Erasmus Plus GeoPlaNet Strategic Partnership

IO11: Teaching Material

FINAL REPORT

MATERIAL ORGANIZATION

This document has been prepared by the University d'Annunzio in collaboration with the University of Padova and the whole consortium of the Erasmus+ Strategic Partnership GeoPlaNet-SP (ref. 2020-1-FR01-KA203-079773). The context is the summer school on Planetary Geological Mapping and Field Analogues organized in the framework of the same partnership.

The teaching material includes lectures and some materials for exercises.

Lectures are grouped in a single document with the different lectures.

Lectures (abbr. Lez) 1 to 16 are focused on data processing and GIS integration with the aim of realizing a geological map. In this framework, DEMs realization is the object of the tutorial of Intellectual Output 6, while the science associated with geological mapping is addressed by Intellectual Output 7.

Lecture 17 introduces the second part of the school with an introduction to the geology of the Dolomites. The field trip guide represents Intellectual Output 8, but more detailed geological maps are also here as an appendix.

Lecture 18 addresses the photogrammetry and virtual reality part, while the material for the practical exercises is included here:

https://universitachieti-my.sharepoint.com/:u:/g/personal/monica_pondrelli_unich_it/ETza5OthzbZFjRhrgOIarQwBn1TeJFatxdNR4gkCN0TVJg?e=96LjoT

Co-funded by the
ERASMUS + Programme
of the European Union

Mapping the Moon

LUCIA MARINANGELI

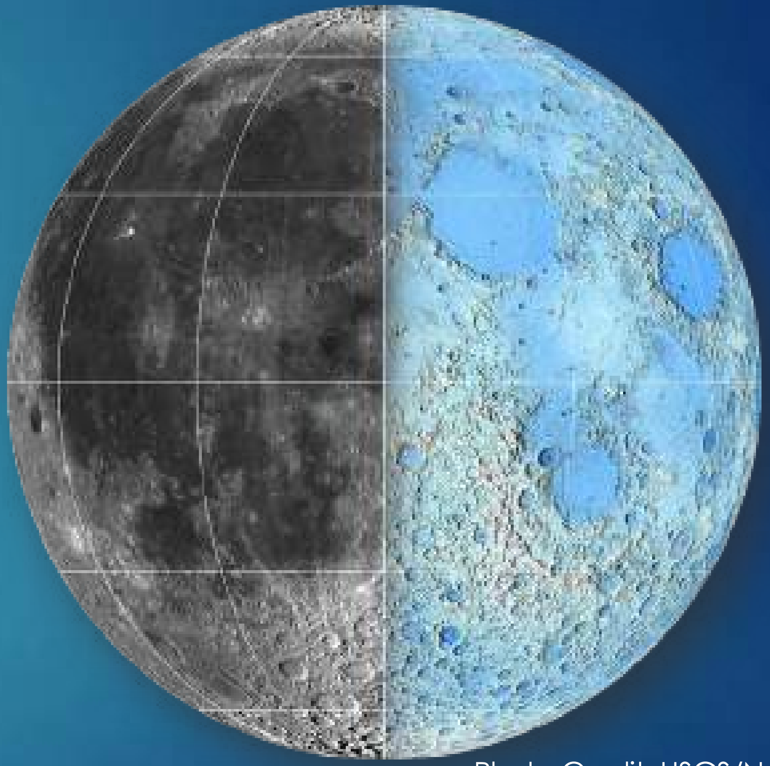


Photo Credit: USGS/NASA/ASU

Decipher the Geology of a planet

PROPERTIES → OBSERVATIONS → INTERPRETATIONS

lithology → composition and rock types → formation processes

stratigraphy → relative time → history of geological processes

tectonics → deformations → crustal dynamics

geomorphology → physical geography → surface processes evolution

volcanism → mantle activity → crustal differentiation

age → crater counting → relative dating

age → radiometric dating of samples → absolute dating

GEOLOGICAL MAPPING

By definition, a geological unit is a three-dimensional body of rock of essentially uniform composition formed during some specified interval of time and that is large enough to be shown on a conventional map.

Thus, the making of geologic maps involves subdividing surface and near-surface rocks into different units according to their type and age.

GEOLOGICAL MAPPING

On Earth, this involves a combination of field work (ground-truth), laboratory studies, and analyses of aerial photographs.

In planetary geology, geologic mapping must be done primarily by remote sensing methods, commonly the interpretation of photographs.

GEOLOGICAL MAPPING

Mapping units are identified on photographs by their surface appearance (texture, morphology ex. smooth, rugged, hilly, etc.), their albedo (how they reflect sunlight light to dark - tone), their state of surface preservation (degree of erosion), their spectral signature at different wavelength and other properties.

In the image interpretation process, the objects of our interest are Measured* in terms of variations in:

TEXTURE

SHAPE

SIZE

TONE **

ORIENTATION

PATTERN

ASSOCIATION

SITE

* Measurements done at
  - nominal scale (coding)
  - ordinal scale (>,<)
  - seldom used: interval, ratio

** Descriptive terms are often used

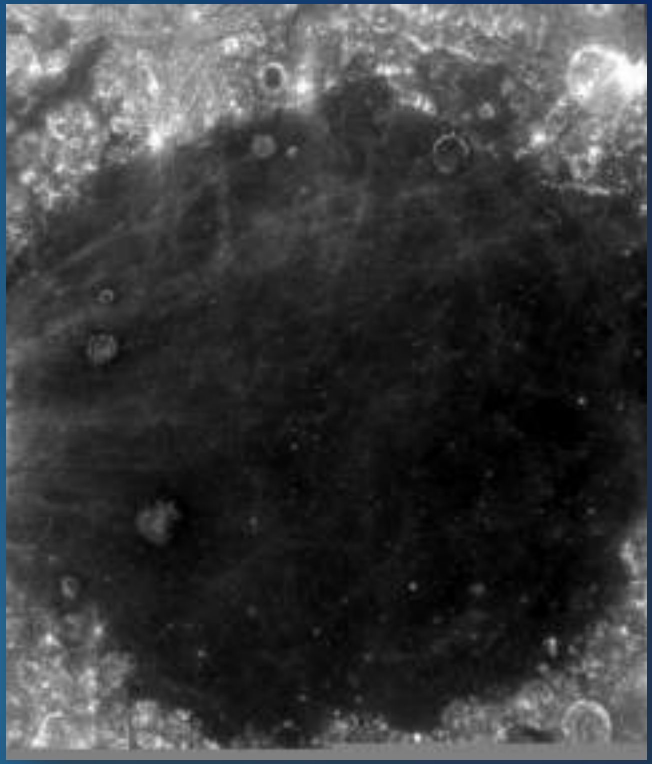
SPECTRAL MAPPING

Crater Counting Dating

lunar rocks radiometric dating

crater density in the lunar sampling sites

comparison with similar crater density of other planets



older surface → high crater density

younger surface → low crater density

Crater Counting Dating

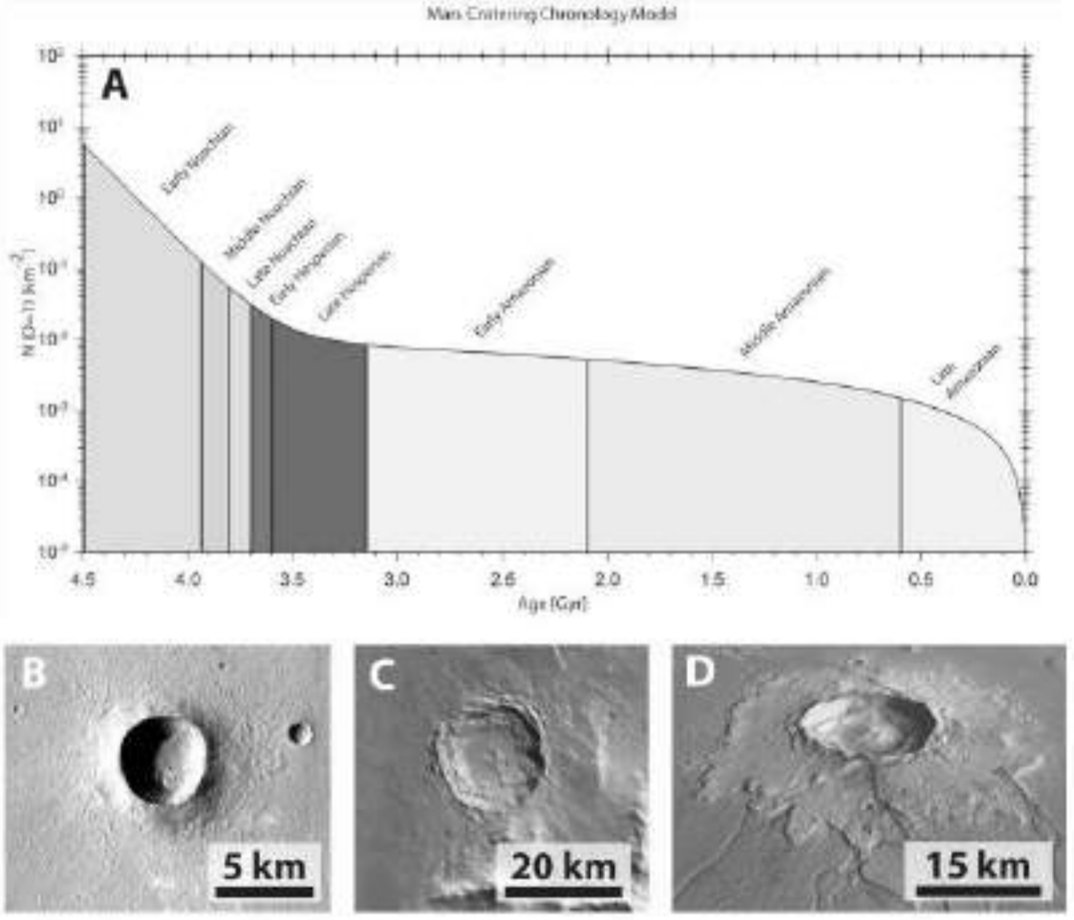
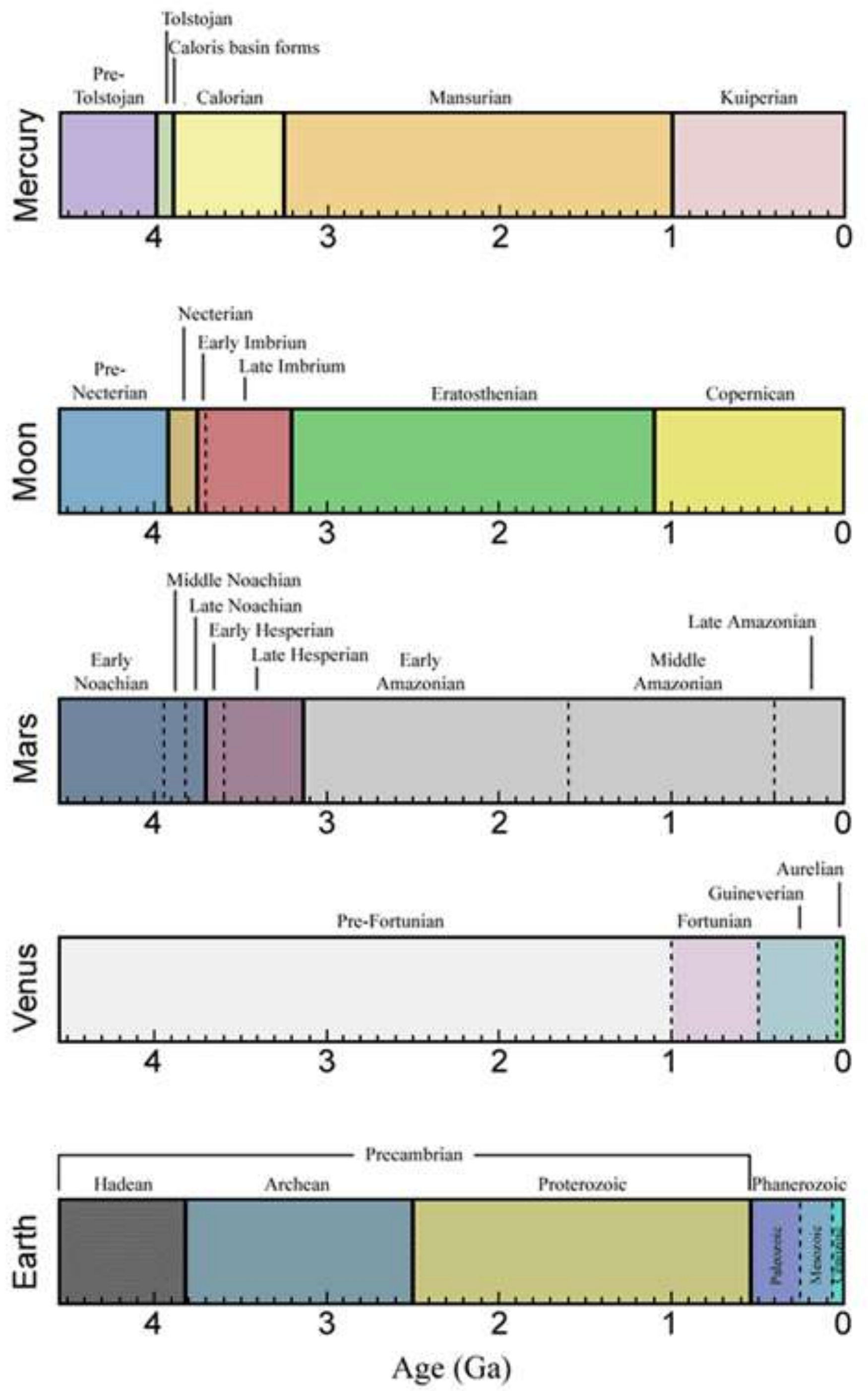
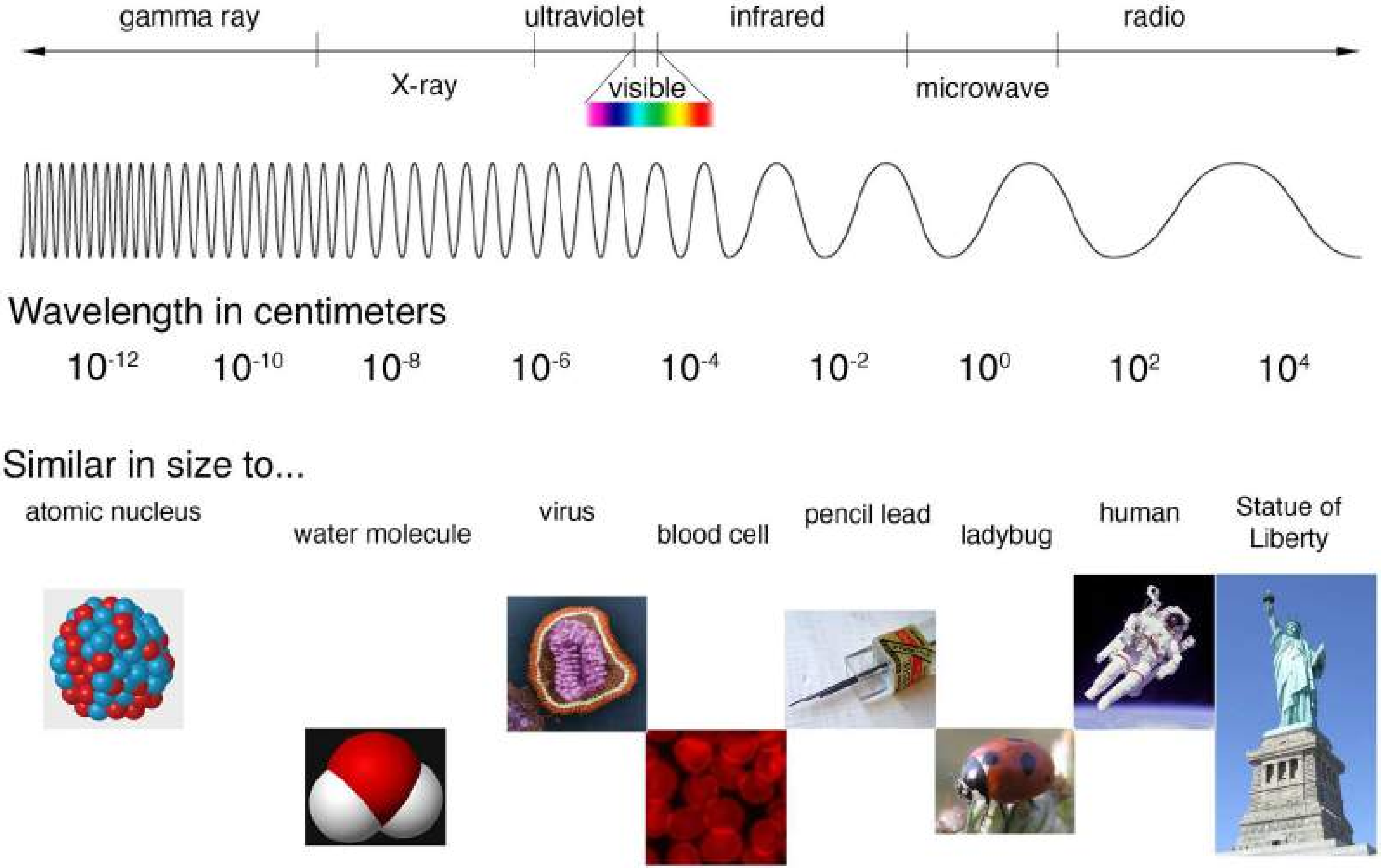
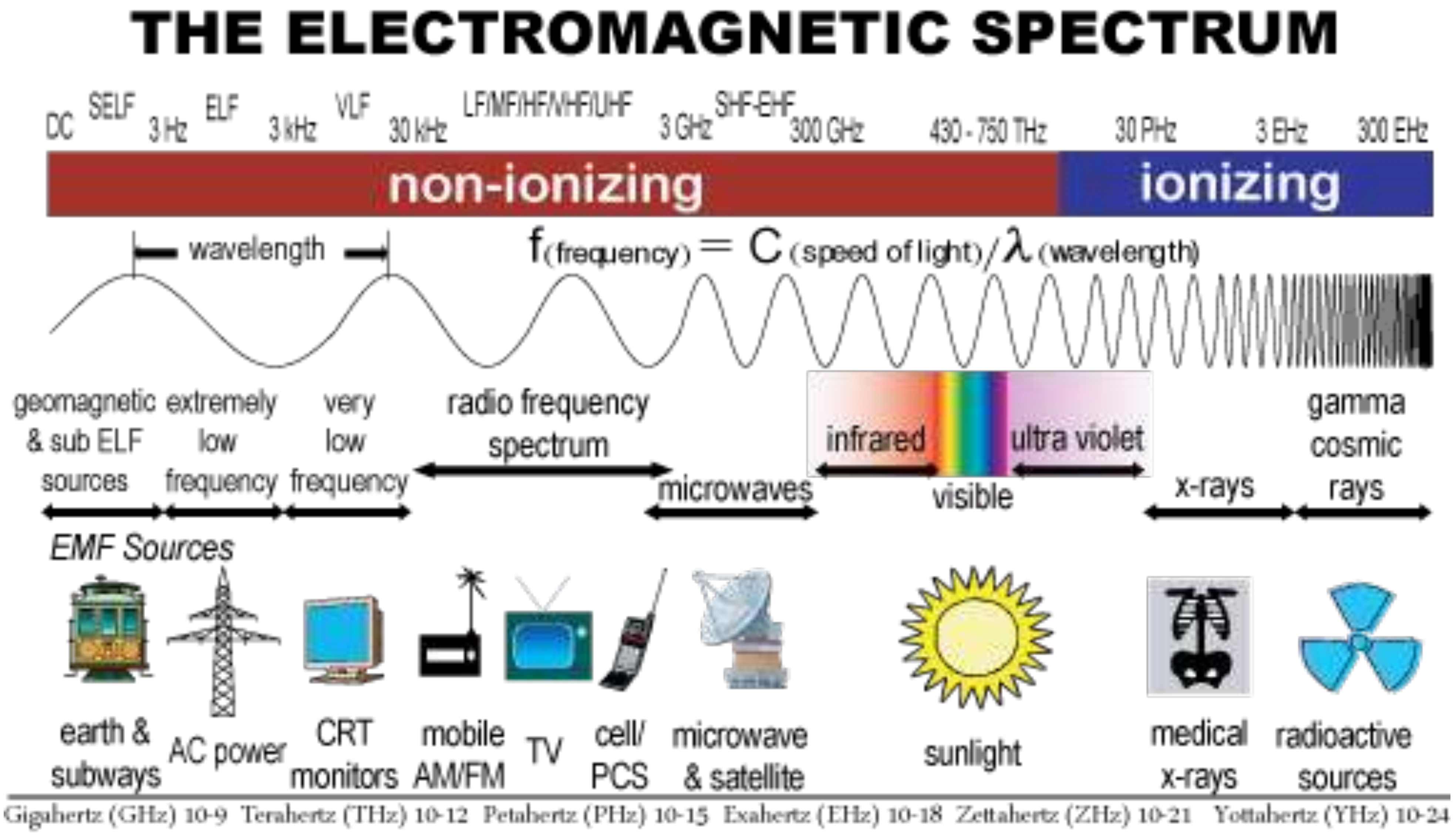


Fig.4 A. Martian chronology model, modified after Hartmann & Neukum (2001), with indicated Martian eras. B. Example of a fresh simple bowl-shaped crater (MRO CTX P05 002830 1511 XI 28S133W). C. Complex central peak crater (MEX HRSC Nadir band from orbit 411). D. Rampart crater. This kind of craters is typical of Mars (MEX HRSC orbit 5122, perspective view).

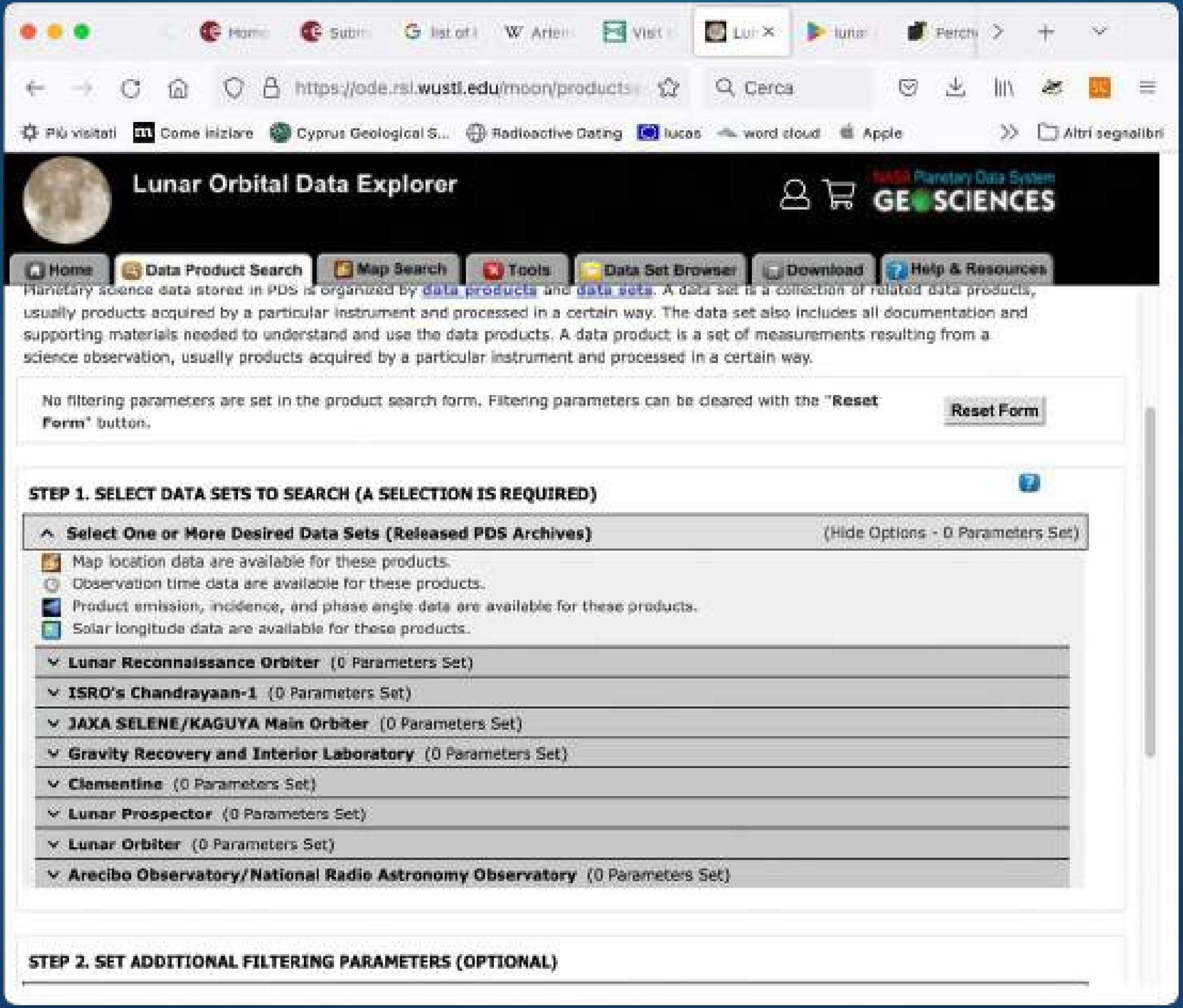
(from Rossi and Van Gasselt, 2010)




gamma ray
ultraviolet
infrared
radio
X-ray
visible
microwave
Wavelength in centimeters
10^{-12} 10^{-10} 10^{-8} 10^{-6} 10^{-4} 10^{-2} 10^{0} 10^{2} 10^{4}
Similar in size to...
atomic nucleus
water molecule
virus
blood cell
pencil lead
ladybug
human
Statue of Liberty


THE ELECTROMAGNETIC SPECTRUM
DC SELF 3 Hz ELF 3 kHz VLF 30 kHz LF/MF/HF/VHF/UHF 3 GHz SHF-EHF 300 GHz 430 - 750 THz 30 PHz 3 EHz 300 EHz
non-ionizing
ionizing
wavelength
f(frequency) = C (speed of light) / λ (wavelength)
geomagnetic & sub ELF sources
extremely low frequency
very low frequency
radio frequency spectrum
microwaves
infrared
visible
ultra violet
x-rays
gamma cosmic rays
EMF Sources
earth & subways
AC power
CRT monitors
mobile AM/FM
TV
cell/ PCS
microwave & satellite
sunlight
medical x-rays
radioactive sources
Gigahertz (GHz) 10-9 Terahertz (THz) 10-12 Petahertz (PHz) 10-15 Exahertz (EHz) 10-18 Zettahertz (ZHz) 10-21 Yottahertz (YHz) 10-24

https://ode.rsl.wustl.edu/moon/productsearch



Lunar Reconnaissance Orbiter (0 Parame

DLRE - DIVINER Lunar Radiometer Experime

- ***Raw Data*** (0 Parameters Set)
- ***Calibrated Data*** (0 Parameters Set)
- ***Derived Data*** (0 Parameters Set)

LAMP - Lyman-Alpha Mapping Project

- ***Raw Data*** (0 Parameters Set)
- ***Calibrated Data*** (0 Parameters Set)
- ***Derived Data*** (0 Parameters Set)

LEND - Lunar Exploration Neutron Detector

- ***Raw Data*** (0 Parameters Set)
- ***Calibrated Data*** (0 Parameters Set)
- ***Derived Data*** (0 Parameters Set)

LOLA - Lunar Orbiter Laser Altimeter

- ***Raw Data*** (0 Parameters Set)
- ***Calibrated Data*** (0 Parameters Set)
- ***Derived Data*** (0 Parameters Set)

LROC - Lunar Reconnaissance Orbiter Camer

- ***Raw Data*** (0 Parameters Set)
- ***Calibrated Data*** (0 Parameters Set)
- ***Derived Data*** (0 Parameters Set)

MRFLRO - MINI-RF LRO

- ***Raw Data*** (0 Parameters Set)
- ***Calibrated Data*** (0 Parameters Set)

Clementine (0 Parameters Set)

A-STAR - A-STAR

- ***Raw Data*** (0 Parameters Set)

B-STAR - B-STAR

- ***Raw Data*** (0 Parameters Set)

HIRES - High Resolution Camera

- ***Raw Data*** (0 Parameters Set)
- ***Derived Data*** (0 Parameters Set)

LIDAR - LIDAR

- ***Derived Data*** (0 Parameters Set)

LWIR - Long Wavelength Infrared Camera

- ***Raw Data*** (0 Parameters Set)
- ***Calibrated Data*** (0 Parameters Set)

NIR - Near Infrared Camera

- ***Raw Data*** (0 Parameters Set)
- ***Derived Data*** (0 Parameters Set)

RSS - Radio Science Subsystem

- ***Raw Data*** (0 Parameters Set)
- ***Calibrated Data*** (0 Parameters Set)
- ***Derived Data*** (0 Parameters Set)

UVVIS - Ultraviolet/Visible Camera

- ***Raw Data*** (0 Parameters Set)
- ***Derived Data*** (0 Parameters Set)

Lunar Prospector (0 Parameters Set)

{GRS, NS, APS, MAG, ER} - Gamma Ray Sp
Magnetometer,Electron Reflectometer Raw Data

- ***Raw Data*** (0 Parameters Set)

ER - Electron Reflectometer

- ***Calibrated Data*** (0 Parameters Set)

GRS - Gamma Ray Spectrometer

- ***Calibrated Data*** (0 Parameters Set)
- ***Derived Data*** (0 Parameters Set)

MAG - Magnetometer

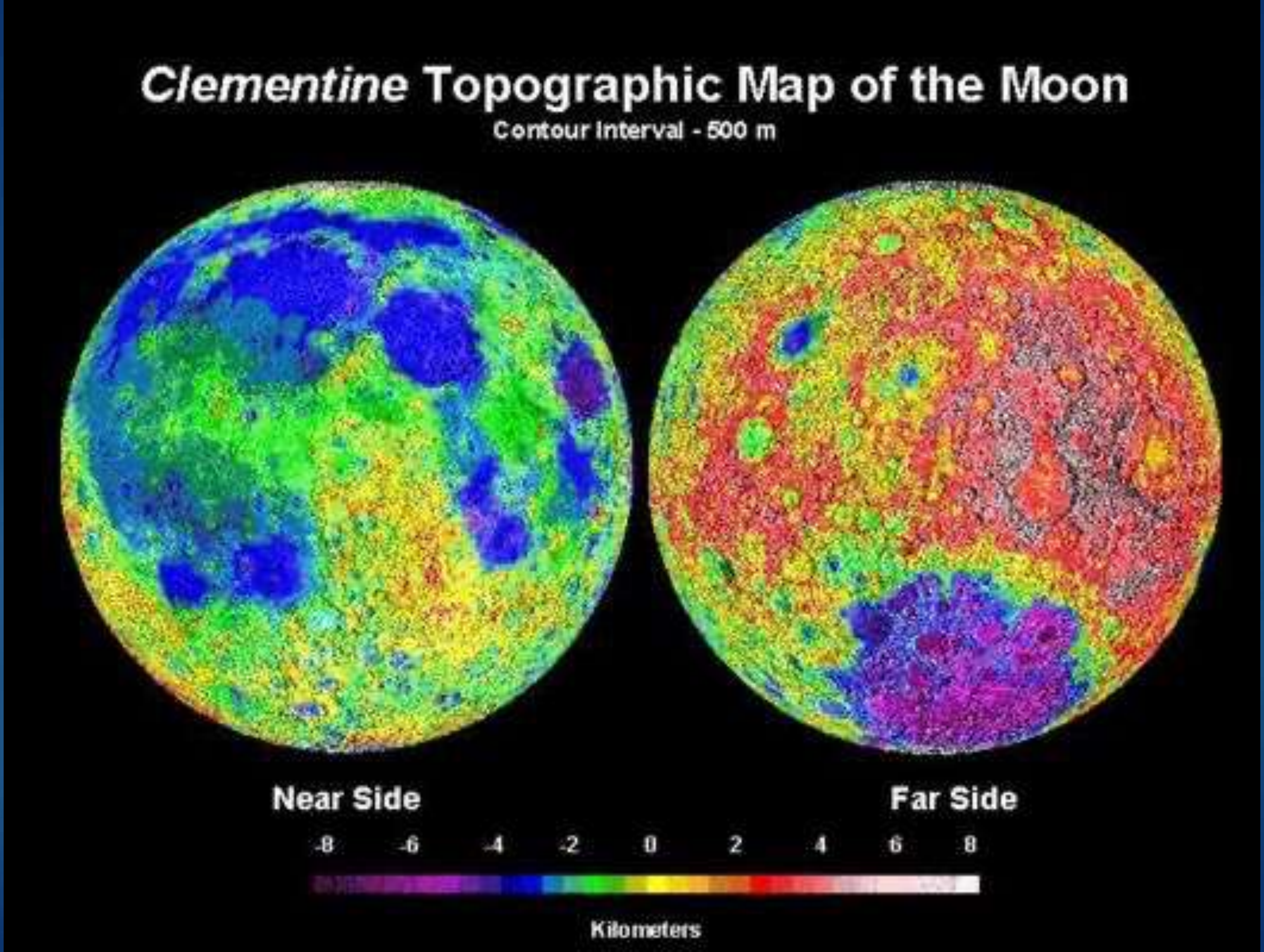
- ***Calibrated Data*** (0 Parameters Set)
- ***Derived Data*** (0 Parameters Set)

NS - Neutron Spectrometer

- ***Calibrated Data*** (0 Parameters Set)

RSS - Radio Science Subsystem

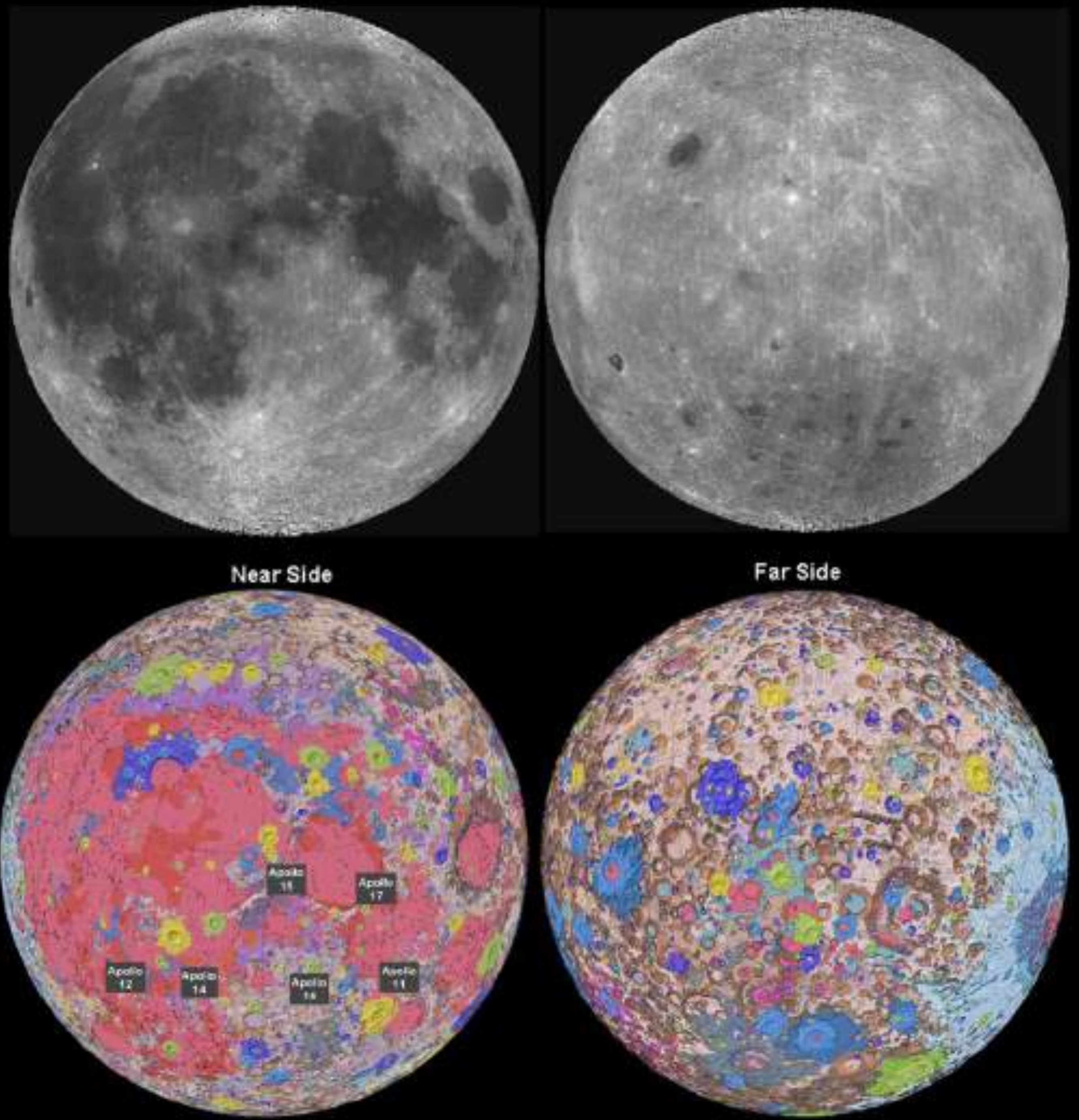
- ***Derived Data*** (0 Parameters Set)

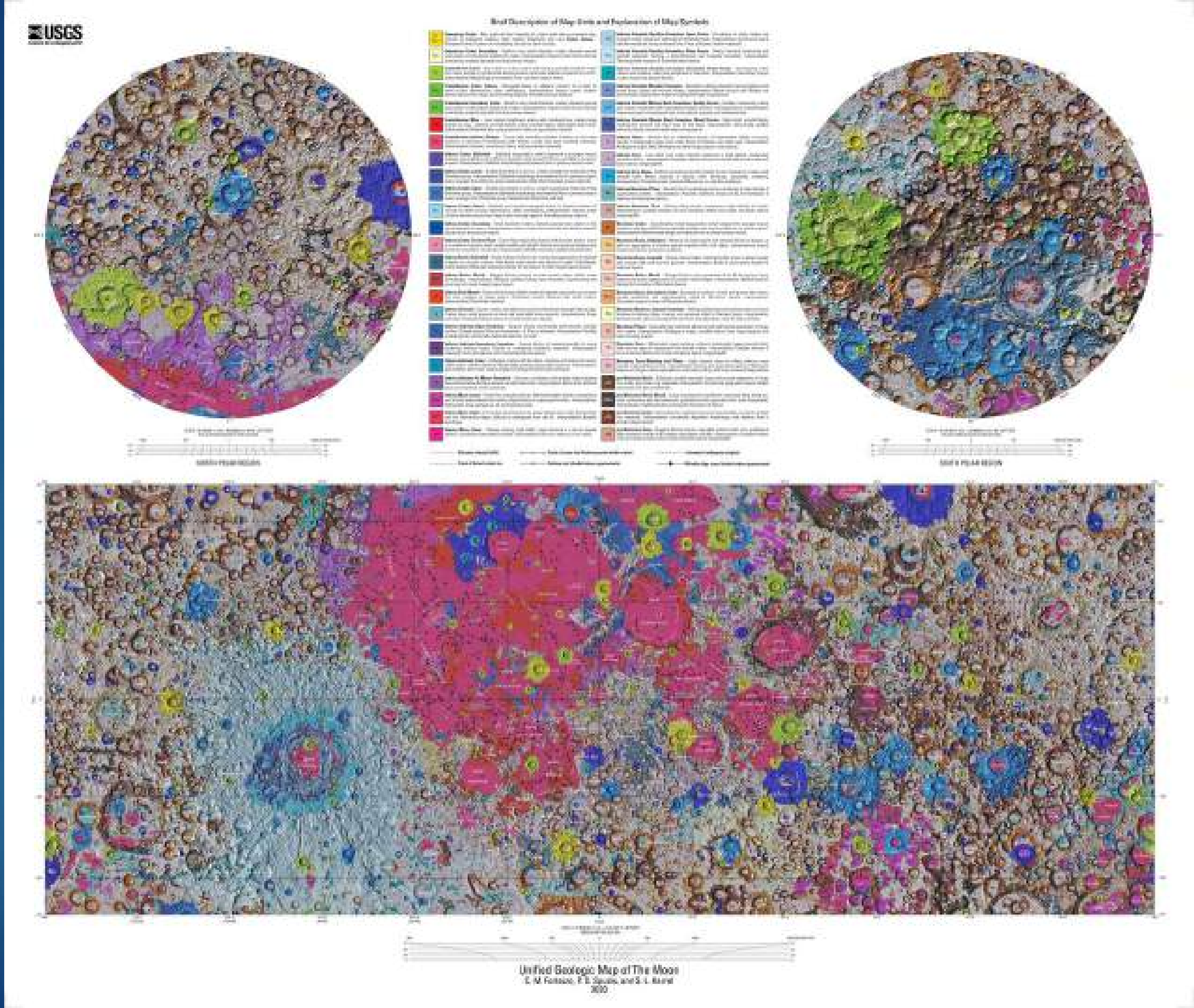

Clementine Topographic Map of the Moon
Contour Interval - 500 m
Near Side
Far Side
-8 -6 -4 -2 0 2 4 6 8
Kilometers

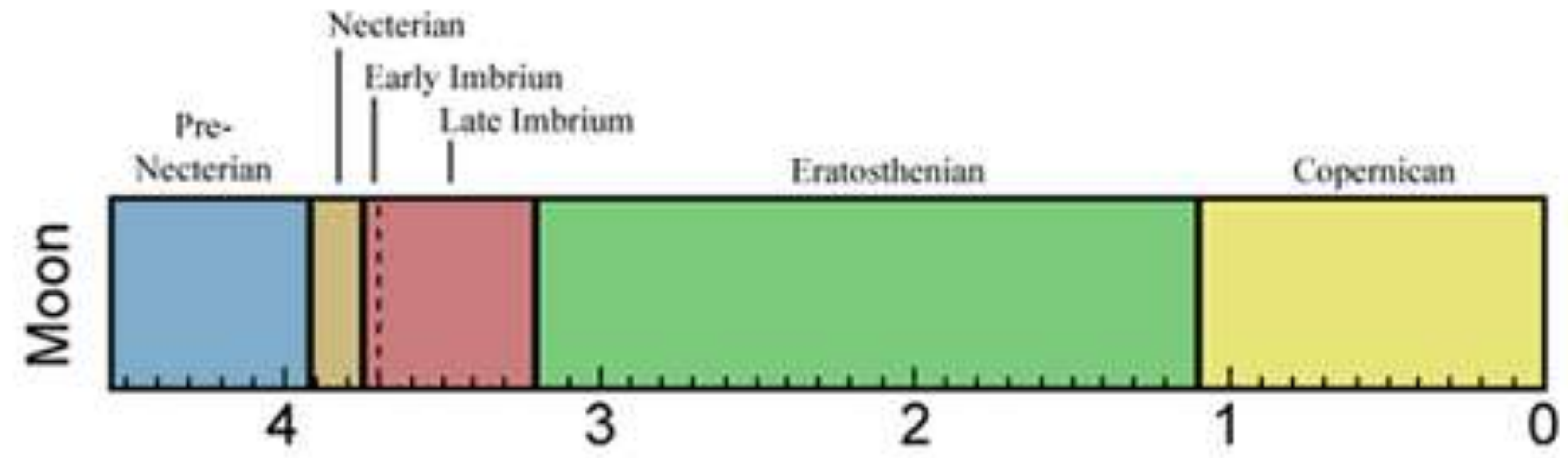
CLEMENTINE MISSION

albedo

geological mapping




USGS
Unified Geologic Map of The Moon



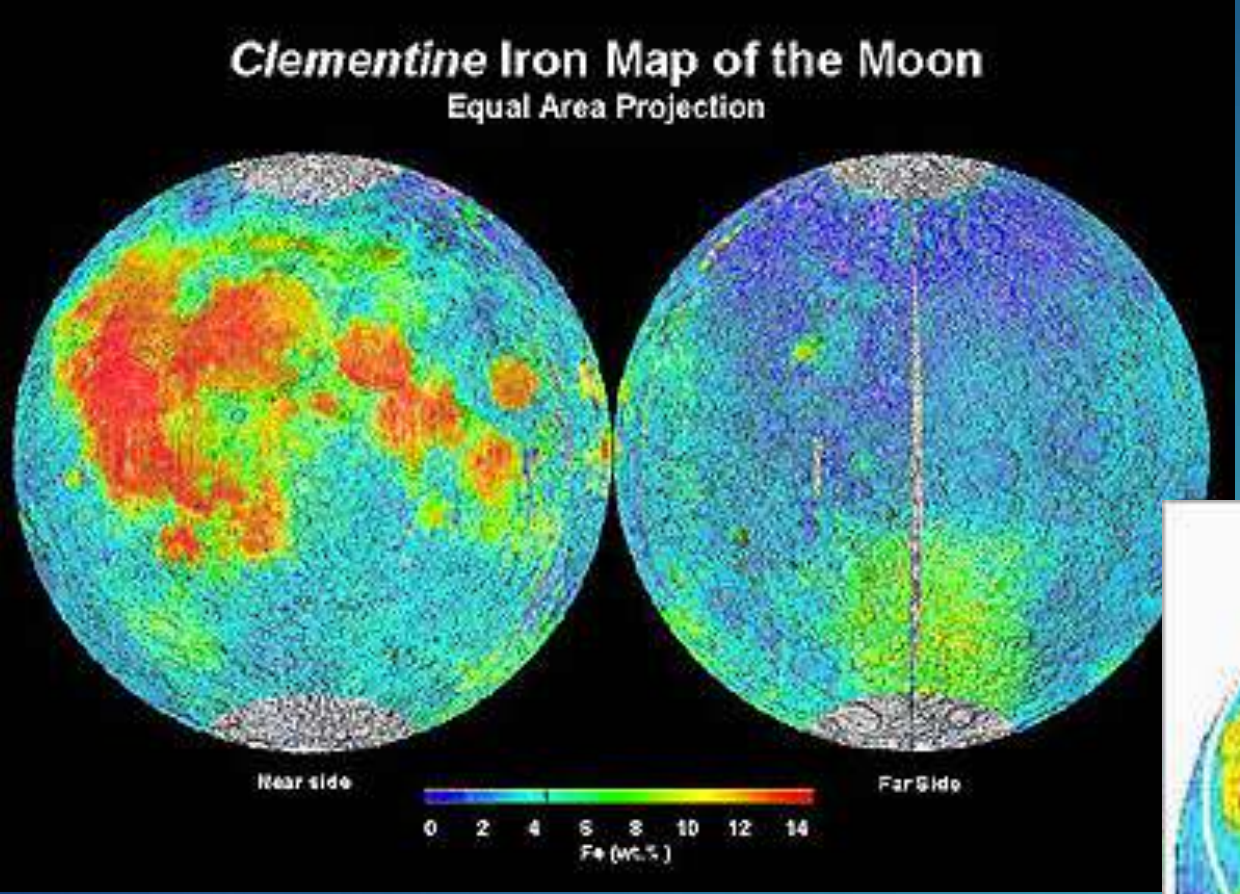
Em **Eratosthenian Mare** - Low relative brightness plains with relatively few craters large enough to map, patches of small domes, sharp-crested ridges, observable flow fronts. *Interpretation:* Relatively thin, young volcanic flows or pyroclastic material.

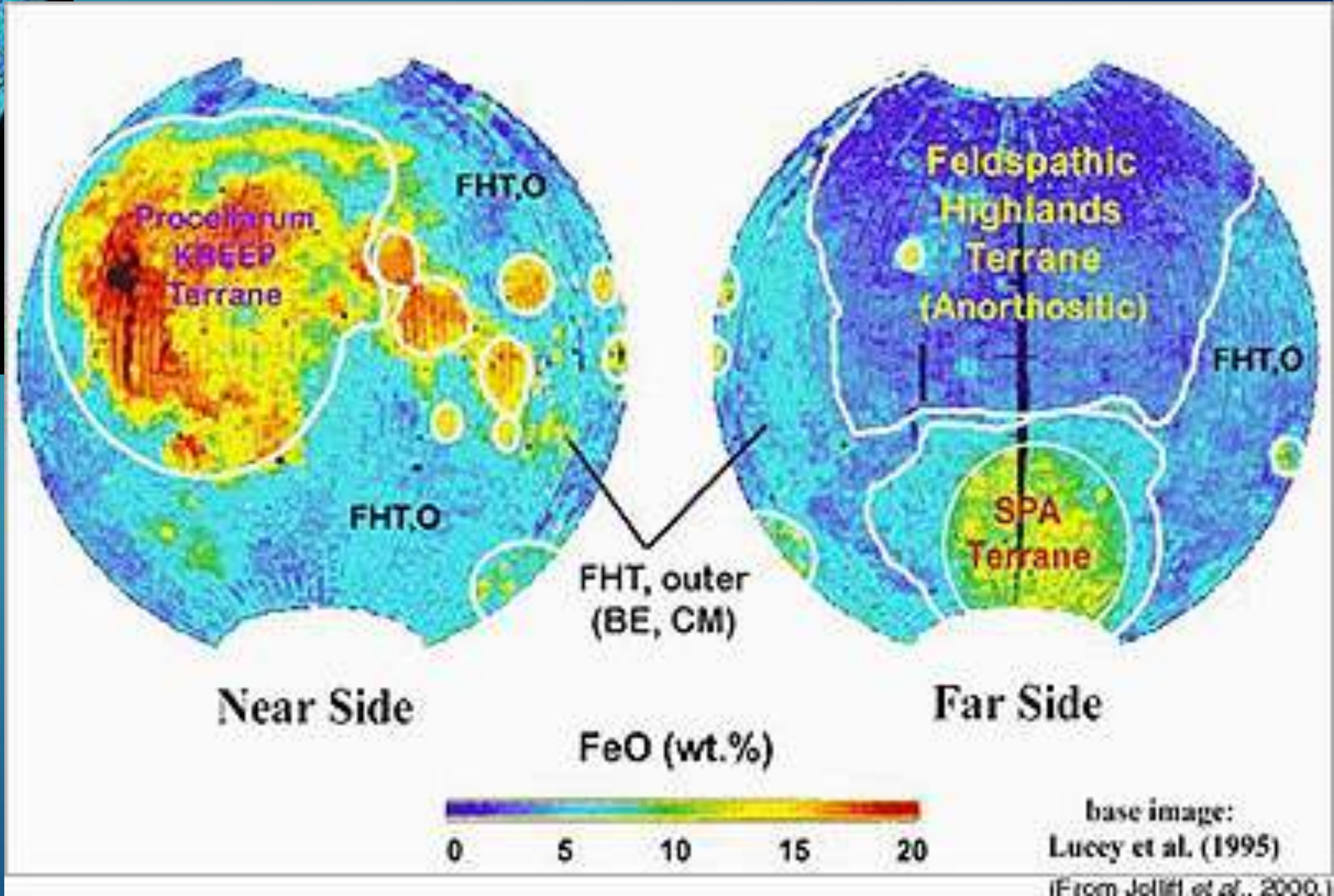
Iorm **Imbrian Orientale Montes Rook Formation, Massif Facies** - High-relief, smooth blocks marking the second and third rings of the basin. *Interpretation:* Structurally uplifted bedrock, thickly veneered with late arriving ejecta.

Nt **Nectarian Terra** - Moderately rough surface, rolling to moderately rugged overall relief, with diverse ages of superposed and buried craters. *Interpretation:* Complex mixture of local erosional debris and crater and basin ejecta; megaregolith.

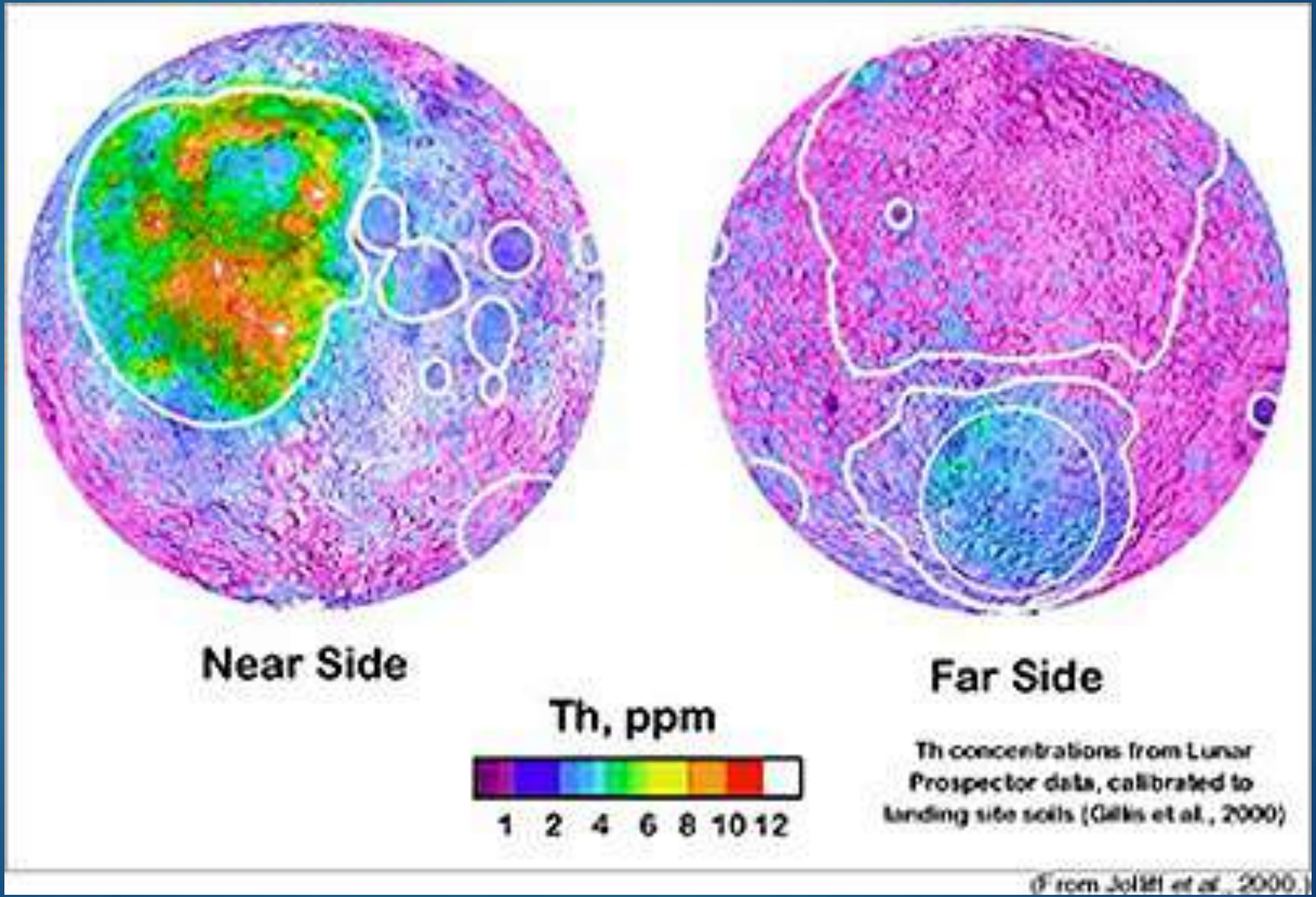
CLEMENTINE
AND
LUNAR PROSPECTOR MAP

Fe content





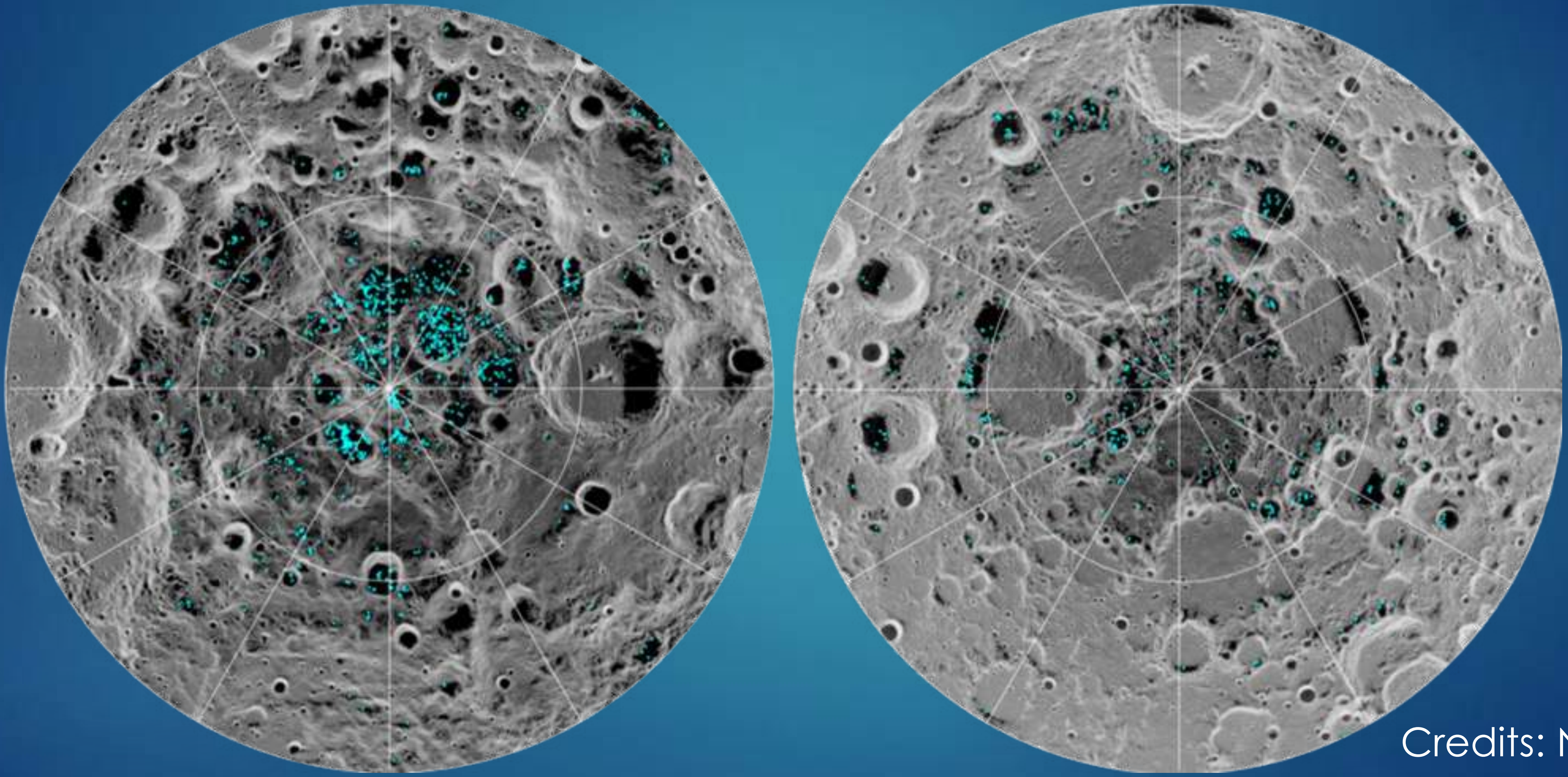
Lunar Prospector. Element thorium is highest on the front side of the Moon, mainly in the highlands south of Mare Imbrium



ICE ON THE SOUTH POLE OF THE MOON

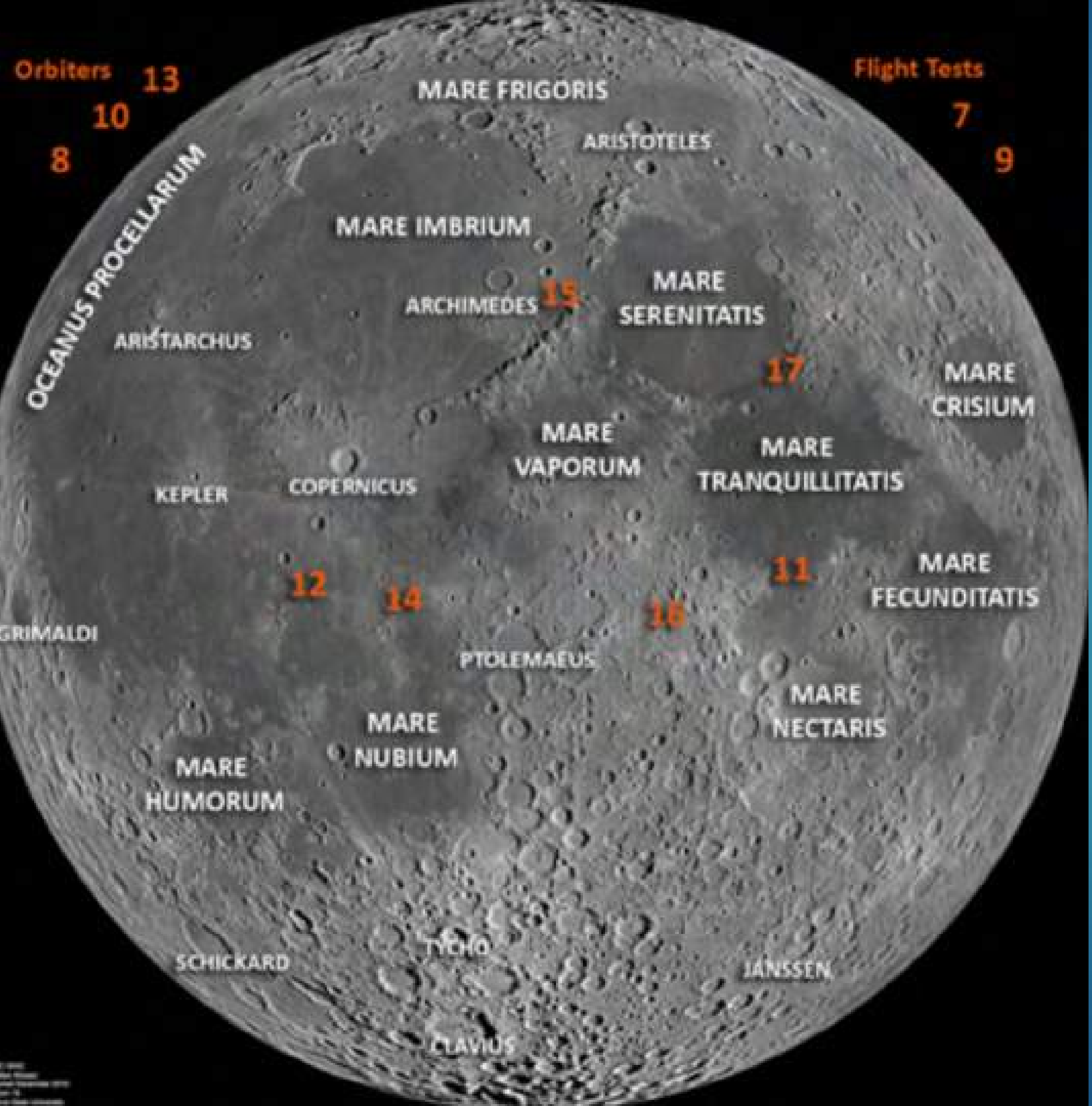
distribution of surface ice at the Moon's south pole (left) and north pole (right)

The ice is concentrated at the darkest and coldest locations, in the shadows of craters



Credits: NASA

Moon Mineralogy Mapper (M3) instrument aboard the Chandrayaan-1 spacecraft

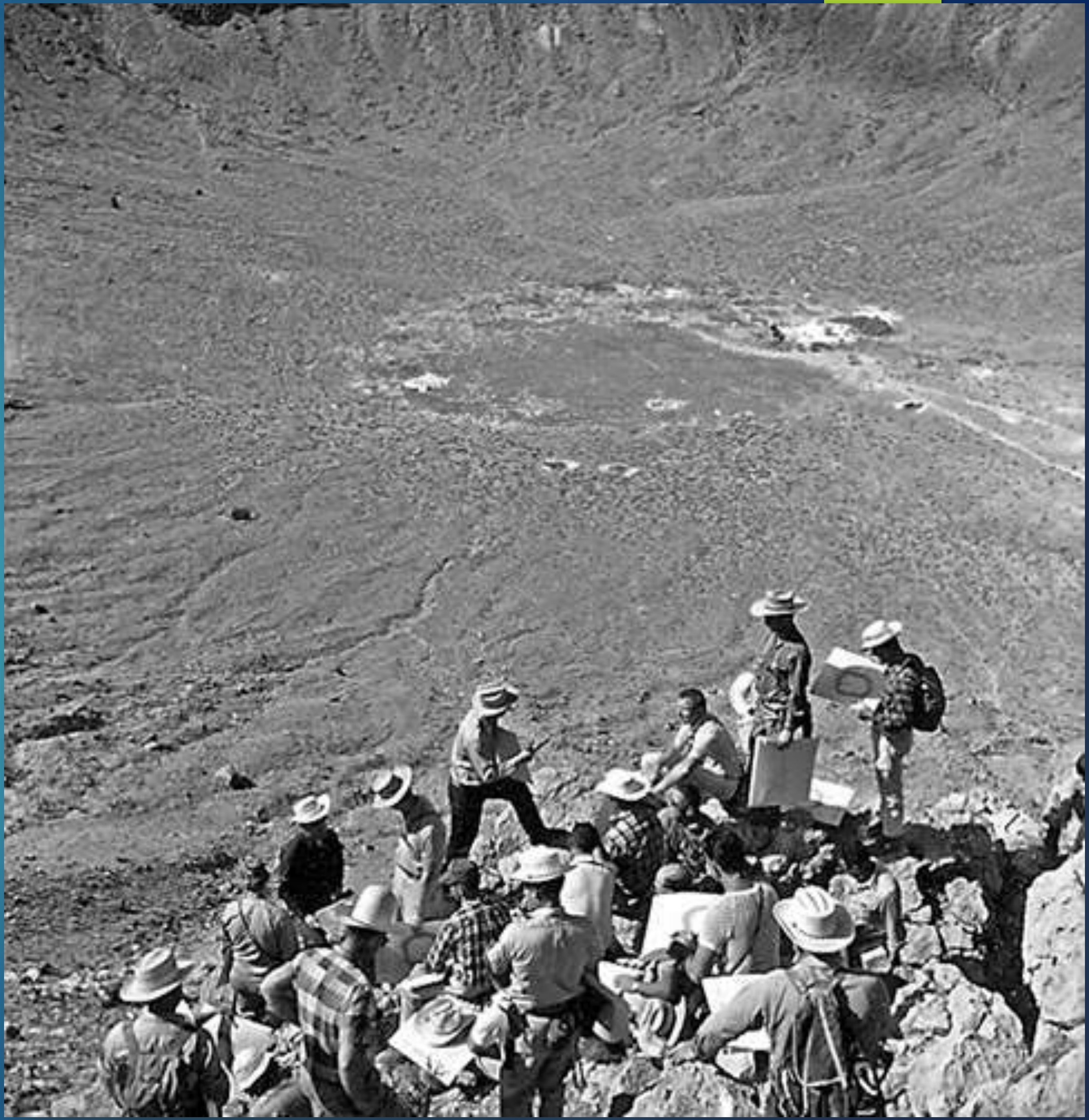


APOLLO MISSIONS

real ground-truth on the Moon!

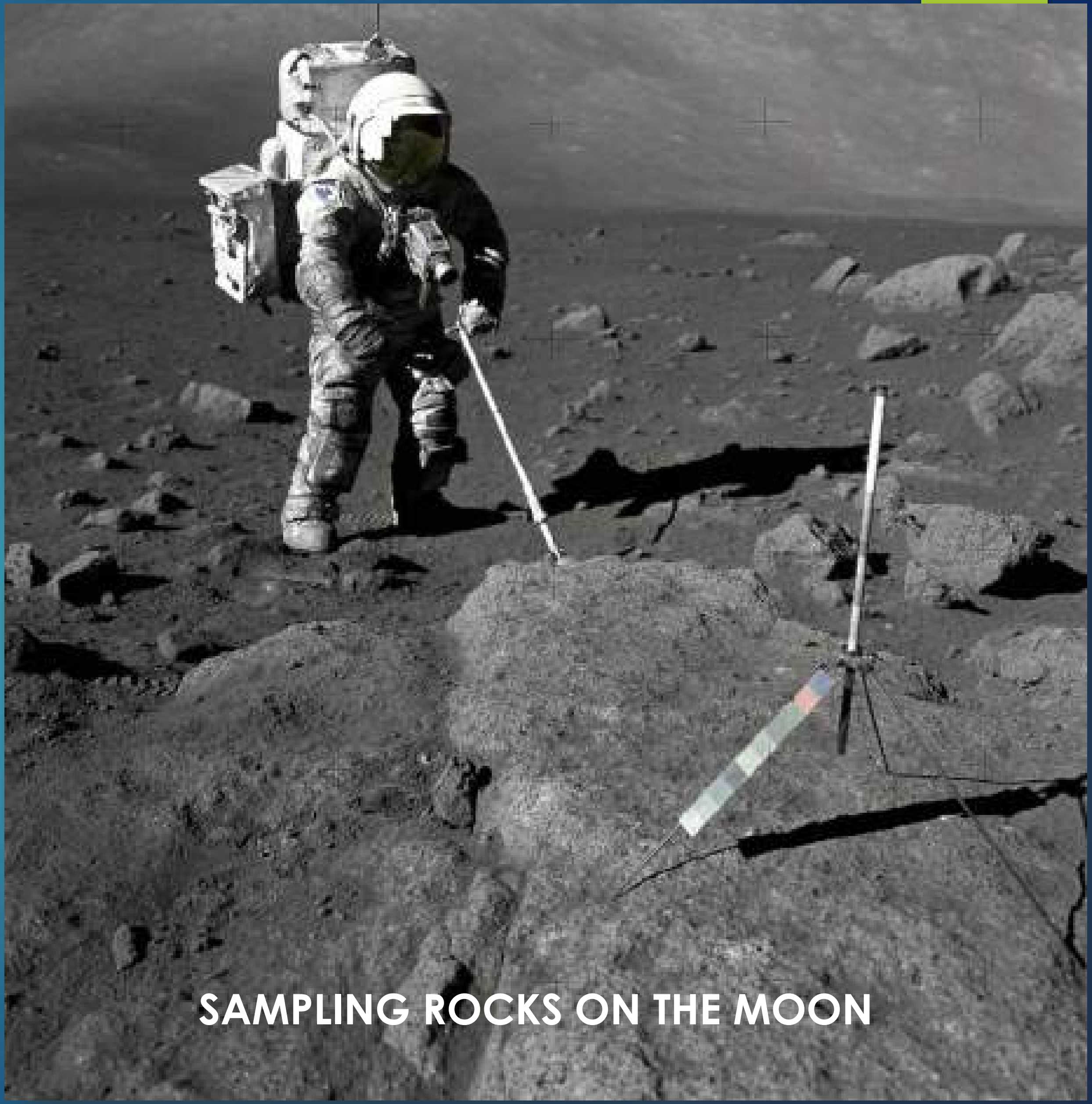
EUGENE SHOEMAKER

geologist and traineer of the Apollo astronauts

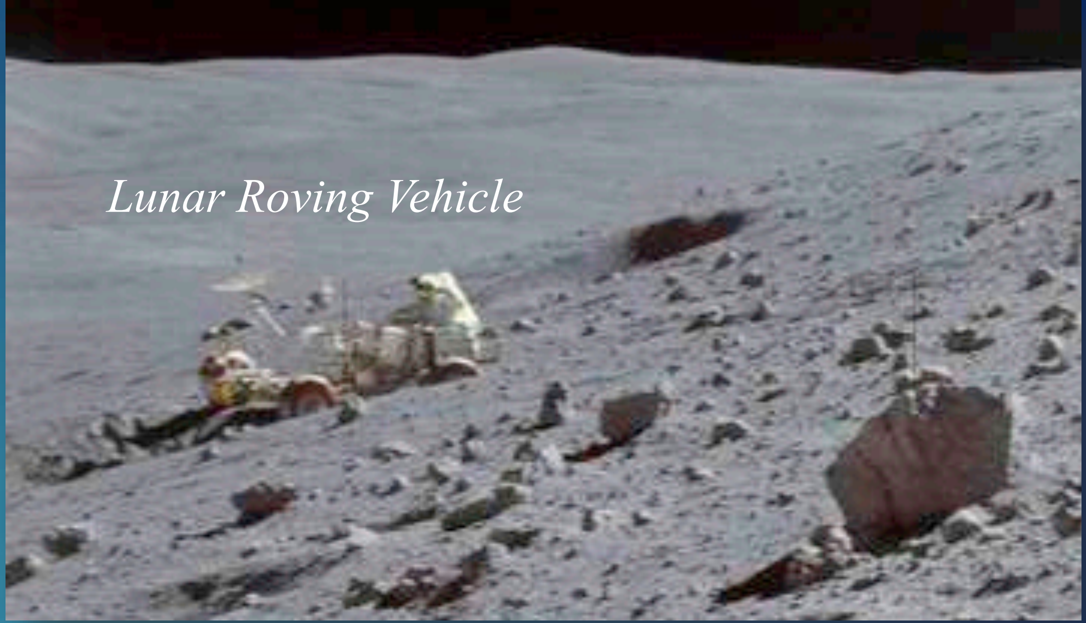


Harrison Hagan "Jack" Schmitt, the first geologist-astronaut

Apollo 17 mission, 1972




Stone Mountain , Apollo 16


Lunar Roving Vehicle

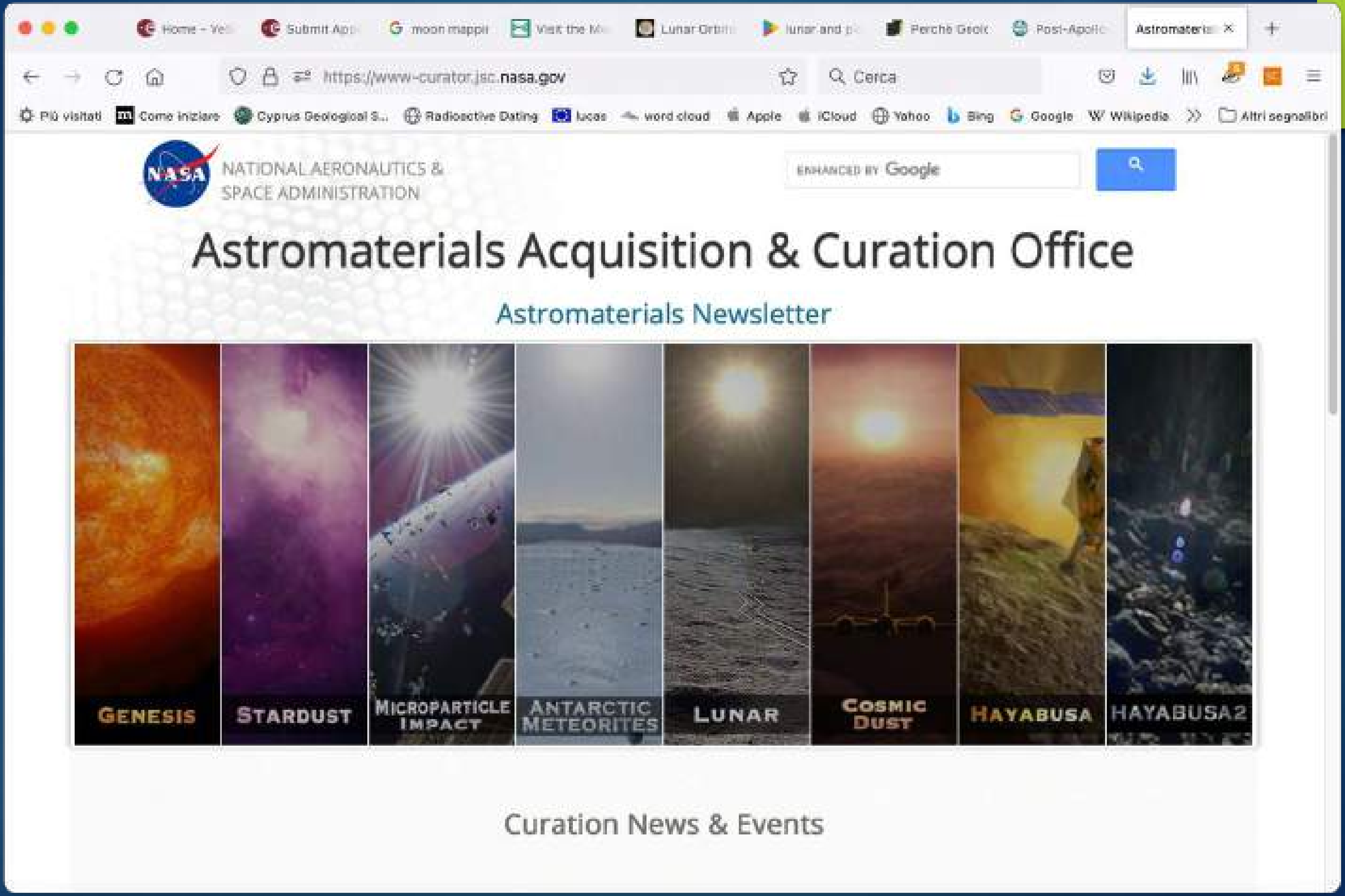
HAMMERING THE MOON!

BASALT

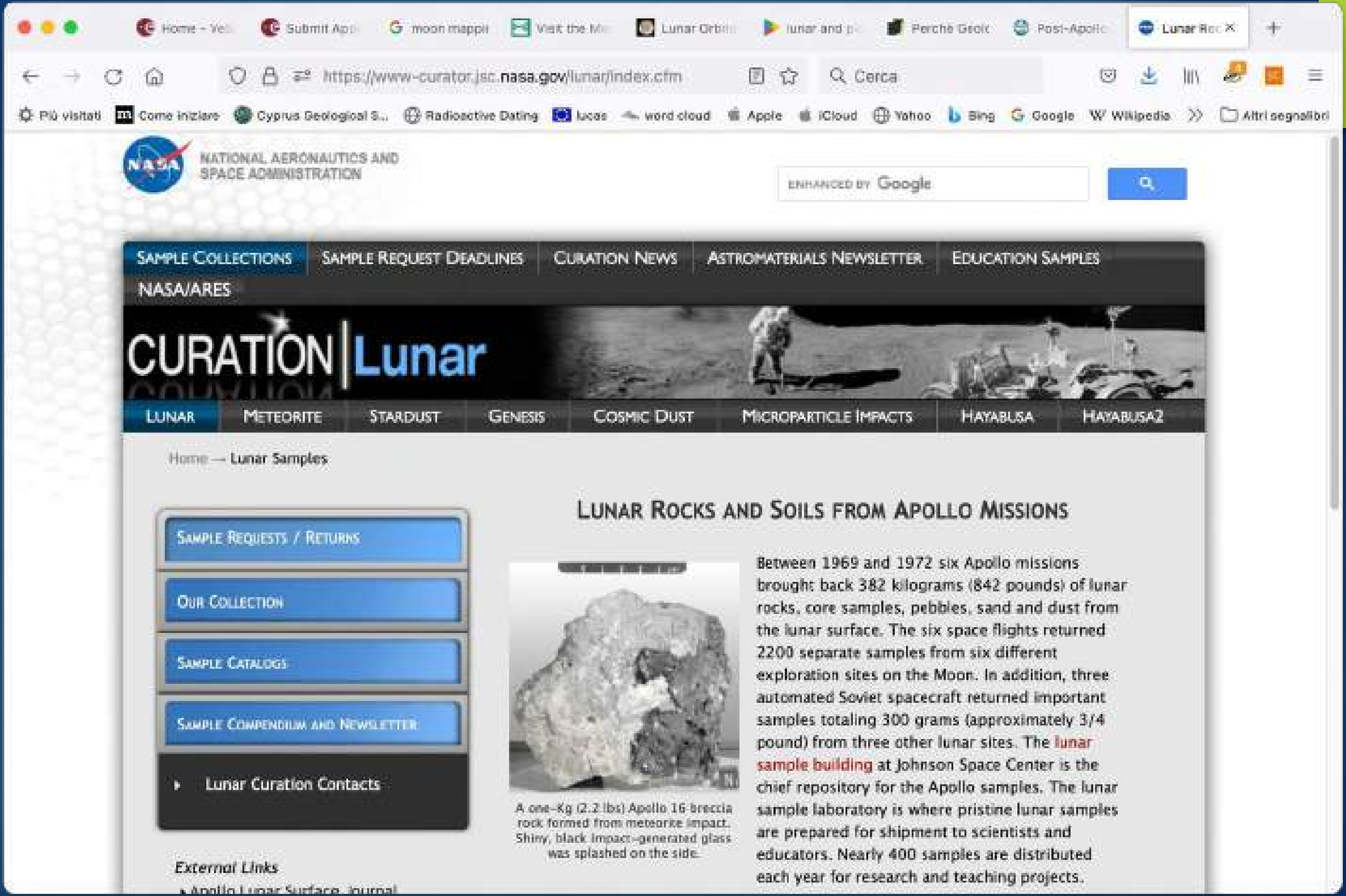
MARIA

ANORTHOSITE

HIGHLAND



https://www-curator.jsc.nasa.gov/

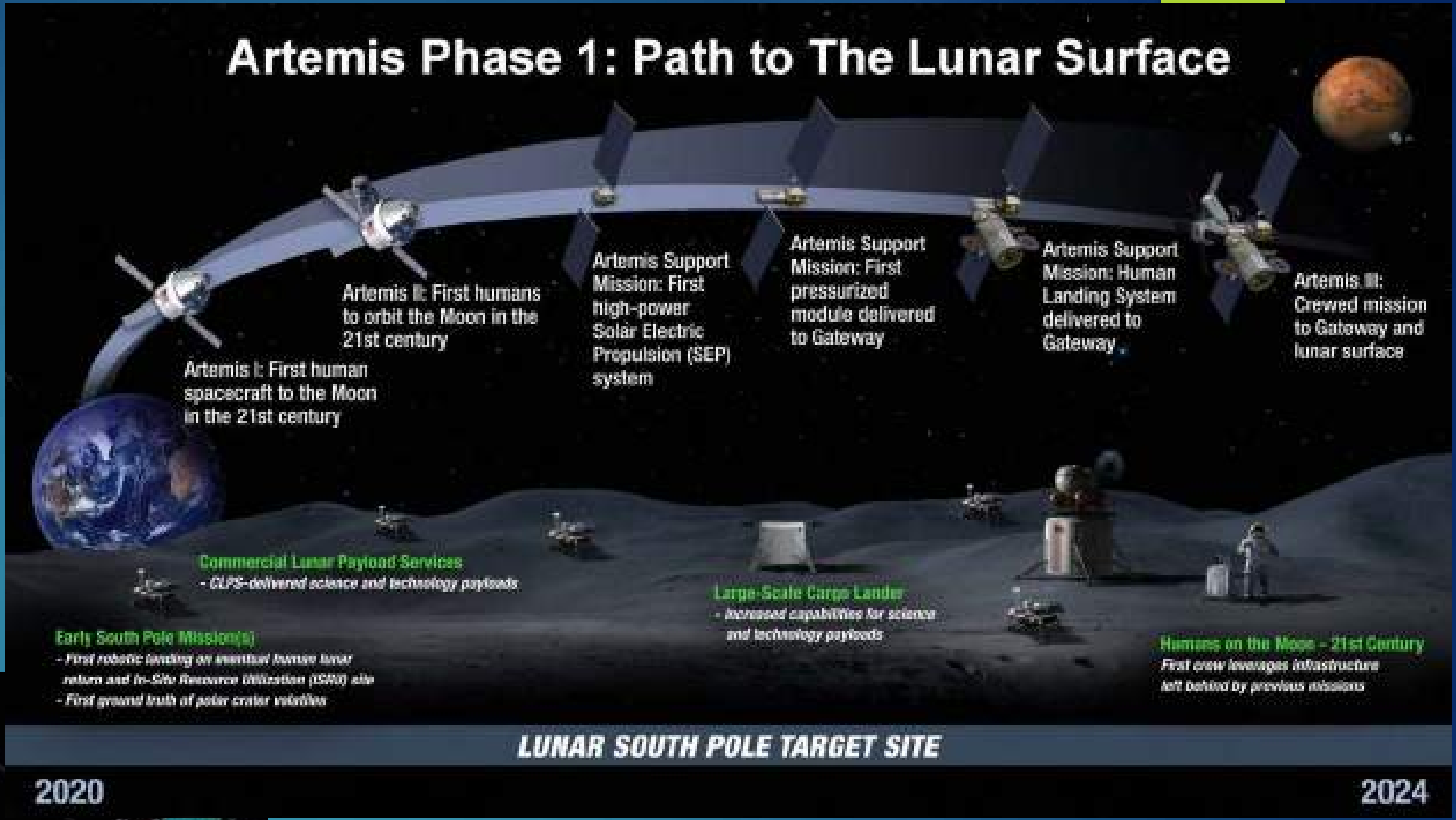

https://www-curator.jsc.nasa.gov/lunar/index.cfm
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Sample Collections
Sample Request Deadlines
Curation News
Astromaterials Newsletter
Education Samples
NASA/ARES
CURATION | Lunar
Lunar
Meteorite
Stardust
Genesis
Cosmic Dust
Microparticle Impacts
Hayabusa
Hayabusa2
Home — Lunar Samples
Lunar Rocks and Soils from Apollo Missions
Sample Requests / Returns
Our Collection
Sample Catalogs
Sample Compendium and Newsletter
Lunar Curation Contacts
External Links
Between 1969 and 1972 six Apollo missions brought back 382 kilograms (842 pounds) of lunar rocks, core samples, pebbles, sand and dust from the lunar surface. The six space flights returned 2200 separate samples from six different exploration sites on the Moon. In addition, three automated Soviet spacecraft returned important samples totaling 300 grams (approximately 3/4 pound) from three other lunar sites. The lunar sample building at Johnson Space Center is the chief repository for the Apollo samples. The lunar sample laboratory is where pristine lunar samples are prepared for shipment to scientists and educators. Nearly 400 samples are distributed each year for research and teaching projects.
A one-Kg (2.2 lbs) Apollo 16 breccia rock formed from meteorite impact. Shiny, black impact-generated glass was splashed on the side.

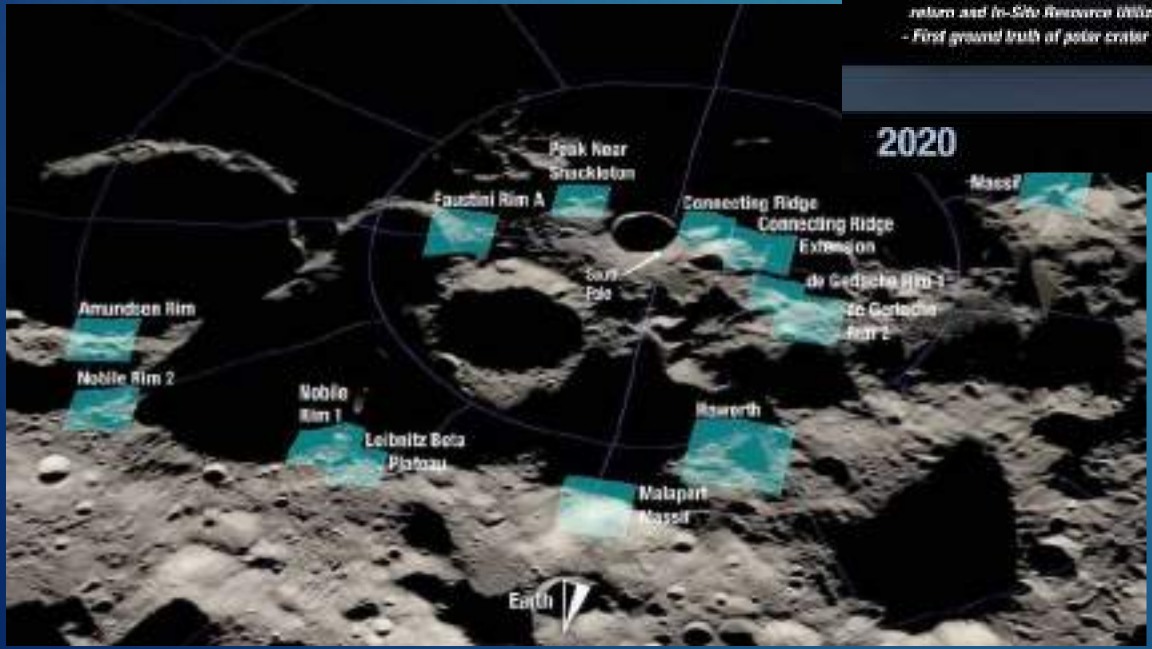
20 Years of Missions to the Moon

Missions to the moon or its orbit in the last 20 years

space craft	launch date	country	type
Chang'e 5*	Nov 24, 2020	China	Robotic lander return mission
Chandrayaan-2	Jul 22, 2019	India	Failed lander and rover mission (hard impact)
Beresheet	Feb 22, 2019	Israel	Failed robotic lander mission (hard impact)
Chang'e-4	Dec 7, 2018	China	Second rover landing on dark side of the moon
Queqiao	May 20, 2018	China	Communication satellite for farside landing
Chang'e 5 test mission	Oct 23, 2014	China	Flyby and return
Chang'e 3	Dec 1, 2013	China	Lander and rover mission
LADEE	Sept 6, 2013	USA	Orbiter surveying atmosphere and dust
GRAIL	Sept 10, 2011	USA	Orbiter measuring lunar gravity
Chang'e 2	Oct 1, 2010	China	Orbiter scouting for landing spots
LCROSS & Lunar Reconnaissance	Jun 17, 2009	USA	Orbiter/impactor finding water on moon
Chandrayaan-1	Oct 22, 2008	India	India's first orbiter and impactor
Chang'e 1	Oct 24, 2007	China	China's first orbiter
Kaguya	Sept 14, 2007	Japan	Orbiter for geological survey
SMART-1	Sept 27, 2003	EU	Orbiter testing solar-powered ion drive

As of Nov 23, 2020
* ongoing
Source: NASA





potential landing sites → detailed geological mapping!

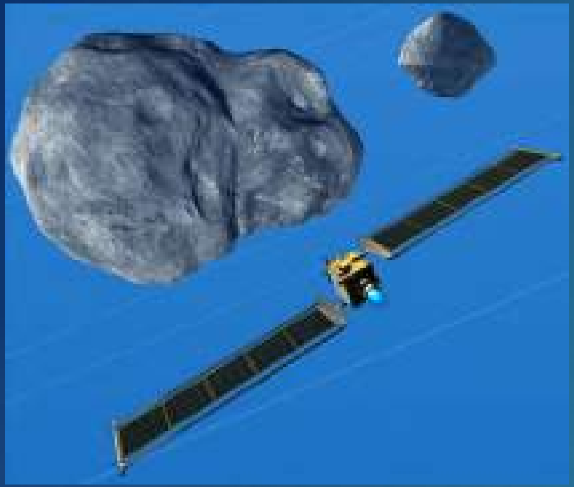
THE CREW OF

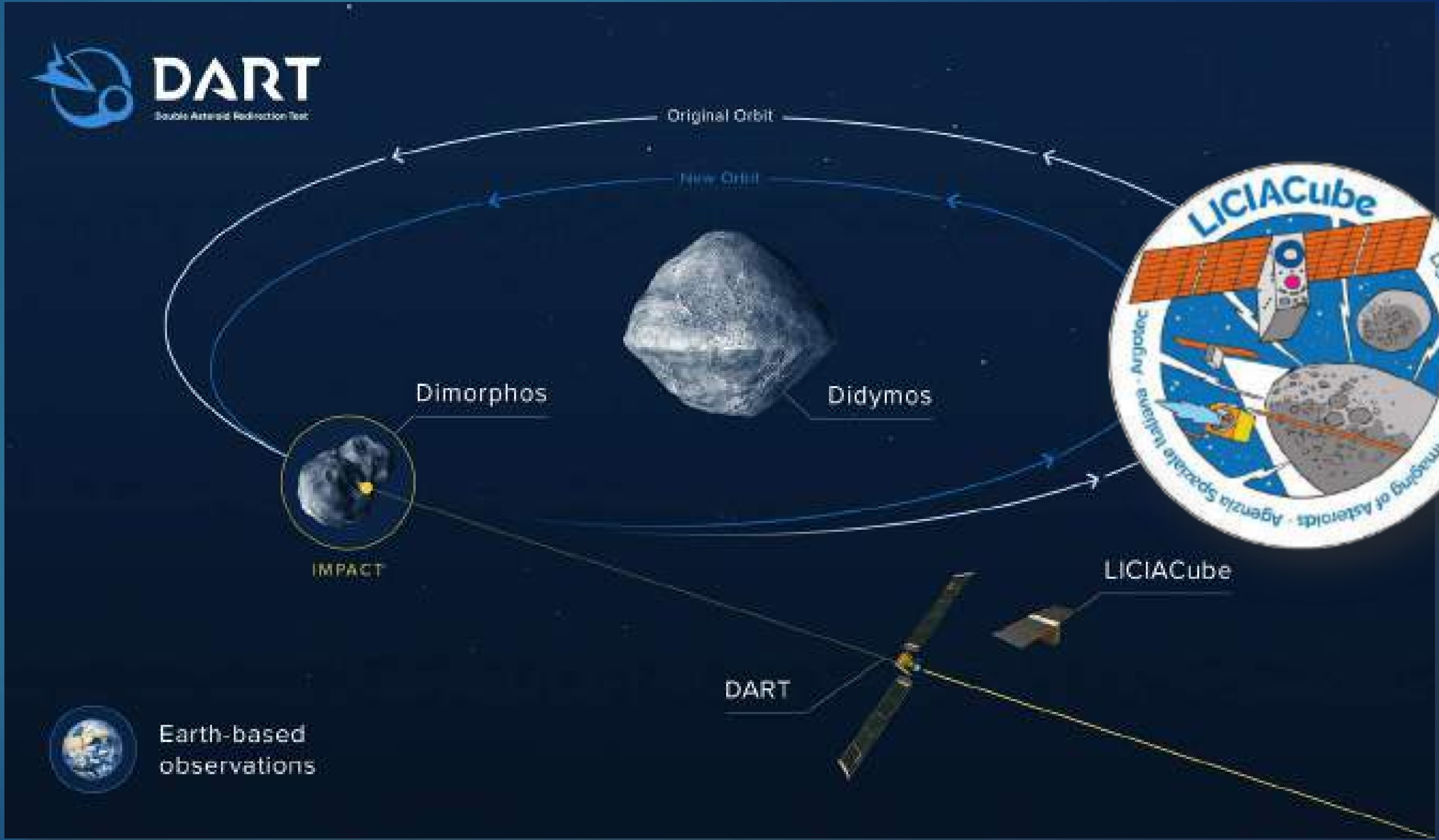
ARTEMIS 1

STAY TUNED FOR ON-GOING MOON EXPLORATION!

DO NOT FORGET…. DART IMPACT TONIGHT

DART: Double Asteroid Redirection Test





DART Impact:
September 26, 2022
7:14 p.m. EDT

1:14 a.m. Italian time
27 September

Co-funded by the
ERASMUS + Programme
of the European Union

Data in planetary science

WHERE AND WHAT

Planetary data: where

- NASA
  - PLANETARY DATA SYSTEM
    - https://pds-geosciences.wustl.edu/default.htm
  - Orbital Data Explorer
    - http://ode.rsl.wustl.edu
- ESA
  - PLANETARY SCIENCE ARCHIVE
    - https://archives.esac.esa.int/psa/

Planetary data: wher

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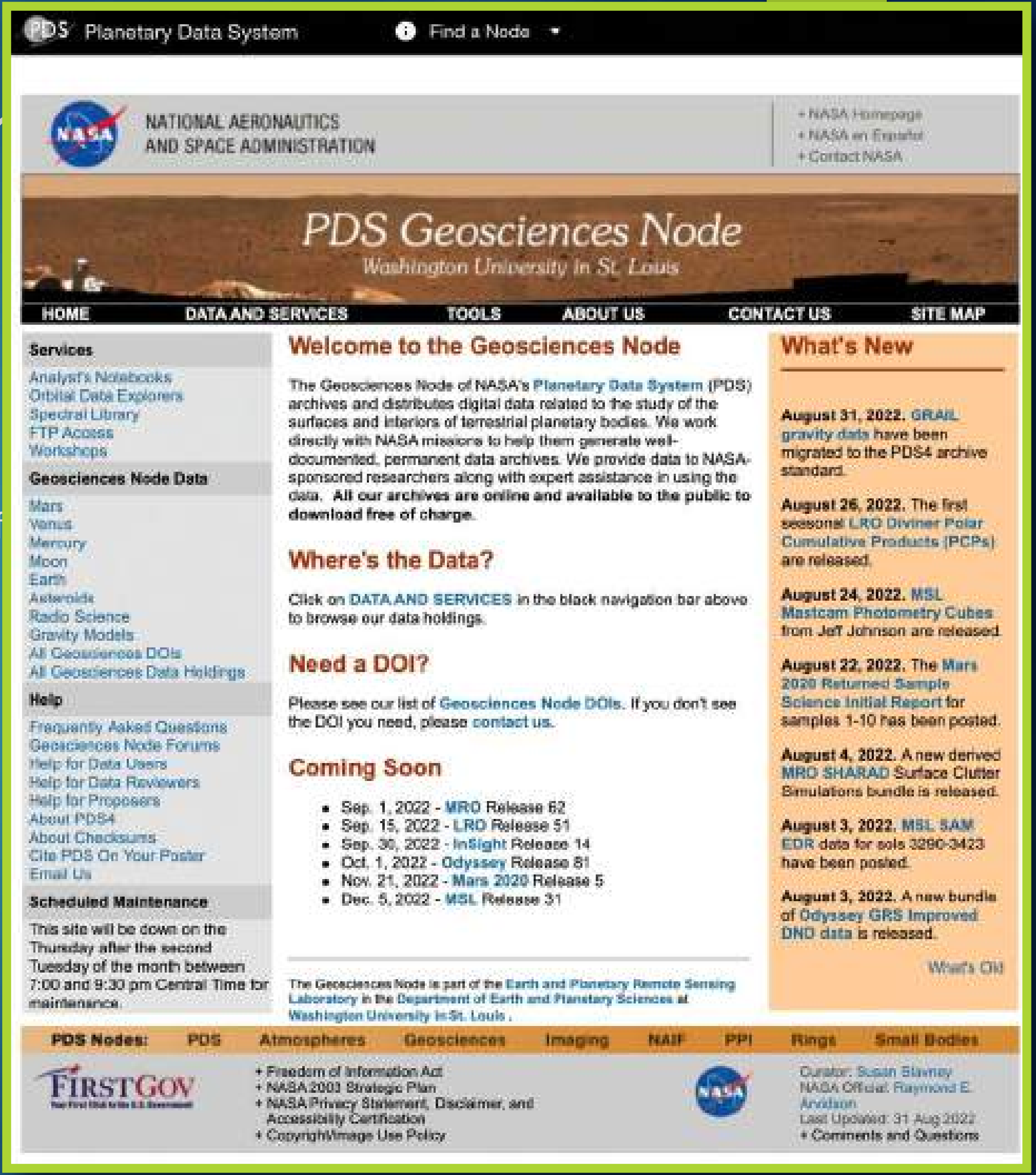

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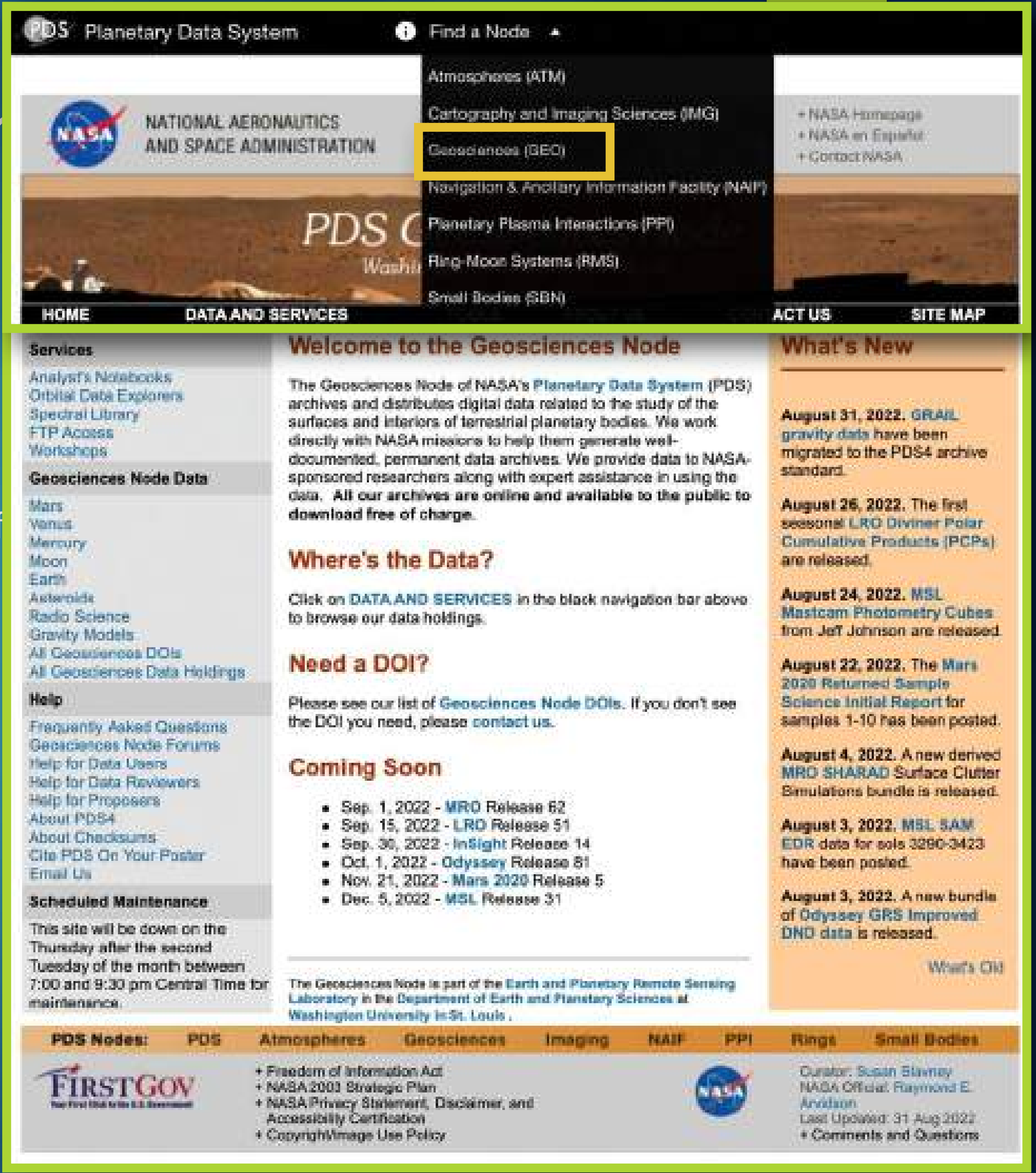

Planetary data: wher

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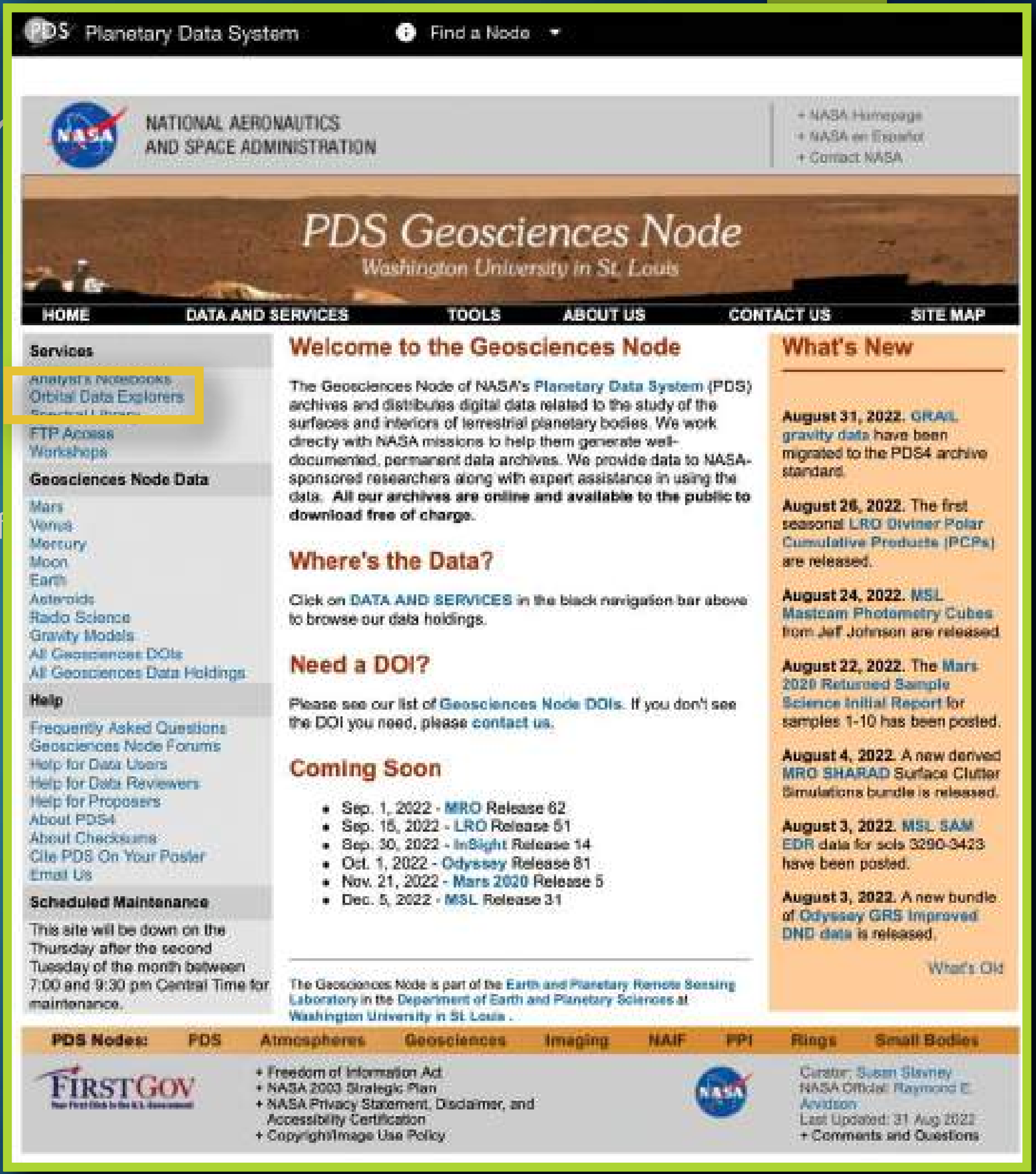

Planetary data: wher

- NASA
  - PLANETARY DATA SYSTEM
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  - Orbital Data Explorer
    - http://ode.rsl.wustl.edu
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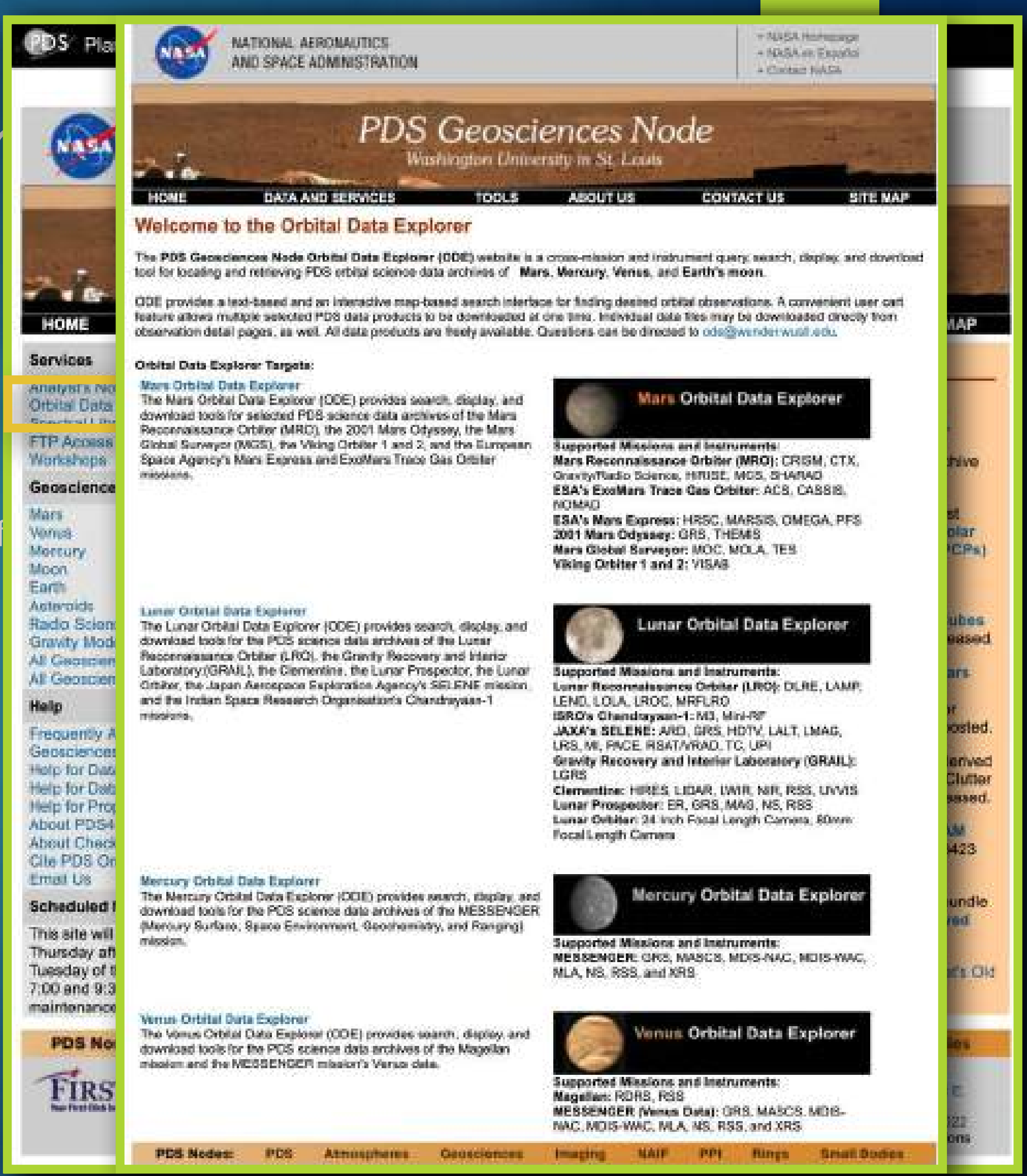
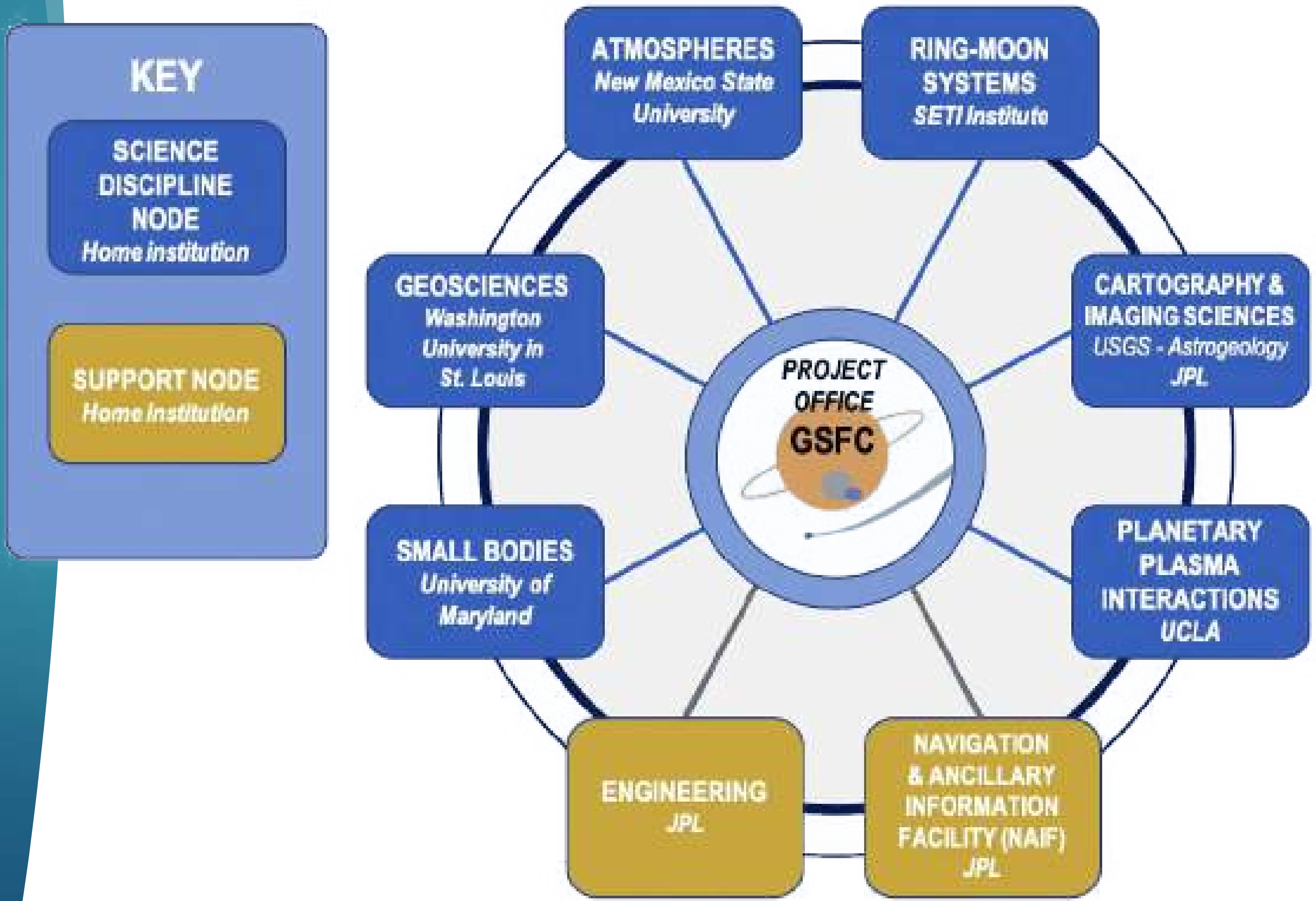
    - https://archives.esac.esa.int/psa/



Planetary Data System (PDS)

- Archive of digital data products returned from NASA's (not only now) planetary missions
- The archive is managed to help ensure its usefulness and usability by the worldwide planetary science community.



https://pds.nasa.gov/home/about/

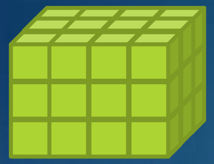
PDS Standards

- The PDS Standards are requirements and constraints designed to insure the usability of data in the PDS Archive throughout the lifetime of the archive.
- PDS4 is the latest version of the PDS Standard.

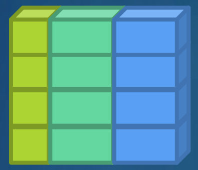
https://pds.nasa.gov/datastandards/about/

Fundamental Data Structures

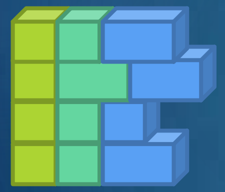
- PDS4 archive products must be describable using one of the following fundamental structures:



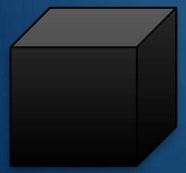
  - **Array** – homogenous binary structures of 1 to 16 dimensions in which all of the elements have the same data type.



  - **Table** – ASCII or binary data with a repeating record structure made up of fixed-width fields.



  - **Parsable Byte Stream** – ASCII data with a repeating record structure made up of variable width fields separated by a field delimiter (e.g. CSV).



  - **Encoded Byte Stream** – Files formatted according to some established standard (e.g., PDF).

PDS4 Archive Organization

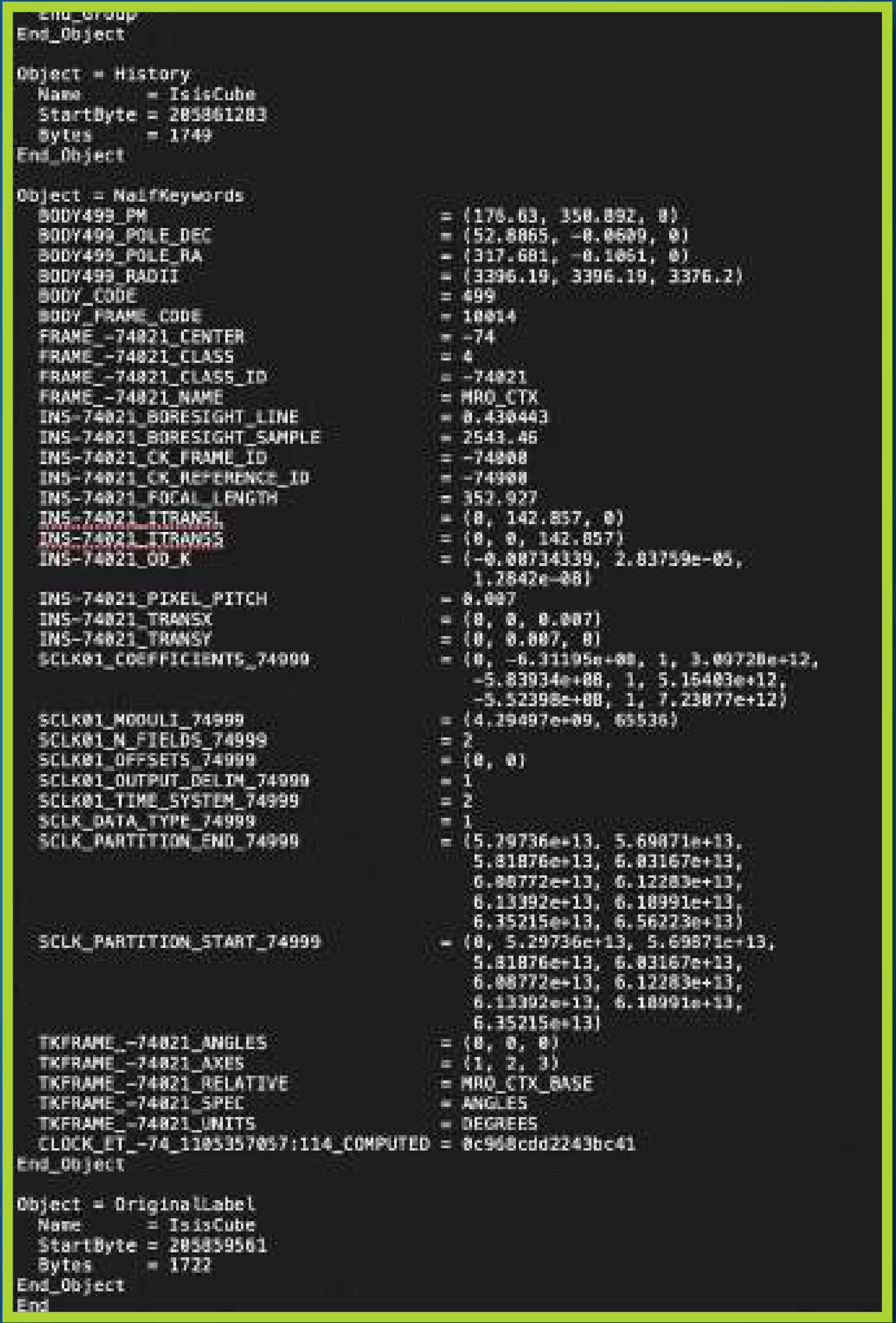
- There are 3 primary types of products in PDS4:
  - A PDS label along with the file or files that it describes constitutes a PDS Product.
    - A file containing PDS metadata is called a PDS Label.
    - PDS labels are co-located with the files that they describe.
  - Related basic products of the same type may be grouped together into a Collection.
  - Related collections may be grouped together into a Bundle.

PDS4 Product

https://pds.jpl.nasa.gov/datastandards/training/

Label

- Label changes after each proc step including the new information



```
  End_Group
End_Object

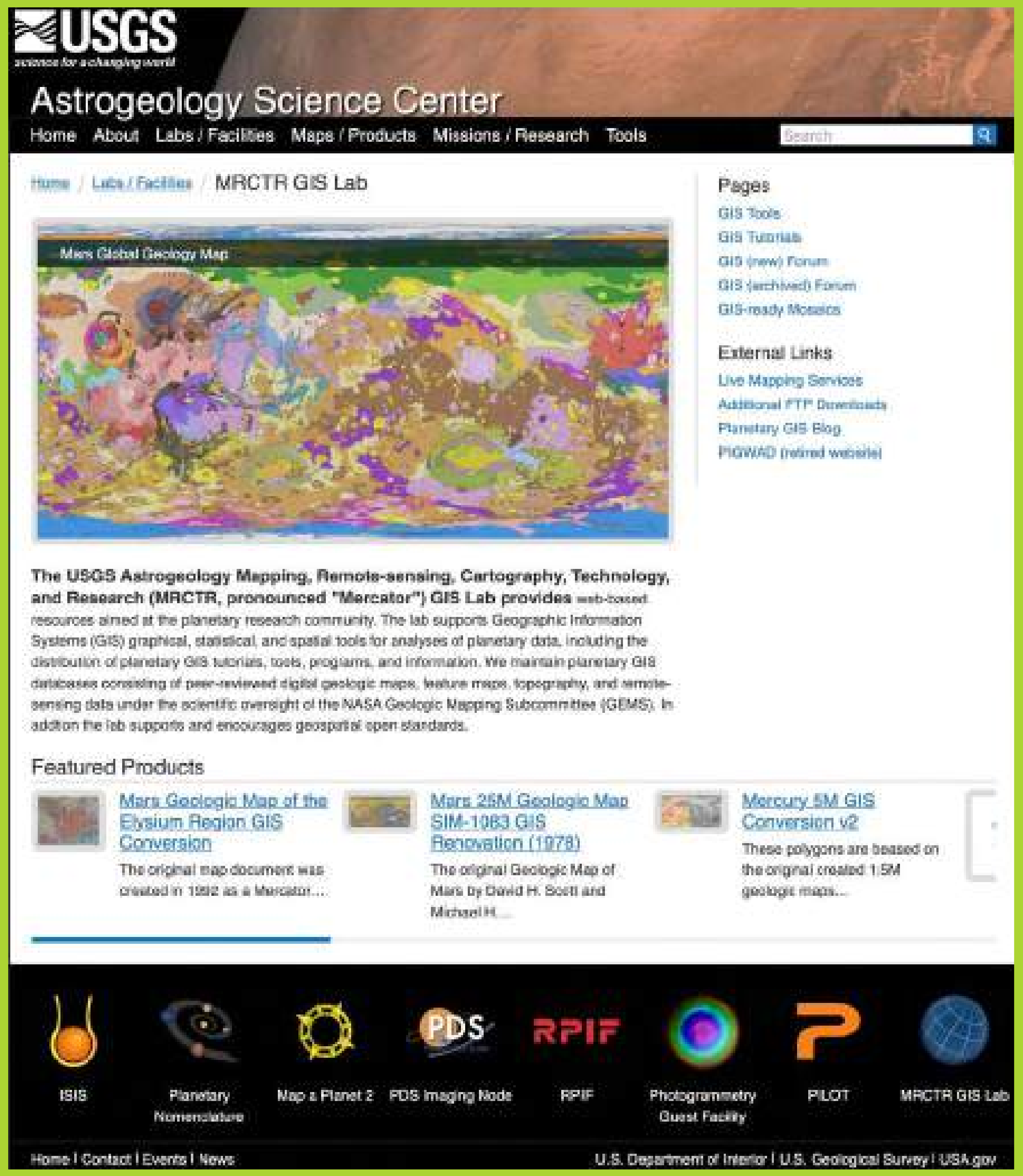
Object = History
  Name      = IsisCube
  StartByte = 285861283
  Bytes     = 1749
End_Object

Object = NaifKeywords
  BODY499_PM                             = (176.63, 350.892, 0)
  BODY499_POLE_DEC                       = (52.8865, -0.0609, 0)
  BODY499_POLE_RA                        = (317.681, -0.1061, 0)
  BODY499_RADII                          = (3396.19, 3396.19, 3376.2)
  BODY_CODE                              = 499
  BODY_FRAME_CODE                        = 10014
  FRAME_-74021_CENTER                    = -74
  FRAME_-74021_CLASS                     = 4
  FRAME_-74021_CLASS_ID                  = -74021
  FRAME_-74021_NAME                      = MRO_CTX
  INS-74021_BORESIGHT_LINE               = 0.430443
  INS-74021_BORESIGHT_SAMPLE             = 2543.46
  INS-74021_CK_FRAME_ID                  = -74000
  INS-74021_CK_REFERENCE_ID              = -74900
  INS-74021_FOCAL_LENGTH                 = 352.927
  INS-74021_ITRANSL                      = (0, 142.857, 0)
  INS-74021_ITRANSS                      = (0, 0, 142.857)
  INS-74021_OD_K                         = (-0.00734339, 2.83759e-05,
                                            1.2842e-08)
  INS-74021_PIXEL_PITCH                  = 0.007
  INS-74021_TRANSX                       = (0, 0, 0.007)
  INS-74021_TRANSY                       = (0, 0.007, 0)
  SCLK01_COEFFICIENTS_74999              = (0, -6.31195e+08, 1, 3.00728e+12,
                                            -5.83934e+08, 1, 5.16403e+12,
                                            -5.52398e+08, 1, 7.23877e+12)
  SCLK01_MODULI_74999                    = (4.29497e+09, 65536)
  SCLK01_N_FIELDS_74999                  = 2
  SCLK01_OFFSETS_74999                   = (0, 0)
  SCLK01_OUTPUT_DELIM_74999              = 1
  SCLK01_TIME_SYSTEM_74999               = 2
  SCLK_DATA_TYPE_74999                   = 1
  SCLK_PARTITION_END_74999               = (5.29736e+13, 5.69871e+13,
                                            5.81876e+13, 6.03167e+13,
                                            6.08772e+13, 6.12283e+13,
                                            6.13392e+13, 6.18991e+13,
                                            6.35215e+13, 6.56223e+13)
  SCLK_PARTITION_START_74999             = (0, 5.29736e+13, 5.69871e+13,
                                            5.81876e+13, 6.03167e+13,
                                            6.08772e+13, 6.12283e+13,
                                            6.13392e+13, 6.18991e+13,
                                            6.35215e+13)
  TKFRAME_-74021_ANGLES                  = (0, 0, 0)
  TKFRAME_-74021_AXES                    = (1, 2, 3)
  TKFRAME_-74021_RELATIVE                = MRO_CTX_BASE
  TKFRAME_-74021_SPEC                    = ANGLES
  TKFRAME_-74021_UNITS                   = DEGREES
  CLOCK_ET_-74_1105357057:114_COMPUTED   = 0c968cdd2243bc41
End_Object

Object = OriginalLabel
  Name      = IsisCube
  StartByte = 285859561
  Bytes     = 1722
End_Object
End
```

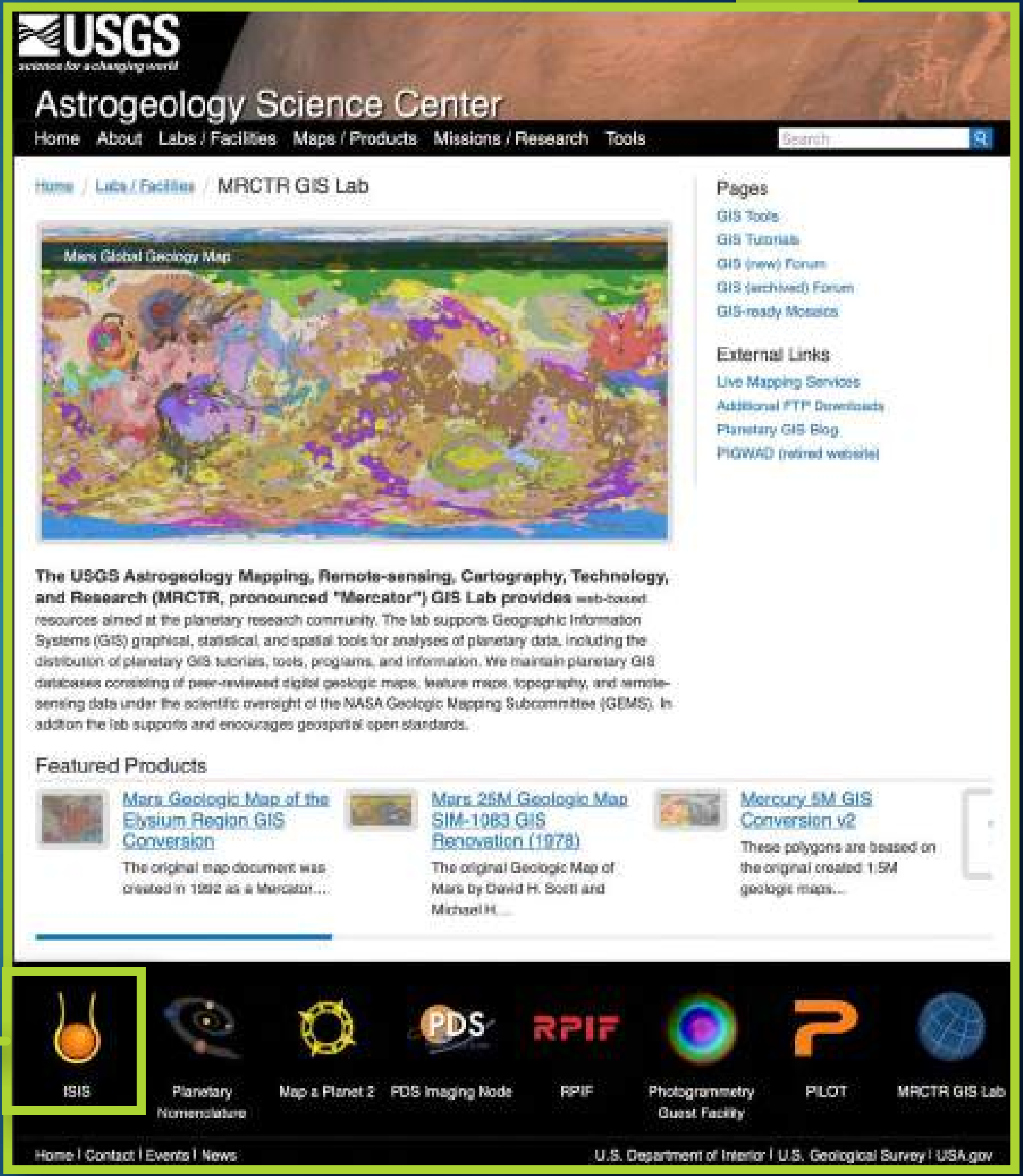
Reference maps/ data

- https://astrogeology.usgs.gov/facilities/mrctr-gis-lab



Reference maps/ data

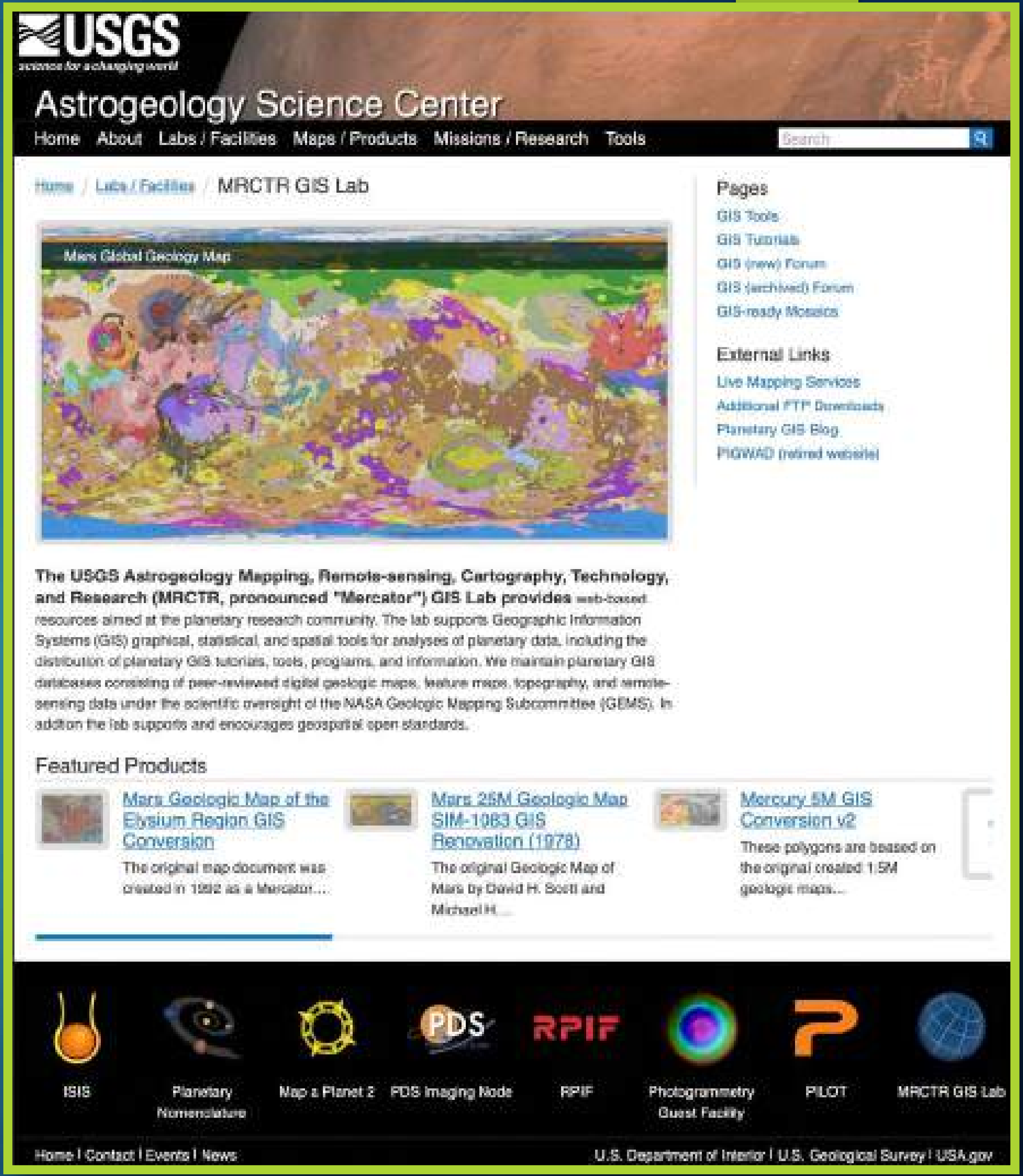
- https://astrogeology.usgs.gov/facilities/mrctr-gis-lab



Processing Data

Reference maps/ data

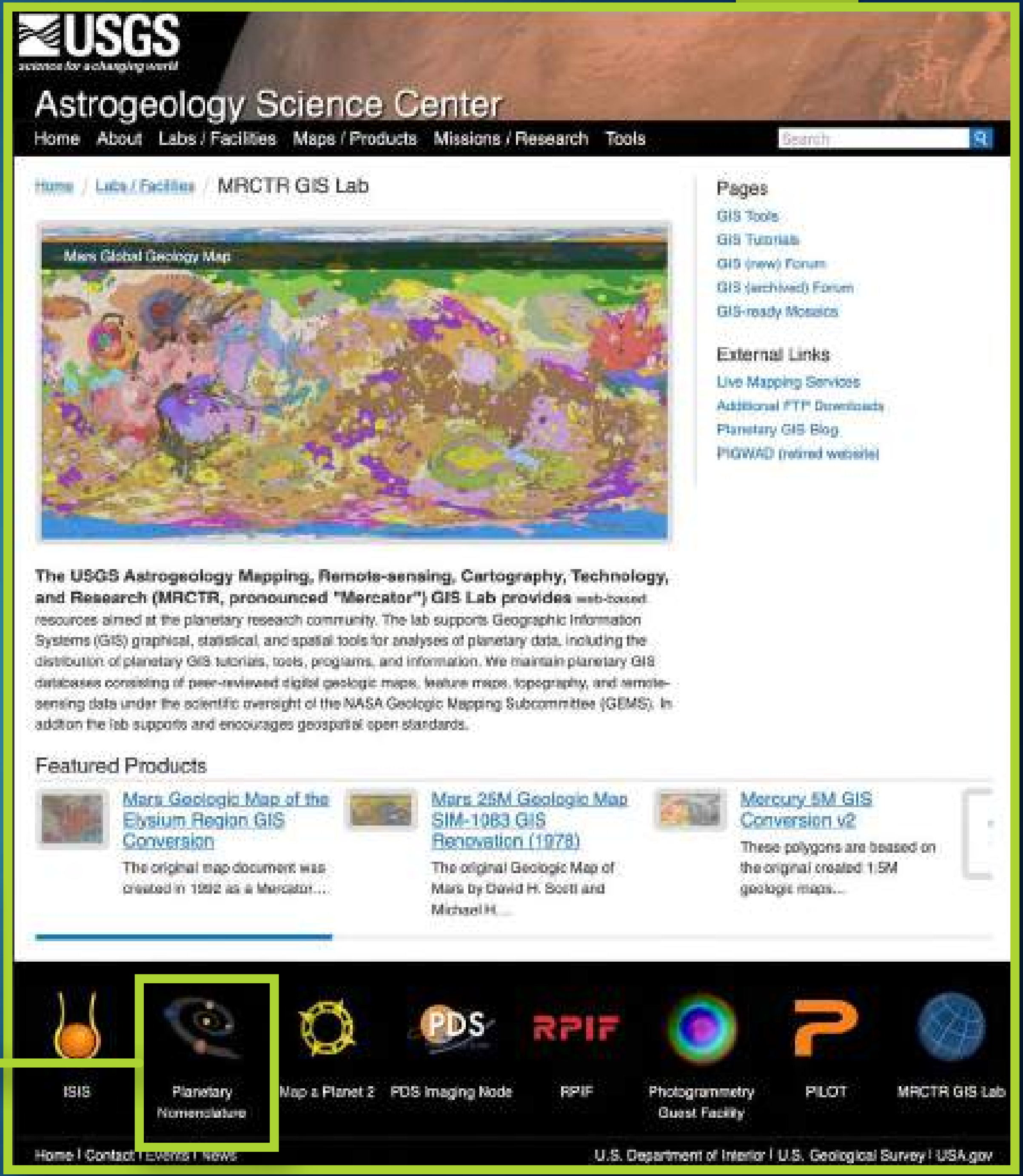
- https://astrogeology.usgs.gov/facilities/mrctr-gis-lab



Reference maps/ data

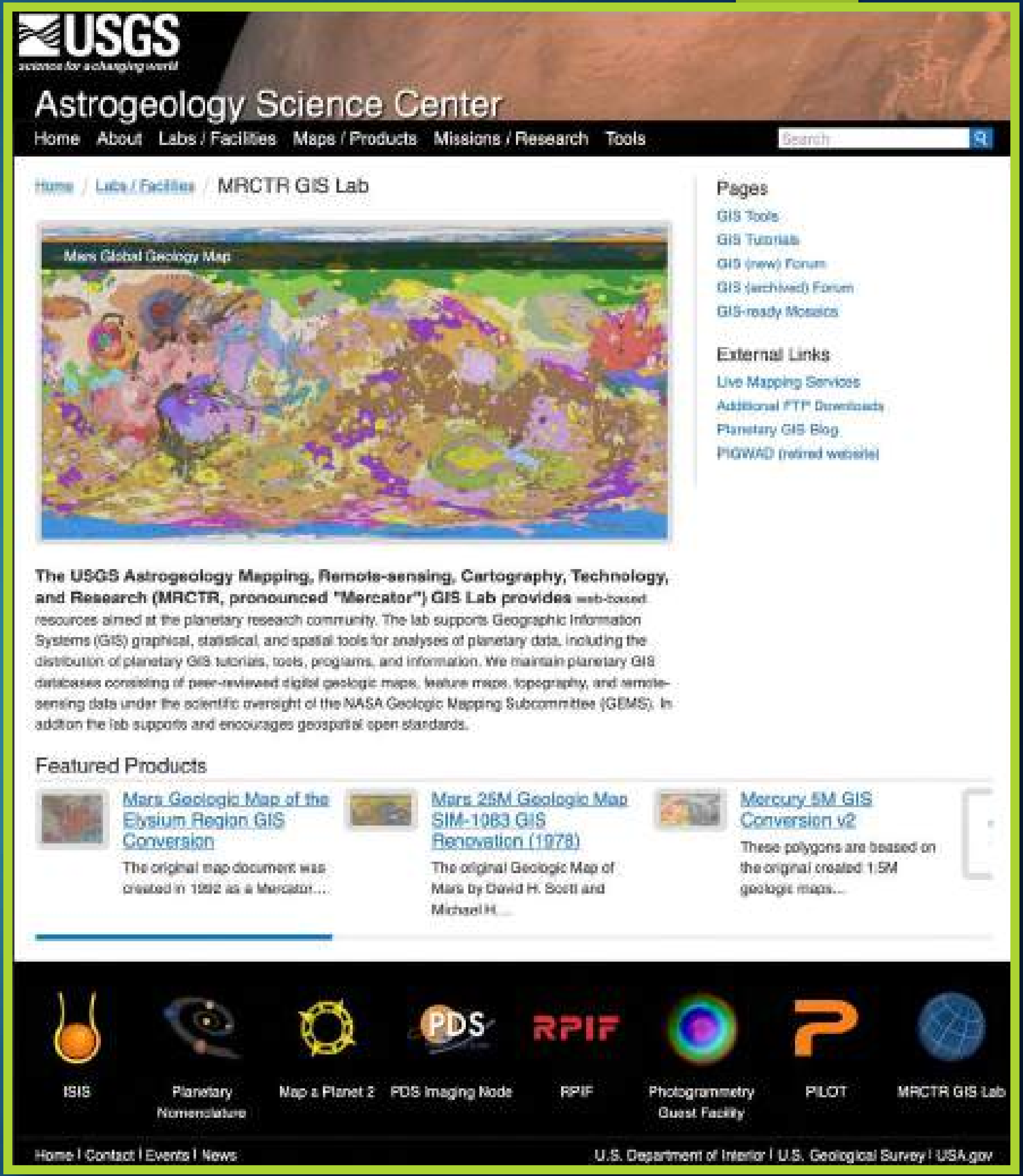
- https://astrogeology.usgs.gov/facilities/mrctr-gis-lab

- Request for naming new features
- Nomenclature GIS-ready file



Reference maps/ data

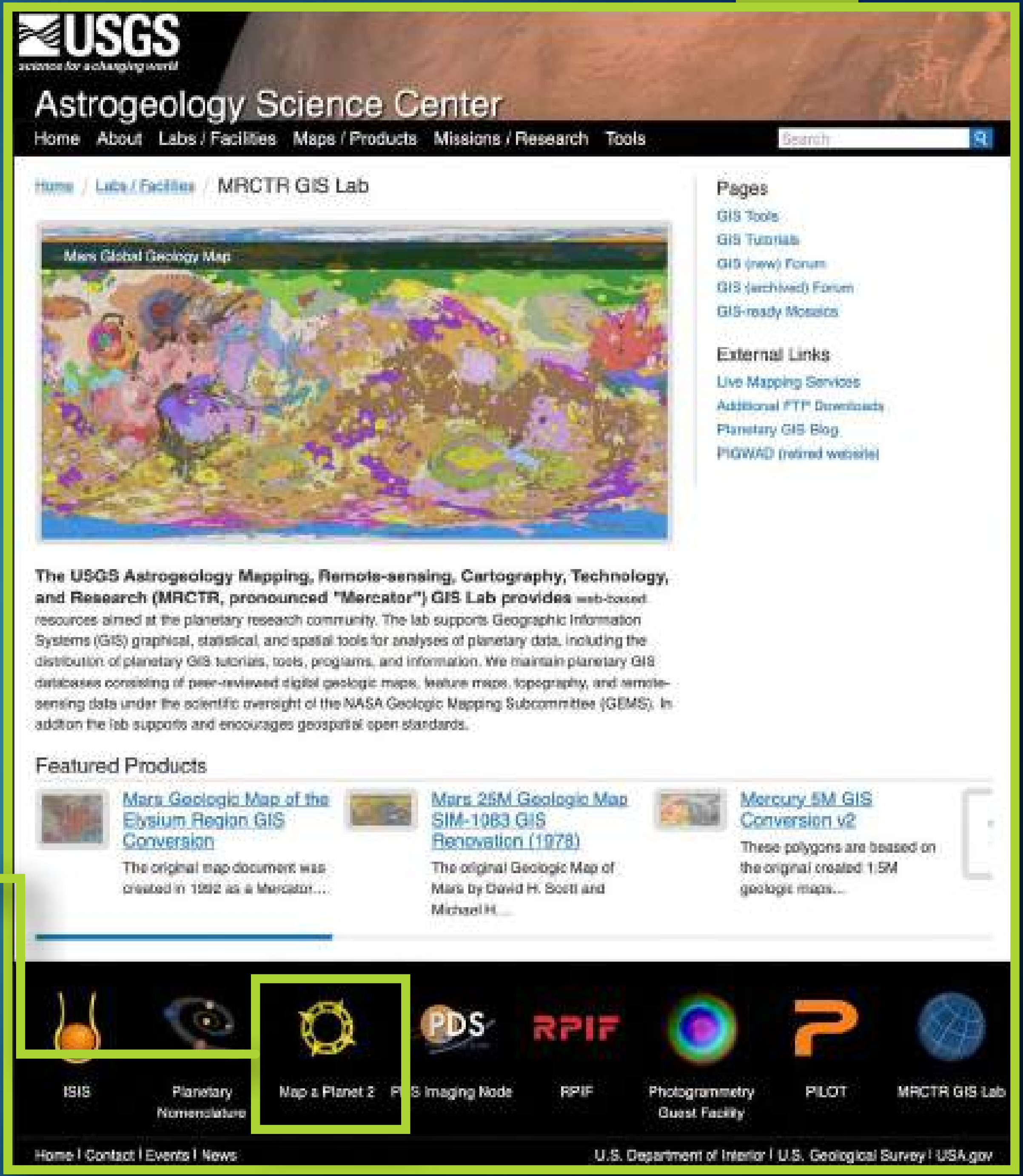
- https://astrogeology.usgs.gov/facilities/mrctr-gis-lab



Reference maps/ data

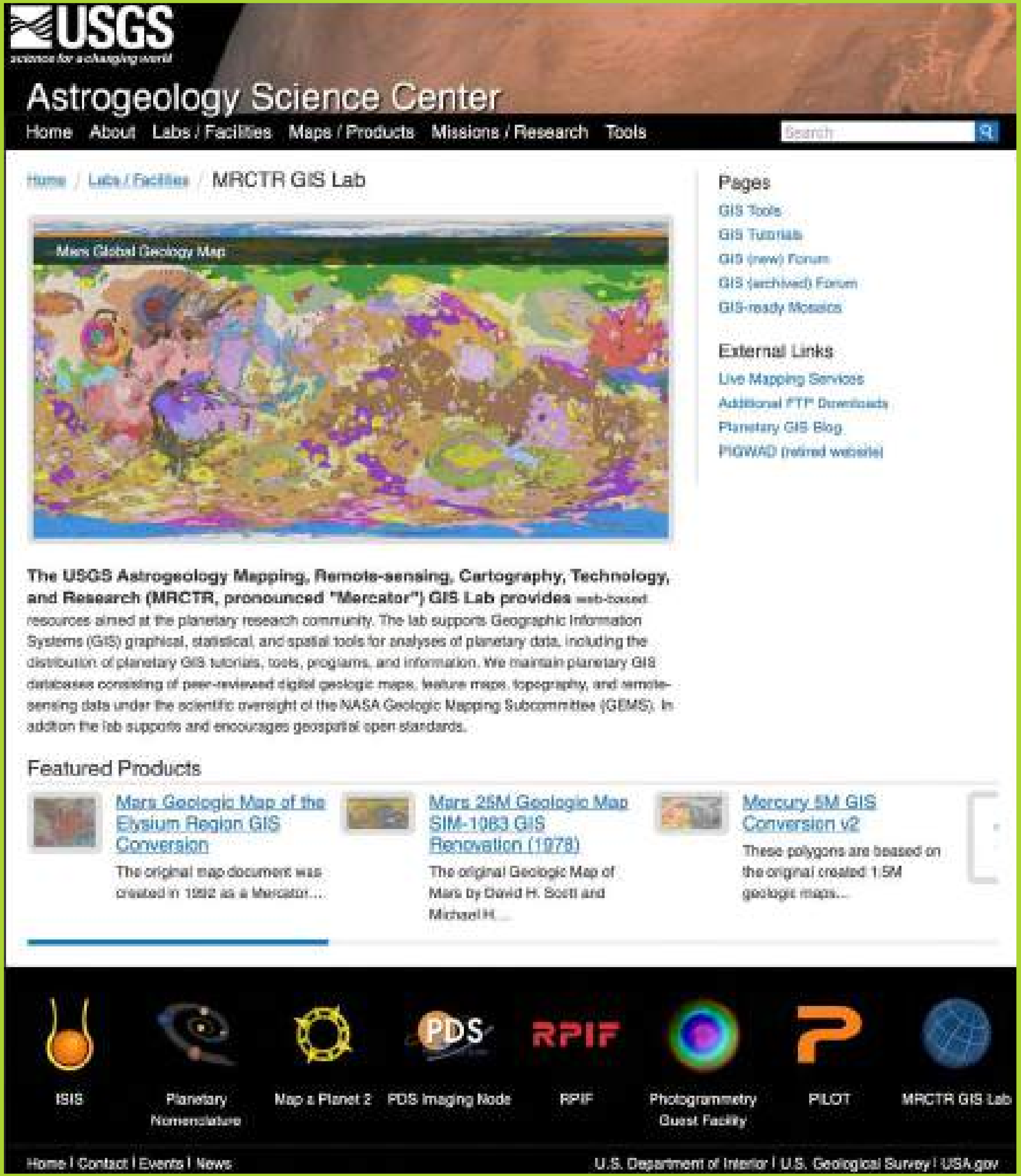
- https://astrogeology.usgs.gov/facilities/mrctr-gis-lab

Global map projected mosaic products



Reference maps/ data

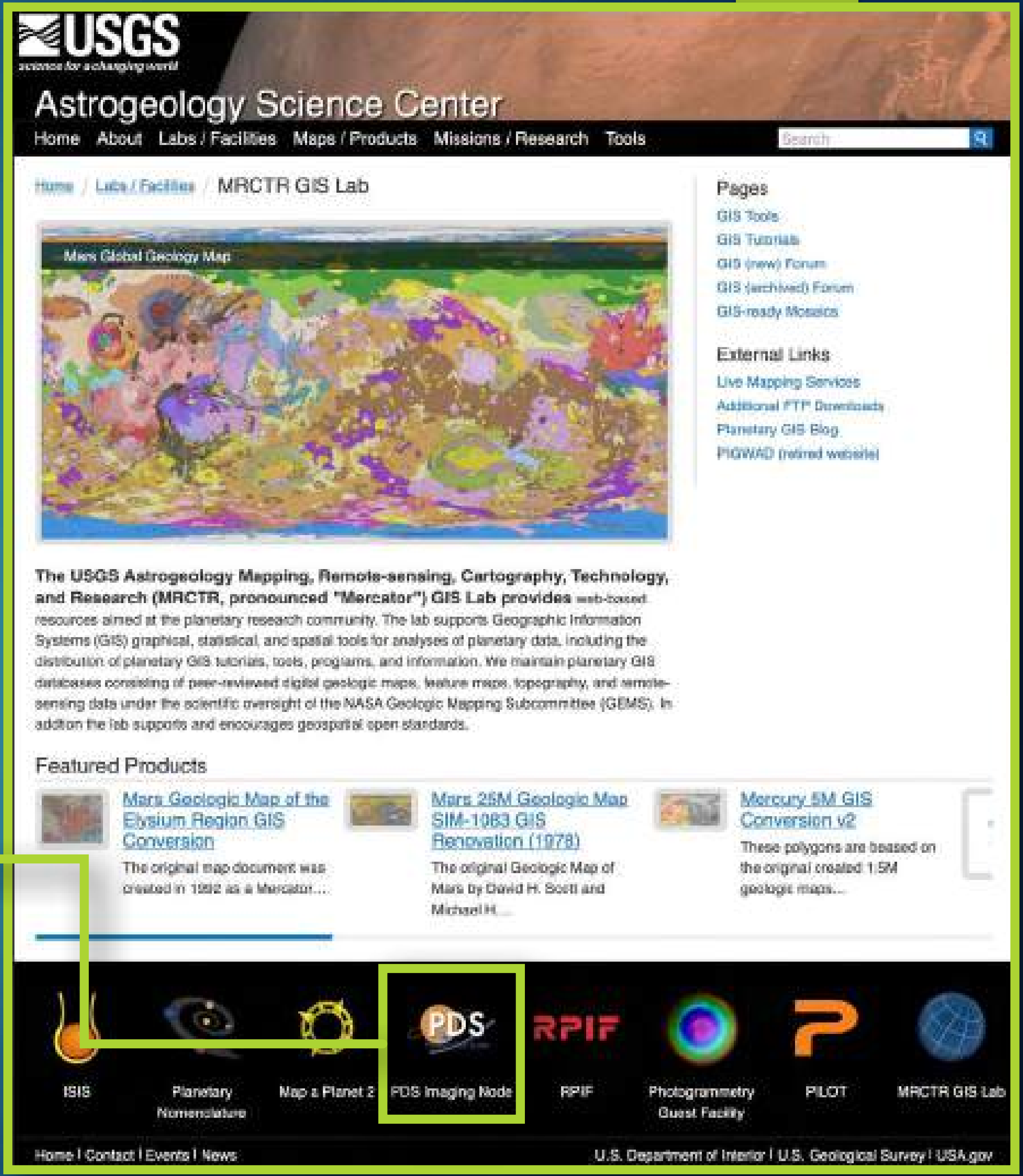
- https://astrogeology.usgs.gov/facilities/mrctr-gis-lab



Reference maps/ data

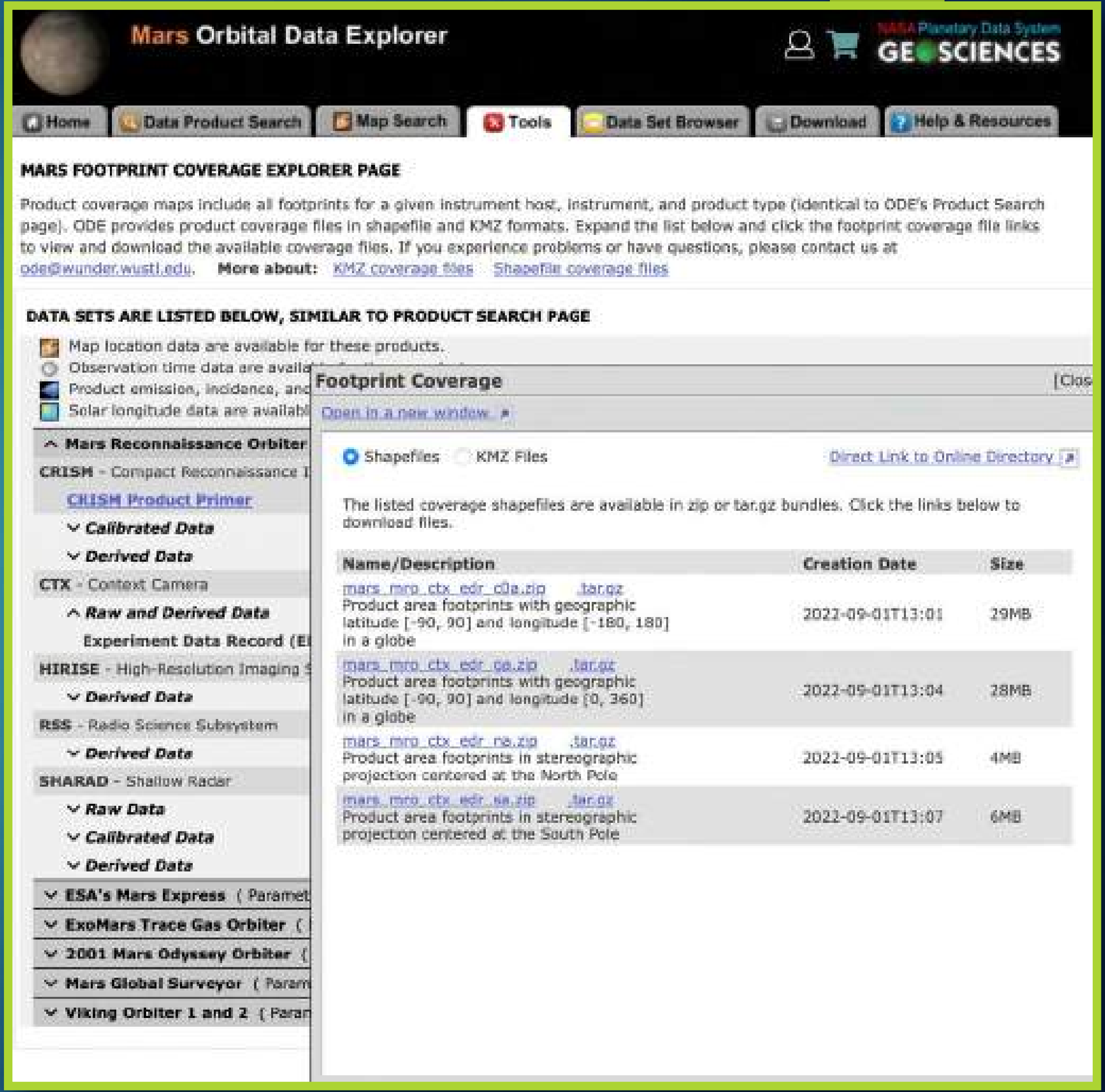
- https://astrogeology.usgs.gov/facilities/mrctr-gis-lab

Select data and additional tools

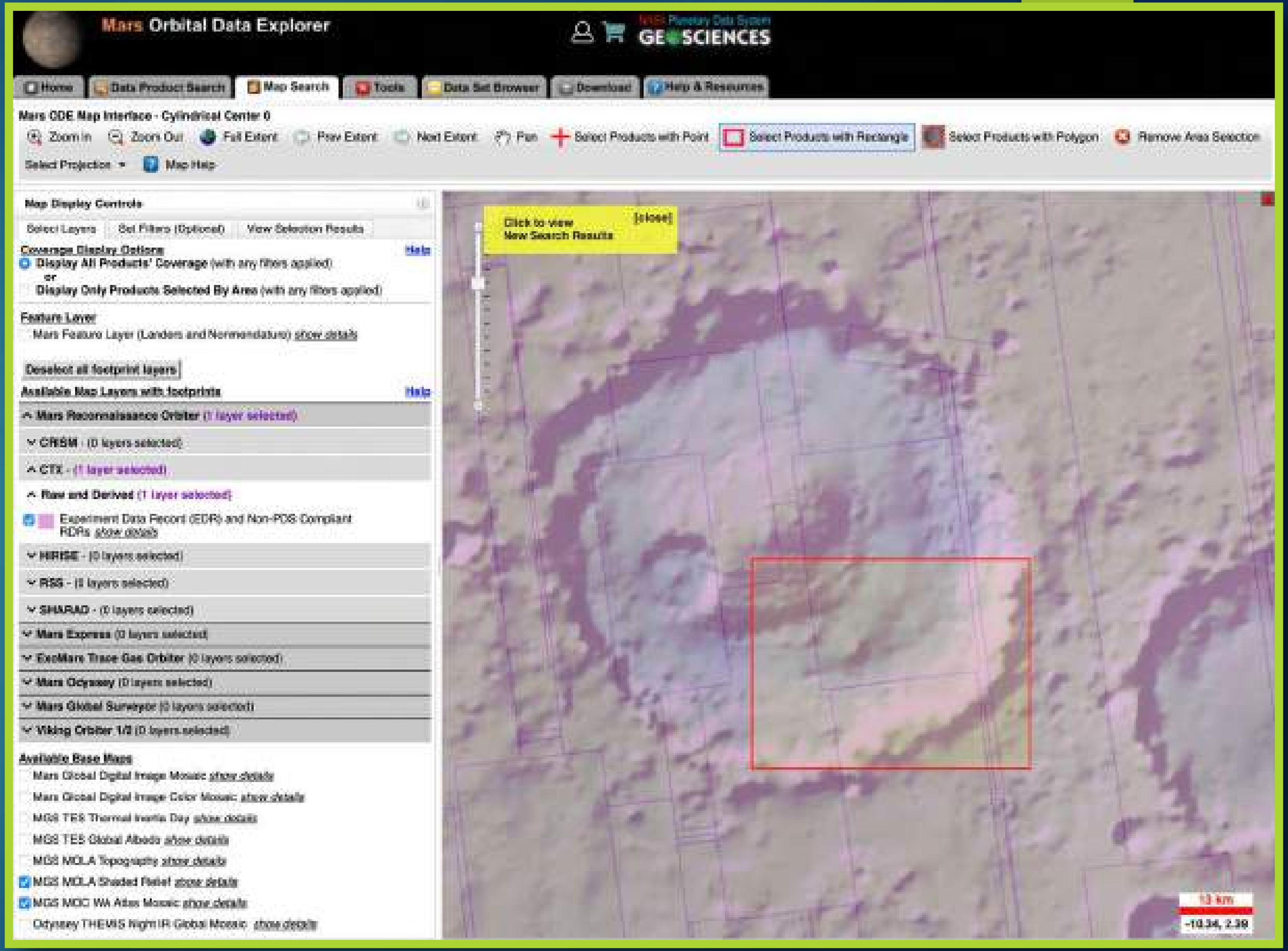


Footprint download

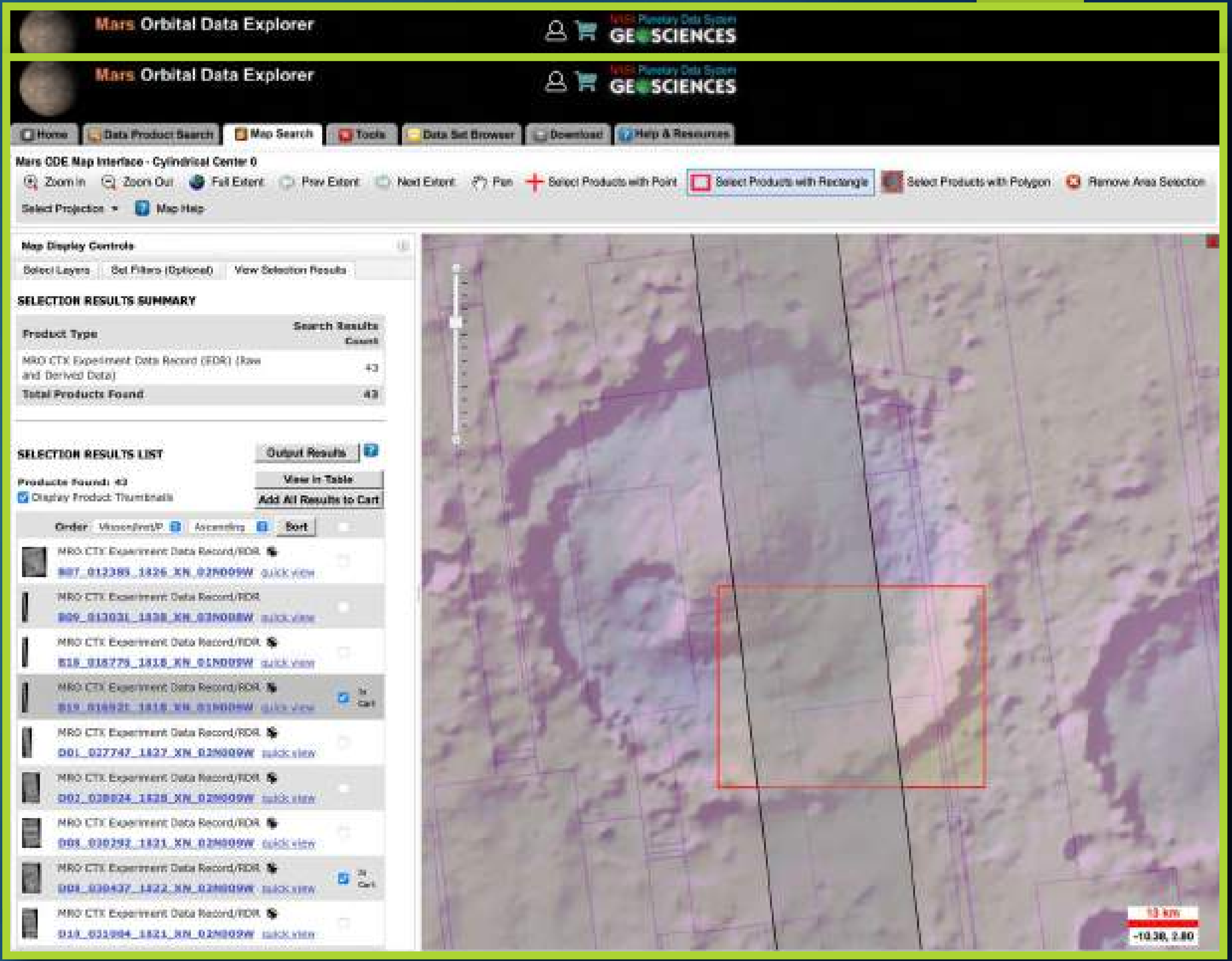
Link to images URLs



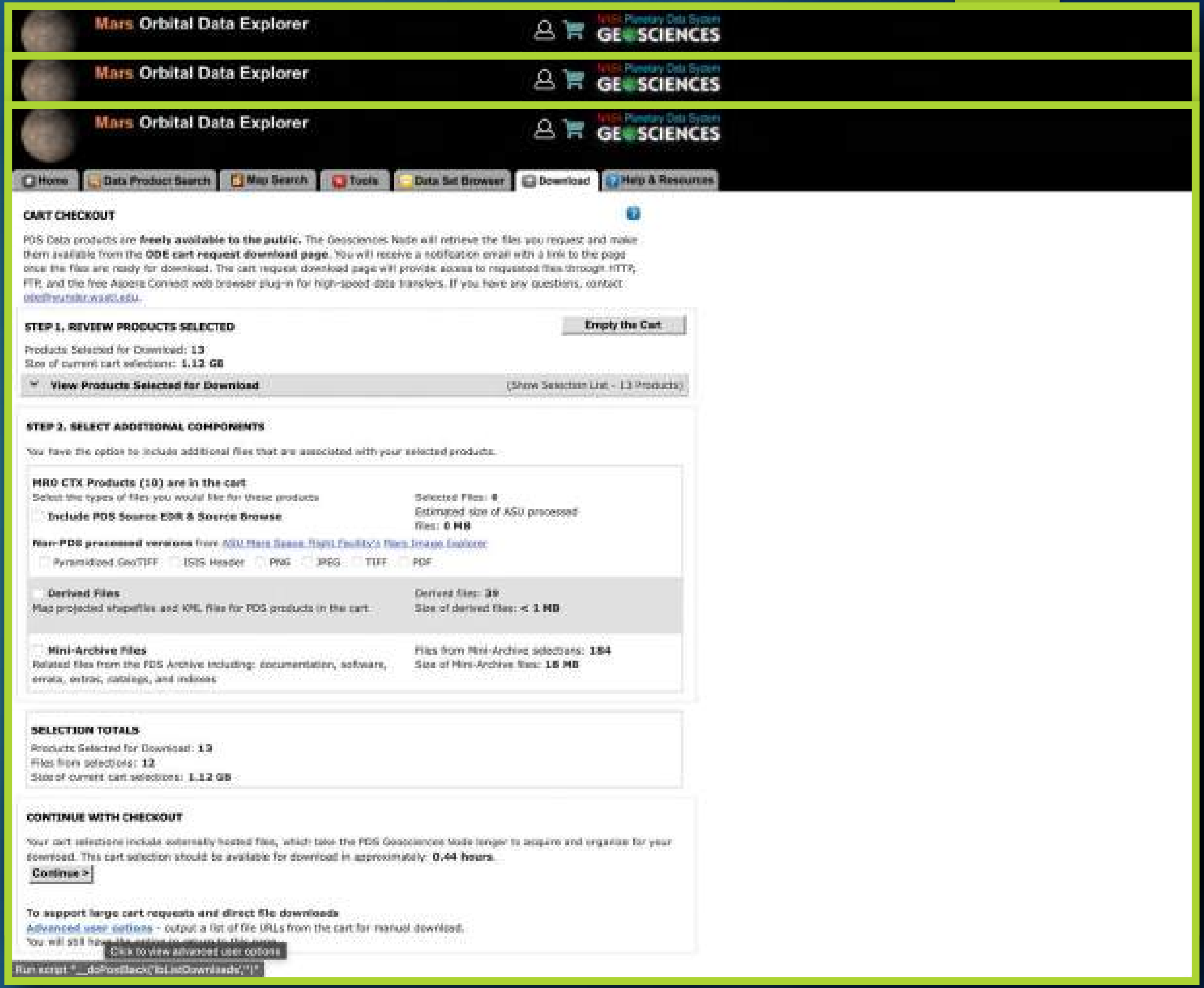
Or from ODE directly…



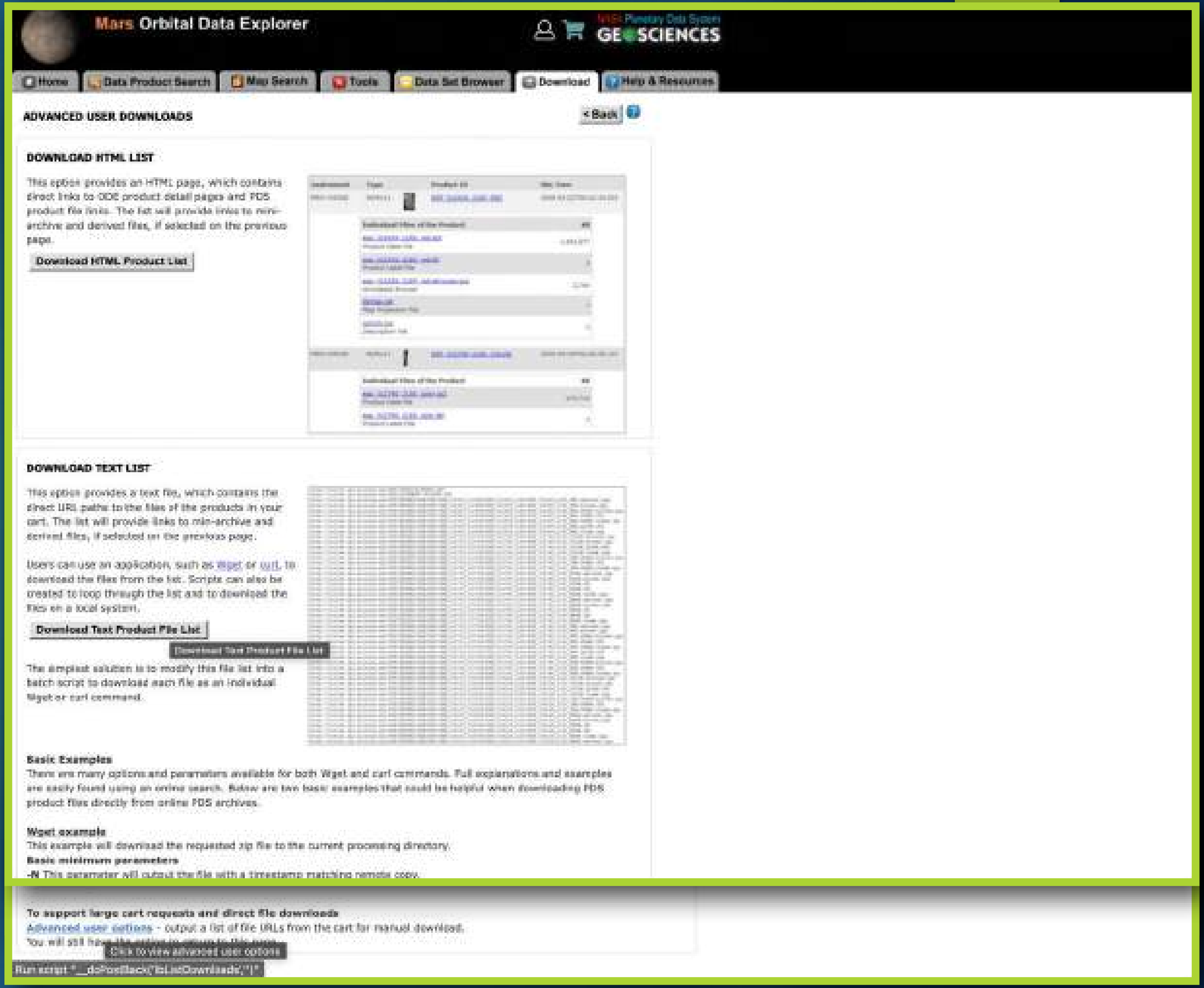
Or from ODE directly…



Or from ODE directly…

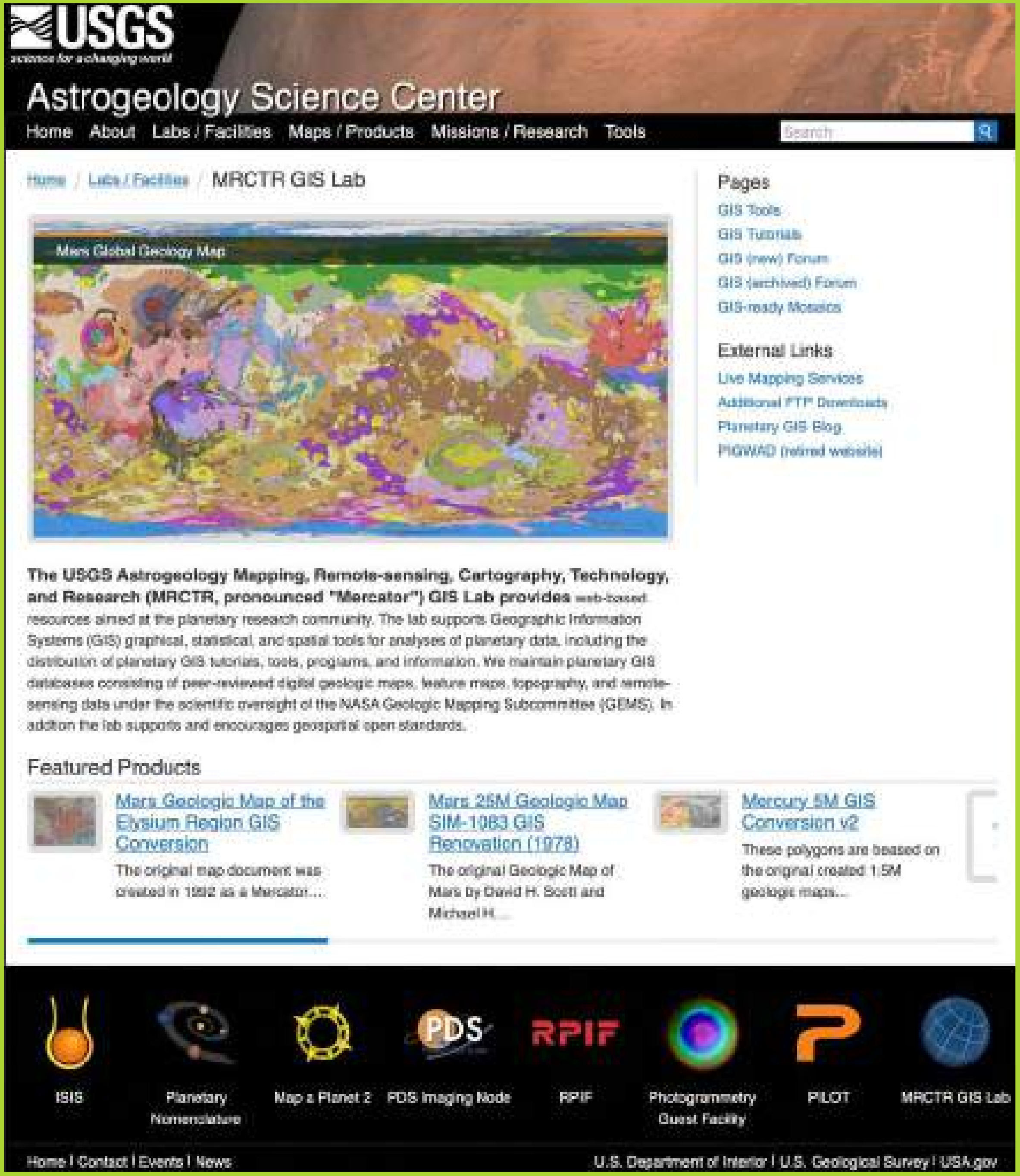


Or from ODE directly…



Reference maps/ data

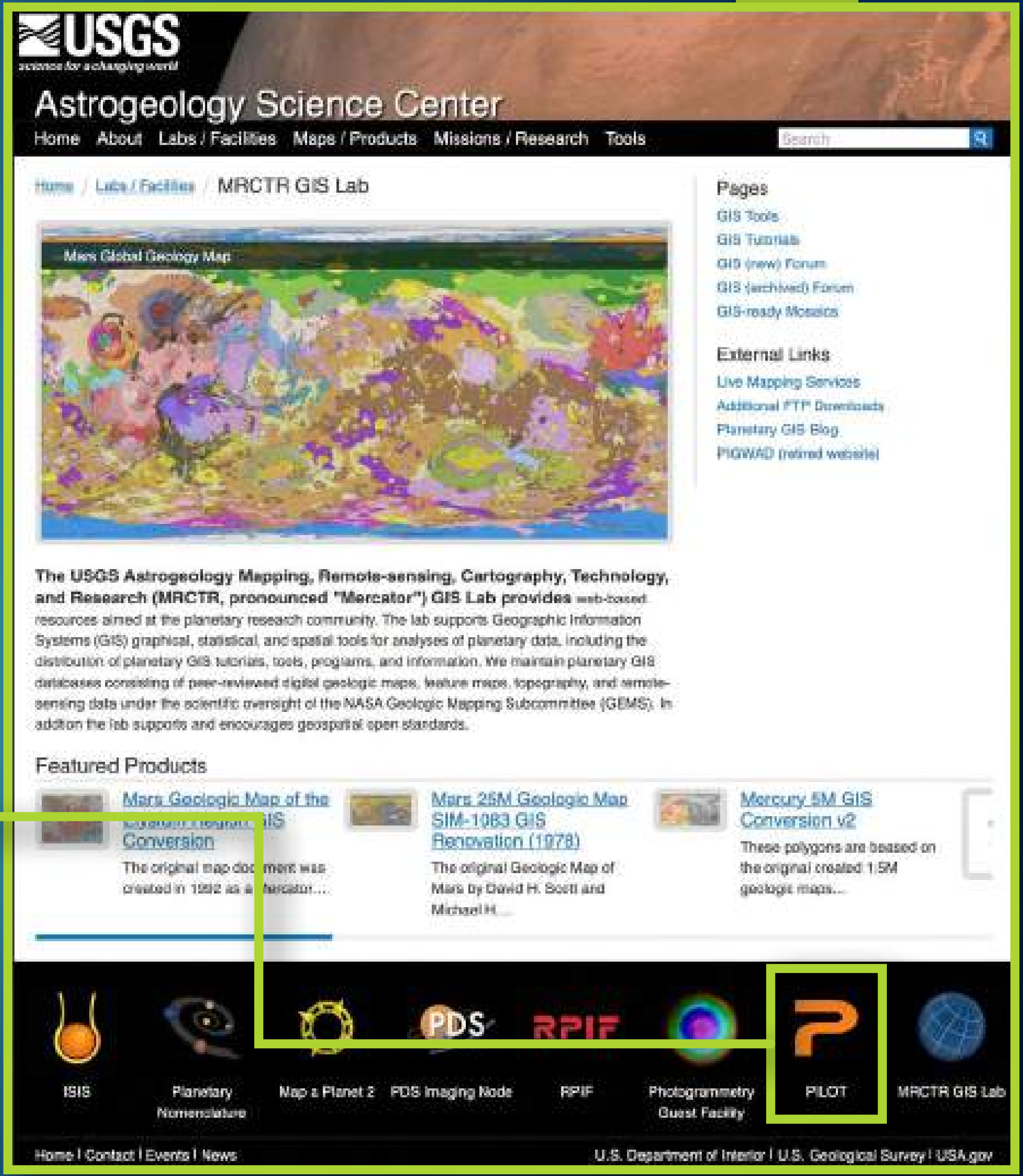
- https://astrogeology.usgs.gov/facilities/mrctr-gis-lab



Reference maps/ data

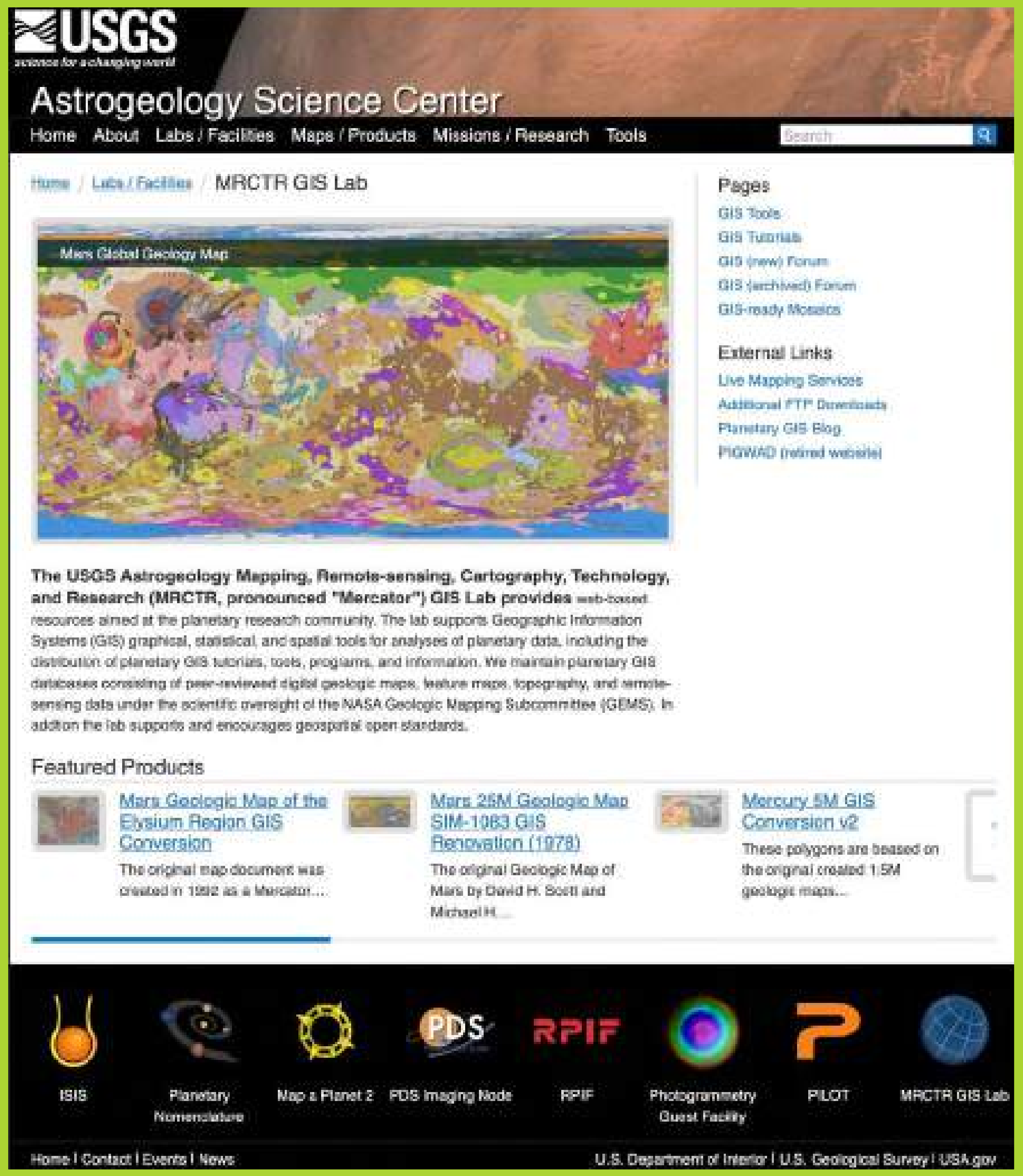
- https://astrogeology.usgs.gov/facilities/mrctr-gis-lab

Planetary Image Locator Tool
Very useful for stereo pair identification



Reference maps/ data

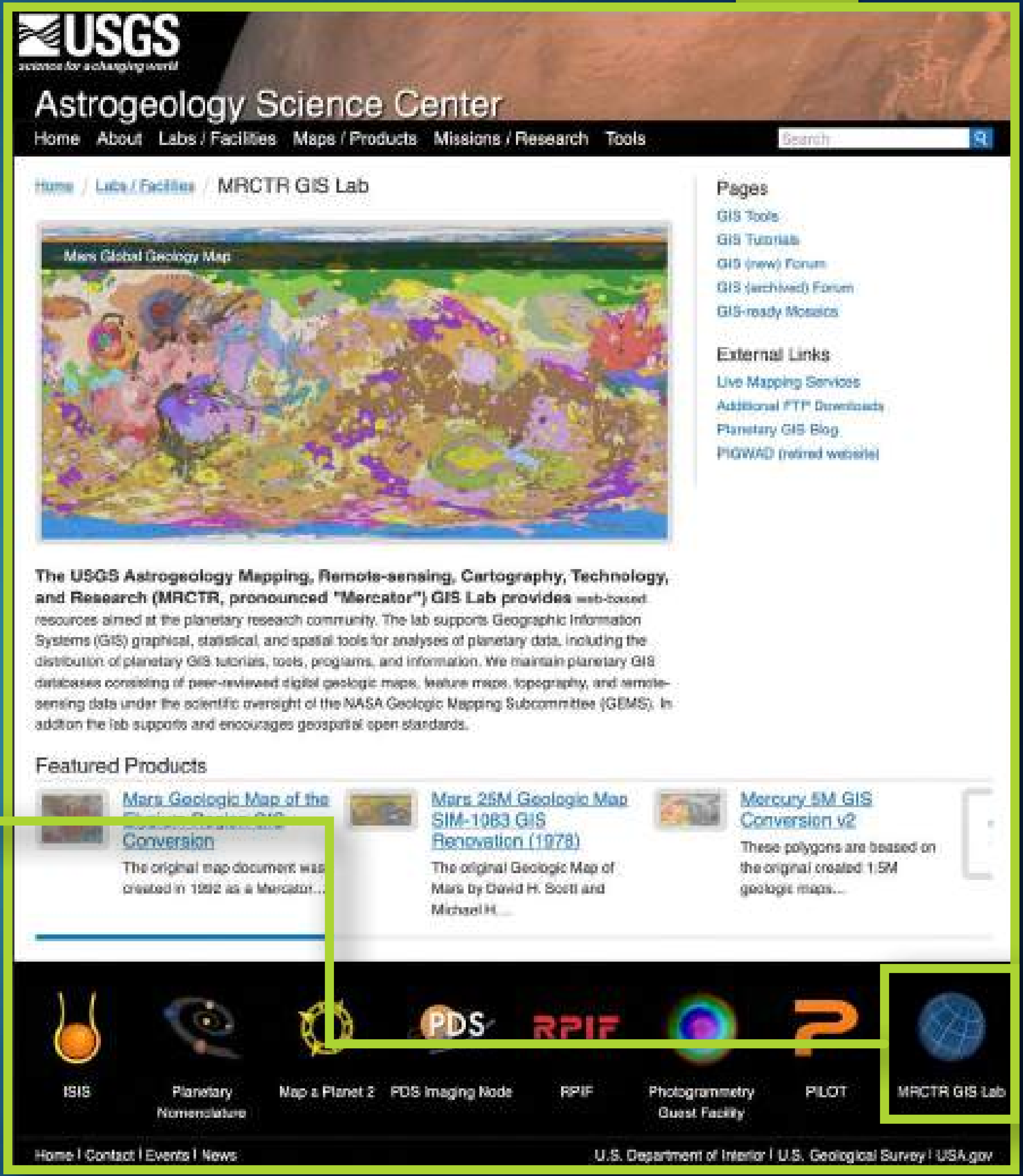
- https://astrogeology.usgs.gov/facilities/mrctr-gis-lab



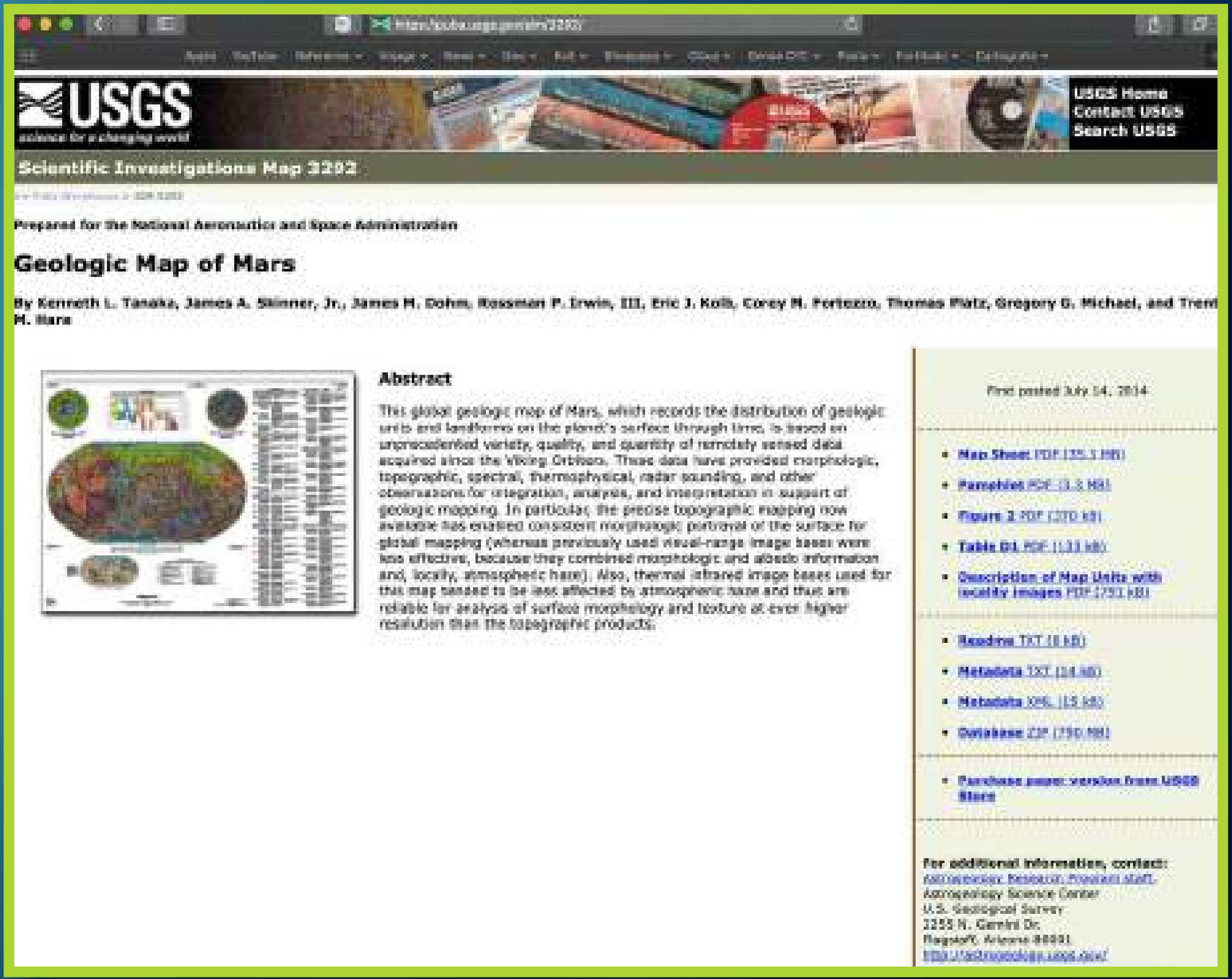
Reference maps/ data

- https://astrogeology.usgs.gov/facilities/mrctr-gis-lab

Many GIS-ready useful tools



Reference Data
Geologic Map of Mars



- https://pubs.usgs.gov/sim/3292/

Working areas/Groups

- Raw data are already downloaded and available in the cluster numbered 1 to 12
- We prepared 12 groups with 3/4 persons
- The number of the group should correspond to the number of the mapping area

Co-funded by the ERASMUS + Programme of the European Union

GeoPlaNet

Material largely downloaded from the ISIS support website

https://isis.astrogeology.usgs.gov/UserDocs/index.html

ISIS

Integrated Software for Imagers and Spectrometers

DEVELOPED BY THE USGS FOR NASA

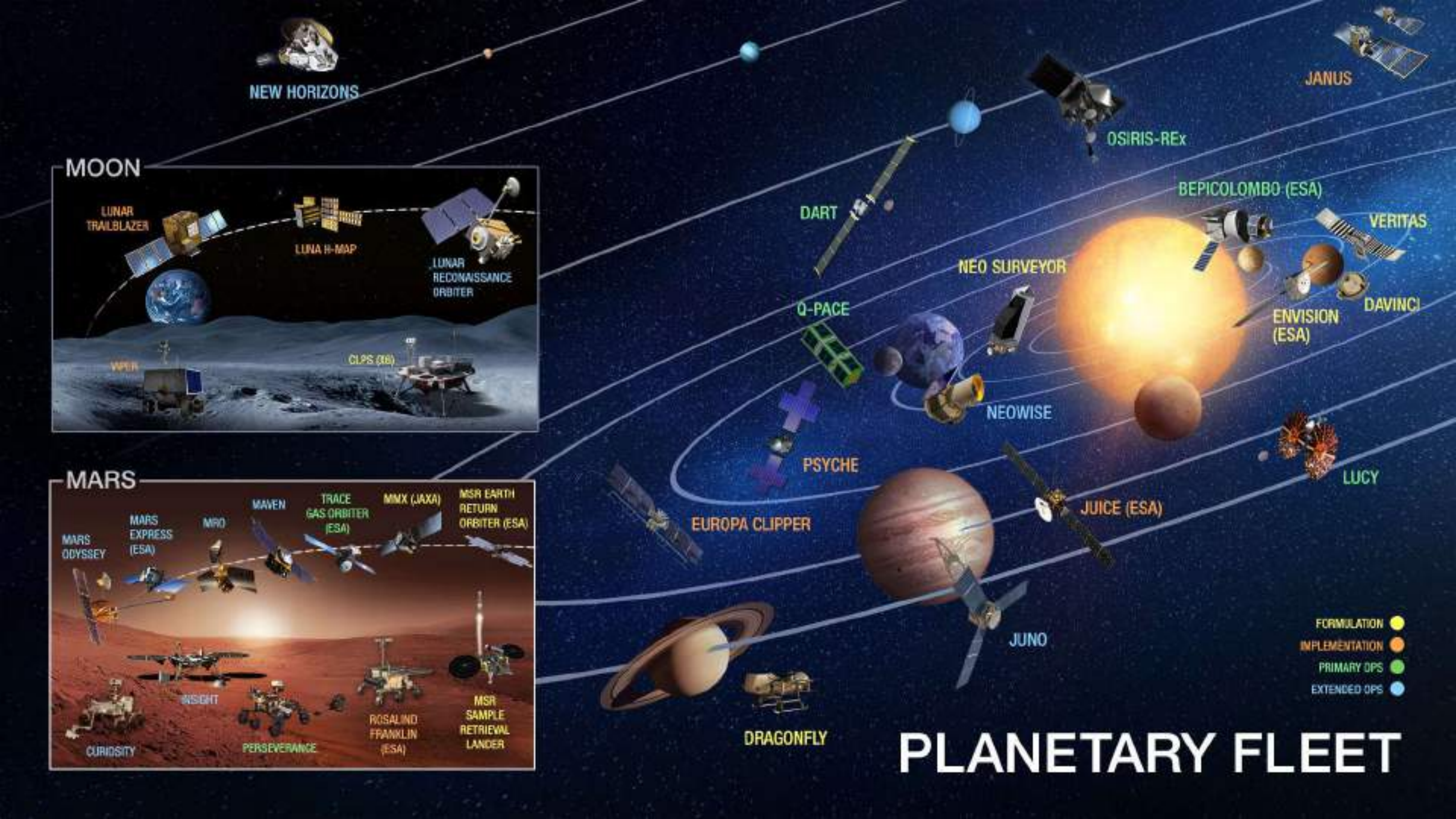
USGS science for a changing world

Nantes Université

1290 UNIVERSIDADE D COIMBRA

U.PORTO

VR2Planets


NEW HORIZONS
JANUS
OSIRIS-REx
MOON
LUNAR TRAILBLAZER
LUNA H-MAP
LUNAR RECONNAISSANCE ORBITER
VIPER
CLPS (X6)
DART
BEPICOLOMBO (ESA)
VERITAS
NEO SURVEYOR
Q-PACE
ENVISION (ESA)
DAVINCI
NEOWISE
PSYCHE
LUCY
MARS
MARS ODYSSEY
MARS EXPRESS (ESA)
MRO
MAVEN
TRACE GAS ORBITER (ESA)
MMX (JAXA)
MSR EARTH RETURN ORBITER (ESA)
INSIGHT
CURIOSITY
PERSEVERANCE
ROSALIND FRANKLIN (ESA)
MSR SAMPLE RETRIEVAL LANDER
EUROPA CLIPPER
JUICE (ESA)
JUNO
DRAGONFLY
FORMULATION
IMPLEMENTATION
PRIMARY OPS
EXTENDED OPS
PLANETARY FLEET

Data: processing levels

- Processing level indicates the amount of data calibration applied, from what is collected from a spacecraft (telemetry), up to data ready to do science and/or mapping
- Terminology can be confusing, but the baseline is that you don't want to use level0 or level1 data for doing science
  - Telemetry: An encoded byte stream used to transfer data from one or more instruments to temporary storage where the raw instrument data will be extracted
  - Raw: Original data from an instrument
  - Partially Processed: Data that have been processed beyond the raw stage, but which have not yet reached calibrated status.
  - Calibrated: Data converted to physical units, which makes values independent of the instrument.
  - Derived: Results that have been distilled from one or more calibrated data products (for example, maps, gravity or magnetic fields, or ring particle size distributions).
  - Supplementary: such as calibration tables or tables of viewing geometry

ISIS (Integrated Software for Imagers and Spectrometers)

- Free digital image processing software package developed by the USGS for NASA.
- Ability to place many types of data in the correct cartographic location, enabling disparate data to be co-analyzed.
- Two-dimensional and three-dimensional cubes derived from imaging spectrometers.
- Documentation
  - https://isis.astrogeology.usgs.gov/UserDocs/index.html
  - https://github.com/USGS-Astrogeology/ISIS3#installation
  - Support: https://isis.astrogeology.usgs.gov/fixit

ISIS ⇢ Fundamentals

- In use for over 30 years
- Software generations: PICS, ISIS2, ISIS3, ISIS4
- Support for over 55 NASA/ESA instruments
- Framing Cameras (e.g., MDIS Narrow Angle and Wide Angle cameras)
- Line Scan Cameras (e.g., THEMIS-IR, HiRISE)
- Push Frame Cameras (e.g., LRO-WAC)
- Special Cases
  - Radar Instruments (e.g., LRO-MiniRF)
  - Spot Instruments (e.g., Cassini-VIMS)

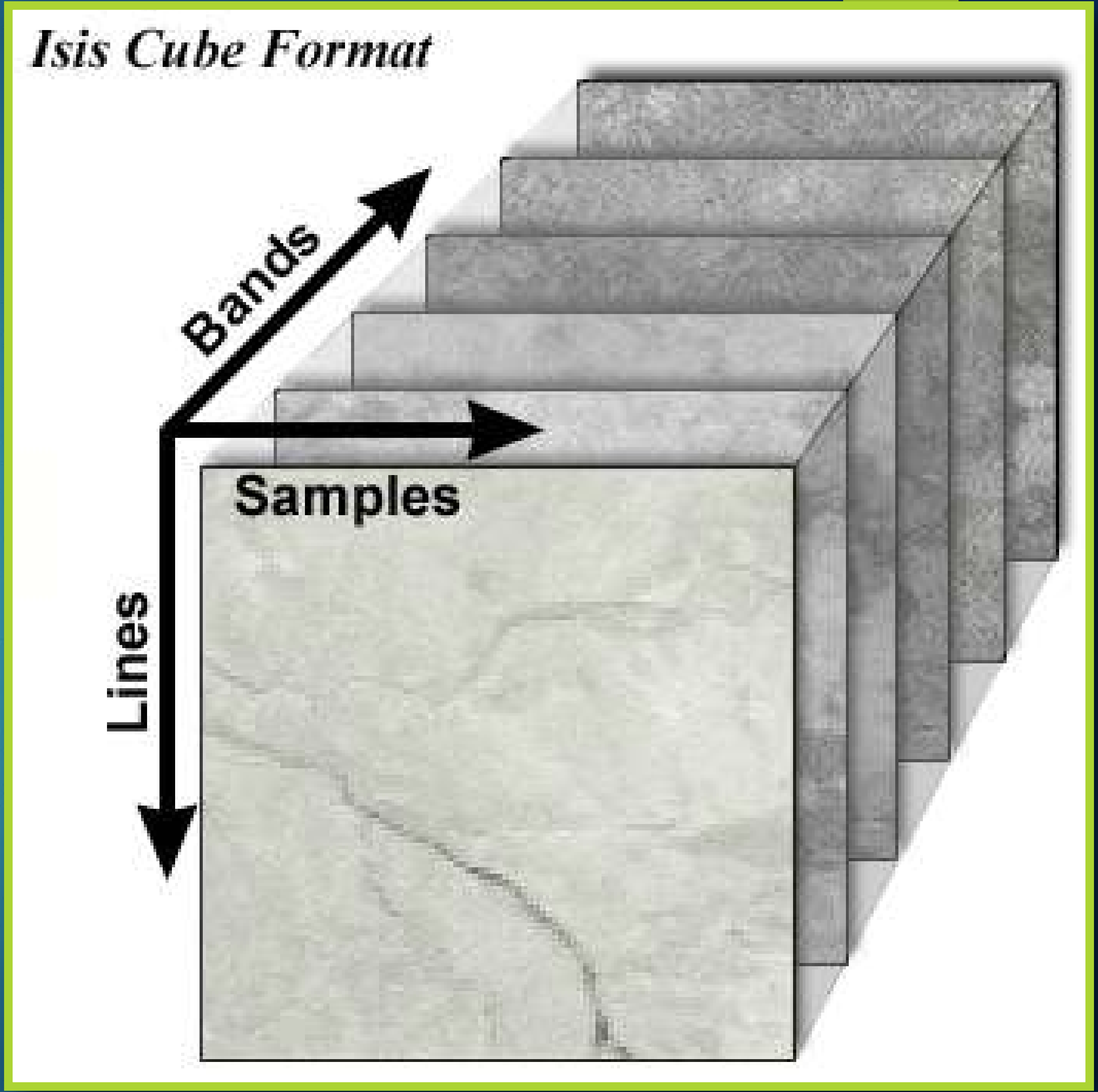
ISIS ⇢ Mission Instruments Supported

- Moon
  - Lunar Orbiter III, IV, &, V (Medium and HiRes)
  - Clementine UVVIS, NIR, HIRES, & LWIR
  - Apollo Metric 15/16/17
  - Apollo Panoramic 15/16/17
  - Lunar Reconnaissance Orbiter NACL, NACR, WAC (VIS & UV), MiniRF
  - Chandrayaan-1 M3, MiniRF
  - KaguyaMI (VIS & NIR)
- Mercury
  - Mariner 10 (A & B)
  - MESSENGER MDIS (NAC & WAC)
- Asteroids
  - Dawn FC (1 & 2), VIR
  - Near Earth Asteroid Rendezvous Shoemaker MSI
  - HayabusaAMICA
  - OSIRIS-RExOCAMS
- Multiple Target Bodies
  - Voyager 1 & 2 (NAC & WAC)
- Mars
  - The ExoMars Trace Gas Orbiter (EMTGO) Cassis
  - Mars Global Surveyor MOC (NAC & WAC)
  - Mars Odyssey THEMIS (VIS & IR)
  - Mars Express HRSC
  - Mars Reconnaissance Orbiter HiRISE, CTX, MARCI, CRISM
  - Viking Orbiter 1 & 2 (A & B)
- Jovian
  - Galileo SSI
- Saturnian
  - Cassini ISS (NAC & WAC), VIMS
- Pluto
  - New Horizons MVIC, LORRI, LEISA
- Other
  - Ideal Camera
  - Special ISIS Perfect Virtual Instrument

Isis data format

ISIS uses CUBES. A cube is a 3D image with axis: samples, lines, and bands.

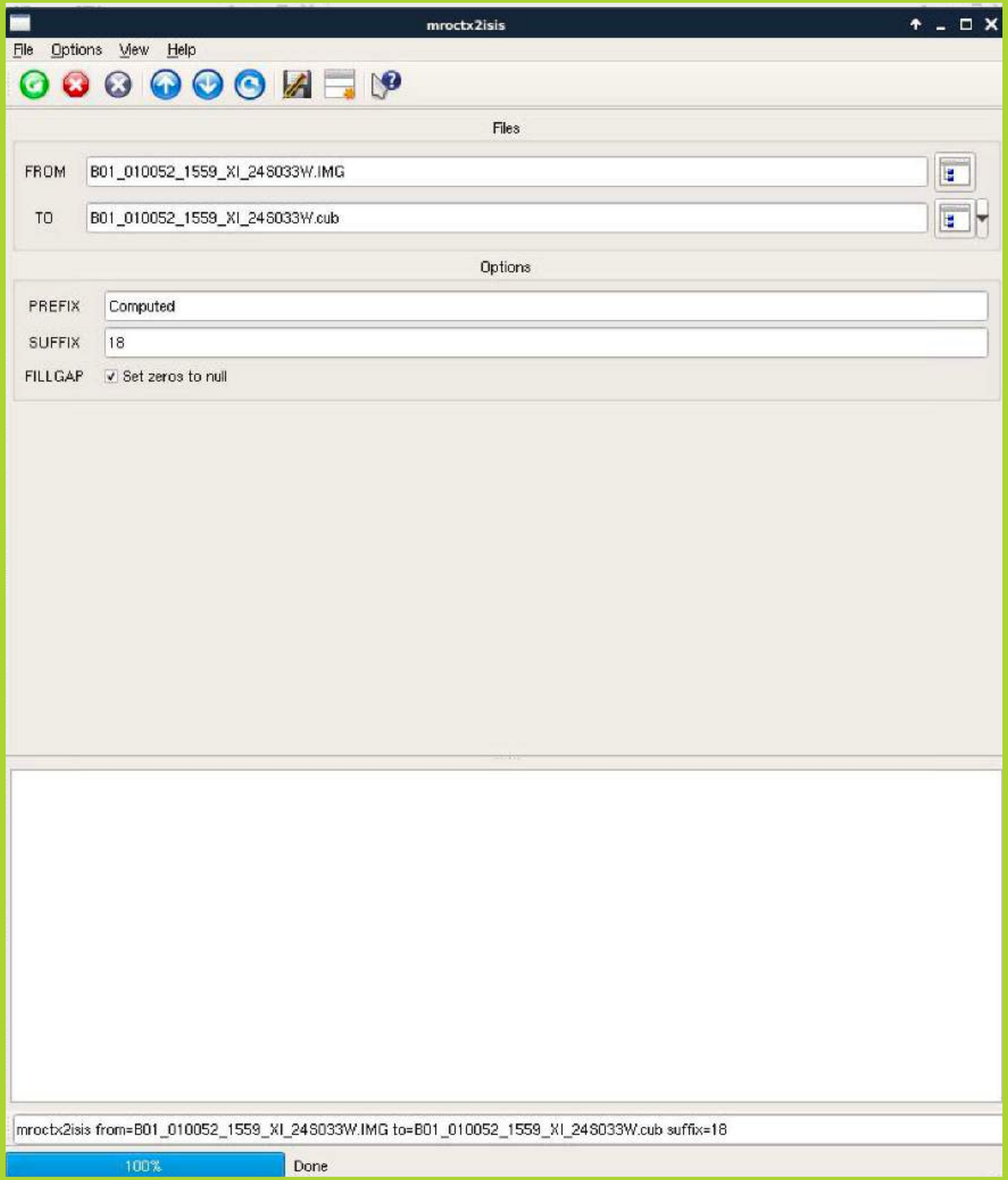
Sample and line dimensions are used to represent spatial information while band dimension represents spectral information.



Executing ISIS Applications

Parameters:

- ✓ FROM
- ✓ TO
- ✓ FORMAT
- ✓ APPEND



Standard Cartographic Processing Flow within ISIS

Radiometric Correction: a technique to reconstruct physically calibrated values by correcting the spectral distortions caused by sensors, sun angle, topography, and the atmosphere

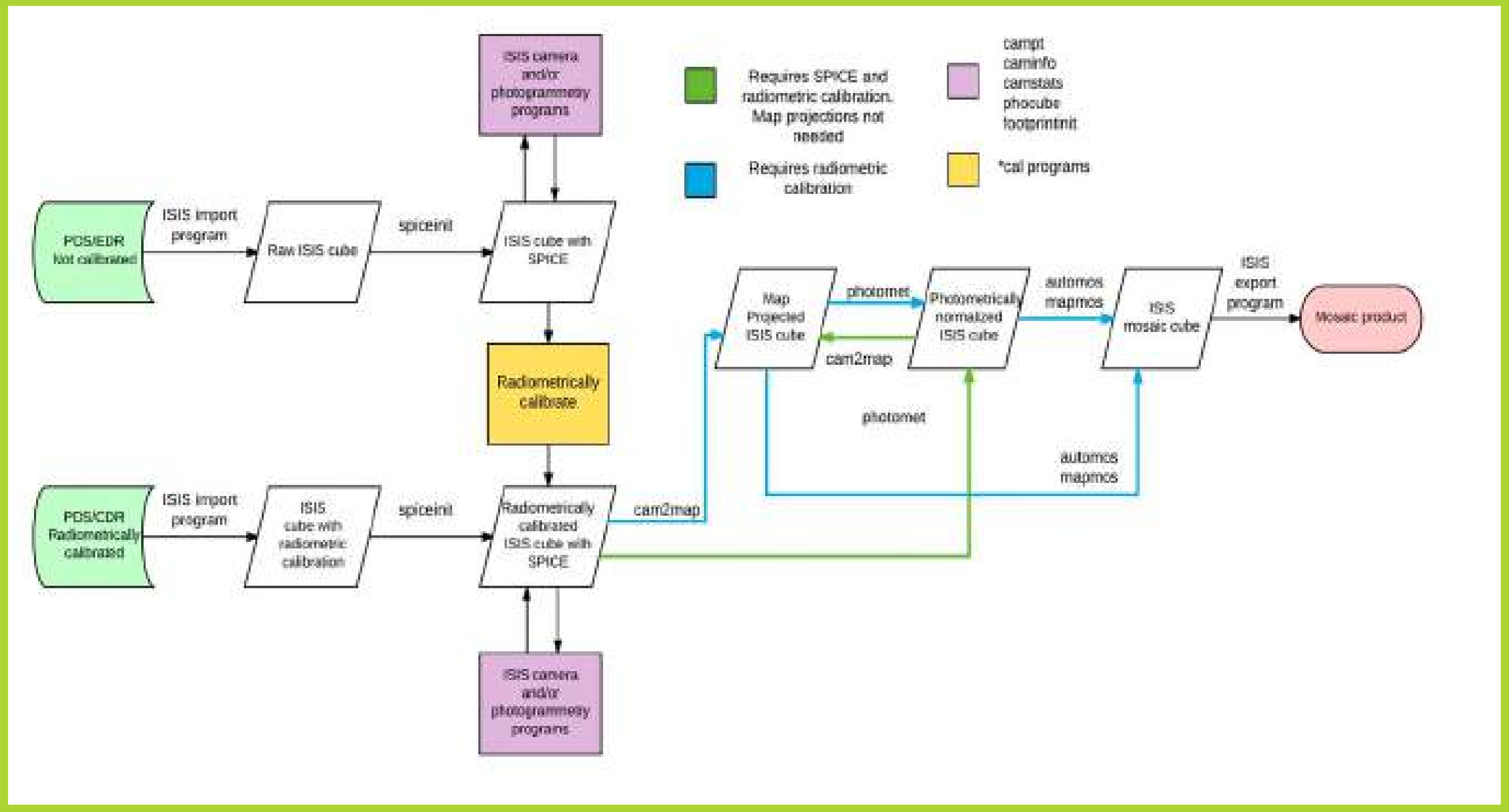


Image import into ISIS

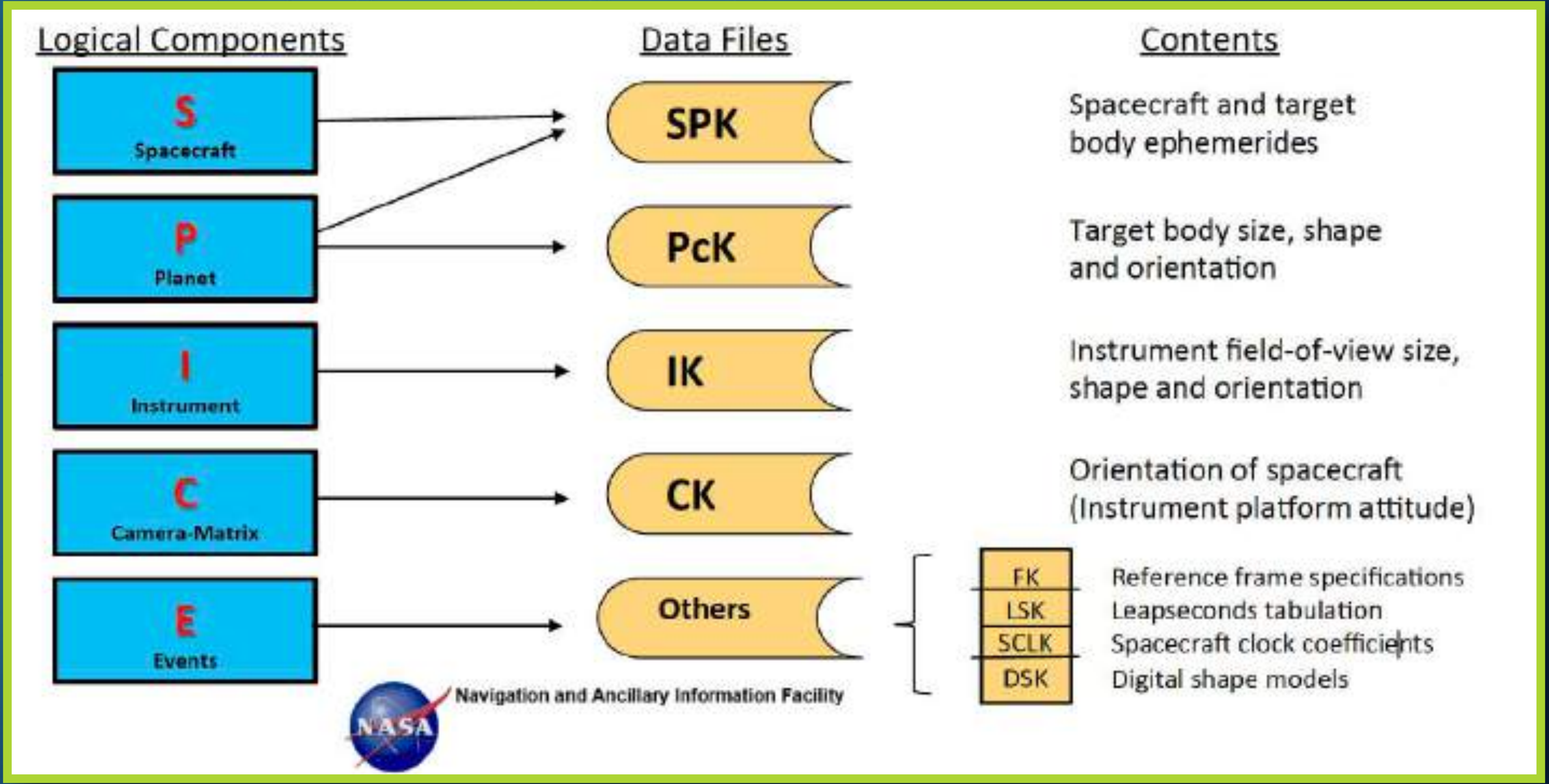
- Mission specific import
  - e.g., mroctx2isis, msi2isis, dawnfc2isis, ciss2isis, thm2isis……
  - Specific Mission/Instrument PDS keywords are translated to ISIS keywords
- General import programs
  - pds2isis, raw2isis, vicar2isis, std2isis (png, jpeg, tiff)
  - These import programs typically do not have camera or map projection information
  - ISIS preserves the labels of the original data set (PDS, VICAR, FITS) (camoriglab will display original labels)

Radiometric Calibration

- All cameras produce digital images with the inherent artifact known as camera shading. Camera shading results from the non-uniform sensitivity across the field of view of the imaging instrument.
- Acquiring a digital image of a target of uniform brightness, e.g., a uniform shade of gray. If the camera sensitivity across the fields of view were ideal, then the acquired digital image would have the same DN (digital number) value for all the pixels in the image. However, because of the non-uniform sensitivity of the camera, the DN values of the resulting image will vary throughout the image array. Camera shading corrections are applied so that the radiometrically corrected image would contain pixels of identical value.

Navigation parameters

SPICE kernels contain ephemeris and orientation data needed for cartographic processing



ISIS map projecting

- Definition of map
  - A representation of a three-dimensional target such as a sphere, ellipsoid, or an irregular-shaped body onto a plane (two-dimensional object such as paper or an image)
  - A map projection is an algorithm or equation for transforming a (latitude, longitude) of a three-dimensional object (planet/asteroid) into a two-dimensional coordinate (x, y)

- Equirectangular
- Lambert Azimuthal Equal Area
- Lambert Conformal
- Lunar Azimuthal Equal Area
- Mercator
- Oblique Cylindrical
- Orthographic
- Point Perspective
- Polar Stereographic
- Robinson
- Simple Cylindrical
- Sinusoidal
- Transverse Mercator

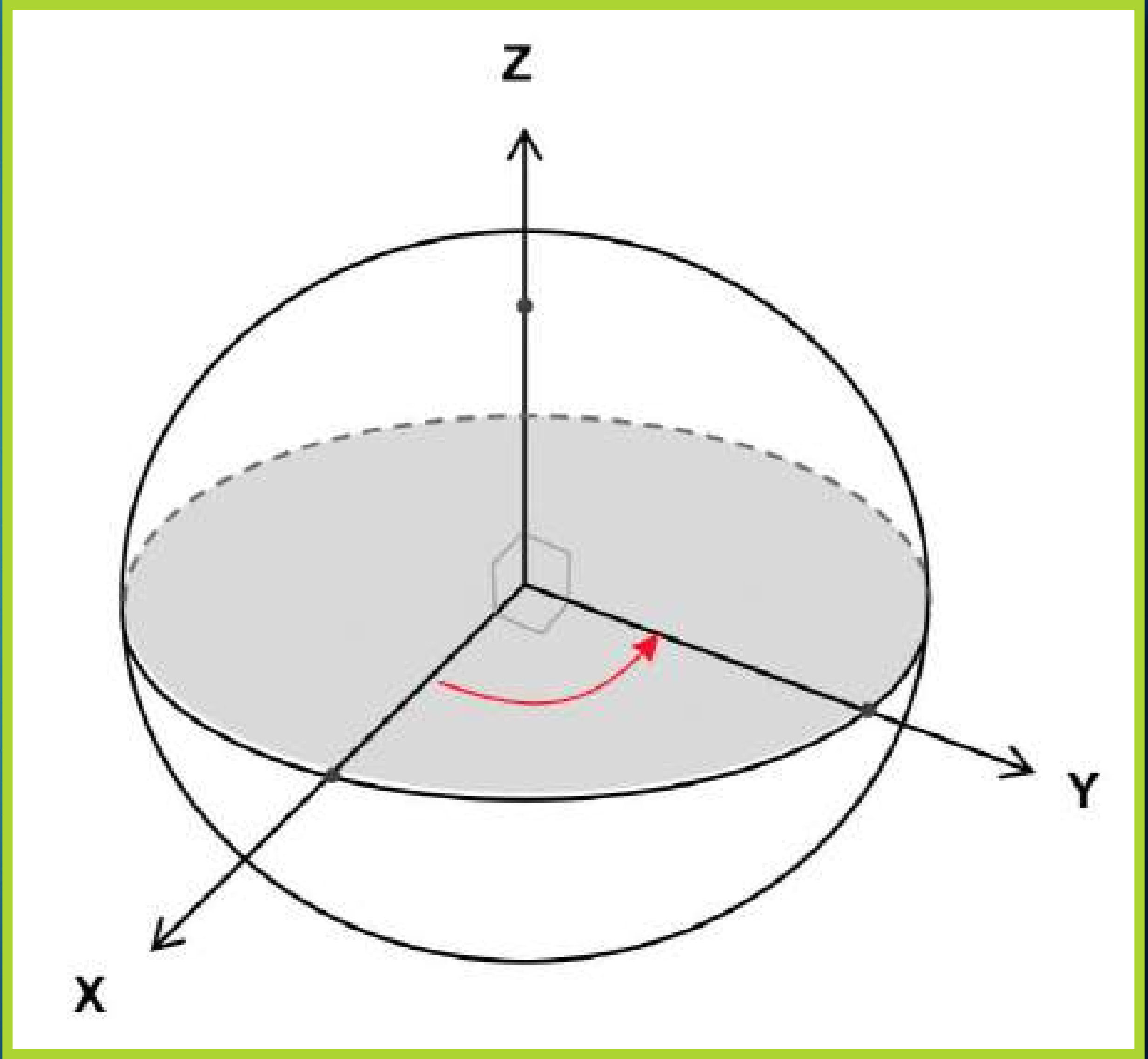
Reference frame and Coordinate System

- A reference frame is specified by an ordered set of three mutually orthogonal, possibly time dependent, unit-length direction vectors.
  - A reference frame has an associated center.
- A coordinate system specifies a mechanism for locating points within a reference frame.
- The International Astronomical Union (IAU) has the responsibility of defining the rotational elements of the planets, satellites, asteroids, and comets of the Solar System.

