Detecting Cave Entrance Candidates on Mars using Deep Learning Computer Vision

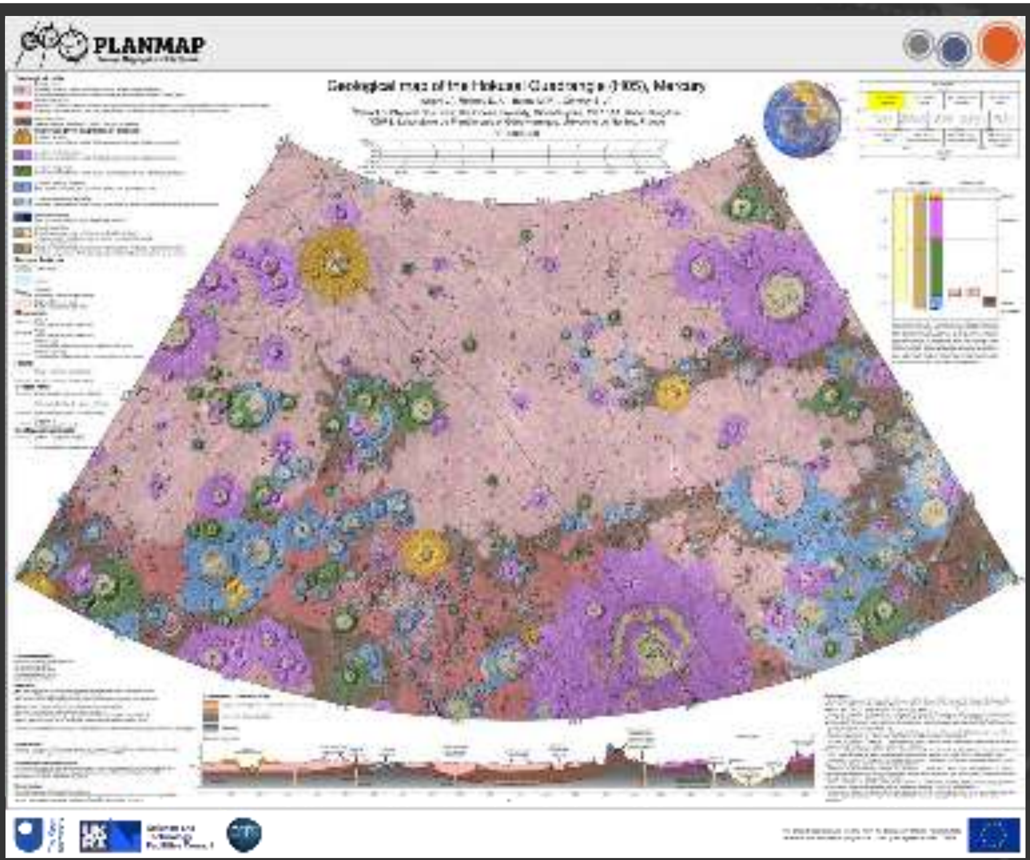
Giacomo Nodjoumi
PhD student

Jacobs University – Bremen

This study is within the Europlanet 2024 RI, and it has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 871149.

Planetary Mapping

- A comprehensive rapresentation of the features that characterize a planetary surface.
- Features and properties: temperature, chemical composition, elevation, texture, color, shape, and more.
- Complex set of tasks: data selection, processing and analysis, symbology, unit and boundaries definitions, geometries creation and more.
- All performed manually or in some cases aided by semi-automated workflows.
- Detailed analyses focused only on small areas.
- Integration of field and remote work, not possible like on Earth.



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Planetary Mapping

Major difficulties in planetary mapping are related to data exploitation:

- Data ground truth, lack of in-situ ground truth data, necessity to use earth analouges as a reference for interpretation and analysis;
- Dataset size. For Mars, more than 40 Petabyte of data have been collected from orbital instruments, including optical, hyperspectral images, radar data and more;
- Dimensions of the area of interests, large area imply more data to be analysed.

Machine Learning and Deep Learning could play a key-role in exploiting and extending the analyses of planetary surfaces.

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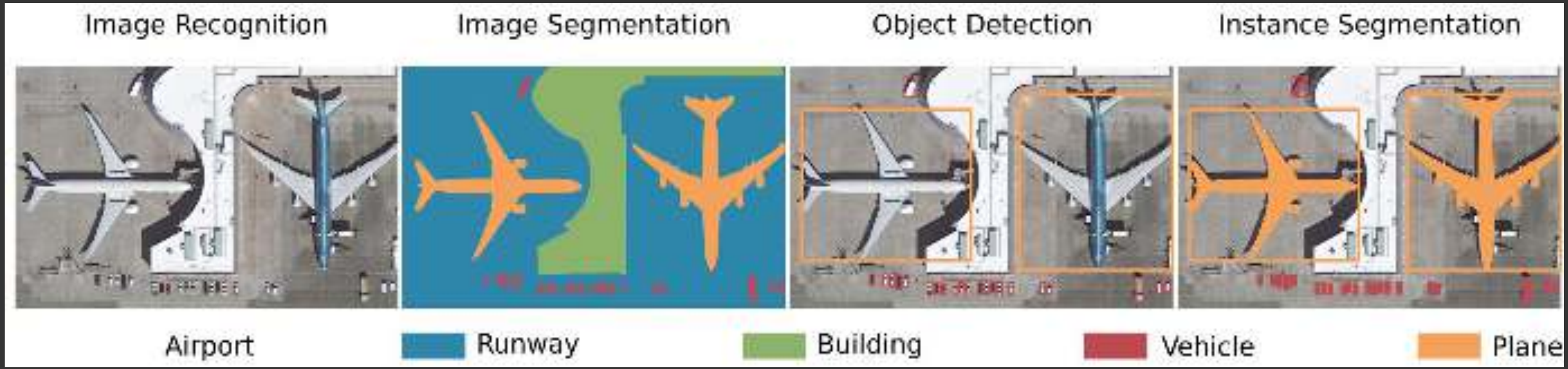
Deep Learning: Detection vs Segmentation

- **Image Classification**: classify the whole image with one or more labels
- **Image Segmentation**: classify the whole image in segments in a pixel-wise level
- **Object Detection**: locate objects as bounding boxes and class labels
- **Instance Segmentation**: similar to Object Detection but the objects are also classified using image segmentation



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Deep Learning: Mapping Tools

- ❑ Good literature of Deep Learning applied to mapping
- ❑ No complete codes/scripts published
- ❑ No ready-to-use tools published
- ❑ Several propetary softwares available, but specific for Earth Observation
- ❑ Necessity to start from scratch

A complete **nightmare** for beginners that want to approach Deep Learning for planetary mapping.

