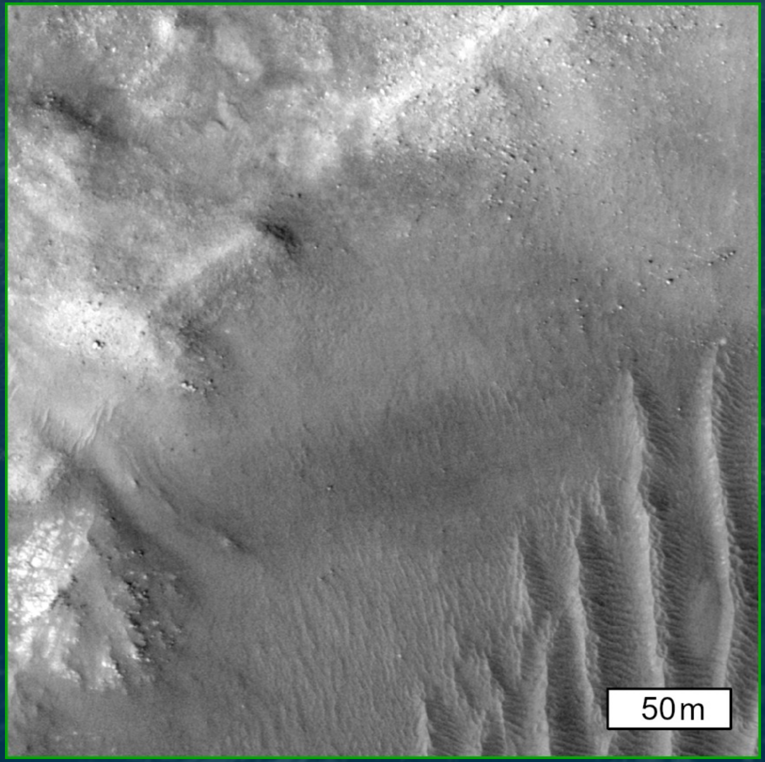
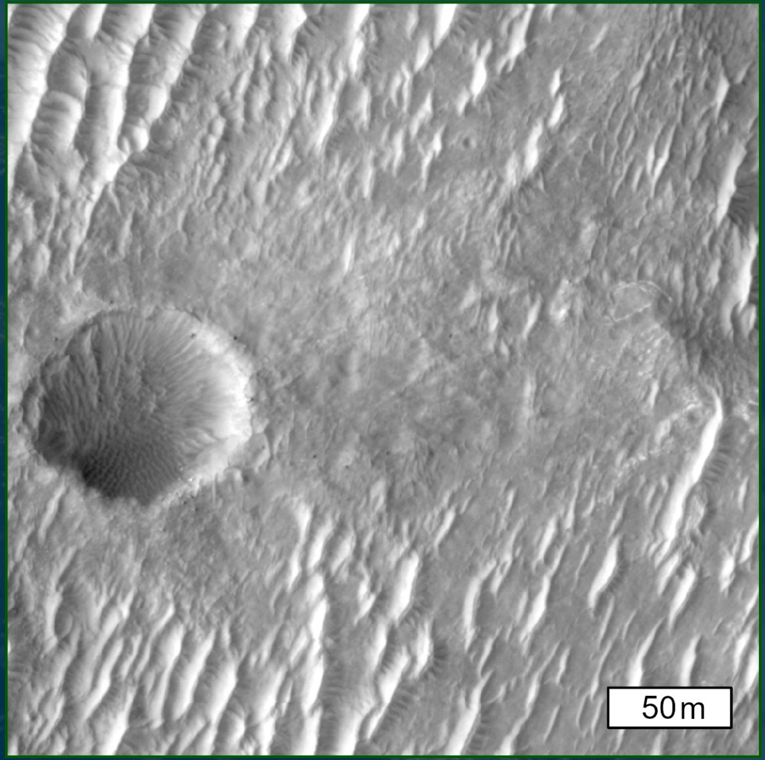
Bedrock | **Non-bedrock** | Large ripples | Small ripples | Boulder fields



Non-bedrock—Smooth, featureless



Non-bedrock—Smooth, lineated



Non-bedrock—Smooth, textured

What are the terrain classes?

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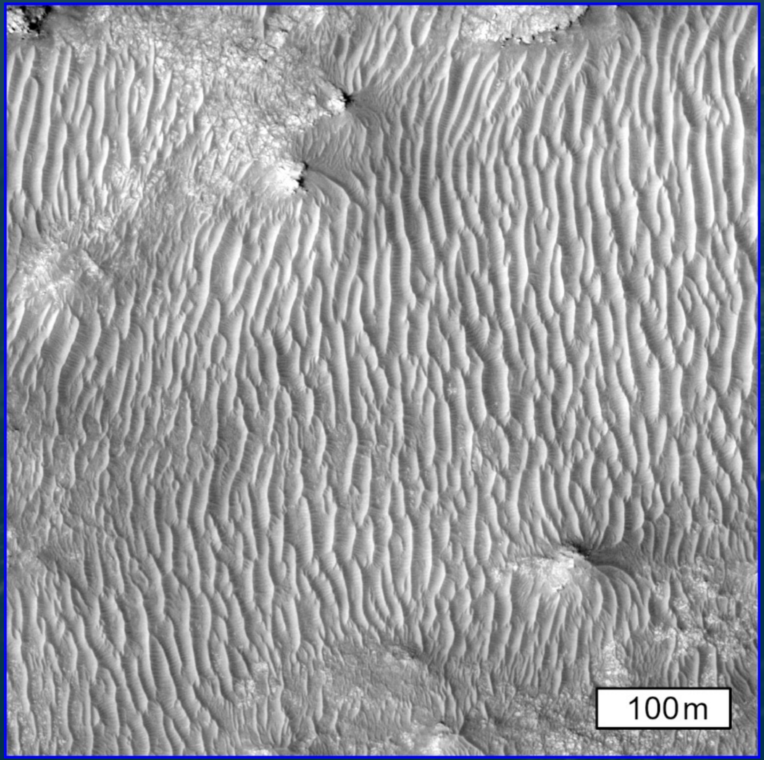
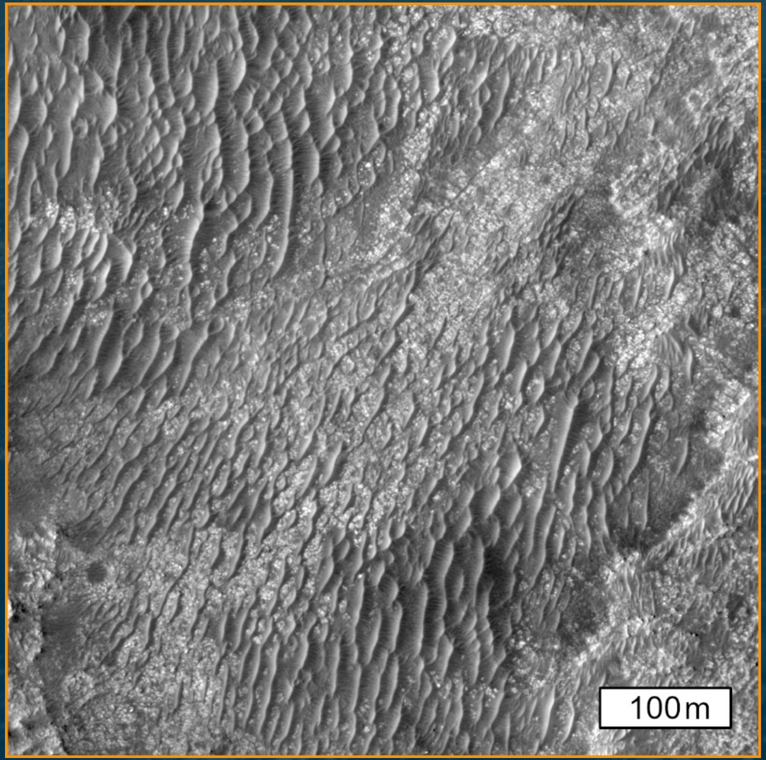
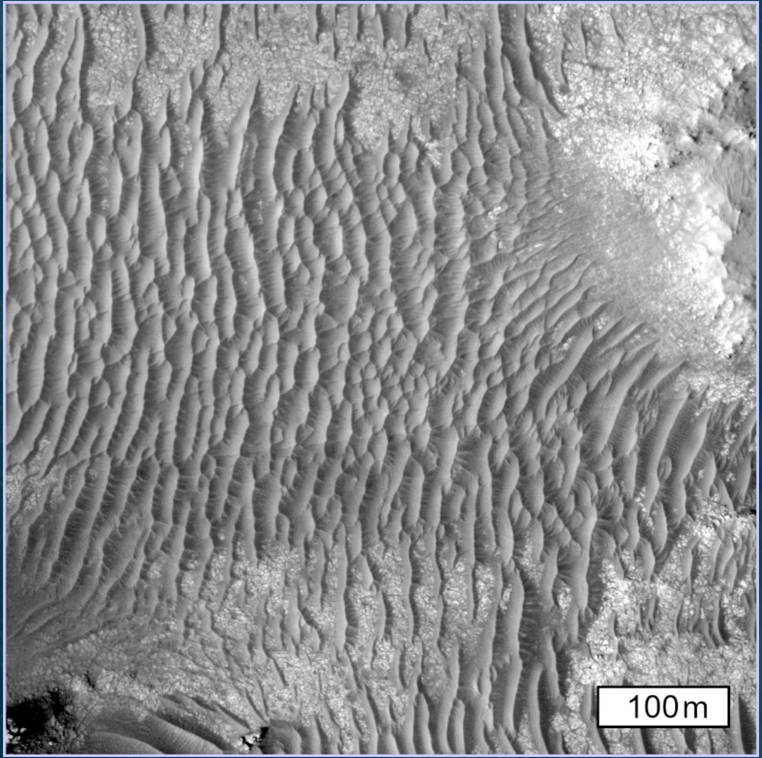
Bedrock | Non-bedrock | **Large ripples** | Small ripples | Boulder fields



Large ripples—continuous



Large ripples—isolated



Large ripples—rectilinear

What are the terrain classes?