Reference frame

All reference frames used within SPICE are right-handed

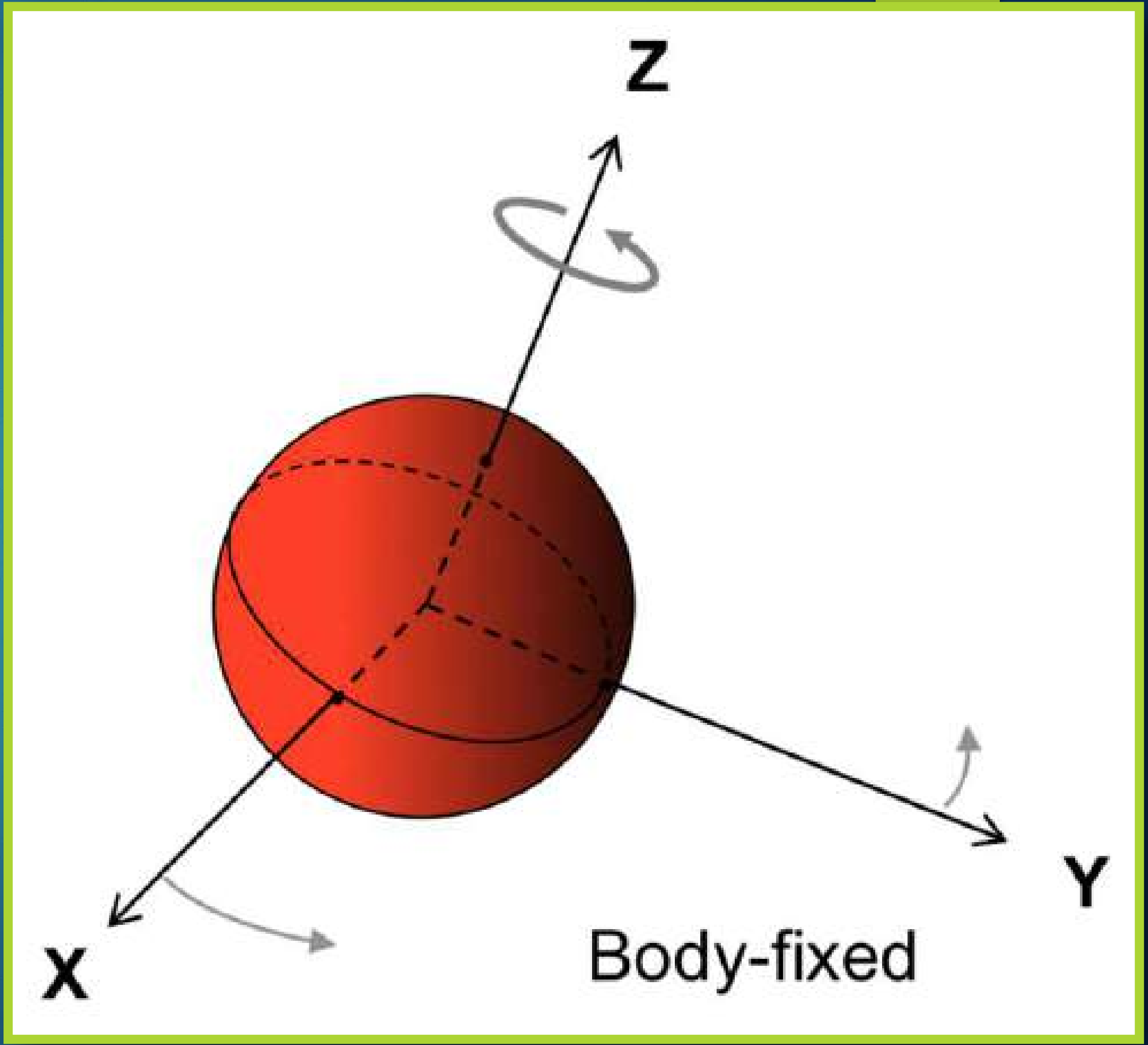
- A reference frame's center must be a SPICE ephemeris object whose location is coincident with the origin (0, 0, 0) of the frame
  - The center of a body-fixed frame (e.g., planet, satellite) is the center of the body (body= natural body: sun, planet, satellite, comet, asteroid)



Body-fixed frames

Specifications for the most common body-fixed frames (Sun, planets, many satellites, and a few asteroids and comets) are hard-coded in SPICE software

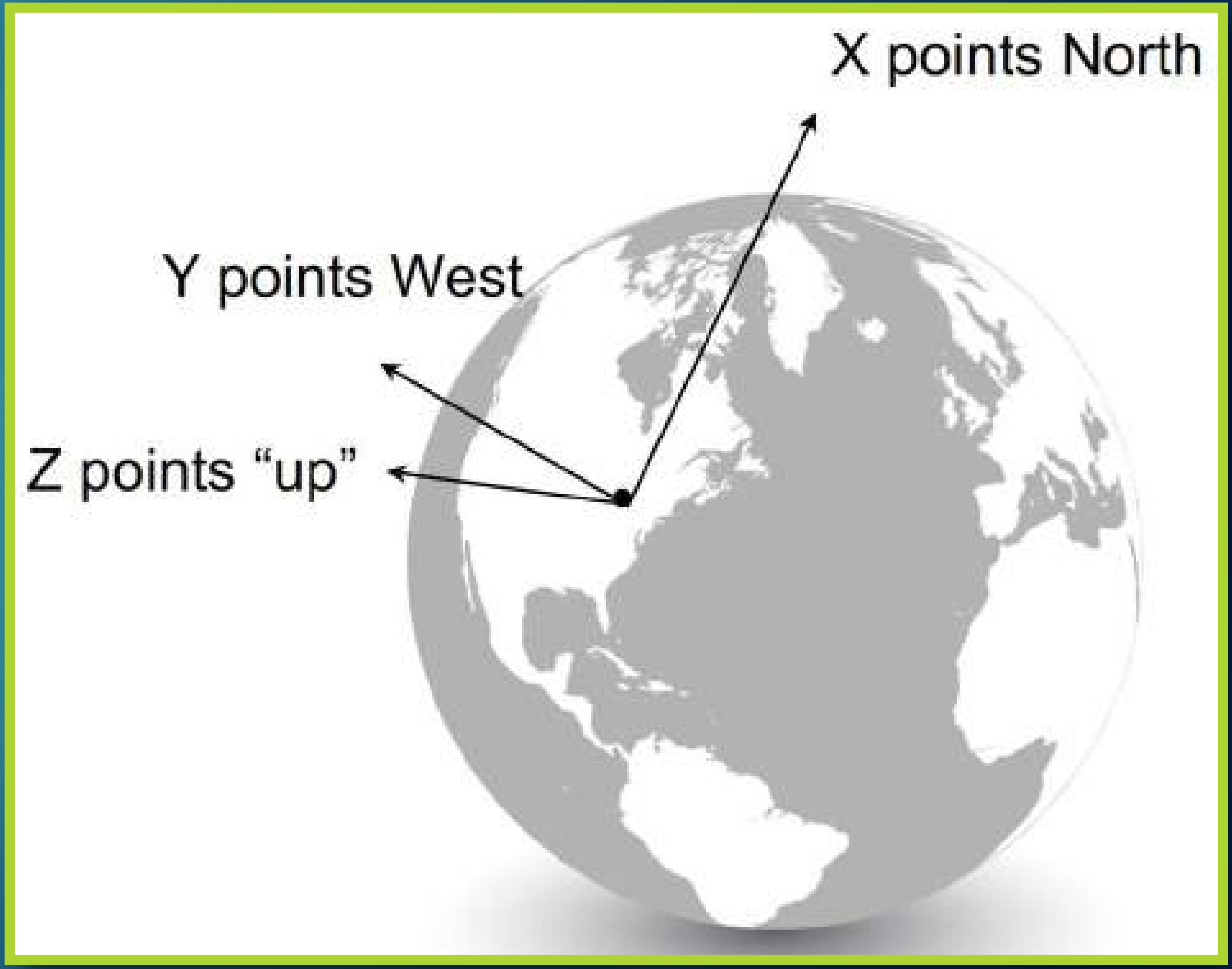
- Body-fixed frames are tied to a named body and rotate with it
- The vertical axis coincides with the top's axis of rotation (spin).
- Frame name style is “IAU_body name” (IAU_MARS, IAU_SATURN …)



Topocentric frames

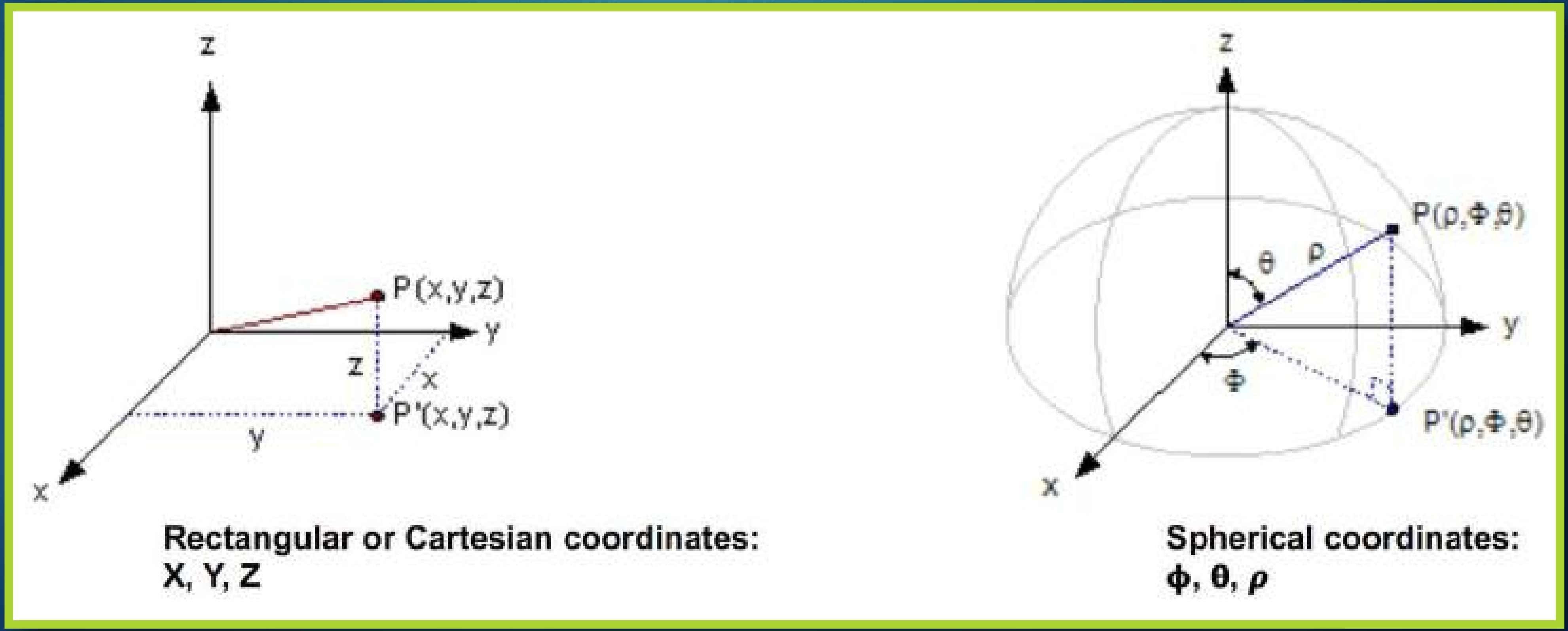
Topocentric frames are located at or near to a body's surface

- One axis is normal to a reference spheroid, or parallel to the gravity gradient
- Examples: frames defined for telecommunications stations, or for landers or rovers



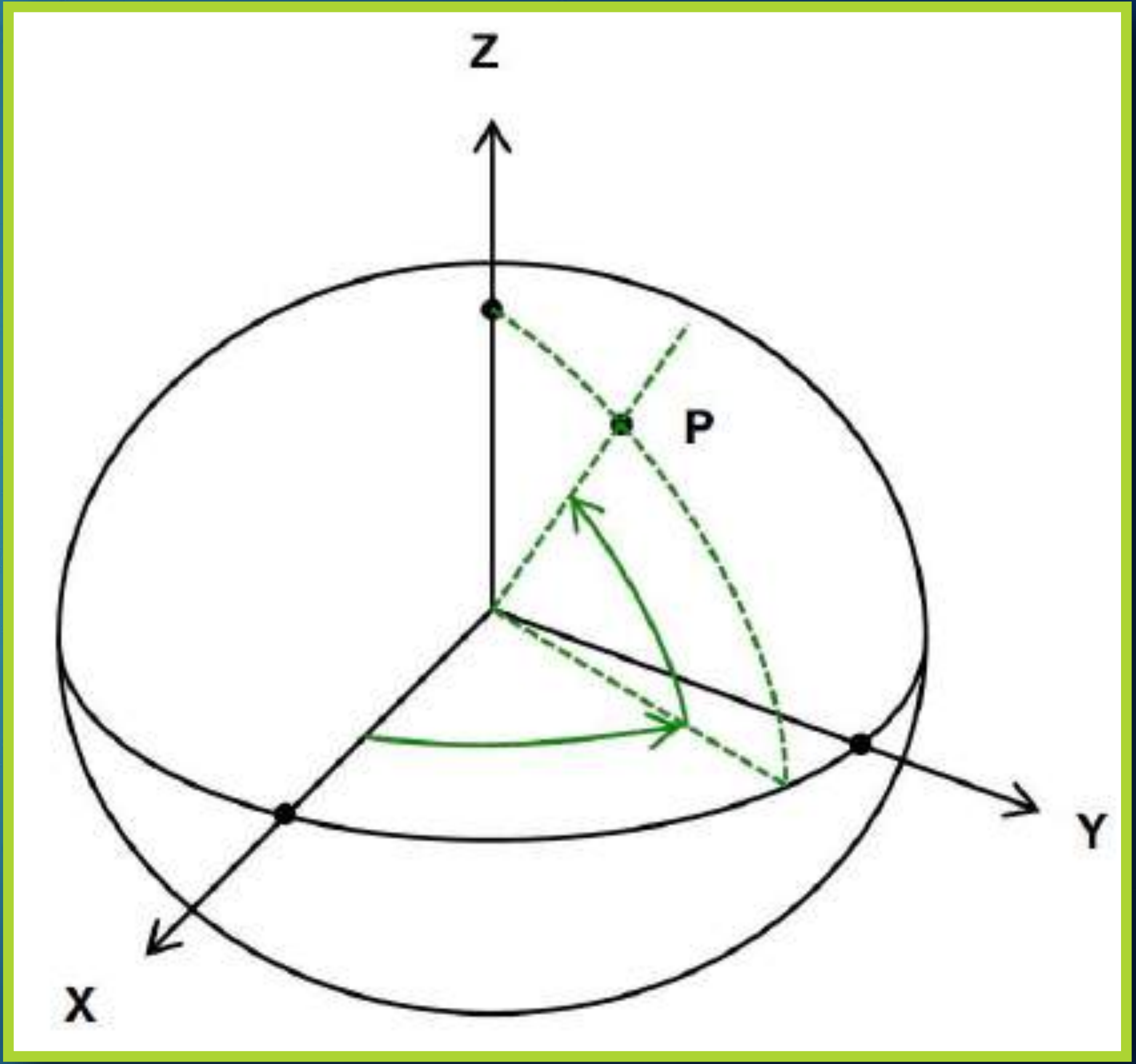
Coordinate Systems

- A coordinate system specifies the method used to locate a point within a particular reference frame.



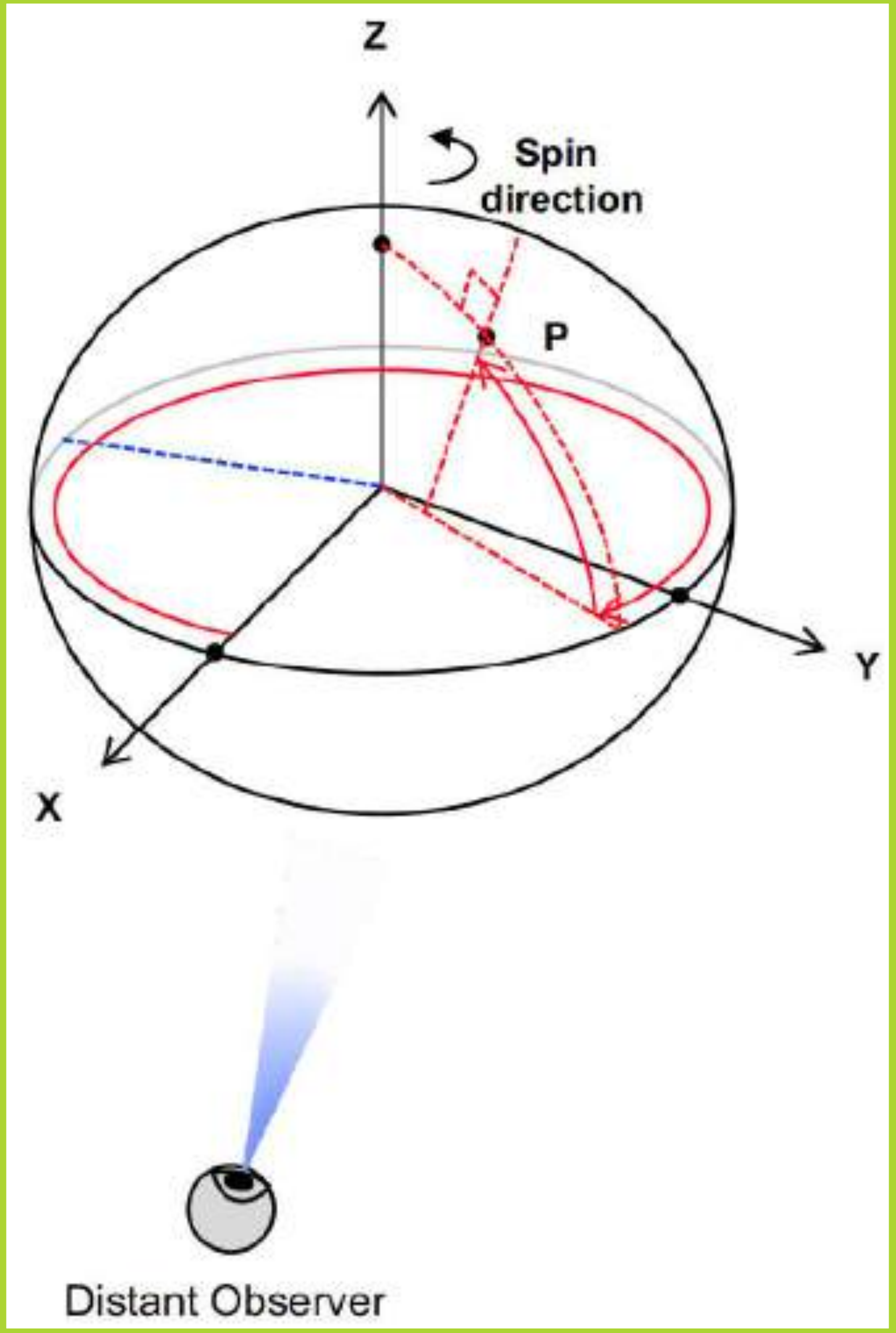
Planetocentric Coordinate System

- For planets and their satellites, the +Z axis (+90 latitude) always points to the north side of the invariable plane (the plane whose normal vector is the angular momentum vector of the solar system)
  - Planetocentric longitude increases positively eastward (-180 to +180)
  - Planetocentric latitude increases positively northward (-90 to +90)



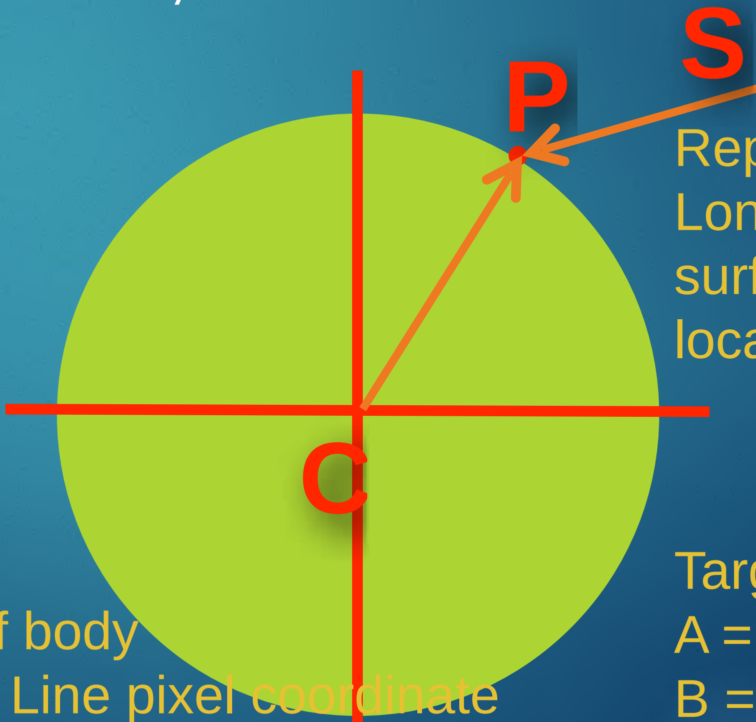
Planetographic Coordinate System

- For planet and satellite planetographic coordinate systems:
  - Planetographic longitude is usually defined such that the sub-observer longitude increases with time as seen by a distant, fixed observer (0 to 360)
  - The earth, moon, and sun are exceptions; planetographic longitude is positive east by default (0 to 360)

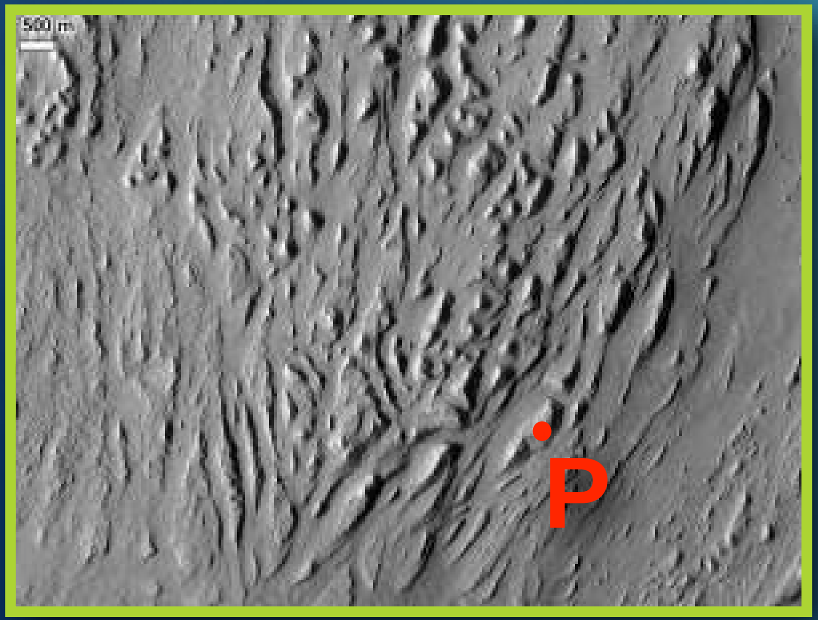


Camera/Sensor Model and SPICE

- Intersecting the surface
  - Given any pixel location on an image (sample, line coordinate)
  - Compute a location on a surface (3-dimensional coordinate)
    - Usually reported as latitude, longitude, radius
    - Also represented as body fixed x, y, z



Reported Latitude and Longitude, Radius on the surface at the image pixel location (P)

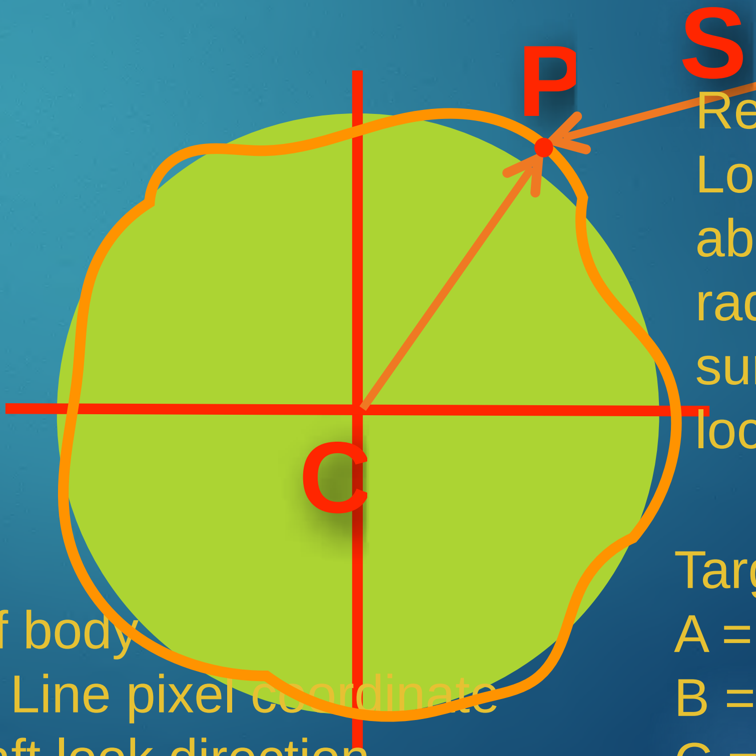


C =Center of body
P = Sample, Line pixel coordinate
S= Spacecraft look direction

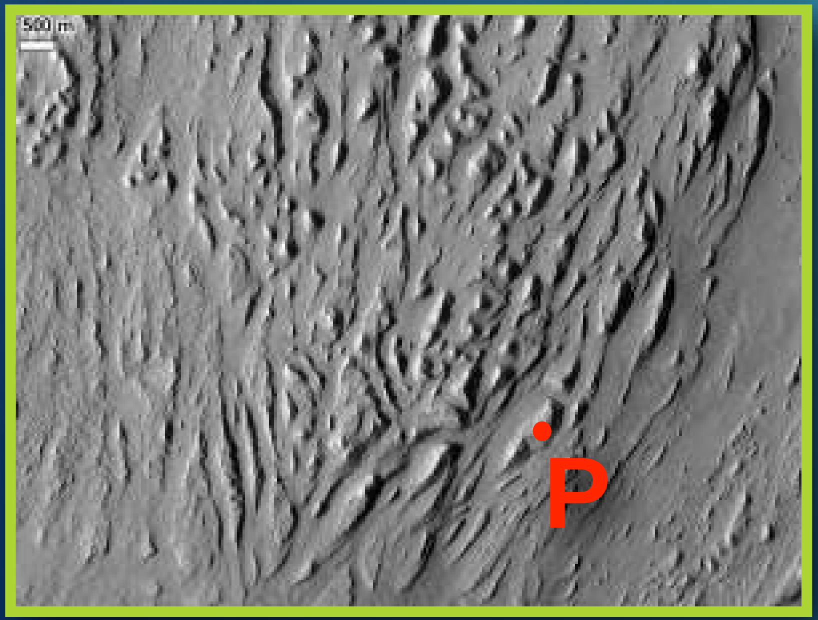
Target body shape (Radius)
A = Major Equatorial Axis
B = Minor Equatorial Axis
C = Minor Polar Axis

Camera/Sensor Model and SPICE

- Digital Elevation Model (DEM)
  - Local topography for accurate computation of surface points
  - Allows for ortho-rectification for 2D map projection
    - Default global DEMS for the Moon & Mars
      - LOLA for Moon
      - MOLA for Mars



Reported Latitude and Longitude, and Local absolute radius (body radius + elevation) on the surface at the image pixel location (P)



C =Center of body
P = Sample, Line pixel coordinate
S= Spacecraft look direction

Target body shape (Radius)
A = Major Equatorial Axis
B = Minor Equatorial Axis
C = Minor Polar Axis

Orthorectification

- A Digital Elevation Model (DEM) can be used when projecting images
  - ISIS defaults to LOLA for the Moon and MOLA for Mars
- Pixels values are in absolute radius
- Removes effects of topography or geometric distortion in the output map projection
- The DEM must be provided in the spiceinit application

In Summary

- Ingest into ISIS (mission-dependant)
  - CTX images: mroctx2isis
- radiometric calibration
  - CTX images: ctxcal
- clean up
  - CTX images: ctxevenodd
- Naif kernels
  - spiceinit
- map project the images
  - cam2map

Level 0 data

Level 1 data

Level 2 data

Co-funded by the ERASMUS + Programme of the European Union

Using ISIS

2D IMAGE PROCESSING

Downloading and installing ISIS

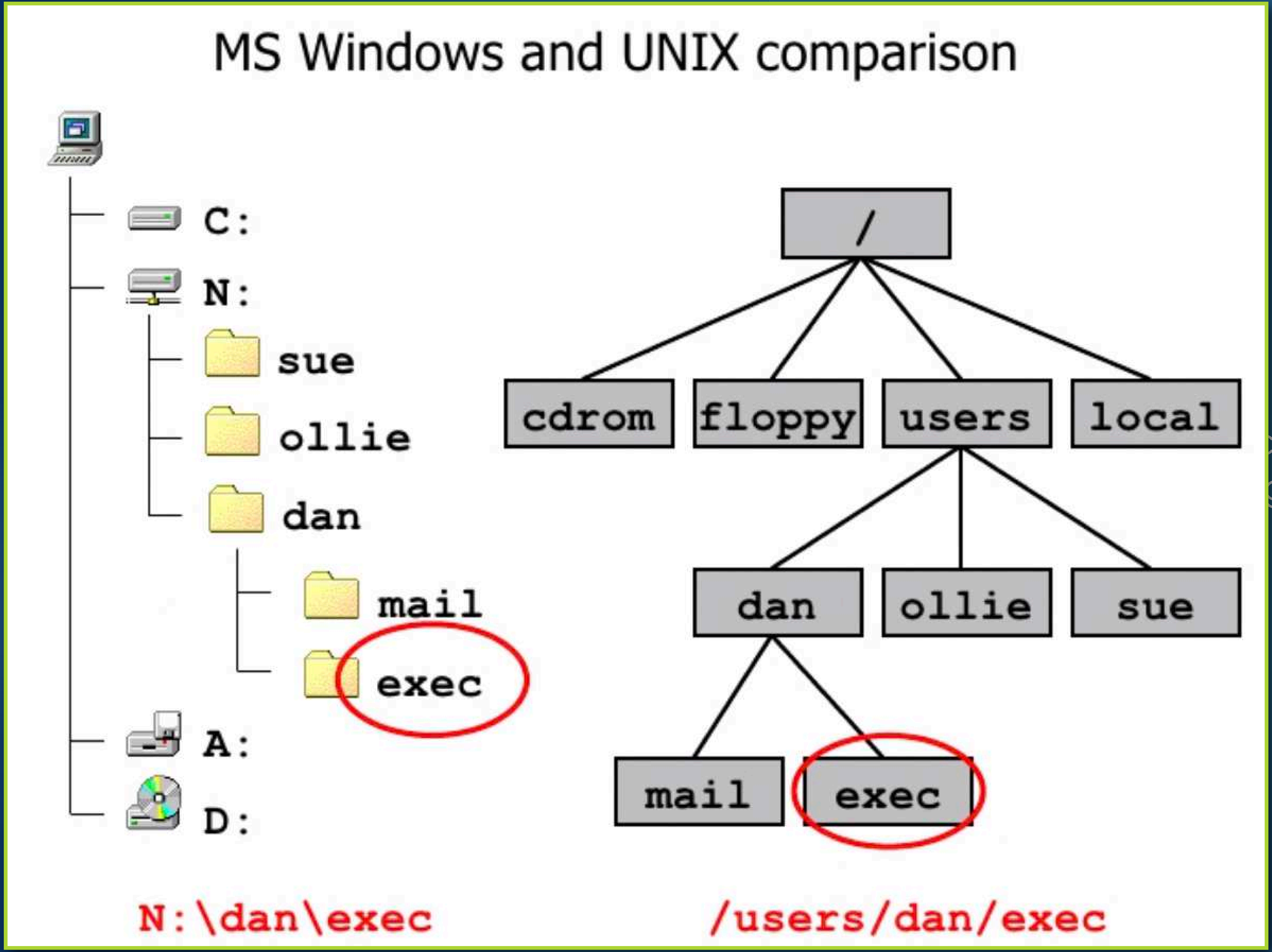
- https://github.com/USGS-Astrogeology/ISIS3#installation
- UNIX-based Supported Platform OSes
  - Ubuntu 18.04 LTS
  - Mac OS X 10.13.6 High Sierra
  - Fedora 28
  - CentOS 7.2
- ✓ Current (August 1) ⇢ ISIS 7.1.0 Release Candidate 1

Citing ISIS

- https://github.com/USGS-Astrogeology/ISIS3/blob/dev/README.md#isis3-installation-with-conda
- This project uses a Zenodo generated DOI. The badge at the top of this README links to the DOI for the latest release. It is good practice (See 'Which DOI Should I Use in Citations?') to cite the version of the software being used by the citing work. To obtain this DOI, one can follow the link to the latest version and then check the right sidebar area titled Versions for a listing of all ISIS versions that currently have a Zenodo DOI.
- Laura, Jason, Acosta, Alex, Addair, Travis, Adoram-Kershner, Lauren, Alexander, James, Alexandrov, Oleg, et al. (2022, February 14). Integrated Software for Imagers and Spectrometers (Version 7.0.0_RC1). Zenodo. https://doi.org/10.5281/zenodo.6072842

UNIX

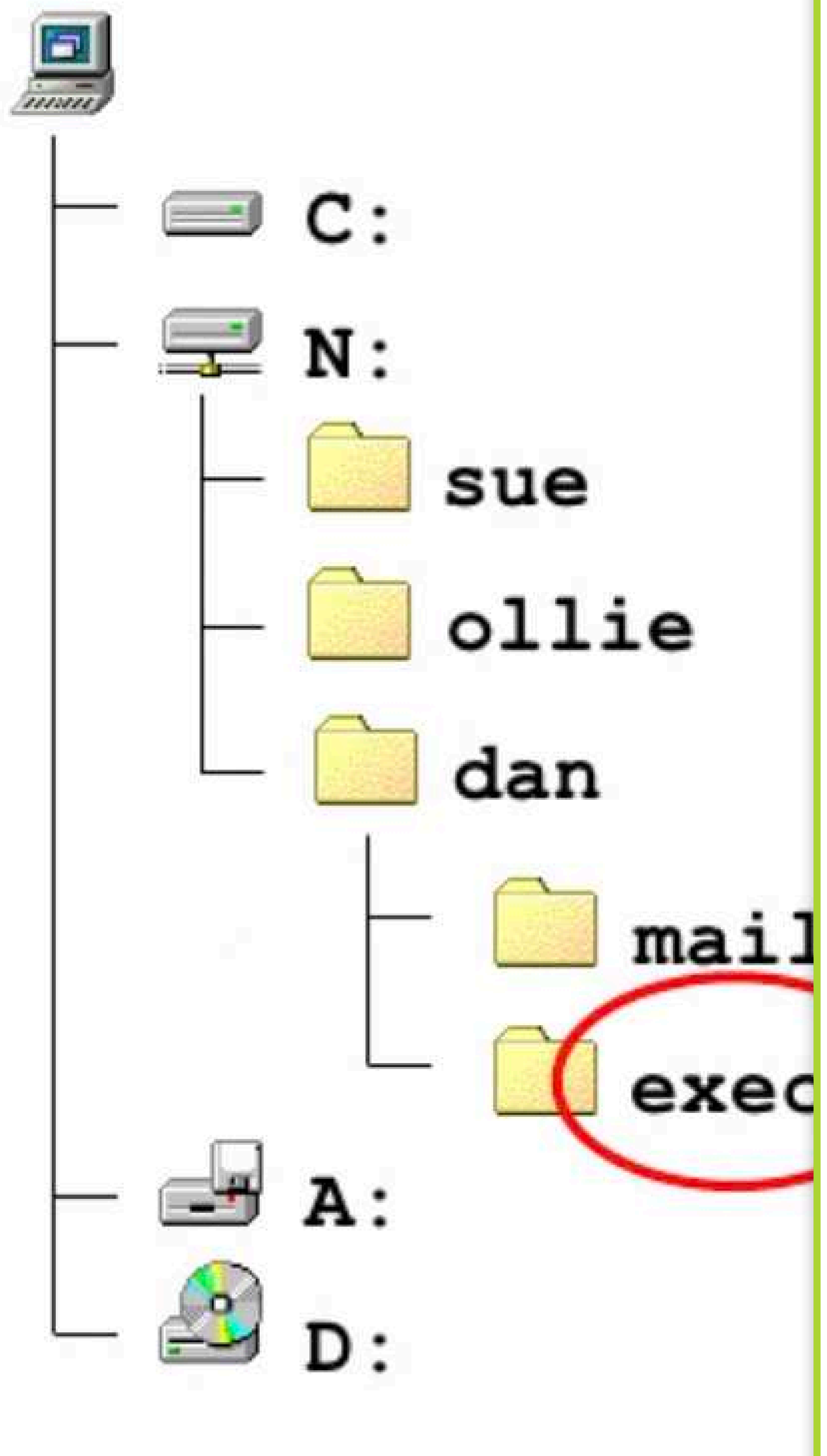
- Operating system analogous to DOS and Windows
- Commands are simple (e.g., `cp` means copy)
- The concept of "local drives" and "network drives" is unnecessary in UNIX. All disks, local or networked, appear as a part of a single file structure as subdirectories of a single "root" directory



cessary in
gle file

File paths

MS Window



N:\dan\exec

[1] Absolute location:

/users/dan/mail/my.doc

[2] Relative to the directory "**sue**"

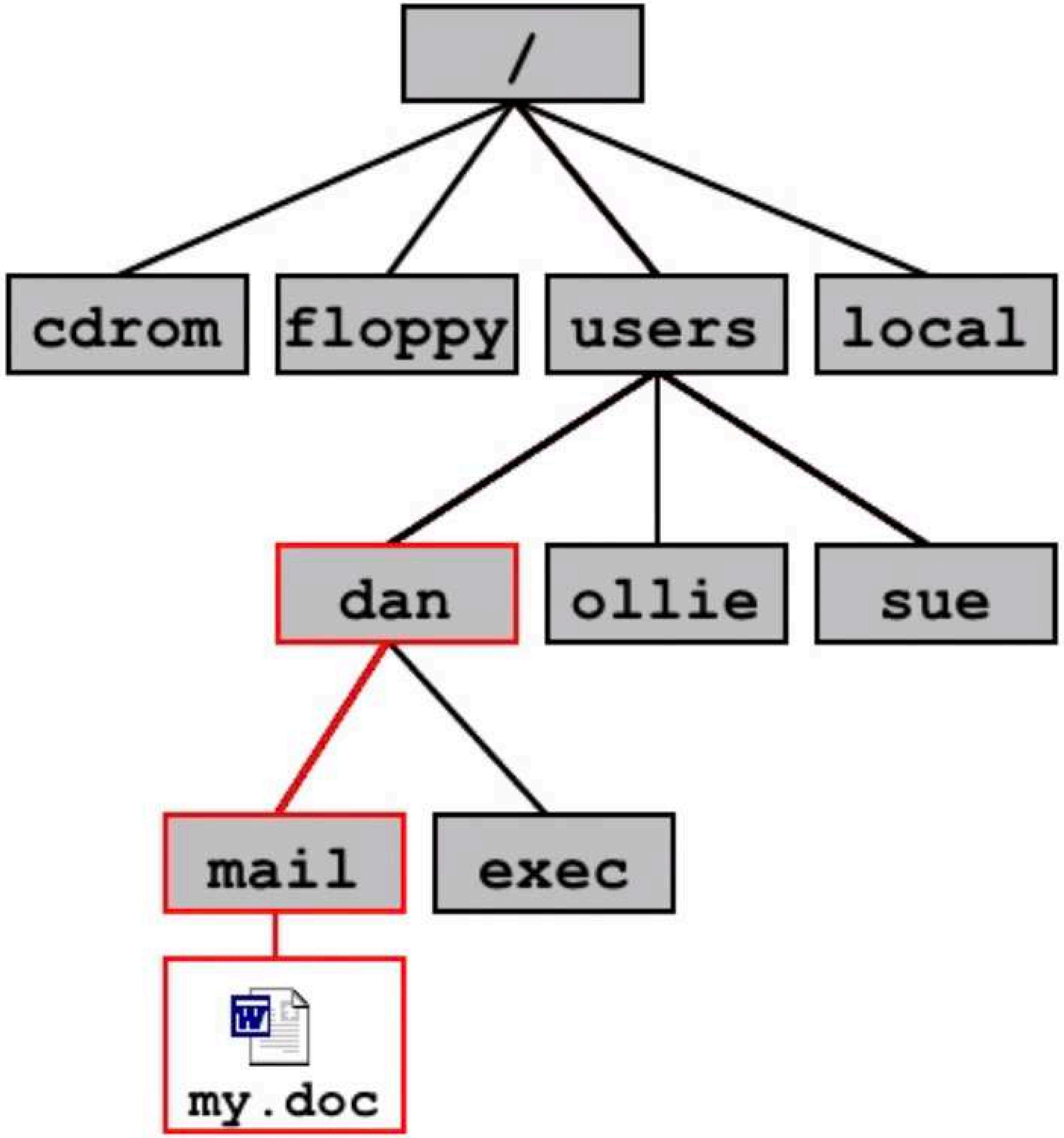
../dan/mail/my.doc

[3] For Dan, relative to his homespace:

~/mail/my.doc

[4] For everyone else, relative to Dan's homespace:

~dan/mail/my.doc



Using the terminal

- The UNIX commands entered at the prompt are interpreted into actions by the “shell interpreter”. The shell requires commands to have the correct syntax so that they are unambiguous.
- The general structure is as follows:

```
COMMAND [ OPTIONS ] FILE OR DIRECTORY NAME(S)
```

- options modify how the command works and are used either to supply extra information required by the command or to use it in a way other than its default manner. The options are usually specified using letters preceded by a “-”.

Basic commands

- CD NAME change directory to name
- LS lists the contents of the current directory
- LS -LA detailed listing of the current directory
- CP FILE1 FILE2 copy a file
- MV FILE1 FILE2 move or rename a file
- RM NAME remove (delete) the file called name
- MKDIR NAME make a new directory called name
- RMDIR NAME remove (delete) the directory called name
- CAT NAME read a file
- PICO NAME simple text editor via terminal (a variant is nano)

Example

- cp myfile /home/Summer_School
  - This means that I will copy my file in the Summer School directory
  - /home/Summer_School is the Absolute path: it will work regardless from my position at that moment

A shell script

- A shell script is a file in which UNIX commands are written in plain text.
- Each line in the shell script contains a UNIX command exactly as it would be typed in at the command prompt.
- The advantage of a shell script is that it makes it easy to combine many UNIX commands, which together perform complex or repetitive tasks, without having to type them in every time.

Example

- mroctx2isis -batchlist=root.lis from=\$1.IMG to=\$1.cub
- ctxcal -batchlist=root.lis from=\$1.cub to=\$1_cal.cub
- ctxevenodd -batchlist=root.lis from=\$1_cal.cub to=\$1_lev1.cub
- spiceinit -batchlist=root.lis from=\$1_lev1.cub

Use of the cluster ⇢ basics

- High Performance Computing
- Unix/Linux Debian (see provided command list)
  - A high-performance computer is built from what are basically many ordinary computers connected with a network and centrally coordinated by some special software. Because computers are usually physically very close together, the common term for a high-performance computer today is a ***cluster***.
  - Slurm is a resource manager and job scheduler
  - To gather information:
    - `SQUEUE` ⇢ shows to which jobs resources are currently allocated and which are currently running
    - `SQUEUE -U [USER]` ⇢ shows to which jobs of the specific user those resources are currently allocated and which are currently running
    - `SCANCEL` ⇢ kill the job (e.g., `SCANCEL 9911`)
    - Job state: R abbreviation for Running - PD abbreviation for Pending.

```
             JOBID PARTITION     NAME     USER ST       TIME  NODES NODELIST(REA
SON)
               205   compute  seed.sh    brent  R   20:00:29      1 node10
               195   compute  seed.sh    brent  R 2-15:14:18      1 node10
(base) ori@frontend0:~/STORAGE_ORI/Summer_School$
```

Creating a Job

- A job consists in two parts: resource requests and job steps
- The typical way of creating a job is to write a submission script. A submission script is a shell script, whose comments, if they are prefixed with SBATCH, are understood by Slurm as parameters describing resource requests and other submissions options.
- The SBATCH directives must appear at the top of the submission file, before any other line except for the very first line which should be the shebang (e.g., #!/bin/bash).

Sbatch

- Example SBATCH

```
#!/BIN/BASH

#SBATCH --ACCOUNT ACC3
#SBATCH -P COMPUTE
#SBATCH -O N.OUT
#SBATCH -E N.ERR
#SBATCH -J DIDATTICA_GEO-02
#SBATCH --GET-USER-ENV
#SBATCH --NODES=4
#SBATCH --NTASKS=48
#SBATCH --HINT=COMPUTE_BOUND
#SBATCH --MAIL-TYPE=ALL
#SBATCH --MAIL-USER=MONICA.PONDRELLI@UNICH.IT
#SBATCH --TIME=2-0


WGET -I CTX
```

Sbatch

- Example SBATCH

```
#!/bin/bash

#SBATCH --account acc3
#SBATCH -p compute
#SBATCH -o N.out
#SBATCH -e N.err
#SBATCH -J didattica_geo-02
#SBATCH --get-user-env
#SBATCH --nodes=4
#SBATCH --ntasks=48
#SBATCH --hint=compute_bound
#SBATCH --mail-type=ALL
#SBATCH --mail-user=monica.pondrelli@unich.it
#SBATCH --time=2-0

wget -i CTX
```

it means: rules within the cluster

Sbatch

- Example SBATCH

```
#!/bin/bash

#SBATCH --account acc3
#SBATCH -p compute
#SBATCH -o N.out
#SBATCH -e N.err
#SBATCH -J didattica_geo-02
#SBATCH --get-user-env
#SBATCH --nodes=4
#SBATCH --ntasks=48
#SBATCH --hint=compute_bound
#SBATCH --mail-type=ALL
#SBATCH --mail-user=monica.pondrelli@unich.it
#SBATCH --time=2-0

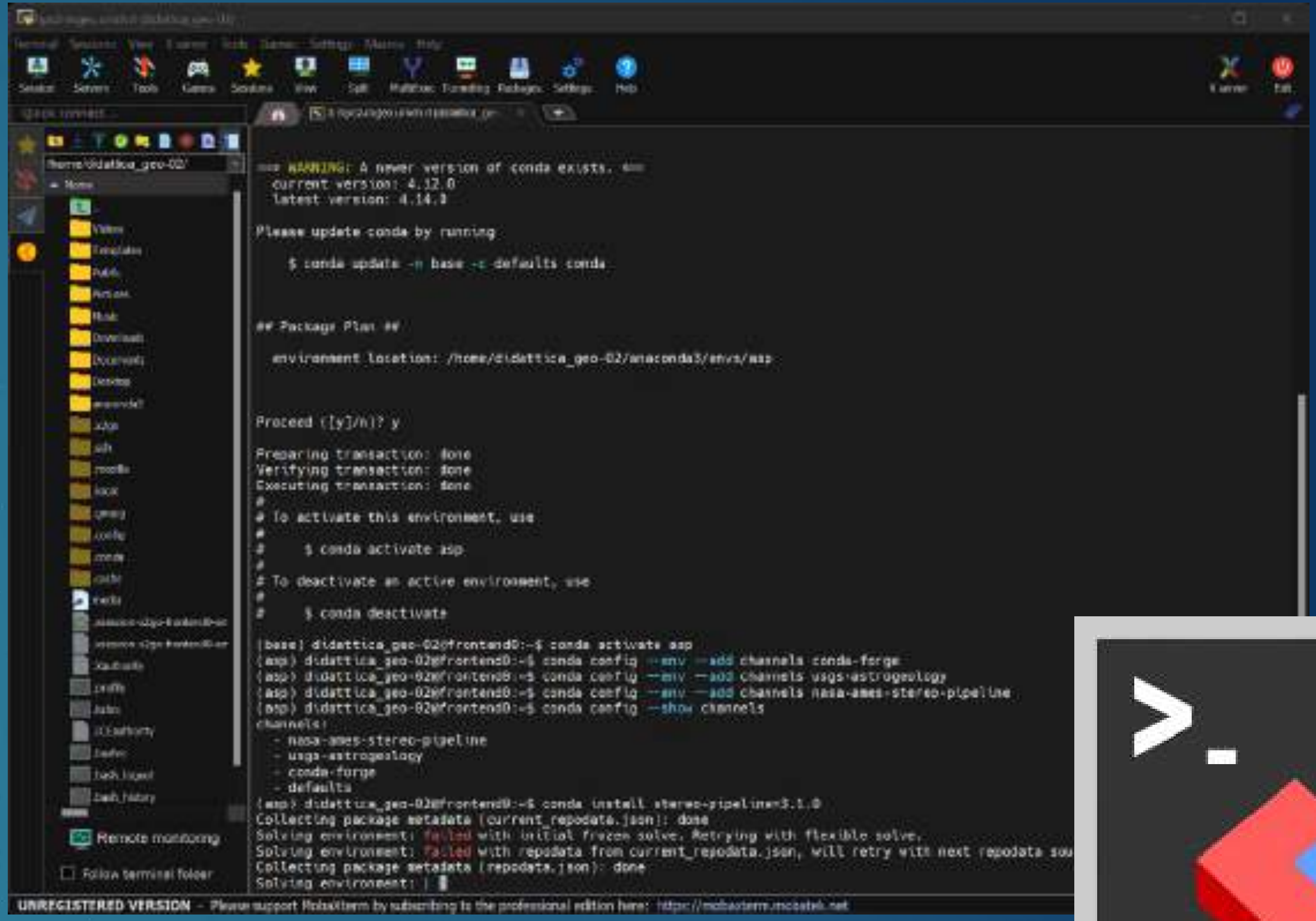
wget -i CTX
```

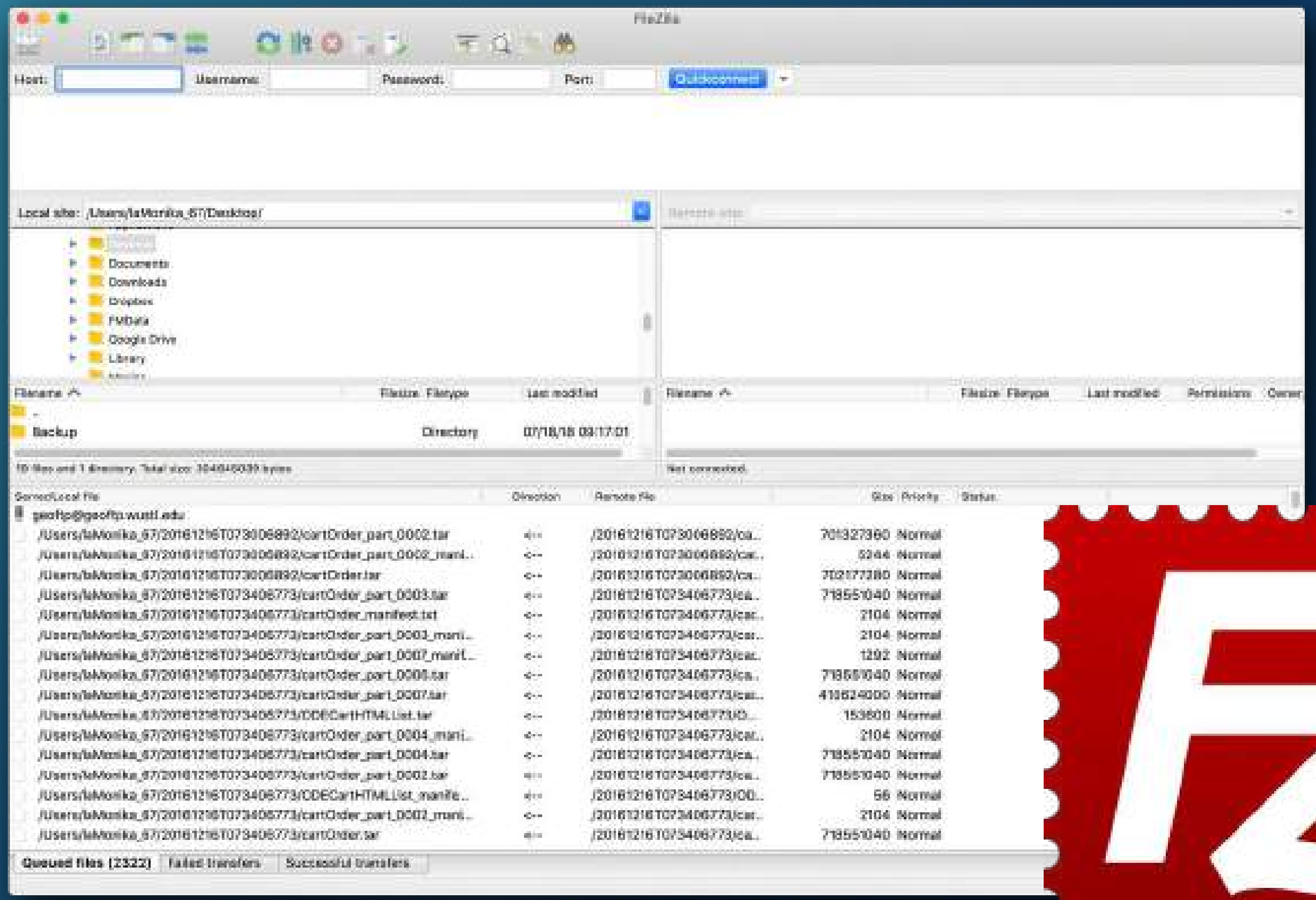
it means: rules within the cluster

this is the actual process

Necessary software to access the cluster and download data

- Remote desktop software
  - (Win) MobaXterm
    - https://mobaxterm.mobatek.net
- Data transfer
  - FileZilla
    - https://filezilla-project.org
- (recommended) Advanced text editor
  - (Windows) Notepad++
    - https://notepad-plus-plus.org/downloads/
  - (MacOs & Unix) Atom
    - https://atom.io/





Folders (directories) and workspace

Our main working directory:
/home/Summer_School

```
(base) didattica_geo-02@frontend0:~$ ls
anaconda3  demProva  Desktop  Documents  Downloads  Music  Pictures  Public  Summer_School  Summer_School_OLD  Templates  Videos
(base) didattica_geo-02@frontend0:~$ cd Summer_School
(base) didattica_geo-02@frontend0:~/Summer_School$ ls
10__Jiji-Sera2  11_Zephyria2  12_Zephyria1  1_Becquerel1  2_Becquerel  3_Nereidum1  4_Nereidum2  5_Eberswalde1  6_Eberswalde2  7_Kotido1  8_Kotido2  9_Jiji-Sera1
(base) didattica_geo-02@frontend0:~/Summer_School$
```

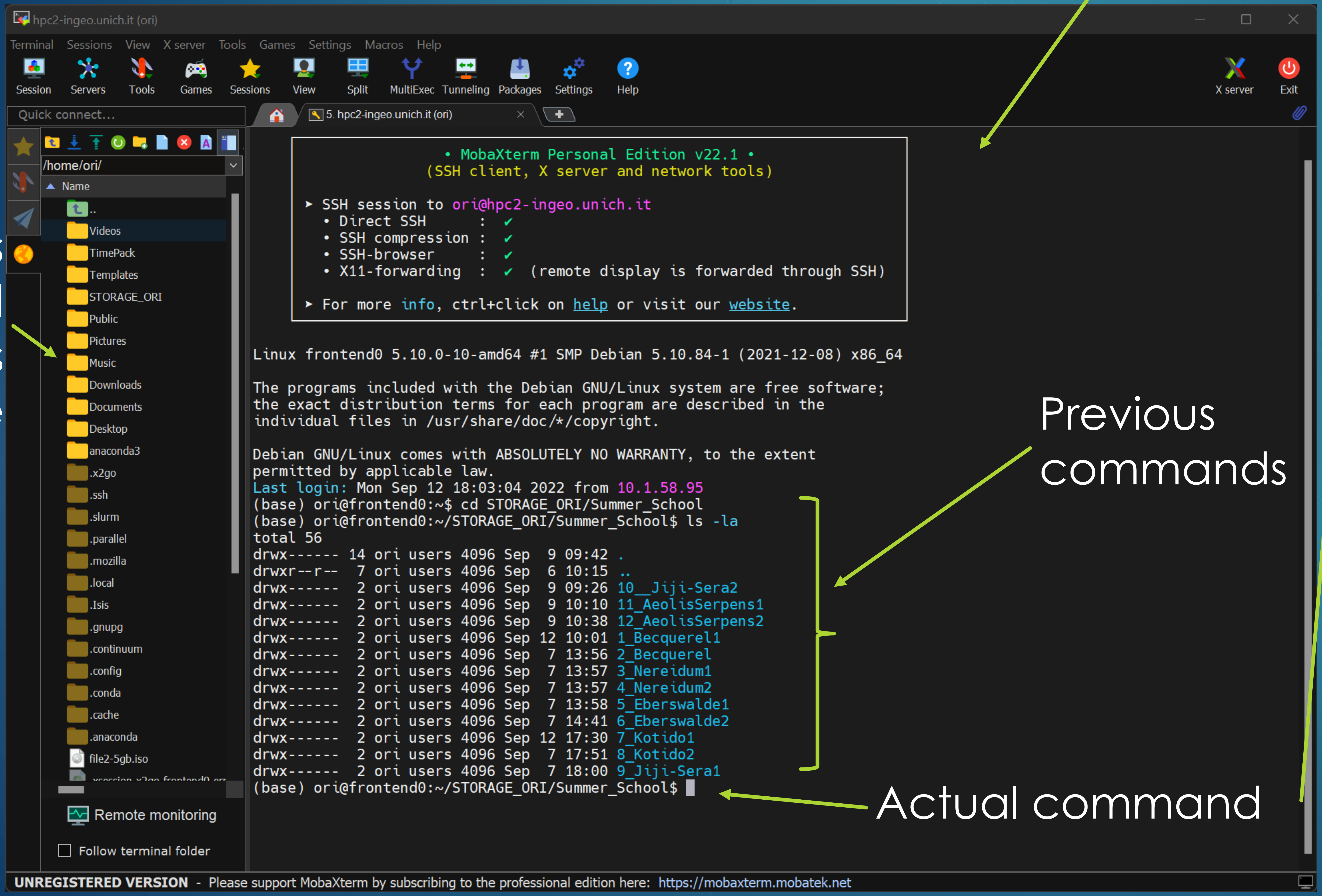
Available STUDY AREAS

Using the terminal

Work Directory

Terminal

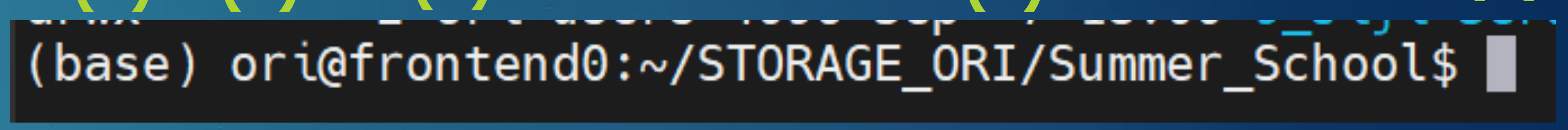
Files and folders tree



Previous commands

Actual command

(1) (2) (3) (4) (5)



(1) Actual conda environment
(2) User
(3) Machine
(4) Work directory (empty when home)
(5) Typing space

Downloading data
This part is already finished: just to see a script

- cd into the folder of the area you are interested in
- Sbatch file wget.sh
  - WGET -I CTX

WGET: free software package for retrieving files

- *.IMG REPRESENT THE RAW CTX PRODUCTS

Downloading data
This part is already finished: just to see a script

- cd into the folder of the area you are interested in
- Sbatch file wget.sh
  - WGET -I CTX

    it means: read from a file

  WGET: free software package for retrieving files

- *.IMG REPRESENT THE RAW CTX PRODUCTS

Downloading data
This part is already finished: just to see a script

- cd into the folder of the area you are interested in
- Sbatch file wget.sh
  - WGET -I CTX

    it means: read from a file

  WGET: free software package for retrieving files

- *.IMG REPRESENT THE RAW CTX PRODUCTS

Process 2D data with ISIS

list of the product IDs

- Create a text file with the Product IDs you downloaded BUT NO extension:

```
ls *IMG | sed 's/\.IMG//' > root.lis
```

  - Look at the list:

```
cat root.lis
```

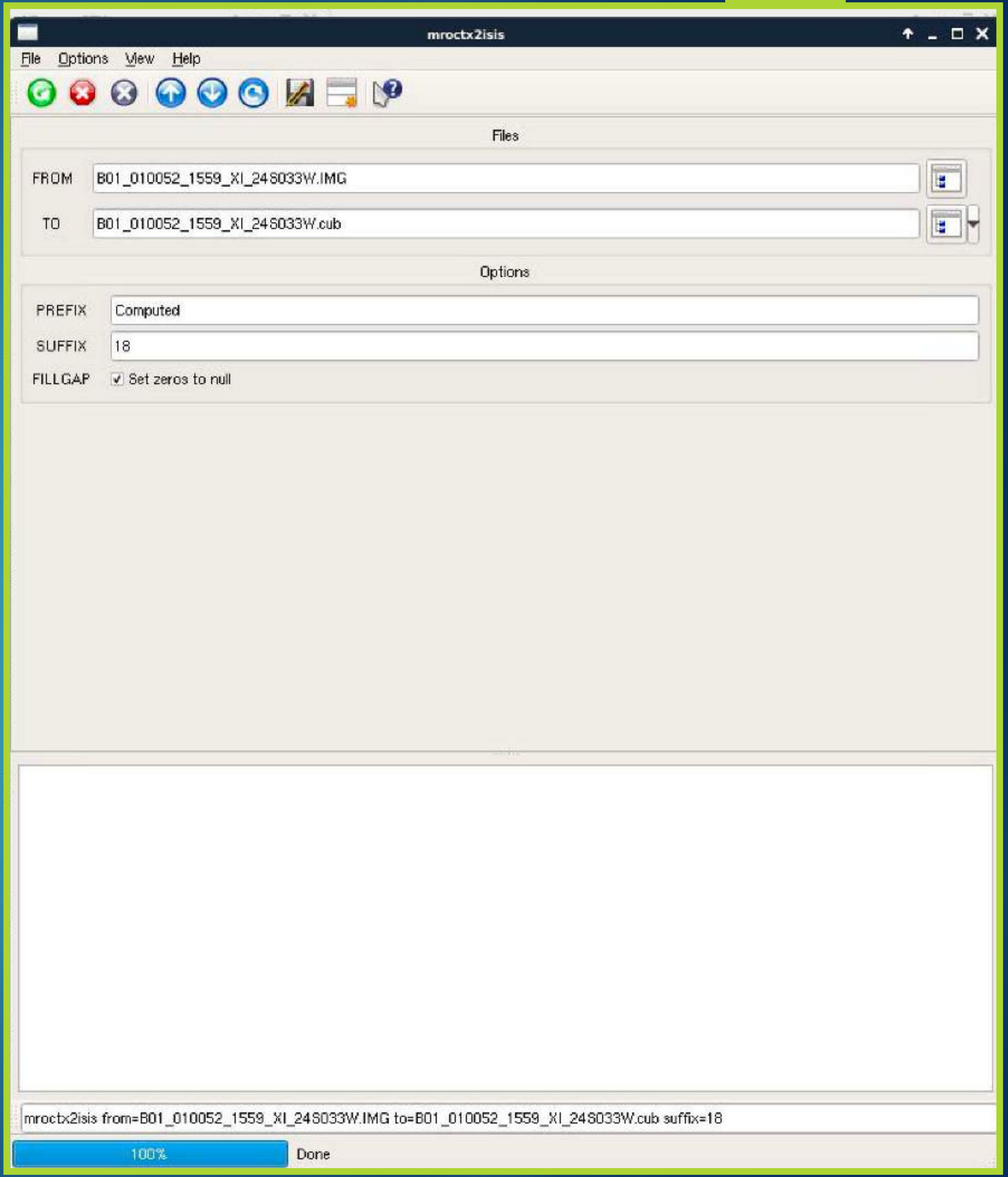
- Why to perform such operation?
- To launch the commands for all the data at the same time

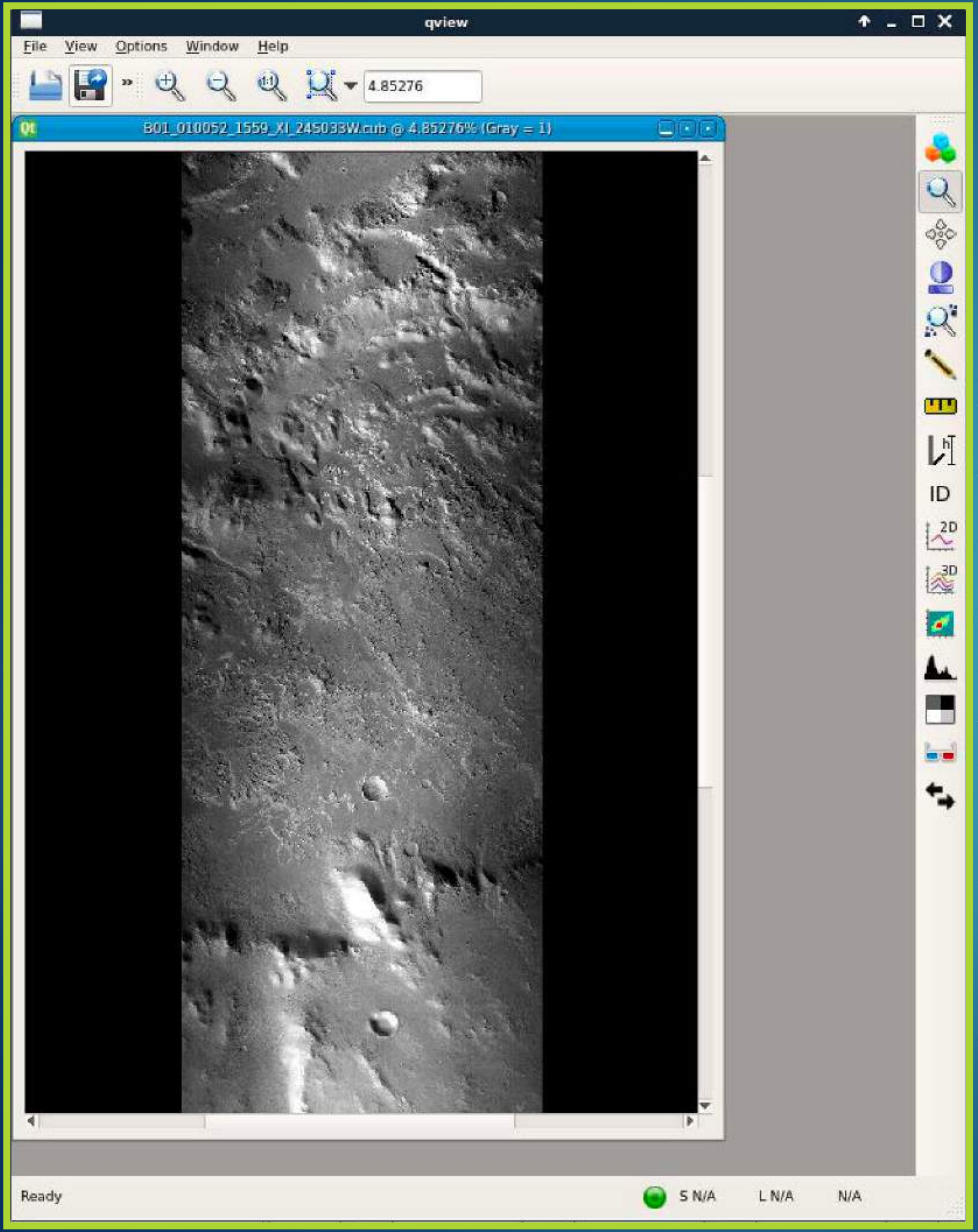
- But first: step by step

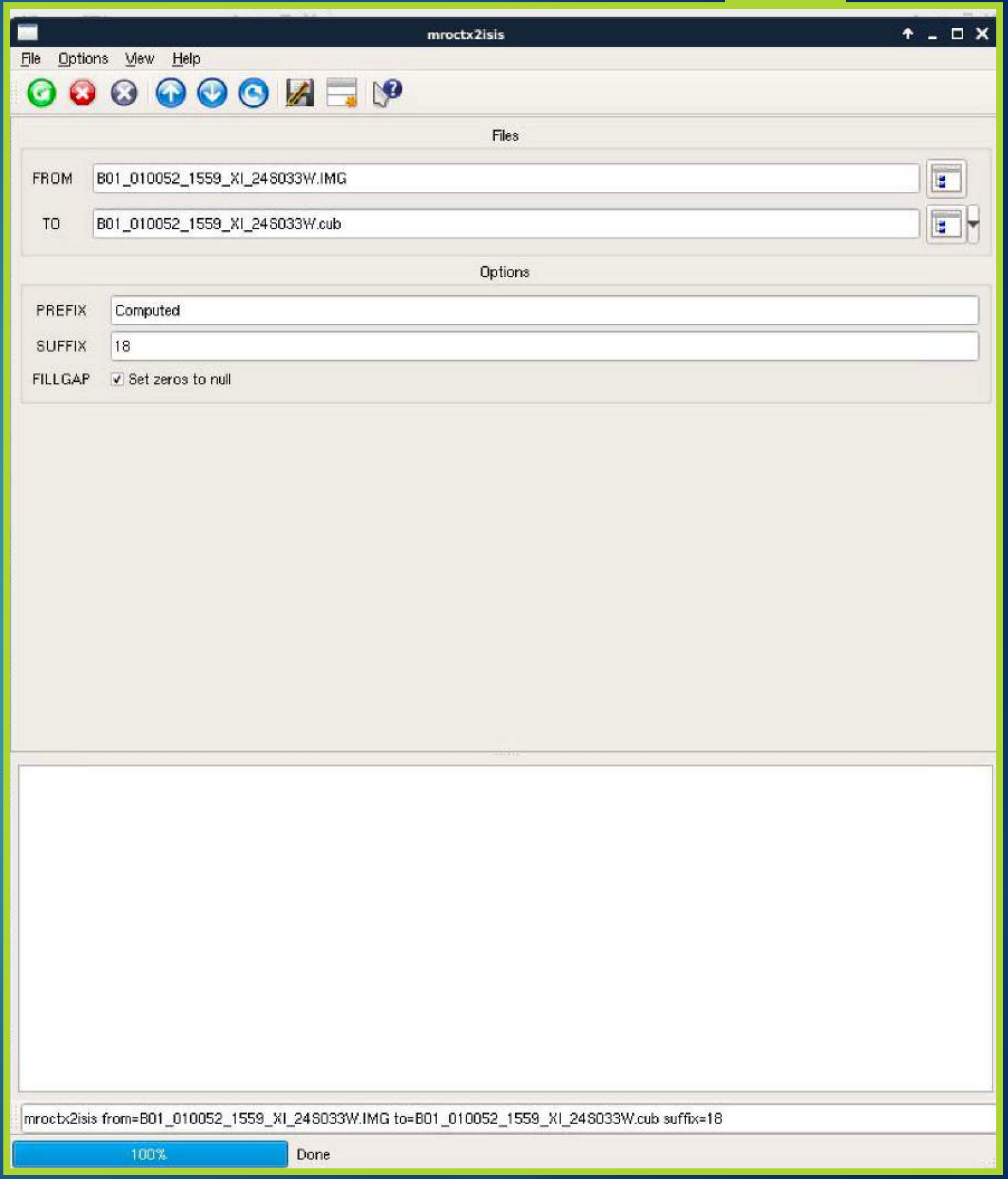
Process 2D data with ISIS

Step 1: ingest into isis3

- command `mroctx2isis`
- command `qview` to have a look and `catlab` to check the label


mroctx2isis
File Options View Help
Files
FROM B01_010052_1559_XI_24S033W.IMG
TO B01_010052_1559_XI_24S033W.cub
Options
PREFIX Computed
SUFFIX 18
FILLGAP Set zeros to null
mroctx2isis from=B01_010052_1559_XI_24S033W.IMG to=B01_010052_1559_XI_24S033W.cub suffix=18
100%
Done

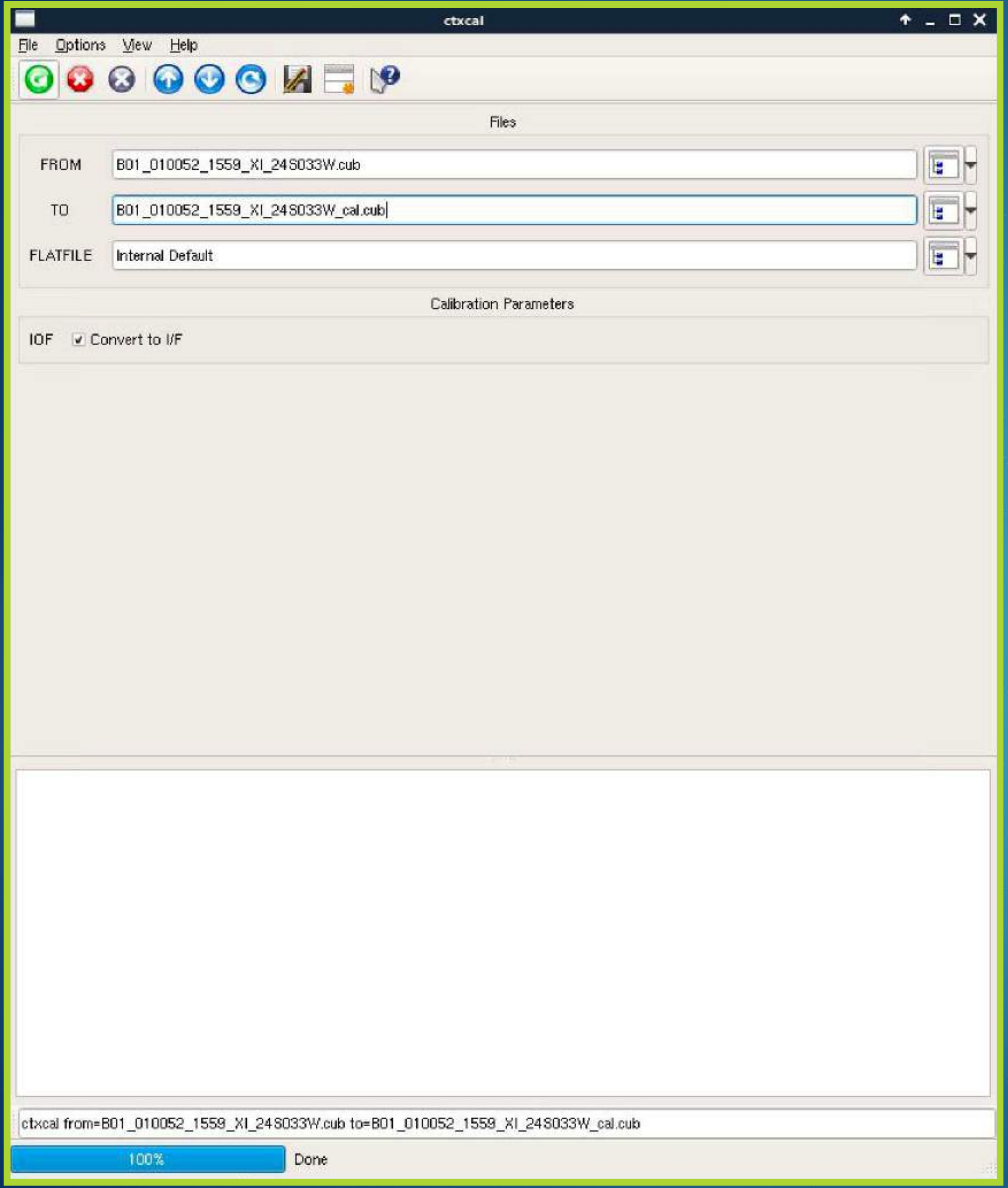

qview
File View Options Window Help
4.85276
B01_010052_1559_XI_24S033W.cub @ 4.85276% (Gray = 1)
ID
2D
3D
Ready
S N/A
L N/A
N/A


mroctx2isis
File Options View Help
Files
FROM B01_010052_1559_XI_24S033W.IMG
TO B01_010052_1559_XI_24S033W.cub
Options
PREFIX Computed
SUFFIX 18
FILLGAP Set zeros to null
mroctx2isis from=B01_010052_1559_XI_24S033W.IMG to=B01_010052_1559_XI_24S033W.cub suffix=18
100%
Done

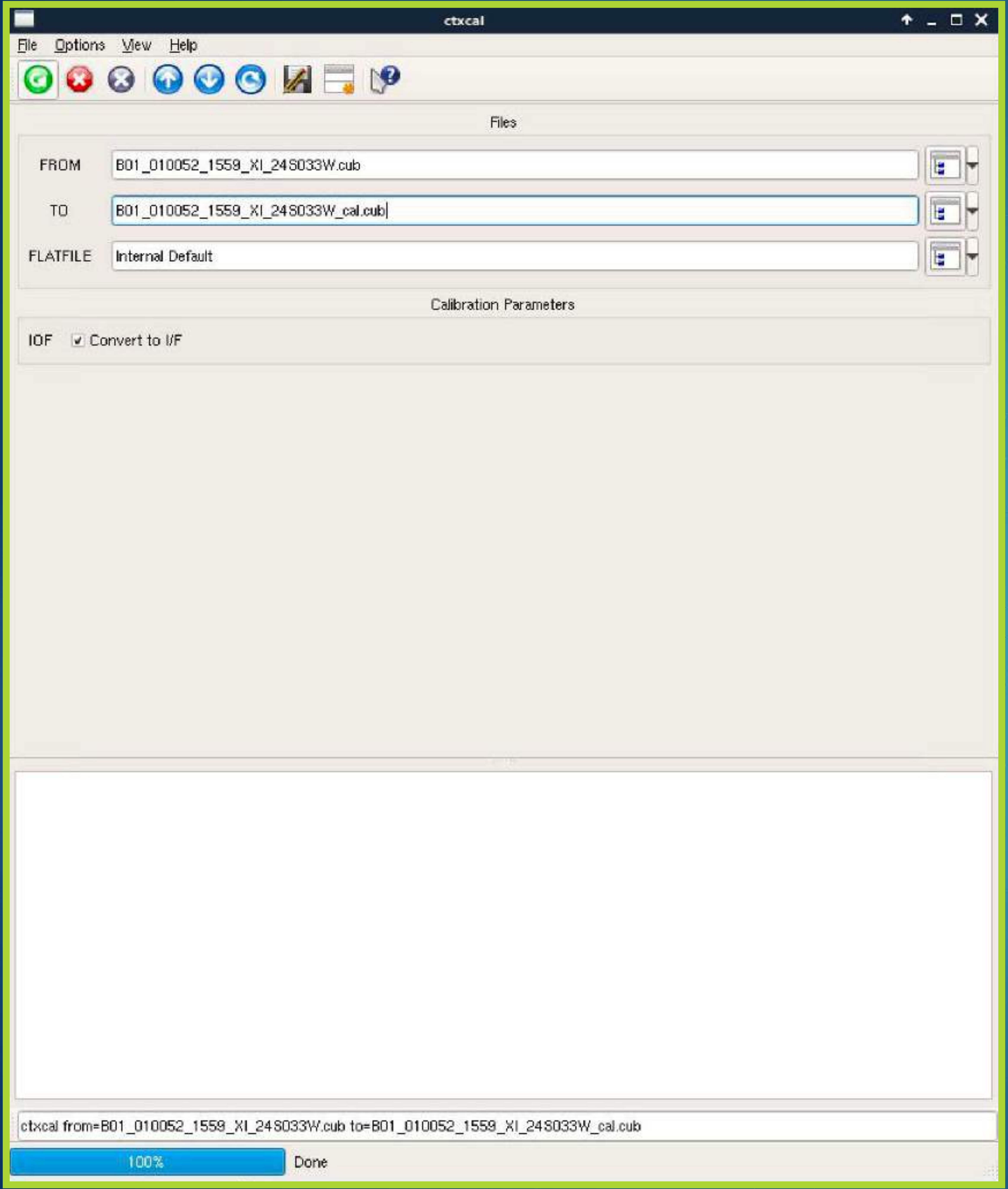
Process 2D data with ISIS

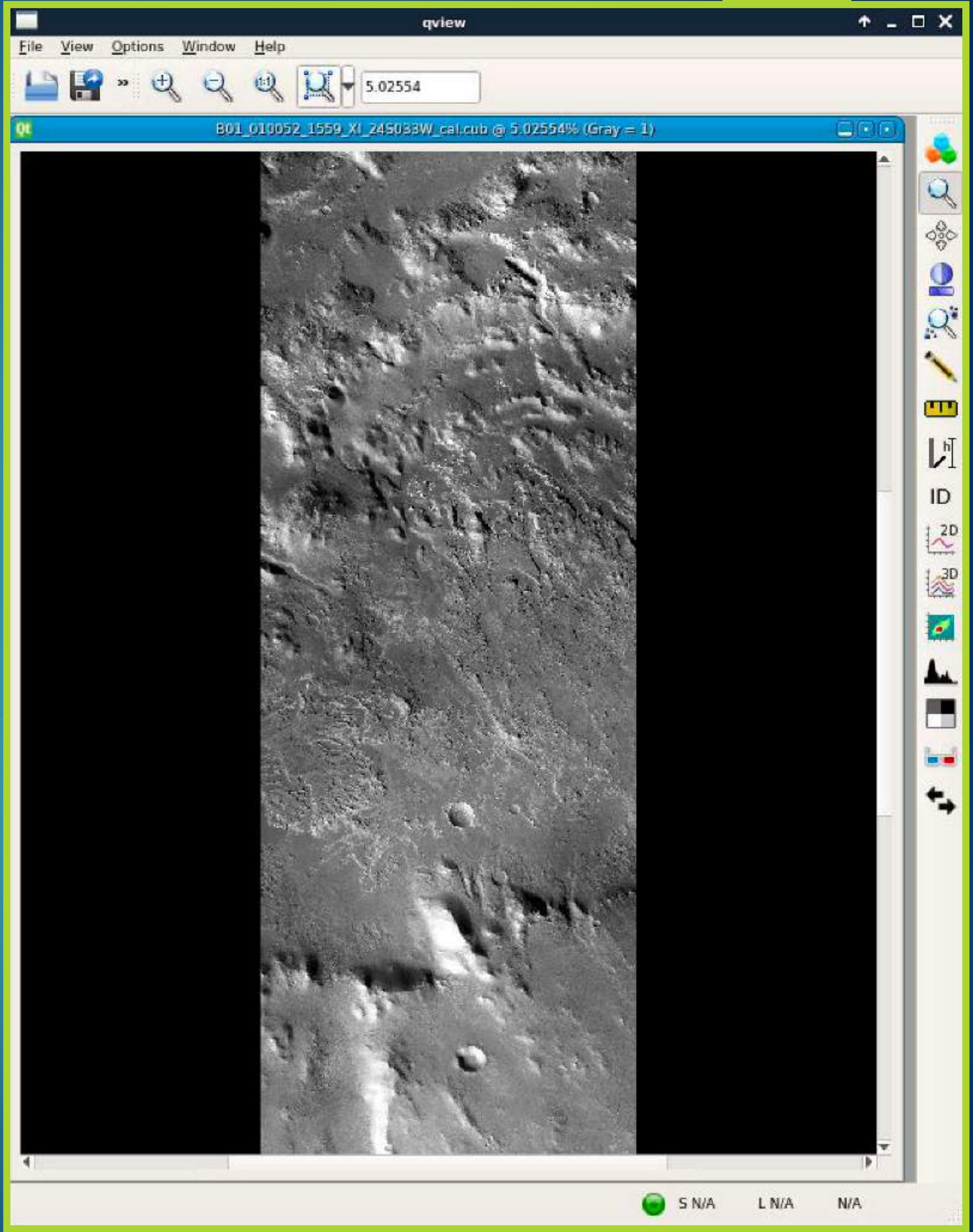
Step 2: radiometric calibration

- command `CTXCAL`
- command `QVIEW` to have a look



ctxcal
File Options View Help
Files
FROM
B01_010052_1559_XI_24S033W.cub
TO
B01_010052_1559_XI_24S033W_cal.cub
FLATFILE
Internal Default
Calibration Parameters
IOF
Convert to I/F
ctxcal from=B01_010052_1559_XI_24S033W.cub to=B01_010052_1559_XI_24S033W_cal.cub
100%
Done

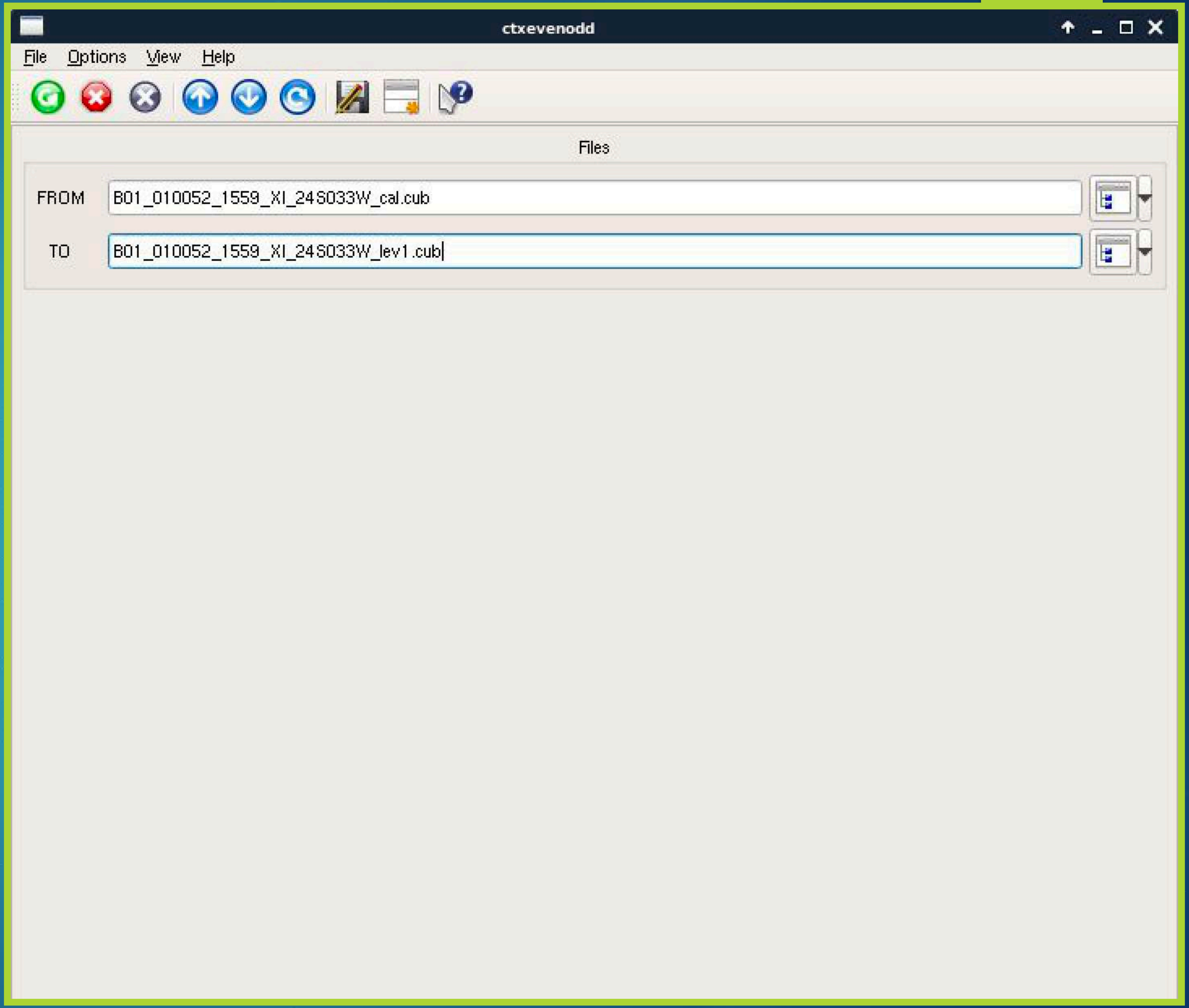

ctxcal
File Options View Help
Files
FROM B01_010052_1559_XI_24S033W.cub
TO B01_010052_1559_XI_24S033W_cal.cub
FLATFILE Internal Default
Calibration Parameters
IOF Convert to I/F
ctxcal from=B01_010052_1559_XI_24S033W.cub to=B01_010052_1559_XI_24S033W_cal.cub
100%
Done

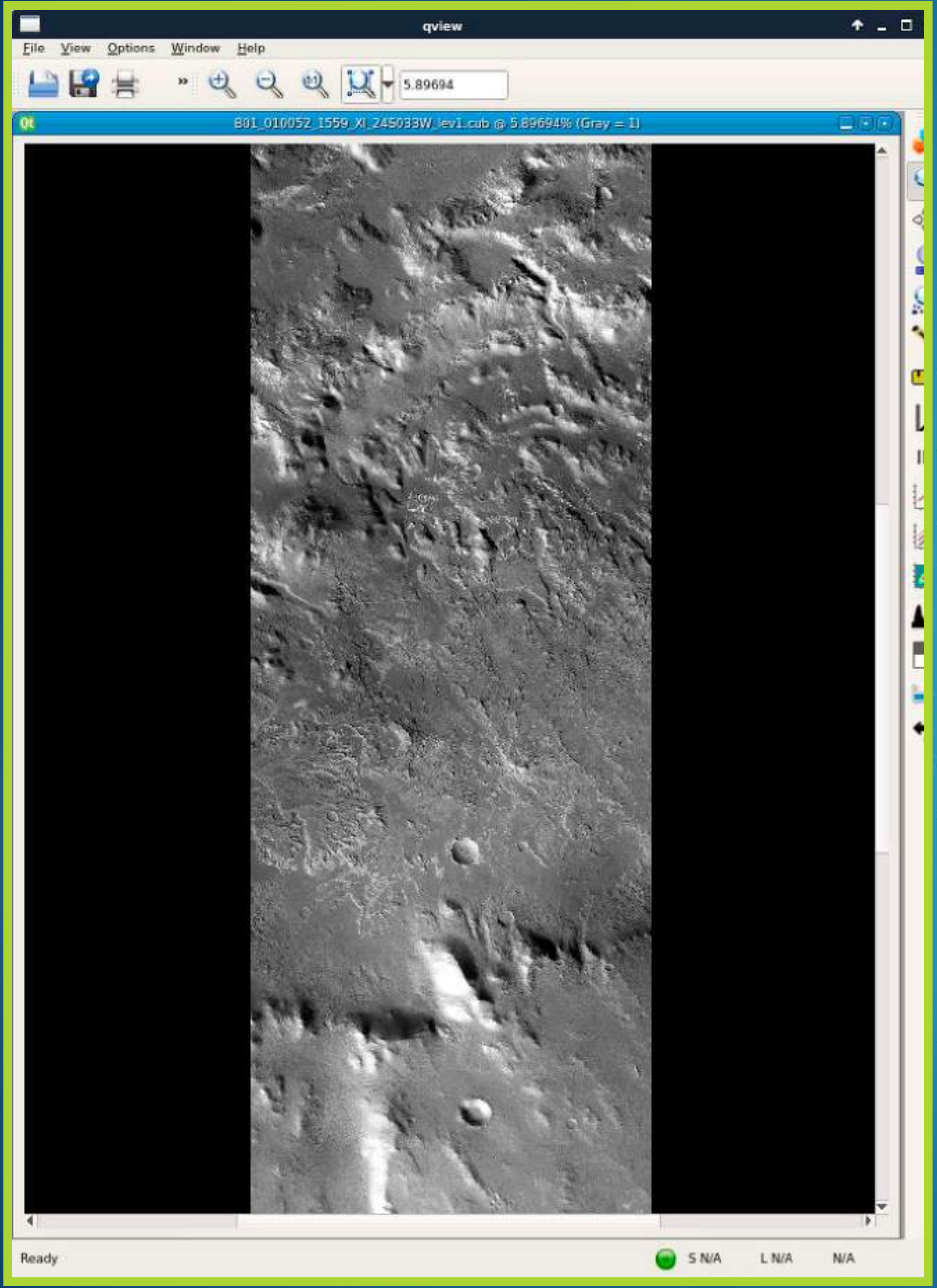

qview
File View Options Window Help
5.02554
B01_010052_1559_XI_24S033W_cal.cub @ 5.02554% (Gray = 1)
ID
2D
3D
S N/A
L N/A
N/A

Process 2D data with ISIS

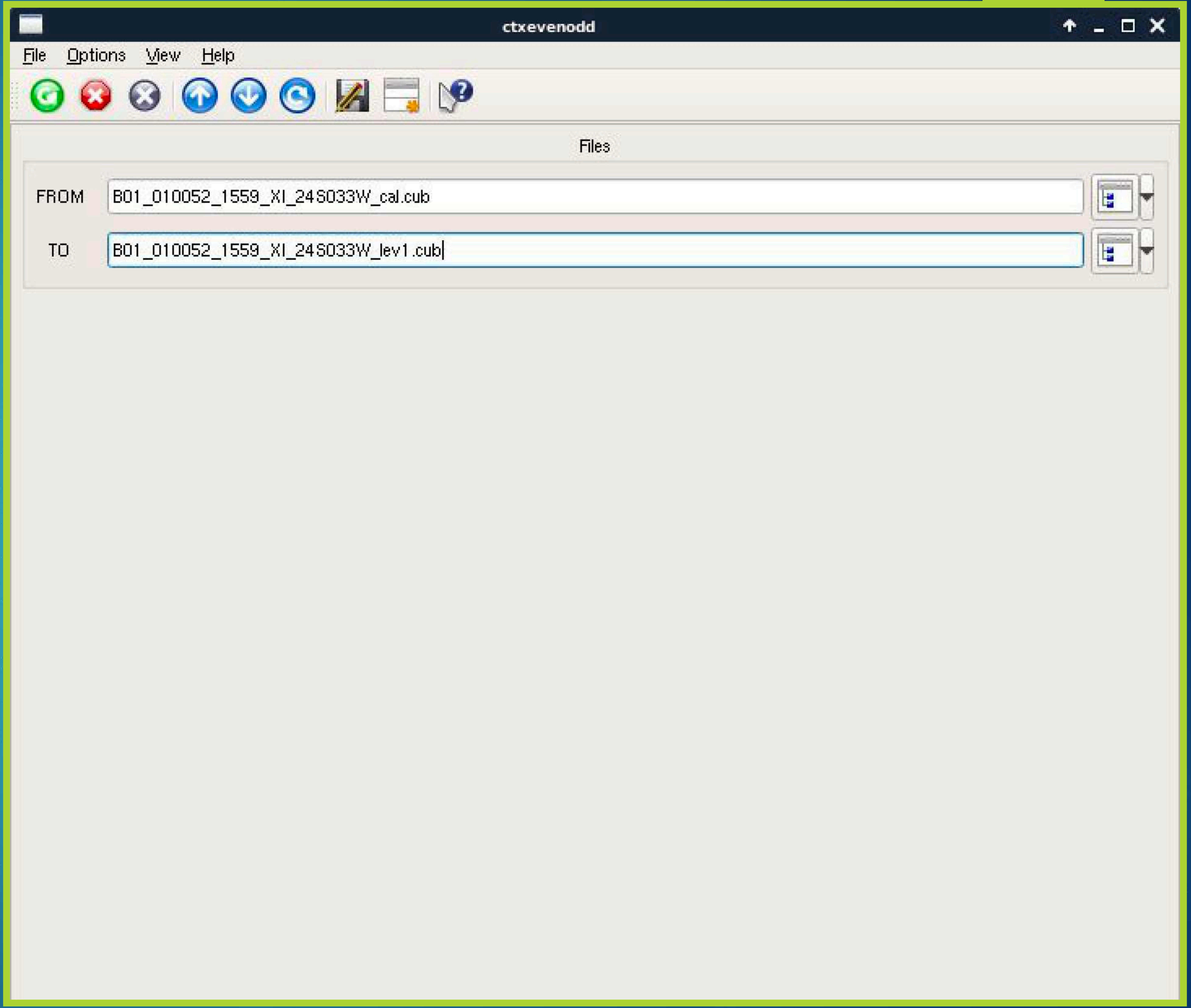
Step 3: clean up

- command `CTXEVENODD`
- command `QVIEW` to have a look


ctxevenodd
File Options View Help
Files
FROM
B01_010052_1559_XI_24S033W_cal.cub
TO
B01_010052_1559_XI_24S033W_lev1.cub



qview
File View Options Window Help
5.89694
B01_010052_1559_XI_24S033W_lev1.cub @ 5.89694% (Gray = 1)
Ready
S N/A
L N/A
N/A

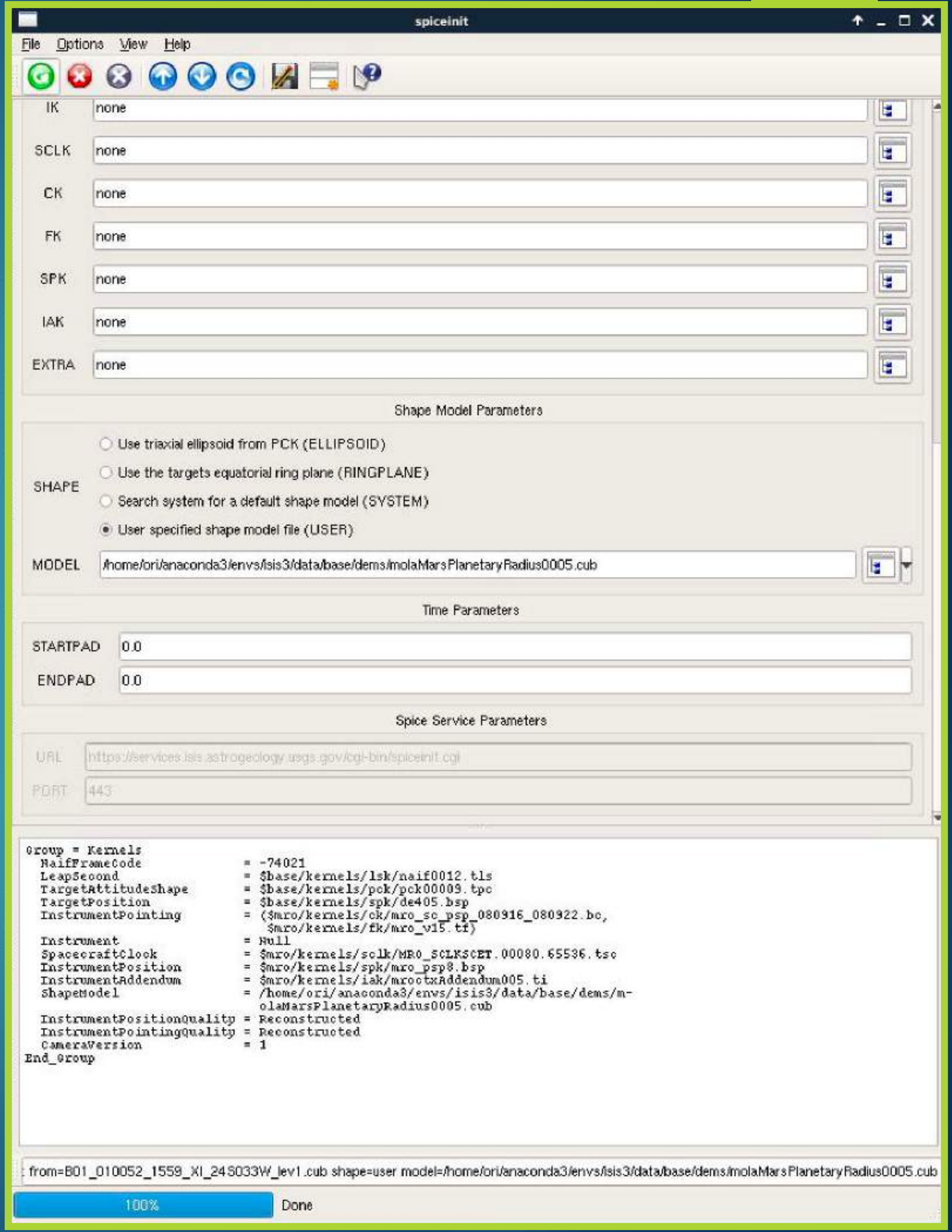


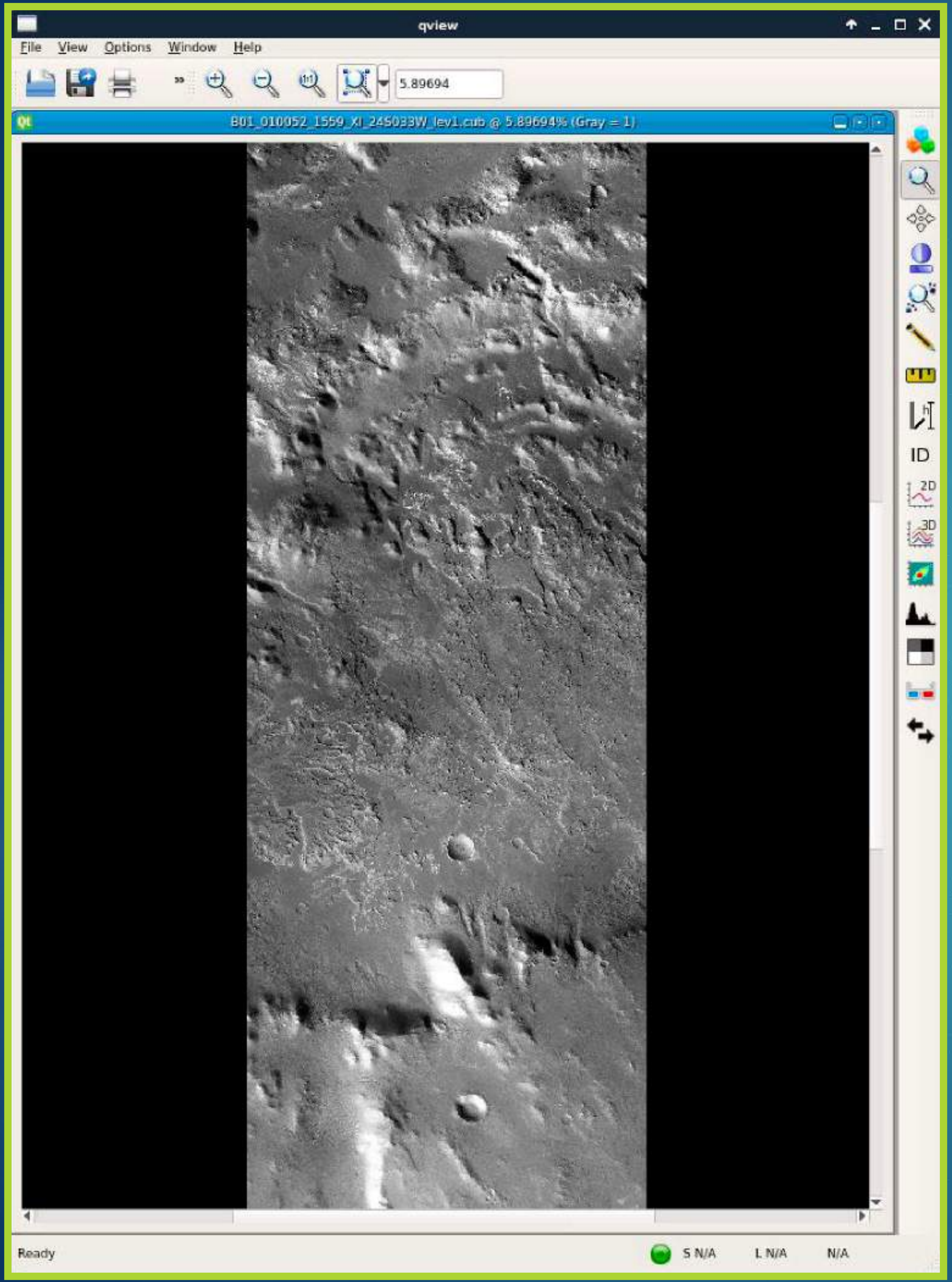
ctxevenodd
File Options View Help
Files
FROM
B01_010052_1559_XI_24S033W_cal.cub
TO
B01_010052_1559_XI_24S033W_lev1.cub

Process 2D data with ISIS

Step 4 : Naif kernels

- command `SPICEINIT`
- command `QVIEW` to have a look and `CATLAB` to check the label


spiceinit
File Options View Help
IK none
SCLK none
CK none
FK none
SPK none
IAK none
EXTRA none
Shape Model Parameters
SHAPE
Use triaxial ellipsoid from PCK (ELLIPSOID)
Use the targets equatorial ring plane (RINGPLANE)
Search system for a default shape model (SYSTEM)
User specified shape model file (USER)
MODEL /home/ori/anaconda3/envs/isis3/data/base/dems/molaMarsPlanetaryRadius0005.cub
Time Parameters
STARTPAD 0.0
ENDPAD 0.0
Spice Service Parameters
URL https://services.isis.astrogeology.usgs.gov/cgi-bin/spiceinit.cgi
PORT 443
Group = Kernels
NaifFrameCode = -74021
LeapSecond = $base/kernels/lsk/naif0012.tls
TargetAttitudeShape = $base/kernels/pck/pck00009.tpc
TargetPosition = $base/kernels/spk/de405.bsp
InstrumentPointing = ($mro/kernels/ck/mro_sc_psp_080916_080922.bc, $mro/kernels/fk/mro_v15.tf)
Instrument = Null
SpacecraftClock = $mro/kernels/sclk/MRO_SCLKSCET.00080.65536.tsc
InstrumentPosition = $mro/kernels/spk/mro_psp8.bsp
InstrumentAddendum = $mro/kernels/iak/mroctxAddendum005.ti
ShapeModel = /home/ori/anaconda3/envs/isis3/data/base/dems/m-olaMarsPlanetaryRadius0005.cub
InstrumentPositionQuality = Reconstructed
InstrumentPointingQuality = Reconstructed
CameraVersion = 1
End_Group
from=B01_010052_1559_XI_24S033W_lev1.cub shape=user model=/home/ori/anaconda3/envs/isis3/data/base/dems/molaMarsPlanetaryRadius0005.cub
100%
Done


qview
File View Options Window Help
5.89694
B01_010052_1559_XI_24S033W_lev1.cub @ 5.89694% (Gray = 1)
ID
2D
3D
Ready
S N/A
L N/A
N/A


spiceinit
File Options View Help
IK none
SCLK none
CK none
FK none
SPK none
IAK none
EXTRA none
Shape Model Parameters
SHAPE
Use triaxial ellipsoid from PCK (ELLIPSOID)
Use the targets equatorial ring plane (RINGPLANE)
Search system for a default shape model (SYSTEM)
User specified shape model file (USER)
MODEL /home/ori/anaconda3/envs/isis3/data/base/dems/molaMarsPlanetaryRadius0005.cub
Time Parameters
STARTPAD 0.0
ENDPAD 0.0
Spice Service Parameters
URL https://services.isis.astrogeology.usgs.gov/cgi-bin/spiceinit.cgi
PORT 443
Group = Kernels
NaifFrameCode = -74021
LeapSecond = $base/kernels/lsk/naif0012.tls
TargetAttitudeShape = $base/kernels/pck/pck00009.tpc
TargetPosition = $base/kernels/spk/de405.bsp
InstrumentPointing = ($mro/kernels/ck/mro_sc_psp_080916_080922.bc, $mro/kernels/fk/mro_v15.tf)
Instrument = Null
SpacecraftClock = $mro/kernels/sclk/MRO_SCLKSCET.00080.65536.tsc
InstrumentPosition = $mro/kernels/spk/mro_psp8.bsp
InstrumentAddendum = $mro/kernels/iak/mroctxAddendum005.ti
ShapeModel = /home/ori/anaconda3/envs/isis3/data/base/dems/m-olaMarsPlanetaryRadius0005.cub
InstrumentPositionQuality = Reconstructed
InstrumentPointingQuality = Reconstructed
CameraVersion = 1
End_Group
from=B01_010052_1559_XI_24S033W_lev1.cub shape=user model=/home/ori/anaconda3/envs/isis3/data/base/dems/molaMarsPlanetaryRadius0005.cub
100%
Done

Georeferencing: Prepare a Map Template with ISIS

- Define the mapping parameters for the projection
- projection: algorithm or equation for mapping a three-dimensional body onto a two-dimensional surface
- Command MAPTEMPLATE

Maptemplate

Example

```
Group = Mapping
  ProjectionName     = Equirectangular
  CenterLongitude    = 0.0
  CenterLatitude     = 0.0
  TargetName         = Mars
  EquatorialRadius   = 3396190.0 <meters>
  PolarRadius        = 3396190.0 <meters>
  LatitudeType       = Planetocentric
  LongitudeDirection = PositiveEast
  LongitudeDomain    = 180
End_Group
End
```

Maptemplate

Pay attention to select your folder

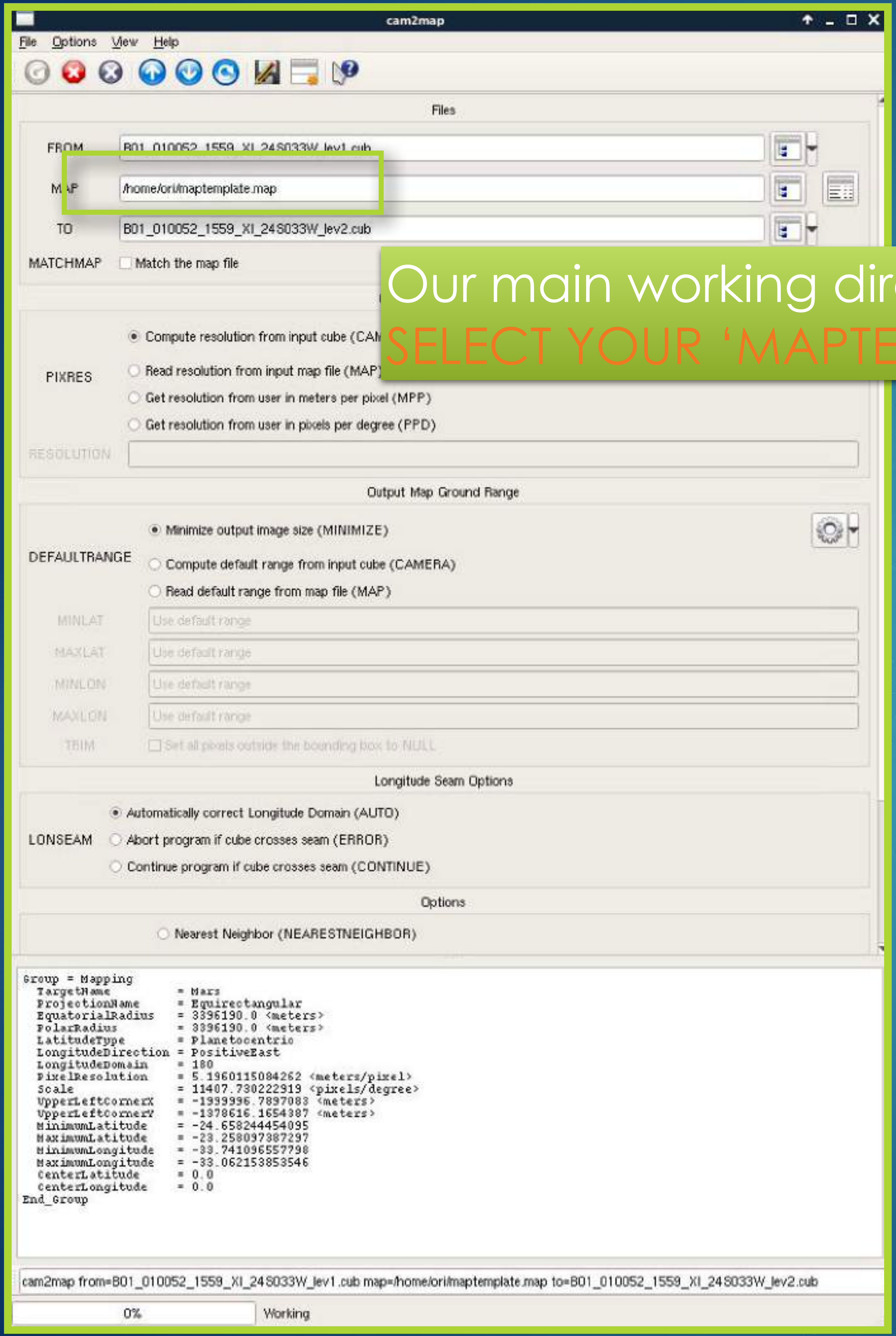
Example

```
Group = Mapping
  ProjectionName     = Equirectangular
  CenterLongitude    = 0.0
  CenterLatitude     = 0.0
  TargetName         = Mars
  EquatorialRadius   = 3396190.0 <meters>
  PolarRadius        = 3396190.0 <meters>
  LatitudeType       = Planetocentric
  LongitudeDirection = PositiveEast
  LongitudeDomain    = 180
End_Group
End
```

Process 2D data with ISIS

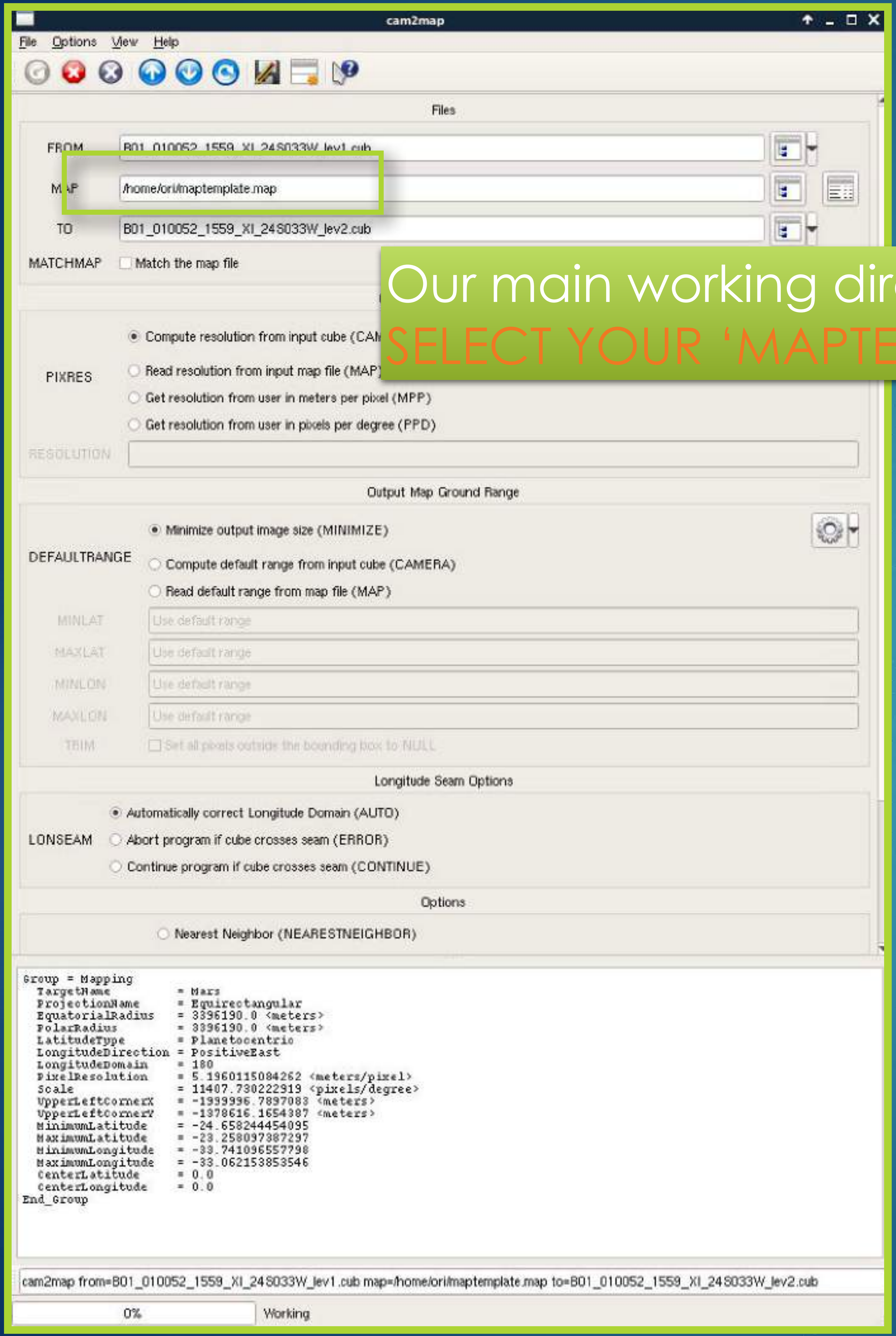
Step 5: Define output map projection details

- Using your map template file
- Command cam2map
- Command qview to have a look and catlab to check the label

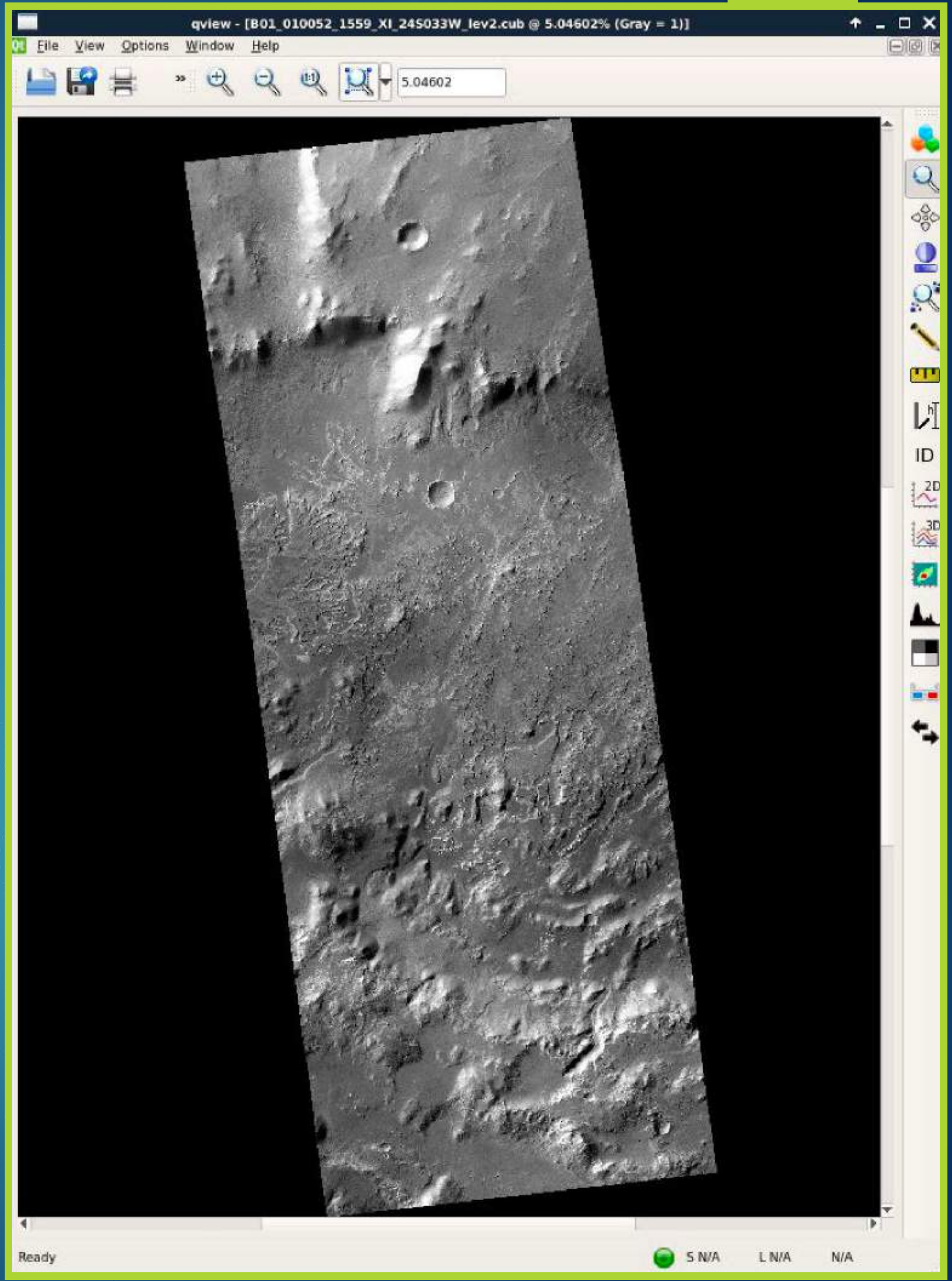


Our main working directory:

SELECT YOUR 'MAPTEMPLATE'

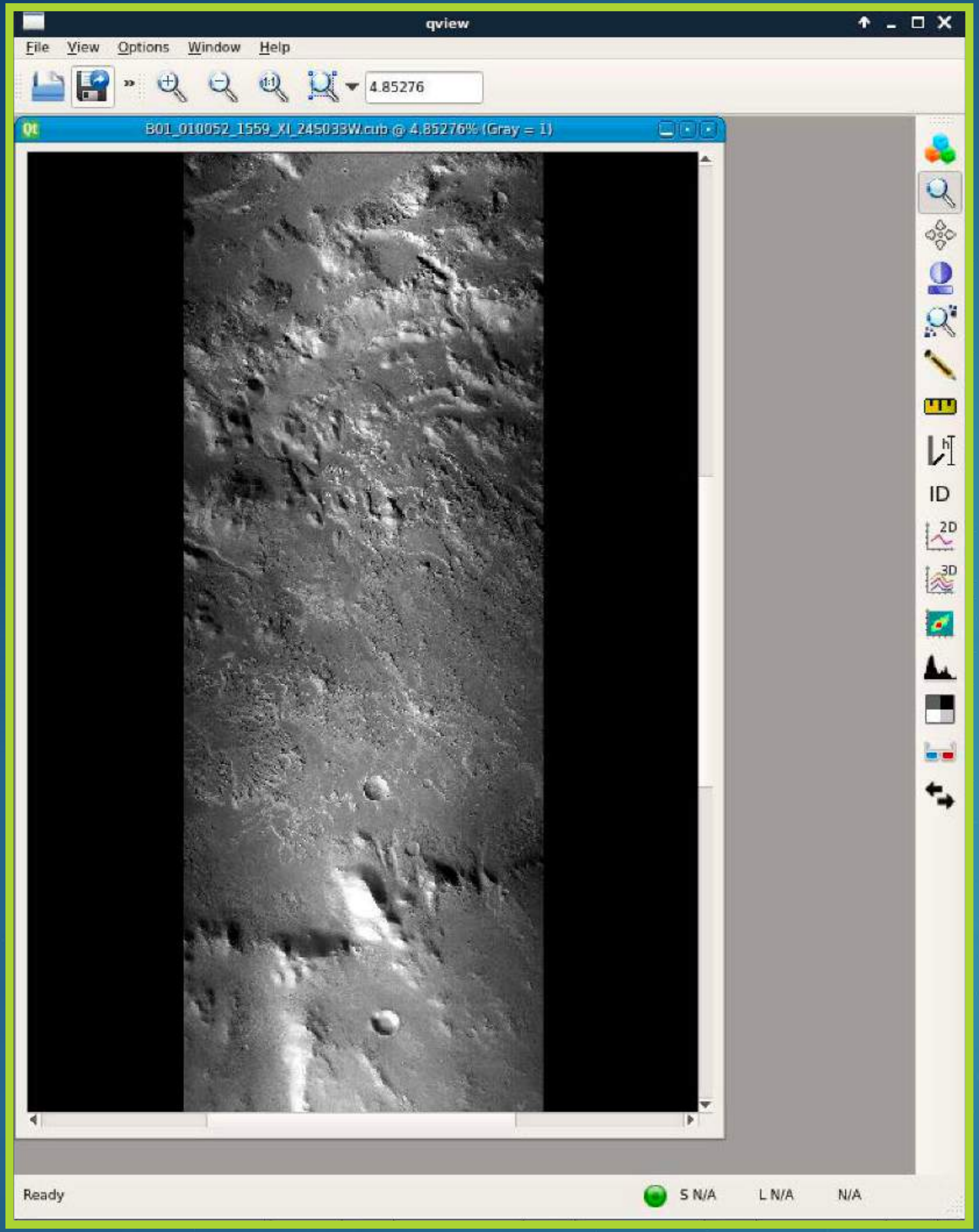


Our main working directory:
SELECT YOUR 'MAPTEMPLATE'

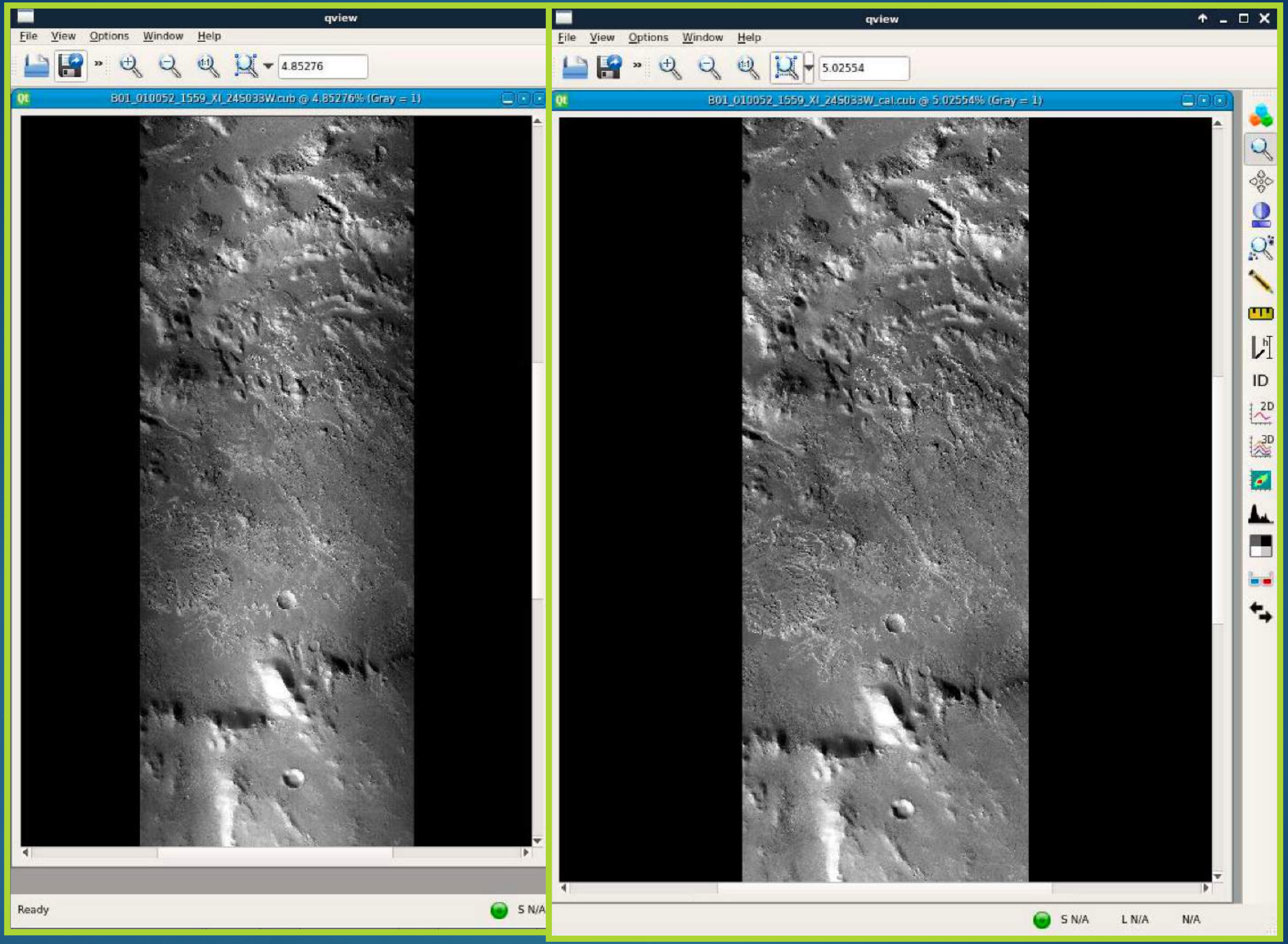


Phases

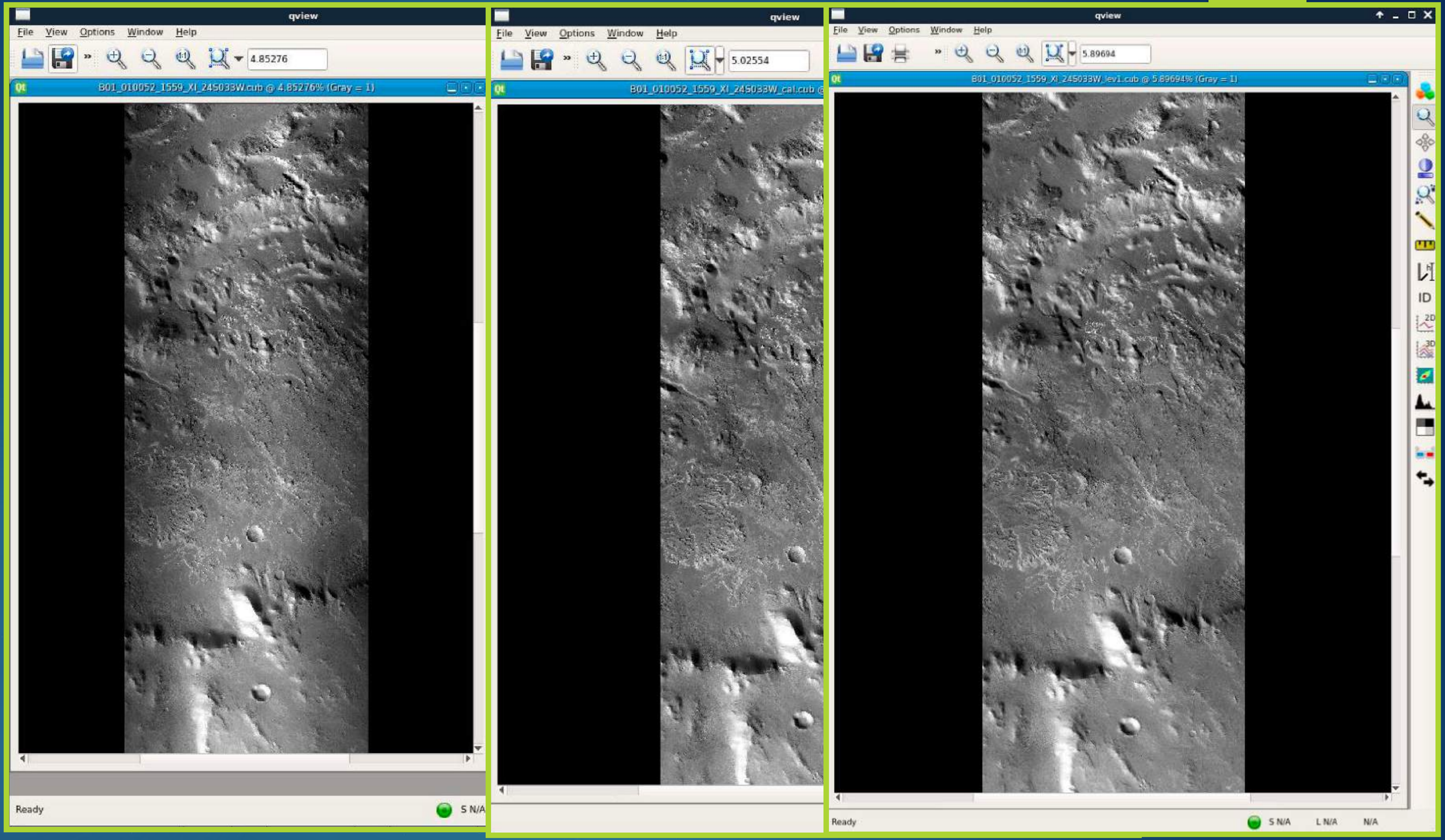
Phase


qview
File View Options Window Help
4.85276
B01_010052_1559_XI_24S033W.cub @ 4.85276% (Gray = 1)
ID
Ready
S N/A
L N/A
N/A

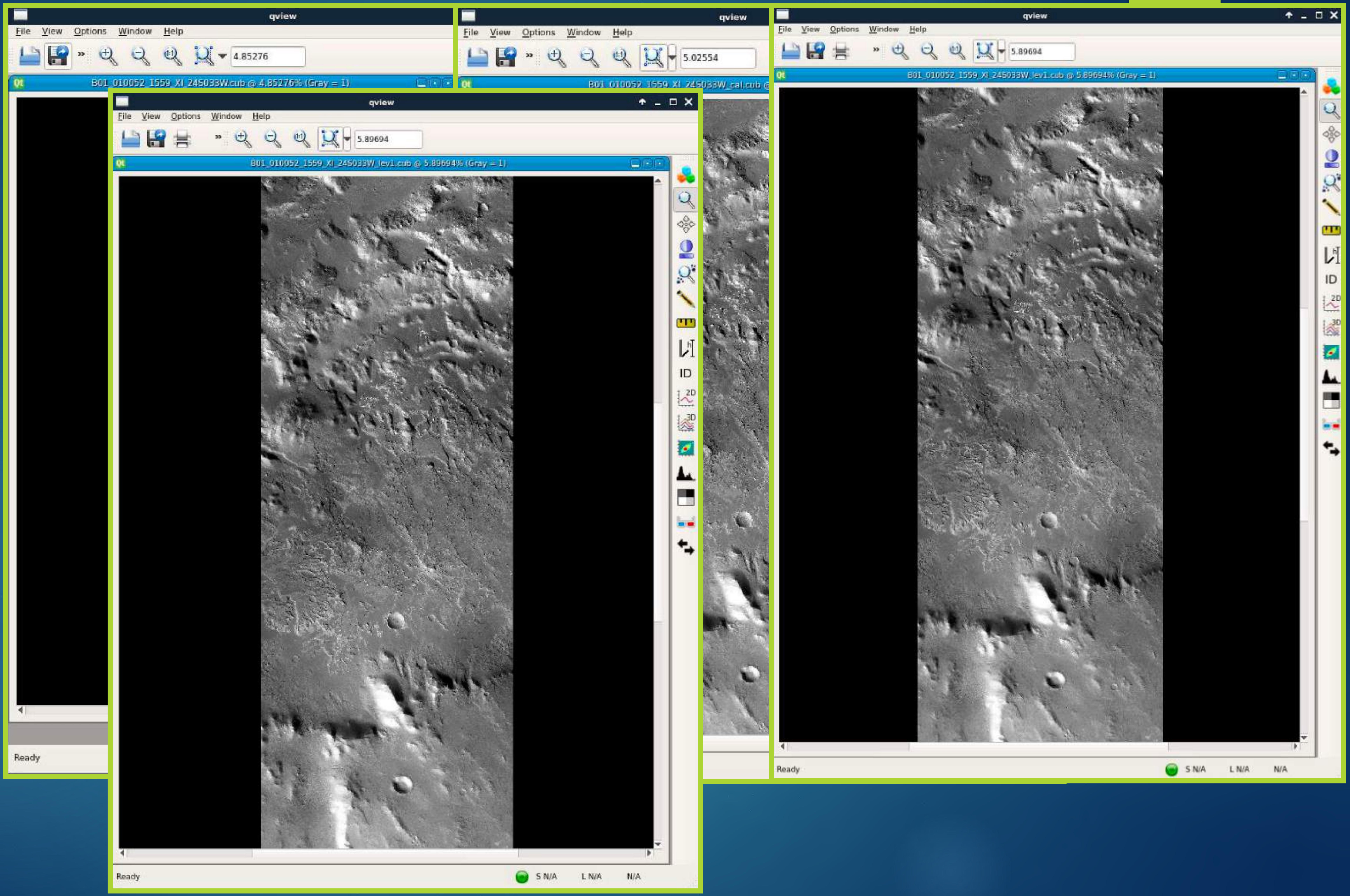
Phase


qview
File View Options Window Help
4.85276
B01_010052_1559_XI_24S033W.cub @ 4.85276% (Gray = 1)
Ready
S N/A
qview
File View Options Window Help
5.02554
B01_010052_1559_XI_24S033W_cal.cub @ 5.02554% (Gray = 1)
S N/A
L N/A
N/A

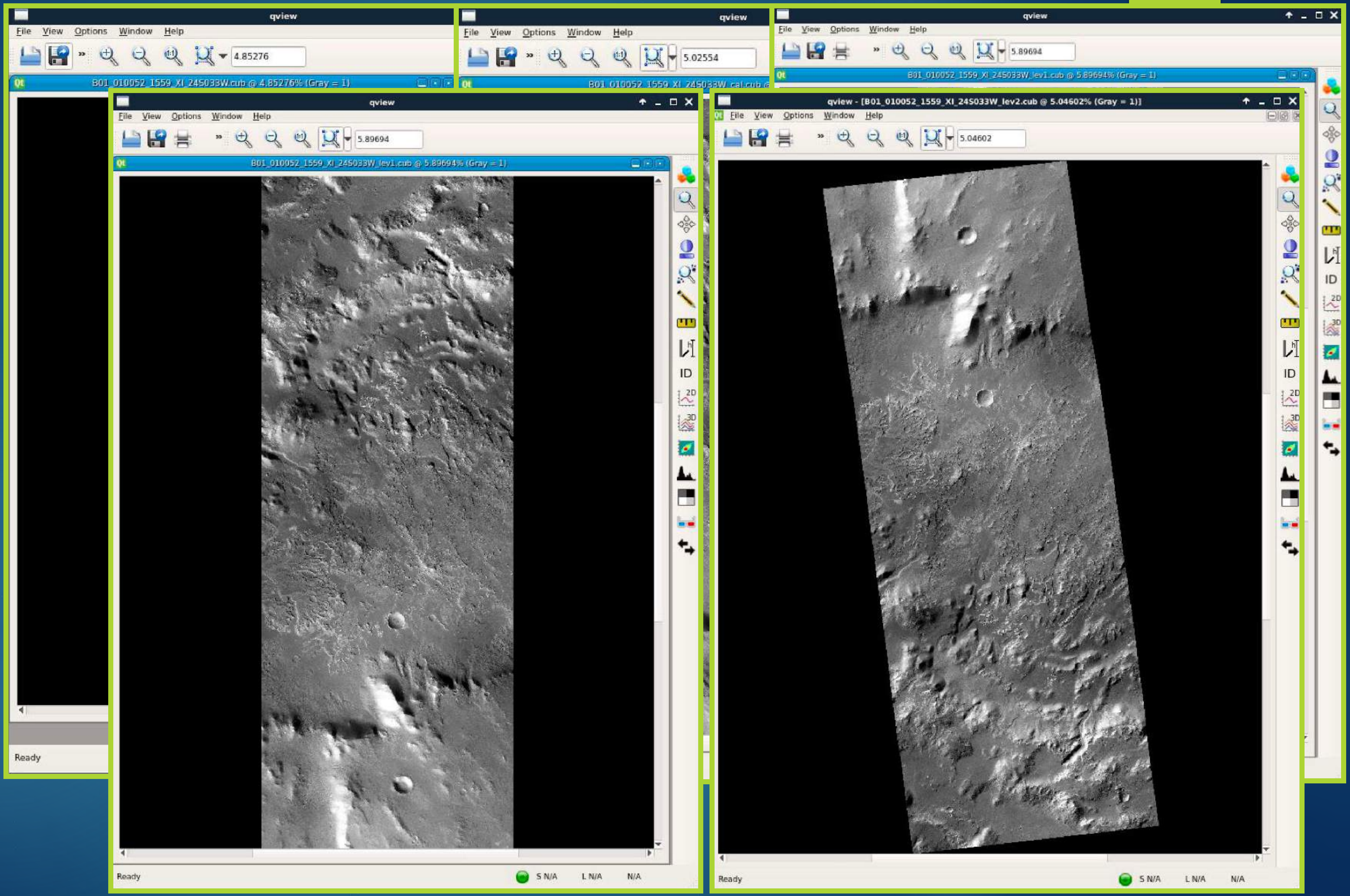
Phase


qview
File View Options Window Help
4.85276
B01_010052_1559_XI_24S033W.cub @ 4.85276% (Gray = 1)
Ready
S N/A
qview
File View Options Window Help
5.02554
B01_010052_1559_XI_24S033W_cal.cub @
qview
File View Options Window Help
5.89694
B01_010052_1559_XI_24S033W_lev1.cub @ 5.89694% (Gray = 1)
ID
Ready
S N/A
L N/A
N/A

Phase


qview
File View Options Window Help
4.85276
B01_010052_1559_XI_24S033W.cub @ 4.85276% (Gray = 1)
Ready
qview
File View Options Window Help
5.02554
B01_010052_1559_XI_24S033W_cal.cub
qview
File View Options Window Help
5.89694
B01_010052_1559_XI_24S033W_lev1.cub @ 5.89694% (Gray = 1)
ID
Ready
S N/A
L N/A
N/A
qview
File View Options Window Help
5.89694
B01_010052_1559_XI_24S033W_lev1.cub @ 5.89694% (Gray = 1)
ID
Ready
S N/A
L N/A
N/A

Phase


qview
File View Options Window Help
4.85276
B01_010052_1559_XI_24S033W.cub @ 4.85276% (Gray = 1)
5.02554
5.89694
B01_010052_1559_XI_24S033W_lev1.cub @ 5.89694% (Gray = 1)
qview - [B01_010052_1559_XI_24S033W_lev2.cub @ 5.04602% (Gray = 1)]
5.04602
Ready
S N/A
L N/A
N/A
ID

Process 2D data with ISIS

Sbatch script

```
#!/bin/bash

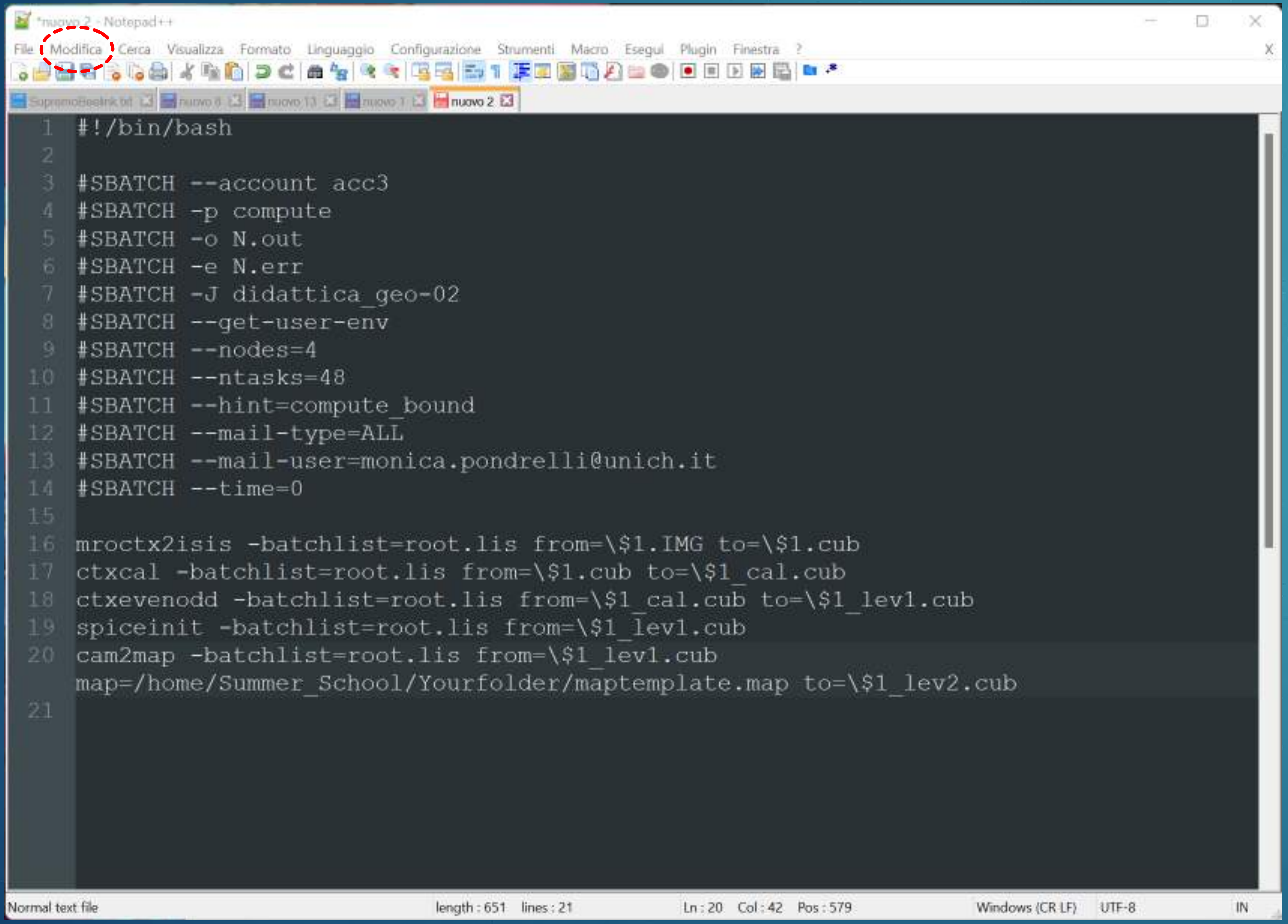
#SBATCH --account unich
#SBATCH -p compute
#SBATCH -o N.out
#SBATCH -e N.err
#SBATCH -J didattica_geo-02
#SBATCH --get-user-env
#SBATCH --nodes=4
#SBATCH --ntasks=48
#SBATCH --hint=compute_bound
#SBATCH --mail-type=ALL
#SBATCH --mail-user=monica.pondrelli@unich.it
#SBATCH --time=2-0

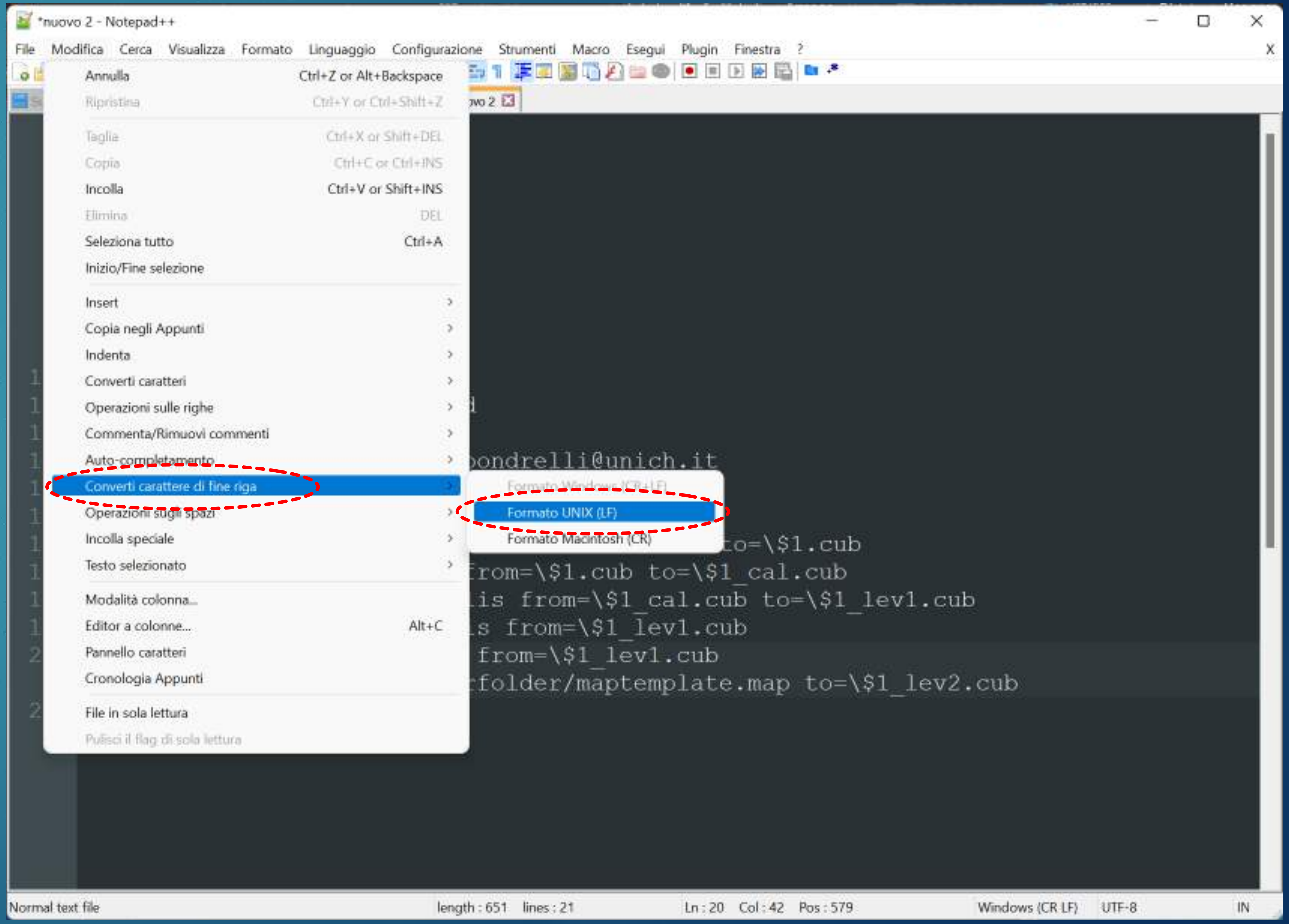
mroctx2isis -batchlist=root.lis from=\$1.IMG to=\$1.cub
ctxcal -batchlist=root.lis from=\$1.cub to=\$1_cal.cub
ctxevenodd -batchlist=root.lis from=\$1_cal.cub to=\$1_lev1.cub
spiceinit -batchlist=root.lis from=\$1_lev1.cub
cam2map -batchlist=root.lis from=\$1_lev1.cub map=/home/Summer_School/Yourfolder/maptemplate.map to=\$1_lev2.cub
```

Prepare your script with ONENOTE

(Windows only) Change new line format

In Windows OS the default End of Line (hidden) character (CRLF) is different from Unix-based systems (LF).
It must be changed or the cluster will not read it!

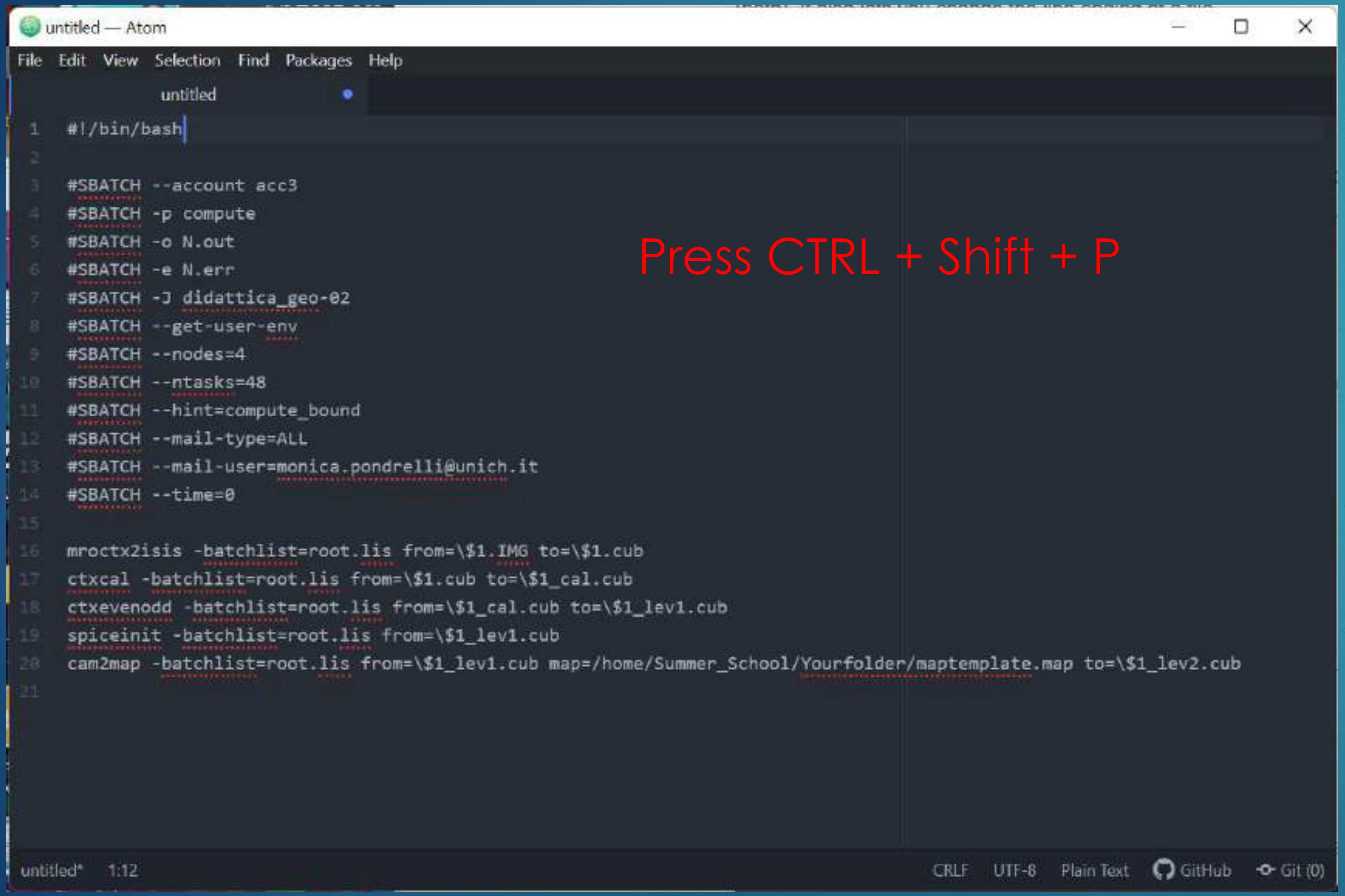


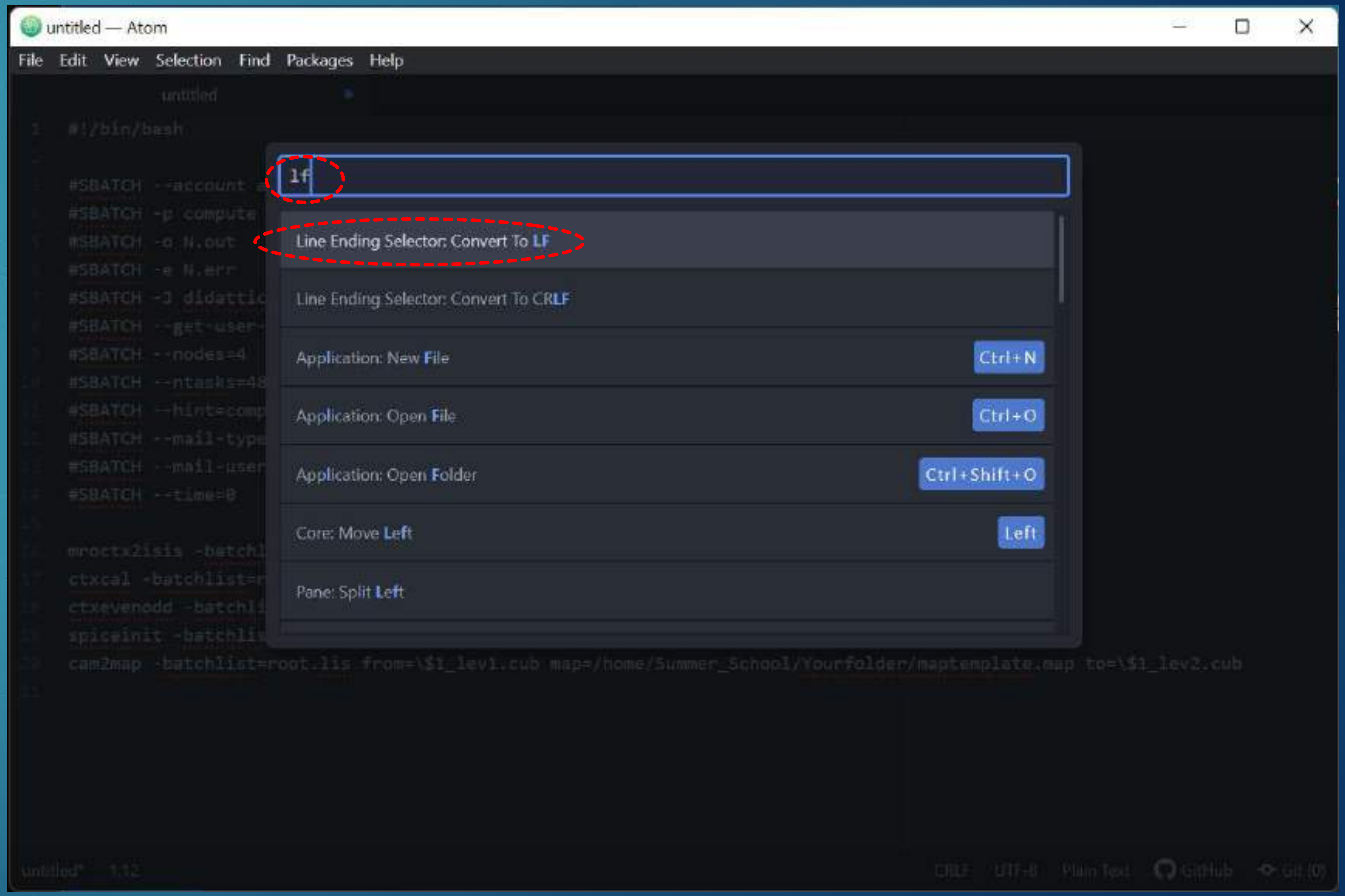


Notepad++

(Windows only) Change new line format

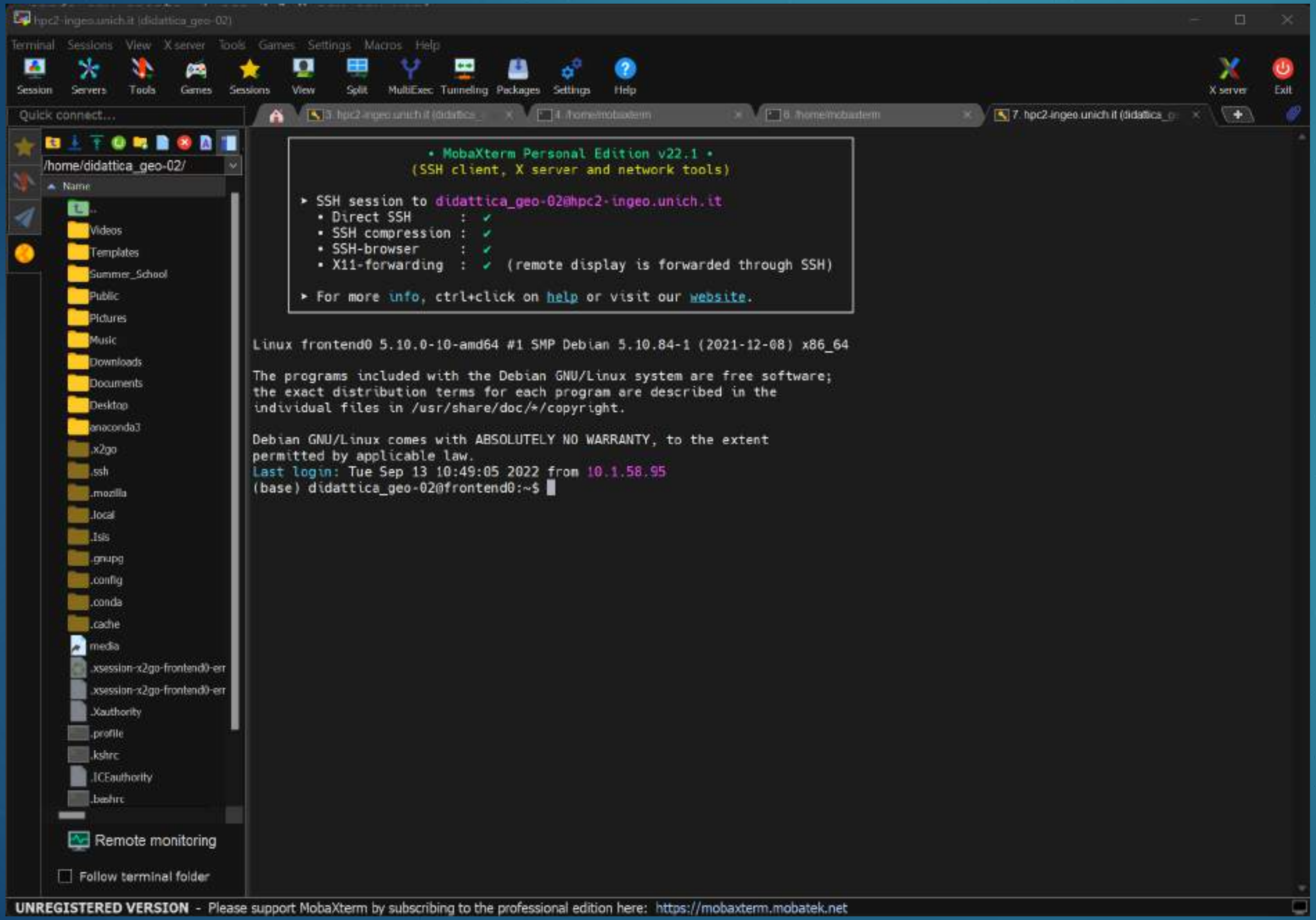
In Windows OS the default End of Line (hidden) character (CRLF) is different from Unix-based systems (LF).
It must be changed, or the cluster will not read it!



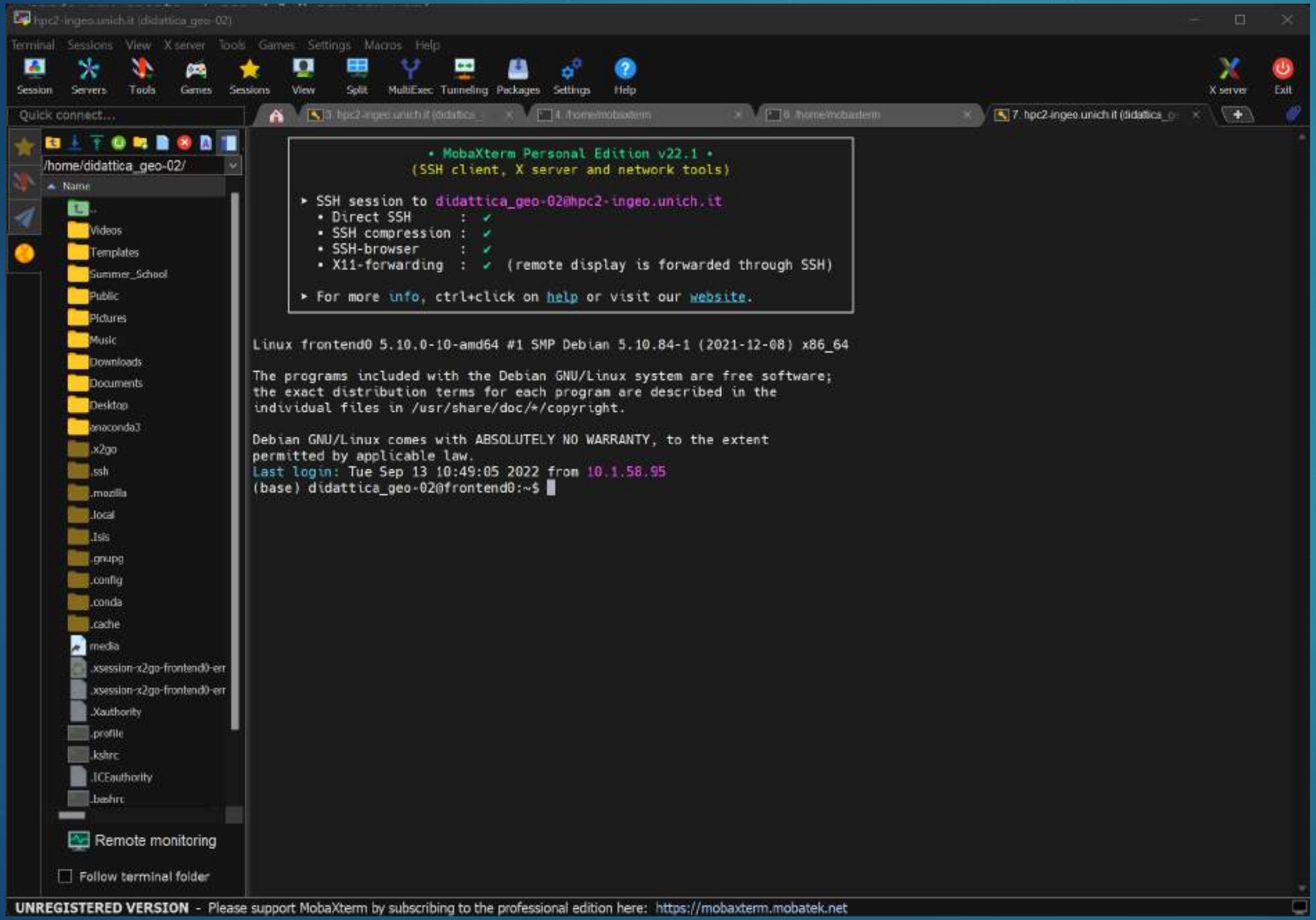


Atom

Connect to the cluster and prepare your script



Connect to the cluster and prepare your script



Example:

- Digit in the terminal: pico ProcCTX2d.sh
- An empty text file named ProcCTX2d.sh will open
- Copy/paste your script
- Save it

Connect to the cluster and prepare your script

```
Last login: Fri Sep 23 16:31:57 2022 from 10.1.58.65
(base) didattica_geo-02@frontend0:~$ cd Summer_School
(base) didattica_geo-02@frontend0:~/Summer_School$
```

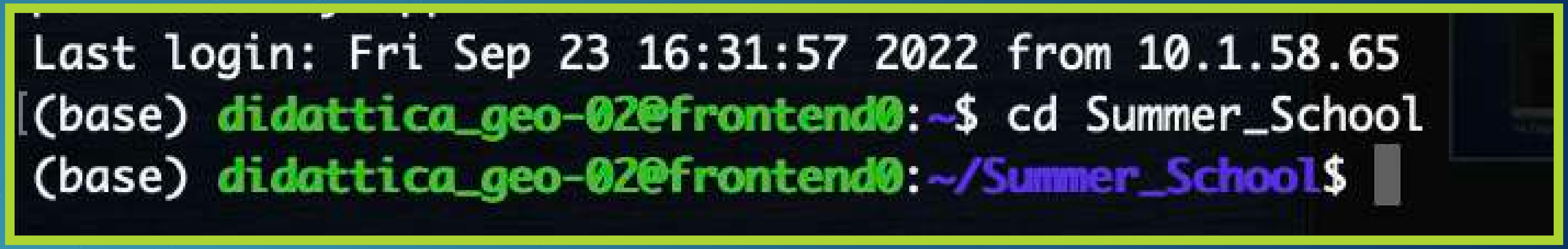
```
Last login: Fri Sep 23 16:31:57 2022 from 10.1.58.65
(base) didattica_geo-02@frontend0:~$ cd Summer_School
(base) didattica_geo-02@frontend0:~/Summer_School$ conda activate asp
```

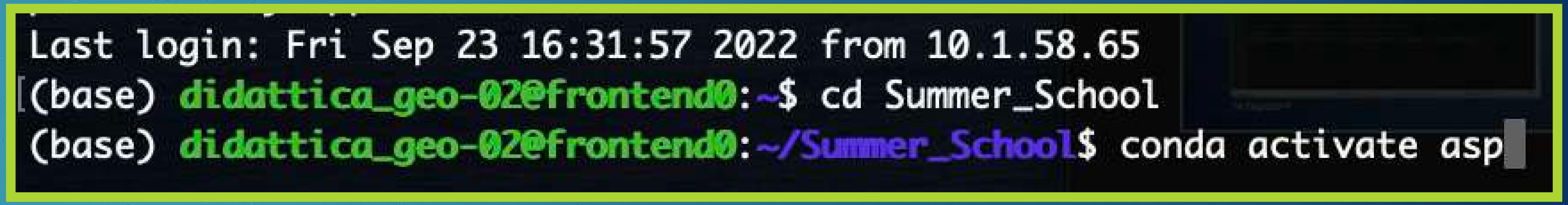
```
Last login: Fri Sep 23 16:31:57 2022 from 10.1.58.65
(base) didattica_geo-02@frontend0:~$ cd Summer_School
(base) didattica_geo-02@frontend0:~/Summer_School$ conda activate asp
(asp) didattica_geo-02@frontend0:~/Summer_School$
```

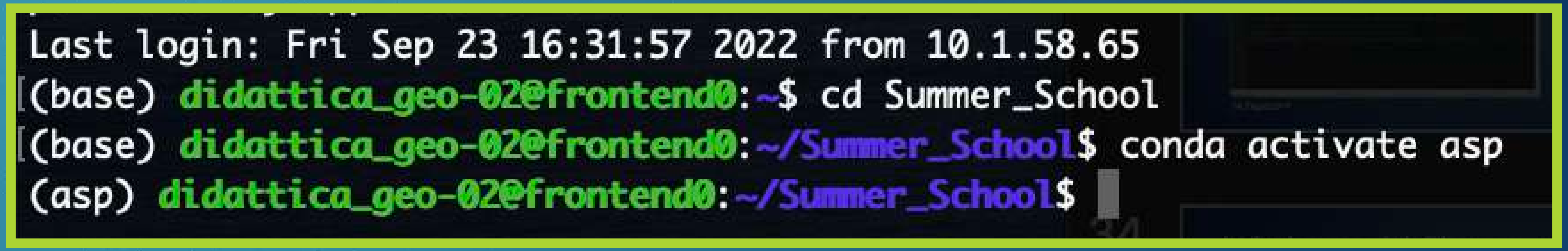
Connect to the cluster and prepare your script

Now you can lauch it, but first prepare the environment:

- Digit in the terminal: conda activate asp



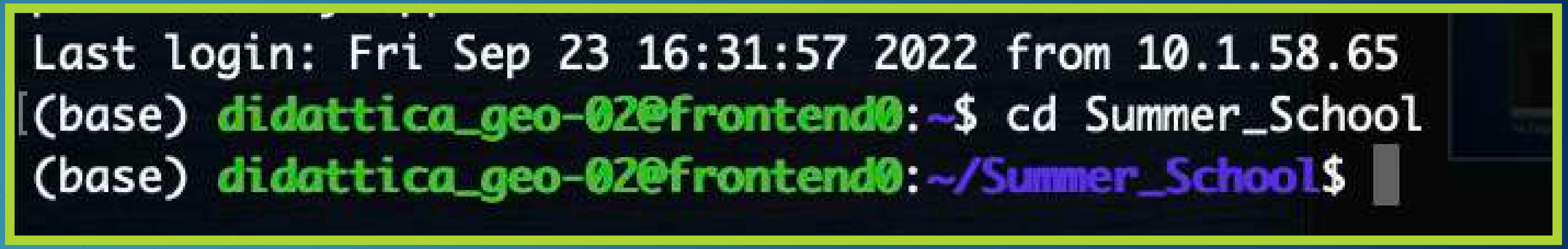


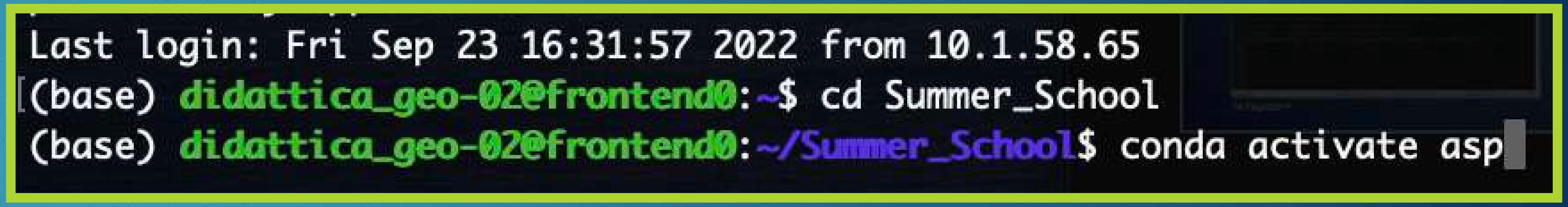


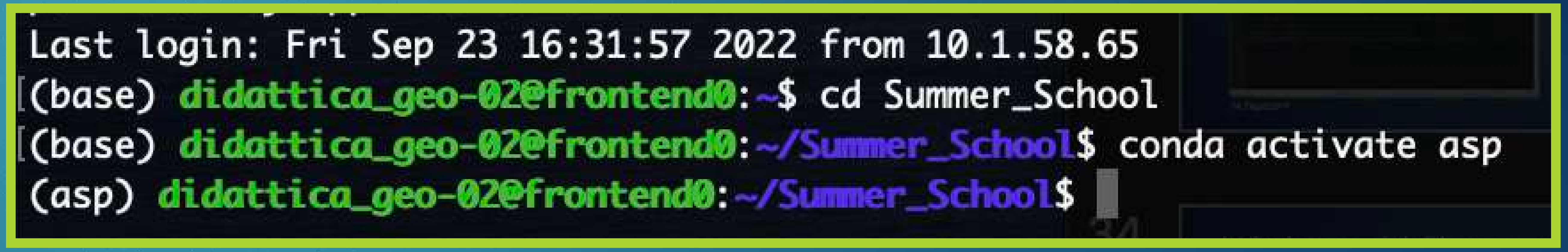
Connect to the cluster and prepare your script

Now you can lauch it, but first prepare the environment:

- Digit in the terminal: conda activate asp



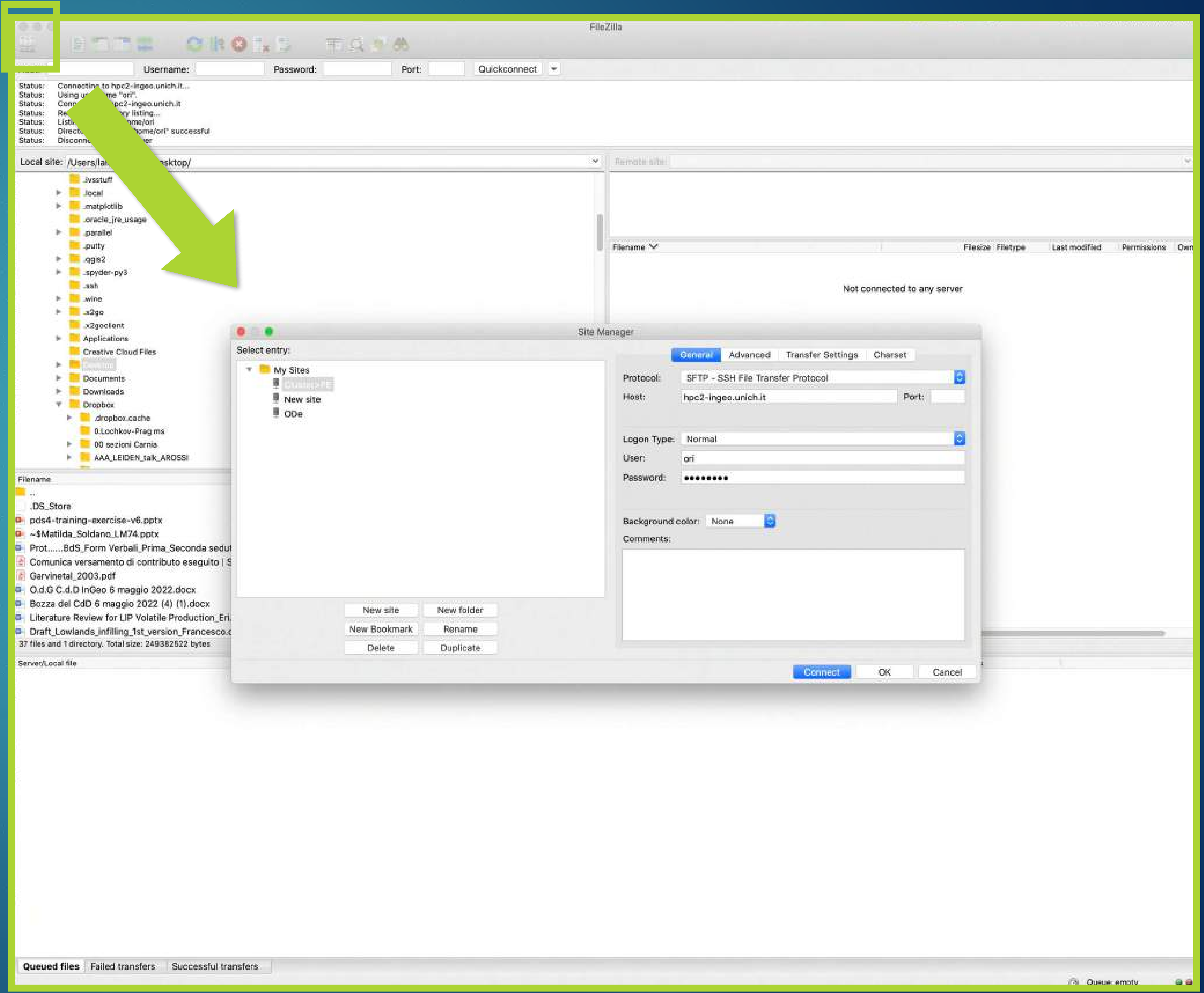




Finally, to launch it:
sbatch ProcCTX2d.sh

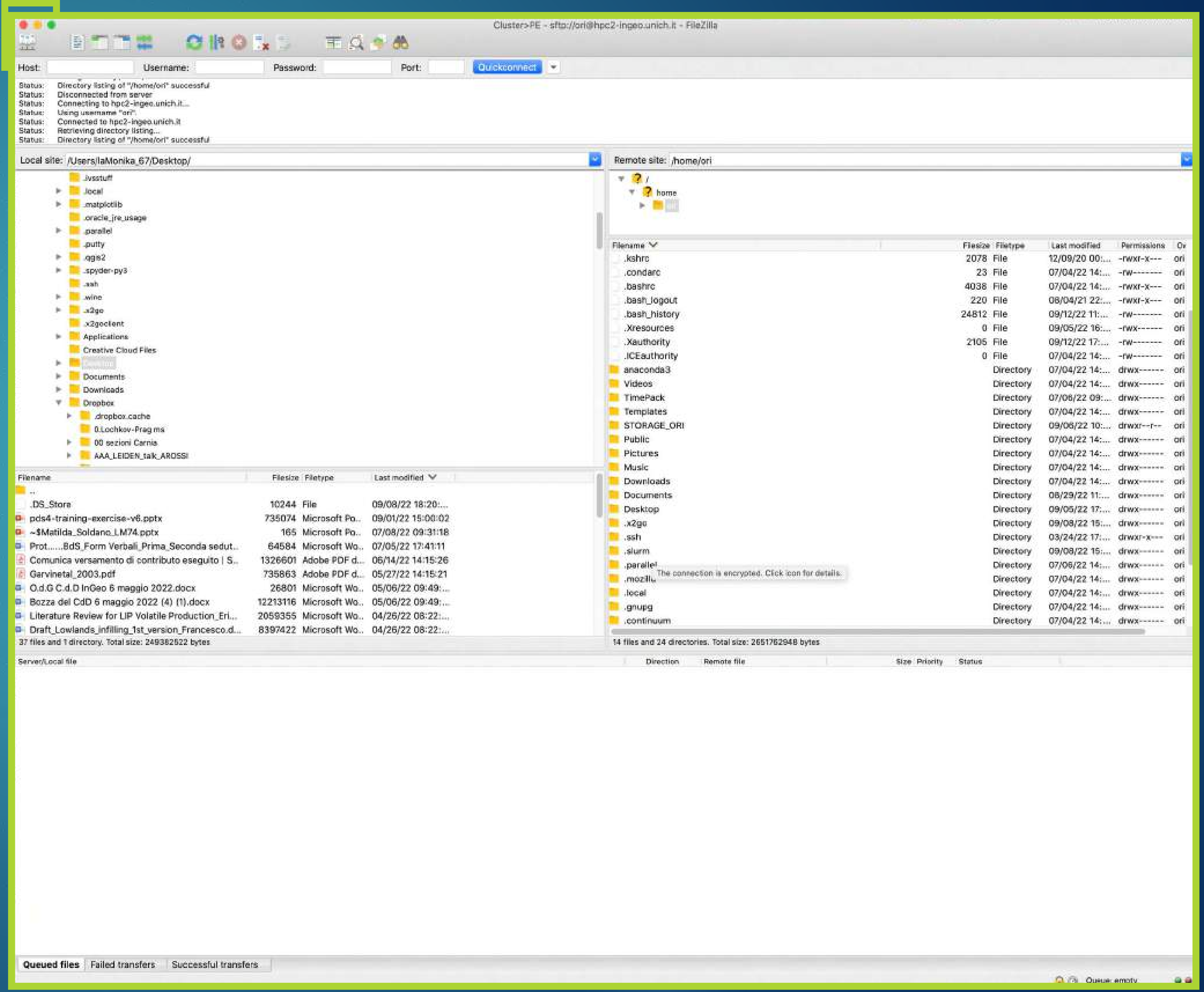
Download your lev2.cub data FileZilla

Click here



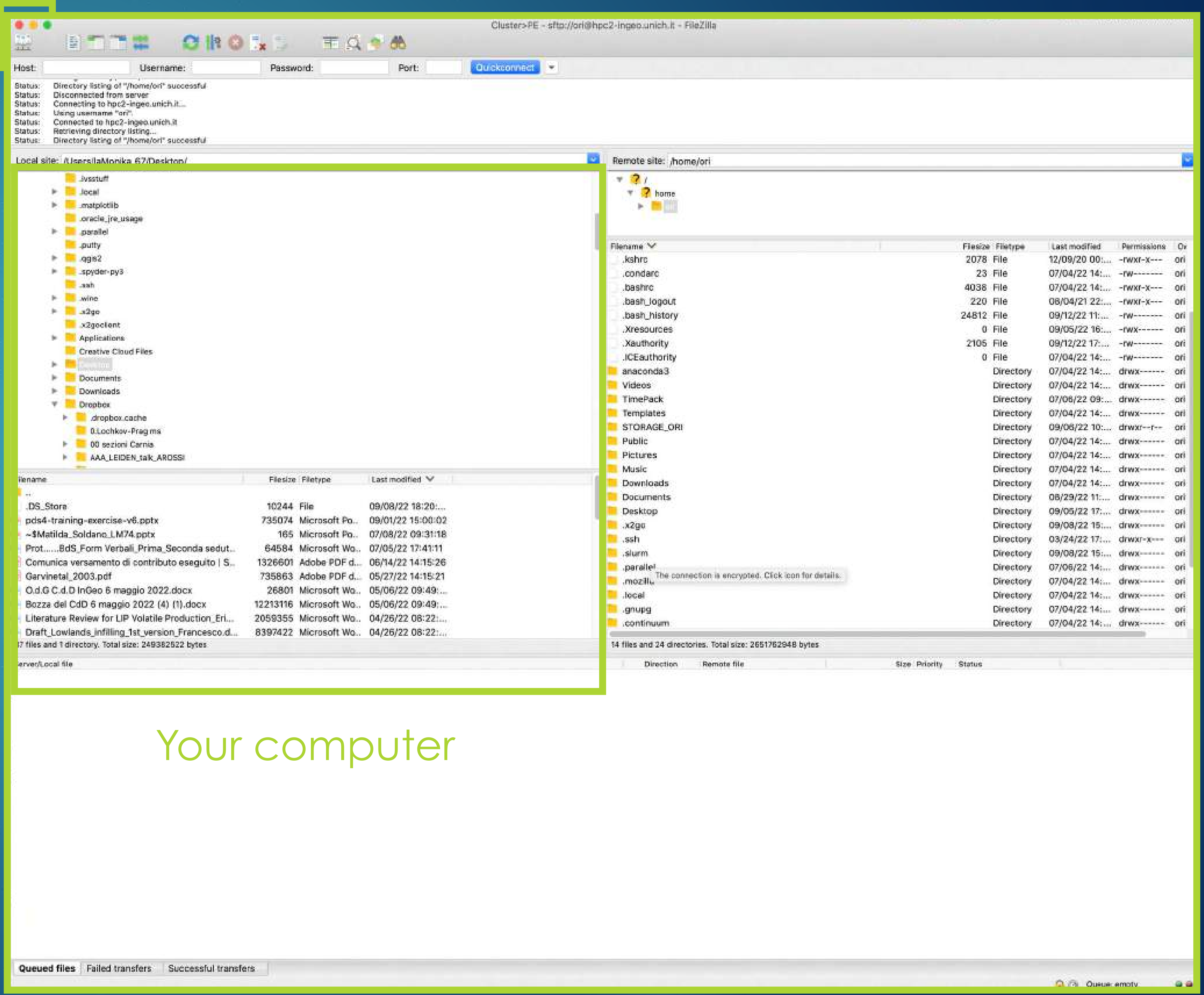
Download your lev2.cub data
FileZilla

Click here



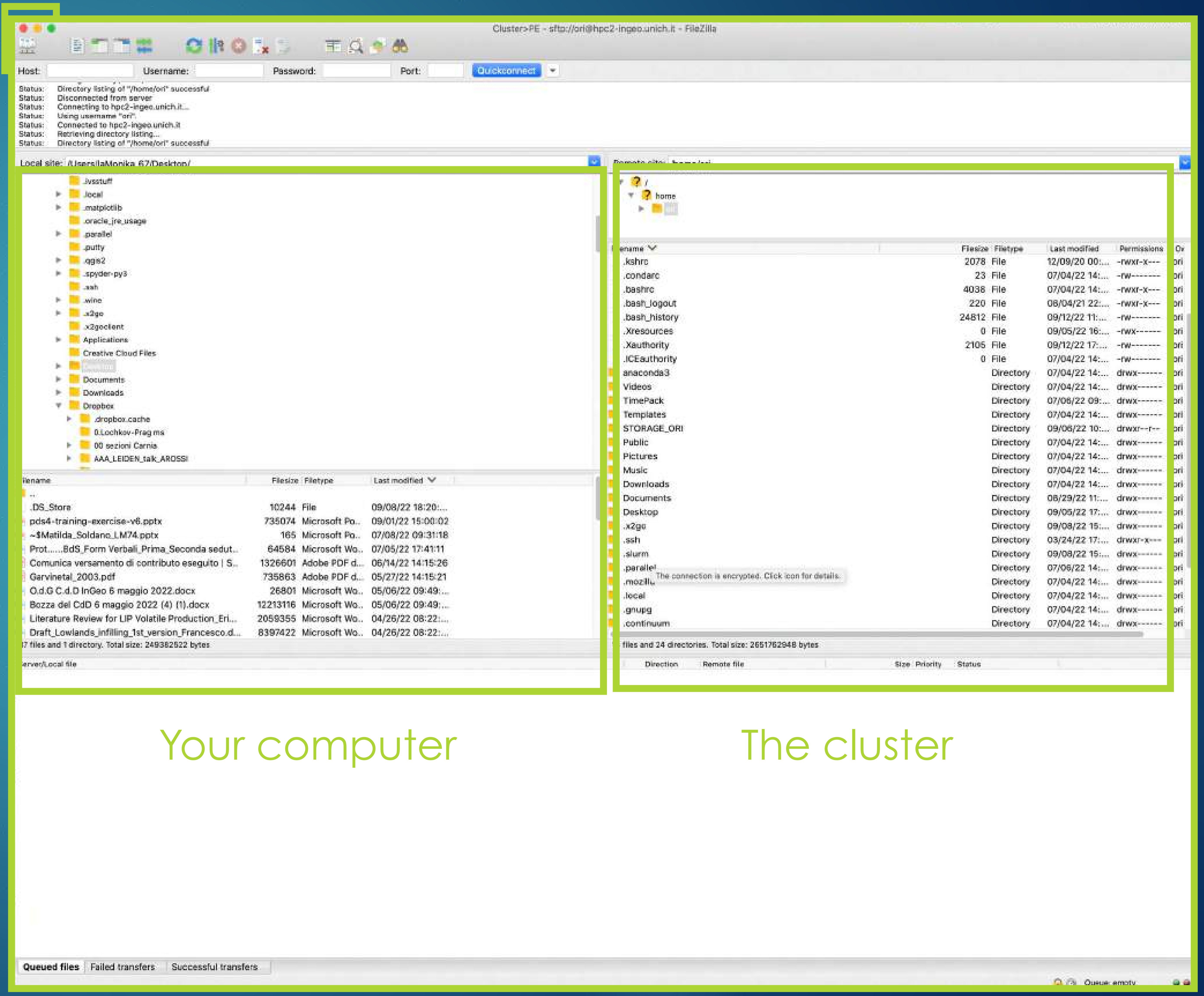
Download your lev2.cub data
FileZilla

Click here



Download your lev2.cub data
FileZilla

Click here



Co-funded by the
ERASMUS + Programme
of the European Union

GeoPlaNet

Ready-to-use-Datasets

EXAMPLES FROM HRSC AND HIRISE

THANKS TO A.P. ROSSI (JAKOBS UNIVERSITY BREMEN)

Nantes Université

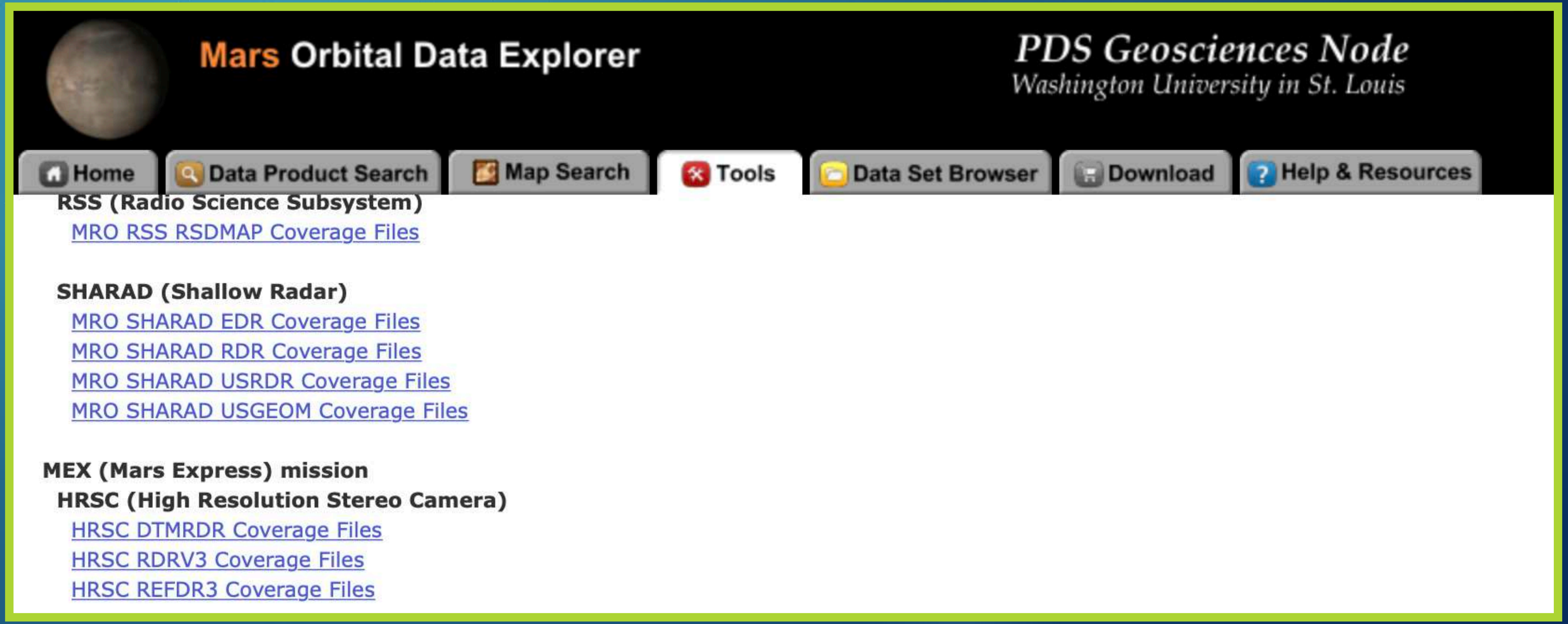
1 2 9 0 UNIVERSIDADE D COIMBRA

U.PORTO

VR2Planets

High Resolution Stereo Camera (HRSC)

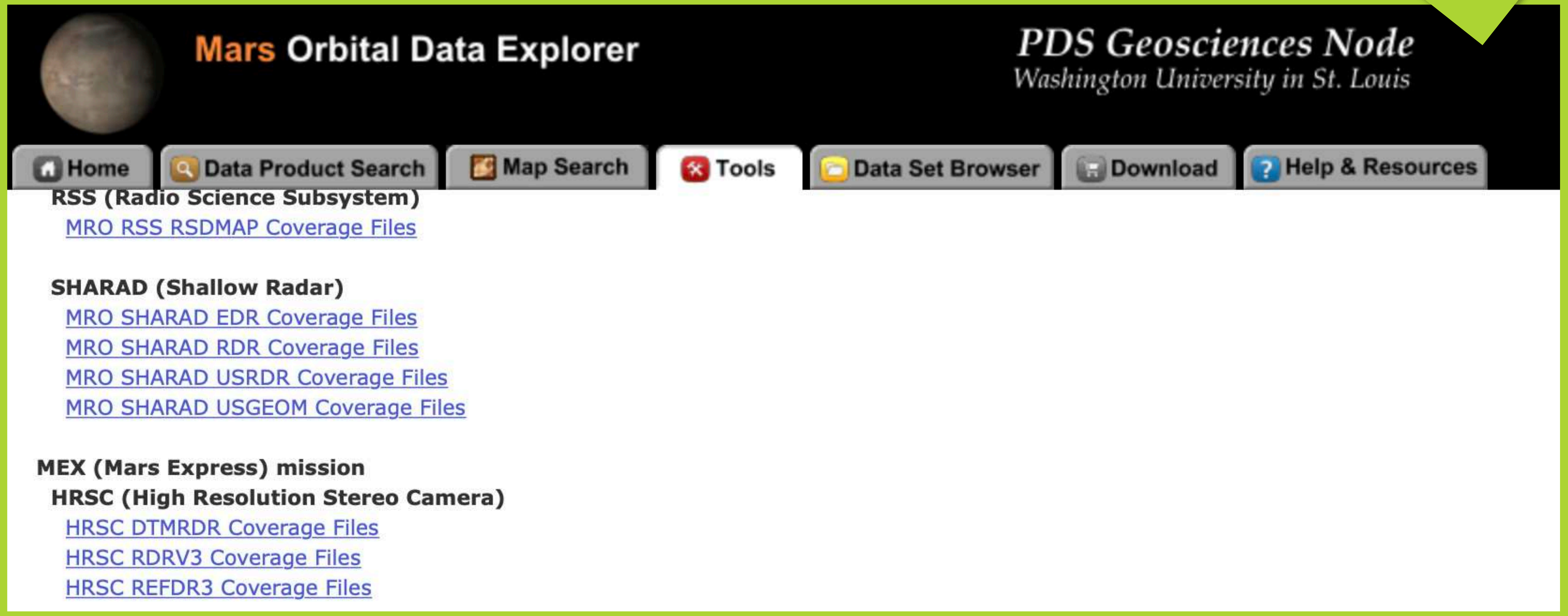
- HRSC Version 3 Reduced Data Record (RDRV3)
- HRSC Version 3 Map-Projected Reduced Data Record (REFDR3)
- HRSC Digital Terrain Map Reduced Data Record (DTMRDR)



High Resolution Stereo Camera (HRSC)

- HRSC Version 3 Reduced Data Record (RDRV3)
- HRSC Version 3 Map-Projected Reduced Data Record (REFDR3)
- HRSC Digital Terrain Map Reduced Data Record (DTMRDR)

These are the map-projected data we need

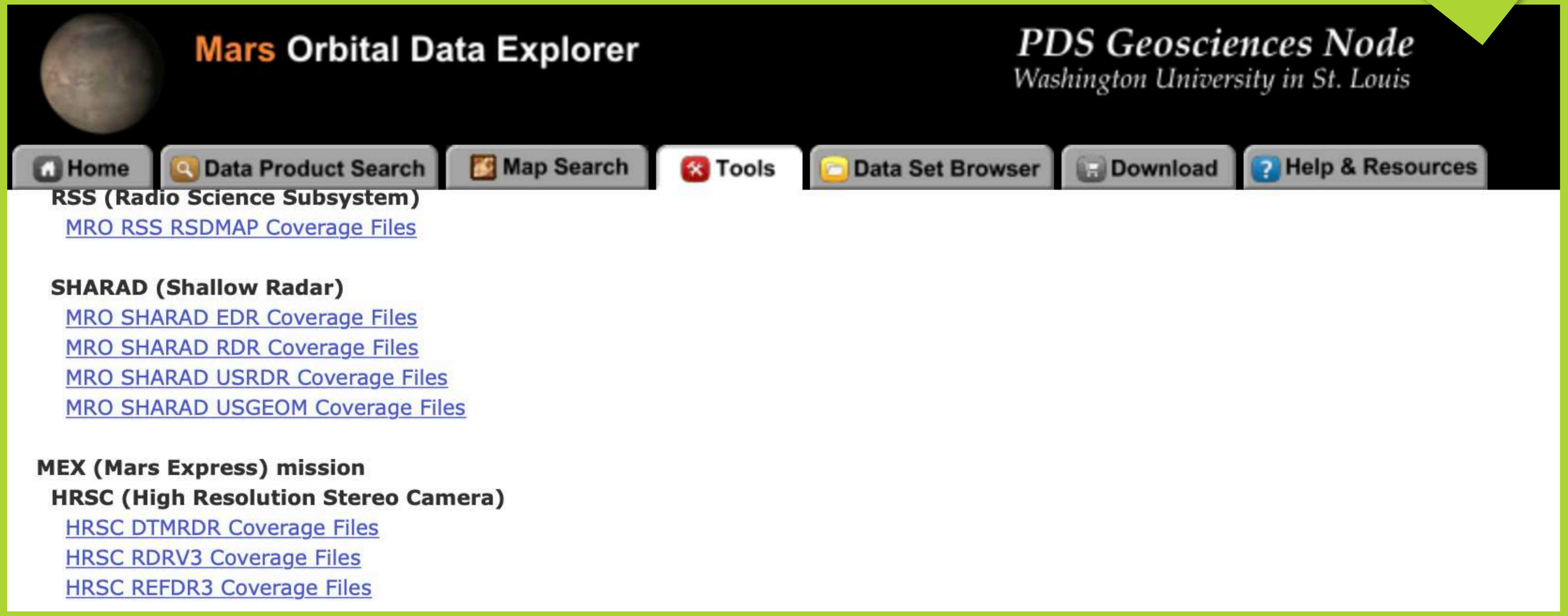


High Resolution Stereo Camera (HRSC)

- HRSC Version 3 Reduced Data Record (RDRV3)
- HRSC Version 3 Map-Projected Reduced Data Record (REFDR3)
- HRSC Digital Terrain Map Reduced Data Record (DTMRDR)

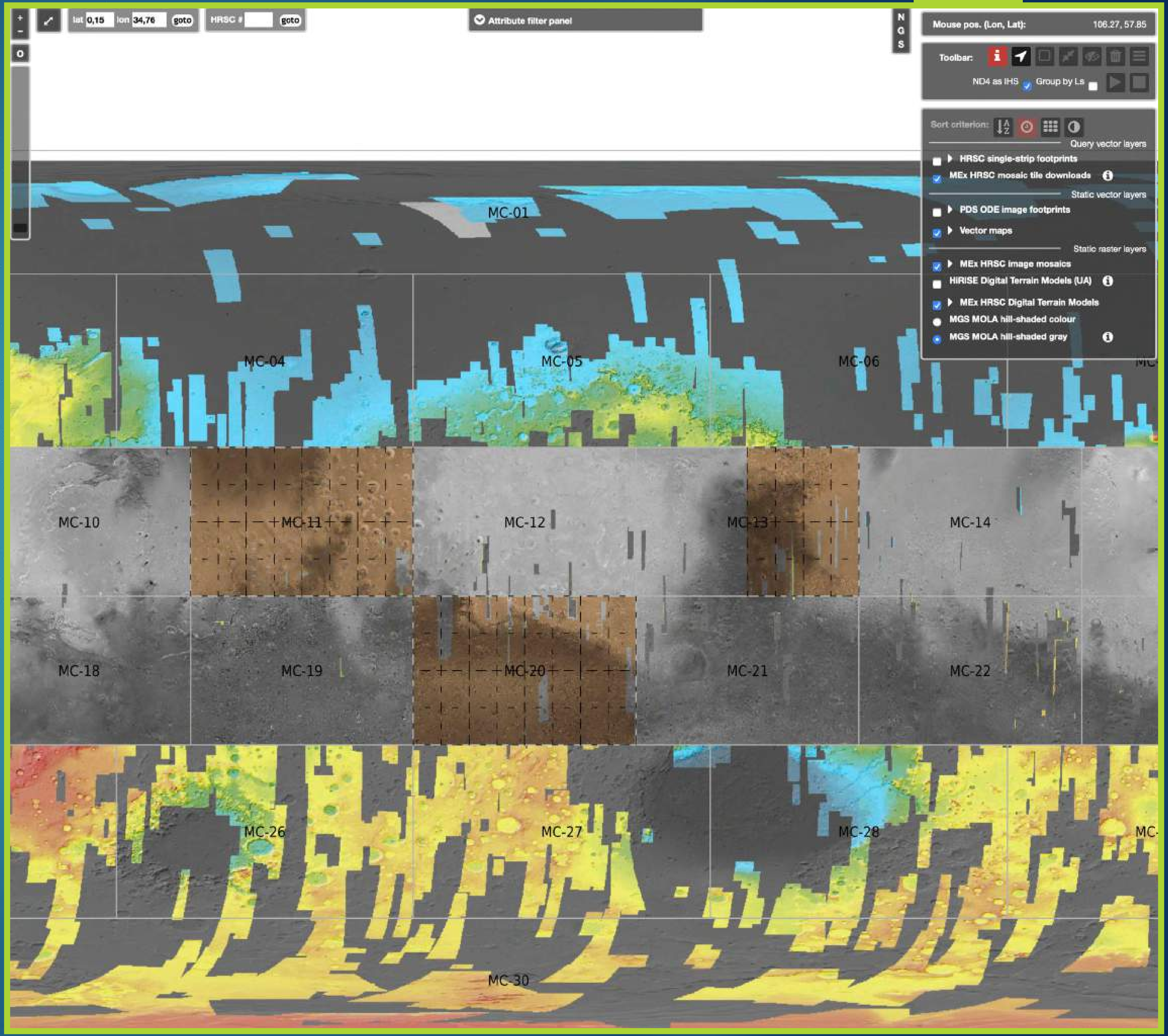
These are the map-projected data we need

These in particular are ready to use level 4 data



High Resolution Stereo Camera (HRSC)

- Also available here with more extensive coverage:
- https://maps.planet.fu-berlin.de/#map=3/2074498.35/0



HRSC Map and Reference Frame

- Sinusoidal projection (Latitudes from 85° S to 85° N)
- Polar-Stereographic projection (polar areas)

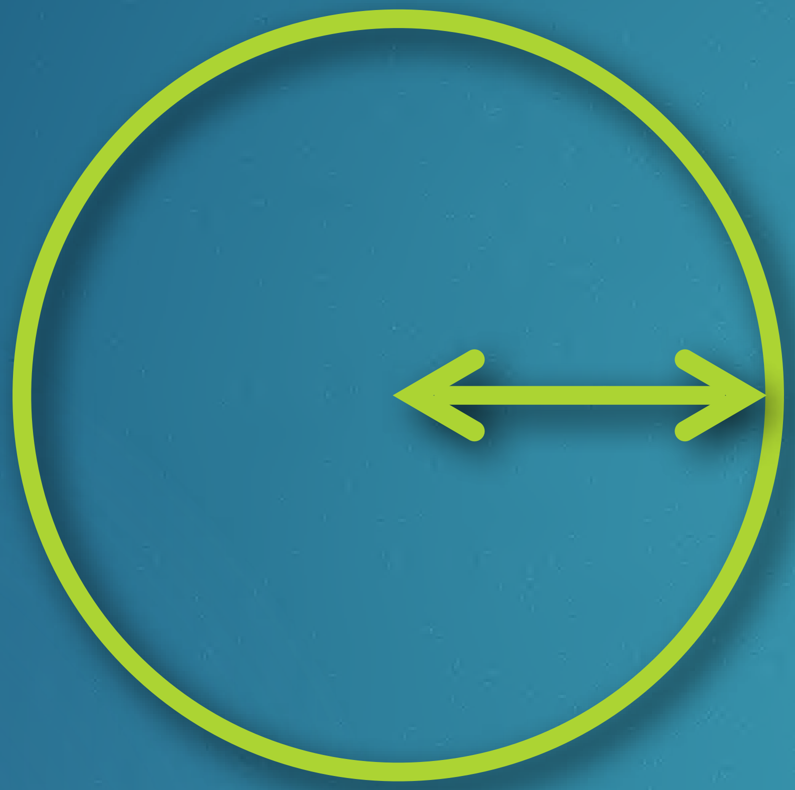
- MAP REFERENCE
  - The map reference body is a sphere with r = 3396.0 km
  - Lev 3 data use the ellipsoid
- HEIGHT REFERENCE ⇢ The vertical reference for DEM is either:
- A sphere with r = 3396.0 km (DT4)
- An aeroid (DA4) directly comparable with MOLA MEGDR

Aeroid

- Average shape of Mars
- The MOLA mean radius of the planet is 3,389,508 meters and the mean equatorial radius is 3,396,000 meters
- Gravitational equipotential surface whose average value at the equator is equal to the mean planetary radius determined by MOLA data.

Sphere & ellipsoid

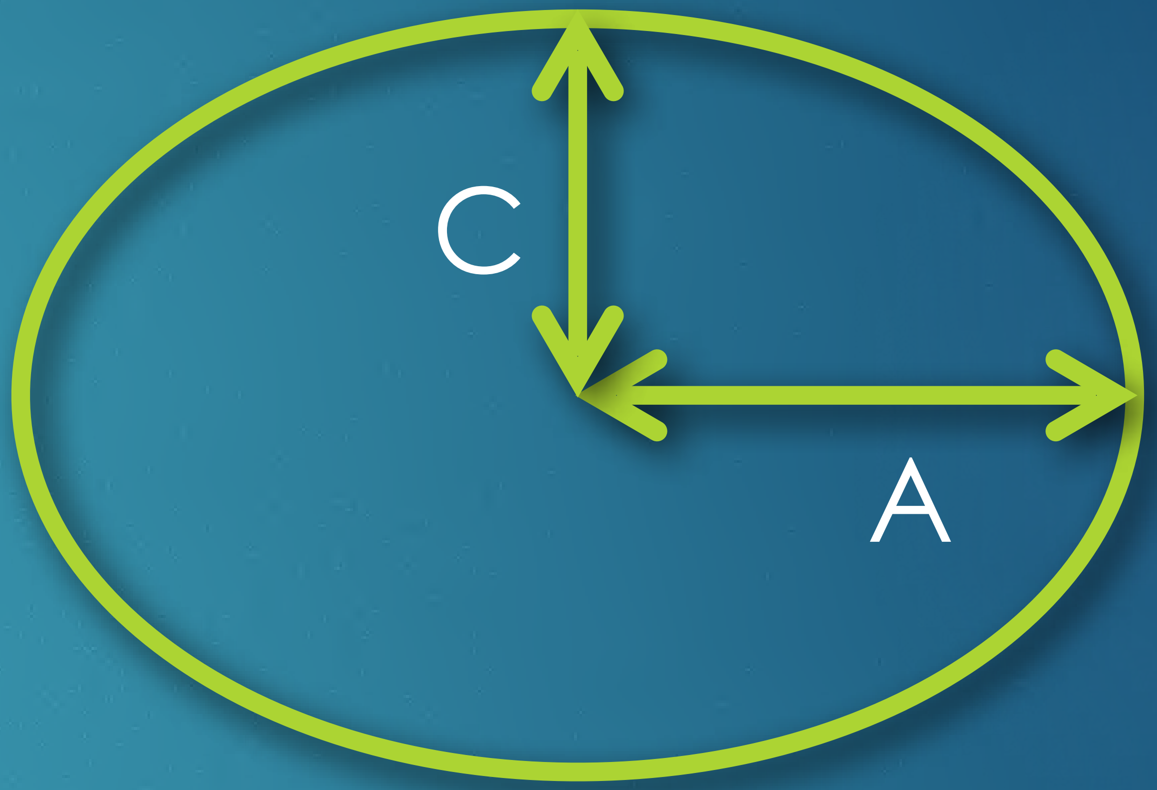
~ MARS MOLA SPHERE



A_AXIS = 3396.0 KM
B_AXIS = 3396.0 KM
C_AXIS = 3396.0 KM

HRSC LEV. 4

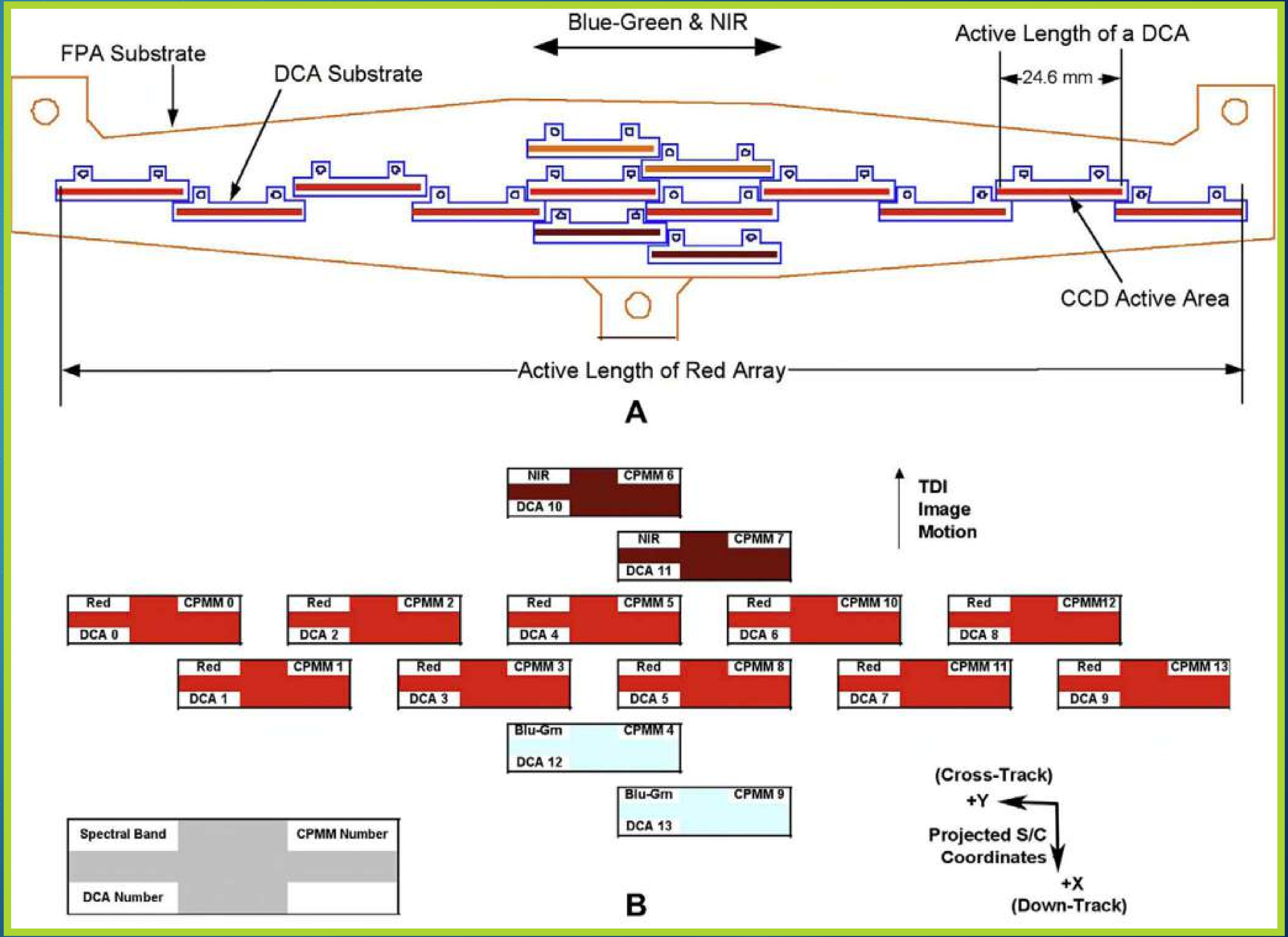
MARS IAU2000 ELLIPSOID



A_AXIS = 3396.19 KM
B_AXIS = 3396.19 KM
C_AXIS = 3376.2 KM

HRSC LEV. 3

High Resolution Imaging Science Experiment (HiRISE)



McEwen et al., 2010

High Resolution Imaging Science Experiment (HiRISE)

https://ode.rsl.wustl.edu/mars/pagehelp/Content/Missions_Instruments/Mars%20Reconnaissance%20Orbiter/HiRISE/HiRISE.htm

PRODUCT	Format / file extension	Description
EDR	.IMG	Raw image data, one per image channel (up to 28 per observation), FELICS decompressed in raster format.
RDR	_RED.JP2, .LBL	Map-projected mosaic of RED-filter CCDs in JPEG2000 format (.JP2) and losslessly compressed with 10- bits per pixel providing a dynamic range 0-1023. The .LBL file is the detached PDS label describing the product.
RDR	_COLOR.JP2, .LBL	Three-color map-projected mosaic of IR , RED, and BG bands in JPEG2000 format and losslessly compressed with 10-bits per pixel providing a dynamic range 0-1023
DTM	.JP2, .IMG, .LBL	Digital Terrain Model products formatted in PDS-labeled raster format (.IMG) and orthoimages stored in the JPEG2000 format with detached PDS labels (.JP2, .LBL).
ANAGLYPH	.JP2	Anaglyph products. These products are offered in the Extras portion of the HiRISE archive. They are presented by ODE as a separate data type to facilitate search and download.

High Resolution Imaging Science Experiment (HiRISE)

PREFIX	**Description**
PSP_	Primary Science Phase observation covered a bit more than one Mars year, from November 2006 until December 2008.
ESP_	Extended Science Phase, started in January 2009, recently passed the 75000-orbit mark.

High Resolution Imaging Science Experiment (HiRISE)

- An EDR (Experiment Data Record) contains unprocessed image data, ancillary engineering data, and information about the instrument commanding used to acquire the image.
- An EDR image has the inherent properties of raw and unprocessed data.
- The HiRISE RDR (Reduced Data Record) products have undergone radiometric correction and geometric processing. RDR products are intended to be the more useful product for science data analysis.
- Stored in JP2000 + LBL

Hi naging Science
Ex E)

Record) contains unprocessed image
ng data, and information about the
used to acquire the image.

herent properties of raw and unprocessed

Data Record) products have undergone
nd geometric processing. RDR products are
useful product for science data analysis.