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Deep Learning: a beginner’s nightmare

My approach to the problem was:

- ❑ Use python
- ❑ Look for frameworks, tools, worflows almost-ready-to-use even if not specific for planetary science, based on python.
- ❑ Evaluate potential adaptation and integration in a planetary mapping context.
- ❑ Proceed gradually from object detection to instance segmentation
- ❑ Create a set of very easy to use tools to train and use models specific to user’s defined landforms.
- ❑ Focus on a familiar specific landform

https://zenodo.org/record/4679653

YOLOv5 by ultralitics

- ❑ Based on python for the frontend,
- ❑ Well documented and mantained
- ❑ Based on pytorch
- ❑ Almost ready-to-use
- ❑ Few modification needed to adapt it to georeferenced data.

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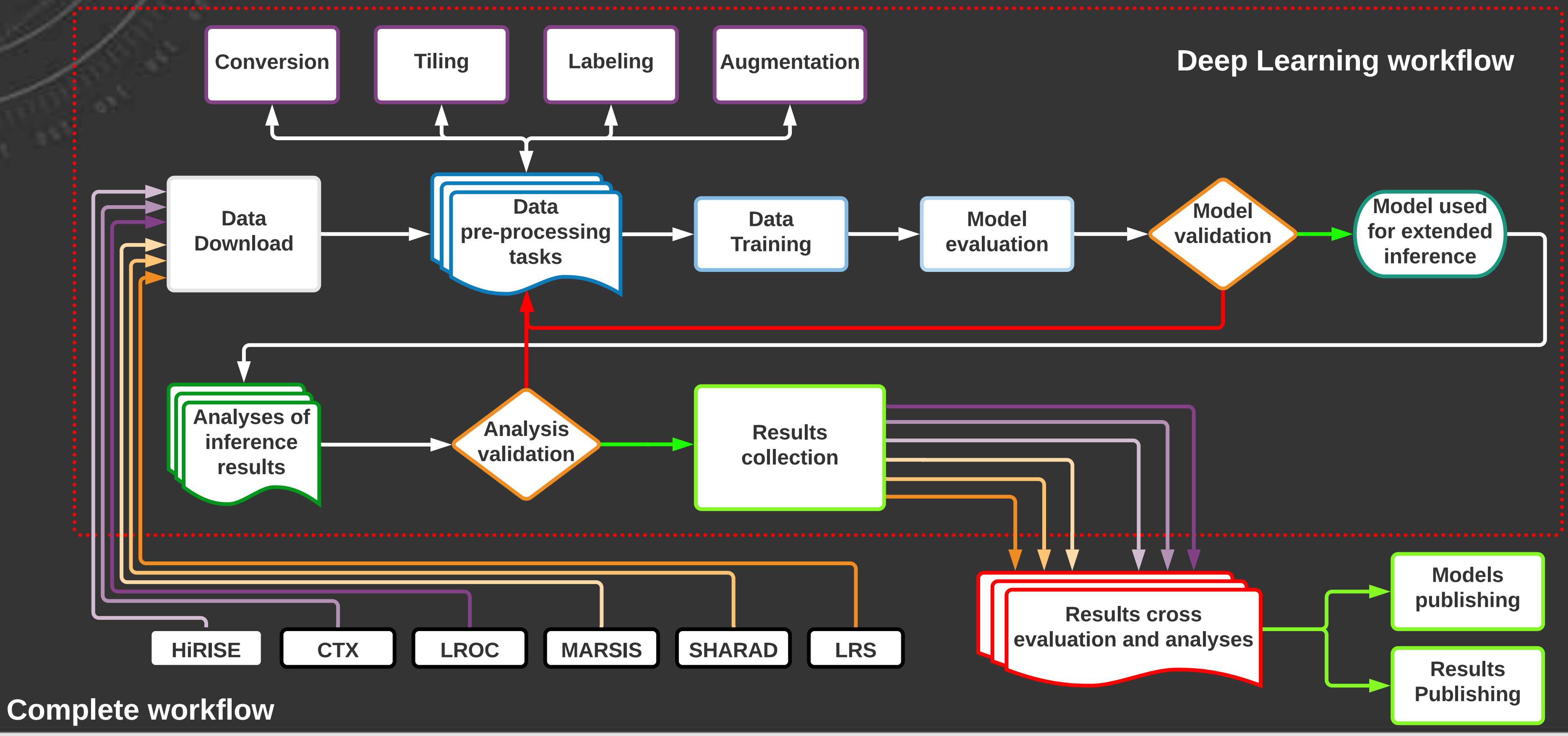
Workflow



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Sinkhole morphologies

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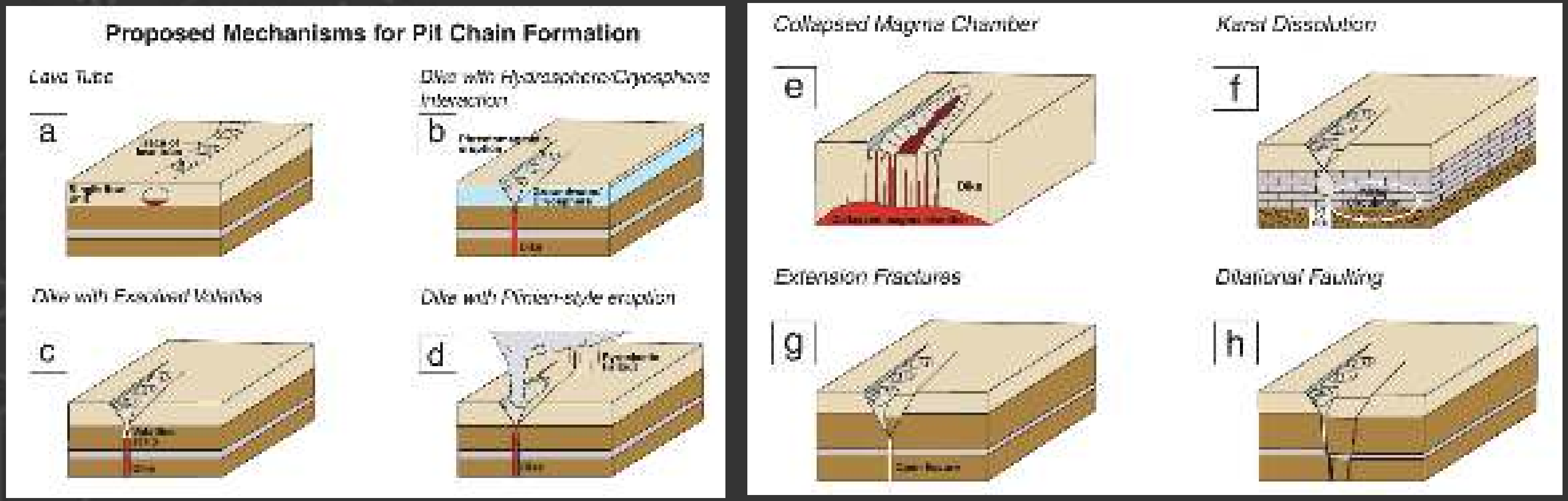
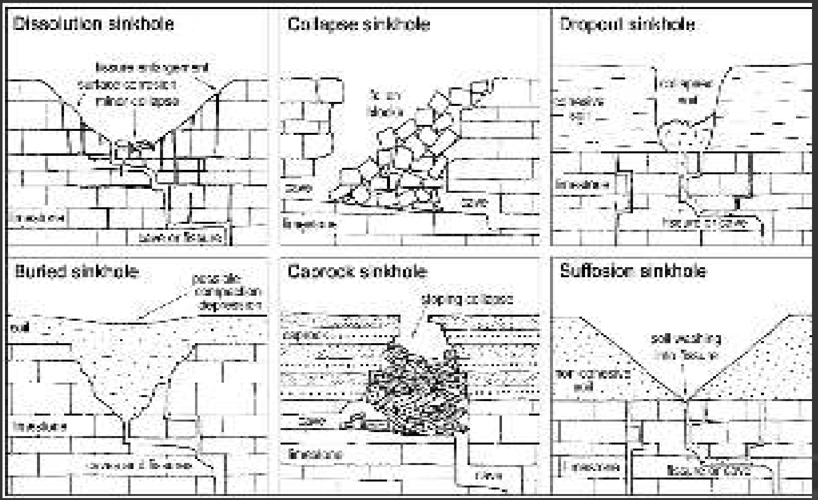
Sinkhole morphologies: genesis mechanisms