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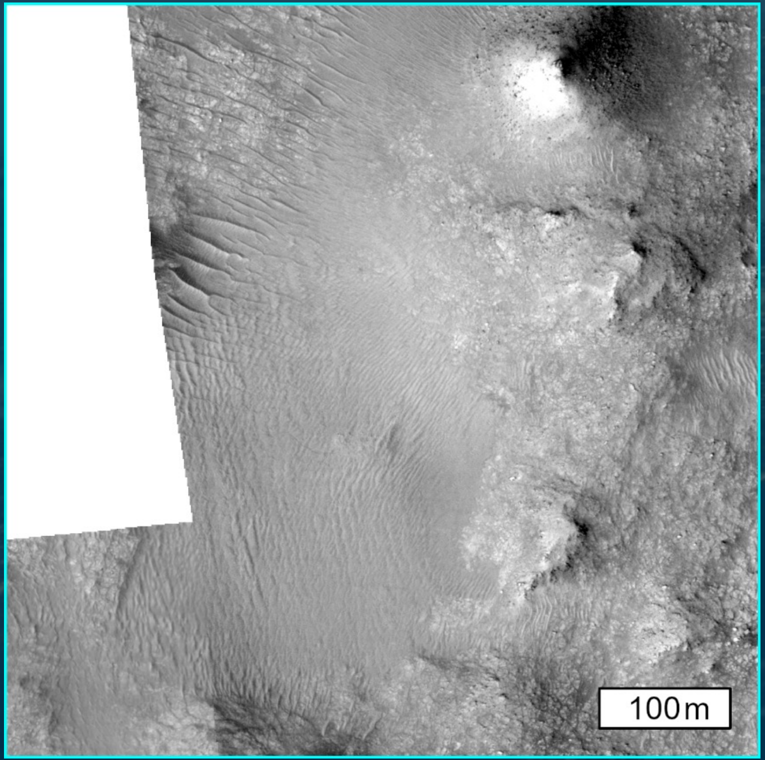
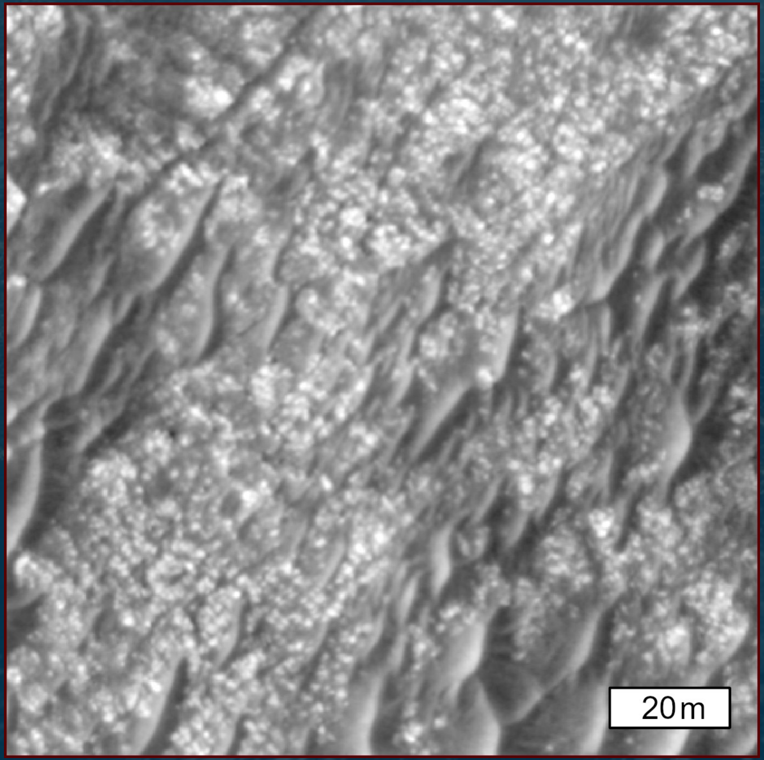
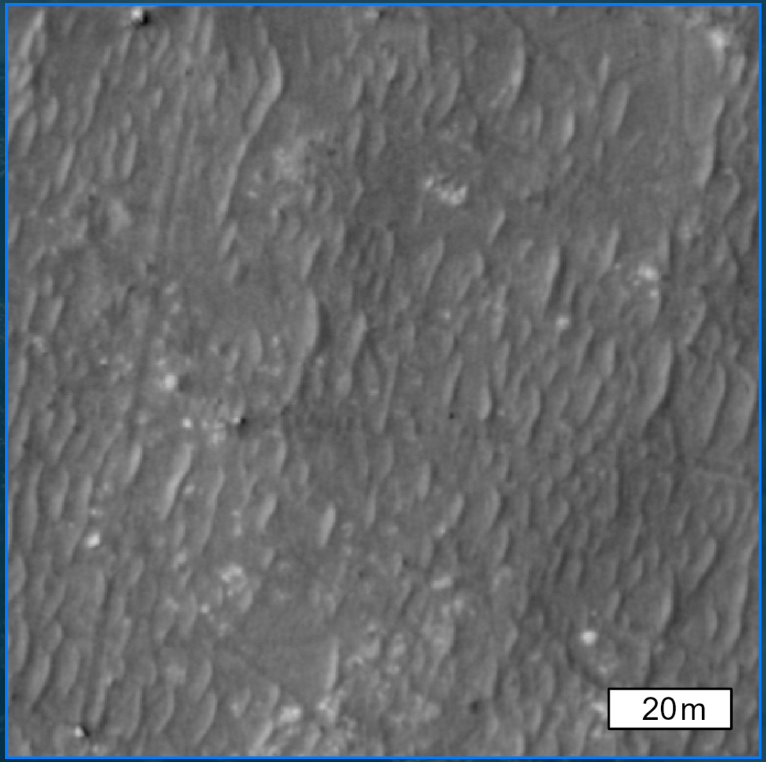
Bedrock | Non-bedrock | Large ripples | **Small ripples** | Boulder fields



Small ripples—continuous



Small ripples—non-continuous, bedrock substrate



Small ripples—non-continuous, non-bedrock substrate

What are the terrain classes?

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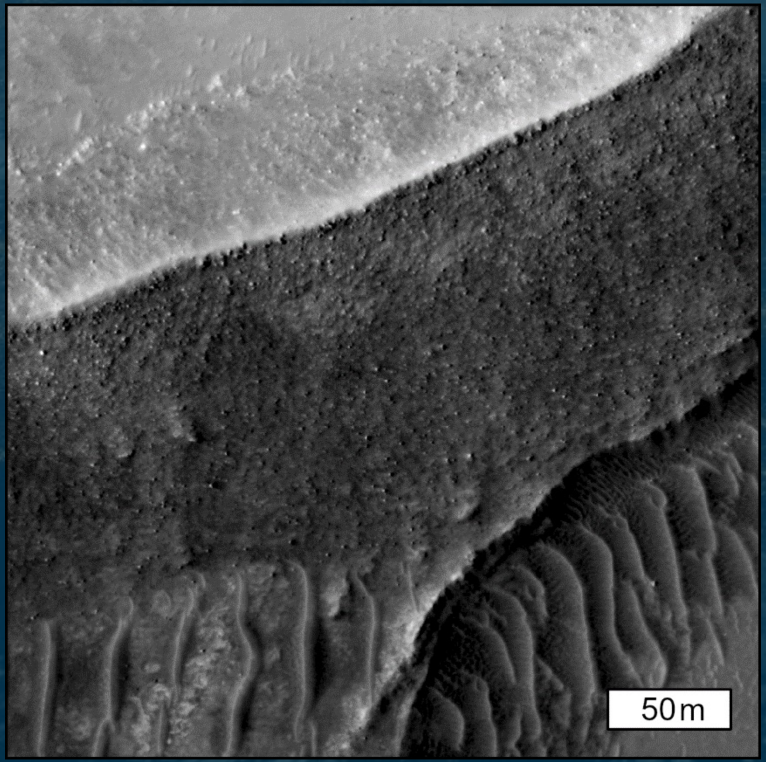
Bedrock | Non-bedrock | Large ripples | Small ripples | **Boulder fields**