Hi naging Scien
Ex E)

Record) contains unp
ng data, and informati
used to acquire the im

herent properties of ra

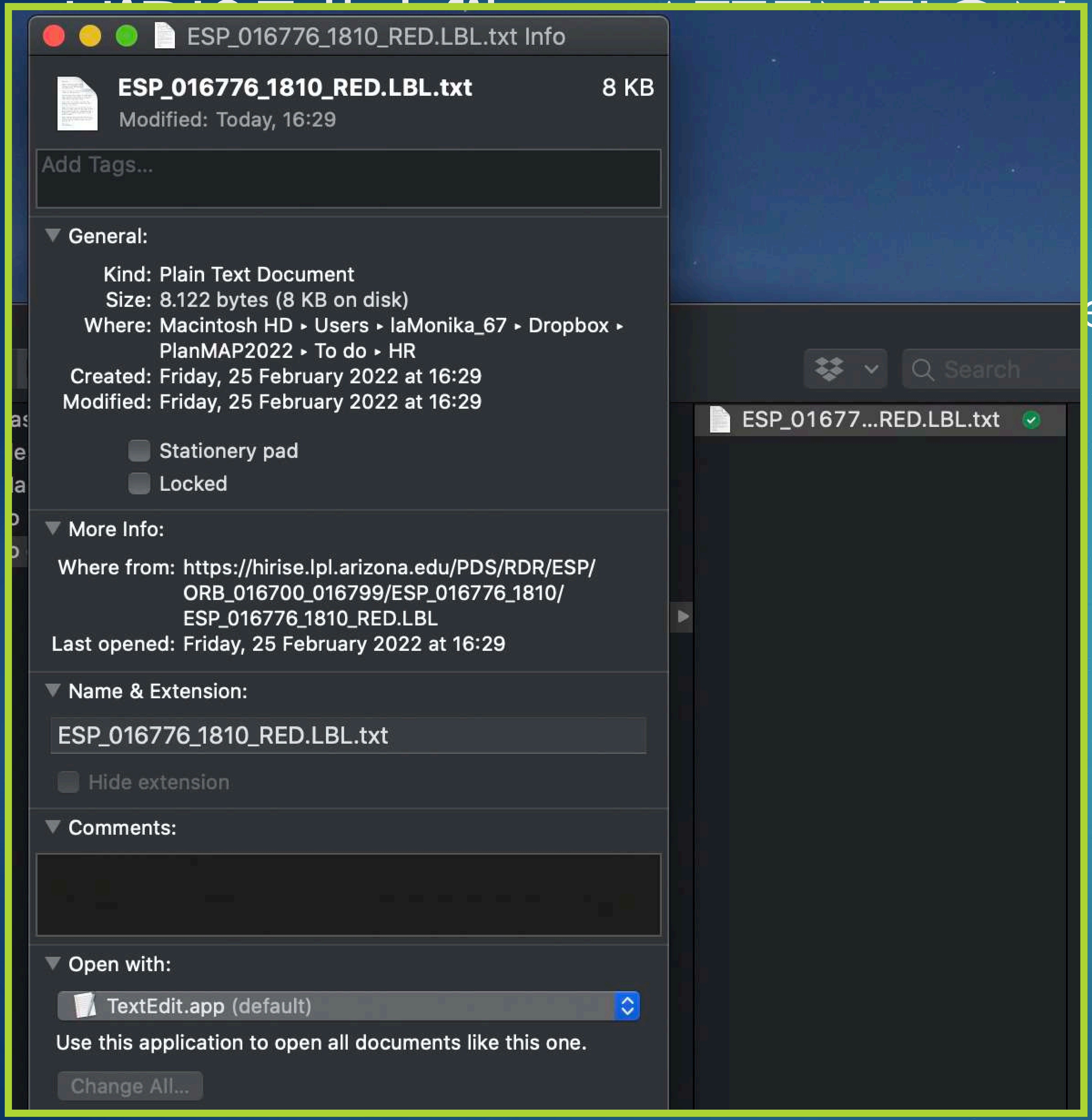
Data Record) produc
nd geometric processi
useful product for scie

Download HRSC and HiRISE Data

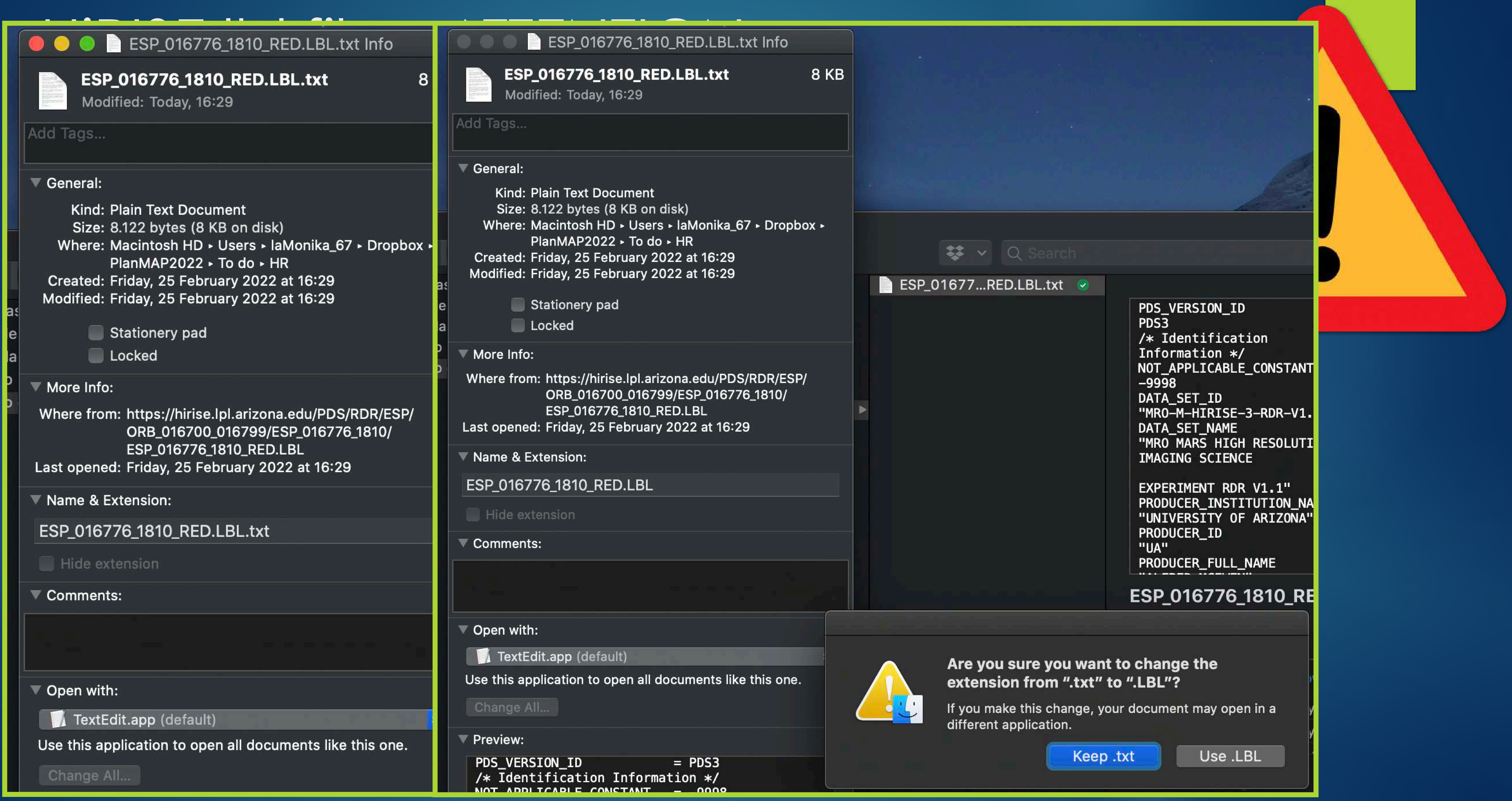
- Connect to the folder with your area in the cluster:
  - HRSC_HiRISEdownload.txt
- DT and ND HRSC images
- HiRISE images (JP2 and LBL) and sometimes DEMs
  - Download both JP2 and LBL
- Copy the links and download them directly from and to your computer

HiRISE lbl files: ATTENTION

- Make sure the label file has indeed the .lbl extension
- The .txt extension might be hidden



e .lbl extension


ESP_016776_1810_RED.LBL.txt Info
ESP_016776_1810_RED.LBL.txt
Modified: Today, 16:29
Add Tags...
General:
Kind: Plain Text Document
Size: 8.122 bytes (8 KB on disk)
Where: Macintosh HD ▸ Users ▸ laMonika_67 ▸ Dropbox ▸ PlanMAP2022 ▸ To do ▸ HR
Created: Friday, 25 February 2022 at 16:29
Modified: Friday, 25 February 2022 at 16:29
Stationery pad
Locked
More Info:
Where from: https://hirise.lpl.arizona.edu/PDS/RDR/ESP/ORB_016700_016799/ESP_016776_1810/ESP_016776_1810_RED.LBL
Last opened: Friday, 25 February 2022 at 16:29
Name & Extension:
ESP_016776_1810_RED.LBL.txt
Hide extension
Comments:
Open with:
TextEdit.app (default)
Use this application to open all documents like this one.
Change All...
ESP_016776_1810_RED.LBL.txt Info
ESP_016776_1810_RED.LBL.txt 8 KB
Modified: Today, 16:29
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Kind: Plain Text Document
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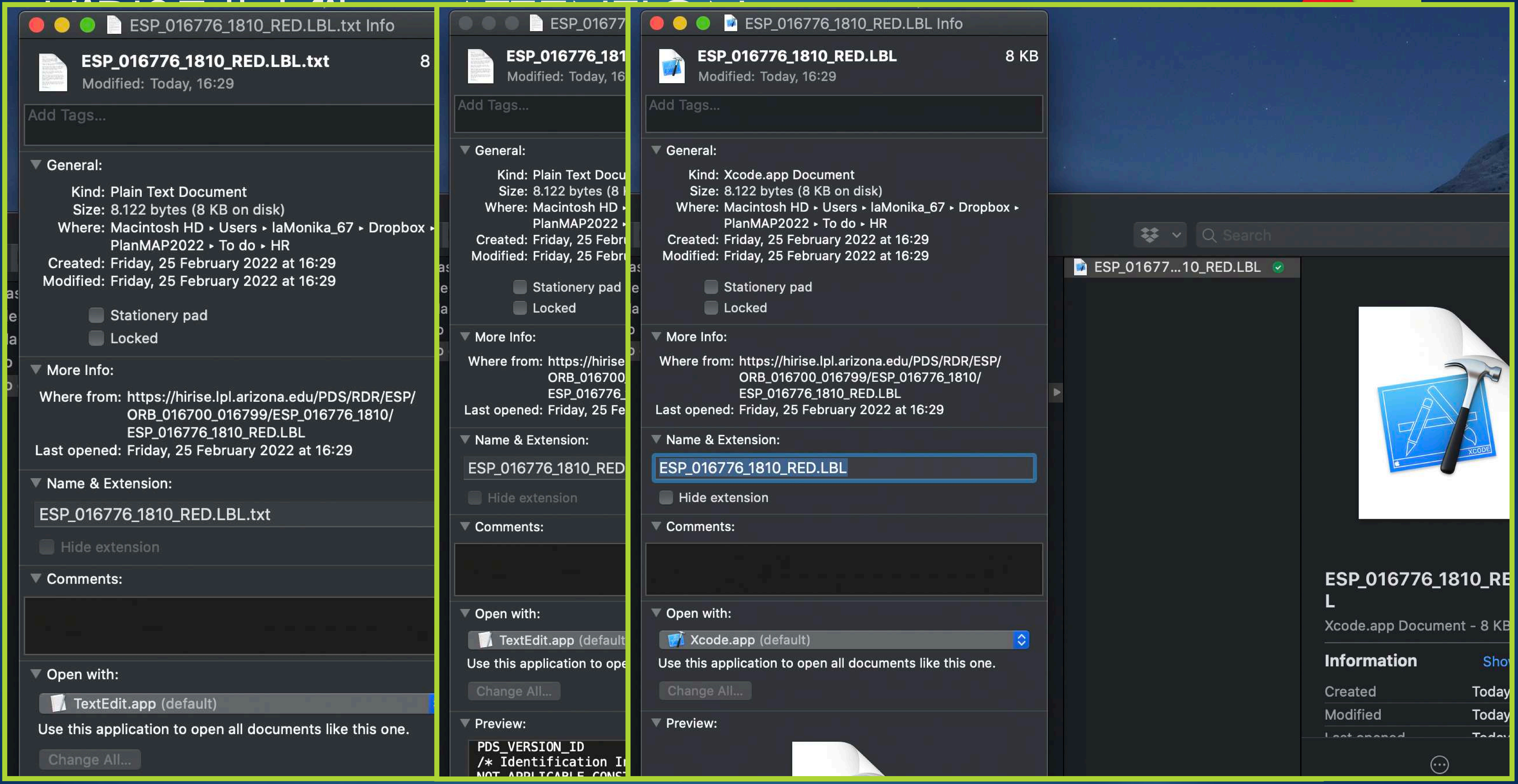
Last opened: Friday, 25 February 2022 at 16:29
Name & Extension:
ESP_016776_1810_RED.LBL
Hide extension
Comments:
Open with:
TextEdit.app (default)
Use this application to open all documents like this one.
Change All...
Preview:
PDS_VERSION_ID = PDS3
/* Identification Information */
Search
ESP_01677...RED.LBL.txt
PDS_VERSION_ID
PDS3
/* Identification
Information */
NOT_APPLICABLE_CONSTANT
-9998
DATA_SET_ID
"MRO-M-HIRISE-3-RDR-V1.
DATA_SET_NAME
"MRO MARS HIGH RESOLUTI
IMAGING SCIENCE
EXPERIMENT RDR V1.1"
PRODUCER_INSTITUTION_NA
"UNIVERSITY OF ARIZONA"
PRODUCER_ID
"UA"
PRODUCER_FULL_NAME
ESP_016776_1810_RE
Are you sure you want to change the extension from ".txt" to ".LBL"?
If you make this change, your document may open in a different application.
Keep .txt
Use .LBL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Modified: Today, 16:29
Add Tags...
General:
Kind: Plain Text Document
Size: 8.122 bytes (8 KB on disk)
Where: Macintosh HD ▸ Users ▸ laMonika_67 ▸ Dropbox ▸ PlanMAP2022 ▸ To do ▸ HR
Created: Friday, 25 February 2022 at 16:29
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Locked
More Info:
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Last opened: Friday, 25 February 2022 at 16:29
Name & Extension:
ESP_016776_1810_RED.LBL.txt
Hide extension
Comments:
Open with:
TextEdit.app (default)
Use this application to open all documents like this one.
Change All...
Preview:
PDS_VERSION_ID
/* Identification I
ESP_016776_1810_RED.LBL Info
ESP_016776_1810_RED.LBL
8 KB
Modified: Today, 16:29
Add Tags...
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More Info:
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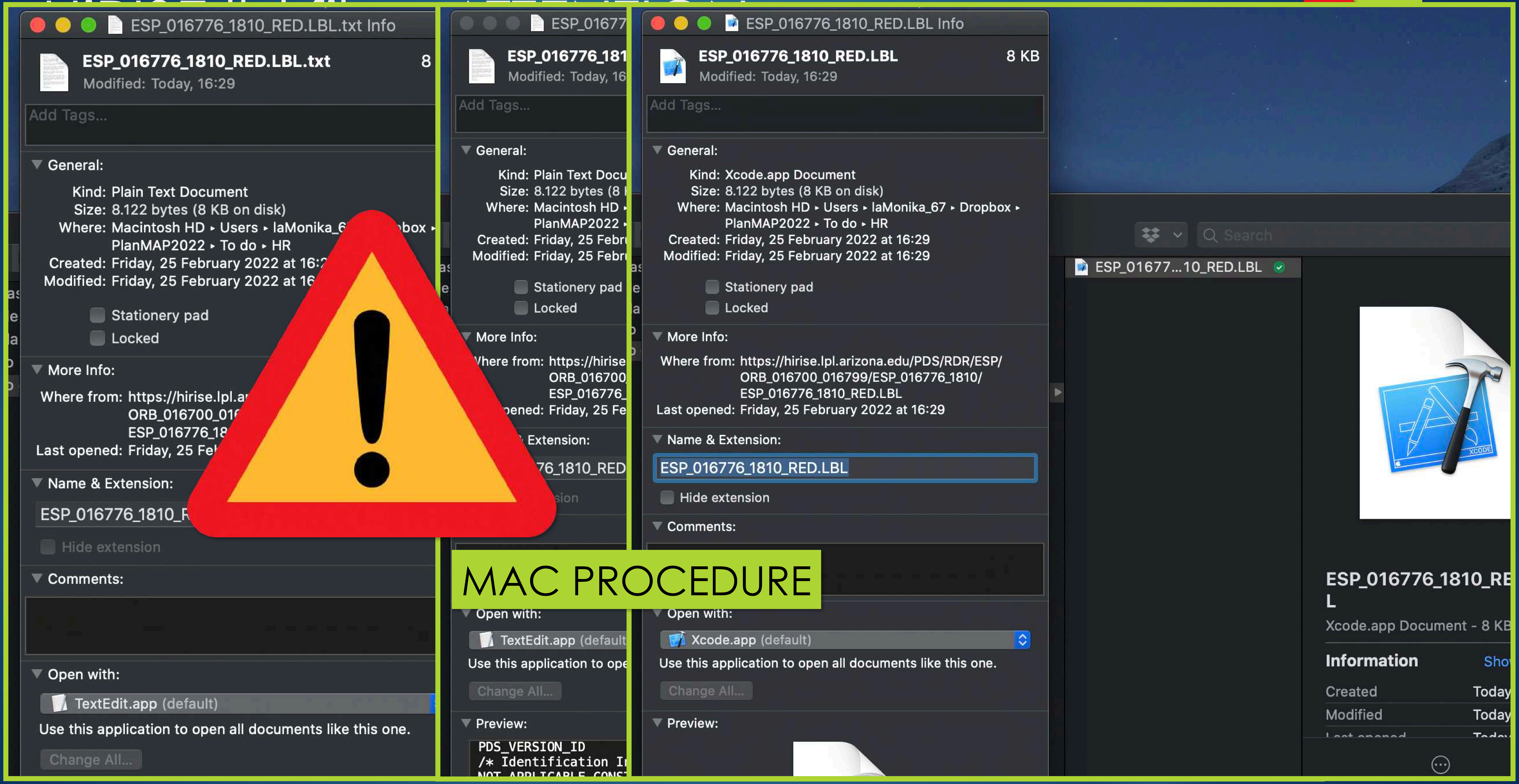
Last opened: Friday, 25 February 2022 at 16:29
Name & Extension:
ESP_016776_1810_RED.LBL
Hide extension
Comments:
Open with:
Xcode.app (default)
Use this application to open all documents like this one.
Change All...
Preview:
Search
ESP_01677...10_RED.LBL
XCODE
Xcode.app Document - 8 KB
Information
Created
Today
Modified
Today


MAC PROCEDURE
ESP_016776_1810_RED.LBL.txt Info
ESP_016776_1810_RED.LBL.txt
Modified: Today, 16:29
Add Tags...
General:
Kind: Plain Text Document
Size: 8.122 bytes (8 KB on disk)
Stationery pad
Locked
More Info:
Name & Extension:
Hide extension
Comments:
Open with:
TextEdit.app (default)
Use this application to open all documents like this one.
Change All...
ESP_016776_1810_RED.LBL Info
ESP_016776_1810_RED.LBL
8 KB
Modified: Today, 16:29
Add Tags...
General:
Kind: Xcode.app Document
Size: 8.122 bytes (8 KB on disk)
Where: Macintosh HD ▸ Users ▸ laMonika_67 ▸ Dropbox ▸ PlanMAP2022 ▸ To do ▸ HR
Created: Friday, 25 February 2022 at 16:29
Modified: Friday, 25 February 2022 at 16:29
Stationery pad
Locked
More Info:
Where from: https://hirise.lpl.arizona.edu/PDS/RDR/ESP/ORB_016700_016799/ESP_016776_1810/ESP_016776_1810_RED.LBL
Last opened: Friday, 25 February 2022 at 16:29
Name & Extension:
ESP_016776_1810_RED.LBL
Hide extension
Comments:
Open with:
Xcode.app (default)
Use this application to open all documents like this one.
Change All...
Preview:
PDS_VERSION_ID
Search
ESP_01677...10_RED.LBL
Xcode.app Document - 8 KB
Information
Created
Modified

Co-funded by the ERASMUS + Programme of the European Union

DEM Production: CTX

NASA AMES STEREO PIPELINE

The Stereo Pipeline

- https://github.com/NeoGeographyToolkit/StereoPipeline
- https://groups.google.com/g/ames-stereo-pipeline-support
- The NASA Ames Stereo Pipeline (ASP) is a suite of free and open source automated geodesy and stereogrammetry tools designed for processing stereo imagery captured from satellites (around Earth and other planets), robotic rovers, aerial cameras, and historical imagery, with and without accurate camera pose information. It produces cartographic products, including digital elevation models (DEMs), ortho-projected imagery, 3D models, and bundle-adjusted networks of cameras. ASP's data products are suitable for science analysis, mission planning, and public outreach.

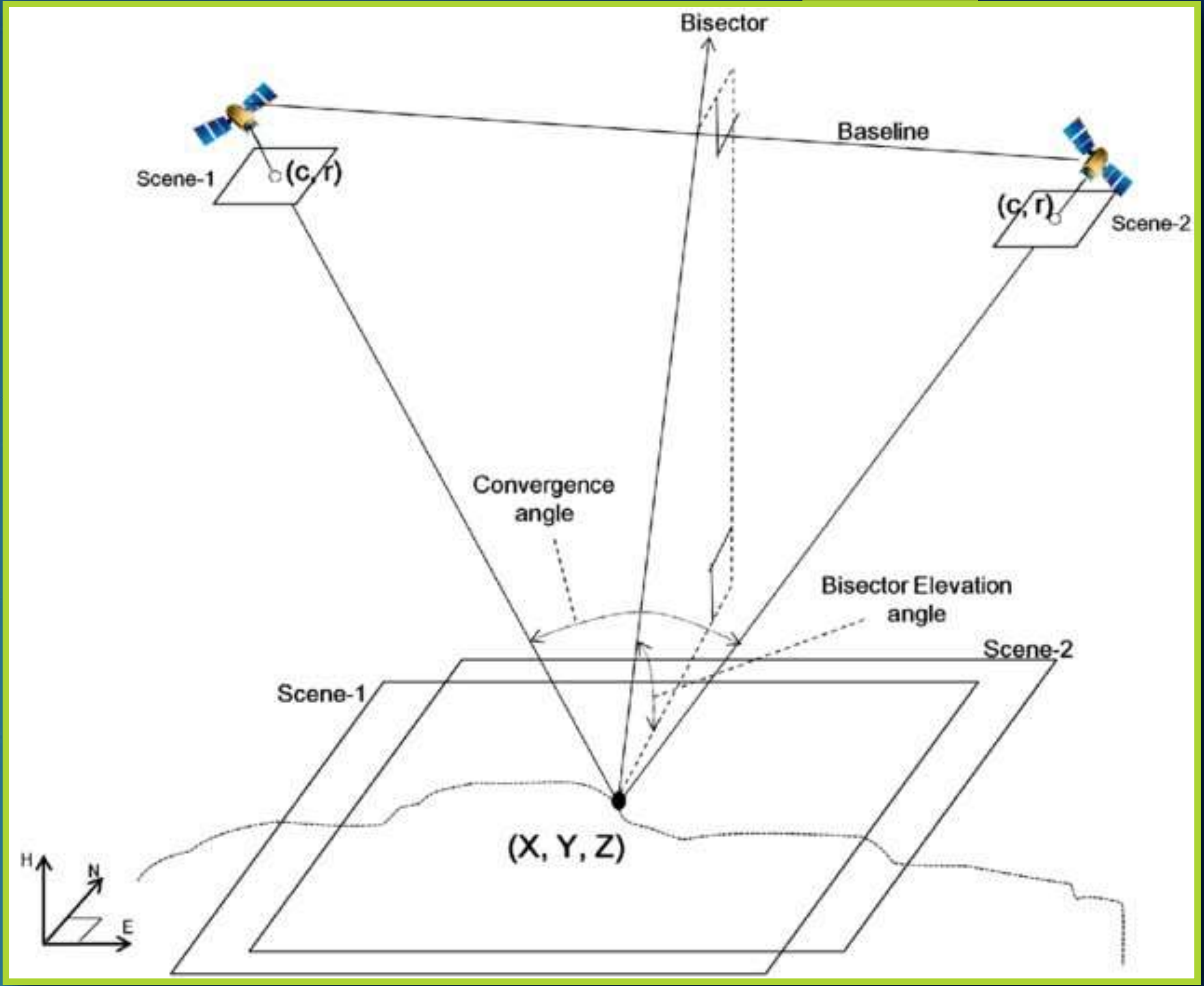
NASA Ames Stereo Pipeline (ASP) overview

- ISIS is a requisite for non-Earth data
- binaries and scripts available on GitHub:
- https://github.com/NeoGeographyToolkit/StereoPipeline
- Installation very simple (pay attention to the dependencies)
  - Choose your version: linux or MacOSX
  - *untar* the downloaded file
  - add to the path

Referencing

- Beyer Ross A., Oleg Alexandrov and Scott McMichael, 2018. The Ames Stereo Pipeline: NASA's open source software for deriving and processing terrain data, Earth and Space Science, 5.
- In addition to the recommended citation, we ask that you also cite the DOI for the specific version of ASP that you used for processing. Every new release (and daily build) of ASP will have its own unique DOI, which can be found:
  - https://zenodo.org/record/7076045#.YyGGwS2cbUI

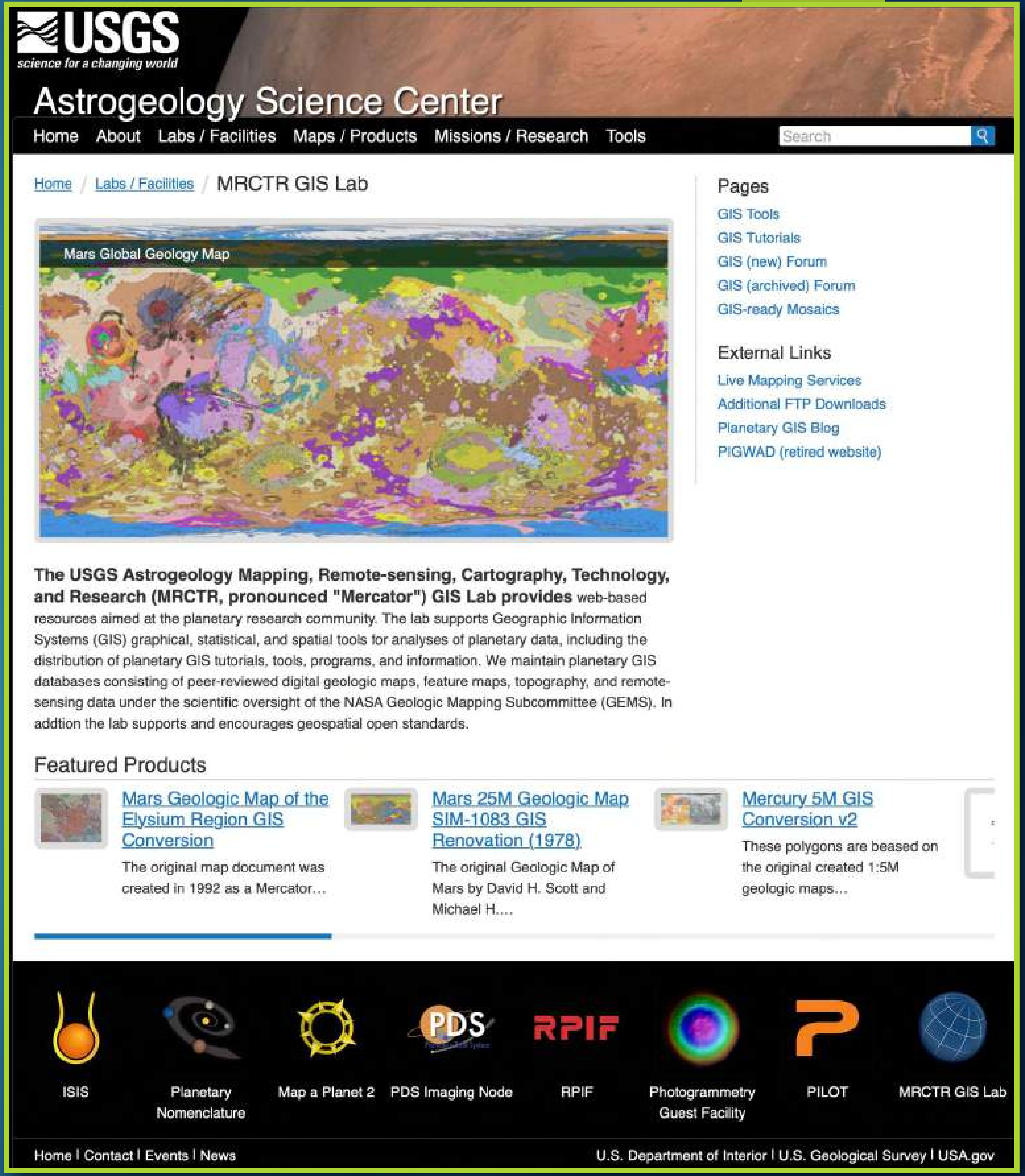
Look for suitable stereo-pairs



- NOT all the missions acquire stereo pairs
  - e.g. HiRISE yes, CTX no
- Overlapping data
- Convergence angle
  - as the convergence angle of a stereo pair increases, the image matching precision decreases approximately linearly, which makes the geopositioning less precise
- The shadow-tip distance and aspect ratio are also roughly linear with image matching precision

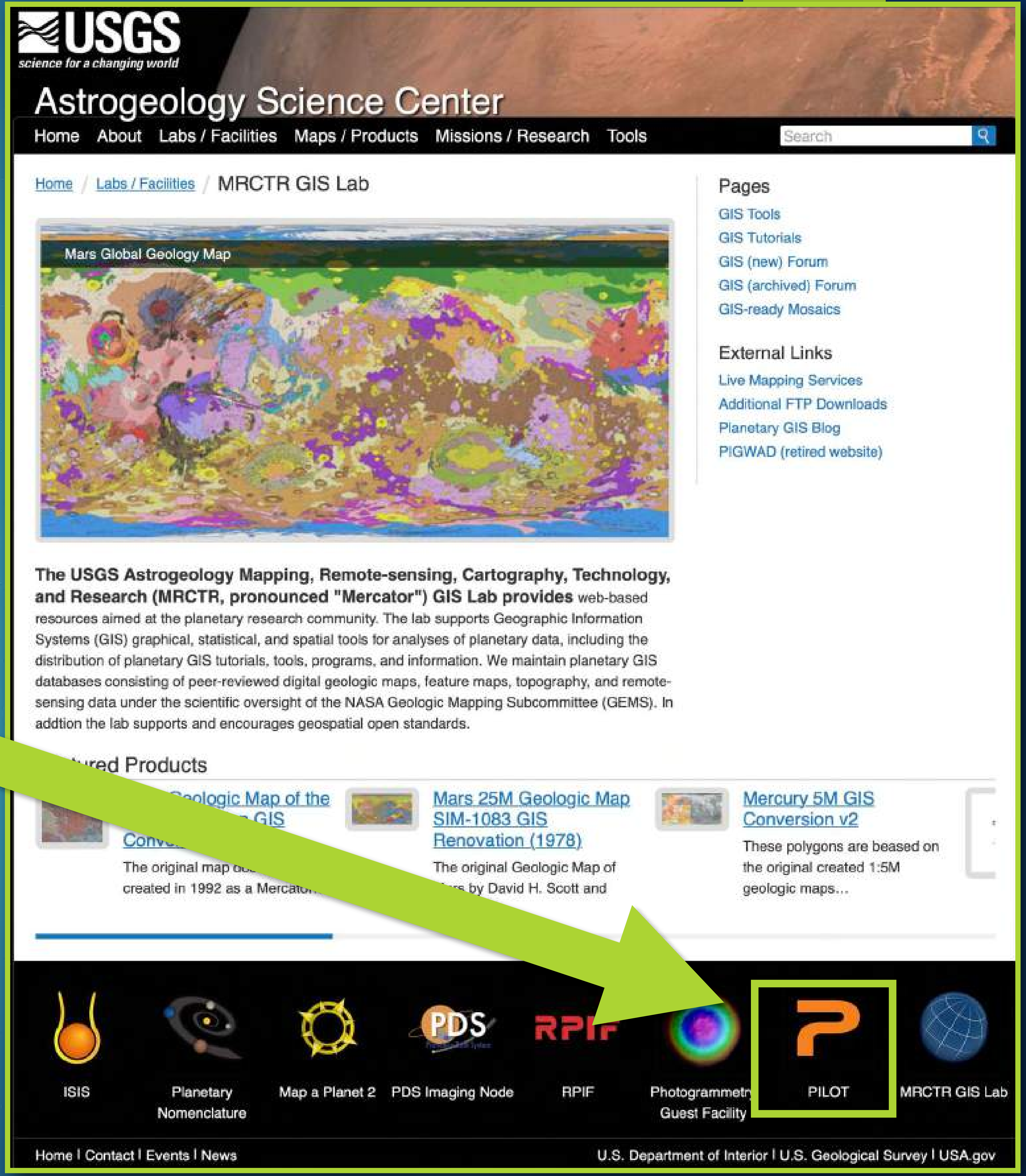
Practically how

- Astrogeology website
- PILOT tool

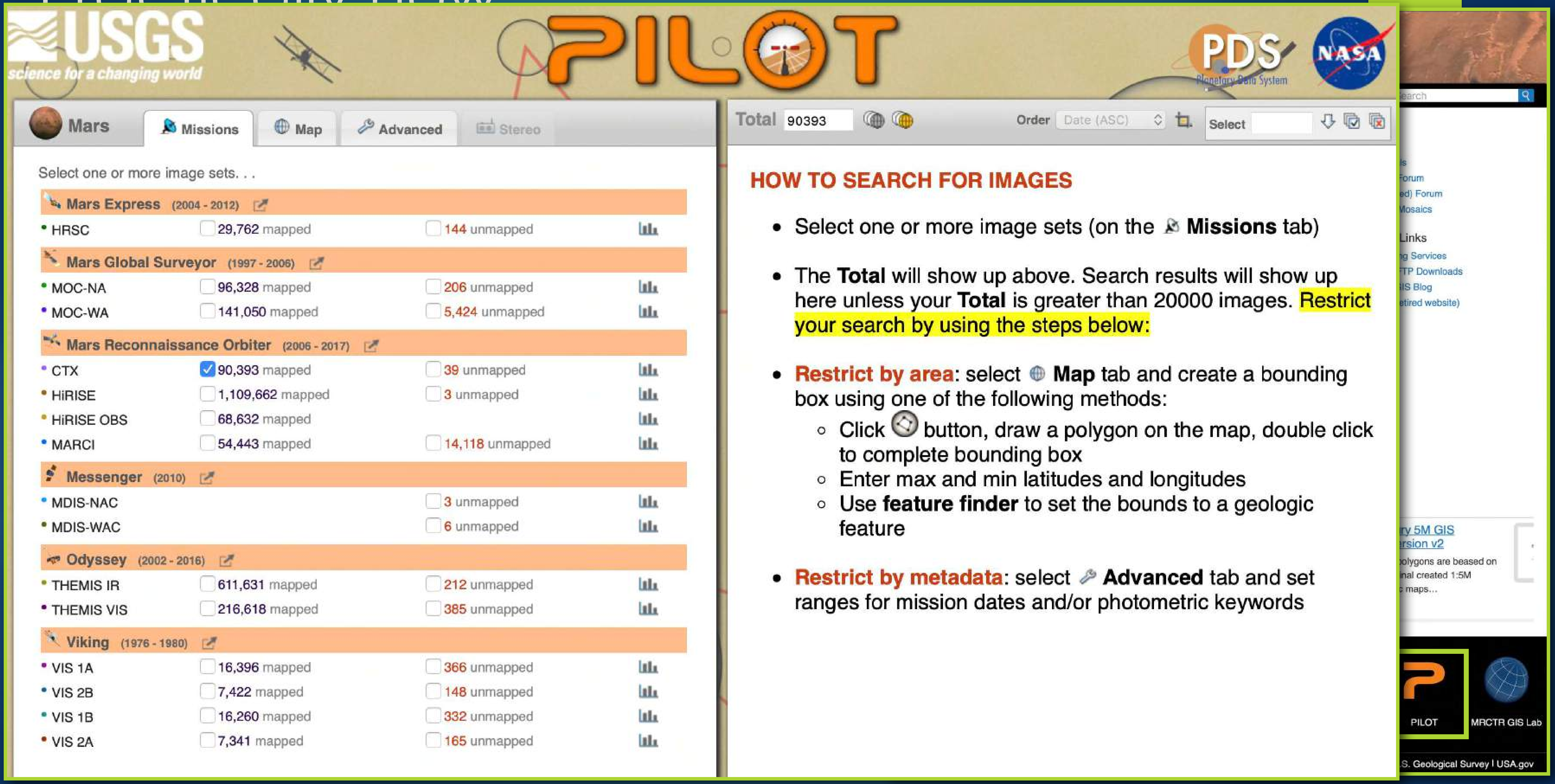


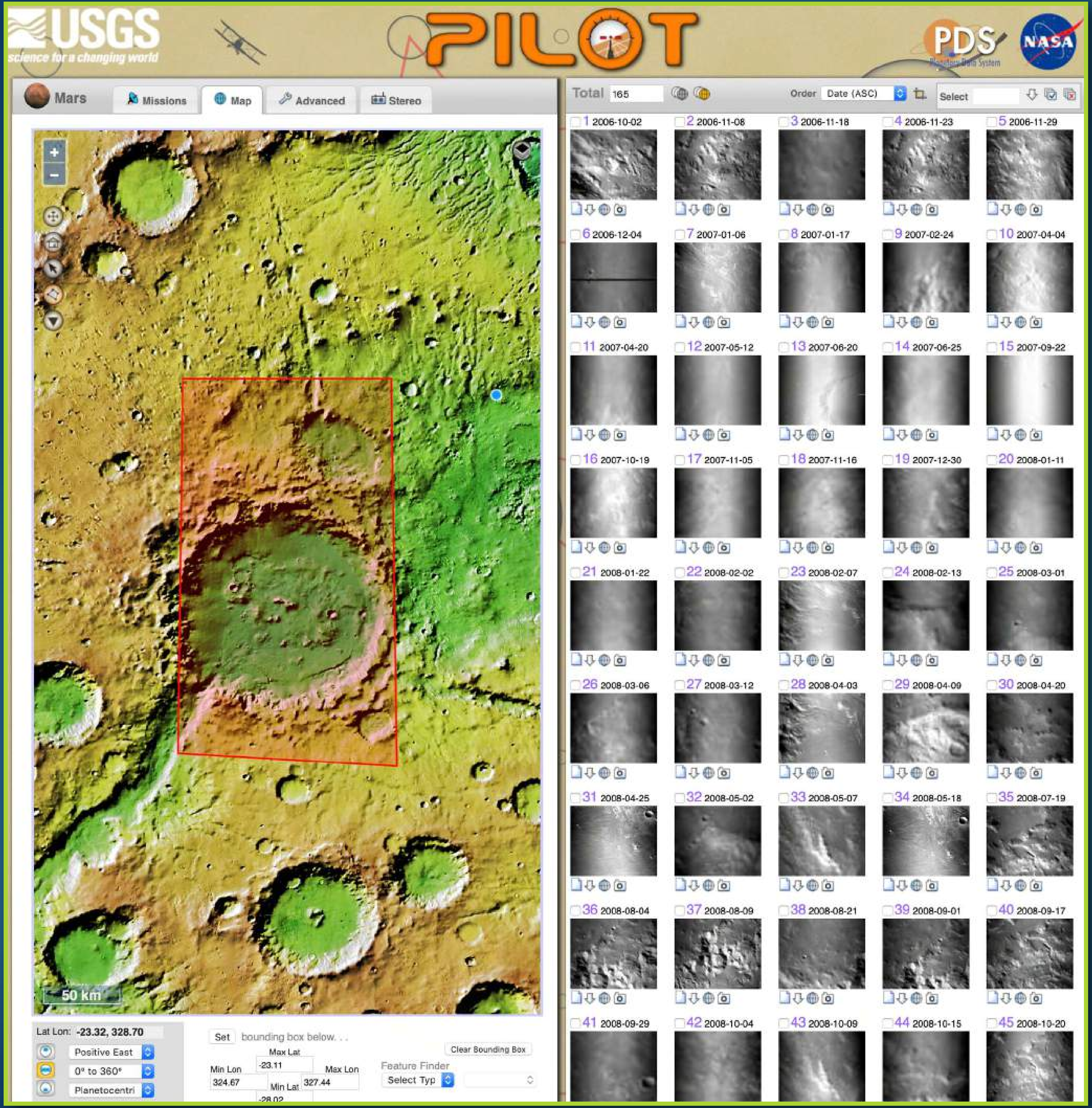
Practically how

- Astrogeology website
- PILOT tool



Practically how





USGS
science for a changing world
PILOT
PDS
NASA
Mars
Missions
Map
Advanced
Stereo
50 km
Lat Lon: -23.32, 328.70
Positive East
0° to 360°
Planetocentri
Set
bounding box below. . .
Clear Bounding Box
Max Lat
-23.11
Min Lon
324.67
Max Lon
327.44
Min Lat
Feature Finder
Select Typ
Total
165
Order
Date (ASC)
Select
1 2006-10-02
2 2006-11-08
3 2006-11-18
4 2006-11-23
5 2006-11-29
6 2006-12-04
7 2007-01-06
8 2007-01-17
9 2007-02-24
10 2007-04-04
11 2007-04-20
12 2007-05-12
13 2007-06-20
14 2007-06-25
15 2007-09-22
16 2007-10-19
17 2007-11-05
18 2007-11-16
19 2007-12-30
20 2008-01-11
21 2008-01-22
22 2008-02-02
23 2008-02-07
24 2008-02-13
25 2008-03-01
26 2008-03-06
27 2008-03-12
28 2008-04-03
29 2008-04-09
30 2008-04-20
31 2008-04-25
32 2008-05-02
33 2008-05-07
34 2008-05-18
35 2008-07-19
36 2008-08-04
37 2008-08-09
38 2008-08-21
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40 2008-09-17
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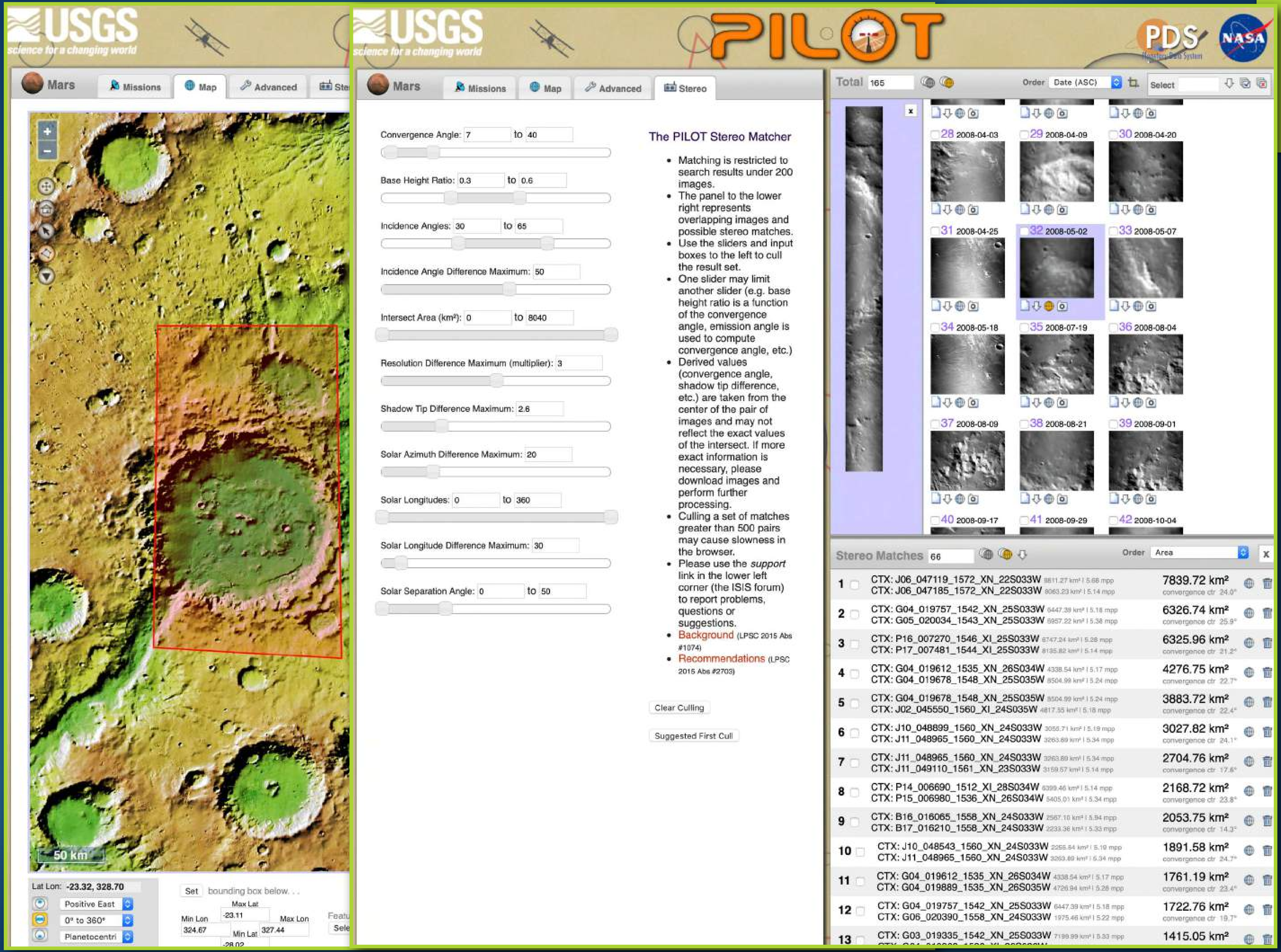
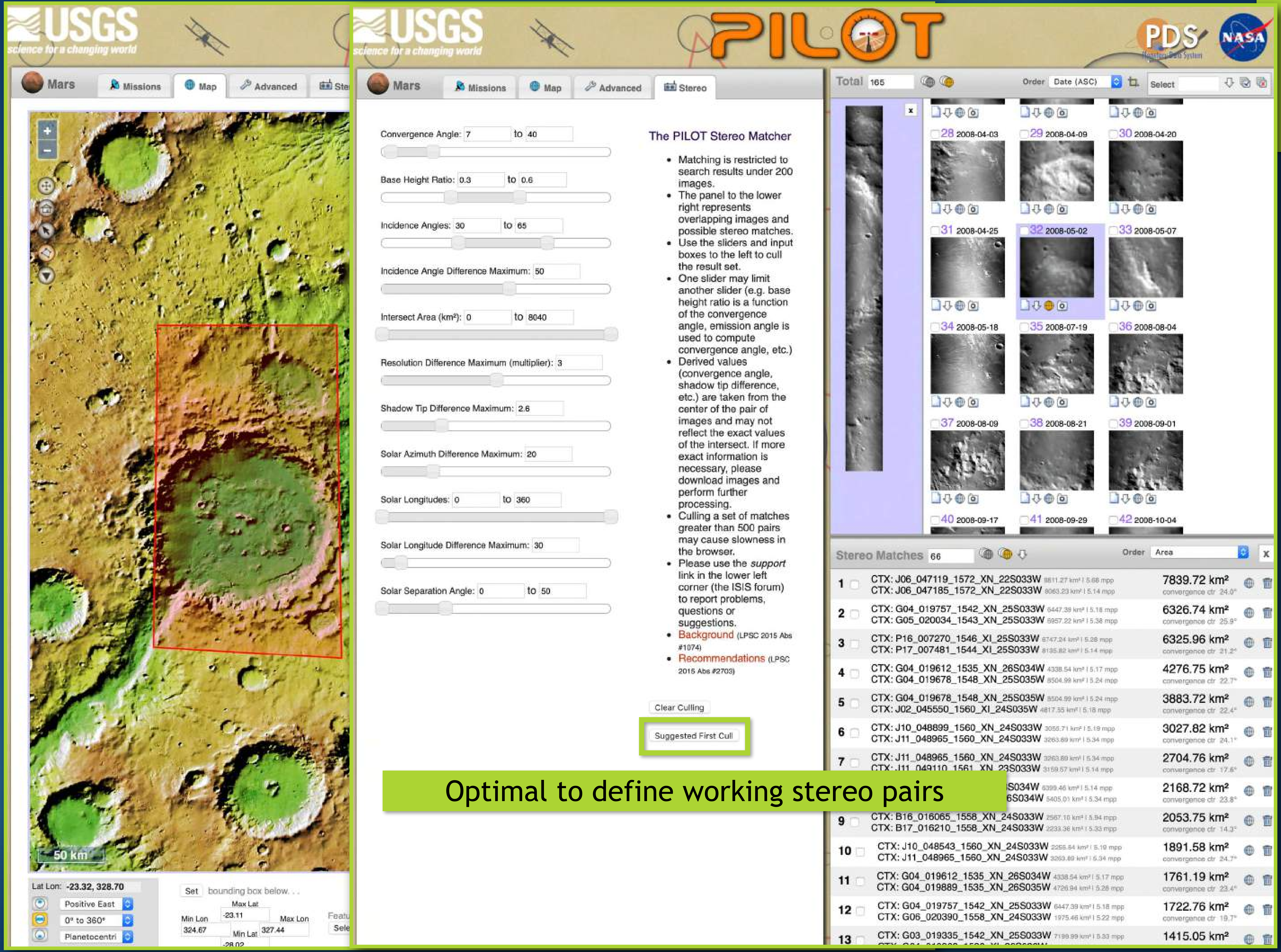
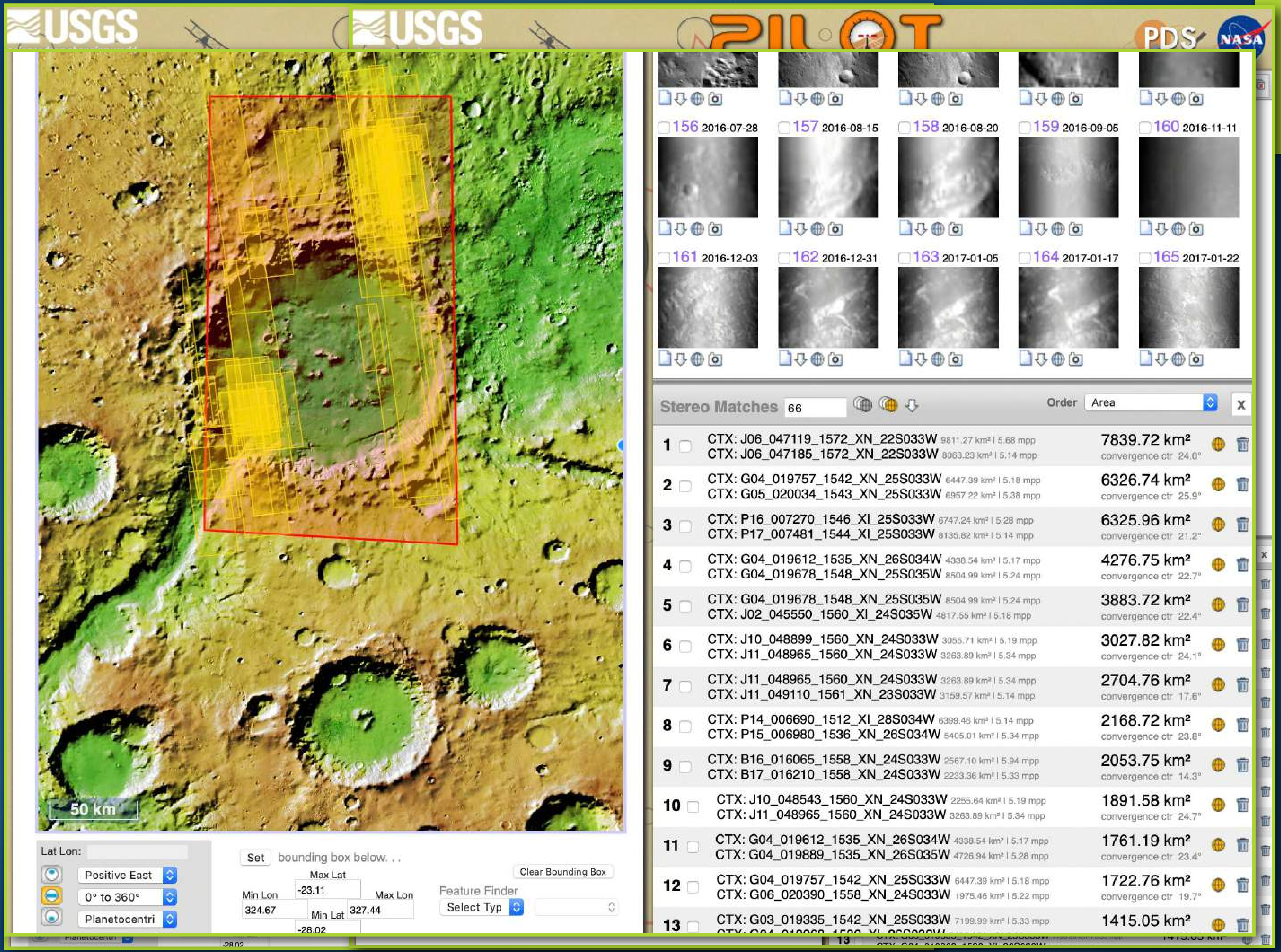
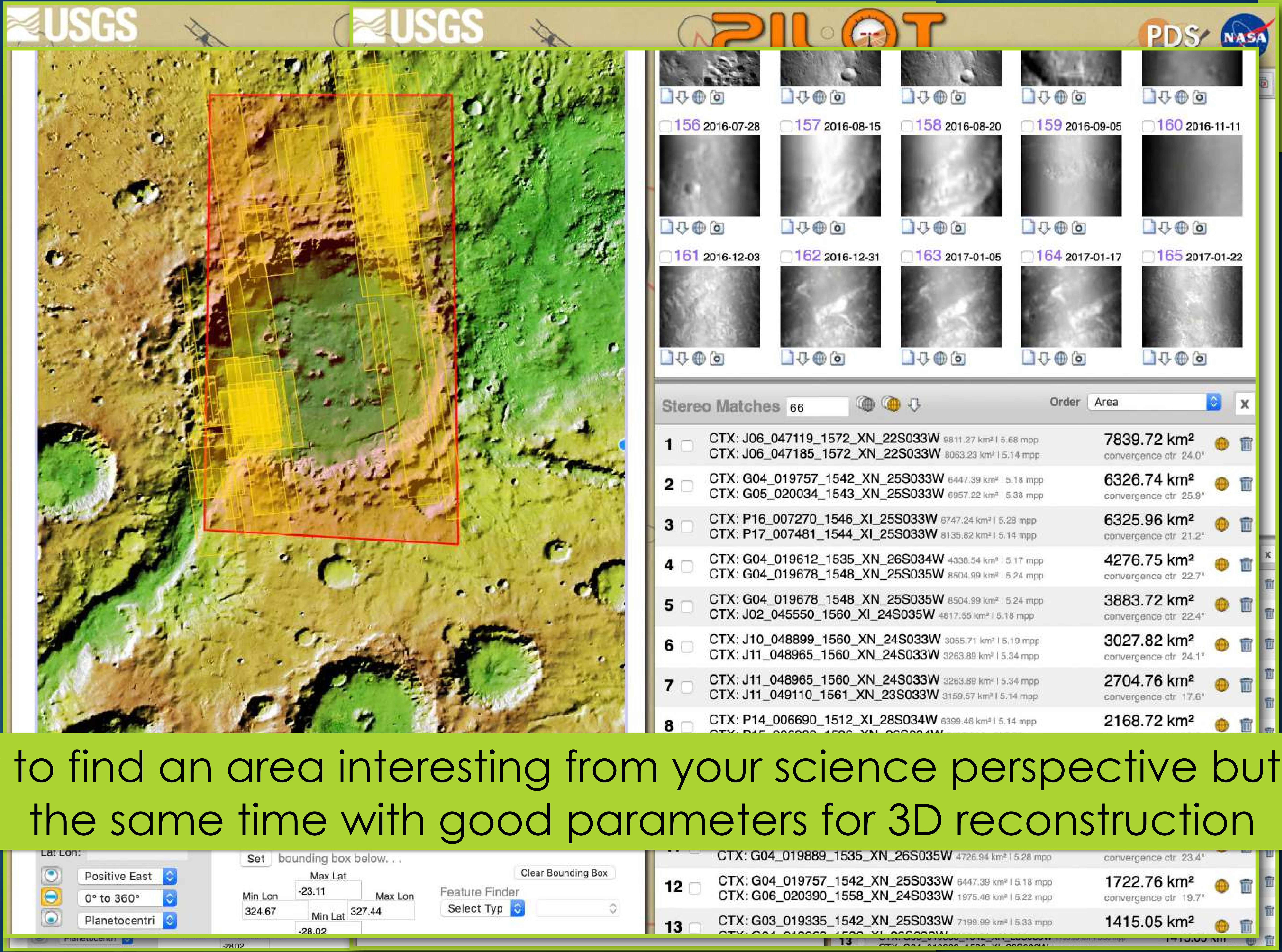
43 2008-10-09
44 2008-10-15
45 2008-10-20


USGS
science for a changing world
PILOT
PDS
NASA
Mars
Missions
Map
Advanced
Stereo
50 km
Lat Lon: -23.32, 328.70
Positive East
0° to 360°
Planetocentri
Set
bounding box below. . .
Max Lat
-23.11
Min Lon
324.67
Max Lon
327.44
Min Lat
-28.02
Convergence Angle: 7 to 40
Base Height Ratio: 0.3 to 0.6
Incidence Angles: 30 to 65
Incidence Angle Difference Maximum: 50
Intersect Area (km²): 0 to 8040
Resolution Difference Maximum (multiplier): 3
Shadow Tip Difference Maximum: 2.6
Solar Azimuth Difference Maximum: 20
Solar Longitudes: 0 to 360
Solar Longitude Difference Maximum: 30
Solar Separation Angle: 0 to 50
The PILOT Stereo Matcher
• Matching is restricted to search results under 200 images.
• The panel to the lower right represents overlapping images and possible stereo matches.
• Use the sliders and input boxes to the left to cull the result set.
• One slider may limit another slider (e.g. base height ratio is a function of the convergence angle, emission angle is used to compute convergence angle, etc.)
• Derived values (convergence angle, shadow tip difference, etc.) are taken from the center of the pair of images and may not reflect the exact values of the intersect. If more exact information is necessary, please download images and perform further processing.
• Culling a set of matches greater than 500 pairs may cause slowness in the browser.
• Please use the support link in the lower left corner (the ISIS forum) to report problems, questions or suggestions.
• Background (LPSC 2015 Abs #1074)
• Recommendations (LPSC 2015 Abs #2703)
Clear Culling
Suggested First Cull
Total 165
Order Date (ASC)
Select
28 2008-04-03
29 2008-04-09
30 2008-04-20
31 2008-04-25
32 2008-05-02
33 2008-05-07
34 2008-05-18
35 2008-07-19
36 2008-08-04
37 2008-08-09
38 2008-08-21
39 2008-09-01
40 2008-09-17
41 2008-09-29
42 2008-10-04
Stereo Matches 66
Order Area
1 CTX: J06_047119_1572_XN_22S033W CTX: J06_047185_1572_XN_22S033W 7839.72 km²
2 CTX: G04_019757_1542_XN_25S033W CTX: G05_020034_1543_XN_25S033W 6326.74 km²
3 CTX: P16_007270_1546_XI_25S033W CTX: P17_007481_1544_XI_25S033W 6325.96 km²
4 CTX: G04_019612_1535_XN_26S034W CTX: G04_019678_1548_XN_25S035W 4276.75 km²
5 CTX: G04_019678_1548_XN_25S035W CTX: J02_045550_1560_XI_24S035W 3883.72 km²
6 CTX: J10_048899_1560_XN_24S033W CTX: J11_048965_1560_XN_24S033W 3027.82 km²
7 CTX: J11_048965_1560_XN_24S033W CTX: J11_049110_1561_XN_23S033W 2704.76 km²
8 CTX: P14_006690_1512_XI_28S034W CTX: P15_006980_1536_XN_26S034W 2168.72 km²
9 CTX: B16_016065_1558_XN_24S033W CTX: B17_016210_1558_XN_24S033W 2053.75 km²
10 CTX: J10_048543_1560_XN_24S033W CTX: J11_048965_1560_XN_24S033W 1891.58 km²
11 CTX: G04_019612_1535_XN_26S034W CTX: G04_019889_1535_XN_26S035W 1761.19 km²
12 CTX: G04_019757_1542_XN_25S033W CTX: G06_020390_1558_XN_24S033W 1722.76 km²
13 CTX: G03_019335_1542_XN_25S033W 1415.05 km²



Optimal to define working stereo pairs


USGS
PDS
NASA
156 2016-07-28
157 2016-08-15
158 2016-08-20
159 2016-09-05
160 2016-11-11
161 2016-12-03
162 2016-12-31
163 2017-01-05
164 2017-01-17
165 2017-01-22
Stereo Matches 66
Order Area
1 CTX: J06_047119_1572_XN_22S033W CTX: J06_047185_1572_XN_22S033W 7839.72 km² convergence ctr 24.0°
2 CTX: G04_019757_1542_XN_25S033W CTX: G05_020034_1543_XN_25S033W 6326.74 km² convergence ctr 25.9°
3 CTX: P16_007270_1546_XI_25S033W CTX: P17_007481_1544_XI_25S033W 6325.96 km² convergence ctr 21.2°
4 CTX: G04_019612_1535_XN_26S034W CTX: G04_019678_1548_XN_25S035W 4276.75 km² convergence ctr 22.7°
5 CTX: G04_019678_1548_XN_25S035W CTX: J02_045550_1560_XI_24S035W 3883.72 km² convergence ctr 22.4°
6 CTX: J10_048899_1560_XN_24S033W CTX: J11_048965_1560_XN_24S033W 3027.82 km² convergence ctr 24.1°
7 CTX: J11_048965_1560_XN_24S033W CTX: J11_049110_1561_XN_23S033W 2704.76 km² convergence ctr 17.6°
8 CTX: P14_006690_1512_XI_28S034W CTX: P15_006980_1536_XN_26S034W 2168.72 km² convergence ctr 23.8°
9 CTX: B16_016065_1558_XN_24S033W CTX: B17_016210_1558_XN_24S033W 2053.75 km² convergence ctr 14.3°
10 CTX: J10_048543_1560_XN_24S033W CTX: J11_048965_1560_XN_24S033W 1891.58 km² convergence ctr 24.7°
11 CTX: G04_019612_1535_XN_26S034W CTX: G04_019889_1535_XN_26S035W 1761.19 km² convergence ctr 23.4°
12 CTX: G04_019757_1542_XN_25S033W CTX: G06_020390_1558_XN_24S033W 1722.76 km² convergence ctr 19.7°
13 CTX: G03_019335_1542_XN_25S033W 1415.05 km²
50 km
Lat Lon:
Positive East
0° to 360°
Planetocentri
Set bounding box below. . .
Max Lat -23.11
Min Lon 324.67
Max Lon 327.44
Min Lat -28.02
Clear Bounding Box
Feature Finder
Select Typ

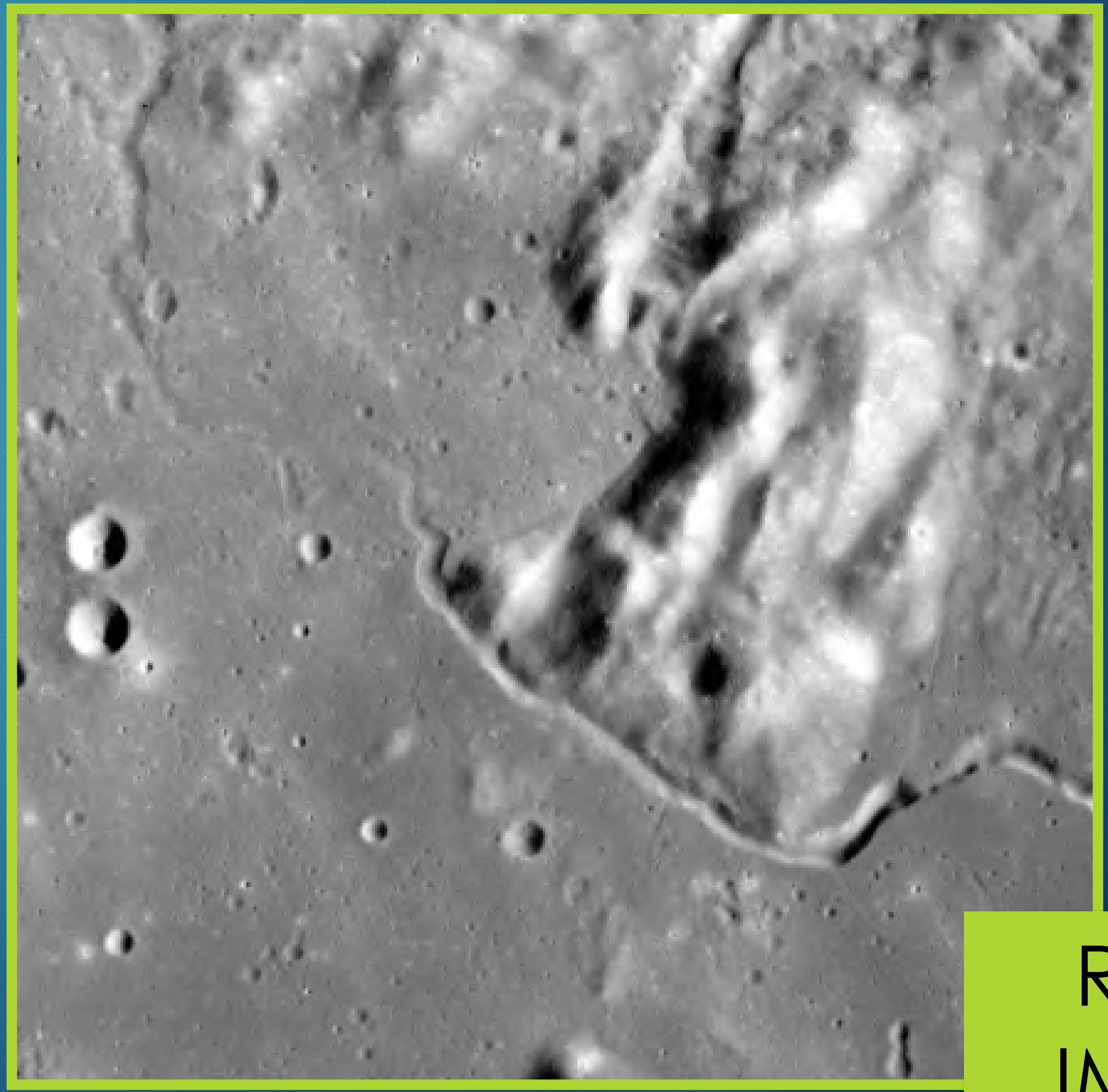


Try to find an area interesting from your science perspective but at the same time with good parameters for 3D reconstruction

Your CTX stereo pair

- You will find your stereo pair in your study area folder (CTX_stereo)
- For this exercize we have CTXleft and CTXright, but in the real life remember which one is the left and which the right image

LEFT IMAGE



RIGHT IMAGE

Pre-processing
same steps as 2d processing

All the commands: left-right

```
#!/bin/bash

#SBATCH --account unich
#SBATCH -p compute
#SBATCH -o Log.out
#SBATCH -e Log.err
#SBATCH -J didattica_geo-02
#SBATCH --get-user-env
#SBATCH --nodes=4
#SBATCH --ntasks=48
#SBATCH --hint=compute_bound
#SBATCH --mail-type=ALL
#SBATCH --mail-user=monica.pondrelli@unich.it
#SBATCH --time=0

LC_ALL=C mroctx2isis from= CTXleft.IMG to= CTXleft.cub
LC_ALL=C mroctx2isis from= CTXright.IMG to= CTXright.cub
LC_ALL=C spiceinit from= CTXleft.cub
LC_ALL=C spiceinit from= CTXright.cub
LC_ALL=C ctxcal from= CTXleft.cub to= CTXleft 1.cal.cub
LC_ALL=C ctxcal from= CTXright.cub to= CTXright.cal.cub
LC_ALL=C ctxevenodd from= CTXleft.cal.cub to= CTXleft.eve.cub
LC_ALL=C ctxevenodd from= CTXright.cal.cub to= CTXright.eve.cub
LC_ALL=C cam2map4stereo.py CTXleft.eve.cub CTXright.eve.cub
```

Pre-processing
same steps as 2d processing

All the commands: left-right

```
#!/bin/bash

#SBATCH --account unich
#SBATCH -p compute
#SBATCH -o Log.out
#SBATCH -e Log.err
#SBATCH -J didattica_geo-02
#SBATCH --get-user-env
#SBATCH --nodes=4
#SBATCH --ntasks=48
#SBATCH --hint=compute_bound
#SBATCH --mail-type=ALL
#SBATCH --mail-user=monica.pondrelli@unich.it
#SBATCH --time=0

LC_ALL=C mroctx2isis from= CTXleft.IMG to= CTXleft.cub
LC_ALL=C mroctx2isis from= CTXright.IMG to= CTXright.cub
LC_ALL=C spiceinit from= CTXleft.cub
LC_ALL=C spiceinit from= CTXright.cub
LC_ALL=C ctxcal from= CTXleft.cub to= CTXleft 1.cal.cub
LC_ALL=C ctxcal from= CTXright.cub to= CTXright.cal.cub
LC_ALL=C ctxevenodd from= CTXleft.cal.cub to= CTXleft.eve.cub
LC_ALL=C ctxevenodd from= CTXright.cal.cub to= CTXright.eve.cub
LC_ALL=C cam2map4stereo.py CTXleft.eve.cub CTXright.eve.cub
```

Your mail

Pre-processing
same steps as 2d processing

All the commands: left-right

```
#!/bin/bash

#SBATCH --account unich
#SBATCH -p compute
#SBATCH -o Log.out
#SBATCH -e Log.err
#SBATCH -J didattica_geo-02
#SBATCH --get-user-env
#SBATCH --nodes=4
#SBATCH --ntasks=48
#SBATCH --hint=compute_bound
#SBATCH --mail-type=ALL
#SBATCH --mail-user=monica.pondrelli@unich.it
#SBATCH --time=0

LC_ALL=C mroctx2isis from= CTXleft.IMG to= CTXleft.cub
LC_ALL=C mroctx2isis from= CTXright.IMG to= CTXright.cub
LC_ALL=C spiceinit from= CTXleft.cub
LC_ALL=C spiceinit from= CTXright.cub
LC_ALL=C ctxcal from= CTXleft.cub to= CTXleft 1.cal.cub
LC_ALL=C ctxcal from= CTXright.cub to= CTXright.cal.cub
LC_ALL=C ctxevenodd from= CTXleft.cal.cub to= CTXleft.eve.cub
LC_ALL=C ctxevenodd from= CTXright.cal.cub to= CTXright.eve.cub
LC_ALL=C cam2map4stereo.py CTXleft.eve.cub CTXright.eve.cub
```

Your mail

Next slide

- LC_ALL=C mroctx2isis from= CTXleft.IMG to= CTXleft.cub
- LC_ALL=C mroctx2isis from= CTXright.IMG to= CTXright.cub
- LC_ALL=C spiceinit from= CTXleft.cub
- LC_ALL=C spiceinit from= CTXright.cub
- LC_ALL=C ctxcal from= CTXleft.cub to= CTXleft 1.cal.cub
- LC_ALL=C ctxcal from= CTXright.cub to= CTXright.cal.cub
- LC_ALL=C ctxevenodd from= CTXleft.cal.cub to= CTXleft.eve.cub
- LC_ALL=C ctxevenodd from= CTXright.cal.cub to= CTXright.eve.cub
- LC_ALL=C cam2map4stereo.py CTXleft.eve.cub CTXright.eve.cub

Bundle adjustment

- Refining a visual reconstruction to produce jointly optimal 3D structure and viewing parameter (camera pose and/or calibration) estimates
- The name refers to the ‘bundles’ of light rays leaving each 3D feature and converging on each camera centre, which are ‘adjusted’ optimally with respect to both feature and camera positions. Equivalently all of the structure and camera parameters are adjusted together ‘in one bundle’
- Large sparse geometric parameter estimation problem, the parameters being the combined 3D feature coordinates, camera poses and calibrations
- Correct satellite (and consequently camera) position and orientation errors
- Ensures that the observations in multiple images of a single ground feature are self-consistent

Bundle adjustment

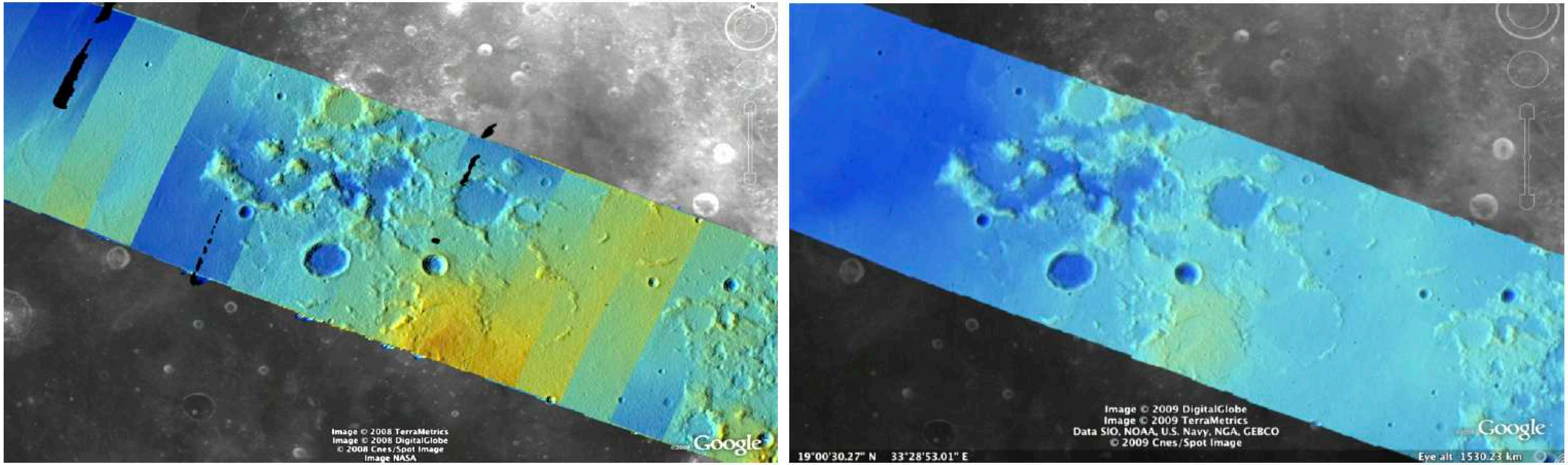


Figure 8.1: Bundle adjustment is illustrated here using a color-mapped, hill-shaded DEM mosaic from Apollo 15, Orbit 33, imagery. (a) Prior to bundle adjustment, large discontinuities can exist between overlapping DEMs made from different images. (b) After bundle adjustment, DEM alignment errors are minimized and no longer visible.

Bundle Adjustment

```
LC_ALL=C bundle_adjust CTXleft.map.cub CTXright.map.cub --threads 48 -o tmp/run
```

Bundle Adjustment

```
LC_ALL=C bundle_adjust CTXleft.map.cub CTXright.map.cub --threads 48 -o tmp/run
```

the option -o refers to the prefix for output filenames, here run_ba/run to create a separate folder ("run_ba") for all of the files, including intermediate, produced. The second "run" indicates the prefix to be given to the result files.

Stereo

- Step 1 (correlation)
  - Collection of algorithms that compute correspondences between pixels in the left image and pixels in the right image. The map of these correspondences is called a disparity map
- Steps 2 (refinement) and 3 (filtering)
  - Every pixel in the disparity map will either have an estimated disparity value, or it will be marked as invalid. All valid pixels are then adjusted in the sub-pixel refinement
- Stage 4 (Triangulation)
  - Once a disparity map has been generated and refined, it can be used in combination with the geometric camera models to compute the locations of 3D points on the surface of Mars

```
LC_ALL=C parallel_stereo --threads-multiprocess 12 --threads-singleprocess 48 CTXleft.map.cub
CTXright.map.cub results/run --bundle-adjust-prefix run_ba/run
```

Stereo

- Step 1 (correlation)
  - Collection of algorithms that compute correspondences between pixels in the left image and pixels in the right image. The map of these correspondences is called a disparity map
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```
LC_ALL=C parallel_stereo --threads-multiprocess 12 --threads-singleprocess 48 CTXleft.map.cub CTXright.map.cub results/run --bundle-adjust-prefix run_ba/run
```

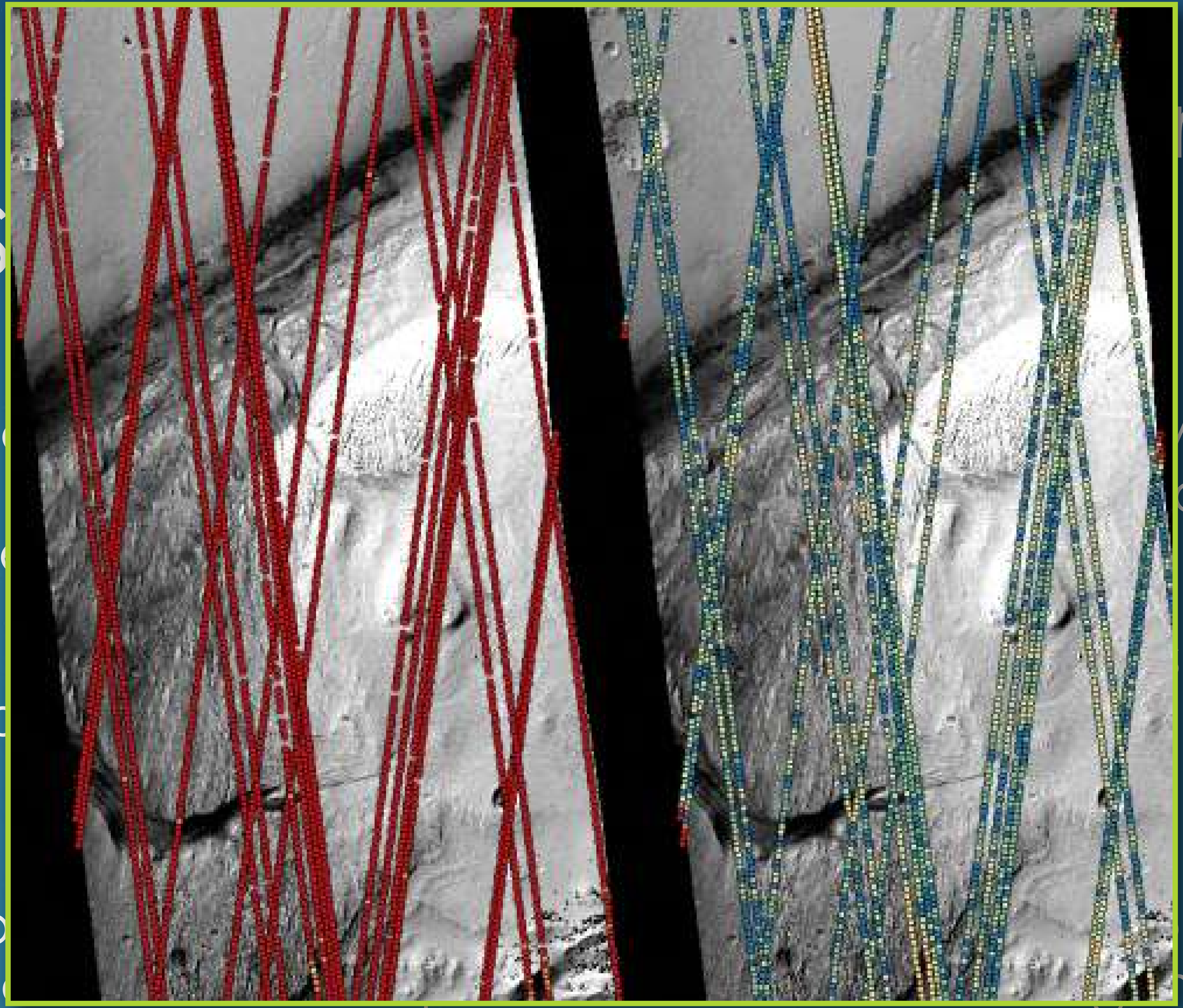
"results/out" are the folder/prefix pair created to store the files, including the intermediate files produced which can be very useful for checking possible errors or bugs. The --bundle-adjust-prefix run_ba/run option specifies where to find the camera adjustments files produced by the bundle_adjust process.

PC align: Alignment to Point Clouds From a Different Source

- 3D terrain models output by stereo can be quite accurate yet their actual position on the planet may be off by several meters or several kilometers
- pc_align aligns a 3D terrain to a much more accurately positioned (if potentially sparser) dataset
- MOLA or HRSC
- The pc_align tool requires another input, an a priori guess for the maximum displacement we expect to see as result of alignment. If not known, a large (but not unreasonably so) number can be specified. It is used to remove most of the points in the source (movable) point cloud which have no chance of having a corresponding point in the reference (fixed) point cloud.

PC align: Ali[…]rom a Different S[…]

- 3D terrain mod[…]et their actual position […]or several kilomet[…]
- pc_align aligns[…]itioned (if potentially sp[…]
- MOLA or HRSC […]
- The pc_align to[…]r the maximum displ[…]ment. If



Example of using pc_align to align a DEM obtained using stereo from CTX images to a set of MOLA tracks. The MOLA points are colored by the offset error initially (left) and after pc align was applied (right) to the terrain model. The red dots indicate more than 100 m of error and blue less than 5 m. The pc_align algorithm determined that by moving the terrain model approximately 40 m south, 70 m west, and 175 m vertically, goodness of fit between MOLA and the CTX model was increased substantially.

PC_align command

- LC_ALL=C pc_align --threads 48 --max-displacement 2000 HRSC_dt4.img results/out-PC.tif --highest-accuracy --save-transformed-source-points -o spheroid_DEM

PC_align command

- LC_ALL=C PC_ALIGN --THREADS 48 --MAX-DISPLACEMENT 2000 HRSC_DT4.IMG RESULTS/OUT-PC.TIF --HIGHEST-ACCURACY --SAVE-TRANSFORMED-SOURCE-POINTS -O SPHEROID_DEM

Your reference DEM

PC_align command

The --max-displacement option represents the maximum displacement in meters of the source points as a result of alignment. The reason for this option is to remove the possible outliers.

- LC_ALL=C PC_ALIGN --THREADS 48 --MAX-DISPLACEMENT 2000 HRSC_DT4.IMG RESULTS/OUT-PC.TIF --HIGHEST-ACCURACY --SAVE-TRANSFORMED-SOURCE-POINTS -O SPHEROID_DEM

Your reference DEM

PC_align command

The --max-displacement option represents the maximum displacement in meters of the source points as a result of alignment. The reason for this option is to remove the possible outliers.

- LC_ALL=C PC_ALIGN --THREADS 48 --MAX-DISPLACEMENT 2000 HRSC_DT4.IMG RESULTS/OUT-PC.TIF --HIGHEST-ACCURACY --SAVE-TRANSFORMED-SOURCE-POINTS -O SPHEROID_DEM

Your reference DEM

Point cloud originated by the stereo program

The option --highest-accuracy implies that the calculation is as accurate as possible, even if slower. The --save-transformed-source-points option means that the points that after the transformation match the source points are saved. The option -o refers to the prefix for output filenames.

Point to DEM

- The point2dem program produces a GeoTIFF terrain model and/or an orthographic image from a set of point clouds

- ```
  LC_ALL=C point2dem --threads 48 -r mars spheroid_DEM-trans_source.tif --dem-hole-fill-len 200 --orthoimage-hole-fill-len 50 --orthoimage results/out-L.tif --t_srs "+proj=eqc +lat_0=0 +lon_0=0 +x_0=0 +y_0=0 +a=3396190 +b=3396190 +units=m +no_defs" --nodata -32767
  ```
  ```

Point to DEM

- The point2dem program produces a GeoTIFF terrain model and/or an orthographic image from a set of point clouds

Chosen Datum

-
```
LC_ALL=C point2dem --threads 48 -r mars spheroid_DEM-trans_source.tif --dem-hole-fill-len 200 --orthoimage-hole-fill-len 50 --orthoimage results/out-L.tif --t_srs "+proj=eqc +lat_0=0 +lon_0=0 +x_0=0 +y_0=0 +a=3396190 +b=3396190 +units=m +no_defs" --nodata -32767
```

Point to DEM

- The point2dem program produces a GeoTIFF terrain model and/or an orthographic image from a set of point clouds

Chosen Datum

Point cloud originated by the pc_align program

- ```
  LC_ALL=C point2dem --threads 48 -r mars spheroid_DEM-trans_source.tif --dem-hole-fill-len 200 --orthoimage-hole-fill-len 50 --orthoimage results/out-L.tif --t_srs "+proj=eqc +lat_0=0 +lon_0=0 +x_0=0 +y_0=0 +a=3396190 +b=3396190 +units=m +no_defs" --nodata -32767
  ```
  ```

Point to DEM

- The point2dem program produces a GeoTIFF terrain model and/or an orthographic image from a set of point clouds

Chosen Datum

Point cloud originated by the pc_align program

- ```
LC_ALL=C POINT2DEM --THREADS 48 -R MARS SPHEROID_DEM-TRANS_SOURCE.TIF --DEM-HOLE-FILL-LEN 200 --ORTHOIMAGE-HOLE-FILL-LEN 50 --ORTHOIMAGE RESULTS/OUT-L.TIF --T_SRS "+PROJ=EQC +LAT_0=0 +LON_0=0 +X_0=0 +Y_0=0 +A=3396190 +B=3396190 +UNITS=M +NO_DEFS" --NODATA -32767
```

Maximum dimensions of a hole in the output DEM to fill in, in pixels
```

Point to DEM

- The point2dem program produces a GeoTIFF terrain model and/or an orthographic image from a set of point clouds

- LC_ALL=C POINT2DEM --THREADS 48 -R MARS SPHEROID_DEM-TRANS_SOURCE.TIF --DEM-HOLE-FILL-LEN 200 --ORTHOIMAGE-HOLE-FILL-LEN 50 --ORTHOIMAGE RESULTS/OUT-L.TIF --T_SRS "+PROJ=EQC +LAT_0=0 +LON_0=0 +X_0=0 +Y_0=0 +A=3396190 +B=3396190 +UNITS=M +NO_DEFS" --NODATA -32767

Chosen Datum

Point cloud originated by the pc_align program

Maximum dimensions of a hole in the output DEM to fill in, in pixels

Describe the output projection

dem_geoid

- The dem_geoid program adjusts the values which are relative to the datum (here the Mars sphere) to be relative to the Mars aeroid, i.e., the equipotential surface of the planet.

- ```
  LC_ALL=C dem_geoid spheroid_DEM-trans_source-DEM.tif --geoid MOLA -o DEM_D16_033601_1831_P15_007018_1831
  ```
  ```

dem_geoid

- The dem_geoid program adjusts the values which are relative to the datum (here the Mars sphere) to be relative to the Mars aeroid, i.e., the equipotential surface of the planet.

- `LC_ALL=C dem_geoid spheroid_DEM-trans_source-DEM.tif --geoid MOLA -o DEM_D16_033601_1831_P15_007018_1831`

The --geoid option specifies the geoid to use for the given datum, that in the Mars case is provided by the MOLA MEGDR

And finally…

- The last command to rename the GIS-ready orthoimage file in the home directory

- `mv spheroid_DEM-trans_source-DRG.tif ORTO_CTX.tif`

Script - Part 2

```
#!/bin/bash

#SBATCH --account unich
#SBATCH -p compute
#SBATCH -o Log.out
#SBATCH -e Log.err
#SBATCH -J didattica_geo-02
#SBATCH --get-user-env
#SBATCH --nodes=4
#SBATCH --ntasks=48
#SBATCH --hint=compute_bound
#SBATCH --mail-type=ALL
#SBATCH —mail-user=monica.pondrelli@unich.it
#SBATCH --time=0

LC_ALL=C parallel_bundle_adjust --threads 48 CTXleft.map.cub CTXright.map.cub -o run_ba/run
LC_ALL=C parallel_stereo --threads-multiprocess 12 --threads-singleprocess 48 CTXleft.map.cub CTXright.map.cub results/out --bundle-adjust-prefix run_ba/run
LC_ALL=C pc_align --threads 48 --max-displacement 2000 HRSC_dt4.img results/out-PC.tif --highest-accuracy --save-transformed-source-points -o spheroid_DEM
LC_ALL=C point2dem --threads 48 -r mars spheroid_DEM-trans_source.tif --dem-hole-fill-len 200 --orthoimage-hole-fill-len 50 --orthoimage results/out-L.tif --t_srs "+proj=eqc +lat_0=0 +lon_0=0 +x_0=0 +y_0=0 +a=3396190 +b=3396190 +units=m +no_defs" --nodata -32767
LC_ALL=C dem_geoid spheroid_DEM-trans_source-DEM.tif --geoid MOLA -o DEM_CTX
mv spheroid_DEM-trans_source-DRG.tif ORTO_CTX.tif
```

Script - Part 2

```
#!/bin/bash

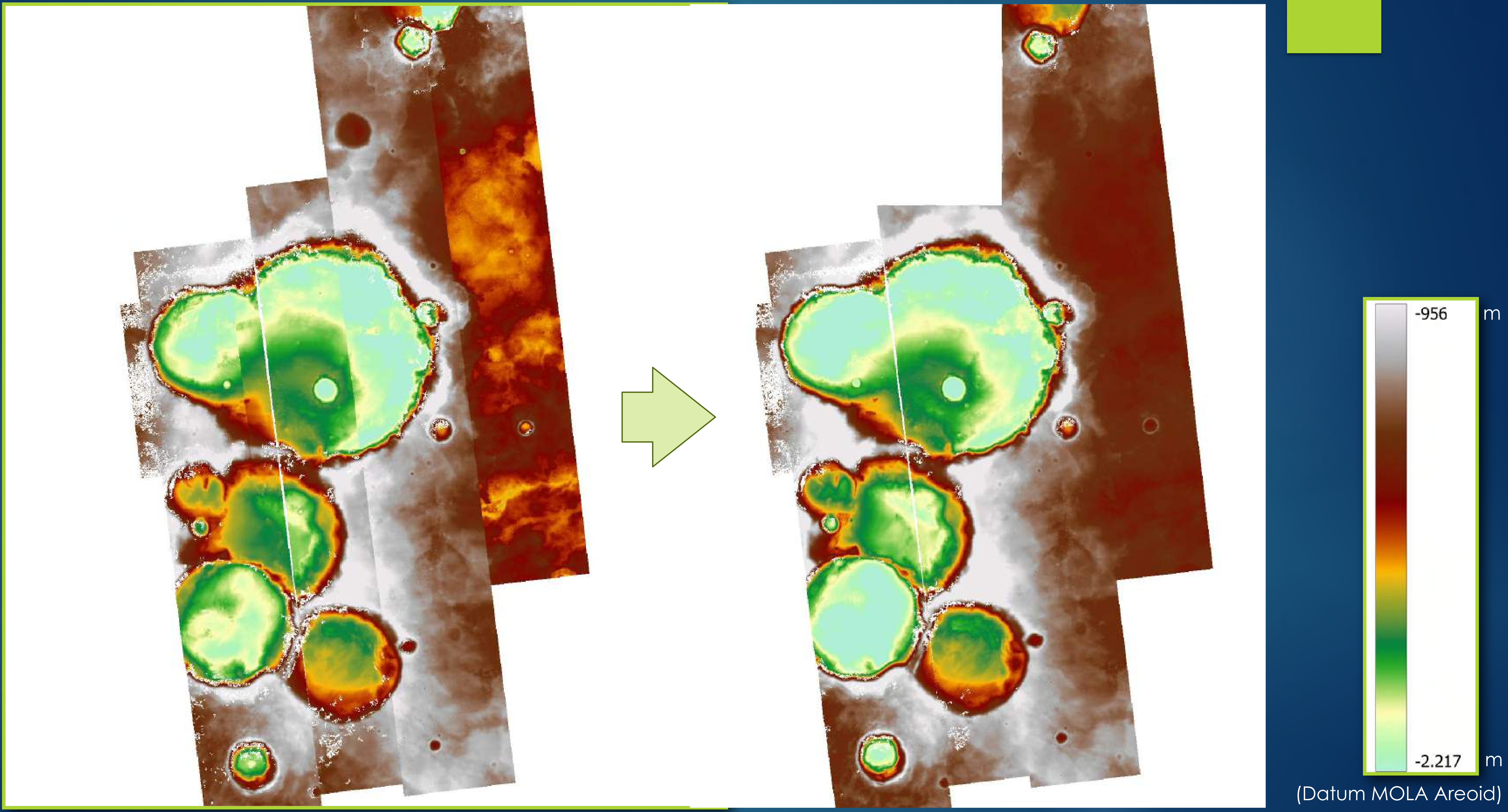
#SBATCH --account unich
#SBATCH -p compute
#SBATCH -o Log.out
#SBATCH -e Log.err
#SBATCH -J didattica_geo-02
#SBATCH --get-user-env
#SBATCH --nodes=4
#SBATCH --ntasks=48
#SBATCH --hint=compute_bound
#SBATCH --mail-type=ALL
#SBATCH —mail-user=monica.pondrelli@unich.it
#SBATCH --time=0
```

```
LC_ALL=C parallel_bundle_adjust --threads 48 CTXleft.map.cub CTXright.map.cub -o run_ba/run
LC_ALL=C parallel_stereo --threads-multiprocess 12 --threads-singleprocess 48 CTXleft.map.cub CTXright.map.cub results/out --bundle-adjust-prefix run_ba/run
LC_ALL=C pc_align --threads 48 --max-displacement 2000 HRSC_dt4.img results/out-PC.tif --highest-accuracy --save-transformed-source-points -o spheroid_DEM
LC_ALL=C point2dem --threads 48 -r mars spheroid_DEM-trans_source.tif --dem-hole-fill-len 200 --orthoimage-hole-fill-len 50 --orthoimage results/out-L.tif --t_srs "+proj=eqc +lat_0=0 +lon_0=0 +x_0=0 +y_0=0 +a=3396190 +b=3396190 +units=m +no_defs" --nodata -32767
LC_ALL=C dem_geoid spheroid_DEM-trans_source-DEM.tif --geoid MOLA -o DEM_CTX
mv spheroid_DEM-trans_source-DRG.tif ORTO_CTX.tif
```

Next slide

- LC_ALL=C parallel_bundle_adjust --threads 48 CTXleft.map.cub CTXright.map.cub -o run_ba/run
- LC_ALL=C parallel_stereo --threads-multiprocess 12 --threads-singleprocess 48 CTXleft.map.cub CTXright.map.cub results/out --bundle-adjust-prefix run_ba/run
- LC_ALL=C pc_align --threads 48 --max-displacement 2000 HRSC_dt4.img results/out-PC.tif --highest-accuracy --save-transformed-source-points -o spheroid_DEM
- LC_ALL=C point2dem --threads 48 -r mars spheroid_DEM-trans_source.tif --dem-hole-fill-len 200 --orthoimage-hole-fill-len 50 --orthoimage results/out-L.tif --t_srs "+proj=eqc +lat_0=0 +lon_0=0 +x_0=0 +y_0=0 +a=3396190 +b=3396190 +units=m +no_defs" --nodata -32767
- LC_ALL=C dem_geoid spheroid_DEM-trans_source-DEM.tif --geoid MOLA -o DEM_CTX
- mv spheroid_DEM-trans_source-DRG.tif ORTO_CTX.tif

dem_mosaic



(Datum MOLA Areoid)

dem_mosaic

The program dem_mosaic is part of ASP and takes as input a list of DEM files and creates a mosaic.

dem_mosaic [options] <dem files> -o output_file_prefix

Es:

```
dem_mosaic -–erode-length 3 DEM_1.tif DEM_2.tif DEM_3.tif –o Mosaic_
```

Or DEMs listed in a text file (one per line):

dem_mosaic [options] -l dem_files_list.txt -o output_file_prefix

Es:

```
dem_mosaic –l List.txt –o OutMosaic.tif
```

List.txt

```
DEM_B16_015958_1831_B17_016235_1830-adj.tif
DEM_f16_042054_1843_f17_042555_1843-adj.tif
DEM_g05_020204_1833_g04_019927_1833-adj.tif
DEM_j06_046999_1855_j08_047790_1855-adj.tif
DEM_k14_058722_1836_k13_058656_1836-adj.tif
```

dem_mosaic: **[options]**

By default, it **seamlessly blends the DEMs where they overlap**.

It can also process the inputs to be combined in other ways:

--first Keep the **first** encountered DEM value (in the input order).

--last Keep the **last** encountered DEM value (in the input order).

--min Keep the **smallest** encountered DEM value.

--max Keep the **largest** encountered DEM value.

--mean Find the **mean** DEM value.

--stddev Find the **standard deviation** of DEM values.

--median Find the **median** DEM value (this can be memory-intensive, fewer threads are suggested).

--nmad Find the **normalized median absolute deviation** DEM value (this can be memory-intensive, fewer threads are suggested).

--count Each pixel is set to the number of **valid** DEM **heights** at that pixel.

dem_mosaic: **[options]**

Other options include:

--tr <double>	Output grid size, that is, the **DEM resolution** in target georeferenced units per pixel. (Default: use the same resolution as the first DEM to be mosaicked.)
--ot <string >	**Output data type.** Supported types: Byte, UInt16, Int16, UInt32, Int32, Float32. If the output type is a kind of integer, values are rounded and then clamped to the limits of that type. (Default: Float32)
--tile-size <integer>	Divide the output in **tiles** and the maximum size of output DEM tile files to write, in pixels. (Default: 1000000)
--erode-length <integer>	Erode the DEM by this many pixels at **boundary**. Useful for avoiding typical errors in edge zones.(Default: 0)
--hole-fill-length <integer>	Maximum dimensions of a hole in the DEM to fill in, in pixels.(Default: 0)

GeoPlaNet

Co-funded by the
ERASMUS + Programme
of the European Union

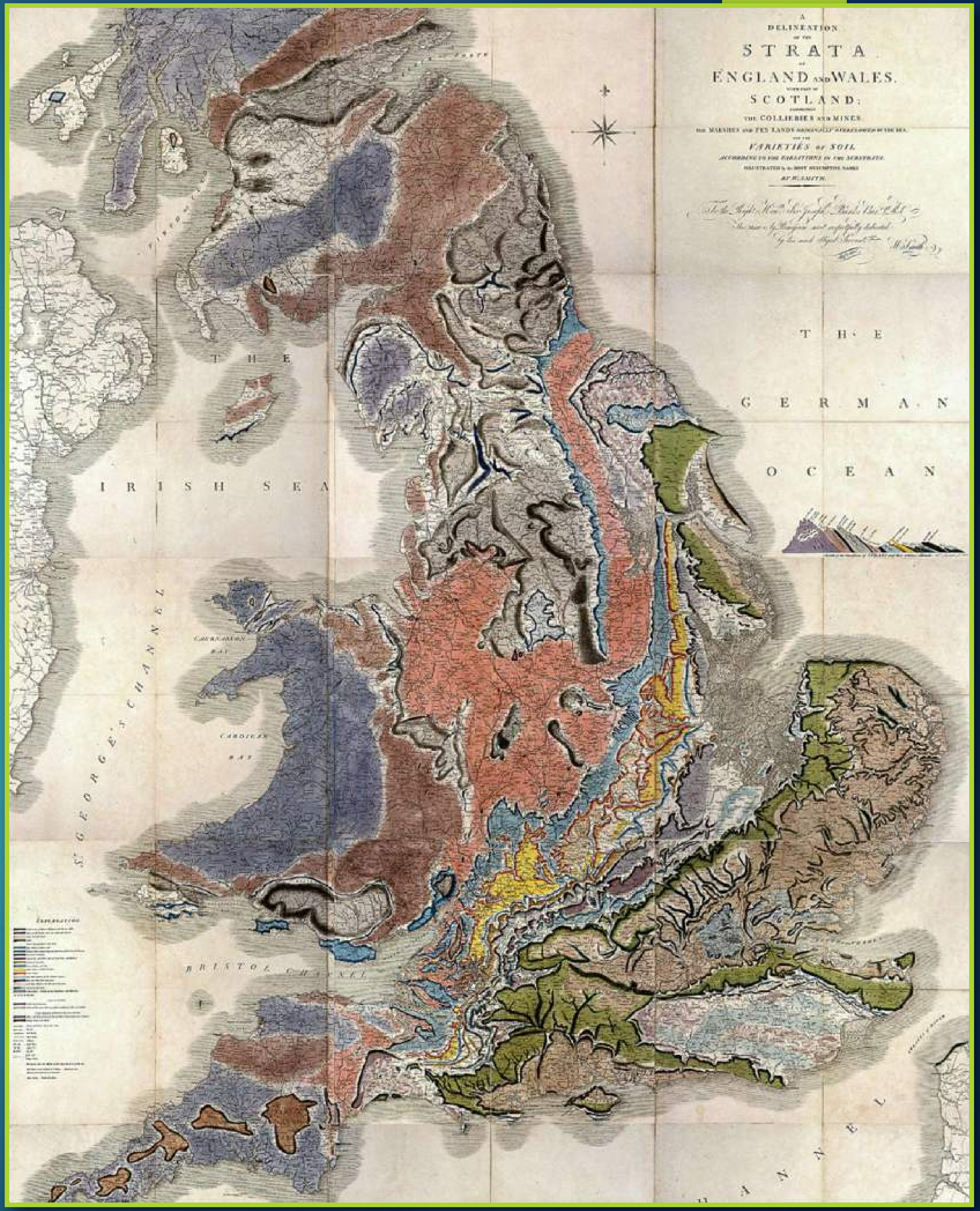
Mapping approaches

HOW AND WHAT TO MAP

Ud'A Università degli Studi "G. d'Annunzio"
IRSPS
Universitas Studii Paduani MCCXXII
Nantes Université
1290 Universidade de Coimbra
U.PORTO
VR2Planets

William Smith's 1815 map ⇢ the birth of geological mapping

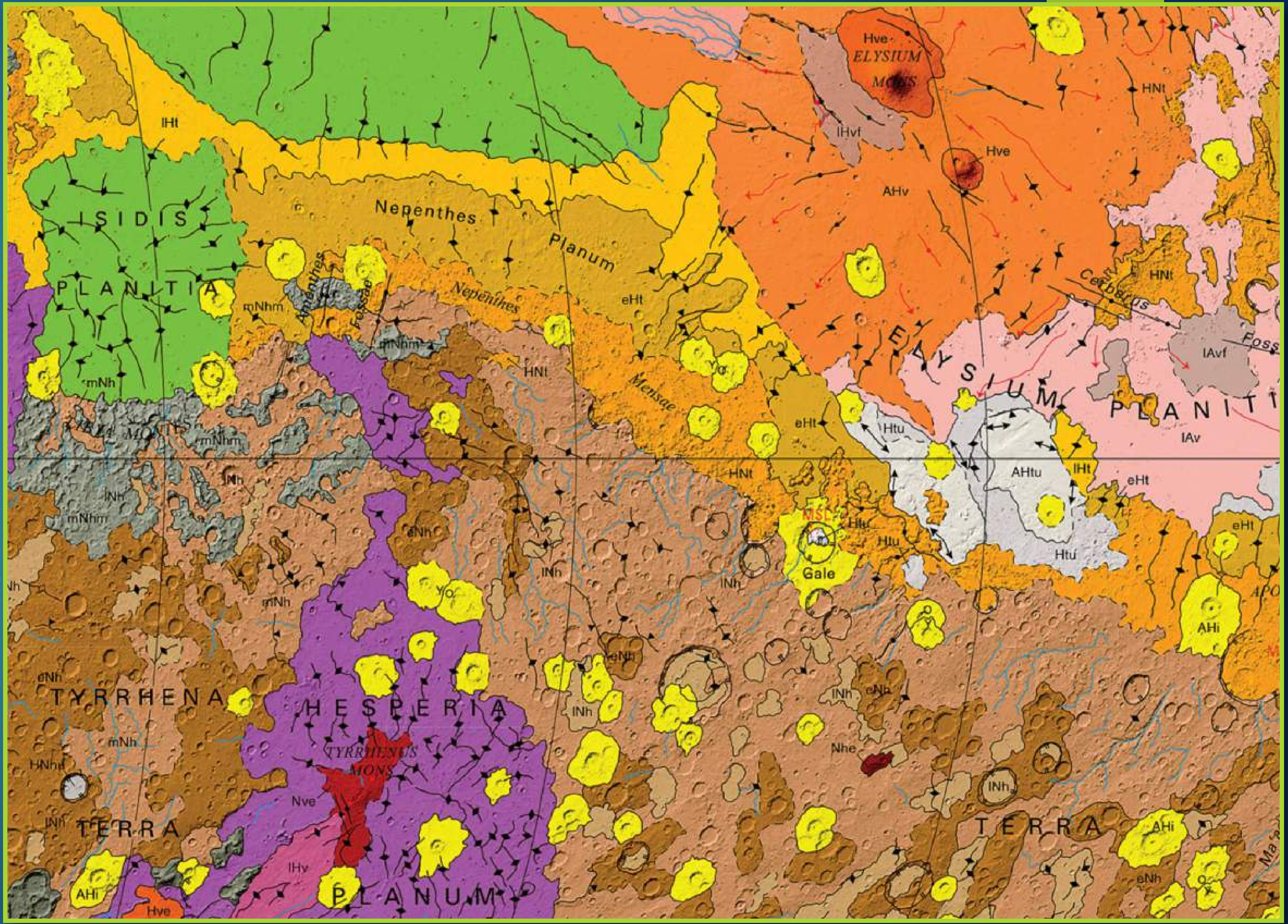
Tom Sharpe, Science 2015;347:230-232



Science AAAS

Geological map of Mars.

The colors represent different rock units of the martian stratigraphy of the Noachian, Hesperian, and Amazonian Periods, based on stratigraphical relationships and cratering density



Tom Sharpe, Science 2015;347:230-232

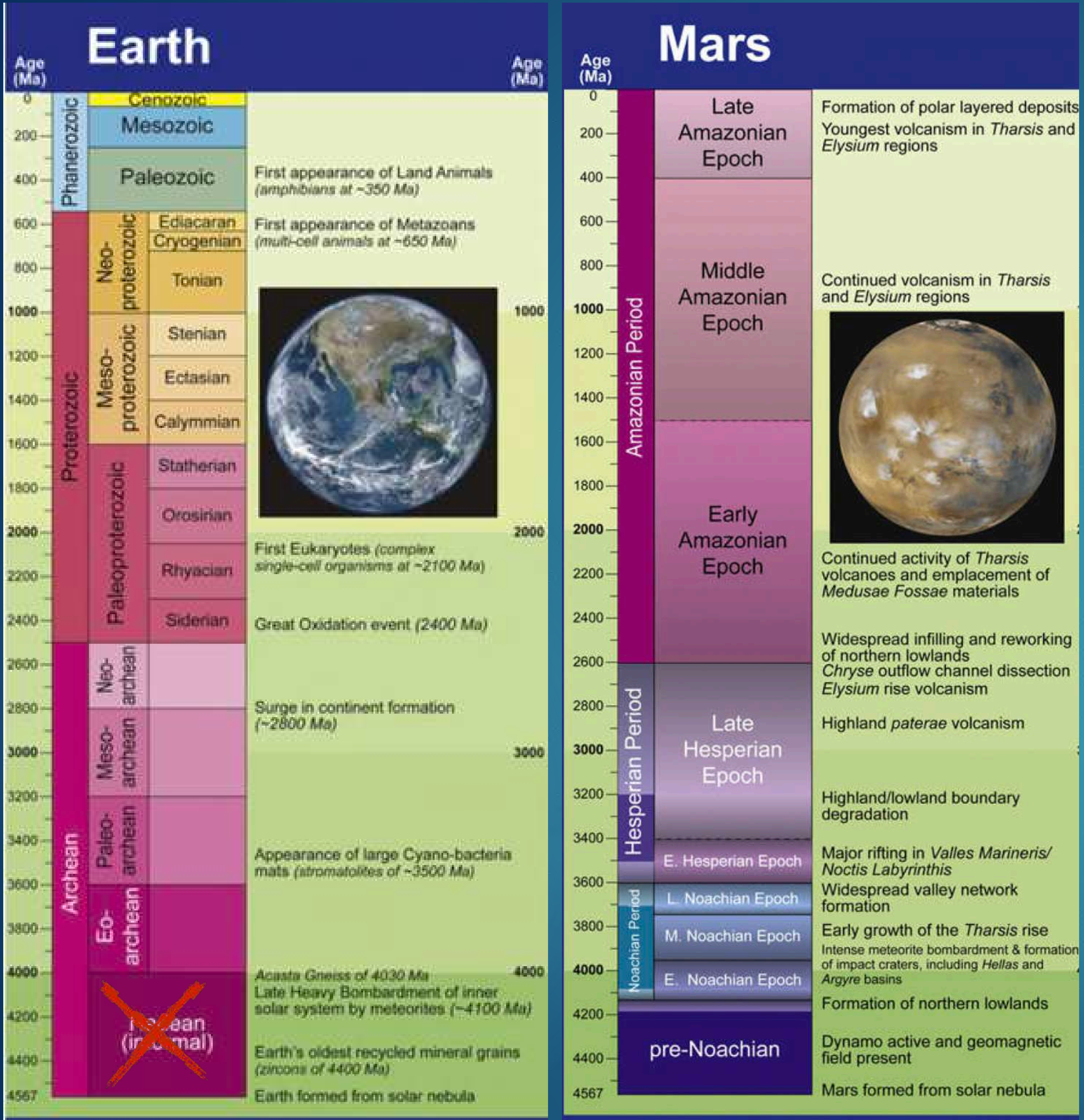
Planetary Geology

- No conceptual difference with Earth, but different amount and type of data
- On Earth more than 300 yrs of geology (fieldwork, geophysics, boreholes, etc….)
- On other planets/satellites 40/50 yrs of geology (no fieldwork with rovers exception)
- Still the basic principles are the same
  - Geological time
  - The present is the key to the past (Hutton, 1788)

“The present is the key to the past (Hutton, 1788)”

To be handled with care

ENPHASIS ON LATERAL AND VERTICAL RELATIONS BETWEEN DIFFERENT GEOLOGICAL UNITS

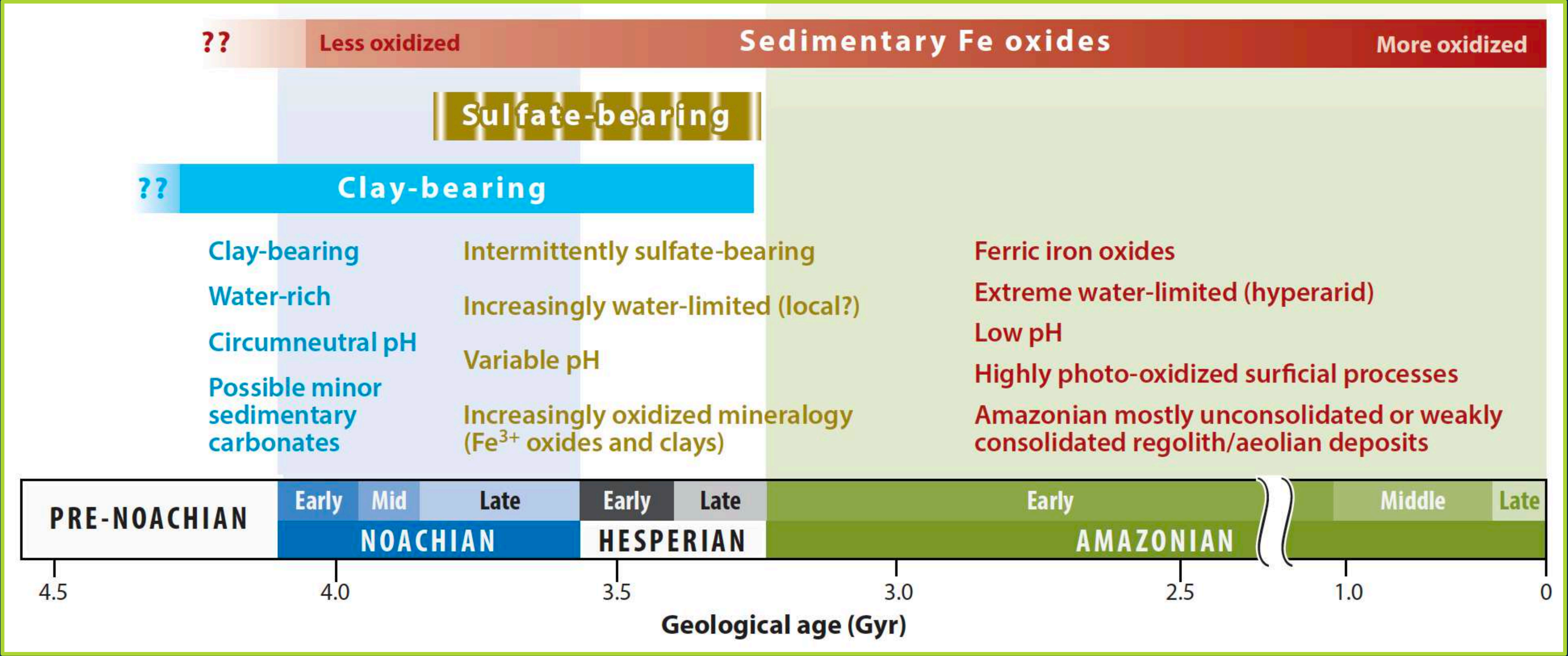


Lost….with some exceptions

Mars

Periods and Epochs

Tanaka and Hartmann 2016



Mc Lennan et al., 2019 - Annu. Rev. Earth Planet. Sci. 2019. 47:91–118

Geological Maps ⇢ generalities

- Geoscience maps, regardless of target body, are spatial and temporal representations of materials and processes recorded on planetary surfaces (Varnes, 1973; Spencer, 2000).
- The information and context provided by these maps promote basic and applied research within and across various geoscience disciplines
- Since 1961, planetary geoscience maps (maps that summarize the geology of all solid surface bodies in the Solar System beyond Earth) have been used in nearly every facet of planetary exploration, from landing site characterization for human and robotic missions to mineralogical analyses of water-alteration on Mars.

Geological Maps ⇢ generalities

Basic stratigraphic principles and techniques provide a basis to organize different landforms in a spatial–temporal framework (vertical/lateral stratigraphic relations)

Only geological mapping can summarize and display all the characters of a unit in a single document (the geological map): therefore, geological mapping should be a pre-requisite for the geological analysis of any planetary surface.

Topical vs. Contextual

Topical Maps

- Flexible in approach (variable scale, variable base)
- Tactical timeline (<u>high</u> response to data curve)
- Reviewed primarily for scientific integrity
- Published in scientific journals
- Observations ≤ Interpretations

Contextual Maps

- Rigid in approach (set scale, standard base)
- Strategic timeline (<u>low</u> response to data curve)
- Reviewed for scientific as well as cartographic and technical integrity
- Published by standard survey
- Observations > Interpretations

Source: Skinner (2014)

Contextual Map (~USGS products)

MUST conform to:

- The map must be directly supported by a NASA proposal.
- Submitted for review in GIS format, using standards, guidelines, and conventions established by the USGS Planetary Mapping Group.
- Produced and published with a single, Primary Map Base, and the rationale for that primary data set selection must be documented.
- The map will not contain excessive interpretive detail
- The map will be an accurate, concise, and clear representation of the geology of the selected region at the Publication Map Scale, regardless of the resolution afforded by the Primary Map Base. An accurate depiction of the geology at full data resolution has the potential to result in linework that is far too dense to be legible at the selected Publication Map Scale. As such, it is critical for the Author to understand that a USGS Standardized Map is a representation of the geology that is discernible and representable at the selected Publication Map Scale.
- The map will be subjected to the Technical Review Process, which includes evaluations from two or more external reviewers, and the Author is expected to thoughtfully consider and satisfactorily address reviewer-recommended corrections in a professional manner in order for the Map Package to be Accepted for publication.
- The map Author is expected to attend the Annual Planetary Geologic Mapper's Meeting, and to conduct two external Technical Reviews of other maps over the course of their project.
- If a USGS or journal-based geologic map has already been published for a map region at a similar or different scale, the new map must clearly demonstrate that it fundamentally improves upon, enhances, and (or) refines the context established by previous maps (including those published in peer-reviewed journals).

USGS Mapping workflow (1)

Geodatabase Production Milestones	1	USGS Notified Of New Start
	2	Project Added to PGM Website
	3	Project GIS Compiled
	4	Map Package Checked and Delivered

Source: USGS

USGS Mapping workflow (1)

Geodatabase Production Milestones	1	USGS Notified Of New Start
	2	Project Added to PGM Website
	3	Project GIS Compiled
	4	Map Package Checked and Delivered
Technical Review Milestones	5	Map Submitted to Map Coordinator
	6	Pre-Review Completed
	7	Technical Reviewer 1 Assigned
	8	Technical Reviewer 2 Assigned
	9	Technical Reviewer 3 Assigned
	10	Review 1 Completed
	11	Review 2 Completed
	12	Review 3 Completed
	13	Review Comments Delivered to Author
	14	Author Responses Submitted to MC
	15	Technical Reviews Completed
	16	MC Comments Delivered to Author
	17	MC Review Completed
	18	Nomenclature Review Completed
	19	GIS Compatibility Review Completed

Source: USGS

USGS Mapping workflow (2)

Source: USGS

USGS Mapping workflow (2)

Publication Milestones	20	Map Package Delivered to USGS PSC
	21	PSC Contract Signed by MC
	22	PSC Edits Completed
	23	USGS Proof Check Completed
	24	Author Proof Check Completed
	25	Map Delivered to Printer
	26	GIS Map Components Finalized
	27	Map Printed and Delivered
	28	Map Complete (Recent Maps Online)

Source: USGS

Symbology Standards

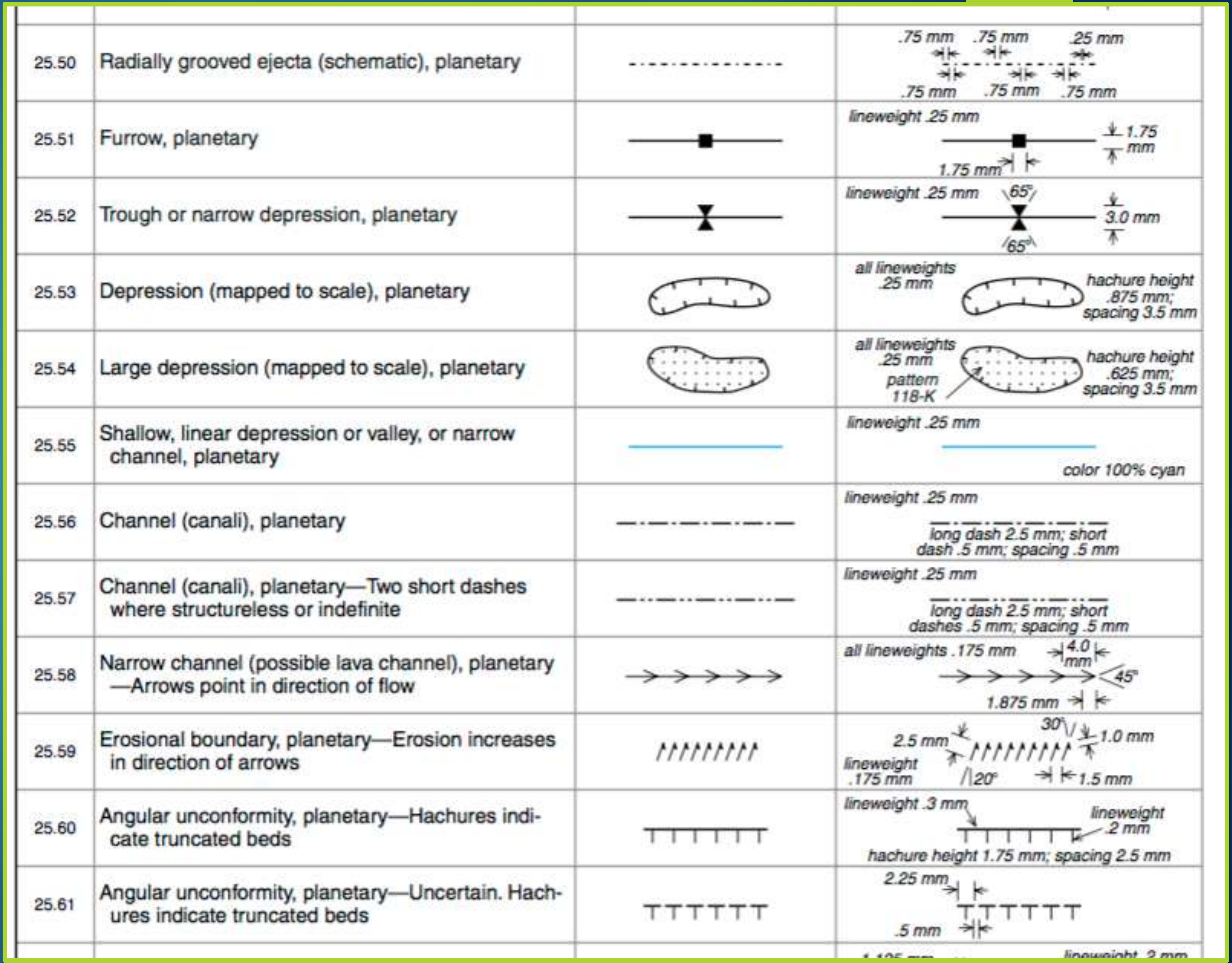
FGDC Digital Cartographic Standard for Geologic Map Symbolization

https://ngmdb.usgs.gov/fgdc_gds/geolsymstd.php

Use of the symbols in QGIS

Developed by Alessandro Frigeri, IASP-INAF

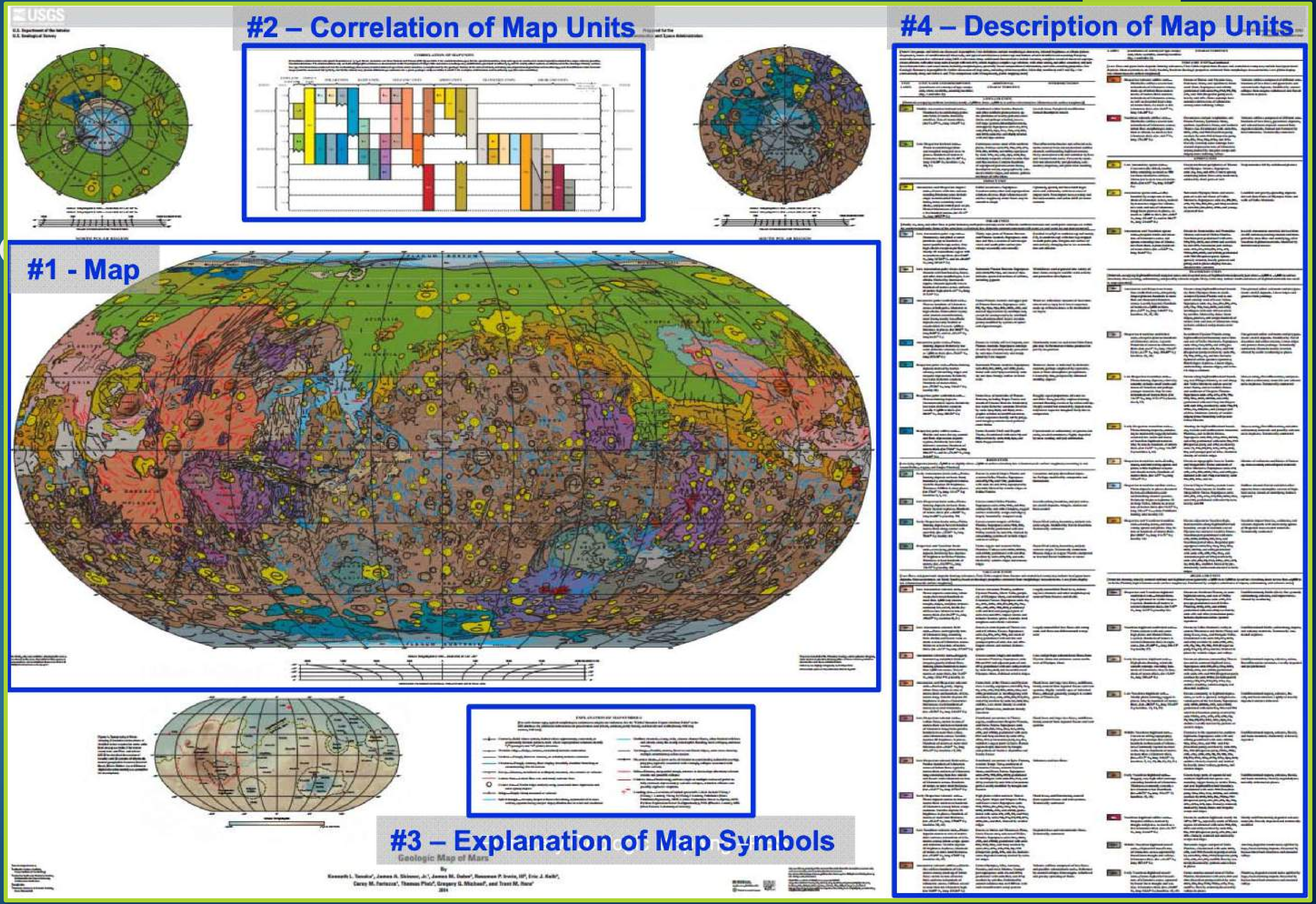
https://github.com/afrigeri/geologic-symbols-qgis



25.50	Radially grooved ejecta (schematic), planetary		.75 mm .75 mm .25 mm .75 mm .75 mm .75 mm
25.51	Furrow, planetary		lineweight .25 mm 1.75 mm 1.75 mm
25.52	Trough or narrow depression, planetary		lineweight .25 mm 65° 3.0 mm 65°
25.53	Depression (mapped to scale), planetary		all lineweights .25 mm hachure height .875 mm; spacing 3.5 mm
25.54	Large depression (mapped to scale), planetary		all lineweights .25 mm pattern 118-K hachure height .625 mm; spacing 3.5 mm
25.55	Shallow, linear depression or valley, or narrow channel, planetary		lineweight .25 mm color 100% cyan
25.56	Channel (canali), planetary		lineweight .25 mm long dash 2.5 mm; short dash .5 mm; spacing .5 mm
25.57	Channel (canali), planetary—Two short dashes where structureless or indefinite		lineweight .25 mm long dash 2.5 mm; short dashes .5 mm; spacing .5 mm
25.58	Narrow channel (possible lava channel), planetary —Arrows point in direction of flow		all lineweights .175 mm 4.0 mm 45° 1.875 mm
25.59	Erosional boundary, planetary—Erosion increases in direction of arrows		2.5 mm 30° 1.0 mm lineweight .175 mm 20° 1.5 mm
25.60	Angular unconformity, planetary—Hachures indicate truncated beds		lineweight .3 mm lineweight .2 mm hachure height 1.75 mm; spacing 2.5 mm
25.61	Angular unconformity, planetary—Uncertain. Hachures indicate truncated beds		2.25 mm .5 mm

Section 25 -- Planetary Geology Features

Result: geological m



Source: Skinner (2014)

Topical map

- Data improved (and are still improving) dramatically
- Flexibility for specific necessities (e.g., landing sites, science topics)
- Possibility to test standards for detailed cartographic projects

Cartographic approaches in geoscientific mapping

- Feature-based mapping
- Chronostratigraphic Maps
- Process-based ‘interpretative’: Geomorphological/Morphostratigraphic Map
- Process-based ‘objective’: Geological Map
- Landing site characterization
- Resource maps for in situ resource utilization (ISRU)

Rossi et al., 2021 - https://wiki.europlanet-gmap.eu/bin/view/Main/Deliverables/

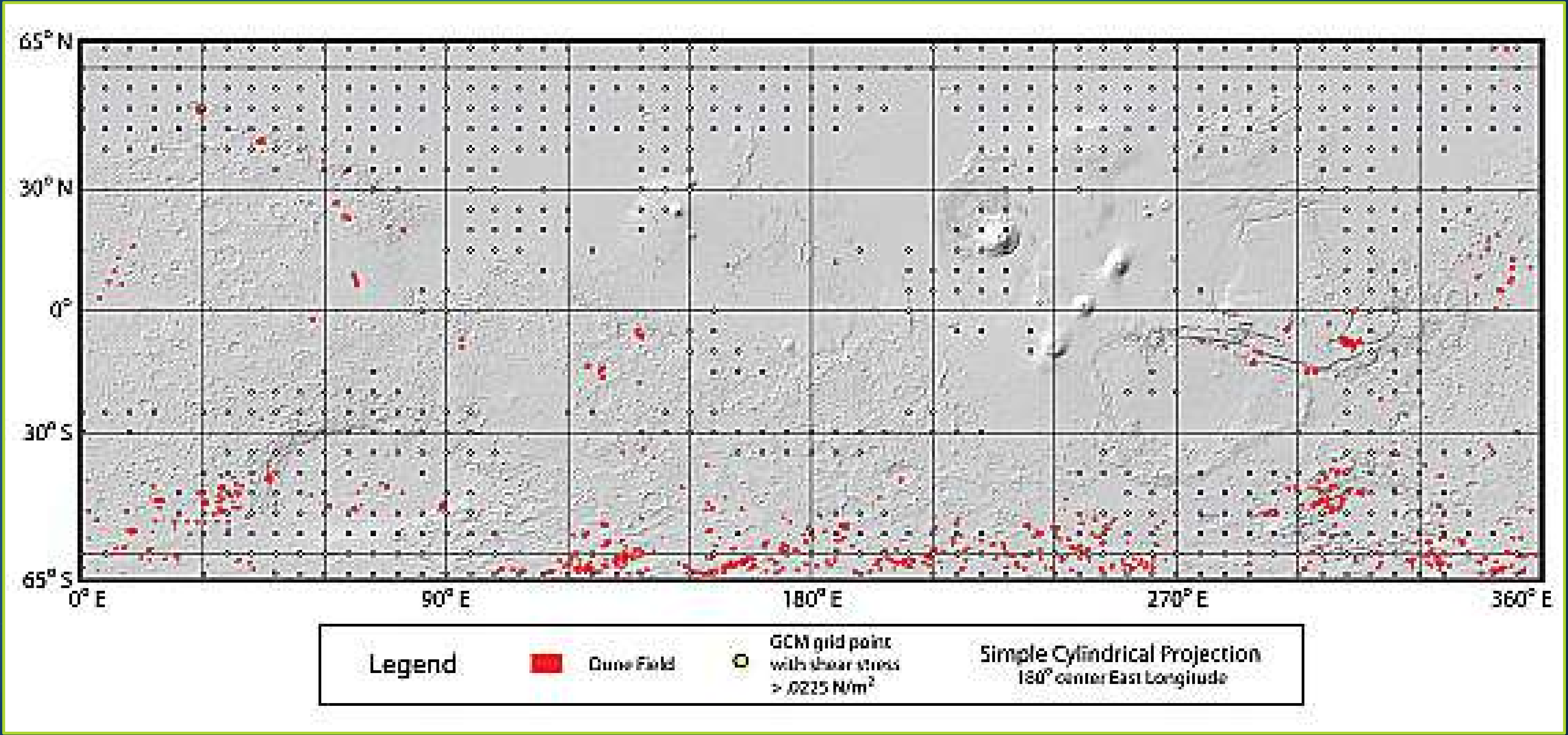
Feature-based mapping

approaches in geoscientific mapping

Rationale

- The cartography of one (or few) specific landform(s), structure(s), and/or mineral(s) address the distribution of such elements over the whole planetary body (or a large portion of it)

Example ⇢ Mars Global Digital Dune Database



Hayward et al., 2007. Journal of Geophysical Research: Planets, 10.1029/2007JE002943

Attribute table

MA132843GT_Mars2000 — Features Total: 132843, Filtered: 132843, Selected: 0

	Lon_E	Lat	p	Name	Radius_deg	Radius_km
1	2,363280	73,593748	1,000000	S000001B00371R11256C00269T75557Y2005S (144,-4;20,-4;128,-184)	0,151909	8,988000
2	-170,335936	60,656246	1,000000	S000002B00603R10024K20241T75303Y2005S (84,-8;-4,0;108,-284)	0,145563	8,612526
3	-108,886714	60,167967	1,000000	S000003B01099R06820K20279T75084Y2005S (84,0;12,-4;108,-284)	0,183144	10,836081
4	-37,417967	56,761718	1,000000	S000004B01803R05240C00134K20533T74496Y2005S (0,0;4,8;120,-308)	0,225853	13,363044
5	37,992187	58,617187	1,000000	S000005B02753R13896K20444T74775Y2005S (0,0;4,-4;104,-292)	0,10686	6,322586
6	112,425777	58,675777	1,000000	S000006B04456R19225C00762K20395T74879Y2005S (0,0;0,0;108,-296)	0,07321	4,331616
7	-178,480467	27,593748	1,000000	S000007B05742R15282C00513K23109T60916Y2005S (0,0;12,0;100,-276)	0,101329	5,995333
8	-142,742184	34,015620	1,000000	S000008B00700R09967T61918Y2005S (0,0;4,0;112,-308)	0,136975	8,104400
9	-106,992187	24,382812	1,000000	S000009B06120R12987T63269Y2005S (0,0;12,12;104,-272)	0,120404	7,123943
10	-72,957029	31,027342	1,000000	S000010B01311R08872K22792T65176Y2005S (0,0;20,0;104,-304)	0,162883	9,637298
11	-38,640623	26,460937	1,000000	S000011B07886R03253C00080K23201T69396Y2005S (0,0;12,4;100,-276)	0,291313	17,236116
12	0,660155	32,835937	1,000000	S000012B03926R03014T46706Y2005S (0,0;12,0;108,-316)	0,308203	18,235447
13	37,472652	26,156248	1,000000	S000013B09386R02385C00045T49287Y2005S (0,0;-8,4;100,-276)	0,343768	20,339721
14	71,660155	32,753905	1,000000	S000014B04762R12194T52608Y2005S (0,0;12,0;104,-304)	0,119199	7,052647
15	107,964842	30,343748	1,000000	S000015B04638R15305C00623K22911T55419Y2005S (0,0;4,0;104,-296)	0,087985	5,205808
16	143,429687	30,710937	1,000000	S000016B05179R07375K22856T58525Y2005S (0,0;8,-8;104,-304)	0,179027	10,592491

Salamunićcar et al., 2012 - Catalogue of Martian craters

Chronostratigraphic Maps

approaches in geoscientific mapping

Rationale

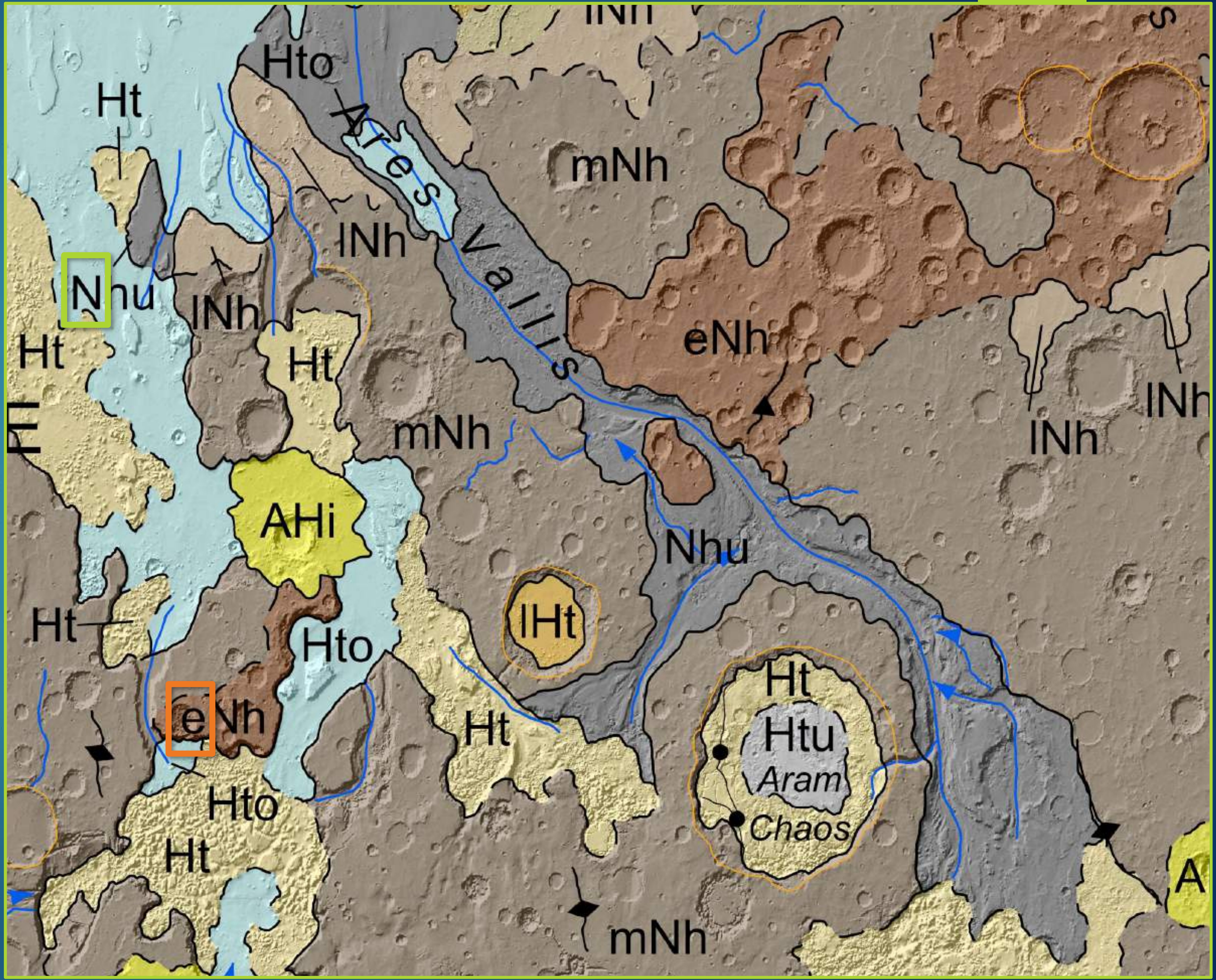
- Geological units are linked to stratigraphic ages
  - Relative or absolute
- Timing of rock formation or a modification event for the surface
- Stratigraphies on planetary bodies often use crater chronology

Example ⇢ Mars global map

Capital letters (N-H-A): Periods (Noachian-Hesperian-Amazonian)

Lower case (e-m-l): Epochs (early … – middle…- late…)

Tanaka et al., 2014



Attribute table

- Age (absolute/relative) of the different units.

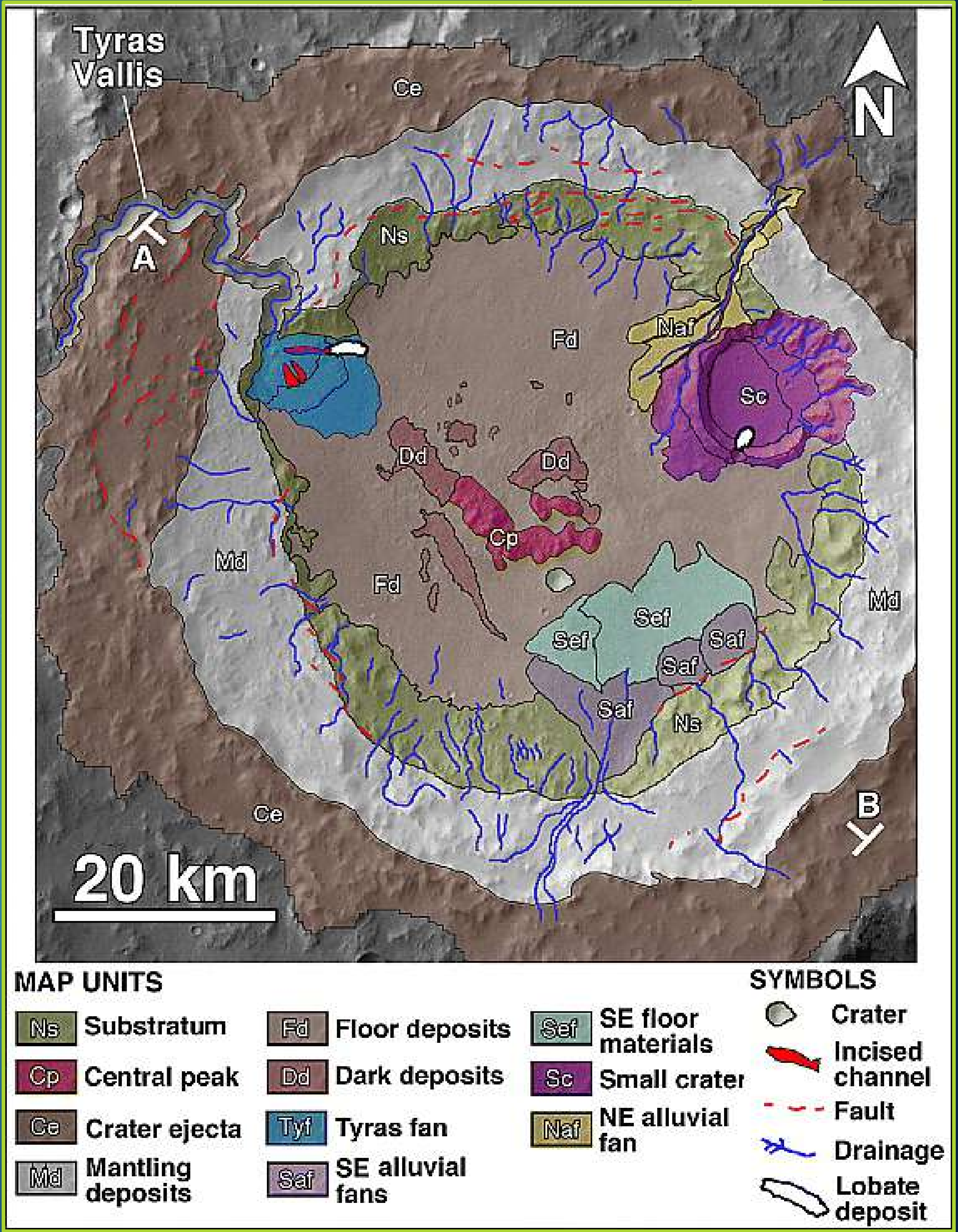
GEOMORPHOLOGICAL Maps

approaches in geoscientific mapping

Rationale

- Geomorphological maps are based on the qualitative-quantitative representation and genetic interpretation of landforms.
- Topical maps mostly oriented to science investigations.

Example ⇢ Geomorphological Map of Tyras Vallis (Mars)



Di Achille et al., 2006. Journal of Geophysical Research: Planets, 10.1029/2005JE002561

Attribute table

- Depend on the interpretation of the single landforms/structures
- Other fields might be added
  - Preservation
    - Poorly preserved
    - Eroded
    - Partially buried
    - Subdued
    - Well preserved
    - Pristine

GEOLOGICAL Maps

approaches in geoscientific mapping

Rationale

- On Earth: first and basic geological knowledge of a specific territory, based on lithological characteristics and changes.
- On the planets: generally impossible.

Rationale

- On Earth: first and basic geological knowledge of a specific territory, based on lithological characteristics and changes.
- On the planets: generally impossible.

BUT

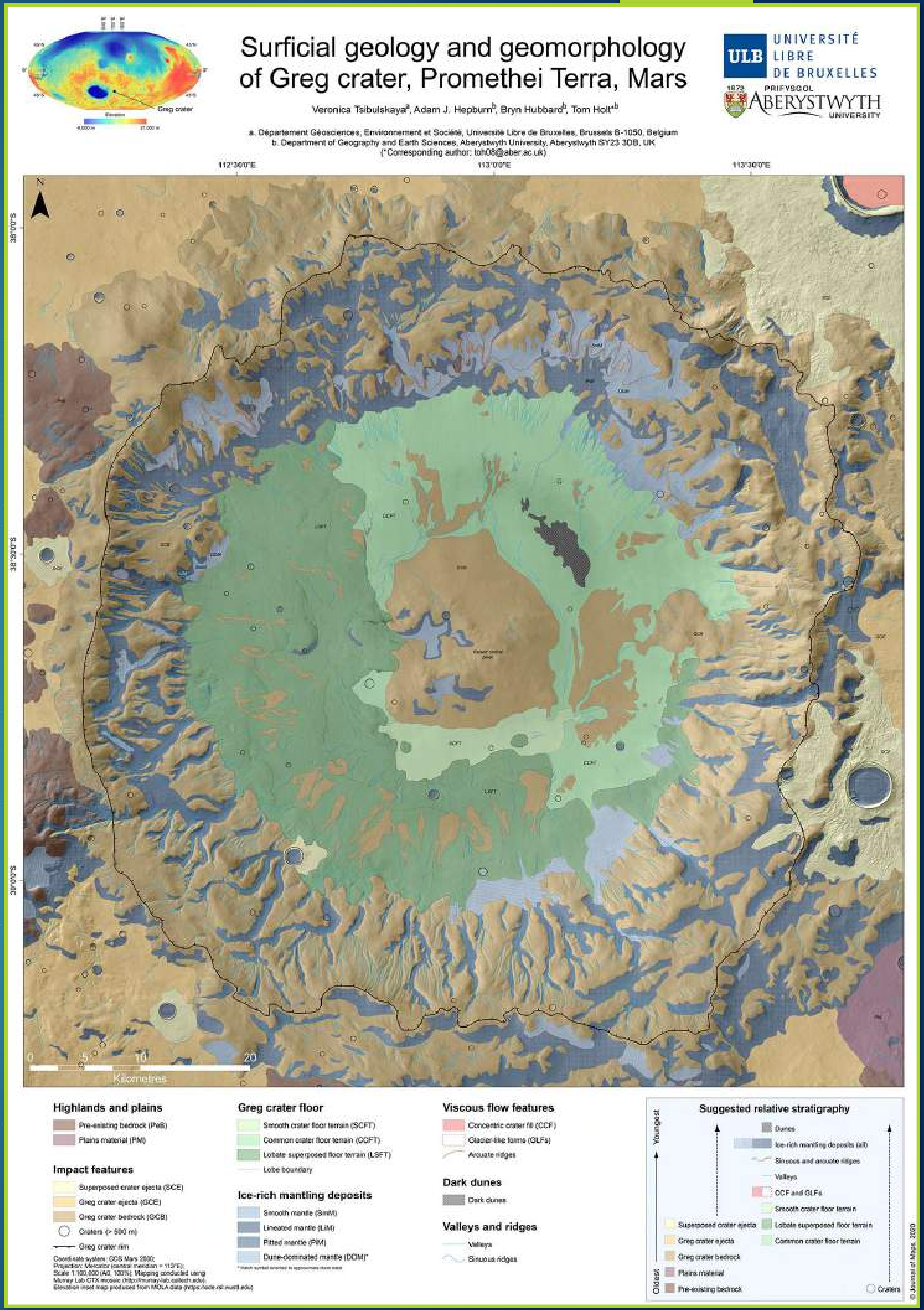
When a relatively more 'objective' cartography product is needed

Rationale

- Distinguishing observations from interpretation.
- Emphasis on stratigraphic boundaries

Three different layers with the different information:
distinguished, BUT in the same cartographic product

Example ⇢ Surficial geology and geomorphology of Greg crater, Promethei Terra, Mars



Tsibulskaya et al., 2020. Journal of Maps

attribute table

- Contacts (lines)
  - Continuous, certain
- Continuous, inferred
- Disconformity, certain

attribute table

Focus on Stratigraphic relations

Focus on Description

- Contacts (lines)
  - Continuous, certain

- Continuous, inferred
- Disconformity, certain

Focus on Genetic Interpretation

attribute table ⇢ defining units

- Colour, texture, association with non-genetic morphologies (geometries without interpretation, e.g., mound, peak), presence/ absence of layering and sedimentary structures.
- Mineralogical hints (attention to different resolutions of hyperspectral and imagery data).
  - Image sharpening processes might help.
- Position within the stratigraphic succession

Landing site characterization

approaches in geoscientific mapping

Science and engineering Rationale

- Geological characteristics of the region.
- Landing site properties and conditions.
- Risk assessment and mitigation.
- Planning of mission operations.
- Supporting entry, descent, and landing.

Approaches

- Morphological and chronostratigraphic maps at different scales.
- Topography, slopes, and illumination conditions.
- Thermophysical properties.
- Boulder and crater maps.

Approaches

- Morphological and chronostratigraphic maps at different scales.
- Topography, slopes, and illumination conditions.
- Thermophysical properties.
- Boulder and crater maps.

By combining multiple sources of geospatial information, it is possible to plan detailed mission operations for proposed missions while considering both scientific goals and engineering constraints.

Example ⇢ Apollo 17 pre-mission detail map of the Taurus-Littrow region of the Moon with a scale of 1:50,000

Lucchitta, 1972

Resource maps for in situ resource utilization (ISRU)

approaches in geoscientific mapping

Science, exploration, and commercial rationale

- Sustainable path for both exploration and science activities (e.g., oxygen extraction, building materials…).
- Potentially supporting a commercial planetary resources industry.
- Compositional remote sensing data to define the surficial extent of potential resource deposits.

Approaches

- Starting point: use the available compositional remote sensing data to define the surficial extent of potential resource deposits
- Inclusion in a geological context to ‘make sense’ of the compositional hints and *predict* their vertical and lateral distribution.

Mapping scales vs approaches in mapping

	Feature-based mapping	Geomorphological Mapping	Geological Mapping	Chronostratigraphic Mapping	Landing site characterization	Resource maps for ISRU
GLOBAL	X			X		
REGIONAL	X	X	X	X		
LOCAL		X	X	X		
DETAIL			X	X	X	X

Mapping scales vs approaches in mapping

	Feature-based mapping	Geomorphological Mapping	Geological Mapping	Chronostratigraphic Mapping	Landing site characterization	Resource maps for ISRU
GLOBAL	X			X		
REGIONAL	X	X	X	X		
LOCAL		X	X	X		
DETAIL			X	X	X	X

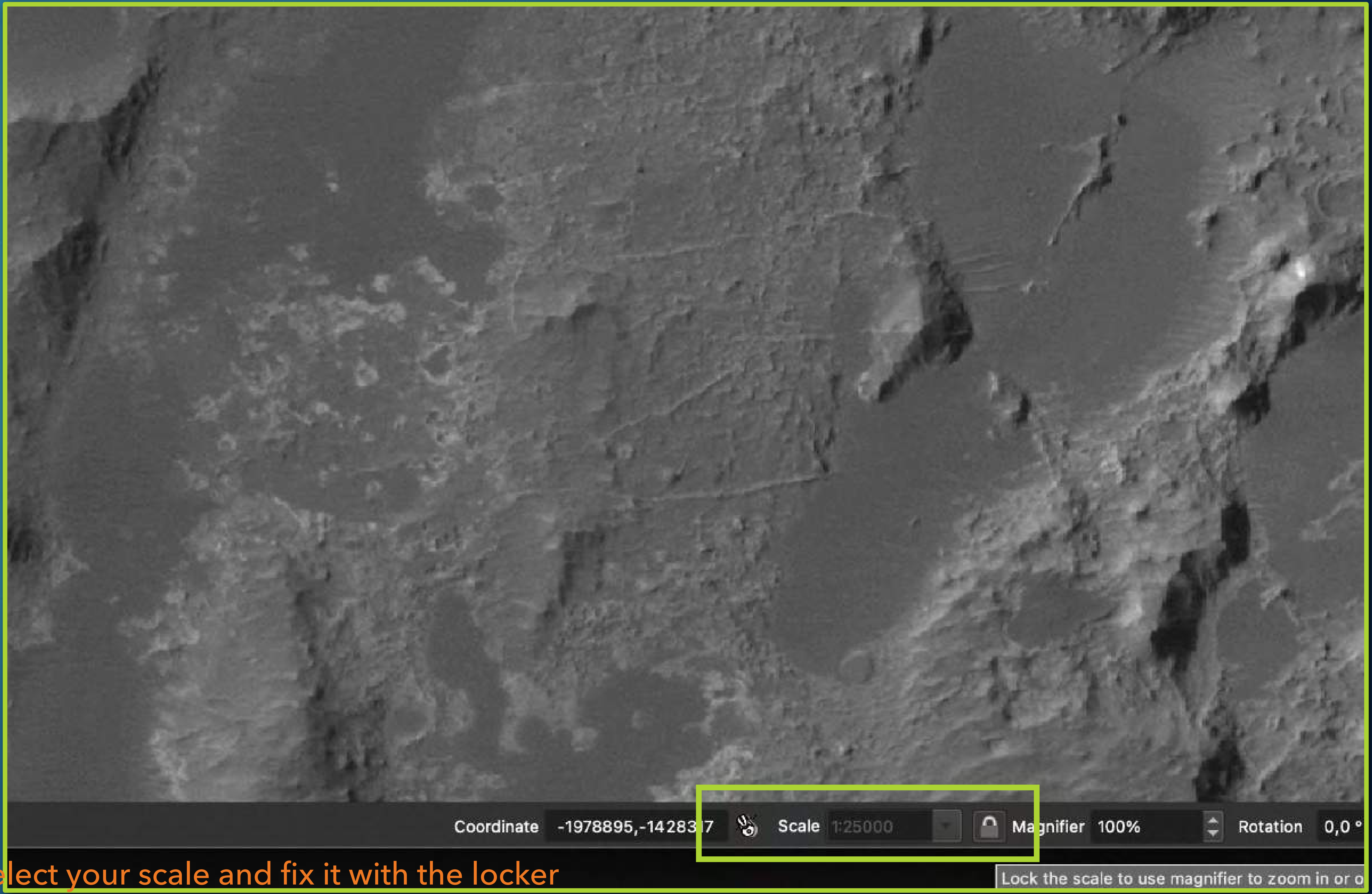
Choice of map approach and scale depends on your science and/or technical goals

Scale of work

- Map should be uniform (dataset choice)
  - Select a mapping scale and keep it throughout the work
- Features should be visible
  - vertex spacing of about 3mm at the map scale
  - mapping scale at least 2-5 larger than the planned published map
  - single features at least 2mm wide at map scale

Tip ⇢ Keep your scale fixed in QGIS

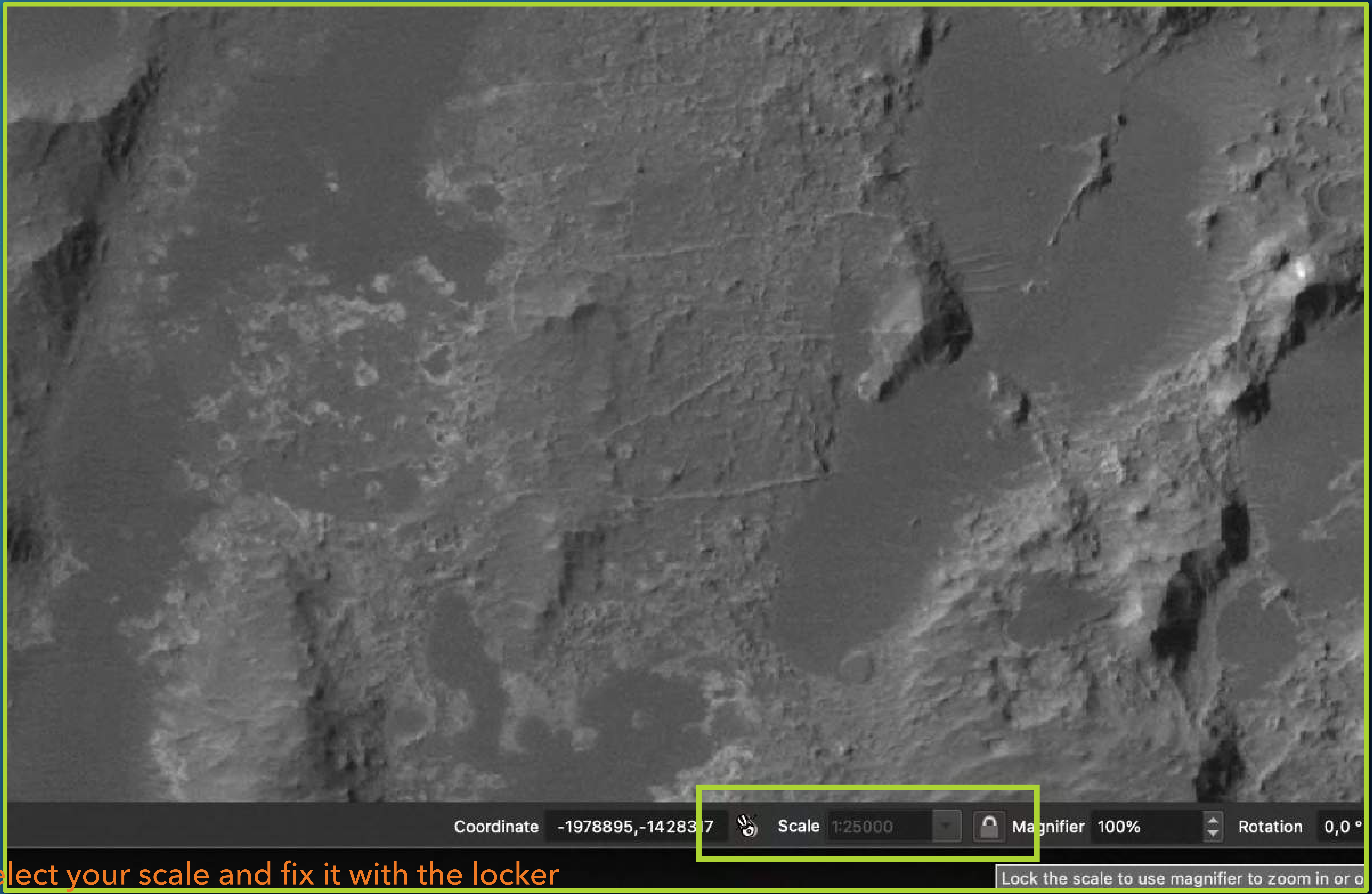
Tip ⇢ Keep your scale fixed in QGIS



Select your scale and fix it with the locker

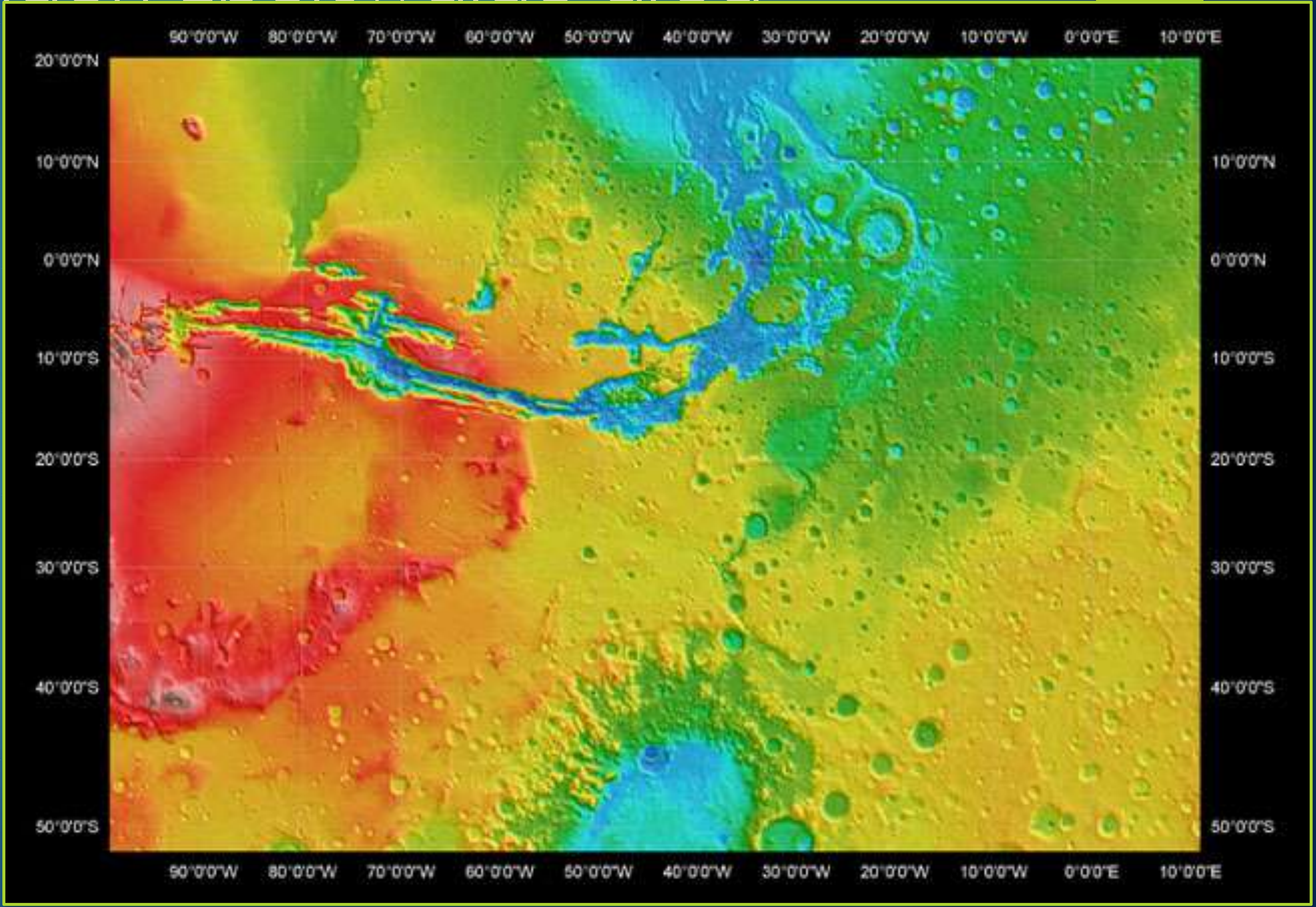
Tip ⇢ Keep your scale fixed in QGIS

It might result in an unnecessary complicate process if you often need to make observations at different scale



Select your scale and fix it with the locker

Example: Holden-Eberswalde area



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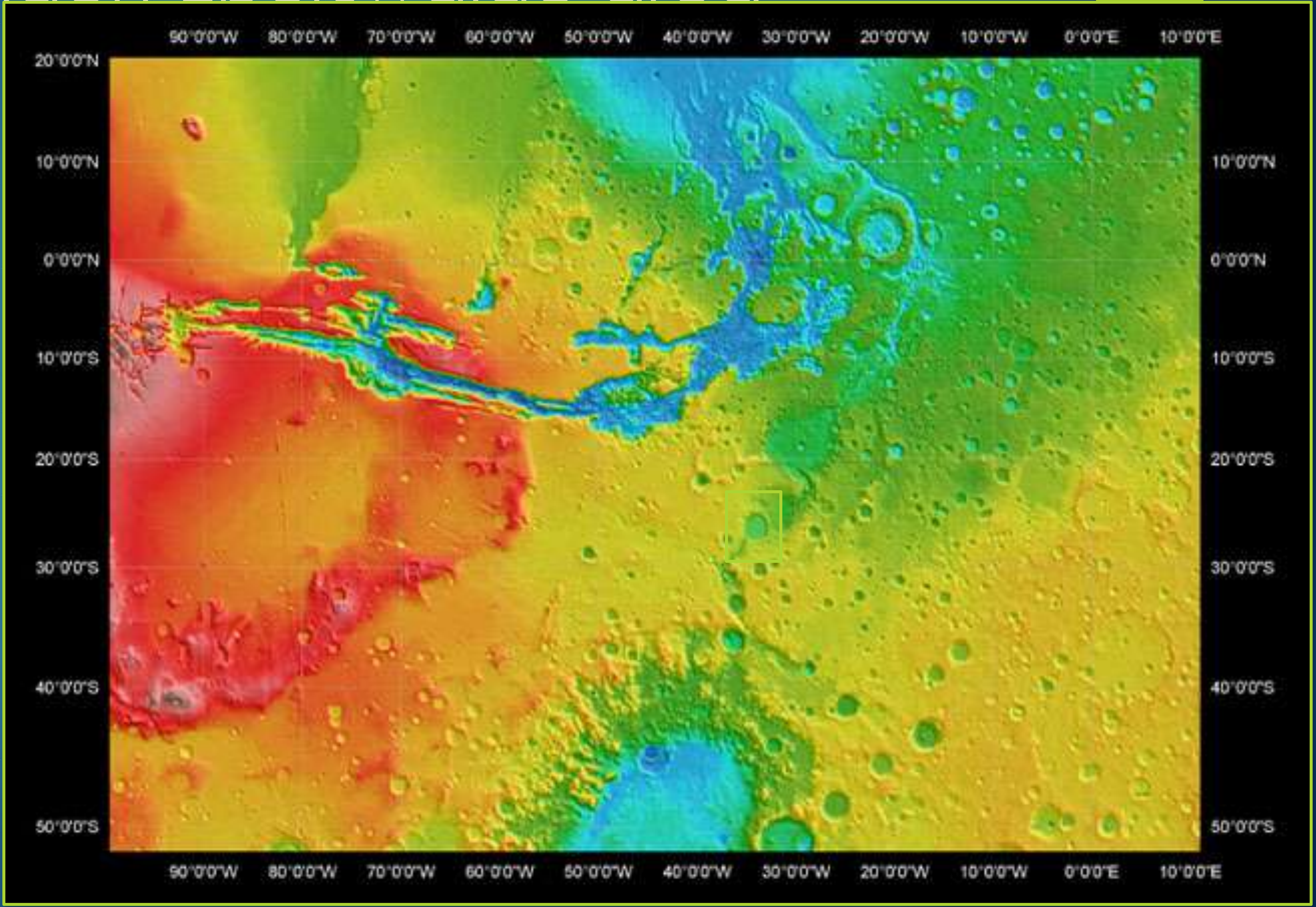
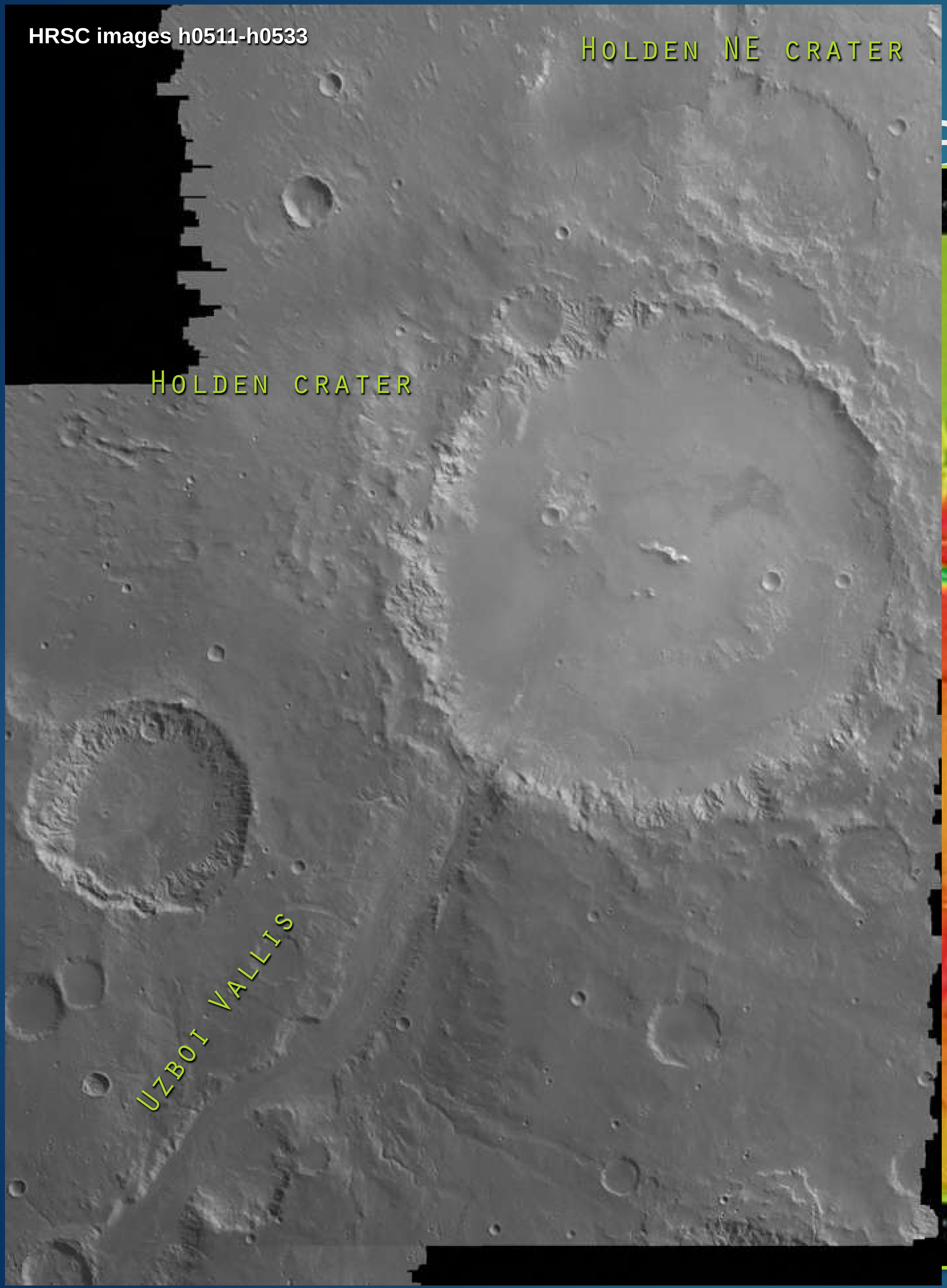
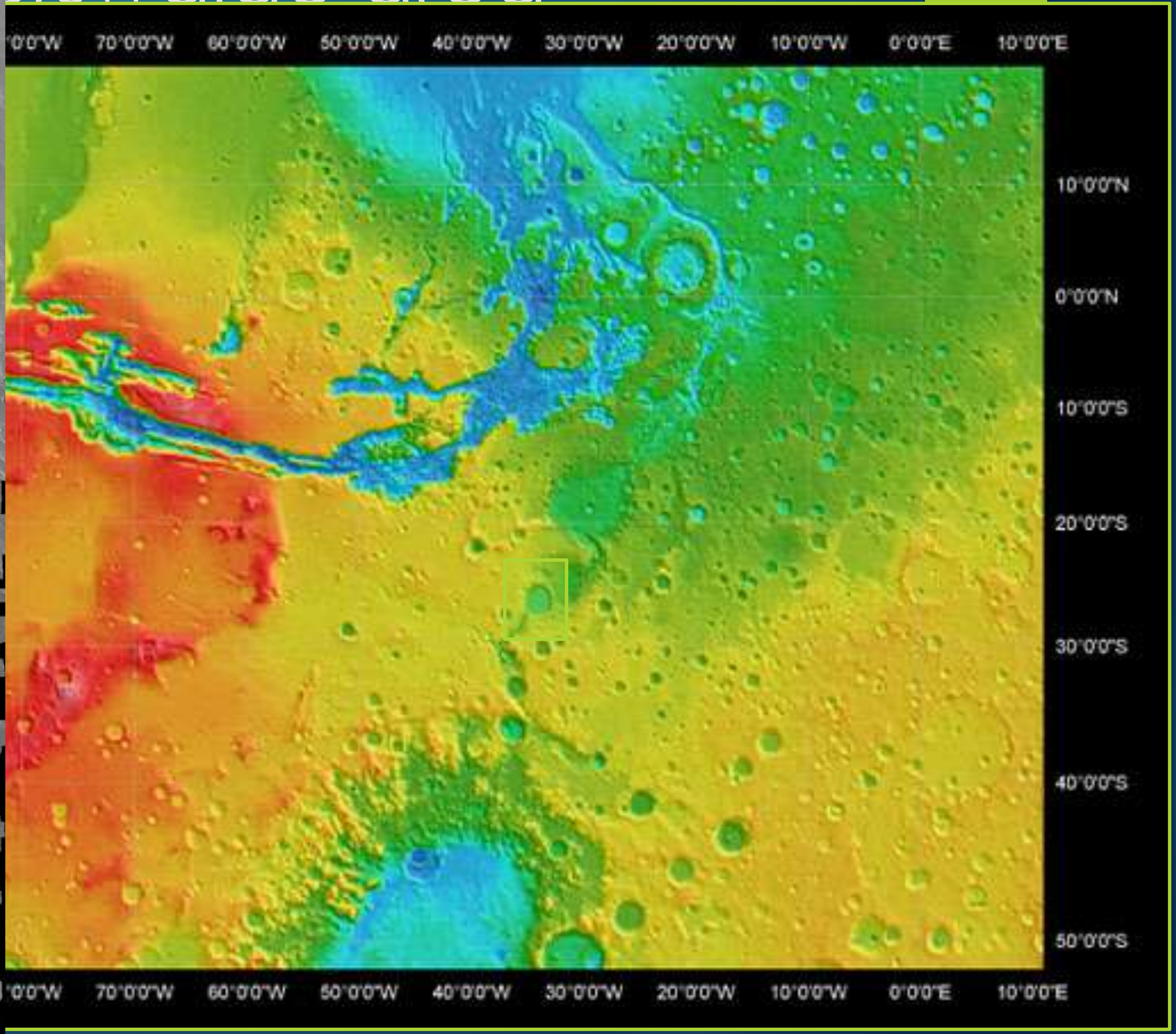
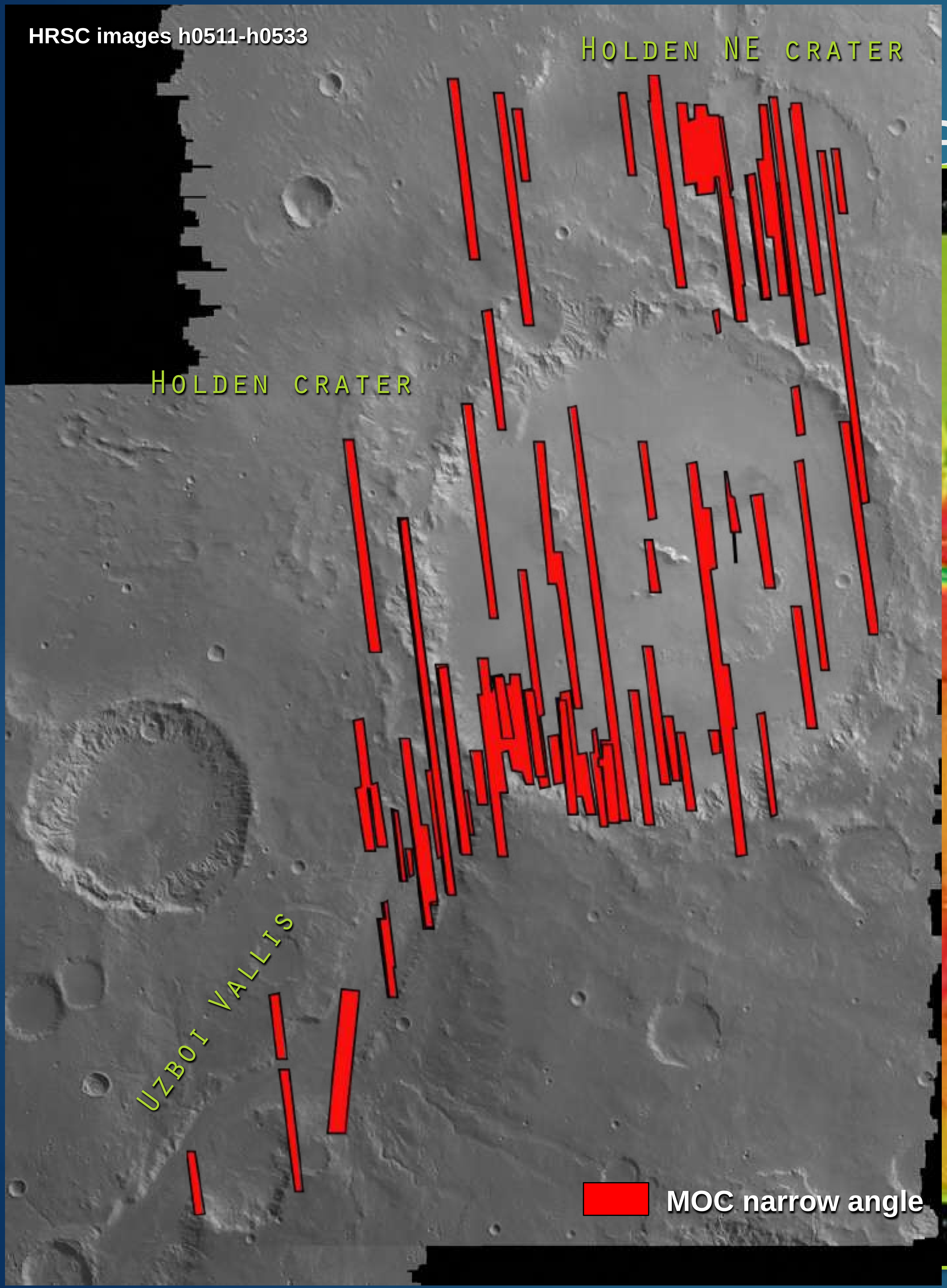


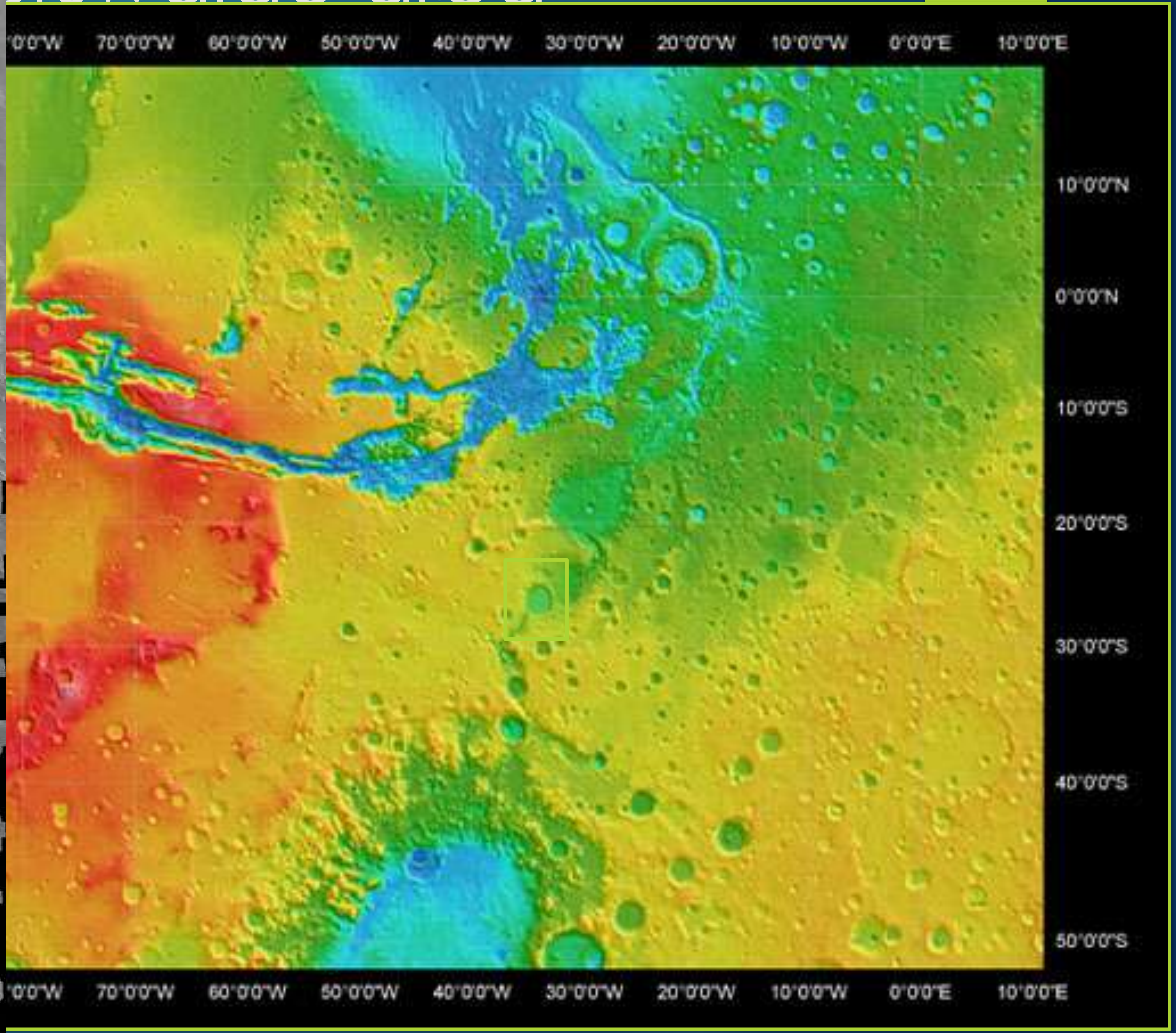
erswalde area



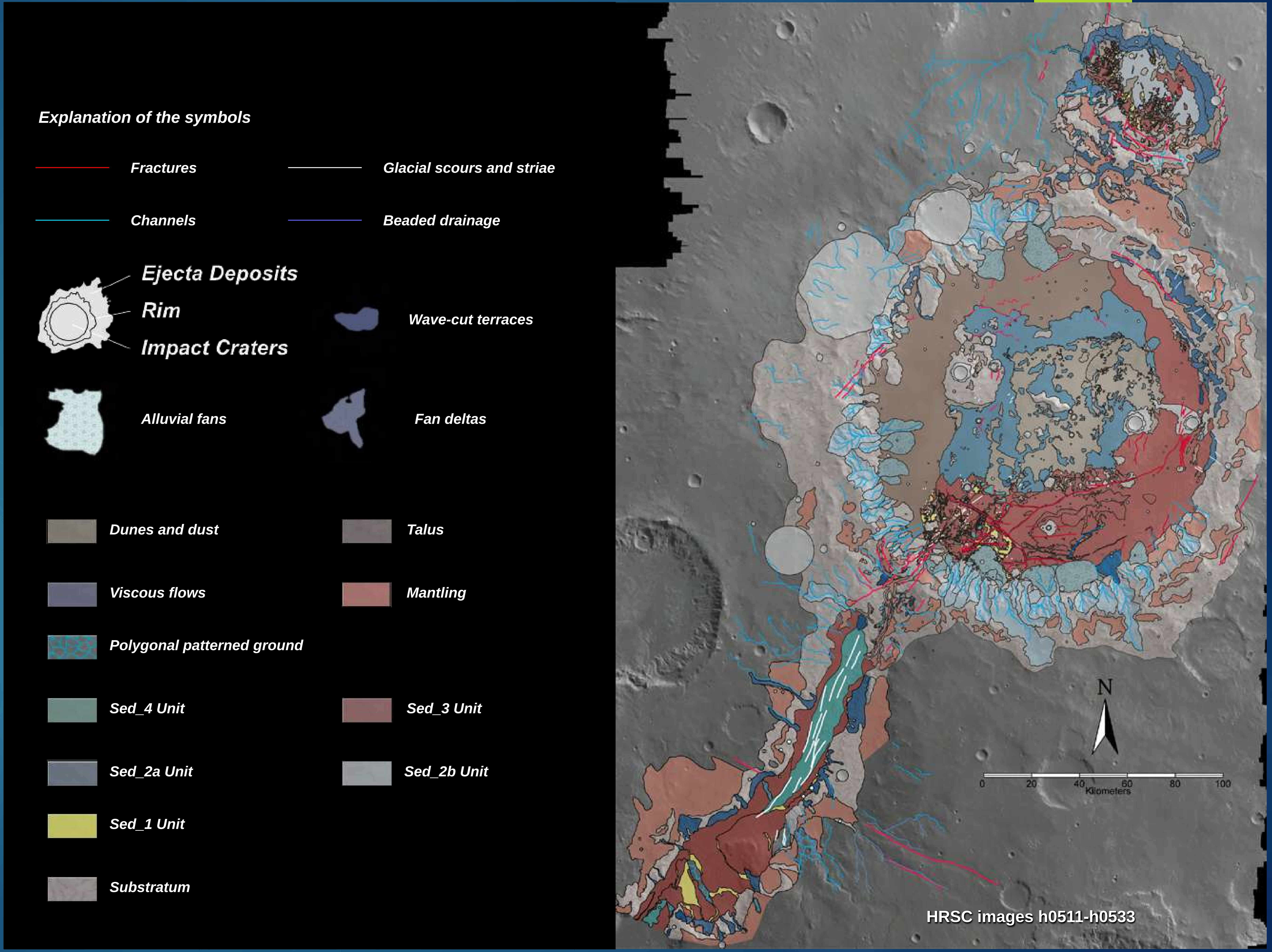


erswalde area





Geological map of the Uzboi Vallis - Holden crater system



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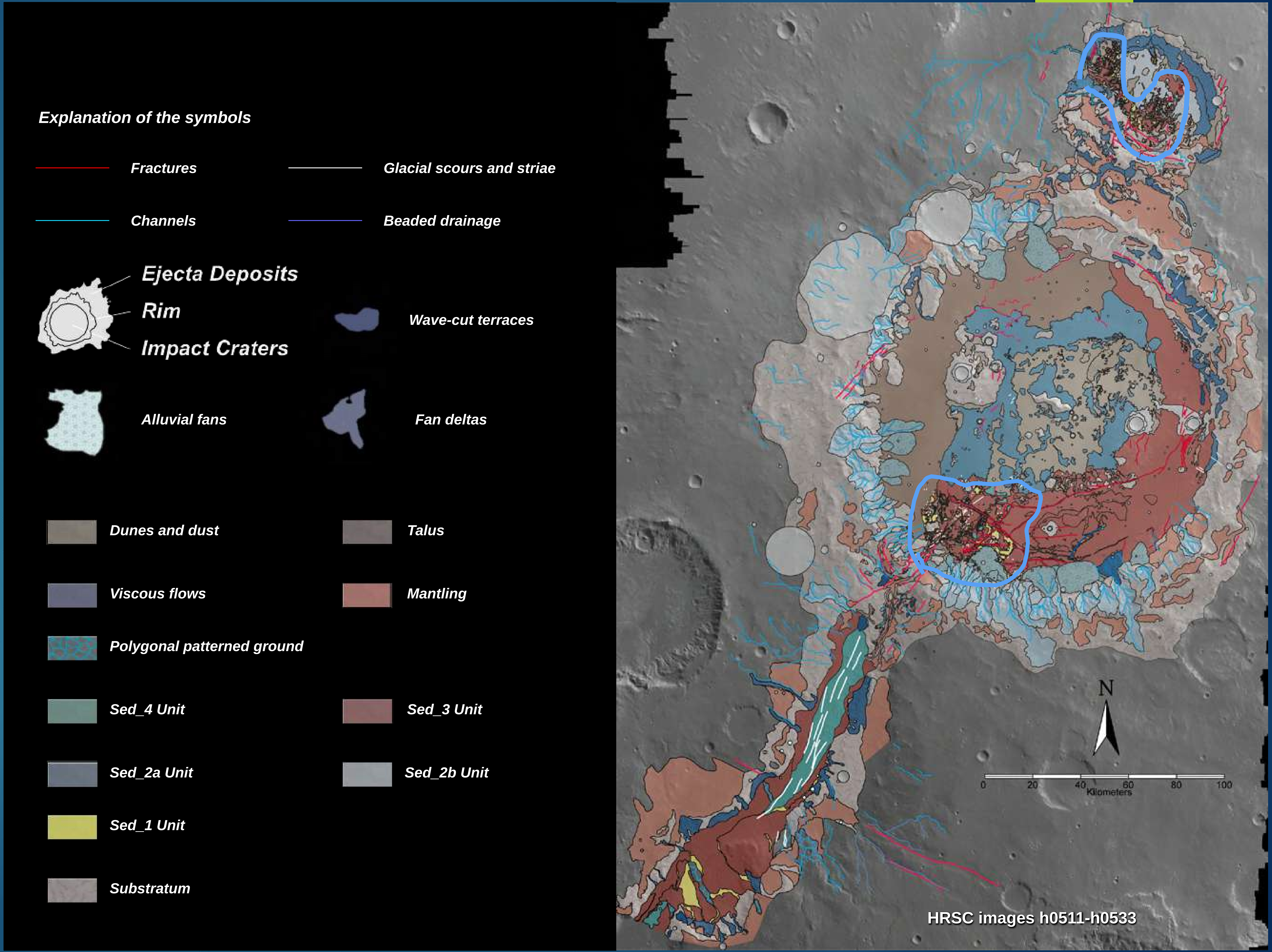

Geology and Geomorphology

Some more-in-depth-concepts to consider

Geoscientific Mapping of planetary bodies: problems and peculiarities

- Scales instrument-dependent
- Remote sensing with no or very limited groundtruth
- Limited information on rock composition
- Relatively limited weathering preservation of morphologies
- Dating

Geoscientific Mapping of planetary bodies: problems and peculiarities

- Scales instrument-dependent
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- Limited information on rock composi n
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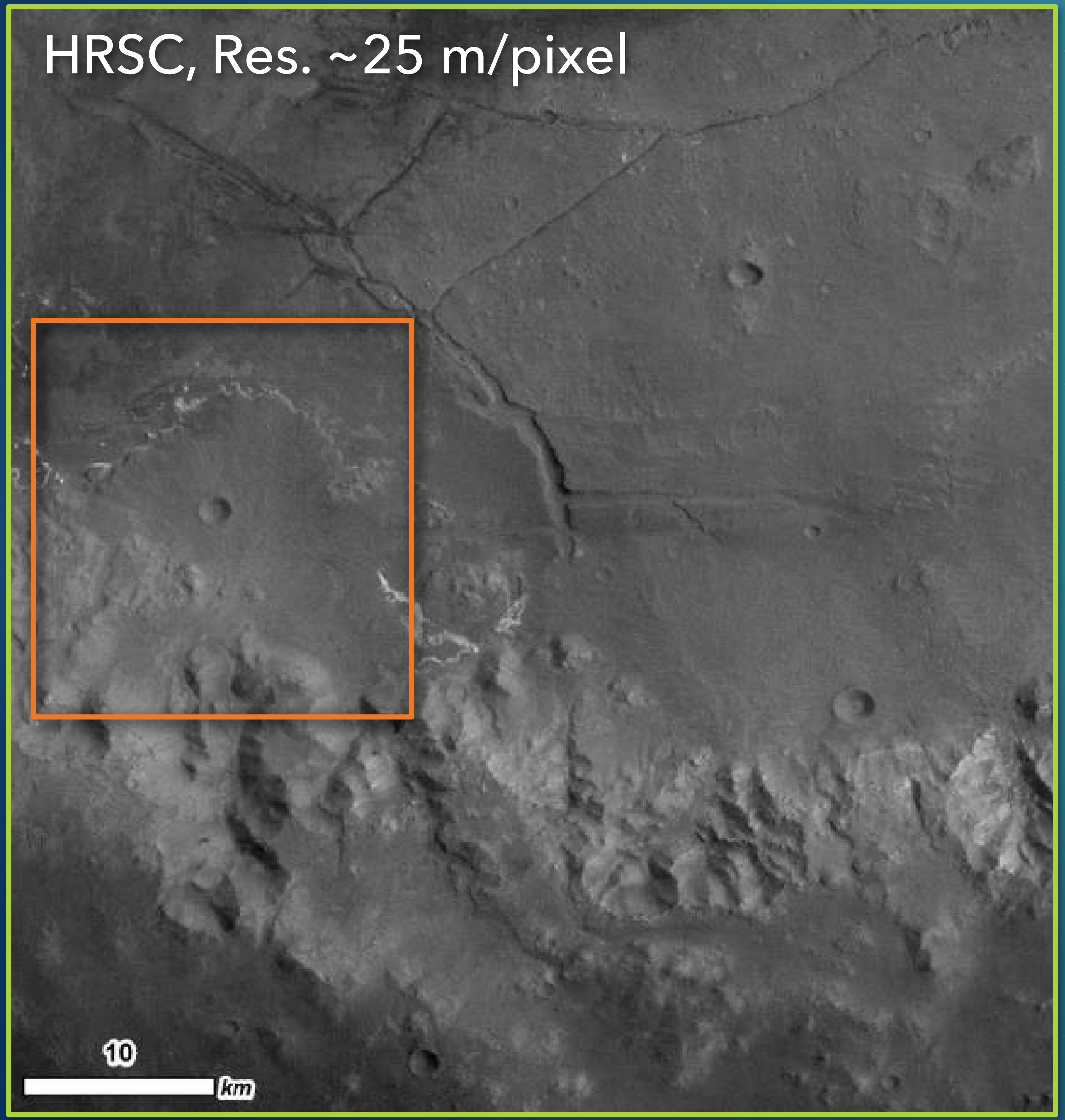
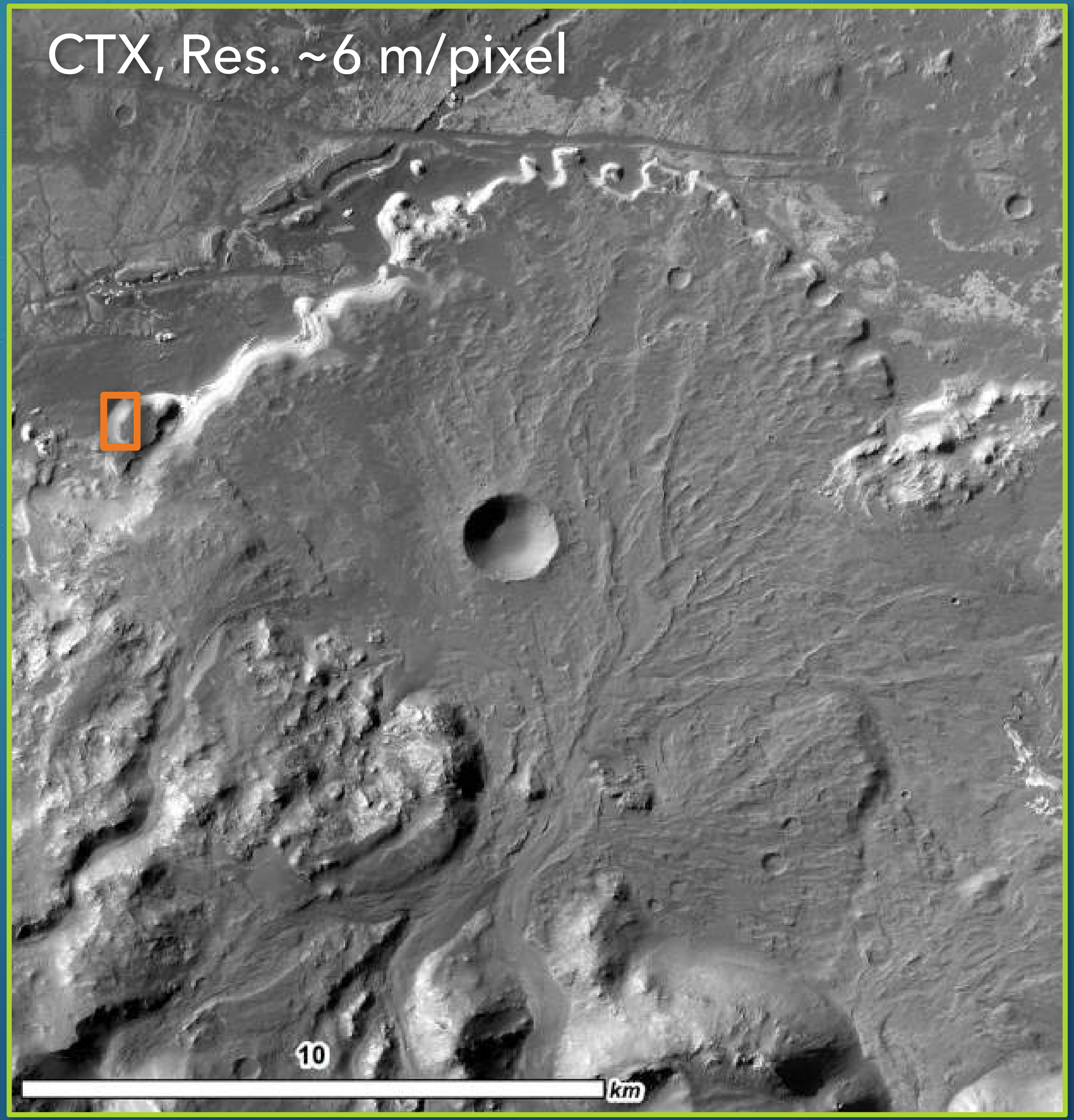
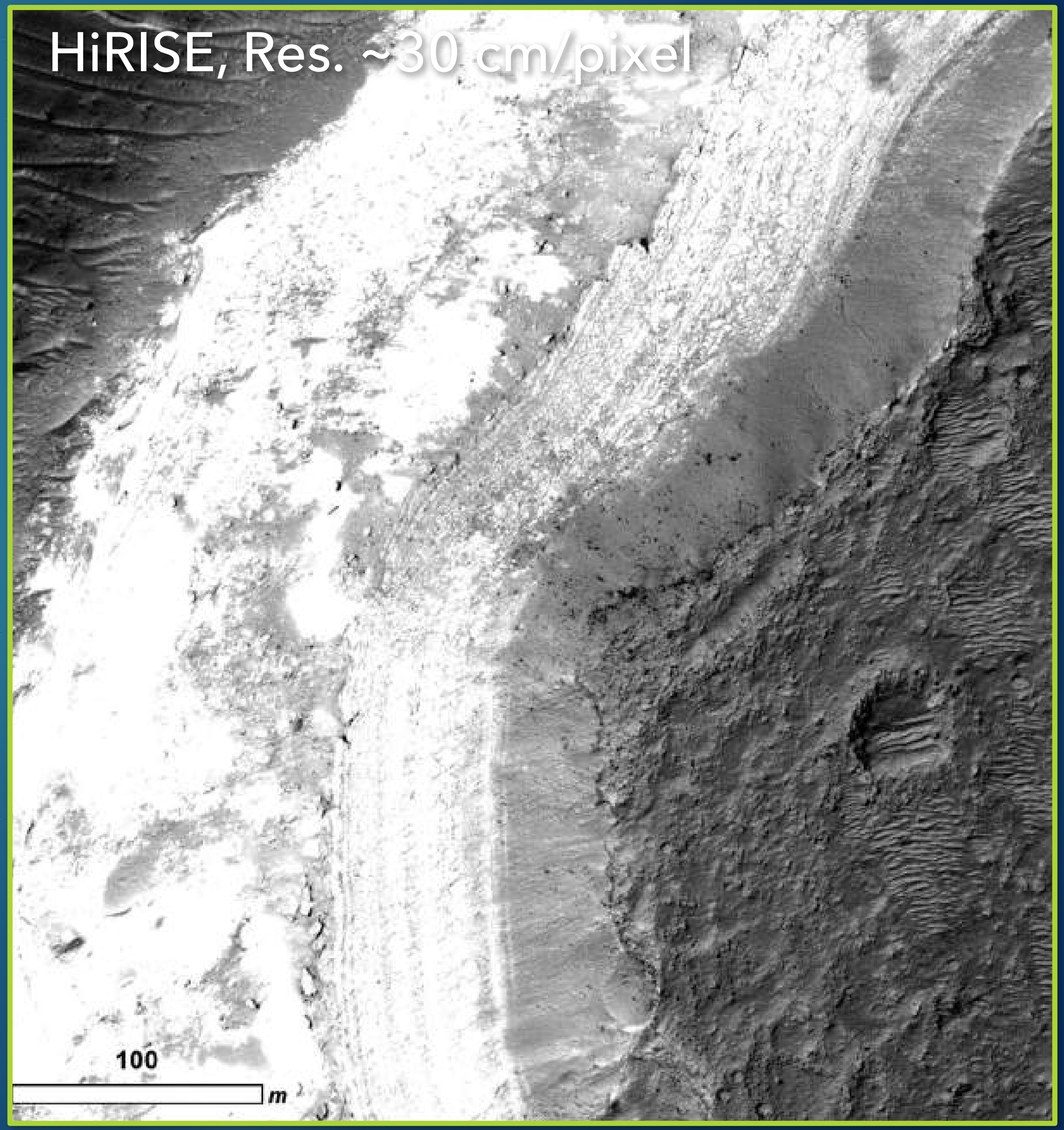
→ Traditional approach in planetary mapping either chronostratigraphic or morphological rather than 'strictly' geological

→ Problems of SCALE and EQUIFINALITY

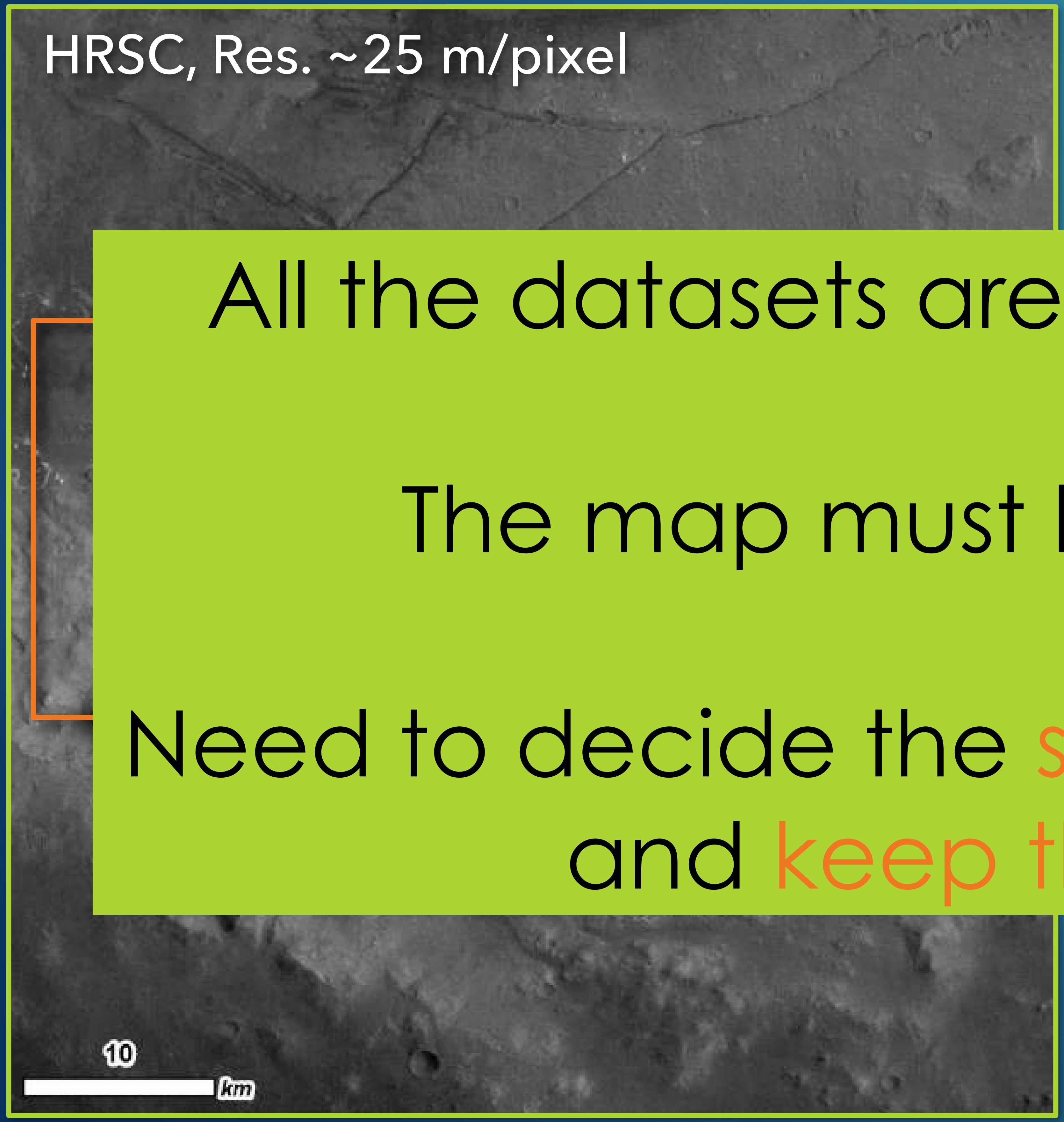
The problem of scale as instrument-dependent

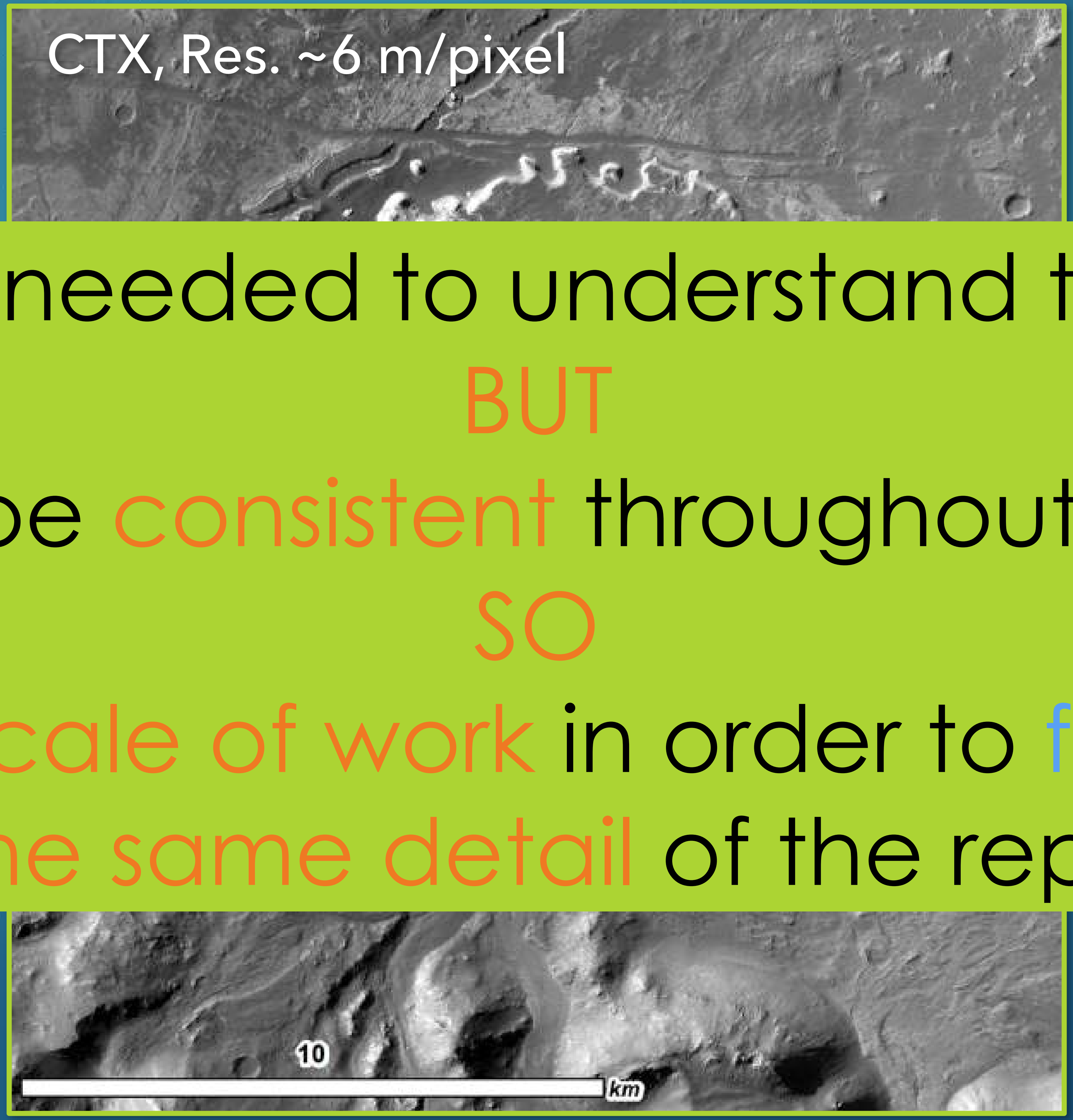


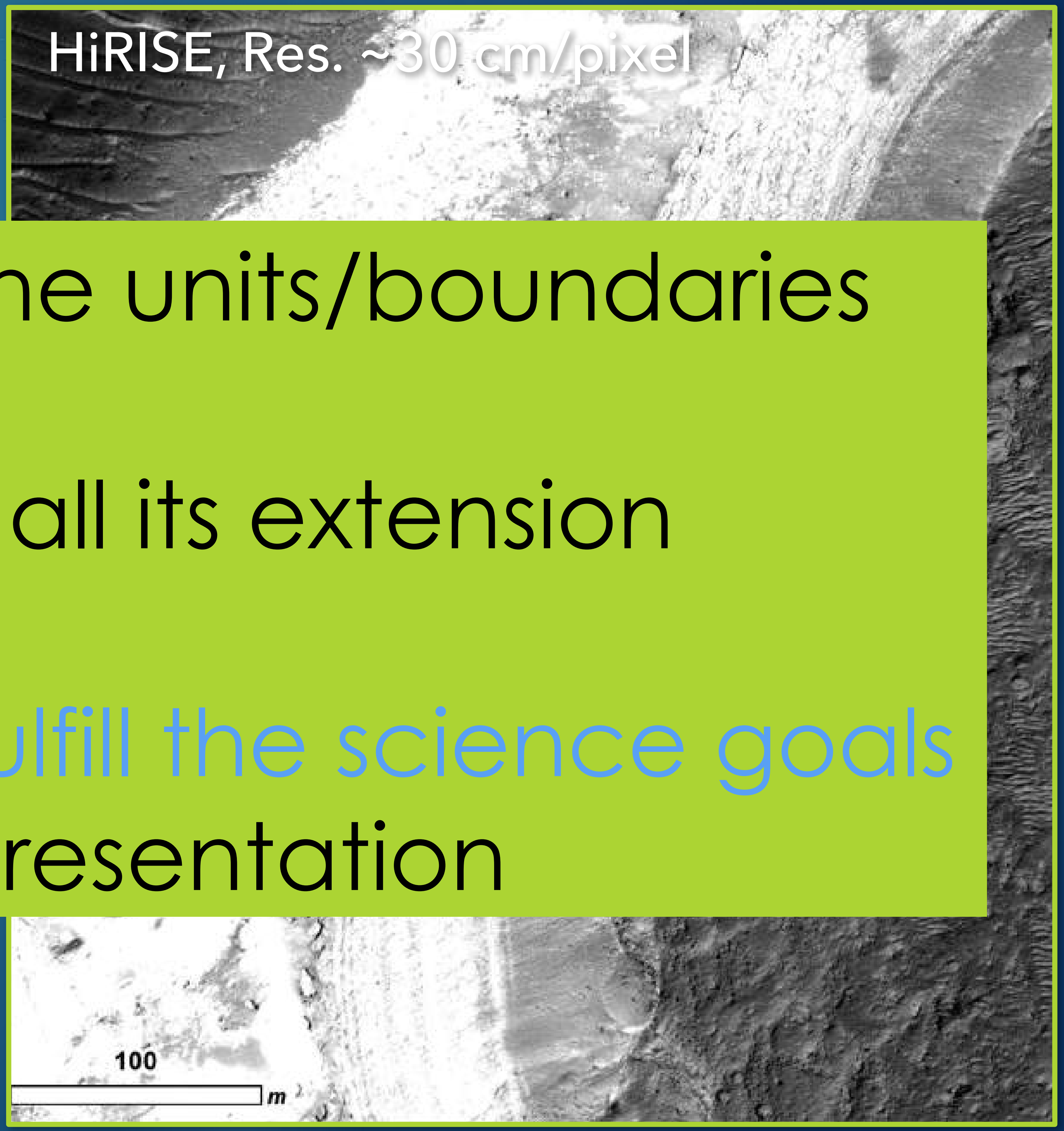




The problem of scale as instrument-dependent







All the datasets are needed to understand the units/boundaries

BUT

The map must be consistent throughout all its extension

SO

Need to decide the scale of work in order to fulfill the science goals and keep the same detail of the representation

Mapping scales vs approaches in mapping

- Global (or at least regional) distribution of a specific feature (e.g., deltas)
  - E.g., Feature-based mapping-Chronostratigraphic Mapping
- Regional to Basin
  - Depositional environments (e.g., channel/delta/lake)
- Basin to sub-basin
  - Depositional elements (e.g., delta plain/delta front/prodelta)

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Possible only if very high-resolution data (~HiRISE) are available

Mapping scales vs approaches in mapping

Choice of the scale depends on your science goals

deltas)

- E.g., Feature-based mapping-Chronostratigraphic Mapping

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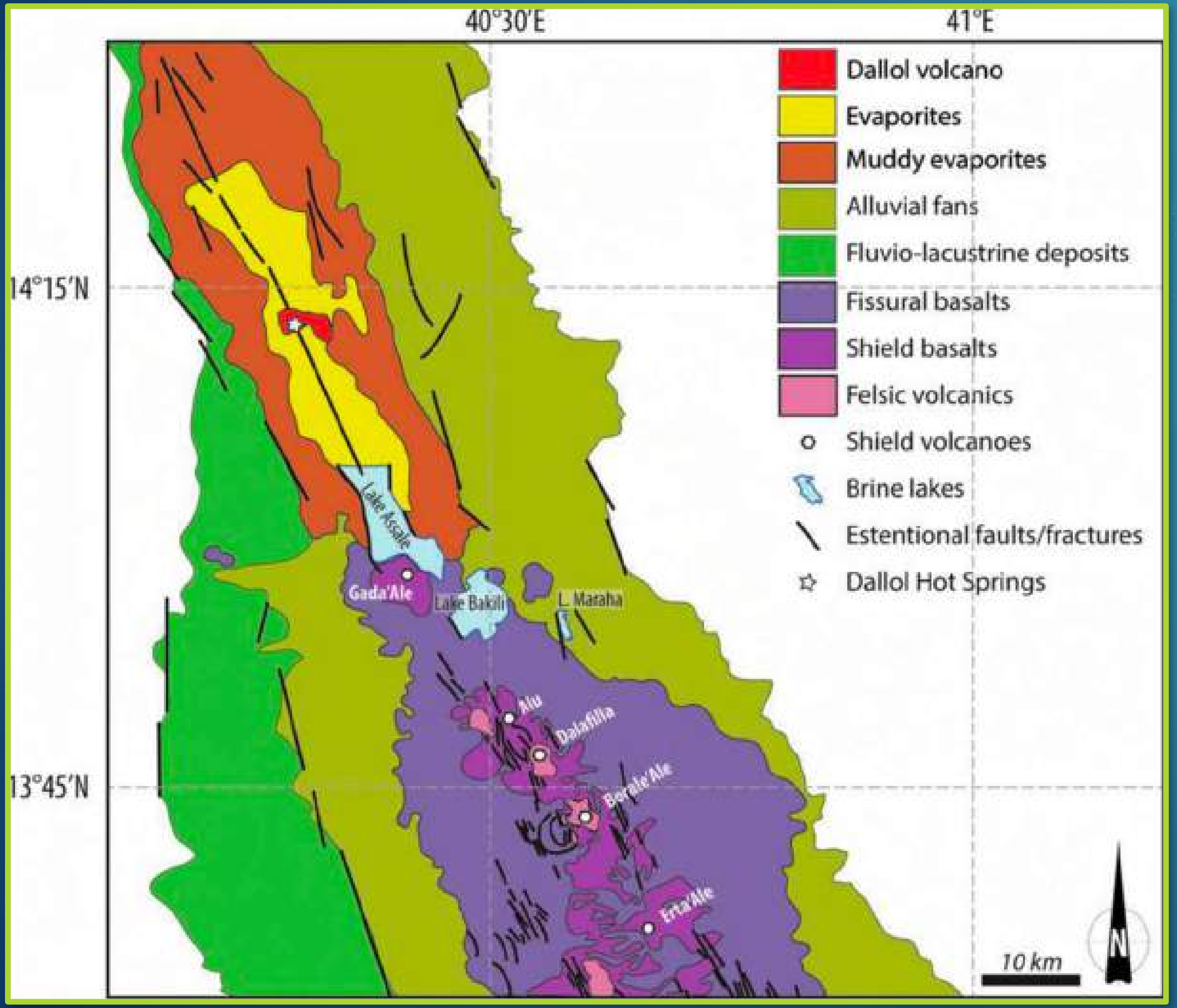
Possible only if very high-resolution data (~HiRISE) are available

The problem of SCALE

- In situ data acquired by rover missions are extremely limited

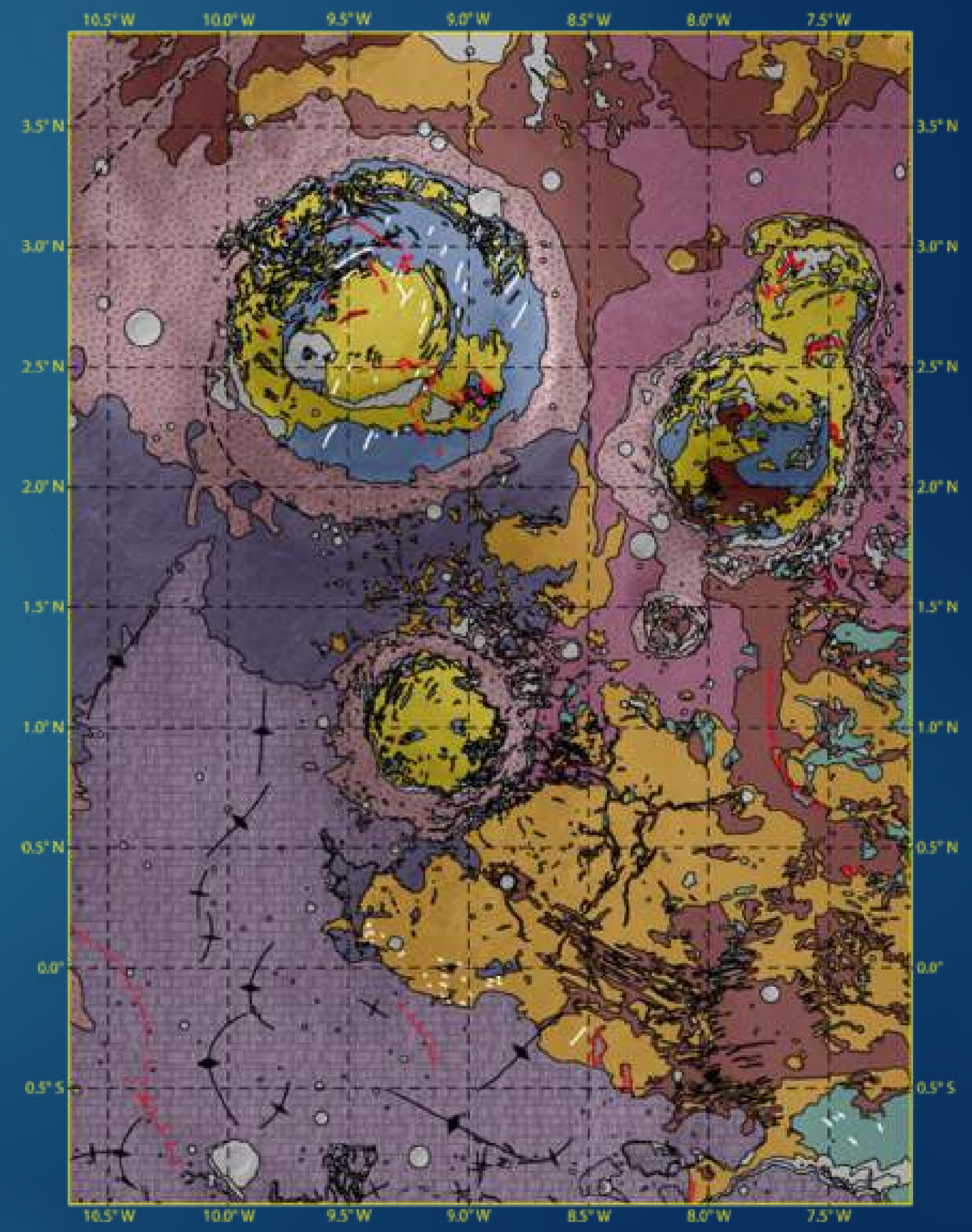
Earth (Dallol, Ethiopia)



Cavalazzi et al., 2019 -Astrobiology

Scale of the analyses
FROM
Geological context
10s to 100s Kms
TO
Observations/Measurements

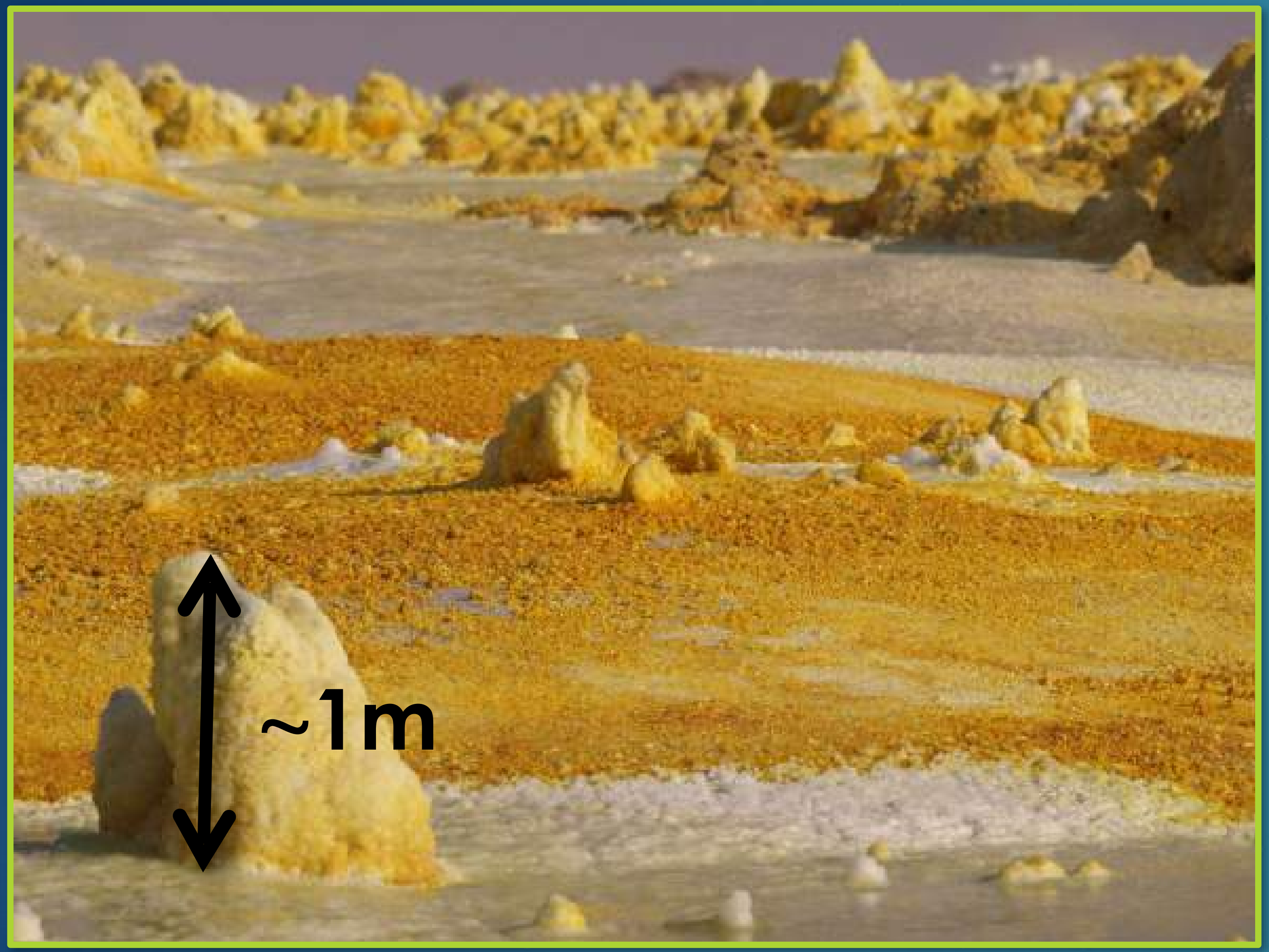
Mars (Firsoff area)



Pondrelli et al., 2015 – GSA Bulletin

The problem of SCALE

Earth (Dallol, Ethiopia)



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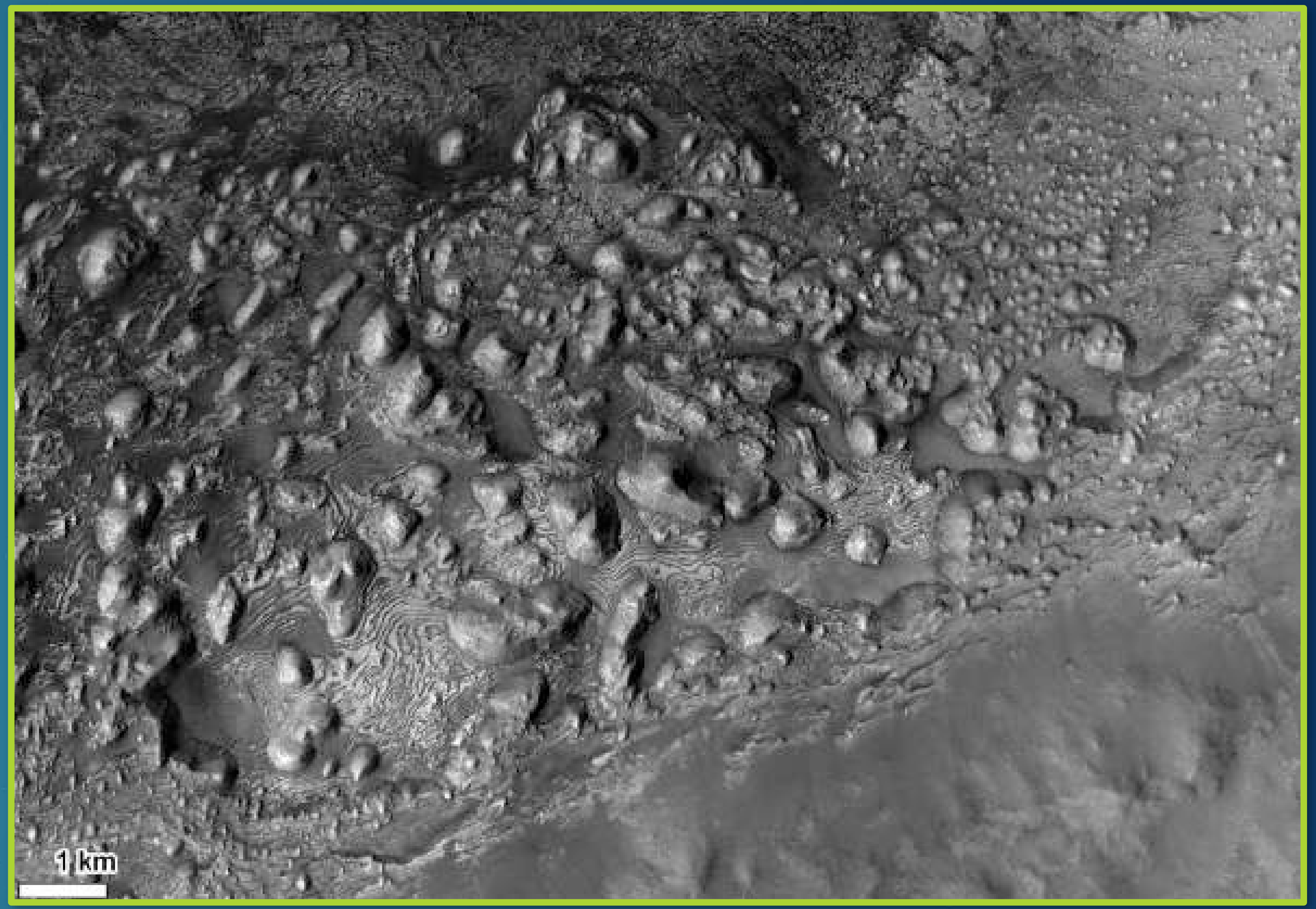

From ~10s m to mm

From ~100 m to ~m

The problem of SCALE

Earth (Dallol, Ethiopia)

Mars (Firsoff area)

Scale of the analyses
FROM
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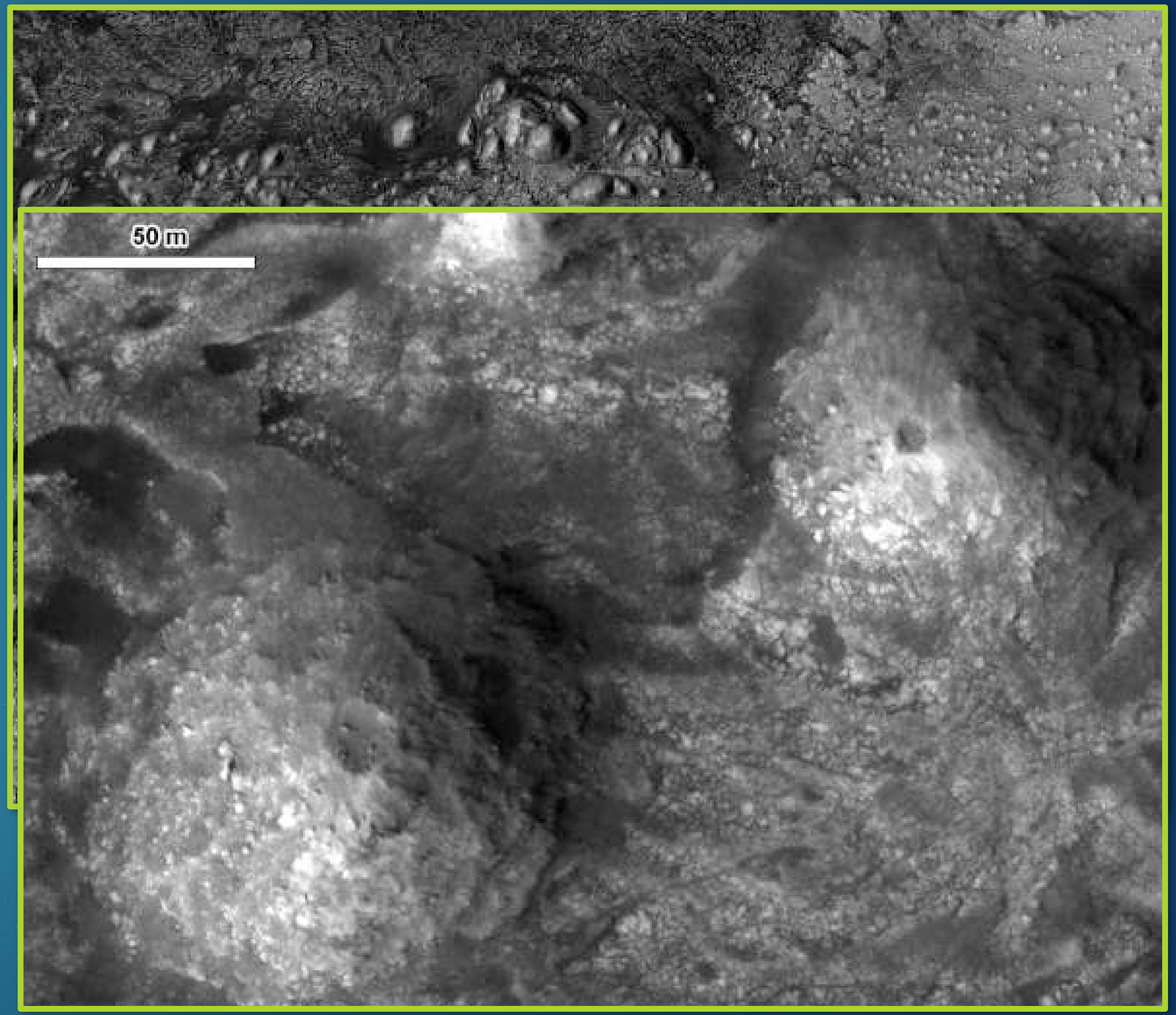

From ~10s m to mm

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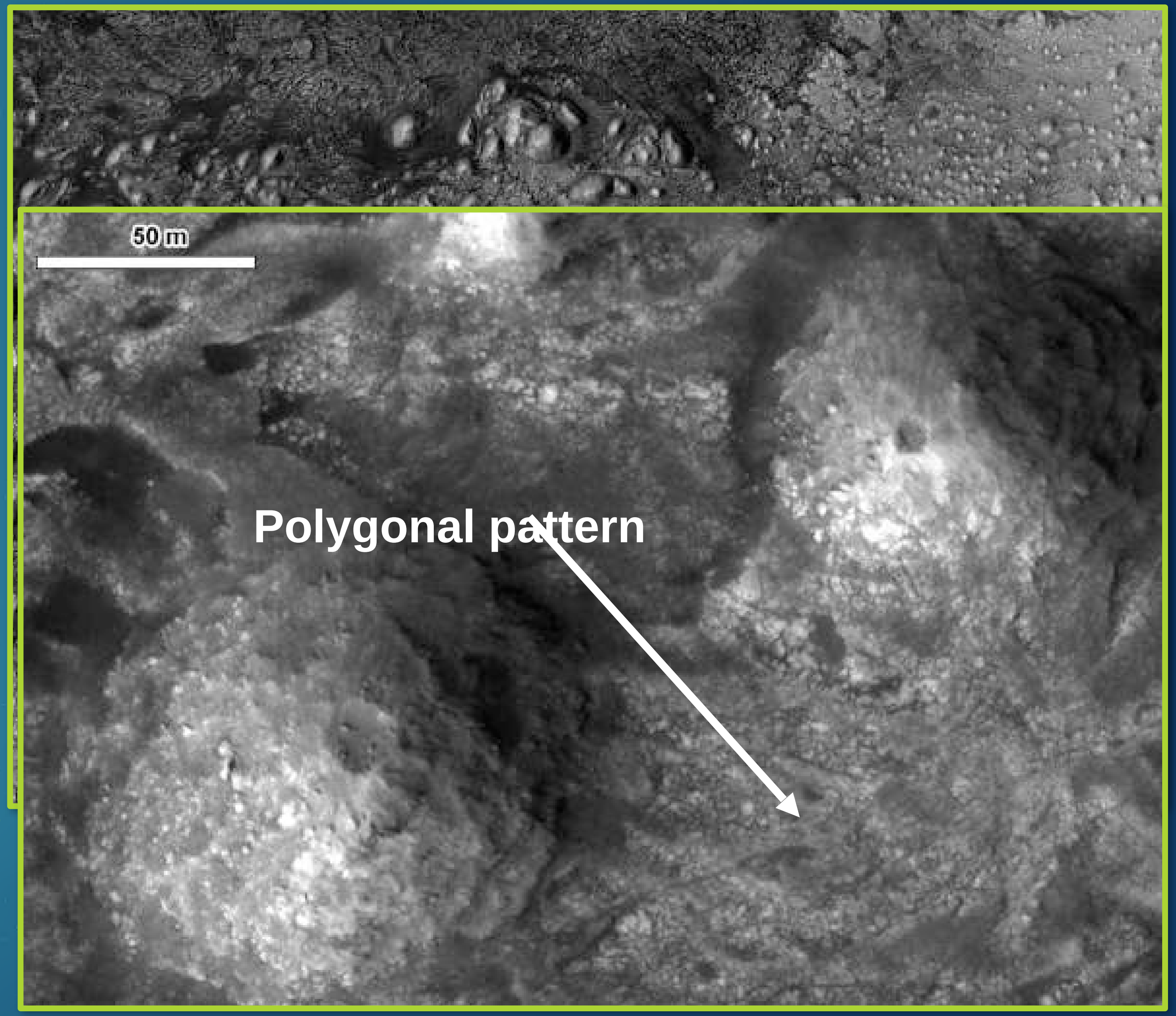

From ~10s m to mm

From ~100 m to ~m

The problem of EQUIFINALITY

- Similar effects may be generated by different combinations of causative processes

Genetic Interpretation

Landform/Deposit

Mounds, Firsoff crater

The problem of EQUIFINALITY

- Similar effects may be generated by different combinations of causative processes

Landform/Deposit

Mounds, Firsoff crater

Erosional Remnant

Genetic Interpretation

The problem of EQUIFINALITY

- Similar effects may be generated by different comb causative processes

Landform/Deposit

Mounds, Firsoff crater

The problem of EQUIFINALITY

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causative processes

Landform/Deposit

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Mounds, Firsoff crater

The problem of EQUIFINALITY

- Similar effects may be generated by different combinations of causative processes

Genetic Interpretation

Landform/Deposit

Erosional Remnant

Pi

Mu

Volcanoes

Mounds, Firsoff crater

The problem of EQUIFINALITY

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Mounds, Firsoff crater

The problem of EQUIFINALITY

Erosional

- Similar effects may be generated by different combinations of causative processes

Genetic Interpretation

Landform/Deposit

Mounds, Firsoff crater

How do we cope with that?

- Integration of data and definition of the GEOLOGICAL CONTEXT
  - Passing from single landforms to associated landforms (=landscape)
- Unit lateral and vertical distribution
  - Geological Map
  - Stratigraphic relations
- THEN: Interpretation
  - Multiple working hypothesis approach (Baker, 2014)
  - Analogues Studies
    - Formulation of genetic hypotheses
    - Following of consequences
    - Testing hypotheses

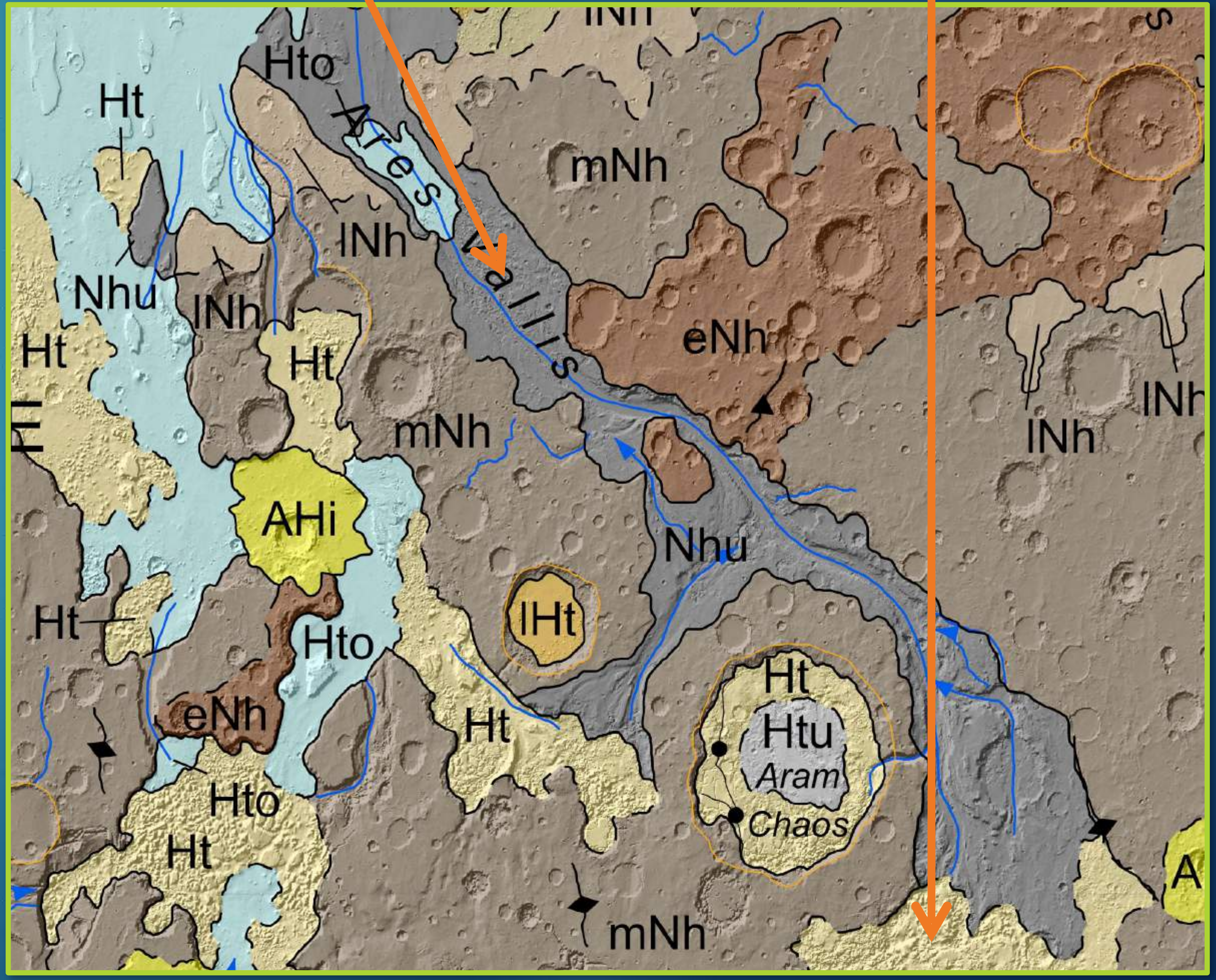
Global mars planetary mapping

Hesperian transition unit

Noachian highland undivided unit

Older Channel Materials

Chaotic Materials



Global mars planetary mapping

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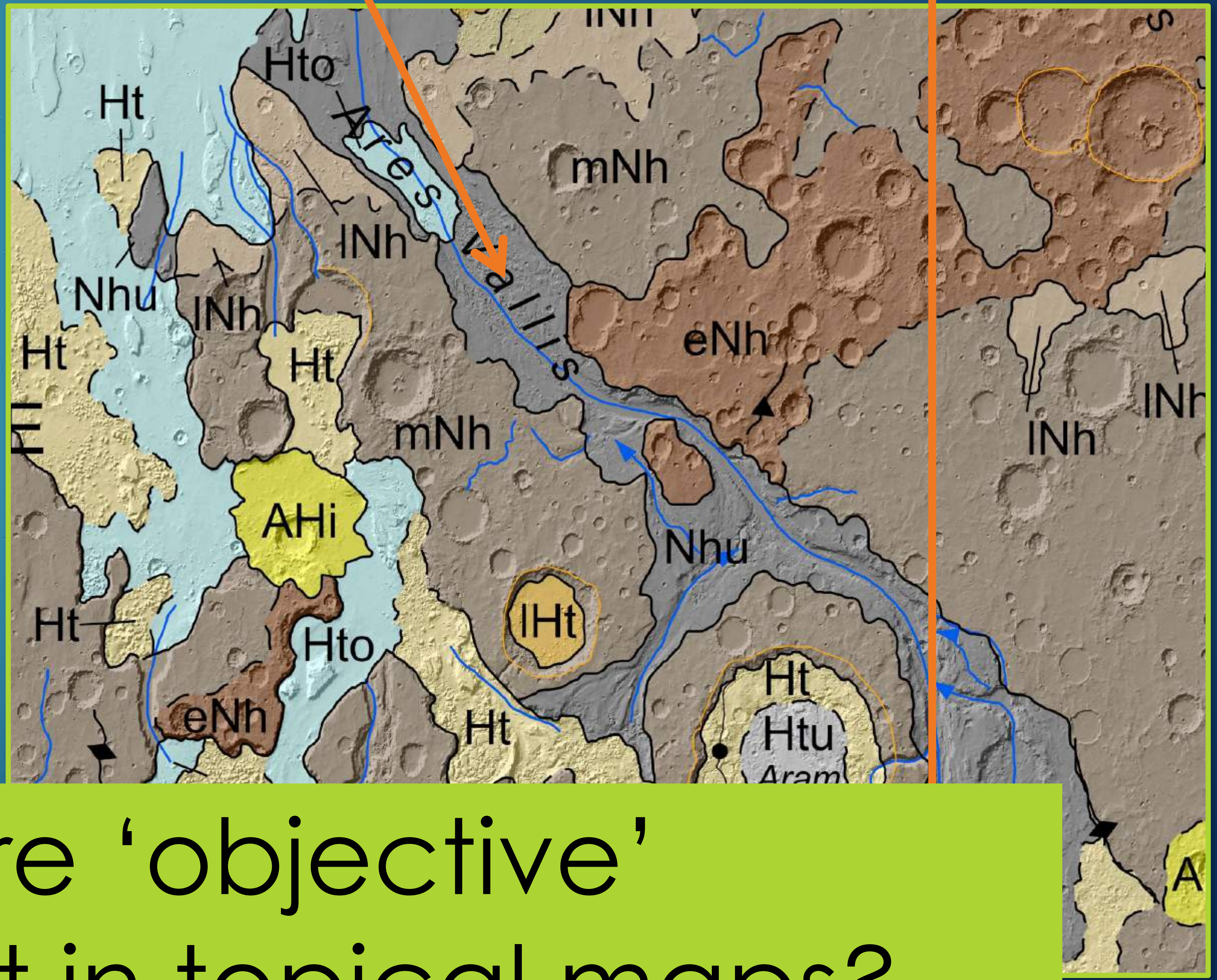


Moving towards a more 'objective' approach...but what about in topical maps?

Processes and products

Courtesy A.P. Rossi

PROCESSES

Visible only if measured, either by:

- Direct measurement
- Remote sensing or in-situ experiments

LANDFORM

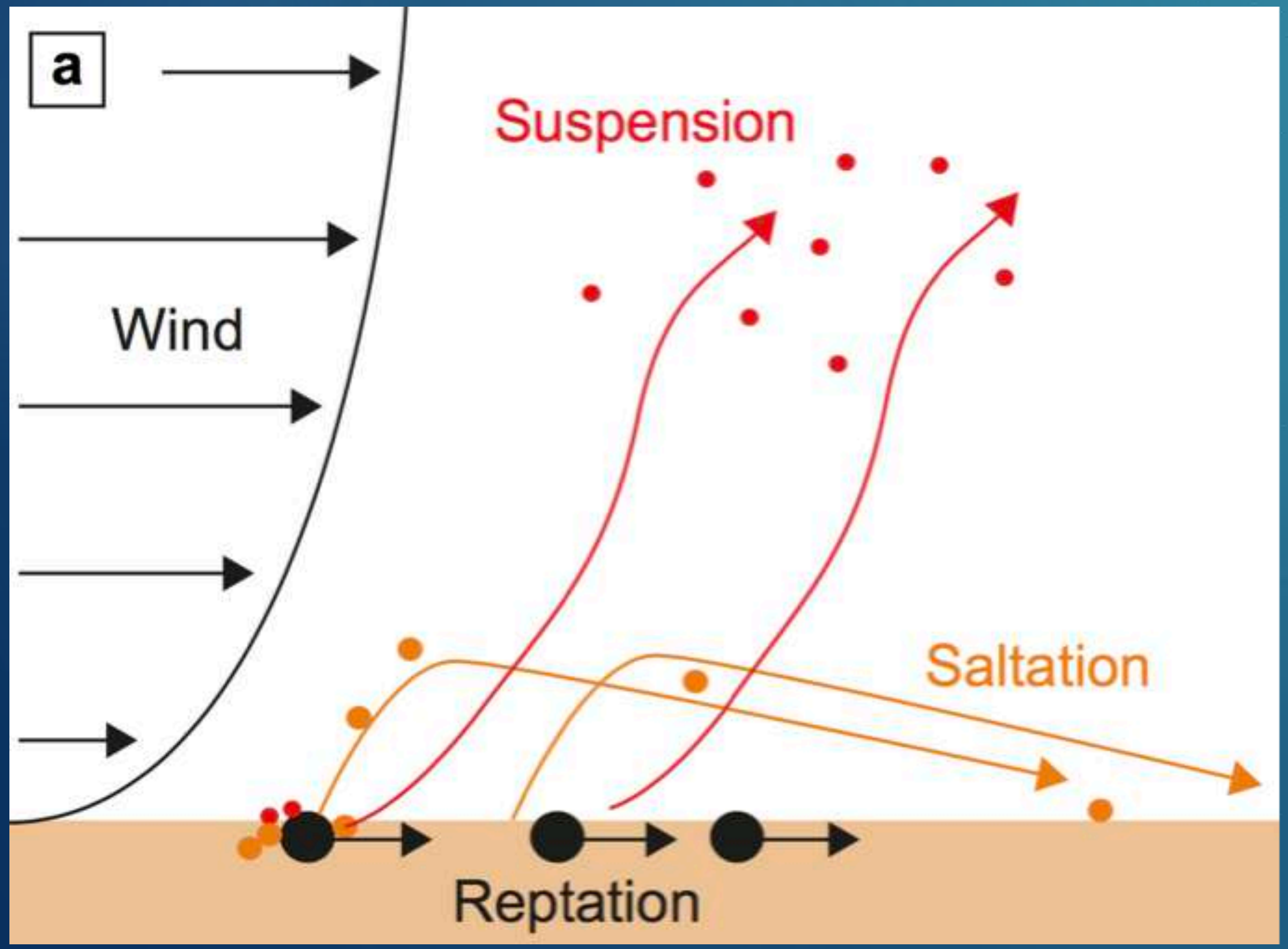
Either active or fossil
Visible typically:

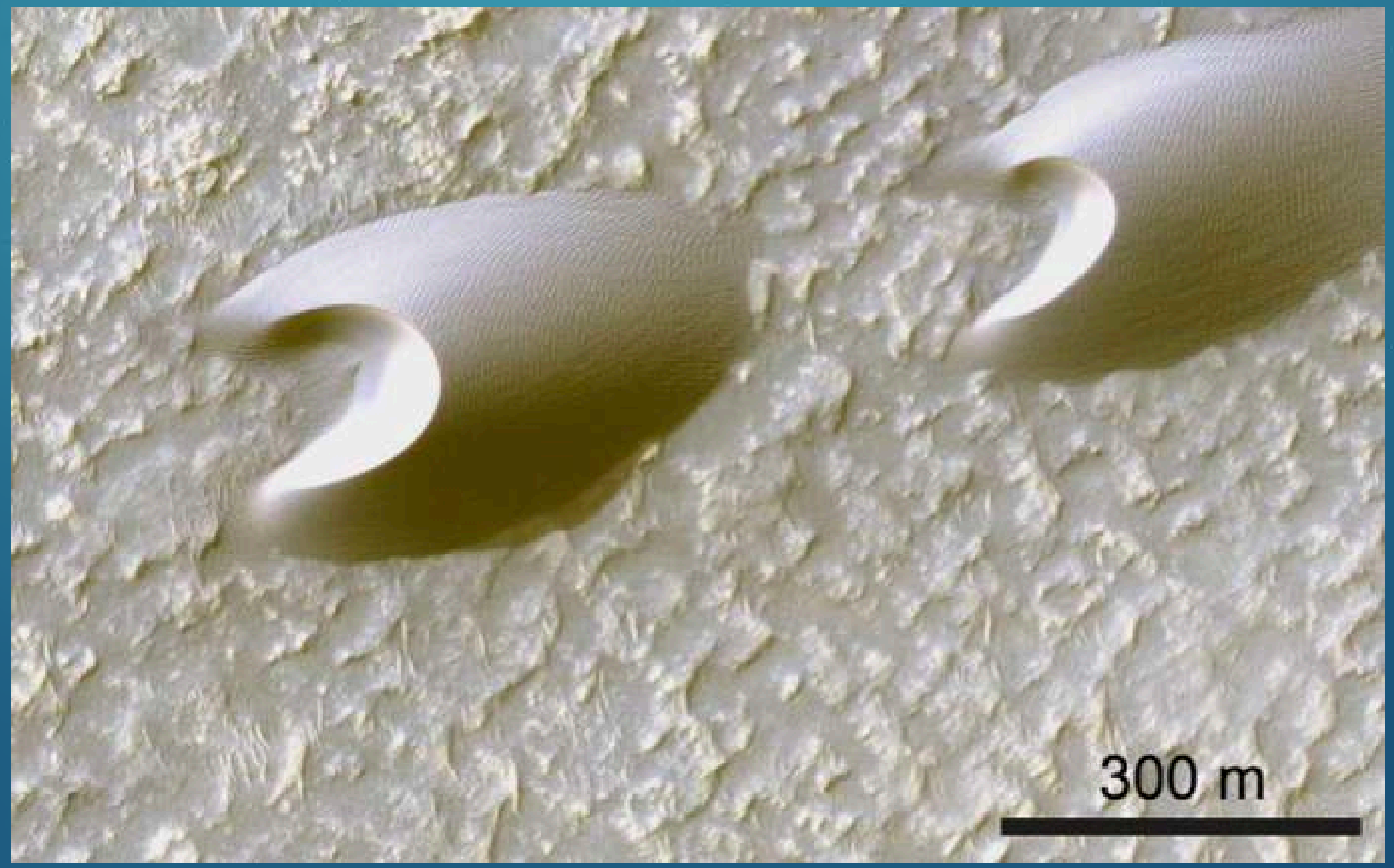
- Short-term (Earth)
- Long-term (Mars)

DEPOSIT

More complex attribution
Visible typically:

- Long-term (Earth)
- Long-term (Mars)
- needs erosion and exhumation





Processes and products

Courtesy A.P. Rossi

PROCESSES

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Ideally → Geomorphological Map

LANDFORM

- Short-term (Earth)
- Long-term (Mars)

DEPOSIT

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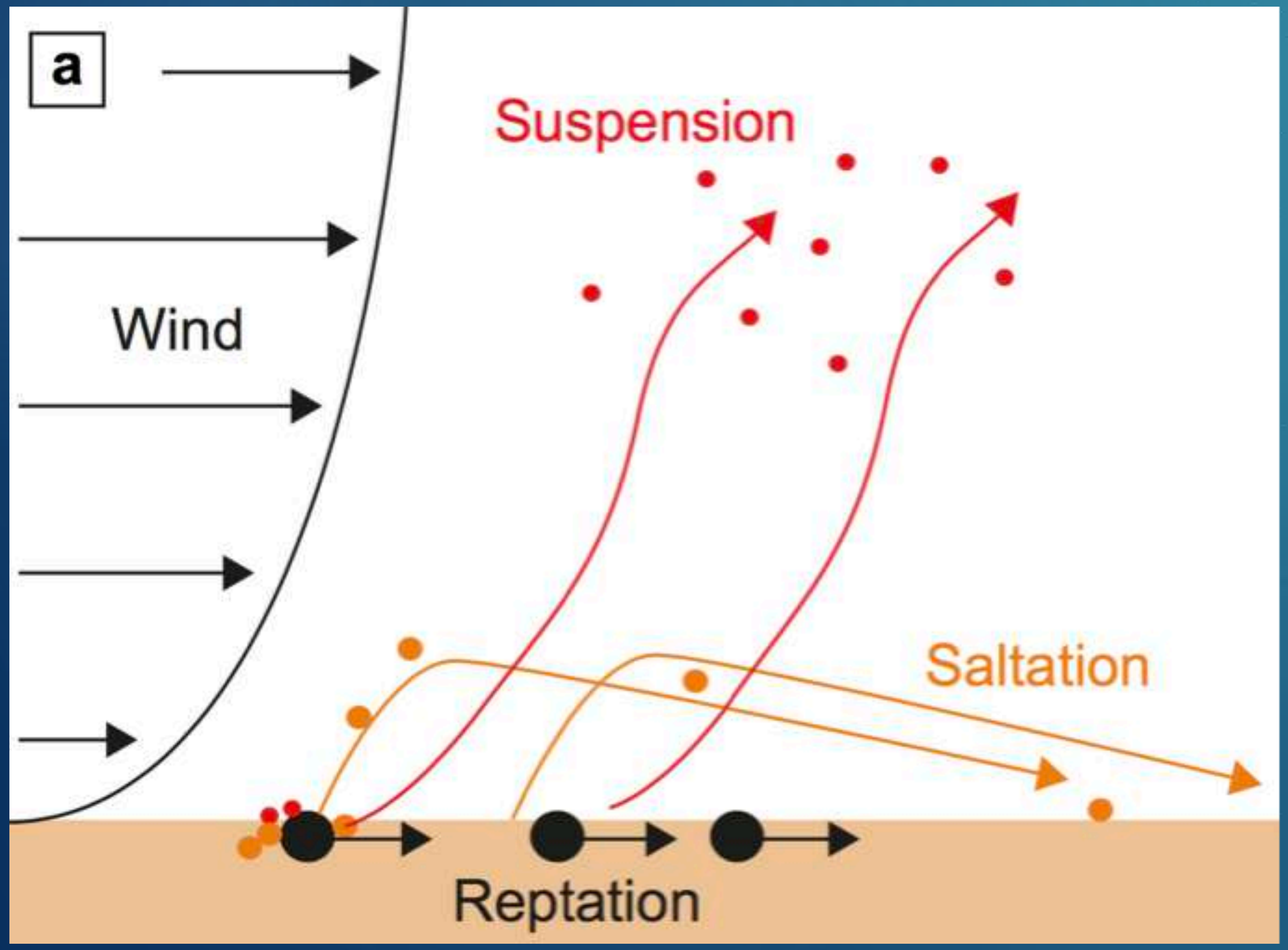

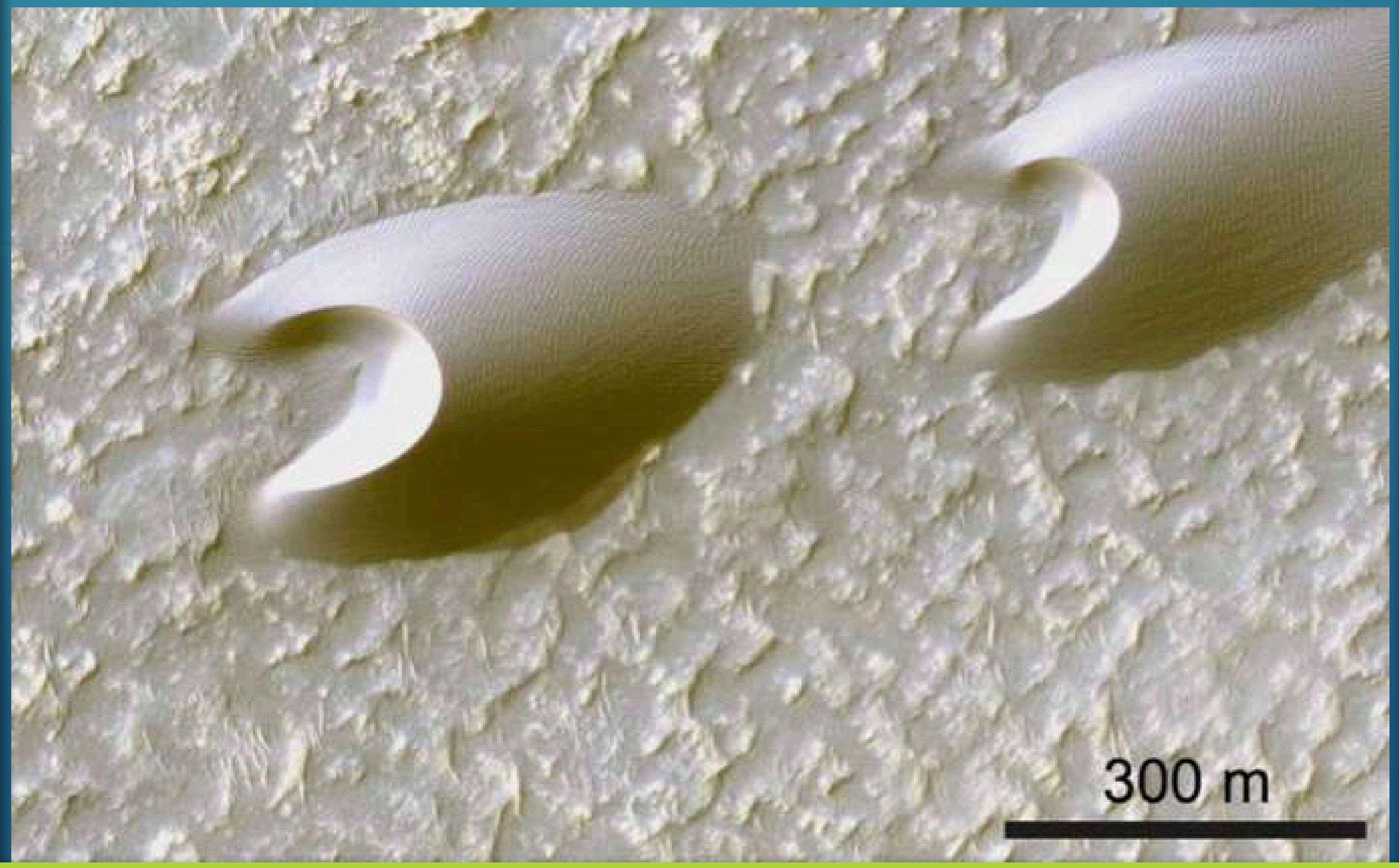

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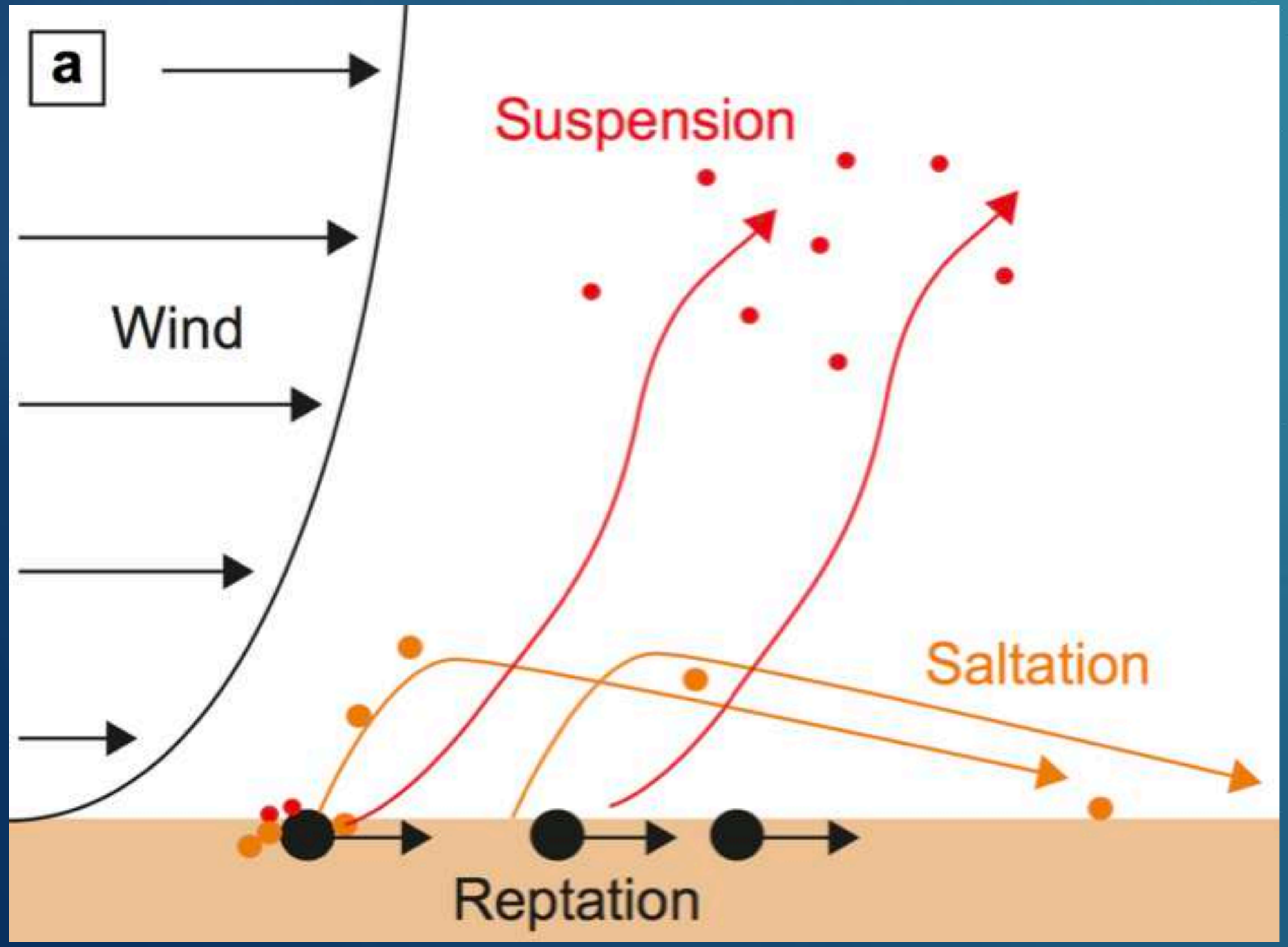
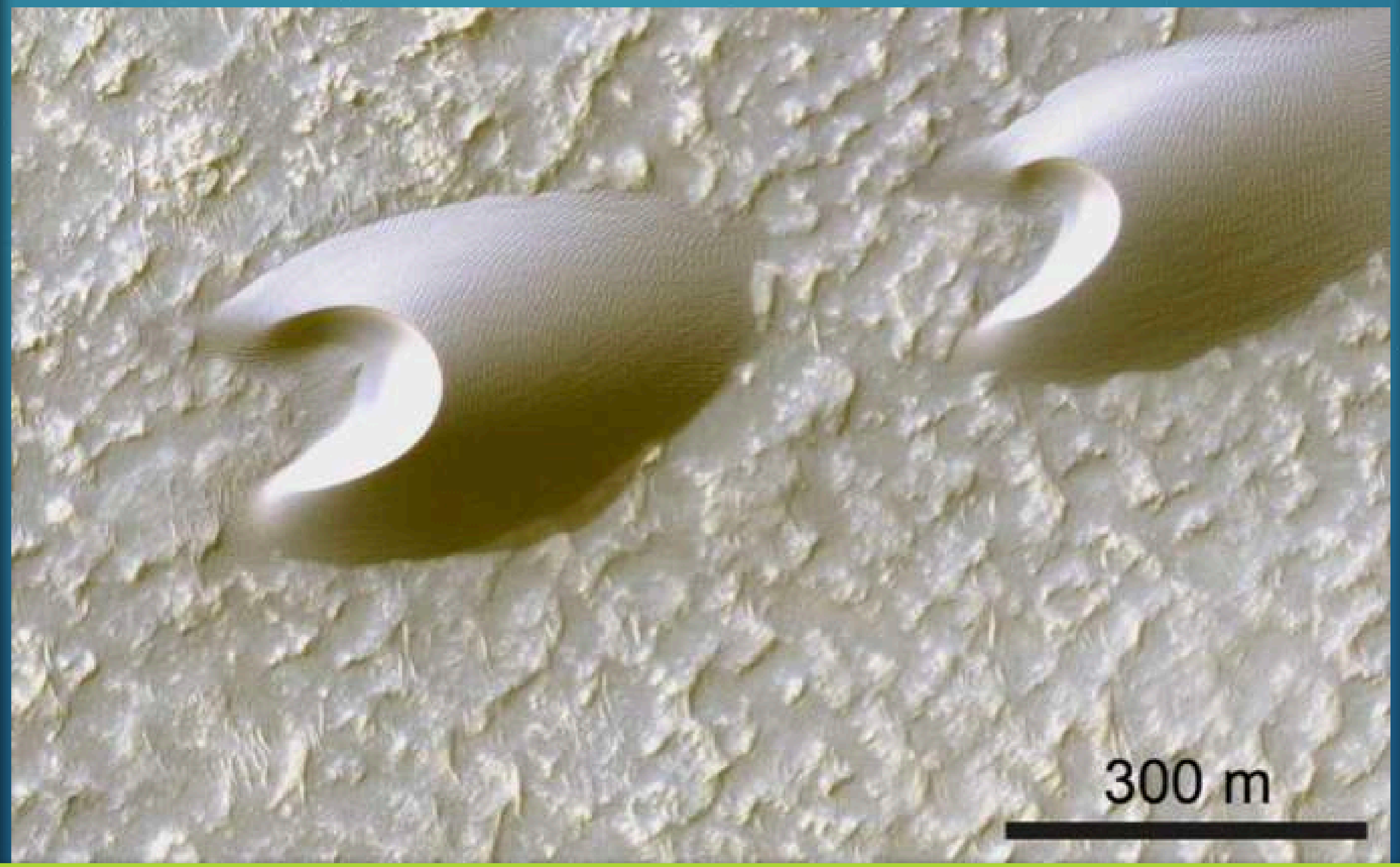


LANDFORM

Ideally → Geomorphological Map

- Long-term (Mars)



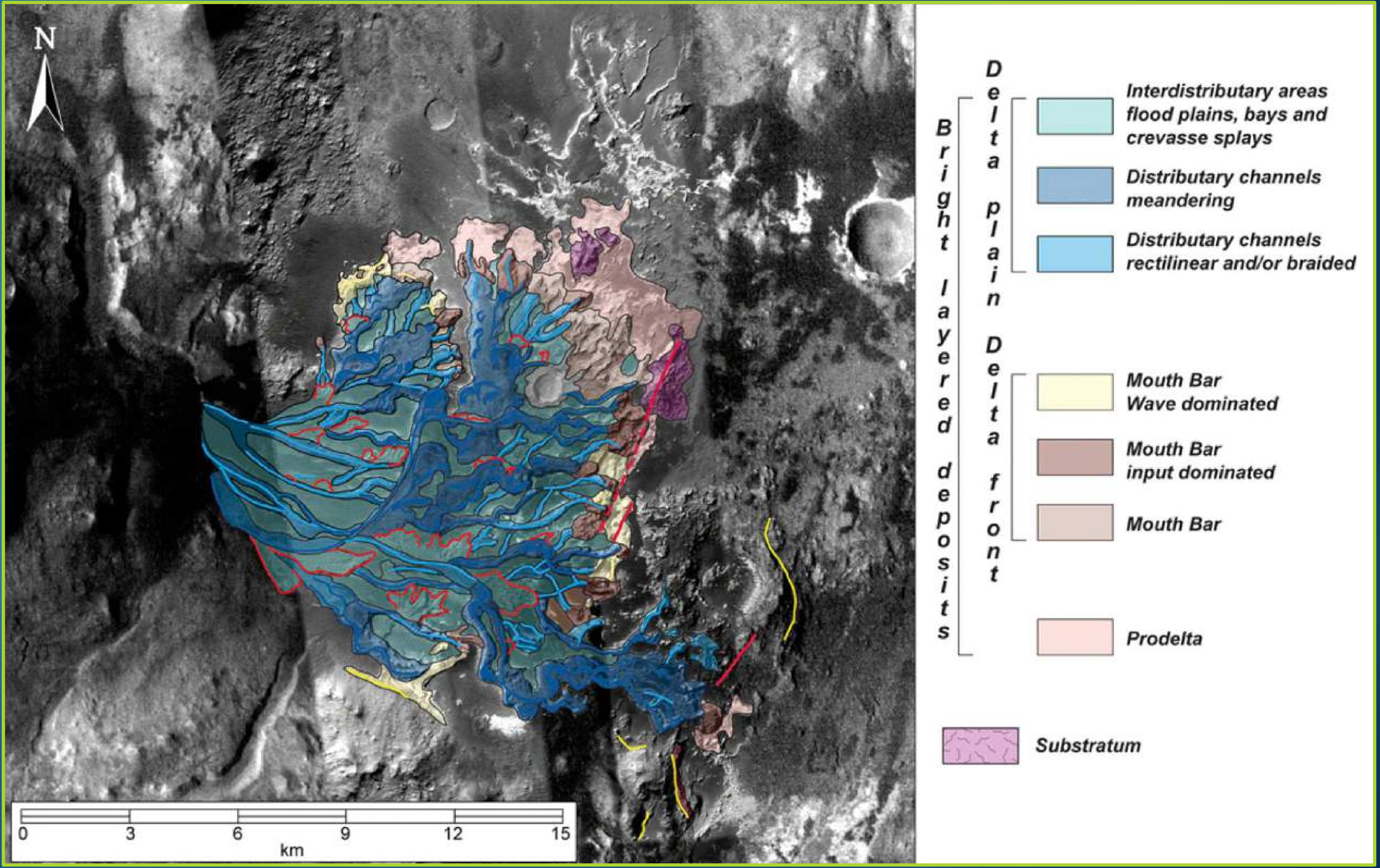
DEPOSIT

Ideally → Geological Map

- Long-term (Mars)
- needs erosion and exhumation

Geomorphological and Geological Maps

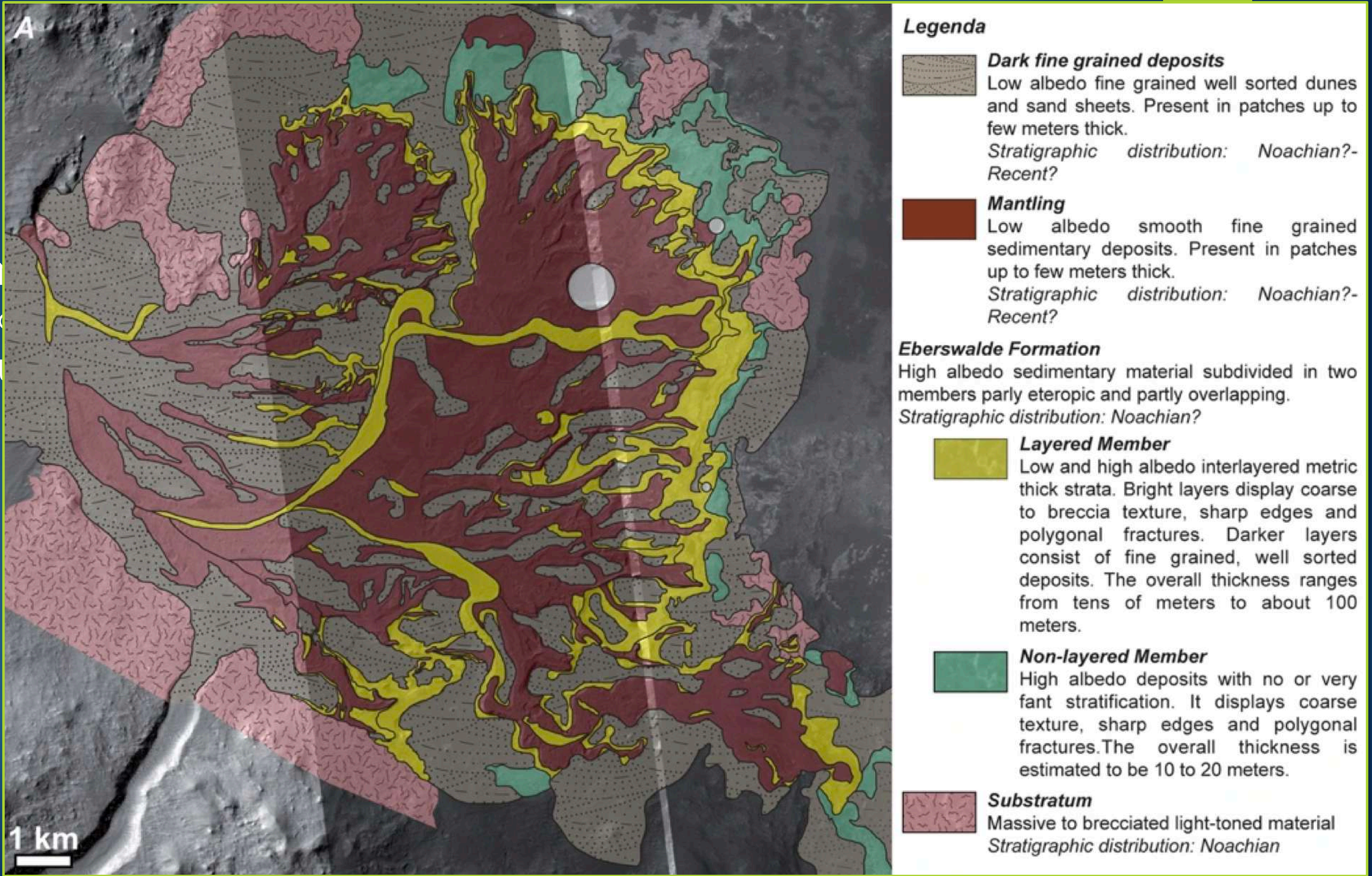
- Landforms with genetic interpretation



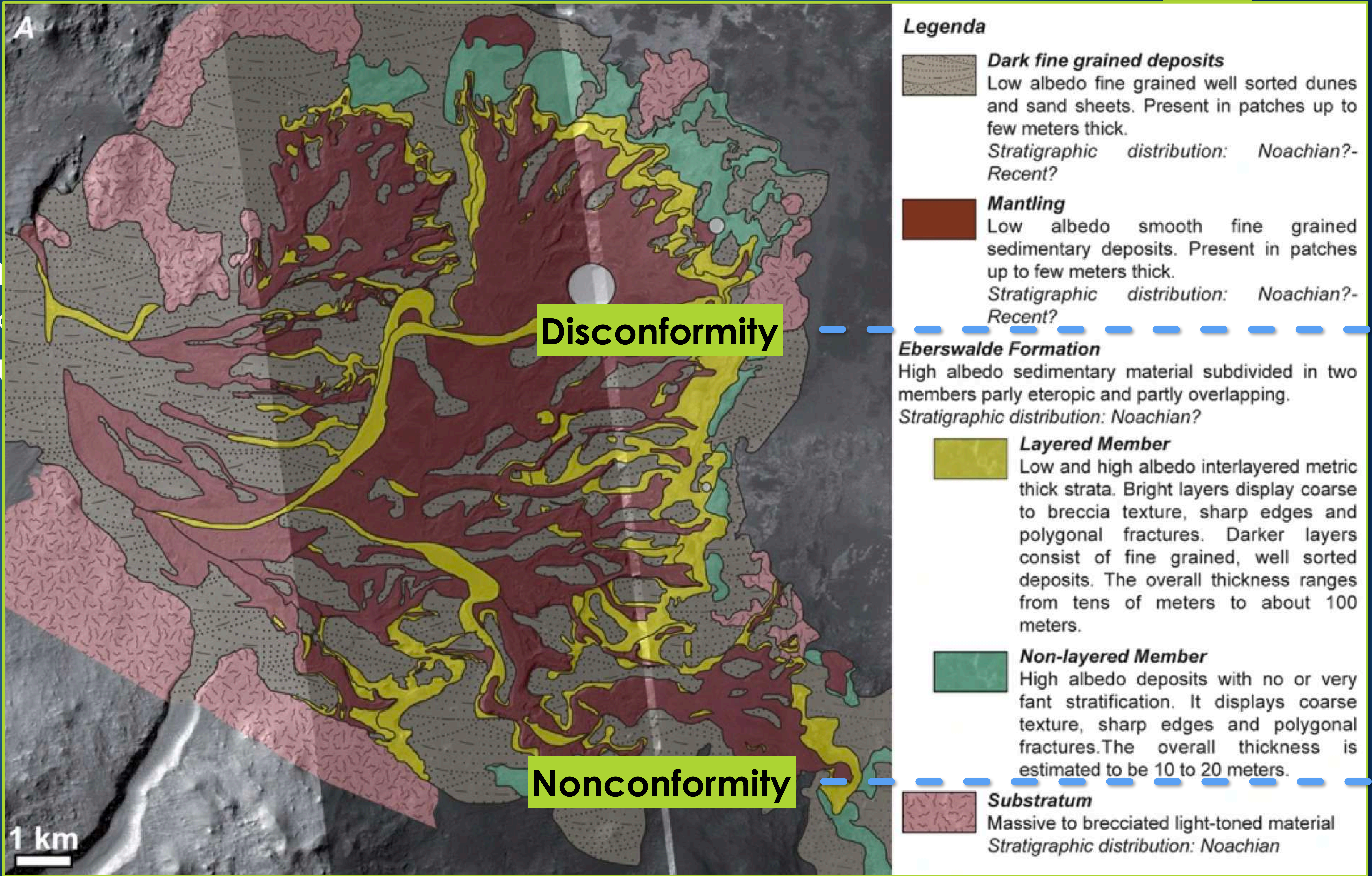
Geomorphological and Geological Maps

- NO lithological information (with the exception of limited hyperspectral-derived mineralogical hints)
- Units defined on the base of relatively 'objective' means:
  - characteristics of the deposits (colour, texture, layered/non layered, sedimentary structures)
    - HRSC, CTX, and HiRISE scale
  - morphologies (geometries without interpretation of environments) both at large and small scale (thicknesses, erosional and depositional geometries);
  - stratigraphic position within the succession

Ge
Ma


A
1 km
Legenda
Dark fine grained deposits
Low albedo fine grained well sorted dunes and sand sheets. Present in patches up to few meters thick.
Stratigraphic distribution: Noachian?-Recent?
Mantling
Low albedo smooth fine grained sedimentary deposits. Present in patches up to few meters thick.
Stratigraphic distribution: Noachian?-Recent?
Eberswalde Formation
High albedo sedimentary material subdivided in two members parly eteropic and partly overlapping.
Stratigraphic distribution: Noachian?
Layered Member
Low and high albedo interlayered metric thick strata. Bright layers display coarse to breccia texture, sharp edges and polygonal fractures. Darker layers consist of fine grained, well sorted deposits. The overall thickness ranges from tens of meters to about 100 meters.
Non-layered Member
High albedo deposits with no or very fant stratification. It displays coarse texture, sharp edges and polygonal fractures.The overall thickness is estimated to be 10 to 20 meters.
Substratum
Massive to brecciated light-toned material
Stratigraphic distribution: Noachian

Ge
Ma


A
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Substratum
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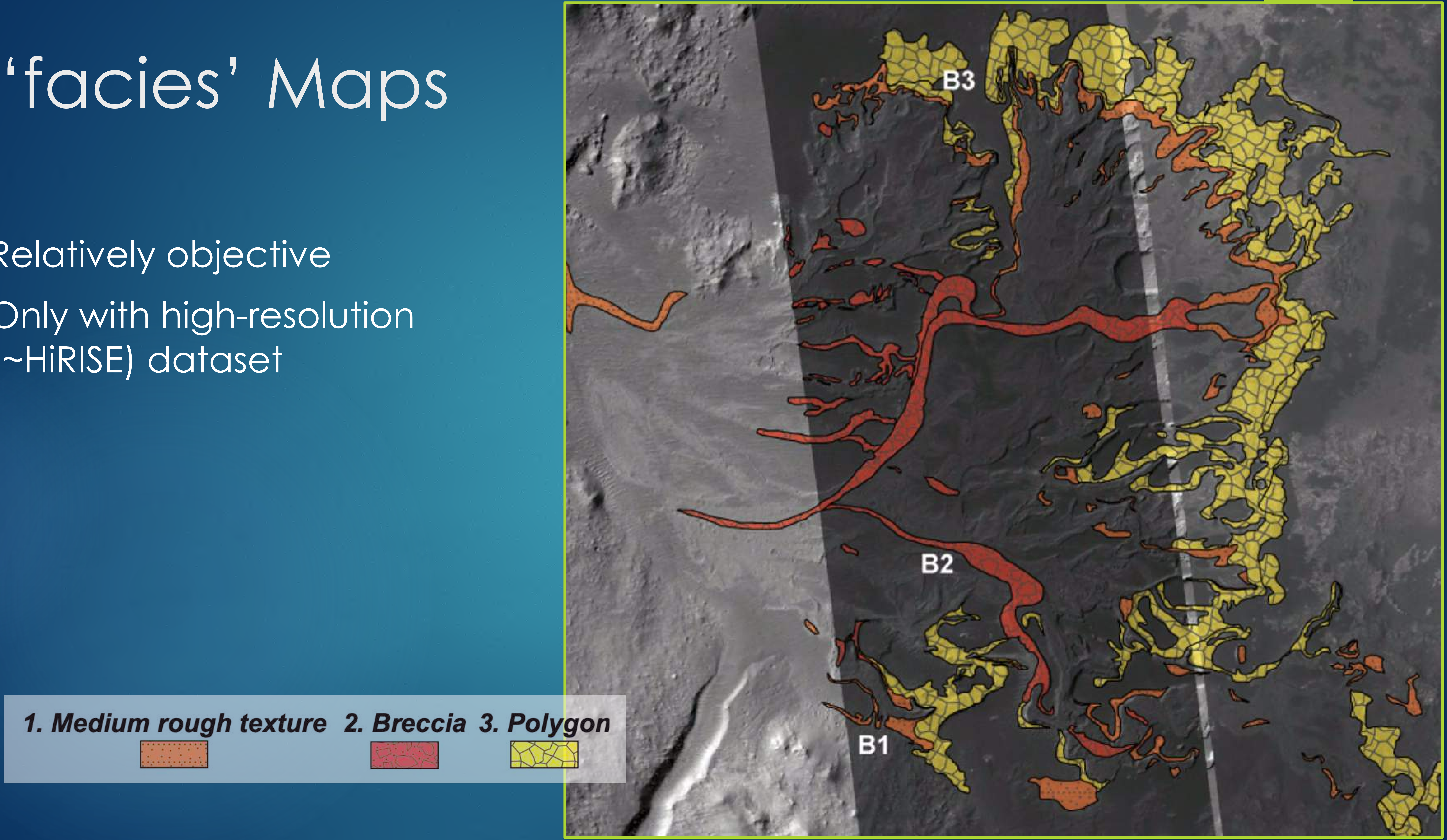
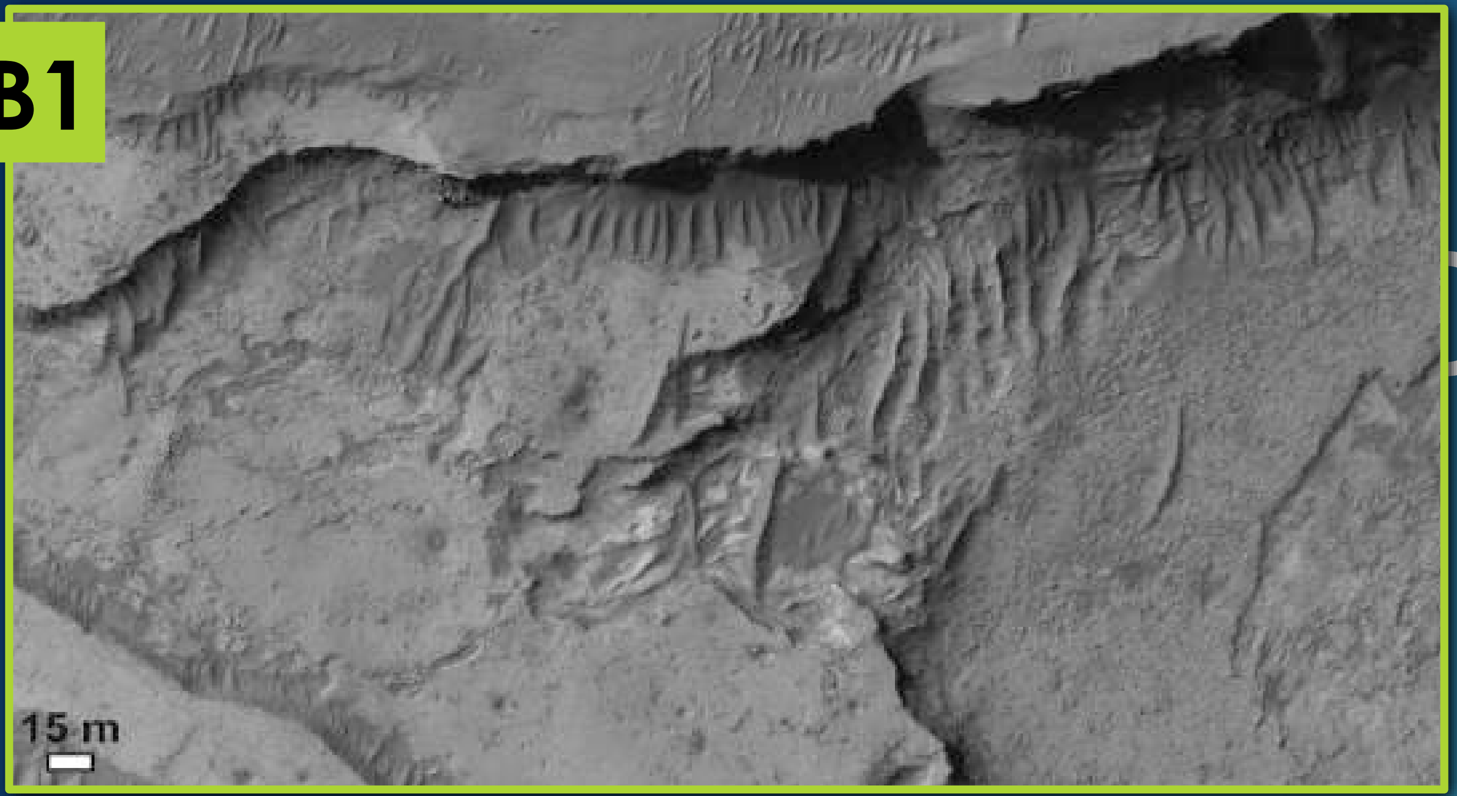
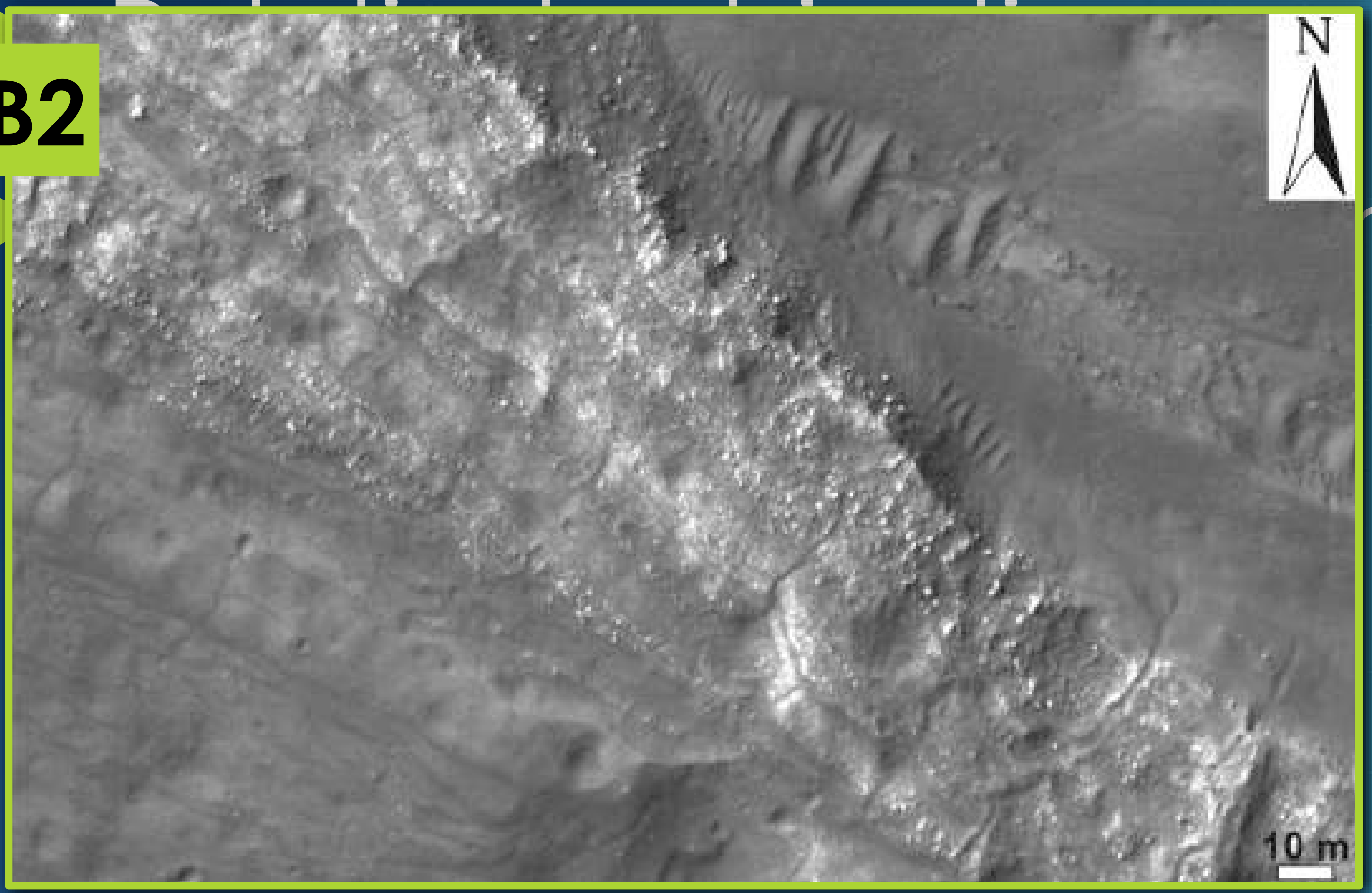
Stratigraphic distribution: Noachian

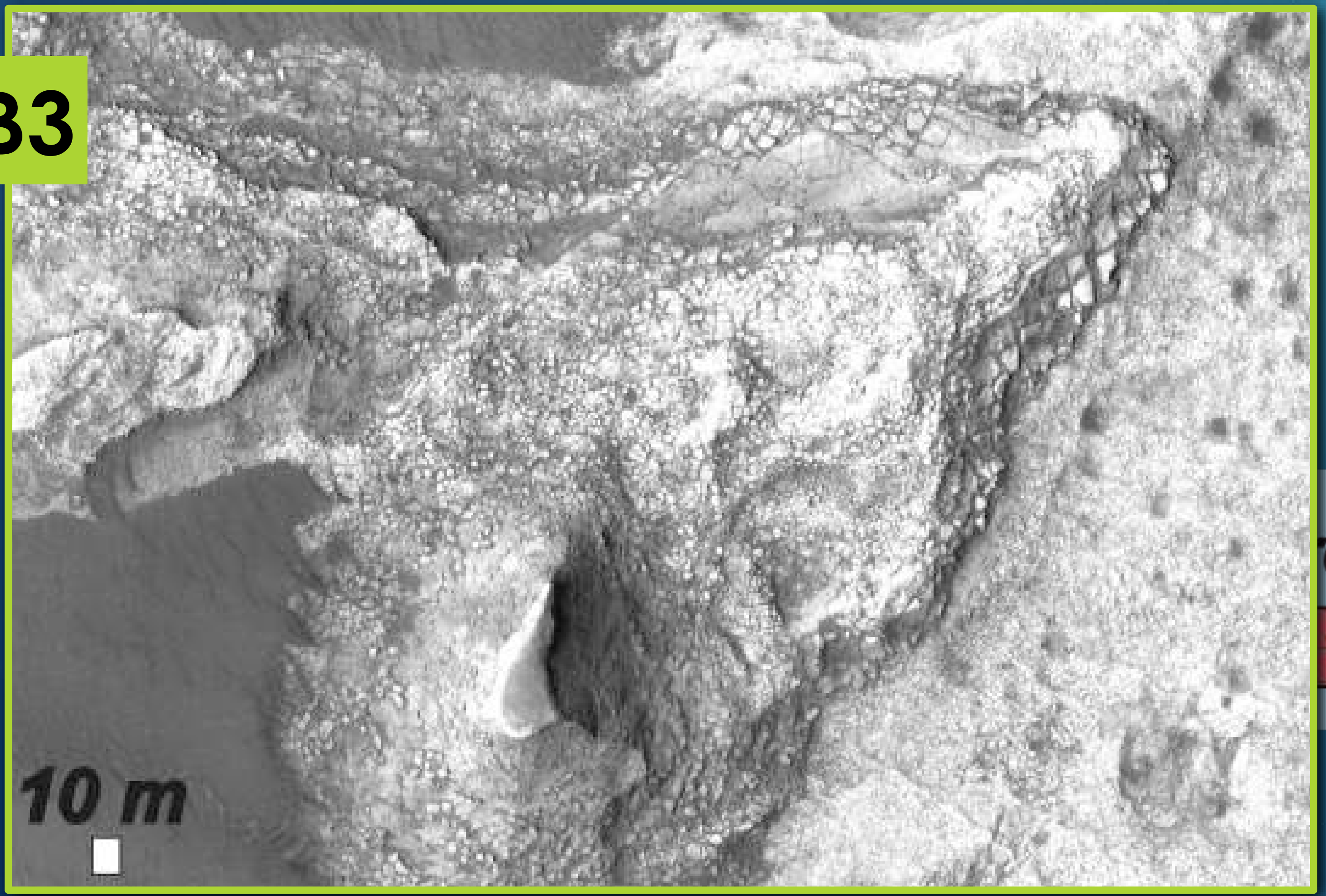
‘facies’ Maps

- Relatively objective
- Only with high-resolution (~HiRISE) dataset

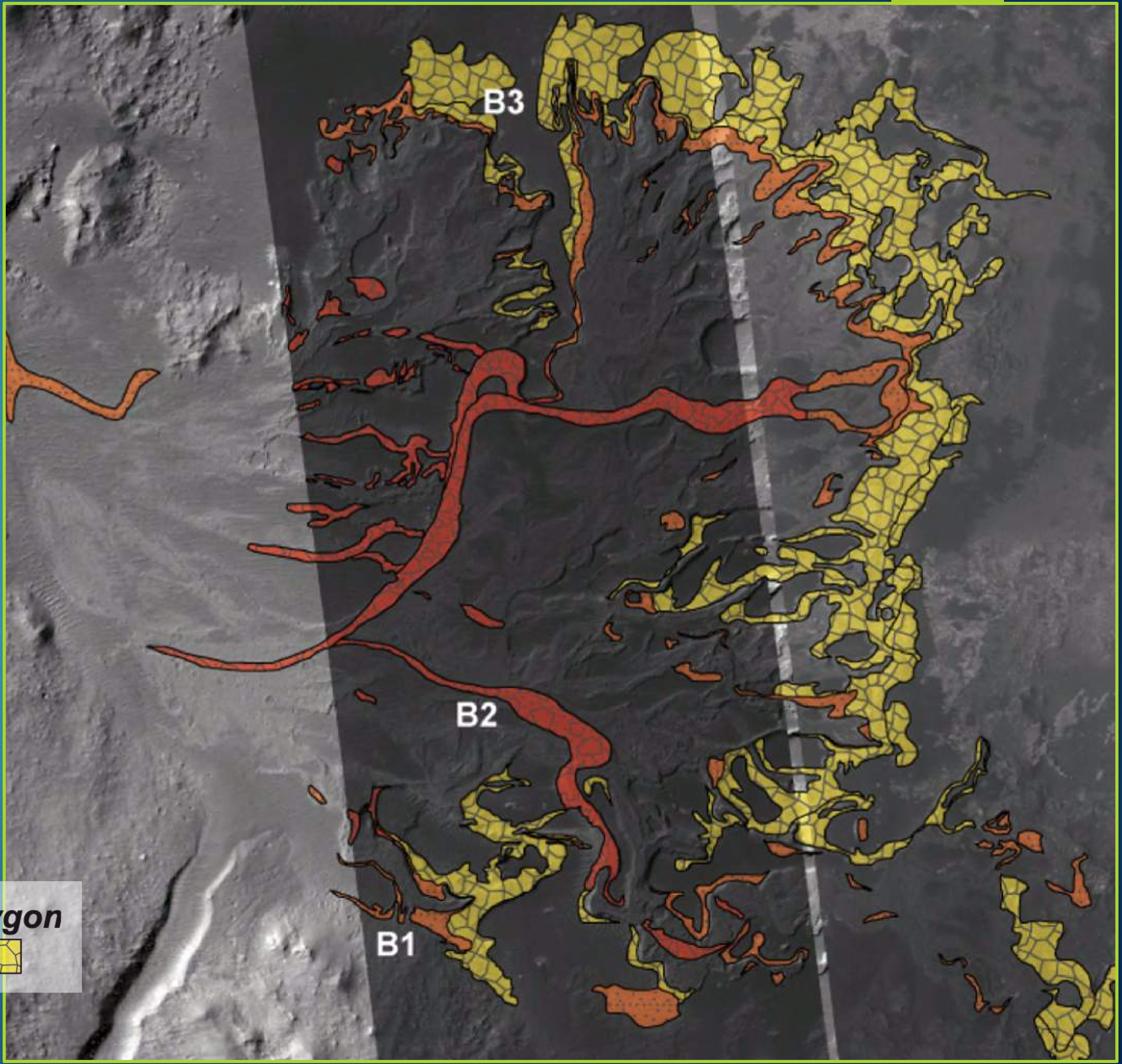








eccia 3. Polygon



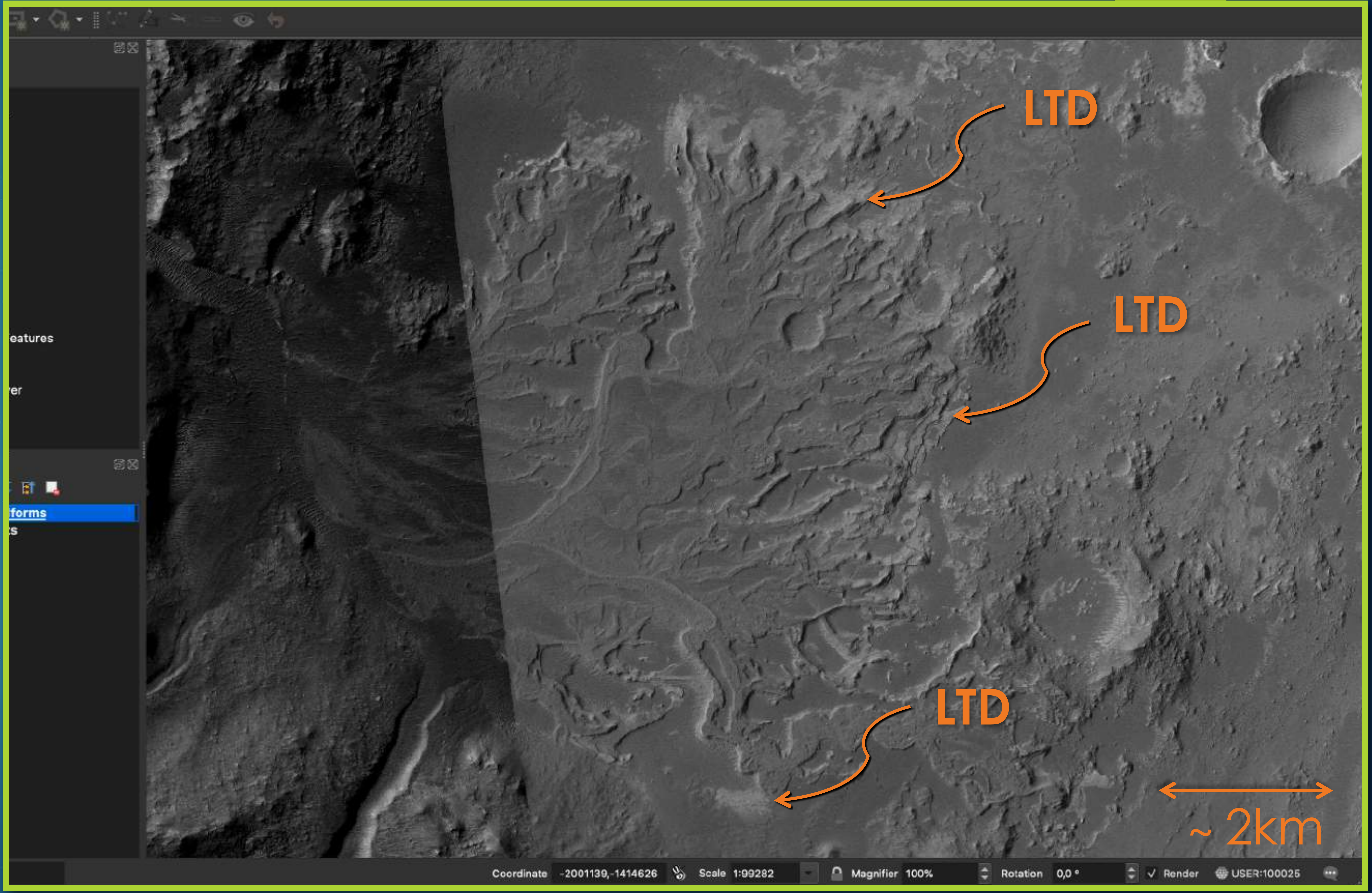
The concept of ‘stratotype’ in planetary mapping

- **REFERENCE AREA**
- The type section of a stratigraphic unit that serves as the standard of reference for the definition and characterization of the unit.
- It means a physical place where all the characteristics of a given unit of any kind can be observed
- Should precede the actual map phase
- Best occurrence of a given unit, at all scales (i.e., different imagery/ resolution)

Reference area example ⇢ LTD (light-toned deposits) in Eberswalde crater

HRSC

- Light-toned
- Associated to a fan-like landform. Distributed only in correspondence of this feature.



Reference area example ⇢ LTD (light-toned deposits) in Eberswalde crater

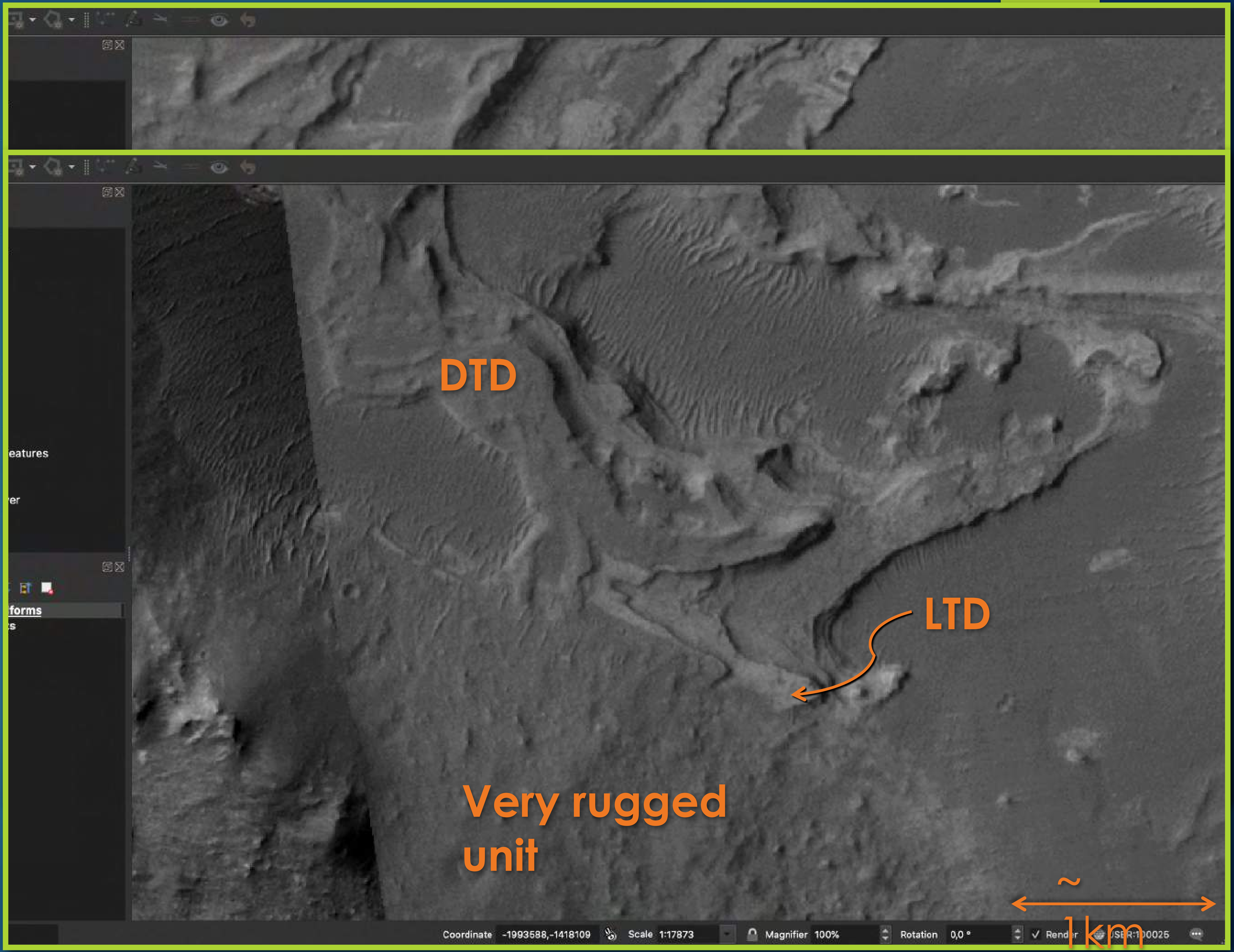
CTX

- Rugged, light-toned, layered, onlap the very rugged unit, covered by the DTD.

Reference area example ⇢ LTD (light-toned deposits) in Eberswalde crater

CTX

- Rugged, light-toned, layered, onlap the very rugged unit, covered by the DTD.

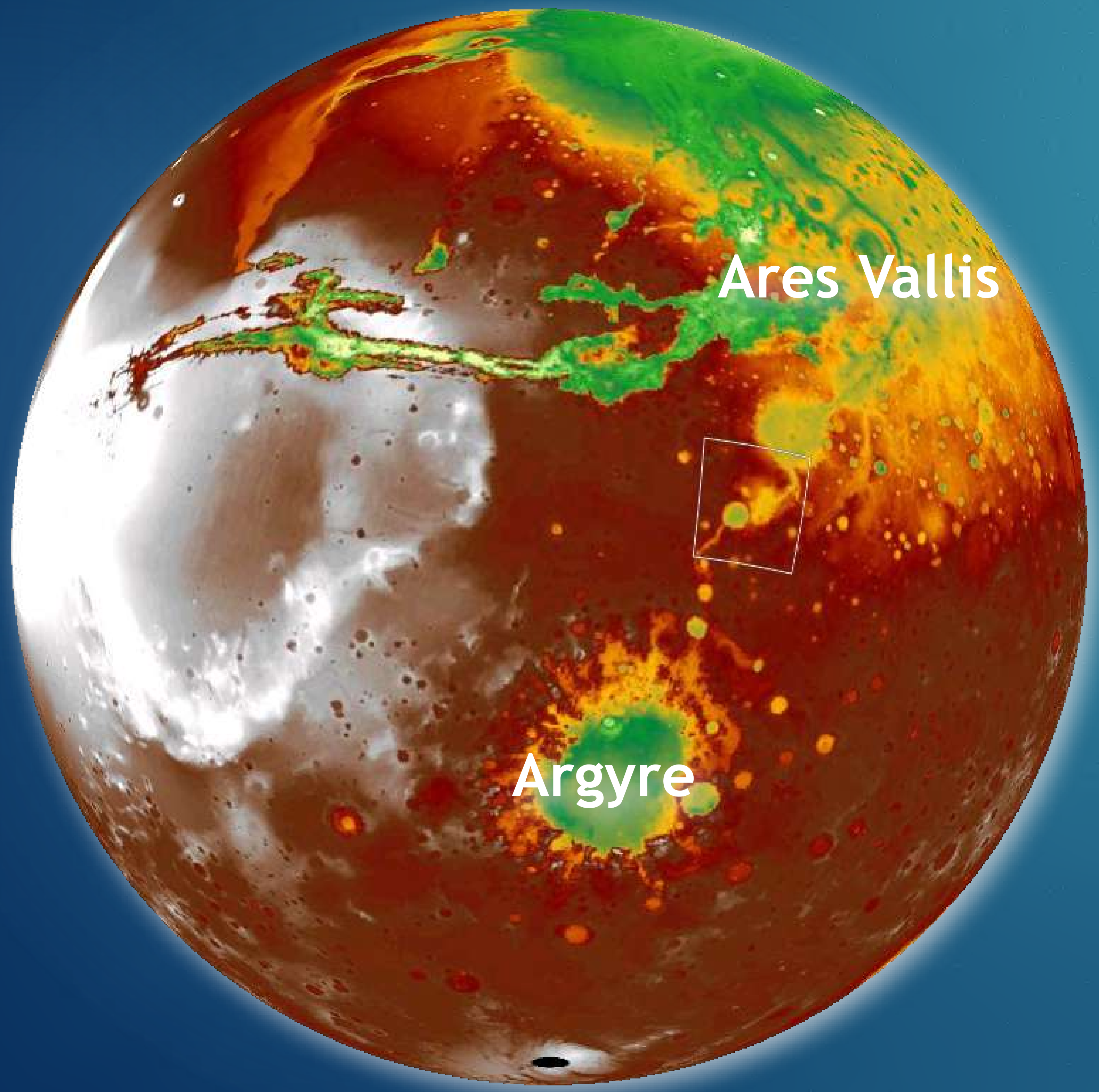


Reference area example ⇢ LTD (light-toned deposits) in Eberswalde crater

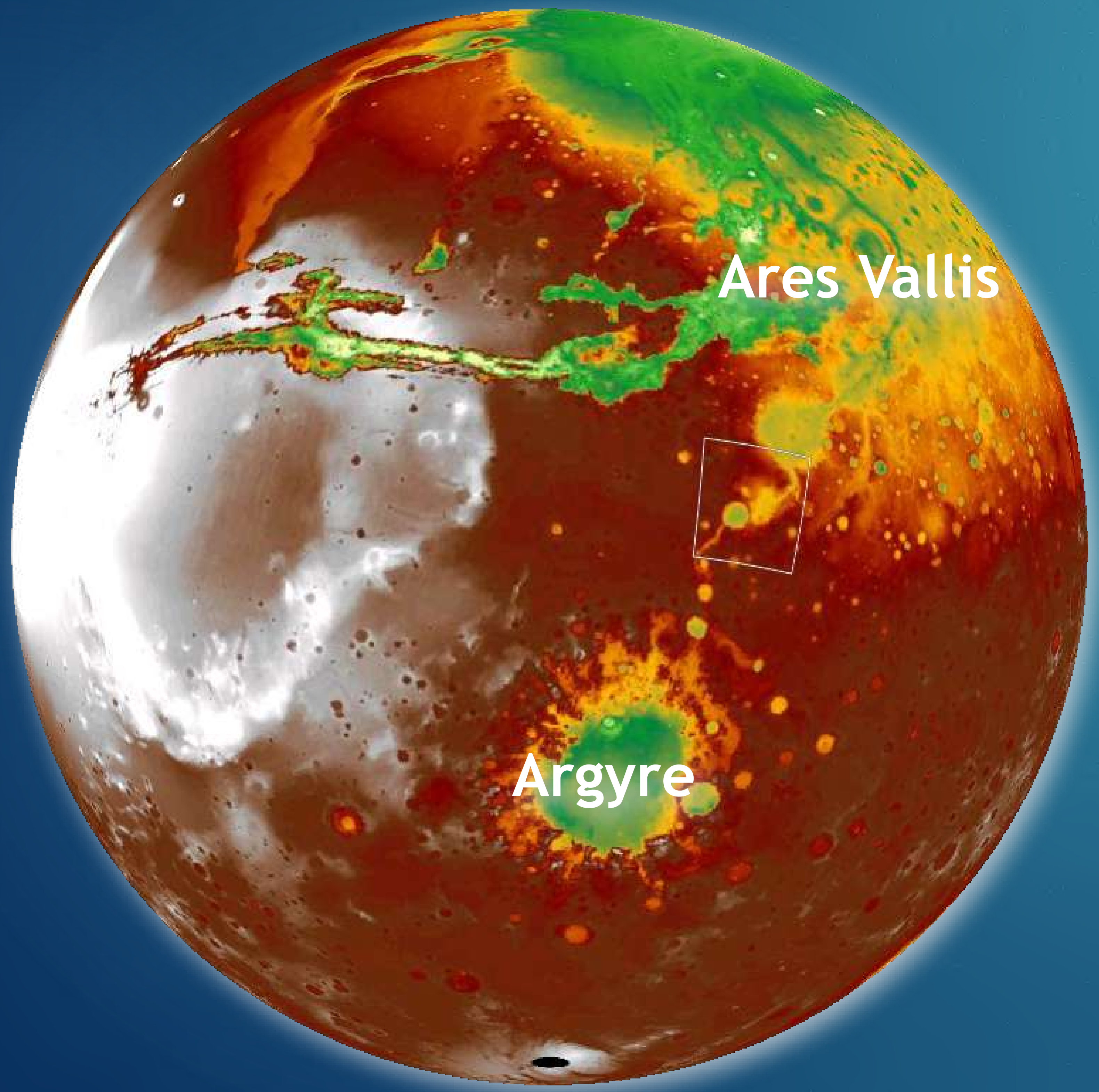
HiRISE

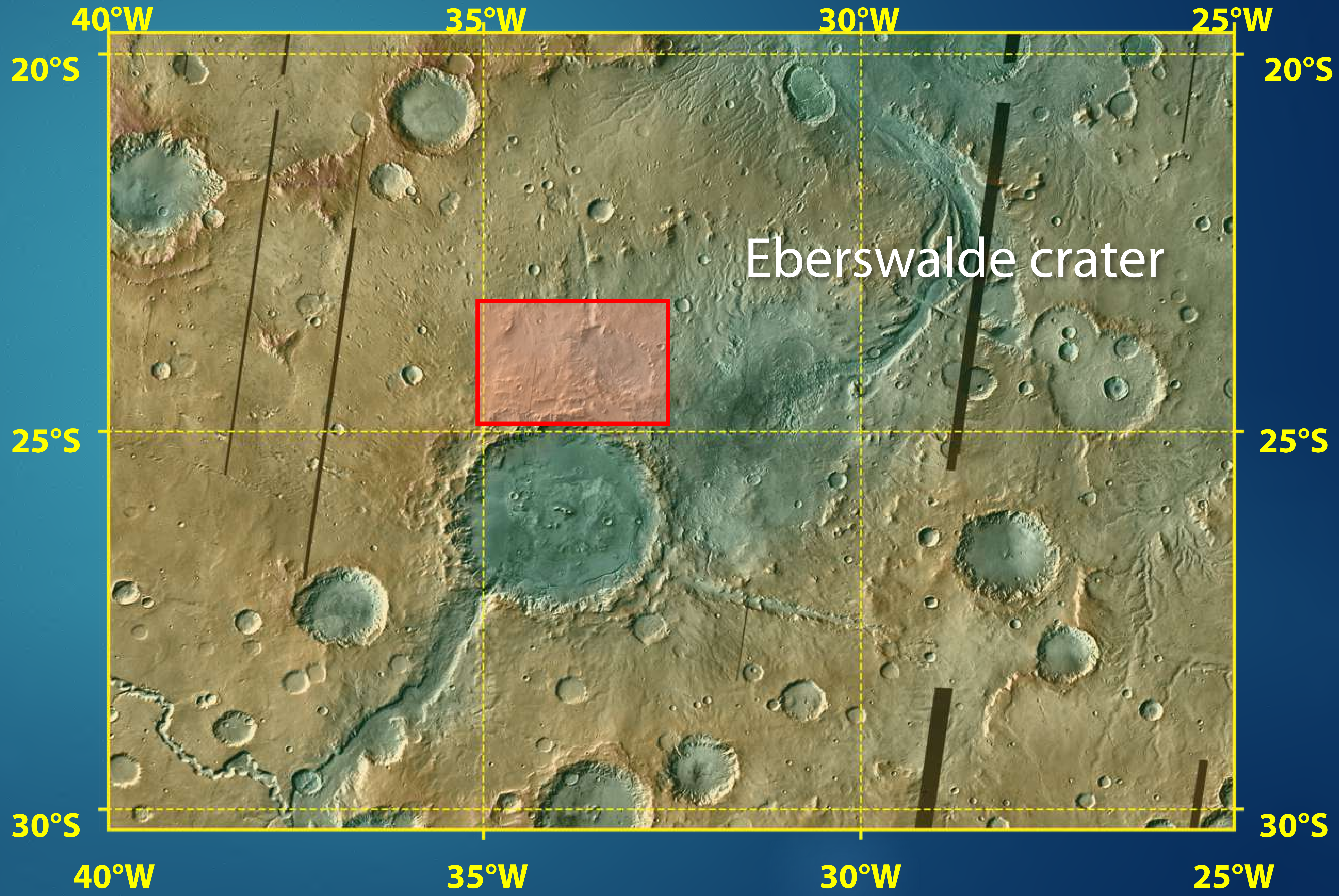
- Light-toned beds disrupted in a polygonal pattern
- DTD lies disconformably

The importance of stratigraphy: example from the fan-like feature in Eberswalde crater



The importance of stratigraphy: example from the fan-like feature in Eberswalde crater





Eberswalde 'delta-like' feature

- Considered the 'smoking gun' evidence to prove the presence of persistent water flow on Mars.
- BUT Olivine detected in the crater (McKeown and Rice, 2011)

Malin and Edgett, 2003

Eberswalde ‘delta-like’ feature

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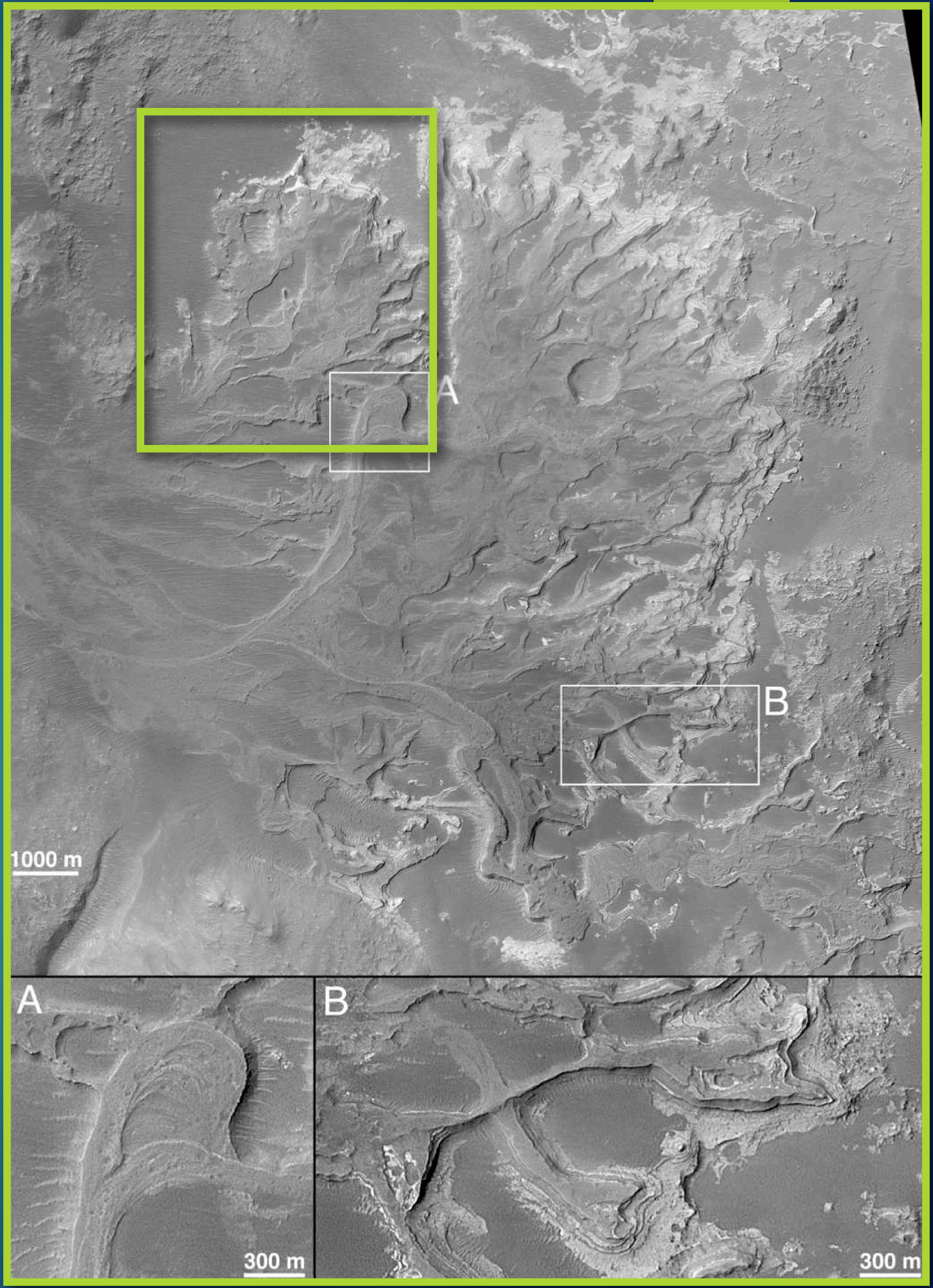
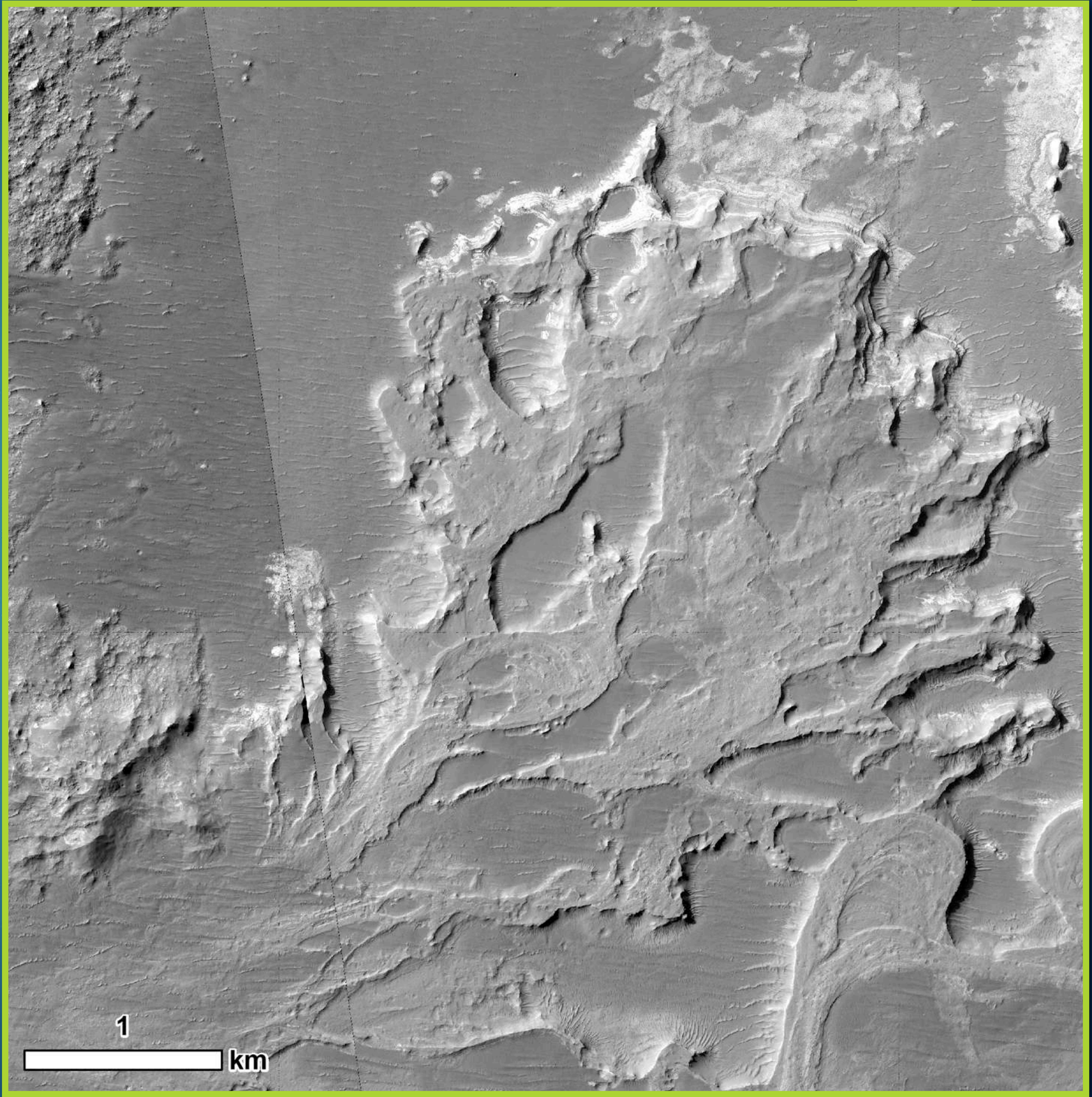


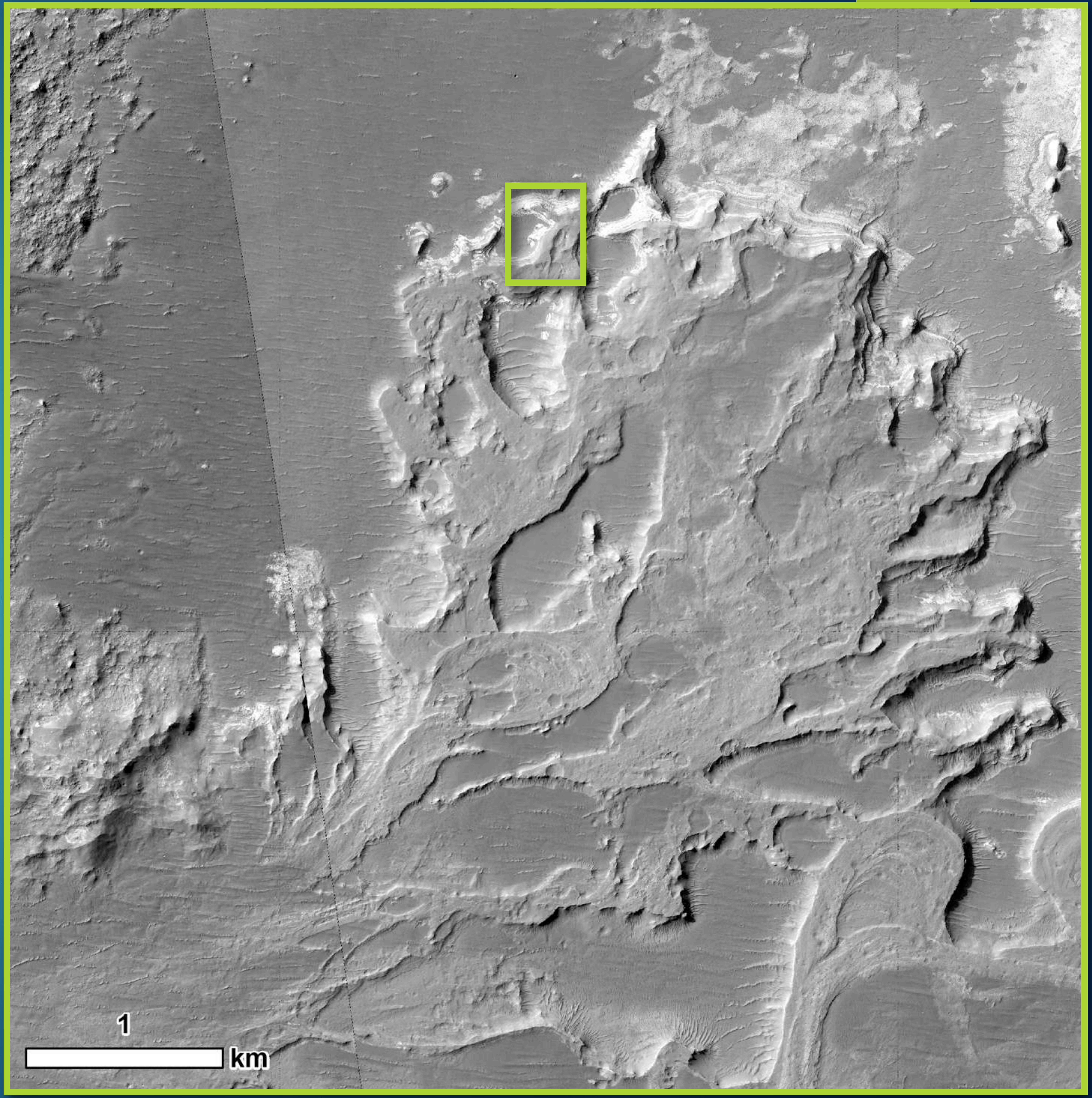
Malin and Edgett, 2003

Light-toned and dark-toned olivine-bearing deposits

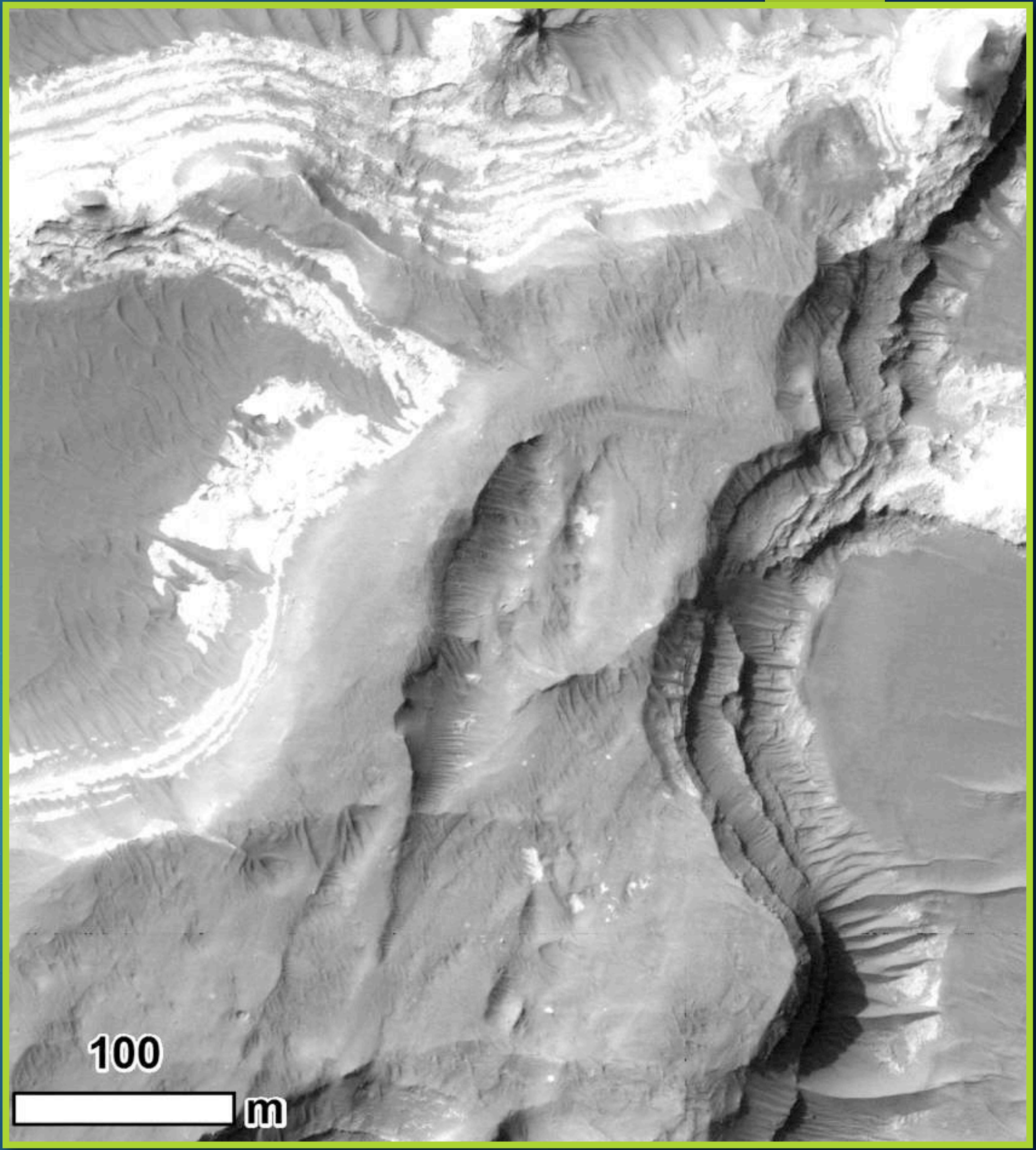


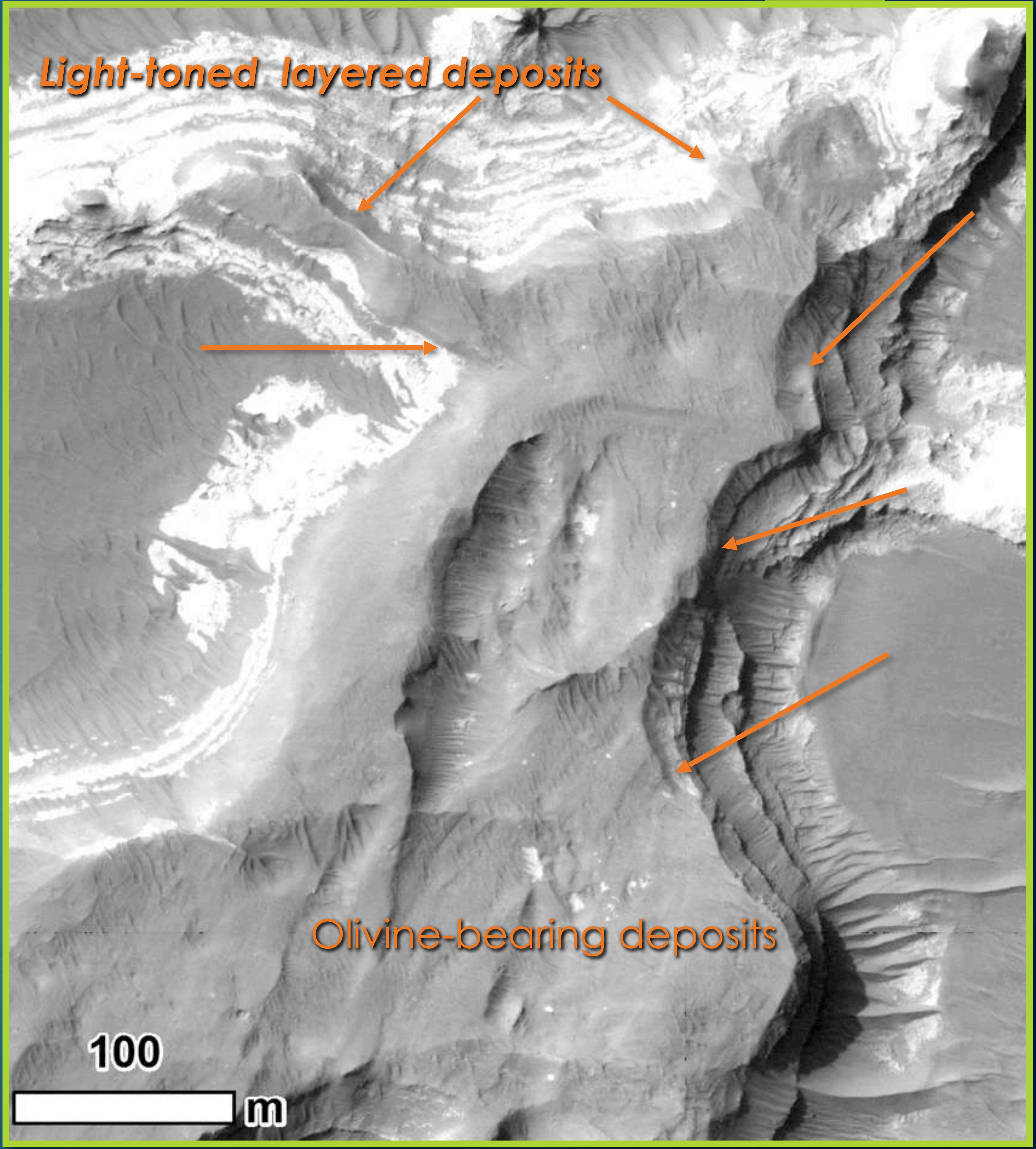
Disconformity between putative deltaic deposits and olivine-bearing deposits

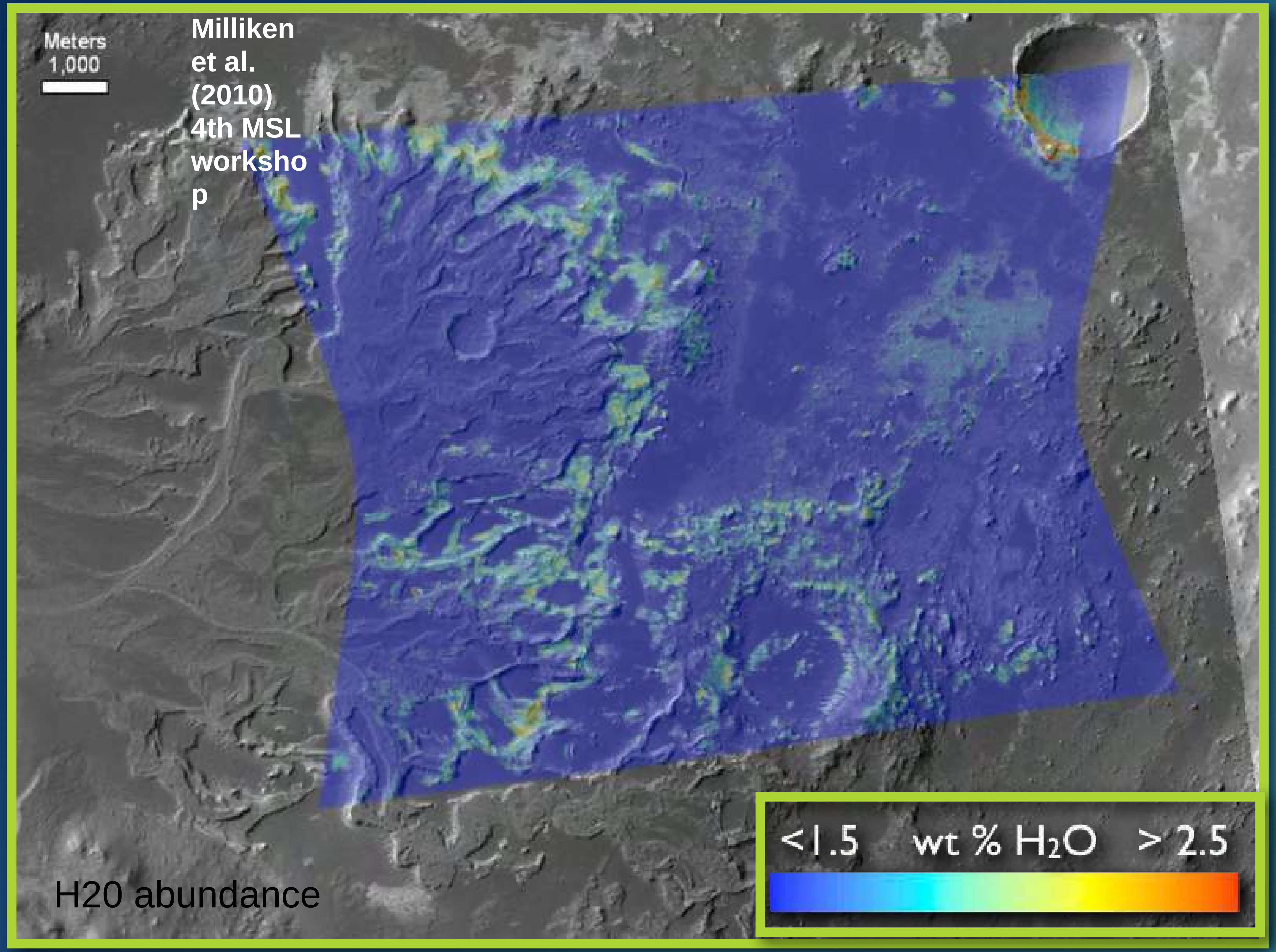
Light-toned and dark-toned olivine-bearing deposits

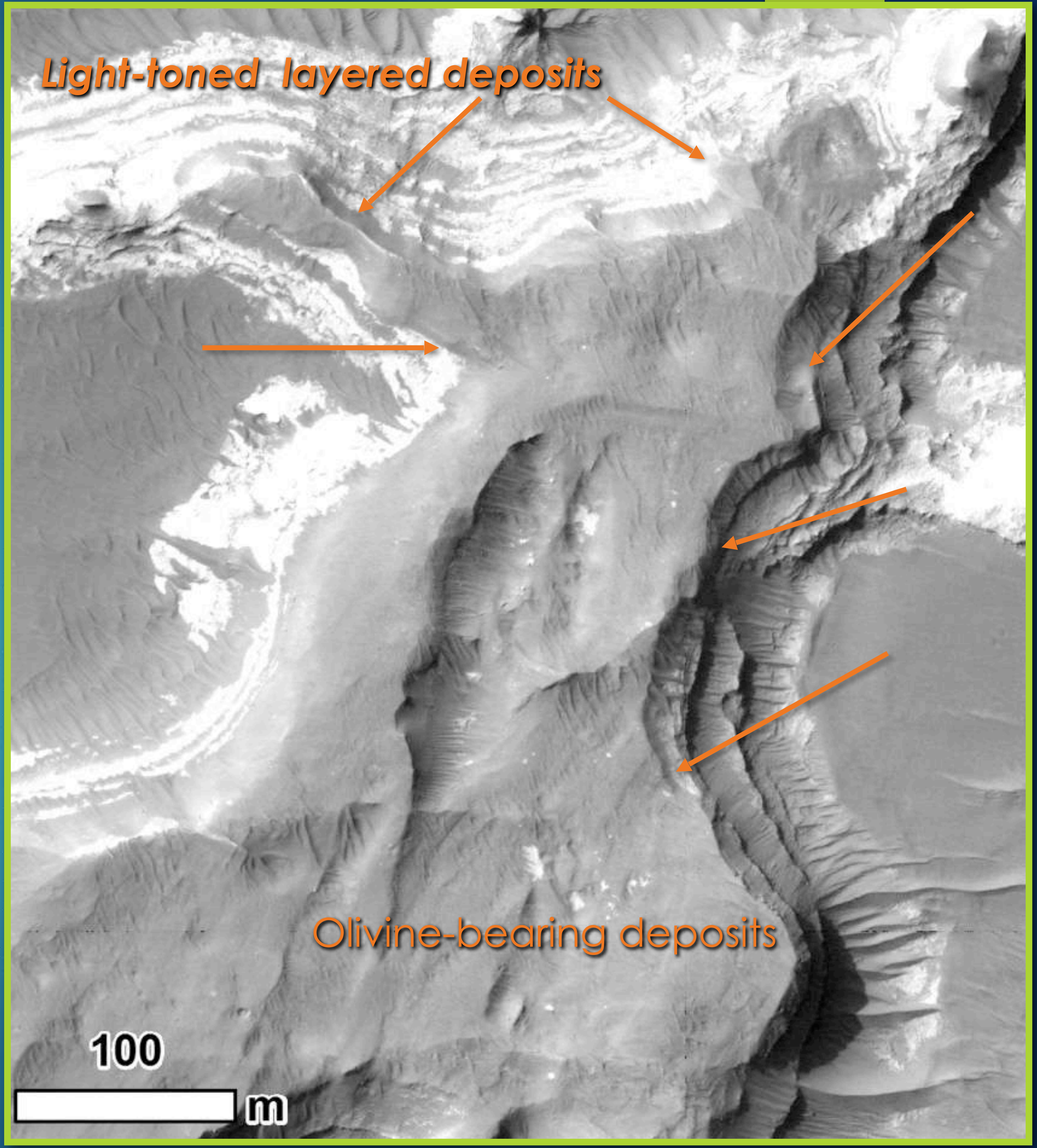


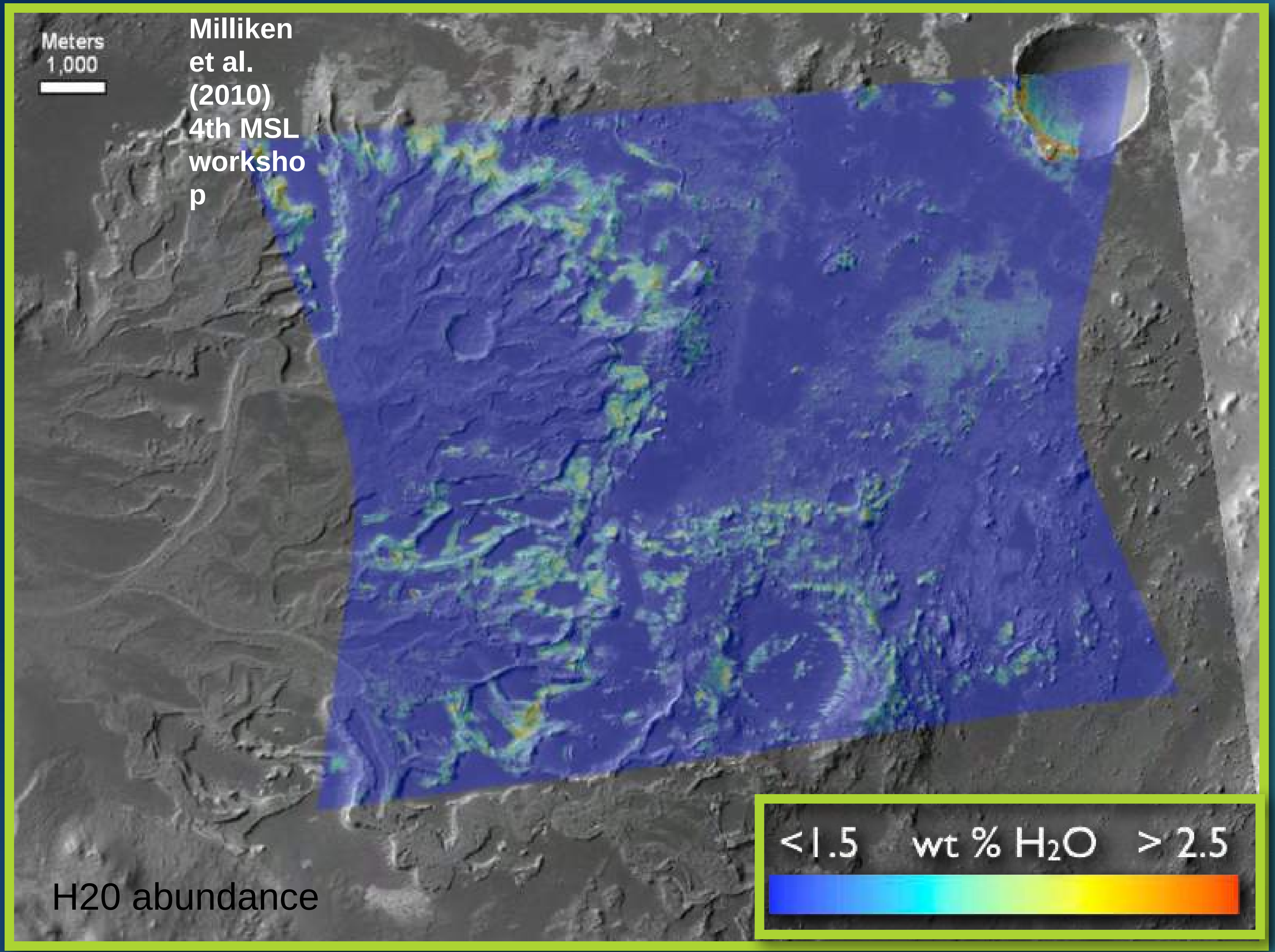
Disconformity between putative deltaic deposits and olivine-bearing deposits

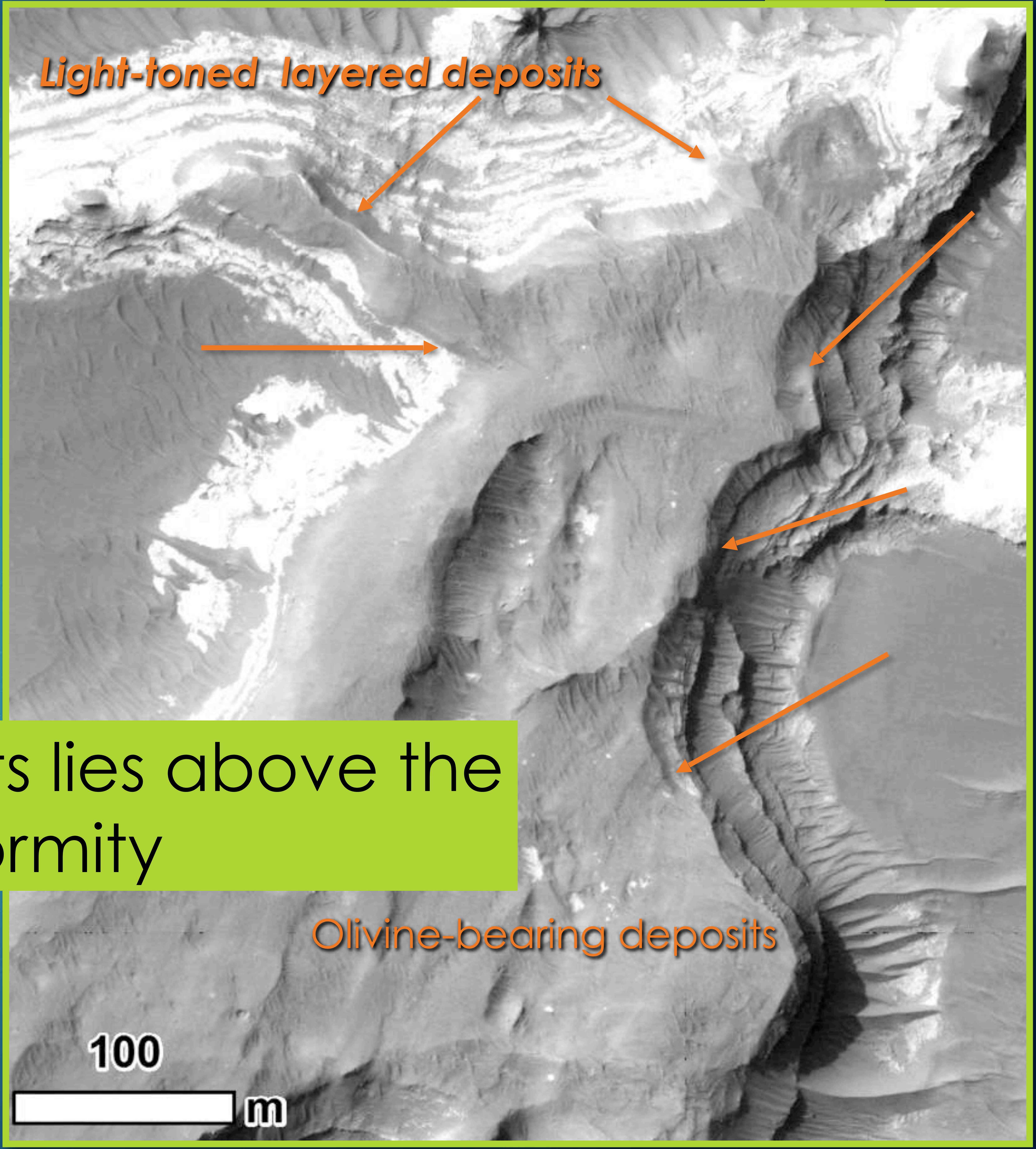

100
m


Light-toned layered deposits
Olivine-bearing deposits
100
m


Meters
1,000
Milliken et al. (2010) 4th MSL workshop
<1.5 wt % H2O > 2.5
H20 abundance


Light-toned layered deposits
Olivine-bearing deposits
100 m





Olivine-rich deposits lies above the disconformity

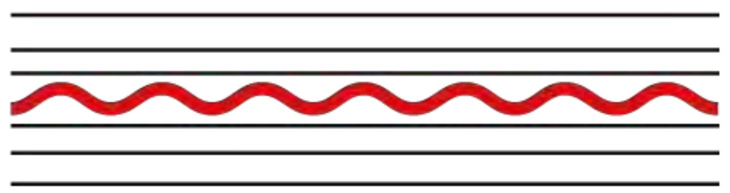
The missing Time

A. **Unconformity** = significant hiatus ± erosion (usually with erosion)

A substantial break or gap in the geological record … It normally implies uplift and erosion with loss of the previously formed record. … Relationship between rock strata in contact, characterized by a lack of continuity in deposition, and corresponding to a period of nondeposition, weathering, or esp. erosion (either subaerial or subaqueous) prior to the deposition of the younger beds.

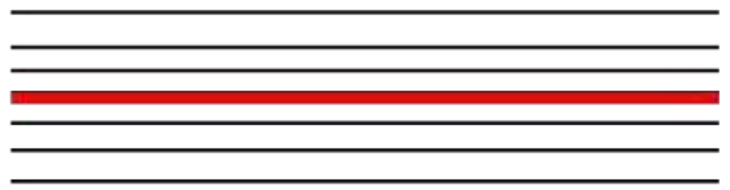
1. **Disconformity** = hiatus + erosion

   An unconformity in which the bedding planes above and below the break are essentially parallel, indicating a significant interruption in the orderly sequence of sedimentary rocks, generally by a considerable interval of erosion ..., and usually marked by a visible and irregular or uneven erosion surface of appreciable relief.



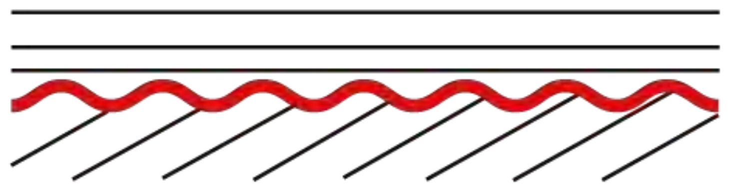
2. **Paraconformity** = hiatus ± erosion (no discernable erosion)

   An obscure or uncertain unconformity in which no erosion surface is discernable ..., and in which the beds above and below the break are parallel.



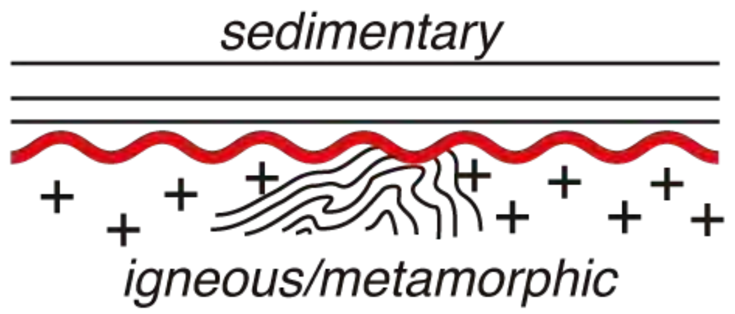
3. **Angular unconformity** = hiatus, erosion, and tilt

   An unconformity between two groups of rocks whose bedding planes are not parallel or in which the older, underlying rocks dip at a different angle (usually steeper) than the younger, overlying strata.



4. **Nonconformity** = top of basement rocks

   An unconformity developed between sedimentary rocks and older igneous or metamorphic rocks that had been exposed to erosion before the overlying sediments covered them.



B. **Diastem** = short hiatus ± erosion (a minor paraconformity)

A relatively short interruption in sedimentation, involving only a brief interval of time, with little or no erosion before deposition is resumed; a depositional break of lesser magnitude than a paraconformity, or a paraconformity of very small time value.

C. **Conformity** = no hiatus

Undisturbed relationship between adjacent sedimentary strata that have been deposited in orderly sequence... True stratig   phic continuity in the sequence of beds.

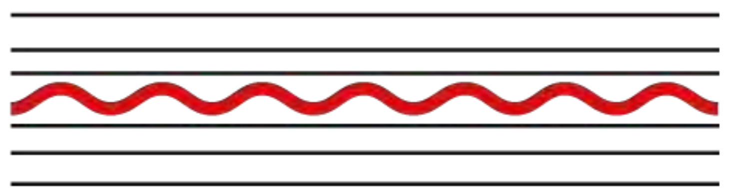
The missing Time

A. **Unconformity** = significant hiatus ± erosion (usually with erosion)

A substantial break or gap in the geological record … It normally implies uplift and erosion with loss of the previously formed record. … Relationship between rock strata in contact, characterized by a lack of continuity in deposition, and corresponding to a period of nondeposition, weathering, or esp. erosion (either subaerial or subaqueous) prior to the deposition of the younger beds.

1. **Disconformity** = hiatus + erosion

An unconformity in which the bedding planes above and below the break are essentially parallel, indicating a significant interruption in the orderly sequence of sedimentary rocks, generally by a considerable interval of erosion ..., and usually marked by a visible and irregular or uneven erosion surface of



paraconformity, or a paraconformity of very small time value.

C. **Conformity** = no hiatus

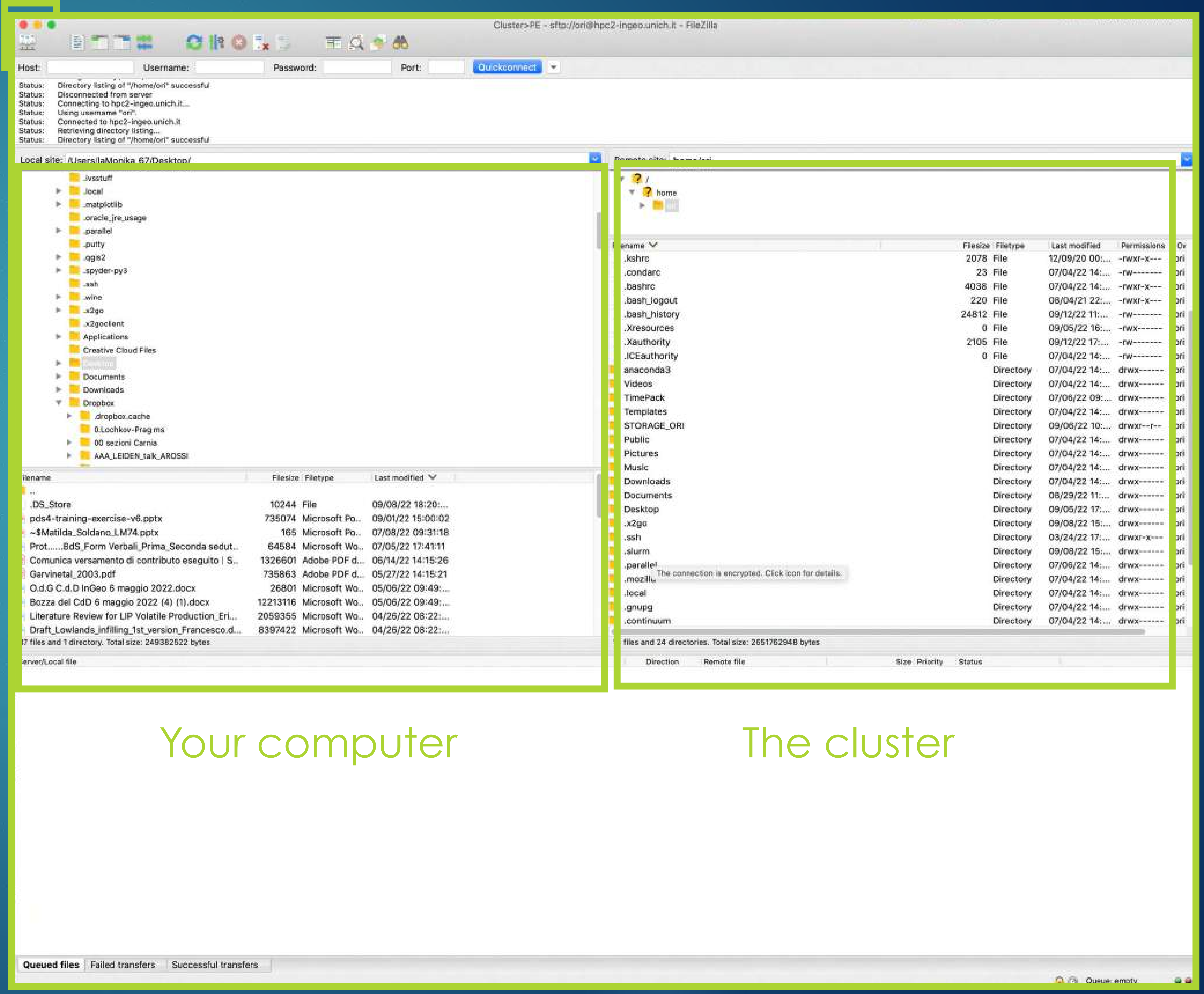
Undisturbed relationship between adjacent sedimentary strata that have been deposited in orderly sequence... True stratig phic continuity in the sequence of beds.

Banham et al., 2018, Sedimentology

Download your lev2.cub data FileZilla

Click here

Simply drag and drop to your chosen folder in your computer



Your computer

The cluster

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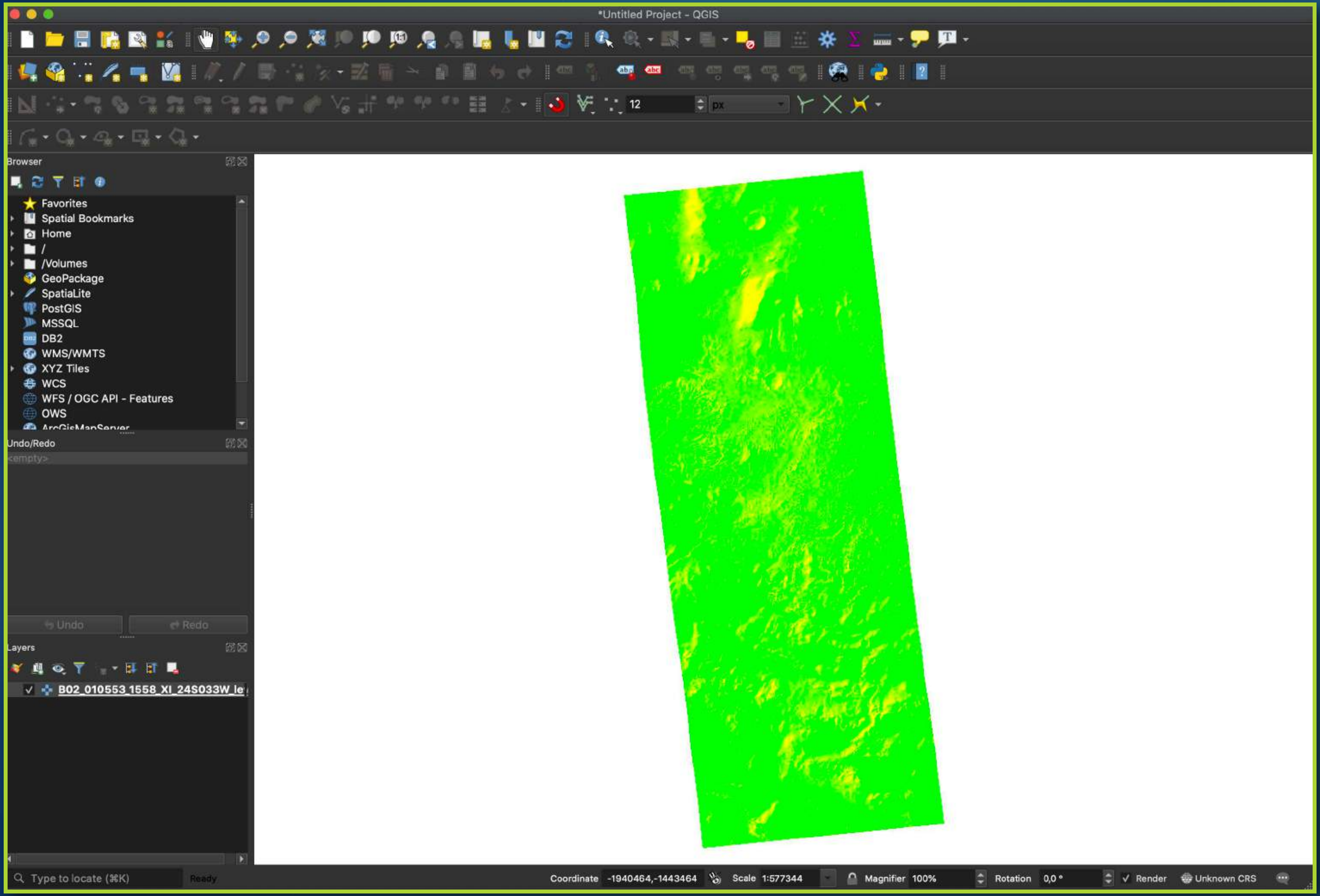
GIS INTEGRATION

Why GIS

- GIS is a system which groups together several functions for spatial referenced data (databases). These functions are as follows:
    1. collecting (capturing) and updating data;
    2. storing and managing data;
    3. searching data;
    4. integrating, manipulating, analyzing and modeling data;
    5. visualizing (displaying) data.

Import your images in GIS

- Start with CTX
- Then HRSC and HiRISE


*Untitled Project - QGIS
12
px
Browser
Favorites
Spatial Bookmarks
Home
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/Volumes
GeoPackage
SpatiaLite
PostGIS
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DB2
WMS/WMTS
XYZ Tiles
WCS
WFS / OGC API - Features
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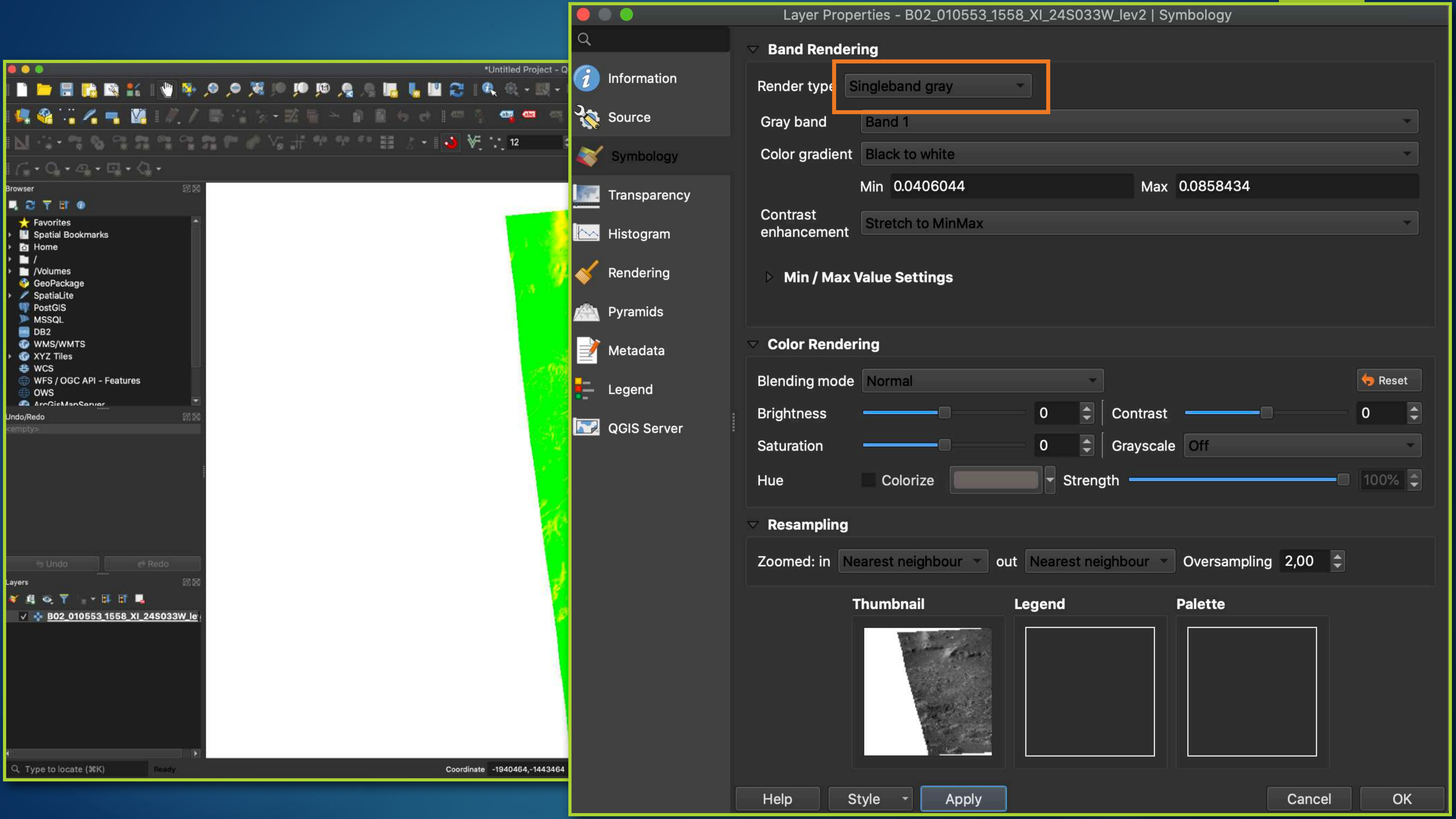
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Information
Source
Symbology
Transparency
Histogram
Rendering
Pyramids
Metadata
Legend
QGIS Server
Band Rendering
Render type
Singleband gray
Gray band
Band 1
Color gradient
Black to white
Min
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Max
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Contrast enhancement
Stretch to MinMax
Min / Max Value Settings
Color Rendering
Blending mode
Normal
Reset
Brightness
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Contrast
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Saturation
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Grayscale
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Hue
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Strength
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Resampling
Zoomed: in
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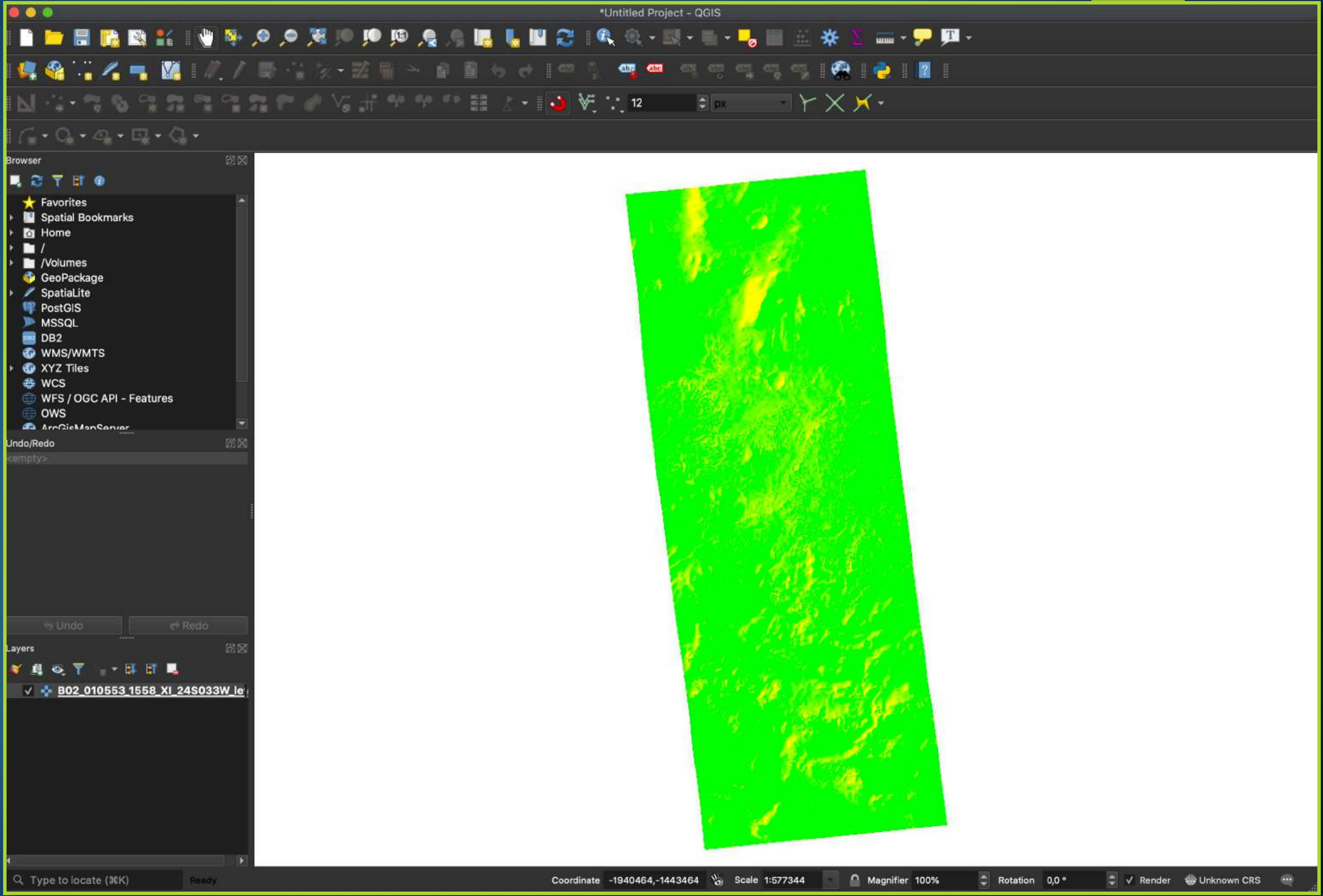

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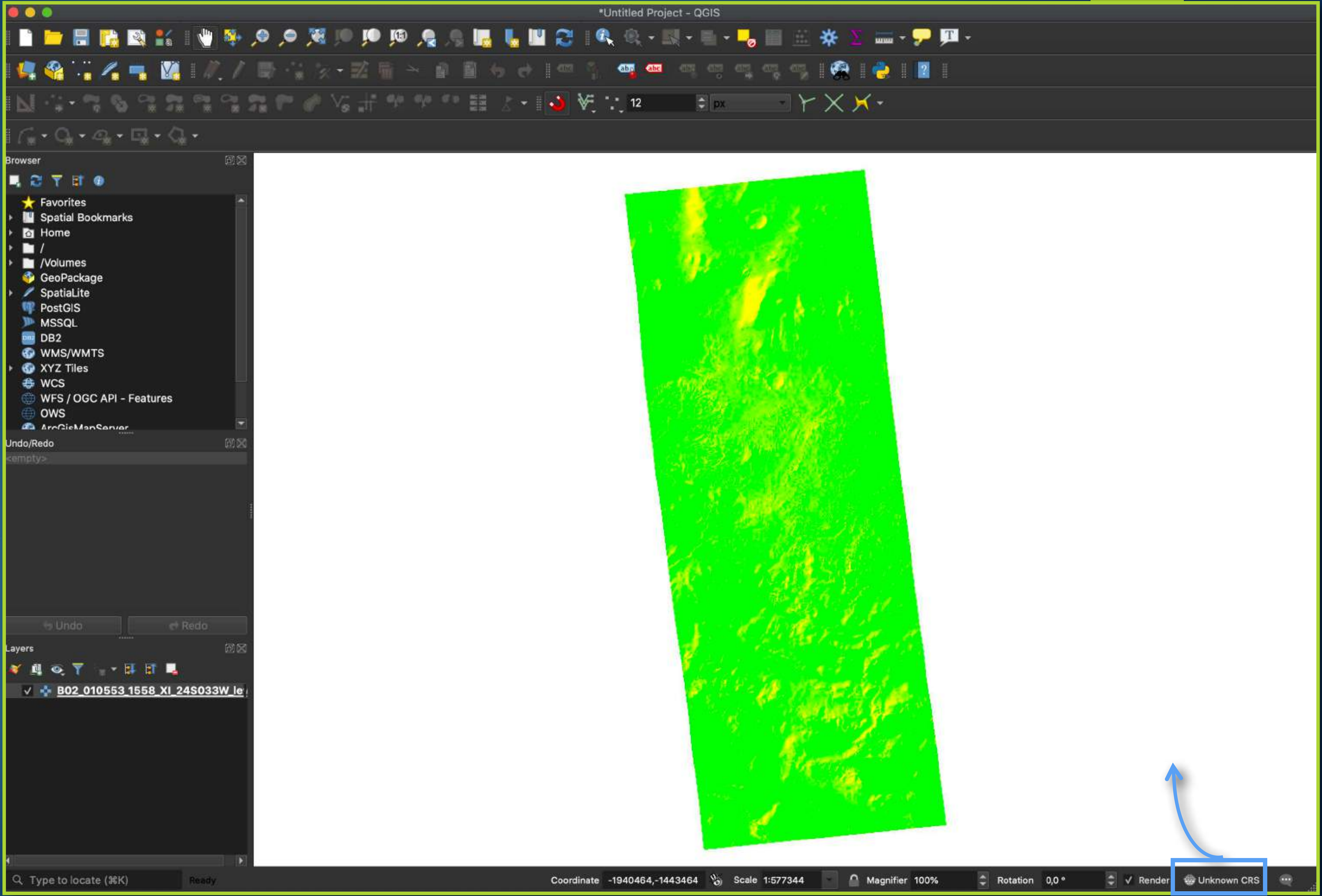
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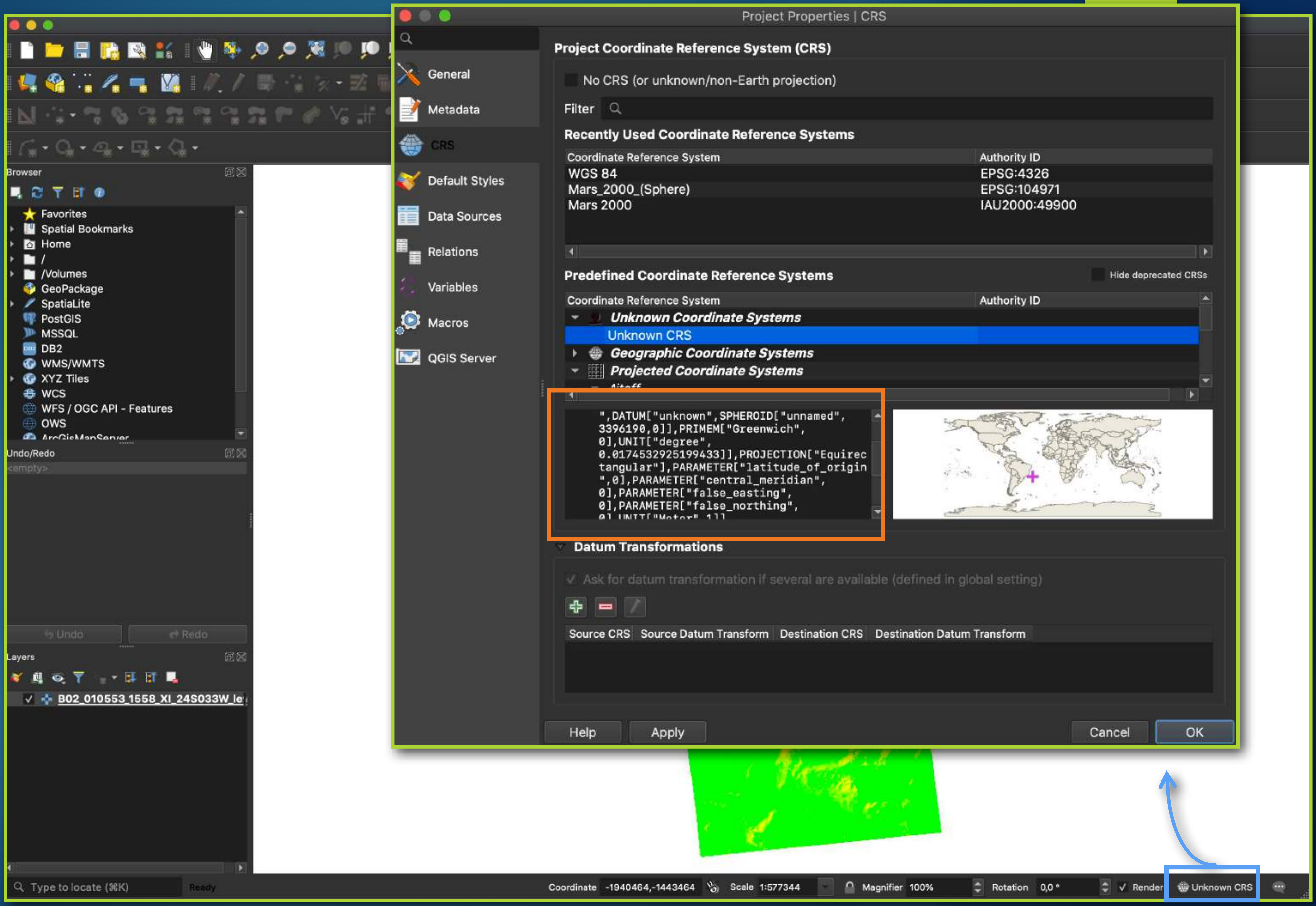
EVEN IF IT WRITTEN 'UNKNOWN' THE VALUES ARE CORRECT



Coordinate Reference Syst

https://www.ogc.org

WKT (well known text)

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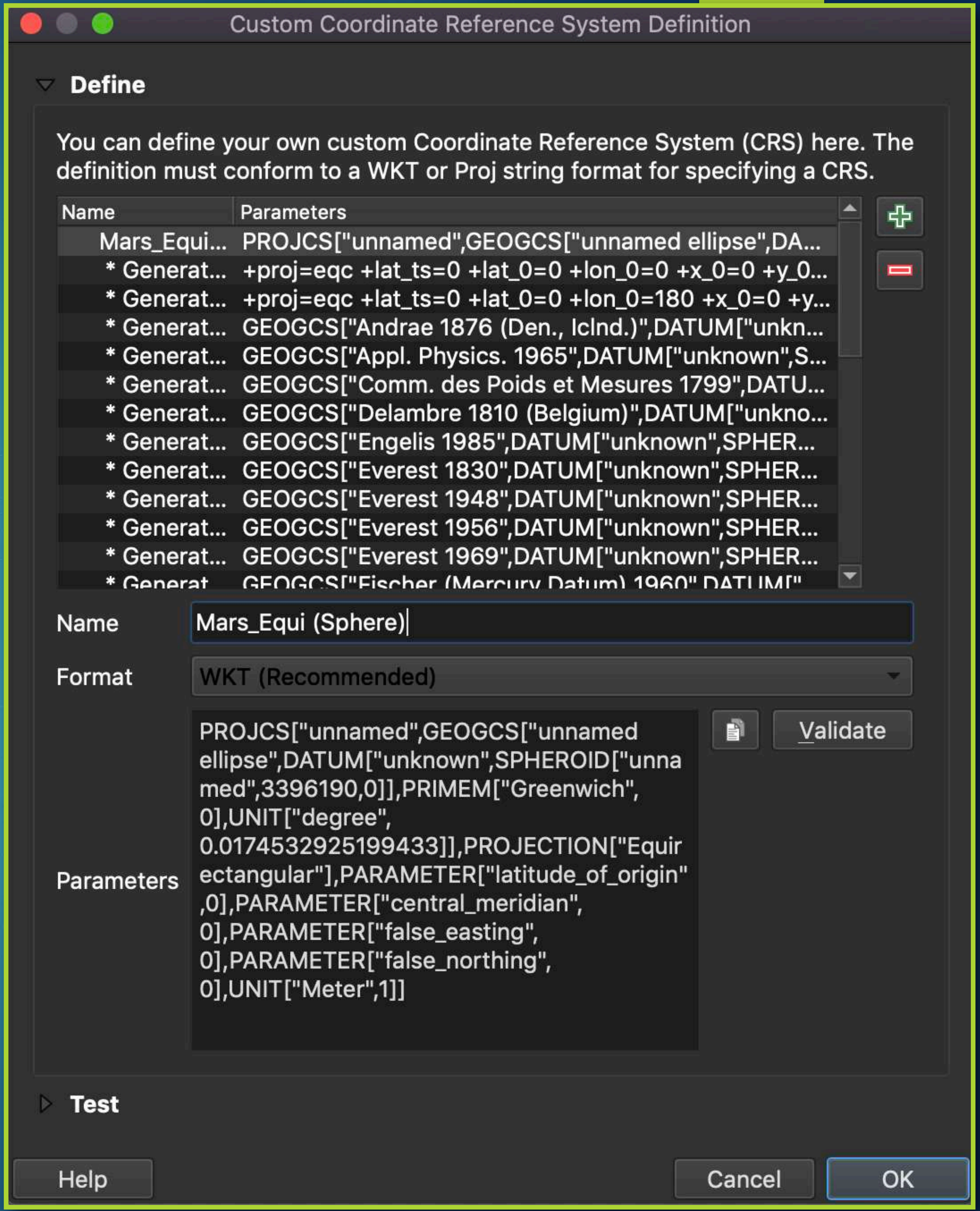

Coordinate Reference Syst

https://www.ogc.org

WKT (well known text)

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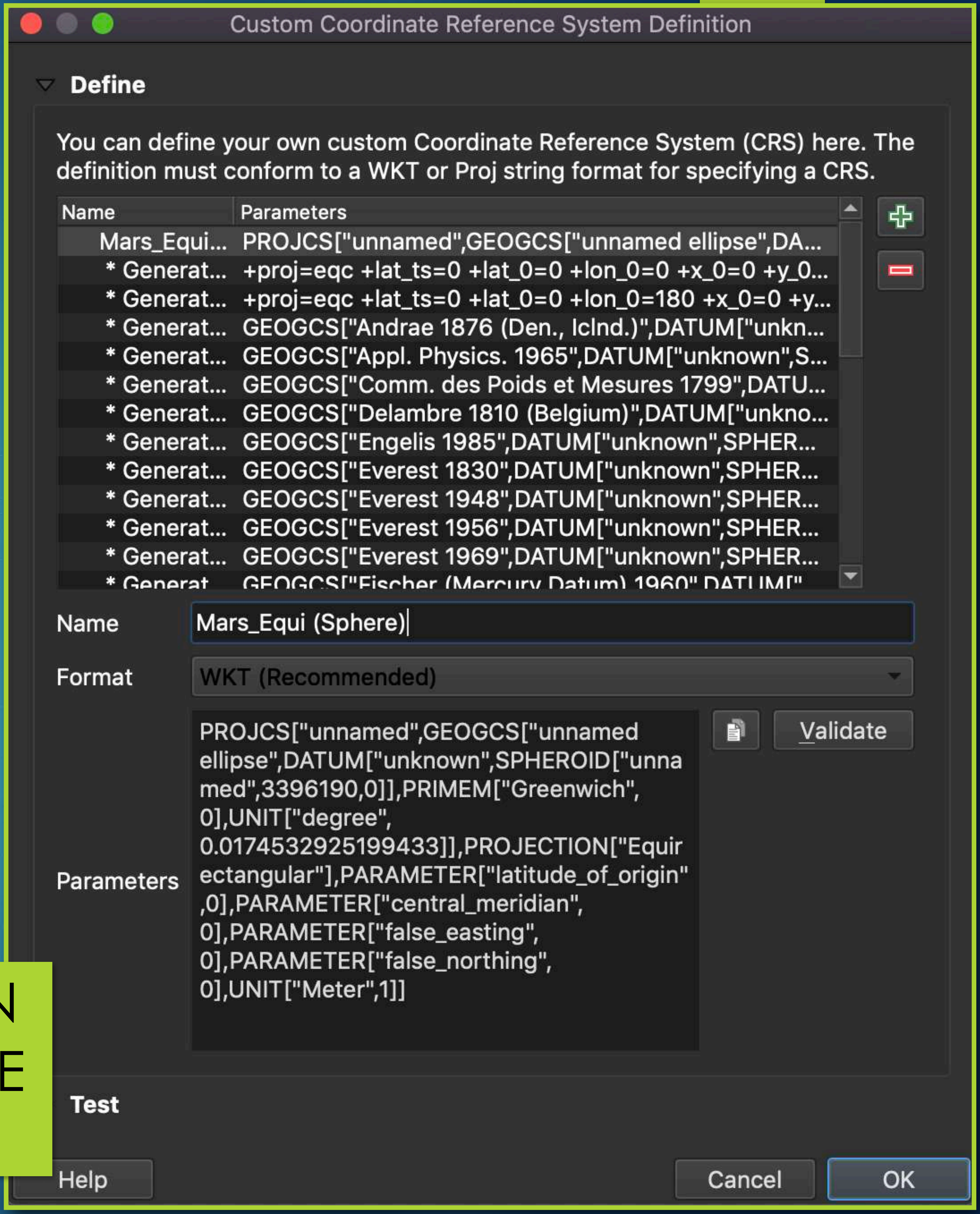
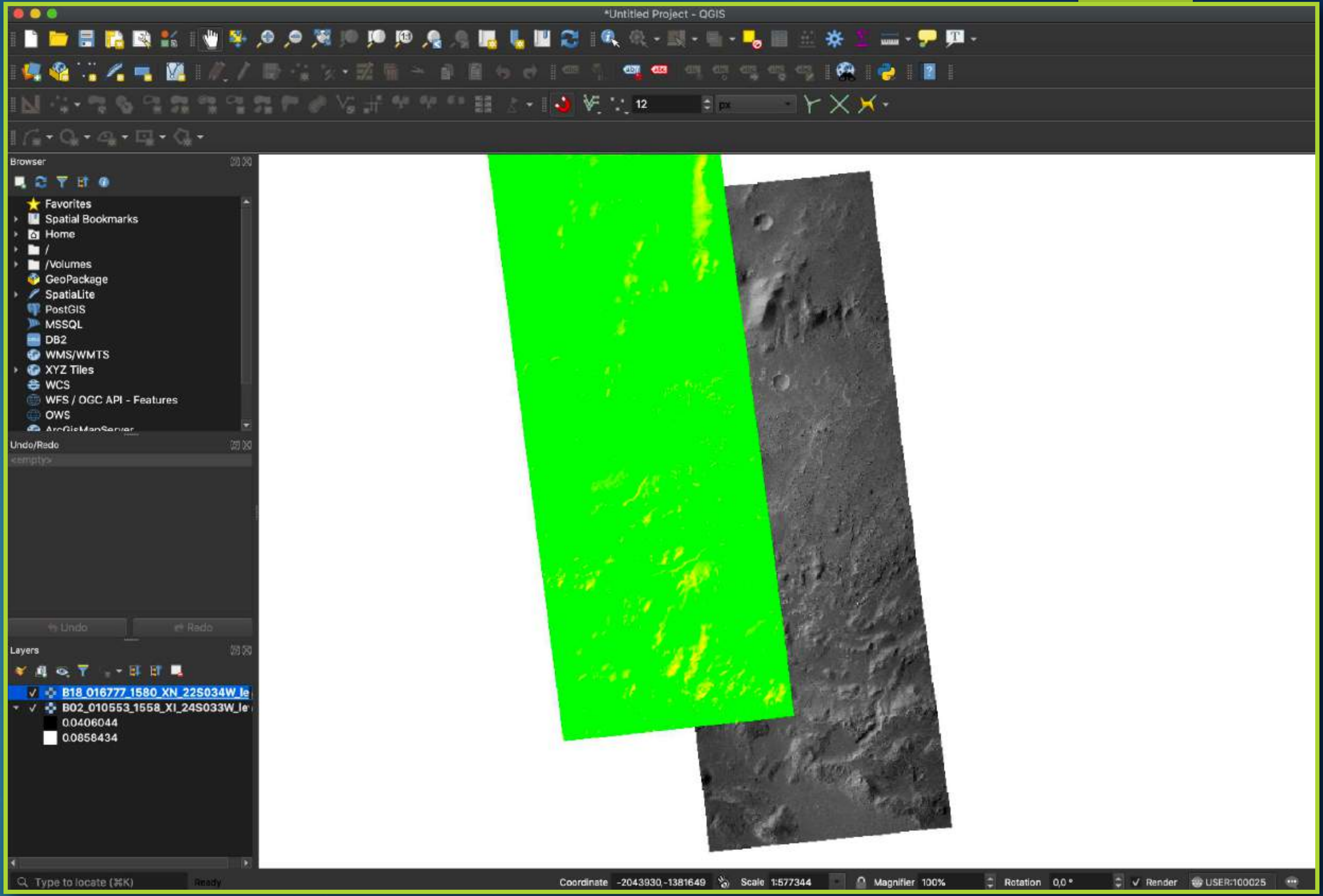


CREATE YOUR OWN CRS BY COPY/PASTE (USE WKT)

Add the other CTXs

- Copy/paste the styles



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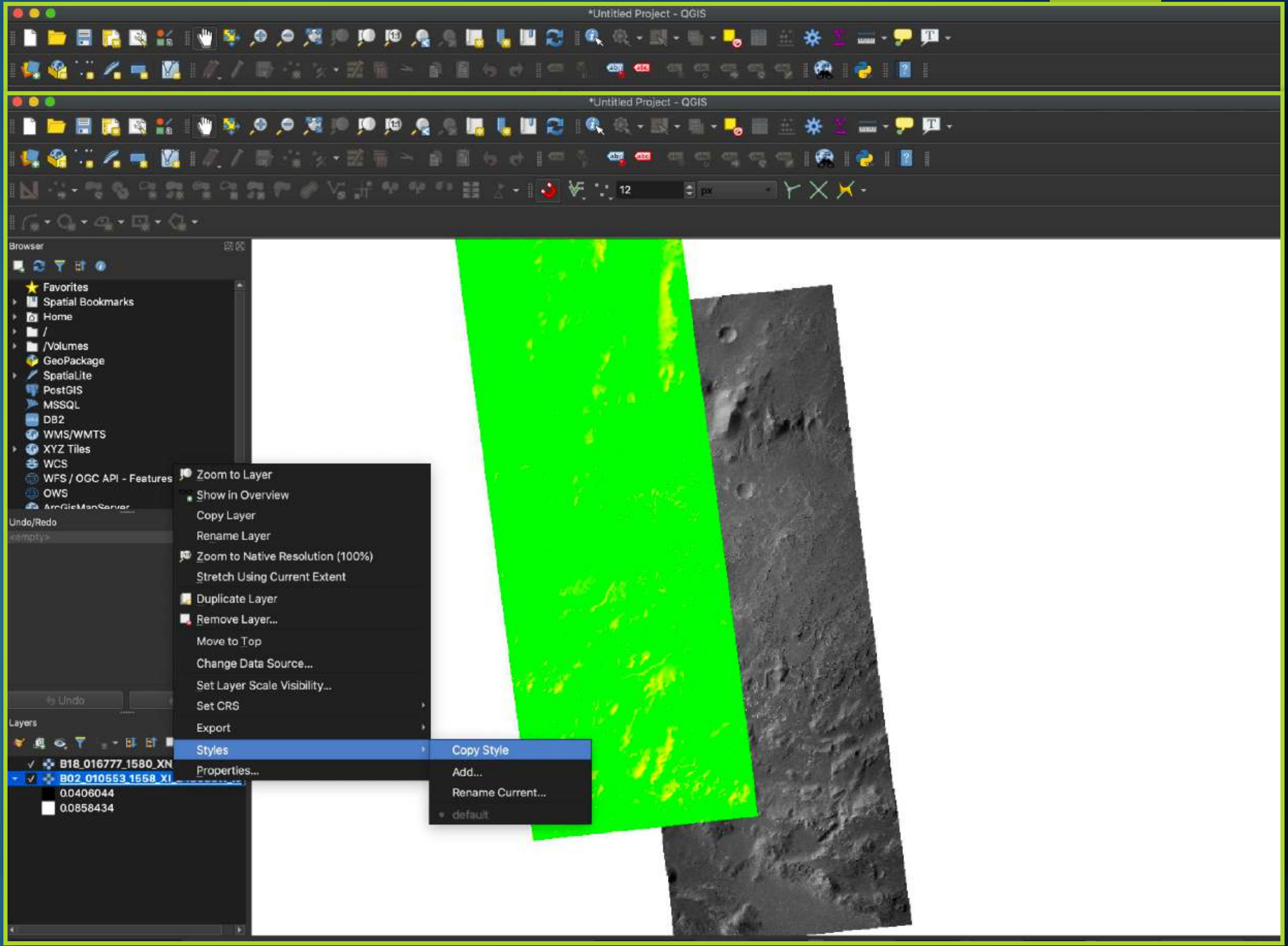

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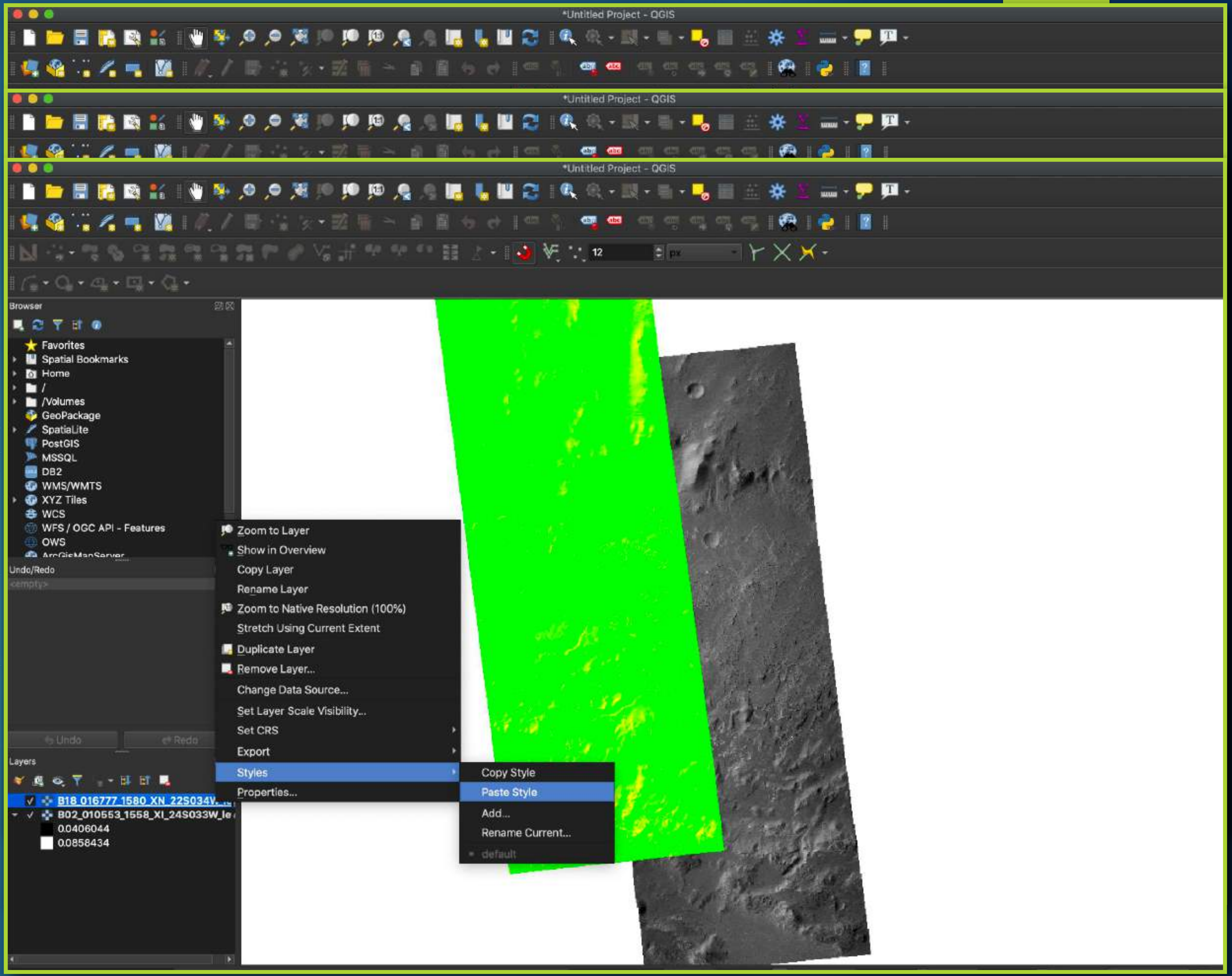

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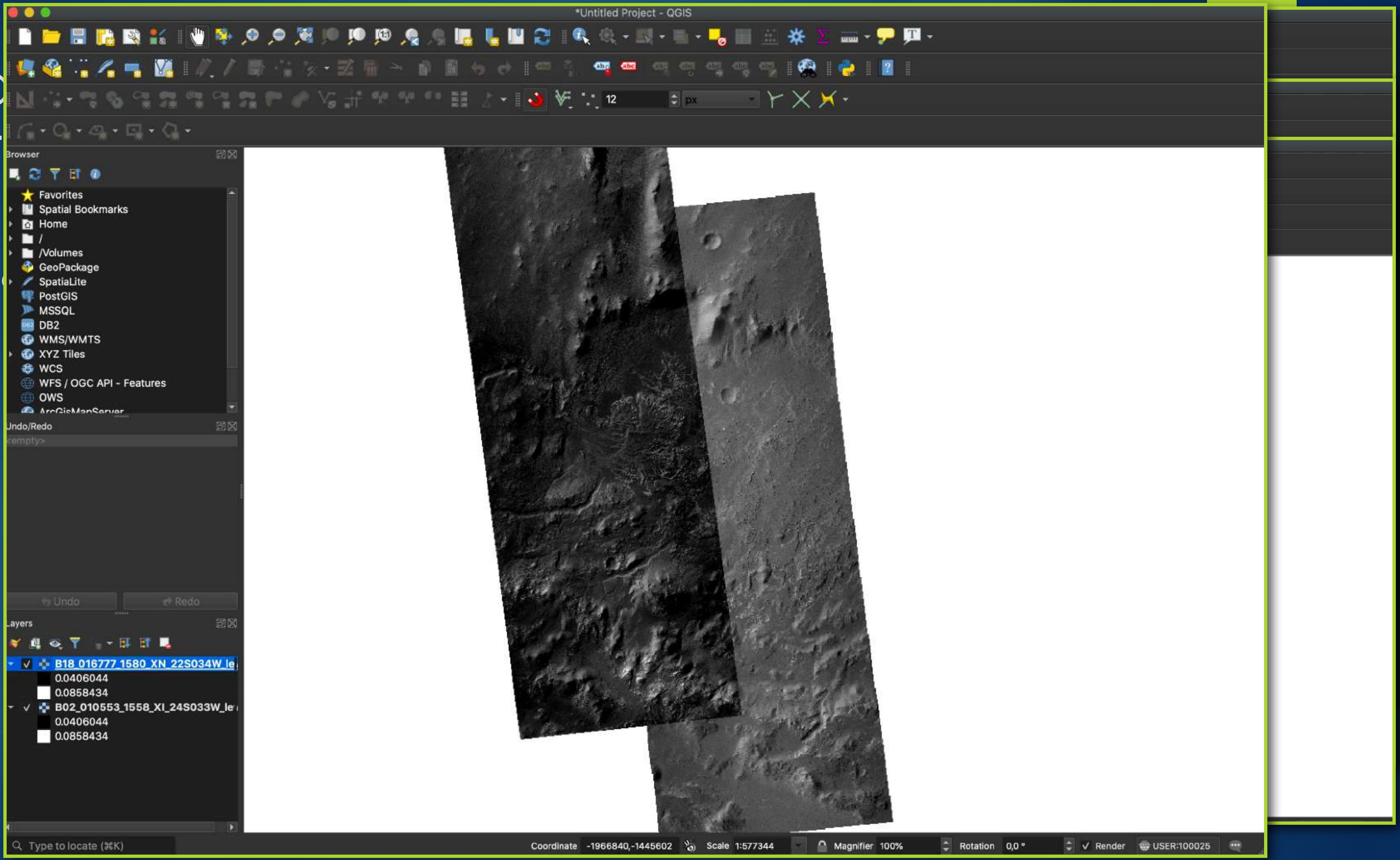

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Add HRSC

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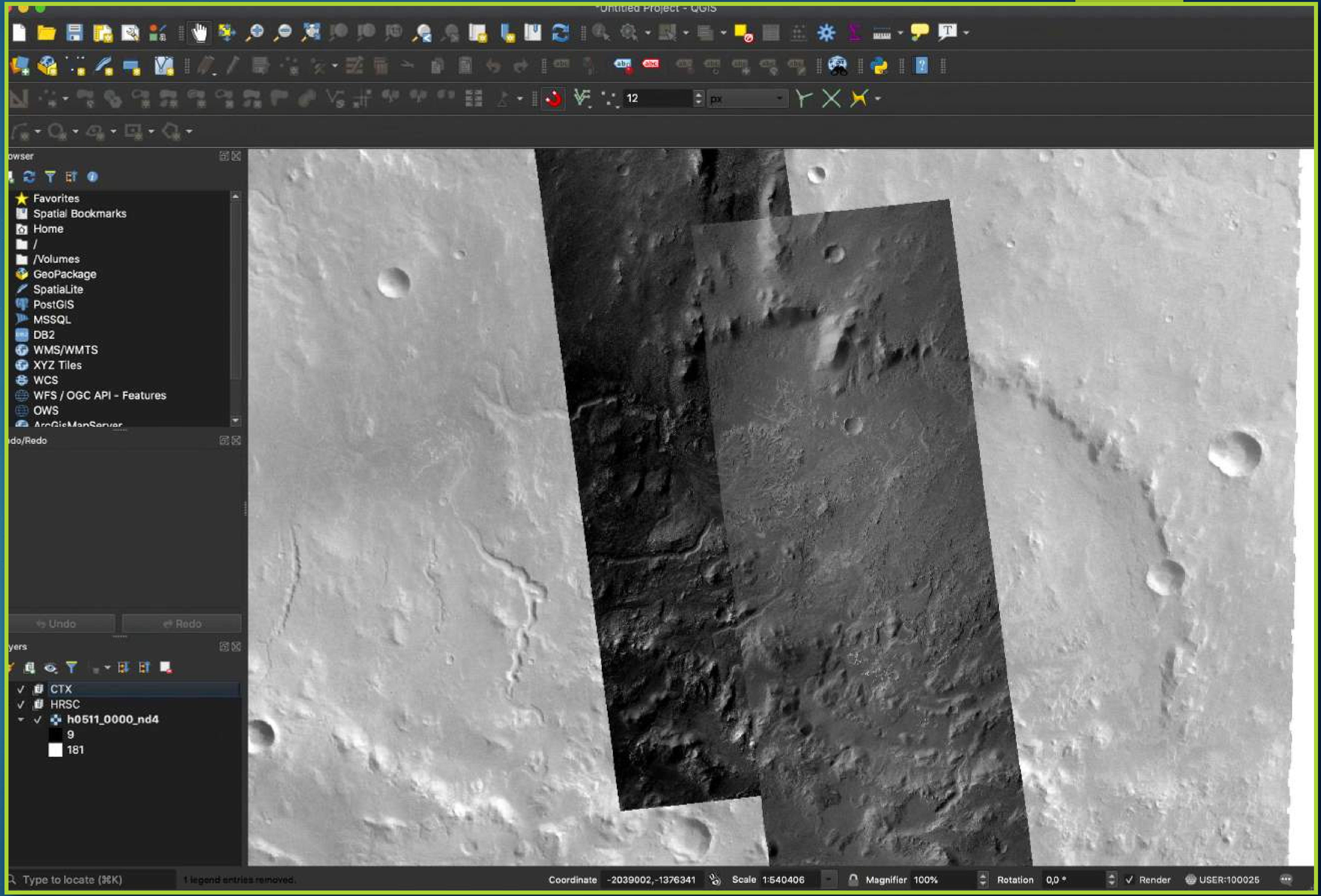
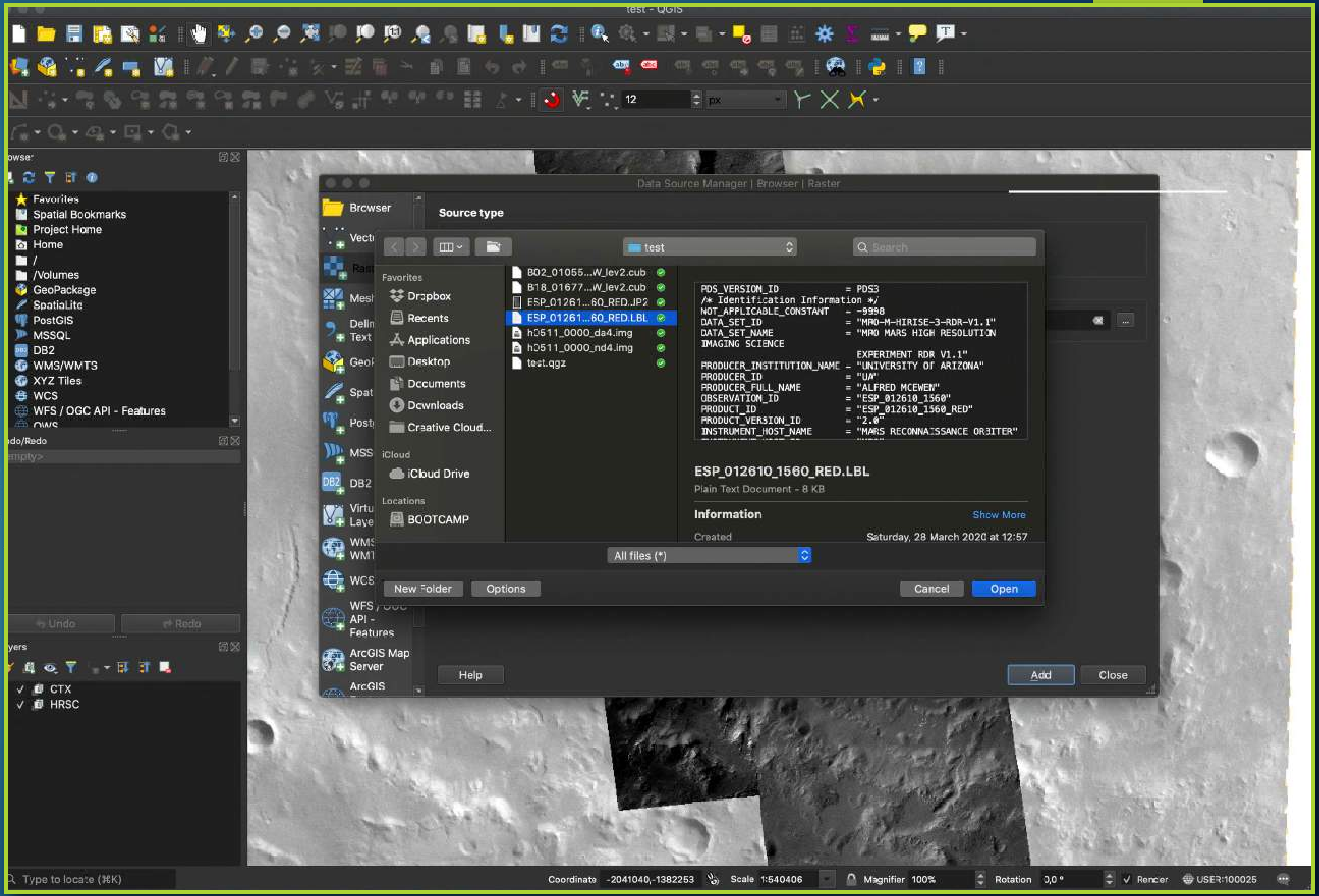


Add HiRISE

Select the .LBL file

The SRC is recognised and the image is projected on the fly

Select the transparency for the NO DATA

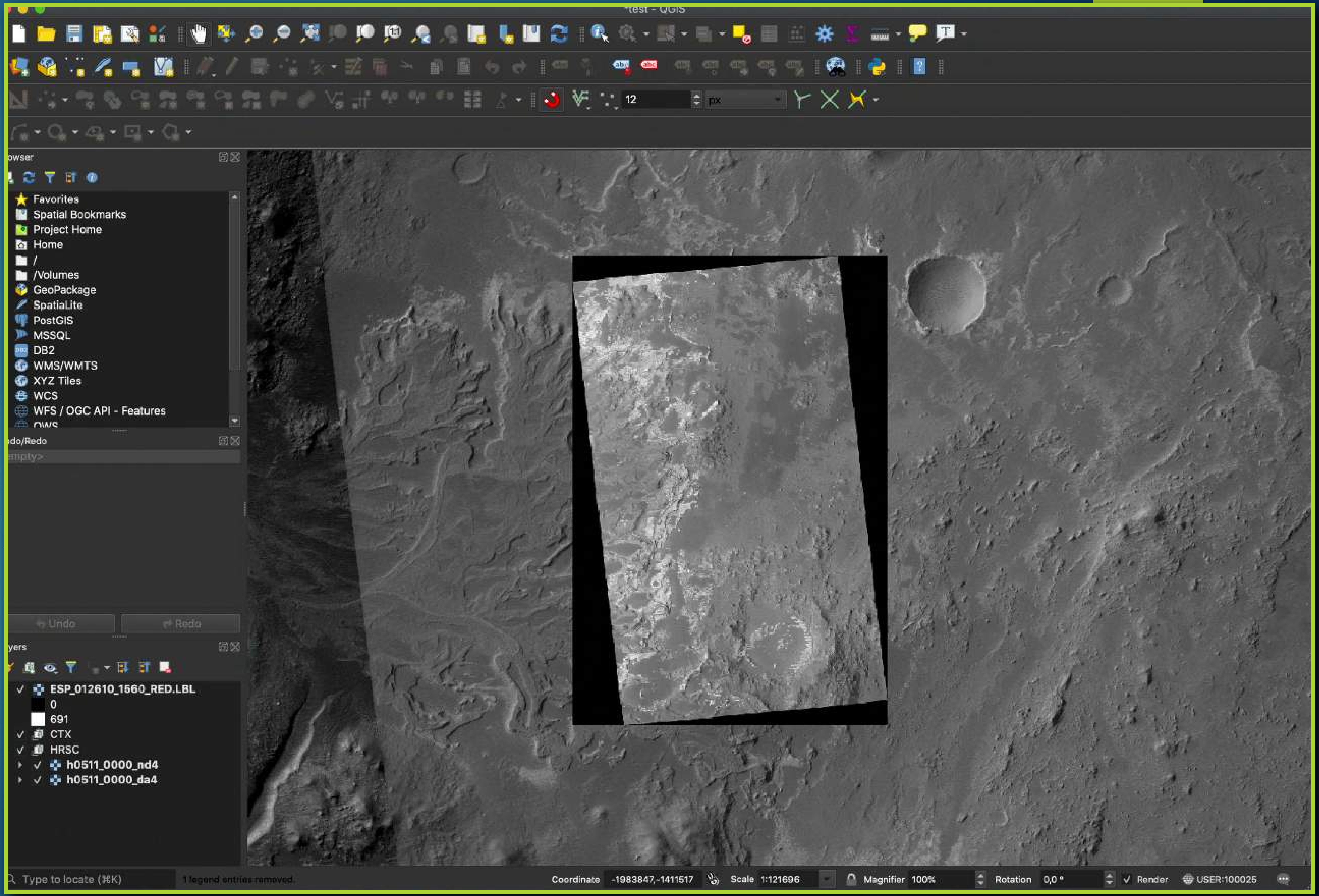


Add HiRISE

Select the .LBL file

The SRC is recognised and the image is projected on the fly

Select the transparency for the NO DATA

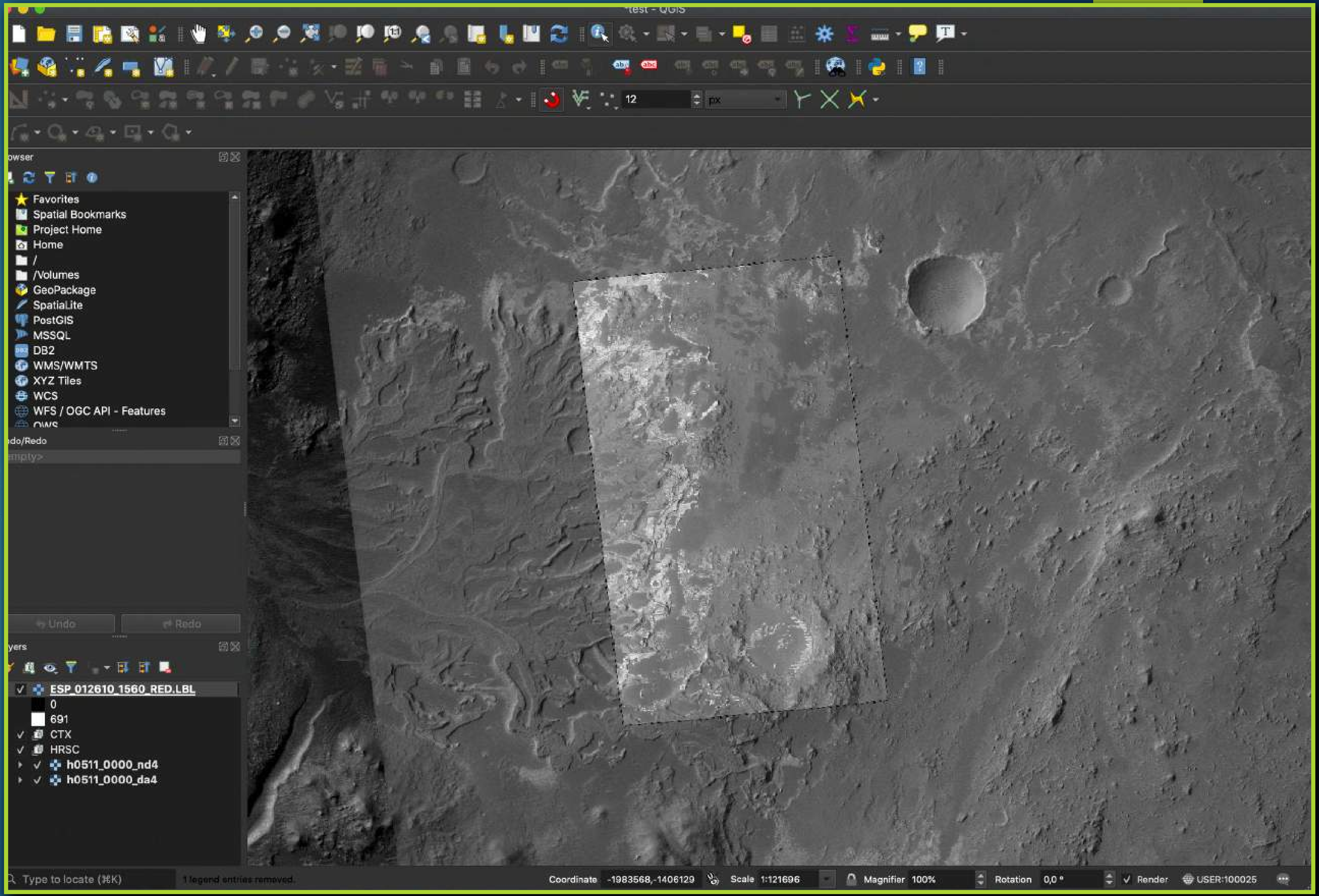


Add HiRISE

Select the .LBL file

The SRC is recognised and the image is projected on the fly

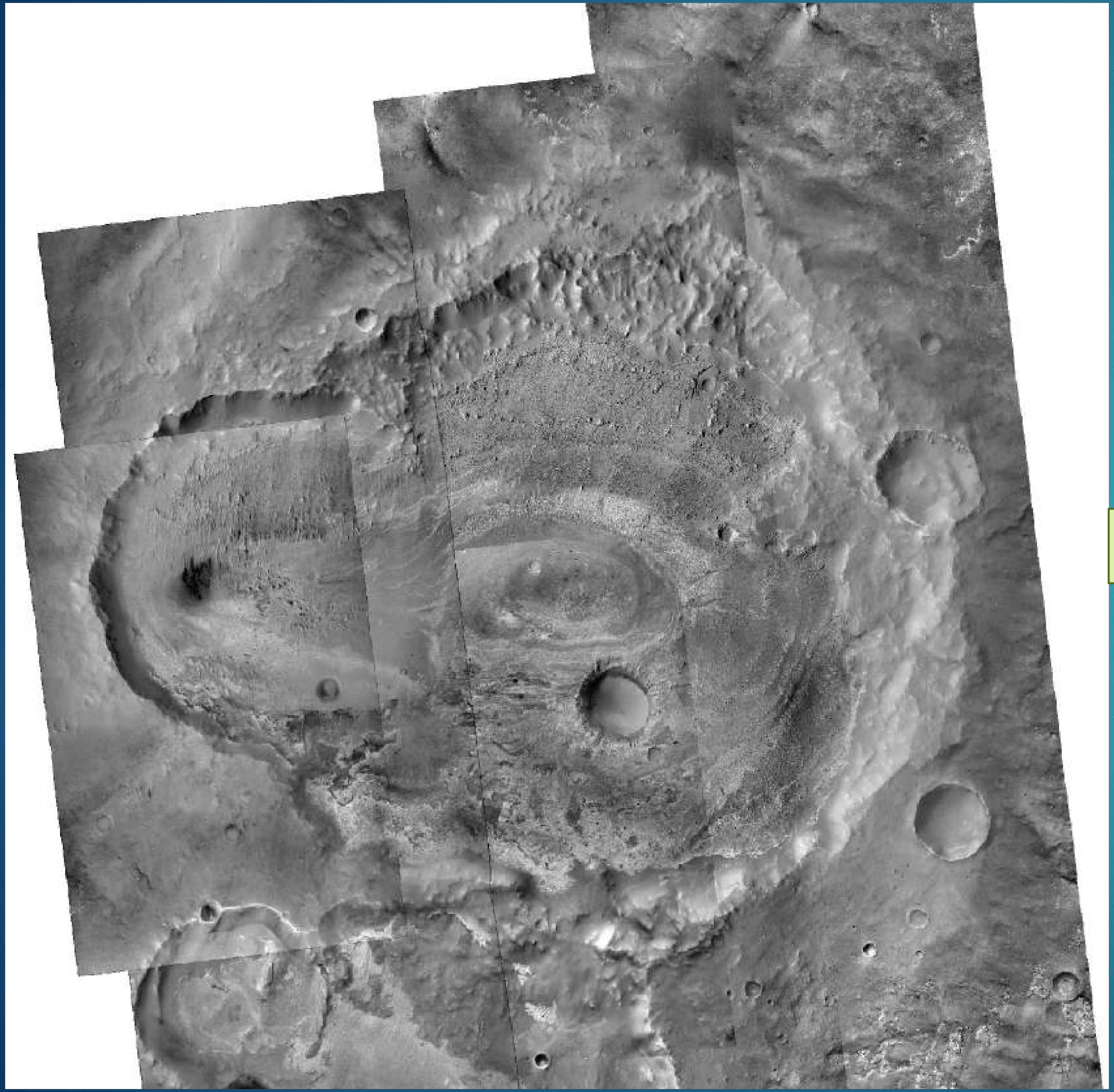
Select the transparency for the NO DATA

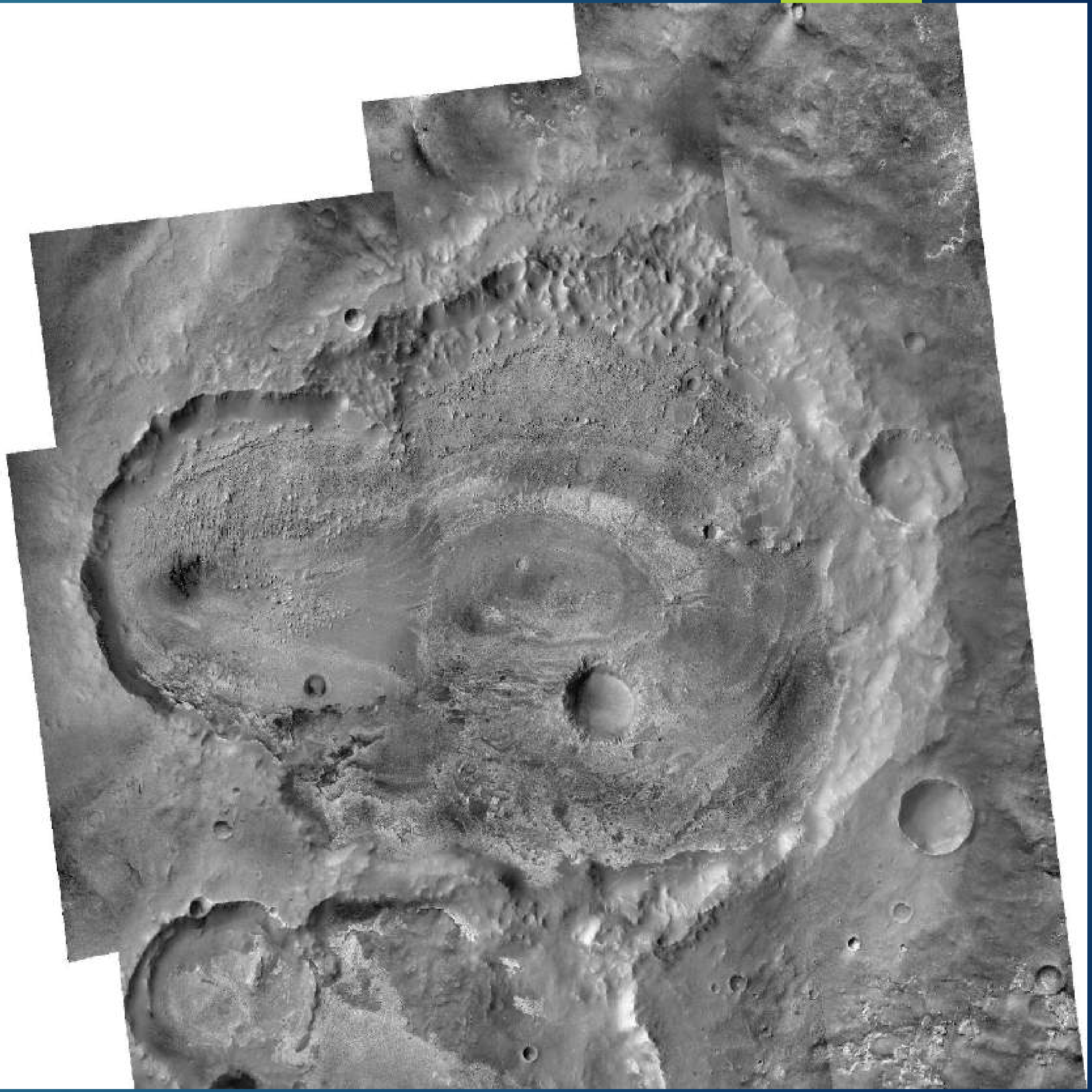


Import the images in QGIS

- CTX
  - Define CRS
- Edit symbology
  - Properties/Symbology/⇢ Singleband Gray
  - Copy/paste layer style to all of the images
- Edit symbology deleting no data value (HiRISE RDR)
- Create group layers for each dataset
- Order top/down data sets according the their resolution

Seamless Mosaic Generation





Calculating the paths of least contrast among overlapping images ("seamlines")

Seamlines are used when mosaicking the raster data in a mosaic dataset. They are used instead of footprints to define the line along which the rasters in the mosaic dataset will be mosaicked when using the Seamline mosaic method. Those can be created by examining the values and patterns in the intersecting area and to compute a path between the intersecting points. This path is then merged with the footprint to create the seamline for each single image in the mosaic dataset.

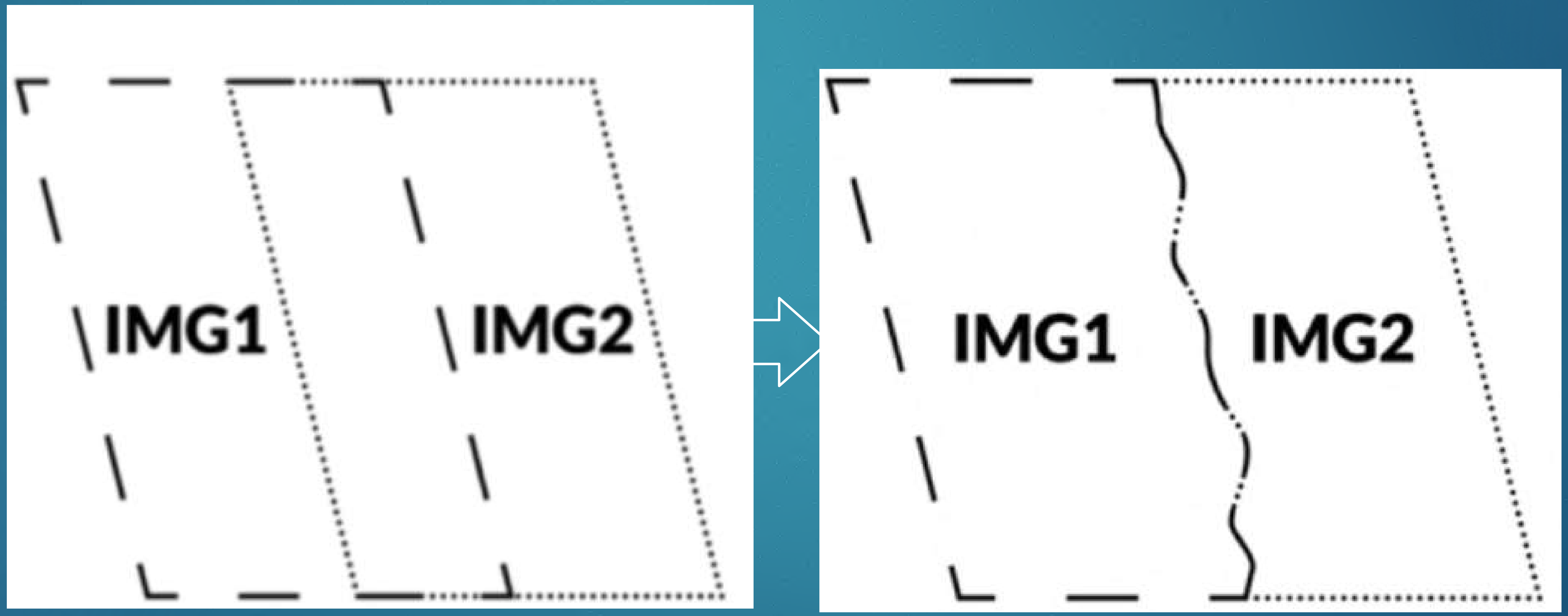
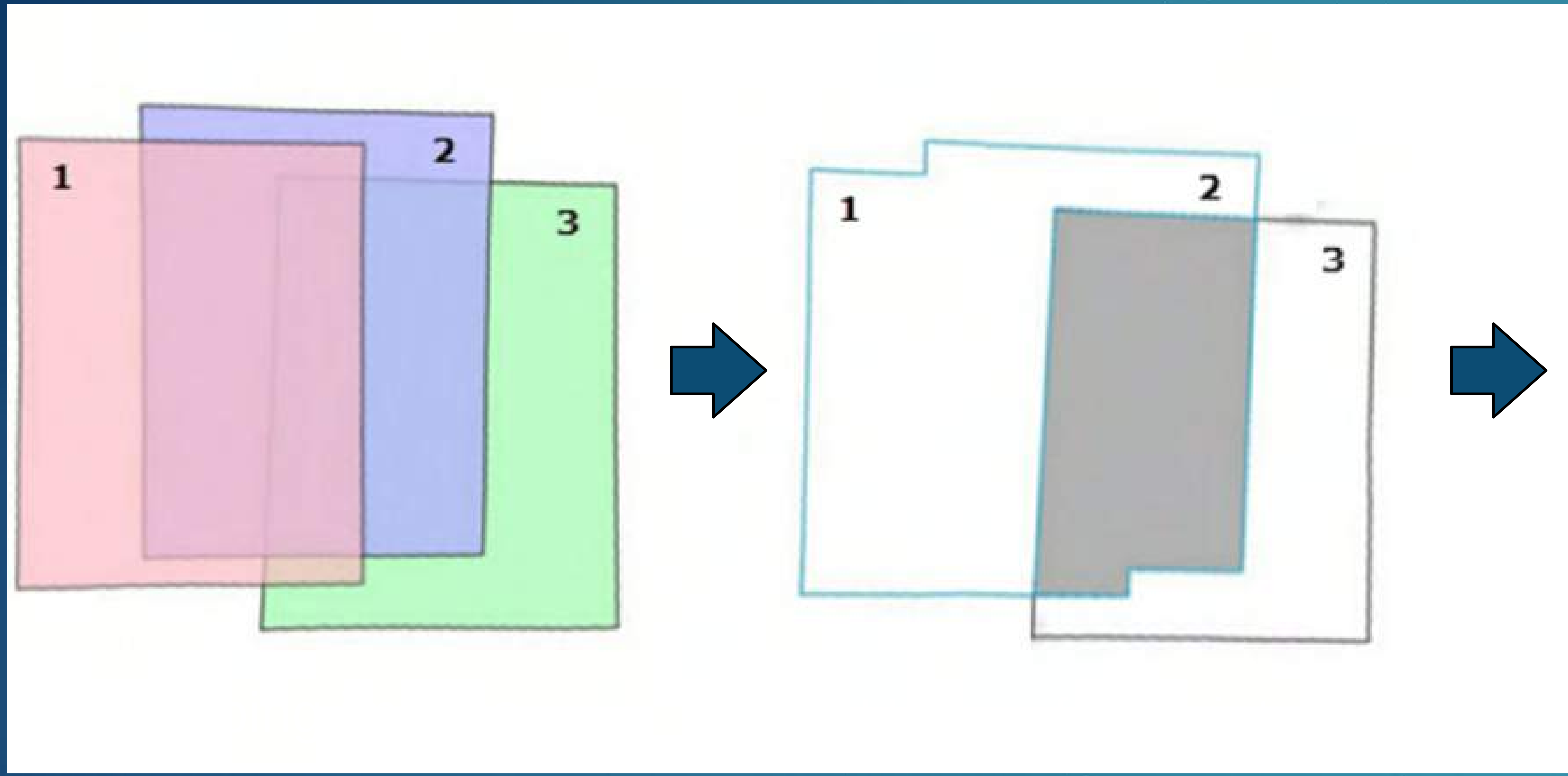
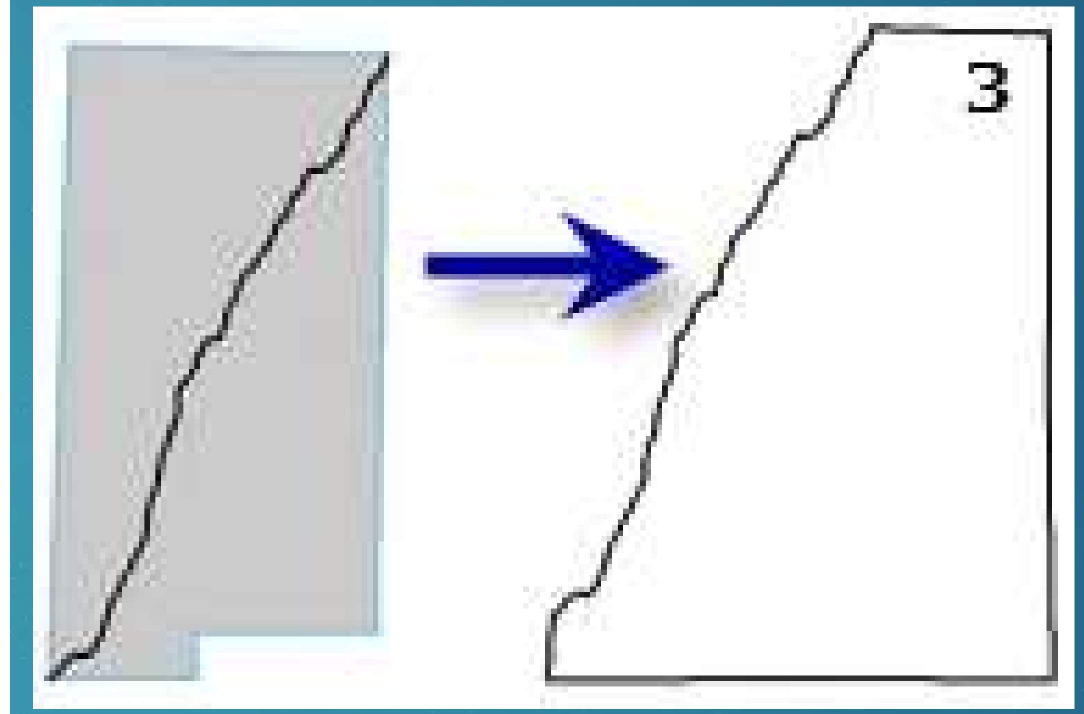


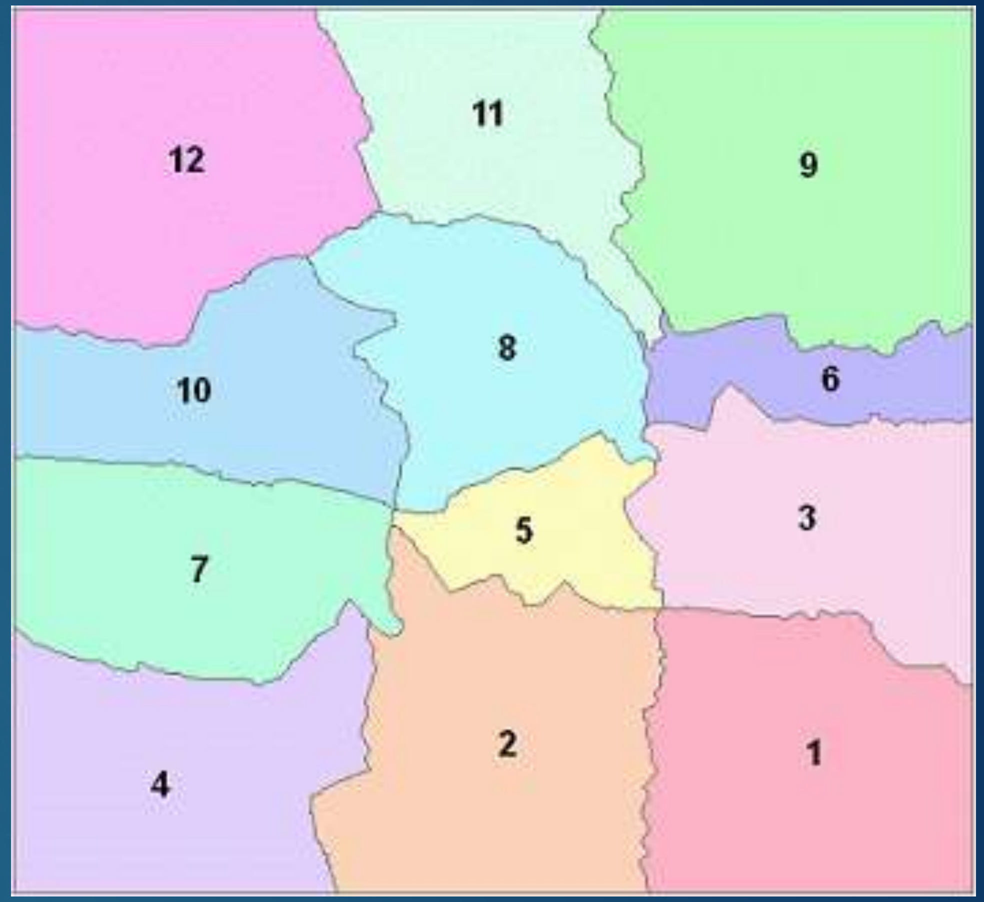
Image modified from: Dickson, J.L. et al. 2018. A Global, Blended Ctx Mosaic Of Mars With Vectorized Seam Mapping.

Workflow





Seamlines construction



Seamlines based mosaic

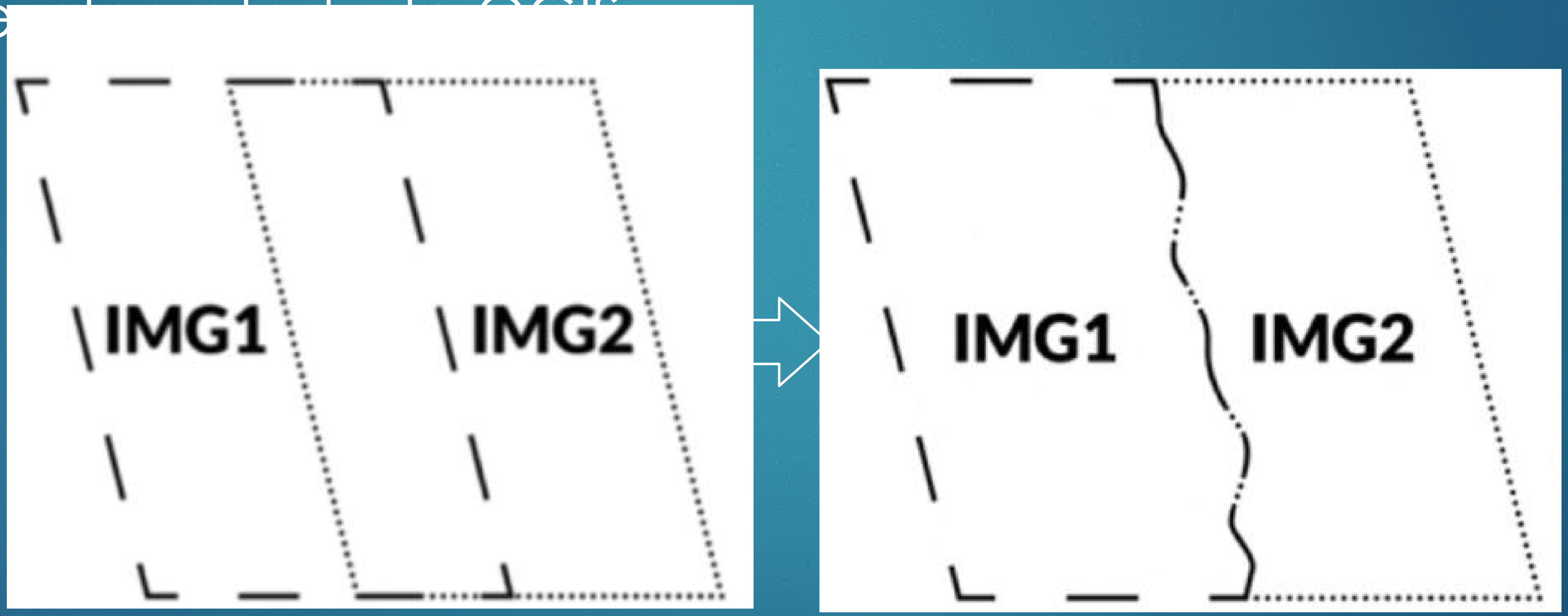
Images modified from ArcGIS for Desktop Manua

How to:

Different commercial software now offers the ability to create mosaics via seamlines including ArcGIS Pro, ArcGIS for Desktop and Geoharris ENVI. Open source alternatives are still under development and not mature enough for scientific use.

An alternative to mosaicking with seamlines is "Mosaic with Feathering" which involves weighted averaging of overlapping pixels where the discriminating factor is the distance from the edges of the DEMs.

Mosaic with Feathering is available in the open source toolbox Whitebox Geospatial Analysis Tools (GAT), which can be



From Dickson et al., 2018

Procedures:

- **ArcGIS Pro:**
https://pro.arcgis.com/en/pro-app/latest/help/data/imagery/mosaic-dataset-seamlines-pro-.htm

- **ArcMap:**
https://desktop.arcgis.com/en/arcmap/10.3/tools/data-management-toolbox/build-seamlines.htm

- **GeoHarris ENVI**
https://www.l3harrisgeospatial.com/docs/mosaicseamless.html

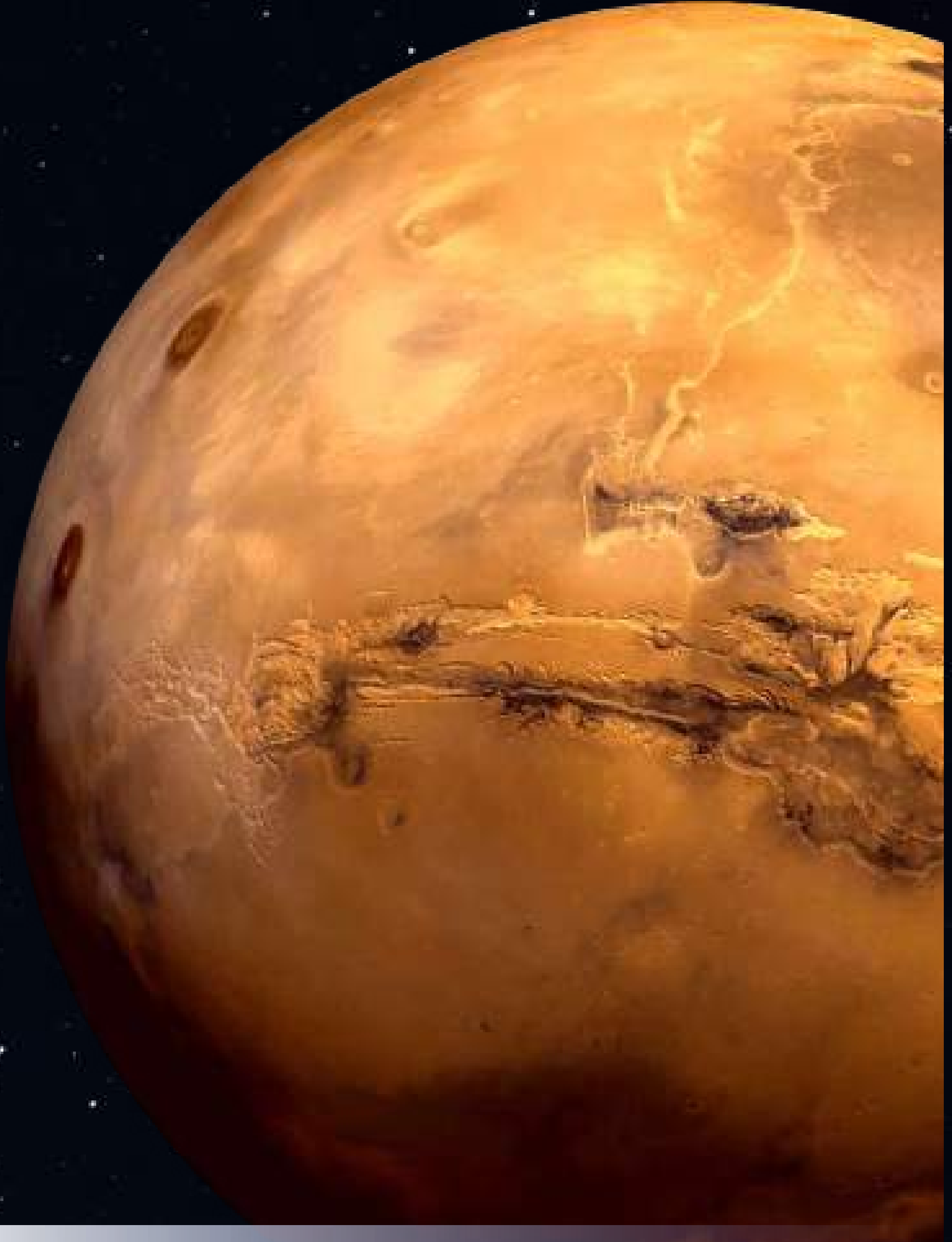
- **Whitebox GAT (Mosaic with Feathering)**
https://jblindsay.github.io/ghrg/Whitebox/Help/MosaicWithFeathering.html

Whitebox GAT Plugin for QGIS:
https://www.whiteboxgeo.com/manual/wbt_book/qgis_plugin.html

Spectral data on planetary bodies

Beatrice Baschetti[1,2] and Cristian Carli[2]

[1]Department of Geosciences, **University of Padua**; [2]INAF-IAPS



GeoPlaNet
Co-funded by the Erasmus+ Programme of the European Union

Outline

- Introduction to spectroscopy and reflectance spectroscopy
- Reflectance spectroscopy on planetary bodies
- Spectroscopy on Mars and CRISM spectrometer
- Understanding and analysing CRISM data products
- Conclusions

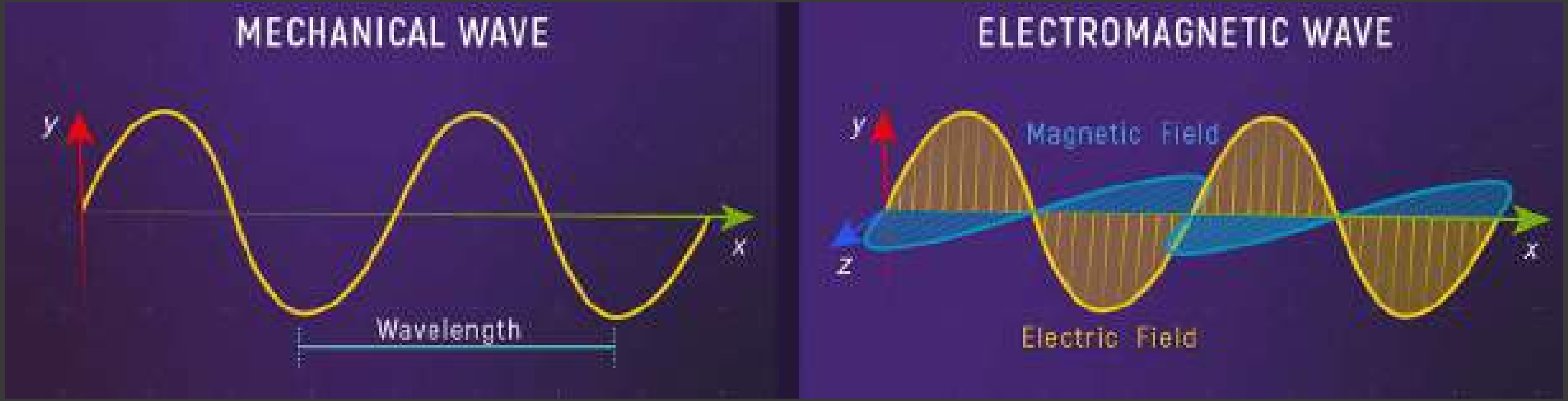
Outline

- **Introduction to spectroscopy and reflectance spectroscopy**
- Reflectance spectroscopy on planetary bodies
- Spectroscopy on Mars and CRISM spectrometer
- Understanding and analysing CRISM data products
- Conclusions

Introduction: spectroscopy and light

Spectroscopy investigates the interaction between electromagnetic radiation (light) and matter.

Credits: NASA, ESA, Leah Hustak (STScI)



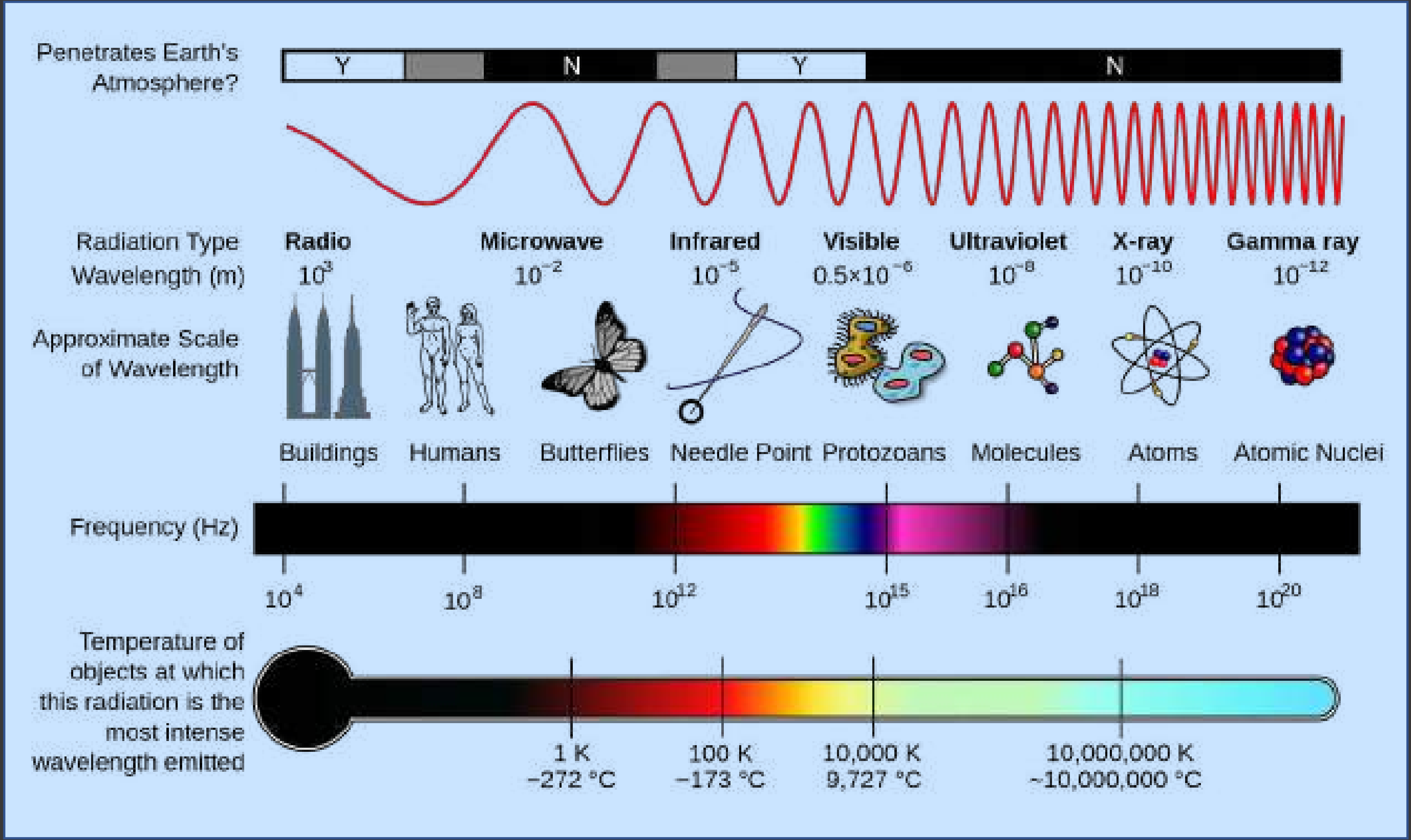
Dual nature of light:

- **Electromagnetic waves**, from Maxwell's electromagnetic theory.
- **Photons** (particle), from quantum theory.

Maxwell's theory treats the *propagation* of light, whereas the **quantum theory** describes the *interaction* of light and matter or the *absorption and emission* of light.

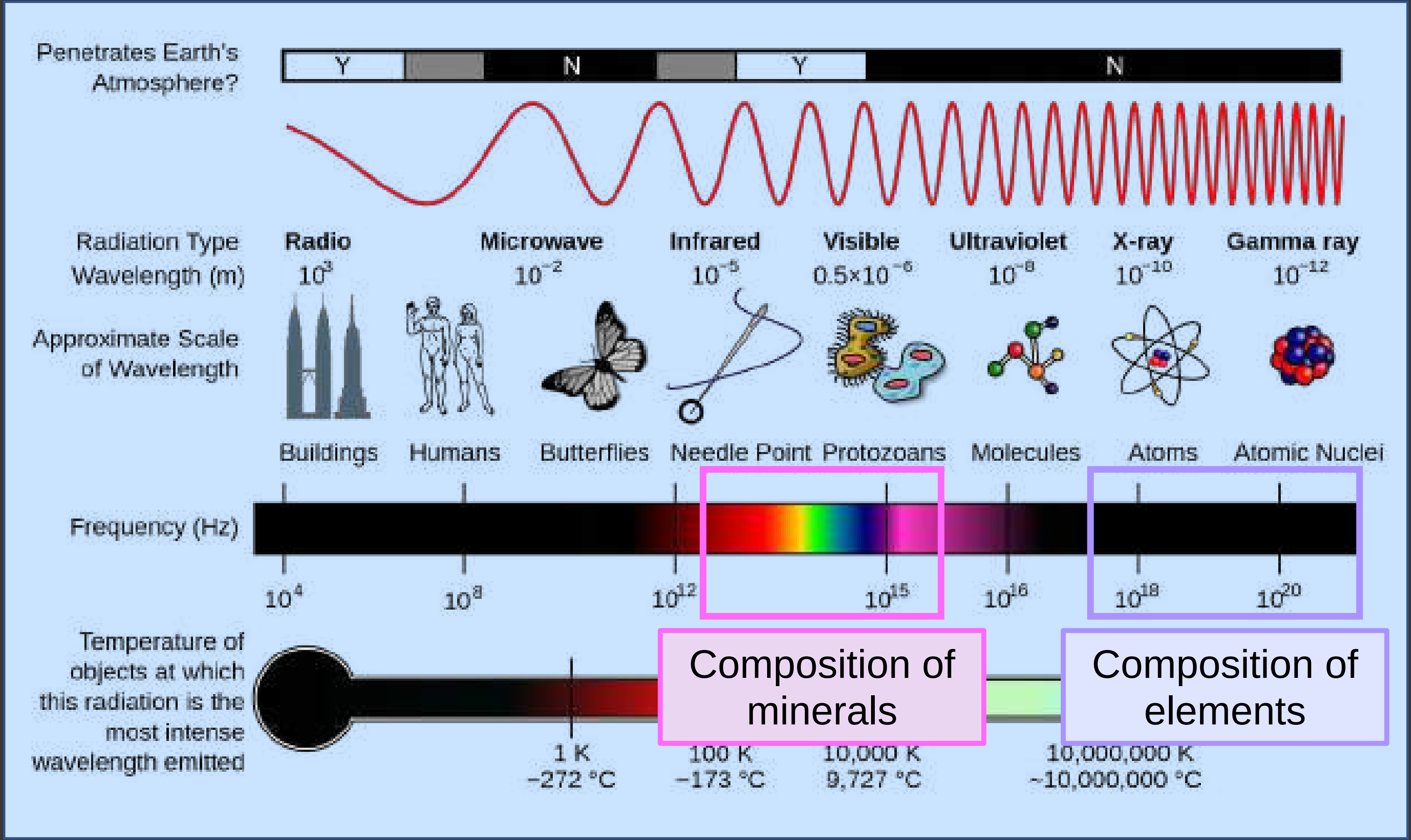
Introduction: spectroscopy and light

The components of electromagnetic radiation: the electromagnetic spectrum



Introduction: spectroscopy and light

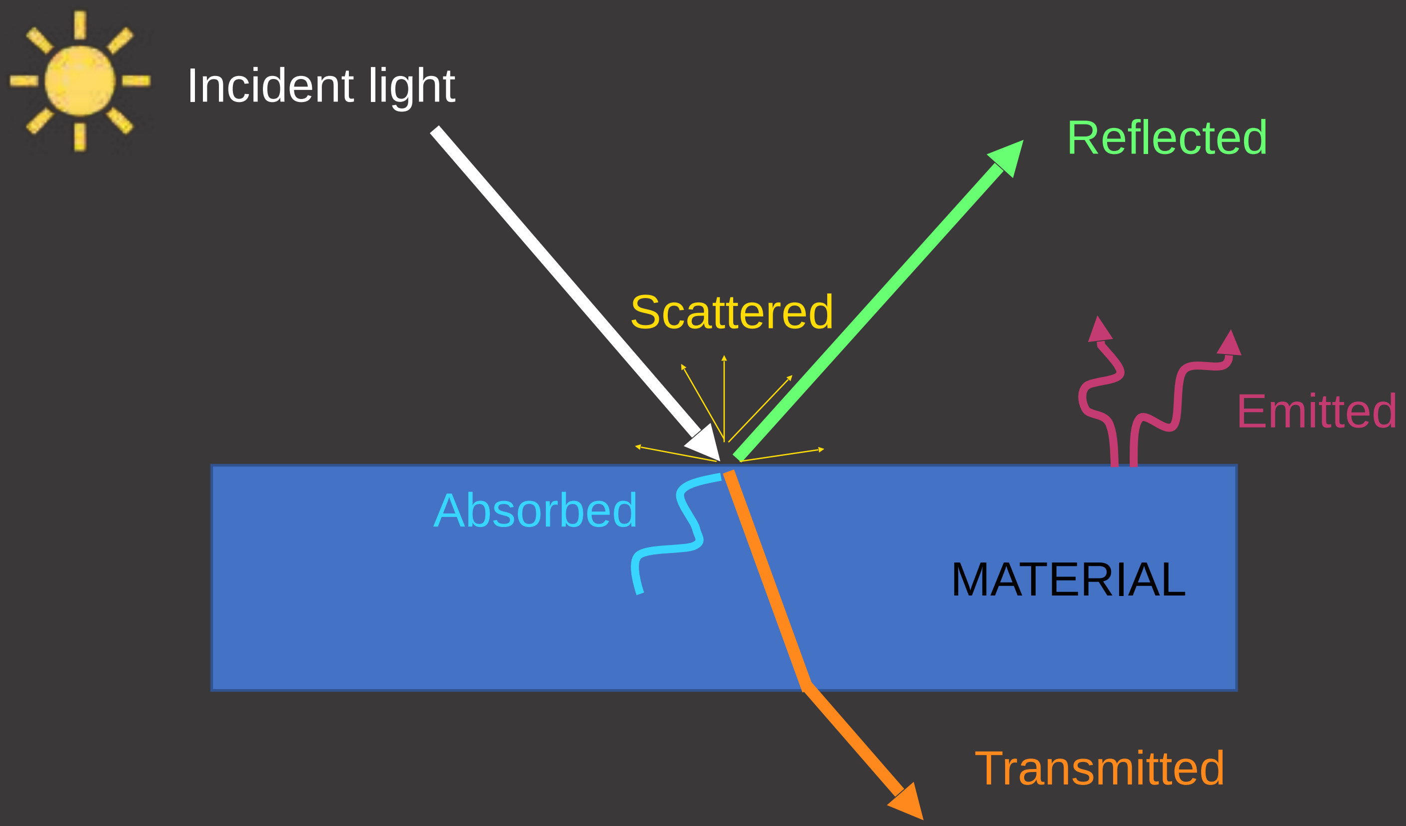
The components of electromagnetic radiation: the electromagnetic spectrum



Introduction: spectroscopy and light

Spectroscopy investigates the interaction between electromagnetic radiation (light) and matter.

What happens when light hits a material?

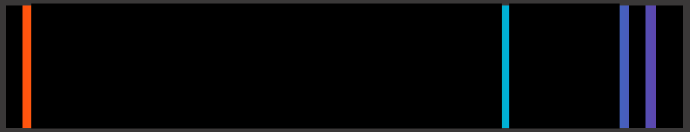


Introduction: spectroscopy and light

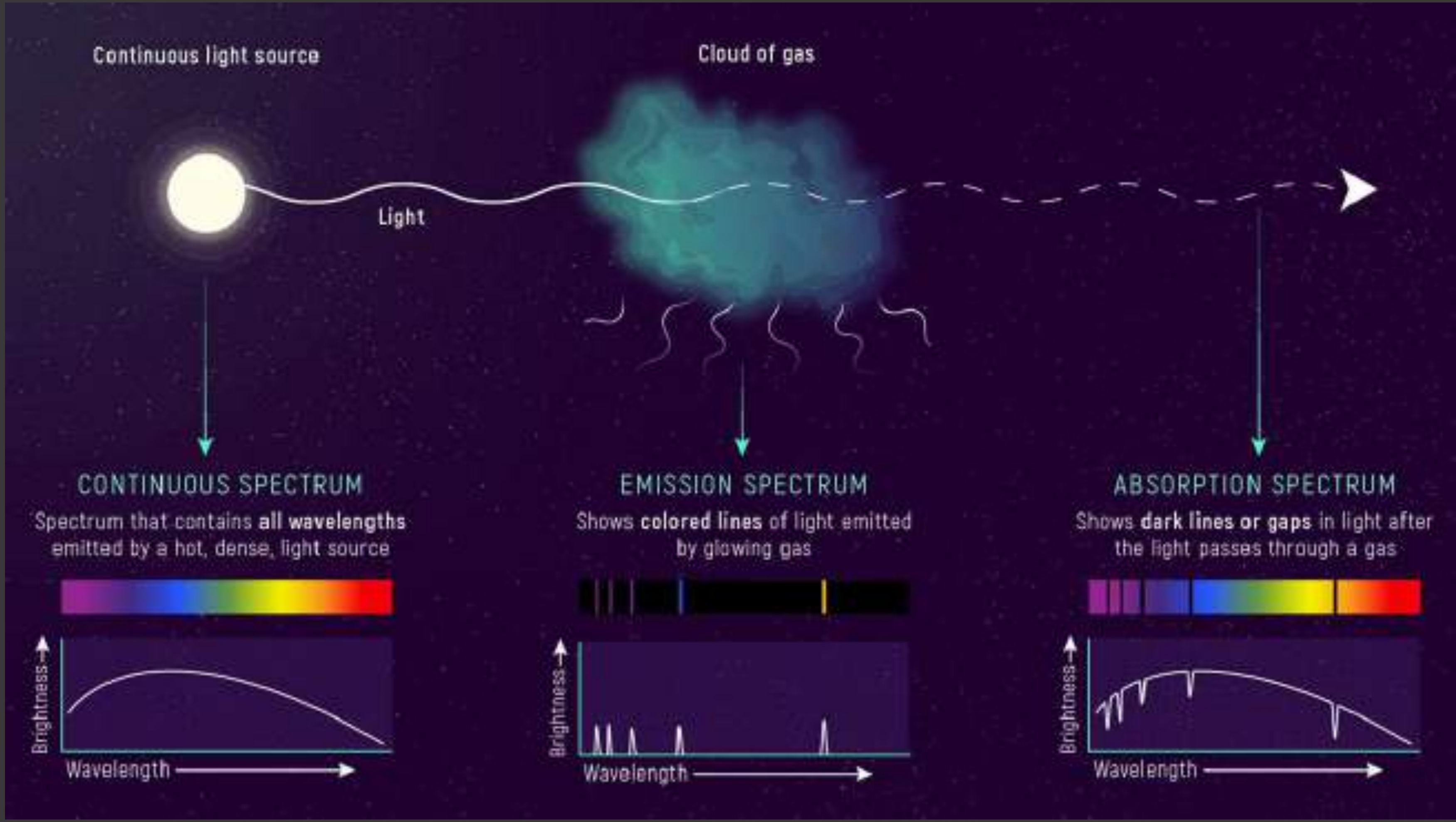
Types of spectrum

Continuous spectrum

Emission spectrum



Absorption spectrum



Credits: NASA, ESA, Leah Hustak (STScI)

Introduction: spectroscopy and light

Spectroscopy for planetary surfaces & atmospheres

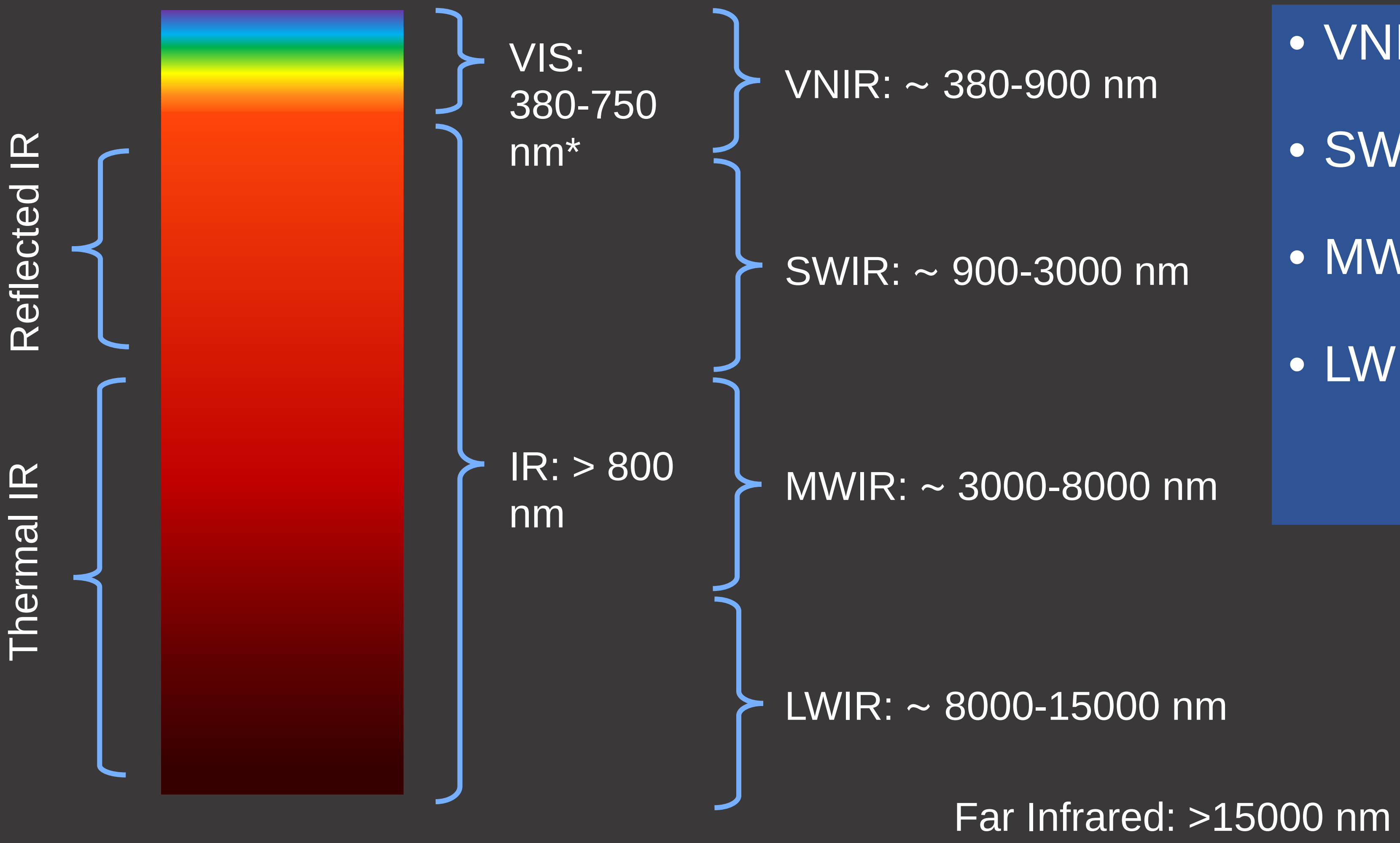
Composition of atmosphere

Minerals on a planet’s surface

Venus and Mars, not to scale

Introduction: spectroscopy and light

Visible-infrared range terminology



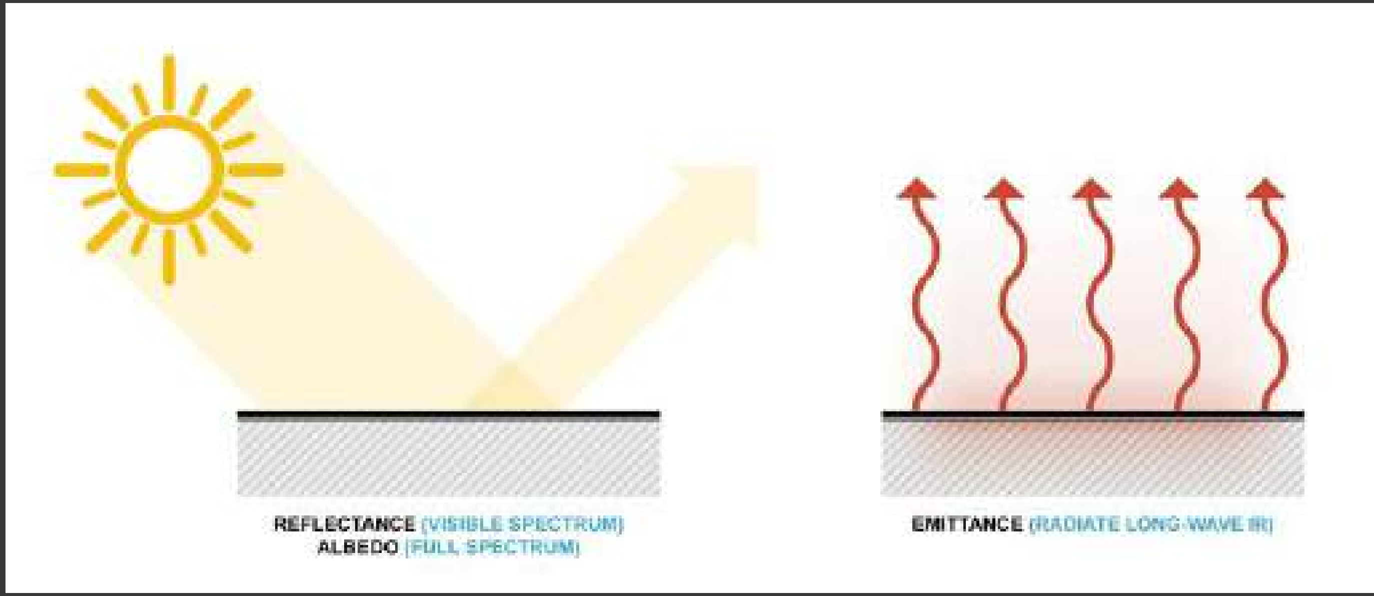
- VNIR: visible-near infrared
- SWIR: short wave infrared
- MWIR: mid-wave infrared
- LWIR: long-wave infrared

*1 nm = 10^{-9}m

Introduction: spectroscopy and light

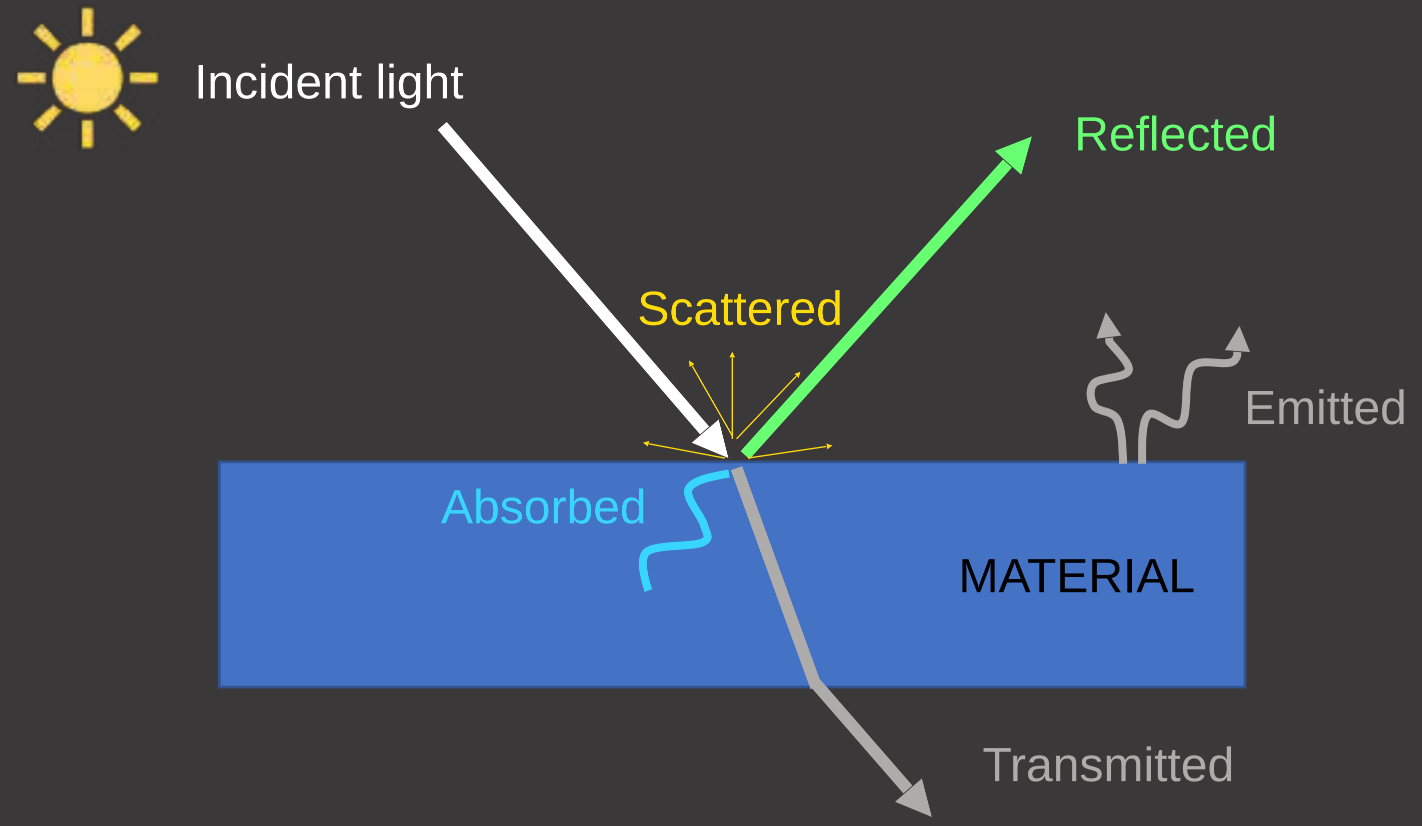
Reflectance and emittance spectroscopy

- **Reflectance spectroscopy**: studies the diffused scattered light from the surface of a planet, as a function of the wavelength (visible-short infrared)
- **Emittance spectroscopy**: studies the light which is emitted from the surface of a planet in the thermal infrared part of the spectrum.



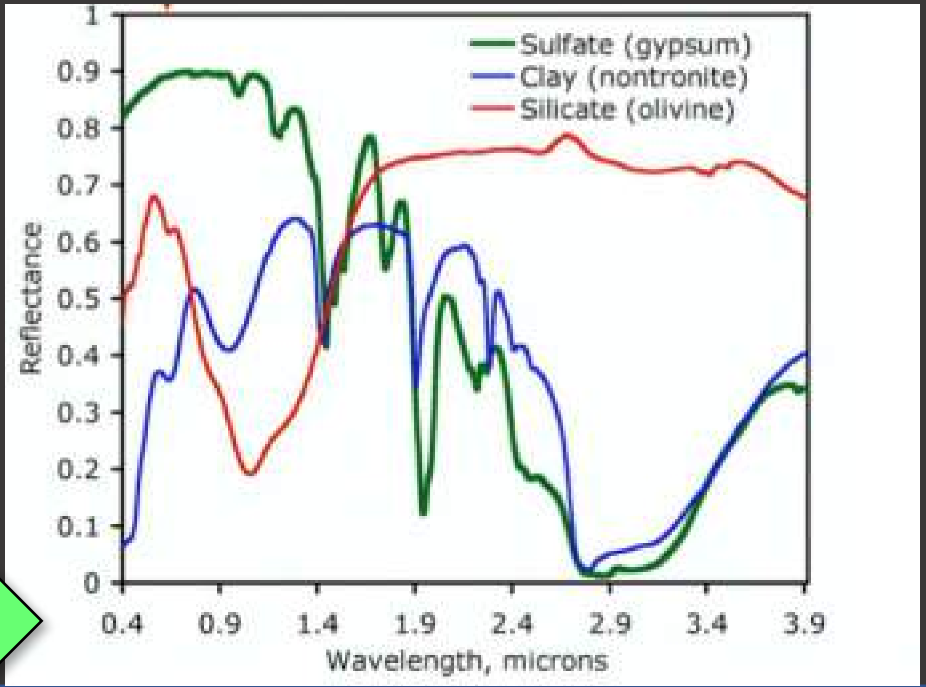
Introduction: spectroscopy and light

Reflectance spectroscopy



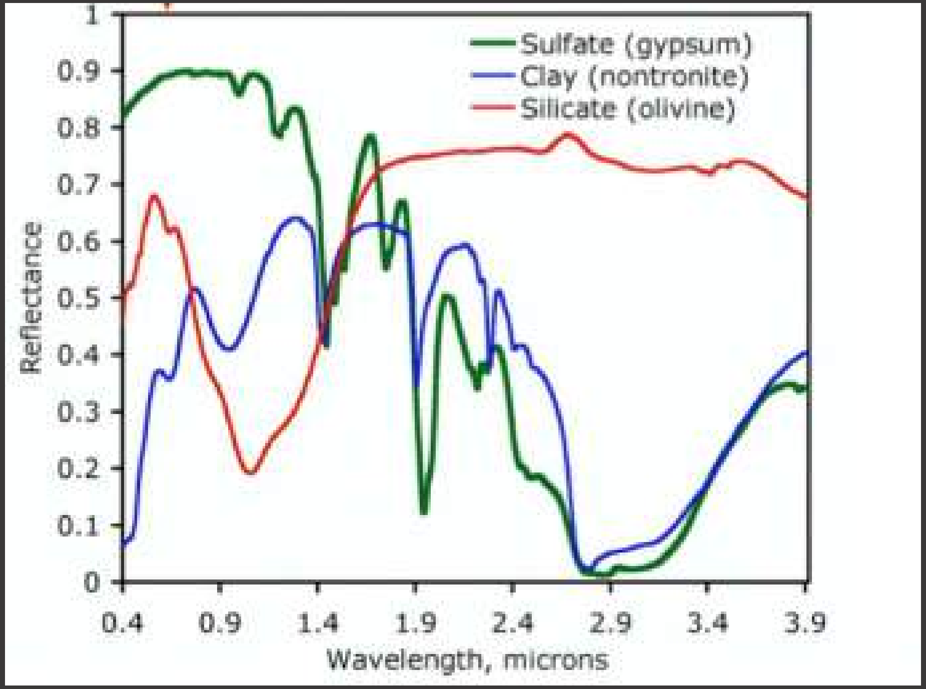
- Reflectance spectroscopy studies the absorption spectrum of the light reflected/ diffused by the object

Visible and Near-Infrared/ Short-infrared range



Introduction: spectroscopy and light

Reflectance spectroscopy



The spectral features we observe are caused by:

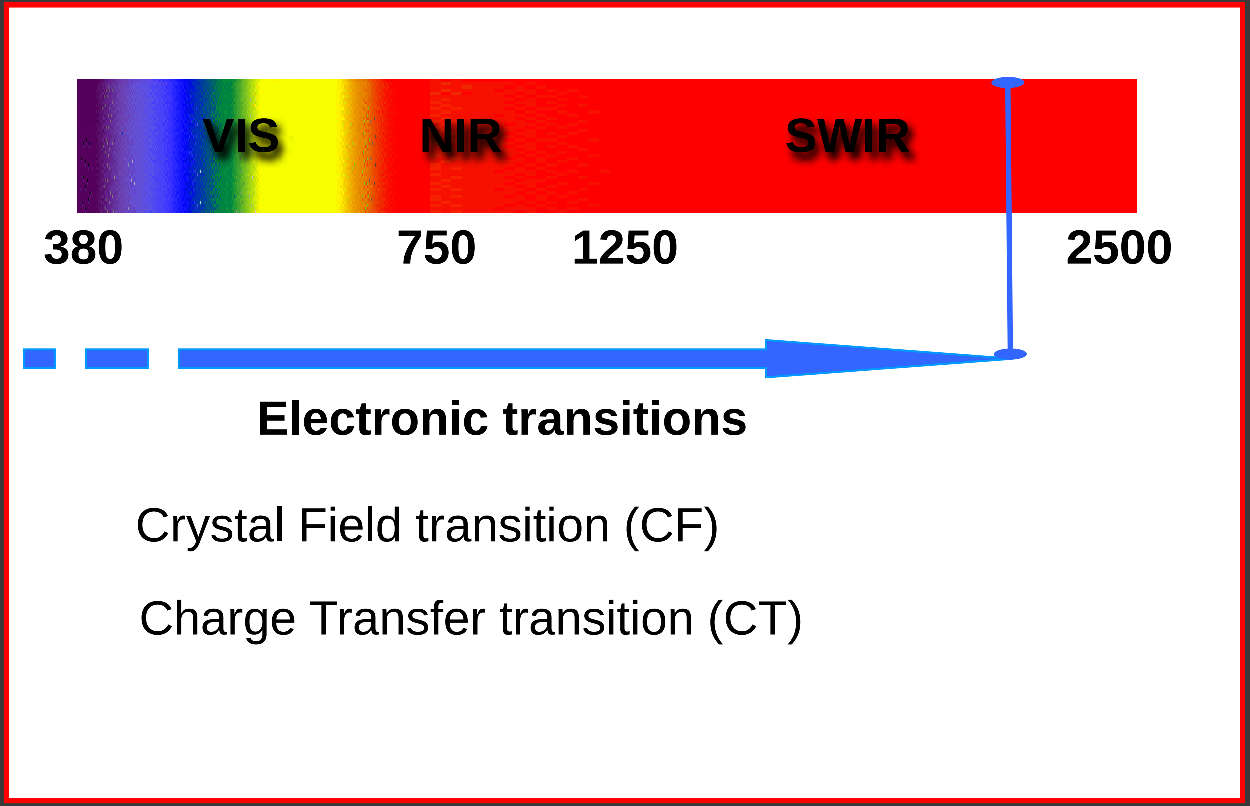
- electronic processes;
- molecular processes.

These happen due to the interaction between electromagnetic radiation and the atoms and molecules that compose the materials.

Introduction: spectroscopy and light

Reflectance spectroscopy: **electronic processes**

- Electrons change from one energy state to another.
- Examples are: **crystal field** (CF), **charge transfer** (CT).

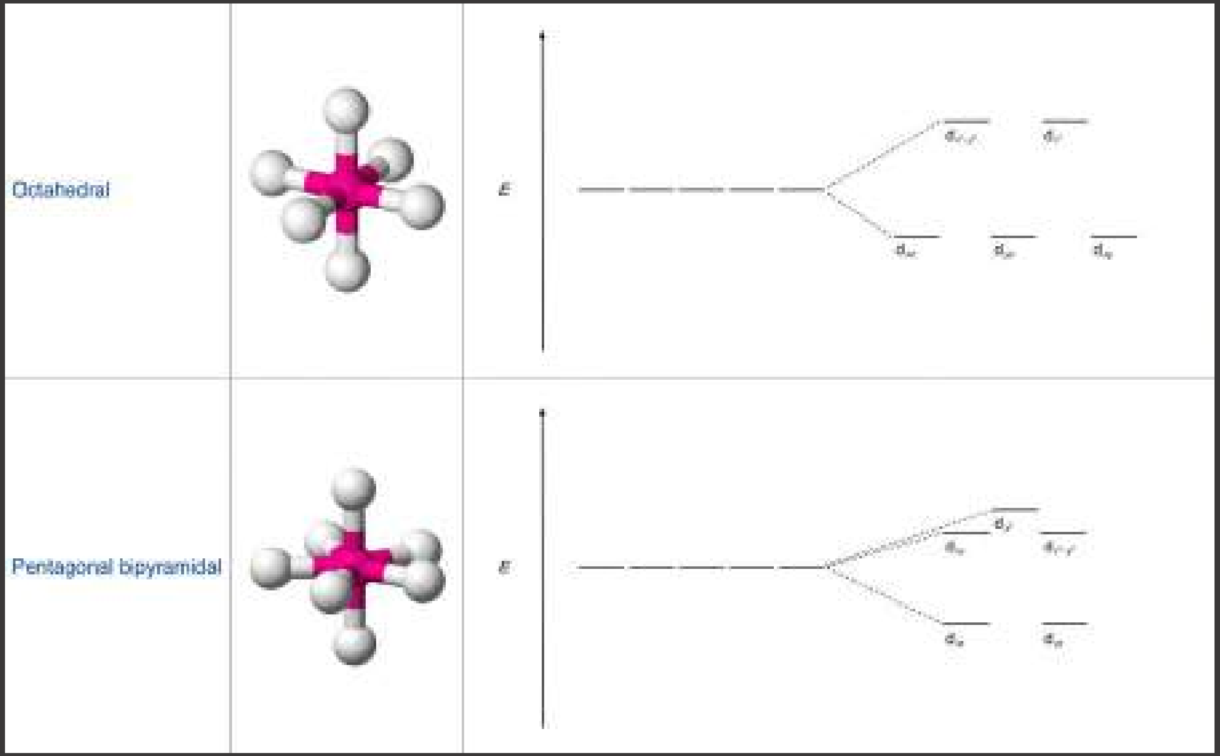


Introduction: spectroscopy and light

Reflectance spectroscopy: **electronic processes**

Crystal field

- For a transition element (Ni, Cr, Co, Fe, etc.) in a crystal field, d orbitals get split into different energy states.
- Electrons can move to a higher energy state by absorbing a photon.

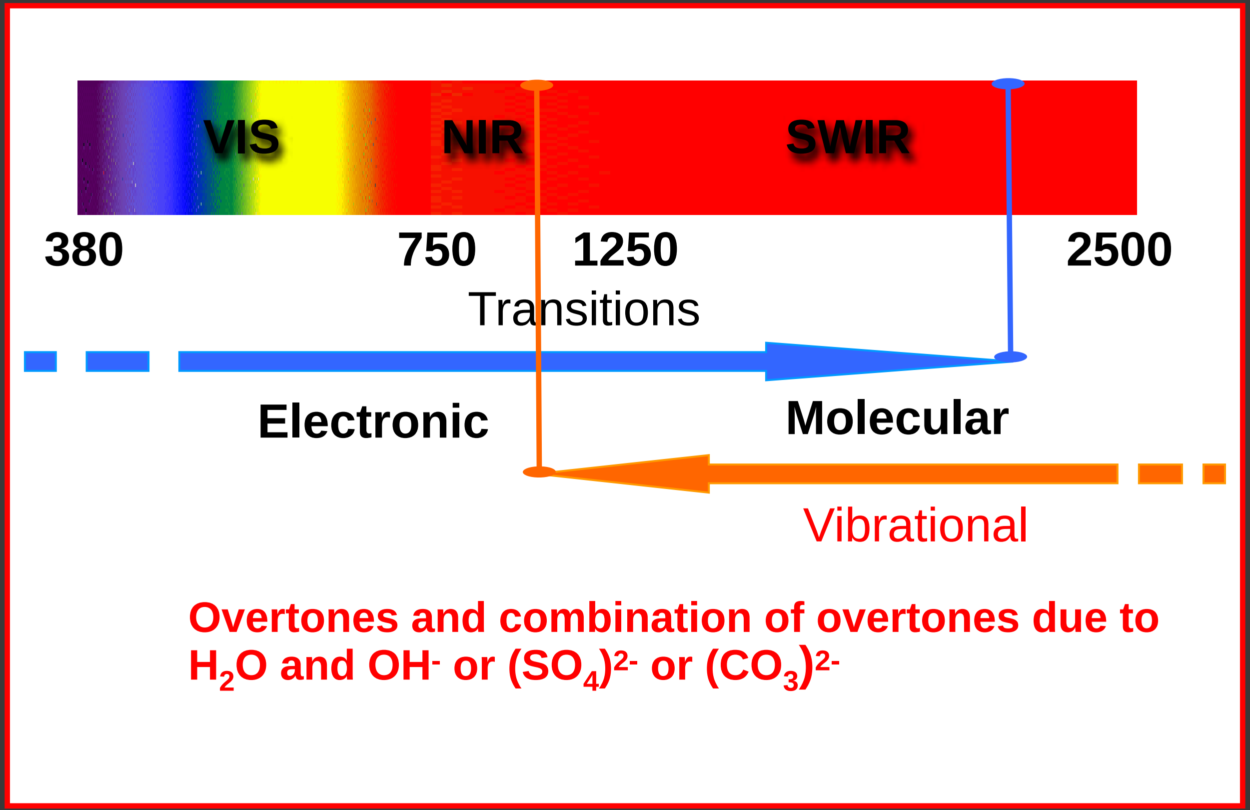


Charge transfer

- Interelement transitions where the absorption of a photon causes an electron to move between ions or between ions and ligands.

Introduction: spectroscopy and light

Reflectance spectroscopy: **molecular processes (vibrational)**



- For a molecule with N atoms, there are 3N-6 normal modes of vibration called *fundamentals*.
- *Overtones*: vibration occurs at frequencies **multiple** of one the original fundamentals.
- *Combinations*: vibration occurs at frequencies that are a **combination** of the fundamentals.

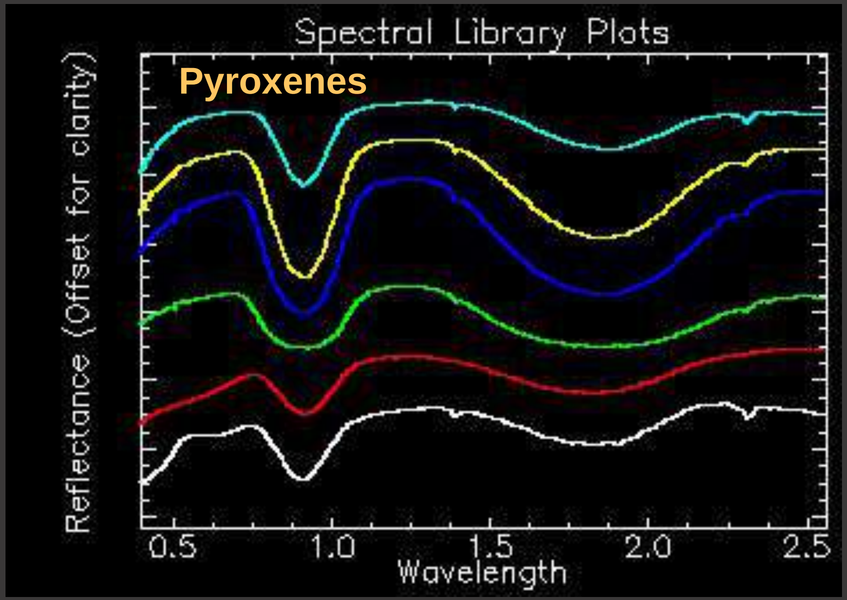
Introduction: spectroscopy and spectra

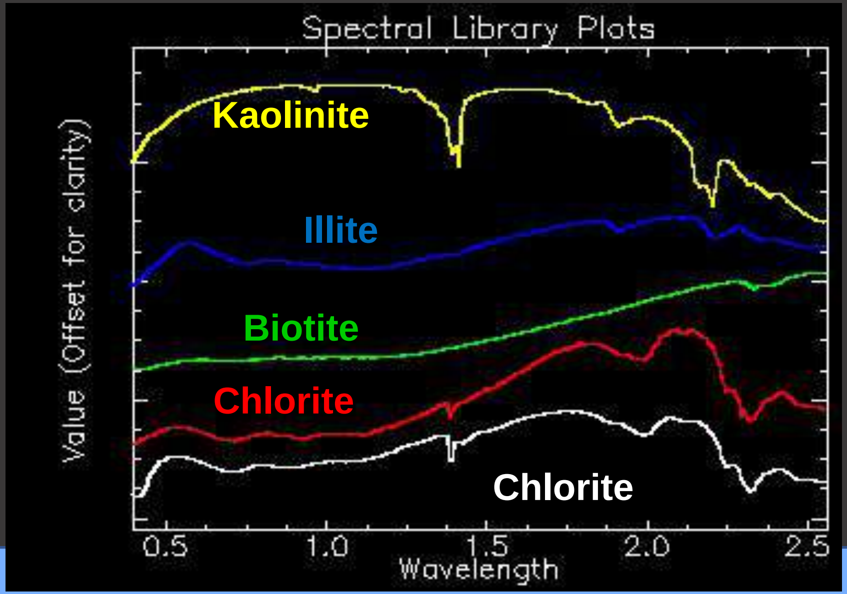
VNIR spectral information, example:
silicates

Absorptions have different position, depth and shape due to:

- Different **cations** in the crystal sites;
- Presence of water or Hydroxyl (OH), in this case they are *hydrated s.*;
- Different **anions**, for example $(SO_4)^{2-}$or $(CO_3)^{2-}$;

Each type of mineral has unique features

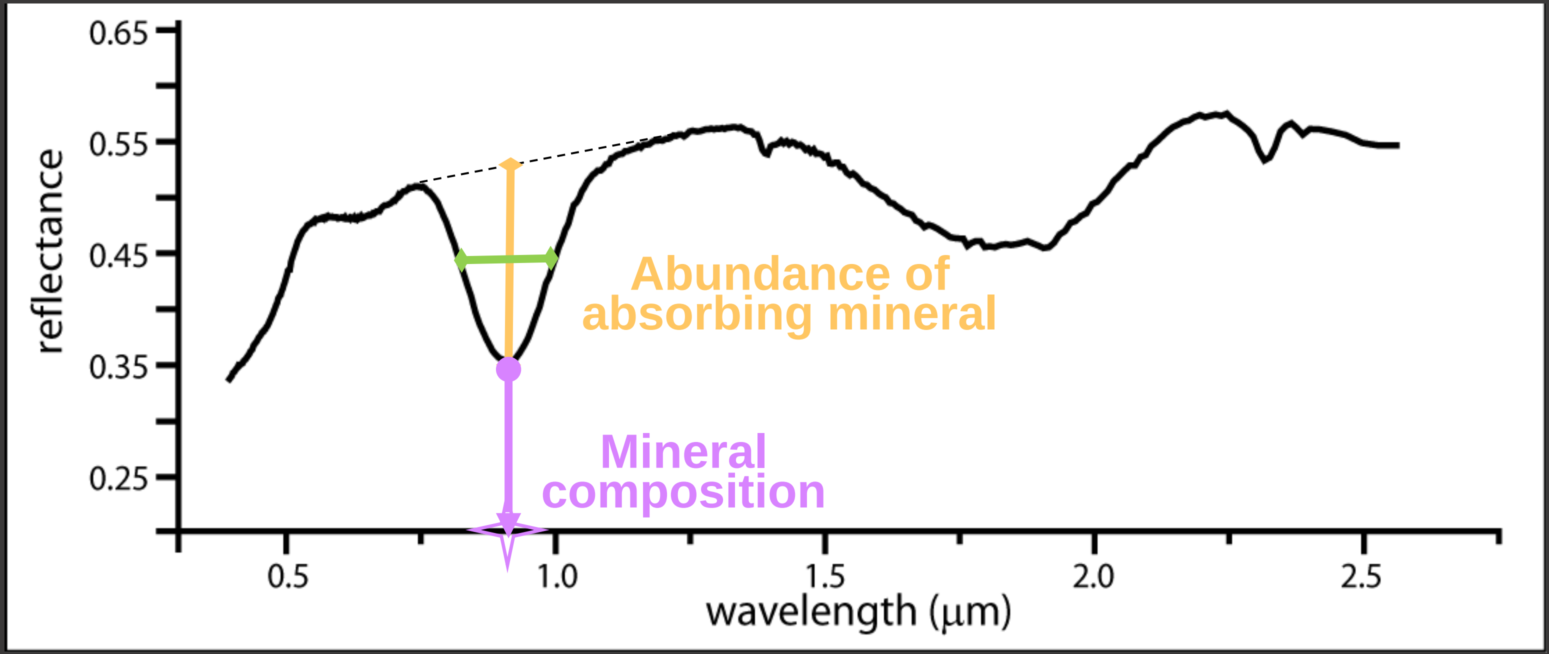




Introduction: spectroscopy and spectra

Spectral parameters: band minimum, band depth, band width

Band minimum	Band depth	Band width
Energy (compositional variations)	Intensity of absorption (grain size/abundance)	Vibronic processes (pressure/ temperature)



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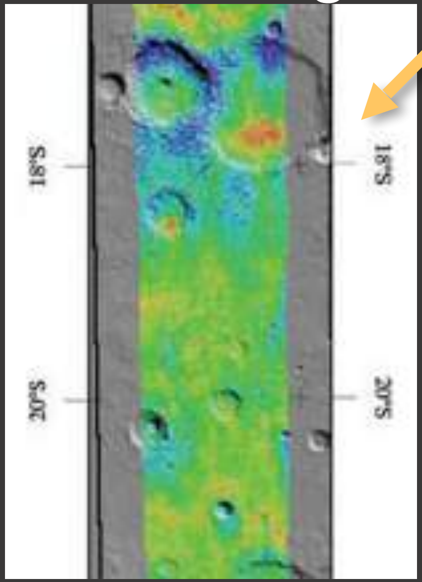
Reflectance spectroscopy on planetary bodies

Multispectral vs hyperspectral

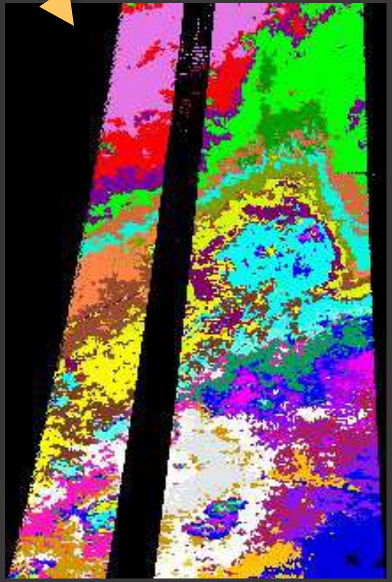
- Multispectral: few wavelengths sampled, color variation + compositional extrapolation;

- Hyperspectral: many wavelengths sampled, mineralogical classification

Color parameter image
(band ratio)

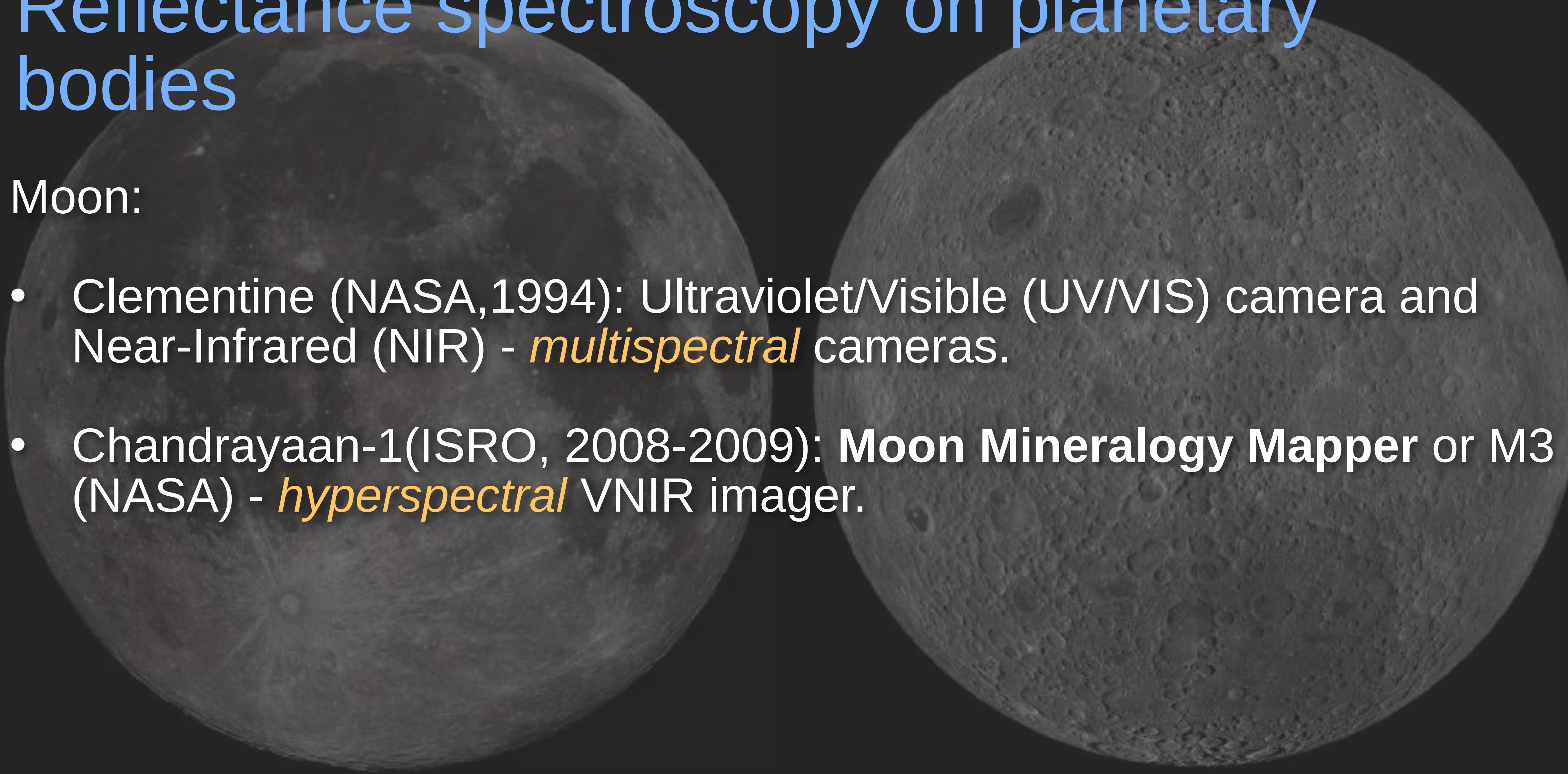


Color parameter image
(band position/depth)



Endmember
classification

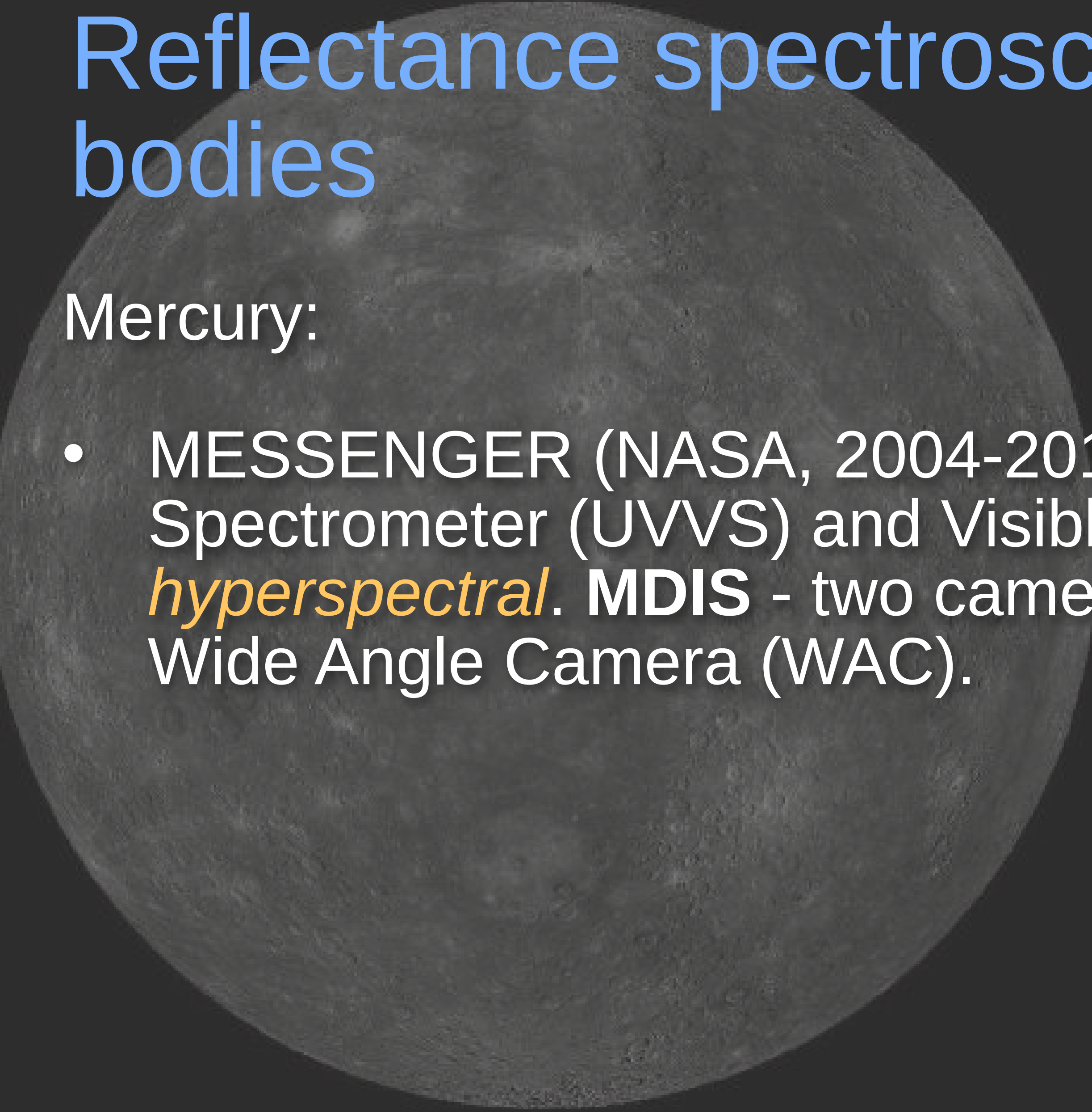
Reflectance spectroscopy on planetary bodies

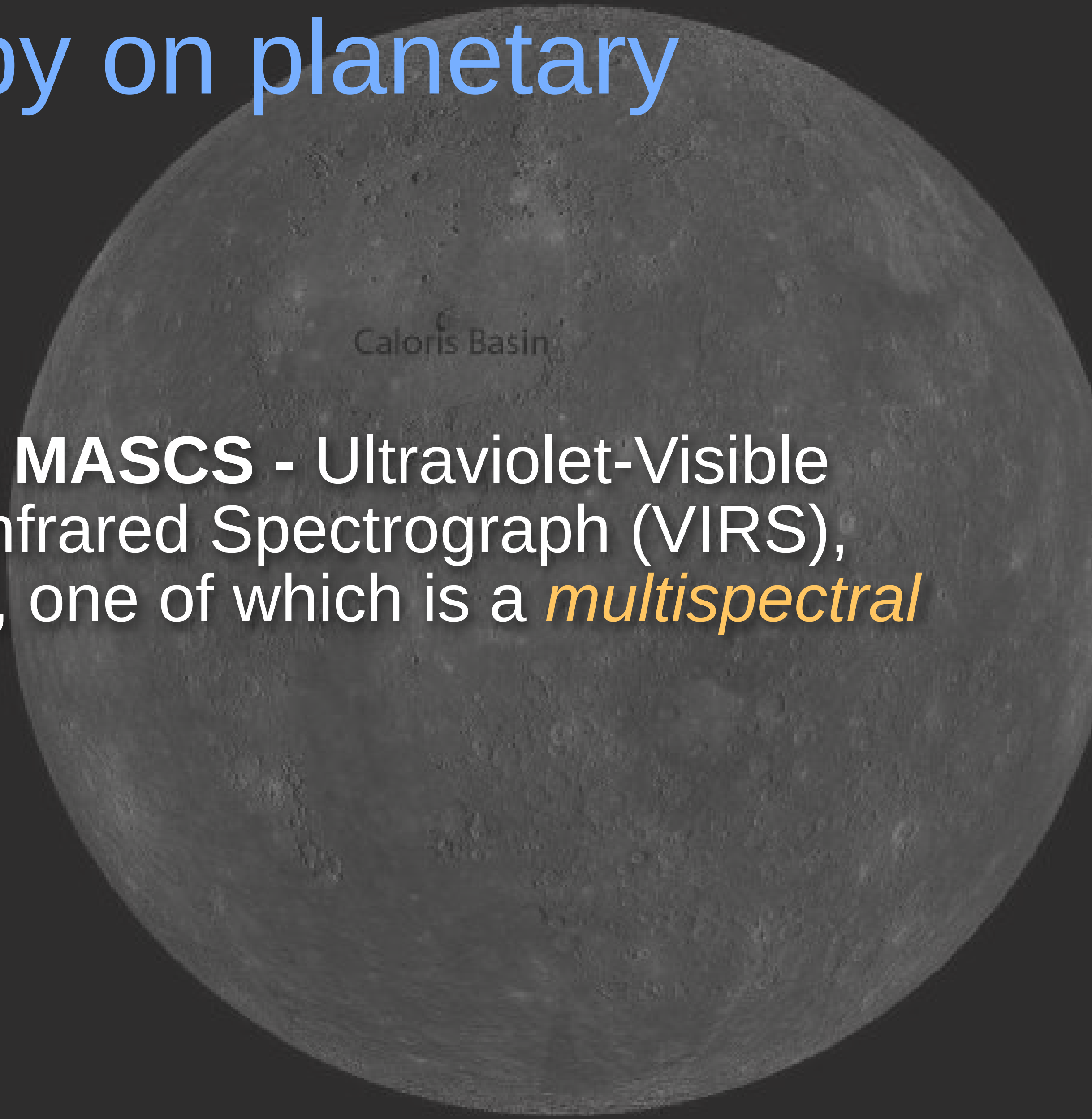


Moon:

- Clementine (NASA,1994): Ultraviolet/Visible (UV/VIS) camera and Near-Infrared (NIR) - *multispectral* cameras.
- Chandrayaan-1(ISRO, 2008-2009): **Moon Mineralogy Mapper** or M3 (NASA) - *hyperspectral* VNIR imager.

Reflectance spectroscopy on planetary bodies





Mercury:

- MESSENGER (NASA, 2004-2015): **MASCS -** Ultraviolet-Visible Spectrometer (UVVS) and Visible-Infrared Spectrograph (VIRS), *hyperspectral*. **MDIS** - two cameras, one of which is a *multispectral* Wide Angle Camera (WAC).

Reflectance spectroscopy on planetary bodies

Vesta and Ceres:

- DAWN (NASA, 2007-2018): **VIR** - Visual and Infrared Spectrometer, *hyperspectral*. **FC** - Framing Camera, VNIR range, *multispectral*

67P/Churyumov-Gerasimenko:

- Rosetta (ESA, 2004-2016): **VIRTIS** - Visible and Infrared Thermal Imaging Spectrometer, *hyperspectral*.

Reflectance spectroscopy on planetary bodies

Mars:

- Mars Global Surveyor (NASA, 1997-2006): Thermal Emission Spectrometer (TES), *hyperspectral*.
- Mars Odyssey (NASA, 2001-present): Thermal Emission Imaging System (THEMIS), *multispectral*.
- Mars Express (ESA, 2003-present) : OMEGA - Visible and Infrared (VNIR) Mineralogical Mapping Spectrometer, *hyperspectral*
- Mars Reconnaissance Orbiter (NASA, 2005-present): CRISM, *hyperspectral* VNIR imager.

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Reflectance spectroscopy on planetary bodies: Mars

Years of operation	Instrument name	Mission	Key characteristics
1997-2006	Thermal emission spectrometer (**TES**)	Mars Global Surveyor - NASA	Thermal infrared point spectroscopy (~6–50 μm; 3 × 6 km spots)
2001- present	Thermal emission Imaging System (**THEMIS**)	Mars Odyssey - NASA	Thermal infrared multispectral imaging (6.7–14.8 μm; 7 bands; 100-m pixels)
2004- present	Observatoire pour la Mineralogie, l'Eau, les Glaces, et l'Activite (**OMEGA**)	Mars Express - ESA	Visible/near-infrared imaging spectroscopy (0.4–5.0 μm; 200–2,000 m/pixel)
2006-present	Compact Reconnaissance Imaging Spectrometer for Mars (**CRISM**)	Mars Reconnaissance Orbiter - NASA	Visible/near-infrared imaging spectroscopy (0.4–4.0 μm; 18–200 m/pixel)

Reflectance spectroscopy on planetary bodies: Mars

Thermal infrared (TIR) spectroscopy

Years of operation	Instrument name	Mission	Key cha
1997-2006	Thermal emission spectrometer (**TES**)	Mars Global Surveyor - NASA	Thermal infrared point spectroscopy (~6–50 µm, × 6 km spots)
2001- present	Thermal emission Imaging System (**THEMIS**)	Mars Odyssey - NASA	Thermal infrared multispectral imaging (6.7–14.8 µm; 7 bands; 100-m pixels)
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Reflectance spectroscopy on planetary bodies: Mars

Thermal infrared (TIR) spectroscopy

Years of operation	Instrument name	Mission	Key cha
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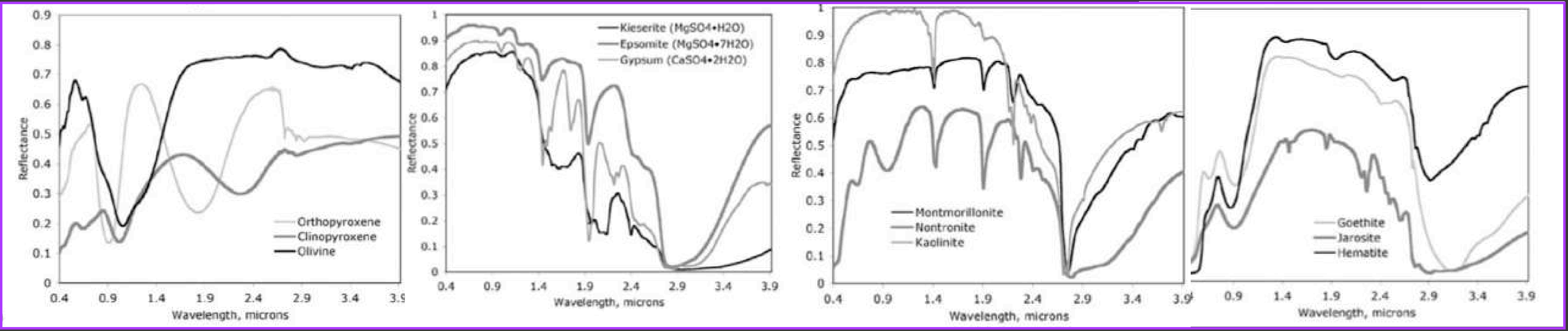
2004- present	Observatoire pour la Mineralogie, l'Eau, les Glaces, et l'Activite (**OMEGA**)	Mars Express - ESA	Visible/near-infrared imag … 4–5.0 µm; 200–2,000 m/pixel)
2006-present	Compact Reconnaissance Imaging Spectrometer for Mars (**CRISM**)	Mars Reconnaissance Orbiter - NASA	Visible/near-infrared imaging spectroscopy (0.4–4.0 µm; 18–200 m/pixel)

VNIR reflectance spectroscopy

Reflectance spectroscopy on planetary bodies: Mars

VNIR: the **0.4 – 5 µm** range retains the **key features of most primary and secondary minerals** of the Martian surface

Primary igneous minerals | Sulfate minerals | Clay minerals | Ferric secondary minerals



Laboratory spectra of minerals identified by MER or OMEGA, at CRISM's wavelength range. Murchie et al. (2007)

Mars surface mineralogy

- **Dust** ➤ nanophase ferric oxides

Mars Viking Global Color Mosaic

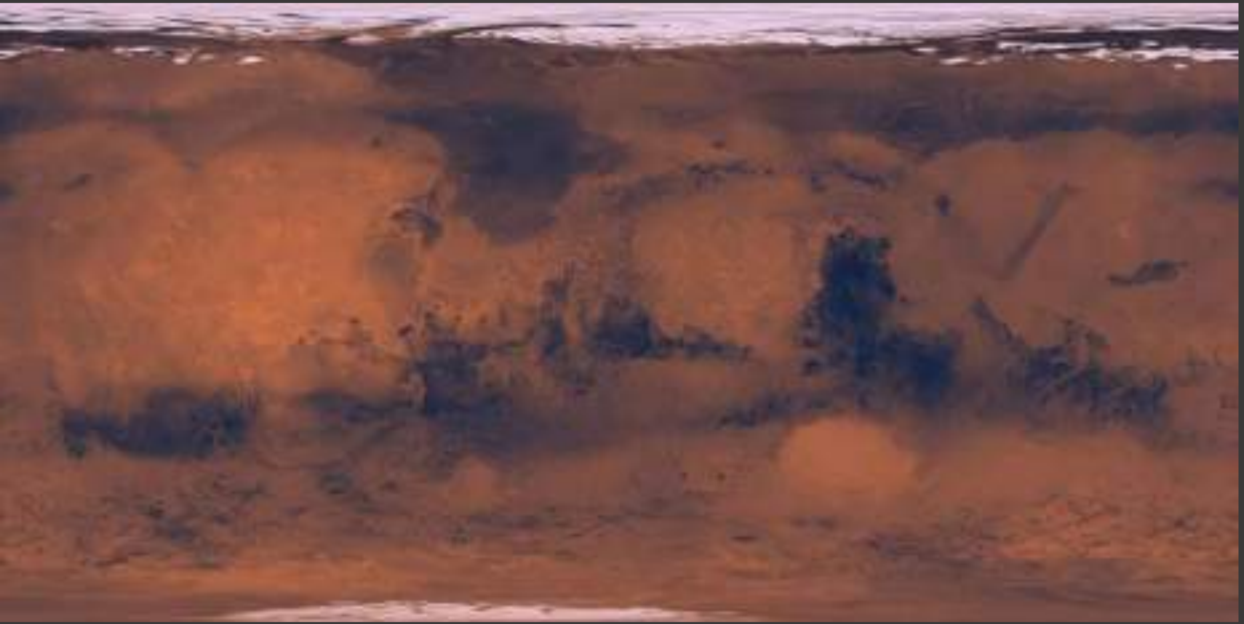


Image credits: NASA/ USGS

Mars Dust Map

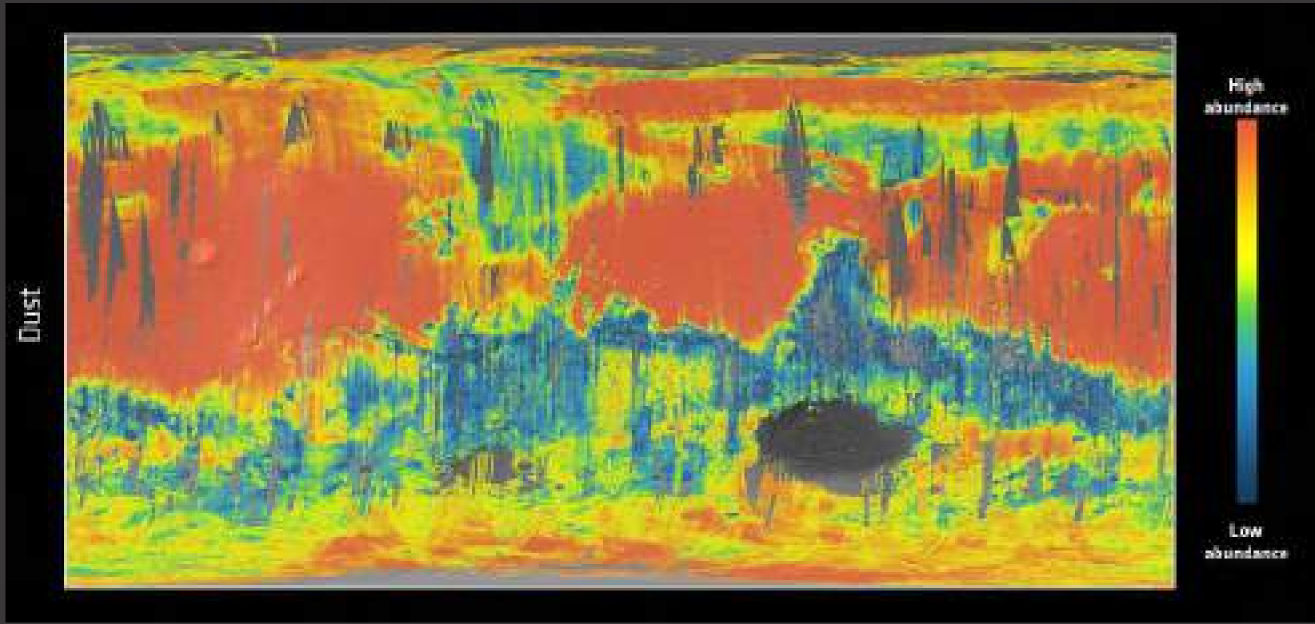
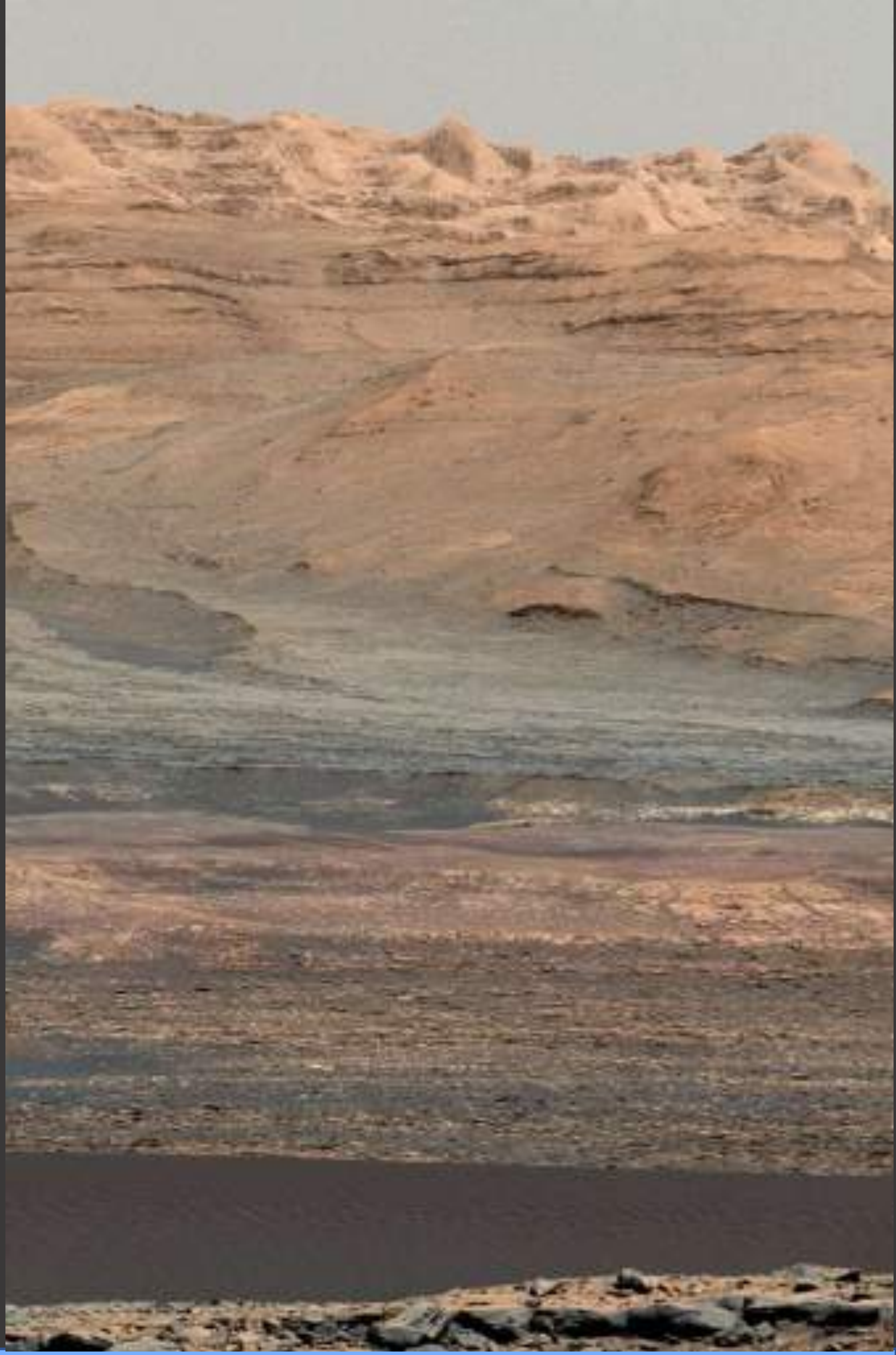


Image credits: ESA

Mars surface mineralogy

- **Primary igneous crust** → Plagioclase, pyroxenes, olivine
- **Minerals derived from secondary processes** (e.g., anhydrous oxidation, physical weathering, interaction with liquid water) → e.g., phyllosilicates (clays), sulfates, carbonates, oxides

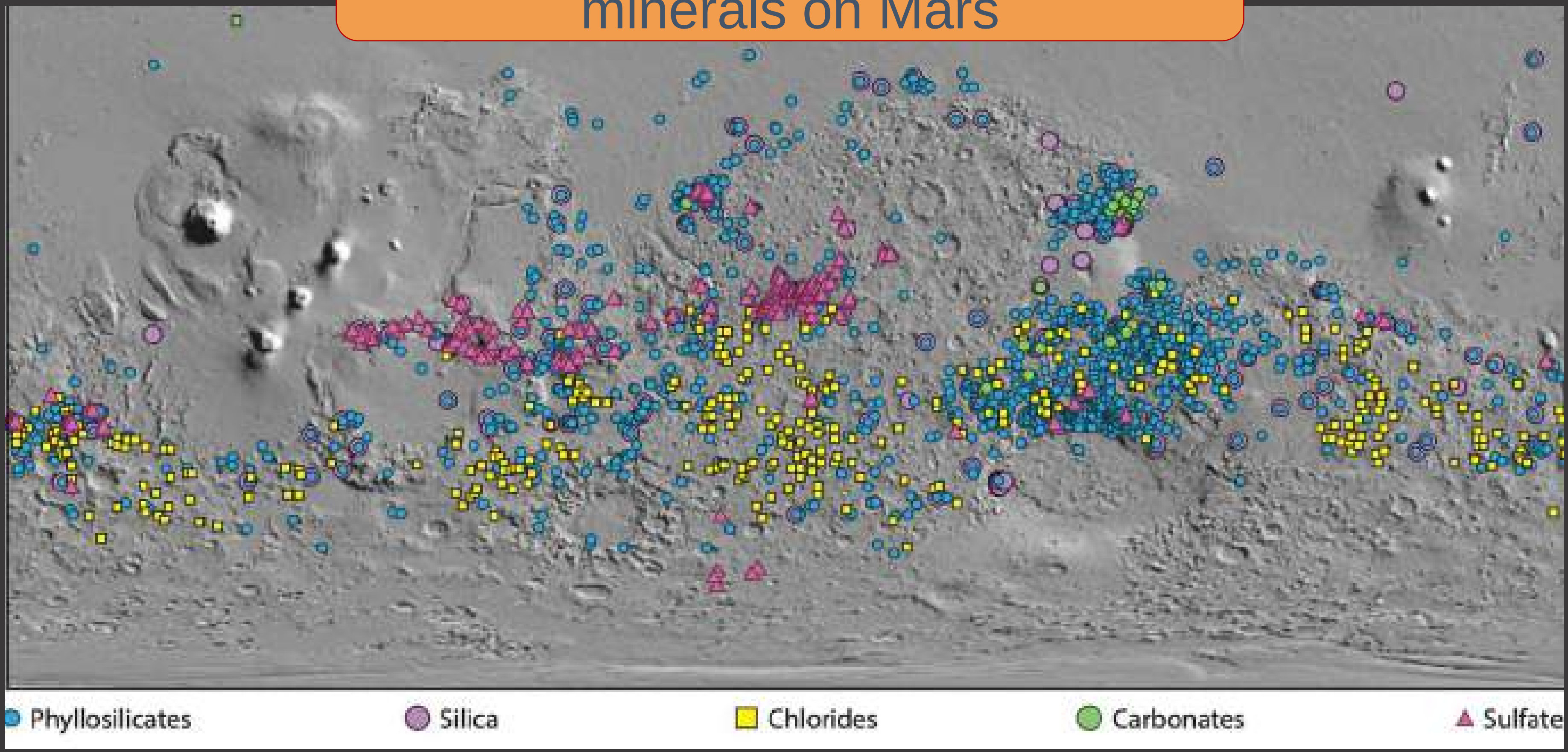


Gale Crater, Mars.
Credits: NASA

Mars surface mineralogy

- **Widespread aqueous alteration** during the past
- Different aqueous environments varying **spatially and temporally** (e.g., fluvio-lacustrine, playas, groundwater)

Global distribution of aqueous minerals on Mars



Ehlmann & Edwards (2014)

Mars surface mineralogy: timeline of large-scale compositional units

Increasingly water limited

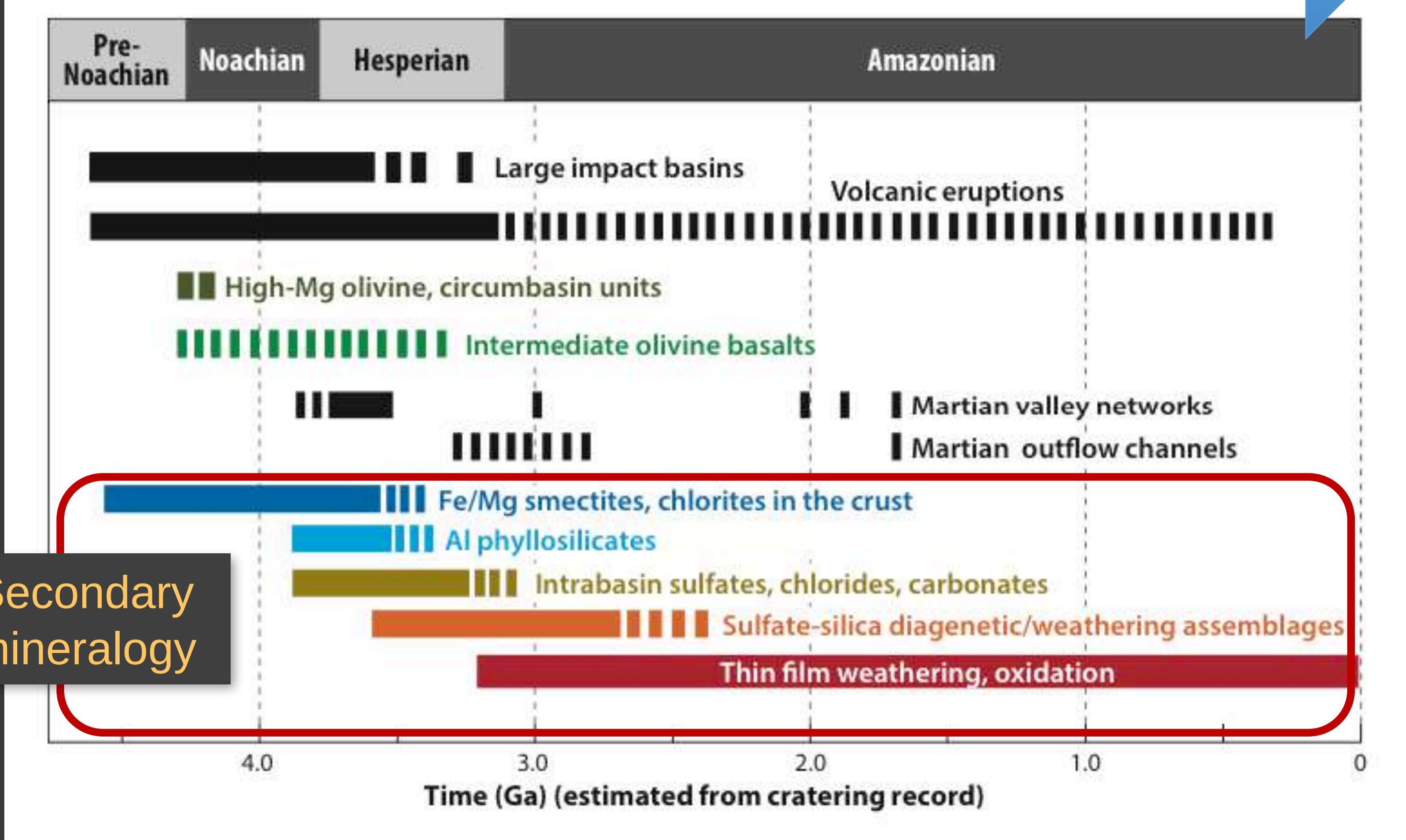
Increasingly oxidized mineralogy

Noachian (4.1-3.7 Gyrs ago): “warm and wet” climate

Hesperian (3.7-3.0 Gyrs ago): dryer and more acidic environment

Amazonian (3 Gyrs ago-present): hyperarid conditions

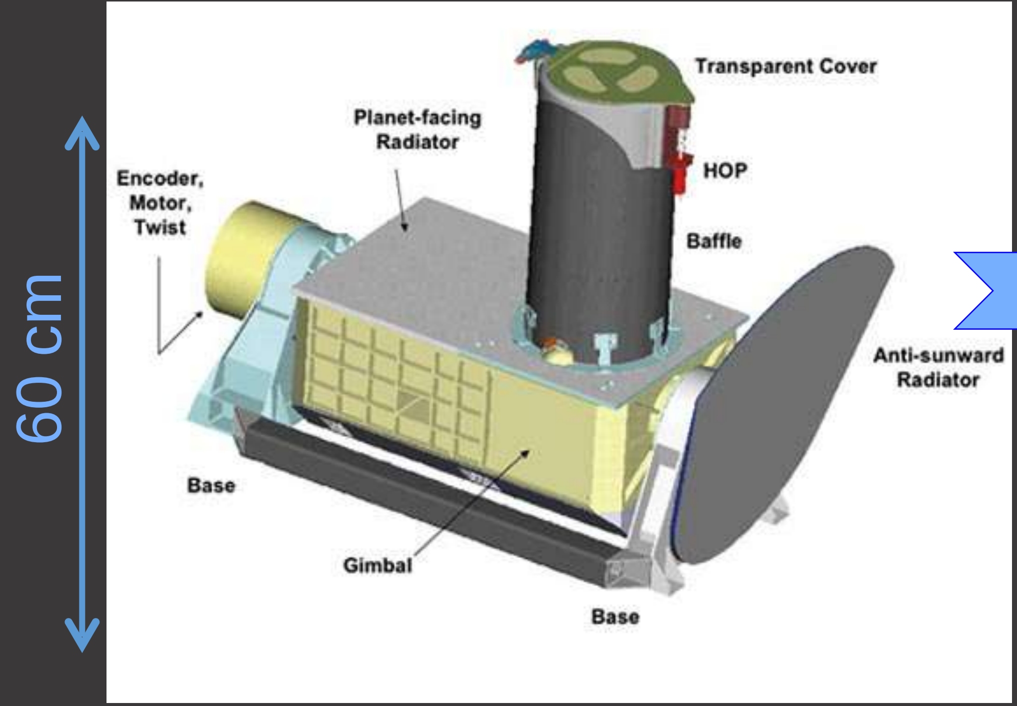
Secondary mineralogy



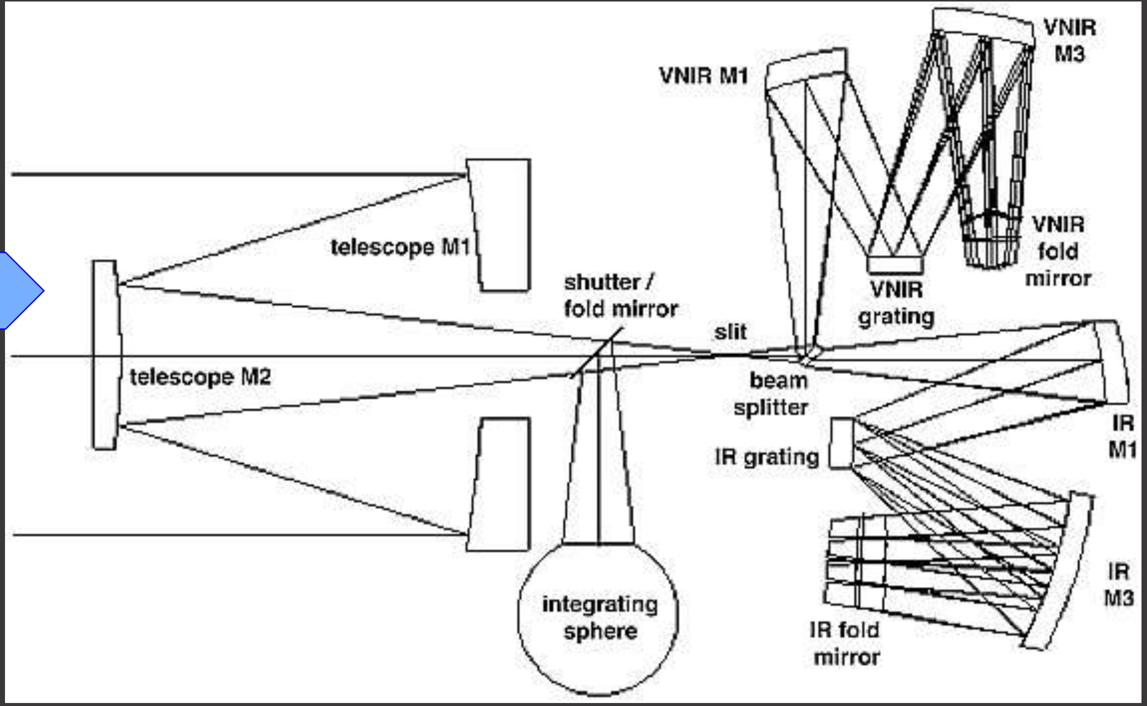
Reflectance spectroscopy on Mars: CRISM

Compact Reconnaissance Imaging Spectrometer for Mars (MRO, 2006-present)

CRISM instrument



Optical design



VNIR sensor
0.4-1.0 µm

IR sensor
1.0-4.0 µm

Image credits: NASA/S. Murchie et al. (2007)

Reflectance spectroscopy on Mars: CRISM

Science objectives:

- Find new targets of interest: aqueous deposits, crustal composition;
- Provide information on spatial/seasonal variations in aerosols, H_2O, CO_2, and ices;
- Measure surface targets with high spatial and spectral resolutions and high signal-to-noise ratio (SNR).

Reflectance spectroscopy on Mars: CRISM

Observation modes:

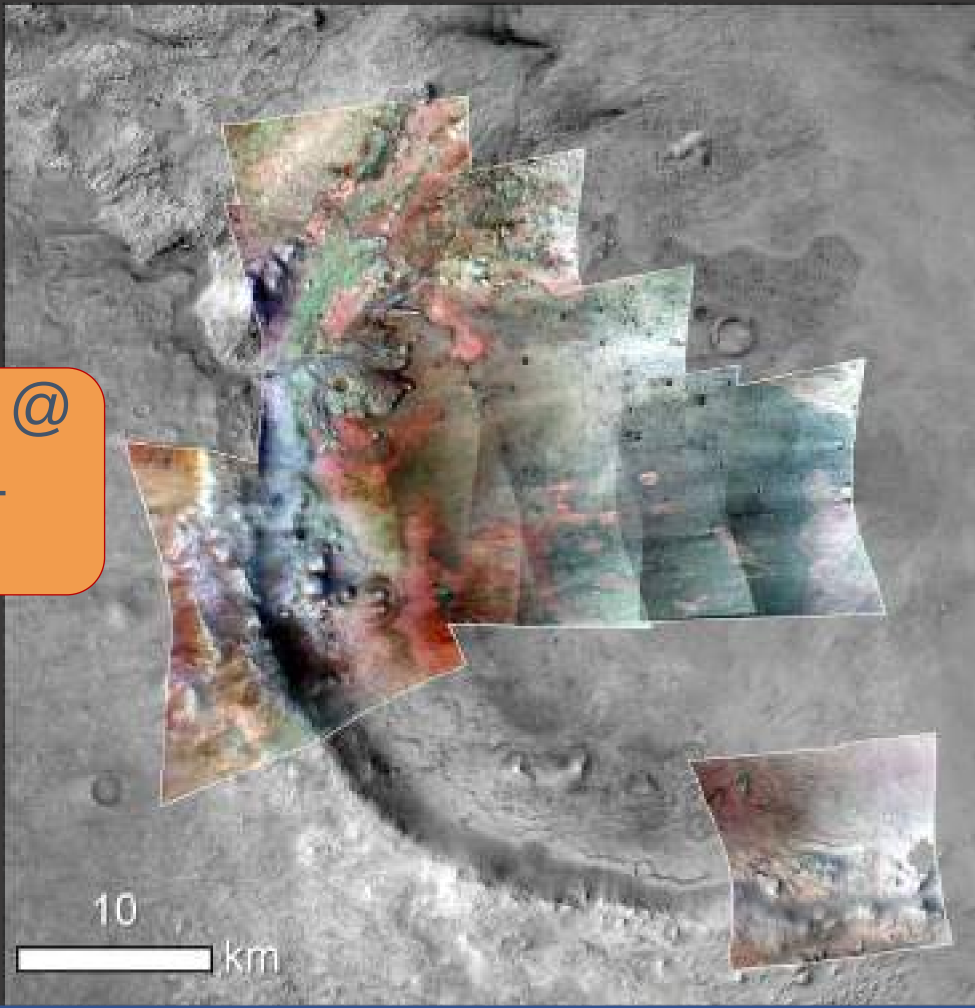
- (Atmospheric, hyperspectral)
- Targeted, hyperspectral
- Mapping, multispectral

Reflectance spectroscopy on Mars: CRISM

Observation modes:

- (Atmospheric, hyperspectral)
- **Targeted, hyperspectral**
- Mapping, multispectral

18-36 m/pixel @ 300km, 544 channels



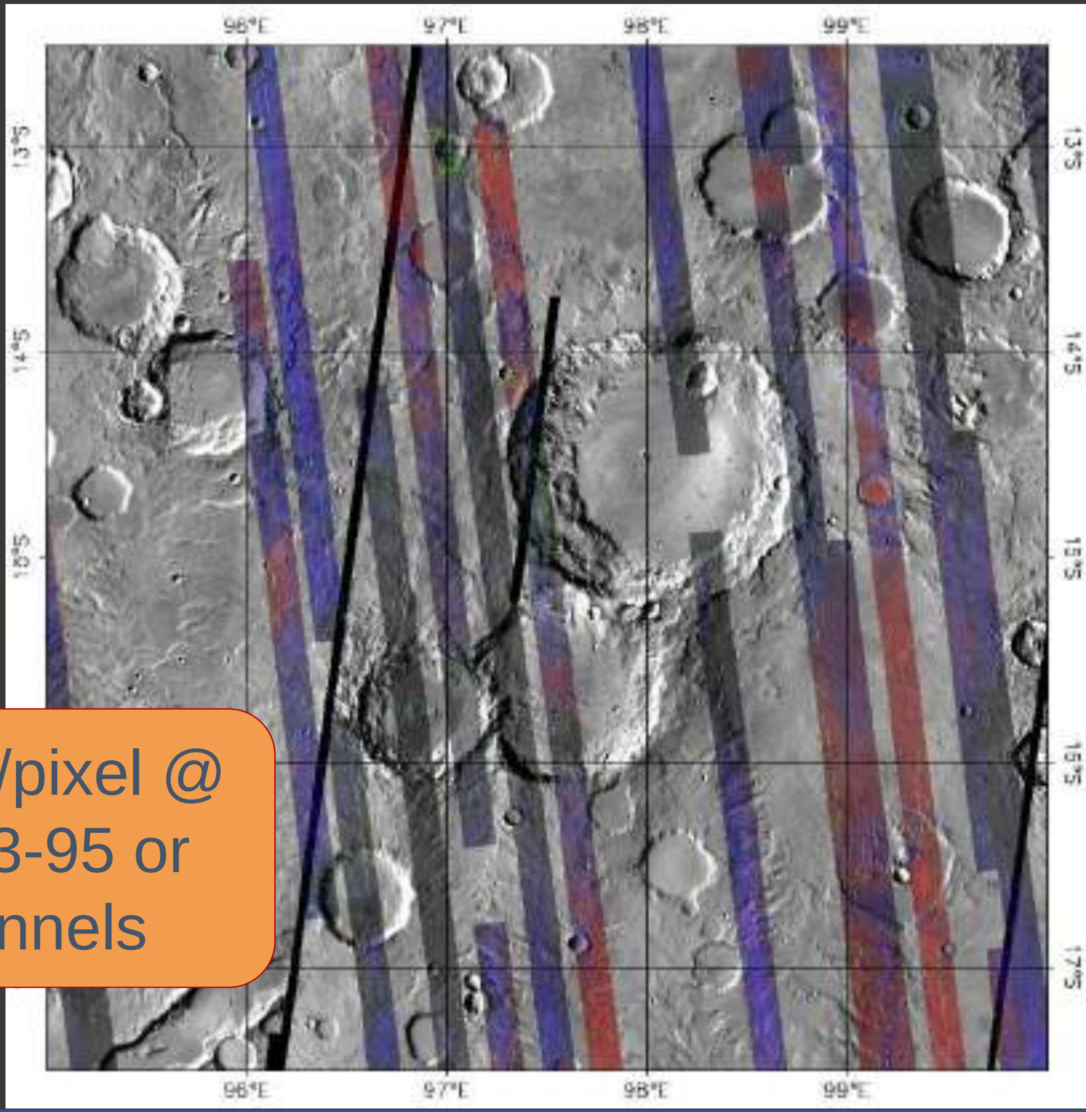
CRISM's targeted observation mosaic in Jezero Crater. Image credits: NASA/JPL-Caltech/MSSS/JHU-APL/Purdue/USGS

Reflectance spectroscopy on Mars: CRISM

Observation modes:

- (Atmospheric, hyperspectral)
- Targeted, hyperspectral
- **Mapping, multispectral**

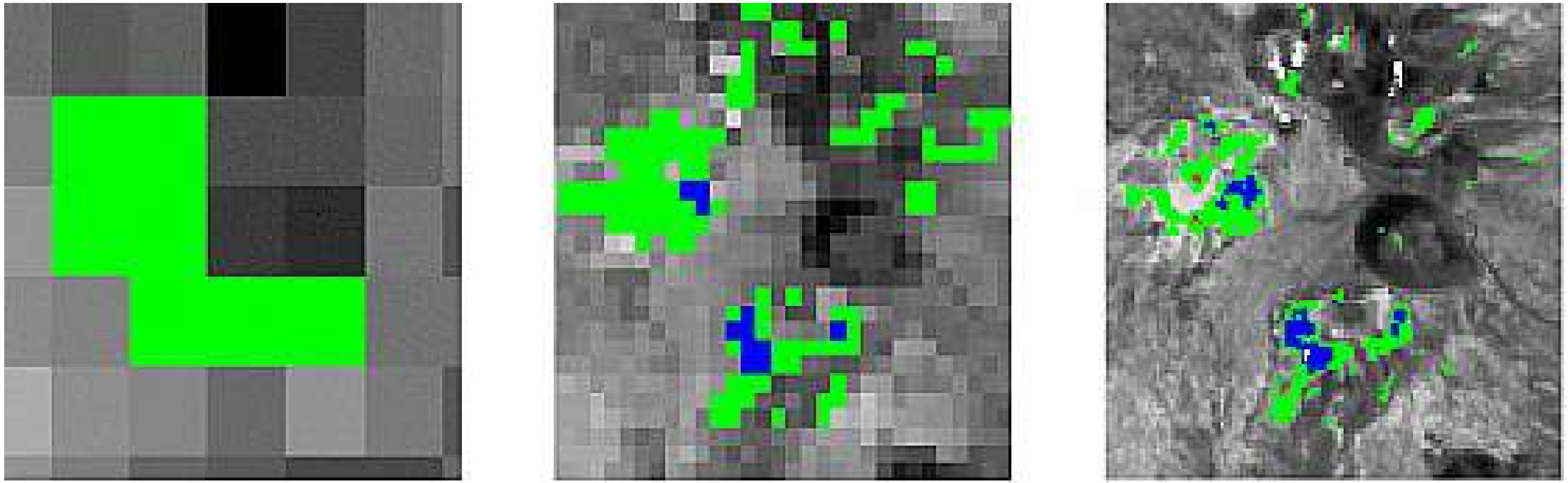
100-200 m/pixel @ 300km, 73-95 or 262 channels



CRISM’s multispectral survey in Tyrrhena Terra. Image credits: NASA/JPL/JHUAPL/Applied Coherent Technology

Reflectance spectroscopy on Mars: CRISM

OMEGA **vs** CRISM multispectral mapping and CRISM targeted observations



OMEGA (300-1000 m/pixel, 13 nm/ch.): discovers large deposits

CRISM multispectral survey (100- 200 m/pix, 70 ch.): discovers small deposits

CRISM targeted hyperspectral (15-38 m/pixel, 6.55 nm/ch): characterizes deposits

Image credits: S. Murchie et al. (2007)

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Understanding and analysing CRISM data products

- CRISM acquires both **spectral** and **spatial information** of the scene.
- Data are organised in **cubes**.

Hyperspectral data cube

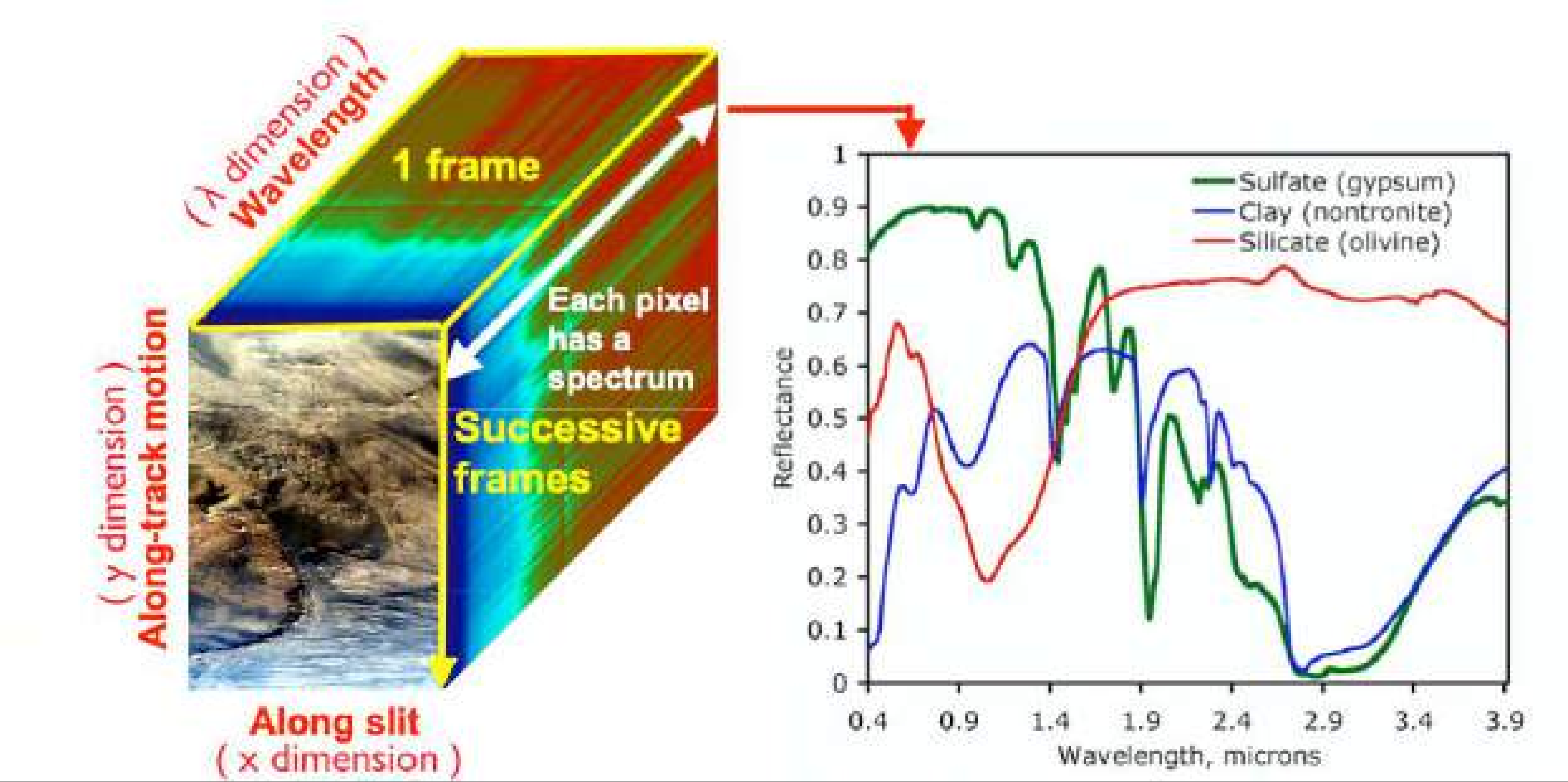


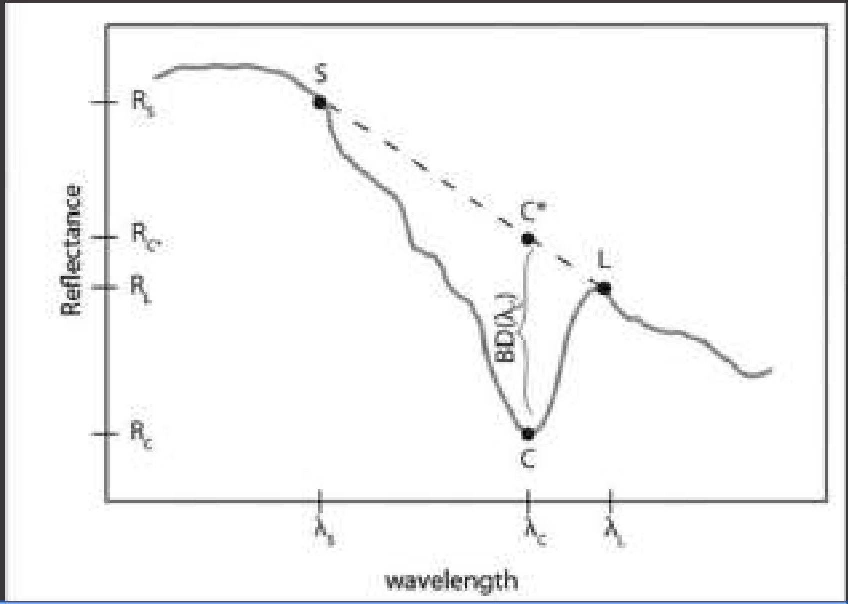
Image credits: JPL/NASA

Understanding and analysing CRISM data products

Summary parameters

- A way to **parametrise** spectral data;
- Mostly measure the strengths and positions of possible mineral absorptions;
- Example: **band depth**

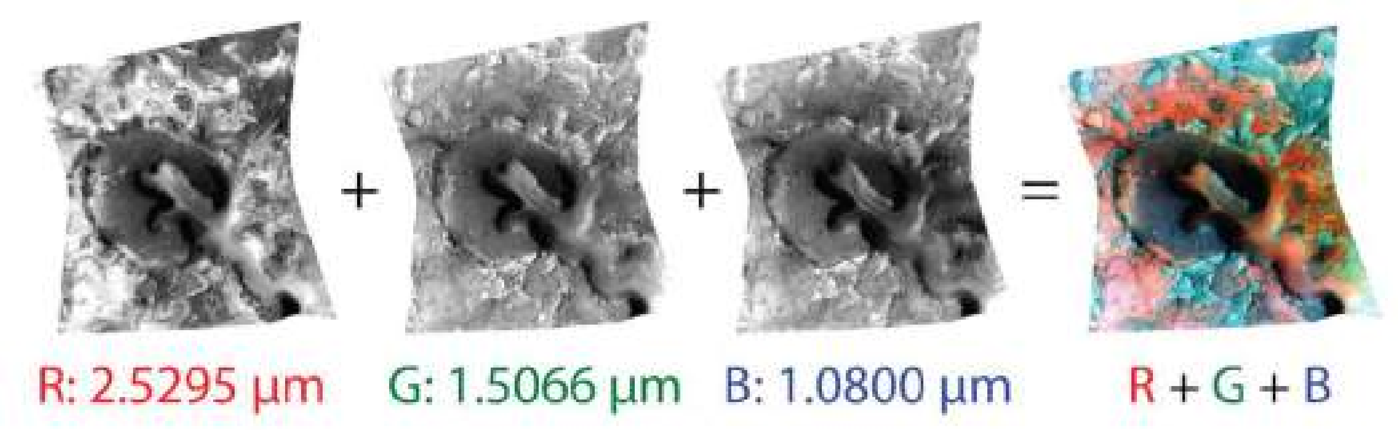
$$BD(\lambda_C) = 1 - \frac{R_C}{R_C^*}$$



Understanding and analysing CRISM data products

Browse products

- **RGB maps** of summary parameters: each colour channel is assigned to a summary parameter;

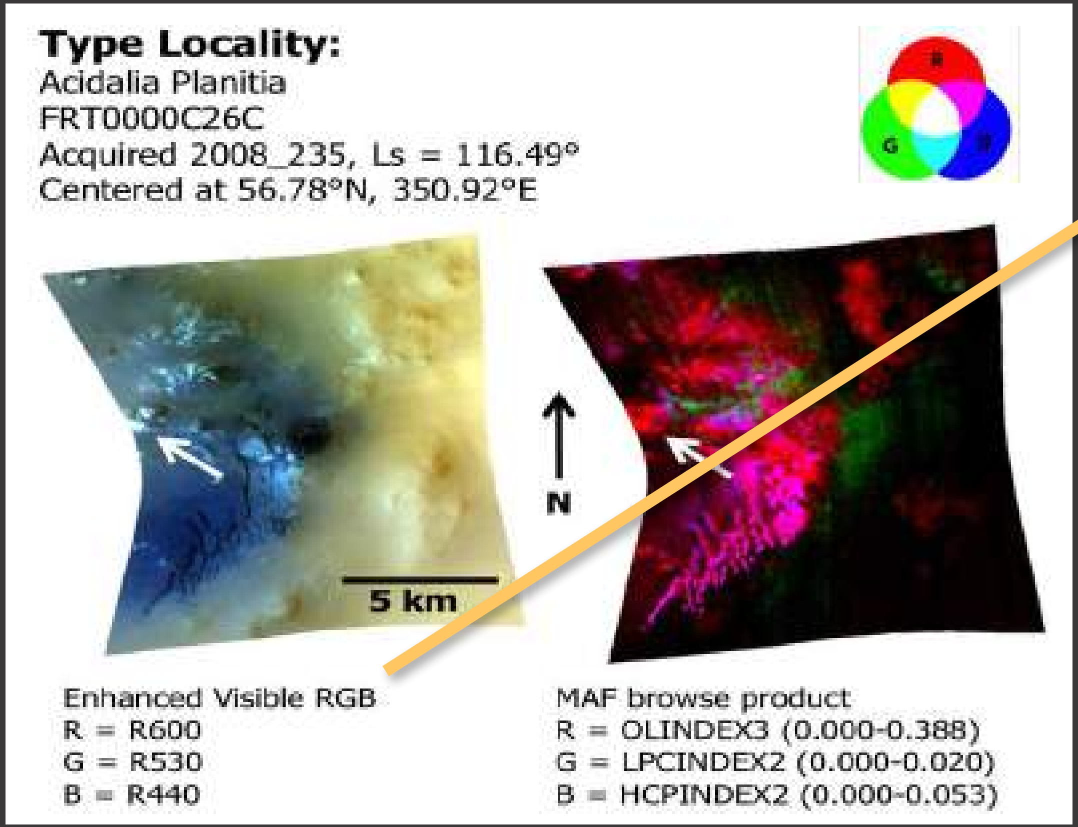


- red = 1st summary parameter
- green = 2nd summary parameter
- blue = 3rd summary parameter

- Highlight **spectral variations** on Mars' surface related to the mineral(s) of interest.

Understanding and analysing CRISM data products

Browse products: example 1

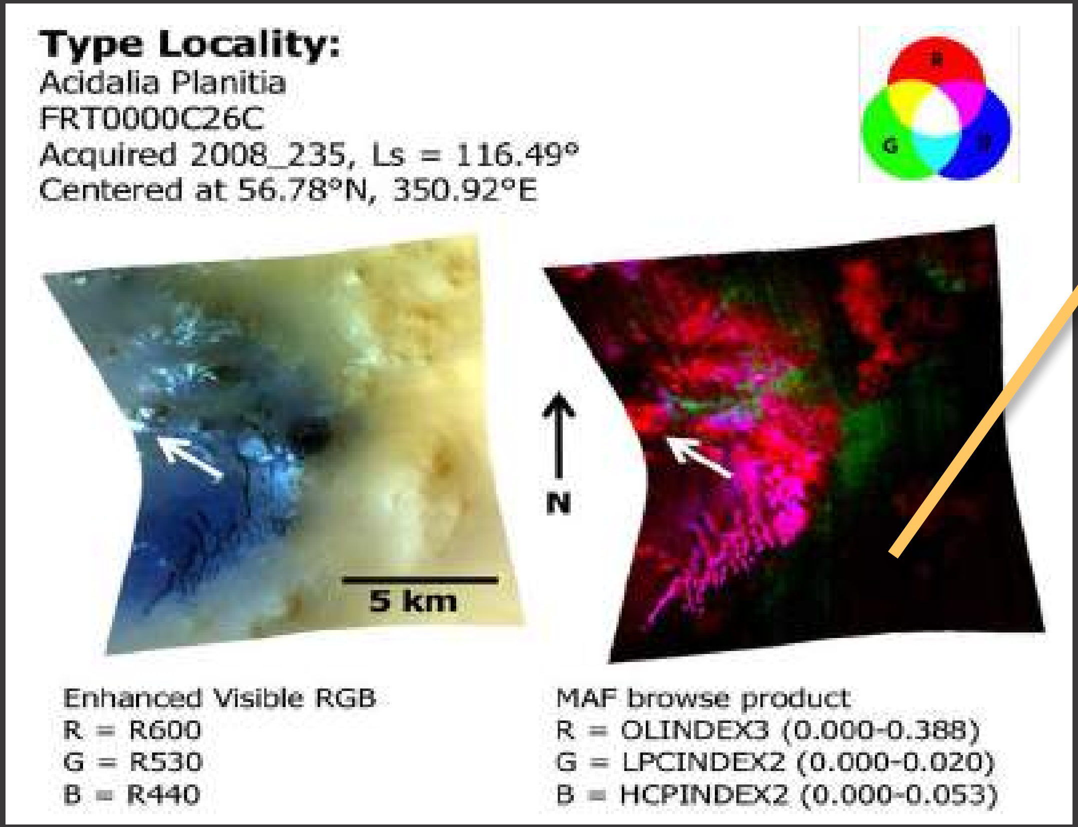


Enhanced visible RGB

- red = **R600** (reflectance at 600 nm)
- green = **R530** (reflectance at 530 nm)
- blue = **R440** (reflectance at 440 nm)

Understanding and analysing CRISM data products

Browse products: example 1

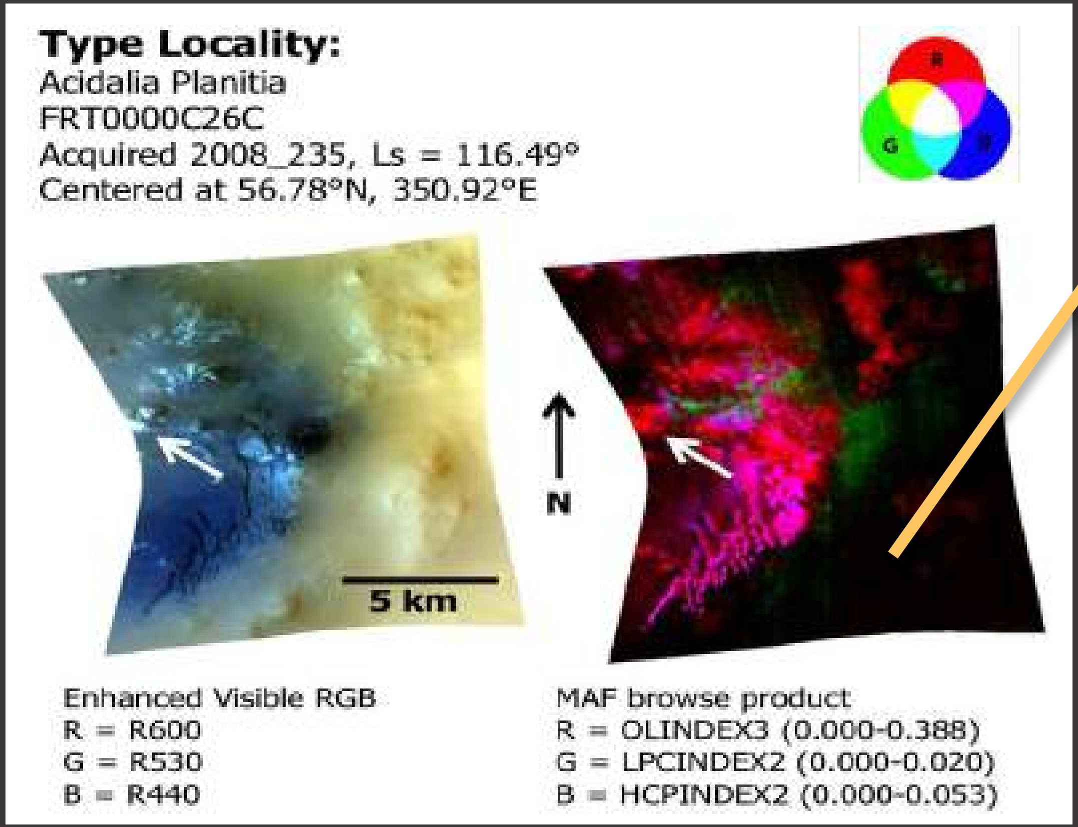


MAF - mafic mineralogy

- red = **OLINDEX2** (Detects broad 1 µm feature typical of olivine)
- green = **LCPINDEX2** (Detects broad absorption at 1.81 µm typical of low-Ca pyroxenes)
- blue = **HCPINDEX2** (Detects broad absorption centered at 2.12 µm typical of high-Ca pyroxenes)

Understanding and analysing CRISM data products

Browse products: example 1

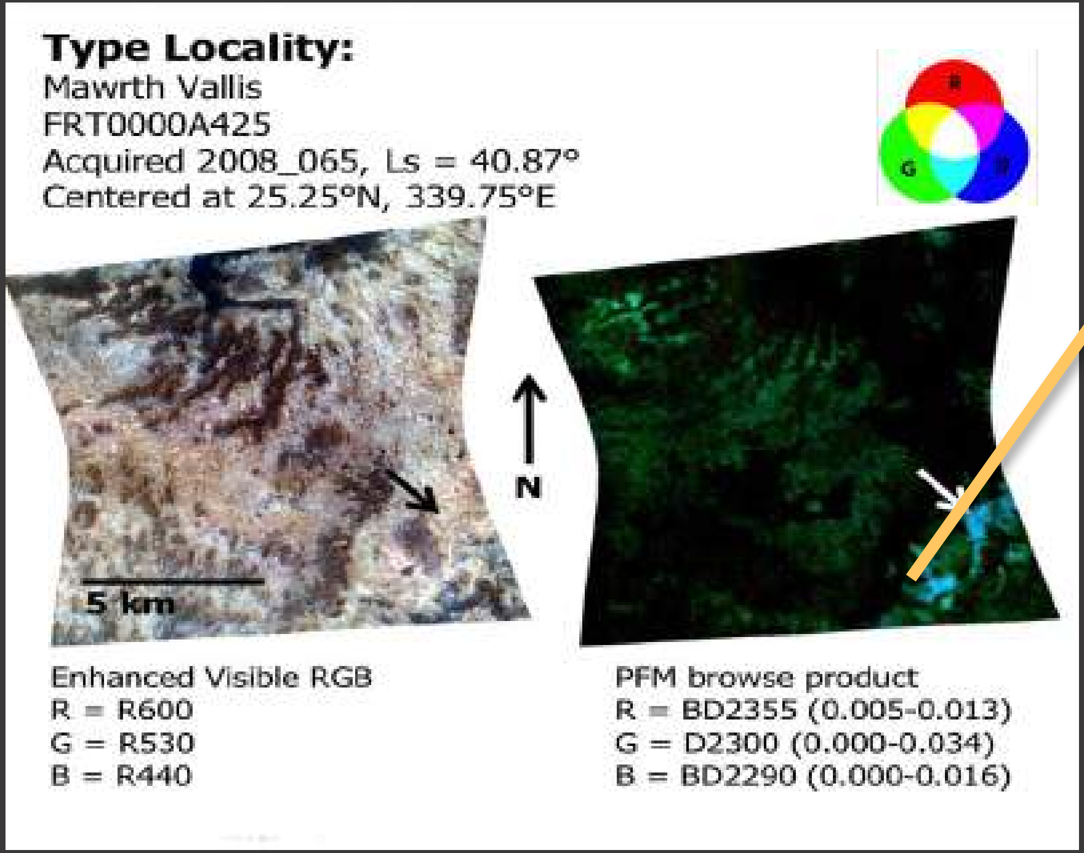


MAF - mafic mineralogy, interpretation:

- Olivine and Fe-phyllosilicate share a 1.0–1.7 µm bowl-shaped absorption and **will appear red** in the MAF browse product.
- Low- and high-Ca pyroxenes display additional ~2.0 µm absorptions and appear **green/cyan and blue/ magenta**, respectively.

Understanding and analysing CRISM data products

Browse products: example 2

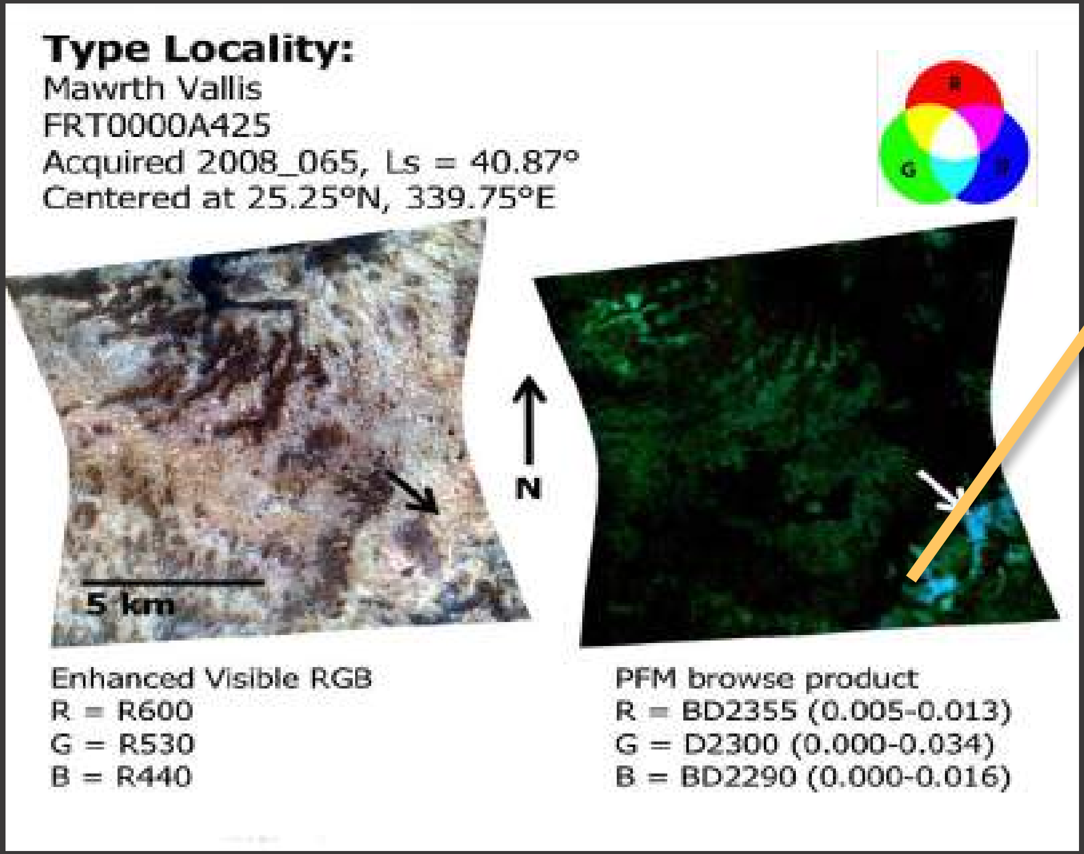


PFM - phyllosilicates with Fe and Mg

- red = **BD2355** (2.35 µm band depth, typical of some clays, e.g. chlorite). green = **D2300** (2.3 µm dropoff).
- blue = **BD2290** (2.3 µm band depth due to Mg,Fe-OH).

Understanding and analysing CRISM data products

Browse products: example 2



PFM - phyllosilicates with Fe and Mg, interpretation:

- **Red/yellow** colours indicate the presence of prehnite, chlorite, epidote, or Ca/Fe carbonate
- **Cyan colours** indicate the presence of Fe/Mg-smectites or Mg-carbonate.

Understanding and analysing CRISM data products

Browse products: summary

Understanding and analysing CRISM data products

Browse products: summary

- **Browse products** are essential if you want to **quickly** get an idea of the **mineralogy** of the area and its extension.

Understanding and analysing CRISM data products

Browse products: summary

- **Browse products** are essential if you want to **quickly** get an idea of the **mineralogy** of the area and its extension.
- You can also play with different combinations of summary parameters and obtain **custom browse products.**

Understanding and analysing CRISM data products

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Downsides:

Understanding and analysing CRISM data products

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Downsides:

- Always **interpret with care**.

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- Different minerals share one or more spectral features, therefore some parameters may **not** provide **sufficient discrimination** between these phases.

Understanding and analysing CRISM data products

Browse products: summary

- **Browse products** are essential if you want to **quickly** get an idea of the **mineralogy** of the area and its extension.
- You can also play with different combinations of summary parameters and obtain **custom browse products.**

Downsides:

- Always **interpret with care**.
- Different minerals share one or more spectral features, therefore some parameters may **not** provide **sufficient discrimination** between these phases.
- Only three channels at time: ”**multispectral approach**”.

Understanding and analysing CRISM data products

Eventually, you need to look at the spectra!

Example 1: Olivine

Example 2: Fe-smectite

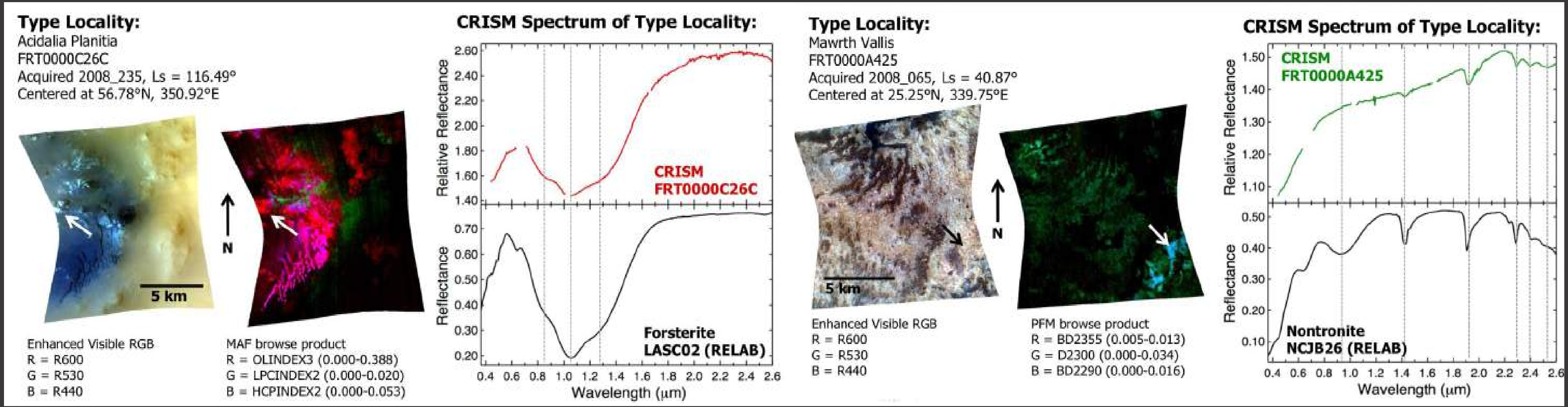


Image credits: Seelos et al. (2019)

Understanding and analysing CRISM data products

Complete list of ”standard” CRISM browse products definition and description in:

Viviano-Beck, C. E., et al. (2014), *Revised CRISM spectral parameters and summary products based on the currently detected mineral diversity on Mars*, J. Geophys. Res. Planets,119,1403–1431, doi:10.1002/2014JE004627

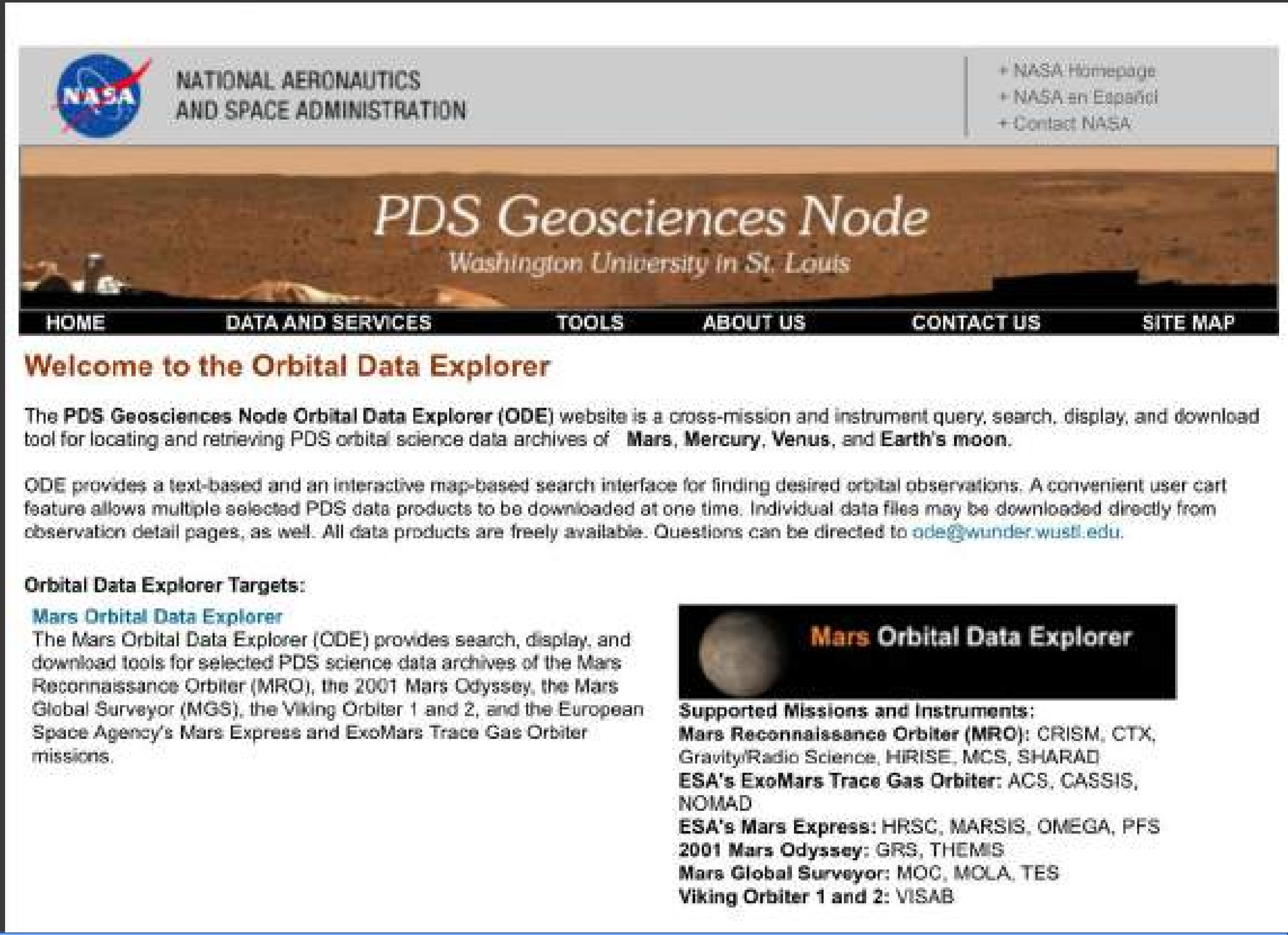
See also:

Seelos, K. D., et al. (2019), *The MICA Files: A Compilation and Reference Document for Minerals Identified Through CRISM Analysis*. Lunar and Planetary Science Conference, p 2745

Downloading data

Where to download CRISM data: NASA Orbital Data Explorer

https://ode.rsl.wustl.edu



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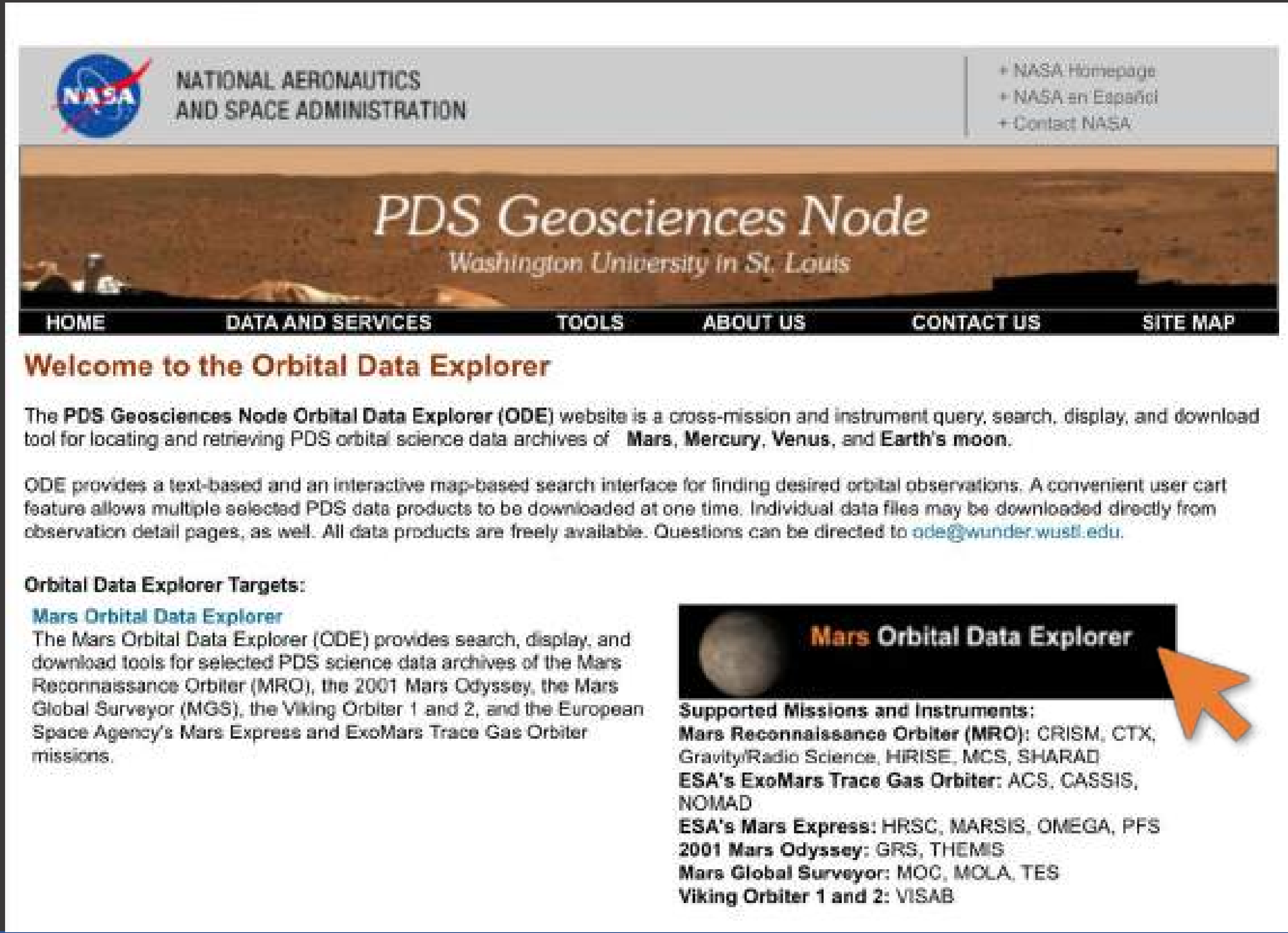

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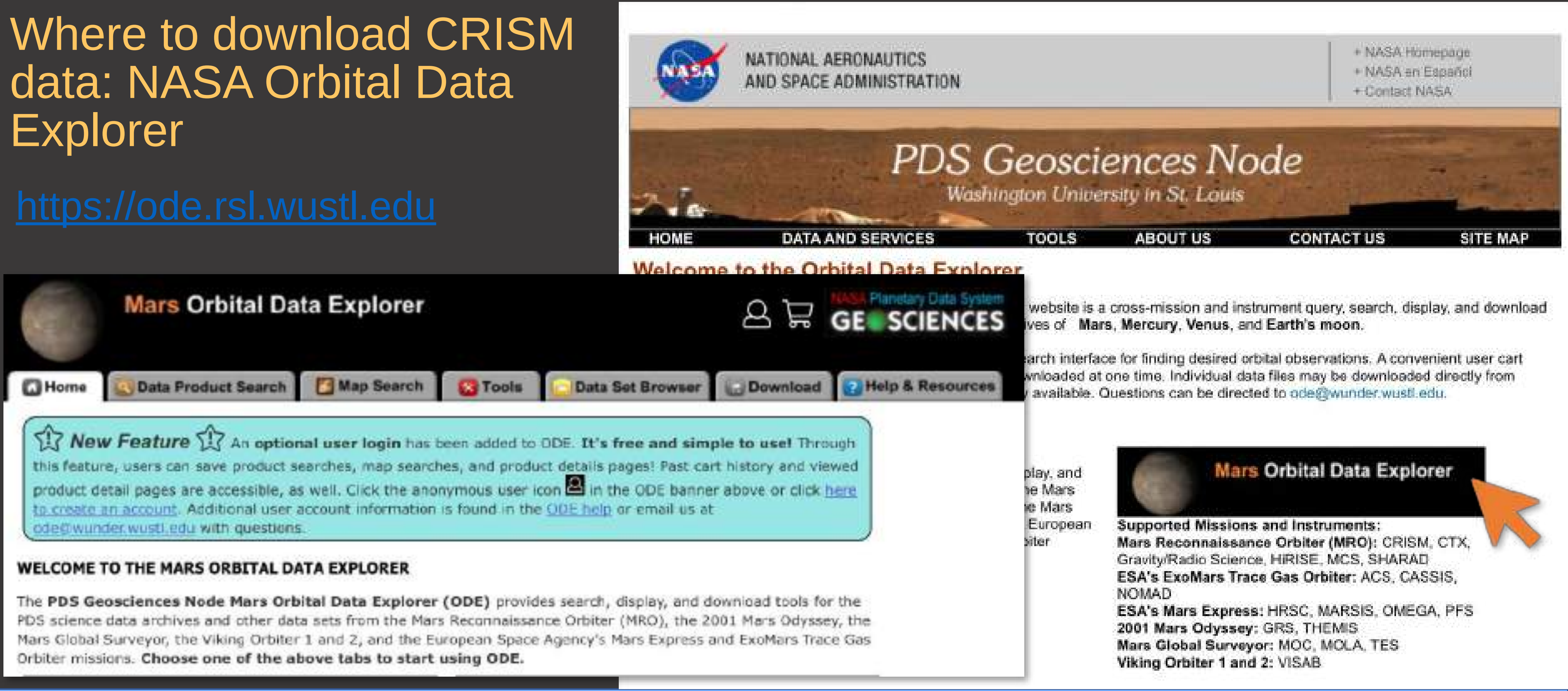
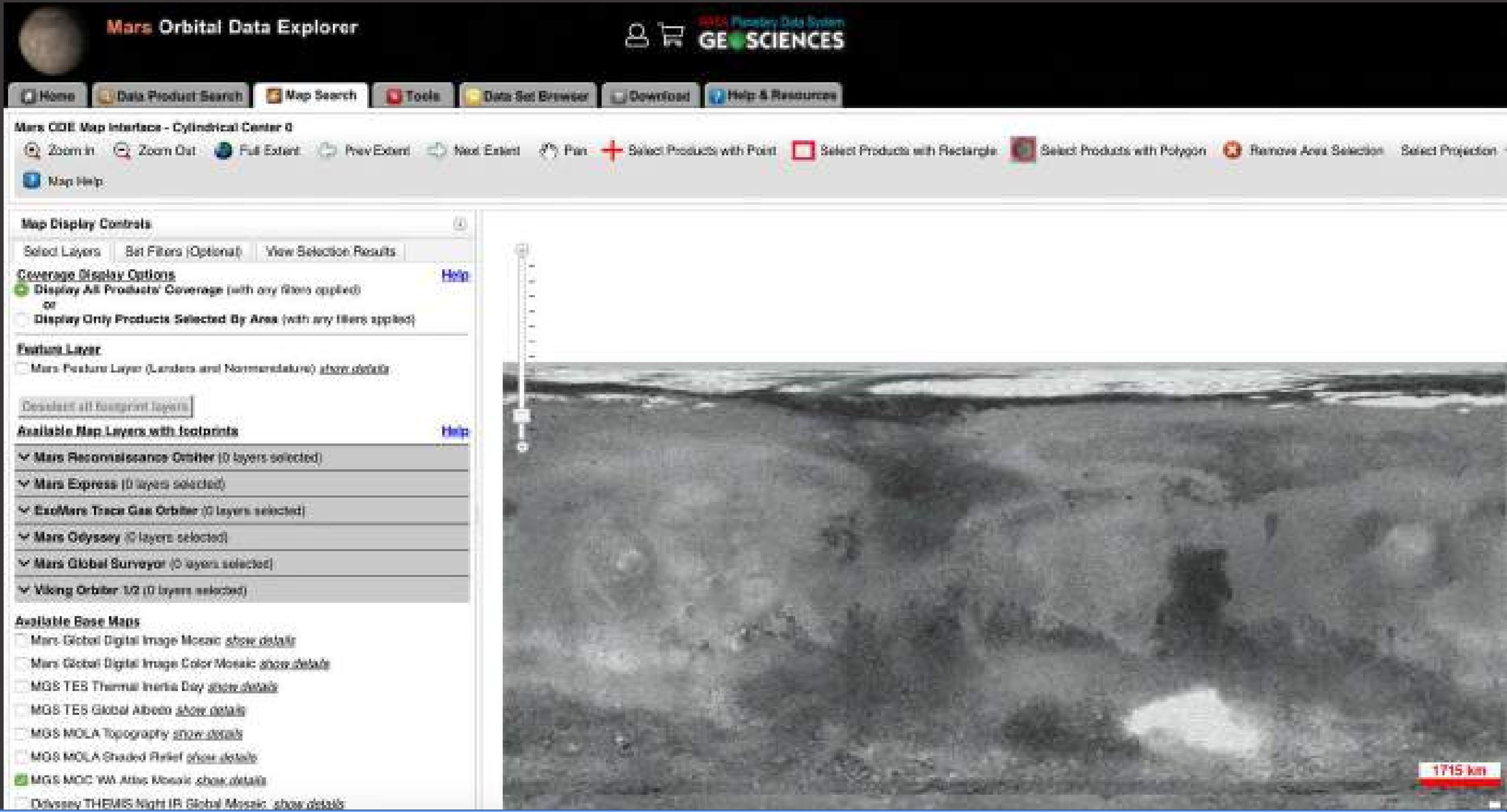
https://ode.rsl.wustl.edu



Downloading data

NASA Orbital Data Explorer: https://ode.rsl.wustl.edu

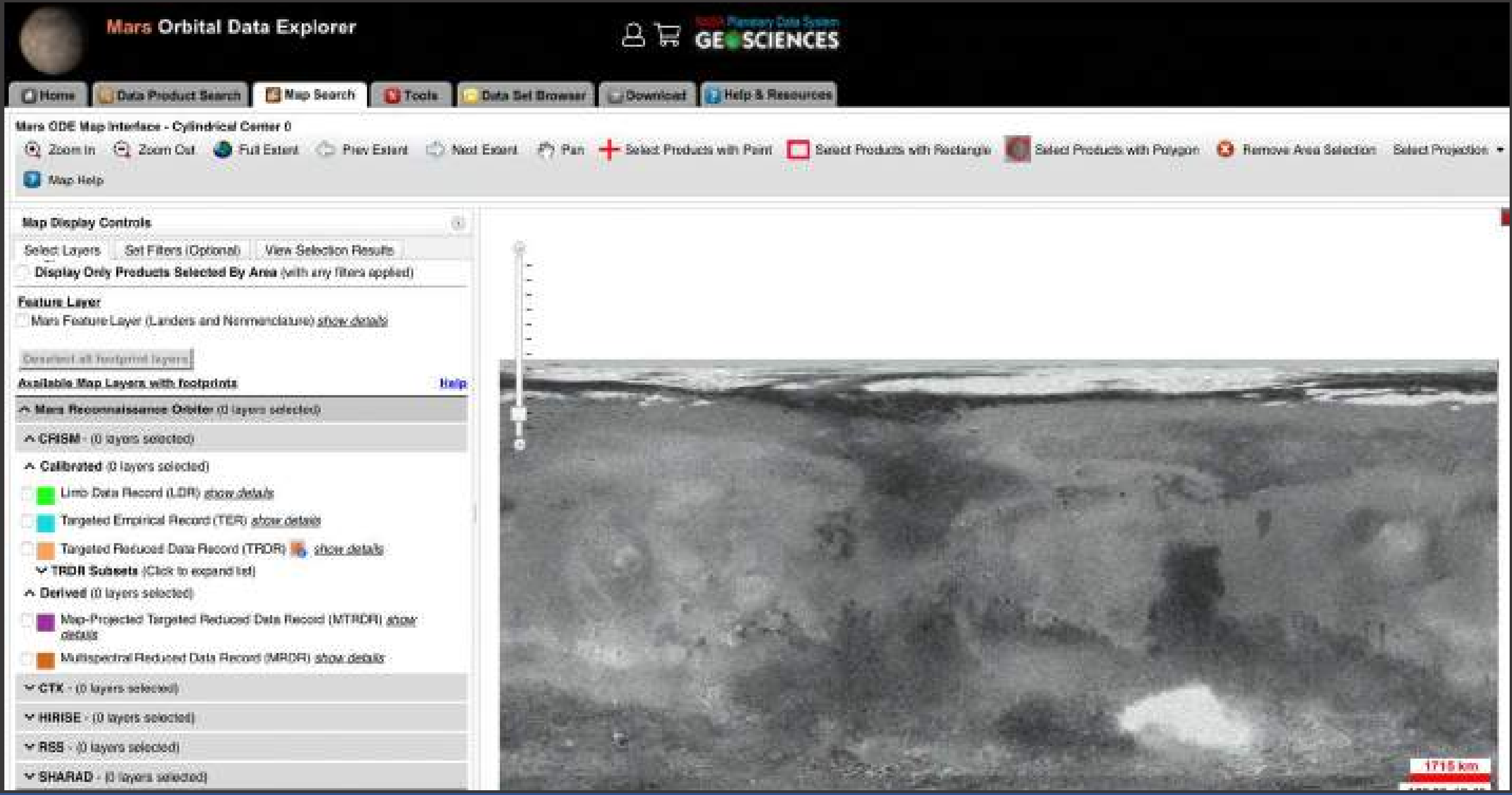
Not only CRISM, many options available!



Downloading data: CRISM data types/versions

NASA Orbital Data Explorer: https://ode.rsl.wustl.edu

So many types of files, which do I need?



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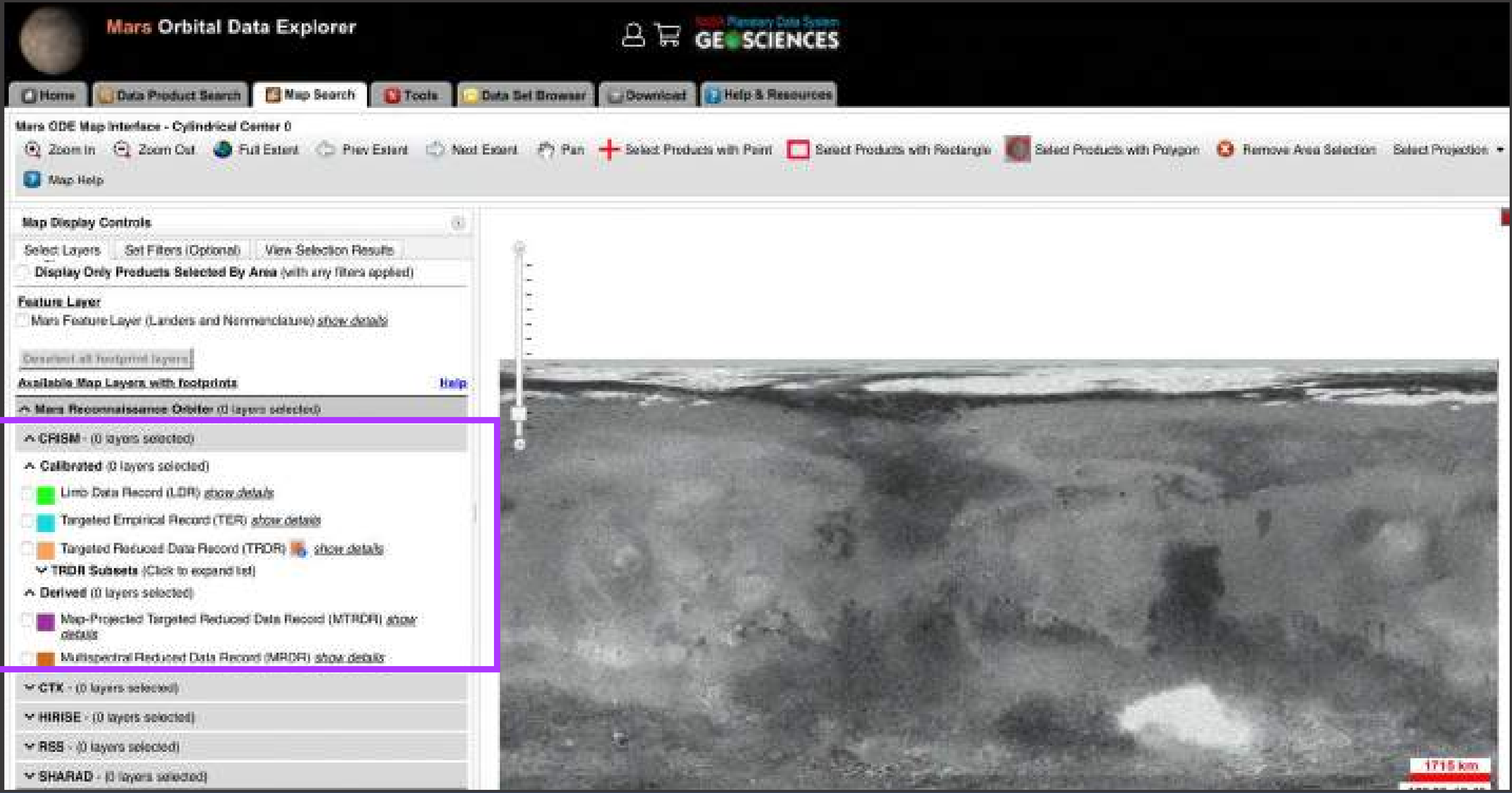


Understanding CRISM data products

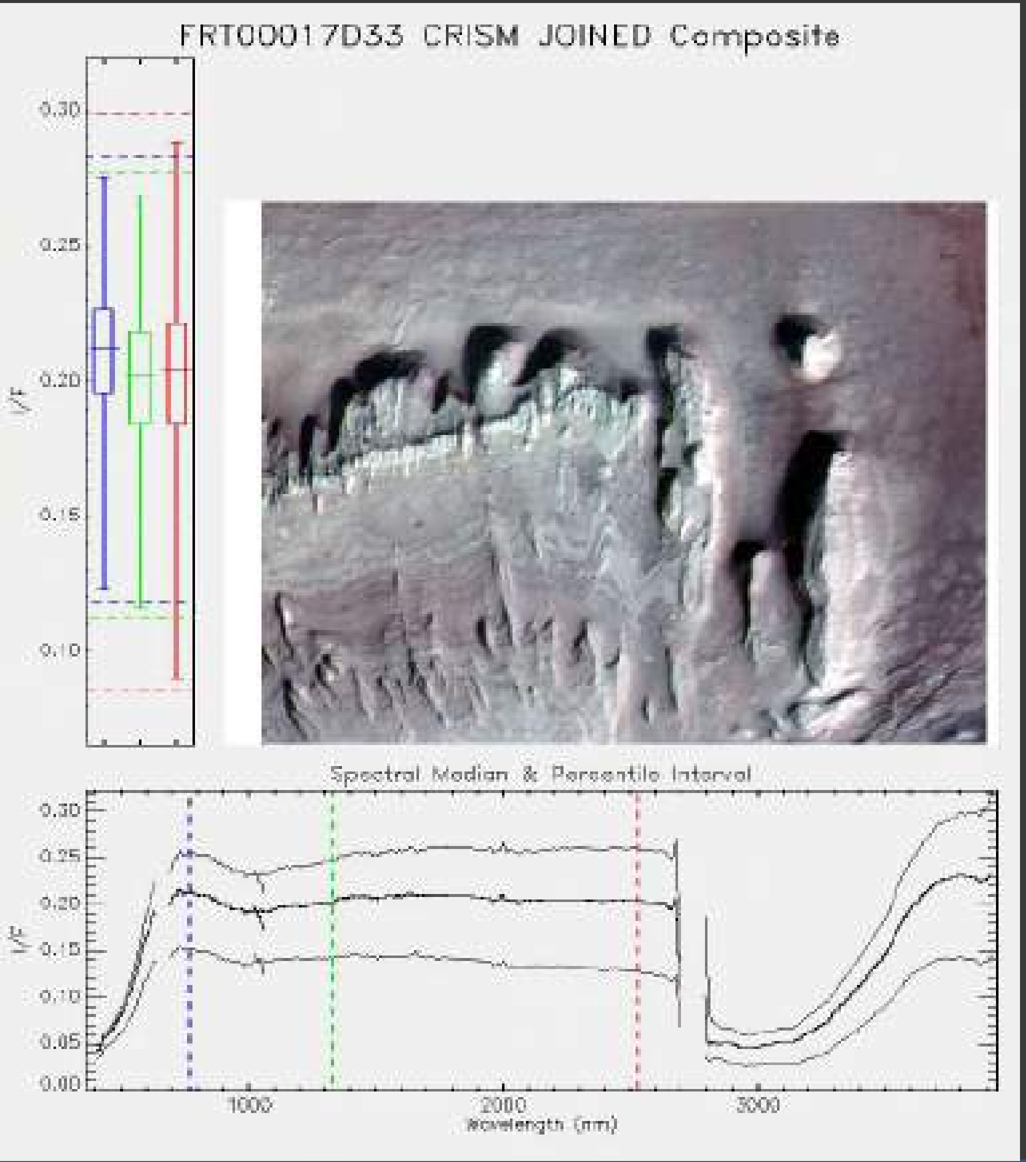
- **Targeted Empirical Records (TERs)**
- **Map-projected Targeted Reduced Data Records (MTRDRs**, filename = MTR)

"New gen" data (best available)

Understanding CRISM data products

Targeted Empirical Records (TERs)

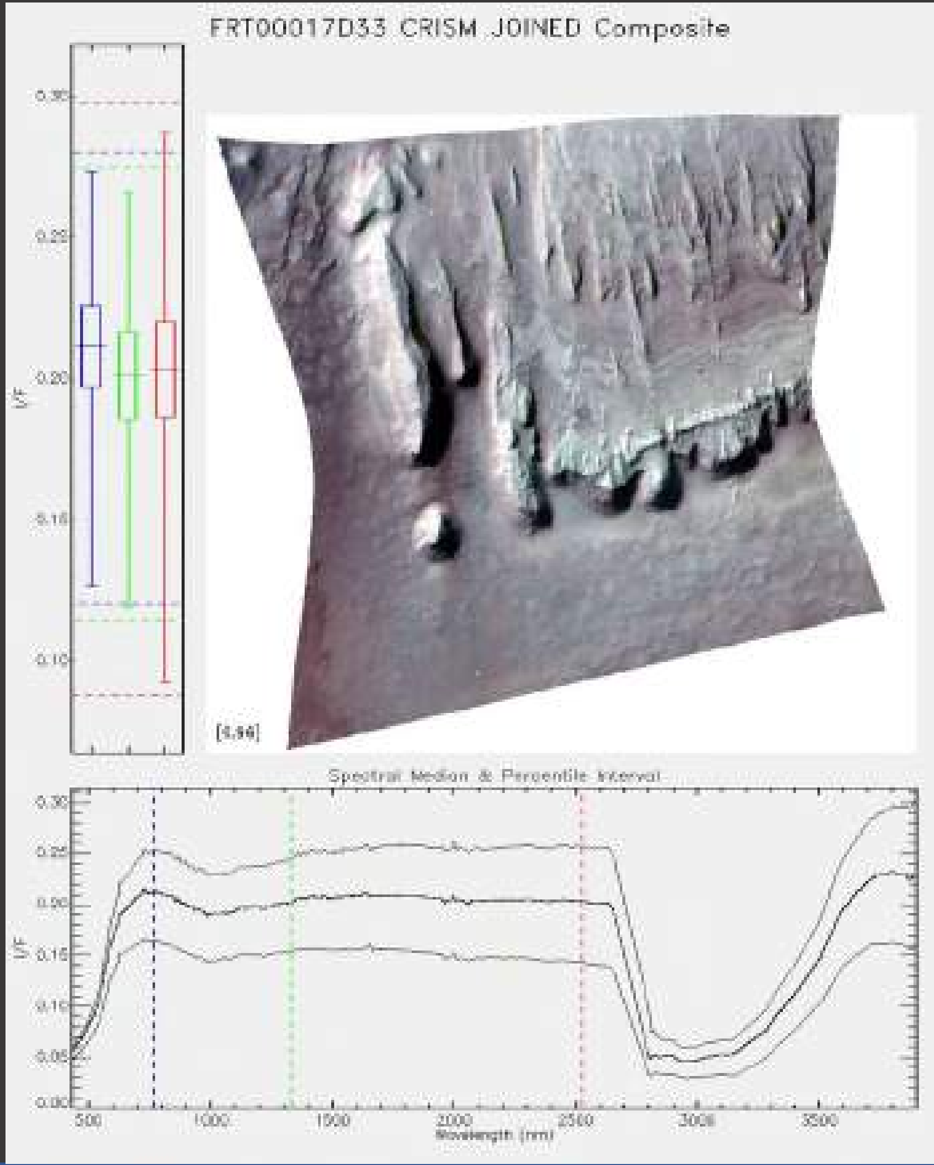
- **Full spectral range** joining VNIR and IR (S- and L- detectors)
- The IR is **already corrected** for geometric, photometric, atmospheric, and instrumental effects (no need to do it yourself!)
- Not map-projected (IR sensor space)



Understanding CRISM data products

Map-projected Targeted Reduced Data Records (MTRDRs, filename = MTR)

- TER corrected spectral information after **map projection;**
- Removal of spectral channels with suspect radiometry (“bad bands”)



CRISM data analysis

Examples of what you can use to analyse CRISM data:

- **ENVI** (license required, https://www.l3harrisgeospatial.com/Software-Technology/ENVI);
- **JCAT**, (free, http://crism.jhuapl.edu/JCAT/);
- **IDL/Python** scripts (if you know some coding).

Tutorials are available, see: http://crism.jhuapl.edu/data/CRISM_workshop_2012/docs/agenda/2012/CRISM_workshop_2012_walk_thru_KDS_DLB.pdf (ENVI) and http://crism.jhuapl.edu/JCAT/JCAT_Tutorial.pdf (JCAT)

Outline

- Introduction to spectroscopy and reflectance spectroscopy
- Reflectance spectroscopy on planetary bodies
- Spectroscopy on Mars and CRISM spectrometer
- Understanding and analysing CRISM data products
- **Conclusions**

Conclusions 1/2

- Spectroscopy investigates the interaction between light and matter and allows us to investigate the composition of materials.
- The composition of planetary surfaces (and in general of any rocky body in the Solar System) can be thoroughly investigated from orbit with reflectance spectroscopy in the visible/near-infrared.
- Many missions to solar system objects include instruments that use reflectance spectroscopy.
- With its high spatial & spectral resolution CRISM spectrometer is able to characterize the mineralogy of small scale deposits on Mars with unprecedented detail.

Conclusions 2/2

- Mars shows a great mineralogical variety (primary rock-forming minerals & many secondary minerals such as clays, sulfates, carbonates and oxides) which tell us lots of information about its history and evolution.
- Water alteration mineralogy is particularly significative.
- Summary parameters & browse products allow for a rapid assessment of the mineralogy in a CRISM scene.
- TERs and MTRs are the best CRISM products available to download. They can be analysed with ENVI and JCAT (some tutorials are available).

References

- Ehlmann B. & Edwards, C. (2014). *Mineralogy of the Martian Surface*. Annual Review of Earth and Planetary Sciences. 42. 291-315. 10.1146/annurev-earth-060313-055024.
- Murchie, S., et al. (2007), *Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) on Mars Reconnaissance Orbiter (MRO),* J. Geophys. Res., 112, E05S03, doi:10.1029/2006JE002682.
- Viviano-Beck, C. E., et al. (2014), *Revised CRISM spectral parameters and summary products based on the currently detected mineral diversity on Mars*, J. Geophys. Res. Planets,119,1403–1431, doi:10.1002/2014JE004627
- Seelos, K. D., et al. (2019), *The MICA Files: A Compilation and Reference Document for Minerals Identified Through CRISM Analysis*. Lunar and Planetary Science Conference, p 2745
- CRISM website: http://crism.jhuapl.edu
- Orbital Data Explorer help: https://ode.rsl.wustl.edu/mars/pagehelp/Content/Missions_Instruments/Mars%20Reconnaissance%20Orbiter%20(MRO)/CRISM/CRISM.htm

GeoPlaNet

Co-funded by the
ERASMUS + Programme
of the European Union

DEM Production: HiRISE

NASA AMES STEREO PIPELINE

Nantes Université

1290 UNIVERSIDADE D COIMBRA

U.PORTO

VR2Planets

Steps ⇢ HiRISE https://www.uahirise.org/

- Find your stereo pairs directly from Google Mars or your footprints
- Create a directory with the name of your stereopairs
- (es., ESP_042991_2020_ESP_043136_2020)

Download

THE UNIVERSITY OF ARIZONA

Acquisition date
25 February 2010

Local Mars time
15:06

Latitude (centered)
-23.159°

Longitude (East)
281.380°

Spacecraft altitude
253.7 km (157.7 miles)

Original image scale range
25.6 cm/pixel (with 1 x 1 binning) so objects ~77 cm across are resolved

Map projected scale
25 cm/pixel and North is up

Map projection
Equirectangular

Emission angle
4.1°

Phase angle
66.2°

Solar incidence angle

JPEG

Black and white
map projected non-map

IRB color
map projected non-map

Merged IRB
map projected

Merged RGB
map projected

RGB color
non-map projected

JP2

Black and white
map-projected (810MB)

IRB color
map-projected (358MB)

JP2 EXTRAS

Black and white
map-projected (408MB)
non-map (419MB)

IRB color
map projected (106MB)
non-map (356MB)

Merged IRB

ANAGLYPHS
Map-projected, reduced-resolution
Full resolution JP2 download
Anaglyph details page

DIGITAL TERRAIN MODEL (DTM)
DTM details page

ADDITIONAL INFORMATION
B&W label
Color label
Merged IRB label
Merged RGB label
EDR products
HiView

NB
IRB: infrared-red-blue
RGB: red-green-blue
About color products (PDF)

Black & white is 5 km across; enhanced color about 1 km
For scale, use JPEG/JP2 black & white map-projected images

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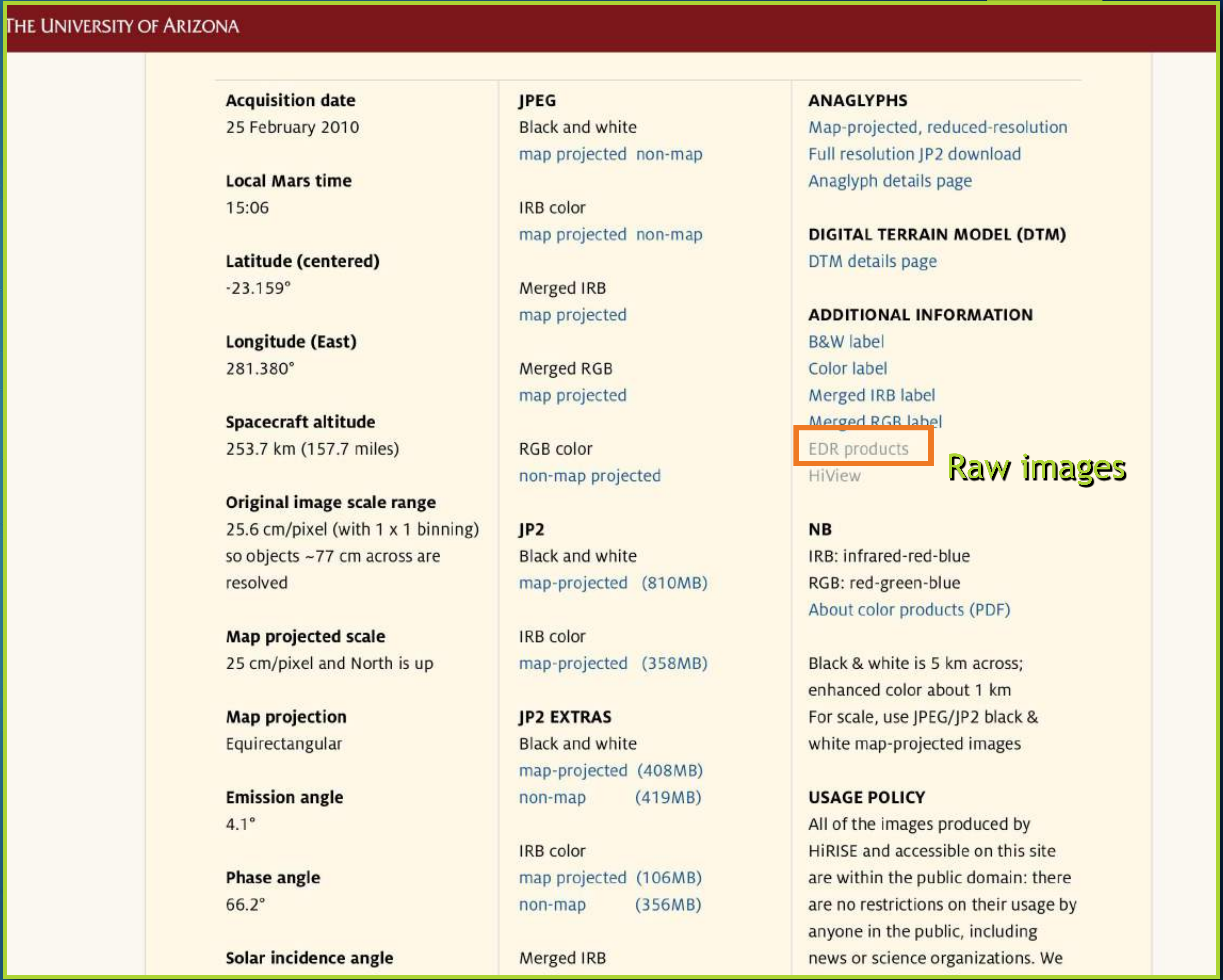
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Black and white
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Anaglyph details page

DIGITAL TERRAIN MODEL (DTM)
DTM details page

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Merged RGB label
EDR products
HiView

Raw images

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Solar incidence angle

Merged IRB

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Left & Right image

Using Qview estimate which is the left and which is the right image

or (much faster) check in the DTM details page (under ‘Anaglyph details page’ you will find the name: left - right image)

Preprocessing

- HIEDR2MOSAIC.PY ingests the EDRs into ISIS, apply SPICE kernels, smooth the SPICE data, perform photometric calibrations and mosaics the individual CCDs from each image.

Command dstripe

- Remove horizontal or vertical stripes/noise from a cube
- Combination of lowpass and highpass filters to remove horizontal or vertical stripes in a cube

Command dstripe

- Remove horizontal or vertical stripes/noise from a cube
- Combination of lowpass and highpass filters to remove horizontal or vertical stripes in a cube

Commands cubenorm and bandnorm

- cubenorm normalize columns or lines in a cube
- bandnorm normalize bands in a cube
- The programs accomplishes the task of taking an input cube and outputting normalized values.

Script - Part 1