Volcanic environments



Schematic illustration of mechanisms for pit chain formation proposed by Wyrick (Wyrick et al., 2004)

Kars and Sedimentary environments



Classification of sinkholes, with respect to the mechanisms of the ground failure and the nature of the material which fails and subsides (Waltham and Fookes, 2003)

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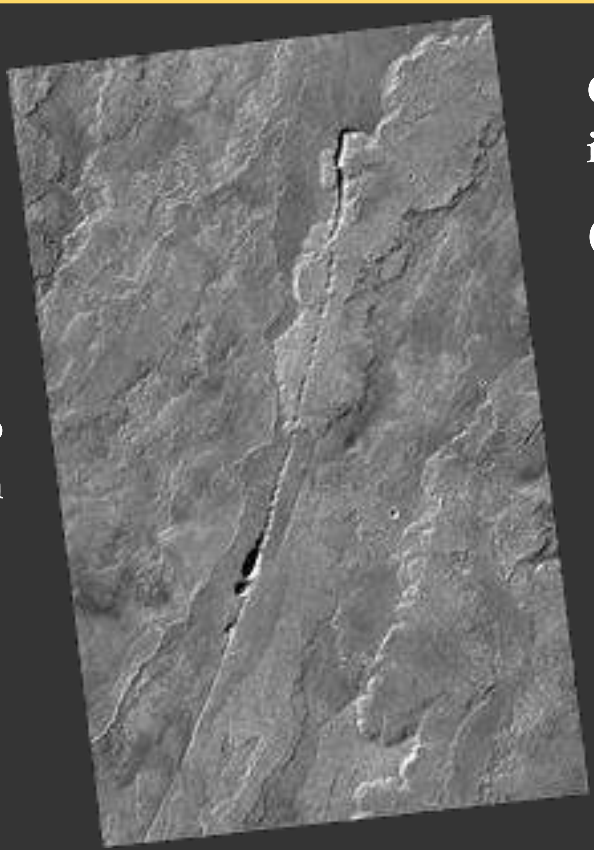
Data: optical datasets - Mars

High Resolution Imaging Science Experiment (HiRISE)

(0.3 m/pixel)

Images's size can reach up to 80000 pixel height/width at full resolution



Context Camera (CTX) images

(6 m/pixel)

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Preliminary Results: initial phases

Objectives:

- ❑ Create a consistent environment and set of tools for the full workflow
- ❑ Create consistent datasets for train, tests and validation.
- ❑ Label train dataset

- ➢ 130 HiRISE RED images over the Tharsis Region on Mars, this region is known in literature as the largest continous volcanic province on Mars, containing the highest volcano in the Solar System, Olympus Mons.
- ➢ A database of Mars cave entrance candidates of this region exists (MGC^3 – Cushing et al, 2012). Containing the location of over 1000 possible pits o similar landform and has been created all manually, but does not include information regarding the specific images that have been used.

- ✓ Manual selection of HiRISE/CTX images of the Tharsis Region.
- ✓ All images have been sliced in 900x900 px tiles and filtered removing all-black or not useful ones, due to the large dimensions.

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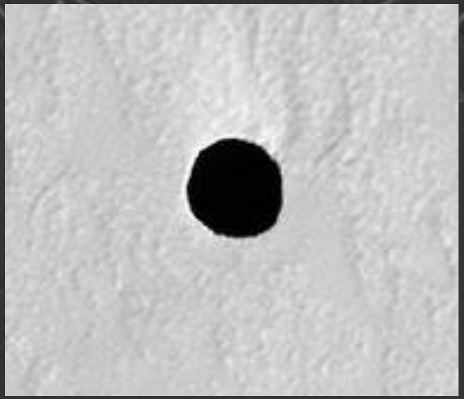
Preliminary Results



Type 1 – Skylight with possible cave entrance, flat rim, no ejecta marks, almost perfect circular shape and no visible bottom. Best candidate

Type 2 – Pit crater with possible relation to lava tube, flat rim, no ejecta marks, almost circular shape and visible bottom.

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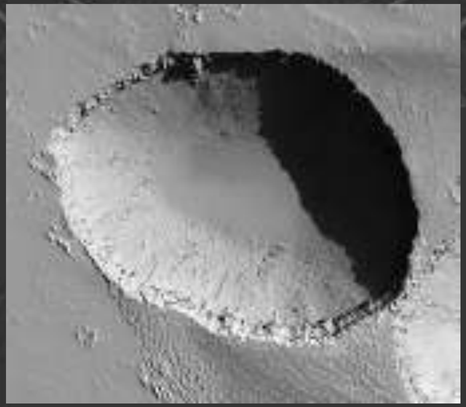
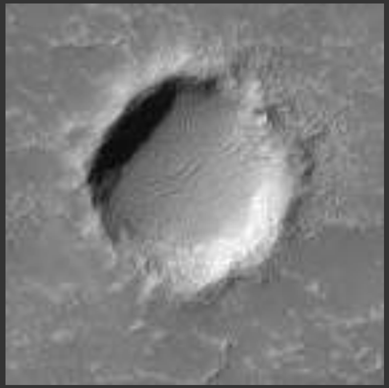
Preliminary Results



Type 3 – Depression with flat rim, no ejecta marks, elongated shape and visible bottom. Possible connection to lava tubes.

Type 4 – Depressions with flat rim, no ejecta marks, shallow to very shallow depth. Circular to elongated shapes and usually aligned with other similar shapes. High probability that is related to lava tube collapse.