Boulder fields

Oxia Planum terrain classification map

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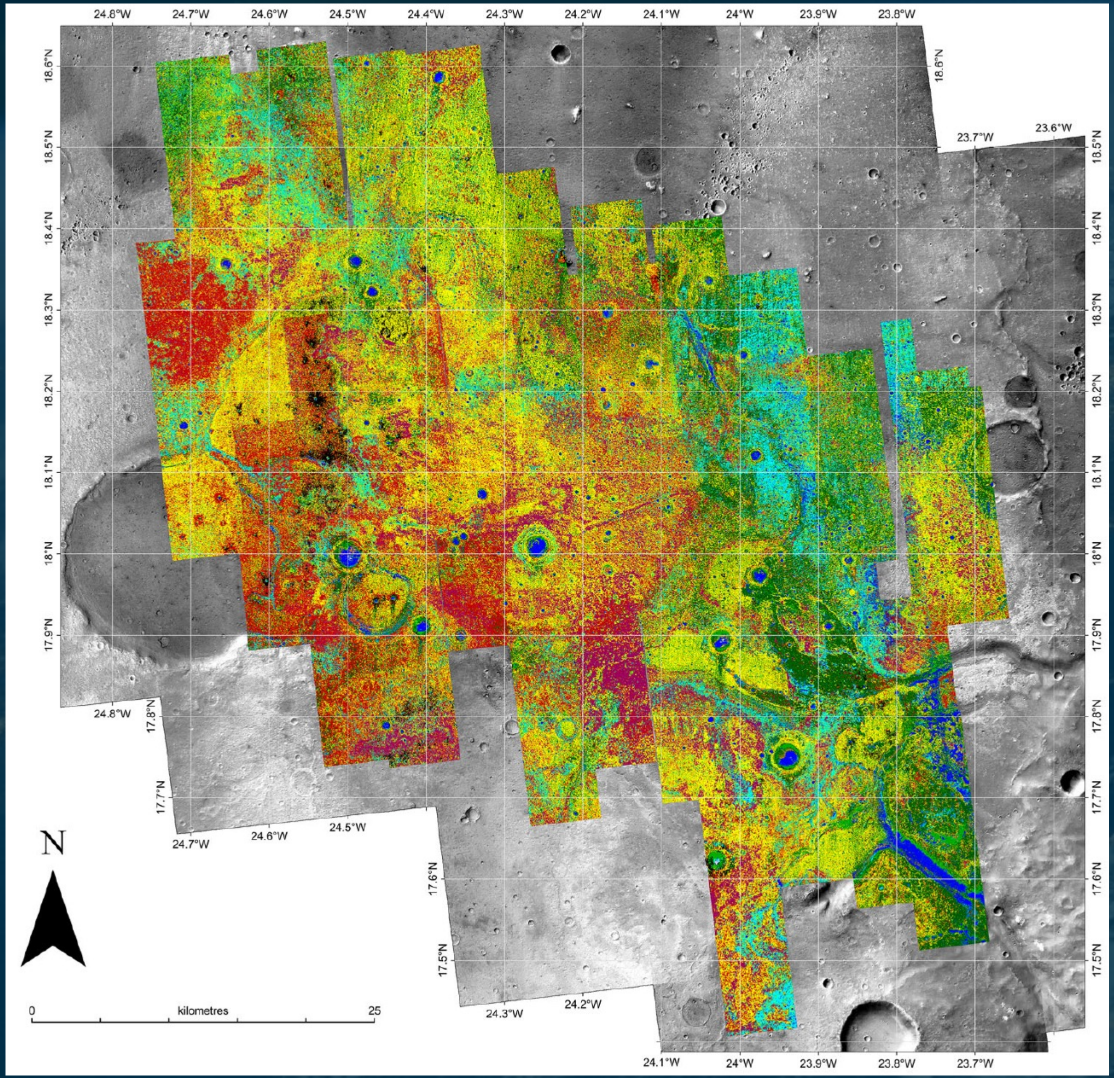
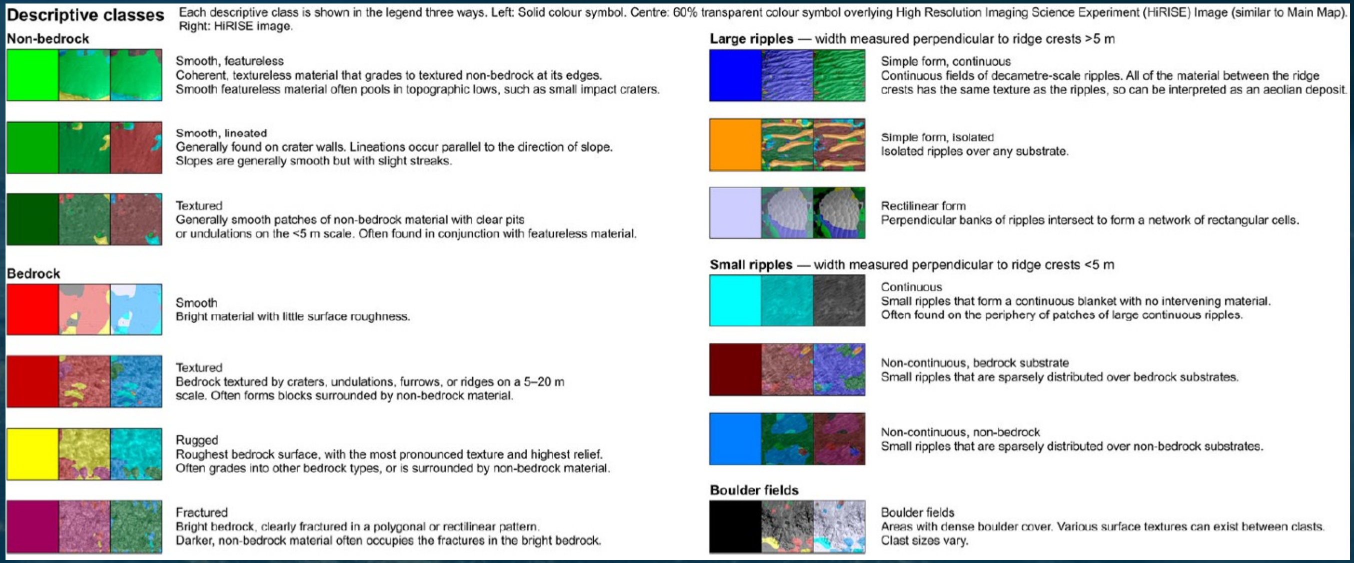


Barrett et al. (2022)