```
#!/bin/bash

#SBATCH --account unich
#SBATCH -p compute
#SBATCH -o Log.out
#SBATCH -e Log.err
#SBATCH -J didattica_geo-02
#SBATCH --get-user-env
#SBATCH --nodes=4
#SBATCH --ntasks=48
#SBATCH --hint=compute_bound
#SBATCH --mail-type=ALL
#SBATCH --mail-user=adriano.tullo@unich.it
#SBATCH --time=0

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LC_ALL=C hiedr2mosaic.py hirise-pds.lpl.arizona.edu/PDS/EDR/ESP/ORB_033600_033699/ESP_033601_1830/*.IMG
LC_ALL=C dstripe from=ESP_033456_1830_RED.mos_hijitreged.norm.cub to=left.striped.cub
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#SBATCH --nodes=4
#SBATCH --ntasks=48
#SBATCH --hint=compute_bound
#SBATCH --mail-type=ALL
#SBATCH --mail-user=adriano.tullo@unich.it
#SBATCH --time=0

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wget -r -l1 -np "https://hirise-pds.lpl.arizona.edu/PDS/EDR/ESP/ORB_033600_033699/ESP_033601_1830/" -A "*RED*IMG"
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LC_ALL=C hiedr2mosaic.py hirise-pds.lpl.arizona.edu/PDS/EDR/ESP/ORB_033600_033699/ESP_033601_1830/*.IMG
LC_ALL=C dstripe from=ESP_033456_1830_RED.mos_hijitreged.norm.cub to=left.striped.cub
LC_ALL=C dstripe from=ESP_033601_1830_RED.mos_hijitreged.norm.cub to=right.striped.cub
LC_ALL=C cubenorm from=left.striped.cub to=left.cubenorm.cub
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NEXT SLIDE

- WGET -R -L1 -NP "HTTPS://HIRISE-PDS.LPL.ARIZONA.EDU/PDS/EDR/ESP/ORB_033400_033499/ESP_033456_1830/" -A "*RED*IMG"
- WGET -R -L1 -NP "HTTPS://HIRISE-PDS.LPL.ARIZONA.EDU/PDS/EDR/ESP/ORB_033600_033699/ESP_033601_1830/" -A "*RED*IMG"
- LC_ALL=C HIEDR2MOSAIC.PY HIRISE-PDS.LPL.ARIZONA.EDU/PDS/EDR/ESP/ORB_033400_033499/ESP_033456_1830/*.IMG
- LC_ALL=C HIEDR2MOSAIC.PY HIRISE-PDS.LPL.ARIZONA.EDU/PDS/EDR/ESP/ORB_033600_033699/ESP_033601_1830/*.IMG
- LC_ALL=C DSTRIPE FROM=ESP_033456_1830_RED.MOS_HIJITREGED.NORM.CUB TO=LEFT.STRIPED.CUB
- LC_ALL=C DSTRIPE FROM=ESP_033601_1830_RED.MOS_HIJITREGED.NORM.CUB TO=RIGHT.STRIPED.CUB
- LC_ALL=C CUBENORM FROM=LEFT.STRIPED.CUB TO=LEFT.CUBENORM.CUB
- LC_ALL=C CUBENORM FROM=RIGHT.STRIPED.CUB TO=RIGHT.CUBENORM.CUB
- LC_ALL=C BANDNORM FROM=LEFT.CUBENORM.CUB TO=LEFT.NORM.CUB
- LC_ALL=C BANDNORM FROM=RIGHT.CUBENORM.CUB TO=RIGHT.NORM.CUB

Bundle adjustment

- Refining a visual reconstruction to produce jointly optimal 3D structure and viewing parameter (camera pose and/or calibration) estimates
- The name refers to the 'bundles' of light rays leaving each 3D feature and converging on each camera centre, which are 'adjusted' optimally with respect to both feature and camera positions. Equivalently all of the structure and camera parameters are adjusted together 'in one bundle'
- Large sparse geometric parameter estimation problem, the parameters being the combined 3D feature coordinates, camera poses and calibrations
- Correct satellite (and consequently camera) position and orientation errors
- Ensures that the observations in multiple images of a single ground feature are self-consistent

Bundle adjustment

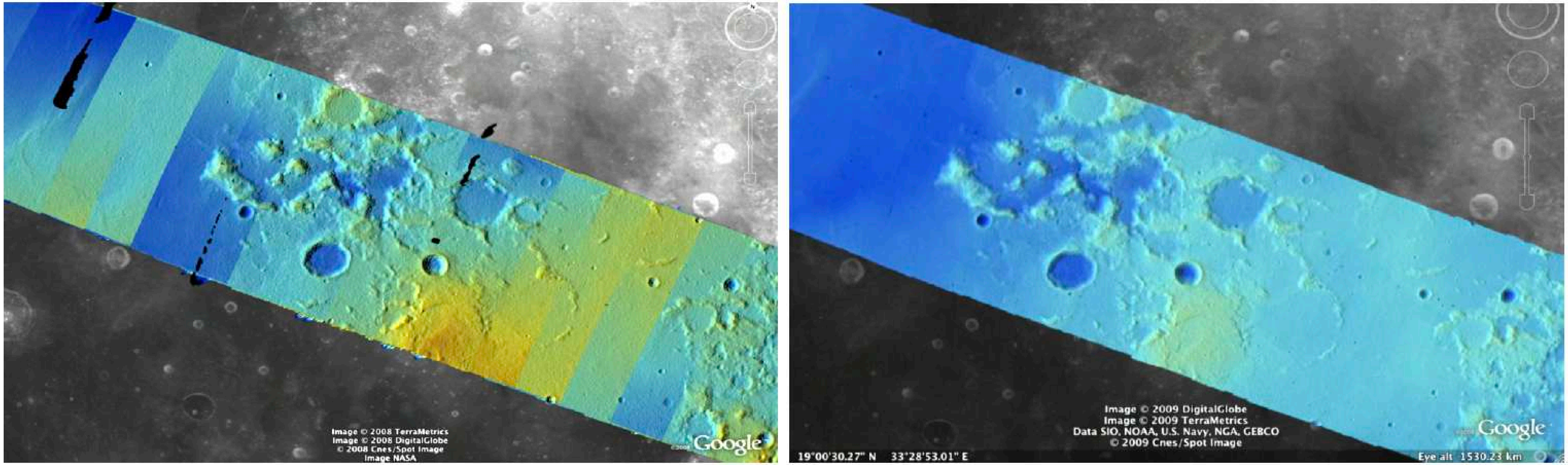


Figure 8.1: Bundle adjustment is illustrated here using a color-mapped, hill-shaded DEM mosaic from Apollo 15, Orbit 33, imagery. (a) Prior to bundle adjustment, large discontinuities can exist between overlapping DEMs made from different images. (b) After bundle adjustment, DEM alignment errors are minimized and no longer visible.

Stereo

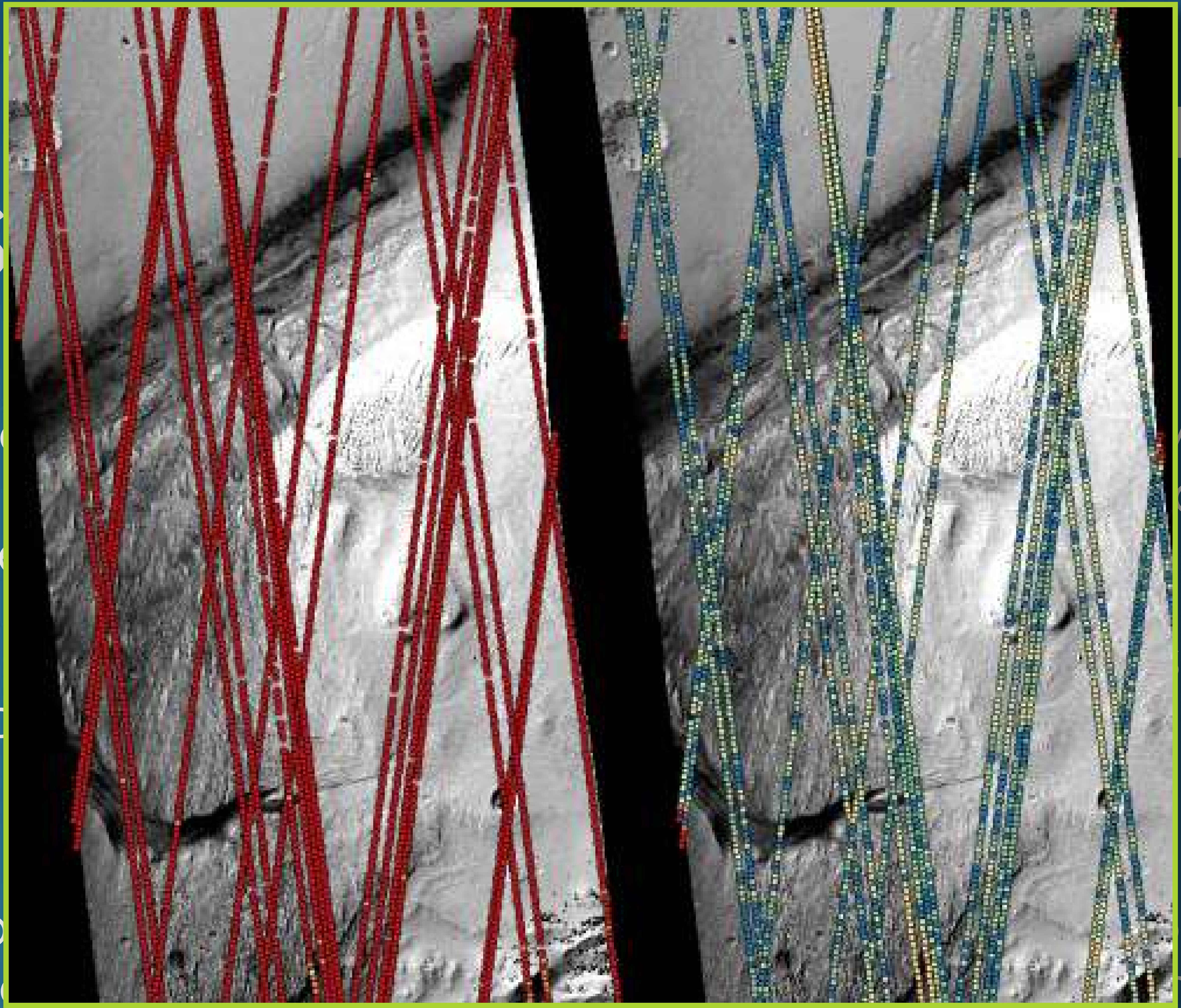
- Step 1 (correlation)
  - Collection of algorithms that compute correspondences between pixels in the left image and pixels in the right image. The map of these correspondences is called a disparity map
- Steps 2 (refinement) and 3 (filtering)
  - Every pixel in the disparity map will either have an estimated disparity value, or it will be marked as invalid. All valid pixels are then adjusted in the sub-pixel refinement
- Stage 4 (Triangulation)
  - Once a disparity map has been generated and re?fined, it can be used in combination with the geometric camera models to compute the locations of 3D points on the surface of Mars

PC align: Alignment to Point Clouds From a Different Source

- 3D terrain models output by stereo can be quite accurate yet their actual position on the planet may be off by several meters or several kilometers
- pc_align aligns a 3D terrain to a much more accurately positioned (if potentially sparser) dataset
- MOLA or HRSC
- The pc_align tool requires another input, an a priori guess for the maximum displacement we expect to see as result of alignment. If not known, a large (but not unreasonably so) number can be specified. It is used to remove most of the points in the source (movable) point cloud which have no chance of having a corresponding point in the reference (fixed) point cloud.

PC align: Ali… …rom a Different S…

- 3D terrain mod… …et their actual position … …or several kilomet…
- pc_align aligns … …itioned (if potentially sp…
- MOLA or HRSC …
- The pc_align to… …r the maximum displ… …ment. If



Example of using pc_align to align a DEM obtained using stereo from CTX images to a set of MOLA tracks. The MOLA points are colored by the offset error initially (left) and after pc align was applied (right) to the terrain model. The red dots indicate more than 100 m of error and blue less than 5 m. The pc_align algorithm determined that by moving the terrain model approximately 40 m south, 70 m west, and 175 m vertically, goodness of fit between MOLA and the CTX model was increased substantially.

Command Point2dem

- The point2dem program creates a Digital Elevation Model (DEM) from the point cloud file

Script - Part 2

```
#!/bin/bash

#SBATCH --account unich
#SBATCH -p compute
#SBATCH -o Log.out
#SBATCH -e Log.err
#SBATCH -J didattica_geo-02
#SBATCH --get-user-env
#SBATCH --nodes=4
#SBATCH --ntasks=48
#SBATCH --hint=compute_bound
#SBATCH --mail-type=ALL
#SBATCH --mail-user=adriano.tullo@unich.it
#SBATCH --time=0

wget -r -L1 -np "https://hirise-pds.lpl.arizona.edu/PDS/EDR/ESP/ORB_033400_033499/ESP_033456_1830/" -A "*RED*IMG"
wget -r -L1 -np "https://hirise-pds.lpl.arizona.edu/PDS/EDR/ESP/ORB_033600_033699/ESP_033601_1830/" -A "*RED*IMG"
LC_ALL=C hiedr2mosaic.py hirise-pds.lpl.arizona.edu/PDS/EDR/ESP/ORB_033400_033499/ESP_033456_1830/*.IMG
LC_ALL=C hiedr2mosaic.py hirise-pds.lpl.arizona.edu/PDS/EDR/ESP/ORB_033600_033699/ESP_033601_1830/*.IMG
LC_ALL=C dstripe from=ESP_033456_1830_RED.mos_hijitreged.norm.cub to=left.striped.cub
LC_ALL=C dstripe from=ESP_033601_1830_RED.mos_hijitreged.norm.cub to=right.striped.cub
LC_ALL=C cubenorm from=left.striped.cub to=left.cubenorm.cub
LC_ALL=C cubenorm from=right.striped.cub to=right.cubenorm.cub
LC_ALL=C bandnorm from=left.cubenorm.cub to=left.norm.cub
LC_ALL=C bandnorm from=right.cubenorm.cub to=right.norm.cub
LC_ALL=C parallel_bundle_adjust --threads 48 left.norm.cub right.norm.cub -o run_ba/run --ip-per-tile 500 --num-random-passes 1 --ip-triangulation-max-error 1.5
LC_ALL=C parallel_stereo --threads-multiprocess 12 --threads-singleprocess 48 left.norm.cub right.norm.cub run_adjust/run --bundle-adjust-prefix run_ba/run --ip-per-tile 500
LC_ALL=C point2dem --threads 48 run_adjust/run-PC.tif --dem-hole-fill-len 400 --orthoimage-hole-fill-len 100 --orthoimage run_adjust/run-L.tif --t_srs "+proj=eqc +lat_0=0 +lon_0=0 +x_0=0 +y_0=0 +a=3396190 +b=3396190 +units=m +no_defs" --nodata -32767  --tr 0.6
LC_ALL=C pc_align --threads 10 --max-displacement 1000 /home/ori/STORAGE_ORI/Adriano/Unnamed3/CTX_UM3/DEM_D16_033601_1831_P15_007018_1831-adj.tif run_adjust/run-DEM.tif --highest-accuracy --compute-translation-only --save-transformed-source-points -o spheroid_DEM
LC_ALL=C point2dem --threads 48 -r mola spheroid_DEM-trans_source.tif --dem-hole-fill-len 400 --t_srs "+proj=eqc +lat_0=0 +lon_0=0 +x_0=0 +y_0=0 +a=3396190 +b=3396190 +units=m +no_defs" --nodata -32767  --tr 0.6 -o ESP_033456_1830_ESP_033601_1830
```

Script - Part 2

```
#!/bin/bash

#SBATCH --account unich
#SBATCH -p compute
#SBATCH -o Log.out
#SBATCH -e Log.err
#SBATCH -J didattica_geo-02
#SBATCH --get-user-env
#SBATCH --nodes=4
#SBATCH --ntasks=48
#SBATCH --hint=compute_bound
#SBATCH --mail-type=ALL
#SBATCH --mail-user=adriano.tullo@unich.it
#SBATCH --time=0

wget -r -l1 -np "https://hirise-pds.lpl.arizona.edu/PDS/EDR/ESP/ORB_033400_033499/ESP_033456_1830/" -A "*RED*IMG"
wget -r -l1 -np "https://hirise-pds.lpl.arizona.edu/PDS/EDR/ESP/ORB_033600_033699/ESP_033601_1830/" -A "*RED*IMG"
LC_ALL=C hiedr2mosaic.py hirise-pds.lpl.arizona.edu/PDS/EDR/ESP/ORB_033400_033499/ESP_033456_1830/*.IMG
LC_ALL=C hiedr2mosaic.py hirise-pds.lpl.arizona.edu/PDS/EDR/ESP/ORB_033600_033699/ESP_033601_1830/*.IMG
LC_ALL=C dstripe from=ESP_033456_1830_RED.mos_hijitreged.norm.cub to=left.striped.cub
LC_ALL=C dstripe from=ESP_033601_1830_RED.mos_hijitreged.norm.cub to=right.striped.cub
LC_ALL=C cubenorm from=left.striped.cub to=left.cubenorm.cub
LC_ALL=C cubenorm from=right.striped.cub to=right.cubenorm.cub
LC_ALL=C bandnorm from=left.cubenorm.cub to=left.norm.cub
LC_ALL=C bandnorm from=right.cubenorm.cub to=right.norm.cub
LC_ALL=C parallel_bundle_adjust --threads 48 left.norm.cub right.norm.cub -o run_ba/run --ip-per-tile 500 --num-random-passes 1 --ip-triangulation-max-error 1.5
LC_ALL=C parallel_stereo --threads-multiprocess 12 --threads-singleprocess 48 left.norm.cub right.norm.cub run_adjust/run --bundle-adjust-prefix run_ba/run --ip-per-tile 500
LC_ALL=C point2dem --threads 48 run_adjust/run-PC.tif --dem-hole-fill-len 400 --orthoimage-hole-fill-len 100 --orthoimage run_adjust/run-L.tif --t_srs "+proj=eqc +lat_0=0 +lon_0=0 +x_0=0 +y_0=0 +a=3396190 +b=3396190 +units=m +no_defs" --nodata -32767  --tr 0.6
LC_ALL=C pc_align --threads 10 --max-displacement 1000 /home/ori/STORAGE_ORI/Adriano/Unnamed3/CTX_UM3/DEM_D16_033601_1831_P15_007018_1831-adj.tif run_adjust/run-DEM.tif --highest-accuracy --compute-translation-only --save-transformed-source-points -o spheroid_DEM
LC_ALL=C point2dem --threads 48 -r mola spheroid_DEM-trans_source.tif --dem-hole-fill-len 400 --t_srs "+proj=eqc +lat_0=0 +lon_0=0 +x_0=0 +y_0=0 +a=3396190 +b=3396190 +units=m +no_defs" --nodata -32767  --tr 0.6 -o ESP_033456_1830_ESP_033601_1830
```

NEXT SLIDE

- LC_ALL=C parallel_bundle_adjust --threads 48 left.norm.cub right.norm.cub -o run_ba/run --ip-per-tile 500 --num-random-passes 1 --ip-triangulation-max-error 1.5
- LC_ALL=C parallel_stereo --threads-multiprocess 12 --threads-singleprocess 48 left.norm.cub right.norm.cub run_adjust/run --bundle-adjust-prefix run_ba/run --ip-per-tile 500
- LC_ALL=C point2dem --threads 48 run_adjust/run-PC.tif --dem-hole-fill-len 400 --orthoimage-hole-fill-len 100 --orthoimage run_adjust/run-L.tif --t_srs "+proj=eqc +lat_0=0 +lon_0=0 +x_0=0 +y_0=0 +a=3396190 +b=3396190 +units=m +no_defs" --nodata -32767 --tr 0.6
- LC_ALL=C pc_align --threads 10 --max-displacement 1000 /home/ori/STORAGE_ORI/Adriano/Unnamed3/CTX_UM3/DEM_D16_033601_1831_P15_007018_1831-adj.tif run_adjust/run-DEM.tif --highest-accuracy --compute-translation-only --save-transformed-source-points -o spheroid_DEM
- LC_ALL=C point2dem --threads 48 -r mola spheroid_DEM-trans_source.tif --dem-hole-fill-len 400 --t_srs "+proj=eqc +lat_0=0 +lon_0=0 +x_0=0 +y_0=0 +a=3396190 +b=3396190 +units=m +no_defs" --nodata -32767 --tr 0.6 -o ESP_033456_1830_ESP_033601_1830

Introduction on icy bodies in the Solar System

GIUSEPPE MITRI

Co-funded by the ERASMUS + Programme of the European Union

GeoPlaNet

Nantes Université

1290 UNIVERSIDADE D COIMBRA

U.PORTO

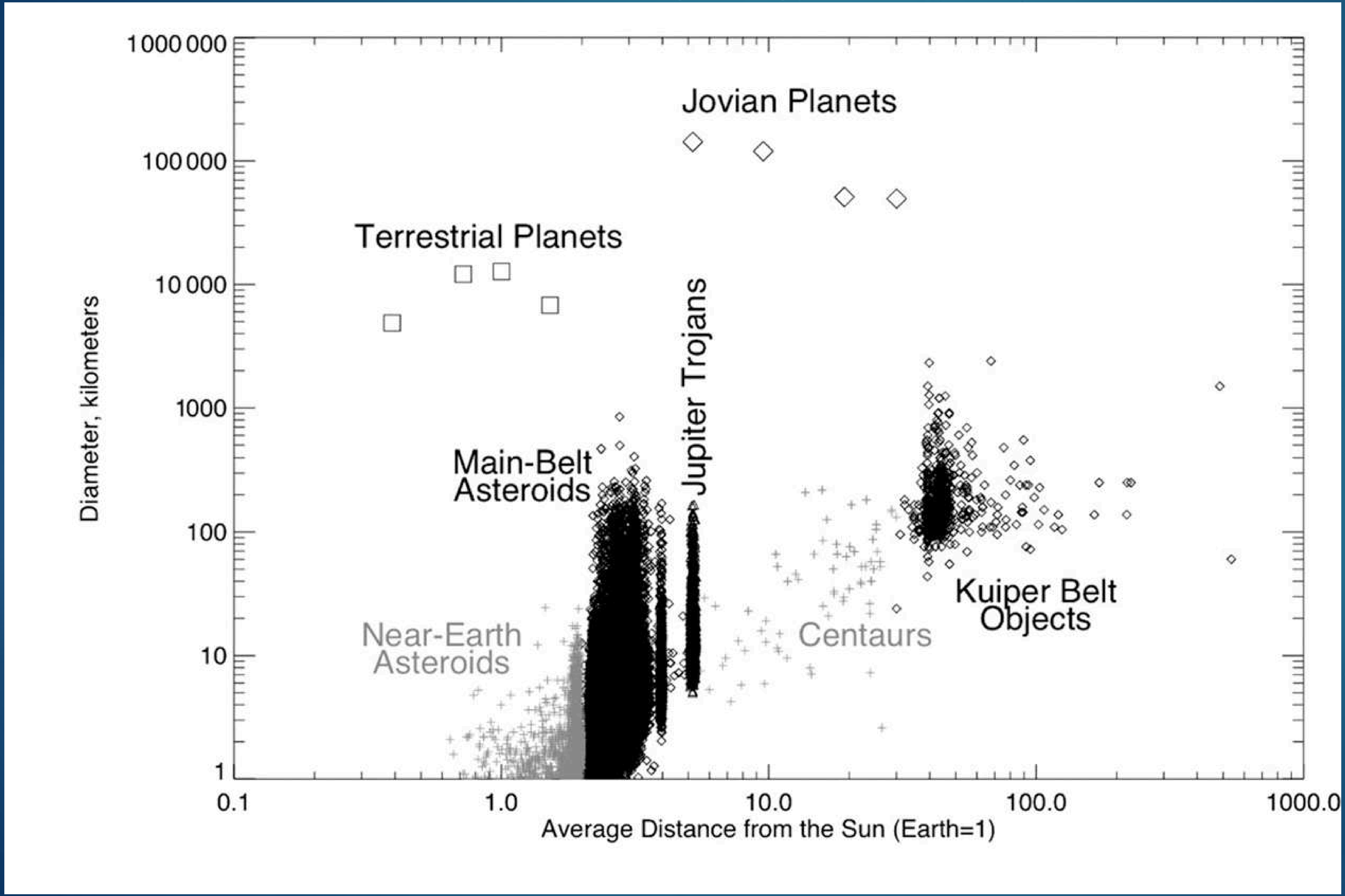
VR2Planets

Program

- Introduction on icy bodies in the Solar System: G. Mitri (9.15-11.00)
- Europa geology: G. Chiarolanza (11.15-12.00)
- Triton geology: D. Sulcanese (12.15-13.00)
- Lunch (13.00-14.00)
- Introduction on cartography of Europa and Triton: G. Chiarolanza and D. Sulcanese (14.15-15.00)
- Class exercise on cartography of Europa or Triton (15.15-17.00)
- Cartography comparison (17.15-18.00)

Solar System

Inventory of the Solar System



Courtesy: J. Spencer

Icy satellites

Icy satellites

Table 1.5 Planetary satellites: Physical properties and rotation rates.

Satellite	Radius (km)	Mass (10^{23} g)	Density (g cm^{-3})	Geom. albedo	Rot. period (days)
Earth	$6378^2 \times 6357$	59 742	5.515	0.367	0.997
Moon	1737.53 ± 0.03	734.9	3.34	0.12	S
Mars	$3396^2 \times 3376$	6419	3.933	0.150	1.026
MI Phobos	$13.1 \times 11.1 \times 9.3(\pm 0.1)$	1.063×10^{-4}	1.90	0.06	S
MII Deimos	$(7.8 \times 6.0 \times 5.1)(\pm 0.2)$	1.51×10^{-5}	1.50	0.07	S
Jupiter	$71\,492^2 \times 66\,854$	1.8988×10^7	1.326	0.52	0.414
JXVI Metis	$(30 \times 20 \times 17)(\pm 2)$			0.06	S
JXV Adrastea	$(10 \times 8 \times 7)(\pm 2)$			0.1	S
JV Amalthea	$(125 \times 73 \times 64)(\pm 2)$			0.09	S
JXIV Thebe	$(58 \times 49 \times 42)(\pm 2)$			0.05	
JI Io	1821.3 ± 0.2	893.3 ± 1.5	3.53 ± 0.006	0.61	S
JII Europa	1565 ± 8	479.7 ± 1.5	3.02 ± 0.04	0.64	S[a]
JIII Ganymede	2634 ± 10	1482 ± 1	1.94 ± 0.02	0.42	S
JIV Callisto	2403 ± 5	1076 ± 1	1.85 ± 0.004	0.20	S
JVI Himalia	85 ± 10	0.042 ± 0.006			0.324
JVII Elara	40 ± 10				0.5
Saturn	$60\,268^2 \times 54\,364$	5.6850×10^6	0.687	0.47	0.44
SXVIII Pan	$17 \times 16 \times 10$	5×10^{-5}	0.41 ± 0.15	0.5	S
SXXXV Daphnis	$(4.5 \times 4.3 \times 3.1)(\pm 0.8)$	8×10^{-7}	0.34 ± 0.21		
SXV Atlas	$21 \times 18 \times 9$	7×10^{-5}	0.46 ± 0.1	0.9	S
SXVI Prometheus	$68 \times 40 \times 30$	0.001 6	0.48 ± 0.09	0.9	S
SXVII Pandora	$52 \times 41 \times 32$	0.001 37	0.49 ± 0.09	0.9	S
SXI Epimetheus	$65 \times 57 \times 53$	0.0053	0.64	0.8	S
SX Janus	$102 \times 93 \times 76$	0.019	0.63 ± 0.06	0.8	S
SI Mimas	$208 \times 196 \times 191$	0.38	1.15	0.5	S
SXXXIII Pallene	$3 \times 3 \times 2$				
SII Enceladus	$257 \times 251 \times 248$	0.65	1.61	1.0	S
SIII Tethys	533 ± 2	6.27	0.99	0.9	S
SXIV Calypso	$15 \times 11.5 \times 7$			0.6	
SXIII Telesto	$16 \times 12 \times 10$			0.5	
SIV Dione	561.7 ± 0.9	11.0	1.48	0.7	S
SXII Helene	$22 \times 19 \times 13$			0.7	
SXXXIV Polydeuces	$(1.5 \times 1.2 \times 1.0)(\pm 0.4)$				
SV Rhea	764 ± 2	23.1	1.24	0.7	S
SVI Titan	2575 ± 2	1345.7	1.88	0.21	~S
SVII Hyperion	$(180 \times 133 \times 103)(\pm 4)$	0.054	0.6	0.2–0.3	C
SVIII Iapetus	$746 \times 746 \times 712$	18.1 ± 1.5	1.09	0.05–0.5	S
SIX Phoebe	$109 \times 109 \times 102$	0.083	1.64	0.08	0.387
Uranus	$25\,559^2 \times 24\,973$	8.6625×10^5	1.318	0.51	0.718
UVI Cordelia	13 ± 2			0.07	
UVII Ophelia	16 ± 2			0.07	
UVIII Bianca	22 ± 3			0.07	
UIX Cressida	33 ± 4			0.07	
UX Desdemona	29 ± 3			0.07	

(*cont.*)

Table 1.5 (*cont.*)

Satellite	Radius (km)	Mass (10^{23} g)	Density (g cm^{-3})	Geom. albedo	Rot. period (days)
UXI Juliet	42 ± 5			0.07	
UXII Portia	55 ± 6			0.07	
UXIII Rosalind	29 ± 4			0.07	
UXIV Belinda	34 ± 4			0.07	
UXV Puck	77 ± 3			0.07	
UV Miranda	$240(0.6) \times 234.2(0.9) \times 232.9(1.2)$	0.659 ± 0.075	1.20 ± 0.14	0.27	S
UI Ariel	$581.1(0.9) \times 577.9(0.6) \times 577.7(1.0)$	13.53 ± 1.20	1.67 ± 0.15	0.34	S
UII Umbriel	584.7 ± 2.8	11.72 ± 1.35	1.40 ± 0.16	0.18	S
UIII Titania	788.9 ± 1.8	35.27 ± 0.90	1.71 ± 0.05	0.27	S
UIV Oberon	761.4 ± 2.6	30.14 ± 0.75	1.63 ± 0.05	0.24	S
Neptune	$24\,764^2 \times 24\,342$	1.0278×10^6	1.638	0.41	0.671
NV Despina	74 ± 10			0.06	
NVI Galatea	79 ± 12			0.06	
NVII Larissa	$104 \times 89(\pm 7)$			0.06	
NVIII Proteus	$218 \times 208 \times 201$			0.06	
NI Triton	1352.6 ± 2.4	214.7 ± 0.7	2.054 ± 0.032	0.7	S
NII Nereid	170 ± 2.5			0.2	0.48

Most data are from Yoder (1995), with updates from http://ssd.jpl.nasa.gov, Porco *et al.* (2007), Jacobson *et al.* (2008), Thomas *et al.* (1998, 2007), Thomas (2010), and Pilcher *et al.* (2012).

Abbreviations: S, synchronous rotation; C, chaotic rotation.

[a] Europa's ice crust may rotate slightly faster than synchronous.

Icy satellites

Table 1.4 Principal planetary satellites: Orbital data and visual magnitude at opposition.

Planet		Satellite	a (10^3 km)	Orbital period (days)	e	i (deg)	m_v
Earth		Moon	384.40	27.321 661	0.054 900	5.15[a]	−12.7
Mars	I	Phobos	9.375	0.318 910	0.015 1	1.082	11.4
	II	Deimos	23.458	1.262 441	0.000 24	1.791	12.5
Jupiter	XVI	Metis	127.98	0.294 78	0.001 2	0.02	17.5
	XV	Adrastea	128.98	0.298 26	0.001 8	0.054	18.7
	V	Almathea	181.37	0.498 18	0.003 1	0.388	14.1
	XIV	Thebe	221.90	0.674 5	0.017 7	1.070	16.0
	I	Io	421.77	1.769 138	0.004 1*f*	0.040	5.0
	II	Europa	671.08	3.551 810	0.010 1*f*	0.470	5.3
	III	Ganymede	1 070.4	7.154 553	0.001 5*f*	0.195	4.6
	IV	Callisto	1 882.8	16.689 018	0.007	0.28	5.6
	XIII	Leda	11 160	241	0.148	27[a]	19.5
	VI	Himalia	11 460	251	0.163	28.5[a]	14.6
	X	Lysithea	11 720	259	0.107	29[a]	18.3
	VII	Elara	11 737	260	0.207	28[a]	16.3
	XII	Ananka	21 280	610	0.169	147[a]	18.8
	XI	Carme	23 400	702	0.207	163[a]	17.6
	VIII	Pasiphae	23 620	708	0.378	148[a]	17.0
	IX	Sinope	23 940	725	0.275	153[a]	18.1
Saturn	XVIII	Pan	133.584	0.575 05	0.000 01	0.000 1	19.4
	XXXV	Daphnis	136.51	0.594 08	0.000 03	0.004	21
	XV	Atlas	137.670	0.601 69	0.001 2	0.01	19.0
	XVI	Prometheus	139.380	0.612 986	0.002 2	0.007	15.8
	XVII	Pandora	141.710	0.628 804	0.004 2	0.051	16.4
	XI	Epimetheus	151.47[b]	0.694 590[b]	0.010	0.35	15.6
	X	Janus	151.47[b]	0.694 590[b]	0.007	0.16	16.4
	I	Mimas	185.52	0.942 421 8	0.020 2	1.53*f*	12.8
	XXXII	Methone	194.23	1.009 58	0.000	0.02	23
	XLIX	Anthe	197.7	1.037	0.02	0.02	24
	XXXIII	Pallene	212.28	1.153 7	0.004	0.18	22
	II	Enceladus	238.02	1.370 218	0.004 5*f*	0.02	11.8
	III	Tethys	294.66	1.887 802	0.000 0	1.09*f*	10.3
	XIV	Calypso (T−)	294.66[b]	1.887 802[b]	0.000 5	1.50	18.7
	XIII	Telesto (T+)	294.66[b]	1.887 802[b]	0.000 2	1.18	18.5
	IV	Dione	377.71	2.736 915	0.002 2*f*	0.02	10.4
	XII	Helene (T+)	377.71[b]	2.736 915[b]	0.005	0.2	18.4
	XXXIV	Polydeuces (T−)	377.71[b]	2.736 915[b]	0.019	0.18	23
	V	Rhea	527.04	4.517 500	0.001	0.35	9.7
	VI	Titan	1 221.85	15.945 421	0.029 2	0.33	8.4
	VII	Hyperion	1 481.1	21.276 609	0.104 2*f*	0.43	14.4
	VIII	Iapetus	3 561.3	79.330 183	0.028 3	7.52	11.0[c]
	IX	Phoebe	12 952	550.48	0.164	175.3[a]	16.5
	XX	Paaliaq	15 198	687	0.36	45[a]	21.2
	XXVI	Albiorix	16 394	783	0.48	34[a]	20.4
	XXIX	Siarnaq	18 195	896	0.3	46[a]	20.0

(*cont.*)

Table 1.4 (*cont.*)

Planet		Satellite	a (10^3 km)	Orbital period (days)	e	i (deg)	m_v
Uranus	VI	Cordelia	49.752	0.335 033	0.000	0.1	24.2
	VII	Ophelia	53.764	0.376 409	0.010	0.1	23.9
	VIII	Bianca	59.166	0.434 577	0.000 3	0.18	23.1
	IX	Cressida	61.767	0.463 570	0.000 2	0.04	22.3
	X	Desdemona	62.658	0.473 651	0.000 3	0.10	22.5
	XI	Juliet	64.358	0.493 066	0.000 1	0.05	21.7
	XII	Portia	66.097	0.513 196	0.000 5	0.03	21.1
	XIII	Rosalind	69.927	0.558 459	0.000 6	0.09	22.5
	XXVII	Cupid	74.393	0.612 825	∼0	∼0	25.9
	XIV	Belinda	75.256	0.623 525	0.000	0.0	22.1
	XXV	Perdita	76.417	0.638 019	0.003	∼0	23.6
	XV	Puck	86.004	0.761 832	0.000 4	0.3	20.6
	XXVI	Mab	97.736	0.922 958	0.002 5	0.13	25.4
	V	Miranda	129.8	1.413	0.002 7	4.22	15.8
	I	Ariel	191.2	2.520	0.003 4	0.31	13.7
	II	Umbriel	266.0	4.144	0.005 0	0.36	14.5
	III	Titania	435.8	8.706	0.002 2	0.10	13.5
	IV	Oberon	582.6	13.463	0.000 8	0.10	13.7
	XVI	Caliban	7 231	580	0.16	141[a]	22.4
	XX	Stephano	8 004	677	0.23	144[a]	24.1
	XVII	Sycorax	12 179	1288	0.52	159[a]	20.8
	XVIII	Prospero	16 256	1978	0.44	152[a]	23.2
	XIX	Setebos	17 418	2225	0.59	158[a]	23.3
Neptune	III	Naiad	48.227	0.294 396	0.00	4.74	24.6
	IV	Thalassa	50.075	0.311 485	0.00	0.21	23.9
	V	Despina	52.526	0.334 655	0.00	0.07	22.5
	VI	Galatea	61.953	0.428 745	0.00	0.05	22.4
	VII	Larissa	73.548	0.554 654	0.00	0.20	22.0
	VIII	Proteus	117.647	1.122 315	0.00	0.55	20.3
	I	Triton	354.76	5.876 854	0.00	156.834	13.5
	II	Nereid	5 513.4	360.136 19	0.751	7.23[a]	19.7
	IX	Halimede	15 686	1875	0.57	134[a]	24.4
	XI	Sao	22 452	2919	0.30	48[a]	25.7
	XII	Laomedeia	22 580	2982	0.48	35[a]	25.3
	XIII	Neso	46 570	8863	0.53	132[a]	24.7
	X	Psamathe	46 738	9136	0.45	137[a]	25.1

Data are from Yoder (1995), with updates from Showalter and Lissauer (2006), Jacobson *et al.* (2009), Nicholson (2009), Jacobson, (2010), http://ssd.jpl.nasa.gov, and other sources.

i = orbit plane inclination with respect to the parent planet's equator, except where noted.

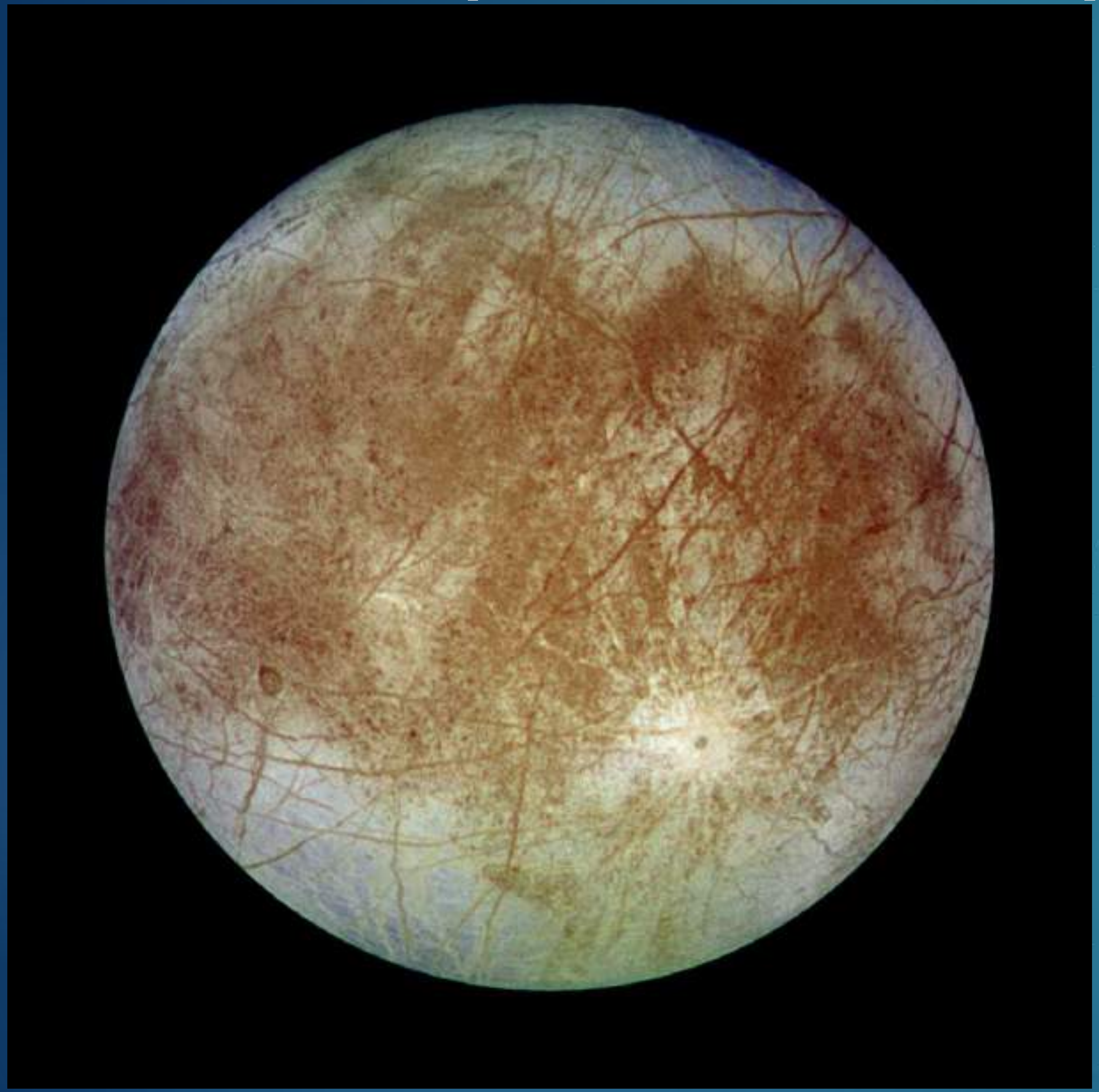
Abbreviations: T, Trojan-like satellite which leads (+) or trails (−) by ∼60° in longitude the primary satellite with same semimajor axis; *f*, forced eccentricity or inclination.

[a] measured relative to the planet's heliocentric orbit, because the Sun (rather than the planetary oblateness) controls the local Laplacian plane of these distant satellites.

[b] varies due to coorbital libration; value shown is long-term average.

[c] varies substantially with orbital longitude; average value is shown.