Impact crater with always visible non-flat rim. Often visible ejecta marks.

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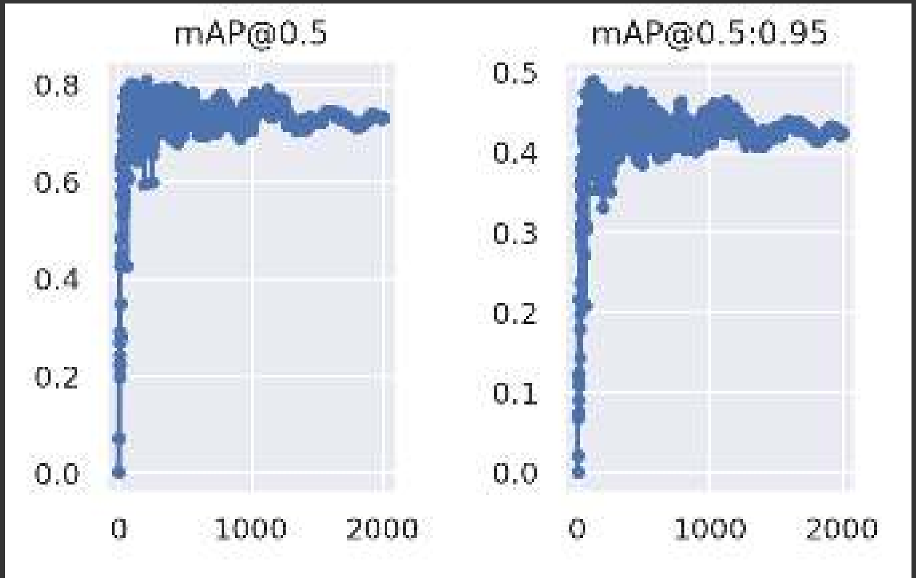
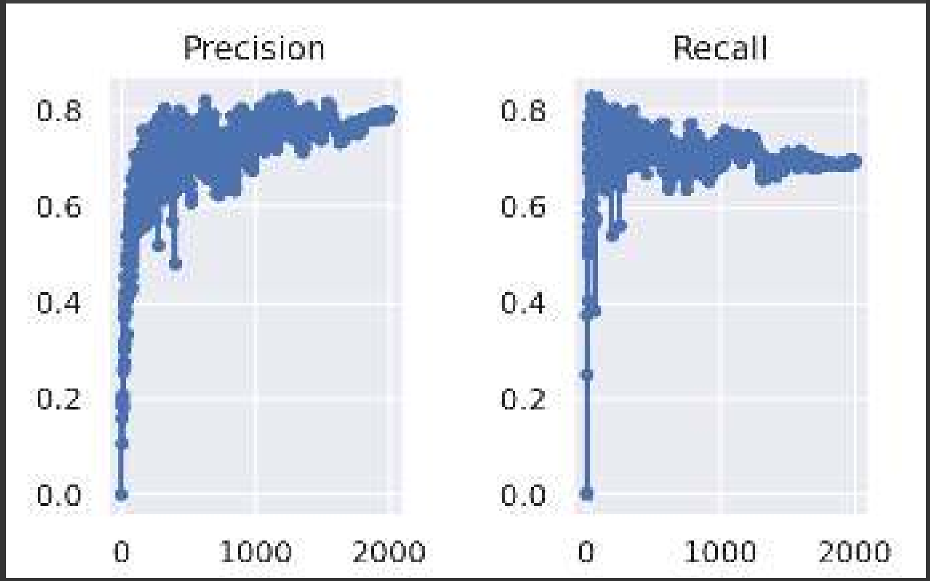
Preliminary Results: Training evaluation

mean Average Precision (mAP): proportion of True Positive

Precision: percentage of correct precisions
Recall: proportion of True Positive out of possible positives