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

Ground truthing the results with Jezero

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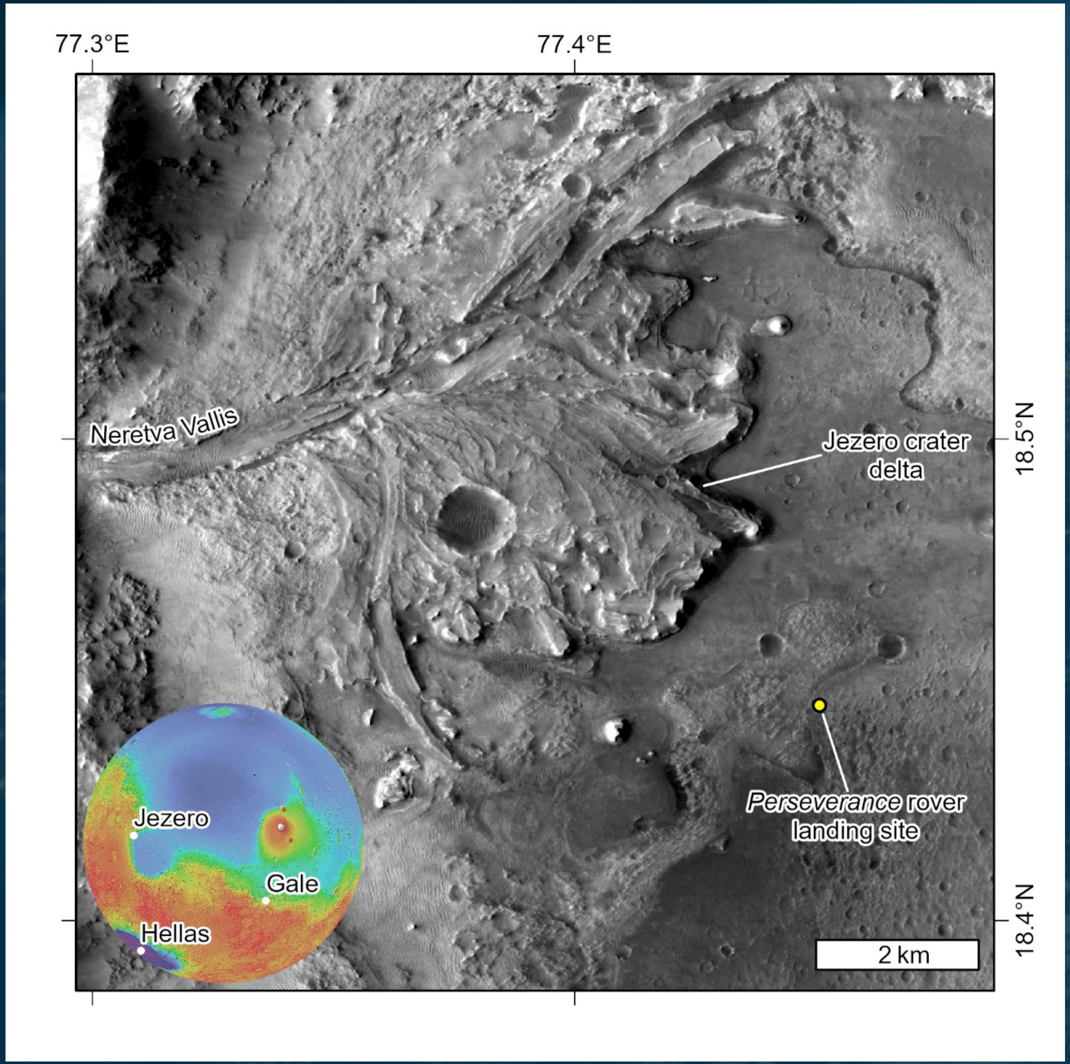
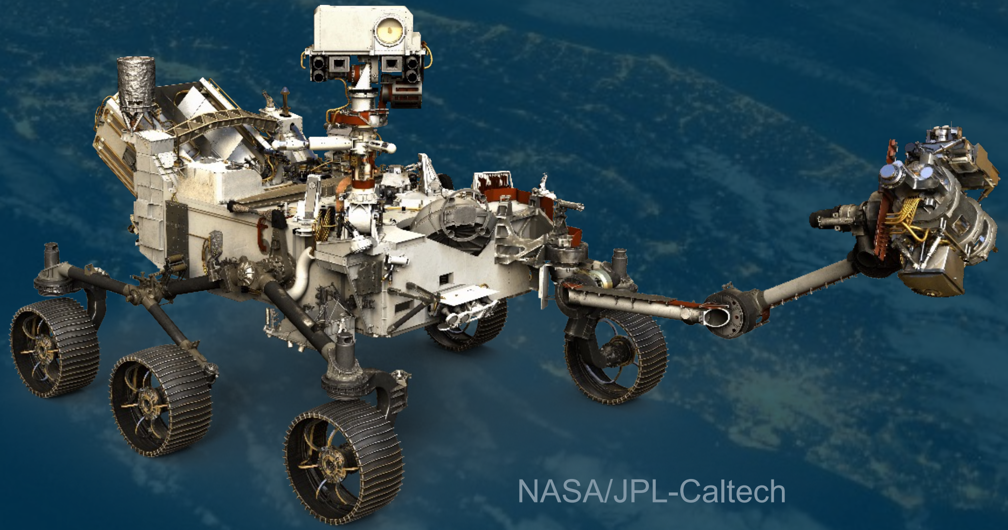


Wright et al. (2022)

NASA/JPL-Caltech



NASA/JPL-Caltech

Comparison with *Ingenuity* helicopter images

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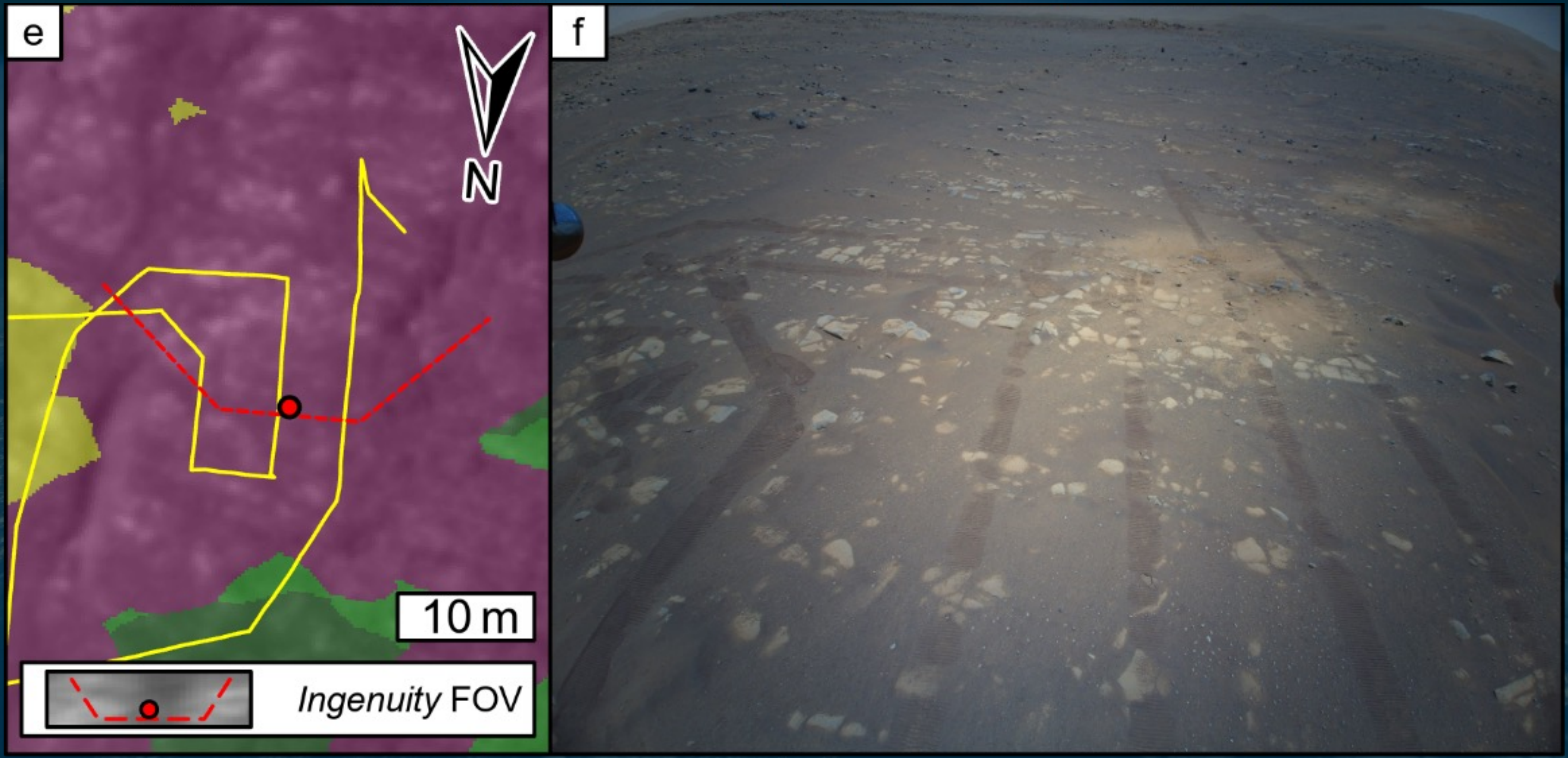

Wright et al. (2022)

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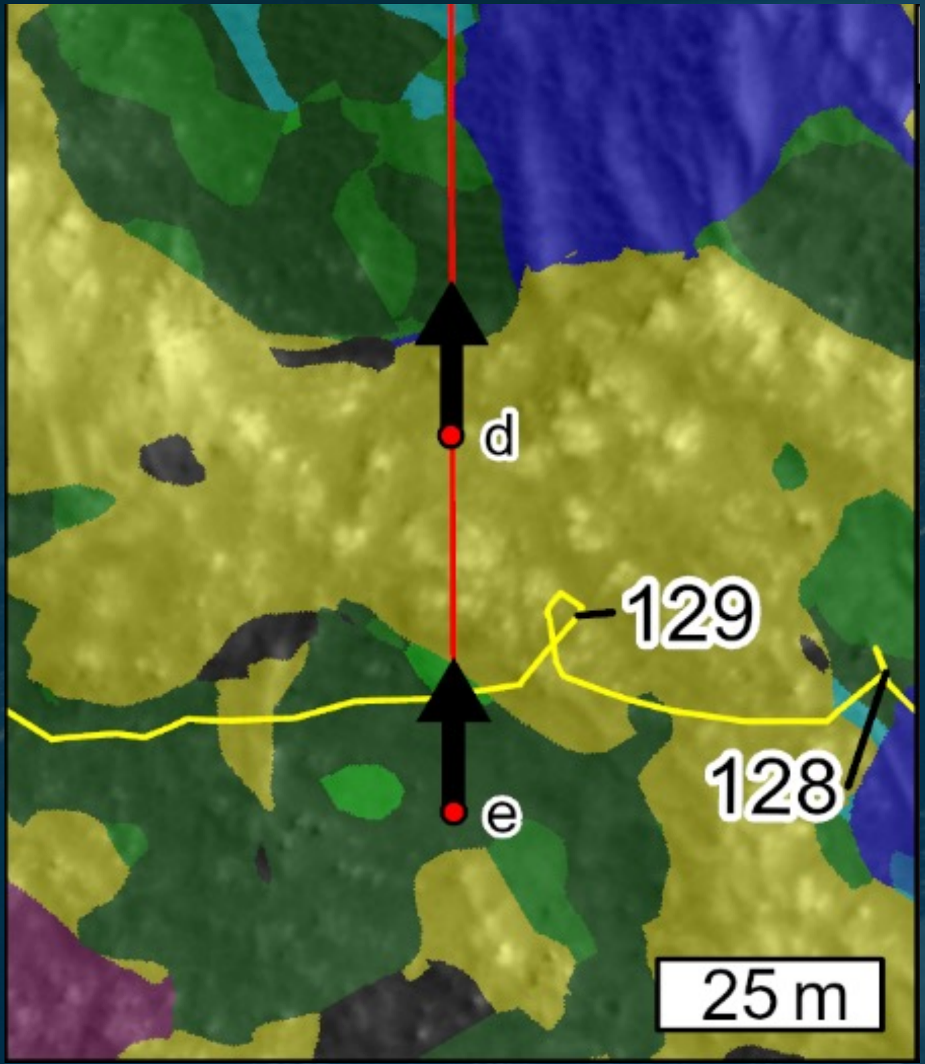