Jupiter system:
Europa, Ganymede and Callisto

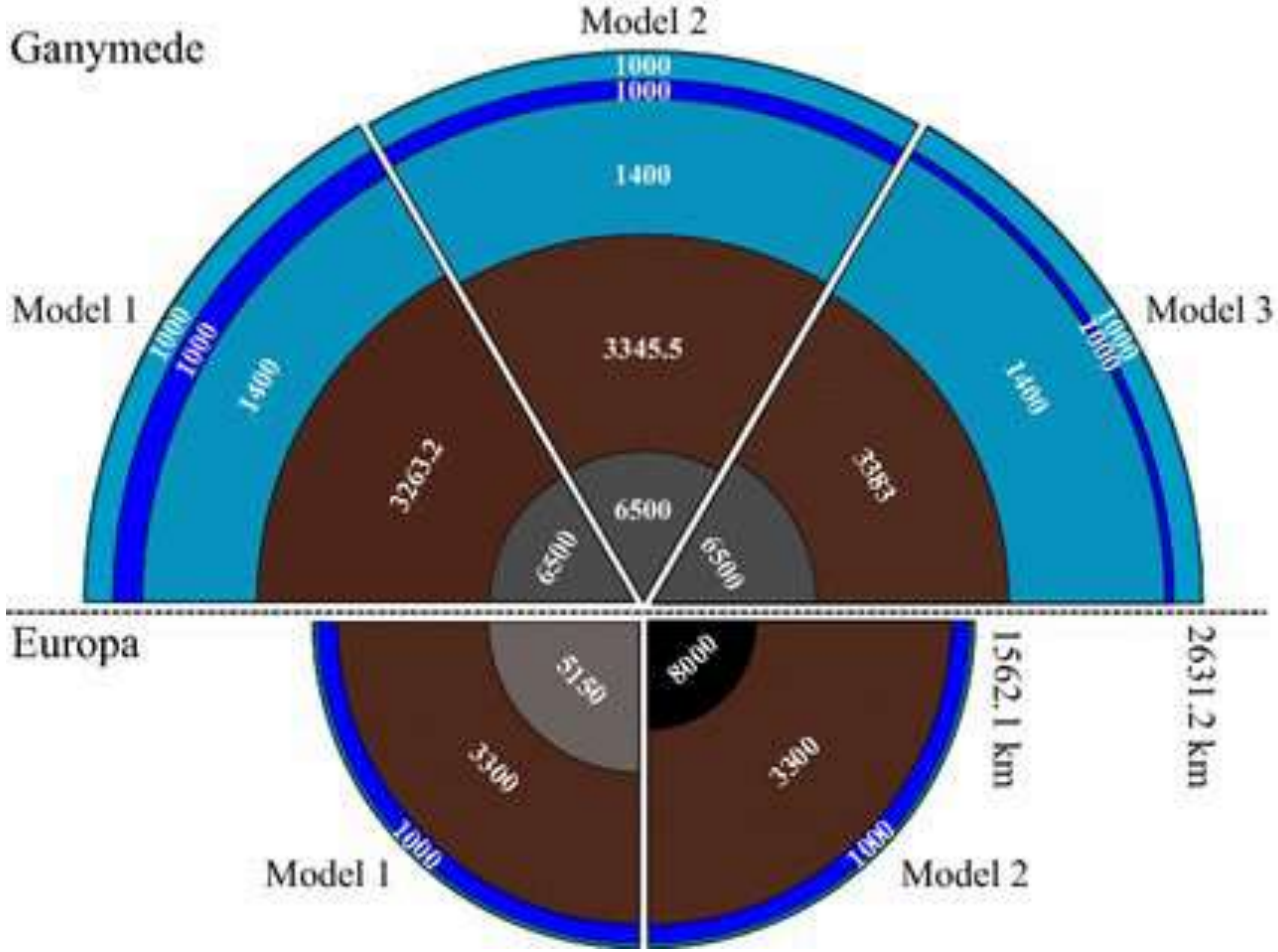


Europa
Radius: 1561 km

Ganymede
Radius: 2634 km

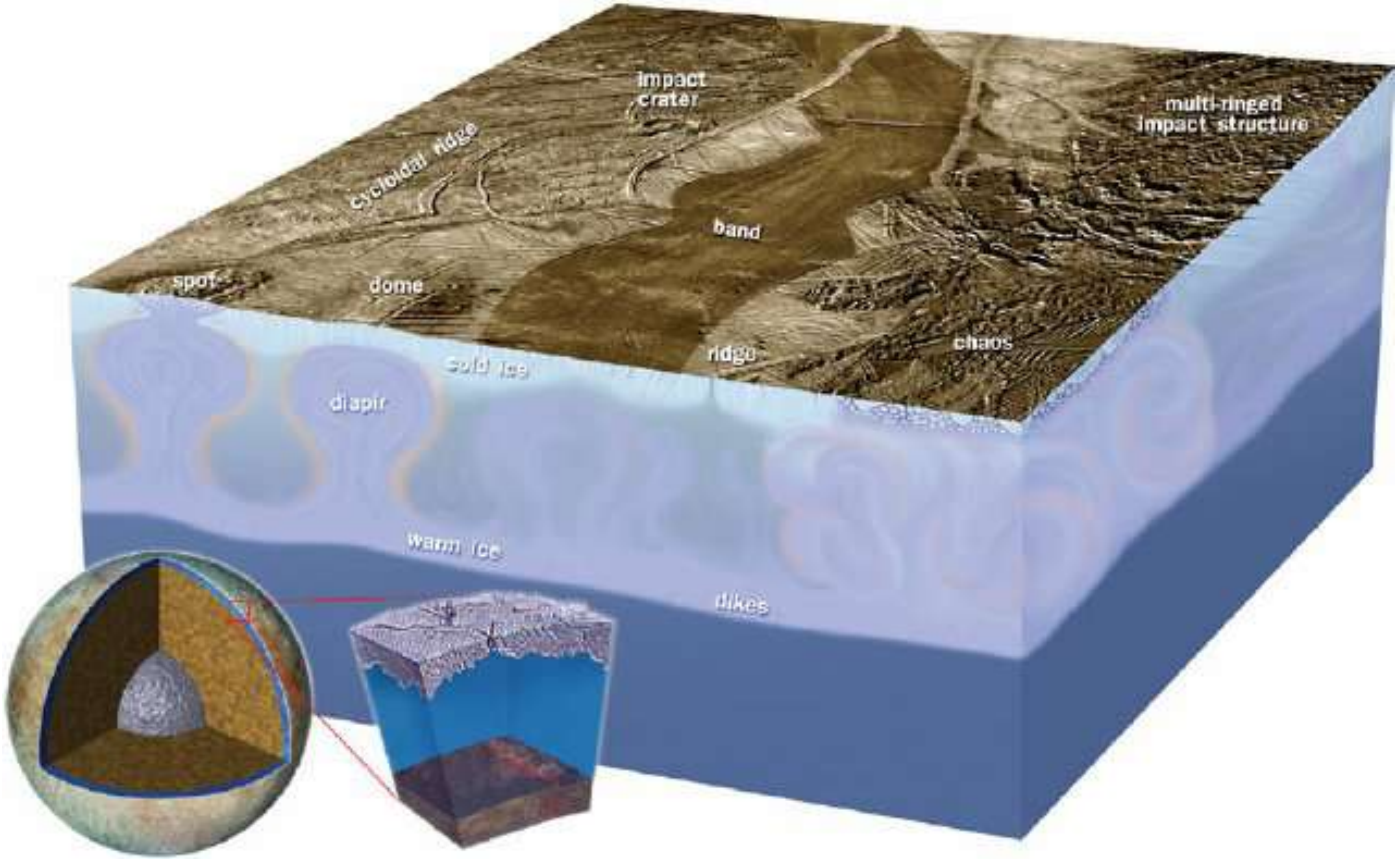
Callisto
Radius: 2410 km

Interior structure of Europa and Ganymede

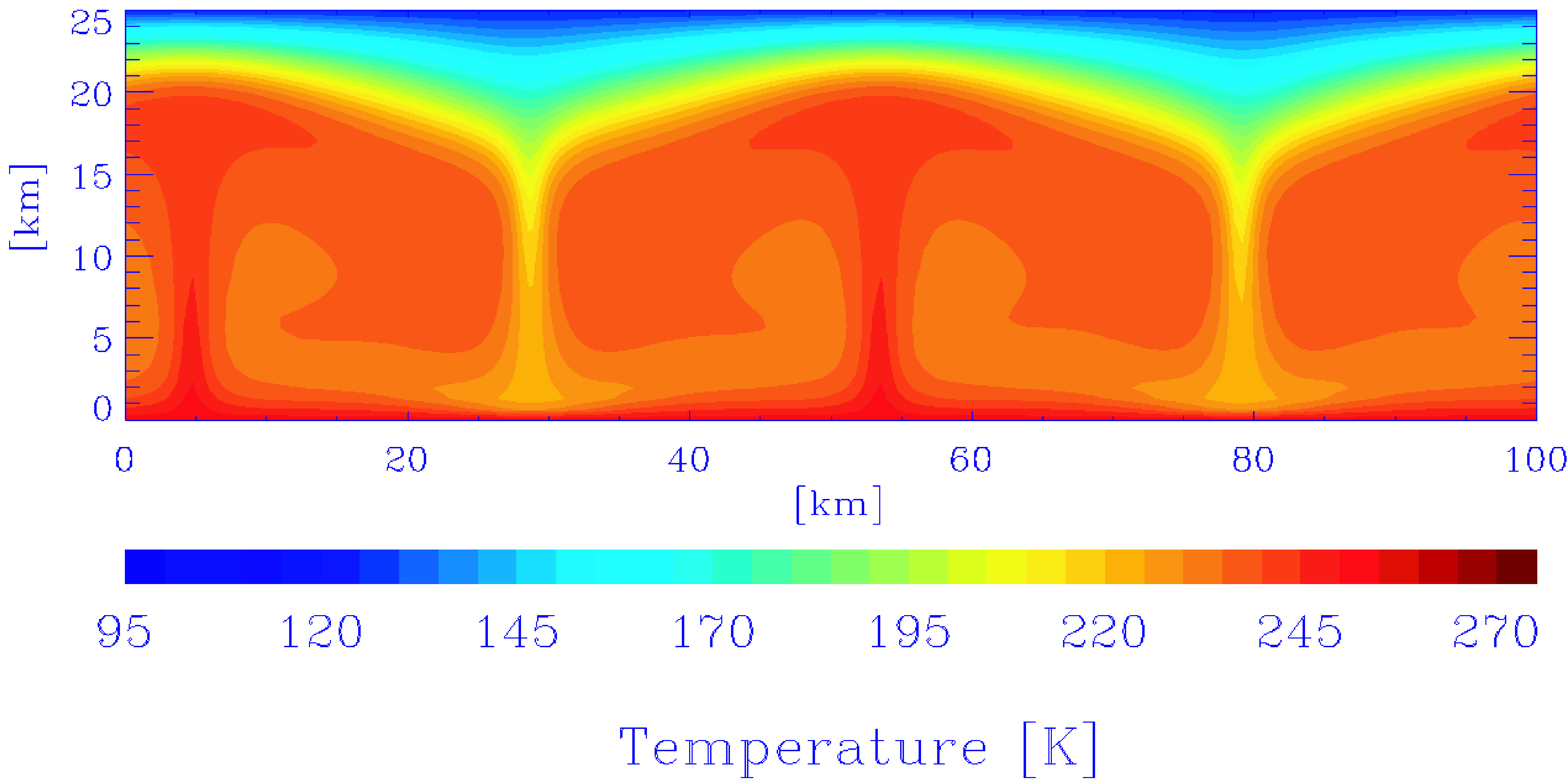


Hussmann et al (2019)

Ice shell dynamics of Europa

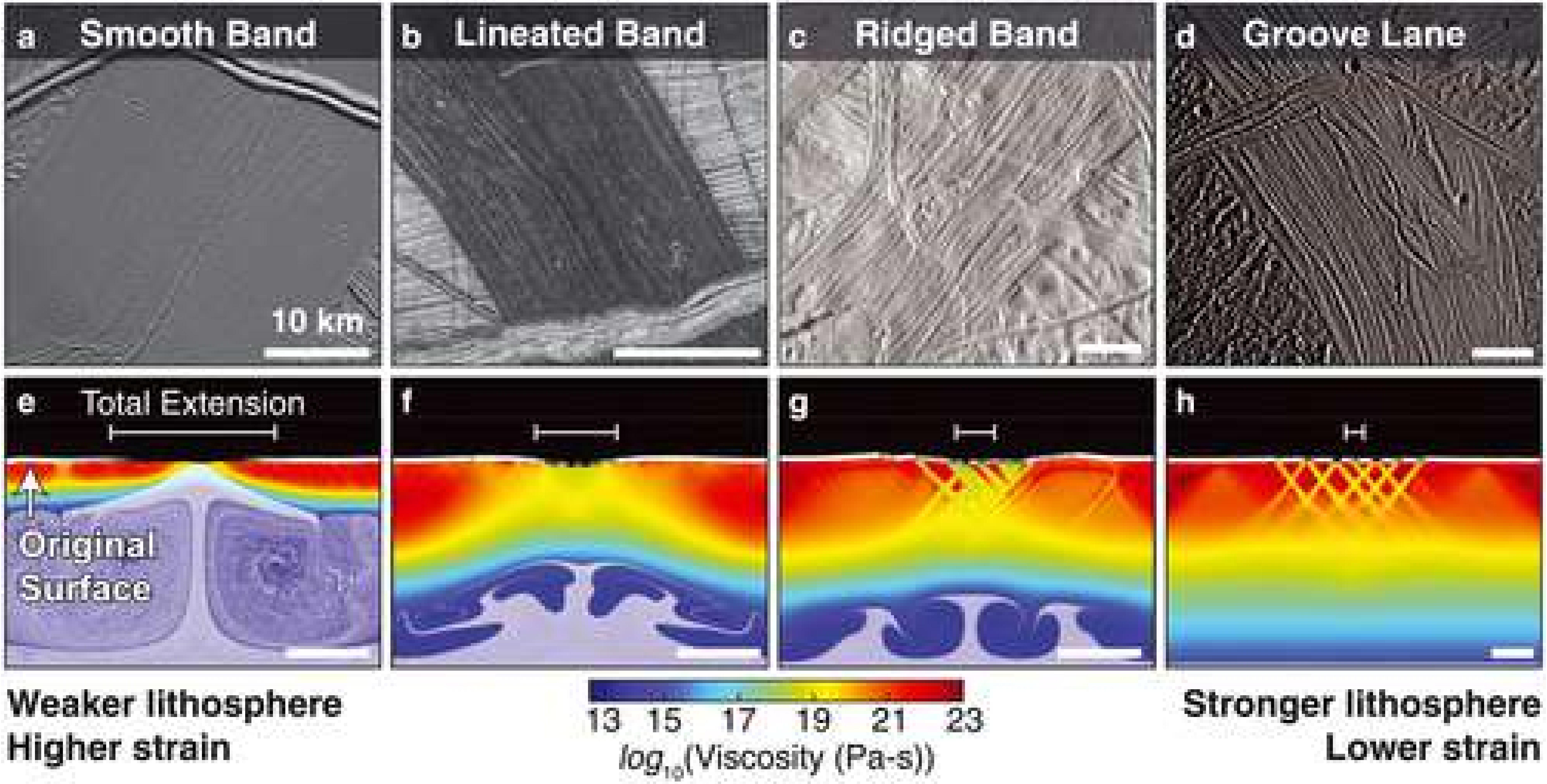


Pappalardo (2019)



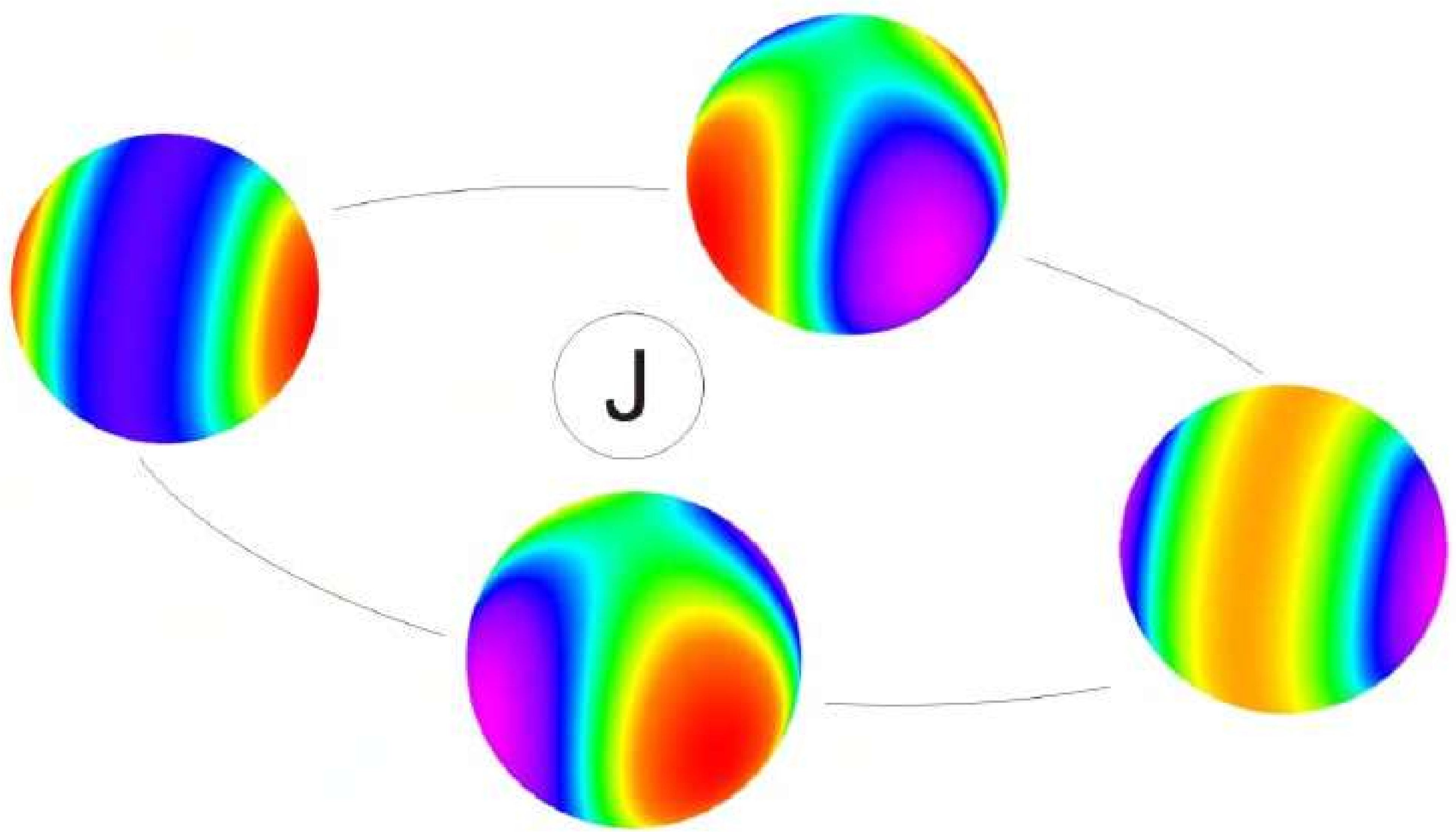
Mitri and Showman (2005)

Ice shell dynamics of Europa

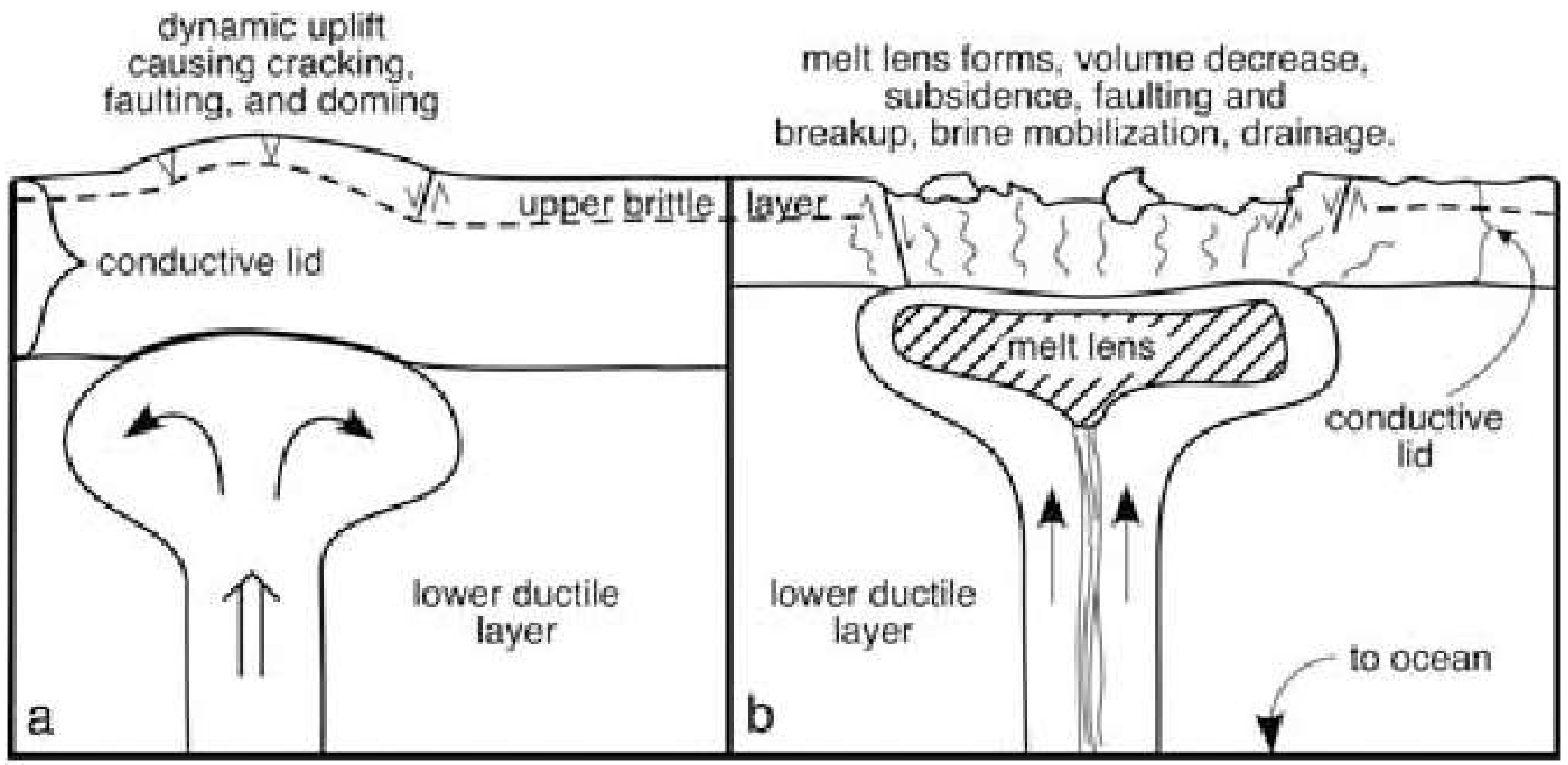


Howell and Pappalardo (2019)

Tides and internal processes

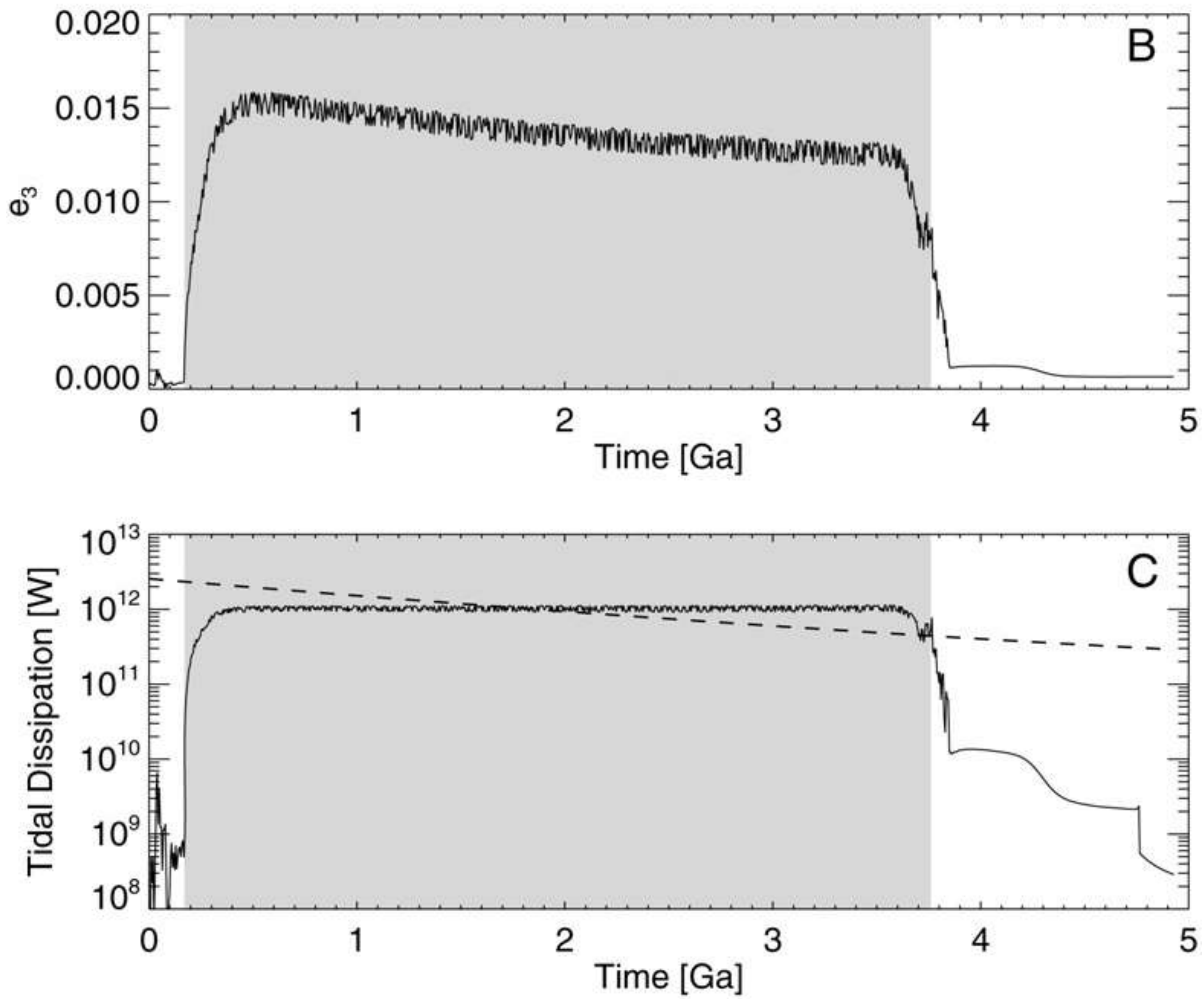


Hussmann



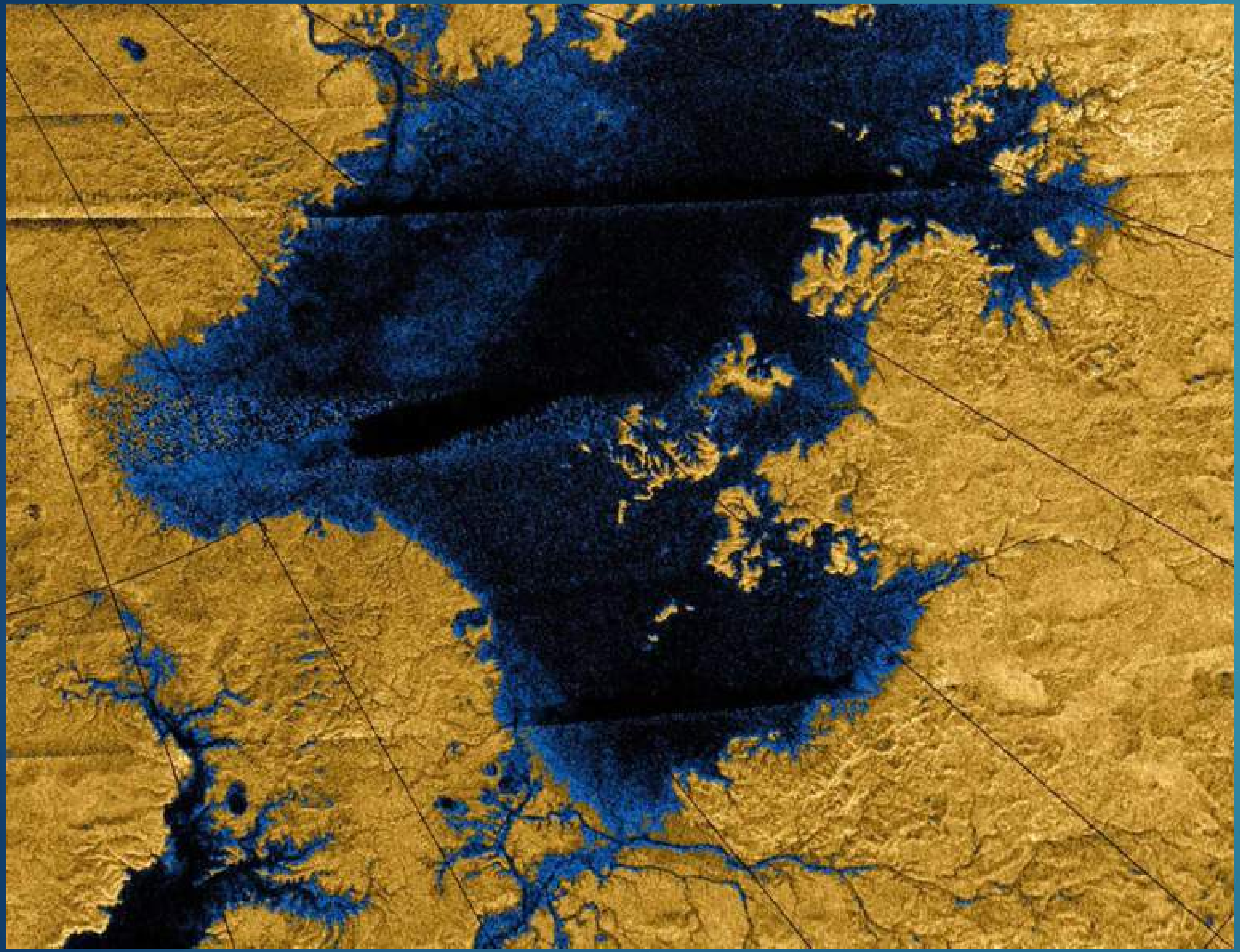
Sotin et al. (2002)

Thermal-orbital evolution of Ganymede

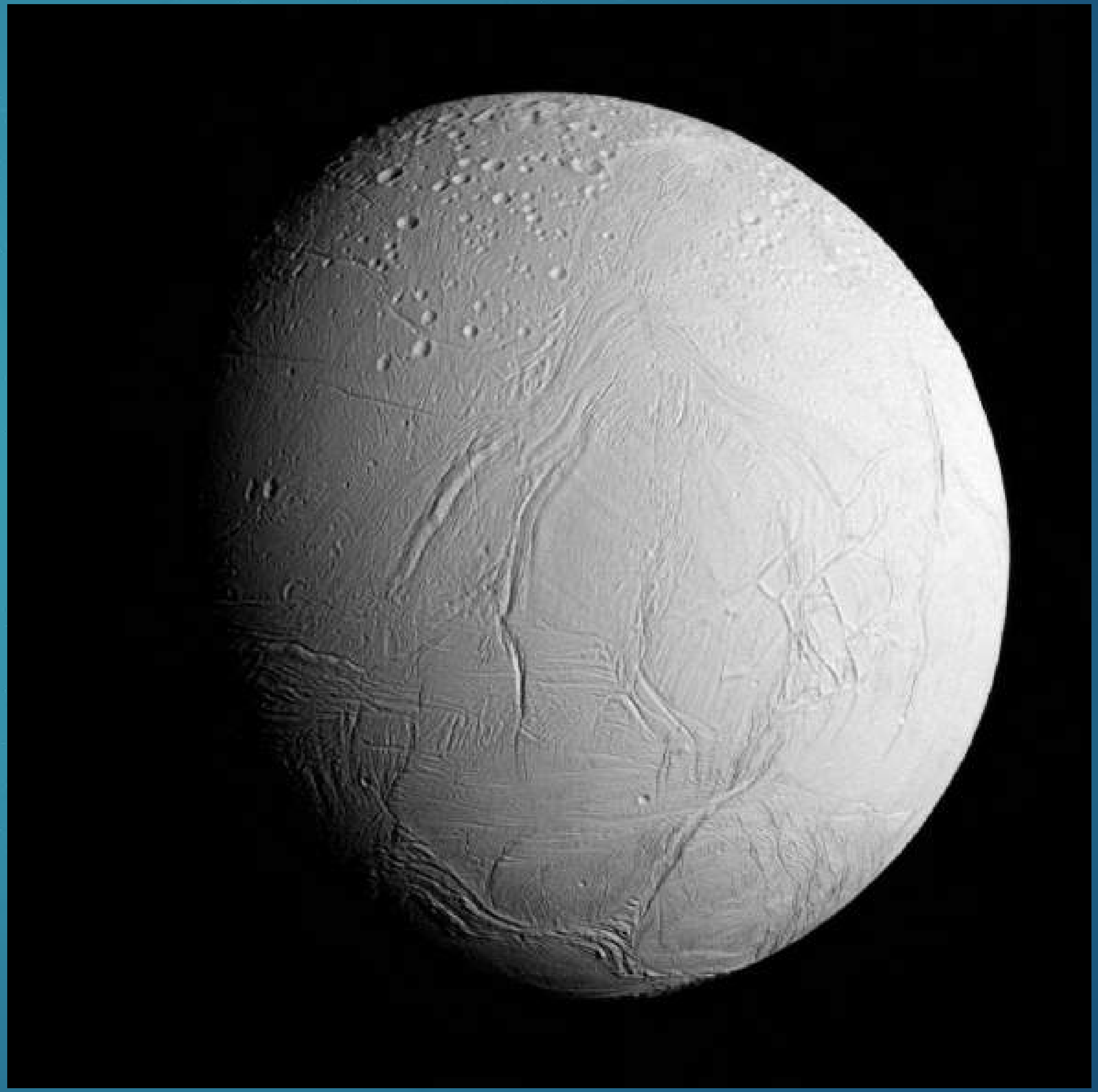


Bland et al. (2008)

Saturn system:
Titan and Enceladus

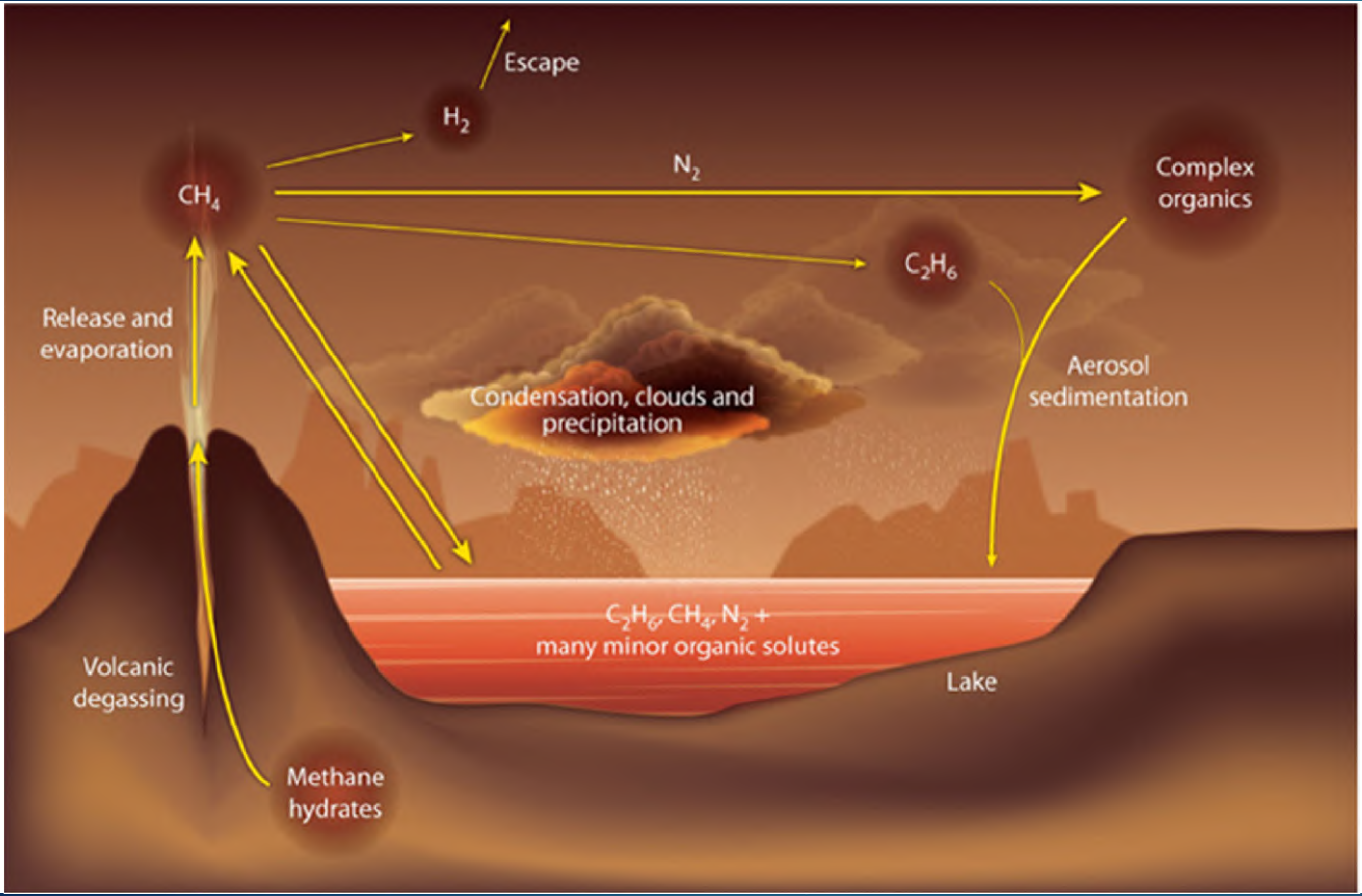


Titan
Radius: 2575 km



Enceladus
Radius: 252 km

Titan methanological cycle



Raulin et al. (2008)

Interior structure of Titan

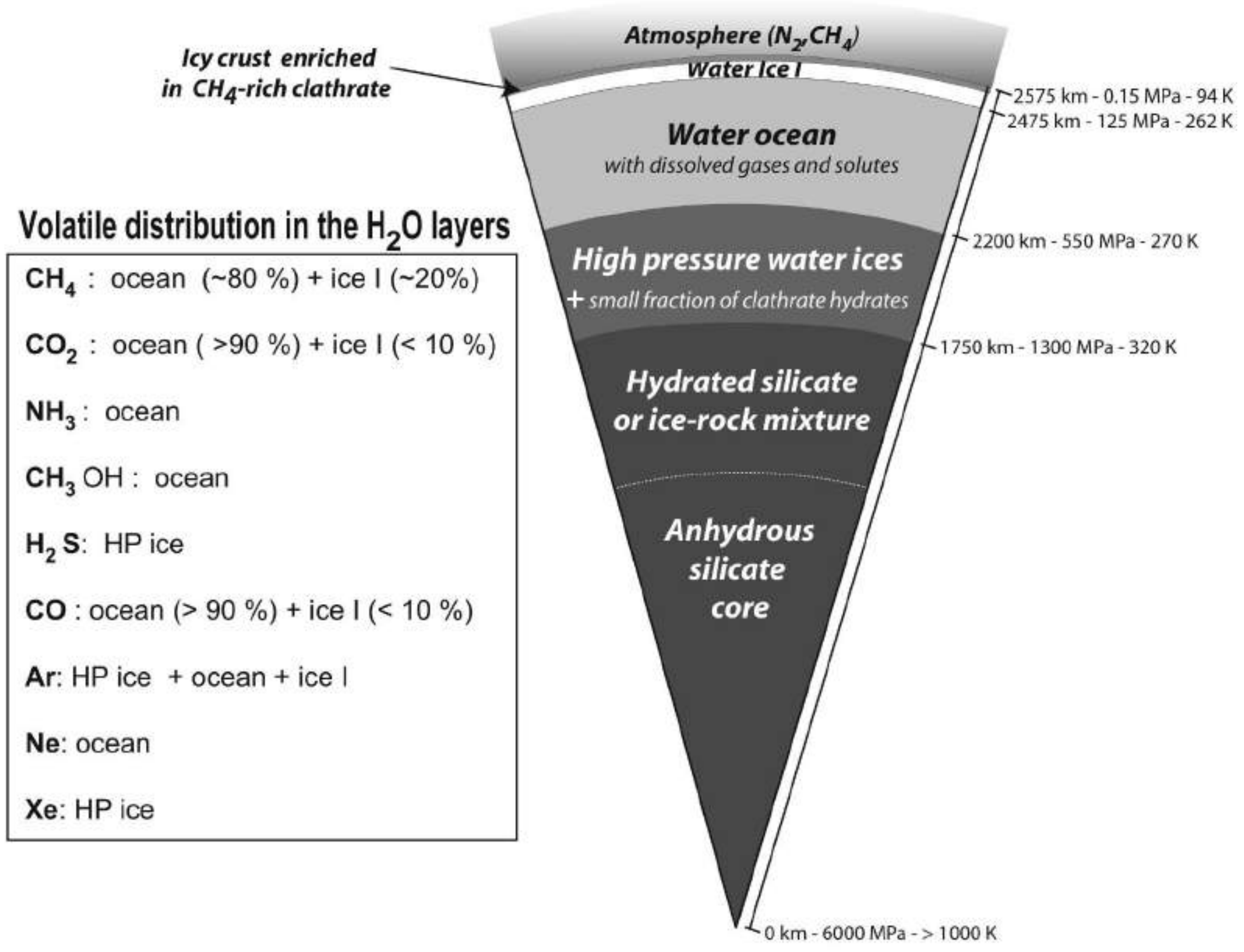
Gravity Field, Shape, and Moment of Inertia of Titan

Luciano Iess,[1*] Nicole J. Rappaport,[2] Robert A. Jacobson,[2] Paolo Racioppa,[1] David J. Stevenson,[3] Paolo Tortora,[4] John W. Armstrong,[2] Sami W. Asmar[2]

Precise radio tracking of the spacecraft Cassini has provided a determination of Titan's mass and gravity harmonics to degree 3. The quadrupole field is consistent with a hydrostatically relaxed body shaped by tidal and rotational effects. The inferred moment of inertia factor is about 0.34, implying incomplete differentiation, either in the sense of imperfect separation of rock from ice or a core in which a large amount of water remains chemically bound in silicates. The equilibrium figure is a triaxial ellipsoid whose semi-axes *a*, *b*, and *c* differ by 410 meters (*a* − *c*) and 103 meters (*b* − *c*). The nonhydrostatic geoid height variations (up to 19 meters) are small compared to the observed topographic anomalies of hundreds of meters, suggesting a high degree of compensation appropriate to a body that has warm ice at depth.

	Multi-arc (SOL1) [value ± 1σ ($\times 10^{+06}$)]	Global (SOL2) [value ± 1σ ($\times 10^{+06}$)]
J_2	31.808 ± 0.404	33.462 ± 0.632
C_{21}	0.338 ± 0.350	0.048 ± 0.115
S_{21}	−0.352 ± 0.438	−0.620 ± 0.496
C_{22}	9.983 ± 0.039	10.022 ± 0.071
S_{22}	0.217 ± 0.041	0.256 ± 0.072
J_3	−1.879 ± 1.019	−0.074 ± 1.051
C_{31}	1.058 ± 0.260	1.805 ± 0.297
S_{31}	0.509 ± 0.202	0.283 ± 0.354
C_{32}	0.364 ± 0.113	0.136 ± 0.158
S_{32}	0.347 ± 0.080	0.159 ± 0.105
C_{33}	−0.199 ± 0.009	−0.185 ± 0.012
S_{33}	−0.171 ± 0.015	−0.149 ± 0.016

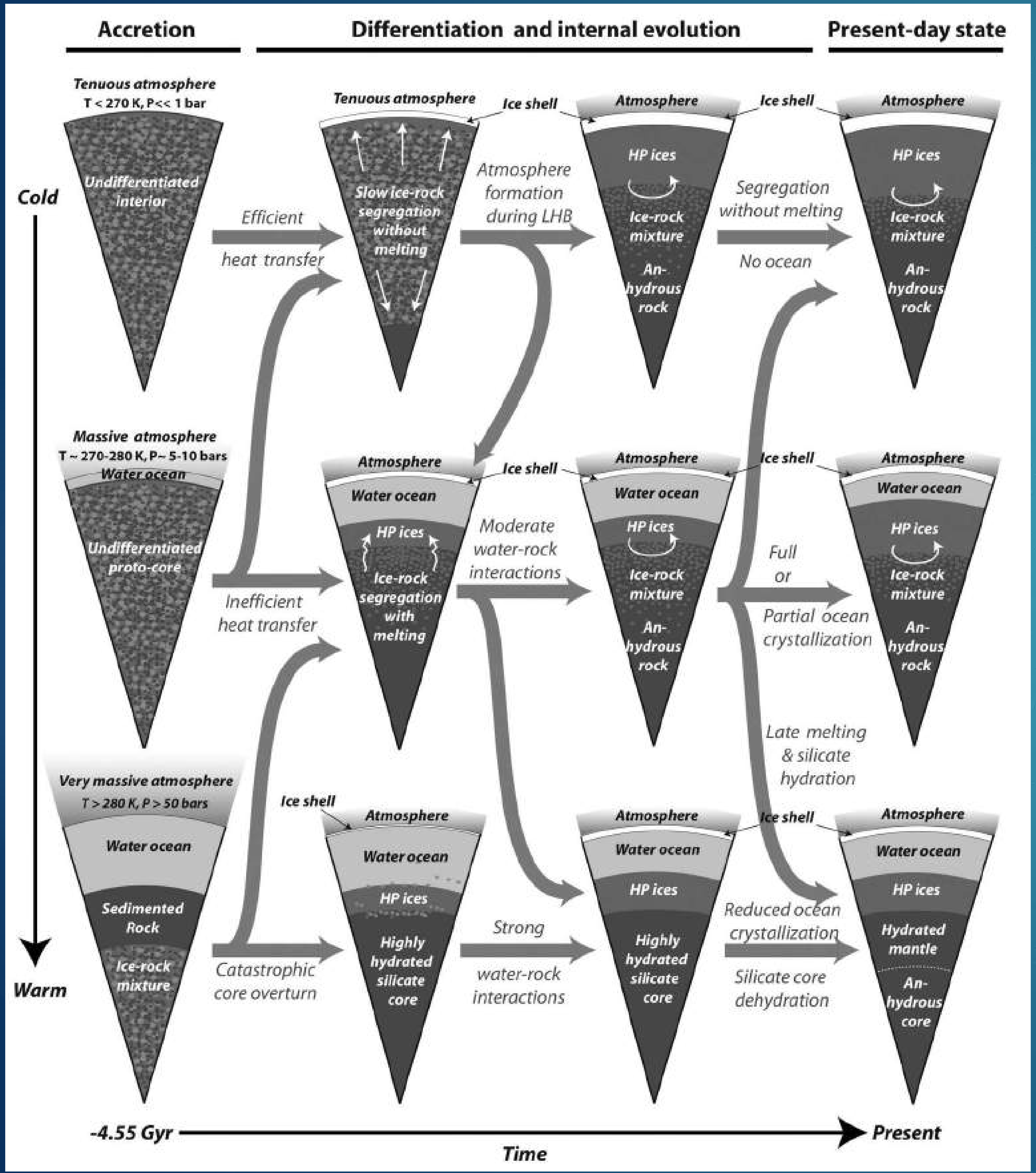
Interior structure of Titan

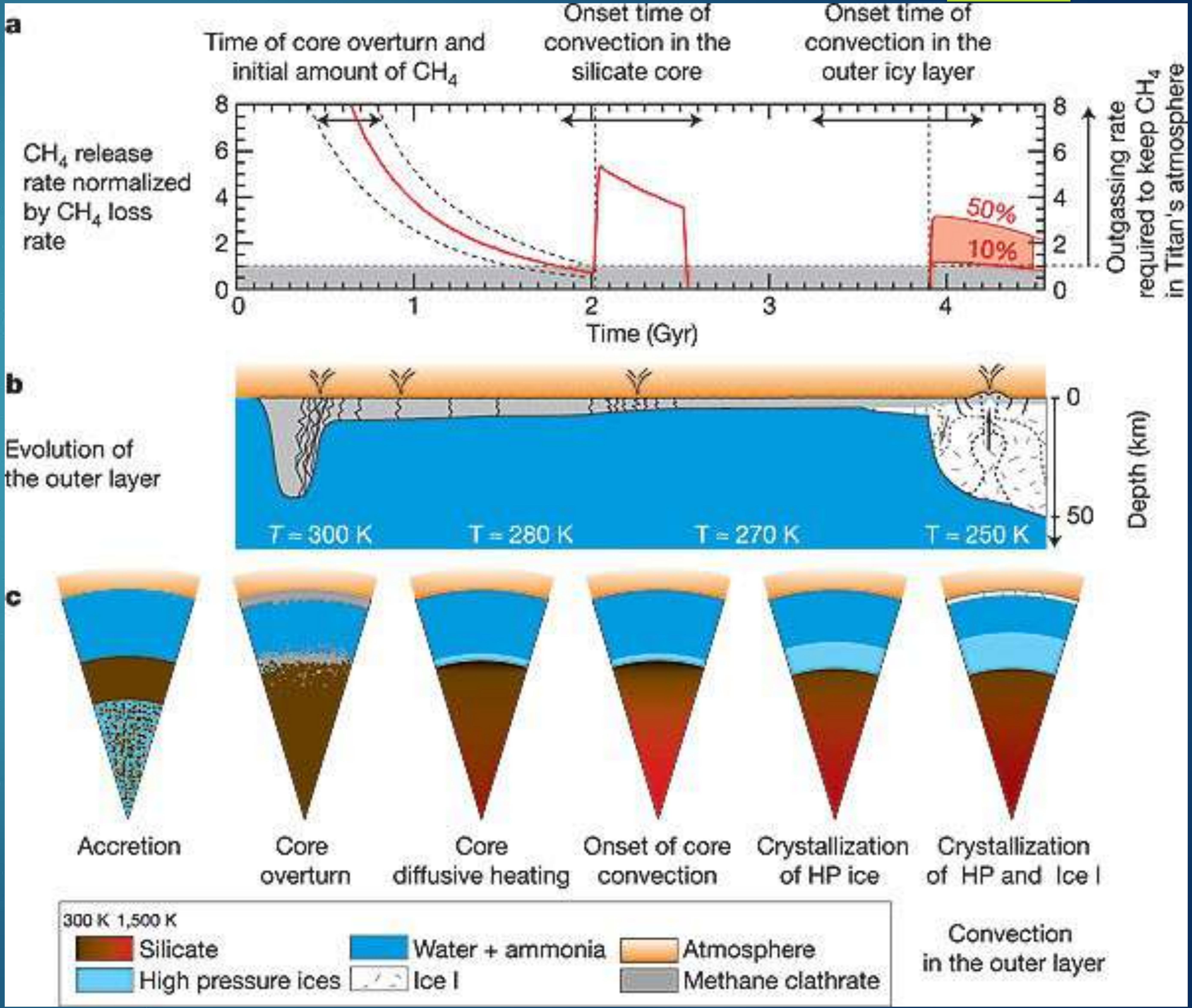


J_2/C_{22} is 3.186 ± 0.042

$$C = 0.3414 \pm 0.0005$$

Evolution of Titan's interior

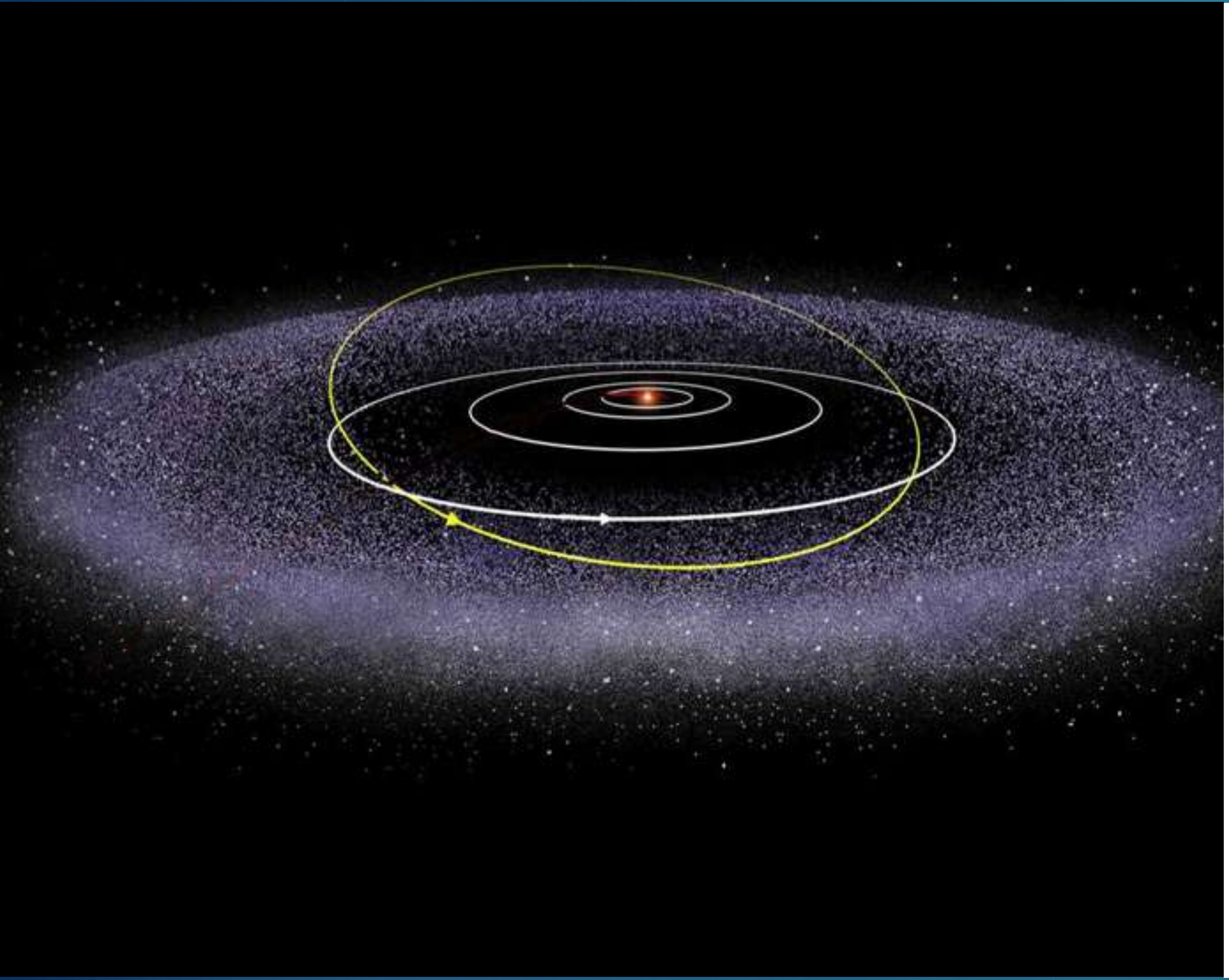


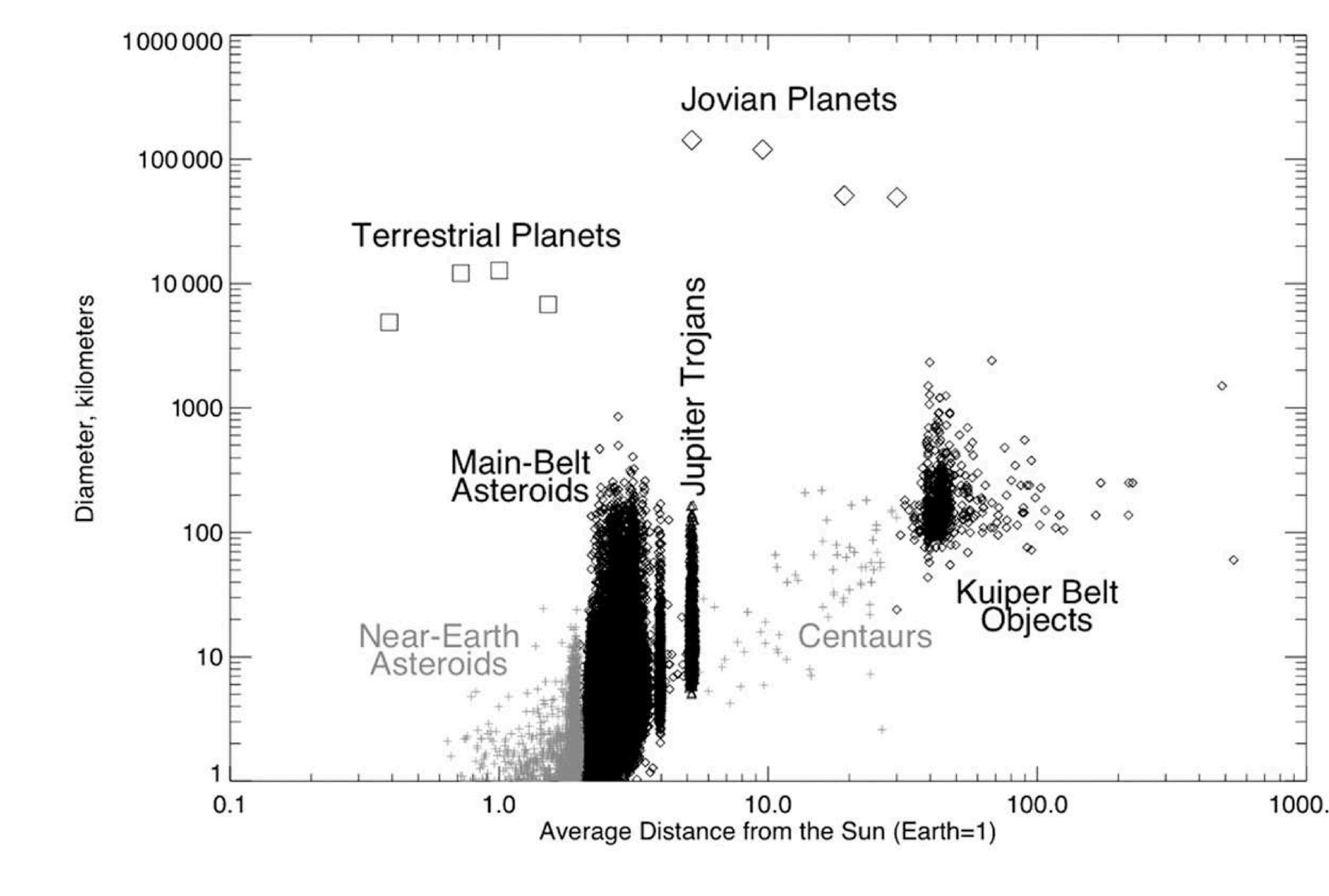


Neptune system: Triton

Triton
Radius: 1353 km

Kuiper Belt Objects (KBOs)

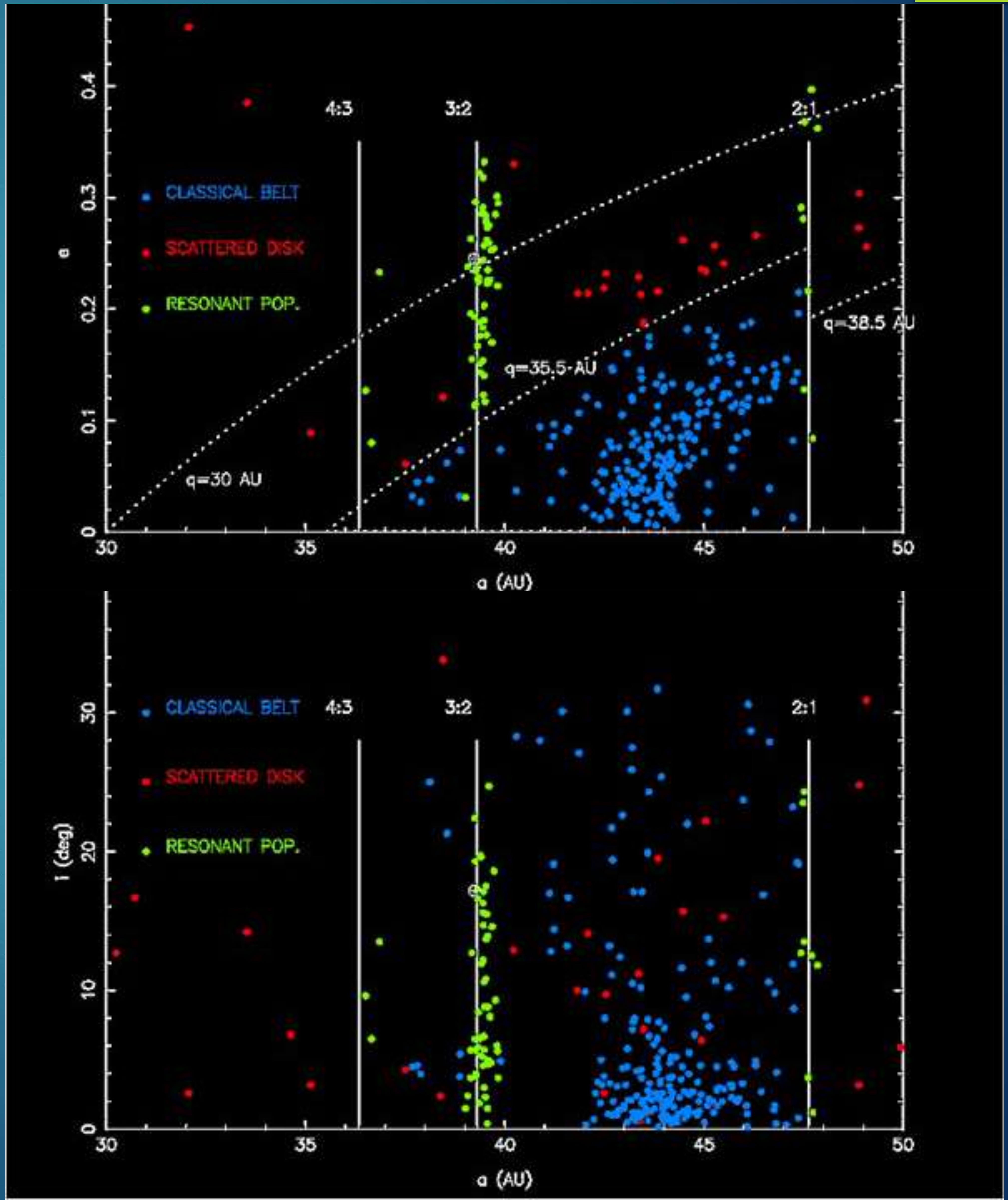




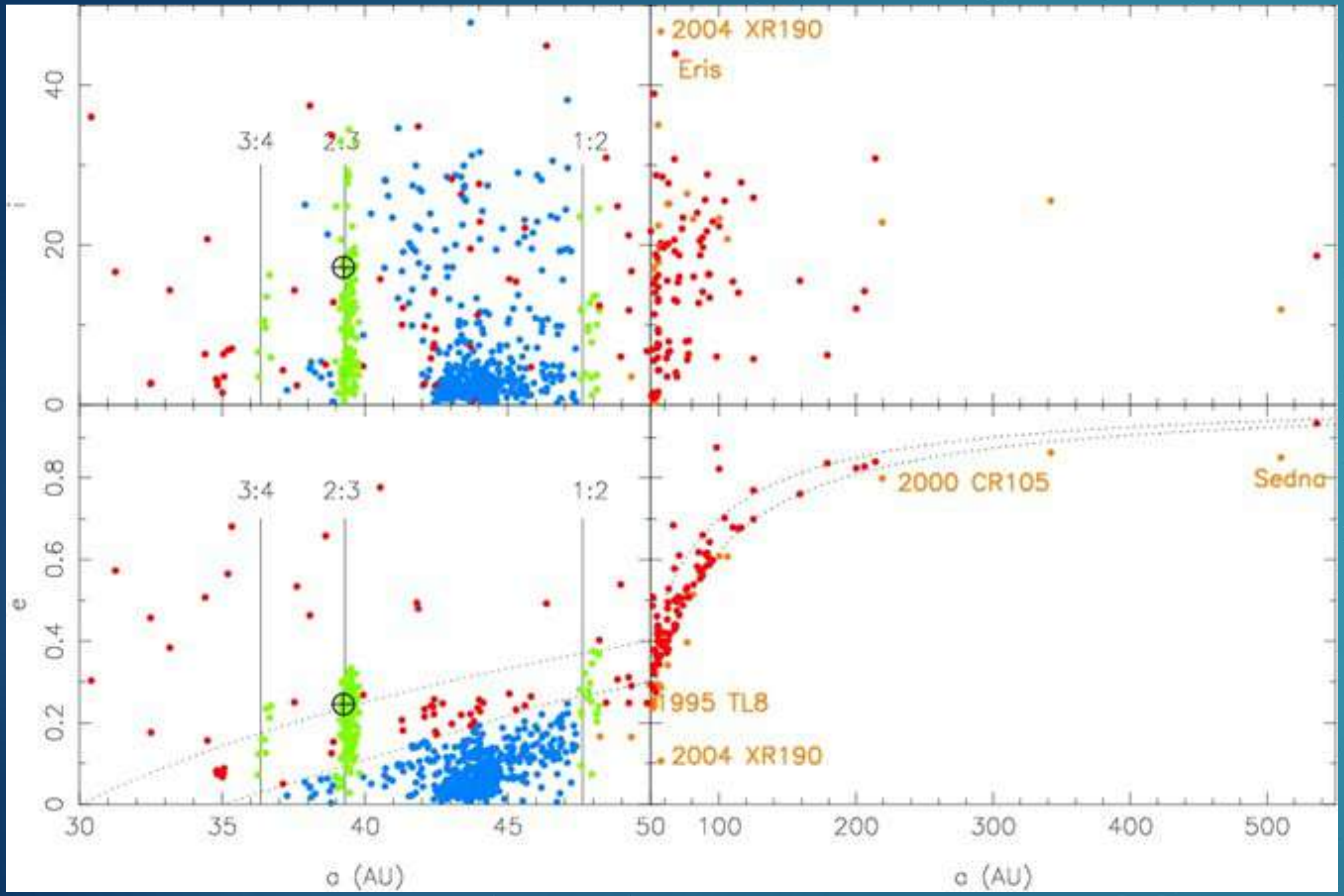
Hot and cold populations of KBOs

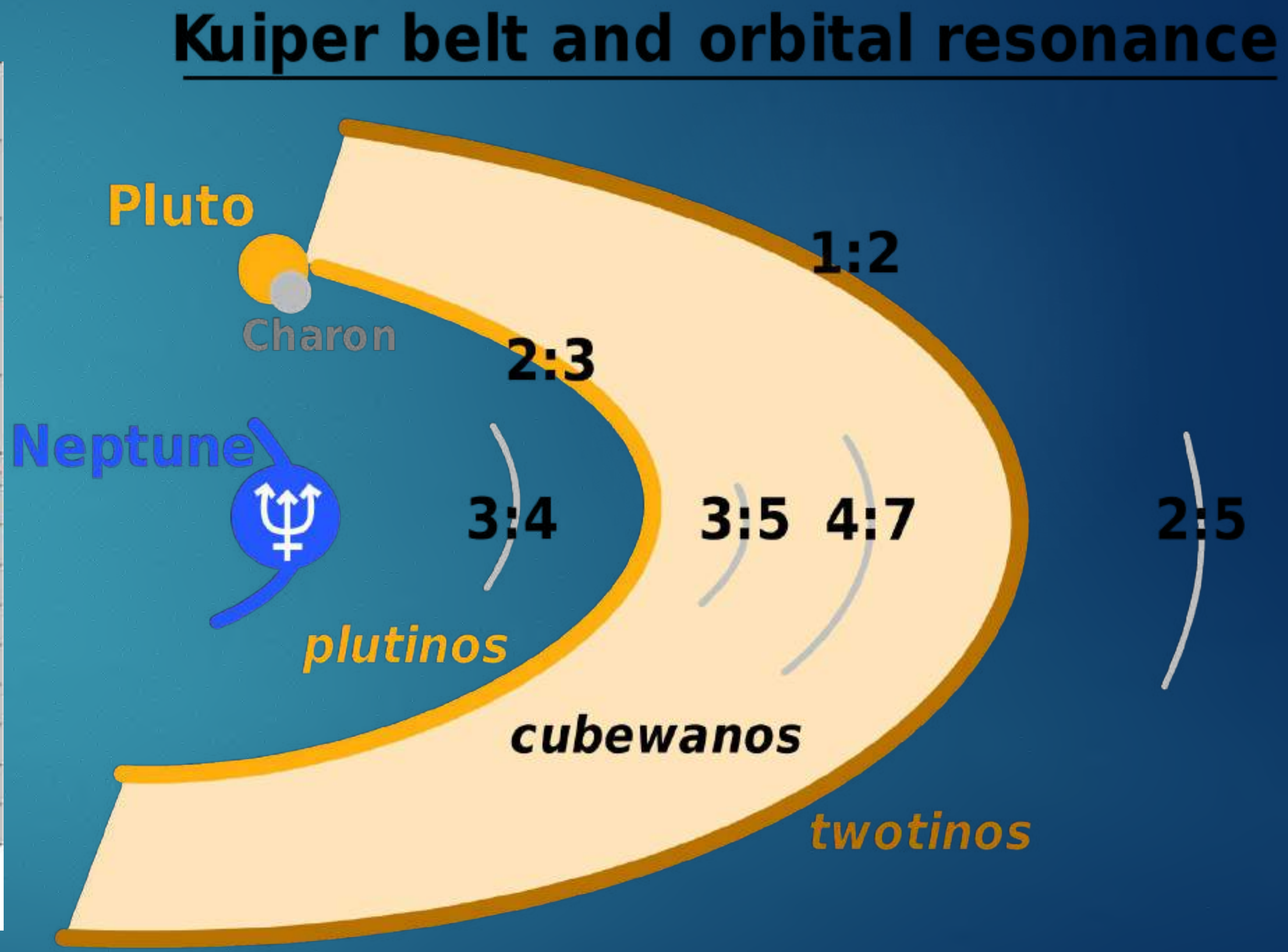
The classical population population is KBOs is composed of two populations:

- **Cold population:** low orbital eccentricity (almost circular), low orbital inclination. Lower albedo of the surface
- **Hot population:** Higher inclination of the orbit. Higher surface albedo

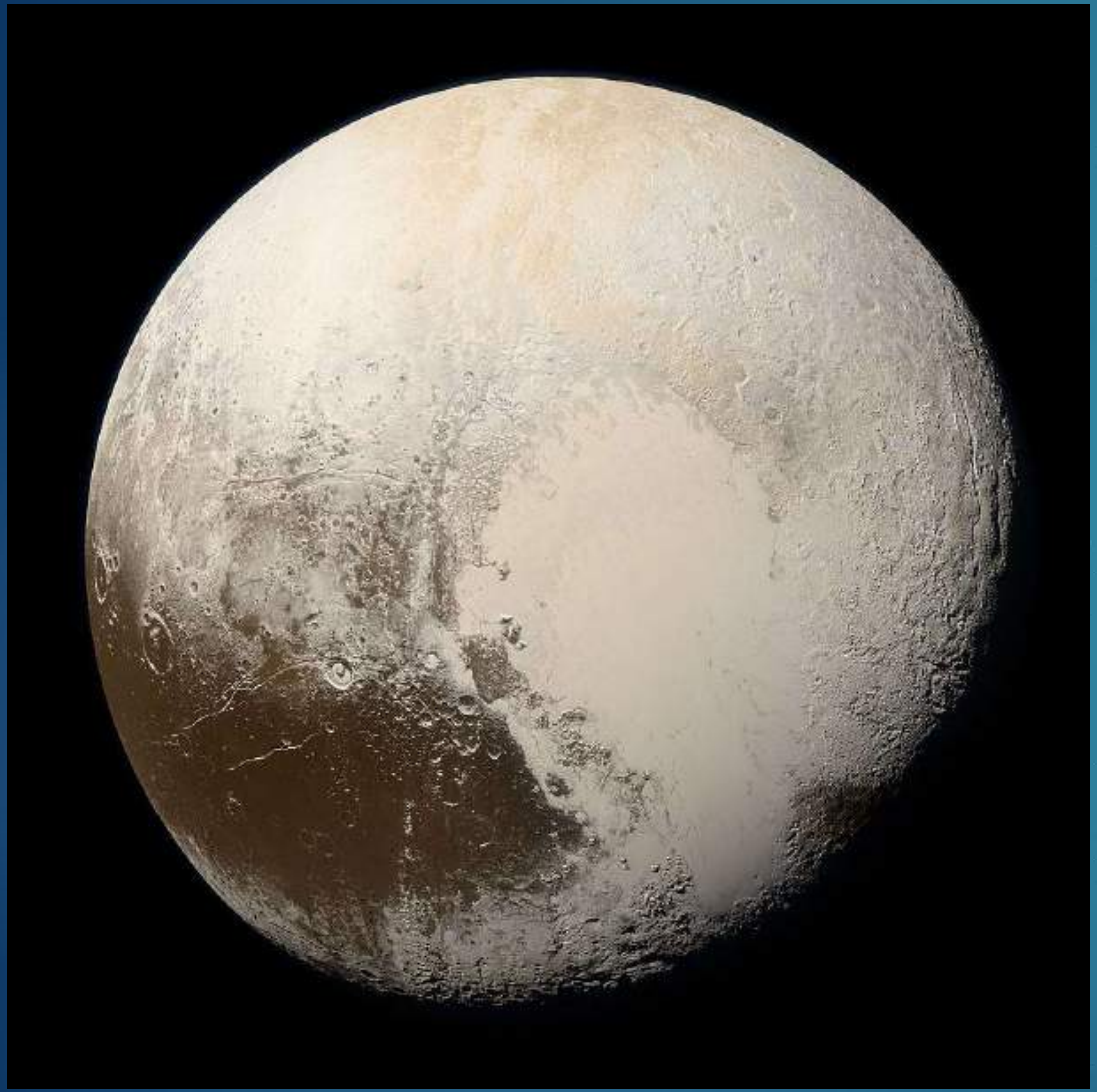


KBOs: Plutinos





Pluto and Charon

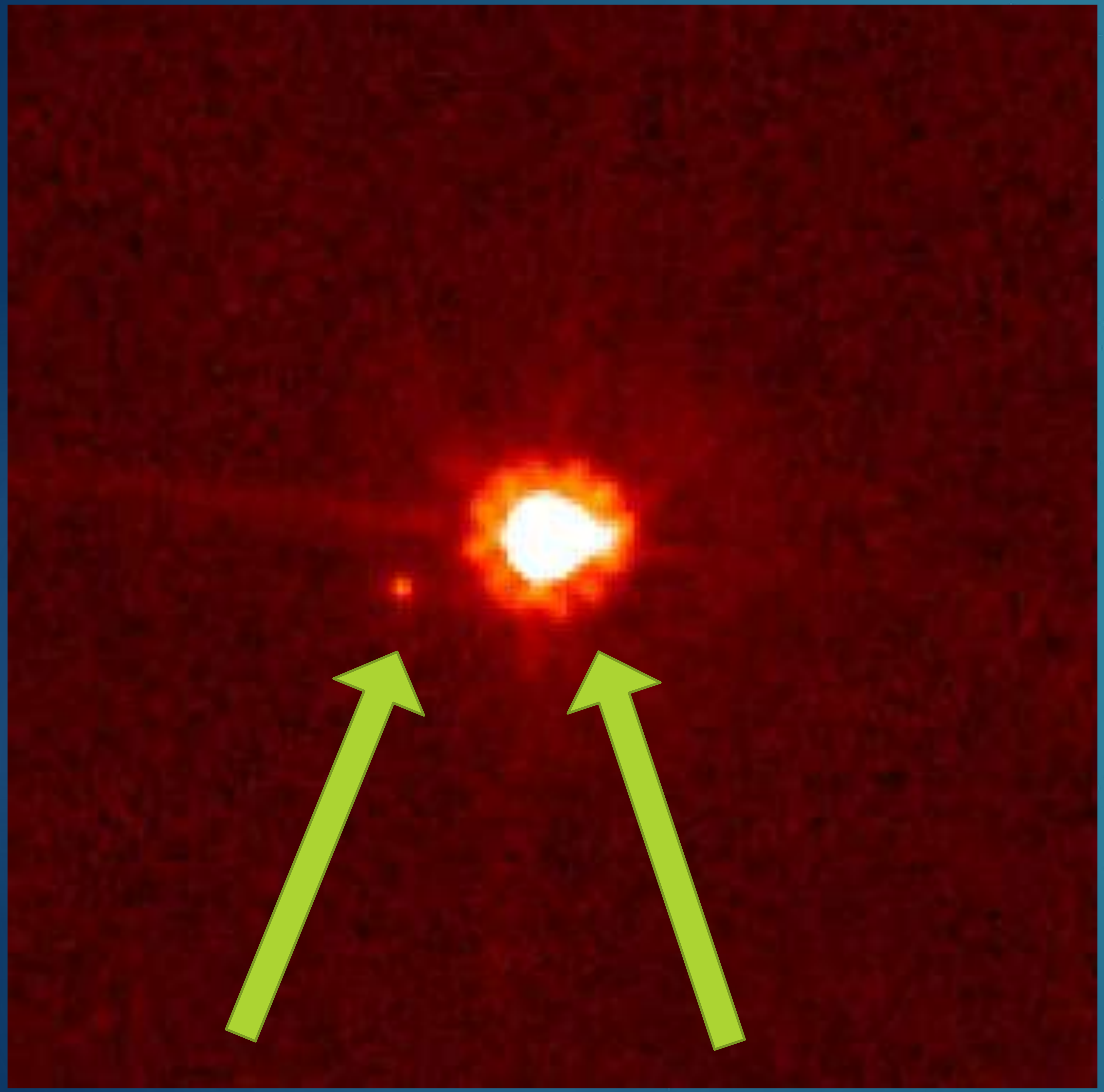


Pluto
Radius: 1188 km

Charon
Radius: 606 km

Trans-Neptunian Objects (TNOs)

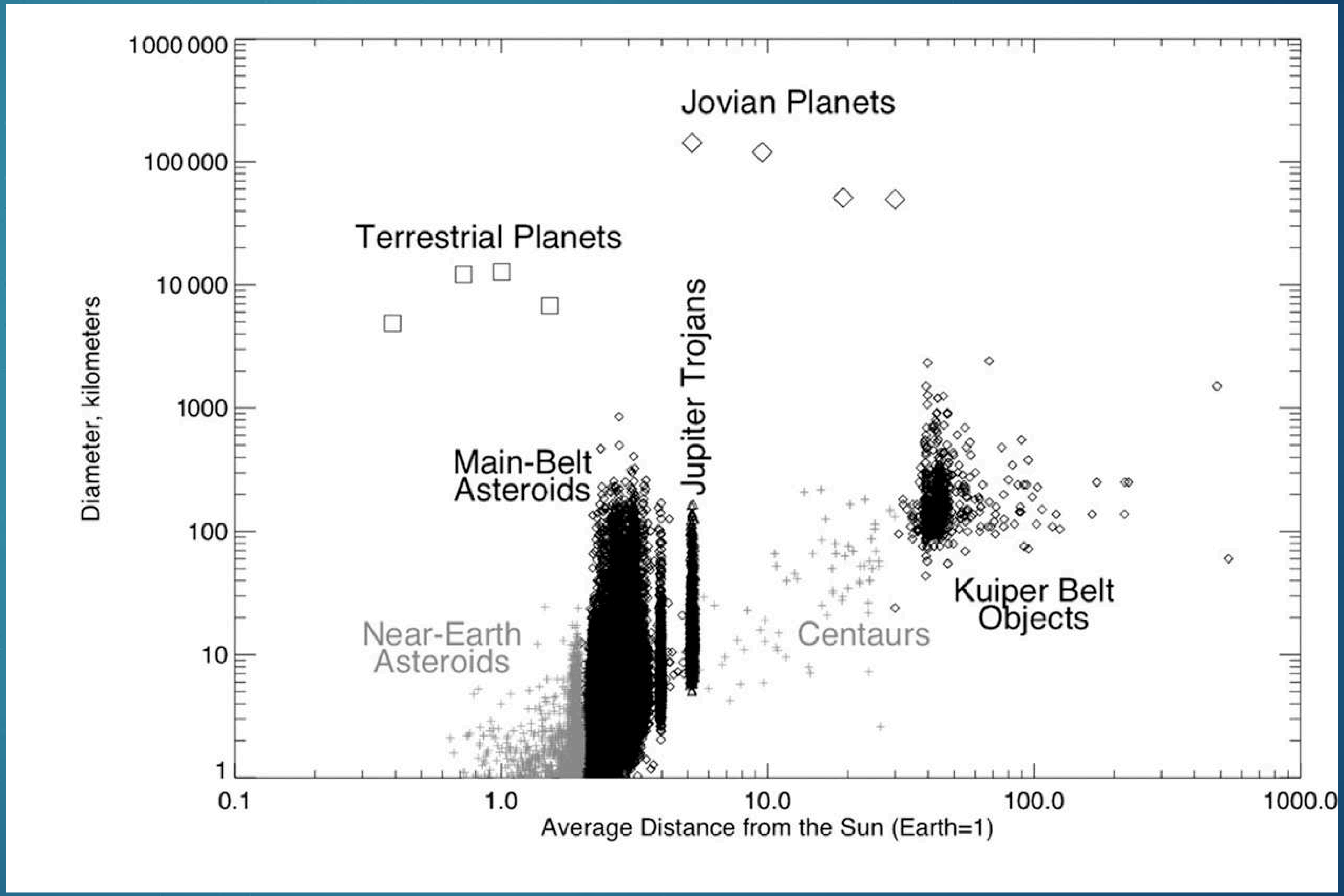
Eris and Dysnomia



Dysnomia
Radius: 1163 km

Eris
Radius: 473 km

Main-Belt Asteroids: the dwarf planet, Ceres



Ceres
Radius: 473 km

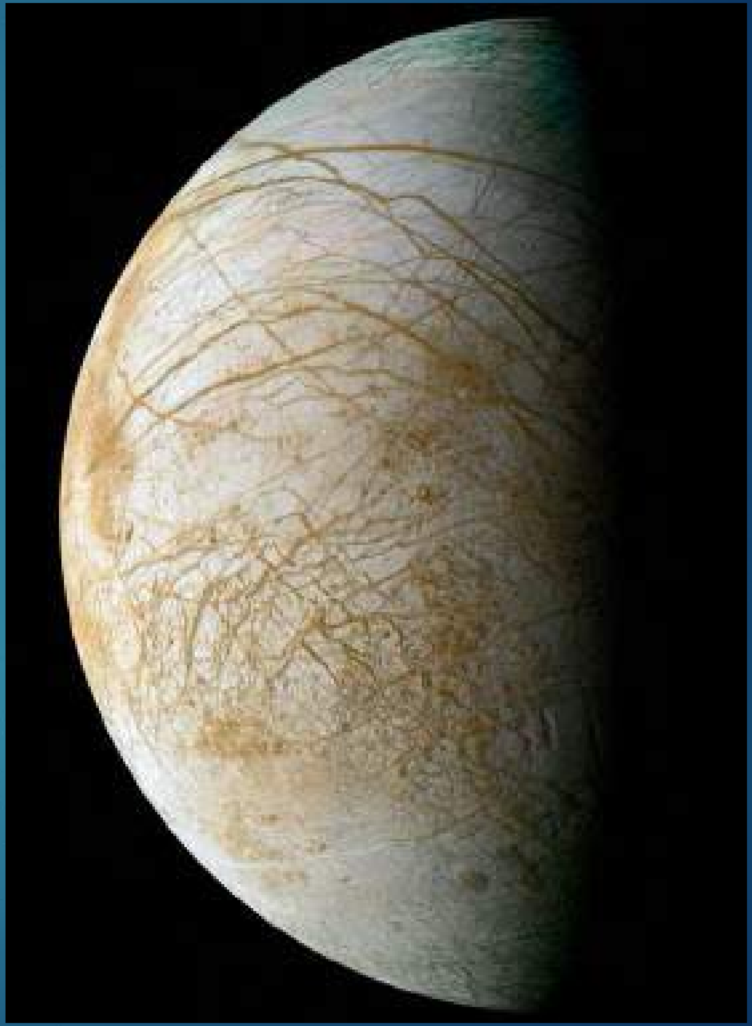
Co-funded by the
ERASMUS + Programme
of the European Union

Geology of Europa

G. CHIAROLANZA

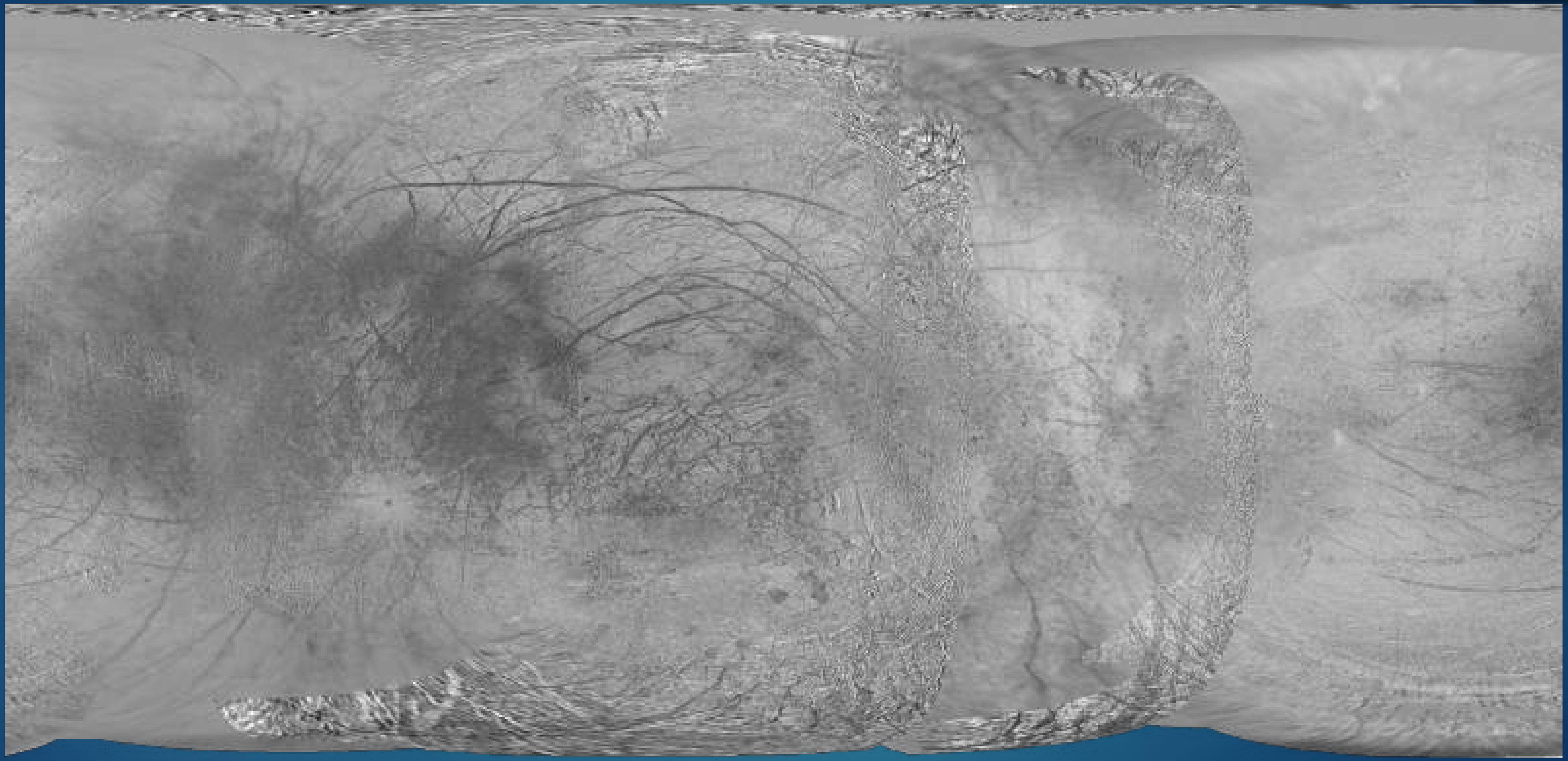
Europa: facts and figures

Name of Satellite	Europa
System	Jupiter
Mean distance from Sun	778,000,000 km (5.2 UA)
Semi-major axis	671,000 km
Mean Radius	1,560.8 km
Density	3.013 g/cm^3
Atmosphere	O_2
Surface Pressure	0.1 µPa (10^{-12} bar)
Surface temperature (mean)	102 K (-171,15 °C)
Internal structure	Icy Crust Liquid water global ocean Silicate Mantle Metallic Core ?



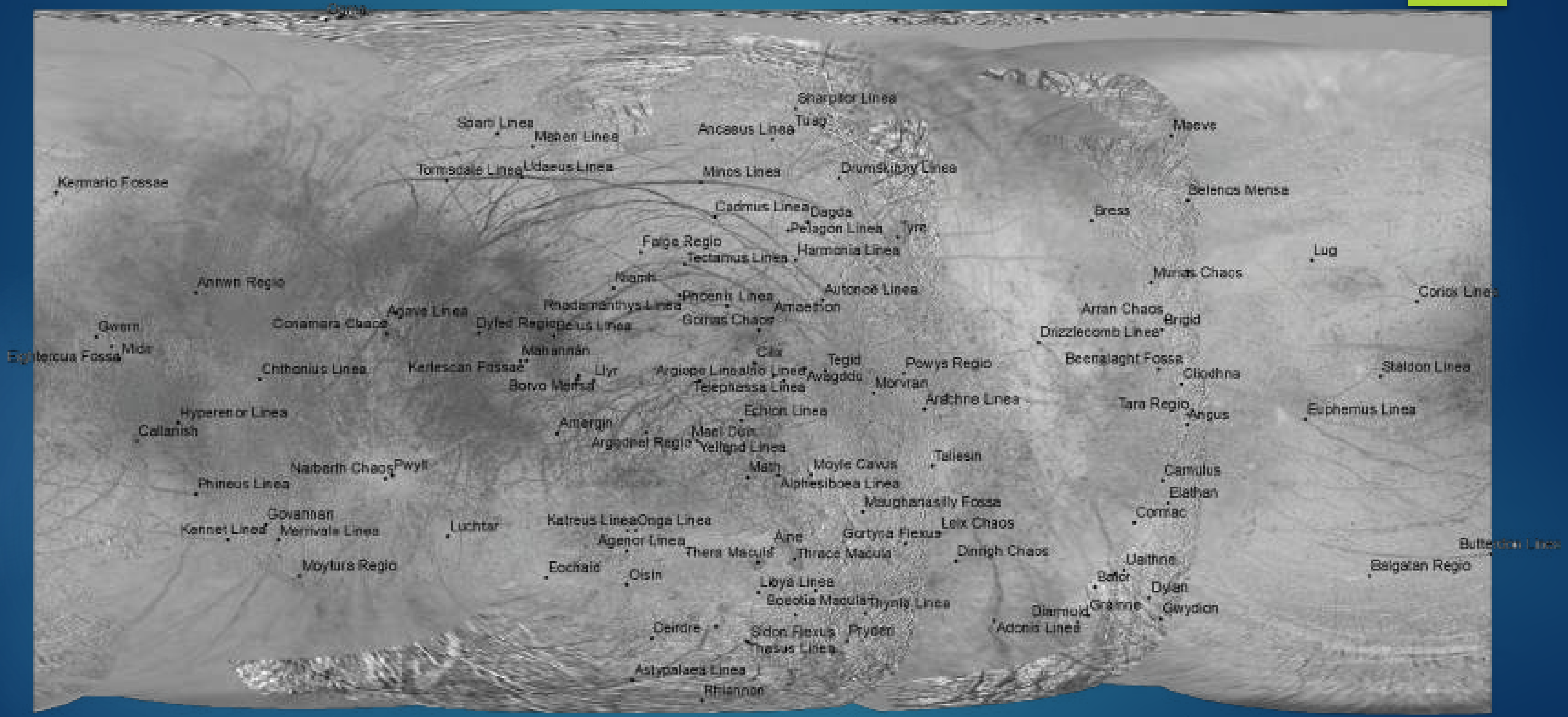
Europa. *NASA / JPL-Caltech / Ted Stryk*

Global view of Europa



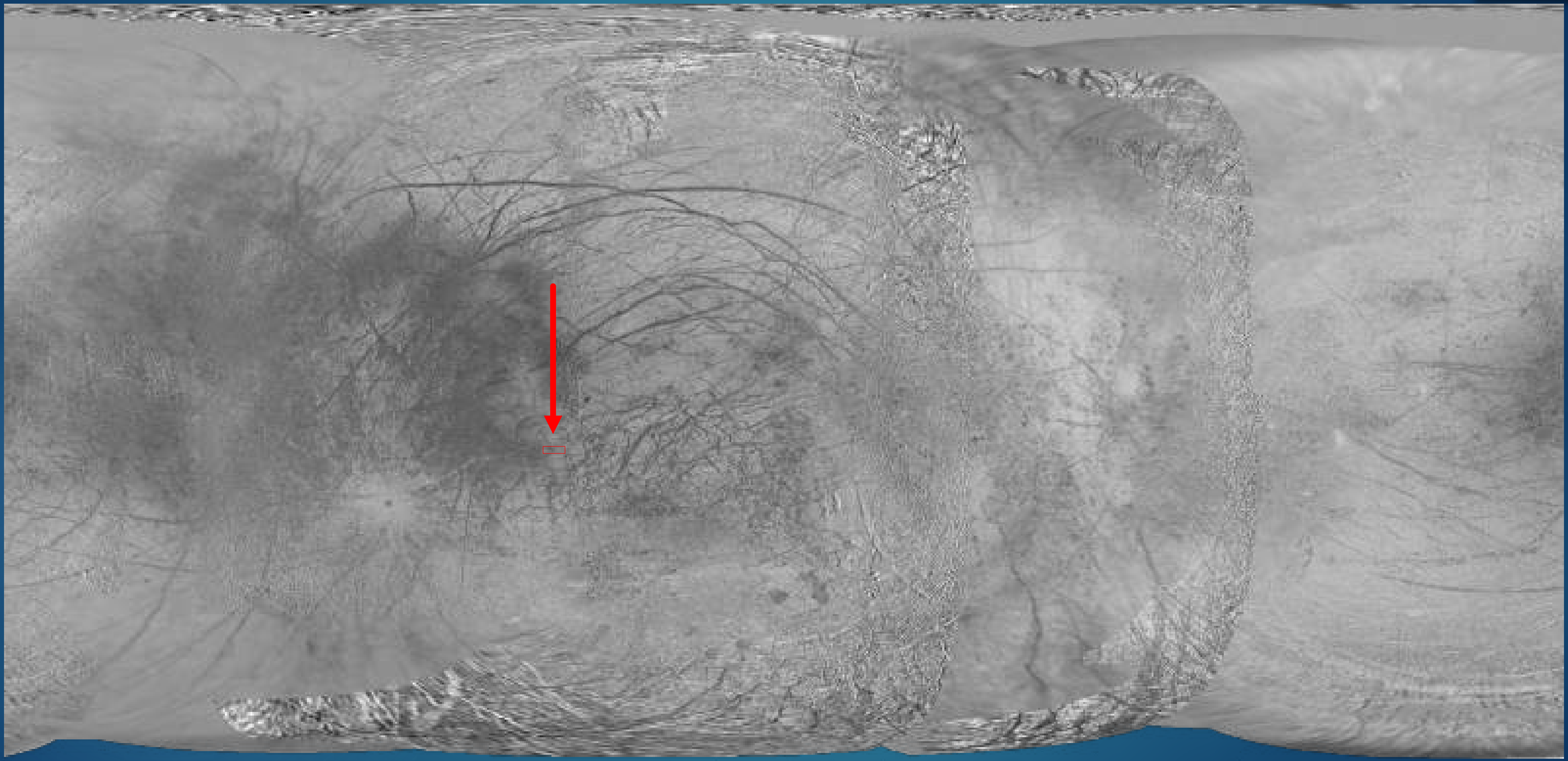
Europa Voyager - Galileo SSI Global Mosaic 500m v2. Source: *astrogeology.usgs.gov*

Global view of Europa



Source: *astrogeology.usgs.gov; International Astronomical Union (IAU) Working Group for Planetary System Nomenclature (WGPSN)*

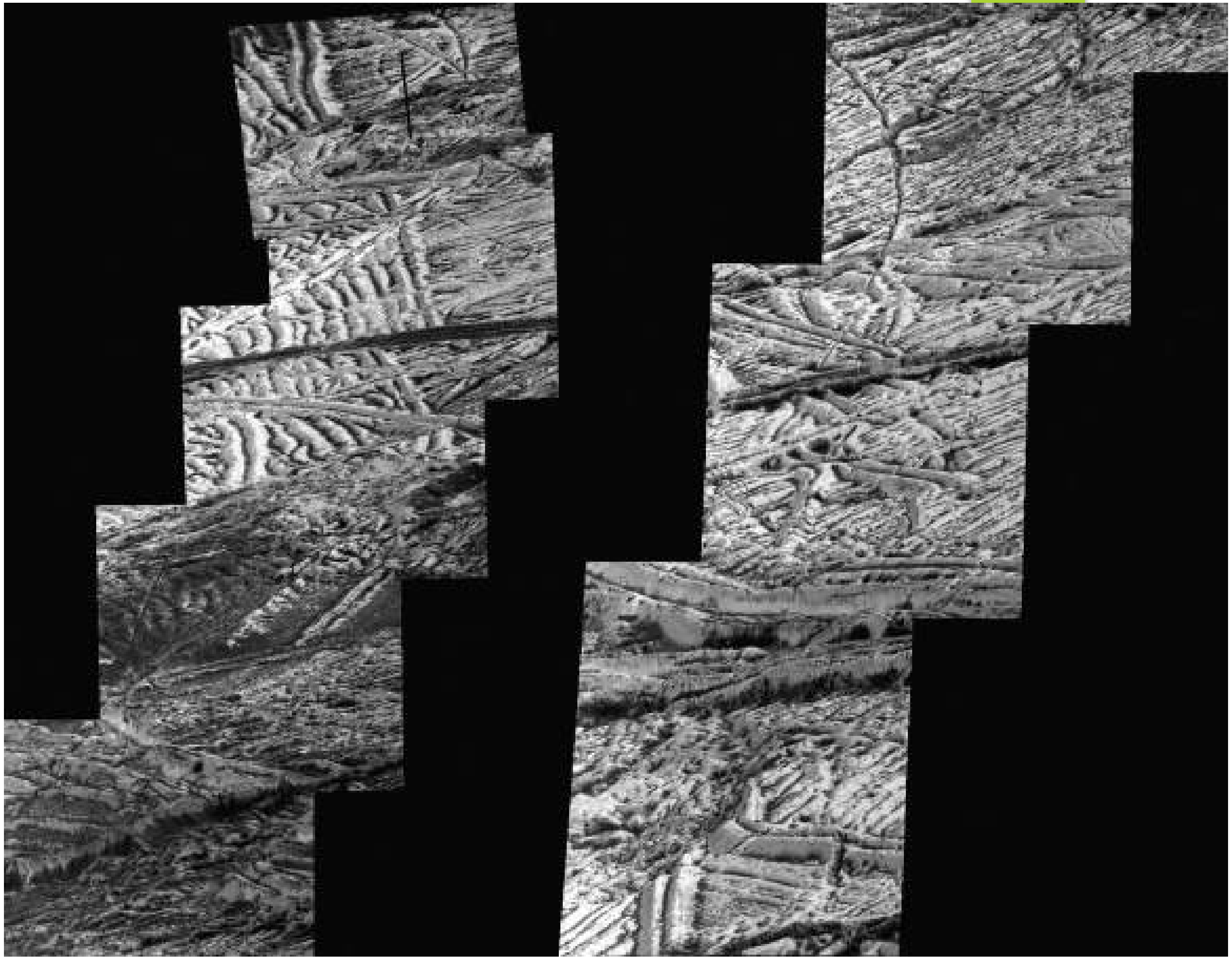
Global view of Europa



Source: *astrogeology.usgs.gov; International Astronomical Union (IAU) Working Group for Planetary System Nomenclature (WGPSN)*

Close-up of Europa's surface

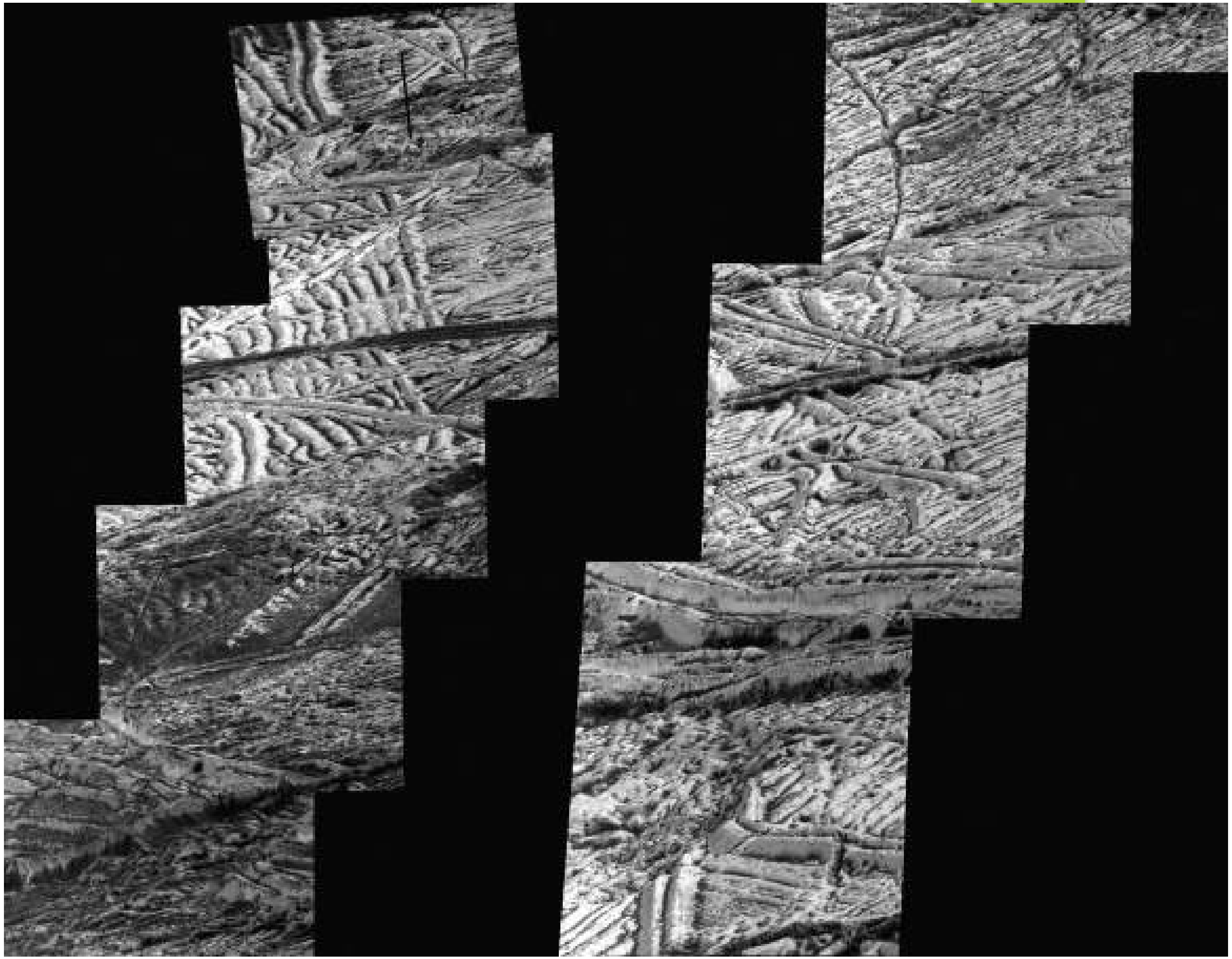
- The most detailed view of the surface obtained by NASA's Galileo mission.
- Numerous, local-scale features can be observed:



Galileo observation 12ESMOTTLE. Spatial resolution: 6-12 m/p. Source: *jpl.nasa.gov*

Close-up of Europa's surface

- The most detailed view of the surface obtained by NASA's Galileo mission.
- Numerous, local-scale features can be observed:
  - Ridged terrains
  - Double ridges
  - Troughs
  - Smooth terrains
  - Talus deposits
  - Fragmented blocks
  - Craters

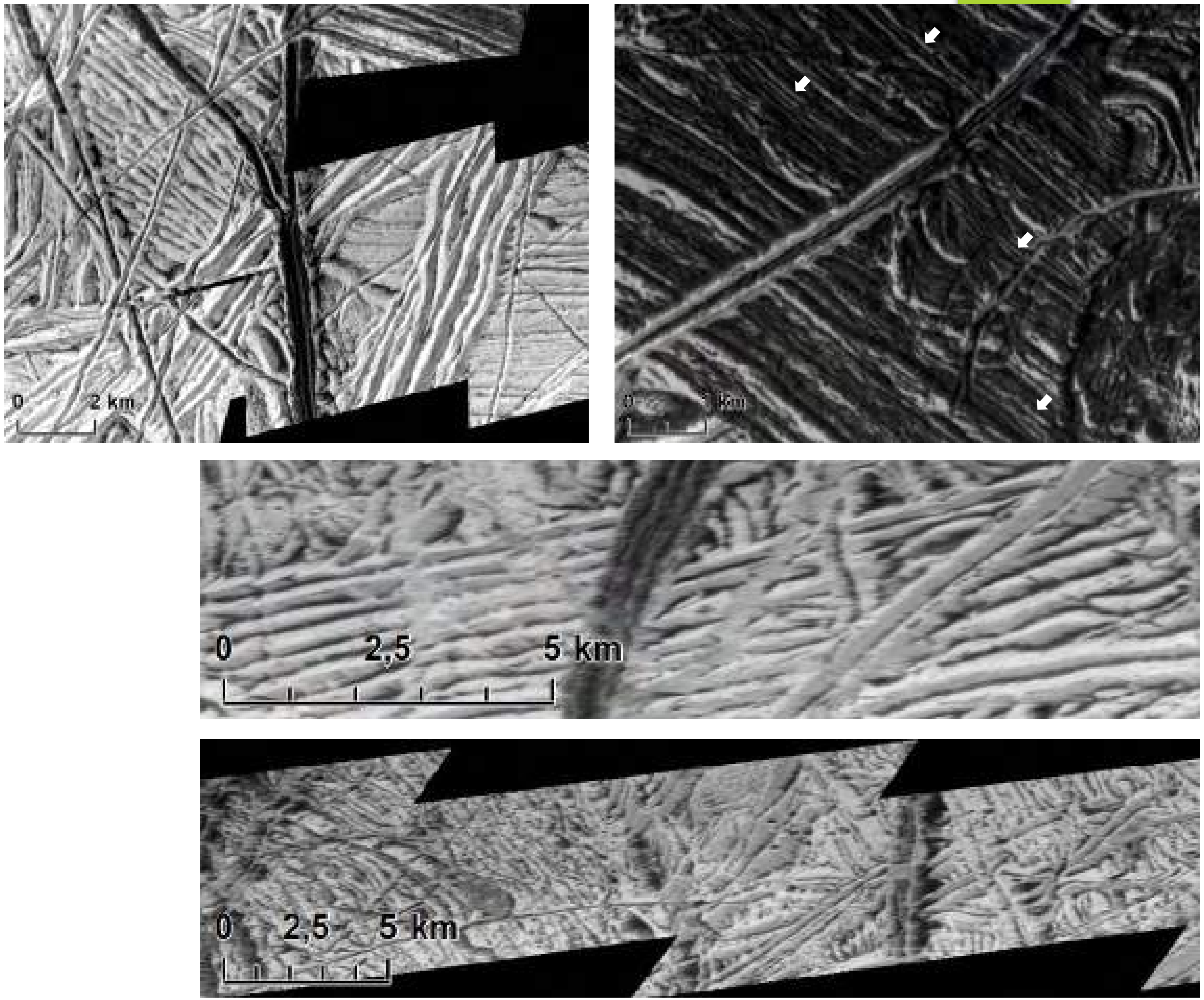


Galileo observation 12ESMOTTLE. Spatial resolution: 6-12 m/p. Source: *jpl.nasa.gov*

Material units

Ridges

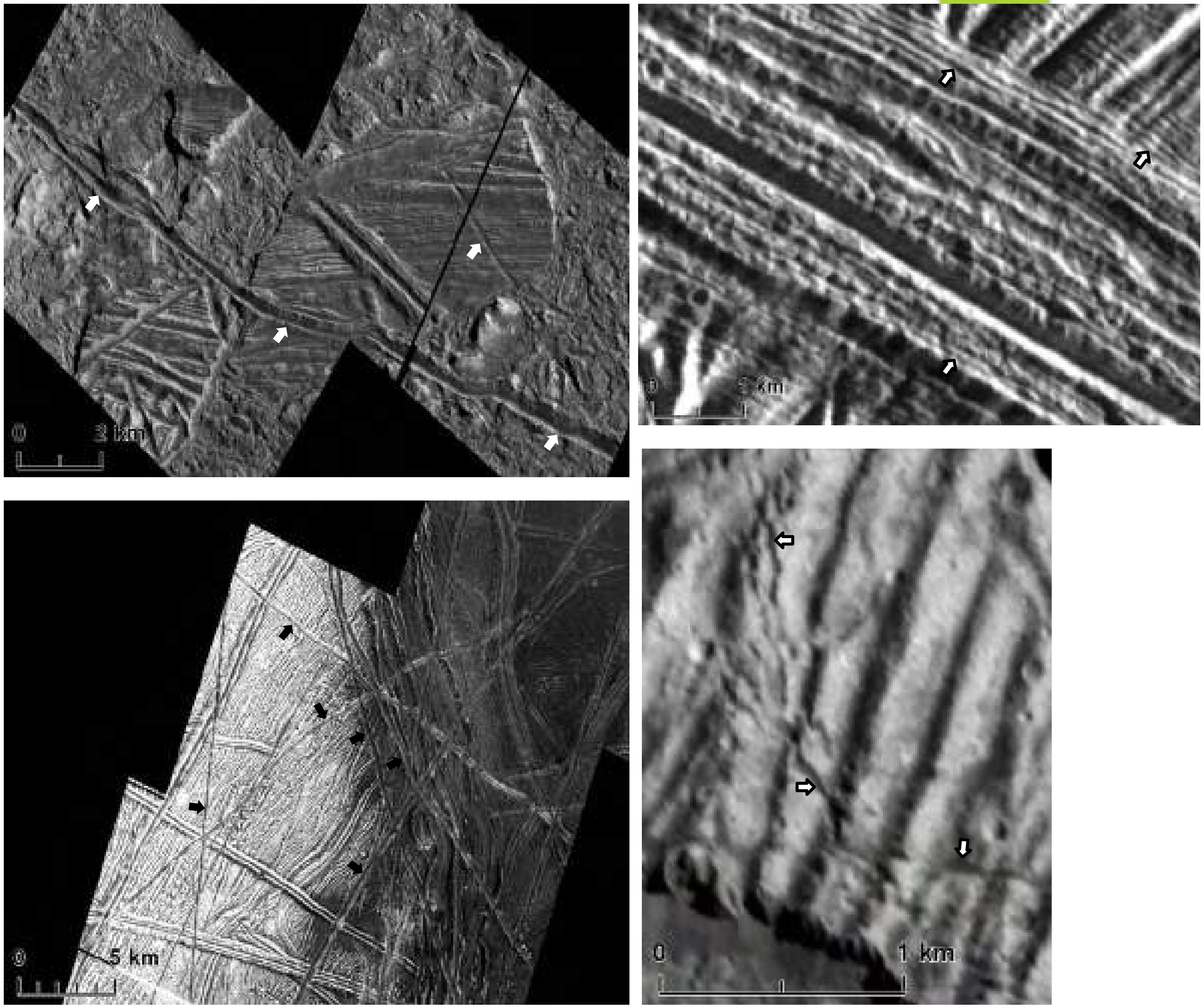
- The most recurring lineaments on Europa.
- **Topographically**, ridges range from barely perceptible to as high as several hundred meters (*Malin and Pieri*, 1986; *Greenberg et al.*, 1998; *Greeley et al.*, 2000).
- Widths range from several tens of meters to a few kilometers (<5 km, *Coulter et al.*, 2009).
- Based on their size and pattern, they range from narrow, slightly raised lineaments up to well-developed ridges; the latter can be arranged in sets of double or multiple ridges.



Galileo observations 12ESWEDGE_01, 12ESWEDGE_02,12ESMOTTLE02

Cracks

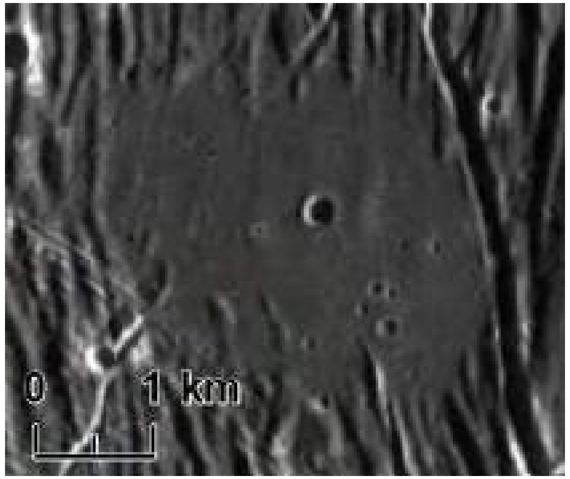
- Cracks are distinguished by the lack of raised edifices along their margins. Troughs are the most common types of cracks. Fractures and furrows are also present.
- **Troughs** are often considered the progenitor of ridges. Troughs with slightly-raised edifices along their margins (half-way between a simple fracture and a double ridge) are referred to as ***raised-flank troughs*** (*Geisseler et al.*, 1998; *Head et al.*, 1999)
- The majority of tectonic features begin as tension fractures represented by troughs; thus, they are often the **youngest** tectonic features based on crosscutting relationships
- **Depth** goes from **~65 m** (*Hoppa et al., 1999*) up to **10 km** (*Golombek and Banerdt, 1990; Leith and McKinnon, 1996; Lee et al., 2005; Panning et al., 2006; Qin et al., 2007*)
- **Furrows** form closely-packed sets with subparallel orientation, whereas **fractures** are small cracks that branch out forming irregular patterns.

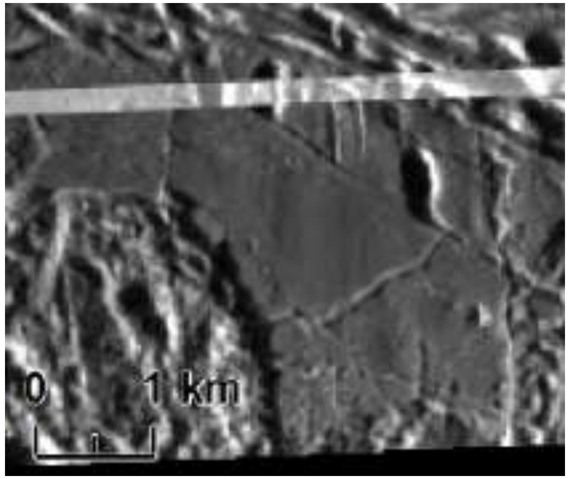


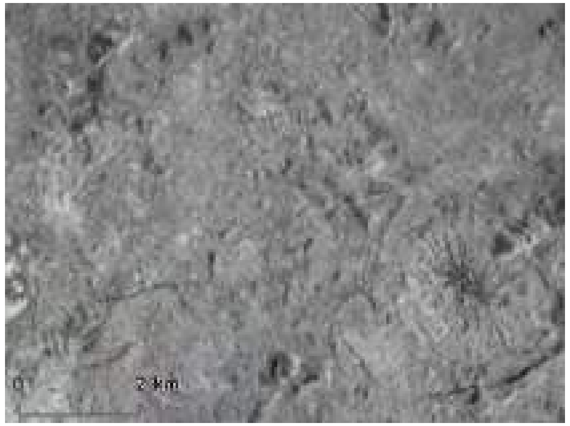
Troughs (top and bottom left), raised-flank troughs (bottom left), furrows (top right), and fractures (bottom right). Galileo observations 12ESMOTTLE01, 17ESTHYLIN01, 17ESNERTRM01

Smooth Terrains

- Terrains characterized by **smooth** to slightly hummocky texture.
- Brighter deposits usually characterize the smooth central units (cs) and the continuous ejecta unit (ce) of multi-ring features and large impact craters.



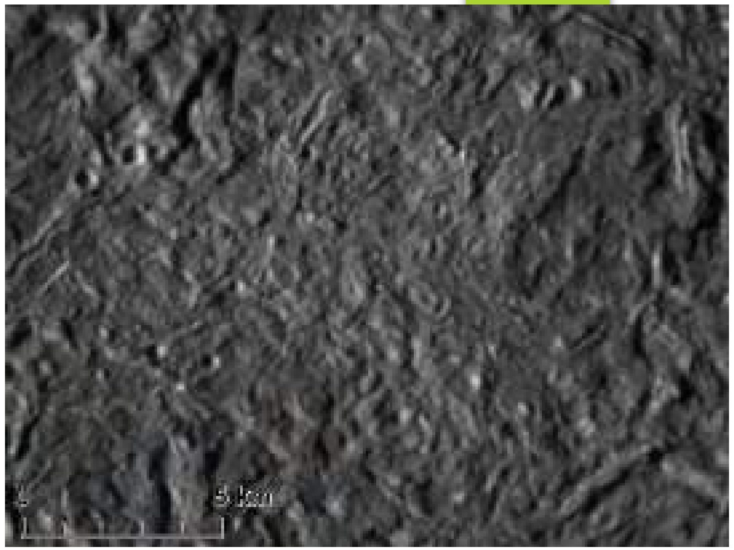
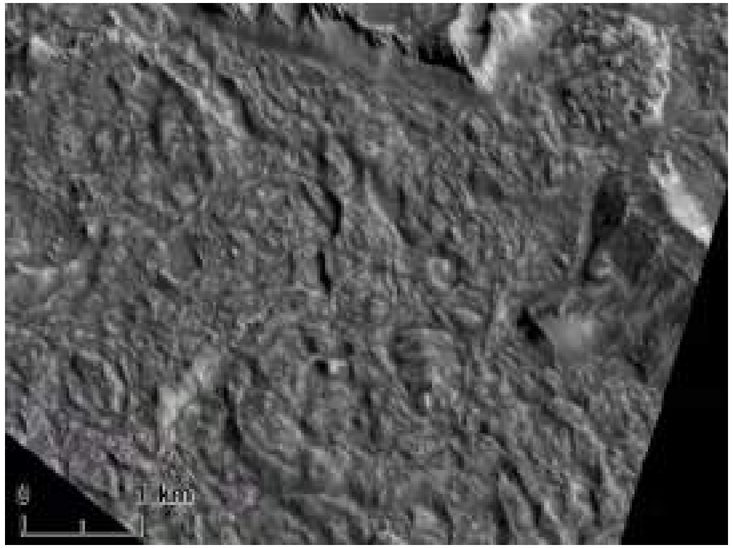


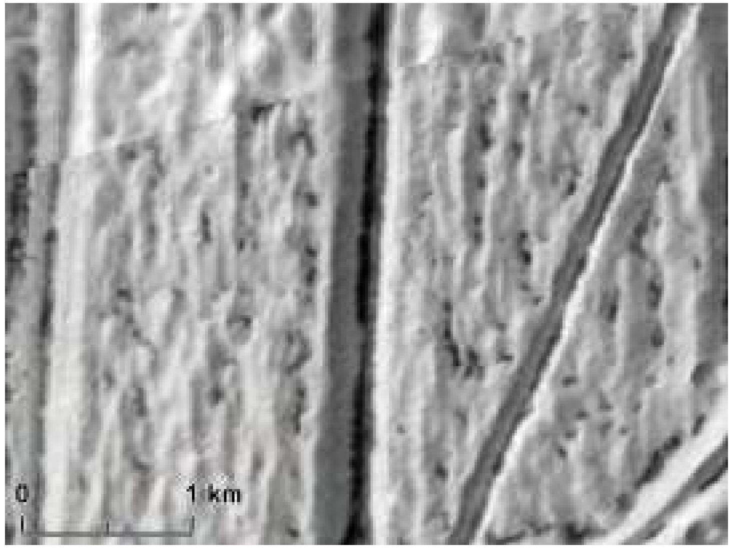


Galileo observations E4ESDRKMAT02, 14ESDRKSPT01, 14ESCRATER02

Hummocky terrains

- **Hummocky terrains** are composed of ice blocks and hillocks with no apparent orientation or order, ranging in size from a few hundred to a thousand meters across.
- Can be found on a variety of different terrains, including chaos, bands, and complex crater subunits.

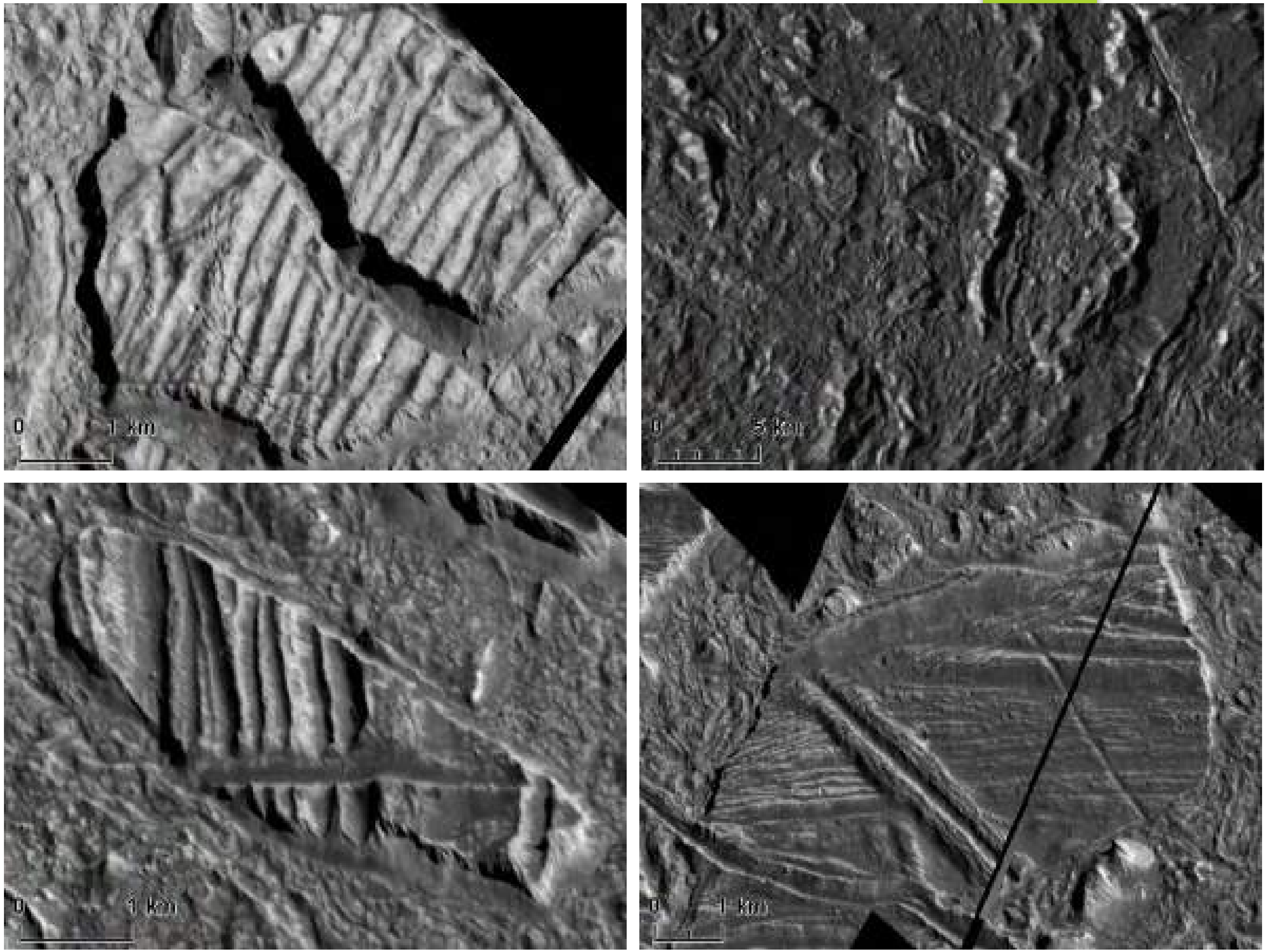





Galileo observation 12ESCHAOS_01, 26ESTERMIN01

Blocks

- **Plates** and slabs are blocks of preexisting terrain, up to 20 km in diameter. Their boundaries can be represented either by steep scarps (few hundreds of meters in height) or by gentle slopes. Dark talus deposit can accumulate at their base.
- Smaller blocks in which preexisting structures cannot be distinguished are termed **knobs**.

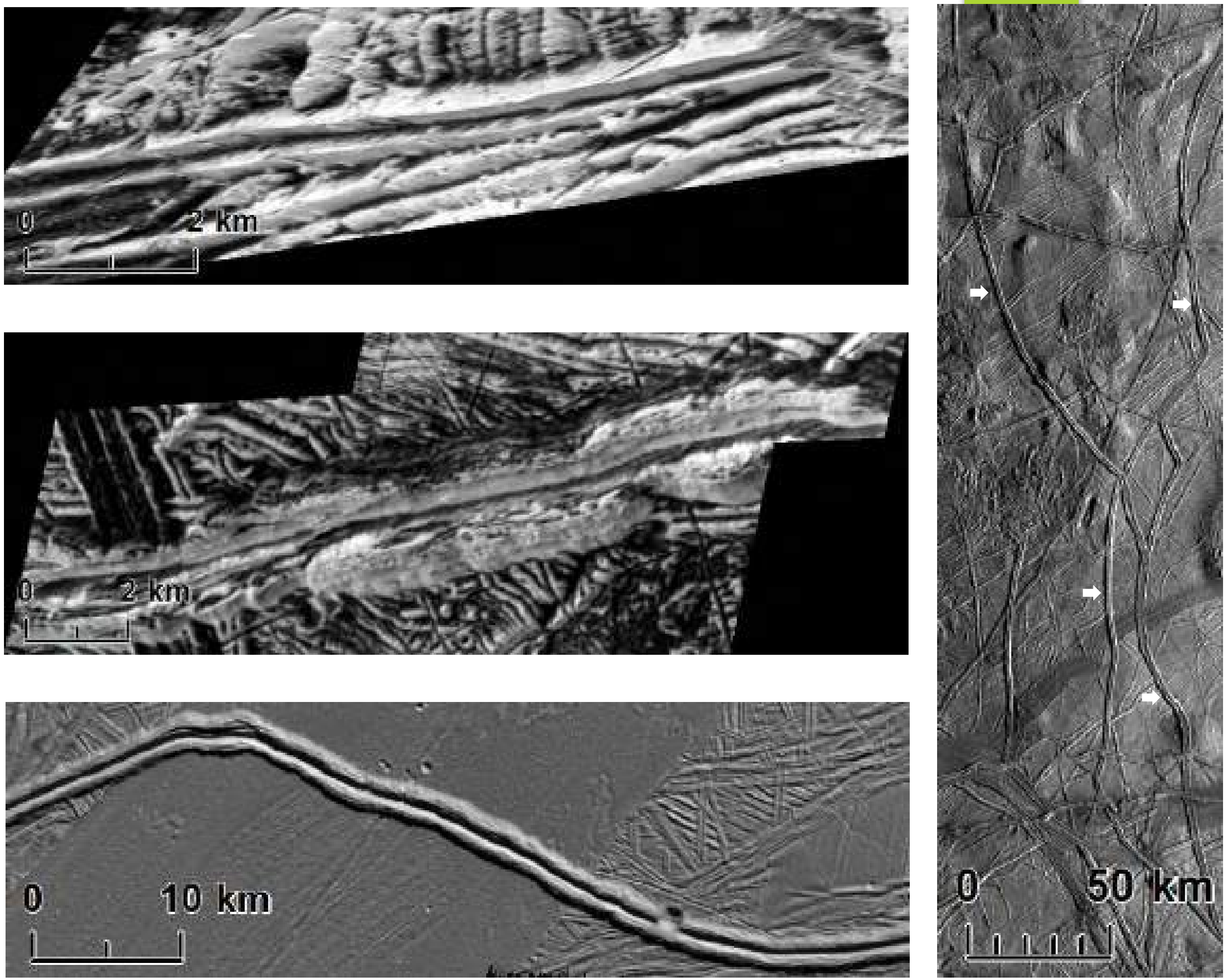


Galileo observation 12ESCHAOS_01, 26ESTERMIN

Surface Feature Types

Double Ridges

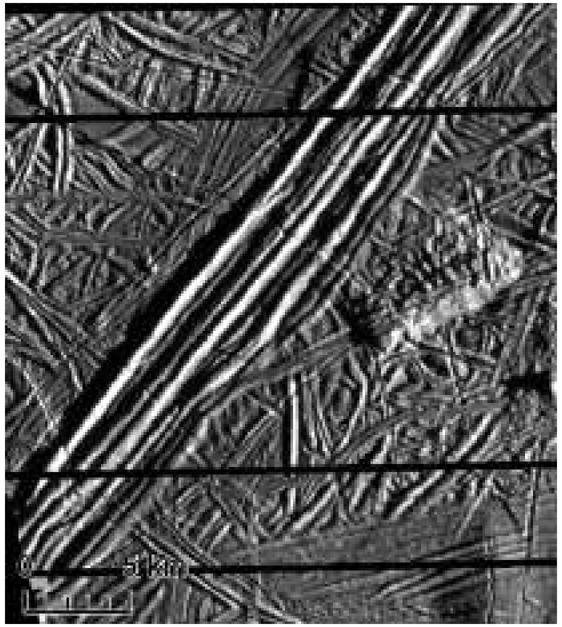
- A central elongated crack flanked by two subparallel and almost symmetric raised edifices
- Can range in width from ~200m to >4 km.
- Can extend from a few kilometers to in excess of 1000 km (*Greeley et al.*, 2000).
- Ridge crests may contain small-scale, ridge-parallel faulting.
- Inner slopes relatively straight (V-shaped).
- Flanks commonly mantled by continuous deposits of dark material, with signatures of mass wasted debris (*Head et al.*, 1999).
- Usually show evidence of strike-slip motion



Galileo observations 12ESMOTTLE01, 17ESTHYLIN01, 17ESNERTRM01

Ridge Complexes

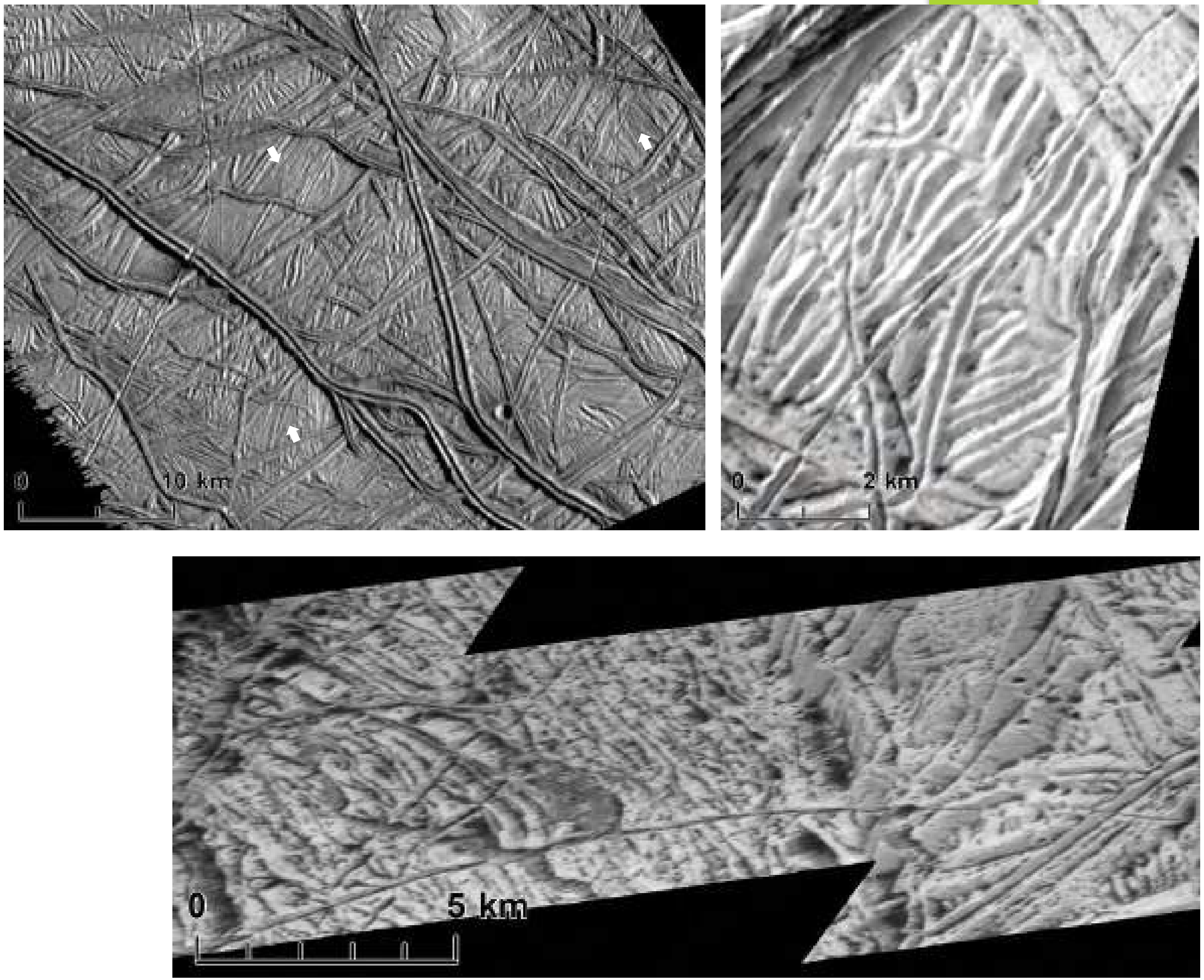
- **Complexes** of several, subparallel, commonly braided/anastomosing single or double ridges, up to 15 km wide (*Greenberg et al.*, 1998)
- Linear to sublinear trends, no bilateral symmetry, sinuous to undulating margins.
- Bright with flanking dark stripes in low-resolution images.
- Ridges and sets of ridges can split away from the main trend of the complex (*Figueredo and Greeley*, 2000)



Galileo observations 12ESWEDGE_01, E6ESBRTPLN01, 19ESRHADAM01

Ridged Plains

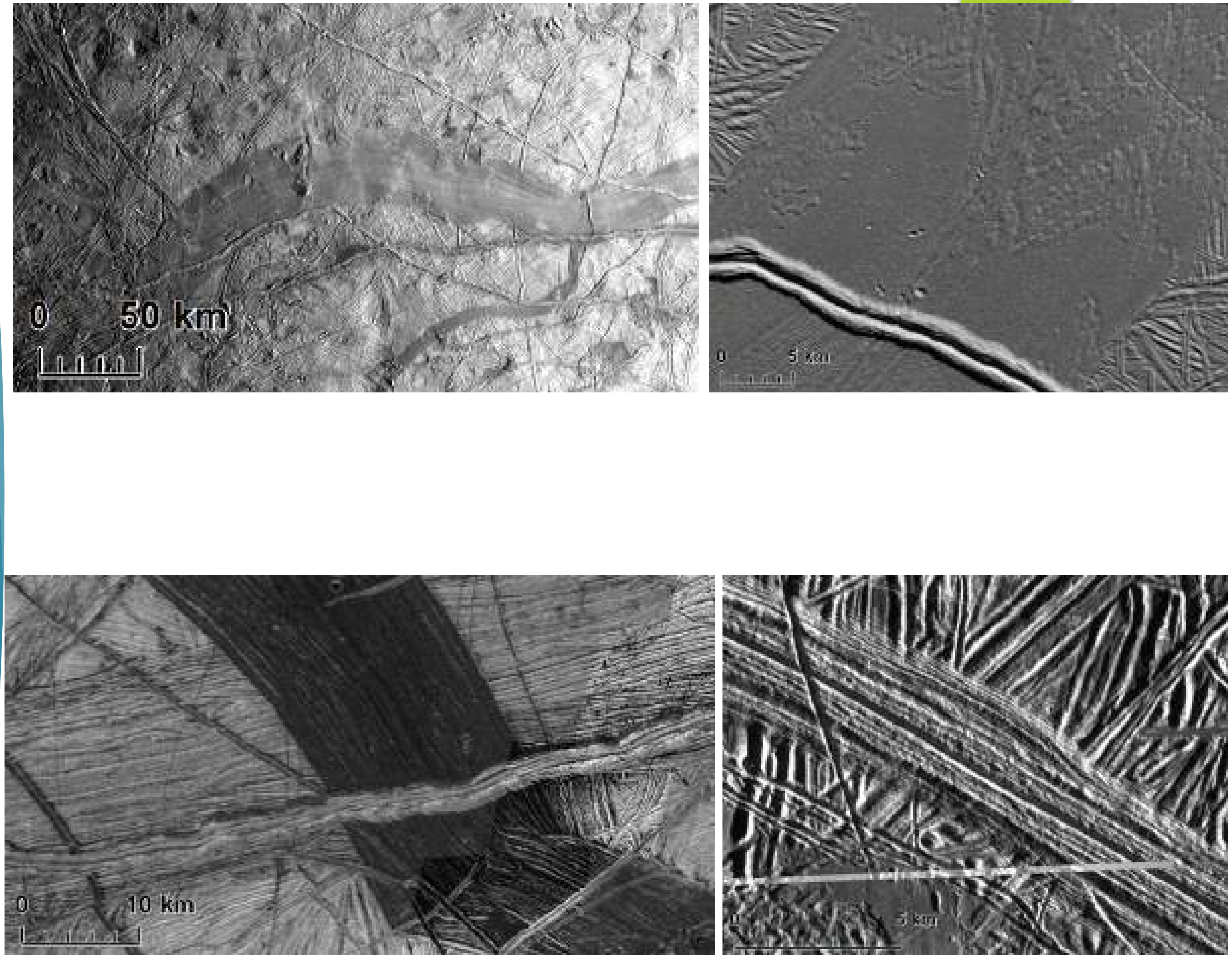
- A major unit composed of multiple, different features such as **ridge and trough** terrains (*Patel et al.*, 1999), double ridges, ridged bands, ridge complexes.
- The inner ridged structures exhibit a wide variety of patterns and orientations, and they are often overprinted by younger features, making this plains stratigraphically **old**.
- At low resolutions, they are normally mapped as undifferentiated plains



Galileo observations 17ESDISSTR01, 12ESWEDGE_02, 12ESMOTTLE02

Dilational Bands

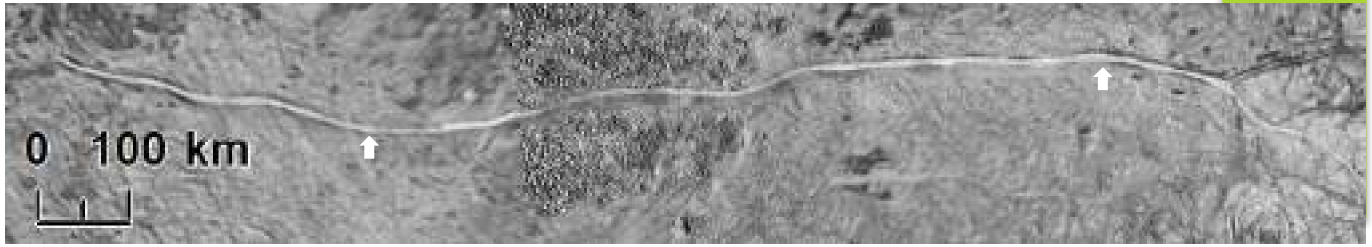
- Tabular zones of **new crustal material** that intruded between the walls of a tension fracture
- Can be up to 200 m in height, 30 km in width, and hundreds of km in length (*Prockter et al.*, 1999 & 2002; *Nimmo et al.*, 2003; *Billings and Kattenhorn*, 2005; *Stempel et al.*, 2005)
- Represent evidence of **dilation** in the icy shell (also referred to as pull-apart bands), analogously to terrestrial mid-ocean ridges.
- Initially dark (youngest), they tend to brighten with time.
- Two main types: lineated bands and smooth bands.
  - **Lineated bands** are further distinguished into ridged bands and faulted bands
  - **Smooth bands** appear as such at low resolution, but hummocky at higher resolution

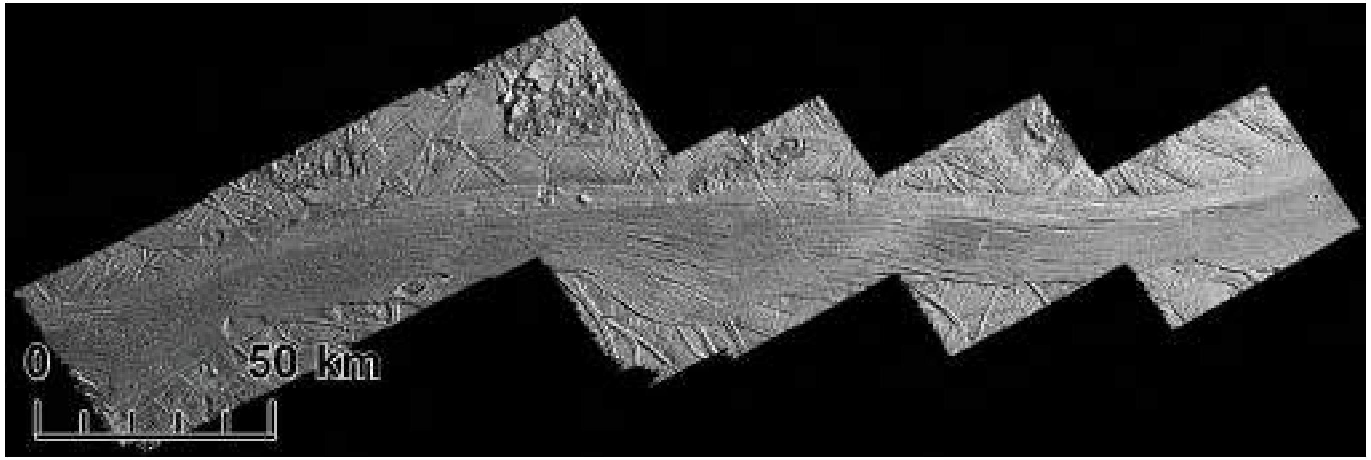


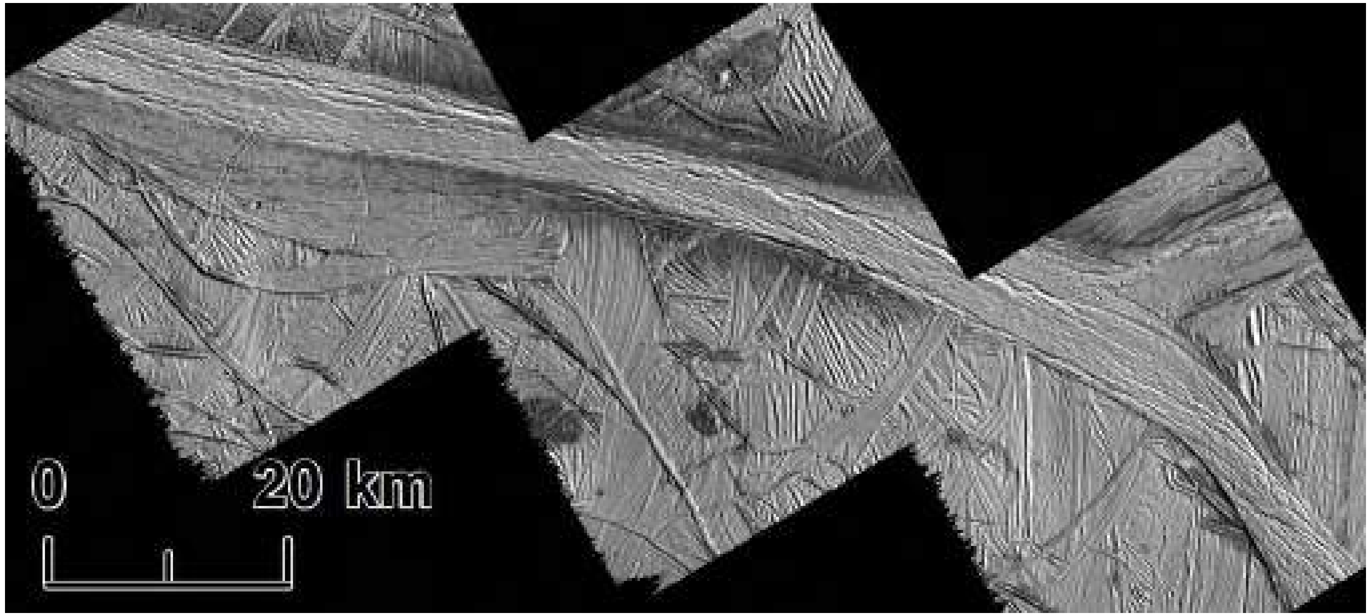
Smooth bands (top), ridged bands (bottom left), faulted band (bottom right.) Galileo observations 11ESREGMAP01, 12ESWEDGE, E4ESDRKMAT02, 17ESTHYLIN01

Bright Bands

- Tabular, linear features characterized by high relative albedo and usually lineated texture, up to 1500 km in length.
- Surface characterized by strike slip duplexes, *en echelon* structures and tailcracks (*Prockter et al.*, 2000).
- Complex origin characterized by successive periods of deformation involving transtension, transpression, and possibly cryovolcanism.



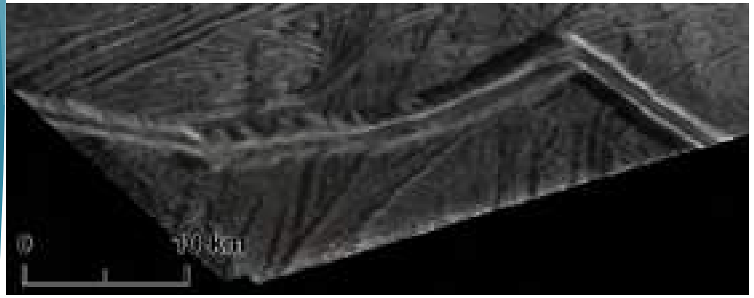


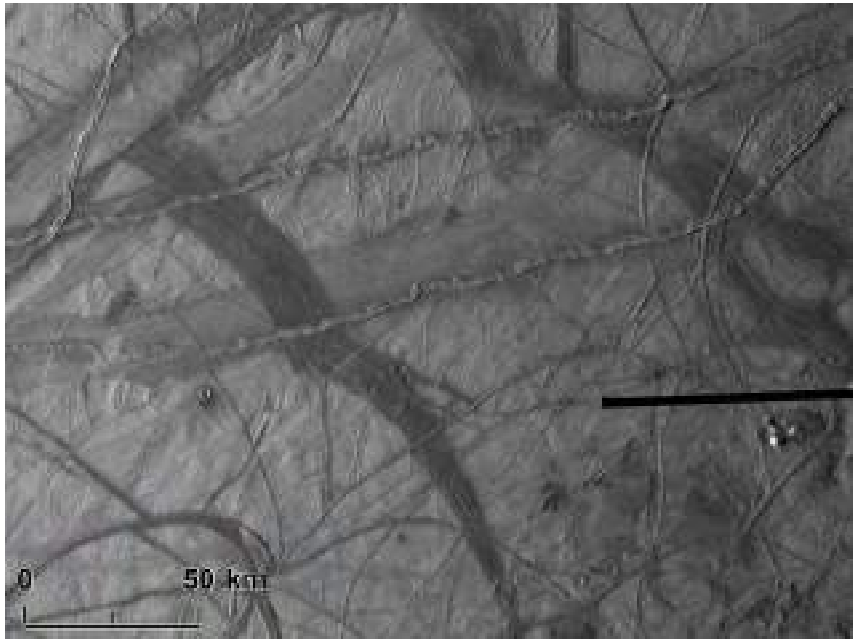


Galileo observations 14ESGLOCOL01, 17ESAGENOR03

Cycloids

- Curved, linear features linked at a cusp, forming chains of multiple concatenated arcuate segments. Also called flexus (pl. flexūs)
- Can extend for hundred to thousands of km.
- Can be constituted by a fracture, a double ridge, or a dilational band.
- May form as a result of tensile cracking in response to diurnally varying tidal stresses produced by Europa's orbital eccentricity (*Hoppa and Tufts*, 1999; *Hoppa et al.*, 1999).

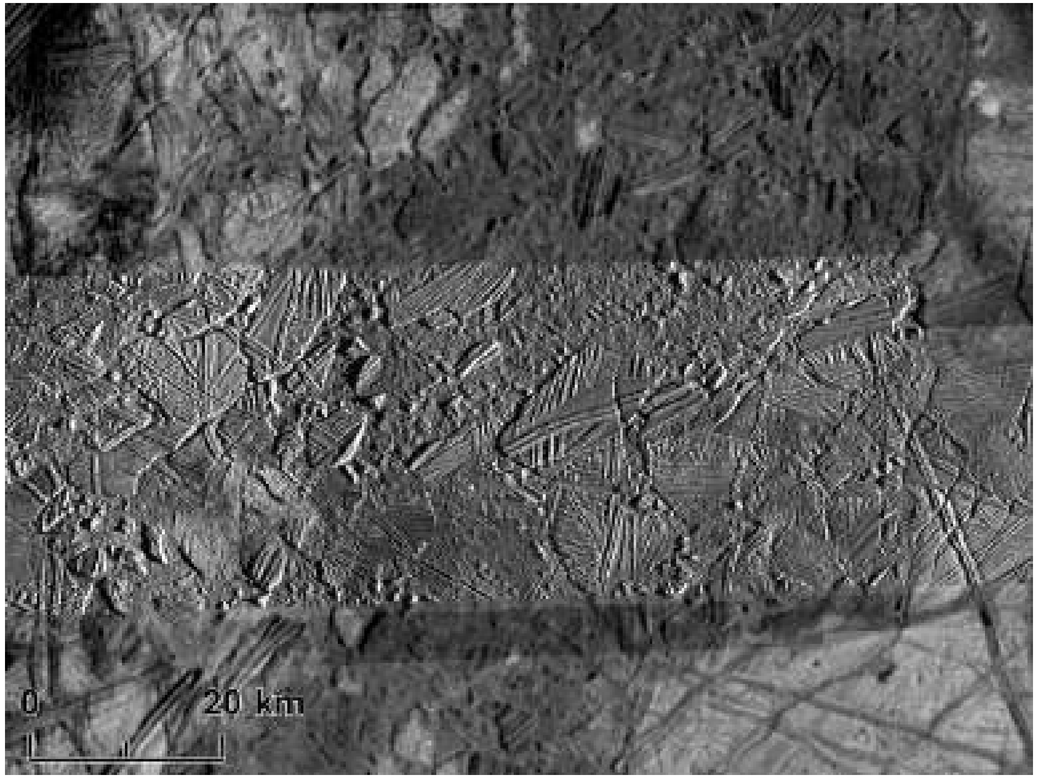


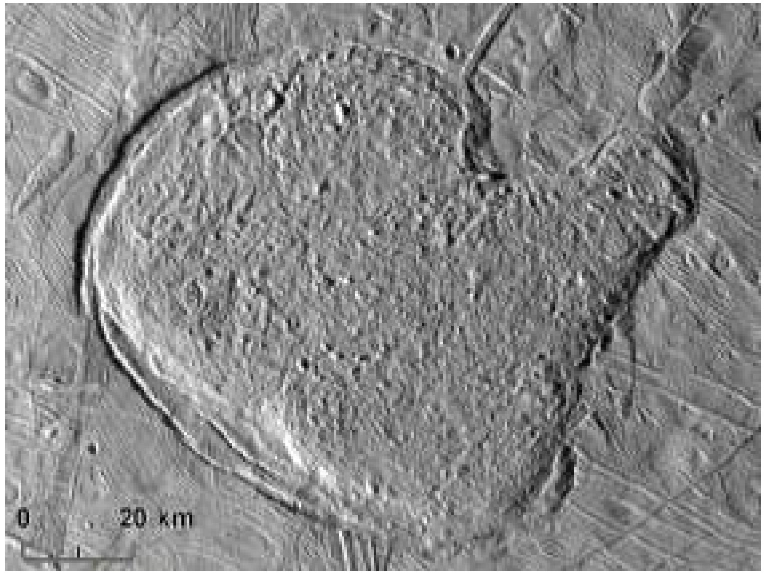


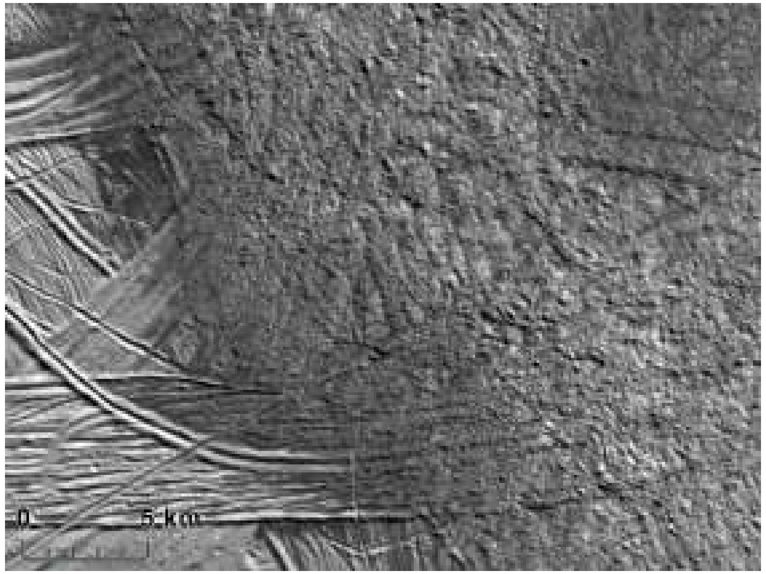
Galileo observations 15ESREGMAP, 19ESCOLOR_02, C3ESWEDGES01

Chaos

- Areas of broken terrain, consisting of polygonal blocks of ridged plains within a matrix of hummocky material that replaced pre-existing terrain (*Carr et al.*, 1998; *Spaun et al.*, 1998).
- Boundaries can be either gradual or abrupt if delimited by steep scarps.
- Matrix is formed by subkilometer-sized ice blocks with no regular pattern. Texture is normally hummocky, though smooth matrix also occurs.
- Plates can shift and rotate, similarly to terrestrial icebergs
- Based on the ratio between plates and matrix they can be divided into:
    - Platy chaos: composed of both plates and matrix.
    - Knobby chaos: mostly composed of hummocky matrix and few local knobs.
- Often covered by dark, reddish hydrated material.
- They cover 1/4 of Europa's surface



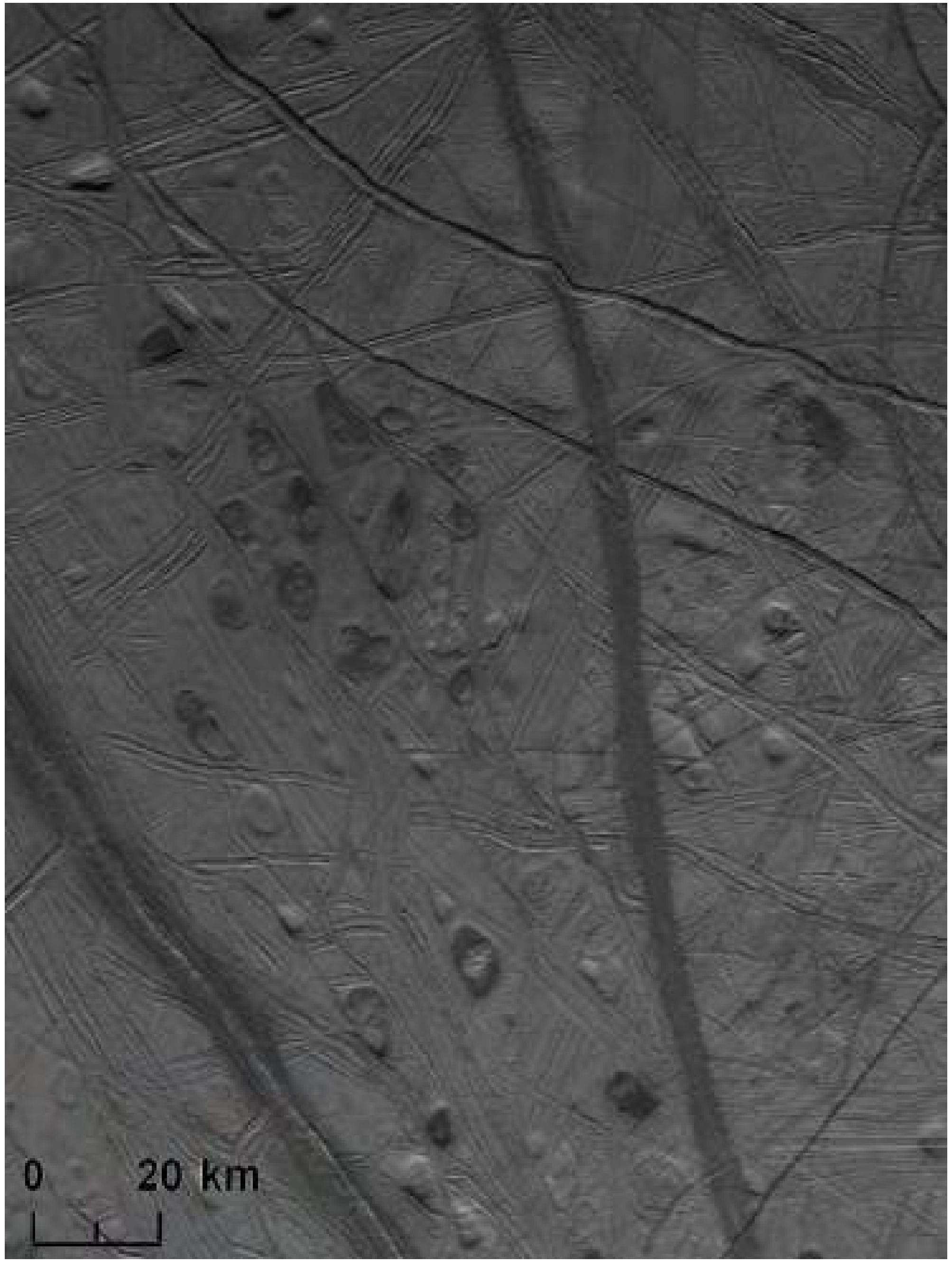




Galileo observations 12ESCHAOS_01, E6ESBRTPLN01, 12ESDKLNCL01, 15ESREGMAP02, 17ESTHRACE01

Lenticulae

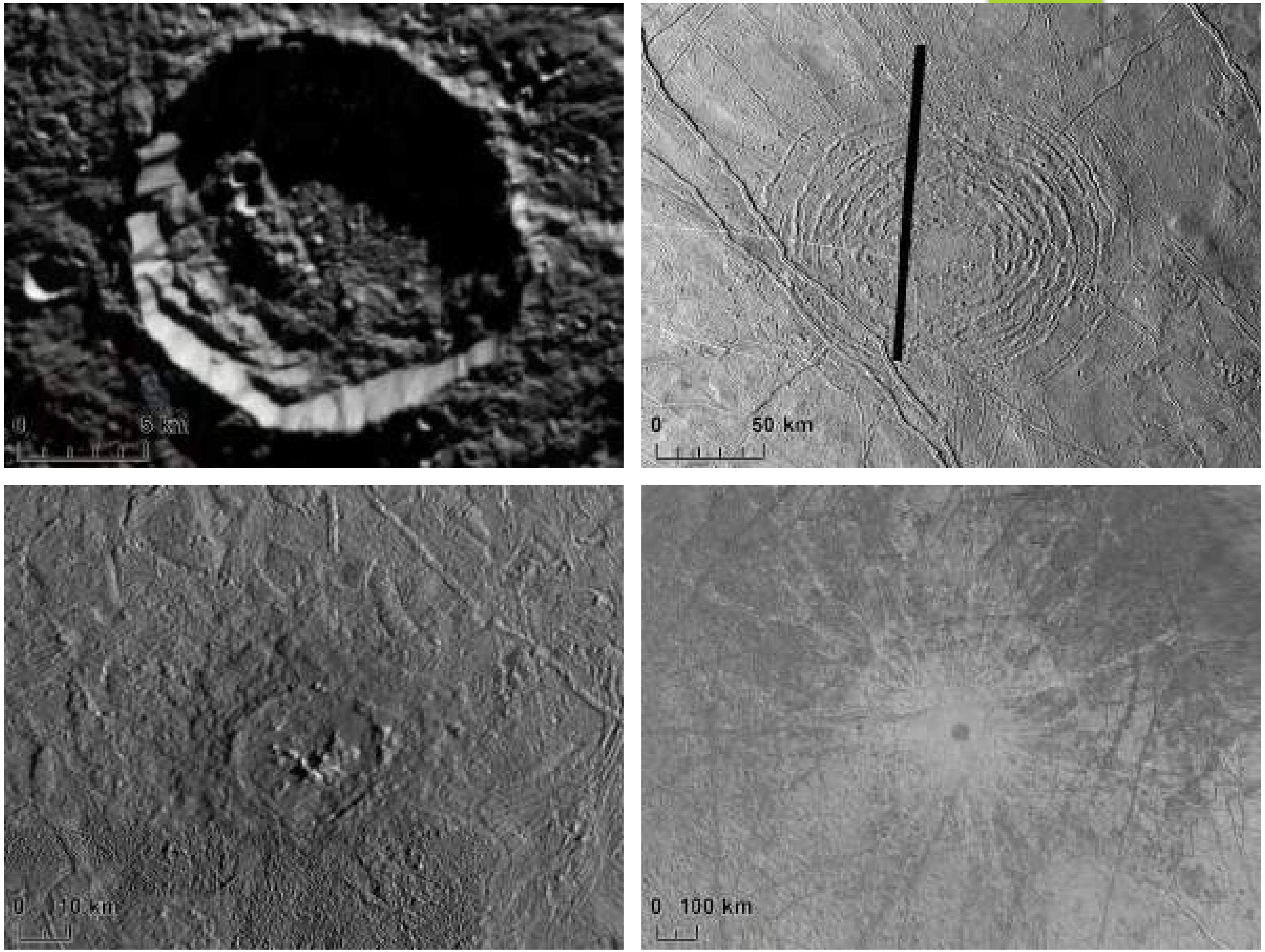
- Small spots, circular to elliptical in shape, tens to hundreds of meters in relief (*Pappalardo et al.*, 1998; *Spaun et al.*, 1998 and 1999; *Pappalardo and Barr*, 2004). Based on their topography they are classified as:
  - **Pits** (negative)
  - **Domes** (positive).
  - **Spots** (flat)
- Low-albedo lanticulae are constituted by chaos-like material (blocks, matrix), whereas non-dark lenticulae usually share the same higher albedo and geological structures of the surrounding terrain
- When forming denser associations, merged lenticulae are termed "microchaos" and form "lenticulated terrains", which also includes surrounding ridged plains.



Galileo observation 15ESREGMAP01

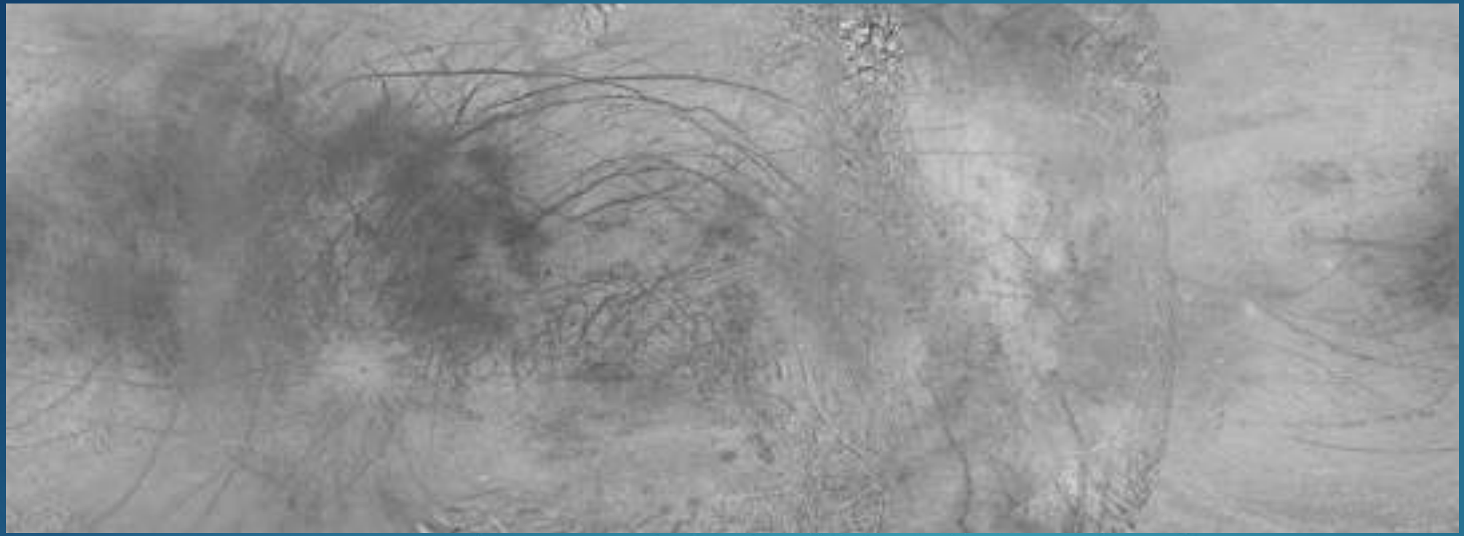
Impact Craters

- Small number of primary impact craters: surface age of ~40-90 m.y. (*Champman et al.*, 1998; *Moore et al.*, 2001).
- Based on their size and morphology, craters on Europa are classified as:
  - **Simple craters**: D ~4.5 km. Bowl shaped. Most of those with D < 1 km are secondary craters (*Bierhaus et al.*, 2001).
  - **"Normal" complex craters**: D ~ 15 km. Small central peaks (rarely chaotic), narrow rim-walls, flat floors, "pancake" ejecta deposits. Terraces are rare. Hummocky deposits at the bases of rim-walls.
  - **Complex craters:** D > ~ 20 km. Fragmented and asymmetric central peak complex, rim-walls variable in elevation or weakly expressed, raised floor, "pancake" and/or continuous ejecta deposits, flow deposits. Only two identified: Pwyll and Manannán.
  - **Multiring features:** D > ~ 30 km. Multiring D ~ 95-150 km. Concentric rings formed due to penetration into liquid water or warm ice. No apparent rim. Melt deposits, small relief . Only two identified: Tyre and Callanish.



Top left: Rhiannon ("normal" complex crater); top right: Tyre (multiring feature); bottom: Pwyll (complex crater). Galileo observations 17ESRHIANN01, E6ESCRATER, 12ESPWYCOL01, 14ESTYREHR01

Geologic map of Europa



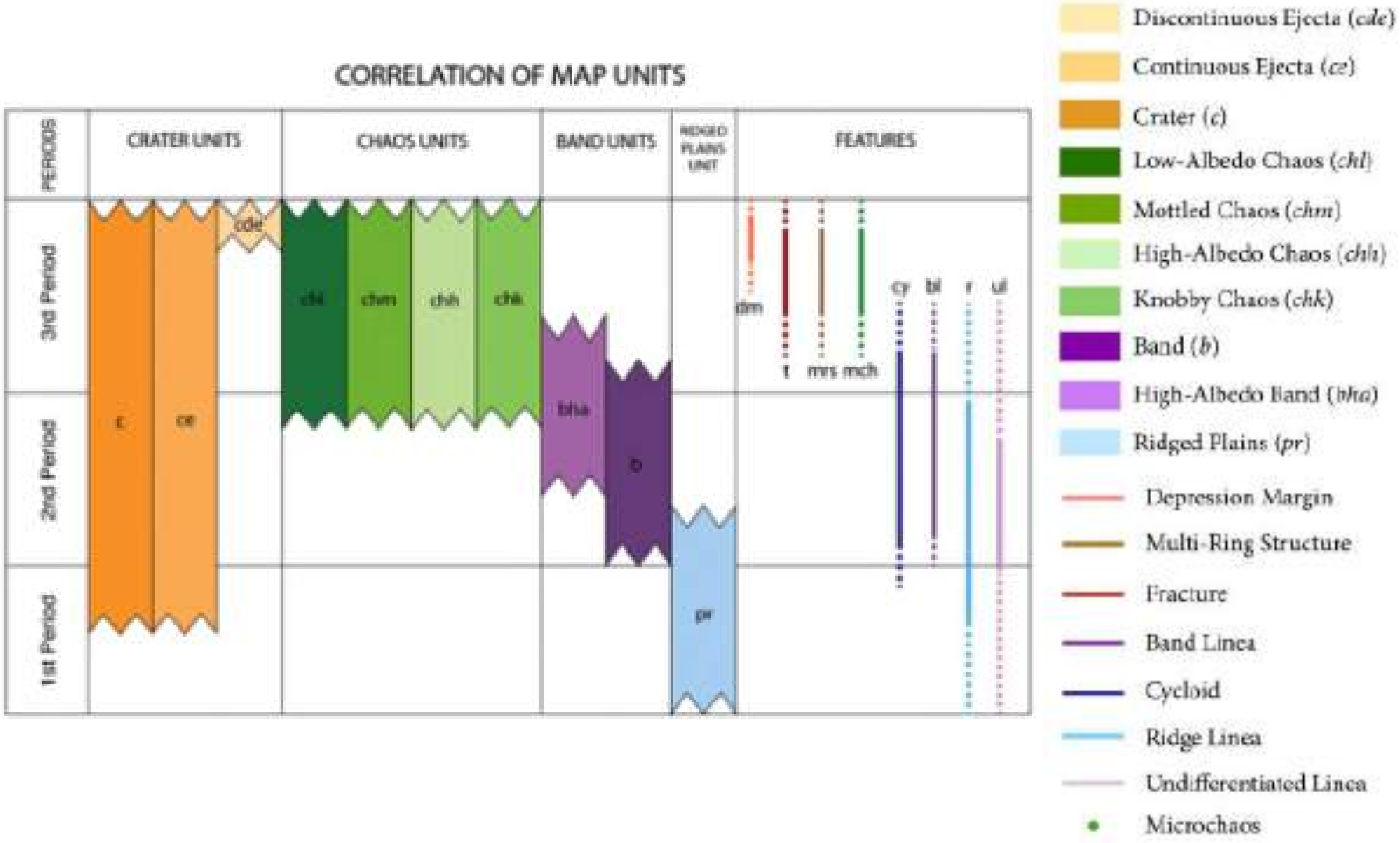
Global base map of Europa. Source: *astrogeology.usgs.gov*

1:15,000,000 global geologic map of Europa. *Senske et al., 2018*

Global-scale geological units

Stratigraphy

- The most recent proposed stratigraphy splits Europa's visible surface history into three separate periods::
  - 1st (oldest): dominated by ridged plains, ridges, and undifferentiated lineae indicating that this period was dominated by ridge building processes.
  - 2nd (middle): dominated by Band and High-Albedo Band formation. These units always appear younger and cross-cut the Ridged Plains unit. Cycloids also appear to be formed during this period.
  - 3rd (recent): dominated by chaos terrain and microchaos formation. These terrains not appear to have any cross-cutting units besides young troughs, craters and their associated deposits.
- These three periods are heavily inter-fingered with one another and are not necessarily discrete periods (*Senske et al.*, 2018).



Europa's most recent stratigraphy proposed by *Senske et al.* (2018).

Juno's close flyby of Europa

September 29, 2022

11:36 (CEST): ongoing right now!

Credit: NASA's Eyes, JPL - Caltech

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Co-funded by the ERASMUS + Programme of the European Union

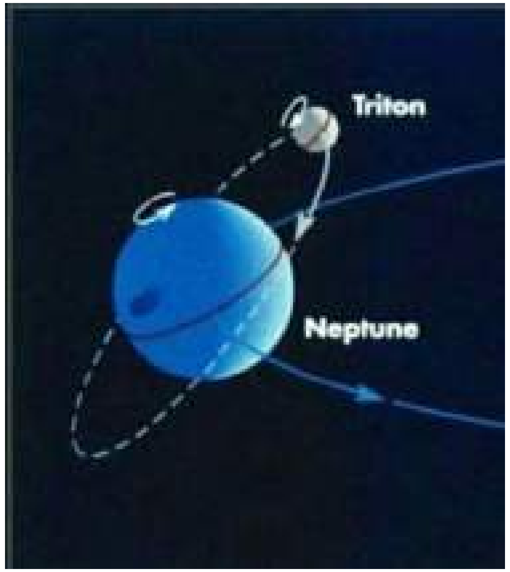
Geology of Triton

D. SULCANESE

Introduction

- ➢ First observations
- ➢ Orbit

Telescope observation, (Bob King).

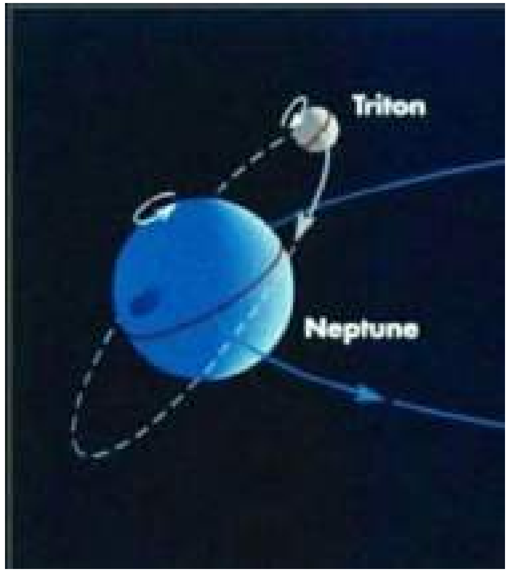


The retrograde orbit of Triton

Introduction

- ➢ First observations
- ➢ Orbit

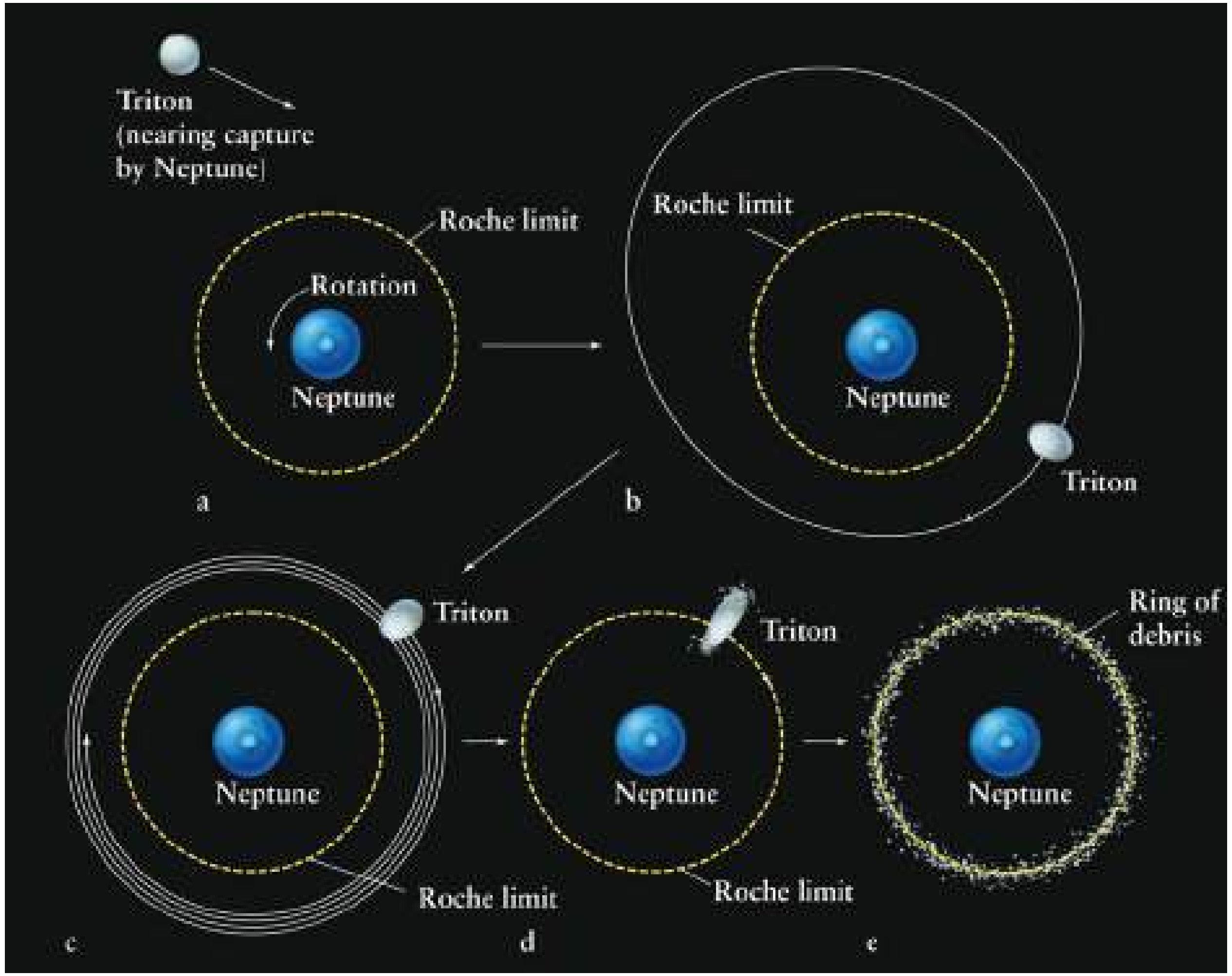
Telescope observation, (Bob King).



The retrograde orbit of Triton

Introduction

- ➢ The origin of Trion
- ➢ Evolution of Triton

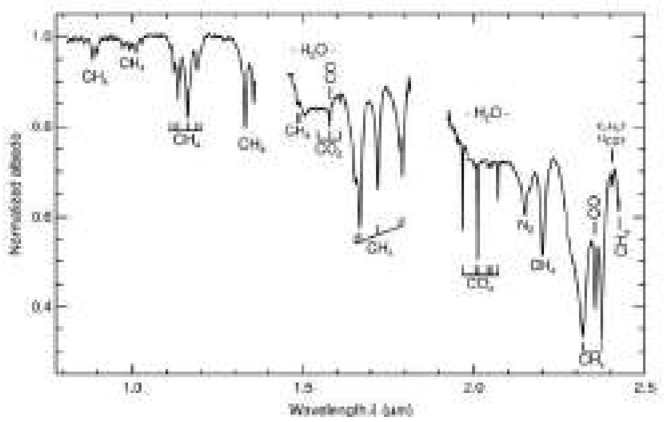


The evolution of Triton's orbit: past (a, b), present (c), and future (d, e).

The investigation of Triton

1. Spectroscopical ground-based observations

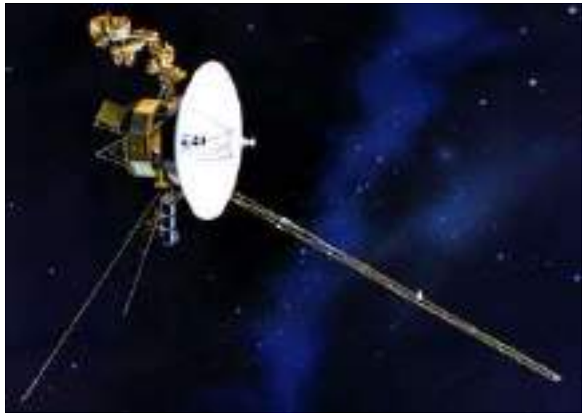
- Surface composition



The reflectance spectrum of Triton in the 0.8–2.5 μm region. (Grundy et al., 2010)

2. Voyager 2 Flyby

- Mass
- Radius
- Density
- Surface geology
- Atmospheric properties



The Voyager 2 spacecraft

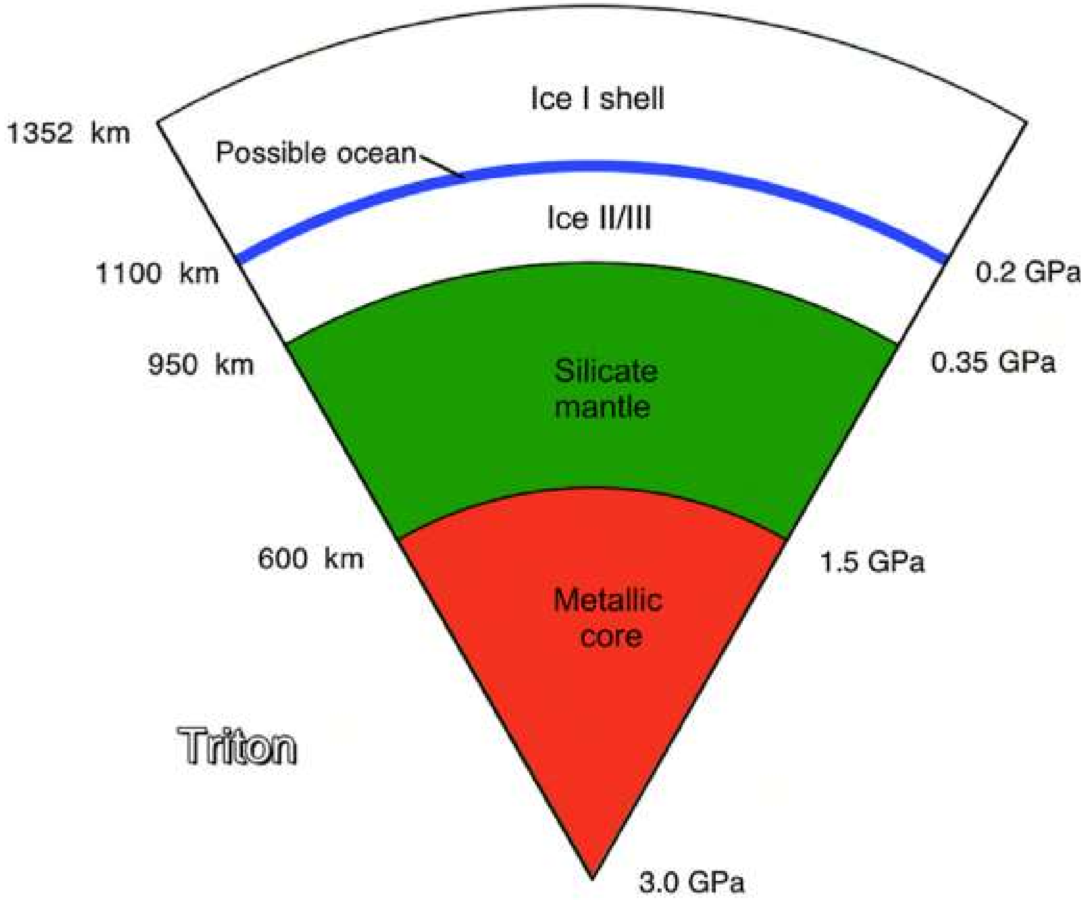
Grundy, W. M., et al. (2010). Icarus, 205, 594e604.

General characteristics

Triton's bulk (or average) composition is constrained by its density. With a mean density of 2000 kg m−3 it is one of the densest outer solar system satellites.

With the size and mass known, internal structural
models can be created based on a set of plausible
chemical components; for bodies formed in the outer
solar system, these would be rock, metal, ices, and
carbonaceous matter. Such models provide context and to
some extent guide interpretations of geological history.

McKinnon, W. B., & Kirk, R. L. (2014). Triton.
In Encyclopedia of the solar system (pp. 861-881). Elsevier.



Internal structure model for present-day Triton. (McKinnon et al., 2014)

The exploration of Triton

- ➢ Voyager 2 Flyby in 1989

Voyager 2- Triton Flyby, august 1989.

The exploration of Triton

- Voyager 2 Flyby in 1989

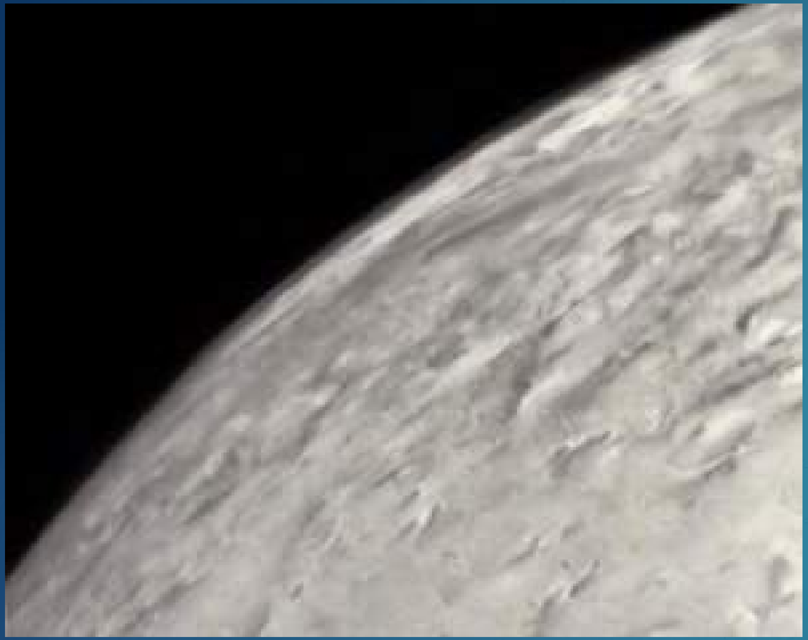
Voyager 2- Triton Flyby, august 1989.

The exploration of Triton

- Voyager 2 Flyby in 1989

Voyager 2- Triton Flyby, august 1989.

Triton is still active today



Portion of the active souther emishpere of Triton.

Three eruption hypotheses for Triton's plumes (Hofgartner et al., 2022).

Hofgartner, J. D., Birch, S. P., Castillo, J., Grundy, W. M., Hansen, C. J., Hayes, A. G., ... & Umurhan, O. M. (2022). Hypotheses for Triton's plumes: New analyses and future remote sensing tests. Icarus, 375, 114835.

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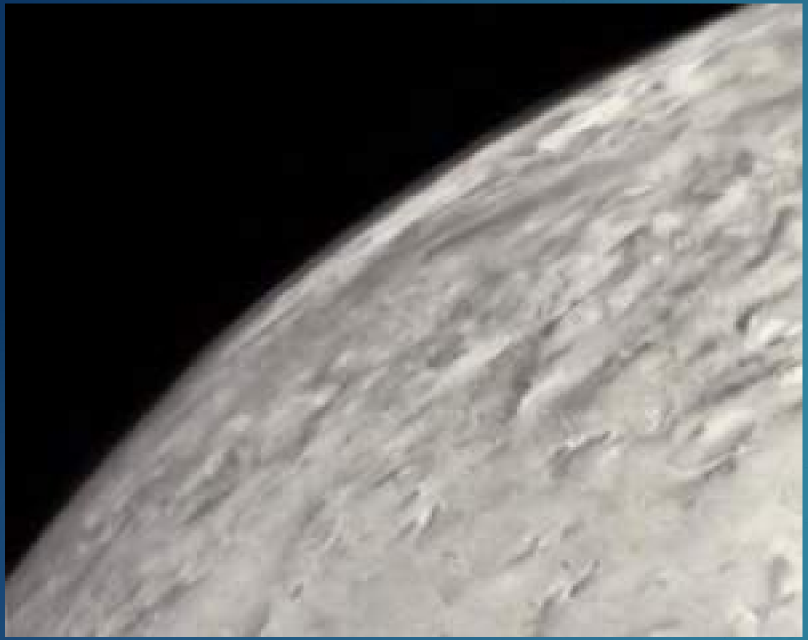

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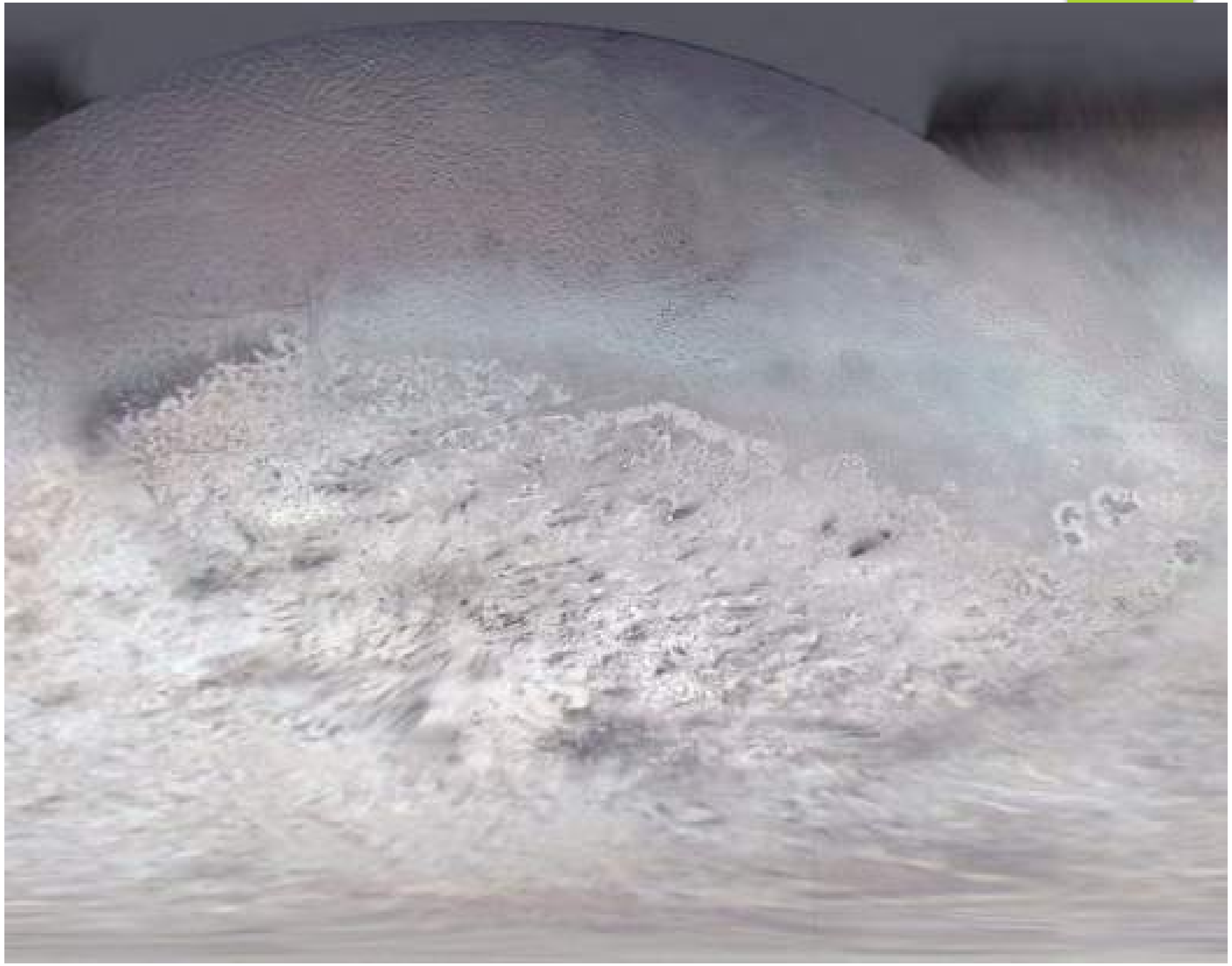
The surface of Triton

- The view, mainly of the southern hemisphere, showed extensive bright polar materials, a bright equatorial fringe with streamers extending to the northeast, and darker low northern latitudes.
- The almost total absence of craters indicates a geological young age

Triton Voyager 2 Global Color Orthomosaic

Geology of Triton

- ➢ High variety of surface features;
- ➢ Several unique morphologies never observed on other icy satellites;
- ➢ Almost craterless surface, denoting a young geological surface



Croft, S. K., Kargel, J. S., Kirk, R. L., Moore, J. M., Schenk, P. M., & Strom, R. G. (1995). The geology of Triton. Neptune and Triton, 879-947.

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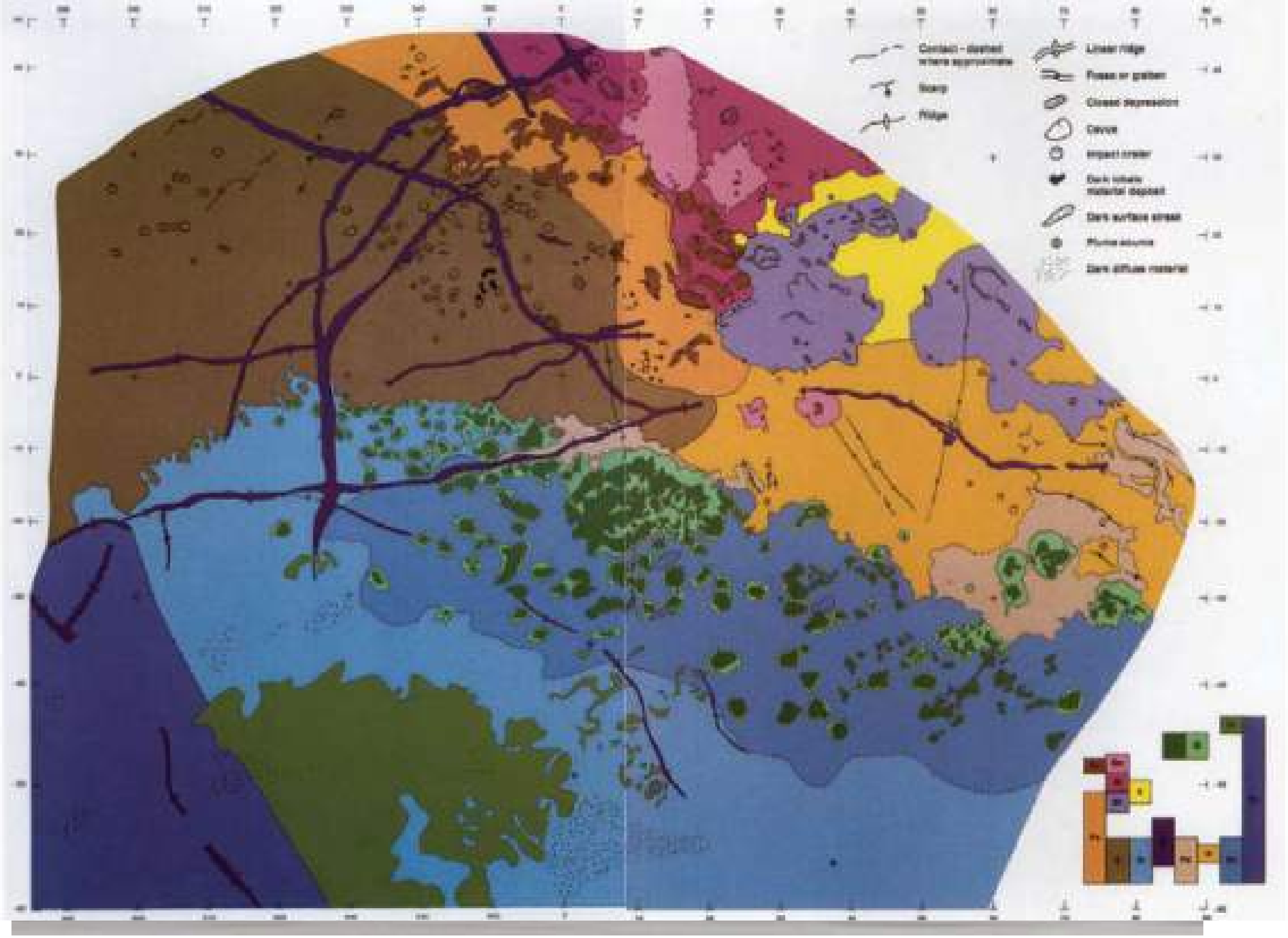


Geological map of Triton 1:4,000,000(Croft et al., 1995)

Tectonic network

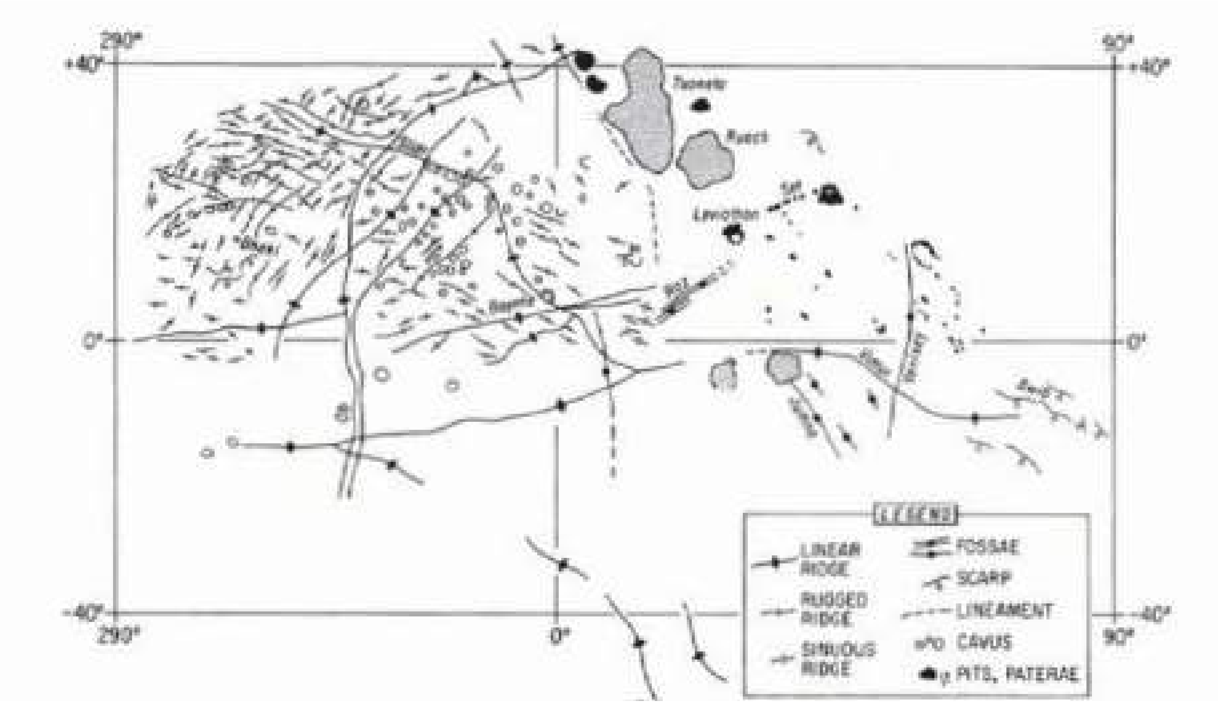
Description:

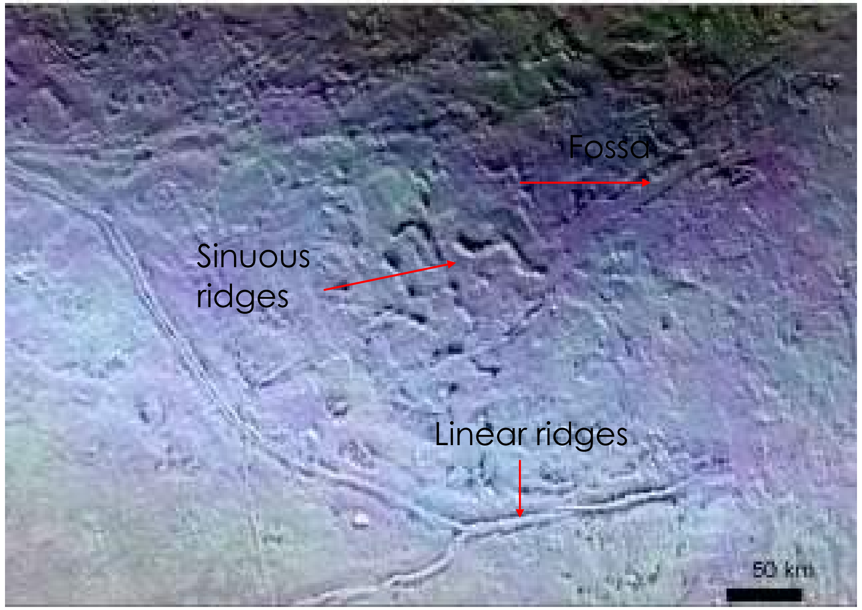
- Global scale multiple ridges cross-cutting several geological units (linear ridges)
- Single ridges lines (sinuous ridges);
- Concentric arcs(rugged ridges)
- long, narrow valleys with nearly constant widths and straight to slightly curving planforms (Fossae)/

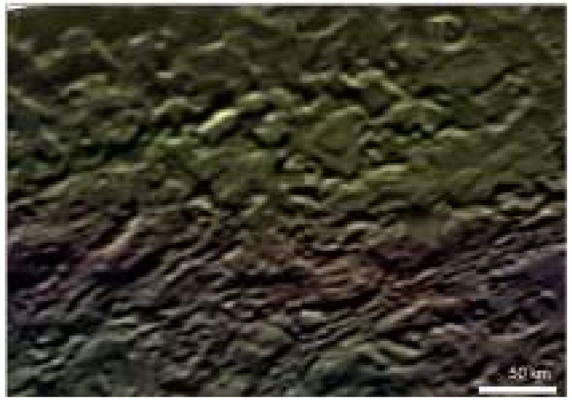
Possible origin:

- Triton and increasing distortion due to its tidally driven approach to Neptune;
- tidal stretching;
- Cryovolcanic constructs along curvilinear tectonic fractures (rugged rudges)

Croft, S. K., Kargel, J. S., Kirk, R. L., Moore, J. M., Schenk, P. M., & Strom, R. G. (1995). The geology of Triton. Neptune and Triton, 879-947.







Rugged ridges

Tectonic network

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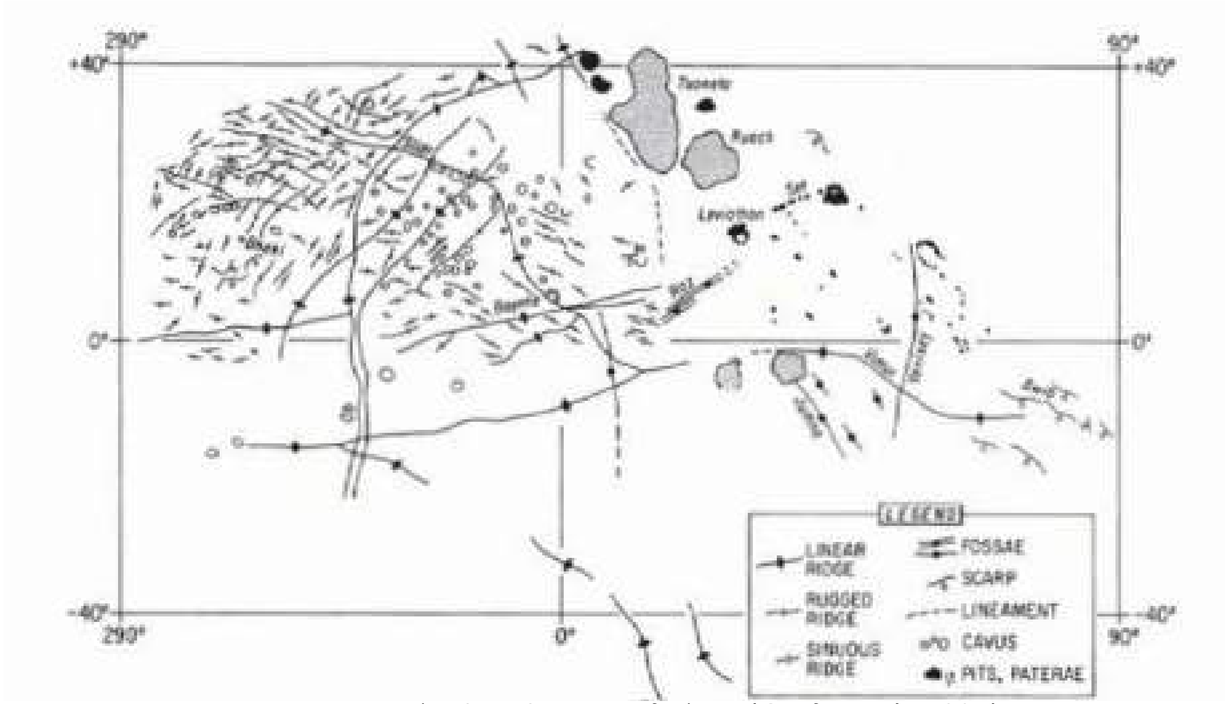
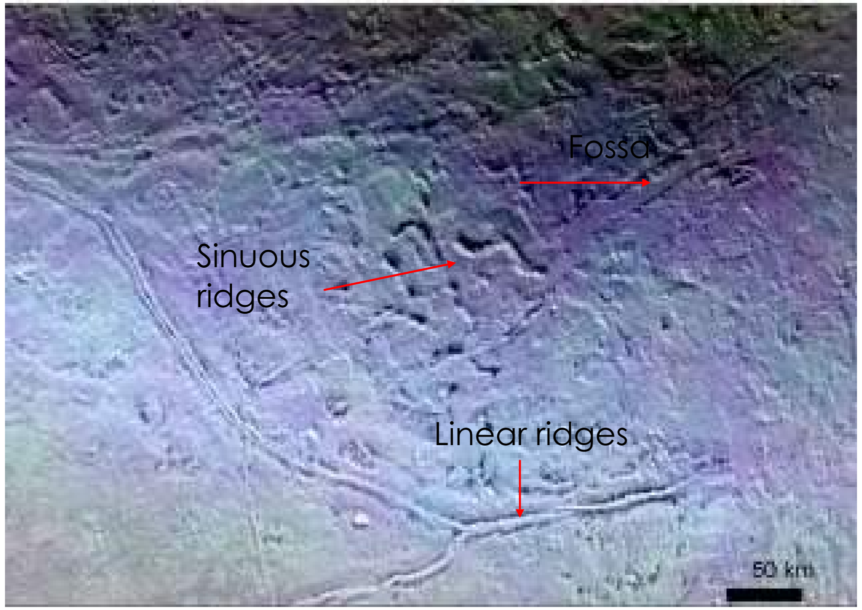
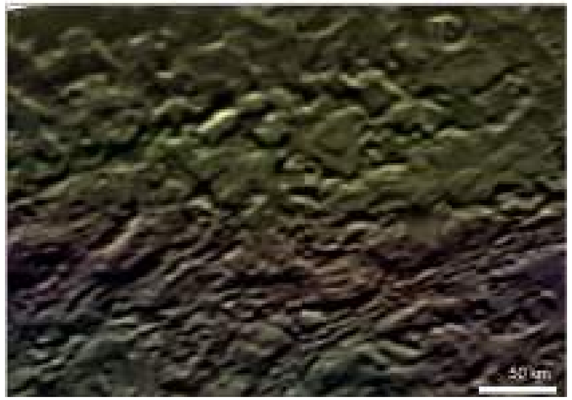


Tectonic sketch map of Triton (Croft et al., 1995)



Linear ridges, Fossae and sinuous ridges


Rugged ridges

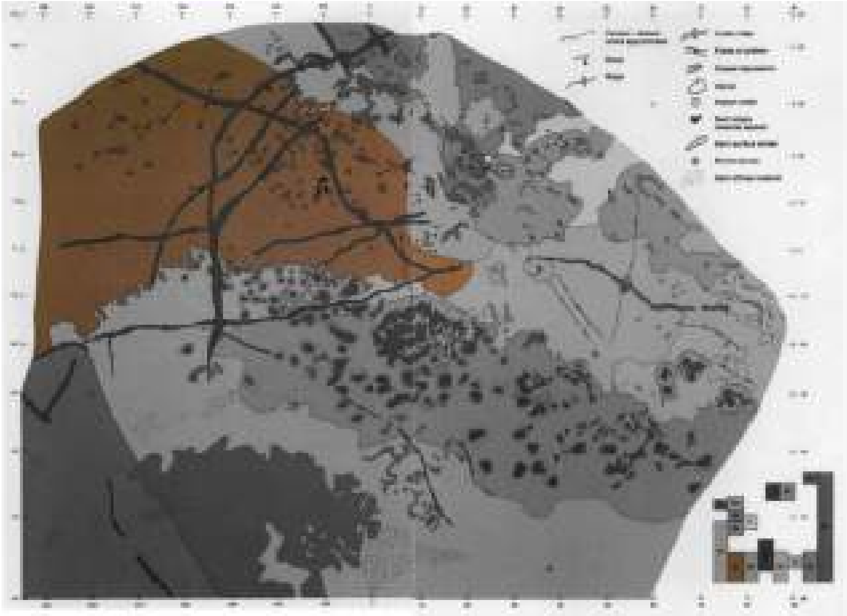
Cantaloupe terrain

Description:

The Cantaloupe terrain is the oldest geomorphological unit of Triton, and it is the most distinctive morphology, consisting of a cellular terrain with almost-circular dimples, also called "cavi", about 20-40 km across, having mean depths of 400 m

Possible origin:

Diapiric-like processes, coherently with a crustal overturn, associated to its compositional layering



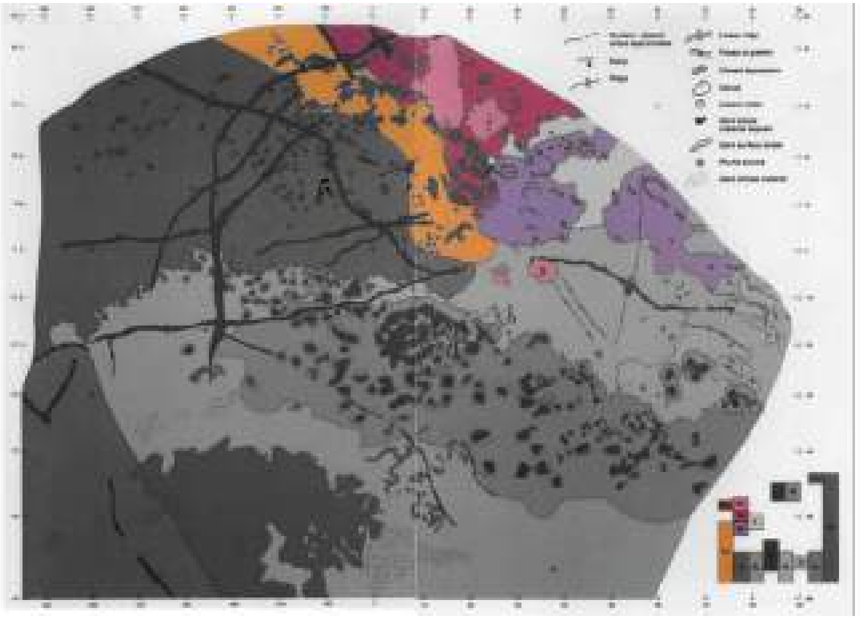
Smooth materials

Description:

Irregular smooth areas at different elevations separated by scarps a few hundred meters high (walled planitia)/ Sinuous inward-facing scarp surrounding a low plain hosting several terraces (smooth terraced materials)/ Quasi-circular patches or elongated lanes entered, respectively, on individual pits and circular groups of pits and on pit chains (The smooth high plains).

Possible origin:

resurfacing by some form of volcanism by materials with an icy composition (volcanic effusion, explosive ash deposition, or both), coupled with possible sublimation processes.



a) Walled planitia

b) A smooth terraced materials

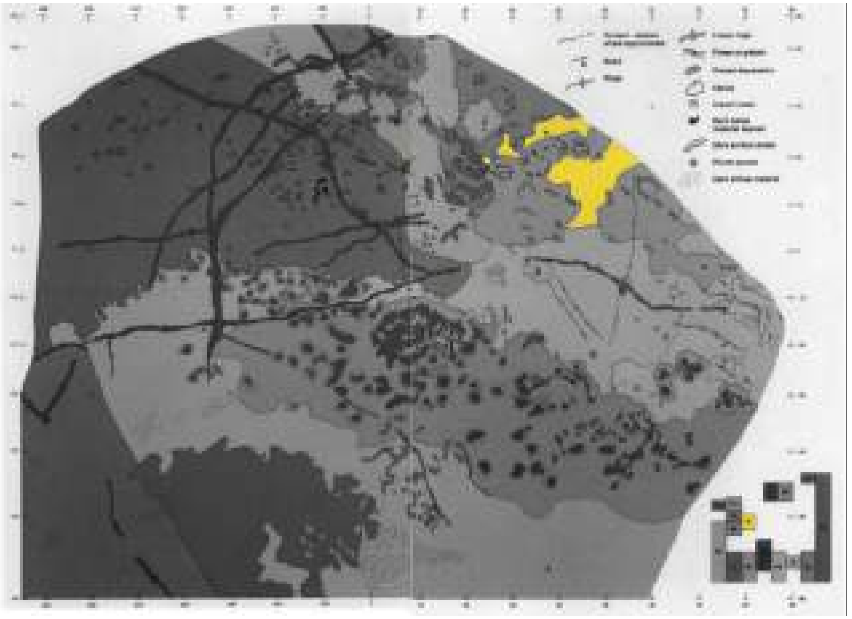
a) The smooth high plains

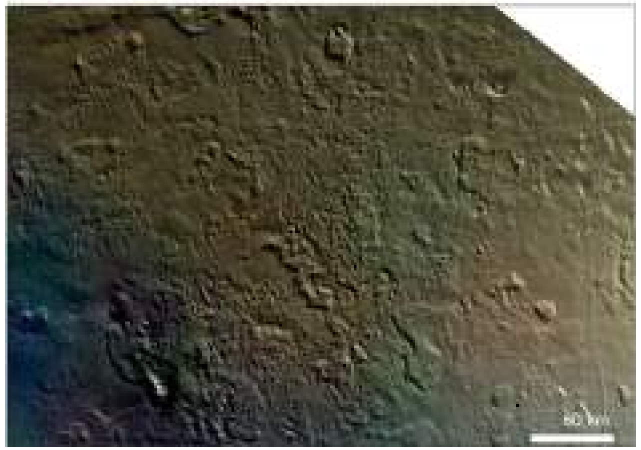
Knobby material

Description:
The knobby materials (K) occur in large patches within and around the high smooth plains and consist of groups of roughly equidimensional knobs 3 to 5 km across, often located on the floors of irregular depressions (Figs. 5 and 8). The contact with the smooth materials is usually sharp

Possible origin:

Sublimation of volatile ices, and scarp retreat.

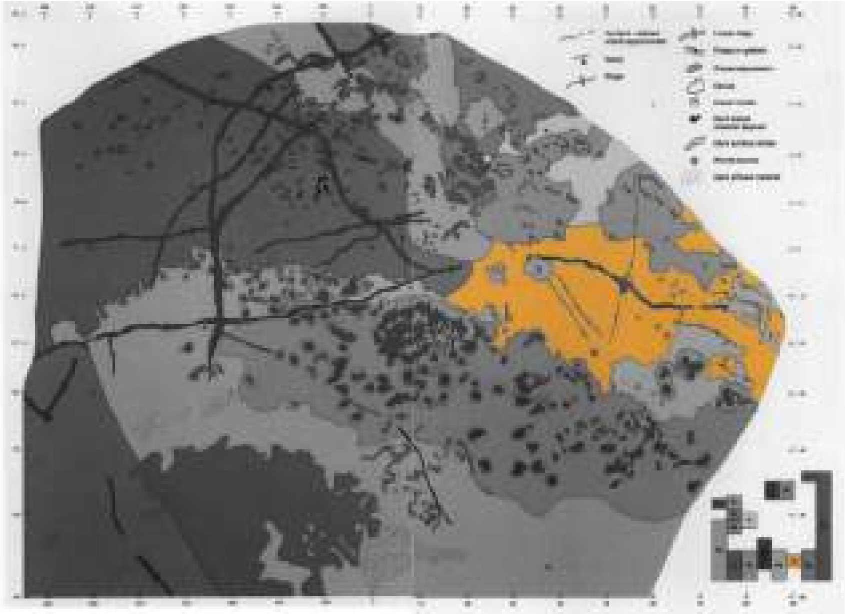


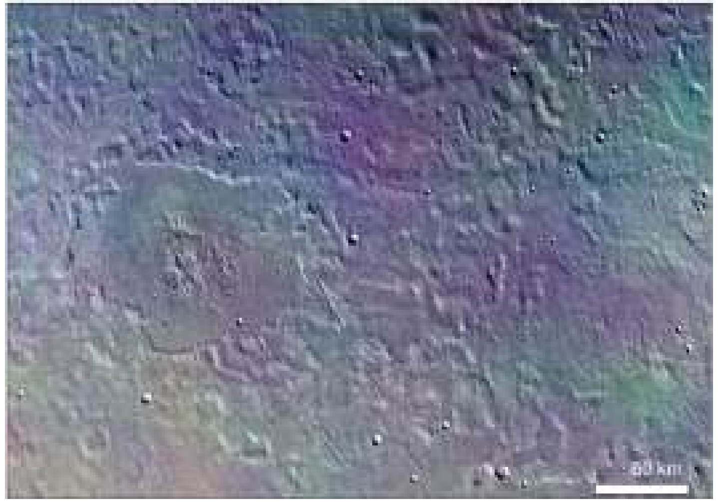


Hummocky Materials

Description:
characterized by low plains marked by sinuous scarps. In several locations, the sinuous scarps in these terrains form closed or nearly closed sigmoidal depressions (Figure 21) that are typically 5–15 km wide and 200–300 m deep.

Possible origin:
Mass wasting due to sublimation of volatile ices





Dark Plains Materials

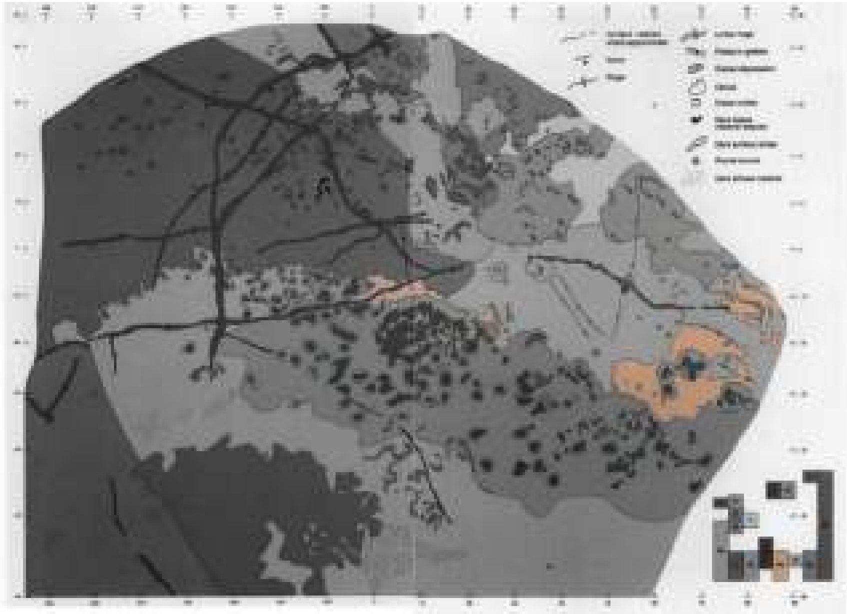
Description:

Patches of mottled, dark, relatively flat terrain. Their contact with the adjacent hummocky and linear ridges is defined by a distincet change in slope and texture.

Possible origin:

1° hypothesis: Cryovolcanic deposits. The dark material indicates a younger age of this deposits compared with surrounding terrains.

2° hypothesis: Remnants of the old surface of Triton before the cantaloupe.



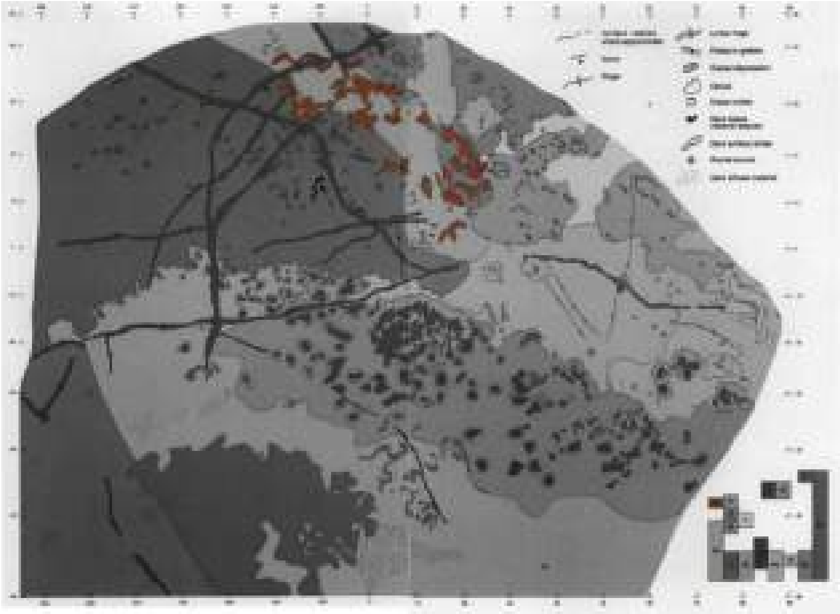
Dark Lobate Materials

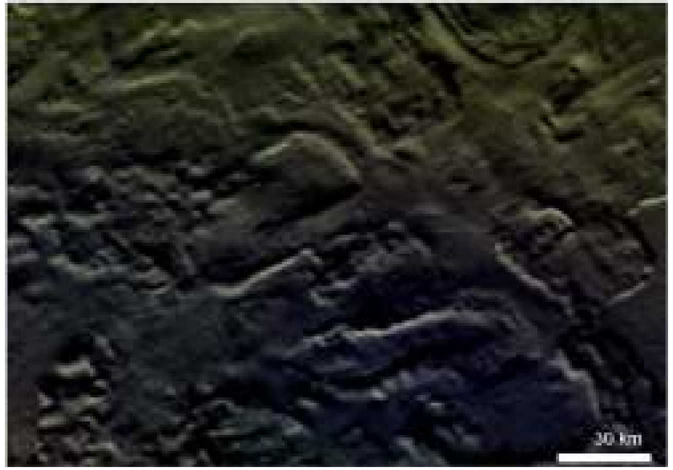
Description:

These extremely dark (A~0 2-O.33) features (Ld) occur as small rounded or blotchy patches typically a few kilometers wide and up to 10 km long. Other patches do appear to be distinct topographic features (Fig. 2, top), exhibiting lobes, mounds and subdued depressions. Thus, the dark materials appear to sit as unconformal, sometimes positive relief, deposits superposed on the lighter underlying units

Possible origin:

Cryovolcanism, the dark material indicates a younger age of this deposits compared with surrounding terrains.





Guttae and Aureoles

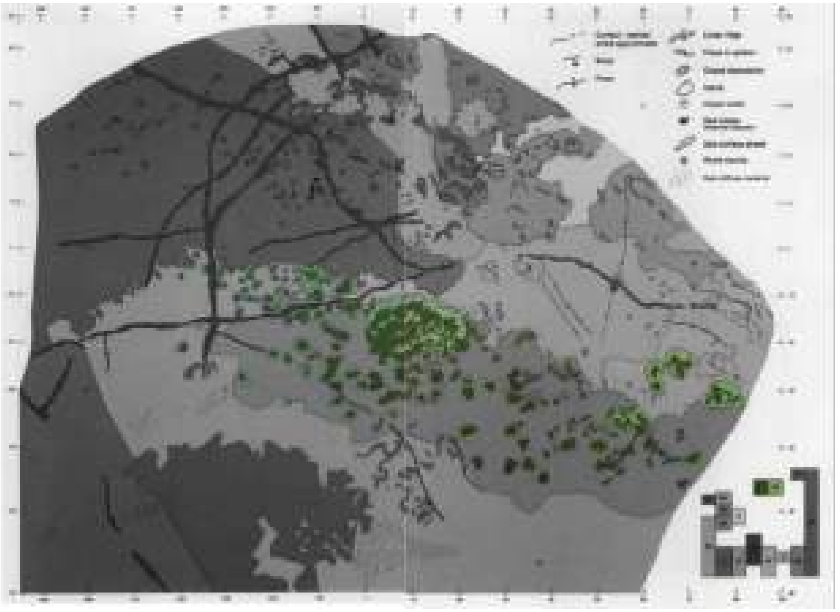
Description:

Dark irregular spots with bright aureoles around them.

- Guttae- very smooth, relatively dark patches with complex rounded edges.
- Aureoles - bright annular features which nearly always surround the darker guttae.

Possible origin:

- Guttae- Flow of viscous material.
- Aureoles- Flow of viscous material (different from the guttae one)/ condensed gases released bt extruded guttae materials/ thermally metamorphosed surface material.



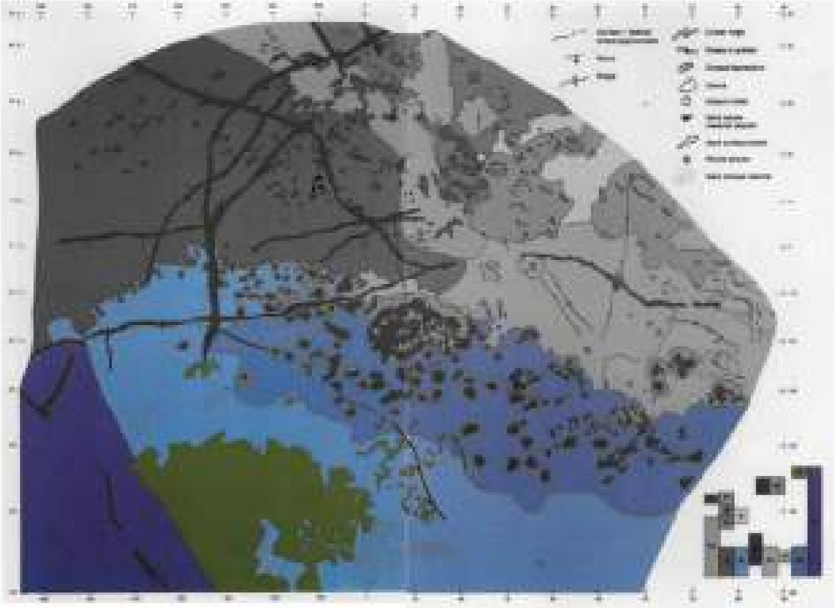
Bright and Fringe Materials

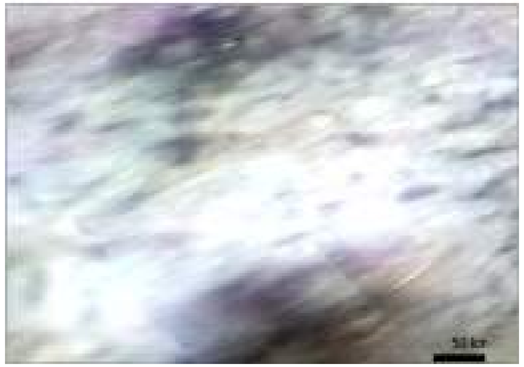
Description:

Deposits characterized by a general high albedo, with patches of darker terrain (Bright Smooth Terrain)/maze of rugged quasi-linear ridges and troughs with a few rugged, rimmed, quasi-circular depressions (Bright Rugged Terrain)/ very bright featureless surface (Bright Featureless Terrain)

Possible origin:

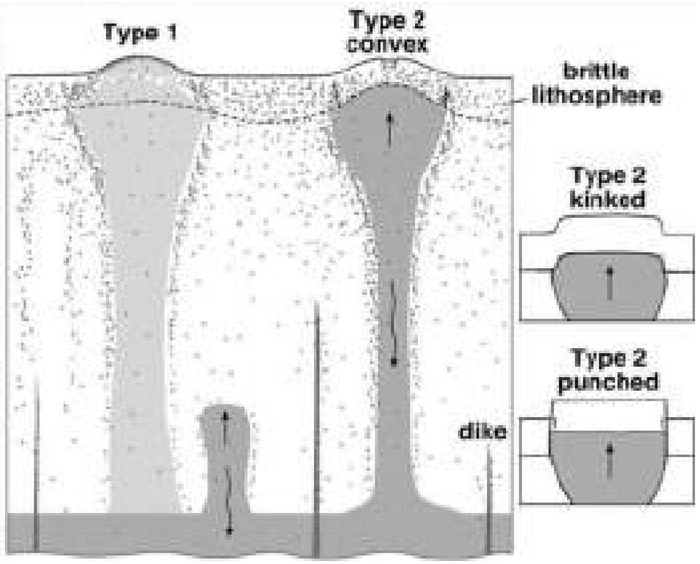
Exposed subsurface material after scarp retreat.

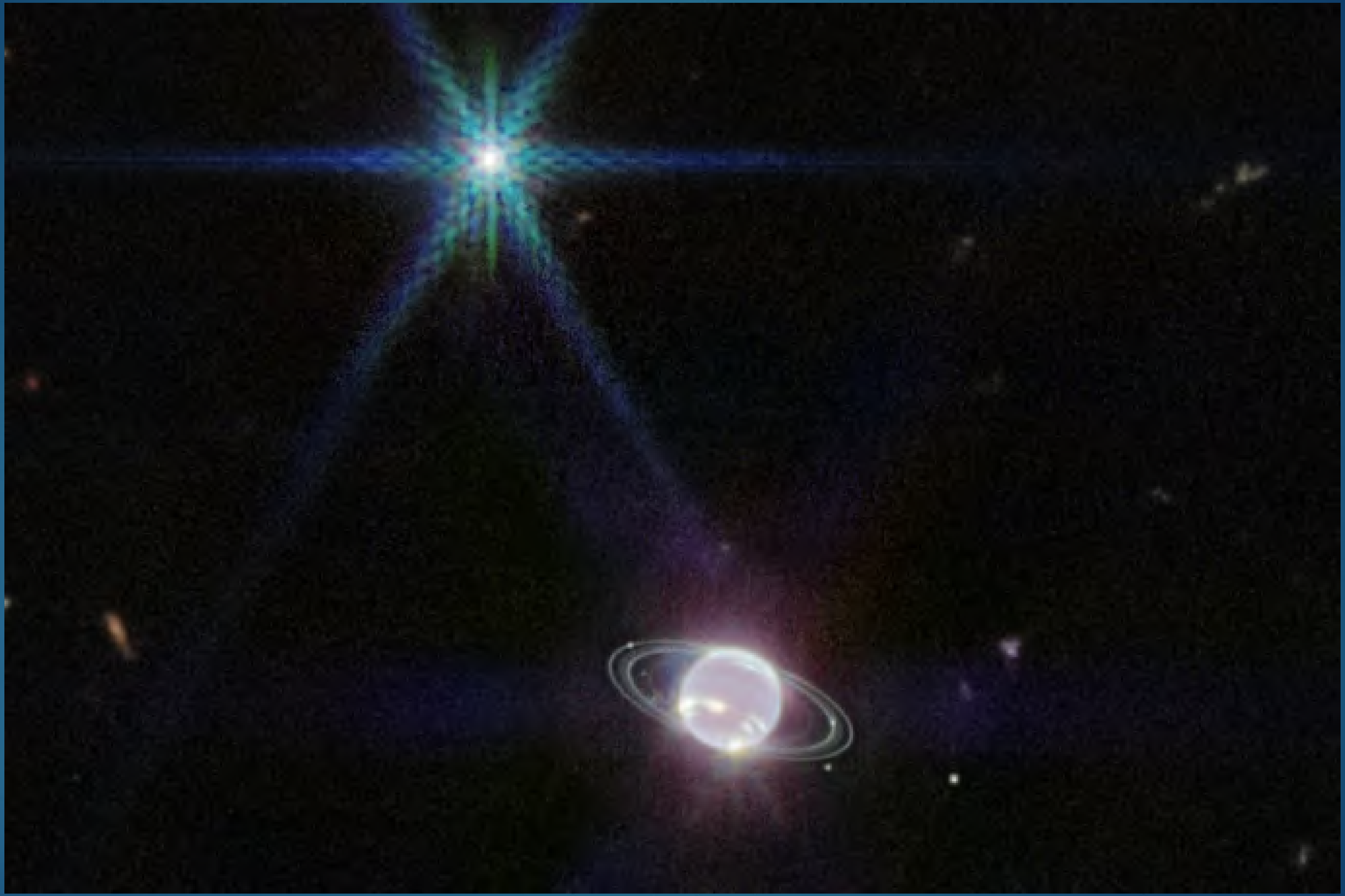




The surface of Triton is mainly modified by endogenic processes

- Cryovolcanism and plume activity
- Diapirism
- Tectonism





Neptune and its moons captured by the James Webb space telescope

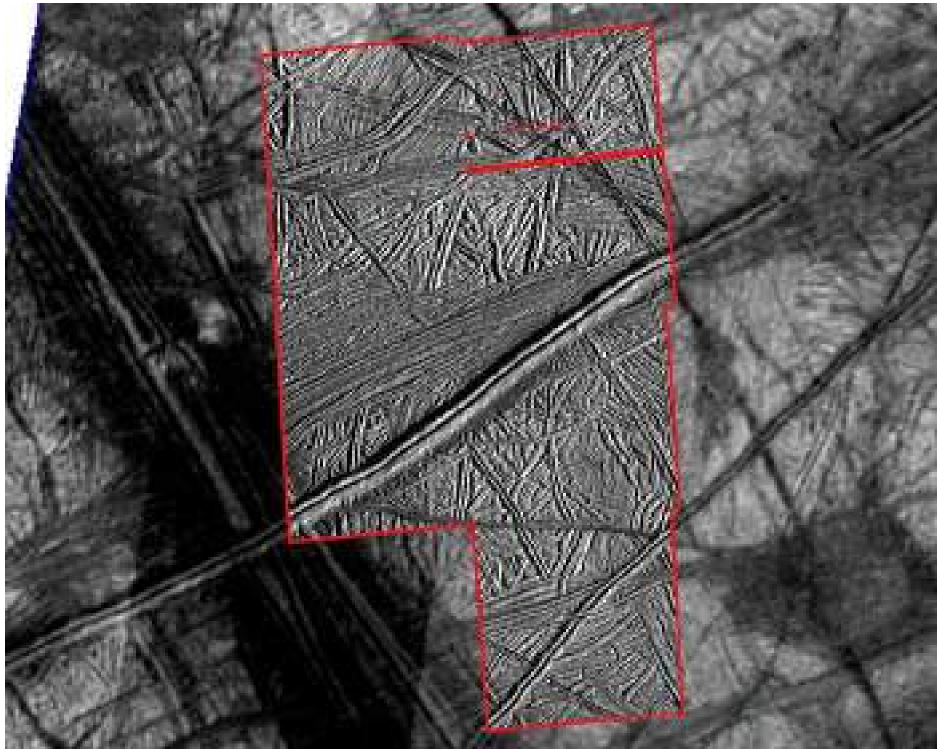
Co-funded by the
ERASMUS + Programme
of the European Union

GIS Mapping of Europa and Triton

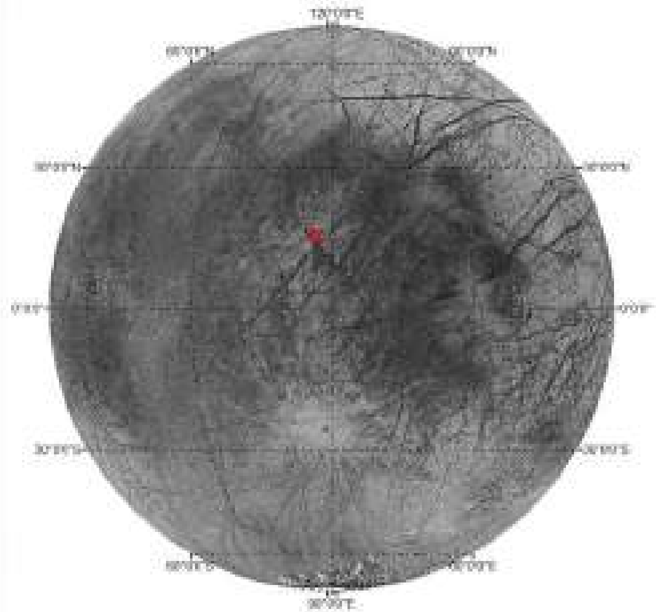
G. CHIAROLANZA, D. SULCANESE

Europa Study Area: Bright Plains

- Availability of multiple-resolution Galileo imagery, including high resolution
- Representative of Europa's most widespread terrains



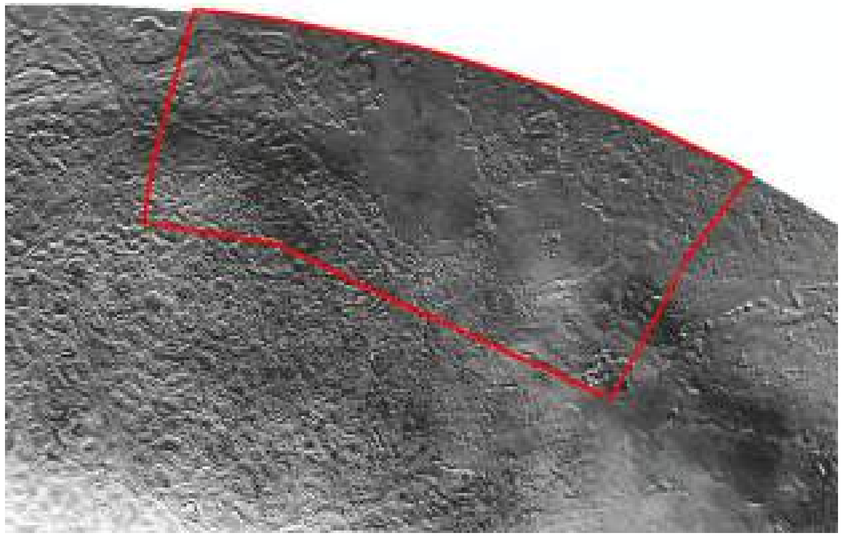
Galileo E6ESBRTPLN02 high resolution observation (20-22 m/p, red polygon) on top of Galileo 12ESDKLNCL01 regional resolution observation (166-174 m/p).