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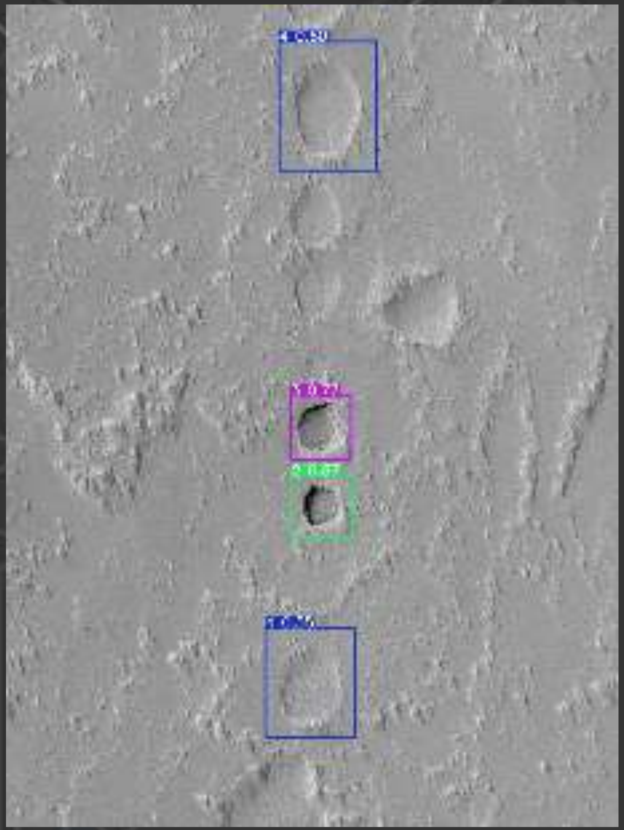
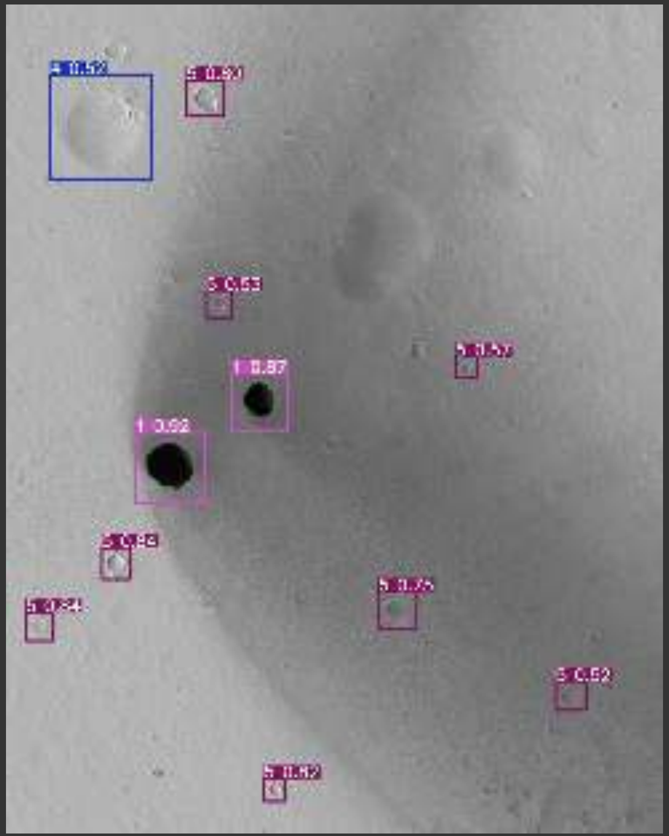
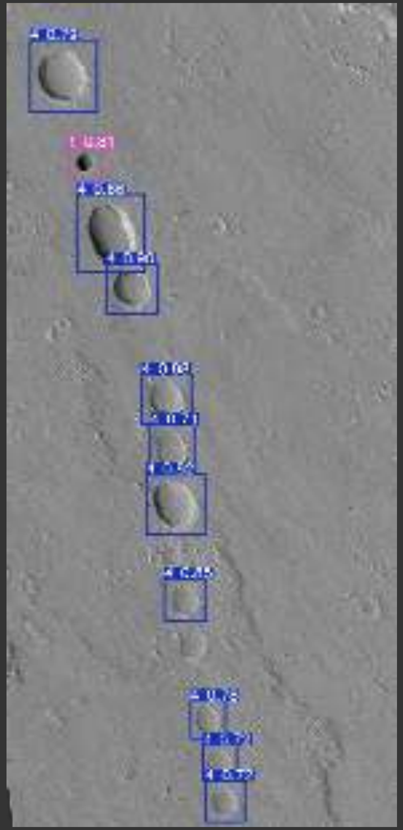
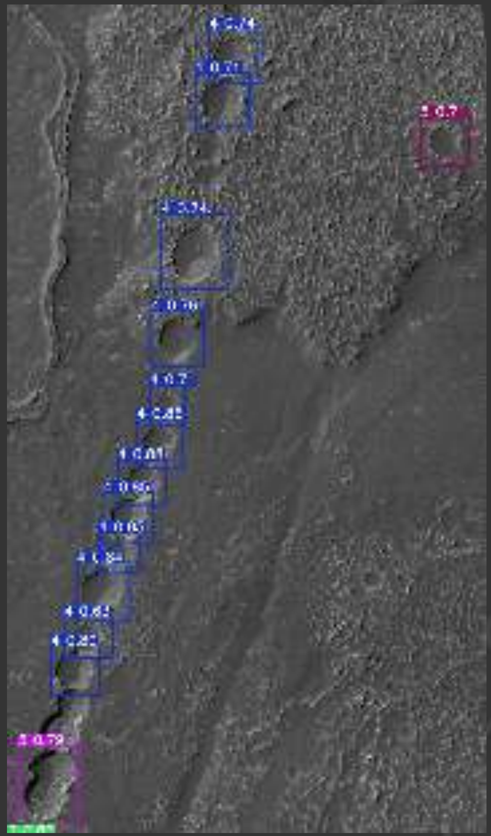
Preliminary Results: Inference on large sample dataset - HiRISE









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Preliminary Results: Inference on large sample dataset - HiRISE

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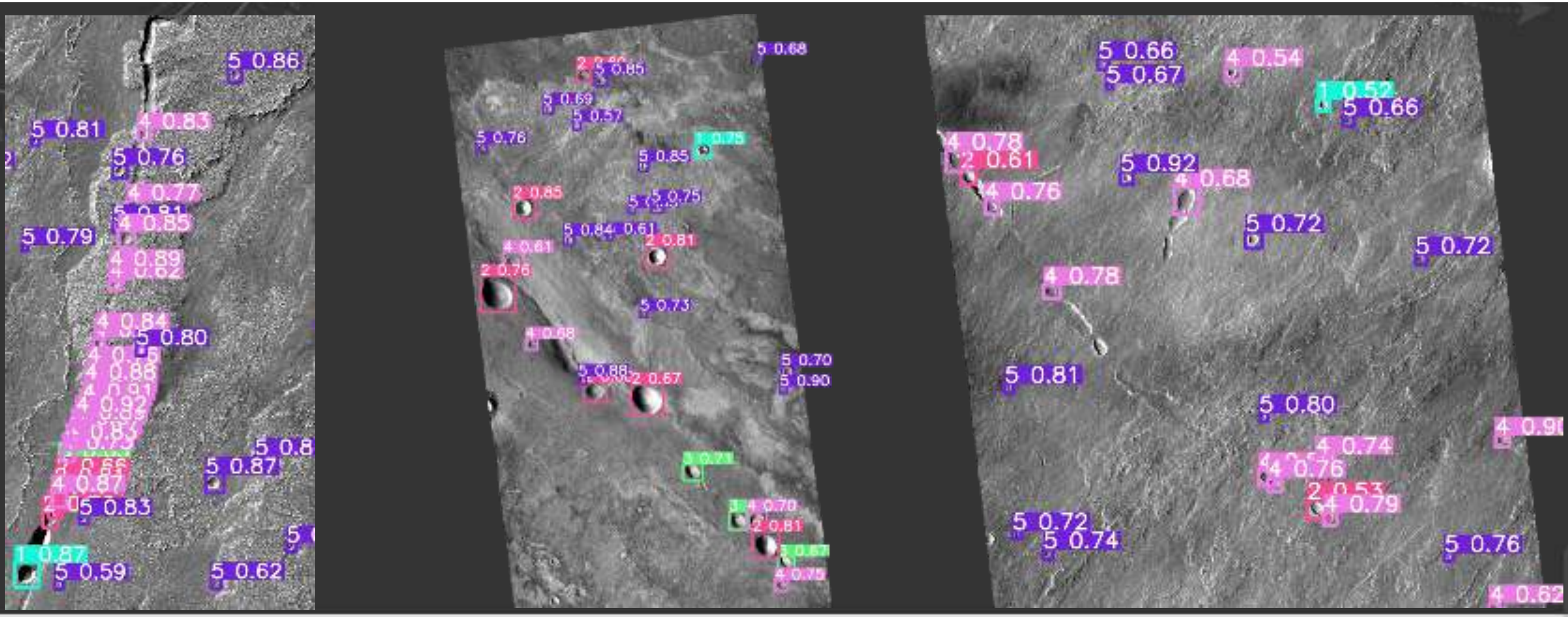
Preliminary Results: Inference on large sample dataset - CTX