Wright et al. (2022)

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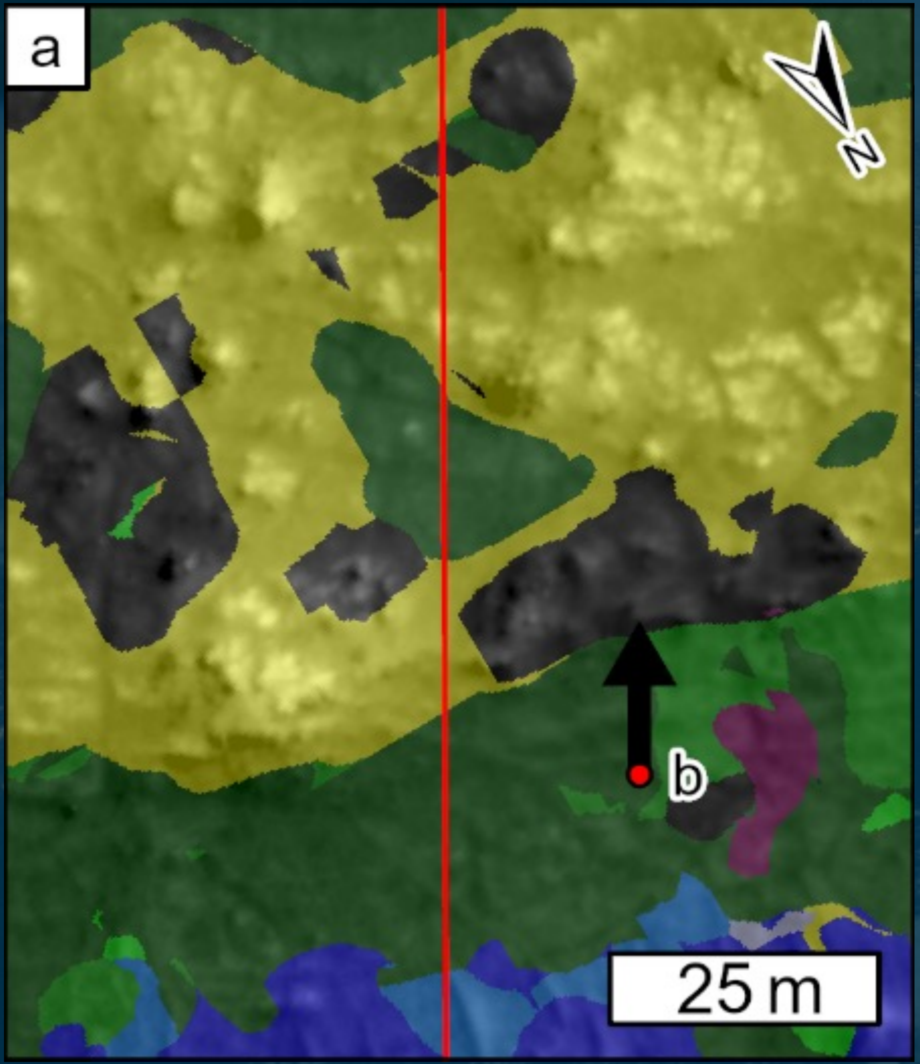
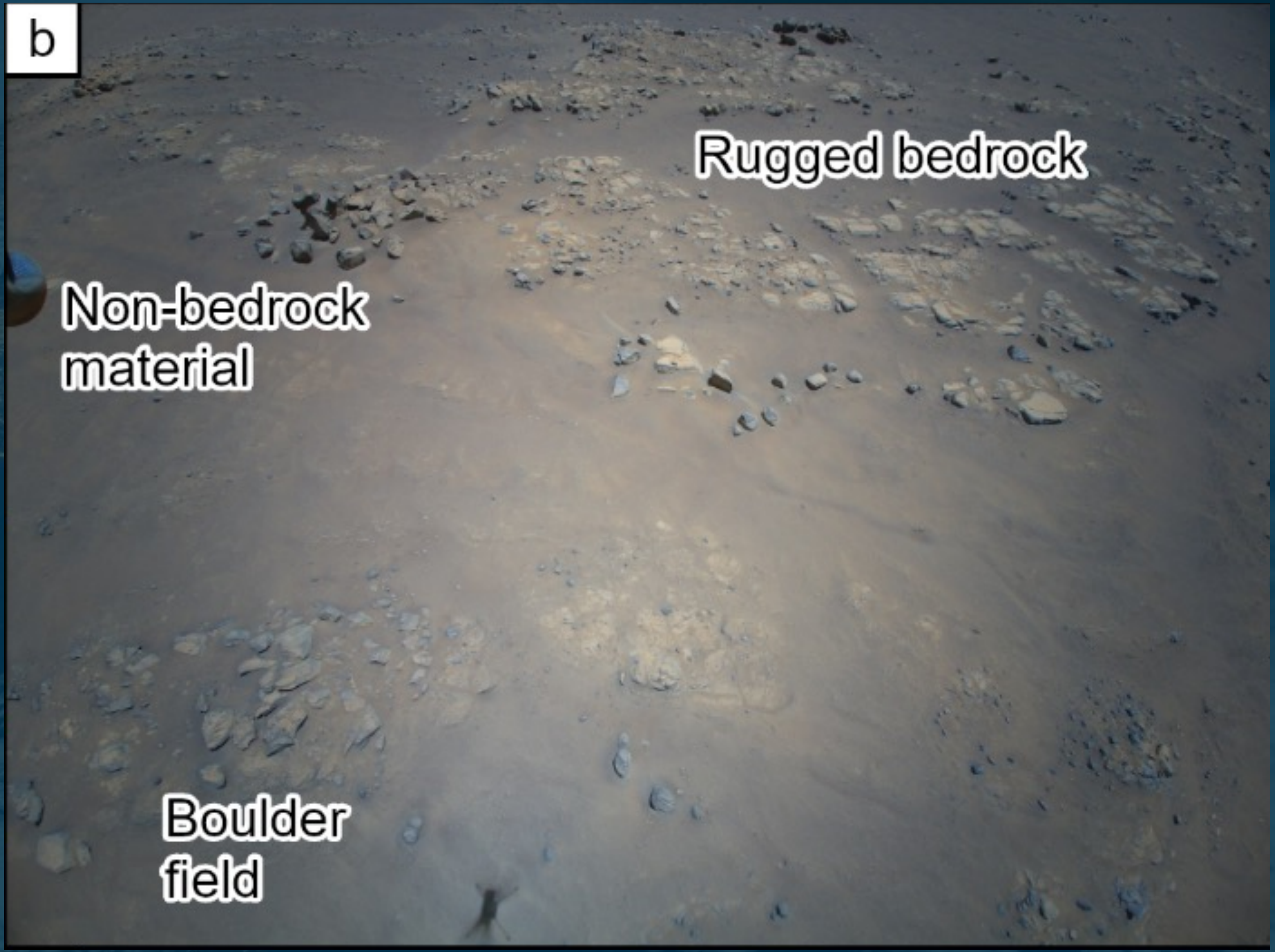


Wright et al. (2022)



Wright et al. (2022)