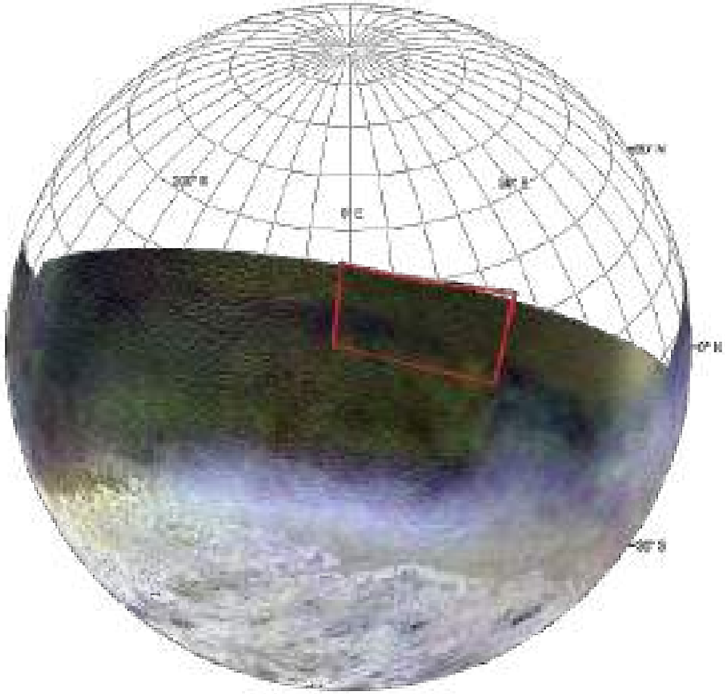
Localization of the study area on the globe (red rectangle, 15° N, 86 E).

Triton Study Area: Monad Regio

- Includes some of the highest-resolution images currently available for Triton, acquired during the Voyager's closest approach
- Hosts several planetary-scale geomorphological units



Triton Voyager Global Color Mosaic 600m V1 (greyscale). Spatial resolution: ~ 600 m/p.



Localization of the study area on the globe (red polygon).

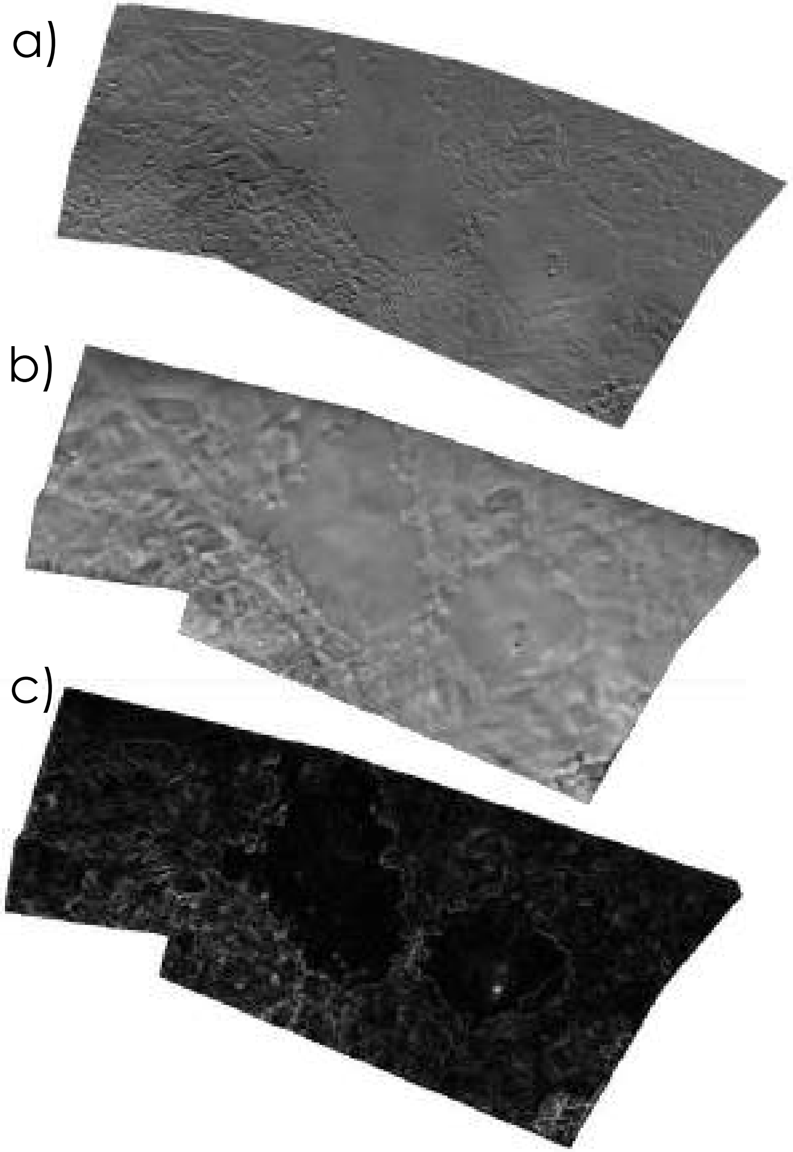
Objectives

Europa

- Produce a geological map of the high-resolution region
- Determine relative ages of mapped units
- **Facultative**: extend the geological map to the surrounding terrains imaged at regional resolution

Triton

- Produce a geological map of the high-resolution region by using the Voyager imagery, the DEM, and the roughness map
- Determine relative ages of mapped units (if possible)
- **Facultative**: extend the geological map to the surrounding terrains imaged at regional resolution



Triton's highest-resolution, image-mosaic available:
a) Monad Regio, Voyager mosaic;
b) DEM;
c) Roughness map

Europa's bright terrains.

How to map

- Both lines and polygons should be used to produce a planetary geological map.
- Use polygons to map features sufficiently extended in two or three dimensions: deposits, domes, reliefs, mesas, depressions, knobs, ejecta, etc.
- Use lines to map contacts, limits and narrow features: faults, scarps, crests, lineations, depressions and any other inferred/concealed linear feature.
- To mark units with their inferred relative age, consider to use point features.
- All images are in the visible spectrum. As such, features can only be distinguished under morphological criteria (shape, texture, pattern) and albedo contrasts.

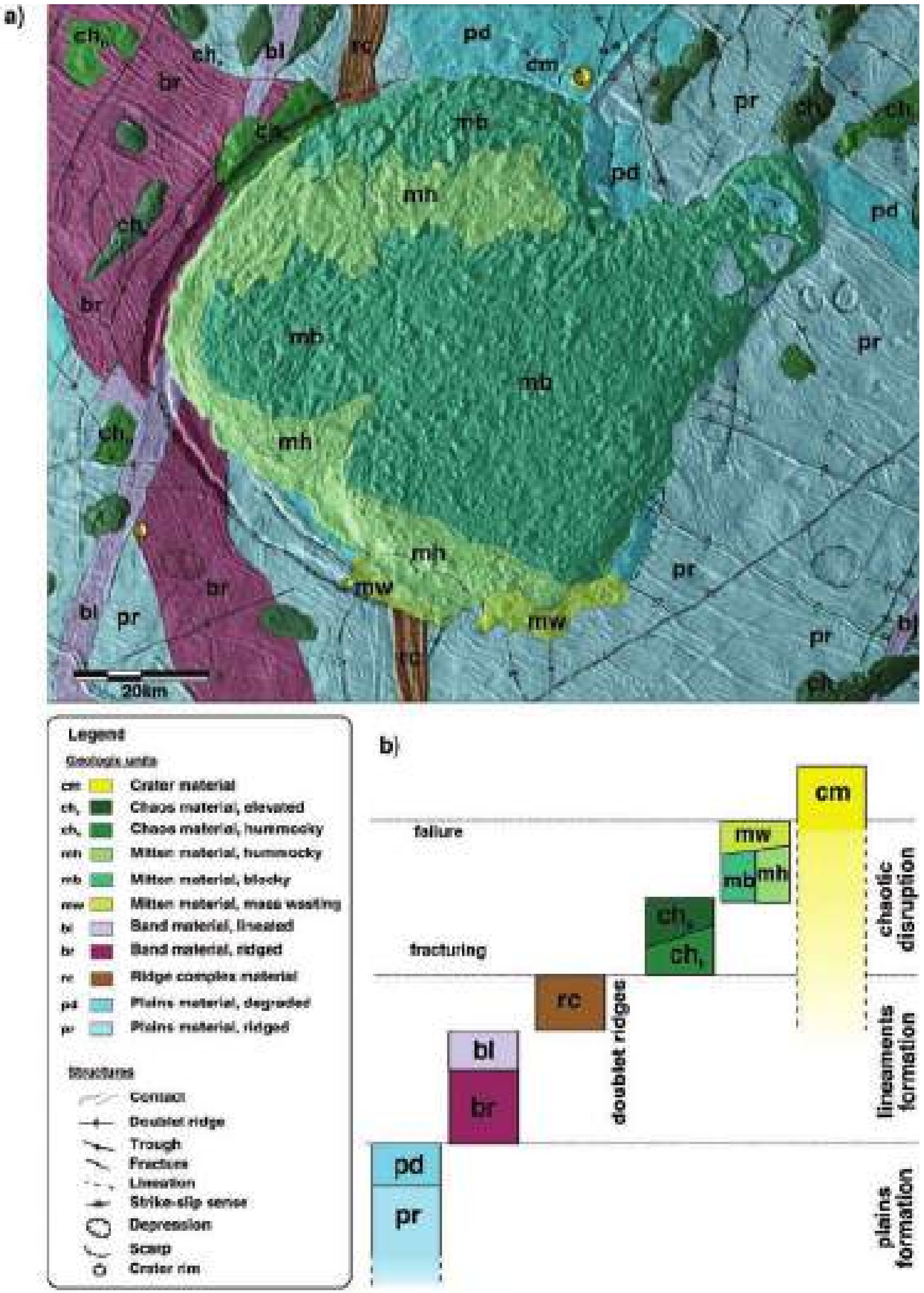
DESCRIPTION	SYMBOL
Dark-colored ejecta, planetary	
Light-colored ejecta, planetary	
Terrace deposits, planetary	
Dark-colored mantling material, planetary	
Secondary crater field, planetary	
Diffuse highland-lowland boundary scarp, planetary	
Joint or fracture pattern, planetary	
Area of reticulate grooves, planetary—Showing trend	
Detached lobe, planetary—Arrow points in direction of interpreted landslide or debris flow	
Low albedo smooth material, planetary—Interpreted as eolian material	
Airburst spot	
Mantling material, planetary—Light-colored	
Splotch, planetary—Circular, radar-bright halo on surface	
Reticulate pattern on plains, planetary	
Fracture zone, planetary	
Superficial crater material having weak radar back-scatter coefficient, planetary	
Crater-associated ejecta halo, planetary	
Halo without associated crater, planetary	

DESCRIPTION	SYMBOL
Contact, planetary—Location accurate	
Contact, planetary—Location approximate	
Contact, planetary—Location inferred	
Contact, planetary—Location concealed	
Fault, planetary, sense of offset unspecified—Location accurate	
Fault, planetary, sense of offset unspecified—Location approximate	
Fault, planetary, sense of offset unspecified—Location inferred	
Fault, planetary, sense of offset unspecified—Location concealed	
Normal fault, planetary—Location accurate. Ball and bar on downthrown block	
Normal fault, planetary—Location approximate. Ball and bar on downthrown block	
Normal fault, planetary—Location inferred. Ball and bar on downthrown block	
Normal fault, planetary—Location concealed. Ball and bar on downthrown block	
Strike-slip fault, planetary, right-lateral offset—Location accurate. Arrows show relative motion	
Strike-slip fault, planetary, right-lateral offset—Location approximate. Arrows show relative motion	
Strike-slip fault, planetary, right-lateral offset—Location inferred. Arrows show relative motion	
Strike-slip fault, planetary, right-lateral offset—Location concealed. Arrows show relative motion	
Strike-slip fault, planetary, left-lateral offset—Location accurate. Arrows show relative motion	
Strike-slip fault, planetary, left-lateral offset—Location approximate. Arrows show relative motion	

Examples of polygonal (left panel) and linear (right panel) units, as defined by the FGDC Digital Cartographic Standard for Geologic Map Symbolization

Geological map: an example

- Geological map of Murias Chaos, a chaotic terrain on Europa. *Credit: Figueredo et al., 2002*.



Initialize the project

- Make sure QGIS 3.x is installed on your computer
- Download on your computer the .zip archive named "UdA_Summer_School_Day4_GIS" from the OneDrive repository. You should have received a link that directs you to the repository.
- Unzip the archive and open one of the two following GIS projects, depending on which planetary body you have been assigned/you wish to map:
  - Europa_Bright_Plains
  - Triton_Monad_Regio

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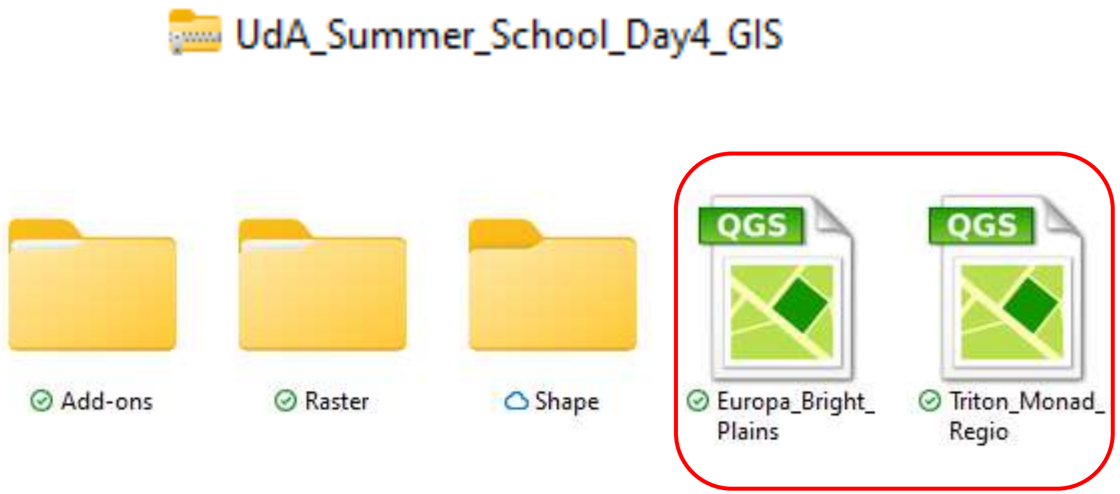

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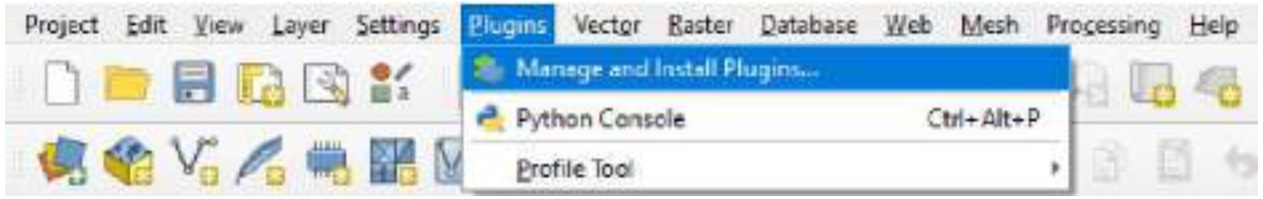

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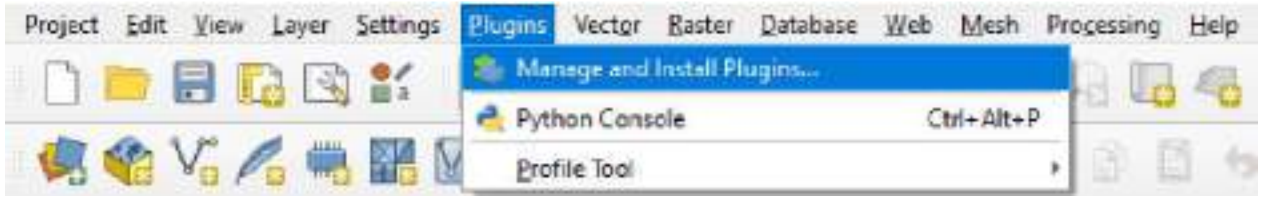

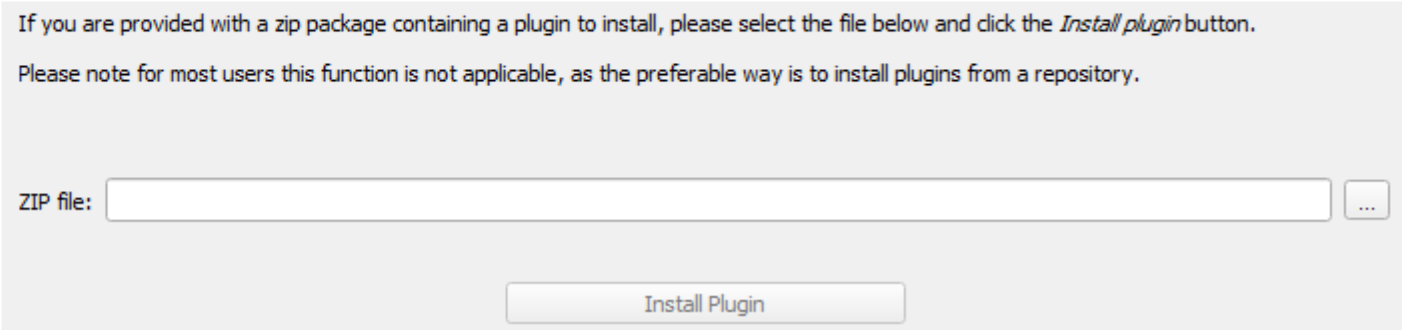

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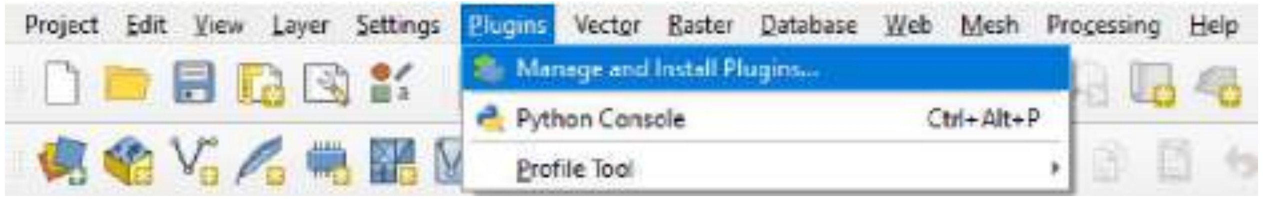

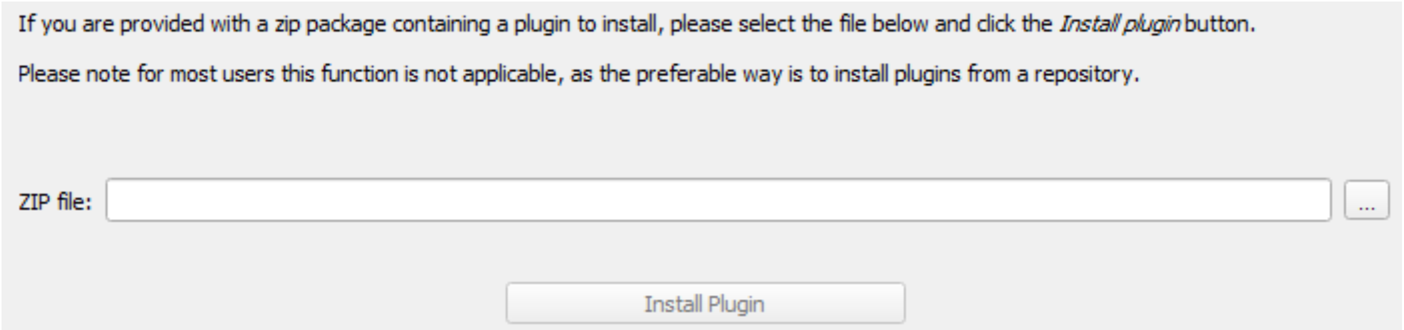

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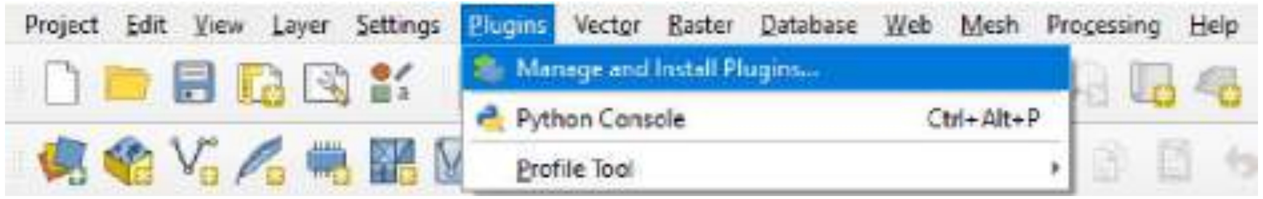

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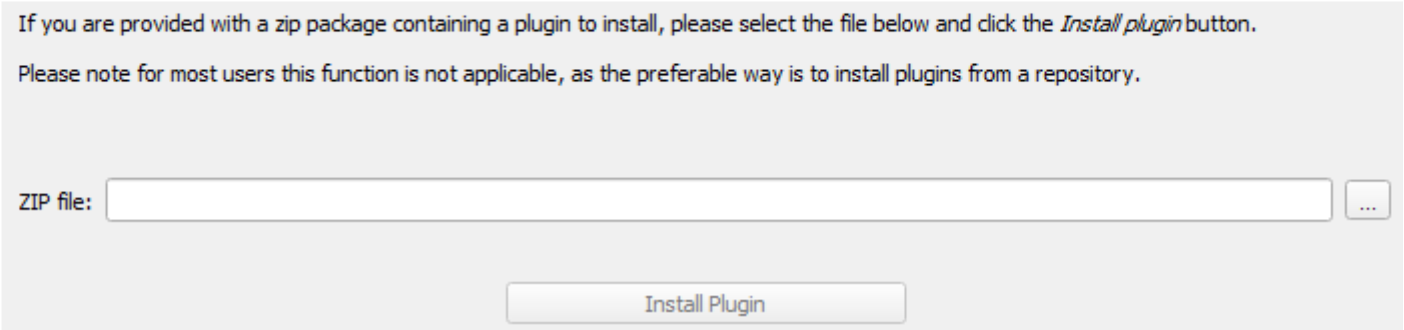
- If you need help to use Mappy, you can consult the user documentation here: https://mappy.readthedocs.io/en/master



Adding FGDC planetary symbols

- If you wish to map using planetary symbols defined by the Federal Geographic Data Committee (FGDC), you can add into QGIS a library created by Alessandro Frigeri (IAPS/INAF) for this purpose:

Source: https://github.com/afrigeri/geologic-symbols-qgis.

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  - Alternatively, you can exploit Mappy's option to auto download and setup planetary symbology (only available from Mappy v0.3.2 on).

First rc featuring all the symbol-set for planetary geology

The gsymblib is a library and development environment for producing geologic symbols to be used in the QGIS desktop GIS. Version 1.0 features all the FGDC symbol-set for planetary geology.

This is the first release candidate for the 1.0 version.

Changelog is here

Thanks to all the contributors!

▾ Assets

Here you are the instructions to install the gsymblib (all symbols and patterns) in your local QGIS installation.

1. Download the latest gsymblib or the official release zip files.
2. Extract the zip archive and move the **gsymblib-svg** directory to a place where you want to store the patterns and symbols. It can be any directory.
3. Now open QGis and go to 'Settings -> Options' (Ubuntu) or 'Preferences' (OSX) and select the second tab from the top: 'System'
4. Under the **SVG Paths** formi, click the add button and select the the **gsymblib-svg** directory from your file system.
5. Exit from QGIS and re-open it to make **SVG Paths** modifications active.
6. In QGis, go to **Settings** -> **Style Manager** and click on **Import/Export** -> **Import items** button (at bottom-left)
7. Select the **geologic_symblib-X.Y.Z.xml** file extracted from the zip file, then **select all** button at the bottom, and then **import** button.
8. Now you should now have the geologic symbols listed and ready to style your geologic maps in your QGis!

Source: https://github.com/afrigeri/geologic-symbols-qgis.

Adding Profile tool

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Plots terrain profile

This tool plots profile lines from raster layers or point vector layer with elevation field. Supports multiple lines as well as graph export to svg, pdf, png or csv file. Supports 3D polyline export to dxf.

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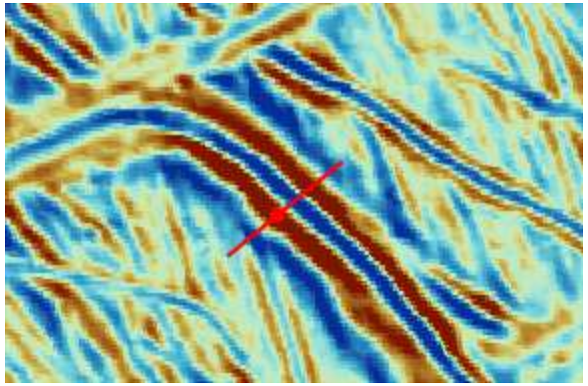

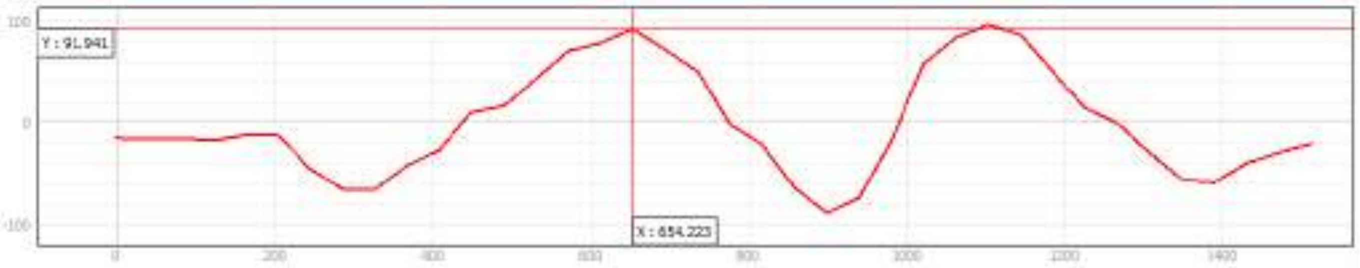

Creating Shapefiles

- Your geological map will be an assemblage of polygons, lines and points. These belong to a common geospatial vector data format known as shapefile. To create a shapefile:

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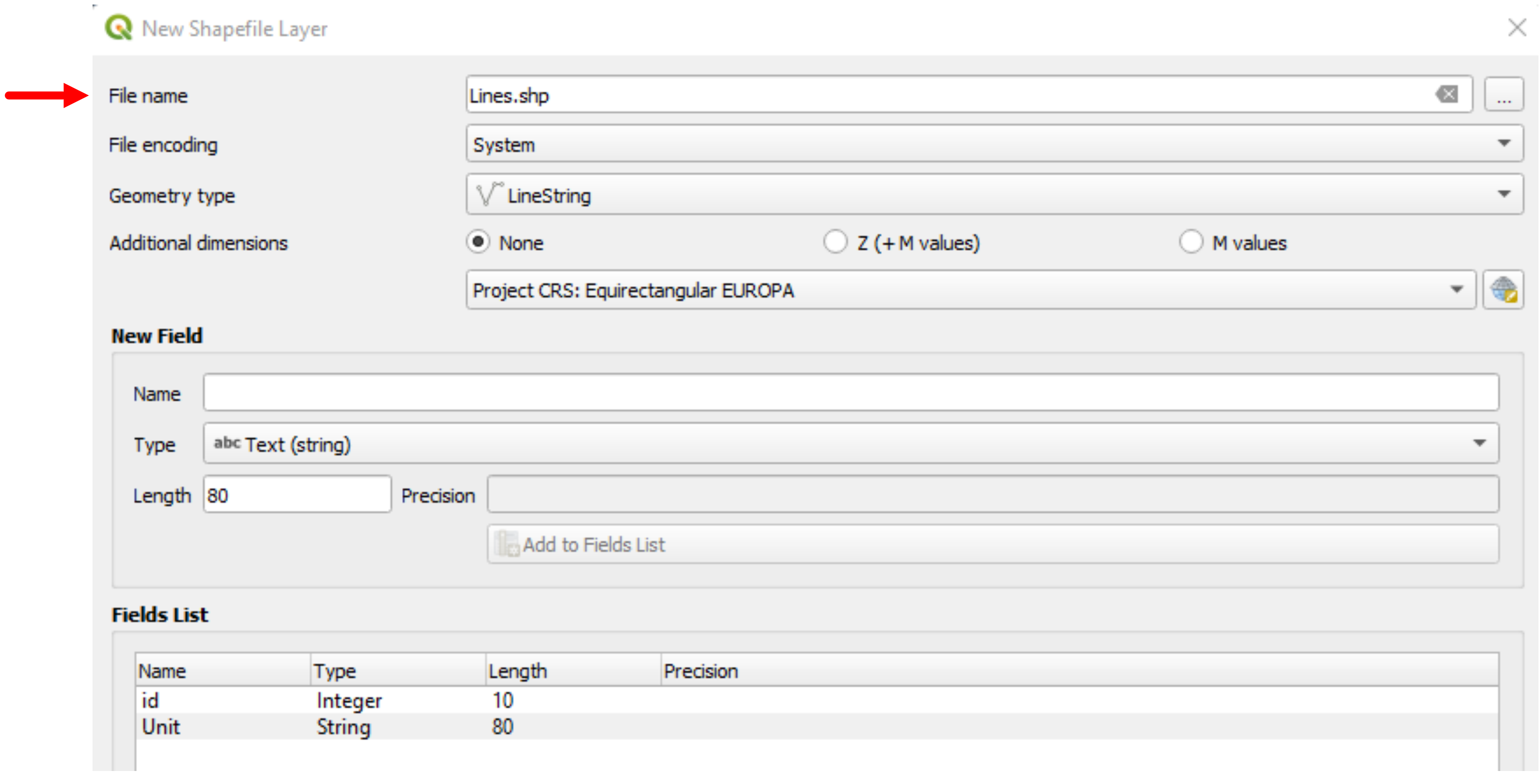

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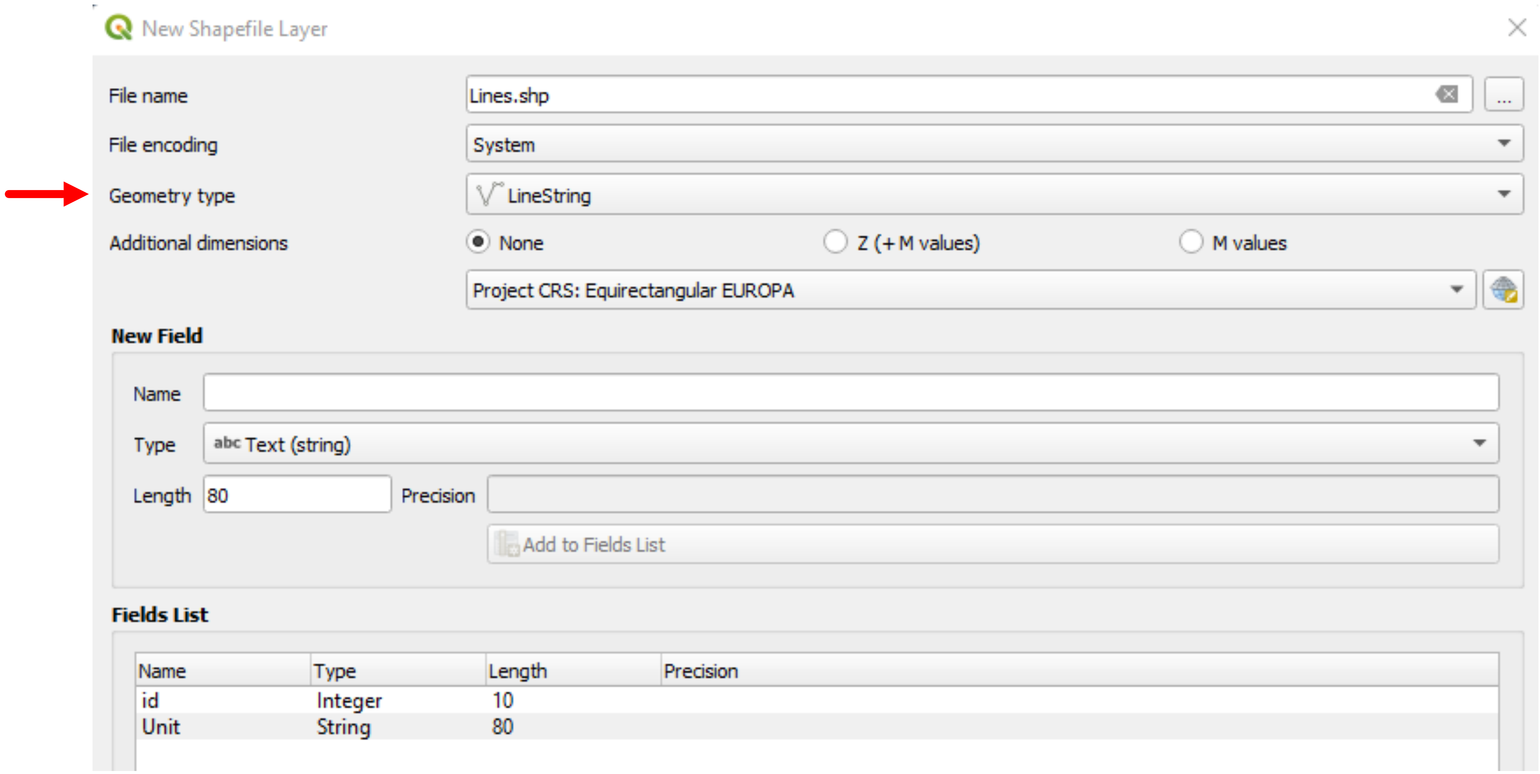

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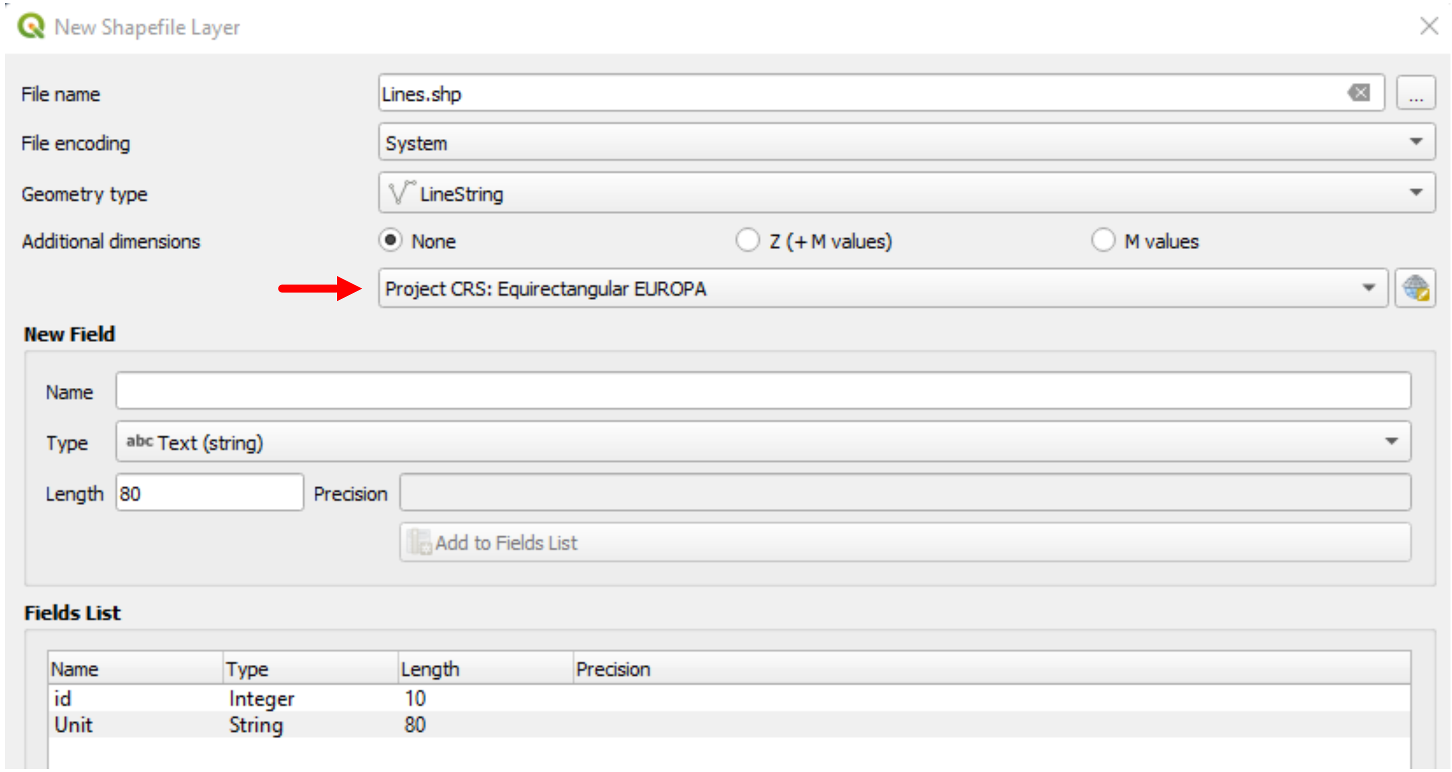

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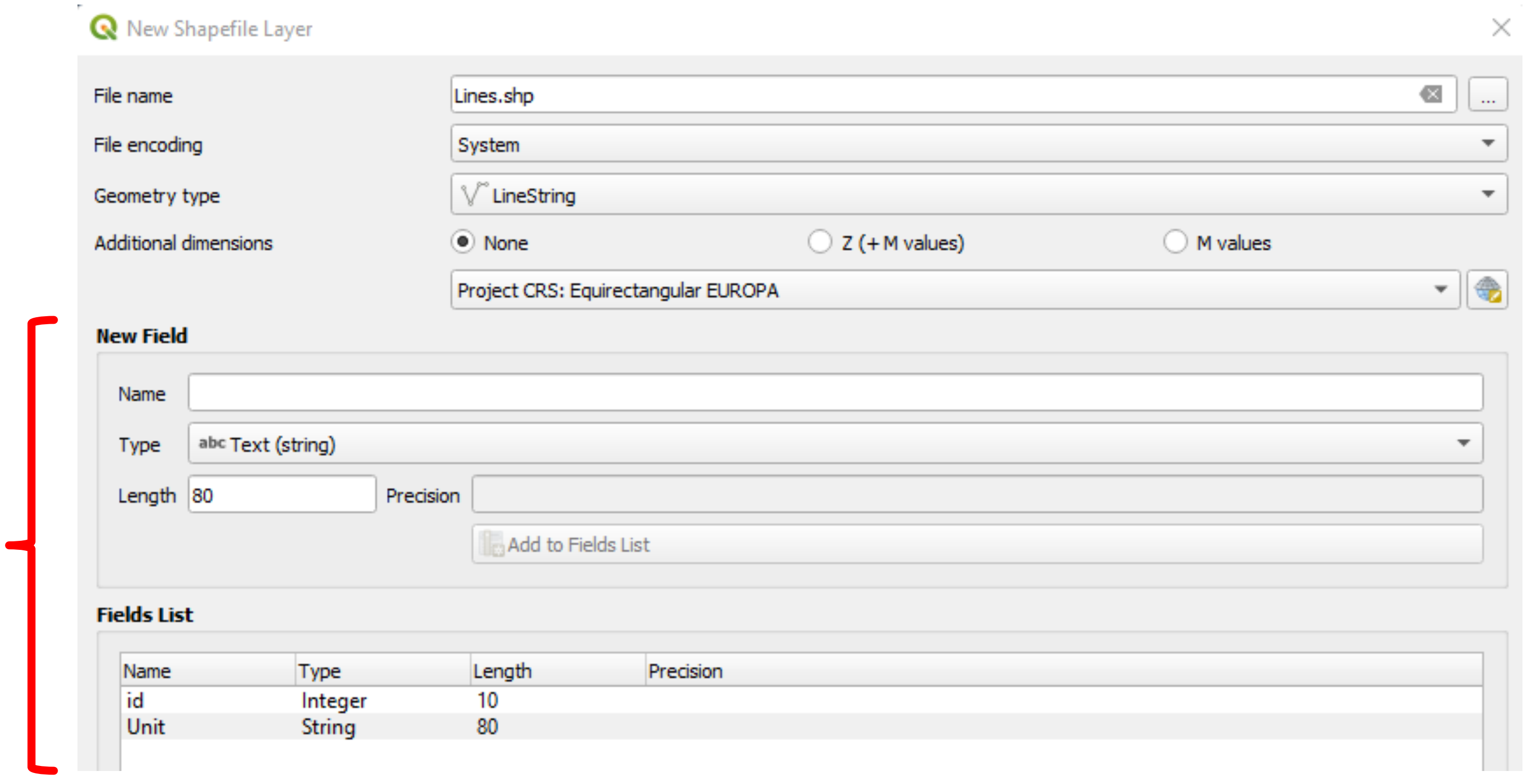
  - Add a text-type field that will be used to categorize your linear shapefile into multiples subunits.



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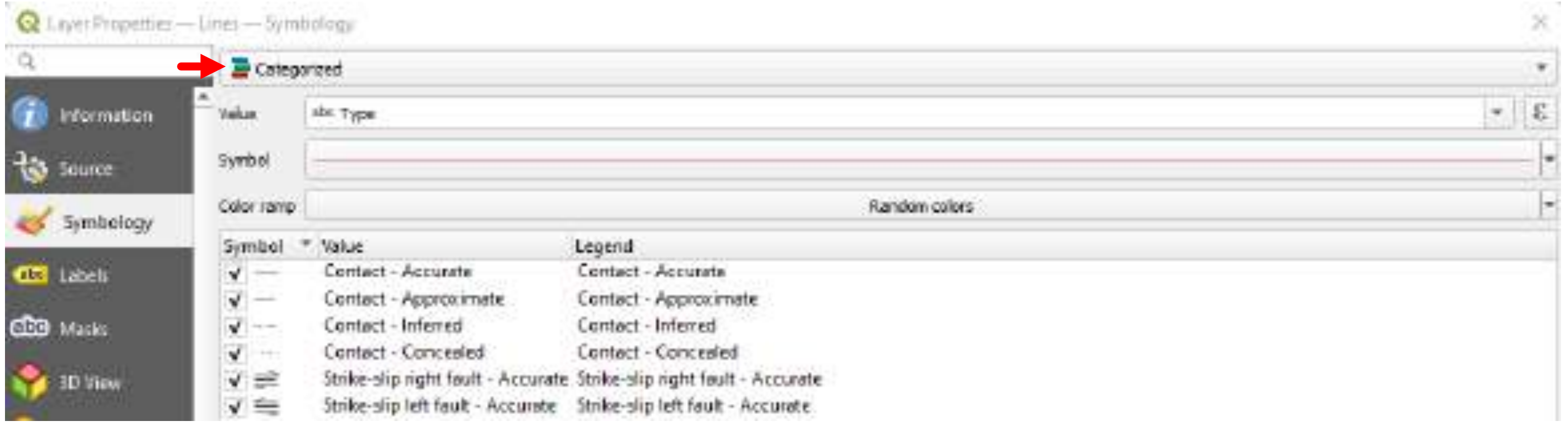

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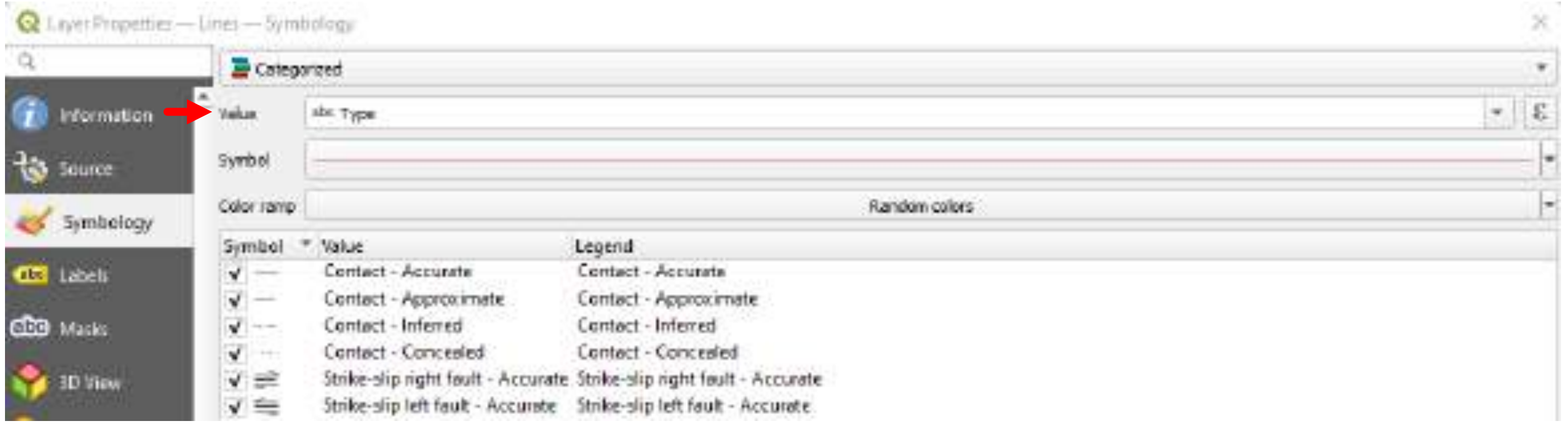

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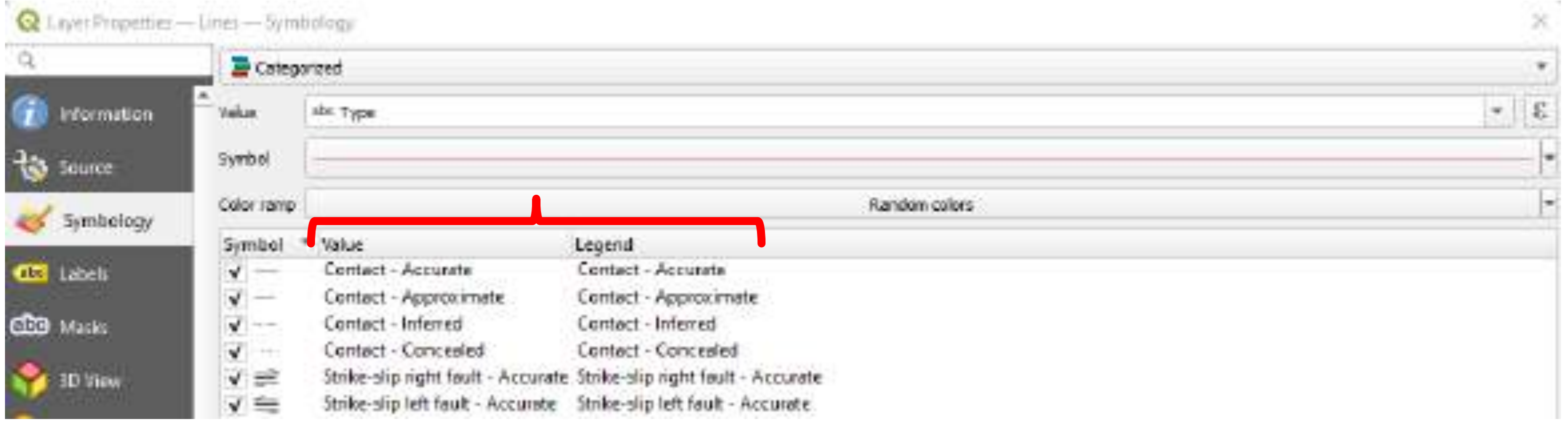
  - Name your unit under both the Value and Legend tags.



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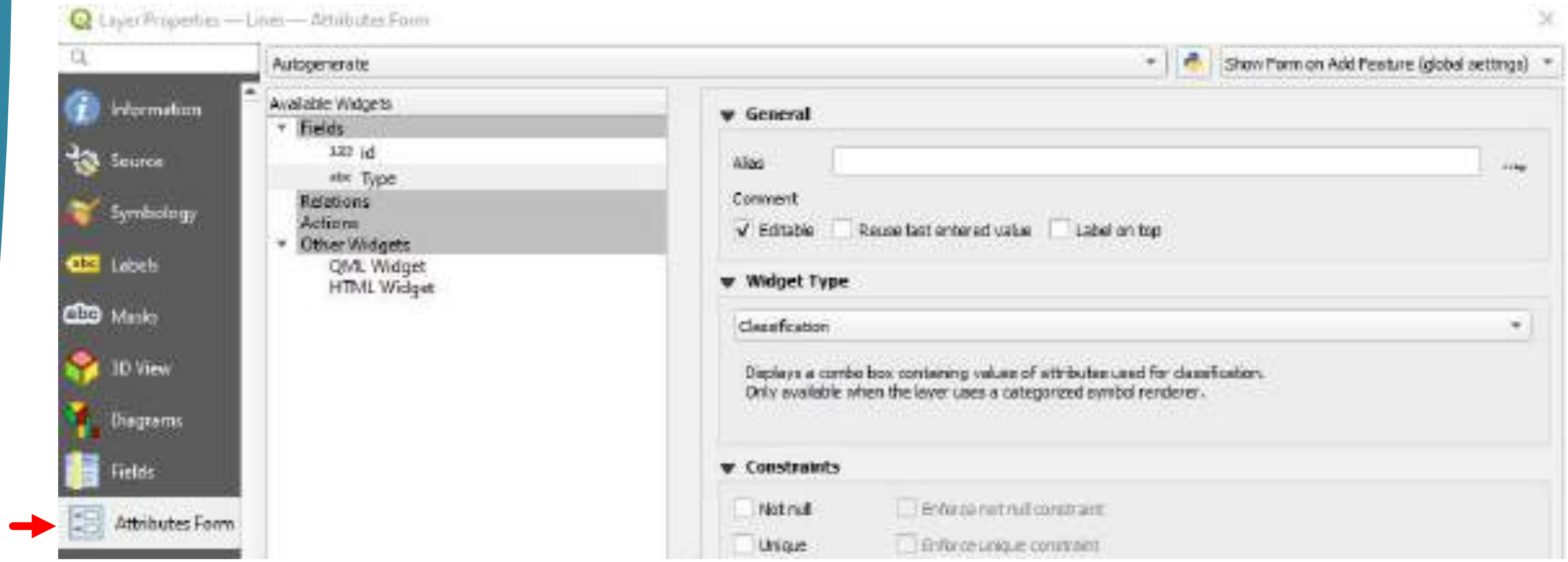
  - As a value, choose the custom field you have added when creating the shapefile (which you may have named as "Unit", "Type", etc.)
  - Choose a symbol to identify that unit. You may either choose one amongst the available FGDC symbols or create a custom one.
  - Name your unit under both the Value and Legend tags.
  - Apply modifications and go to Attributes Form on the left panel.



Define your geological units

- Each shapefile can be categorized into subclasses, which will represent your geological units. To create these units:
  - Access the Properties of your shapefile (ex. Lines) and go to Symbology on the left panel.
  - On top, select Categorized.
  - As a value, choose the custom field you have added when creating the shapefile (which you may have named as "Unit", "Type", etc.)
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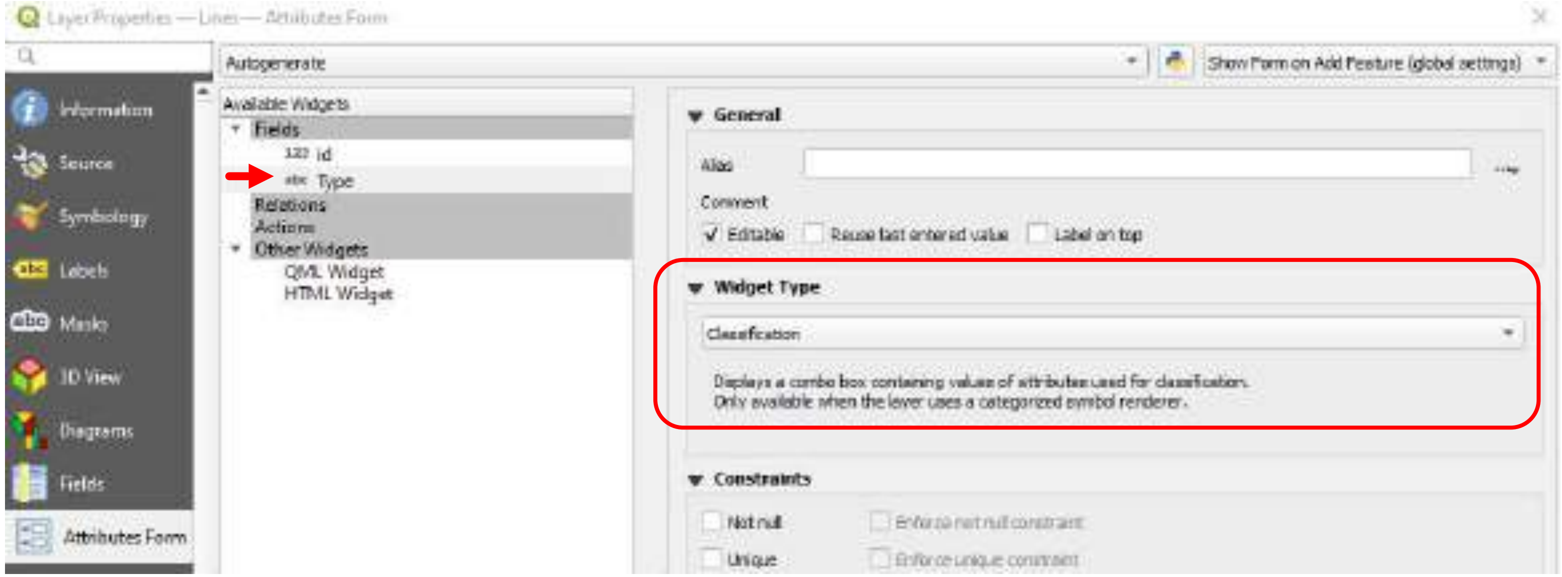
  - Name your unit under both the Value and Legend tags.
  - Apply modifications and go to Attributes Form on the left panel.
  - Click on your custom field under the "Fields" label and choose "Classification" under "Widget Type".



Define your geological units

- The same procedure described in the previous slide should be applied for each type of shapefile.
- If you're planning to use Mappy, you do not need to create polygonal shapefiles, as these will be generated automatically using your lines and points.
- You do not need to stick to the FGDC terminology. Feel free to name units under the term you consider more appropriate, using your own thinking.

Present your results

- Results should be included in a one-slide/ short presentation that will be discussed at the end of the exercise.
- It is suggested to create a layout in QGIS that includes both the geological map and a legend. You may also include a title, labels, and additional items (north arrow, scale bar, etc.). To do so:
  - Open a new layout by clicking on Project – Layout Manager – Create.
  - In the layout window, click on Add Item – Add Map (top toolbar) to draw the area where you intend to show your map. Use icons on the right in "Item Properties" to properly adjust the scale and the extent of your map.
  - Click on Add Item – Add a Legend, untick "Auto update" in Item Properties on the right panel, and edit your legend properly until only geological units are shown.

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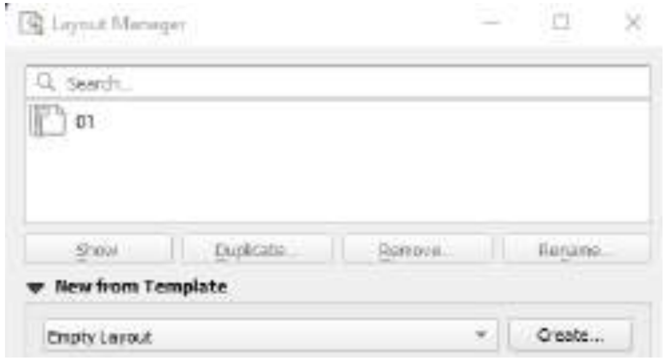

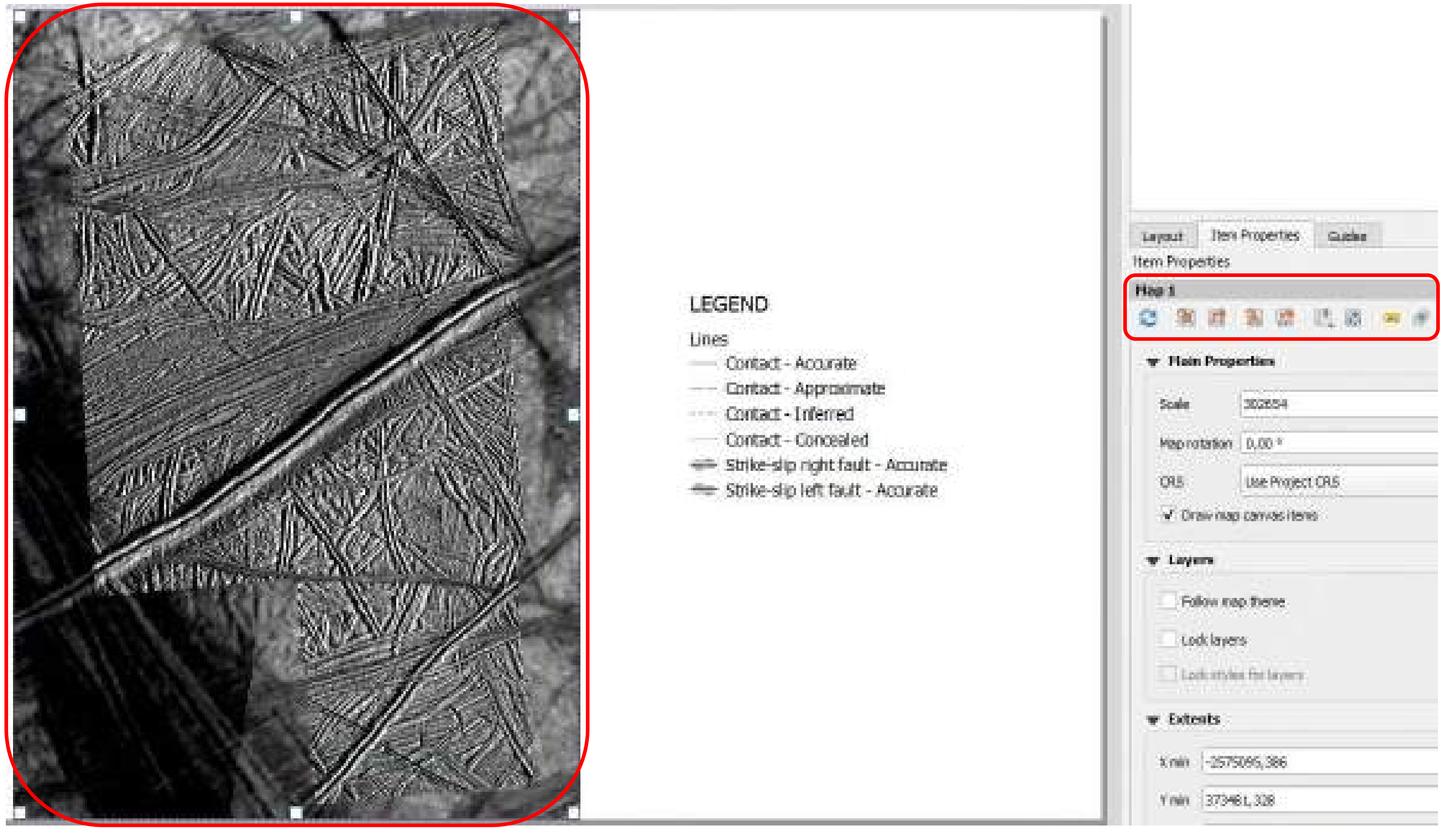

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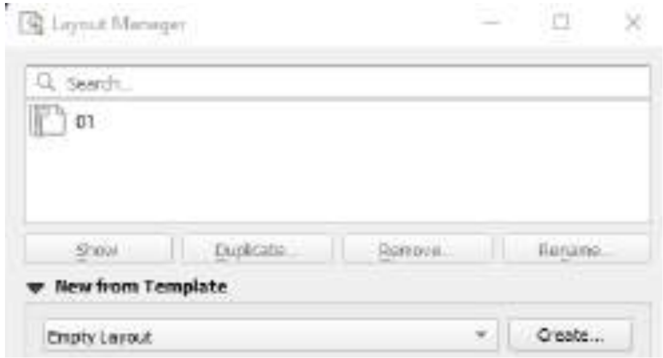

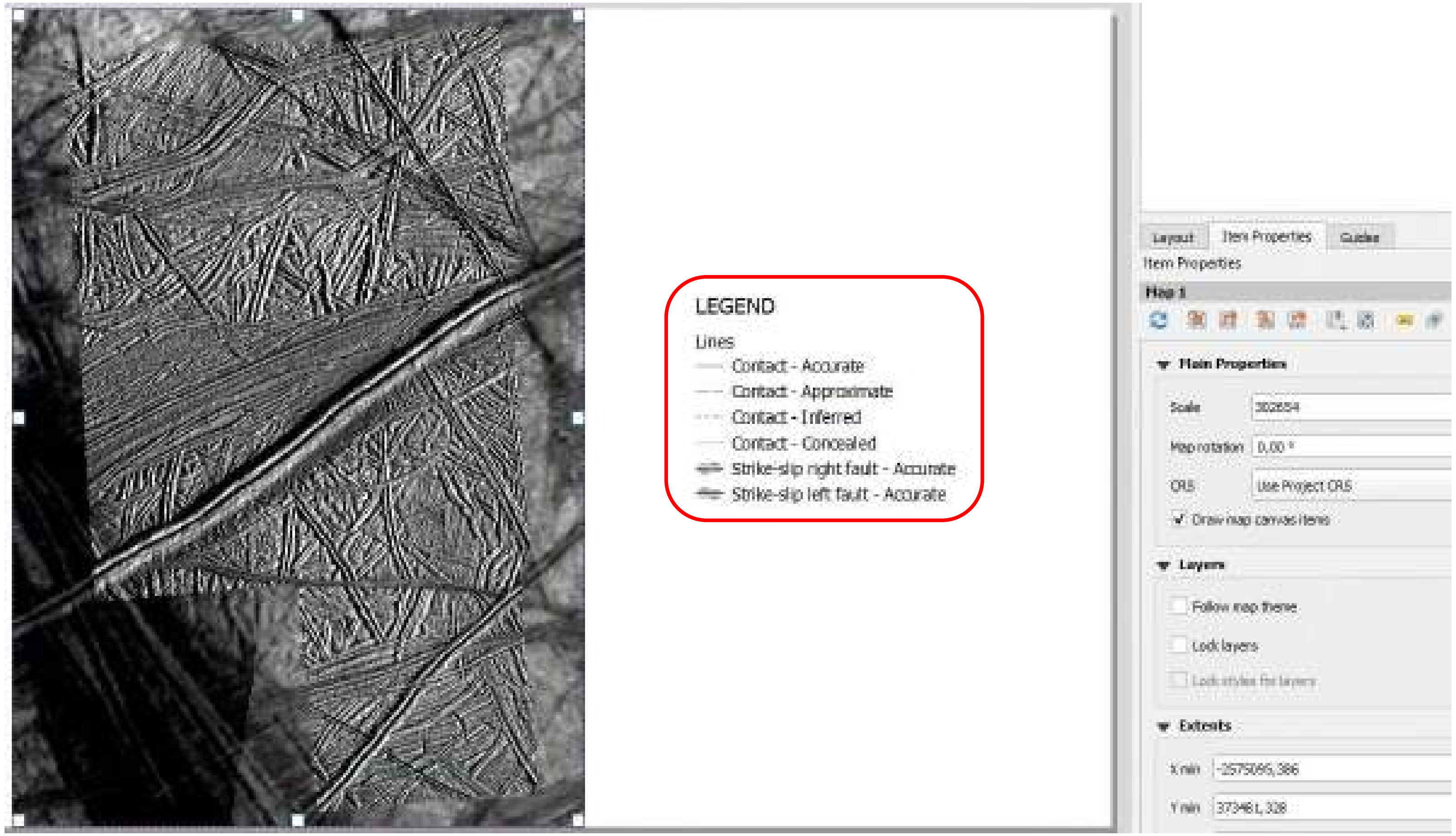

Final Tips

- Save your project and any shapefile editing frequently!
- Turn on the Advanced Digitizing Toolbar and the Snapping Toolbar (you will find them under View – Toolbars). They will help you considerably in increasing mapping accuracy and efficiency while reducing working time.
- Consult the geological features discussed in the morning lesson.
- Save some time to create your presentation.
- Good Luck!

Final Tips

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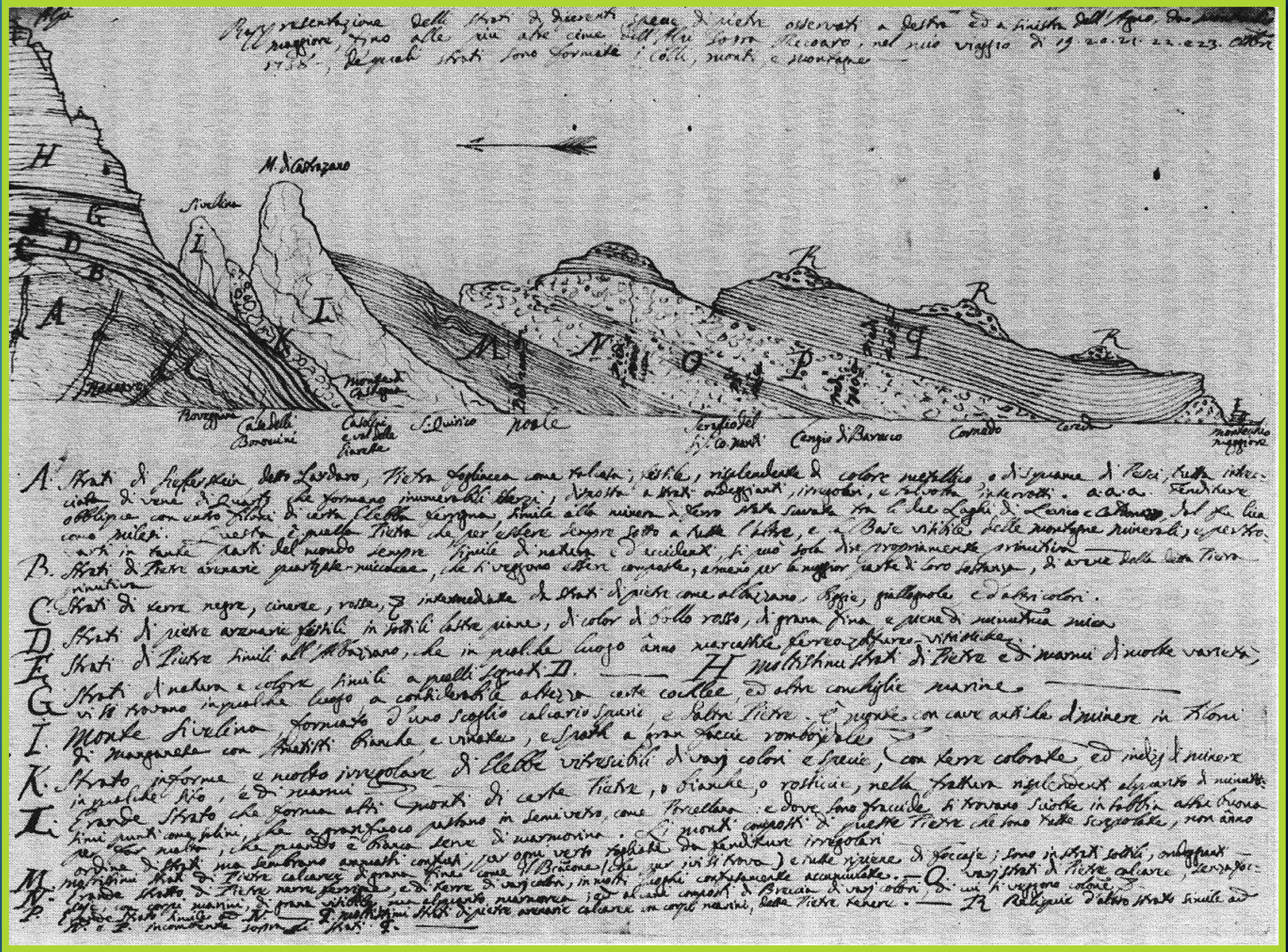
- Turn on the Advanced Digitizing Toolbar and the Snapping Toolbar (you will find them under View – Toolbars). They will help you considerably in increasing mapping accuracy and efficiency while reducing working time.
- Consult the geological features discussed in the morning lesson.
- Save some time to create your presentation.
- Good Luck!

Co-funded by the
ERASMUS + Programme
of the European Union

Cross sections and stratigraphic schemes

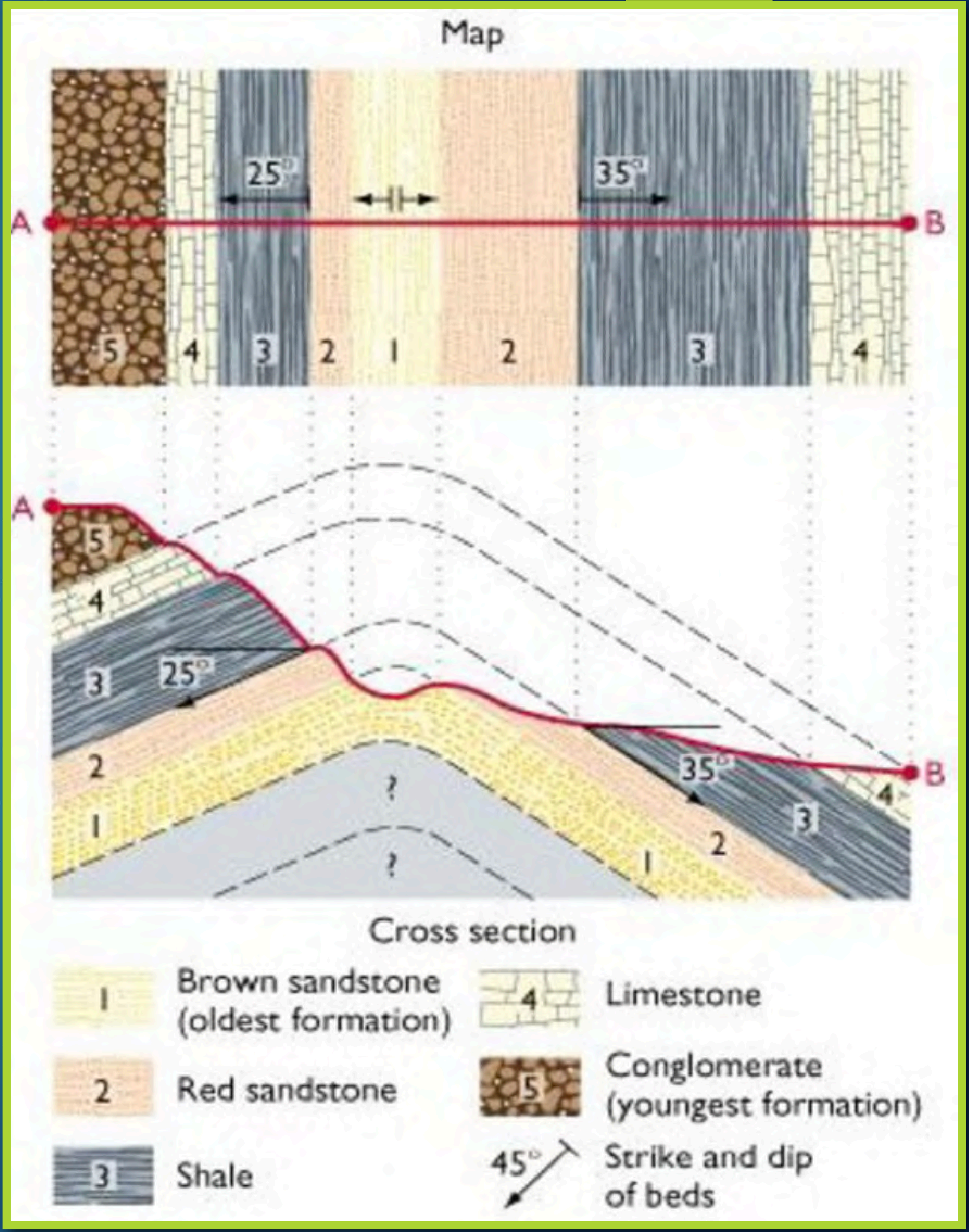
Valle dell'Agno: Giovanni Arduino (1758)

- Classification of the four main layers of the Earth's crust as Primary, Secondary, Tertiary, and Quaternary.



Geological Cross sections

- Complement of the geological maps.
- Geologic features from the side view: intersection of the geological bodies in the subsurface with a vertical plane of a certain orientation.
- The different geological units, their constitution and internal structure and the geometric relationship between them are represented.



Preparing Geological Cross Sections

Earth

- Select a section line
- Topographic profile along the line of section
- Transfer contacts from the map to the topographic profile
- Project dip data into the cross section line
- Calculate and plot apparent dips on the topographic profile
- Construct the subsurface interpretation

Preparing Geological Cross Sections
Planets vs Earth

- ✓ Select a section line
- ✓ Topographic profile along the line of section
- ✓ Transfer contacts from the map to the topographic profile
- ✓ (Project dip data into the cross section line)
- ✓ (Calculate and plot apparent dips on the topographic profile)
- ✓ Construct the subsurface interpretation

Preparing Geological Cross Sections
Planets vs Earth

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- ✓ Transfer contacts from the map to the topographic profile
- ✓ (Project dip data into the cross section line)
- ✓ (Calculate and plot apparent dips on the topographic profile)
- ✓ Construct the subsurface interpretation

Be Aware: much more interp

Select a section line

Earth

- Identify regional structural trends
- Draw section line perpendicular to regional structural trends and through areas that best depict the structure
  - May need more than one section line
- Draw sections through area(s) with the best structural control
  - Most reliable contacts
  - Nearby structural data

Main emphasis is to unravel structural

Select a section line
Planets vs Earth

- ✓ Identify morphological trends or lateral transitions among units
- ✓ Draw section line perpendicular to such trends and through areas that best depict the structure
  - ✓ May need more than one section line
- ✓ Draw sections through area(s) with the best exposure and 'morphological control'
  - ✓ Most reliable contacts

Structural overprint can be absent. Emphasis on relations among (morphological) units.

Topographic profile along the line of section Planets and Earth

- DEM needed (Potentially you can also create contour lines and proceed exactly as you would do with topographic maps on Earth)
- Scale must be consistent with the scale of the geological map
  - practical tip
    - the plugin Terrain profile is very user-friendly and export profiles in vector format
    - the plugin QProf allows to create and export the profile and also to include information on the geology

Transferring Contacts from the Map to the Topographic Profile

Planets and Earth

- Step 1: Mark the intersection of each contact, fault or unconformity with the section line
- Step 2: Transfer the location of each contact, fault or unconformity marked on the section line to the topographic profile
  - ✓ practical tip
    - ✓ QGis QProf allows to include geology

Projecting Dip Data into the Cross Section Line

Planets vs Earth

- Dip data very rare in planetary settings.
- Dip data are generally localized in basins in planetary settings (Mars unique example so far).

Projecting Dip Data into the Cross Section Line

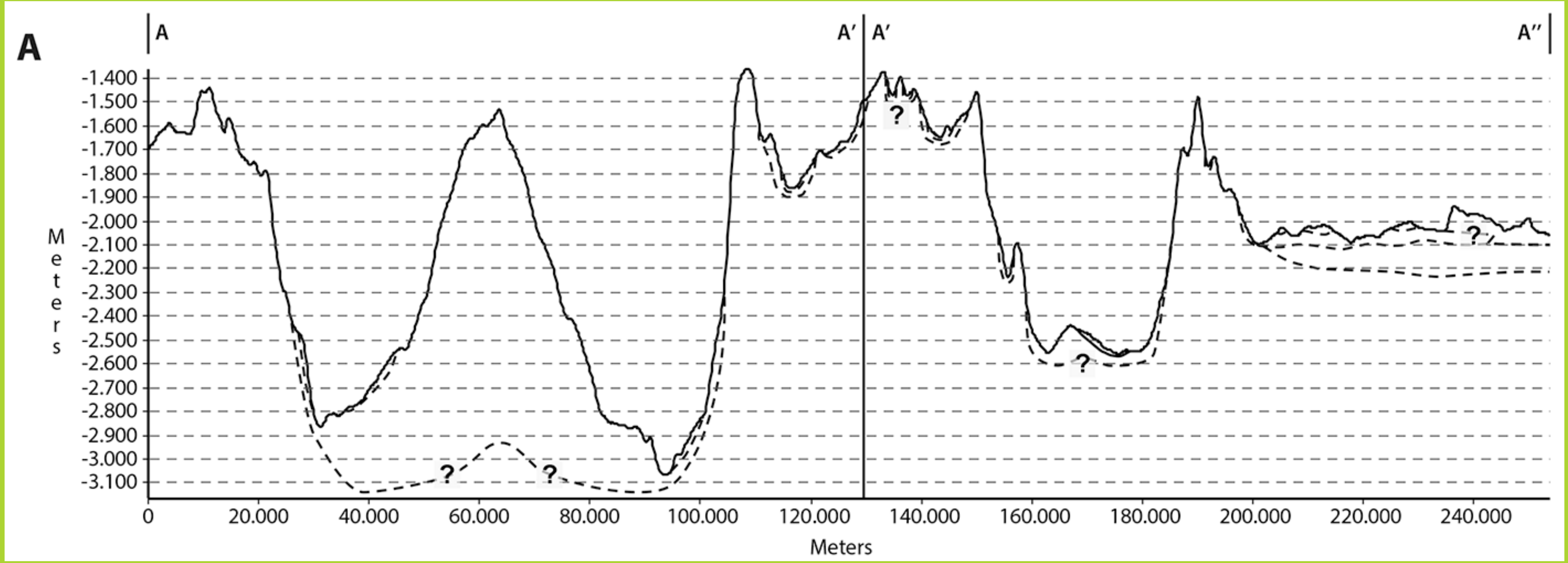
Planets vs Earth

- Dip data very rare in planetary settings.
- Dip data are generally localized in basins in planetary settings (Mars unique example so far).

- ✓ First define your basin boundaries (e.g., crater)
- ✓ Infer the depth of your units/morphologies (e.g., Garvin equations for craters)
- ✓ Don’t be ashamed to put many question marks in your profile

Projecting Dip Data into the Cross Section Line

Planets vs Earth



Craters on Mars: Global geometric properties

Table 1. Diameter Dependent Impact Crater Parameters and Relationships

Parameter		Simple crater relationship	Complex crater relationship	Large crater relationship	Comments
depth	d	$d=0.21D^{0.81}$	$d=0.36D^{0.49}$		Fit to profile data for simple craters, DEM data for complex and large craters.
Rim height	H	$h=0.04D^{0.31}$	$h=0.02D^{0.84}$	$h=0.12D^{0.35}$	Complex 7-100 km, large >100km. Used DEM and Profile data.
Central Peak Height	h_{cp}	—	$h_{cp}=0.04D^{0.51}$	—	Not done for large or simple craters. Complex range 7-100 km. Used DEM and Profile data.
Central Peak Diameter	D_{cp}	—	$D_{cp}=0.25D^{1.05}$	—	Not done for large or simple craters. Complex range 7-Used DEM and Profile data.100 km.
Cavity Shape	z	$z=0.204x^{1.76}$	$z=0.008x^{2.65}$	—	These are for profile data, for the function $z=kx^n$ as discussed in the text. Preliminary simple crater DEM data fit: $z=0.21x^{1.68}$, and complex crater DEM data fit $z=0.014x^{2.34}$
Cavity shape fit coefficient	k	$k=0.76D^{-1.17}$	$k=5.62D^{-2.51}$	—	$z=kx^n$, for profile data "good" fits
Cavity shape fit exponent	n	$n=1.04D^{0.366}$	$n=1.62x^{0.14}$	—	$z=kx^n$, for profile data "good" fits. For "good+fair" (includes central peak and polar filled craters) and "good+fair+poor" fits, the simple crater relationship does not significantly change, while the complex fit changes to $n=1.88x^{0.10}$ and $n=2.10x^{0.07}$, respectively.
Inner Cavity Wall Slope	s	$s=28.40D^{-0.18}$	$s=23.82D^{-0.28}$	—	Complex craters 7-100 km. Simple fit to profile data. Complex fit is to DEM data. Note offset of fits at transition.

Garvin et al., 2003

Projecting Dip Data into the Cross Section Line

Planets vs Earth

- Step 1: Identify which dip data you will use
  - Use data that occurs in a narrow band along either side of your section line (Projection distance is inversely proportional to structural complexity)
- Step 2: Project the data into the cross section line
  - Project parallel to strike to the point where the projection line intersects the section line
- Step 3: Transfer the location of each projected dip data point to the topographic profile
- Calculate Apparent Dips

Projecting Dip Data into the Cross Section Line

Planets vs Earth

- Step 1: Identify which dip data you will use
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Planets (i.e., Mars) ⇢ Generally data are too few, so you have to infer the depositional geometries using 3d data. The result will be a schematic representation.

- Ste
  - F
    i
- Step 3: Transfer the location of each projected dip data point to the topographic profile
- Calculate Apparent Dips

Plot Apparent Dips on the Topographic Profile

Planets vs Earth

- Step 1: At each apparent dip data point, use a protractor to measure down from horizontal, the angle equal to the calculated apparent dip
- Step 2: Draw in the apparent dip symbol at the appropriate angle, and in the appropriate direction
  - These angles must be drawn precisely

Planets (i.e., Mars) ⇢ Generally impossible
BUT some plugins (e.g., Qgsurf) can help a bit

Construct the Subsurface Interpretation

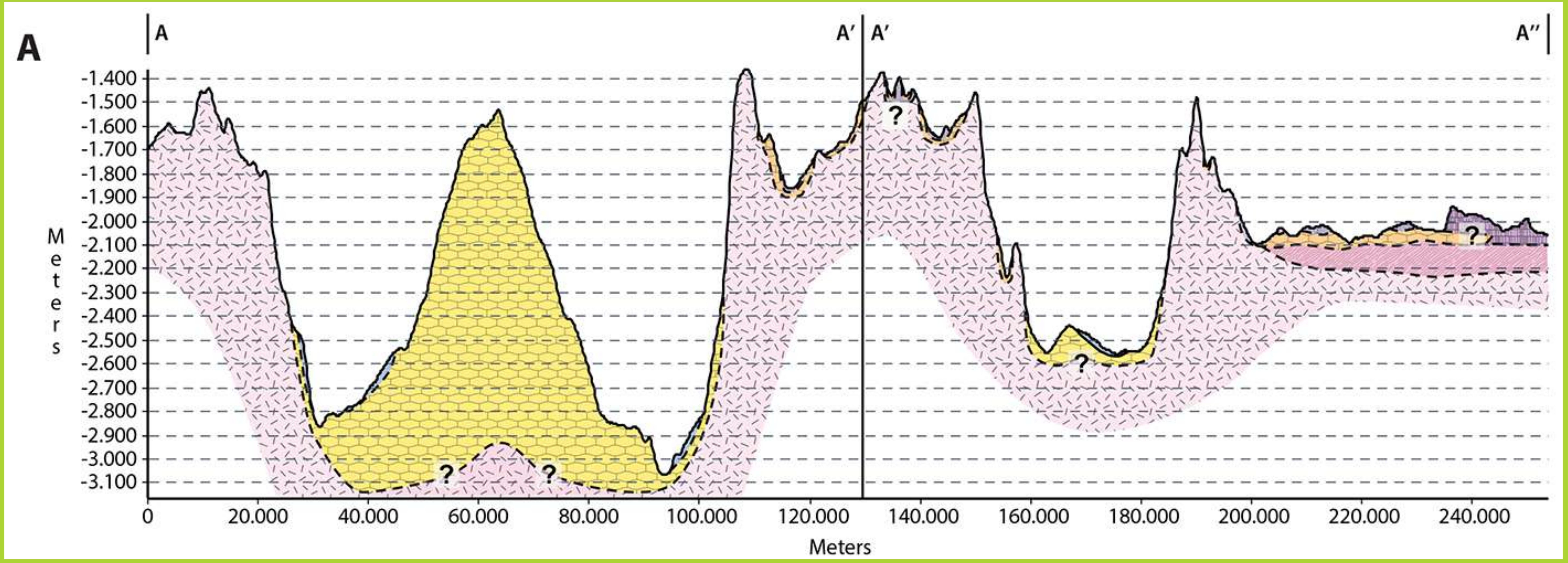
Planets vs Earth

- A cross section is an interpretation!
  - Honor your data
  - Uniform unit thickness unless you have good evidence to the contrary
  - Dip angles may only be valid for a short distance

Use geological/morphological interpretation to infer how to continue with depth

Construct the Subsurface Interpretation

Planets vs Earth



Use geological/morphological interpretation to infer how to continue with depth

Stratigraphy: the Tool to Order Rocks and Time

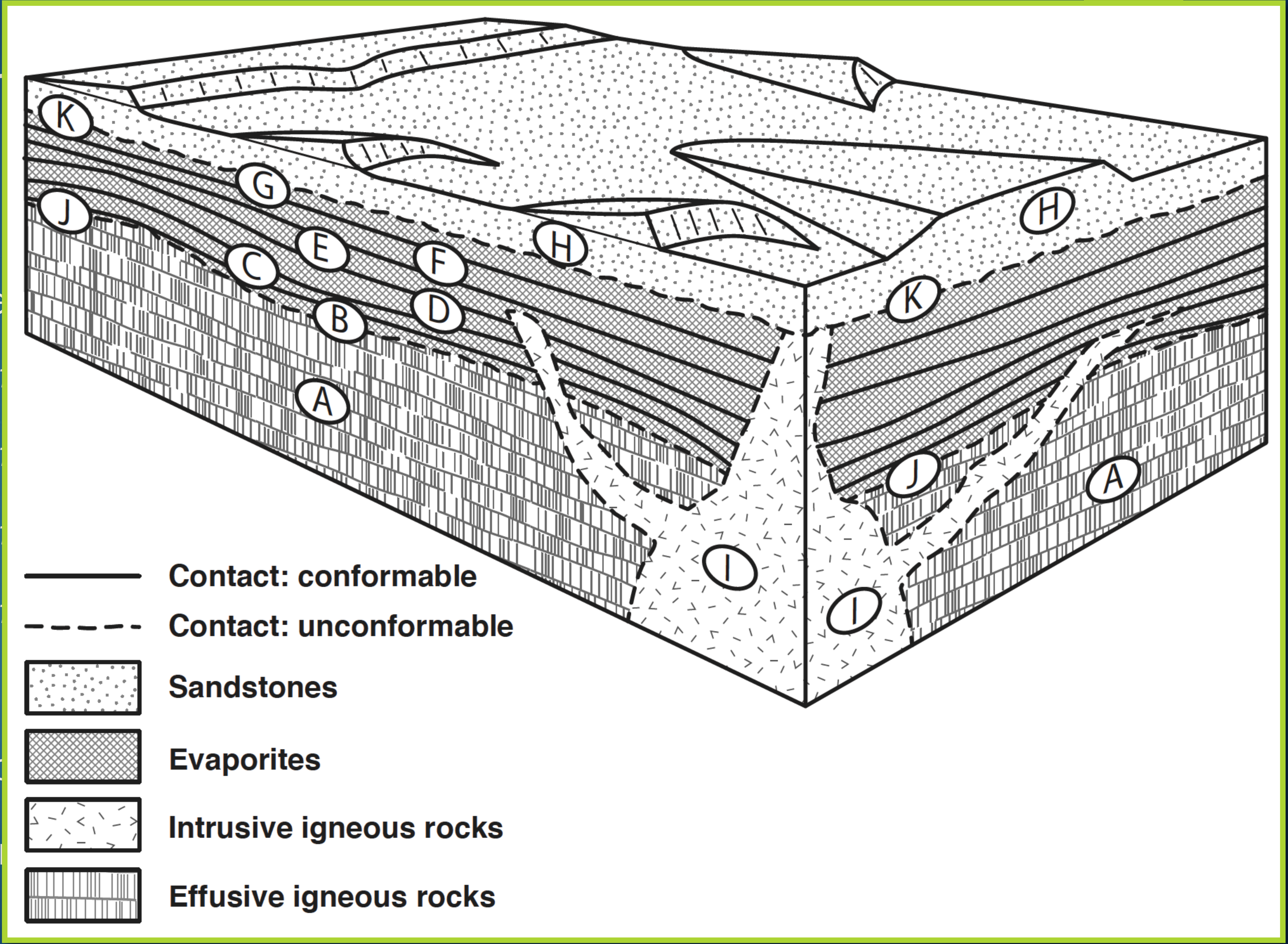
- The Principles of Stratigraphy (Steno, 1669)
  - *Principle of original horizontality*
  - *Principle of superposition*
  - *Principle of lateral continuity*
  - *Principle of cross-cutting relationships*

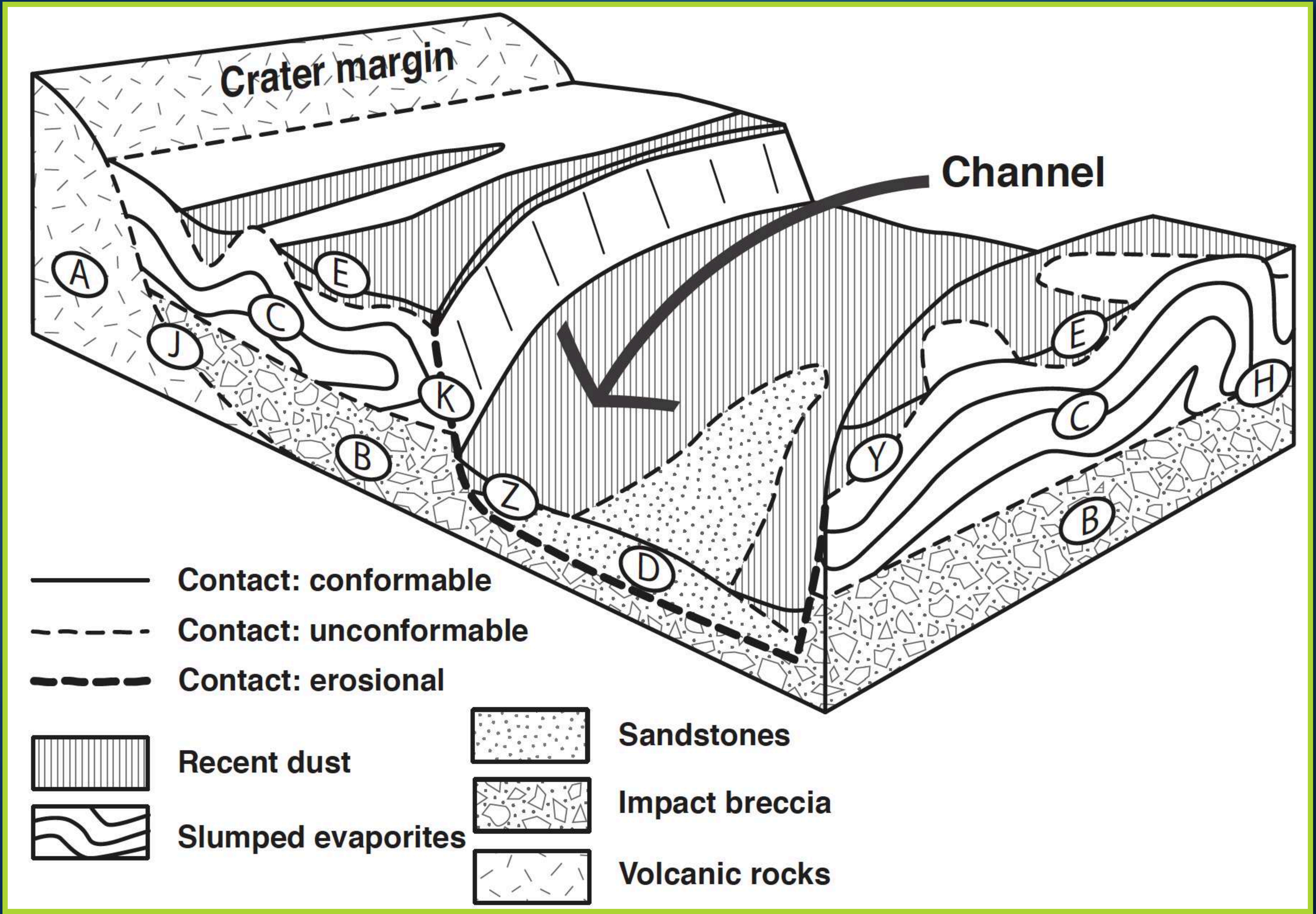
- Steno’s principles of stratigraphy constitute the basic tools to order the rocks of a specific area with respect to time, reconstructing a relative dating of the geological units.

Stratigraph
Time

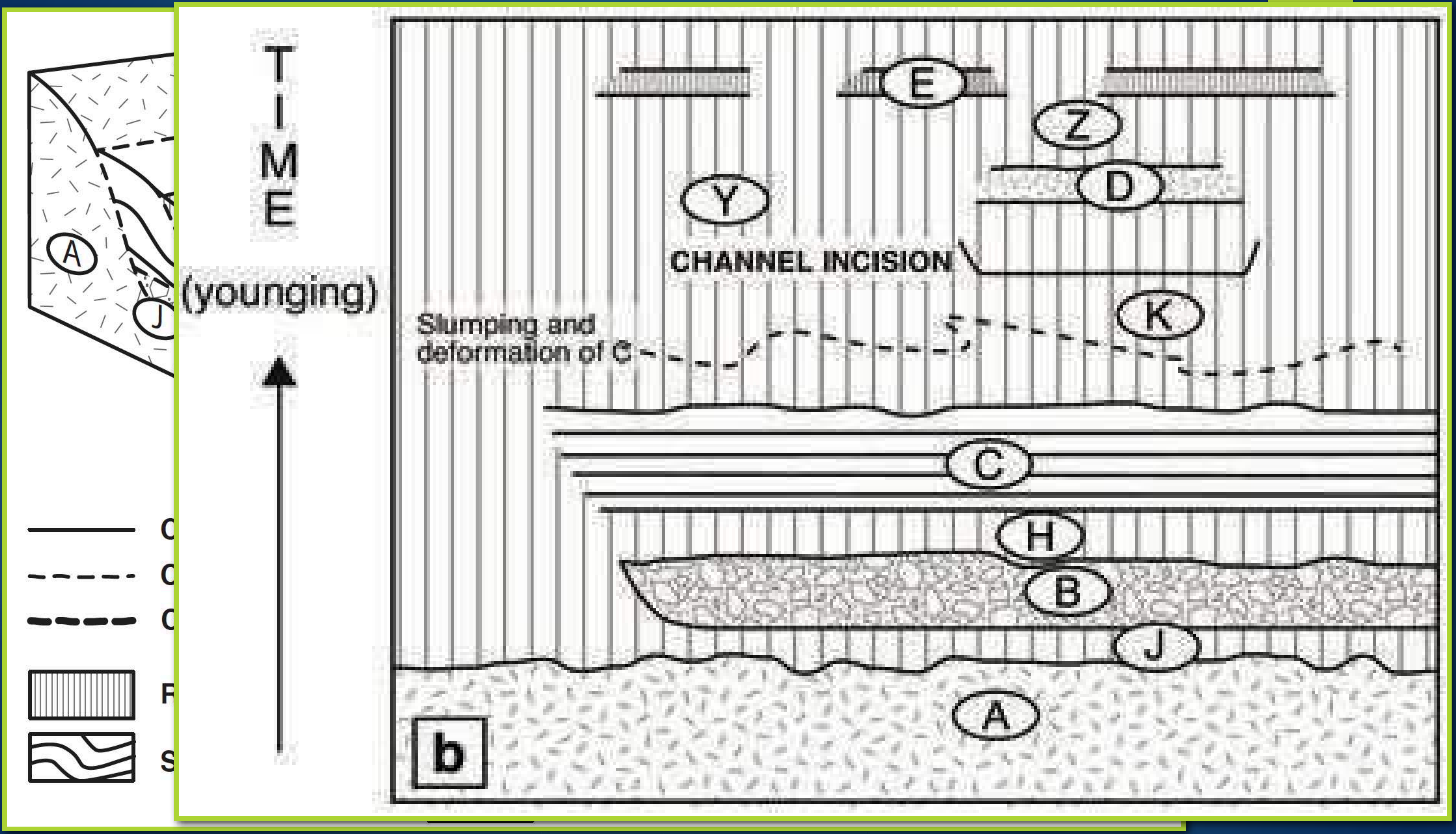
- The Principle
  - *Principle o*
  - *Principle o*
  - *Principle o*
  - *Principle o*

- Steno's princ
  the rocks of
  relative dati

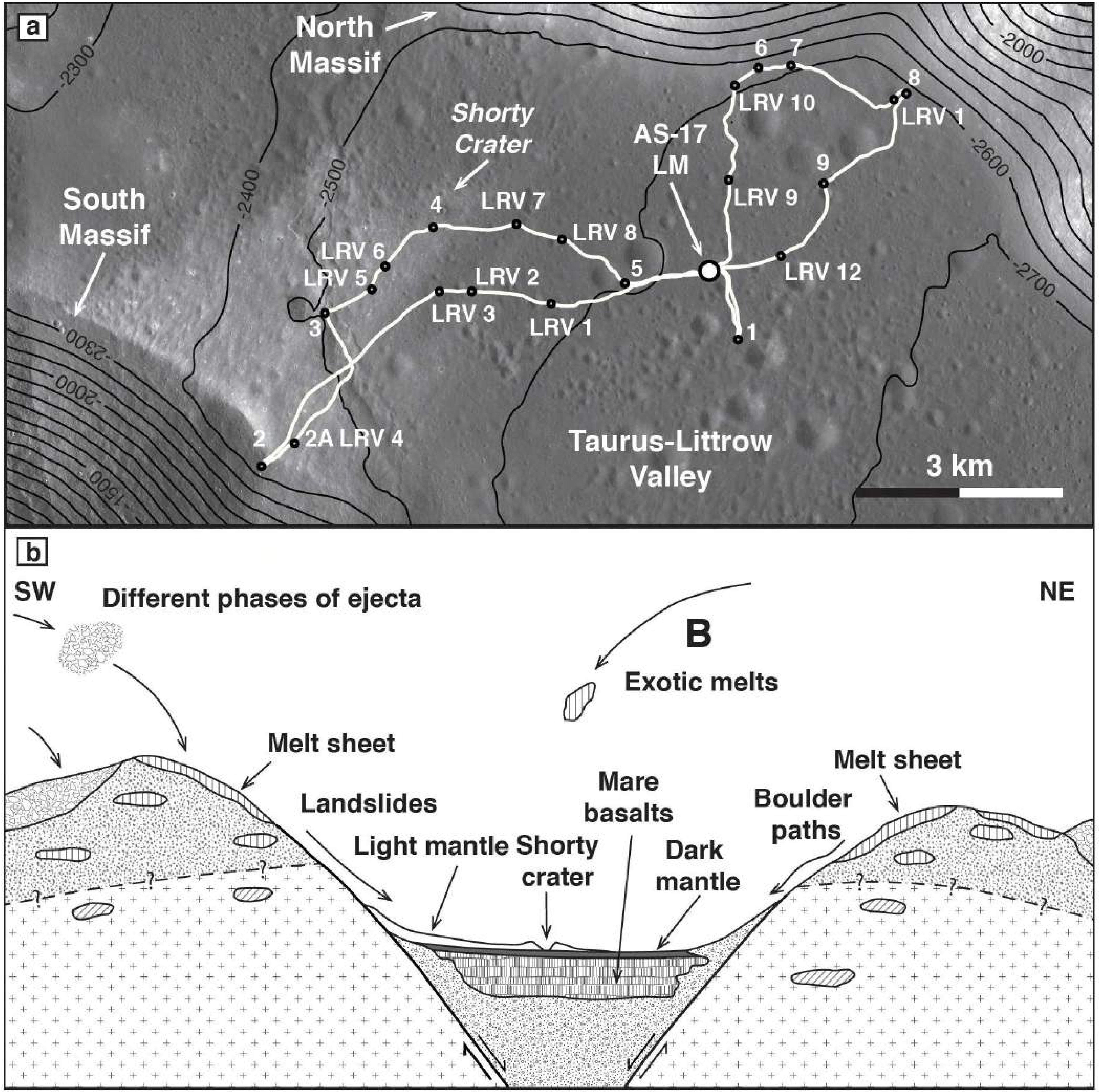




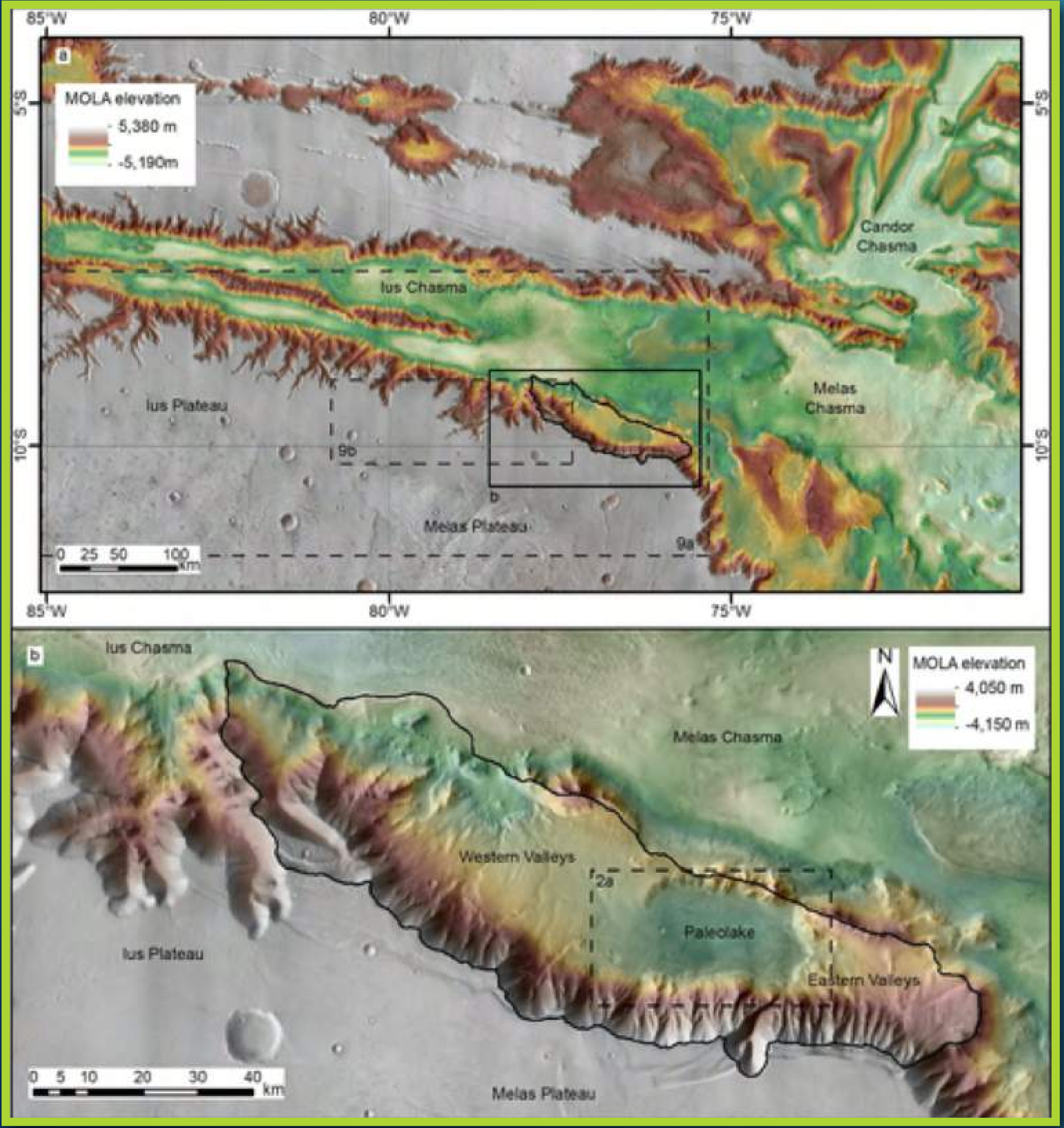
Crater margin
Channel
A
E
C
J
K
B
Z
D
Y
E
H
C
B
Contact: conformable
Contact: unconformable
Contact: erosional
Recent dust
Slumped evaporites
Sandstones
Impact breccia
Volcanic rocks



TIME
(younging)
Slumping and deformation of C
CHANNEL INCISION
E
Z
D
Y
K
C
H
B
J
A
b

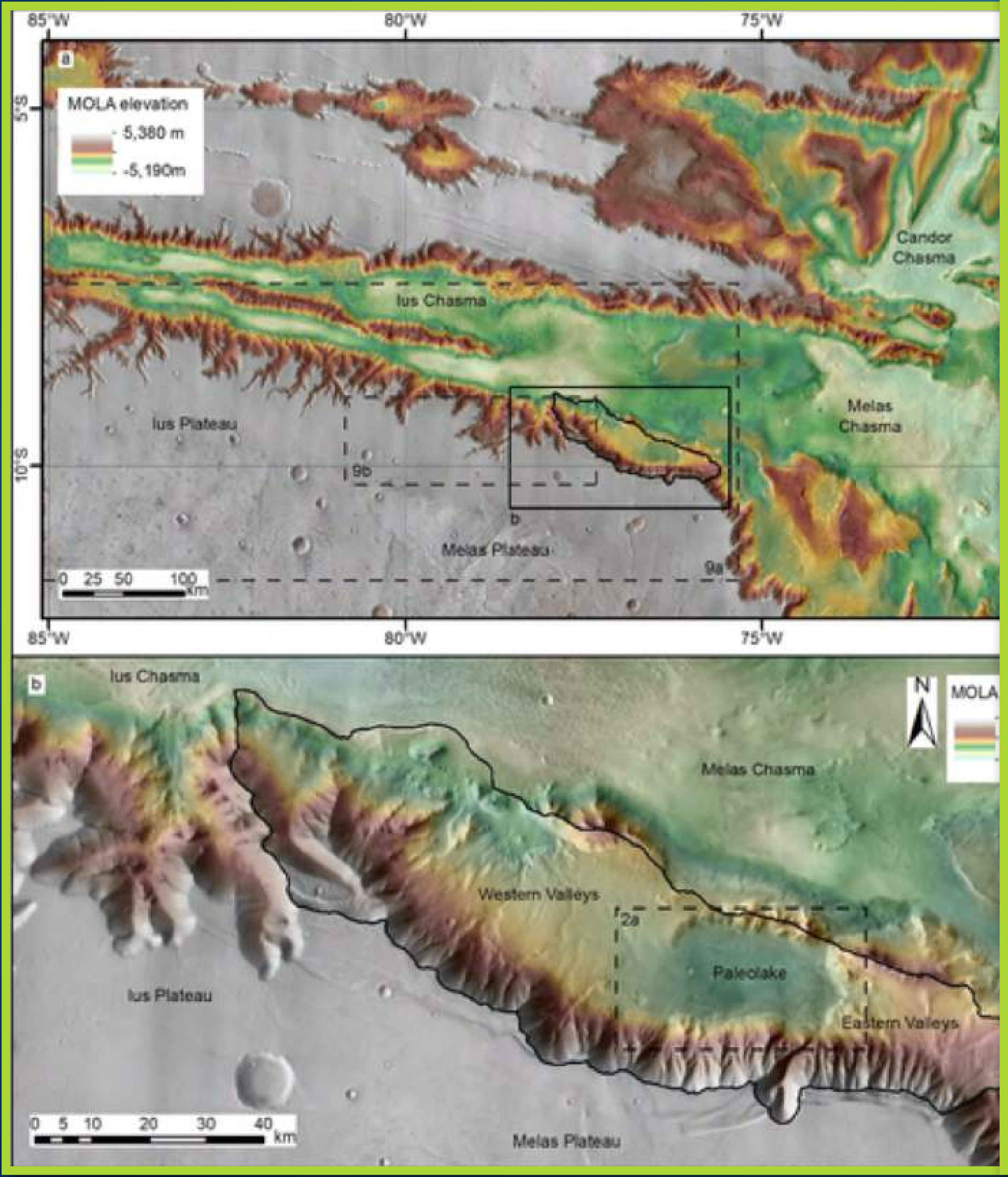

a
North Massif
-2300
Shorty Crater
AS-17 LM
South Massif
-2400
-2500
-2000
-2600
-2700
-1500
4
LRV 7
LRV 8
LRV 6
LRV 5
LRV 2
LRV 3
LRV 1
3
5
6
7
8
LRV 10
LRV 1
9
LRV 9
LRV 12
1
2
2A LRV 4
Taurus-Littrow Valley
3 km
b
SW
NE
Different phases of ejecta
B
Exotic melts
Melt sheet
Landslides
Light mantle
Shorty crater
Mare basalts
Dark mantle
Boulder paths
Melt sheet

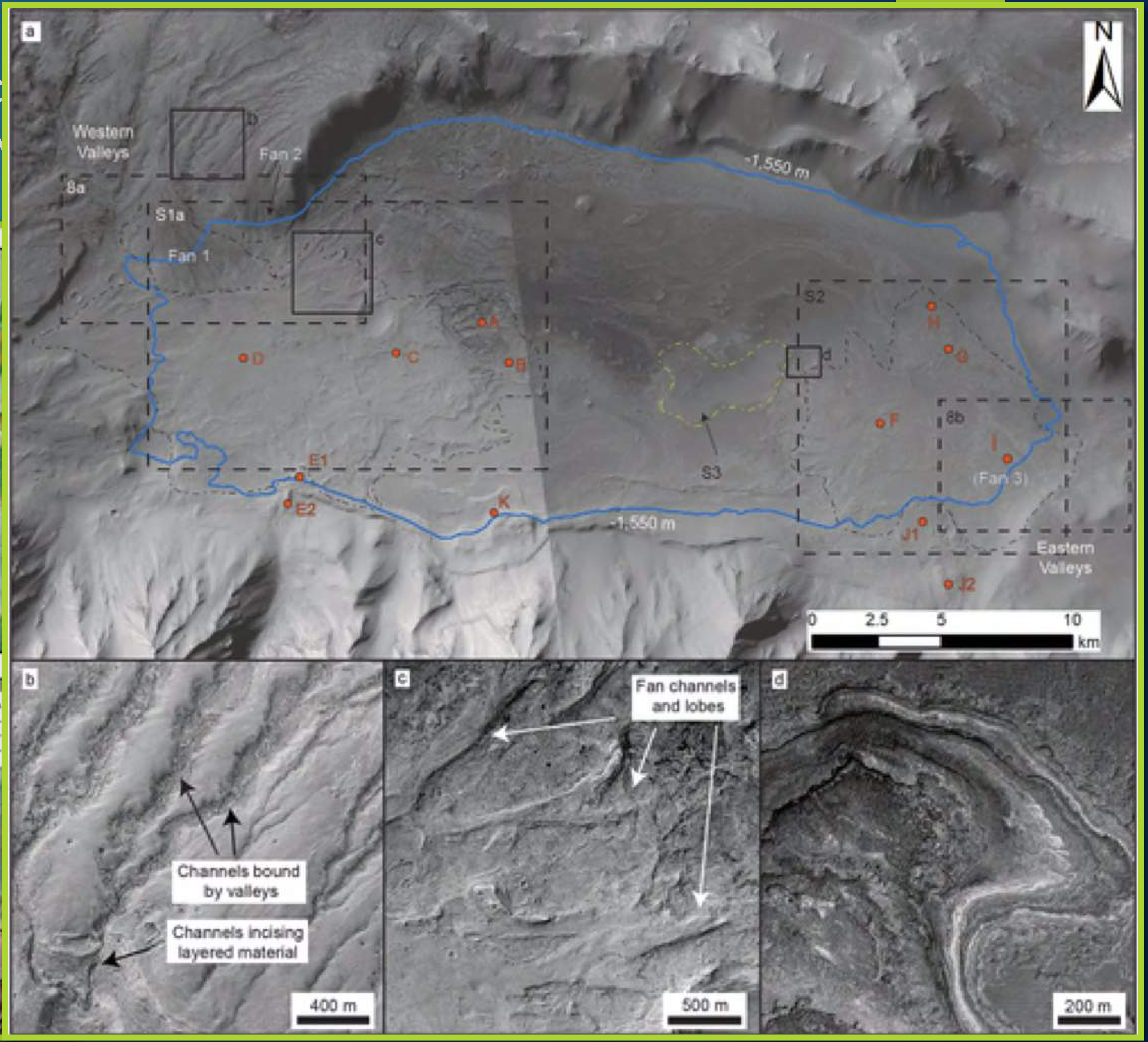
Example: Episodic and Declining Fluvial Processes in Southwest Melas Chasma, Valles Marineris, Mars



- Journal of Geophysical Research: Planets, Volume: 123, Issue: 10, Pages: 2527-2549, First published: 29 August 2018, DOI: (10.1029/2018JE005710)

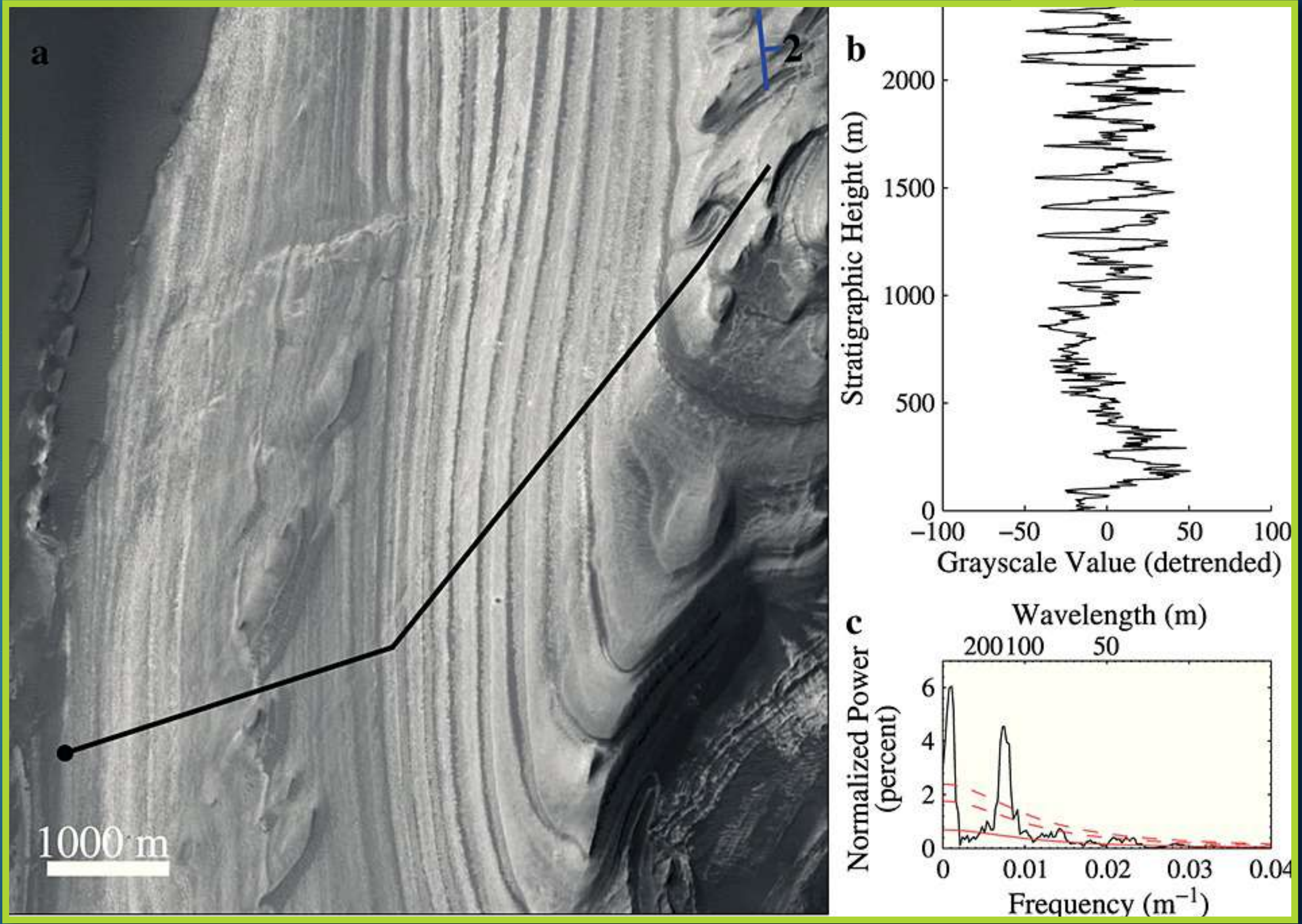
Example: Episodic and Dec
Southwest Melas Chasma, Y





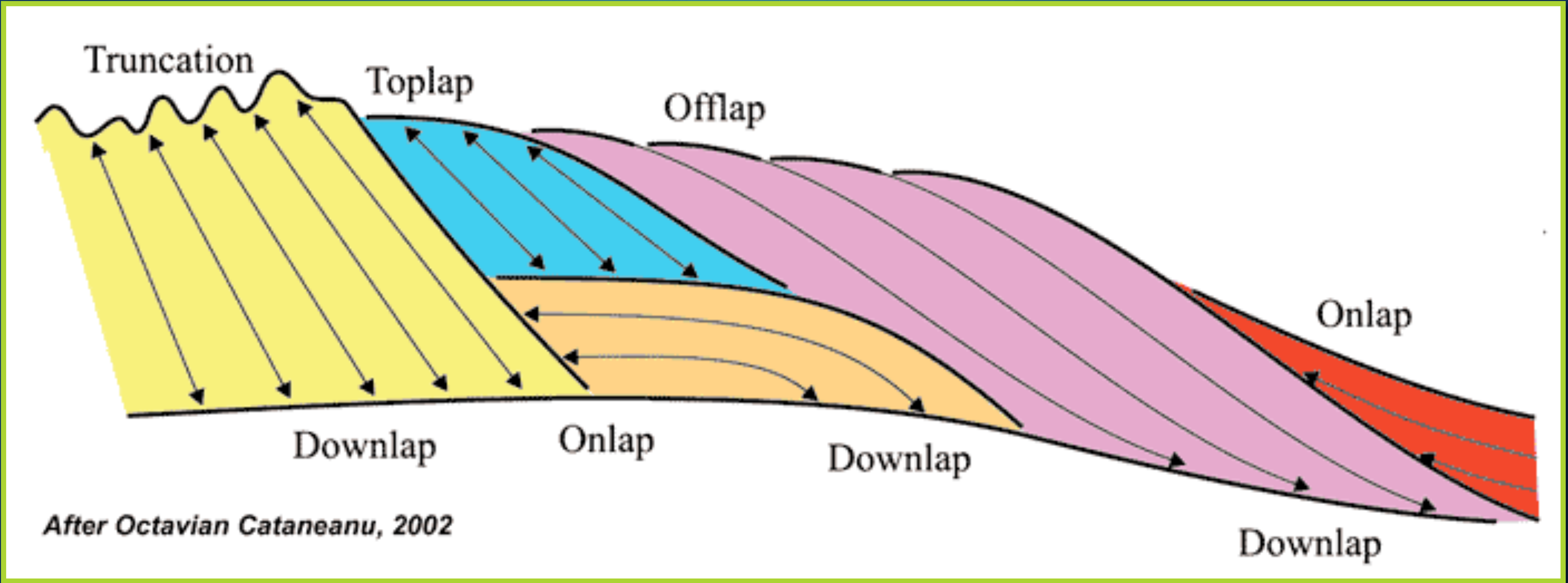
Beds/layers vs bedset

- Bedset: a number of superposed, similar beds.
- More precise than bed/layer because of the limits related to the resolution



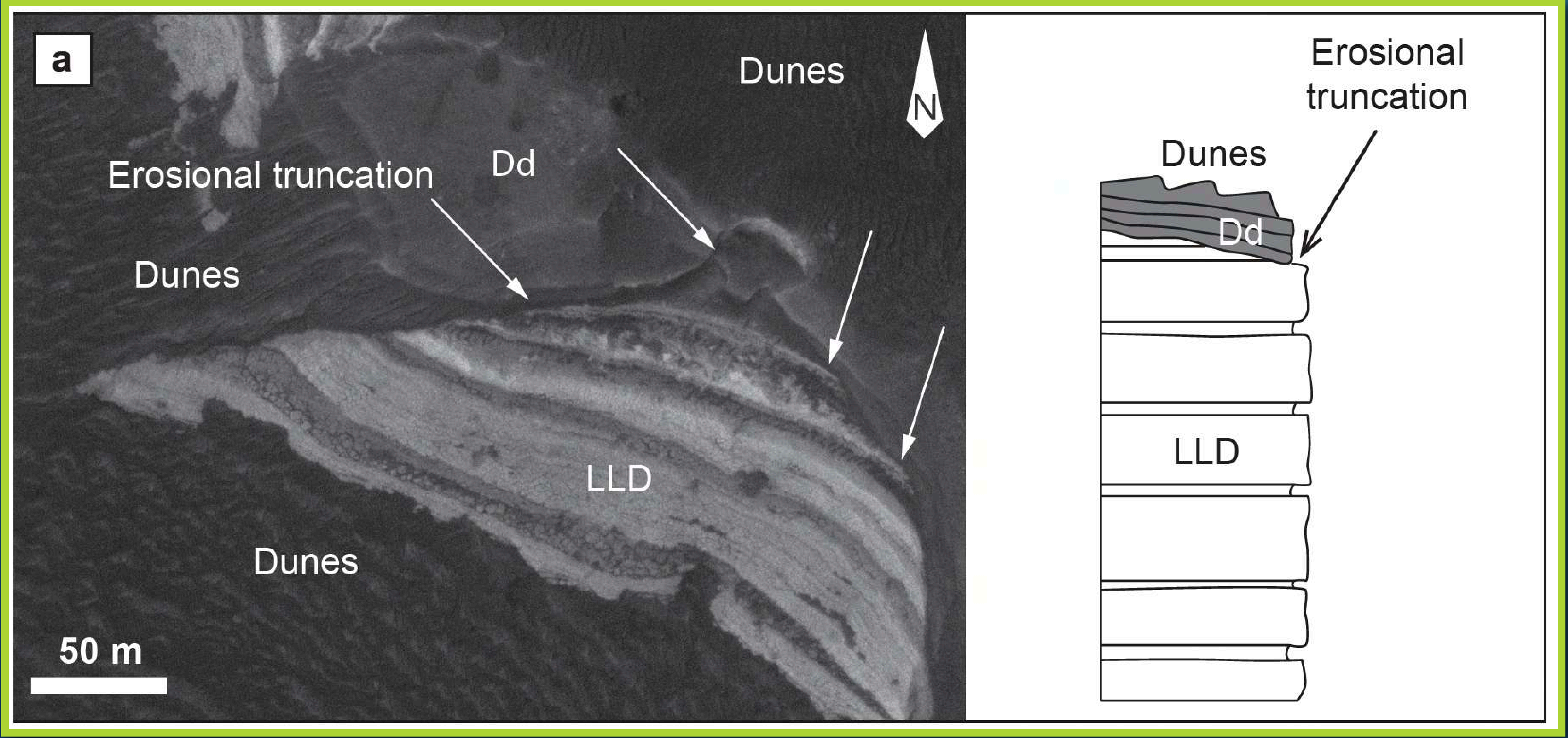
Lewis and Aharonson, 2014. Journal of Geophysical Research: Planets, Volume: 119

Units lateral termination
Layer Terminations and Geometries



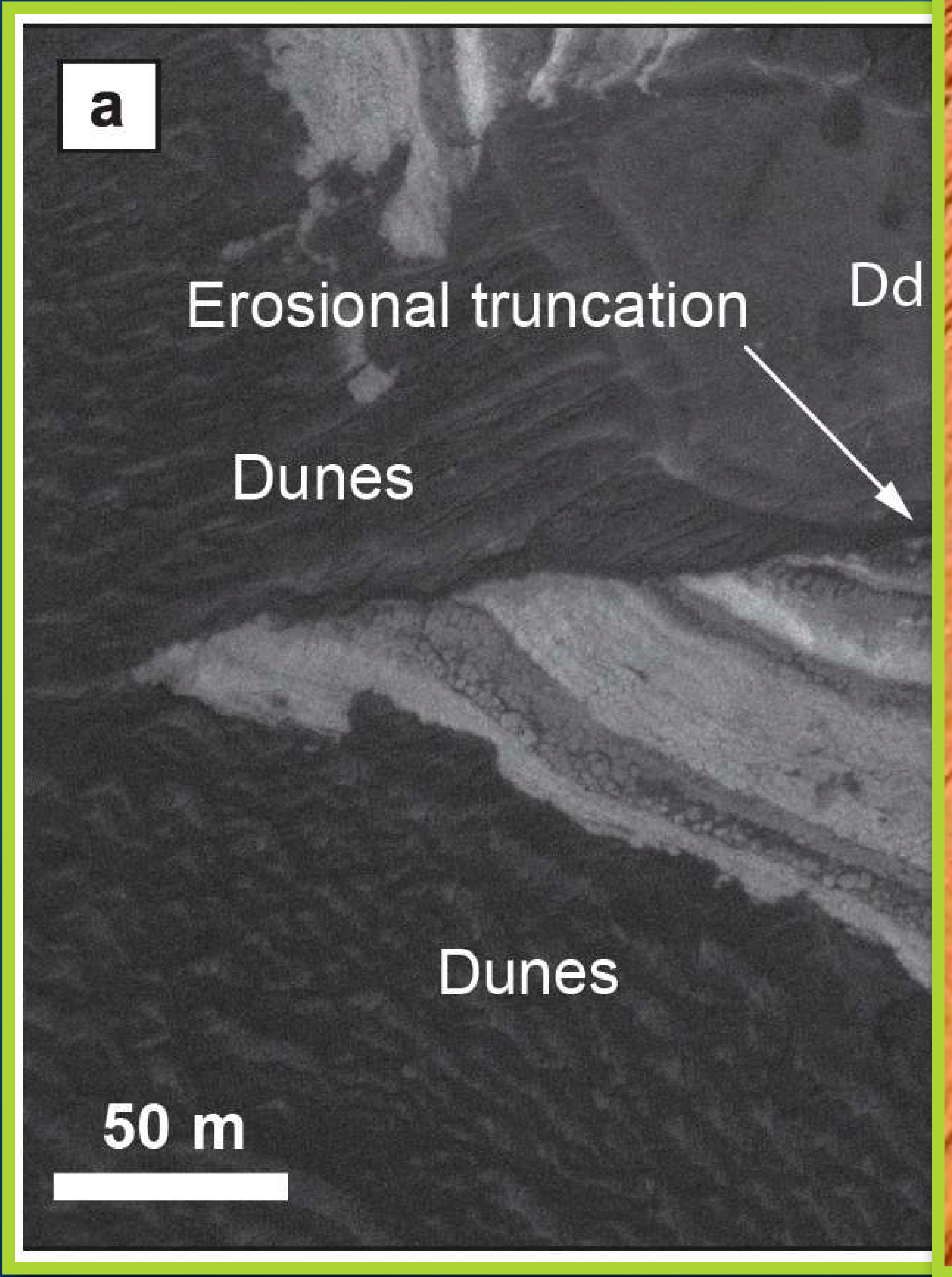
Erosional Truncation

- Some time is missing: implies either the development of erosional relief or the development of an unconformity (Emery, 1996).



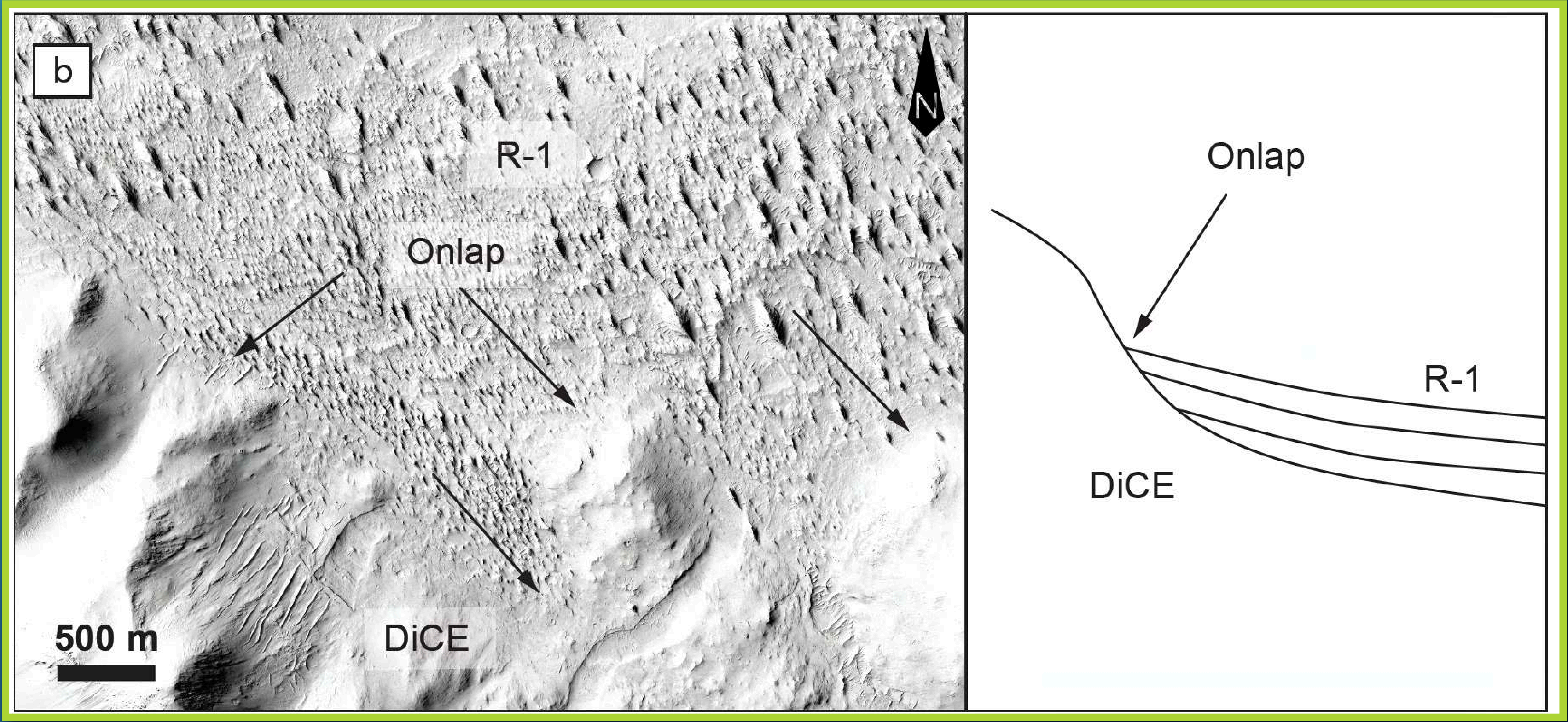
Erosional Tru

- Some time is n
relief or the de

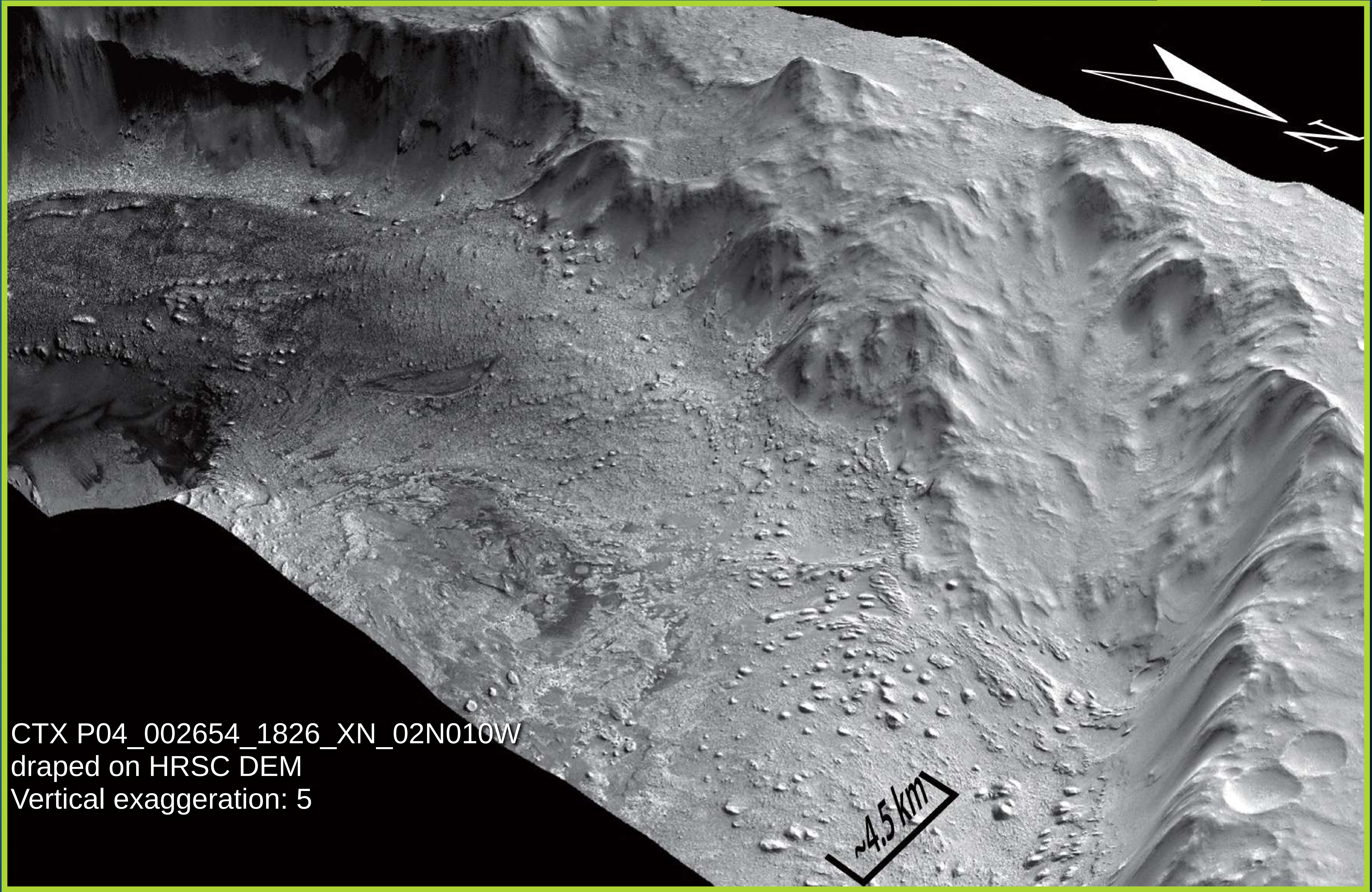


Onlap

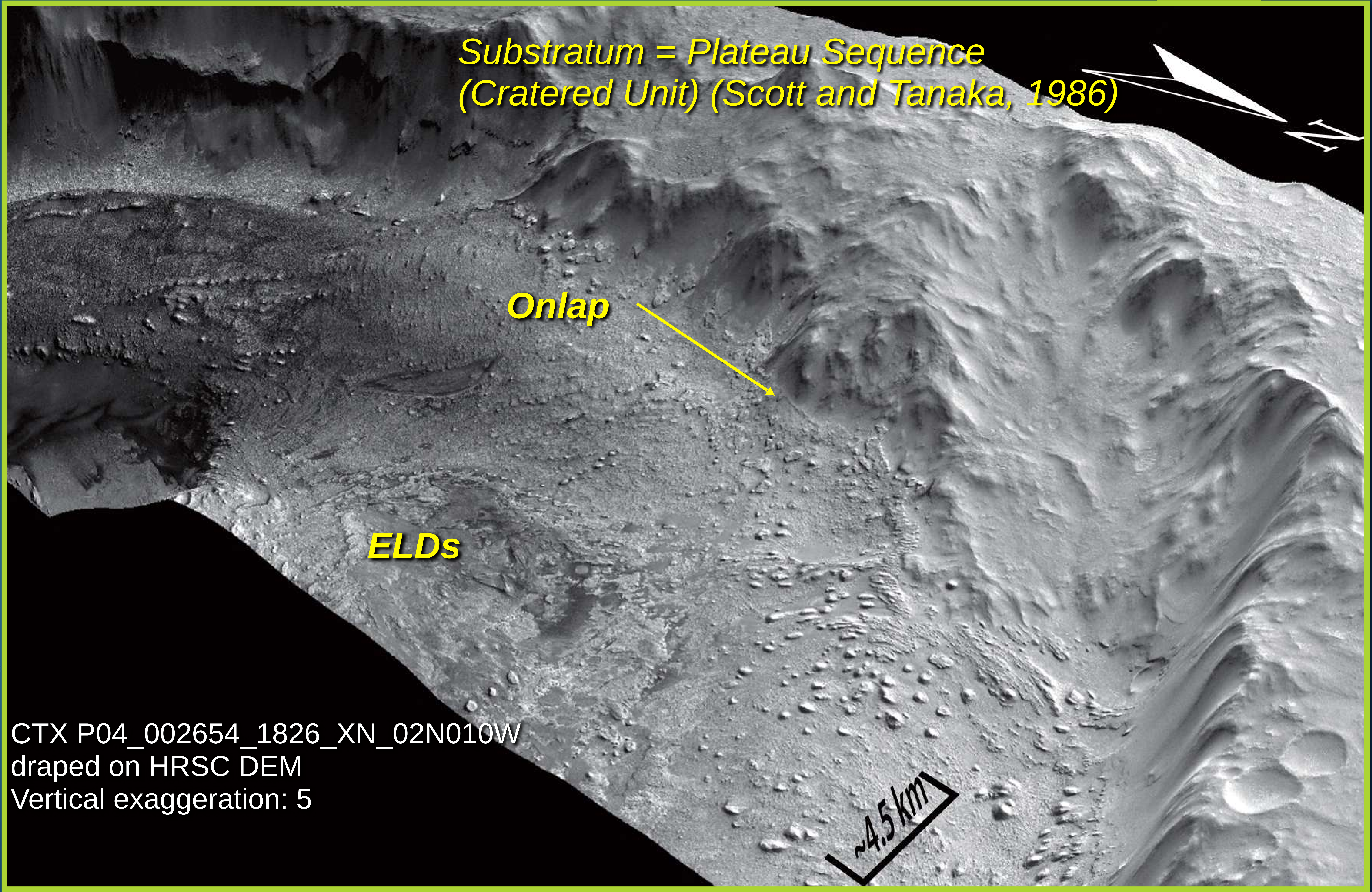
- A base-discordant relation in which initially horizontal strata terminate progressively against an initial inclined surface, or in which initially inclined strata terminate progressively updip against a surface of greater initial inclination (Mitchum, AAPG Memoir 26).



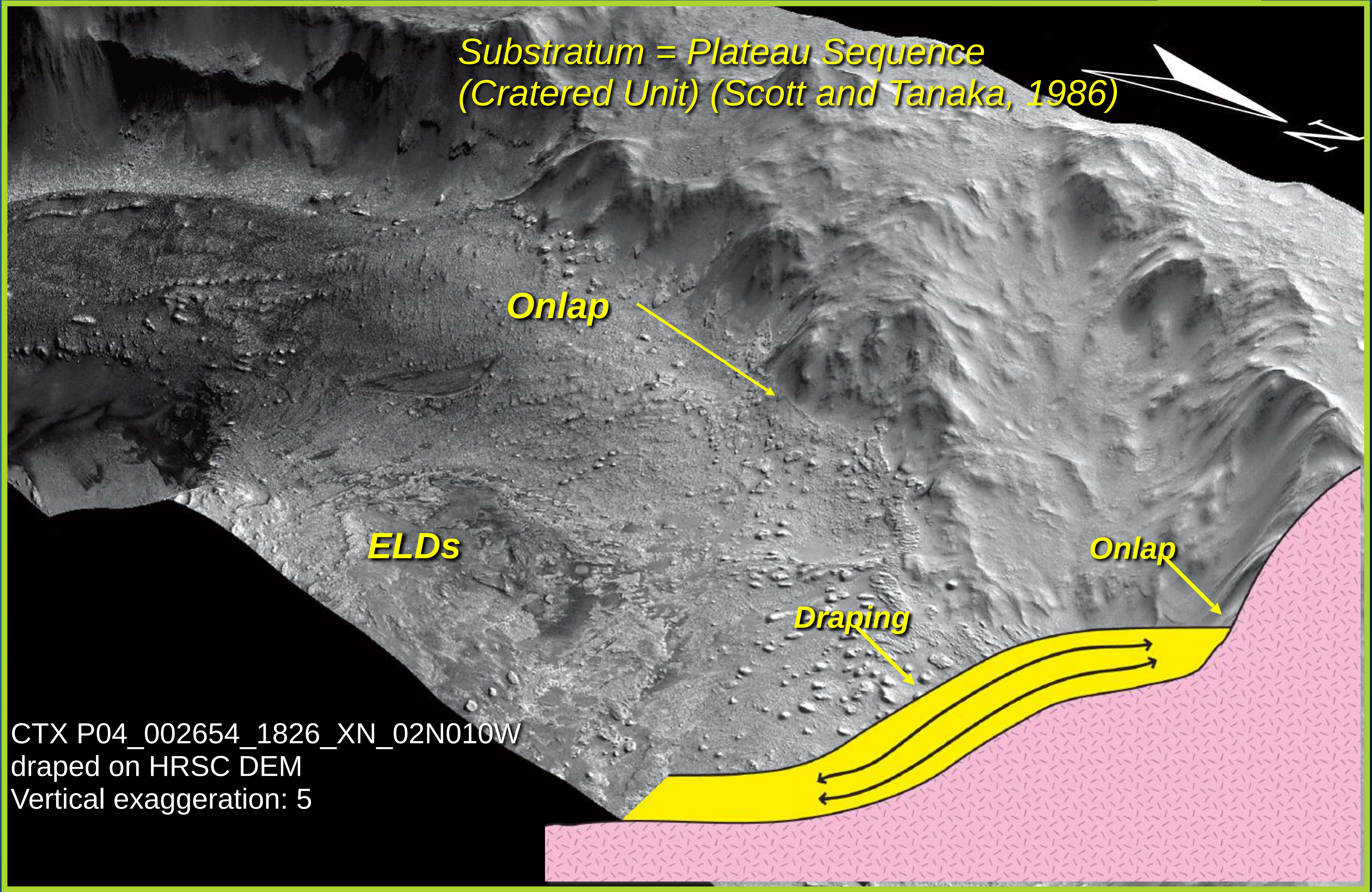

50 km


CTX P04_002654_1826_XN_02N010W
draped on HRSC DEM
Vertical exaggeration: 5
~4.5 km
N


50 km


Substratum = Plateau Sequence
(Cratered Unit) (Scott and Tanaka, 1986)
N
Onlap
ELDs
CTX P04_002654_1826_XN_02N010W
draped on HRSC DEM
Vertical exaggeration: 5
~4.5 km


50 km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N
Onlap
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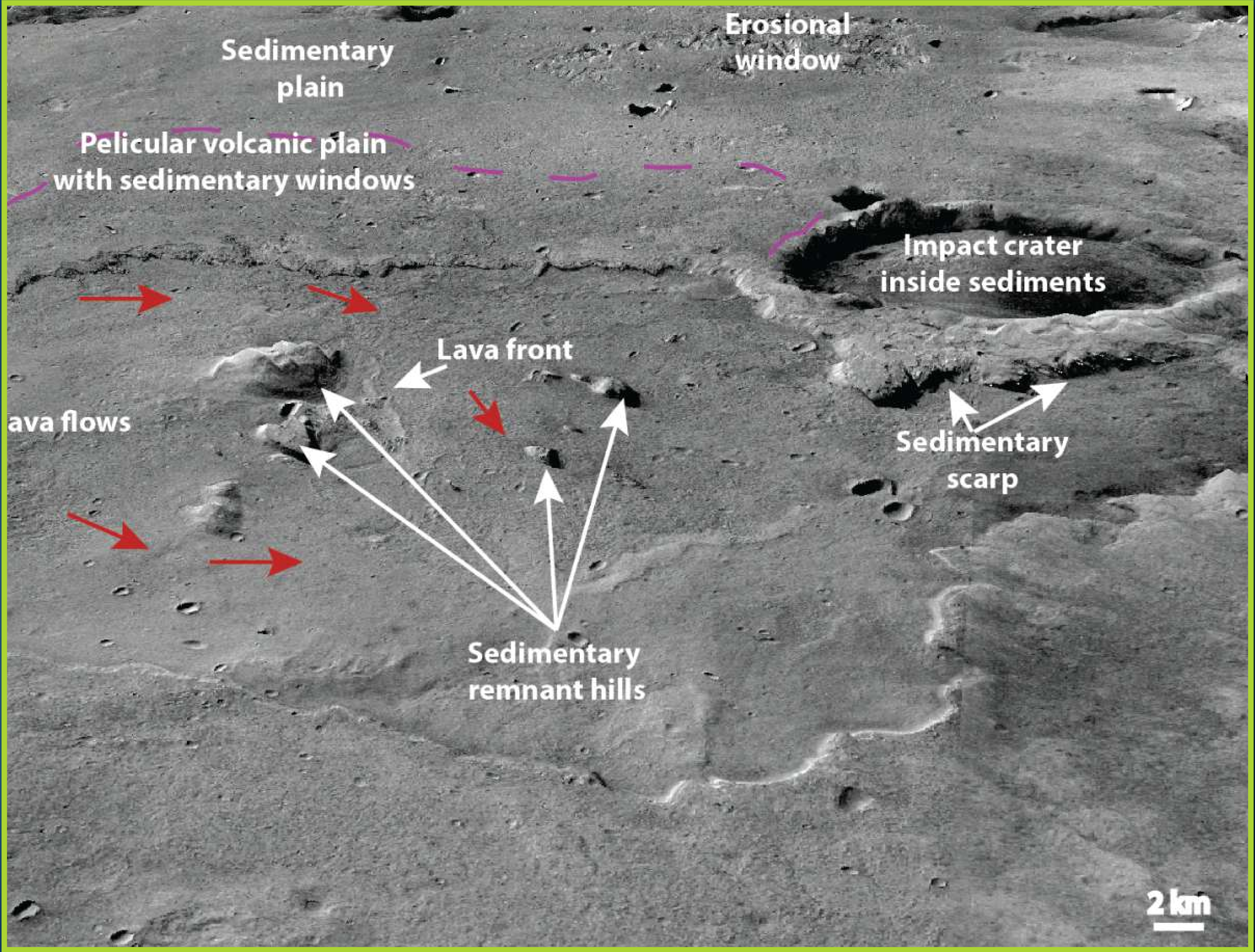
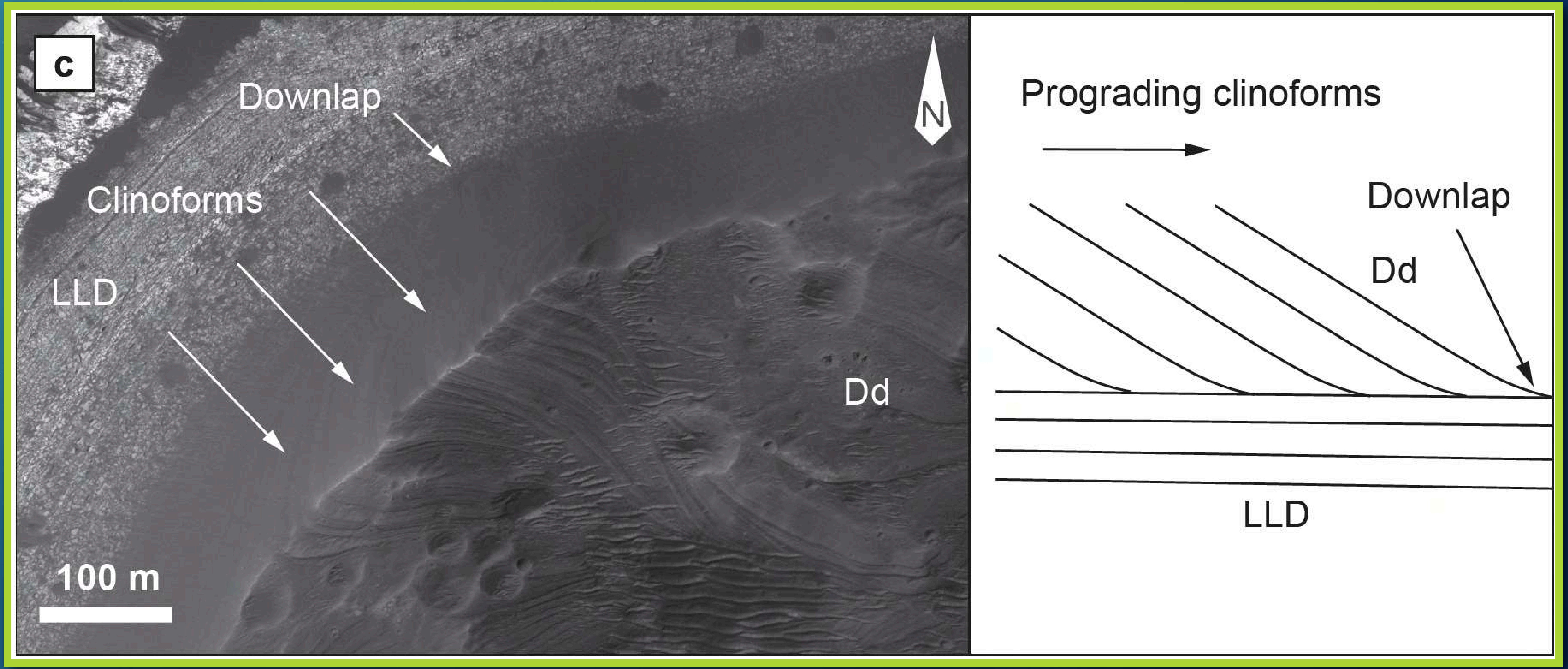
Onlap
Draping
CTX P04_002654_1826_XN_02N010W
draped on HRSC DEM
Vertical exaggeration: 5


Sedimentary plain
Erosional window
Pelicular volcanic plain with sedimentary windows
Impact crater inside sediments
Lava front
ava flows
Sedimentary scarp
Sedimentary remnant hills
2 km

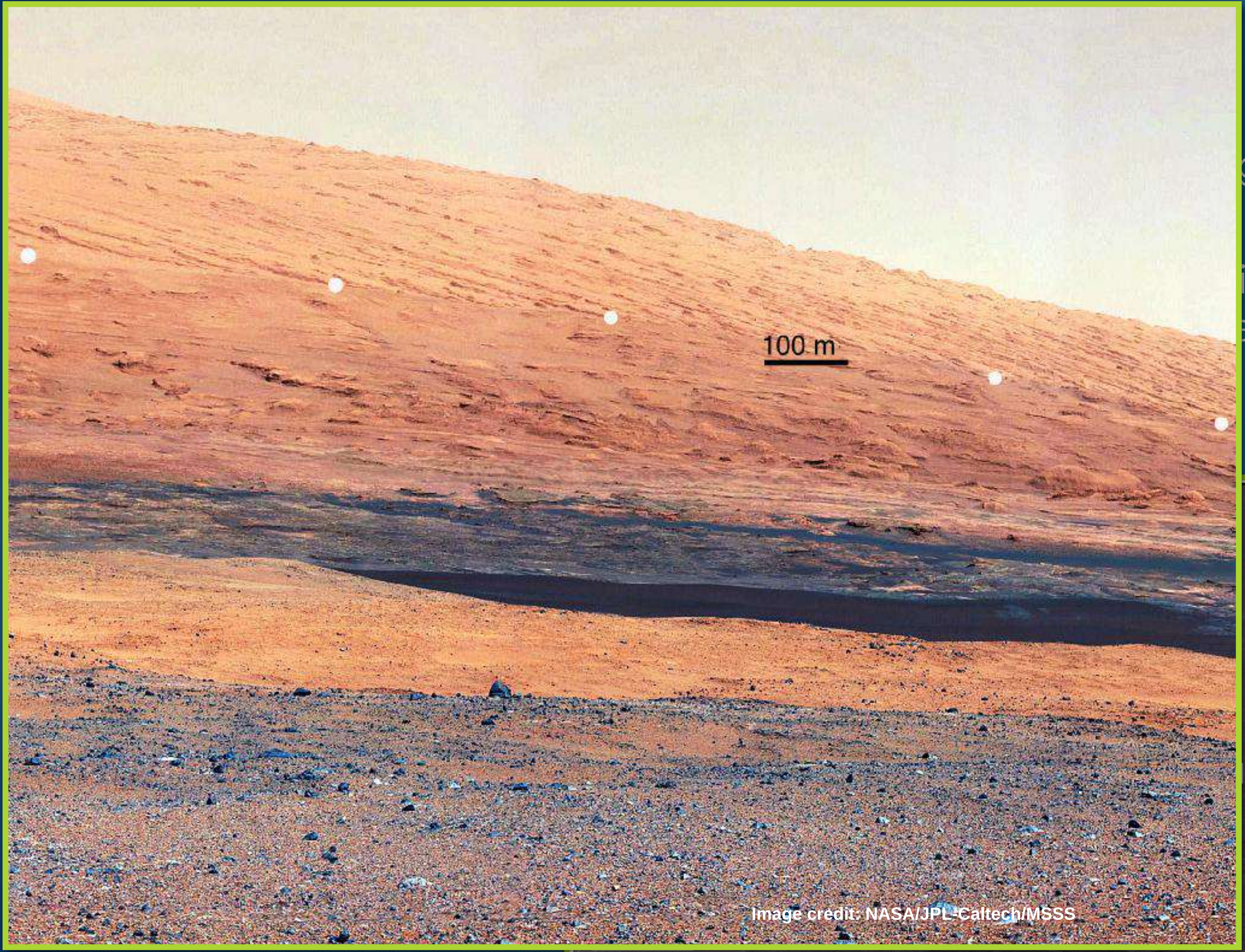
Downlap

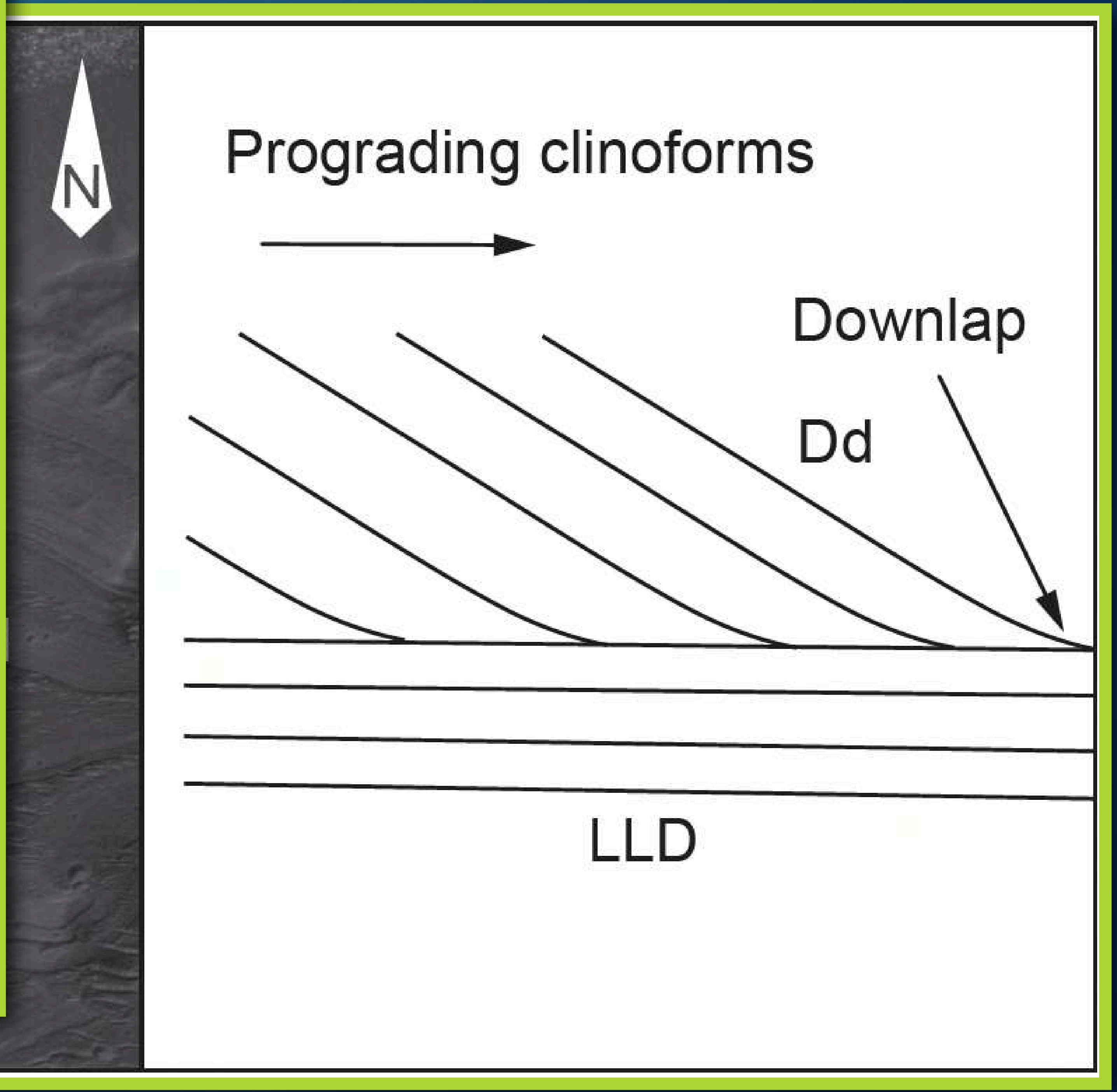
- Offlap: strata prograding into deepwater and terminating in the deeper basin (Mitchum, 1997, AAPG Memoir 26)
- Downlap: a base-discordant relation in which initially inclined strata terminate downdip against an initially horizontal or inclined surface (Mitchum, 1997, AAPG Memoir 26)



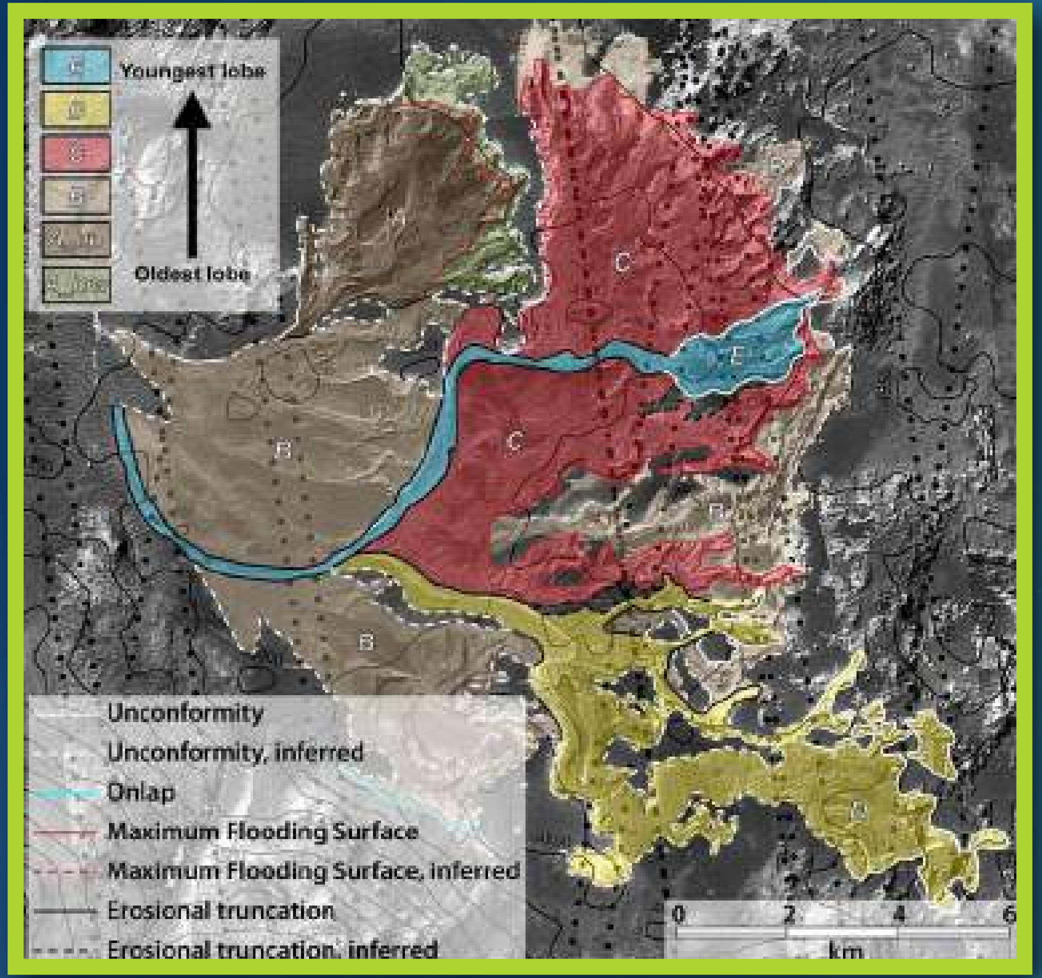
g in the

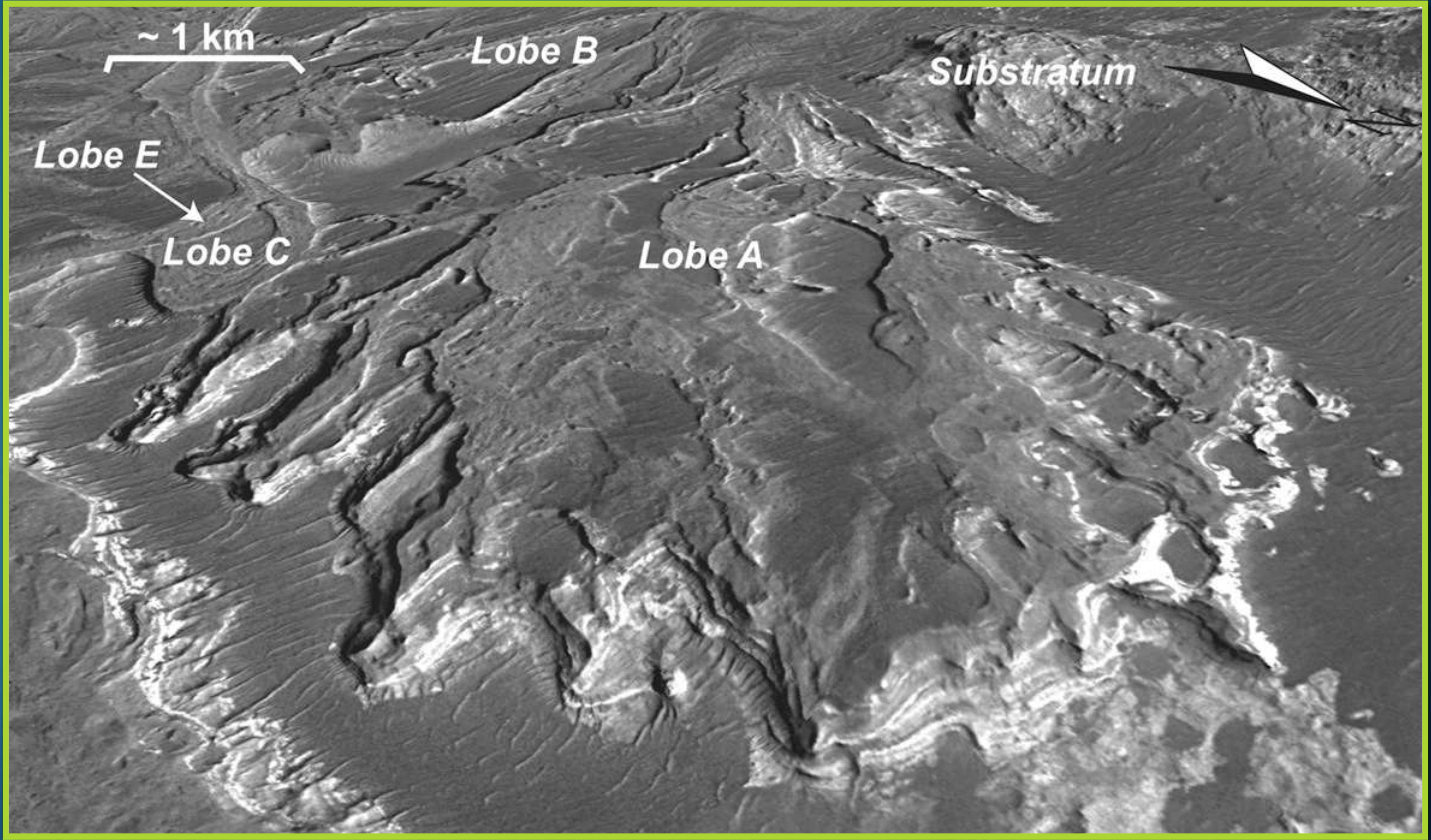
ined strata
ed surface





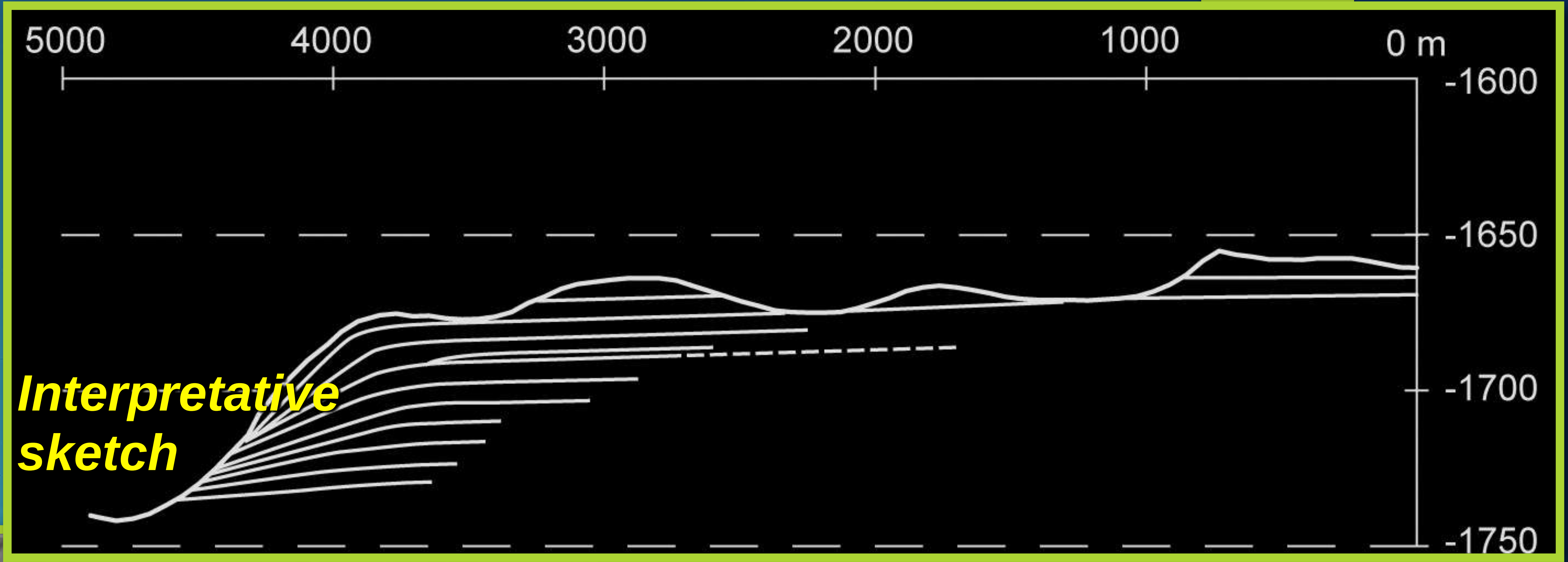
Example

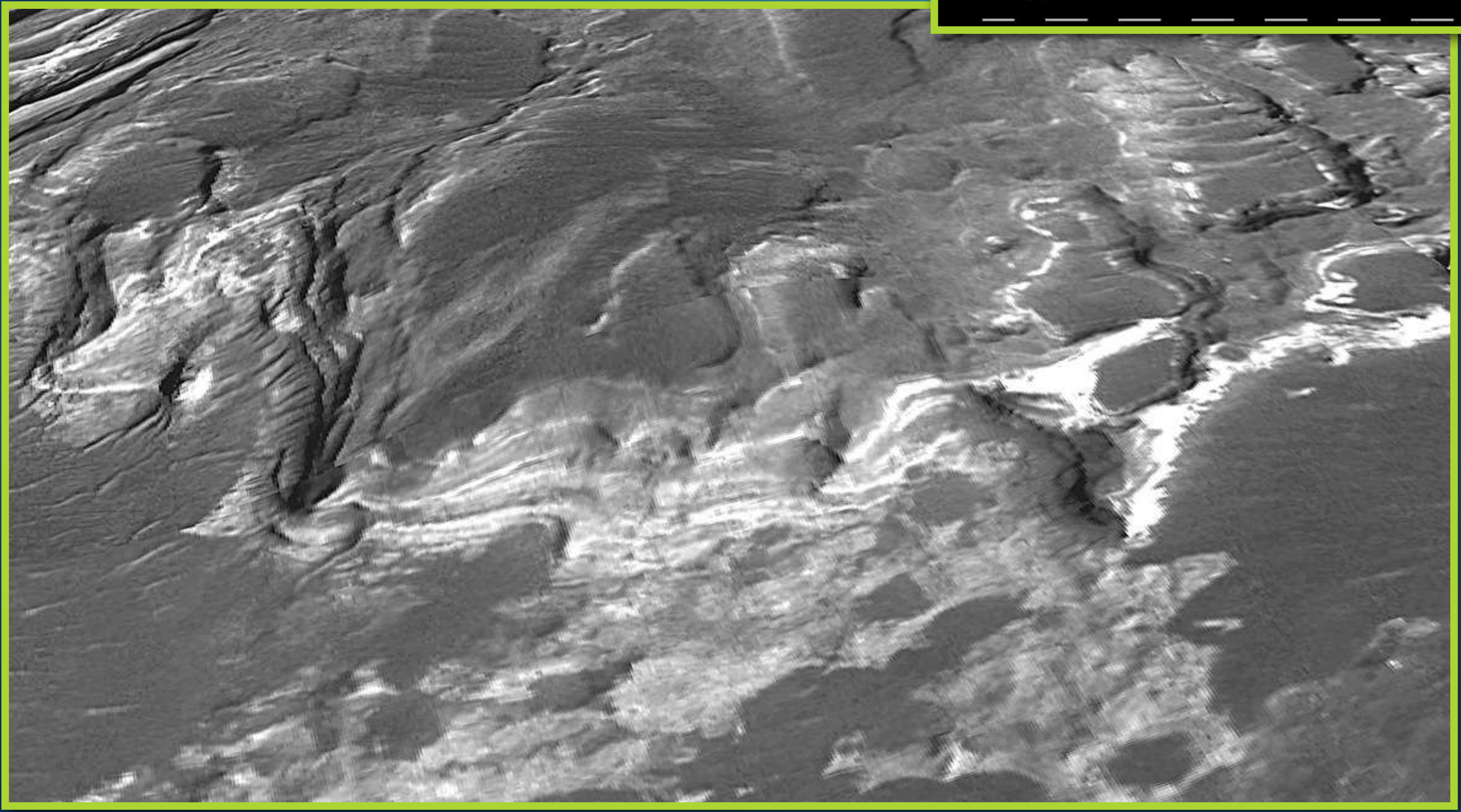




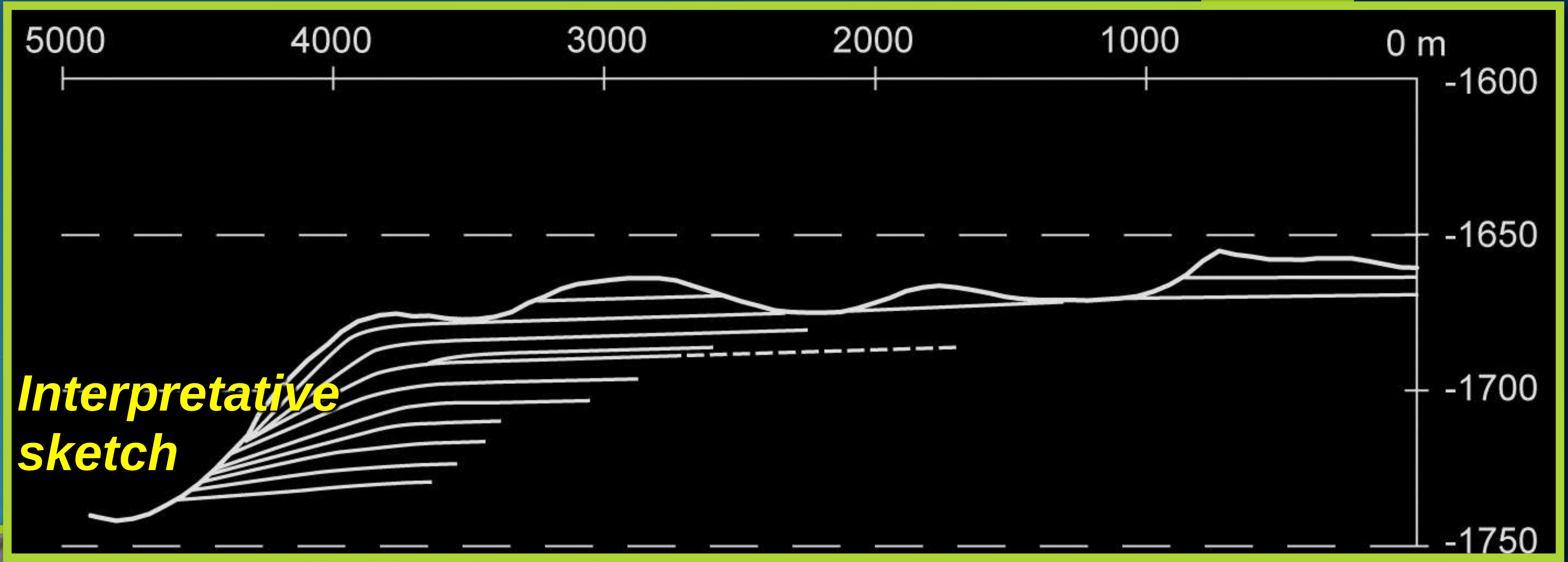
MOC NA mosaic on HRSC_h2013
draped on HRSC DEM
Vert. Exaggeration: 5

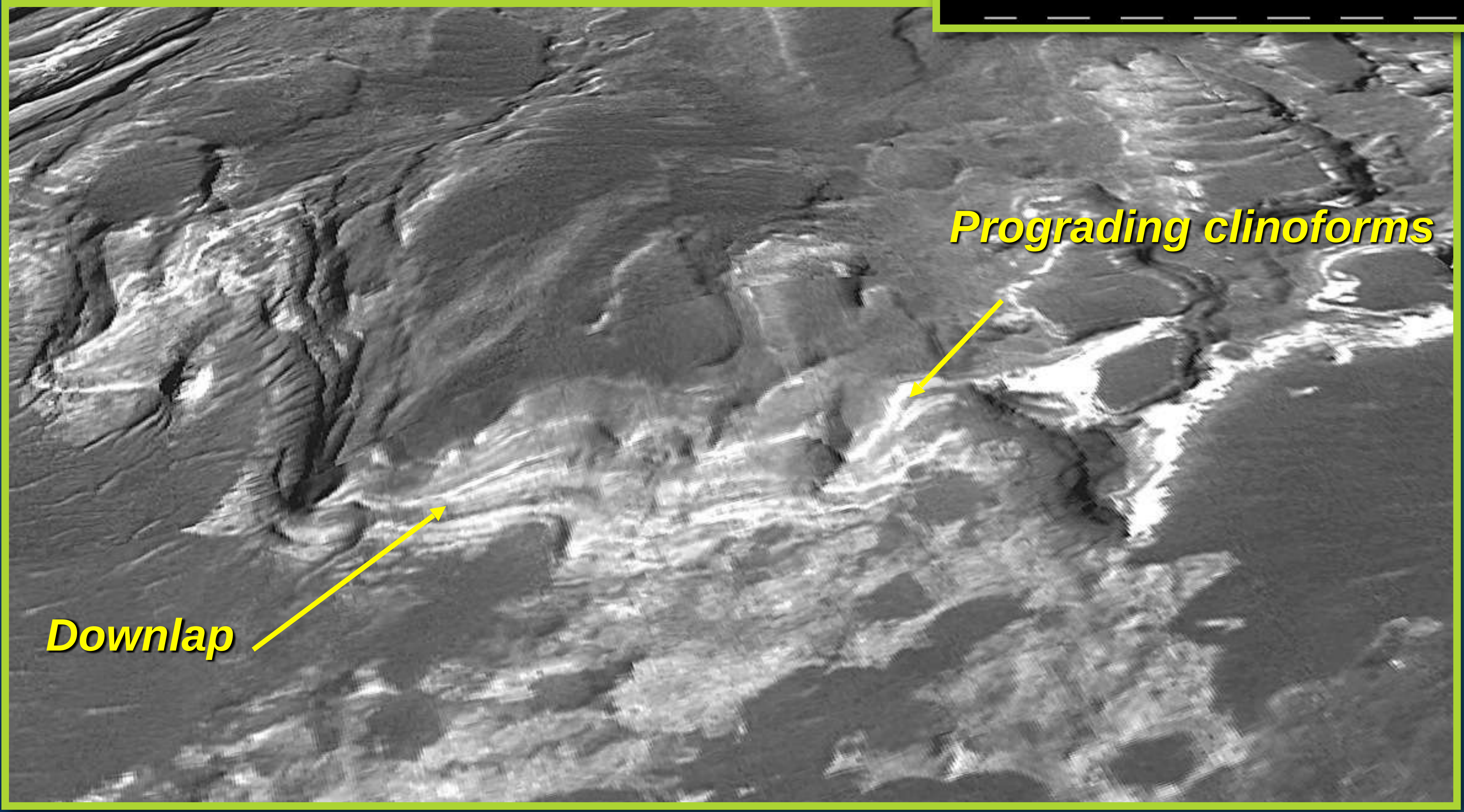
Downlap and possible stacking patterns



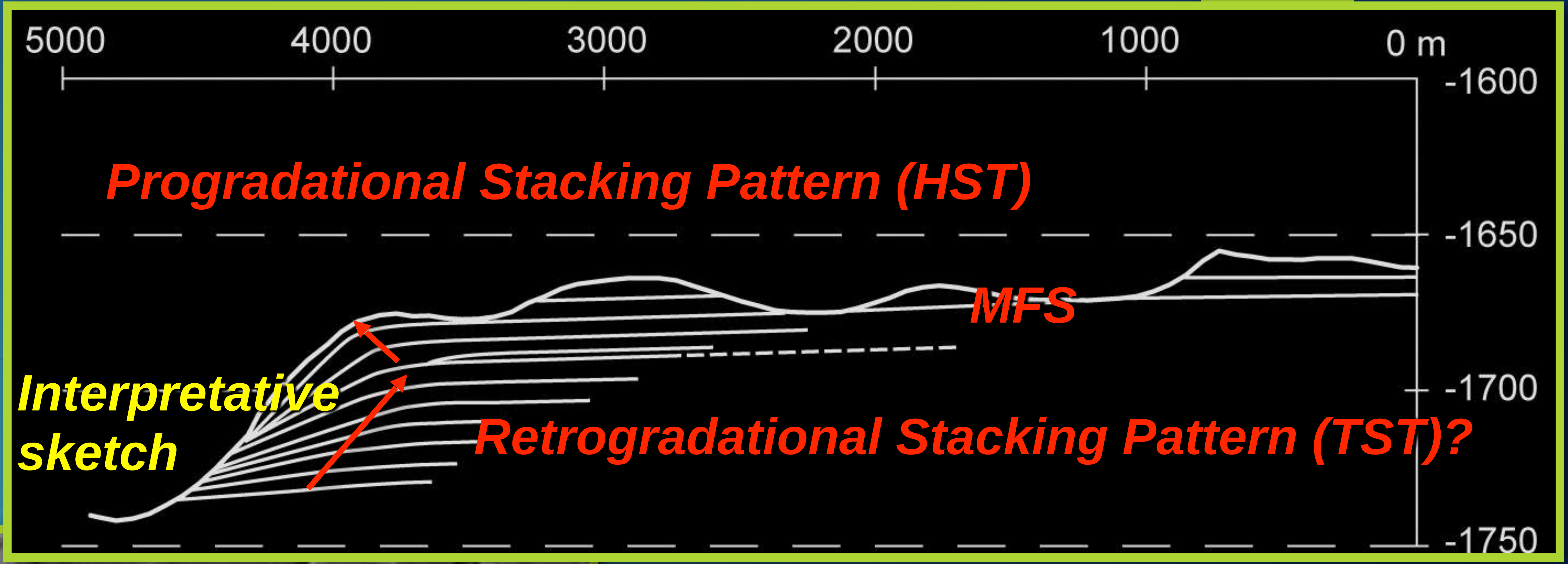


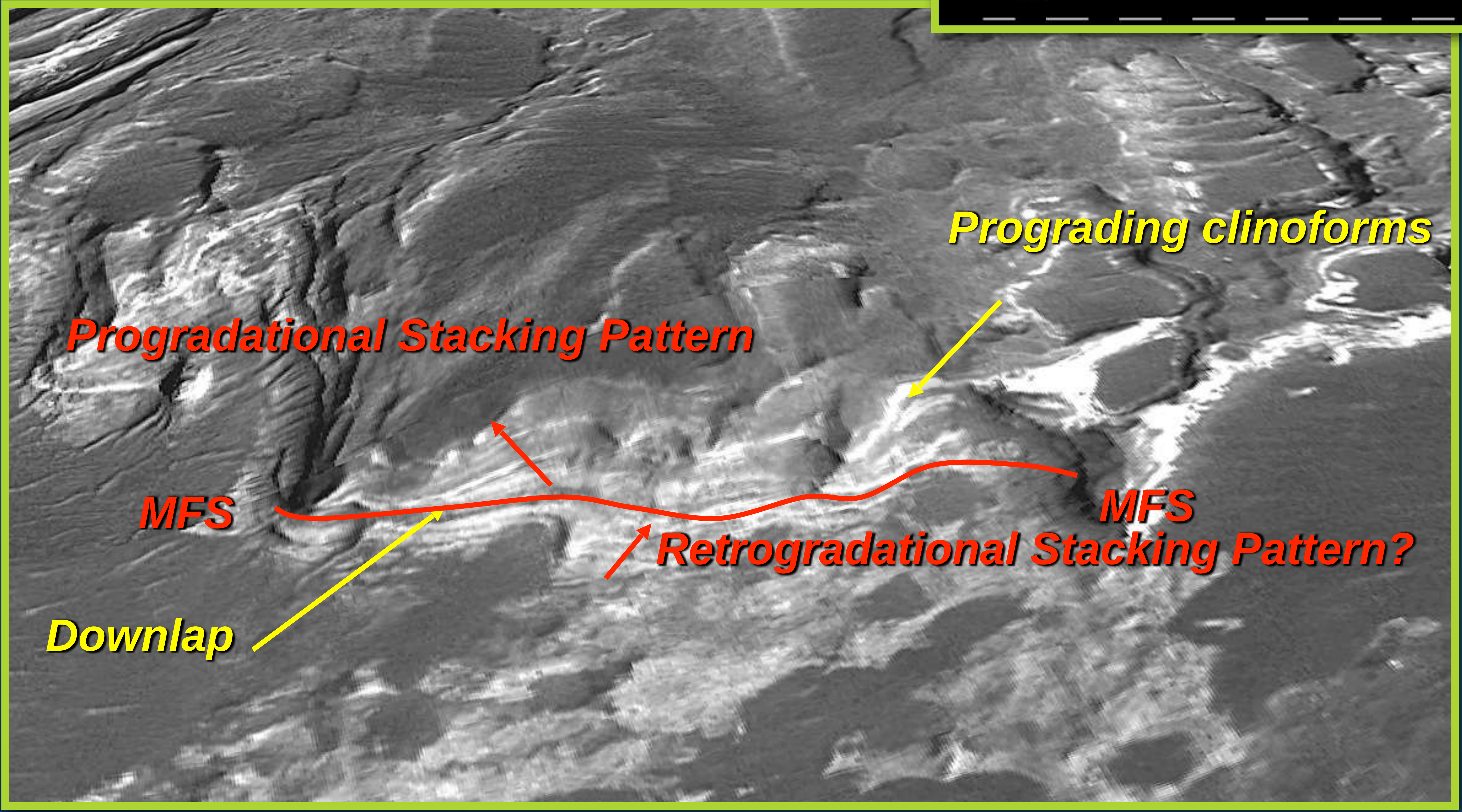
Downlap and possible stacking patterns

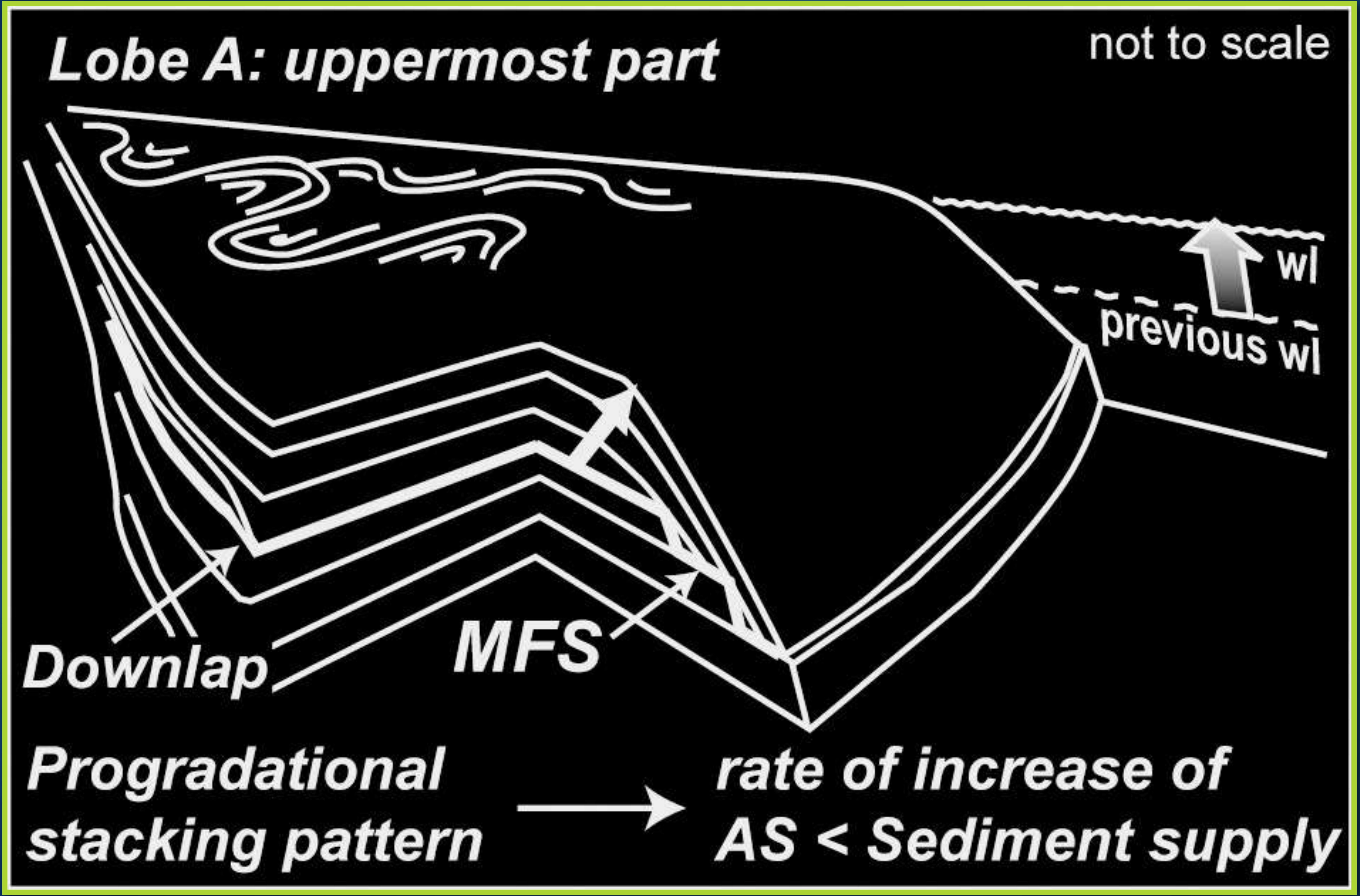




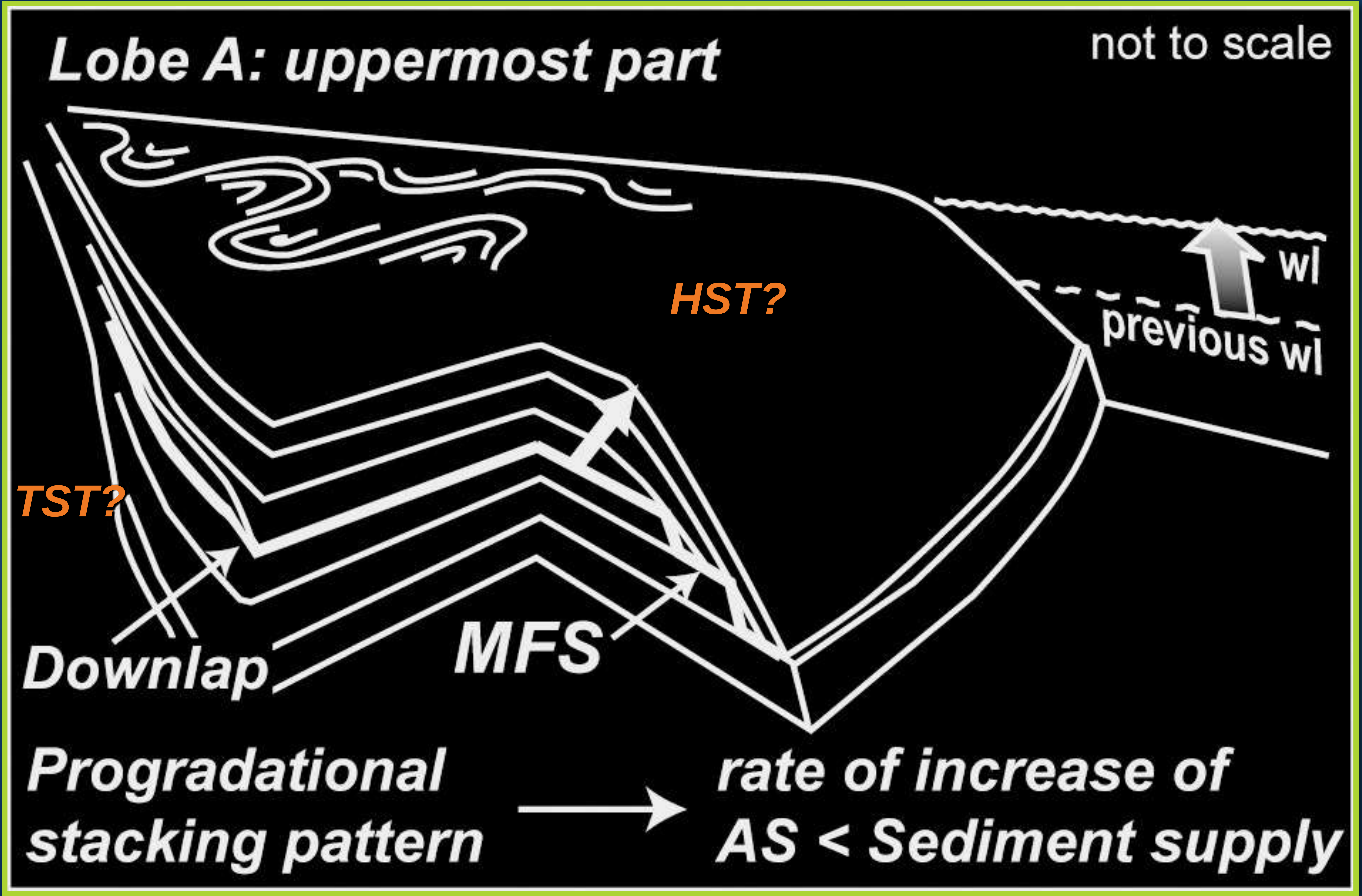
Downlap and possible stacking patterns





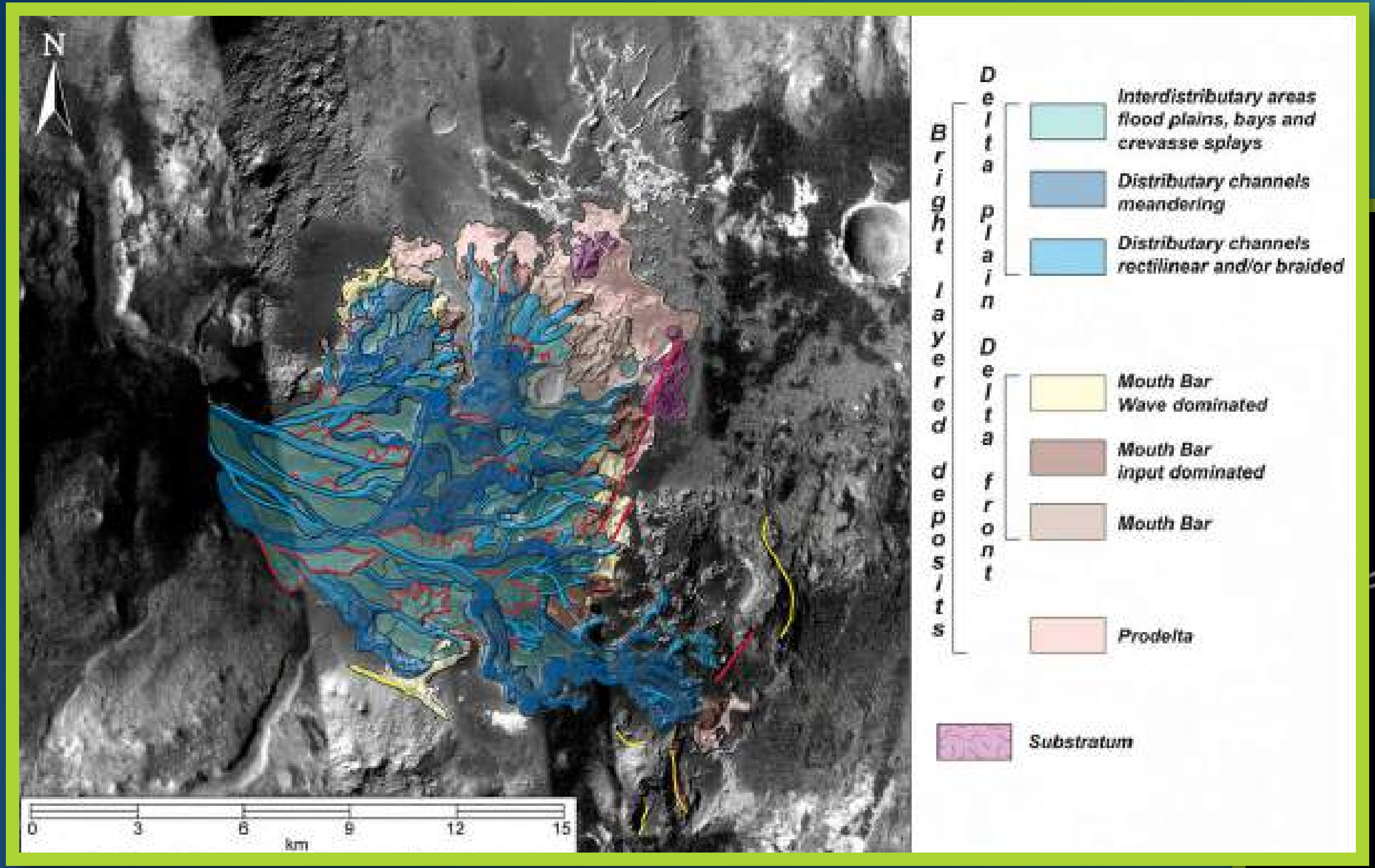


Lobe A: uppermost part
not to scale
wl
previous wl
Downlap
MFS
Progradational stacking pattern
rate of increase of AS < Sediment supply

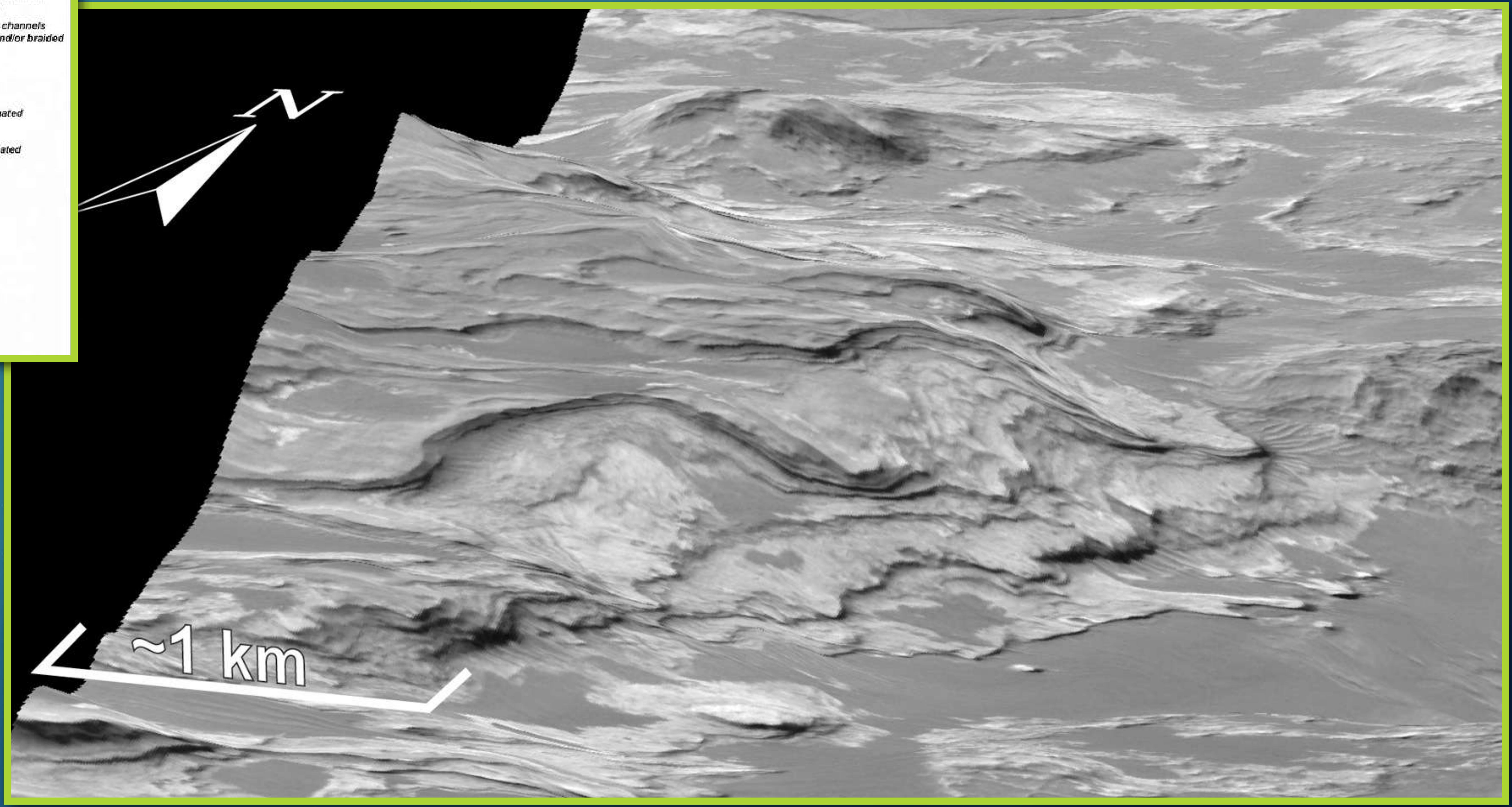


Lobe A: uppermost part
not to scale
HST?
wl
previous wl
TST?
Downlap
MFS
Progradational stacking pattern
rate of increase of AS < Sediment supply

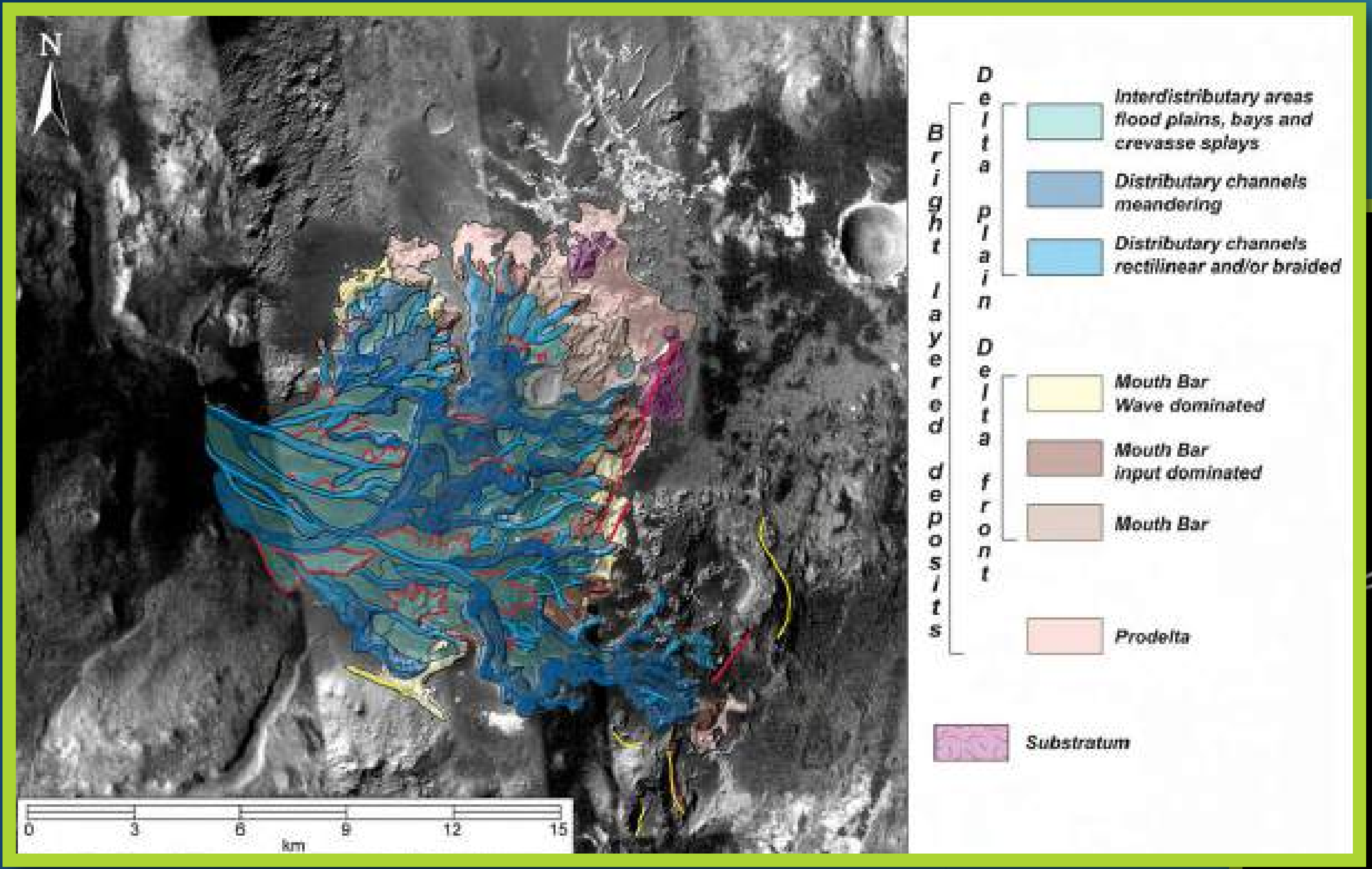
Prograding clinoforms in Eberswalde crater



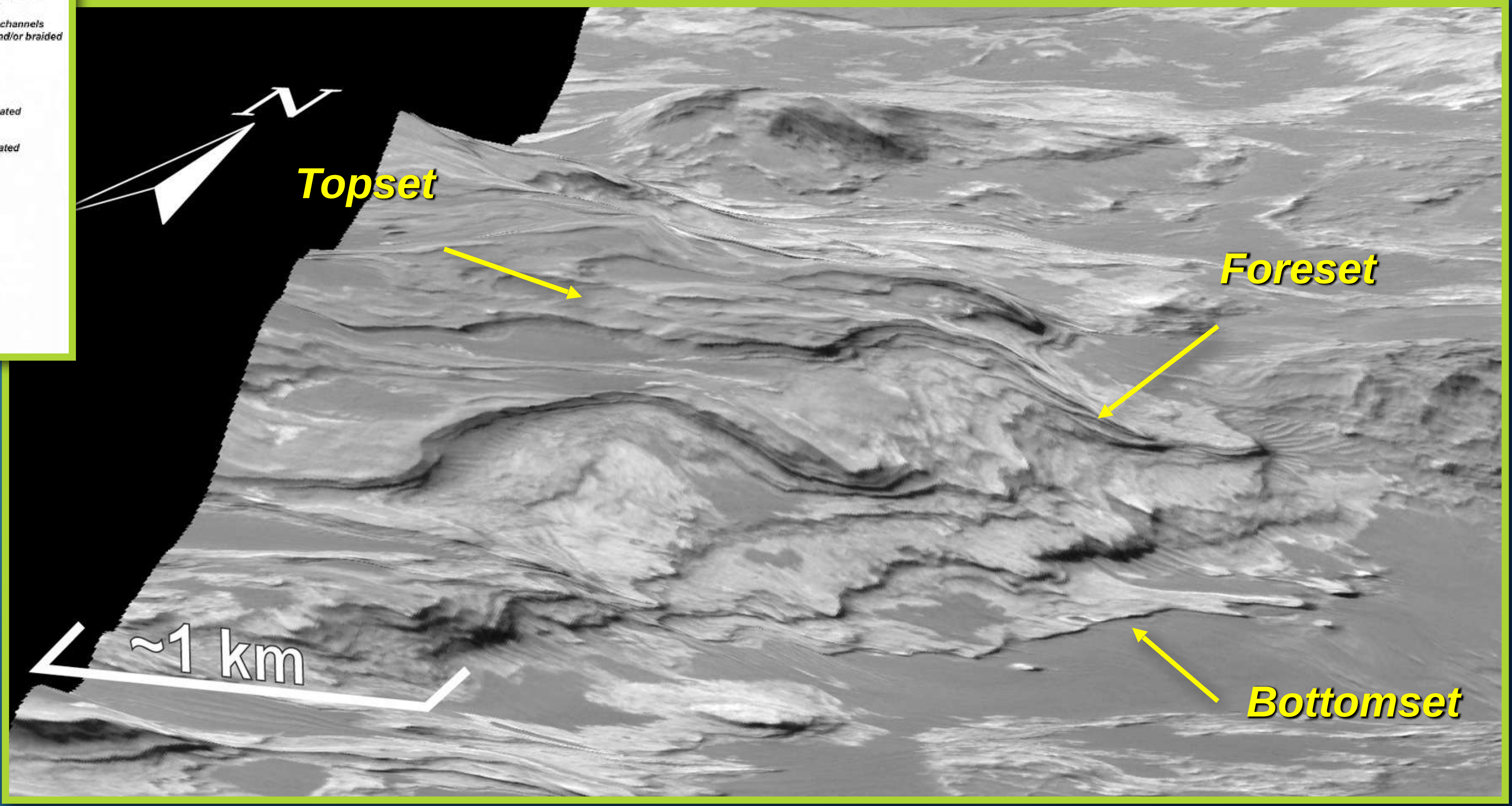
MOC NA e2300003 draped on HRSC DEM
Res. 4.06m/pix
Vertical exaggeration: 5



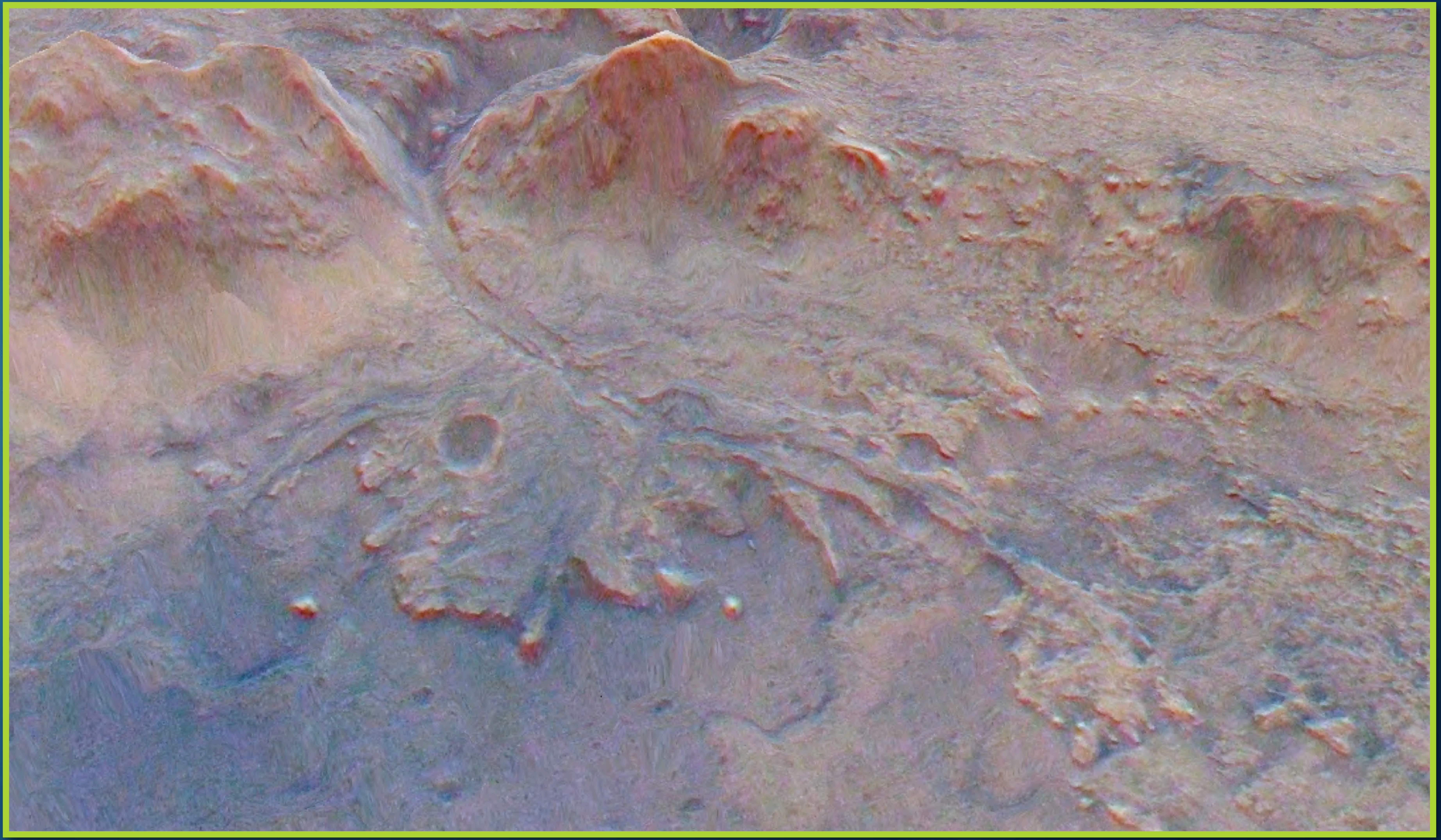
Prograding clinoforms in Eberswalde crater



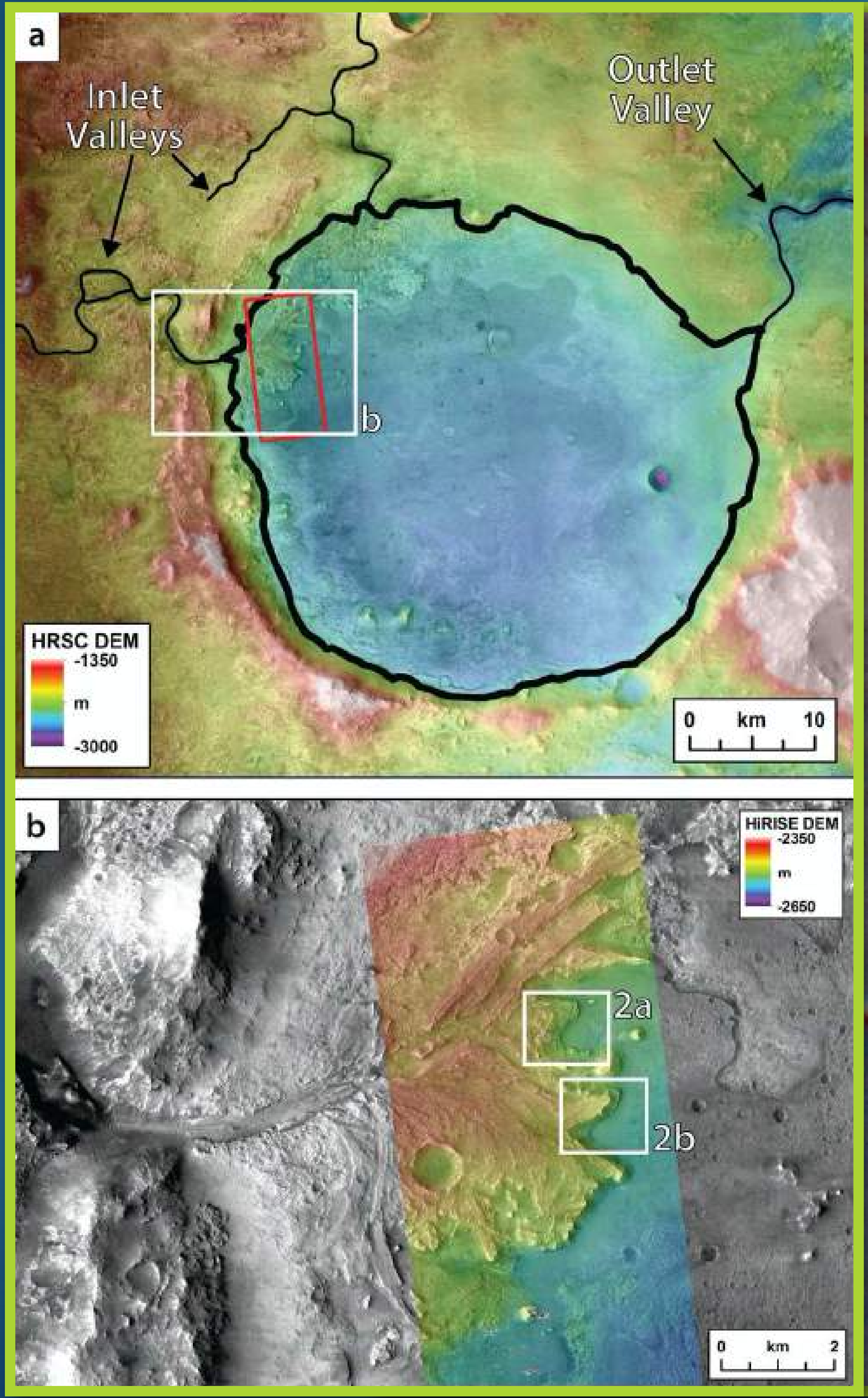
MOC NA e2300003 draped on HRSC DEM
Res. 4.06m/pix
Vertical exaggeration: 5

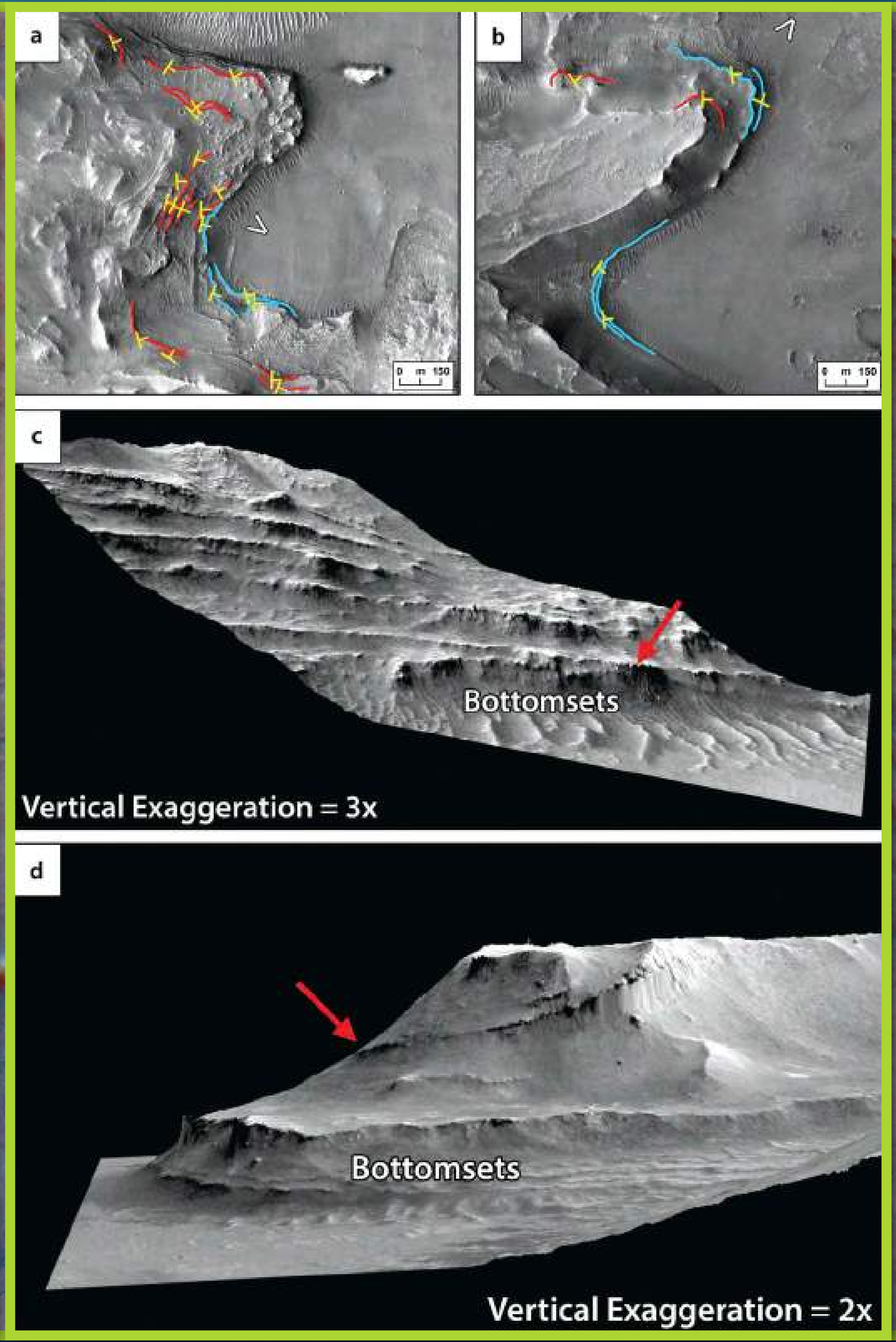


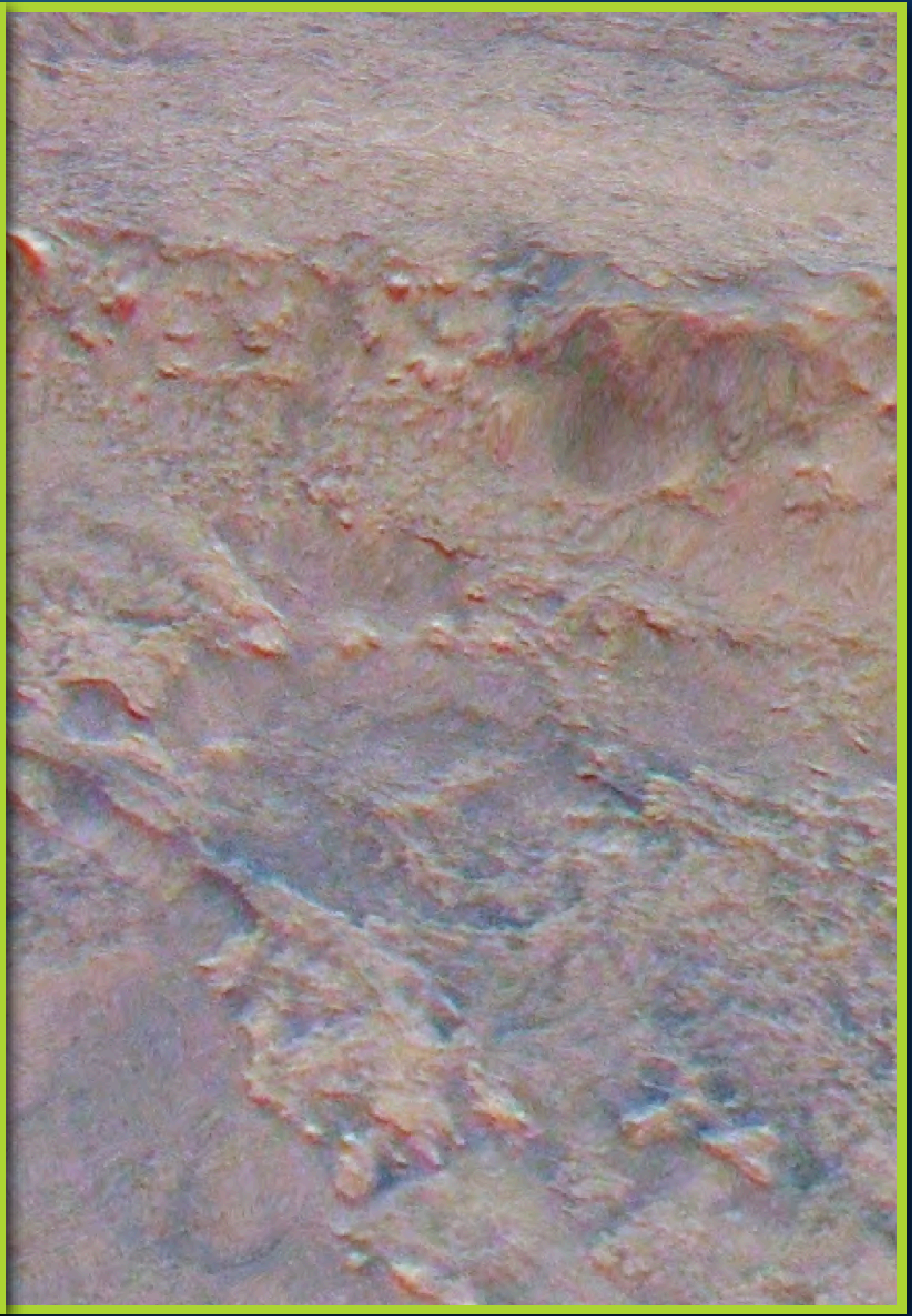
Prograding clinoforms in Jezero crater



Prograding clinoforms in Jezero crater



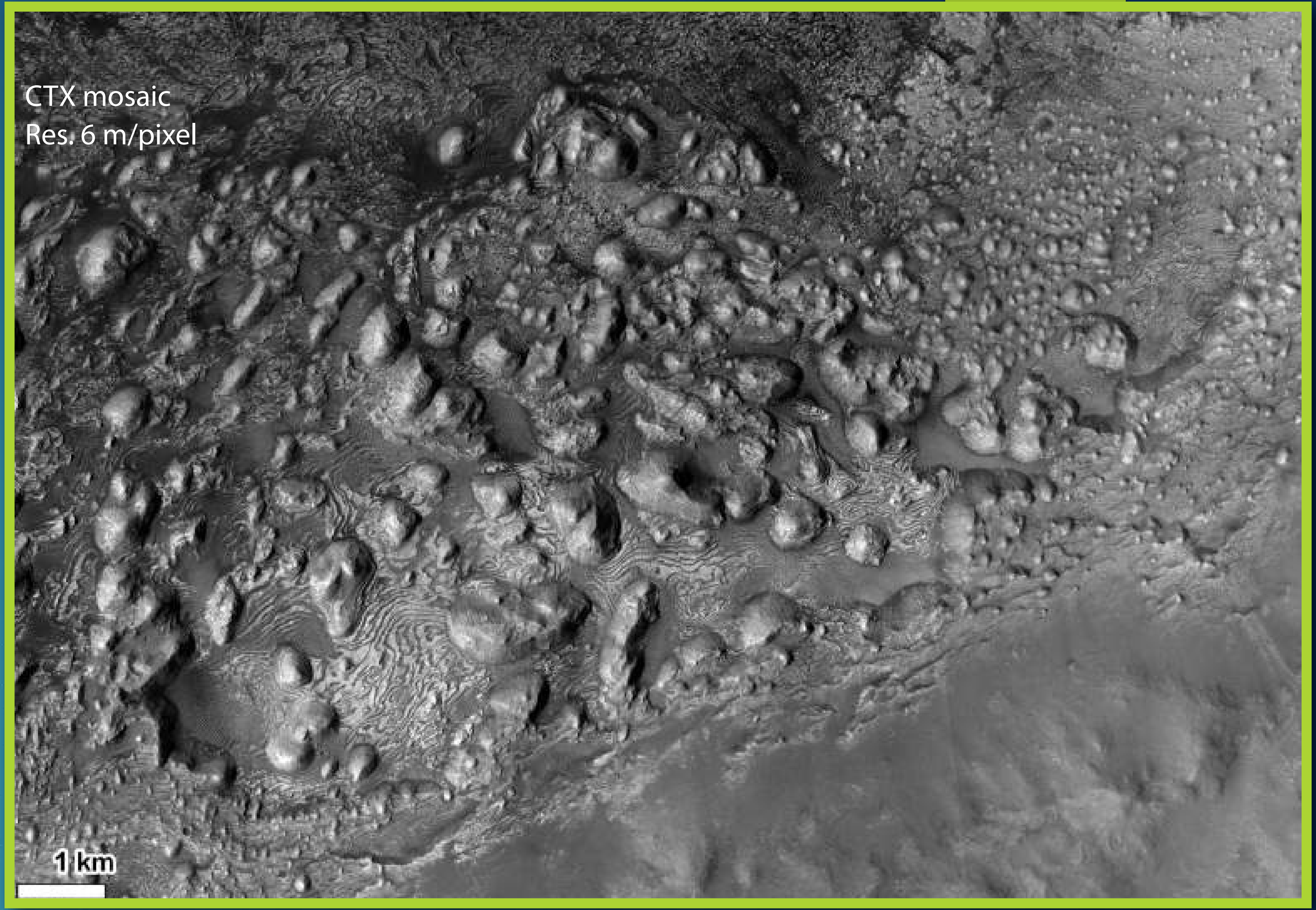


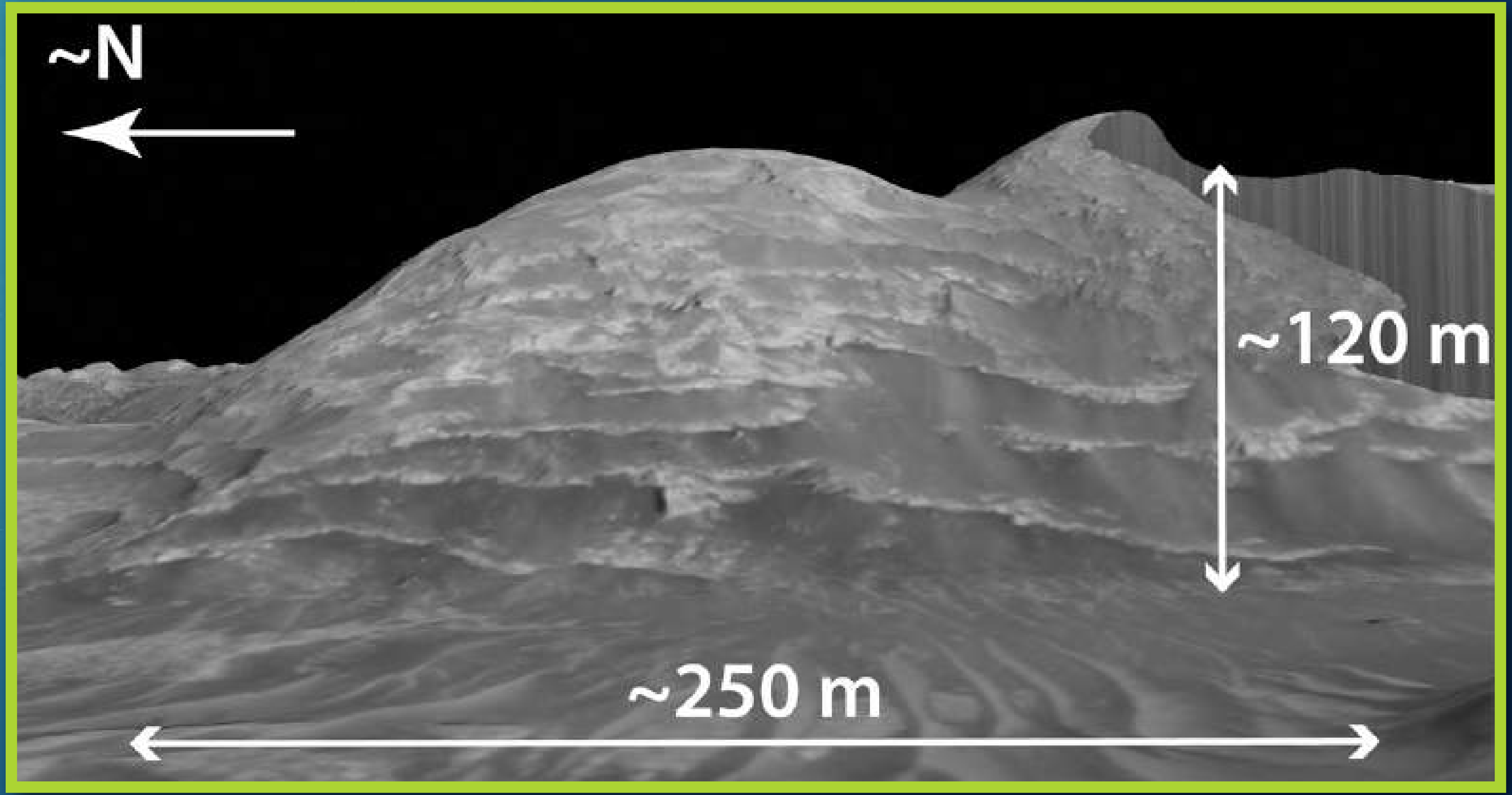


Goudge et al., 2017

Lateral transitions

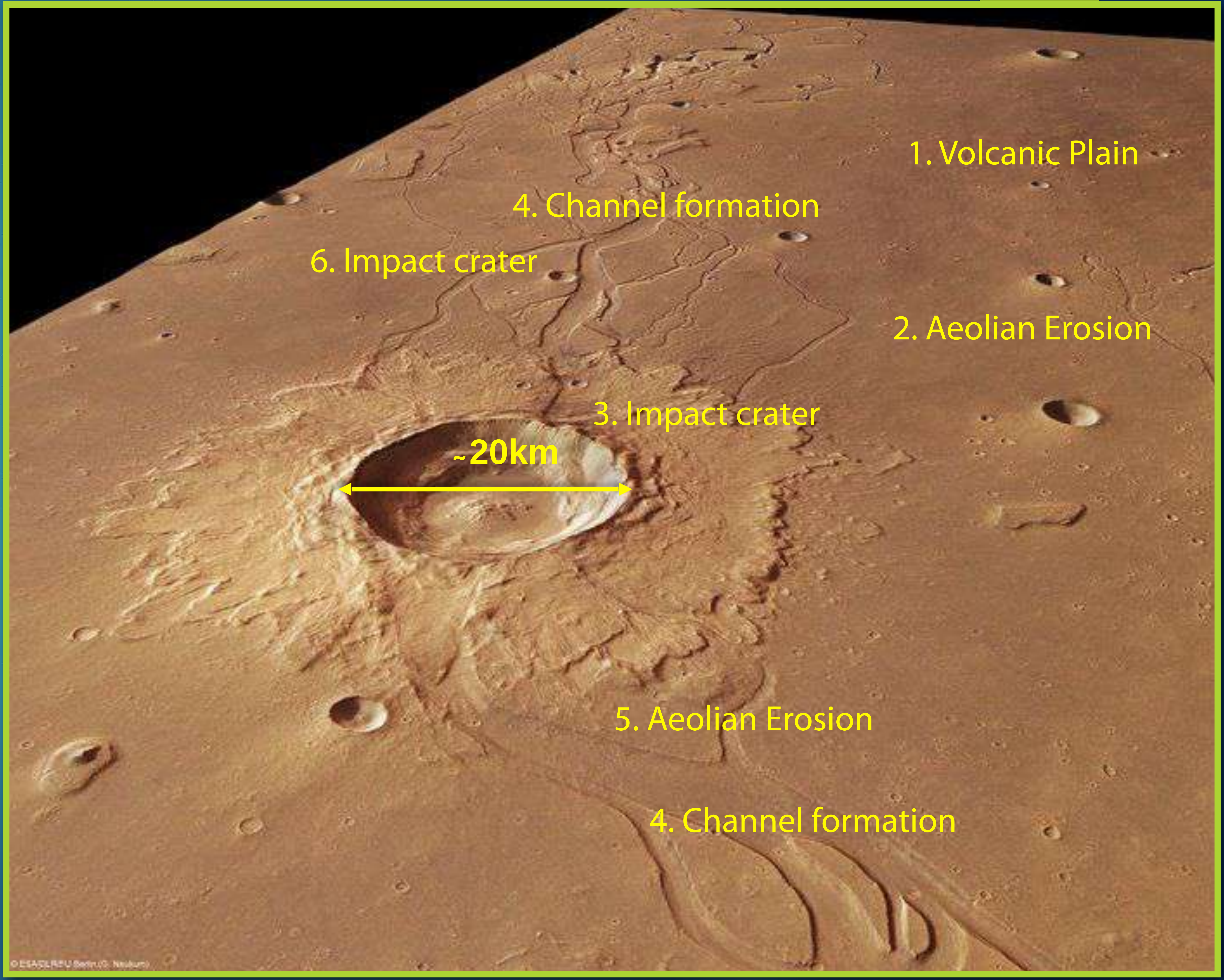
- Lateral continuity
- → deposits are coeval and conform to Walther's Law





HiRISE DEM
PSP_003788_1820/ESP_020679_1820
No vertical exaggeration

Stratigraphy and events succession



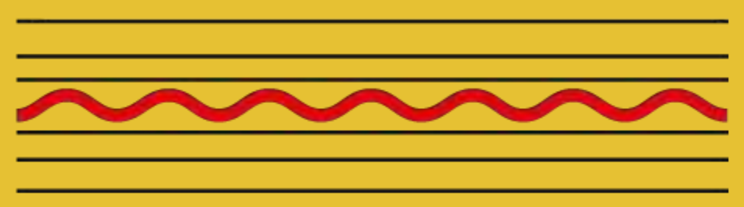
The missing Time

A. **Unconformity** = significant hiatus ± erosion (usually with erosion)

A substantial break or gap in the geological record … It normally implies uplift and erosion with loss of the previously formed record. … Relationship between rock strata in contact, characterized by a lack of continuity in deposition, and corresponding to a period of nondeposition, weathering, or esp. erosion (either subaerial or subaqueous) prior to the deposition of the younger beds.