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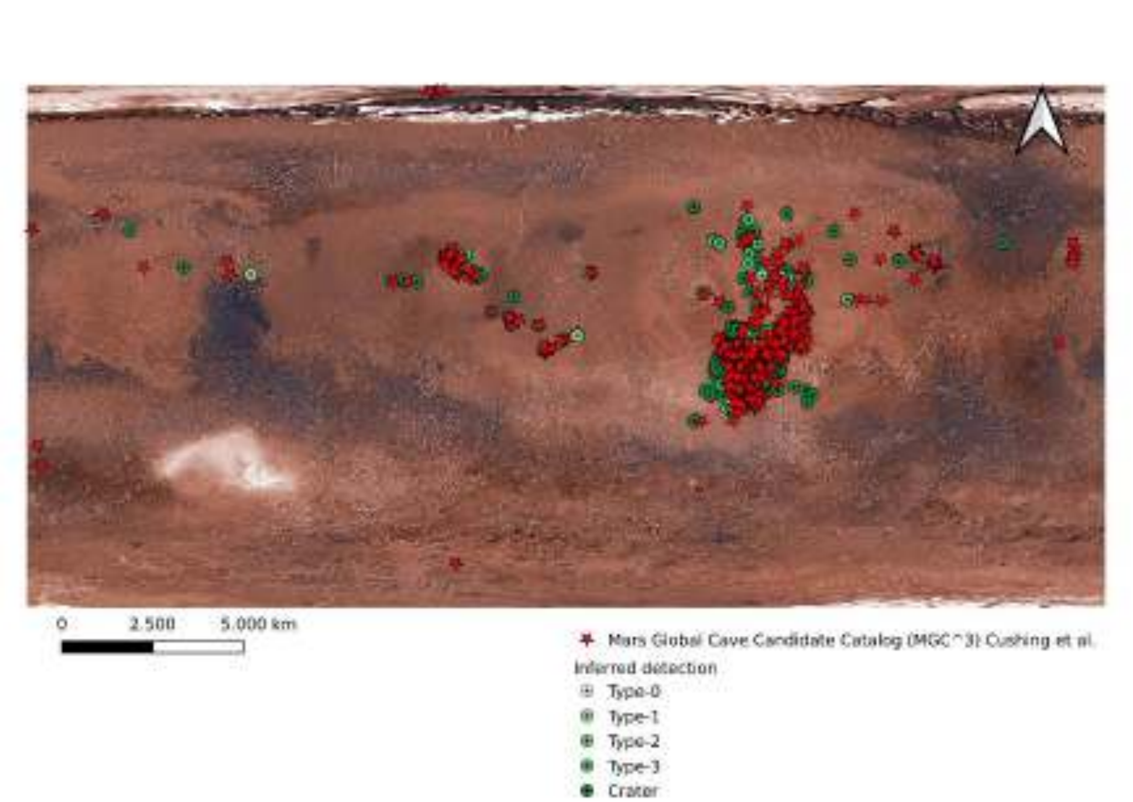
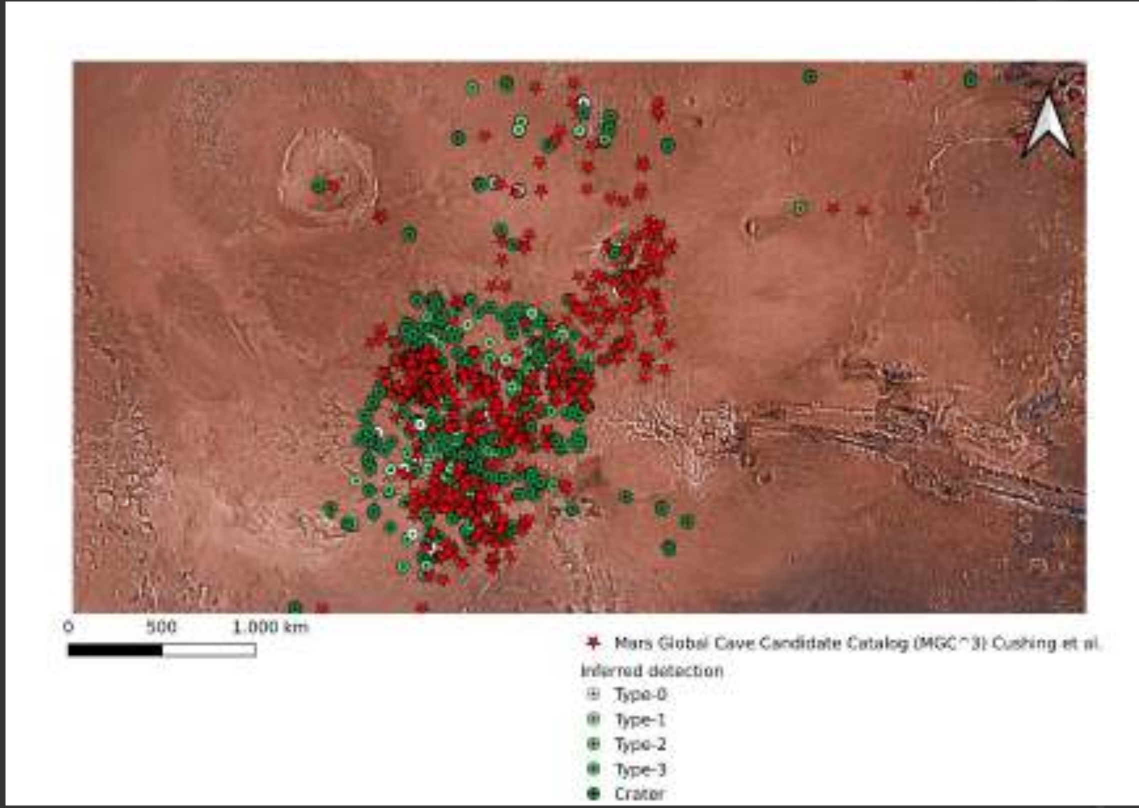
Preliminary Results: Mapping of inferenced results