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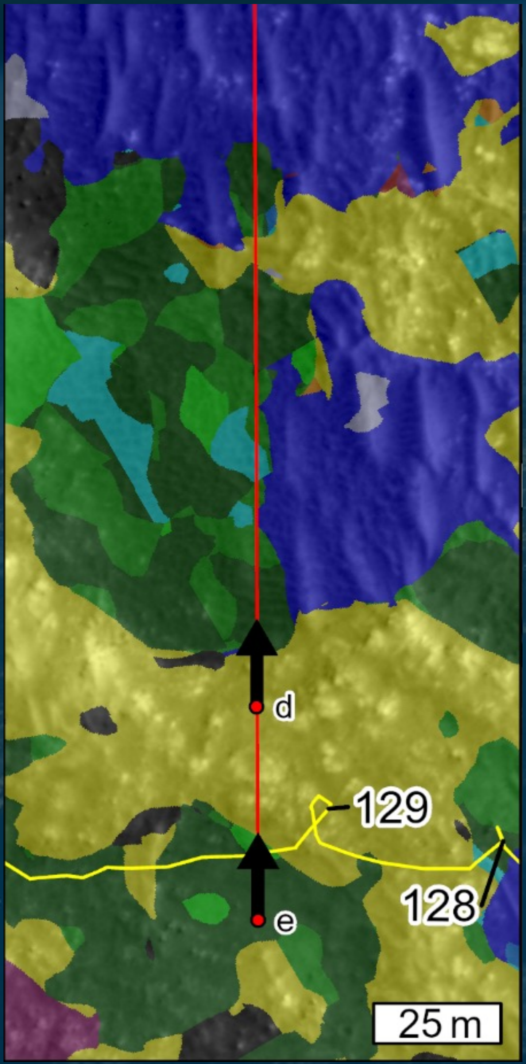
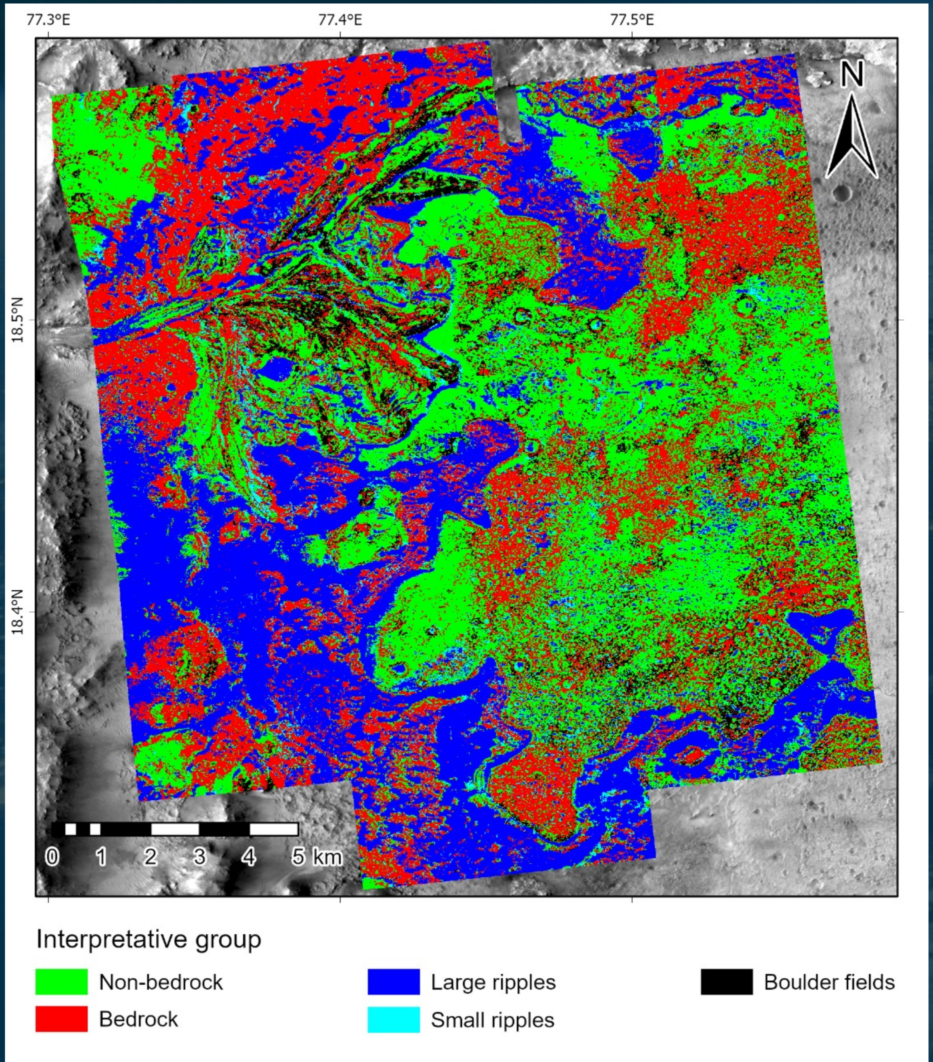


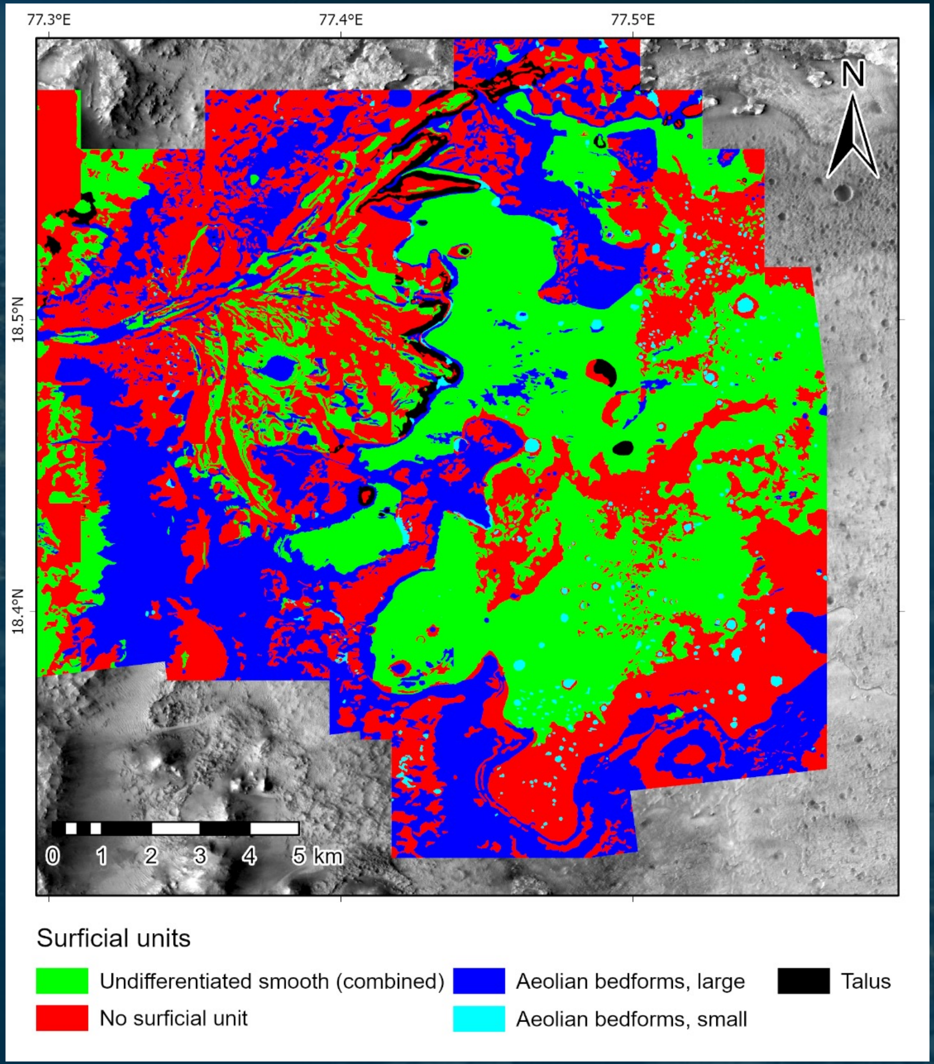
Wright et al. (2022)

Wright et al. (2022)

Comparison with human-made map



Wright et al. (2022)



Stack et al. (2020)

A literal “confusion matrix”!

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		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.

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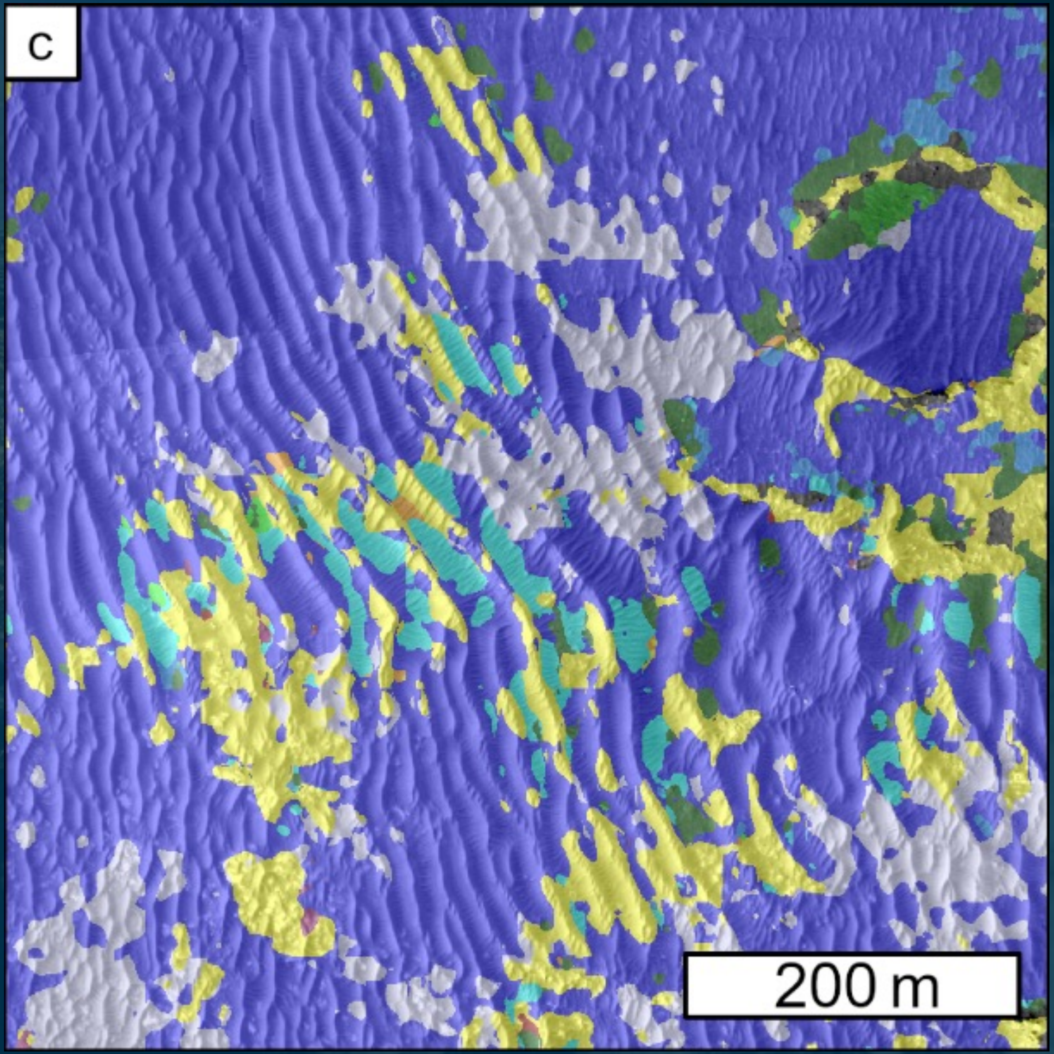
- Purely descriptive, incapable of interpretation from context
    - No concept of origin of rocks/textures