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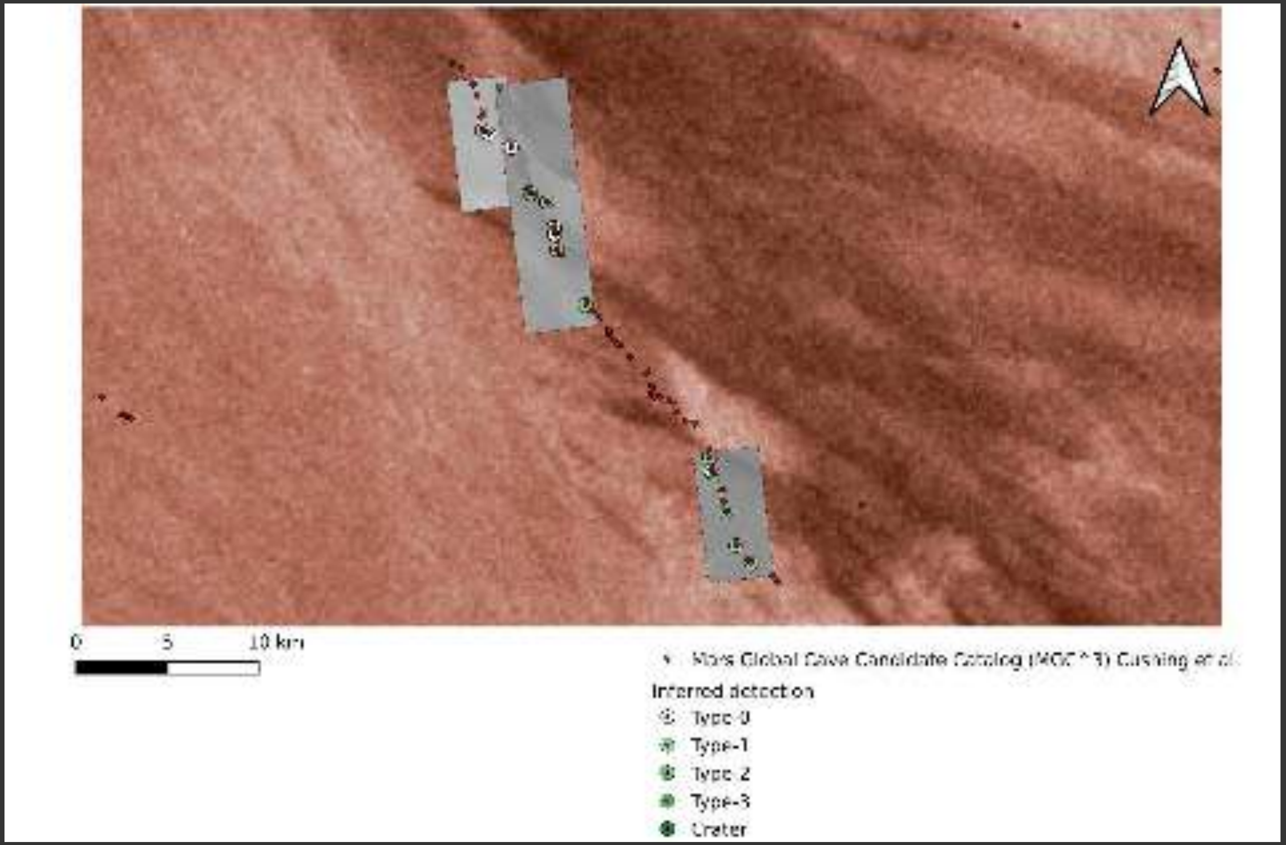
Preliminary Results: Mars Global Cave Candidate Catalog



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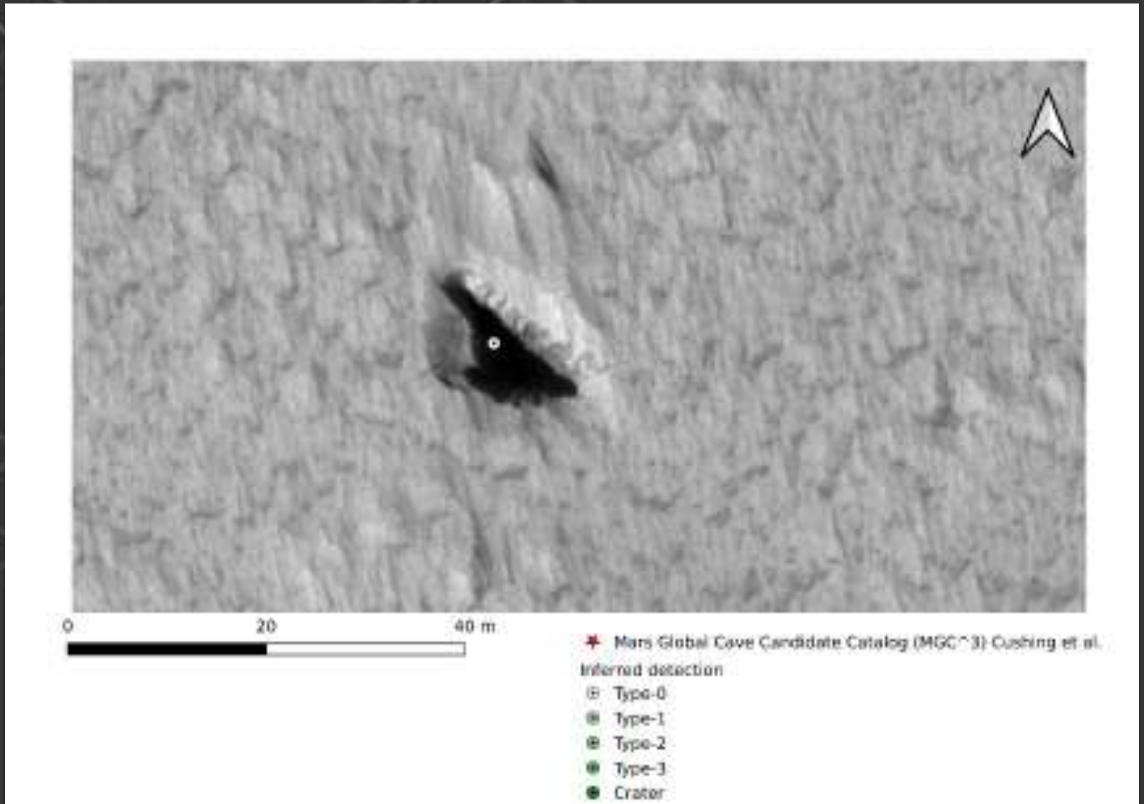
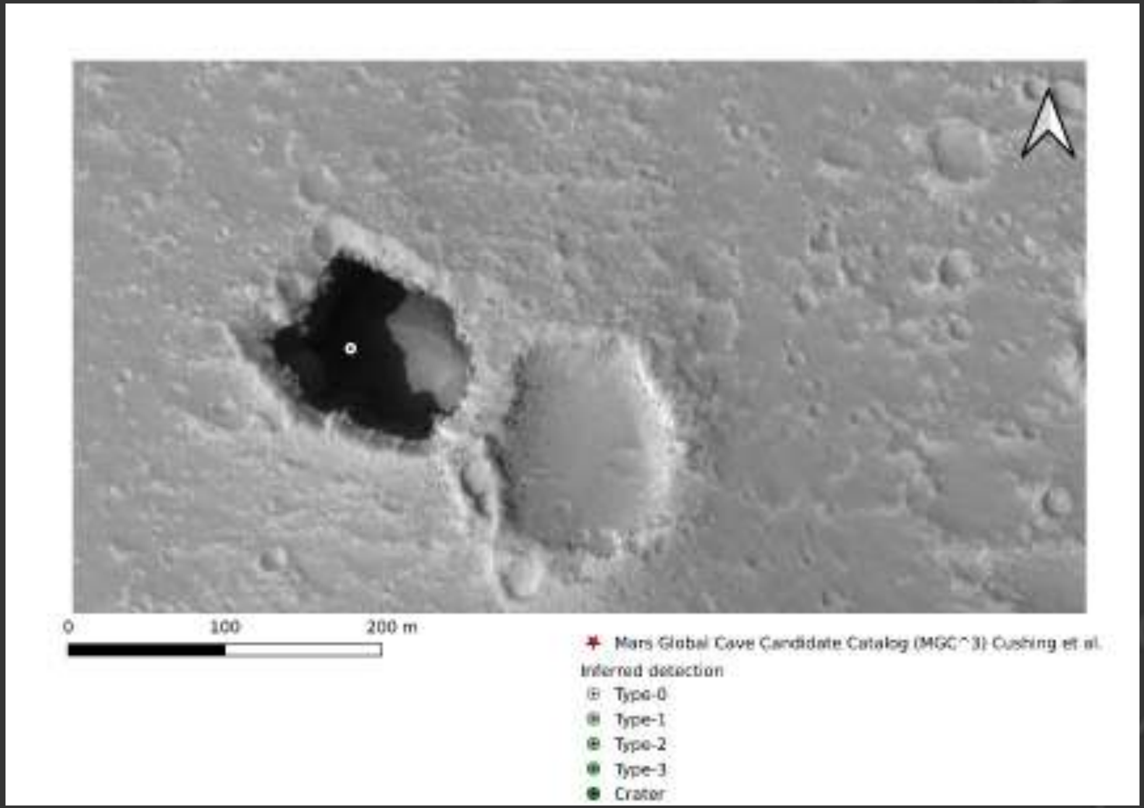
Preliminary Results: Possible Cave Candidates new discoveries