Large ripples—continuous

Bedrock—Rugged



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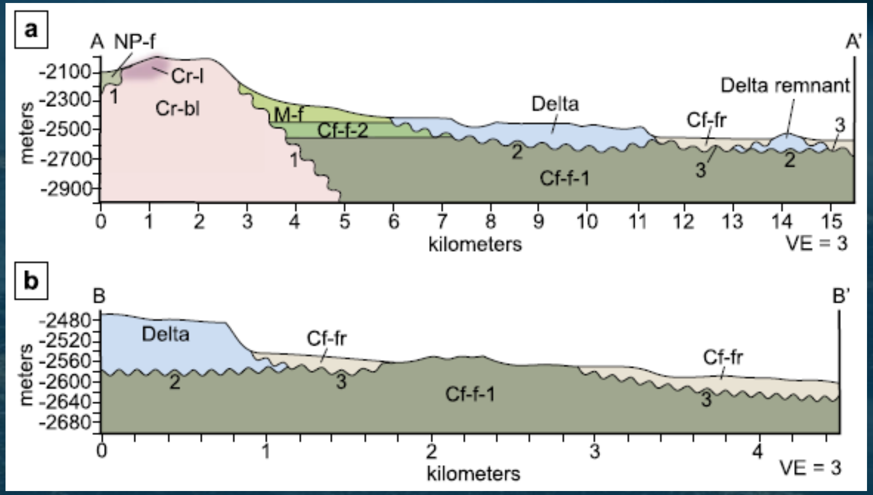
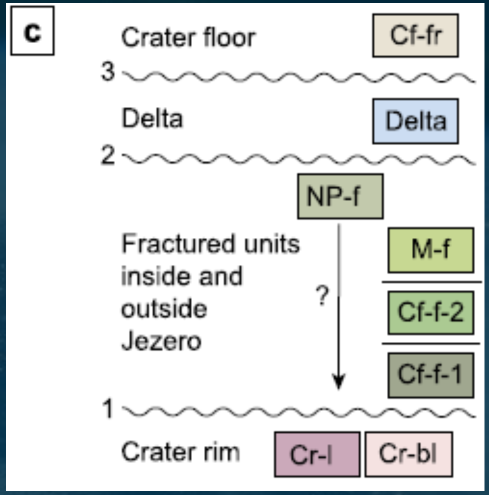
- Purely descriptive, incapable of interpretation from context
  - No concept of origin of rocks/textures
  - No concept of rocks as 3D volumes
  - Cannot produce cross sections
  - Cannot correlate map units
  - No concept of sequence of geological events

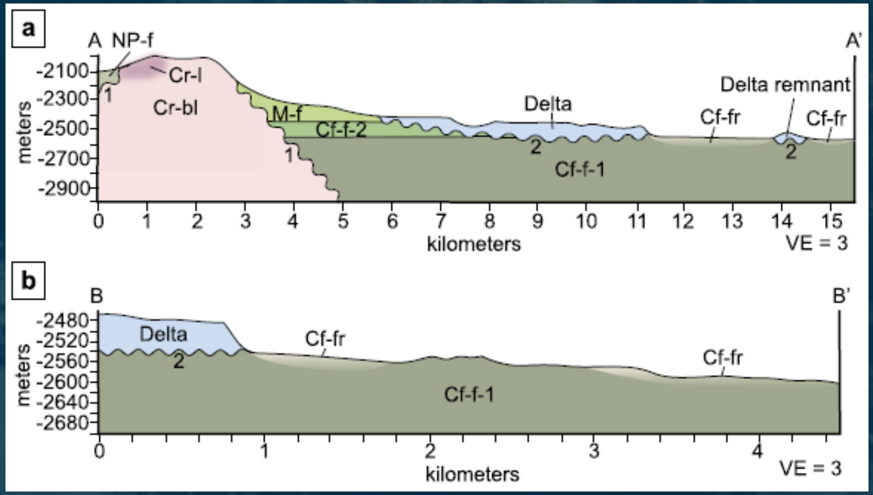
Scenario 1

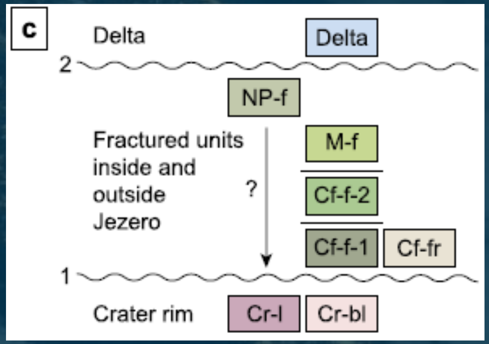


COMU 1



Scenario 2





Stack et al. (2020)

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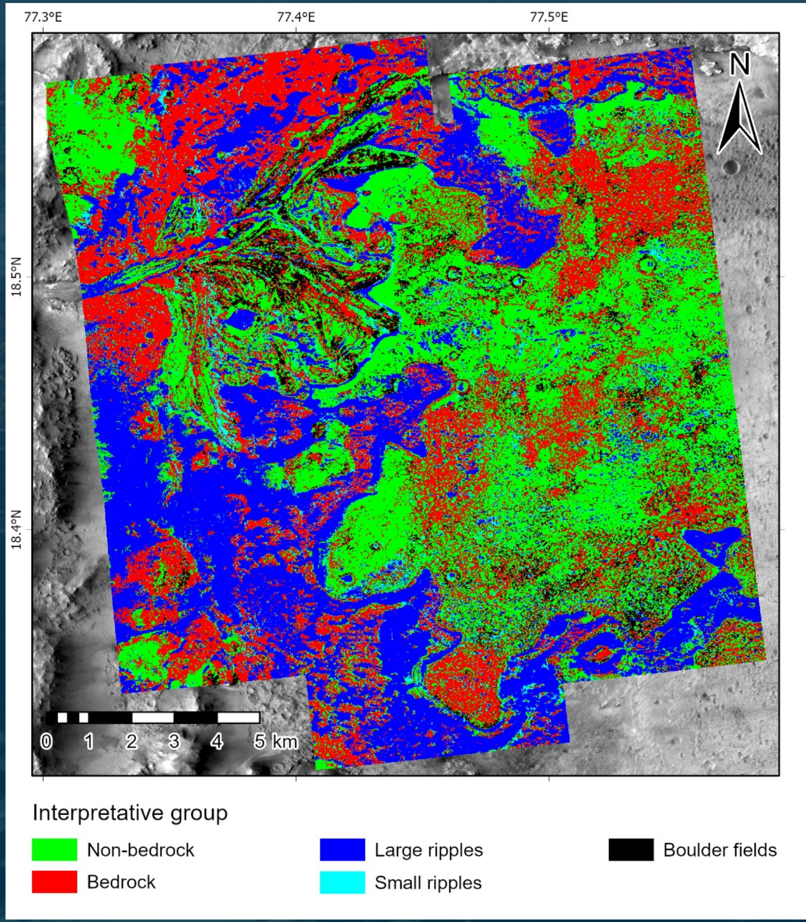
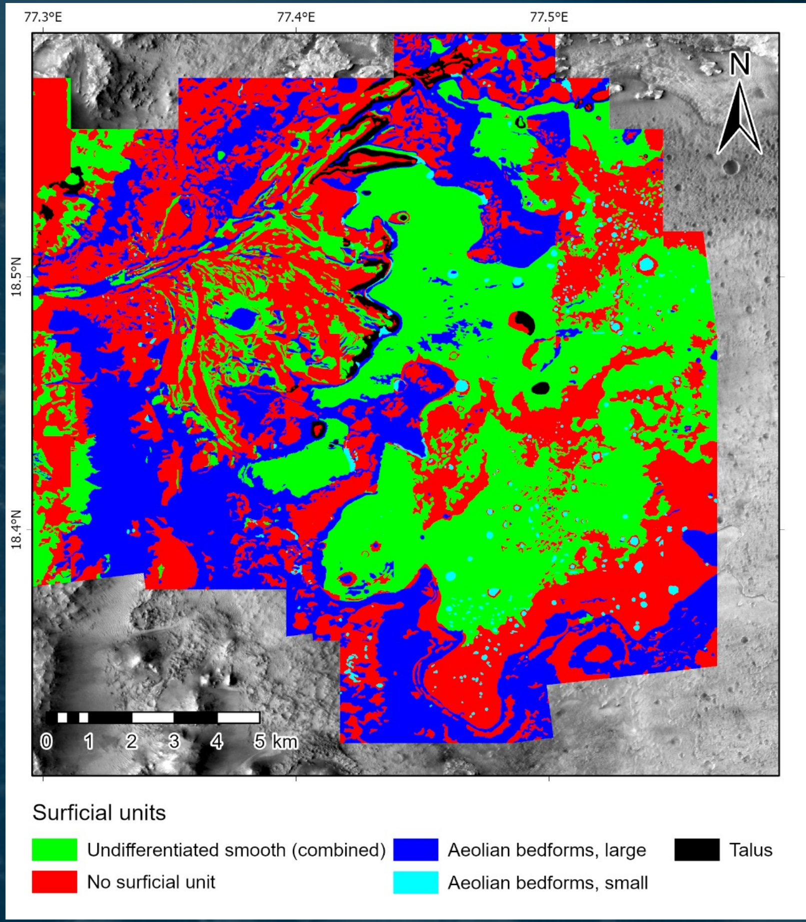
  - No concept of origin of rocks/textures
  - No concept of rocks as 3D volumes
  - Cannot produce cross sections
  - Cannot correlate map units
  - No concept of sequence of geological events
- Does not summarise information to be ingestible by humans