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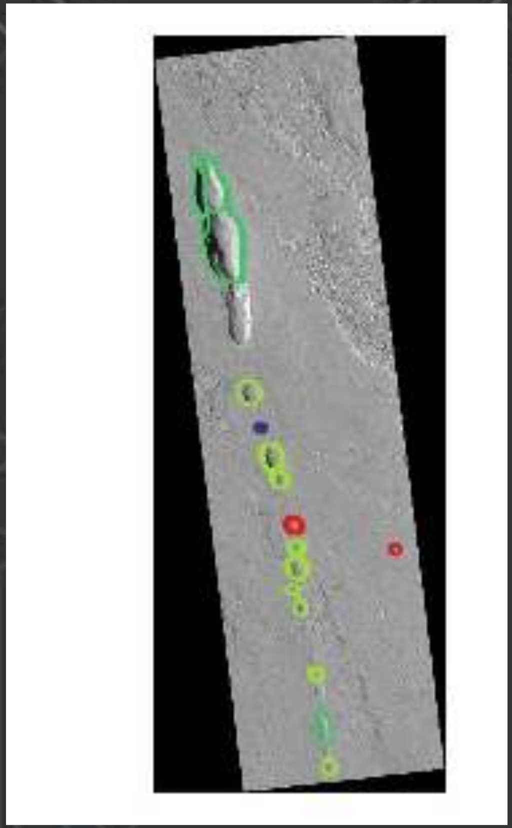
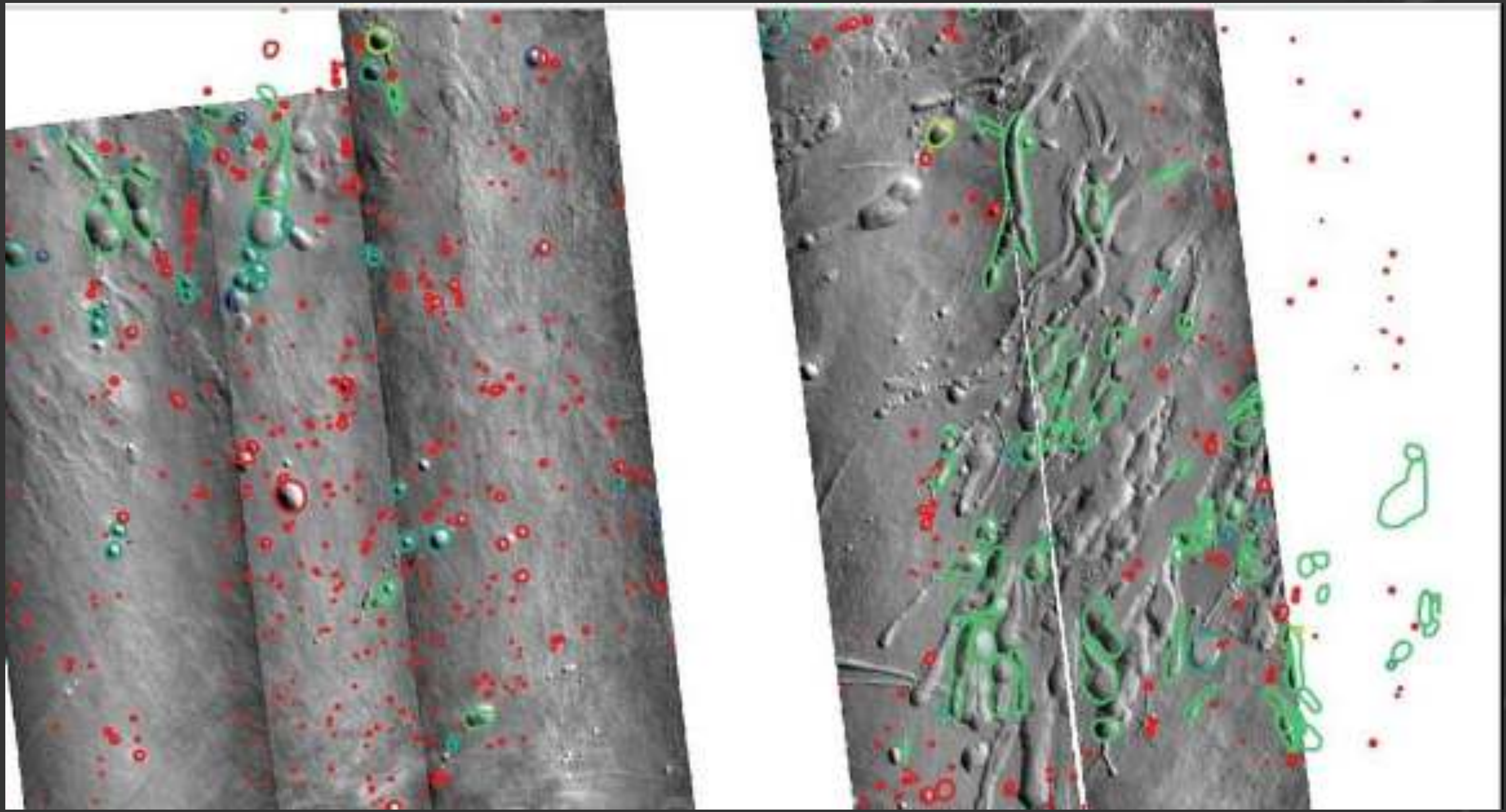
Further works: Instance segmentation





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Thank for your attention

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