Wright et al. (2022)



Stack et al. (2020)

Conclusions

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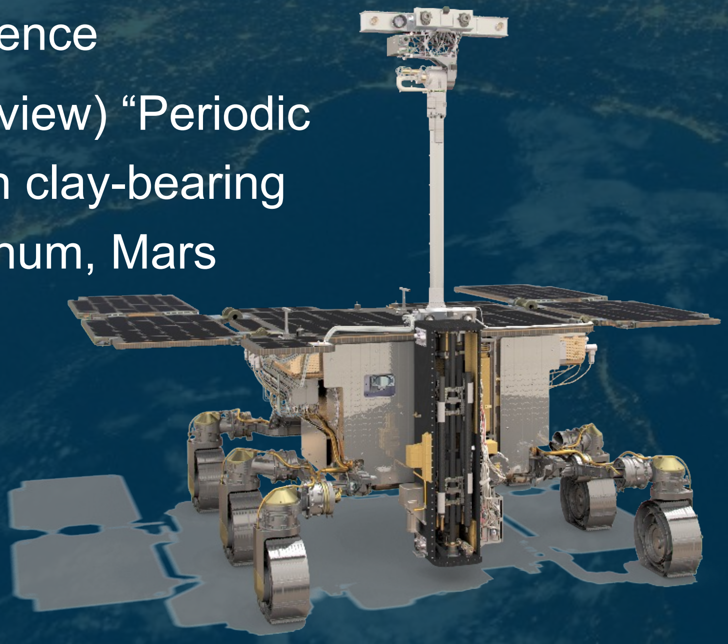
- Can use ML to map Mars terrain
  - Rover traversability/trafficability
  - Aid to geological mapping?
- “Ground truthing” can be possible
- Input for ExoMars Rosalind Franklin rover mission
- Already being used for science
  - Favaro et al. (in review) “Periodic Bedrock Ridges on clay-bearing terrain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



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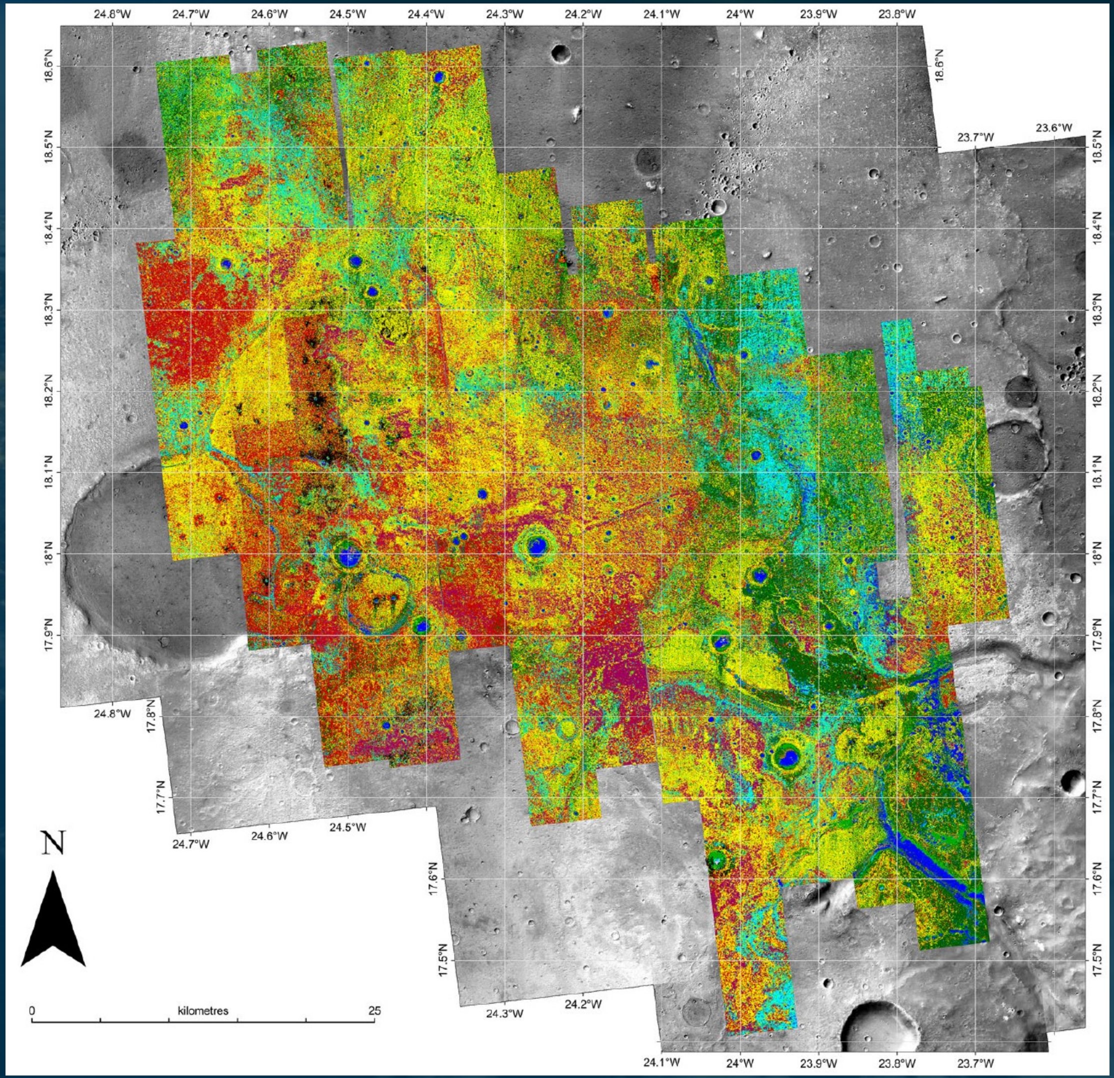

Barrett et al. (2022)

References

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

Favaro et al. (in review). Periodic Bedrock Ridges on clay-bearing terrain at Oxia Planum, Mars.

Quantin-Nataf, C., Carter, J., Mandon, L., Thollot, P., Balme, M., Volat, M., ... & Broyer, J. (2021). Oxia Planum: The landing site for the ExoMars "Rosalind Franklin" rover mission: Geological context and prelanding interpretation. Astrobiology, 21(3), 345-366. https://doi.org/10.1089/ast.2019.2191

Stack, K. M., Williams, N. R., Calef, F., Sun, V. Z., Williford, K. H., Farley, K. A., ... & Aileen Yingst, R. (2020). Photogeologic map of the perseverance rover field site in Jezero Crater constructed by the Mars 2020 Science Team. Space Science Reviews, 216(8), 1–47. https://doi.org/10.1007/s11214-020-00739-x

Wright, J., Barrett, A. M., Fawdon, P., Favaro, E. A., Balme, M. R., Woods, M. J., & Karachalios, S. (2022). Jezero crater, Mars: application of the deep learning NOAH-H terrain classification system. Journal of Maps, 18, 484–496. https://doi.org/10.1080/17445647.2022.2095935