1. **Disconformity** = hiatus + erosion

   An unconformity in which the bedding planes above and below the break are essentially parallel, indicating a significant interruption in the orderly sequence of sedimentary rocks, generally by a considerable interval of erosion ..., and usually marked by a visible and irregular or uneven erosion surface of appreciable relief.

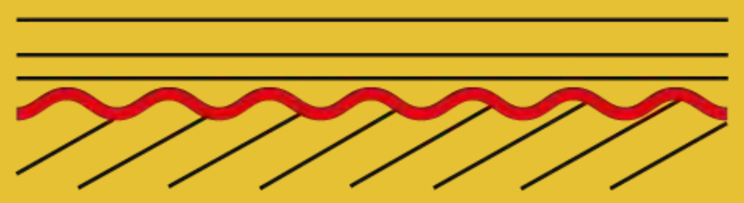


2. **Paraconformity** = hiatus ± erosion (no discernable erosion)

   An obscure or uncertain unconformity in which no erosion surface is discernable ..., and in which the beds above and below the break are parallel.

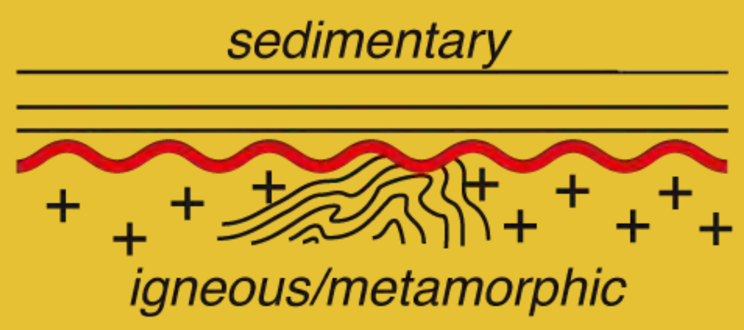
3. **Angular unconformity** = hiatus, erosion, and tilt

   An unconformity between two groups of rocks whose bedding planes are not parallel or in which the older, underlying rocks dip at a different angle (usually steeper) than the younger, overlying strata.



4. **Nonconformity** = top of basement rocks

   An unconformity developed between sedimentary rocks and older igneous or metamorphic rocks that had been exposed to erosion before the overlying sediments covered them.



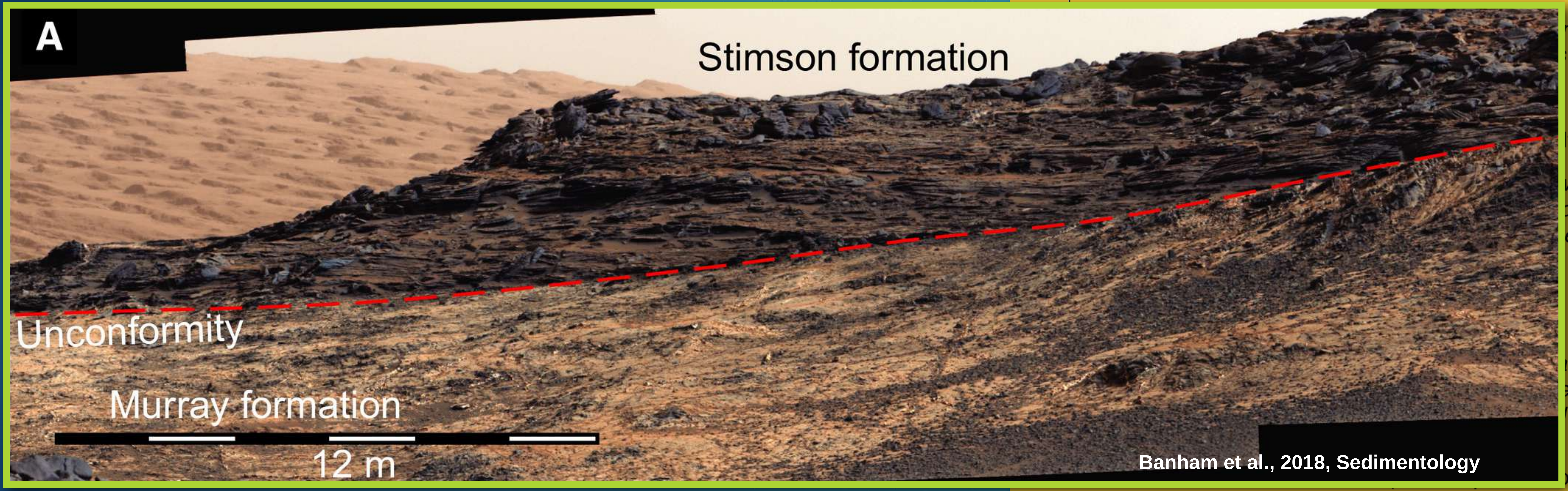
B. **Diastem** = short hiatus ± erosion (a minor paraconformity)

A relatively short interruption in sedimentation, involving only a brief interval of time, with little or no erosion before deposition is resumed; a depositional break of lesser magnitude than a paraconformity, or a paraconformity of very small time value.

C. **Conformity** = no hiatus

Undisturbed relationship between adjacent sedimentary strata that have been deposited in orderly sequence... True stratig phic continuity in the sequence of beds.

The missing Time



A. **Unconformity** = significant hiatus ± erosion (usually with erosion)

A substantial break or gap in the geological record … It normally implies uplift and erosion with loss of the previously formed record. … Relationship between rock strata in contact, characterized by a lack of continuity in deposition, and corresponding to a period of nondeposition, weathering, or esp. erosion (either subaerial or subaqueous) prior to the deposition of the younger beds.

1. **Disconformity** = hiatus + erosion

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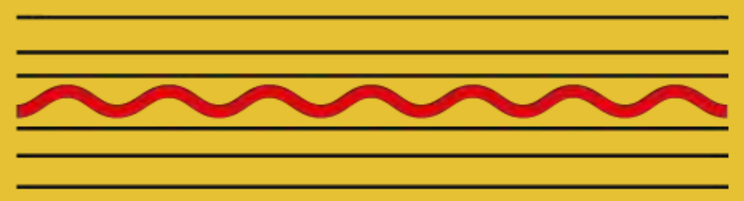

2. **Paraconformity** = hiatus ± erosion (no discernable erosion)

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above and

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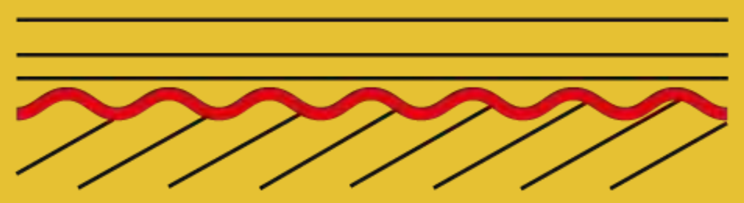
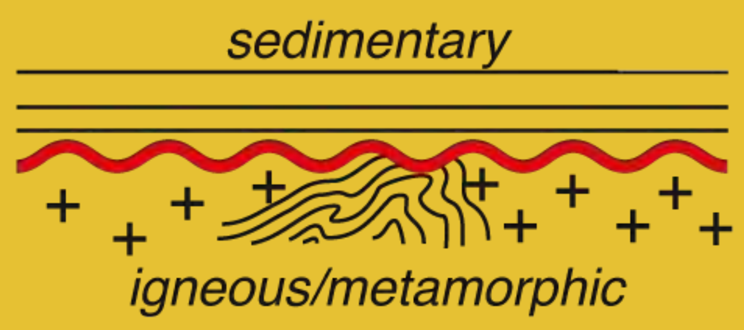


y rocks and
en exposed to
them.



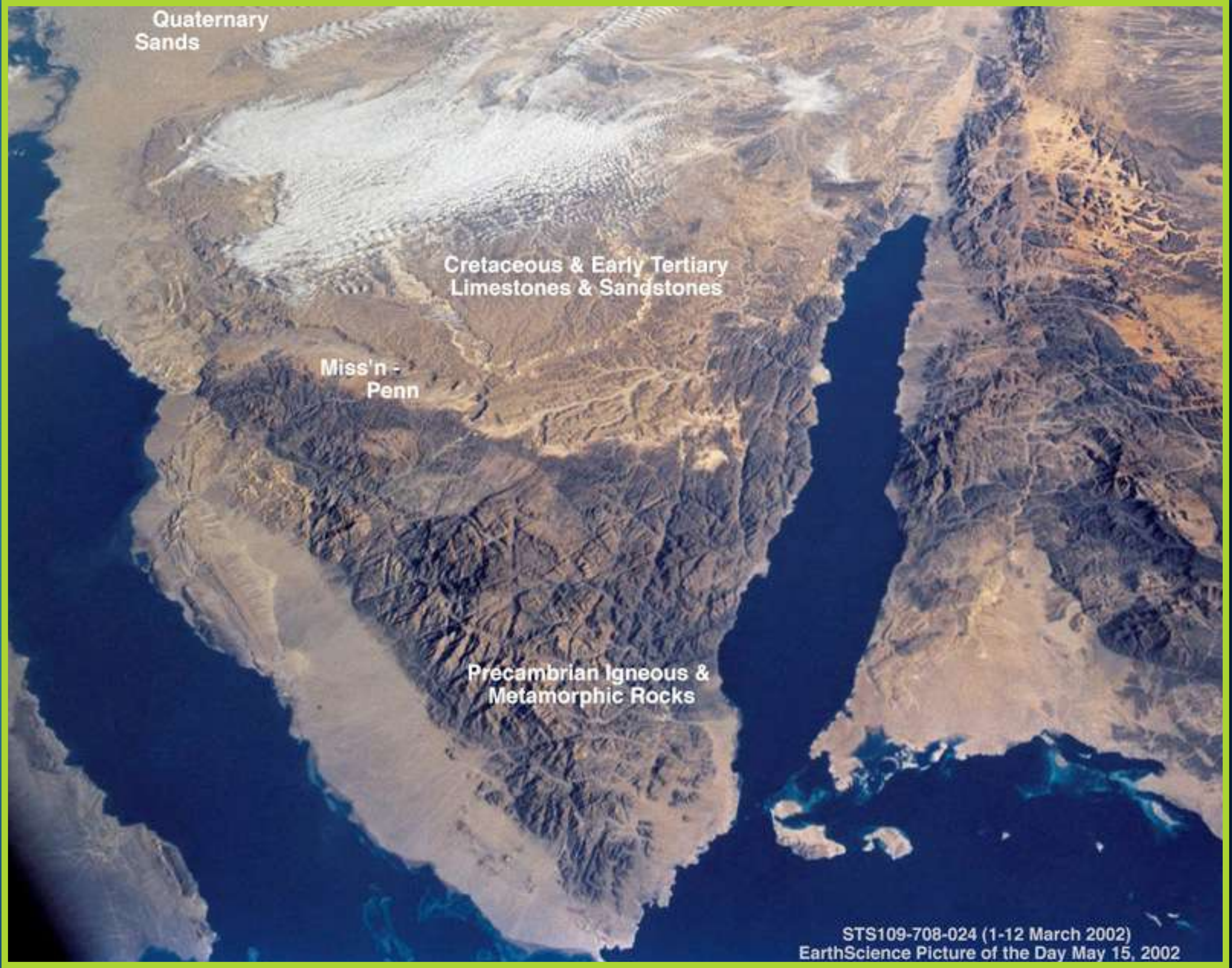
rmity)

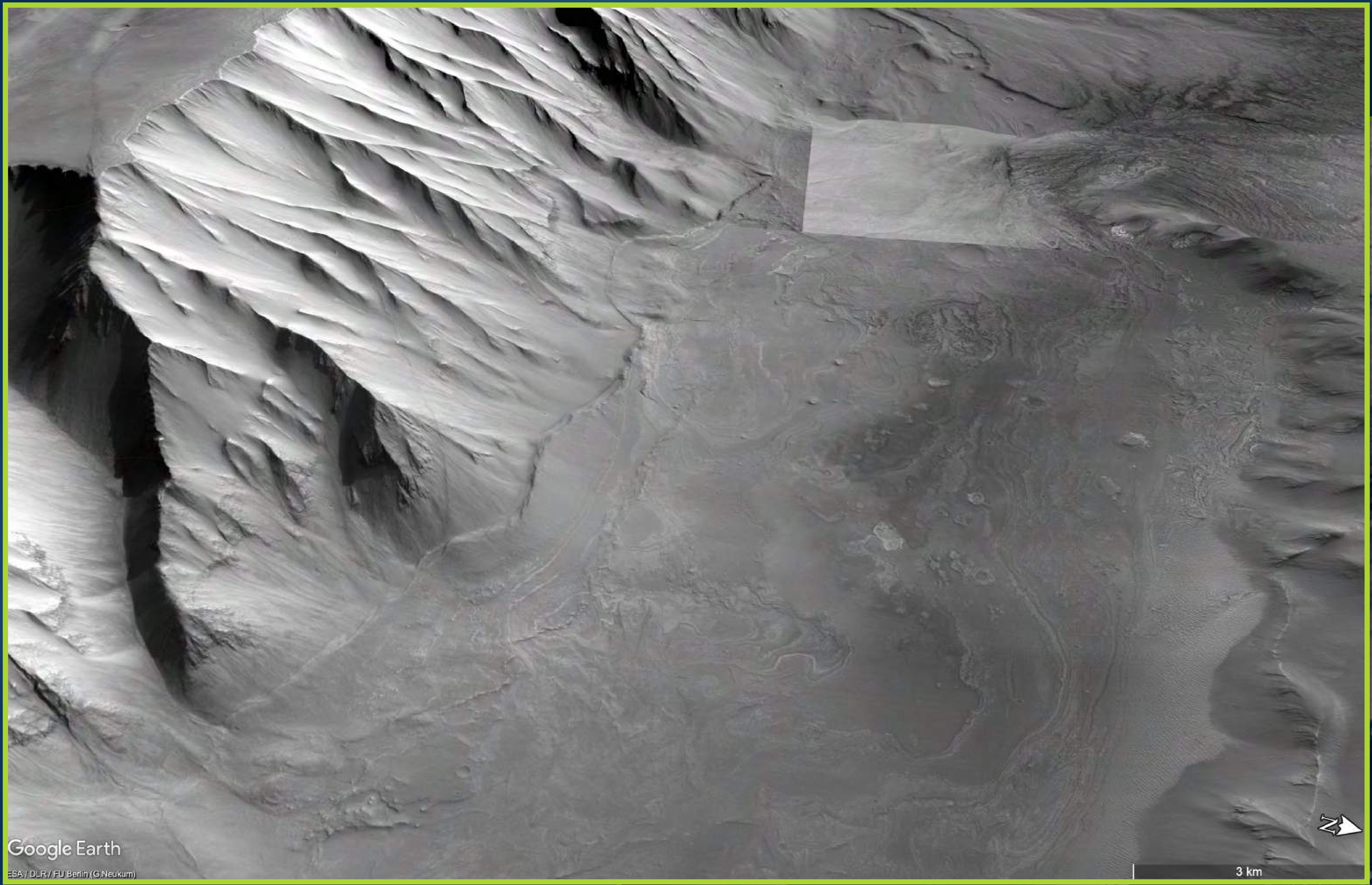
A relatively short interruption in sedimentation, involving only a brief interval of time, with little or no erosion before deposition is resumed; a depositional break of lesser magnitude than a paraconformity, or a paraconformity of very small time value.

C. **Conformity** = no hiatus

Undisturbed relationship between adjacent sedimentary strata that have been deposited in orderly sequence... True stratig phic continuity in the sequence of beds.

Nonconformity

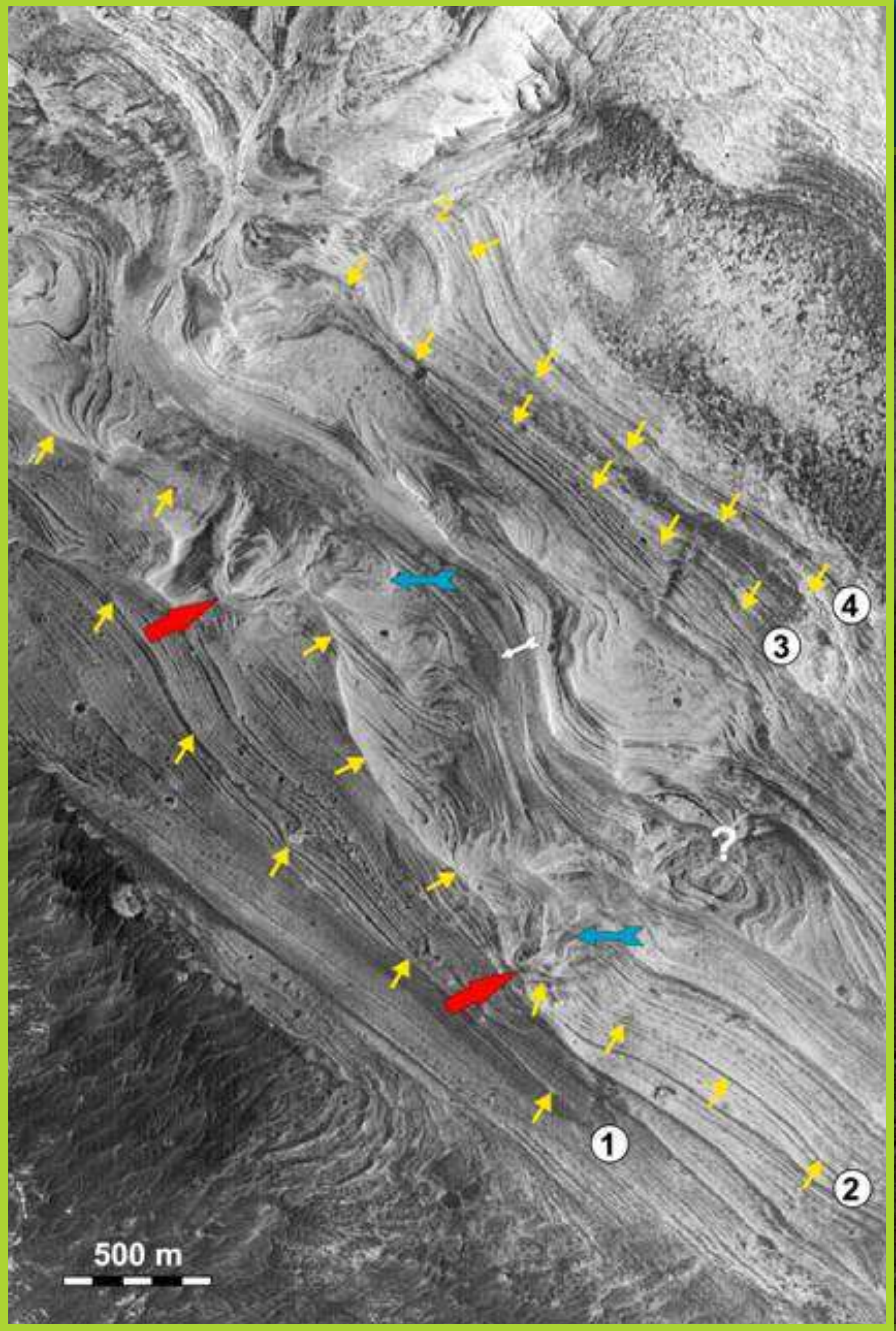



Google Earth
ESA / DLR / FU Berlin (G.Neukum)
3 km


8-024 (1-12 March 2002)
EarthScience Picture of the Day May 15, 2002

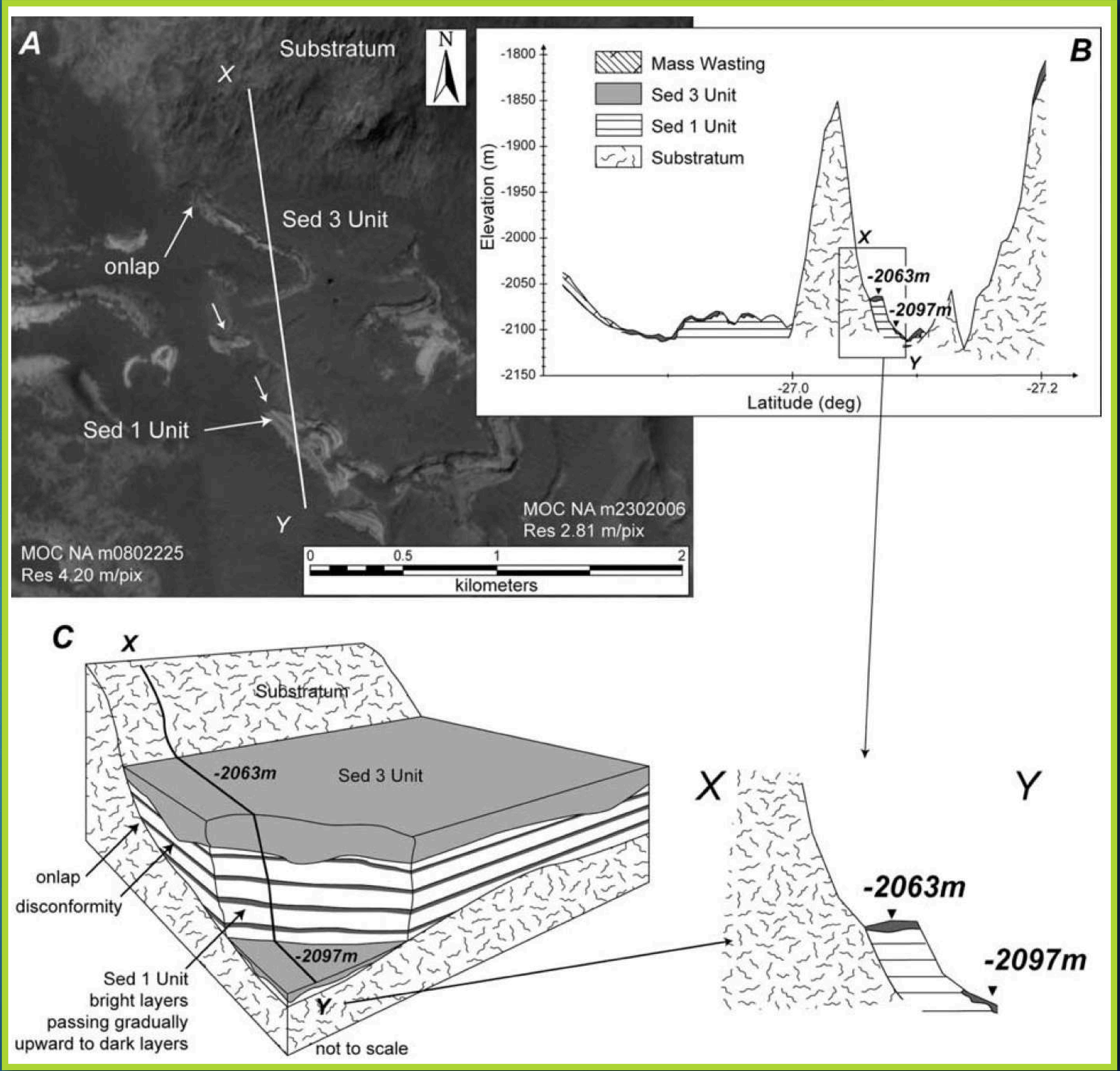
Disconformity

Cantor Chasma
Schieber, J., 2001. Finding life on Mars: A mudrock geologist's perspective. 32nd Lunar and Planetary Sciences Conference, Houston, March 12-16th 2001

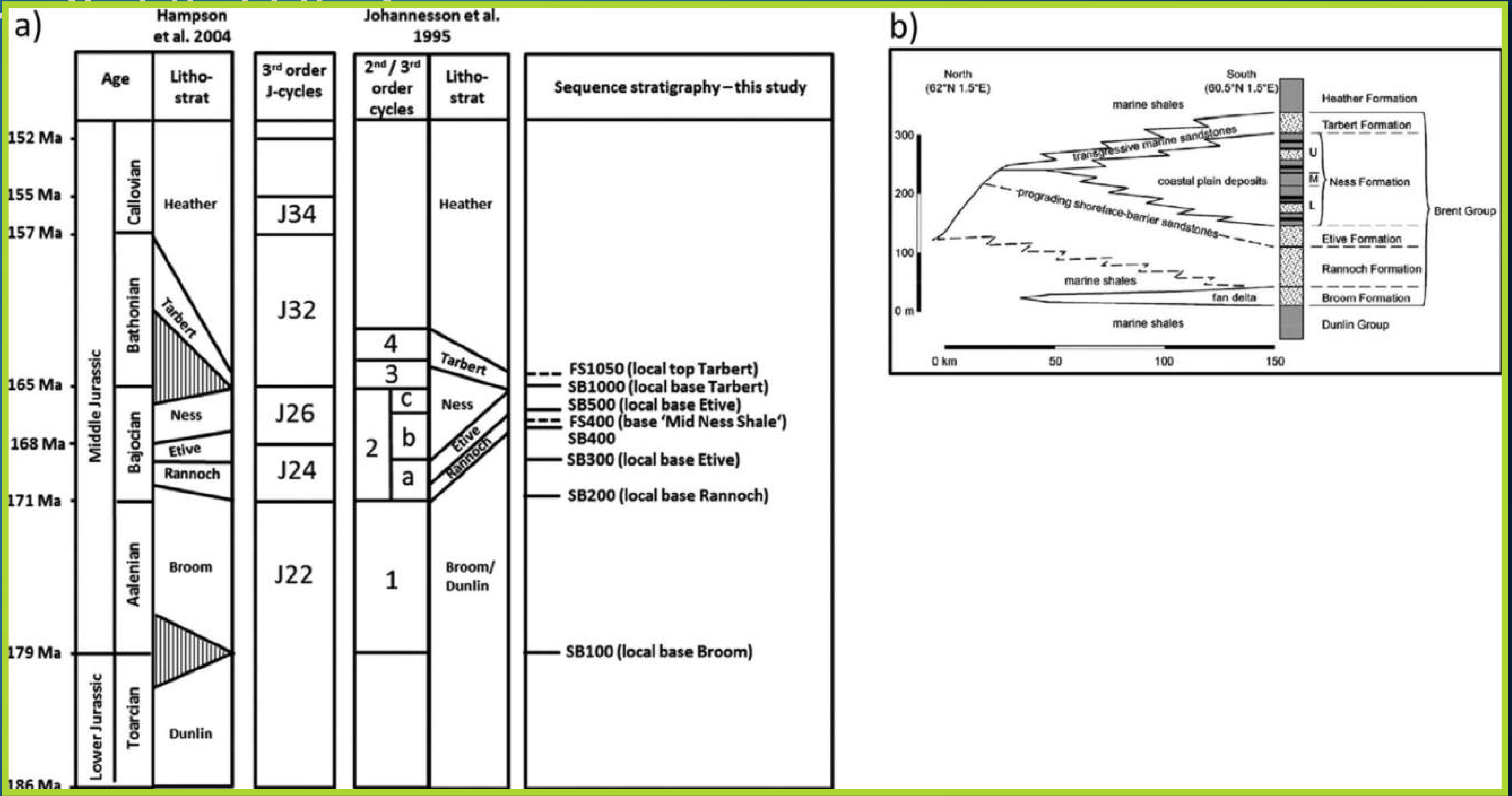


Example ⇢ Evaluate stratigraphic relations

Example → Evaluate stratigraphic relations



How to express these information ····› Stratigraphic Schemes

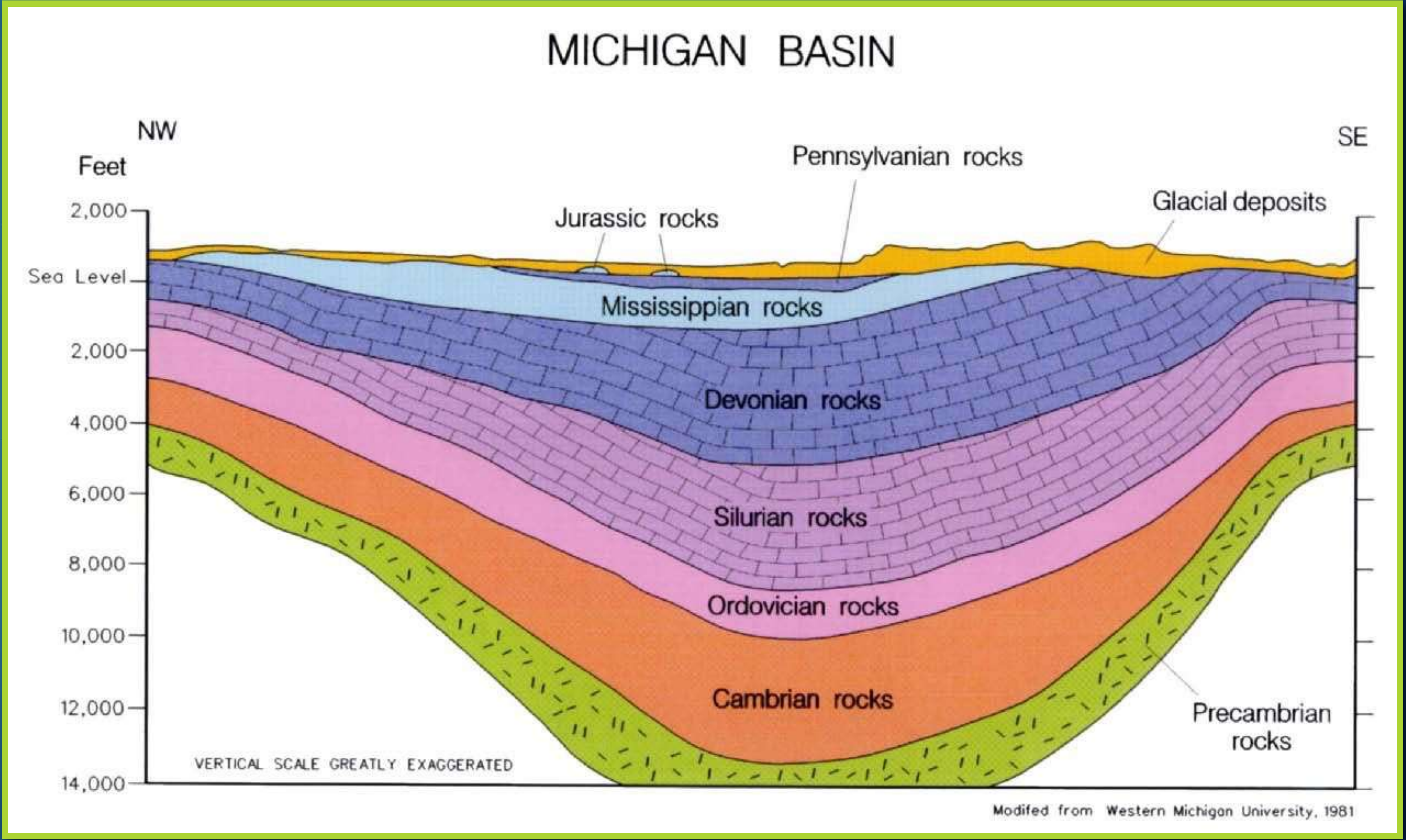


Space vs Time
(emphasis on units duration AND unconformities)

D. J. Went et al. Petroleum Geoscience 2013;19:307-328

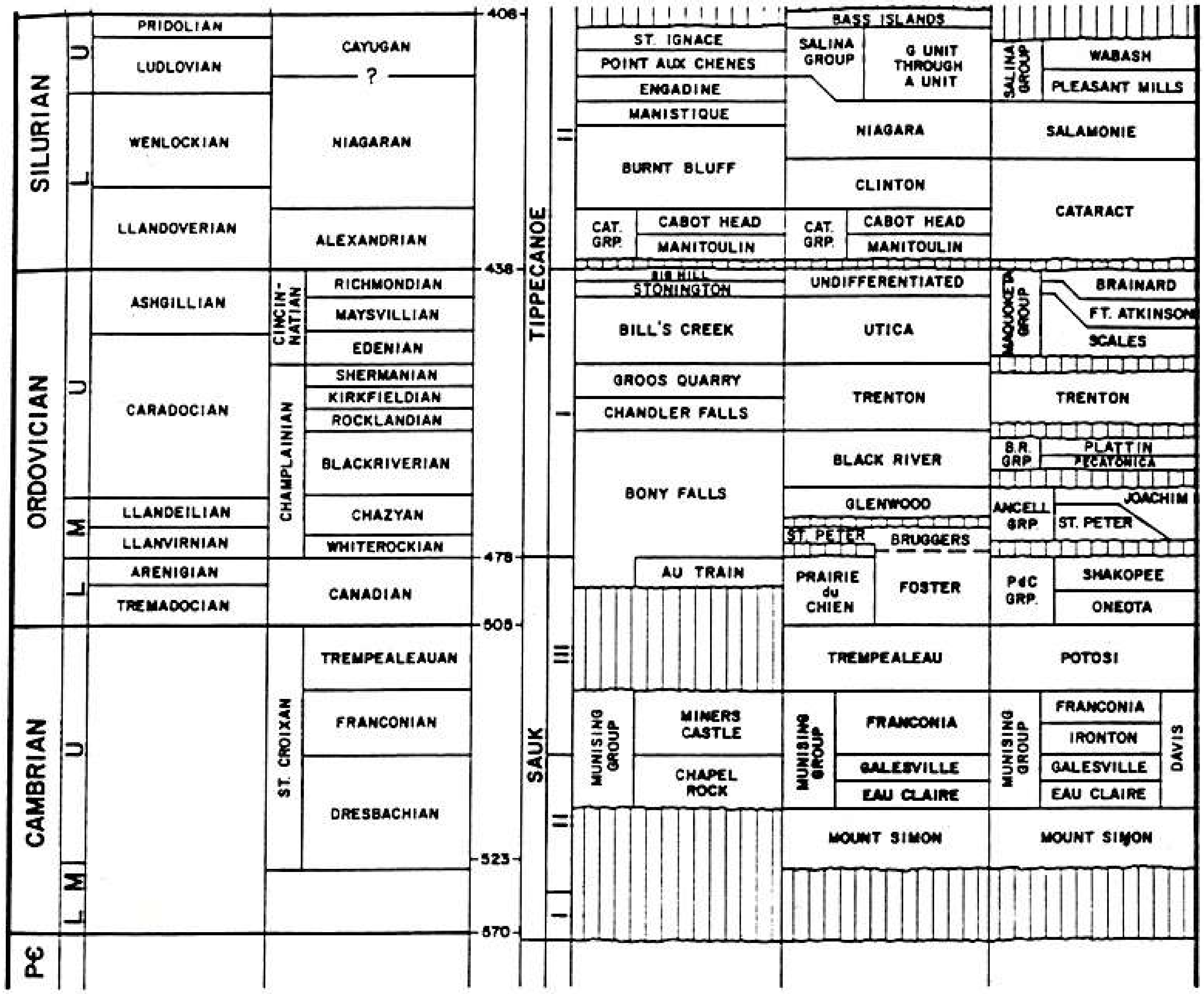
Space vs Space

- ✓ Stratigraphic Relations (vertical and lateral)
- ✓ Geometry of the units (including thickness variability)



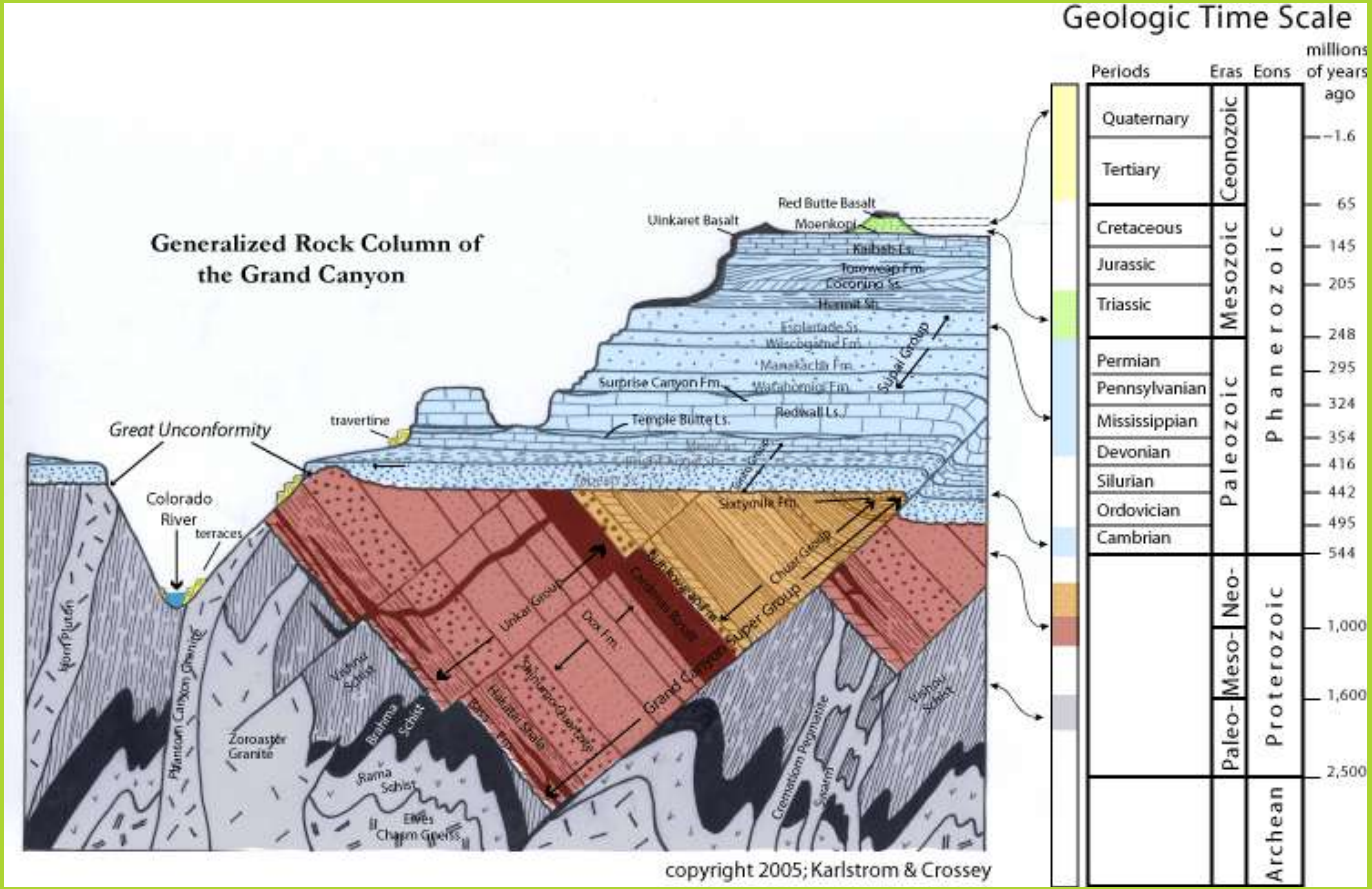
Space vs Time

- ✓ Stratigraphic Relations (vertical and lateral)
- ✓ (Possibly absolute Time-span of each unit AND unconformities



Fisher, J.H. et al., 1988

Figure 8b. Stratigraphic column for the Michigan Basin.

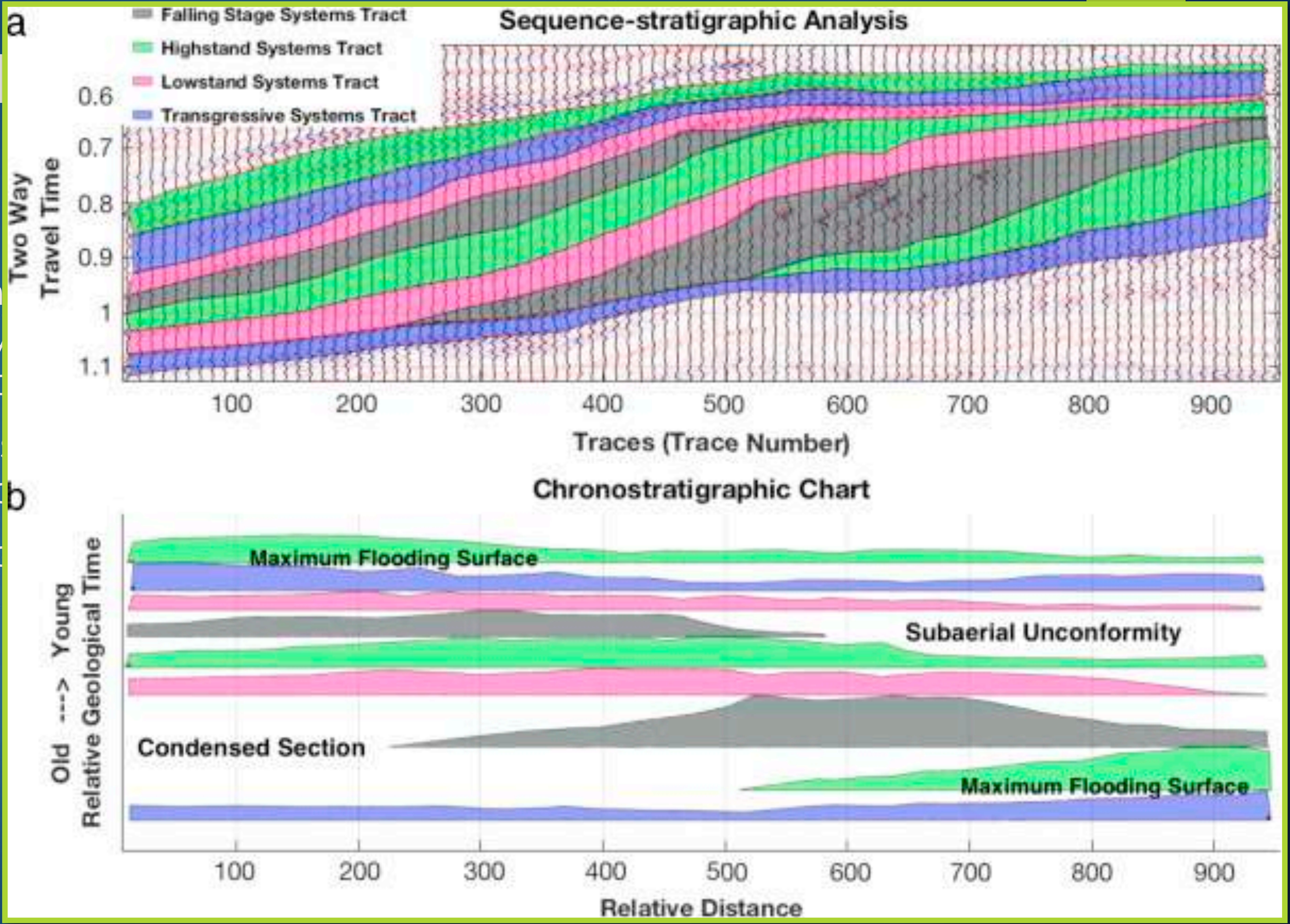

Geologic Time Scale
Generalized Rock Column of the Grand Canyon
Great Unconformity
Colorado River
terraces
travertine
Uinkaret Basalt
Red Butte Basalt
Moenkopi
Kaibab Ls.
Toroweap Fm.
Coconino Ss.
Hermit Sh.
Esplanade Ss.
Wescogame Fm.
Manakacha Fm.
Watahomigi Fm.
Supai Group
Surprise Canyon Fm.
Redwall Ls.
Temple Butte Ls.
Sixtymile Fm.
Chuar Group
Unkar Group
Dox Fm.
Cardenas Basalt
Grand Canyon Super Group
Hakatai Shale
Shinumo Quartzite
Vishnu Schist
Brahma Schist
Rama Schist
Zoroaster Granite
Phantom Canyon Granite
Elves Chasm Gneiss
Cremation Pegmatite
copyright 2005; Karlstrom & Crossey
Periods
Eras
Eons
millions of years ago
Quaternary
Tertiary
Ceonozoic
Cretaceous
Jurassic
Triassic
Mesozoic
Permian
Pennsylvanian
Mississippian
Devonian
Silurian
Ordovician
Cambrian
Paleozoic
Phanerozoic
Neo-
Meso-
Paleo-
Proterozoic
Archean
1.6
65
145
205
248
295
324
354
416
442
495
544
1,000
1,600
2,500

The Wheeler diagram

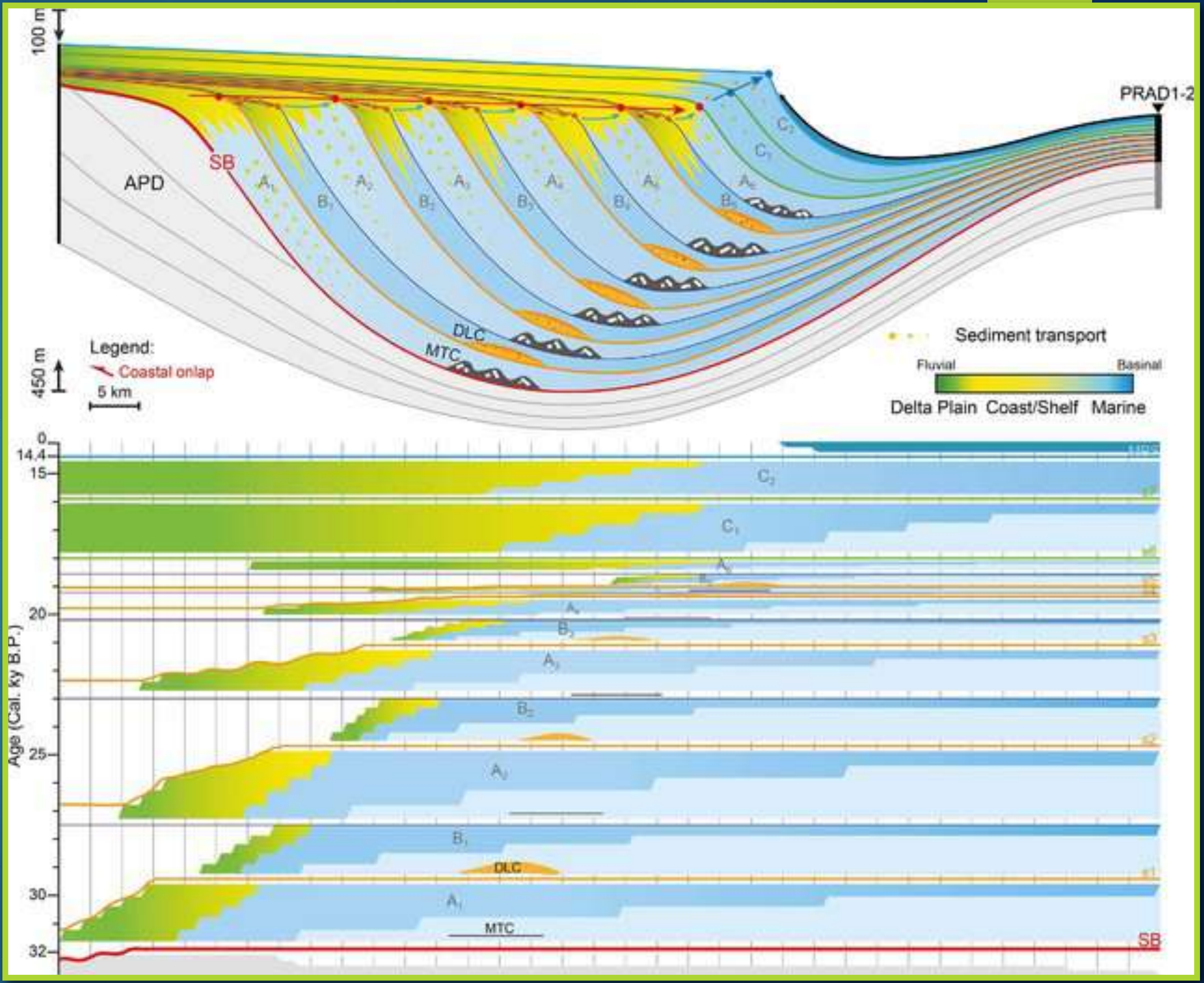
- Identifies and maps the geographic location and order in which sedimentary units, bounded by discontinuities, accumulated in stratigraphic cross-sections.
- The chart displays these contemporaneous units in the order they were laid down and their location.
- These units are represented as horizontal layers of sediment known as "chronosomes" bounded by time planes

The Wheel

- Identifies an
  sedimentary
  stratigraphic
- The chart di
  were laid do
- These units c
  "chronosom

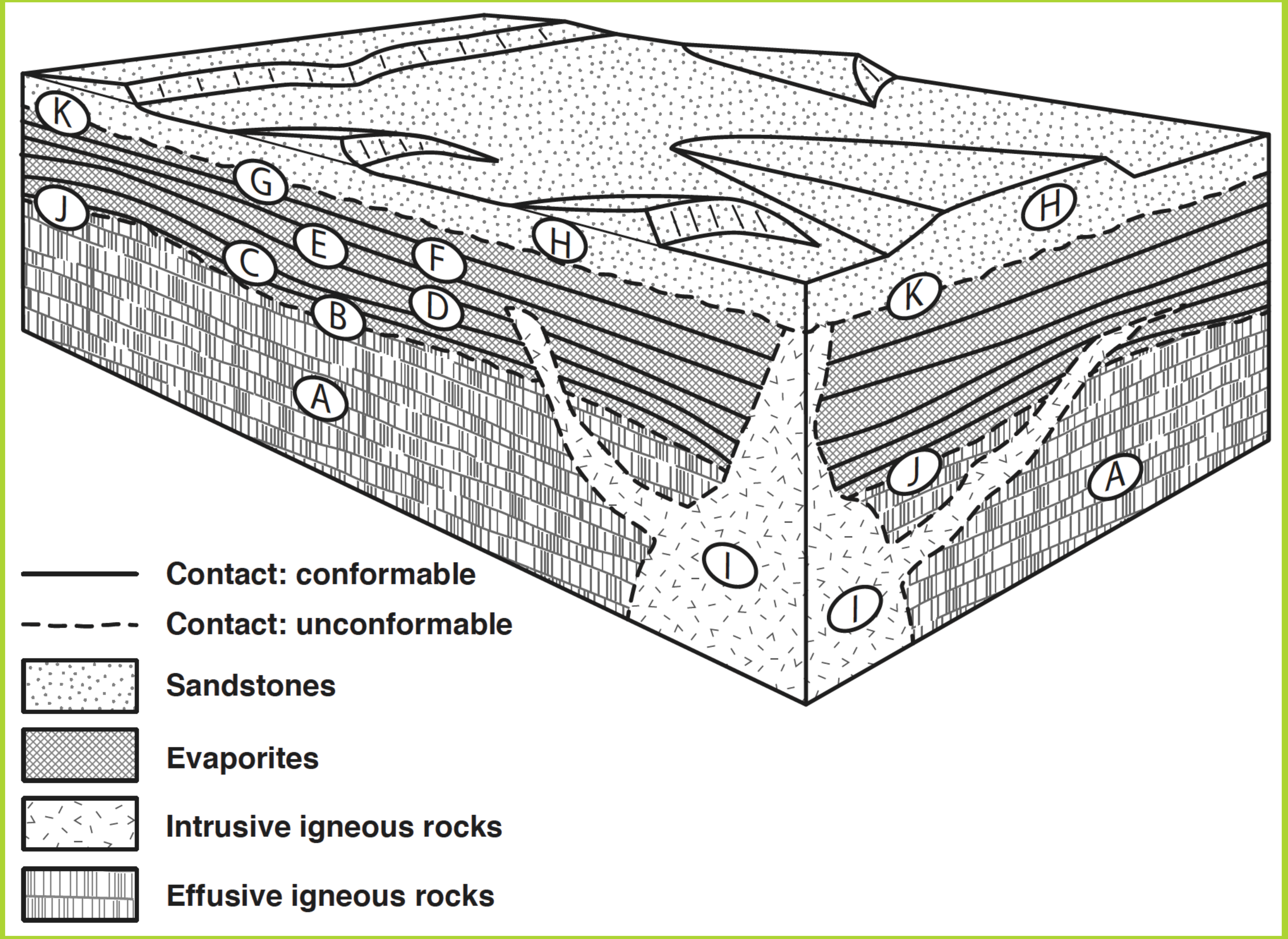


Example from the Pleistocene Po river

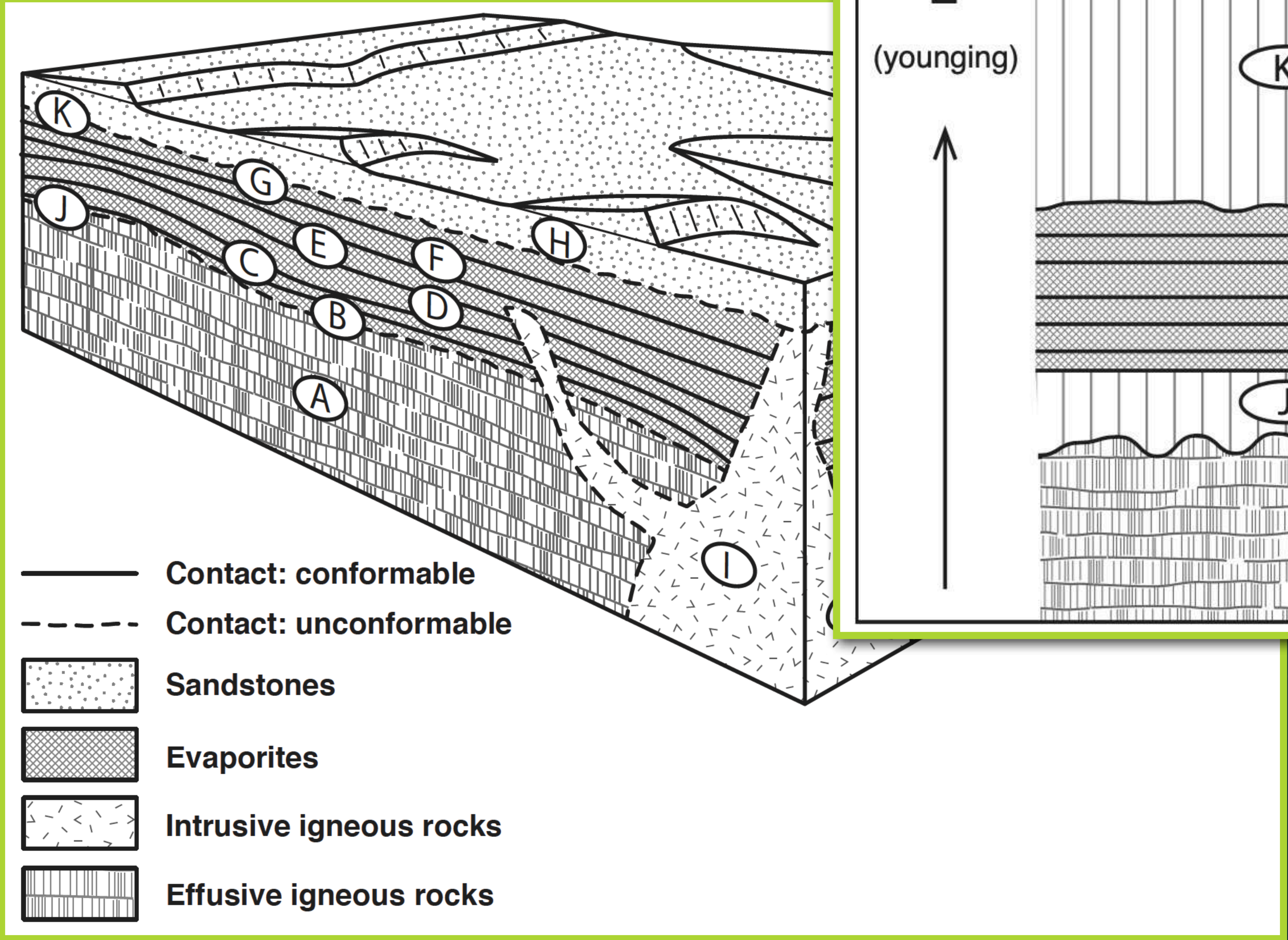


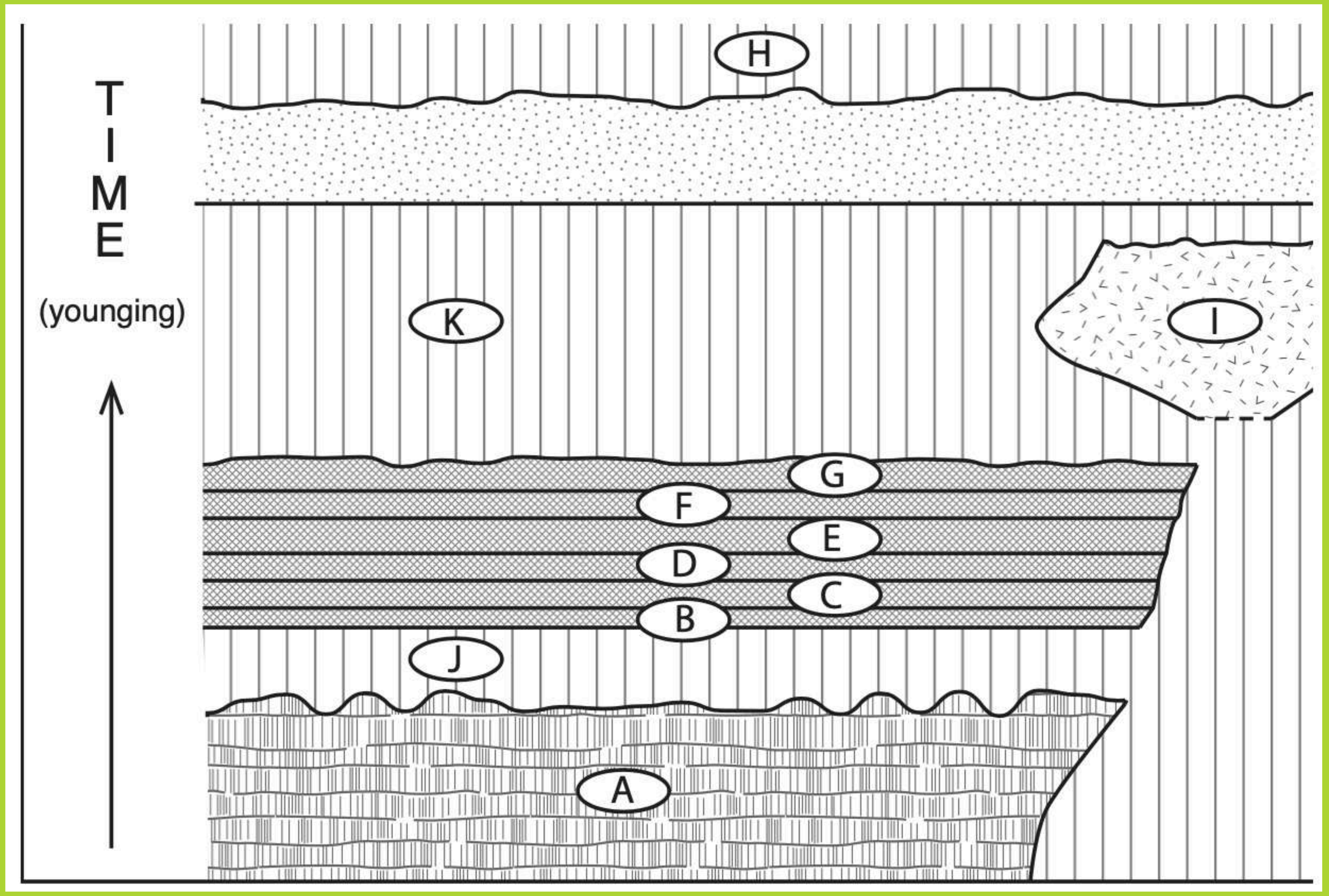
Pellegrini et al., 2018

Examples

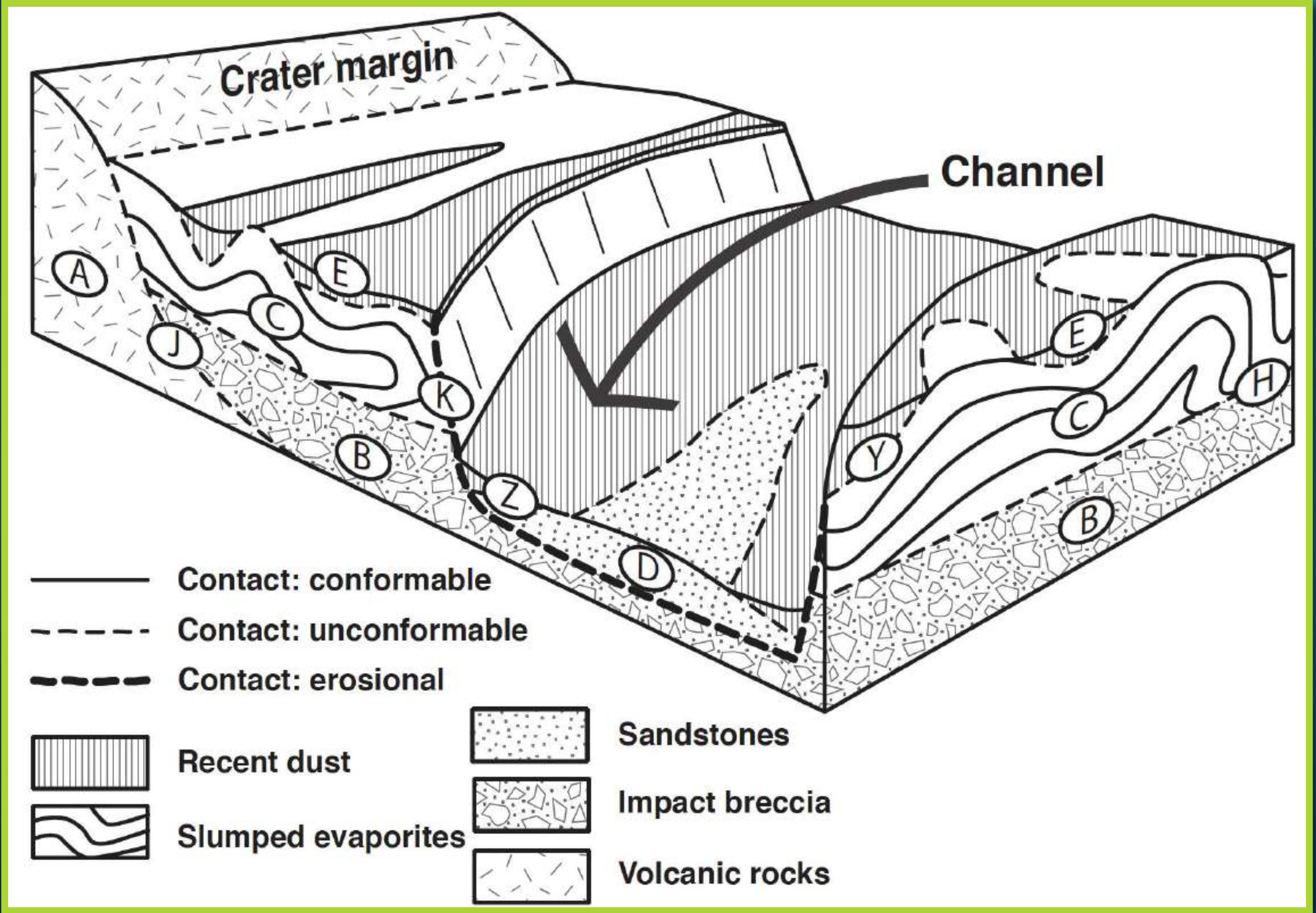

K
G
J
E
C
F
B
D
H
H
K
A
J
A
I
I
Contact: conformable
Contact: unconformable
Sandstones
Evaporites
Intrusive igneous rocks
Effusive igneous rocks

Examples


K
G
J
E
F
H
C
D
B
A
I
Contact: conformable
Contact: unconformable
Sandstones
Evaporites
Intrusive igneous rocks
Effusive igneous rocks

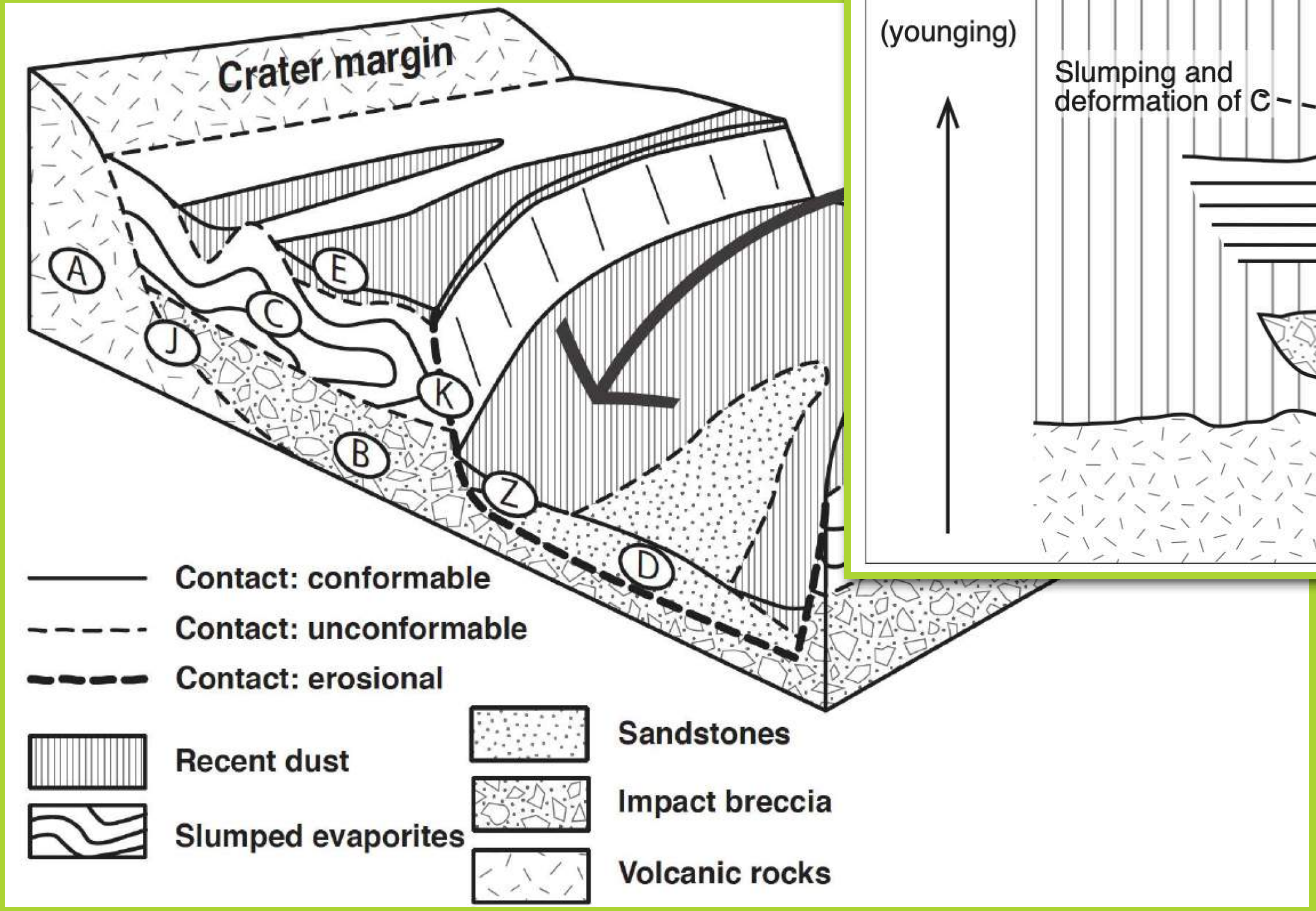

TIME
(younging)
H
K
I
G
F
E
D
C
B
J
A

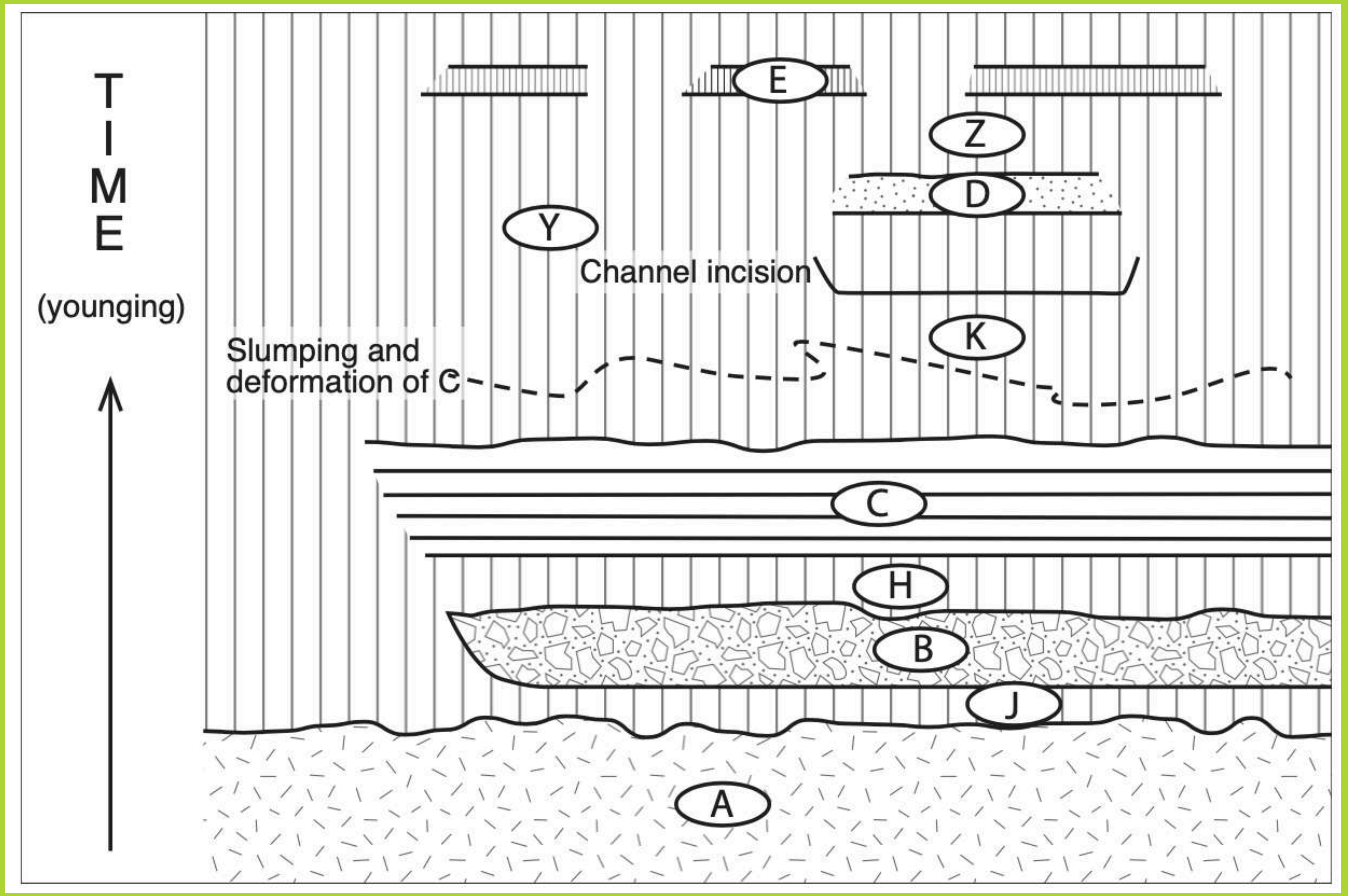
Examples



Crater margin
Channel
A
E
C
J
K
B
Z
D
E
H
C
Y
B
Contact: conformable
Contact: unconformable
Contact: erosional
Recent dust
Slumped evaporites
Sandstones
Impact breccia
Volcanic rocks

Examples


Crater margin
A
E
C
J
K
B
Z
D
Contact: conformable
Contact: unconformable
Contact: erosional
Recent dust
Slumped evaporites
Sandstones
Impact breccia
Volcanic rocks

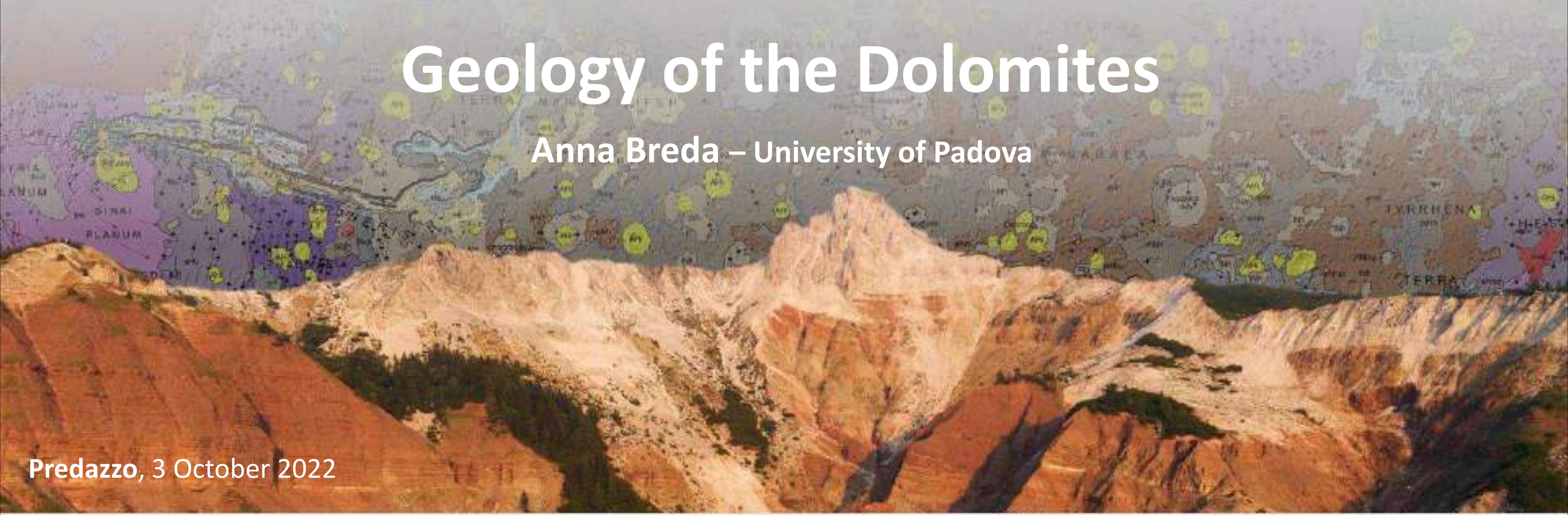

TIME
(younging)
E
Z
D
Y
Channel incision
K
Slumping and deformation of C
C
H
B
J
A

GeoPlaNet

Co-funded by the ERASMUS + Programme of the European Union

DIPARTIMENTO DI GEOSCIENZE

SCHOOL ON PLANETARY GEOLOGICAL MAPPING AND PLANETARY ANALOGUES



Geology of the Dolomites

Anna Breda – **University of Padova**

Predazzo, 3 October 2022

Nantes Université

UNIVERSIDADE D COIMBRA

U. PORTO

FONDAZIONE UNESCO

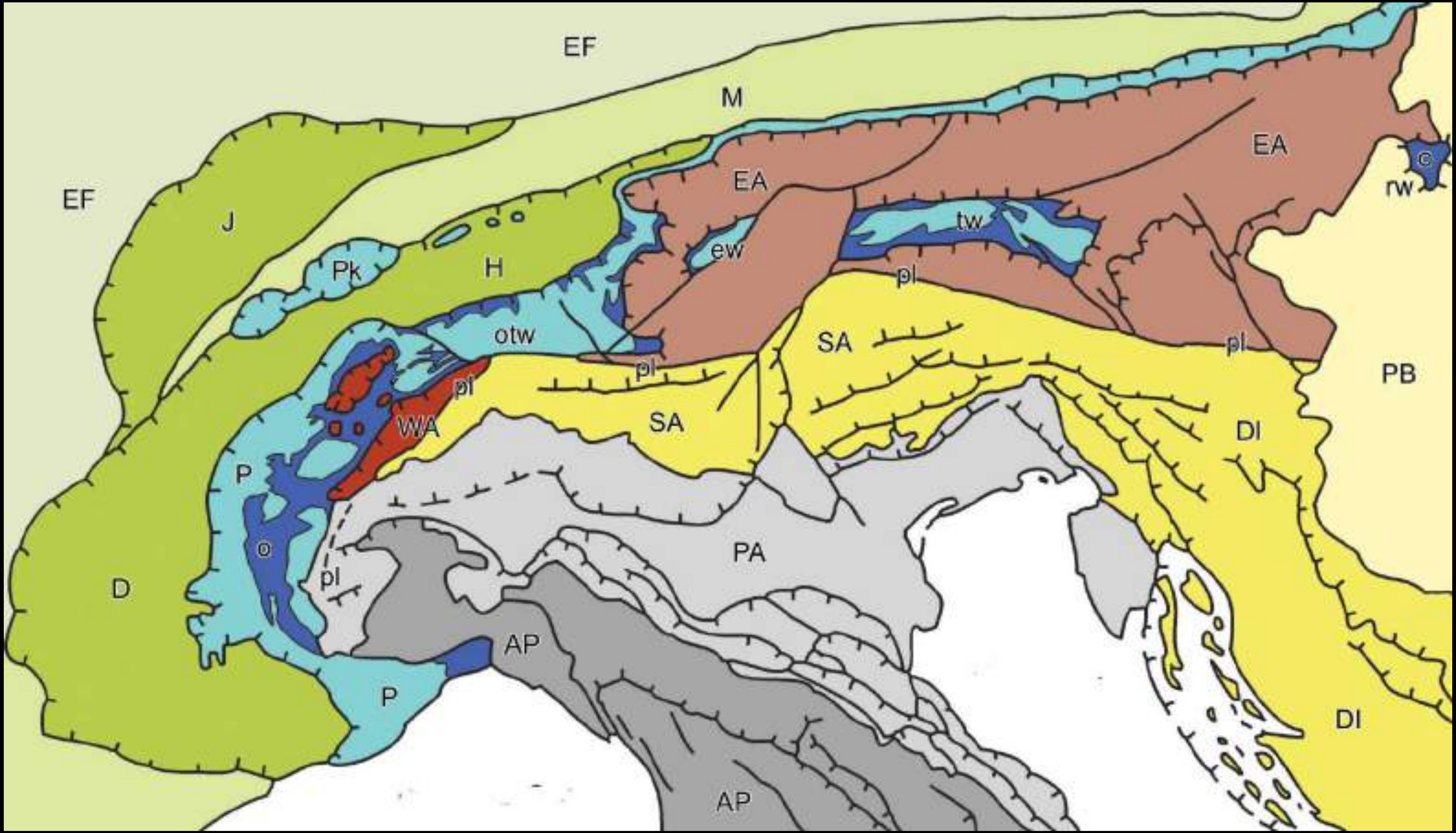
MuSe

GEOPARC Bletterbach

Where we are


Zurich
Innsbruck
Genève
Milano
Torino
Padova
Venezia
Trieste

Alps structural map

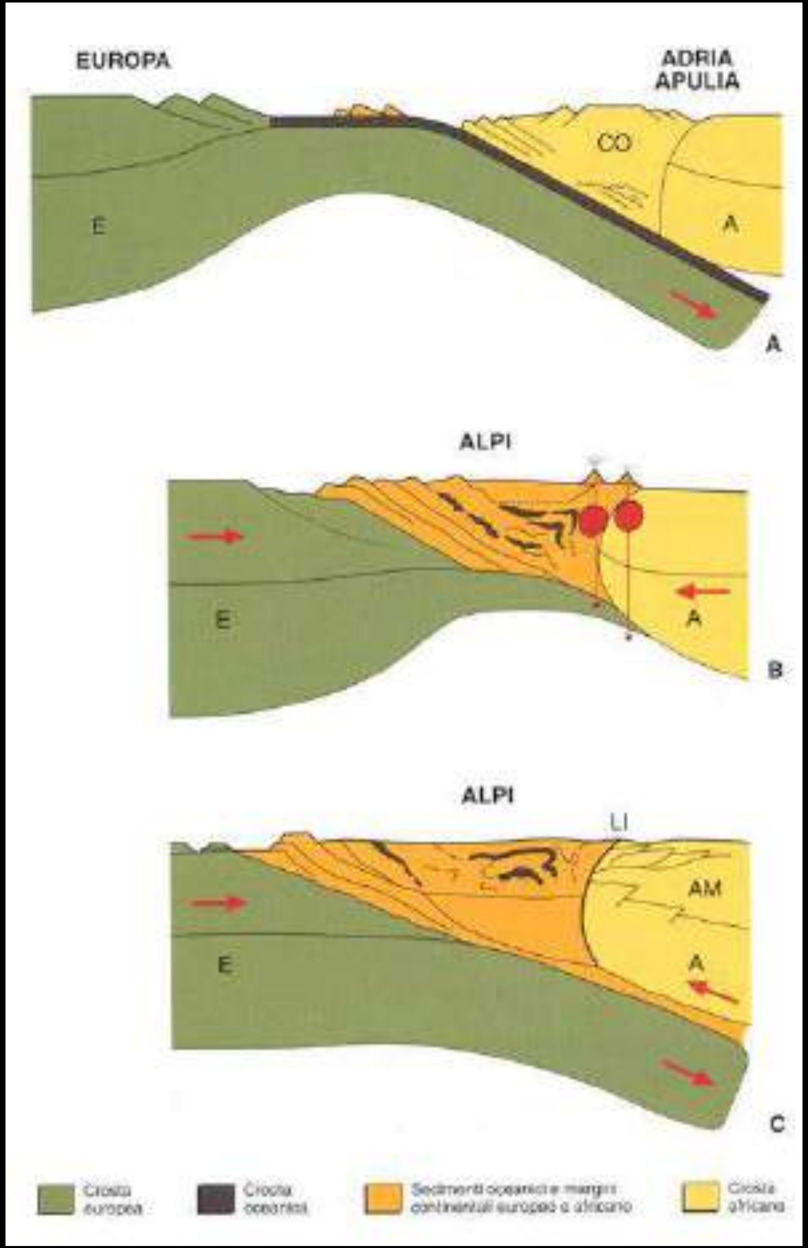


Dal Piaz et al., 2003

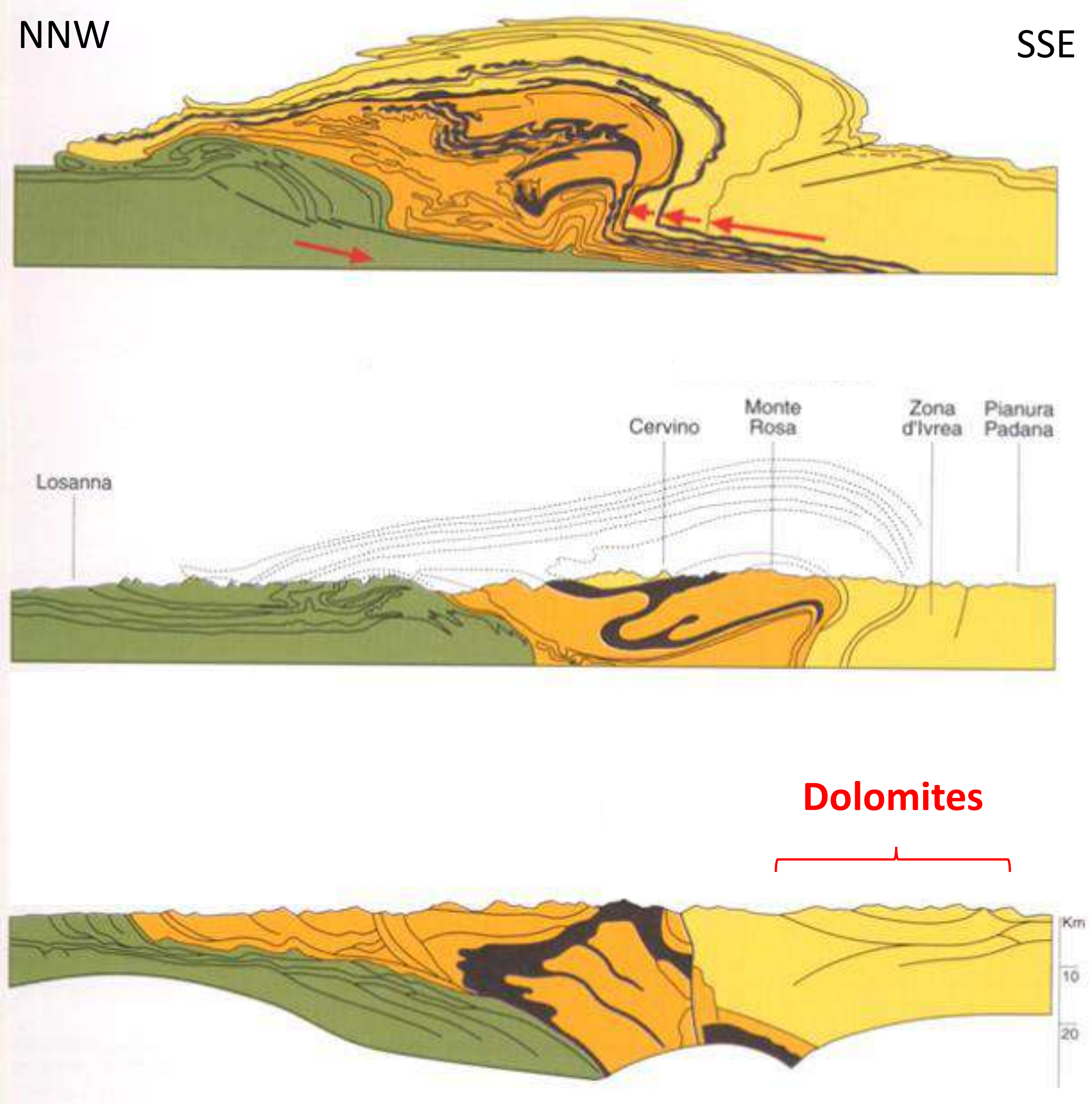
Alpine convergence and collision

Double-vergente chain

NNW SSE



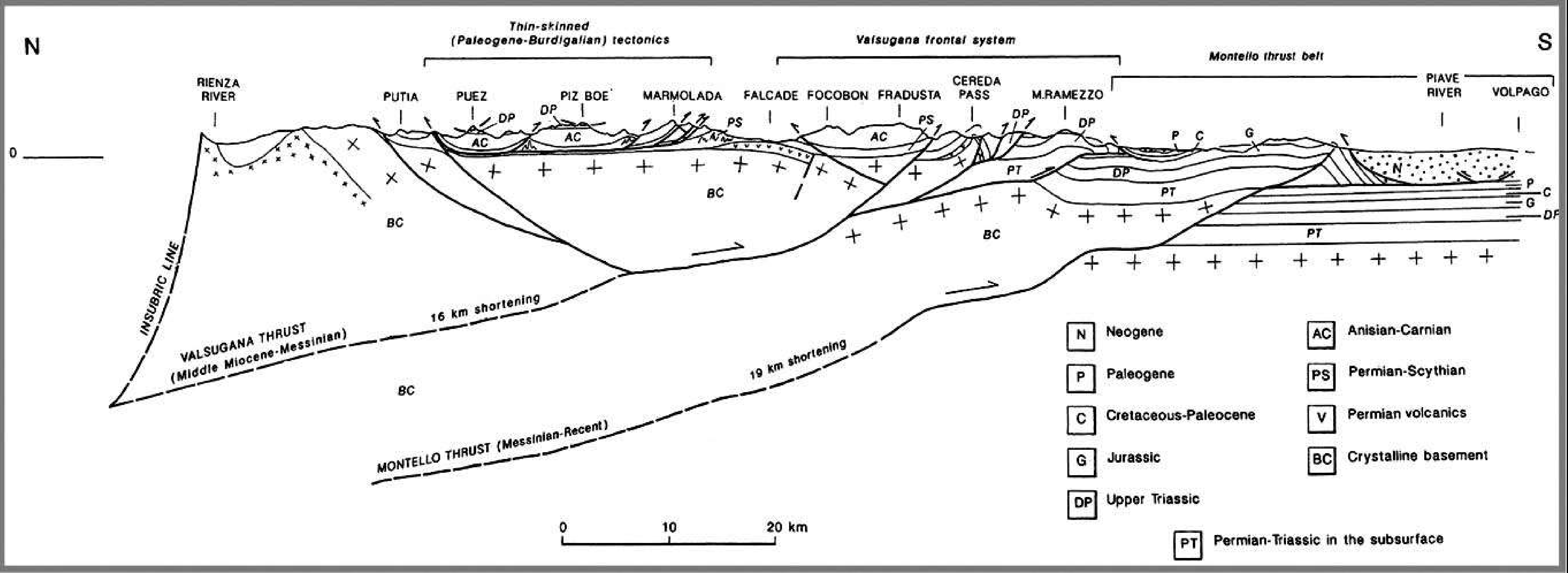
NNW SSE



Dal Piaz et al., 2003, modified

Southern Alpine geological cross-section

foreland →



Castellarin, 1982

Original paleogeography is preserved

Photo: P. Gianolla
Credit: M. Franceschi

Original paleogeography is preserved

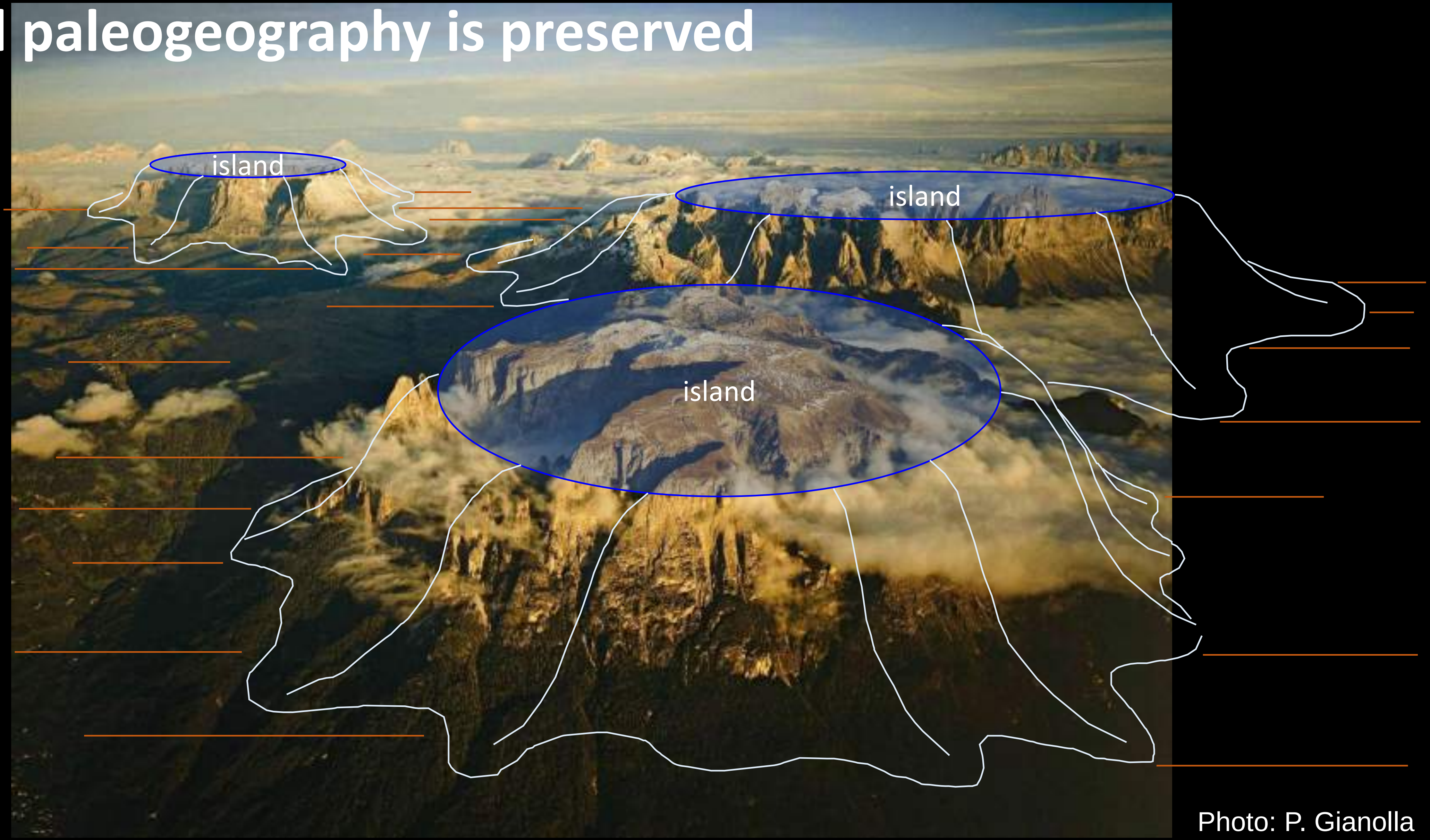


Photo: P. Gianolla
Credit: M. Franceschi

Original paleogeography is preserved

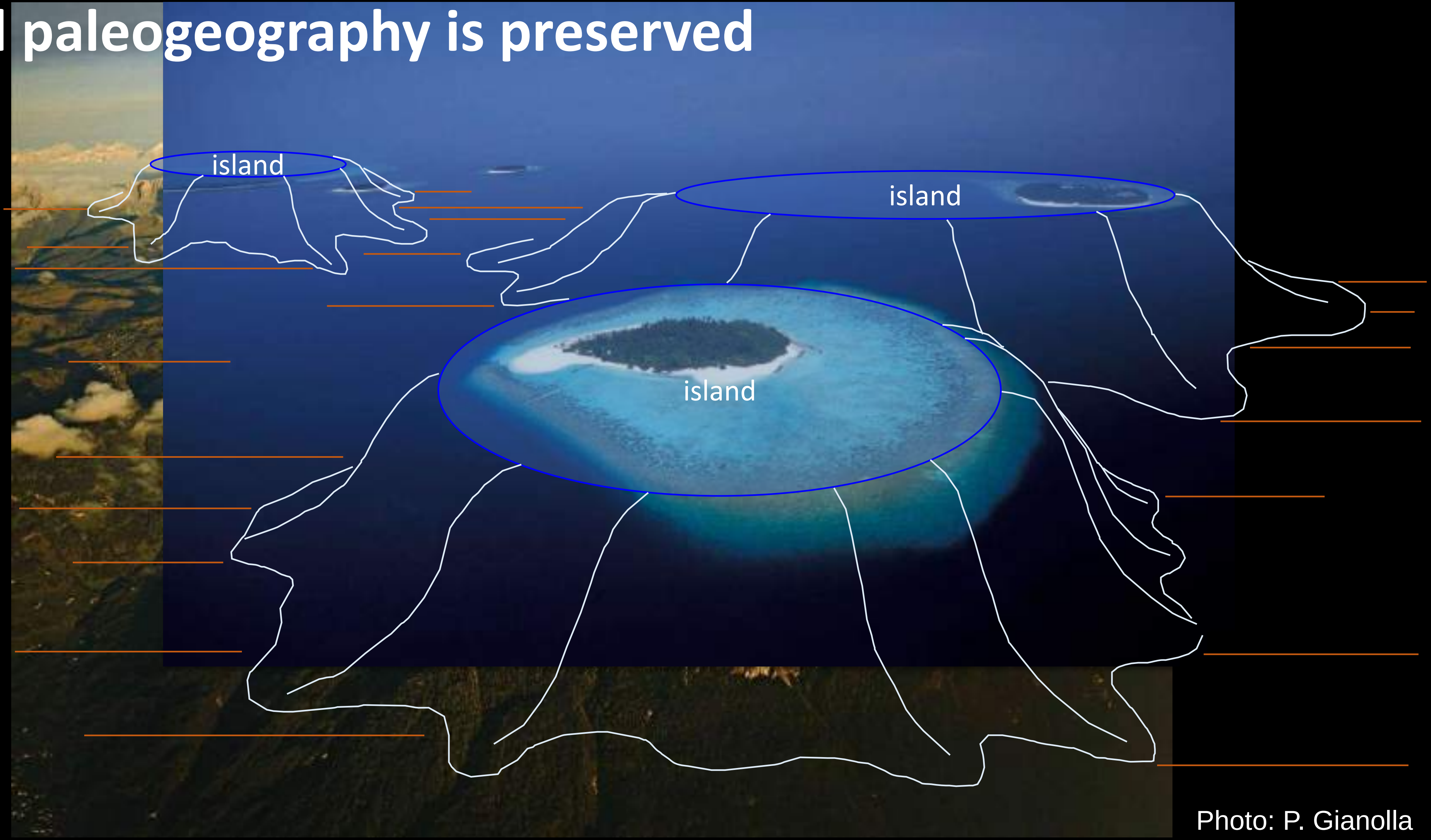
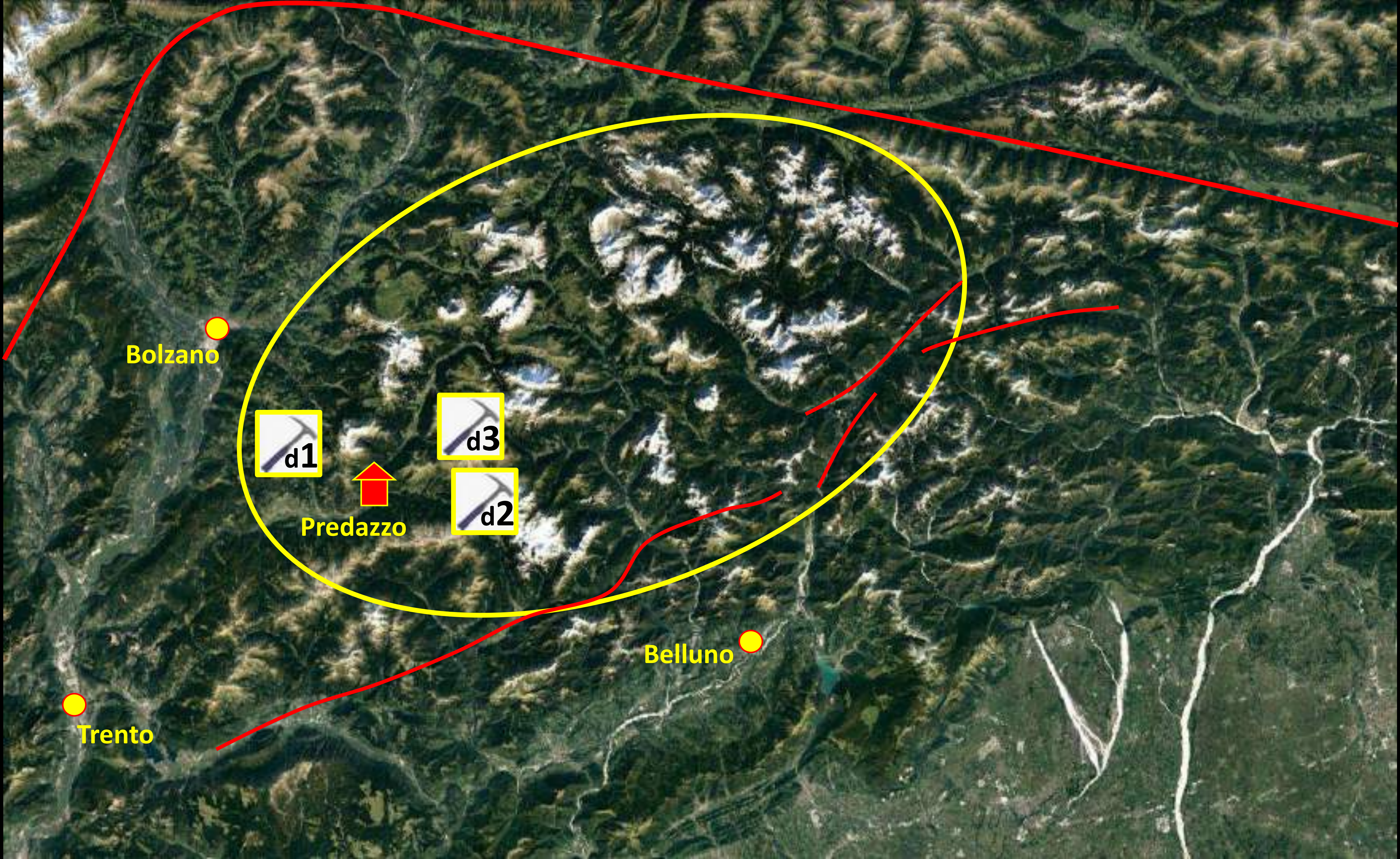
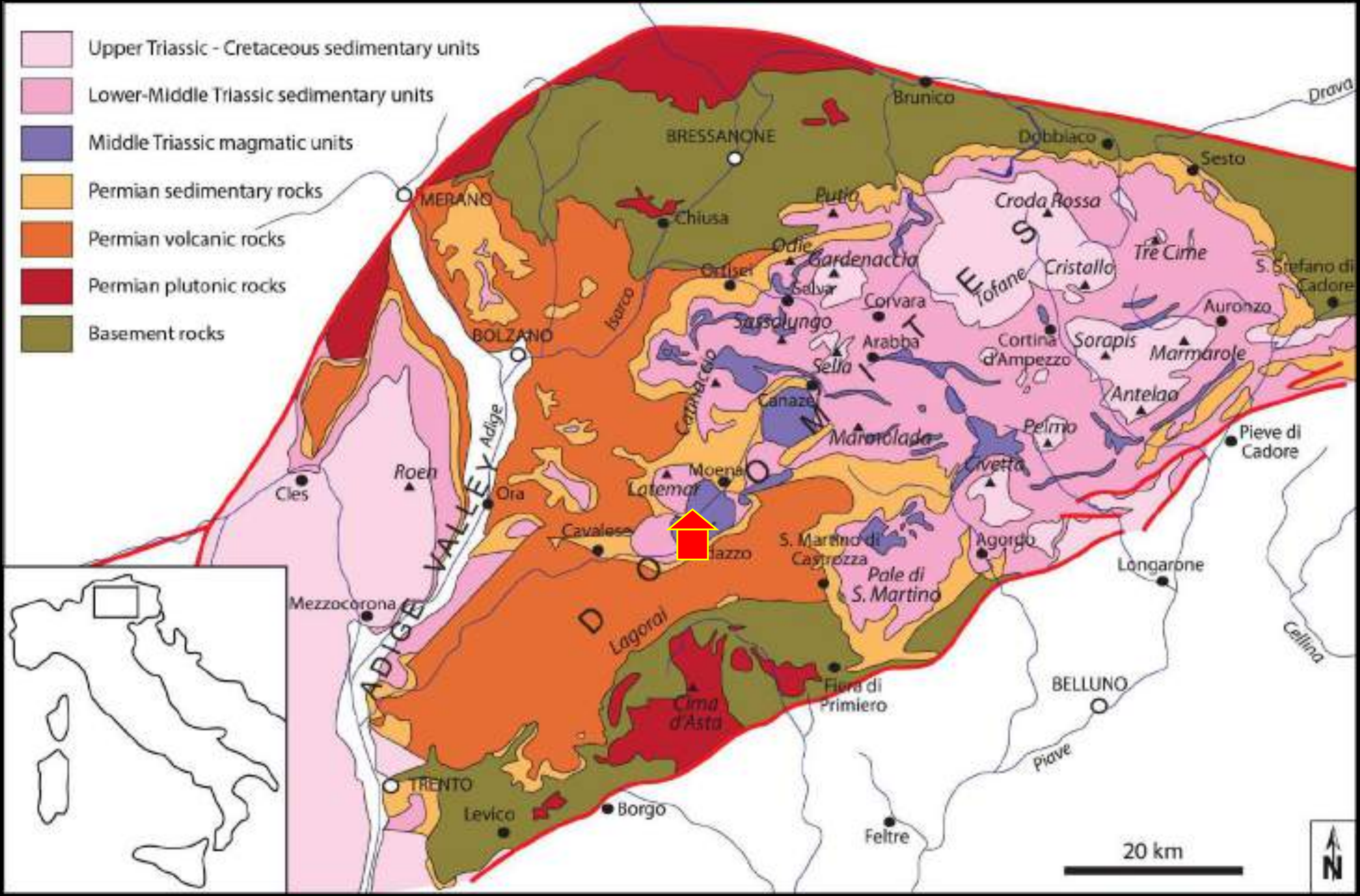


Photo: P. Gianolla
Credit: M. Franceschi

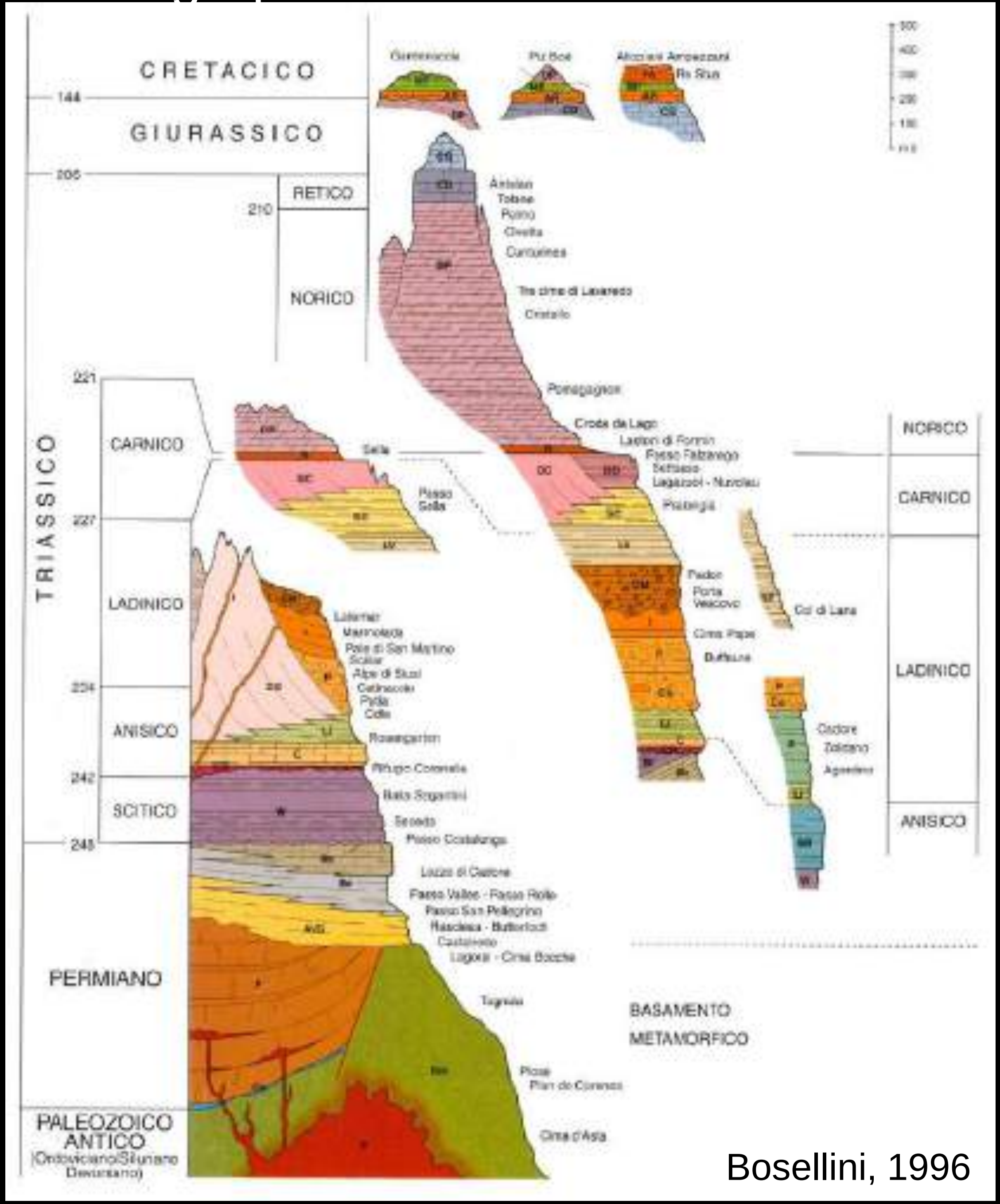

Bolzano
d1
d3
d2
Predazzo
Belluno
Trento

Simplified geological map of the Dolomites



Breda & Preto, 2011 mod.

Stratigraphic succession of the Dolomites



Bosellini, 1996

Upper Jurassic-Cretaceous: pelagic (deep basins)

Upper Carnian-Norian-Rhaetian-Lower Jurassic: peritidal flat

Carnian Pluvial Episode

Lower Carnian: carbonate platforms and basins

Ladinian magmatic event (marine - basic)

Ladinian: high-relief carbonate platforms and deep basins

Anisian tectonic fragmentation

Anisian: fluvial to carbonate banks

Subaerial unconformity

Lower Triassic: mixed carbonate siliciclastic (shallow marine)

Permo-Triassic mass extinction

Upper Permian: evaporitic deposits (coastal sabkhas)

Upper Permian: continental red beds (dryland rivers)

Subaerial unconformity

Lower Permian magmatic event (subaerial - acid)

Transgr.

Transgression

Flat topo.

Complex topo.

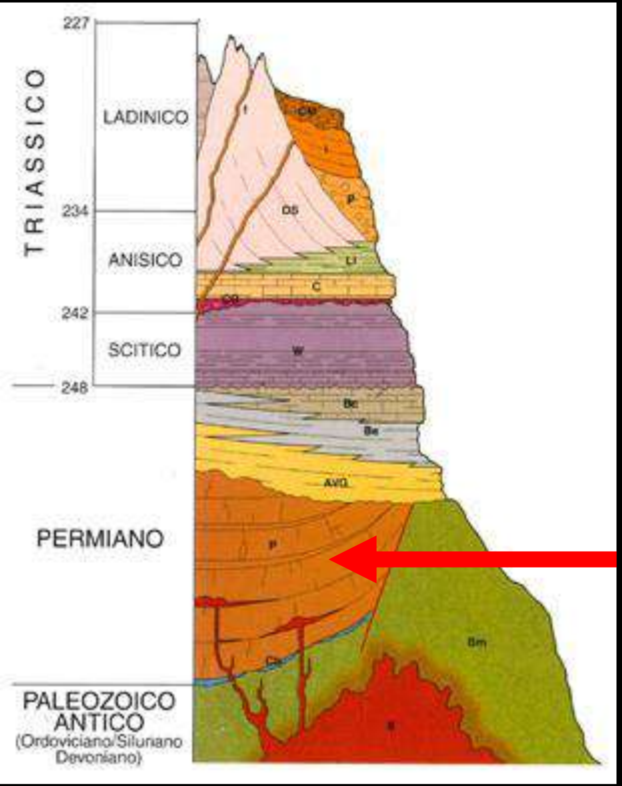
Flat topo.

Lower Permian - Athesian Volcanic Complex

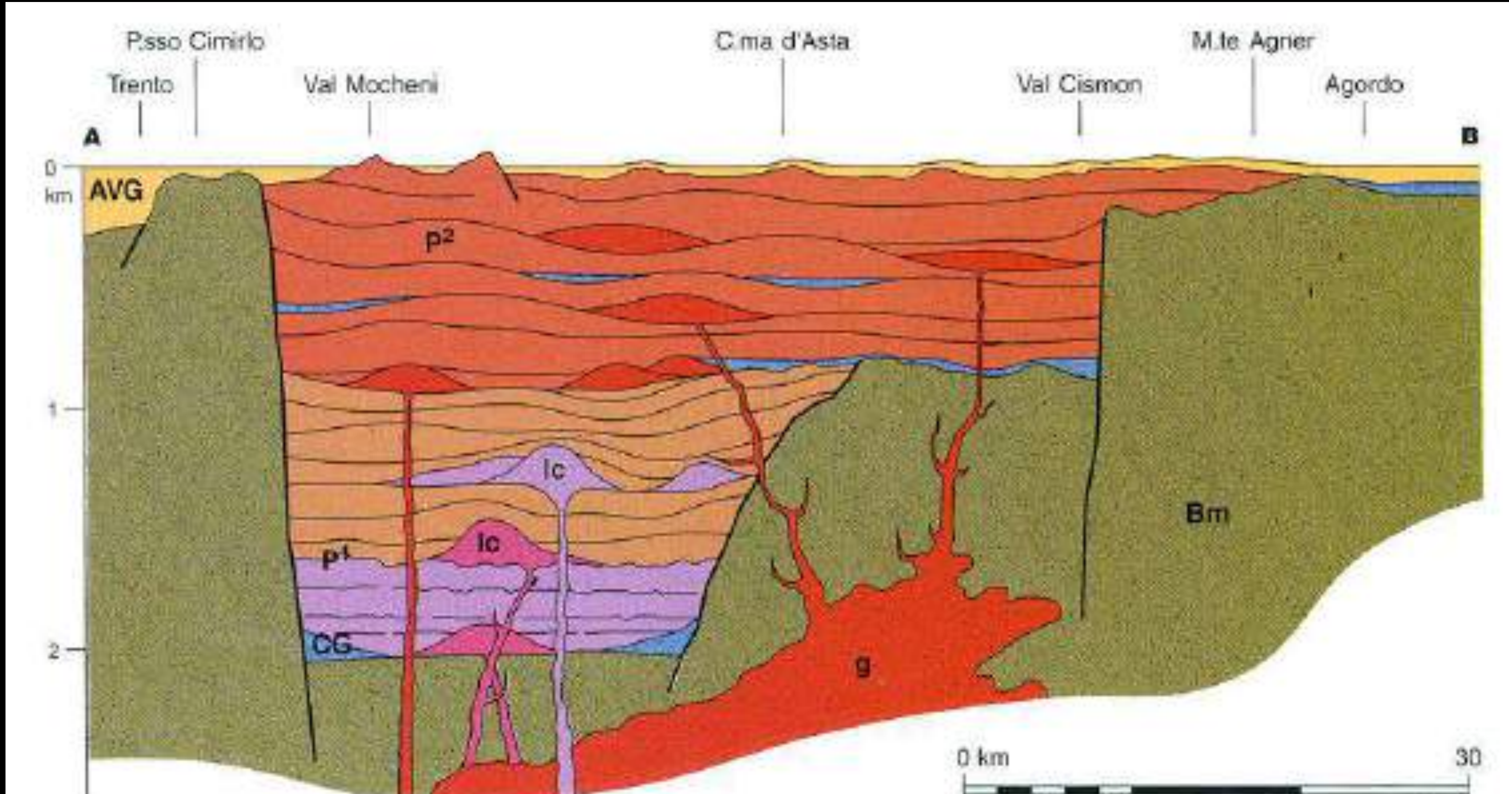
Pyroclastic flow

Extensional tectonics > Caldera di Bolzano
Up to 2000 m thick

Rhyolitic – rhyodacitic magma
Subaerial magmatic activity
Pyroclastic flows > ignimbrites



WSW

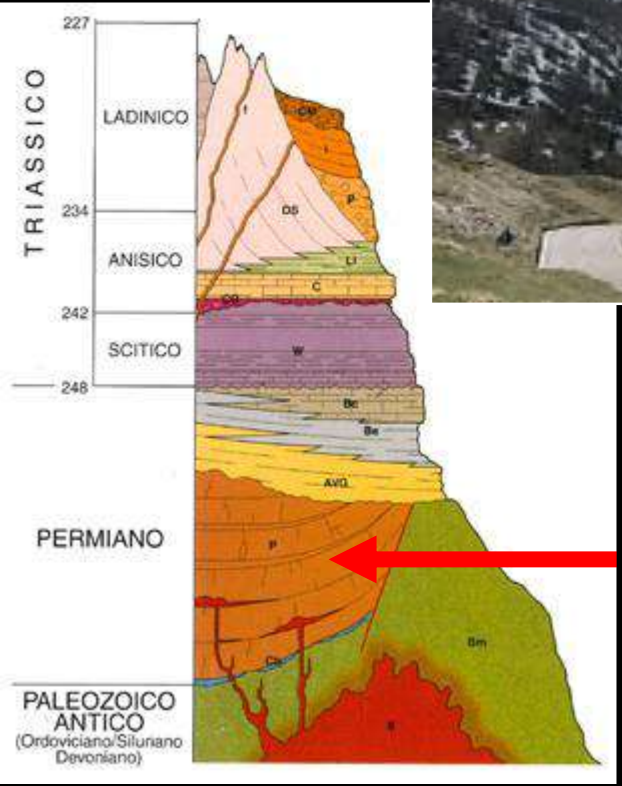


Bosellini, 1996

ENE

Lower Permian - Athesian Volcanic Complex

Passo Rolle – 2° day field trip



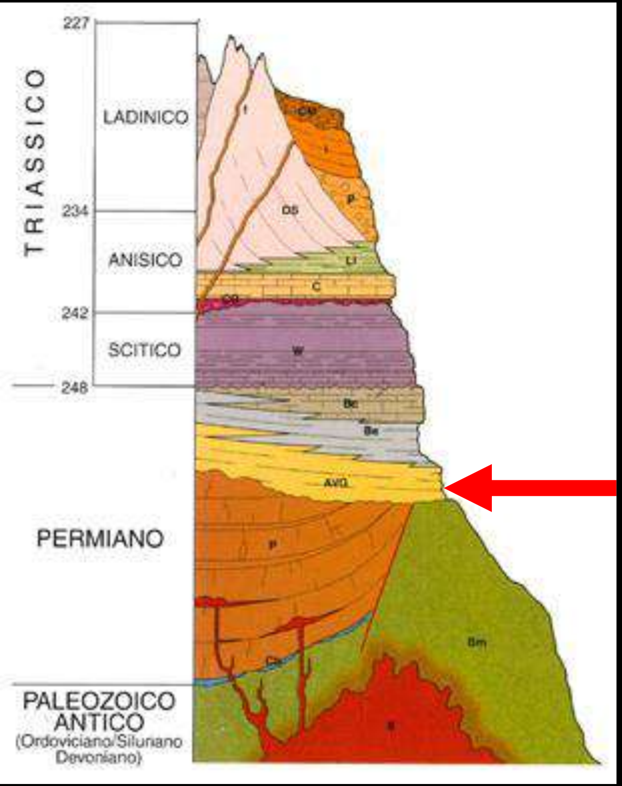
Bletterbach gorge – 1° day field trip

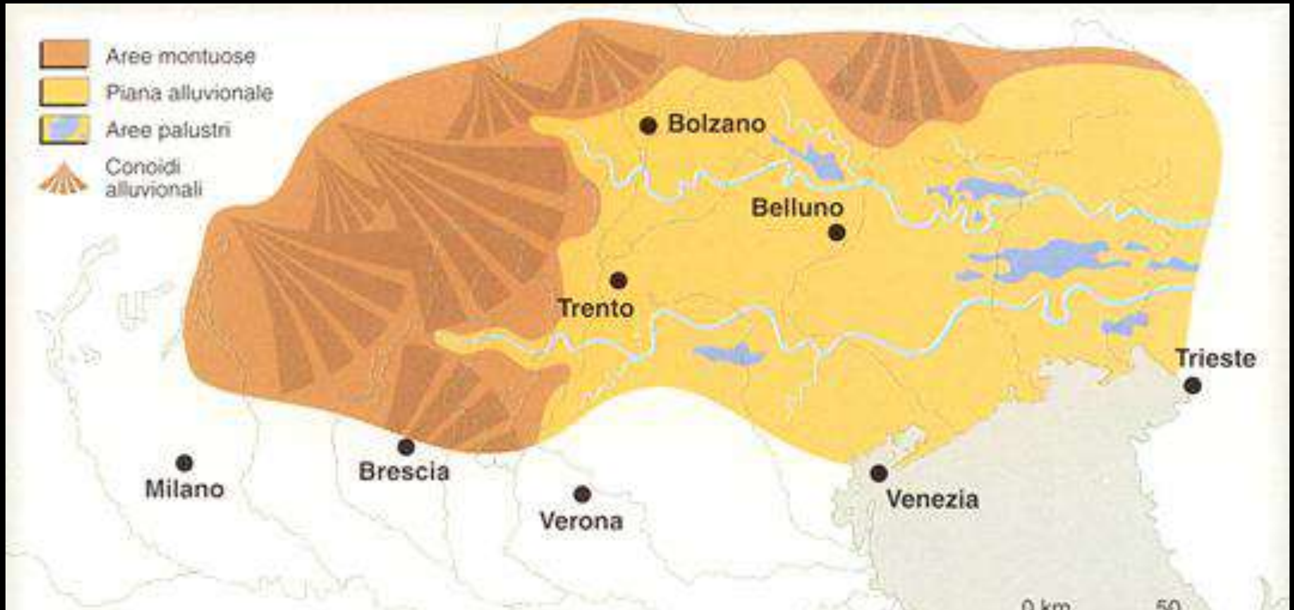
Upper Permian – Val Gardena Sandstone

Continental siliciclastic deposition > red beds > sandstones and siltstones
Up to 150 m thick

Fluvial channels (braided and meandering) + overbank deposits
Arid paleosols (calcrete nodules + sulphates)

Dryland river systems

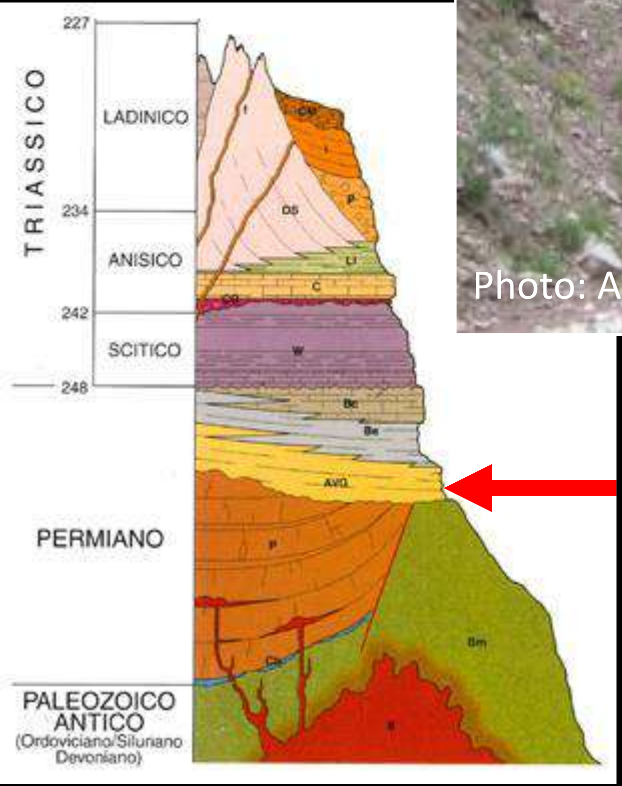




Bosellini, 1996

Tetrapod footprints
from the Bletterbach

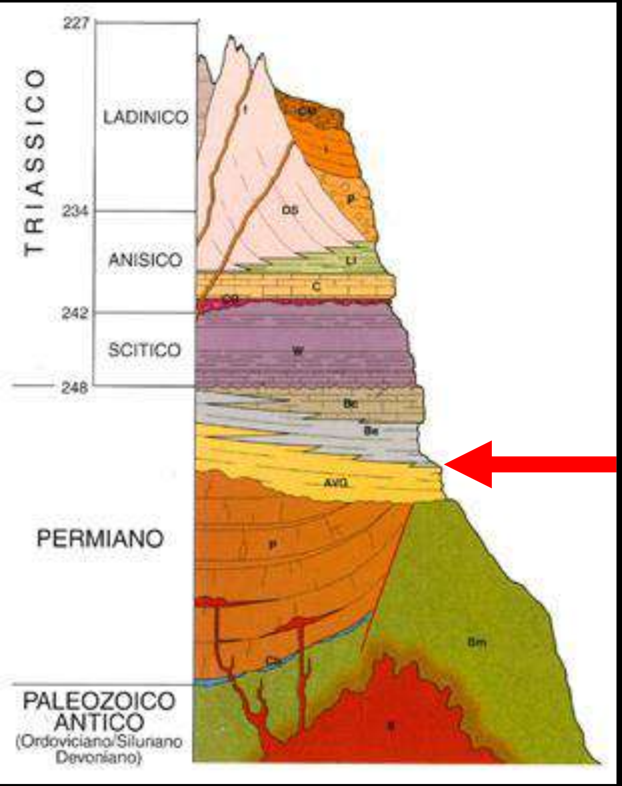
Upper Permian – Val Gardena Sandstone



Bletterbach gorge – 1° day field trip

Upper Permian transgression

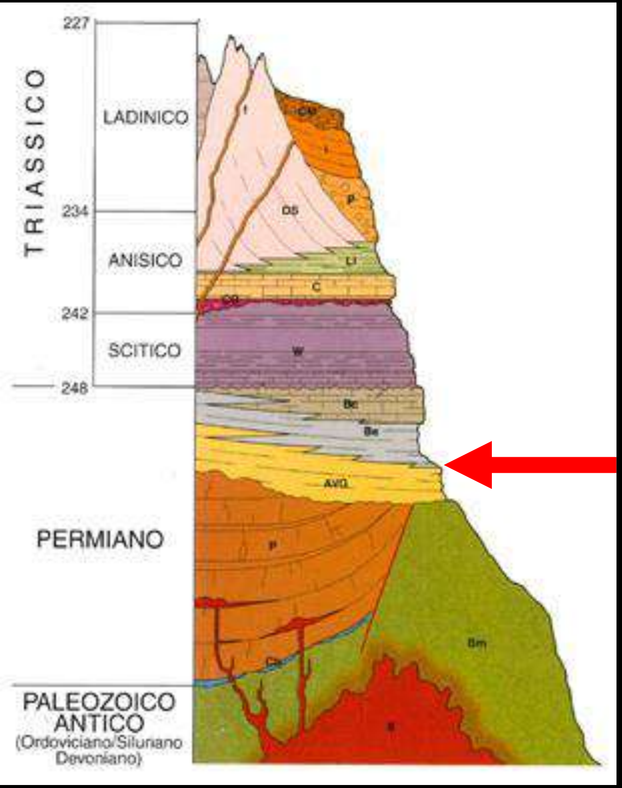
Dryland river system > Coastal sabkha

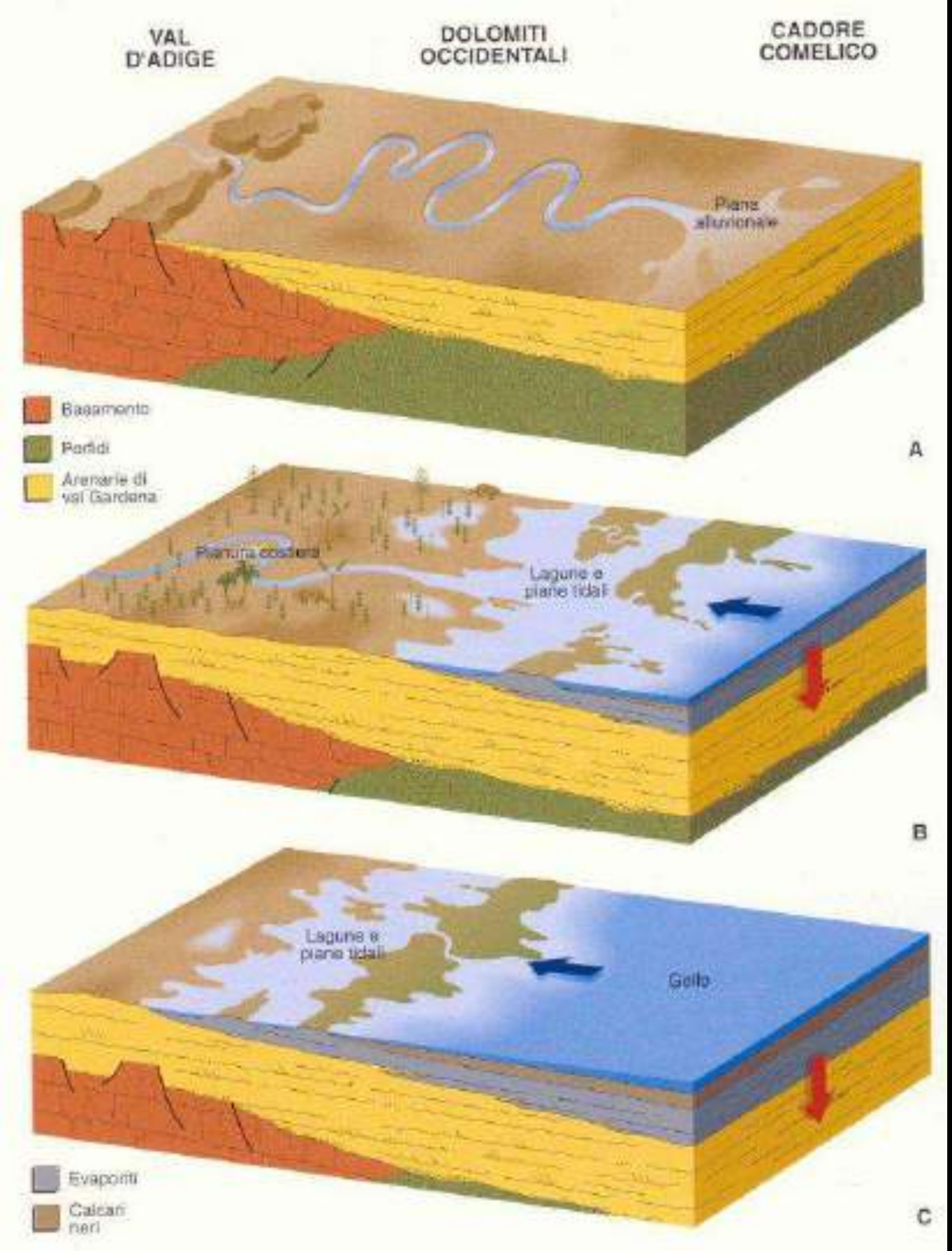


Monte Seceda

Upper Permian transgression

Dryland river system > Coastal sabkha





Bosellini, 1996

Upper Permian – *Bellerophon* Formation

Evaporitic precipitation > coastal sabkha
Up to 250 m thick? (extremely folded)

Vacuolar aphanitic dolostones
Dark clay and marls
Sulphate precipitation

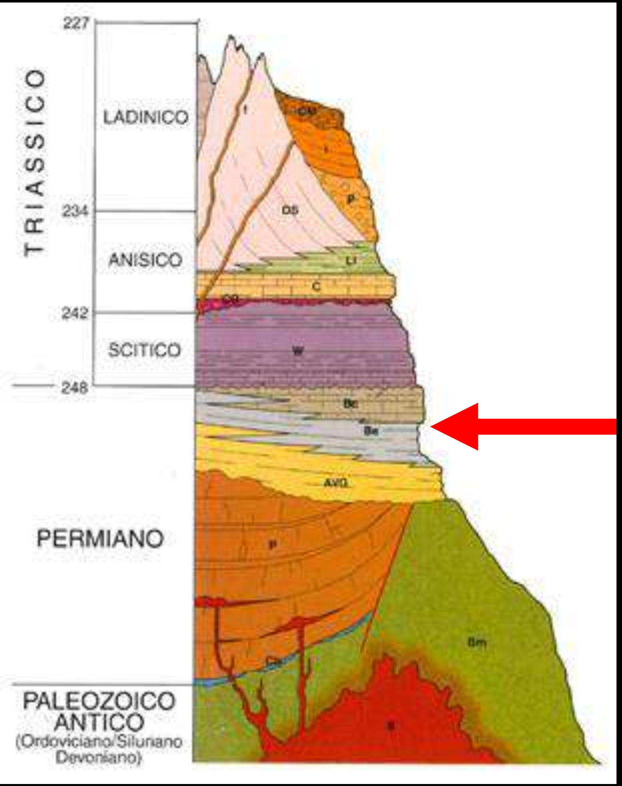



Photo: P. Ferretti

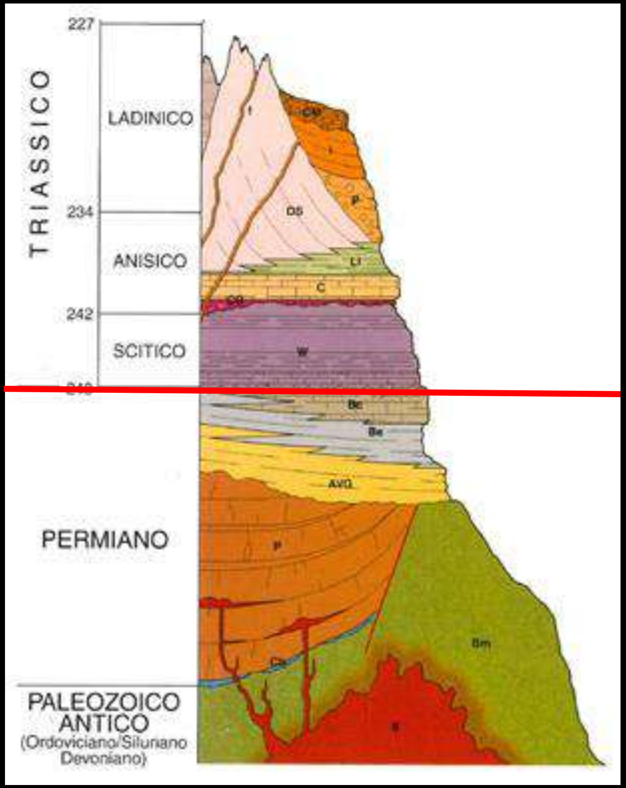
Passo Rolle – 2° day field trip

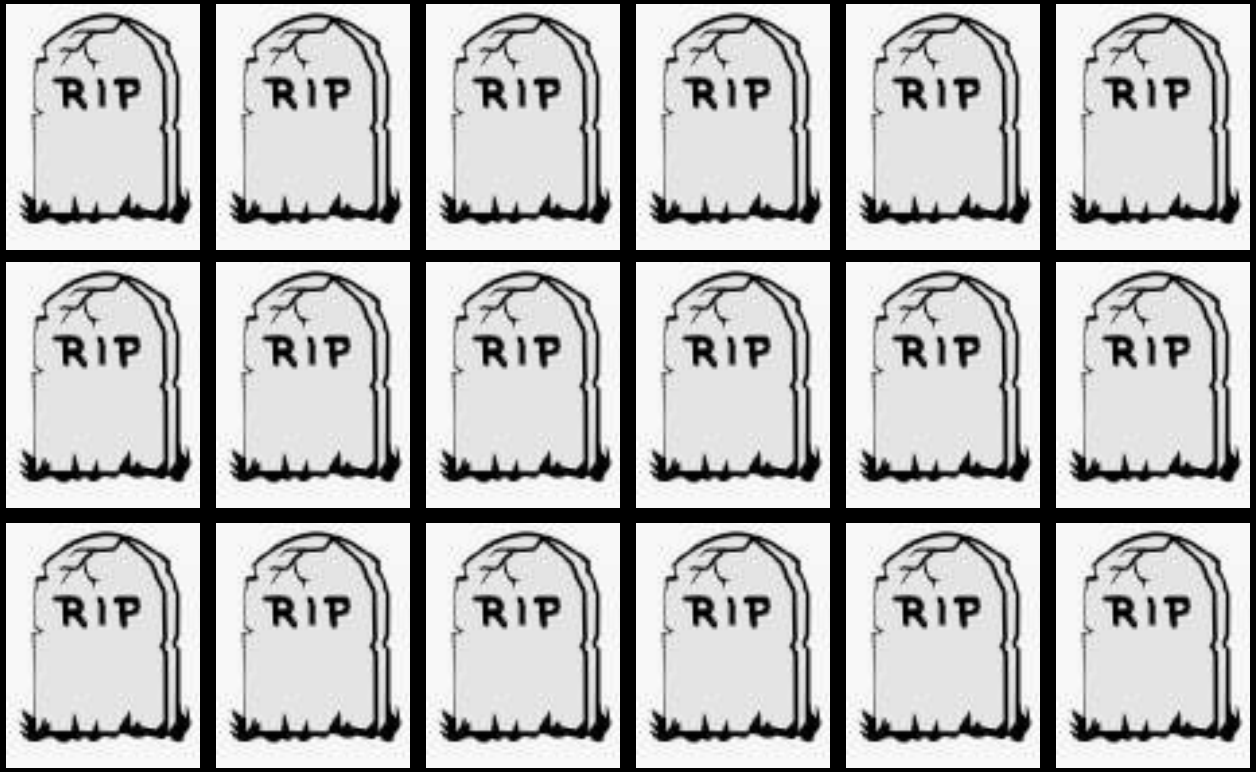
Permo/Triassic boundary – mass extinction

Siberian Traps (LIP)

81% marine species
70% terrestrial vertebrates

Siberian Traps

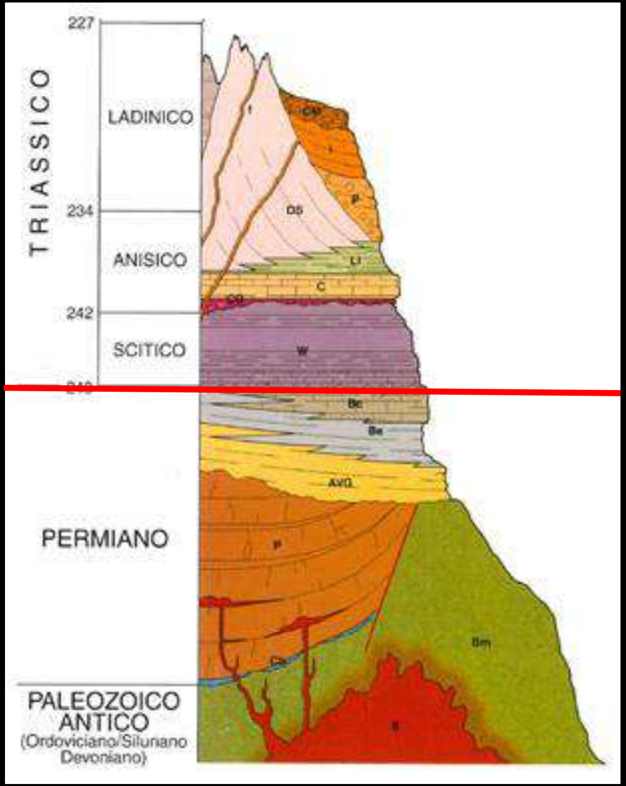


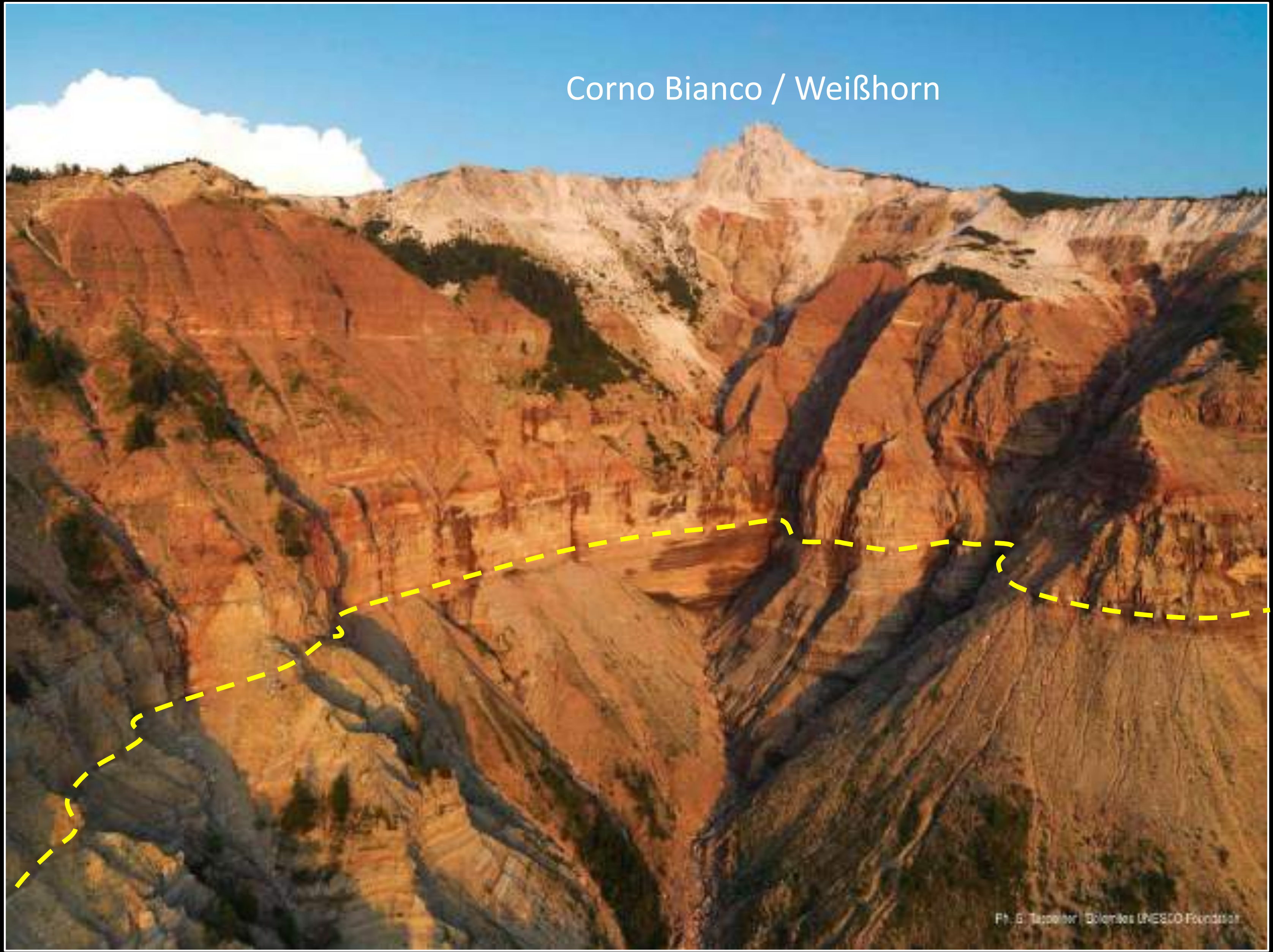


Permo/Triassic boundary – mass extinction

Siberian Traps (LIP)

Bellerophon / Werfen boundary





Bletterbach gorge – 1° day field trip

Lower Triassic – Werfen Formation

Shallow marine (first marine ingression)
Mixed carbonate-siliciclastic sedimentation
Up to 400 m thick

Thin bedding
9 distinct members recognizible in the landscape
for selective weathering (walls and ledges)

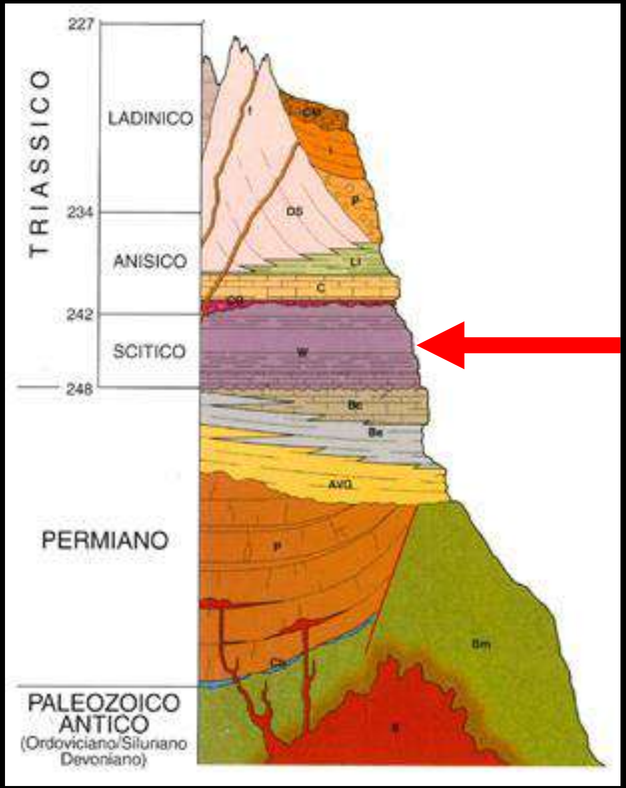



Photo: E. Manfrè

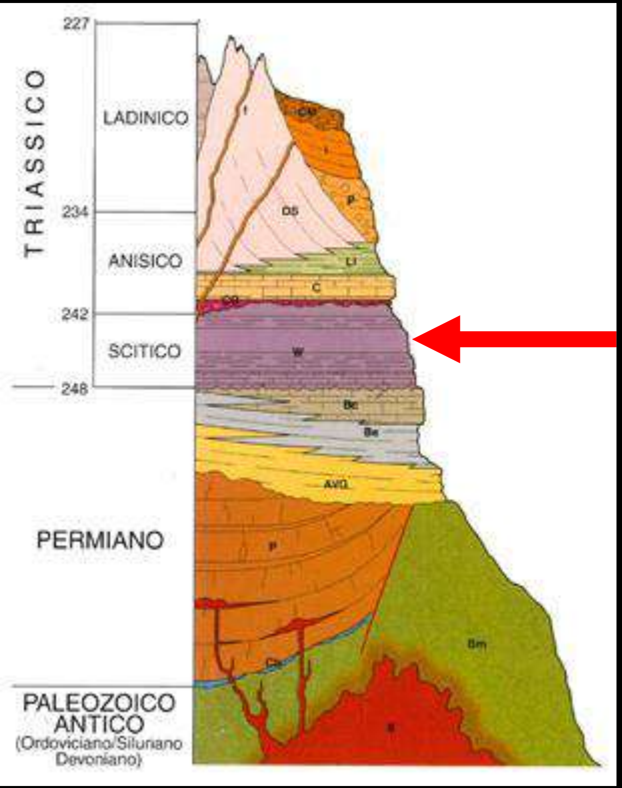
Passo Rolle – 2° day field trip


Photo: P. Ferretti

Passo Valles

Lower Triassic – Werfen Formation

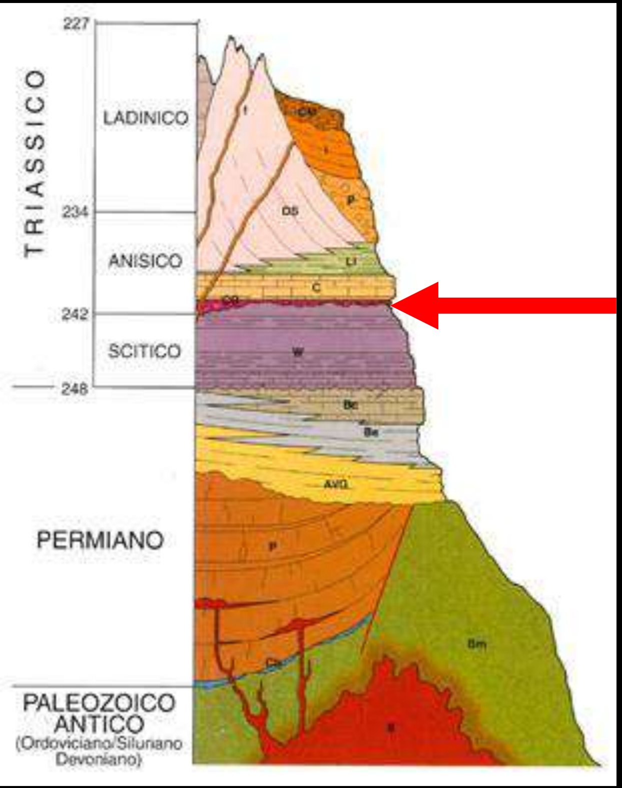
Many sedimentary structures
especially in the Campil member
(ripple marks, mud crack, load casts…)



Anisian – Richtofen Conglomerate

Tectonic tilting
Subaerial erosion > fluvial sedimentation
Fining upward
0-30 m thick

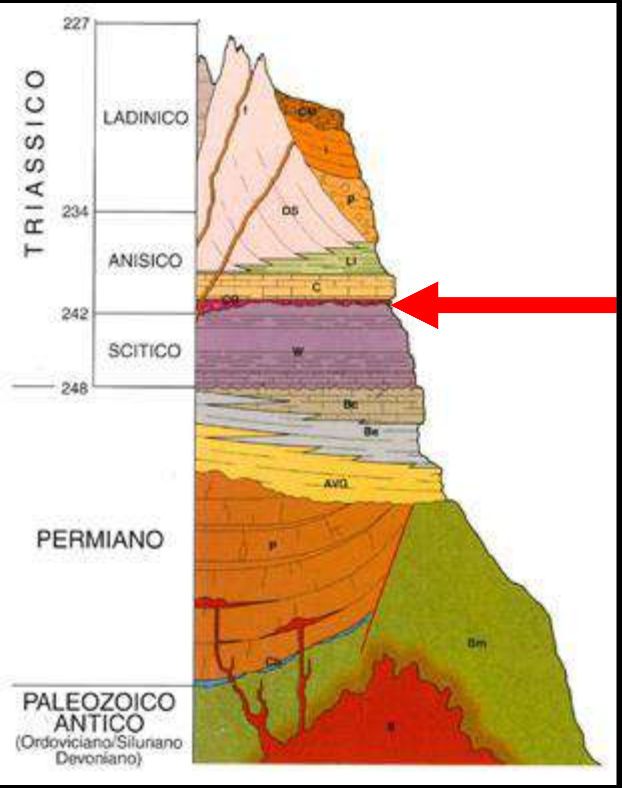
Pebble and cobbles of the underlying units



Anisian – Morbiac Limestone

Transgression proceeds
Shallow lagoon
0-20m thick

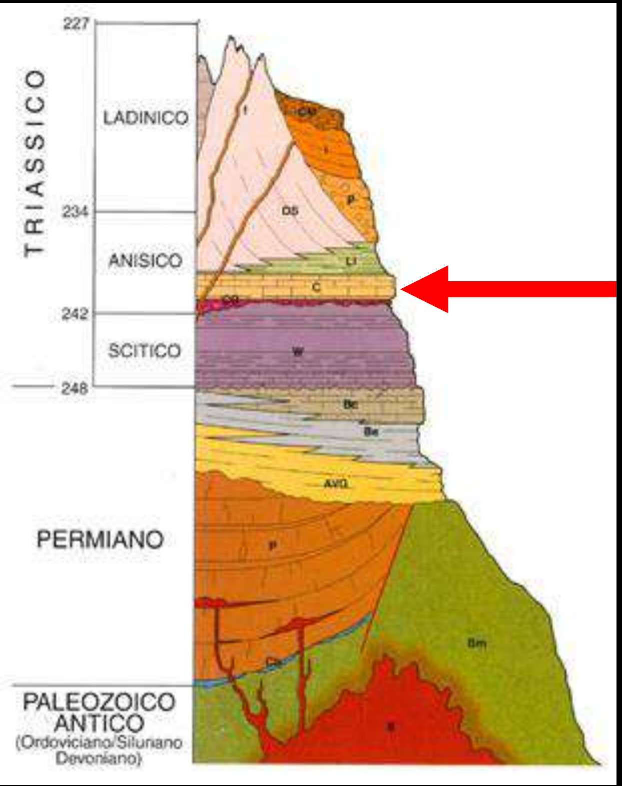
Thin beds
Gray marly nodular limestone



Anisian – Contrin Formation

Transgression proceeds
Shallow marine carbonate bank
Up to 200m thick

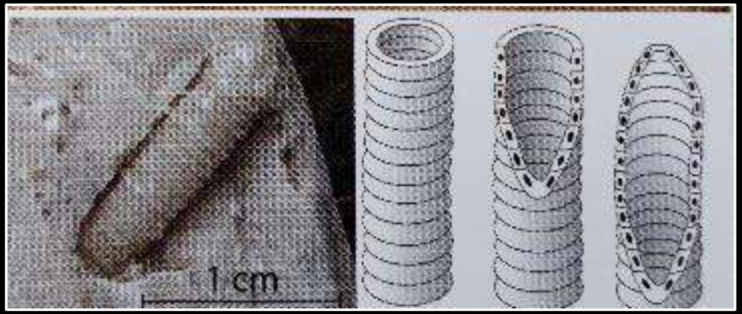
Plurimetric banks
Both limestone and dolostone

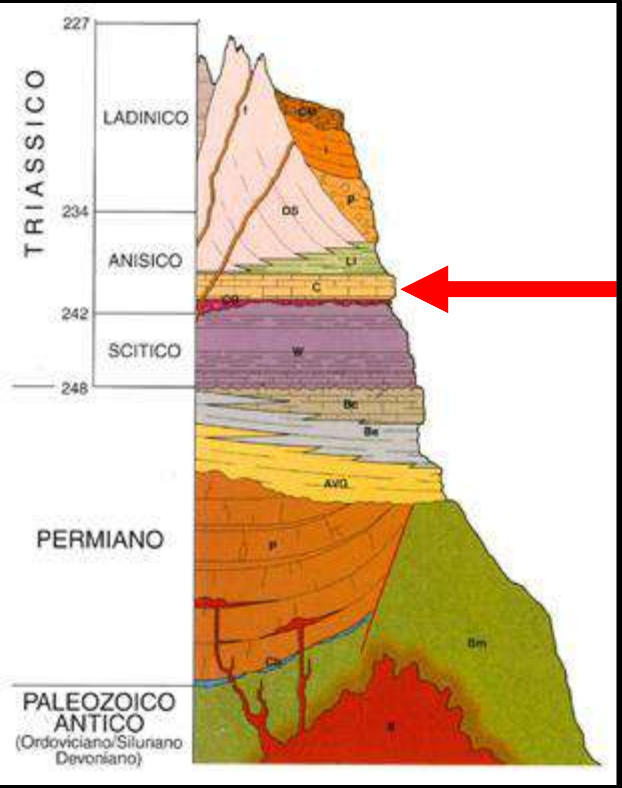


Catinaccio / Rosengarten

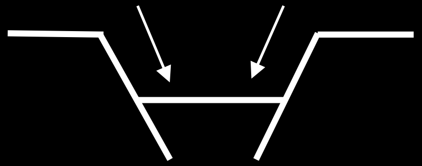
Anisian – Contrin Formation

Locally abundant *Dasycladacean* algae



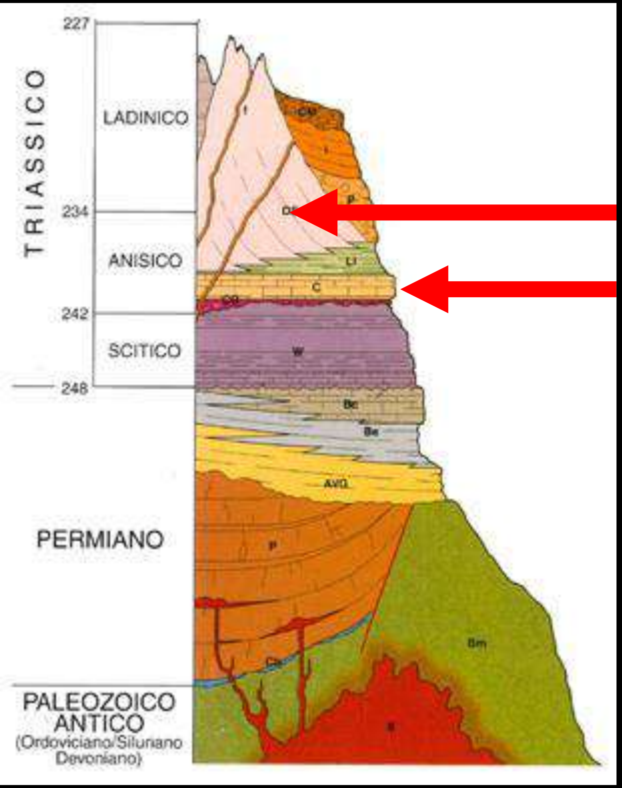


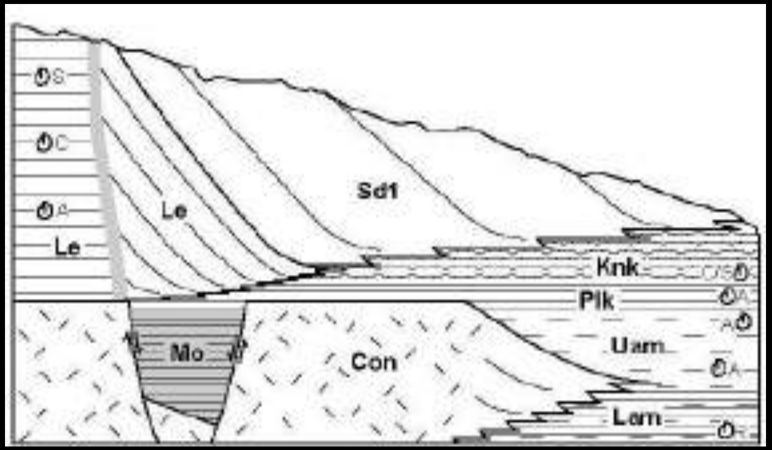
Anisian tectonic activity

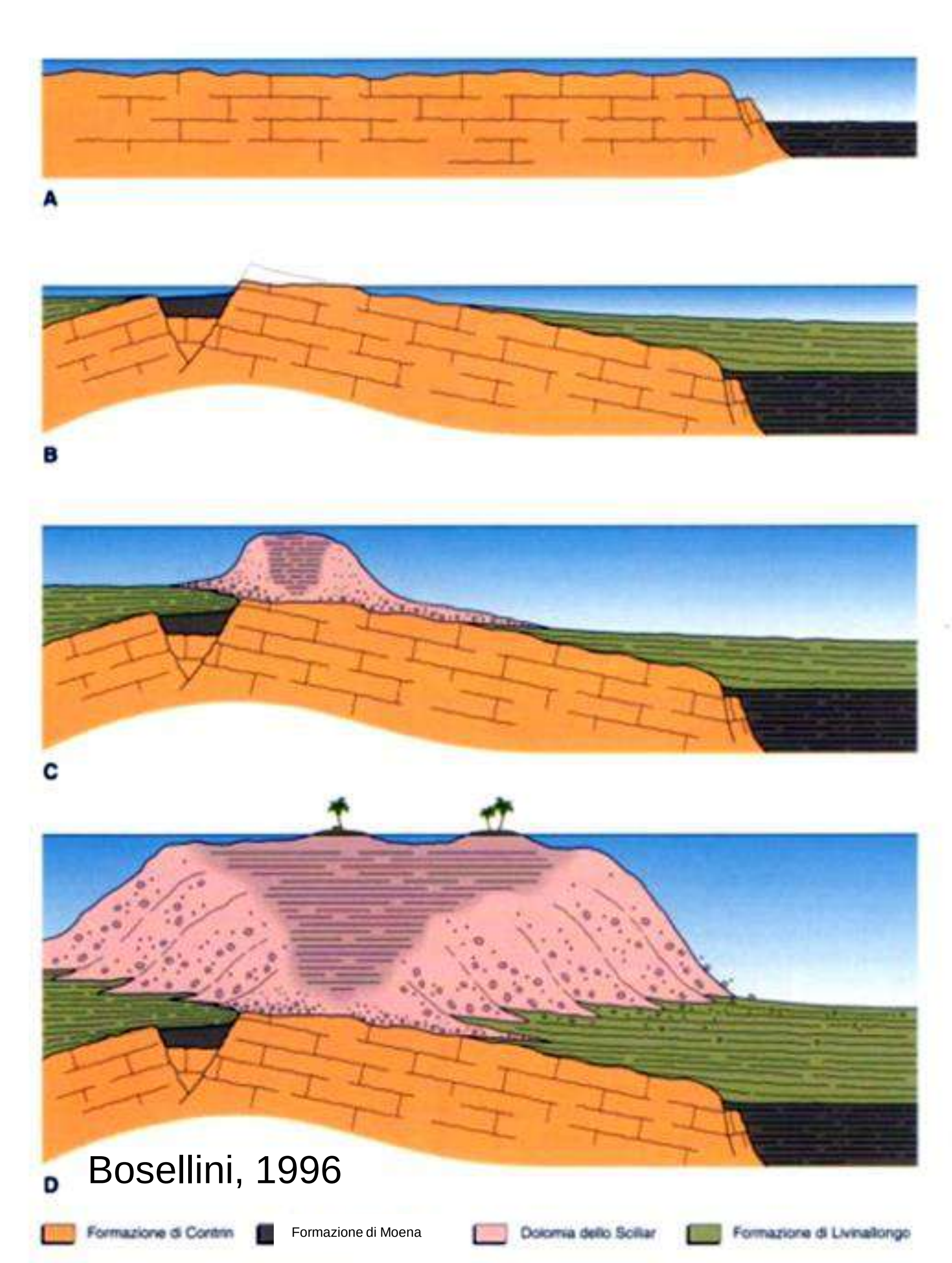


Fragmentation of the carbonate bank

Development of a complex topography
High aggrading and prograding Sciliar platfrorms
Highly subsiding Livinallongo basins





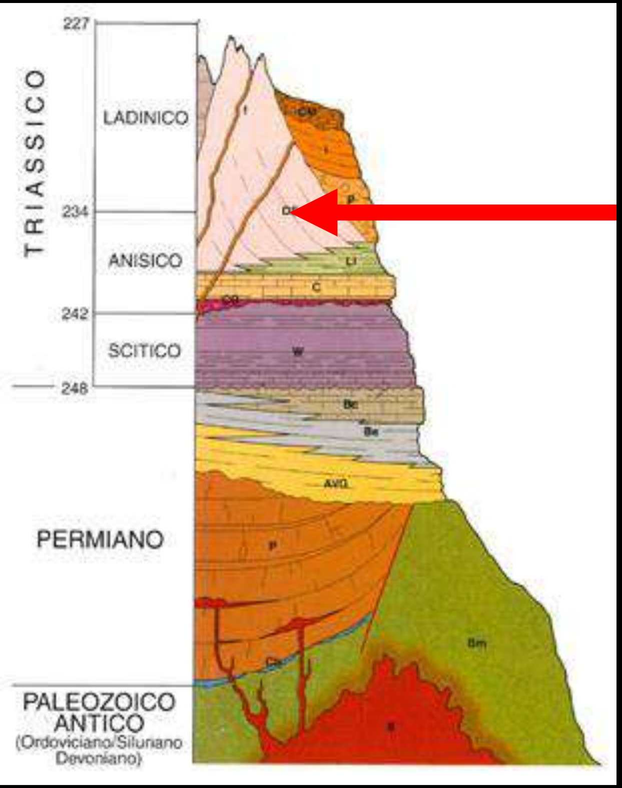


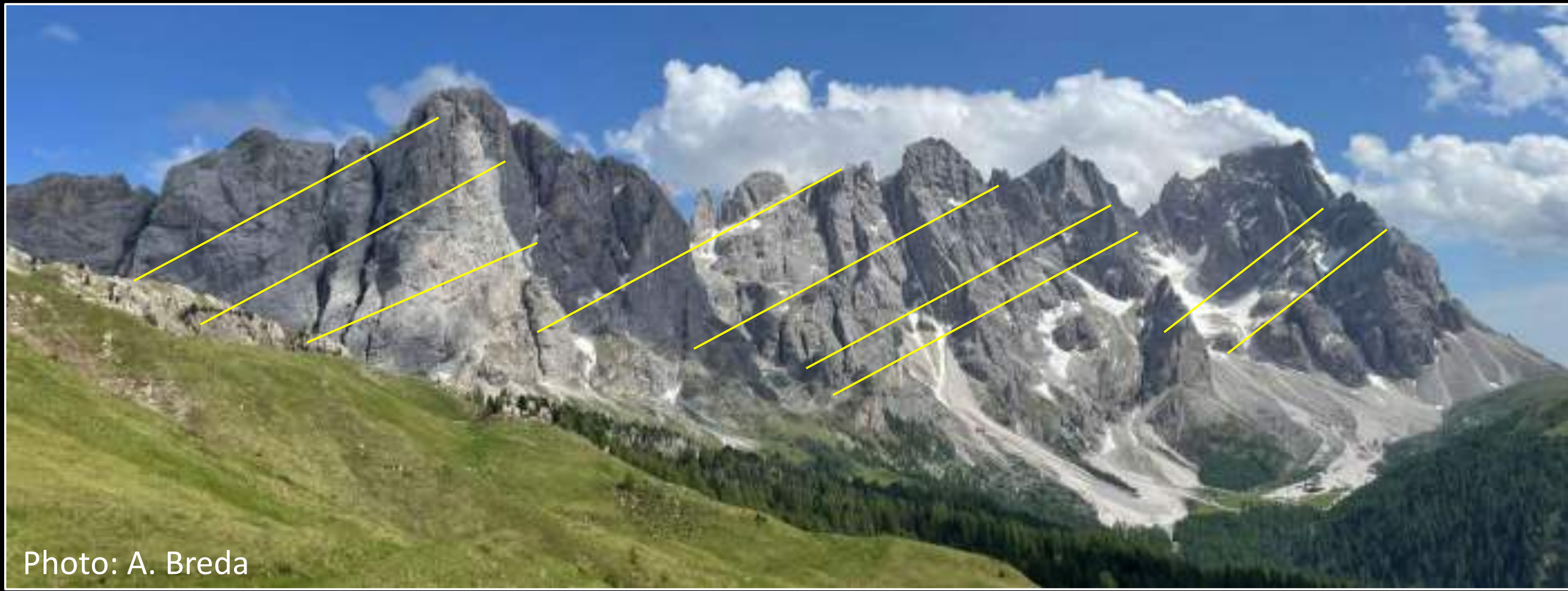
Bosellini, 1996

Anisian/Ladinian carbonate platforms - Sciliar Formation

Sciliar Fm
Microbial carbonate platform
High aggradation (up to 400 m thick)
High progradation (up to 4 km)

Both limestone and dolostone



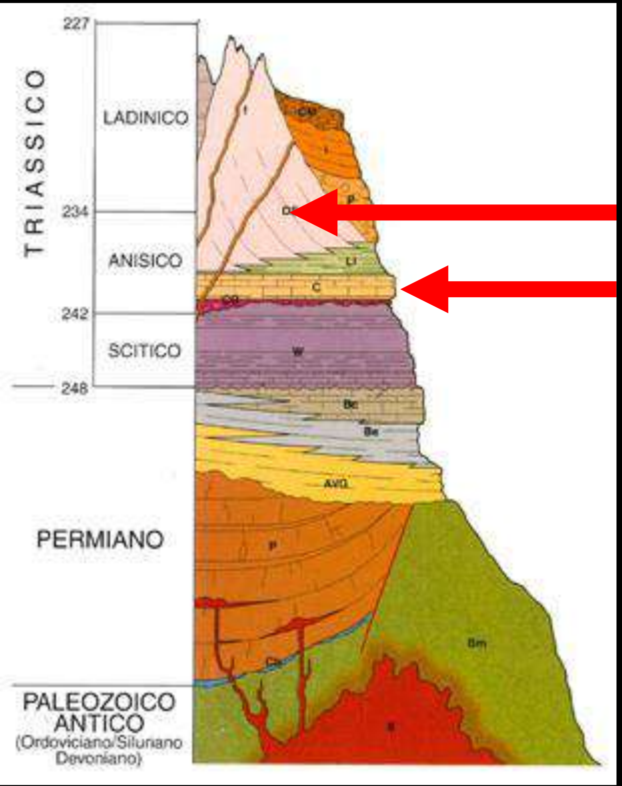


Pale di San Martino - 2° day field trip

Anisian/Ladinian carbonate platforms - Sciliar Formation

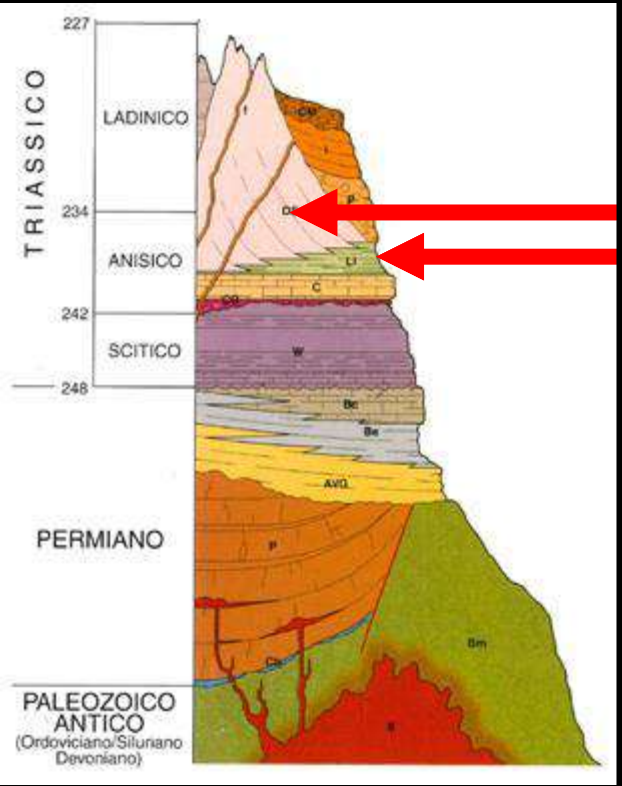
Sciliar Fm
Microbial carbonate platform
High aggradation (up to 400 m thick)
High progradation (up to 4 km)

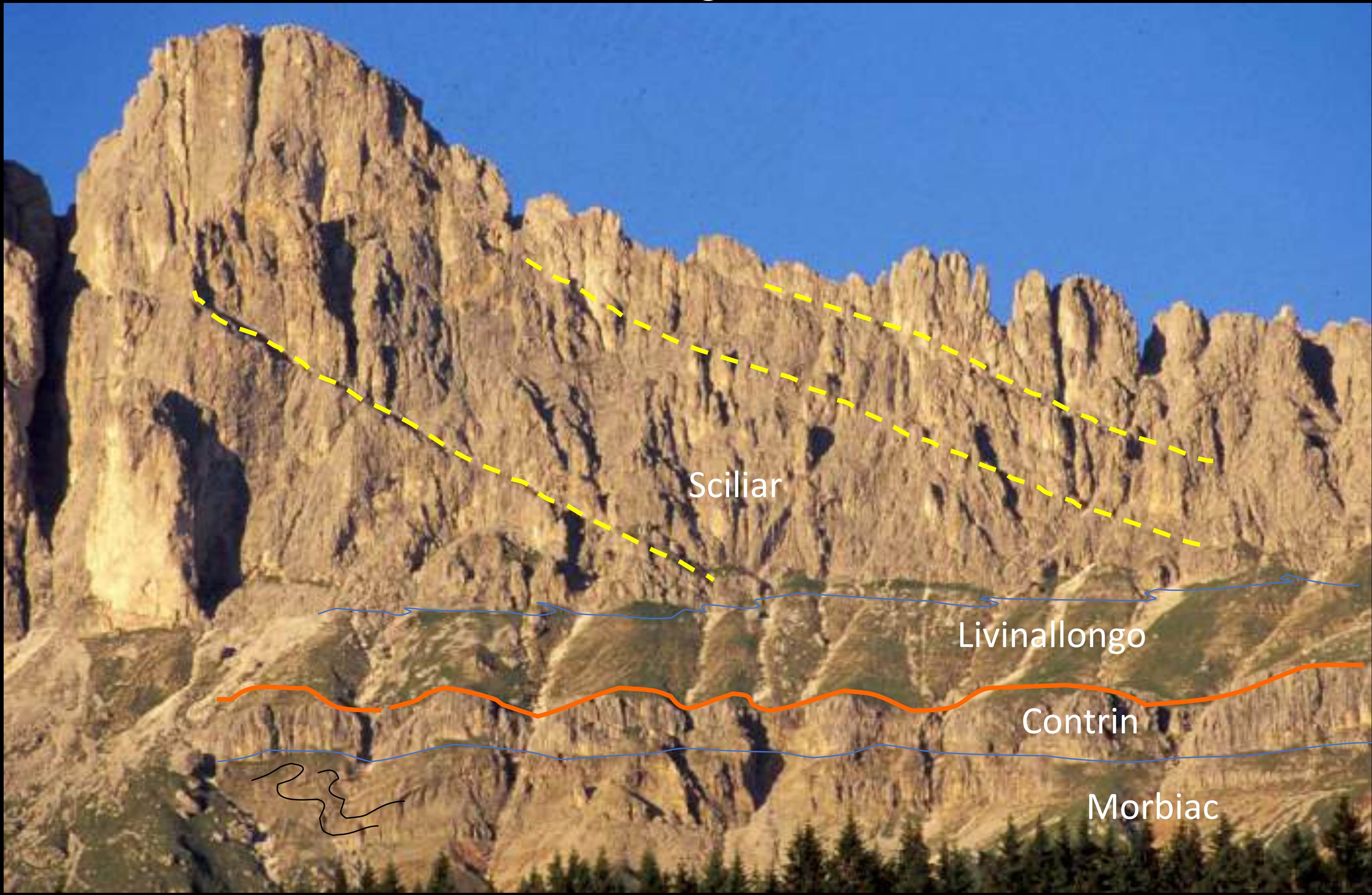
Both limestone and dolostone



Catinaccio / Rosengarten

Ladinian platforms and basins – Sciliar Fm and Livinallongo Fm





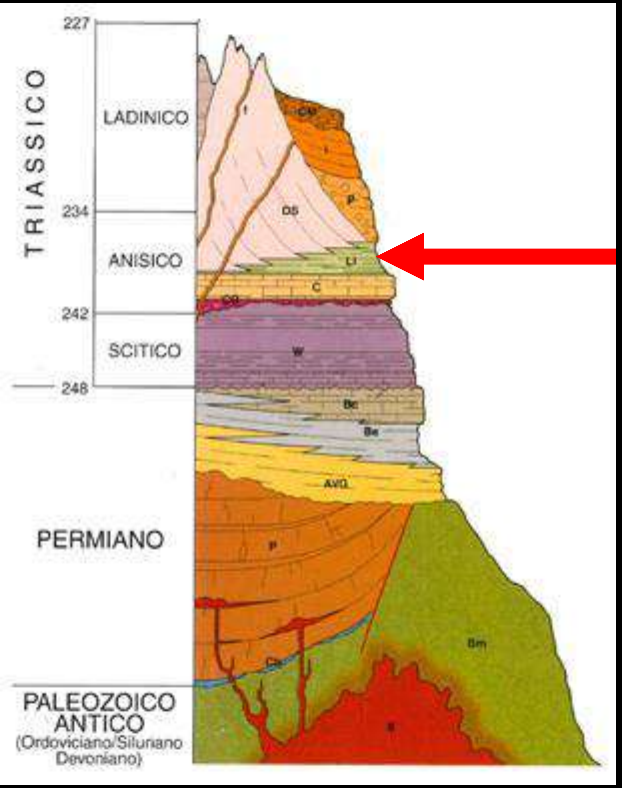
Catinaccio / Rosengarten

Courtesy of P. Gianolla

Ladinian – Livinallongo Formation

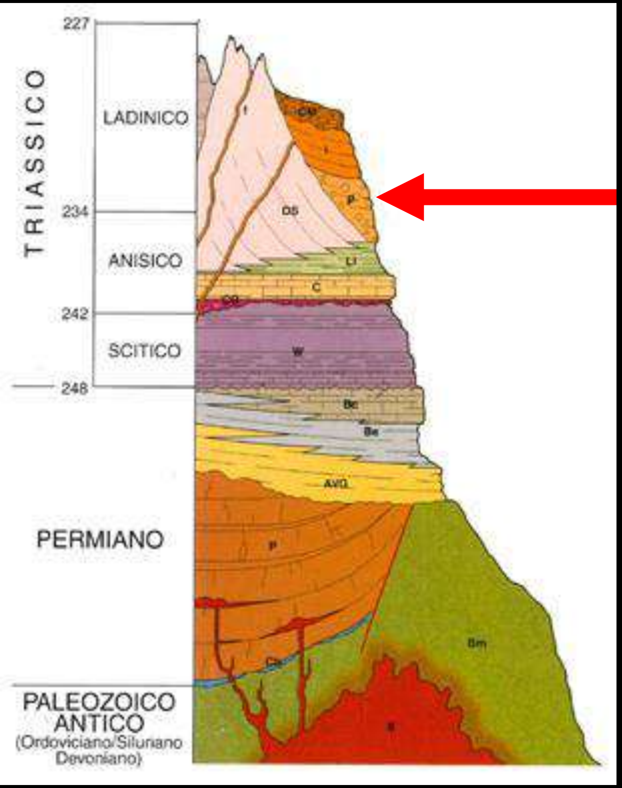
Livinallongo Fm (basin)
Nodular to laminated dark limestones
Up to 60 m thick

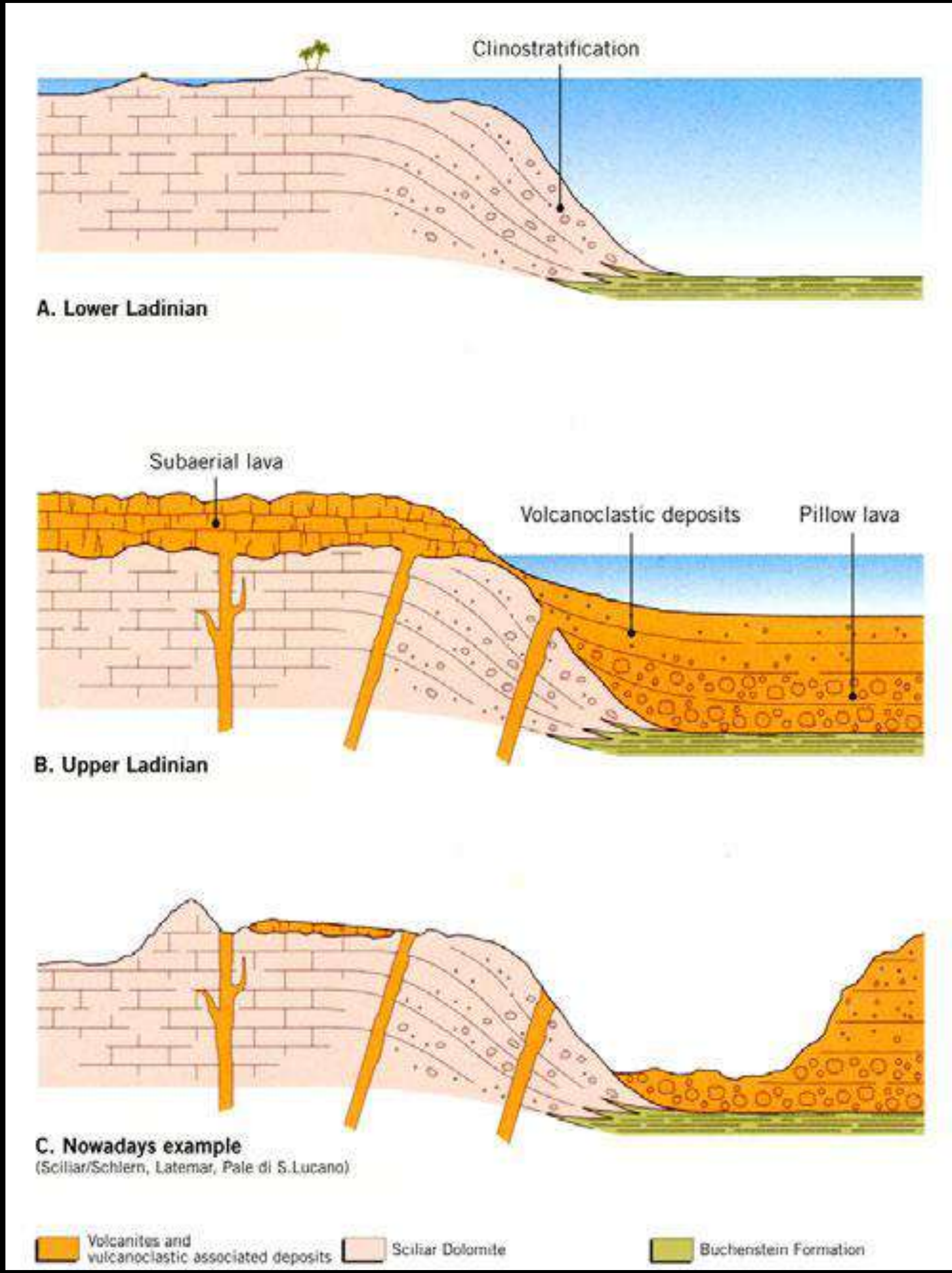
Fine grained
Deep basins



Ladinian – Middle Triassic magmatic event

Mainly submarine volcanos (hyaloclastic breccia)
Dikes and sills cross-cutting the Sciliar platfroms
Pillow lavas
Volcanoclastic sandstones





Bosellini, 1996

Ladinian – Middle Triassic magmatic event

Mainly submarine volcanos (hyaloclastic breccia)
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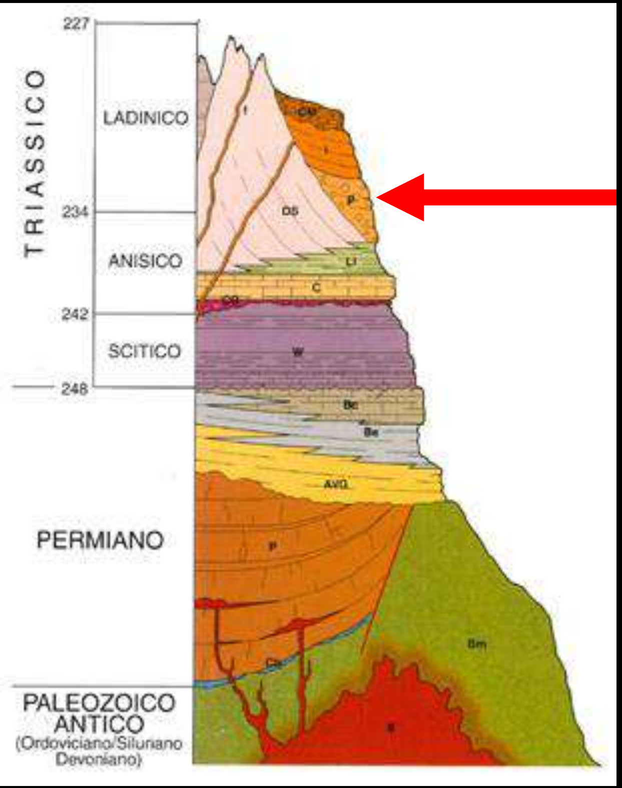
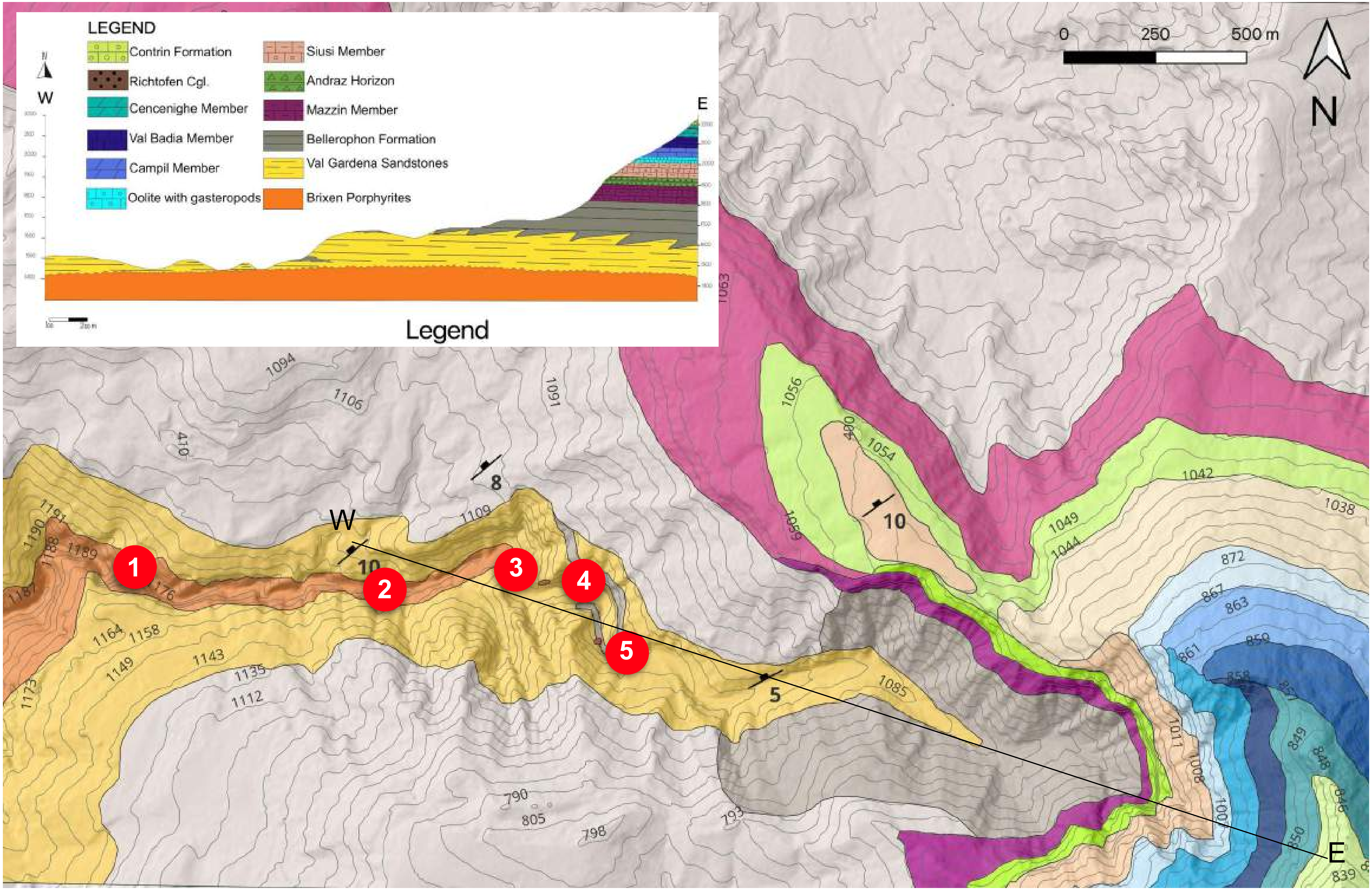
Pillow lavas
Volcanoclastic sandstones



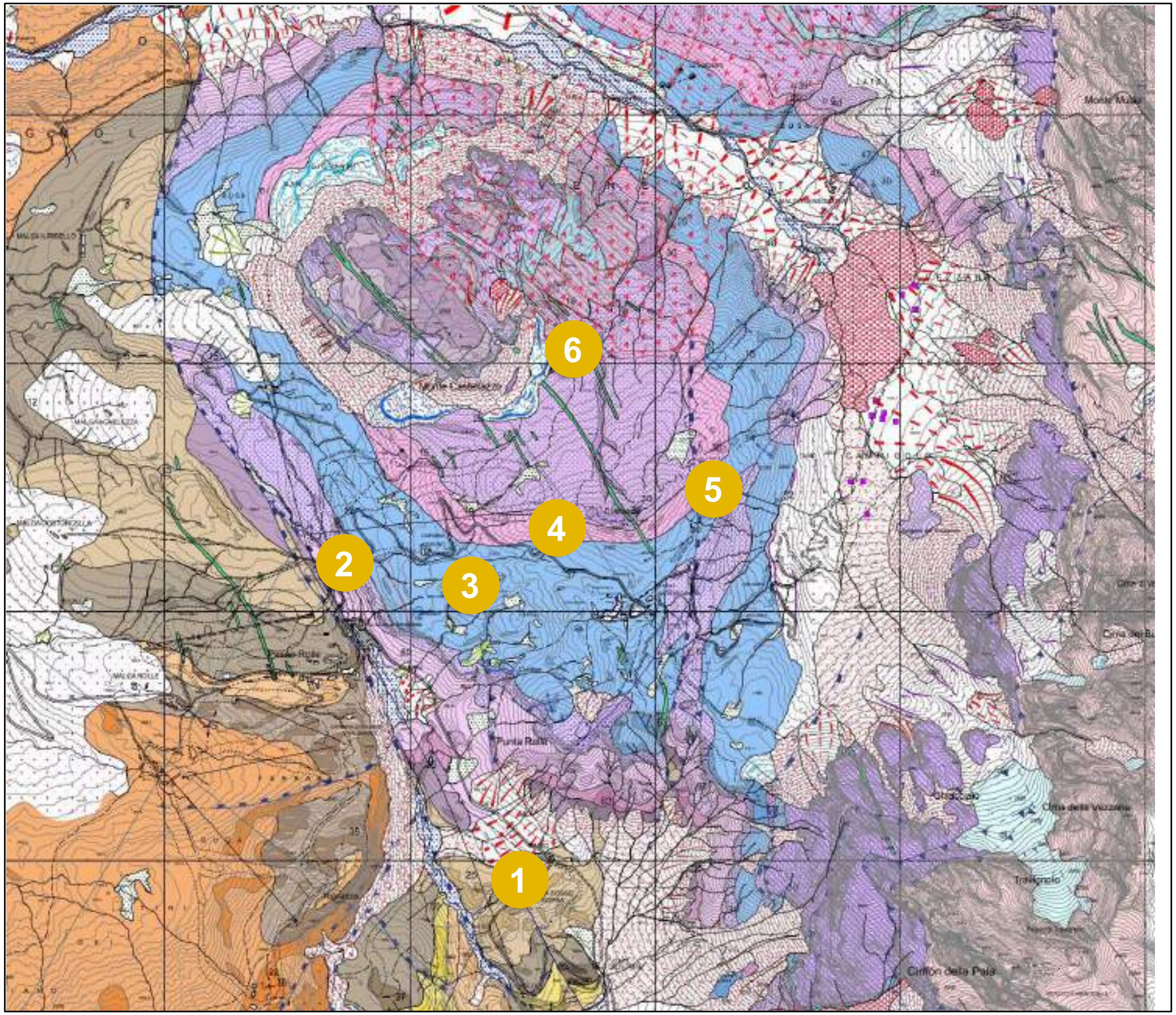
Photos: P. Gianolla

Appendix 1

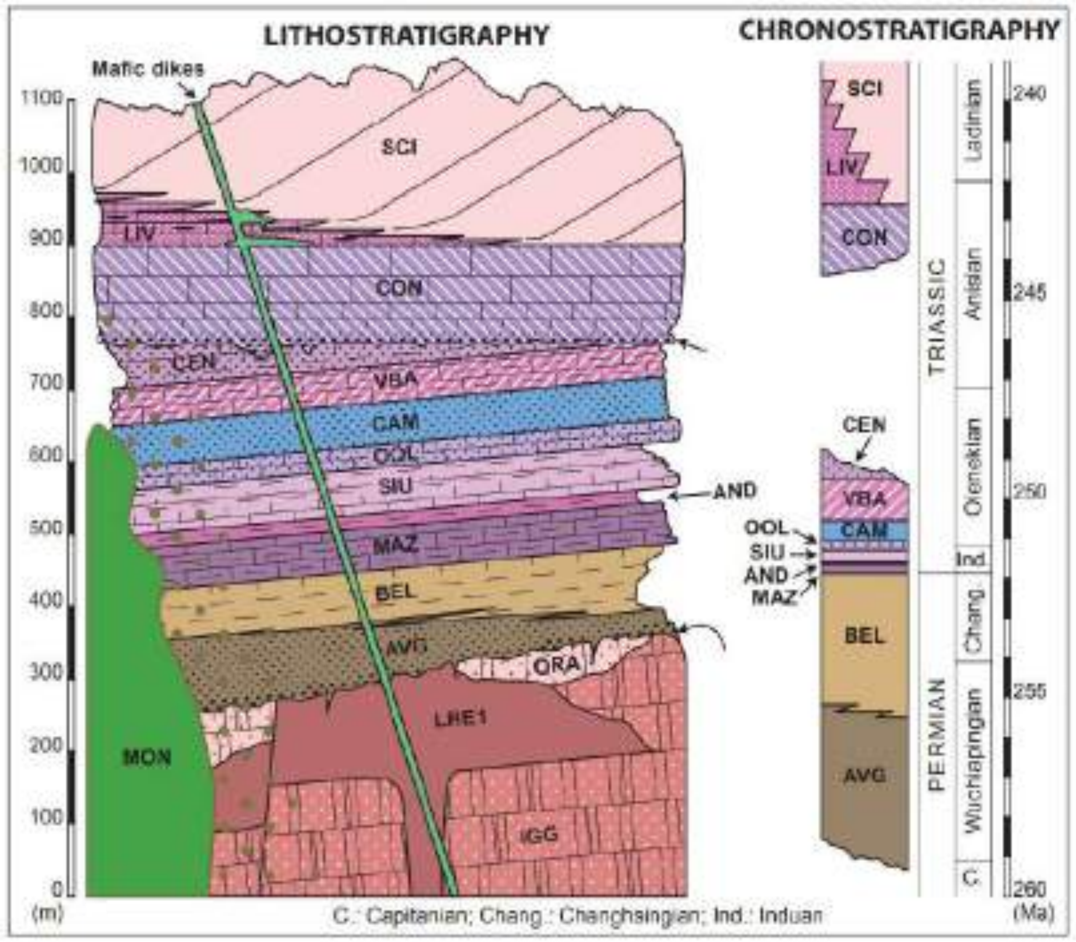


LEGEND
Contrin Formation
Richtofen Cgl.
Cencenighe Member
Val Badia Member
Campil Member
Oolite with gasteropods
Siusi Member
Andraz Horizon
Mazzin Member
Bellerophon Formation
Val Gardena Sandstones
Brixen Porphyrites
W
E
Legend
0
250
500 m
N
1
2
3
4
5

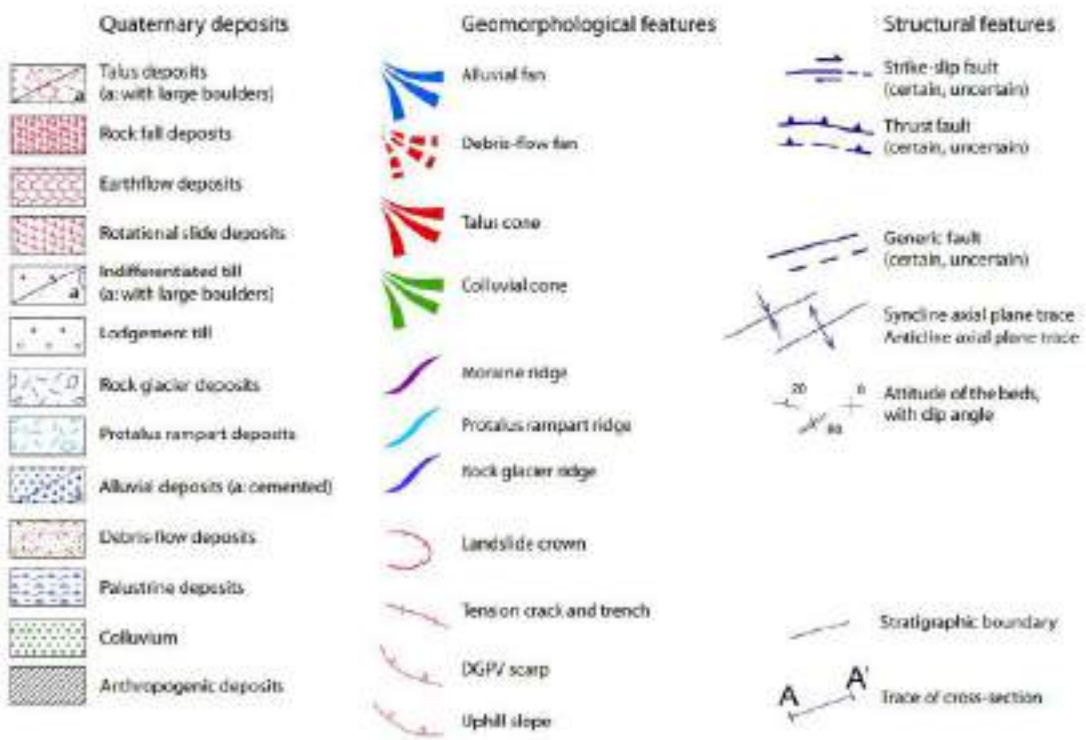
Appendix 2



1
2
3
4
5
6
Punta Rolle
Cimon della Pala
Cima della Vezzana

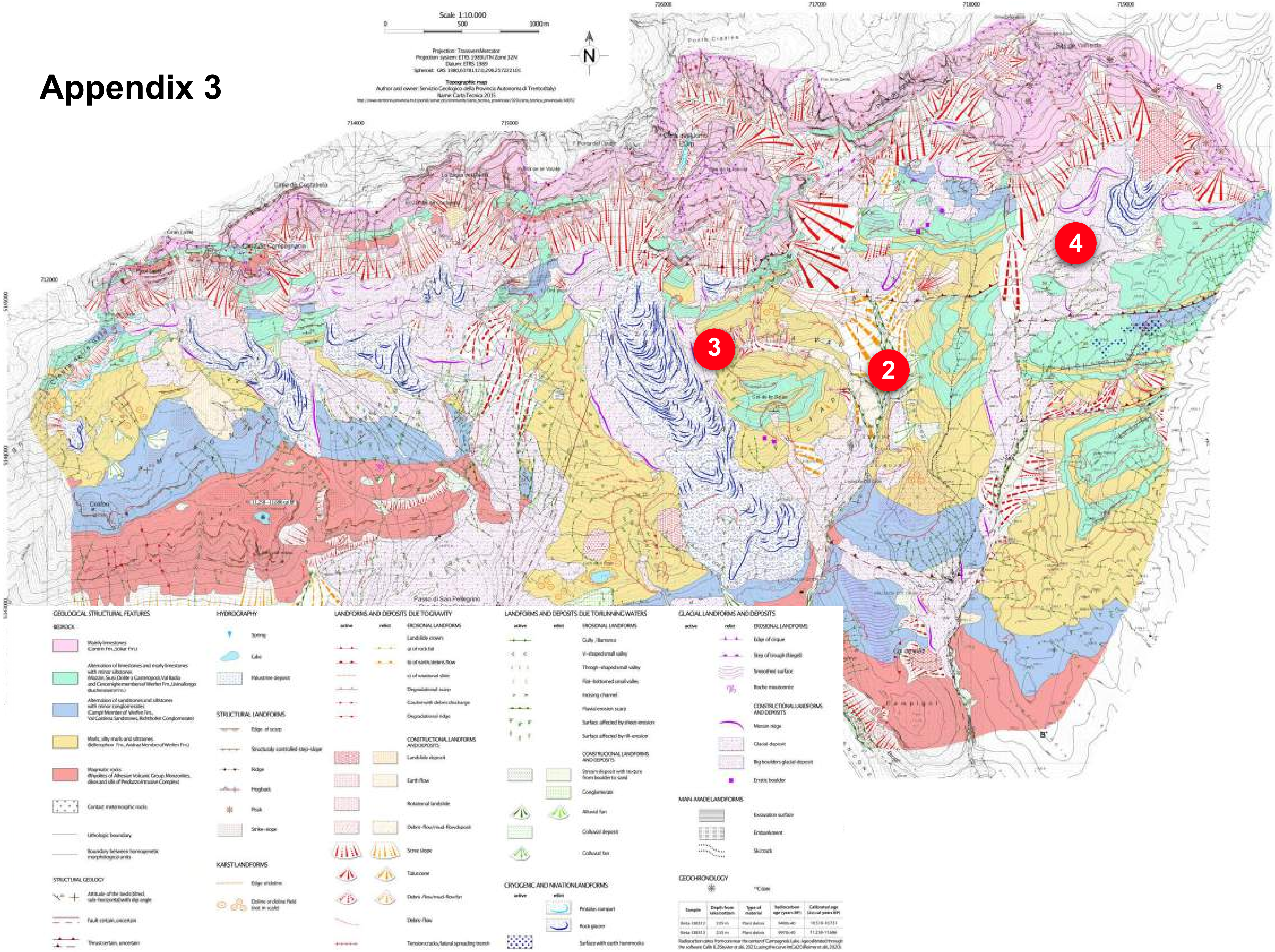


LITHOSTRATIGRAPHY
CHRONOSTRATIGRAPHY
Mafic dikes
SCI
LIV
CON
CEN
VBA
CAM
OOL
SIU
AND
MAZ
BEL
AVG
ORA
LRE1
IGG
MON
TRIASSIC
PERMIAN
Ladinian
Anisian
Olenekian
Ind.
Chang.
Wuchiapingian
C.
(m)
(Ma)
C.: Capitanian; Chang.: Changhsingian; Ind.: Induan



Quaternary deposits
Talus deposits (a: with large boulders)
Rock fall deposits
Earthflow deposits
Rotational slide deposits
Indifferentiated till (a: with large boulders)
Lodgement till
Rock glacier deposits
Protalus rampart deposits
Alluvial deposits (a: cemented)
Debris-flow deposits
Palustrine deposits
Colluvium
Anthropogenic deposits
Geomorphological features
Alluvial fan
Debris-flow fan
Talus cone
Colluvial cone
Moraine ridge
Protalus rampart ridge
Rock glacier ridge
Landslide crown
Tension crack and trench
DGPV scarp
Uphill slope
Structural features
Strike-slip fault (certain, uncertain)
Thrust fault (certain, uncertain)
Generic fault (certain, uncertain)
Syncline axial plane trace
Anticline axial plane trace
Attitude of the beds, with dip angle
Stratigraphic boundary
Trace of cross-section

Appendix 3


Scale 1:10.000
0
500
1000 m
N
3
2
4
Passo di San Pellegrino
GEOLOGICAL STRUCTURAL FEATURES
BEDROCK
STRUCTURAL GEOLOGY
HYDROGRAPHY
STRUCTURAL LANDFORMS
KARST LANDFORMS
LANDFORMS AND DEPOSITS DUE TO GRAVITY
LANDFORMS AND DEPOSITS DUE TO RUNNING WATERS
CRYOGENIC AND NIVATION LANDFORMS
GLACIAL LANDFORMS AND DEPOSITS
MAN-MADE LANDFORMS
GEOCHRONOLOGY

GeoPlaNet

Co-funded by the ERASMUS + Programme of the European Union

DIPARTIMENTO DI GEOSCIENZE

SCHOOL ON PLANETARY GEOLOGICAL MAPPING AND PLANETARY ANALOGUES

Pescara, 26 September - 1 October 2022

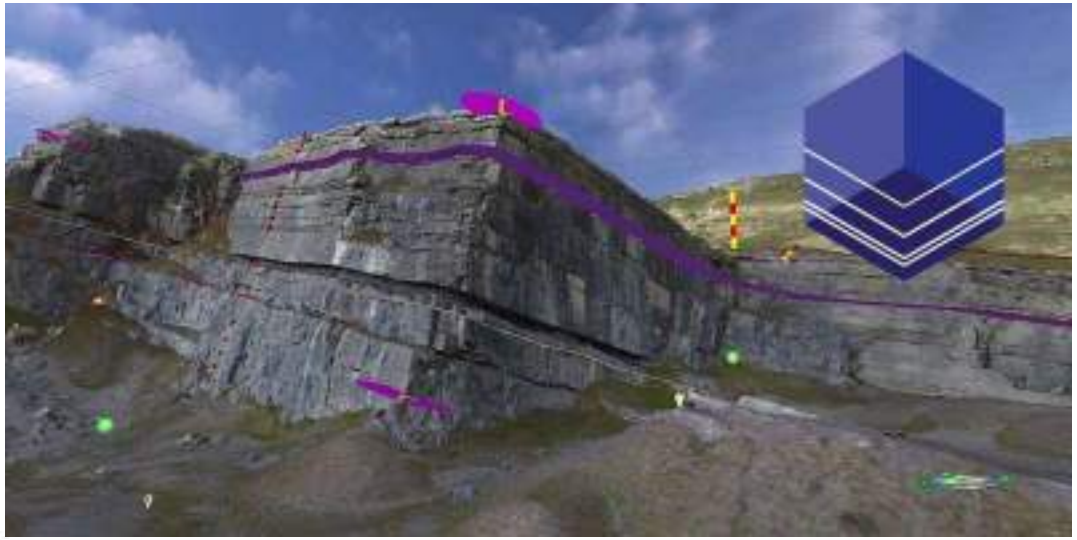
Predazzo, 2-8 October 2022

Photogrammetry and VR

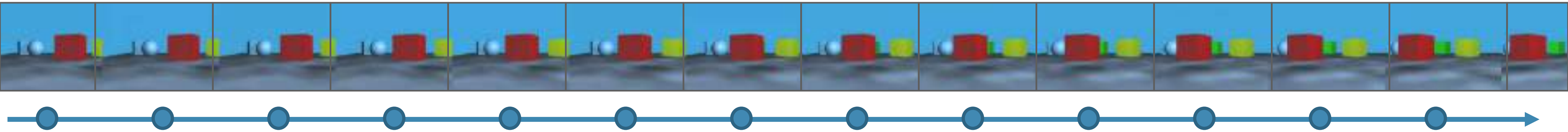
Riccardo Pozzobon – Dipartimento di Geoscienze, Università degli Studi di Padova
riccardo.pozzobon@unipd.it

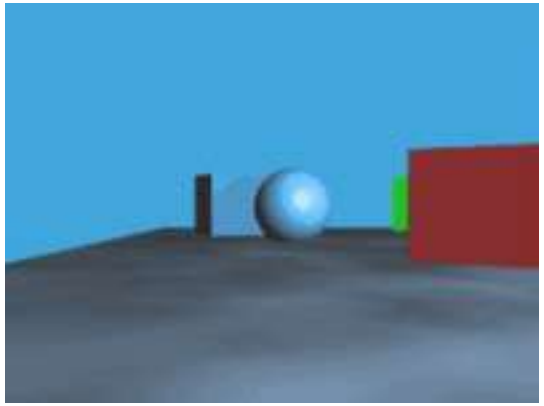
Nantes Université · Universidade de Coimbra · U.Porto · MuSe · Geoparc Bletterbach

What is photogrammetry?



Structure from Motion (SFM)



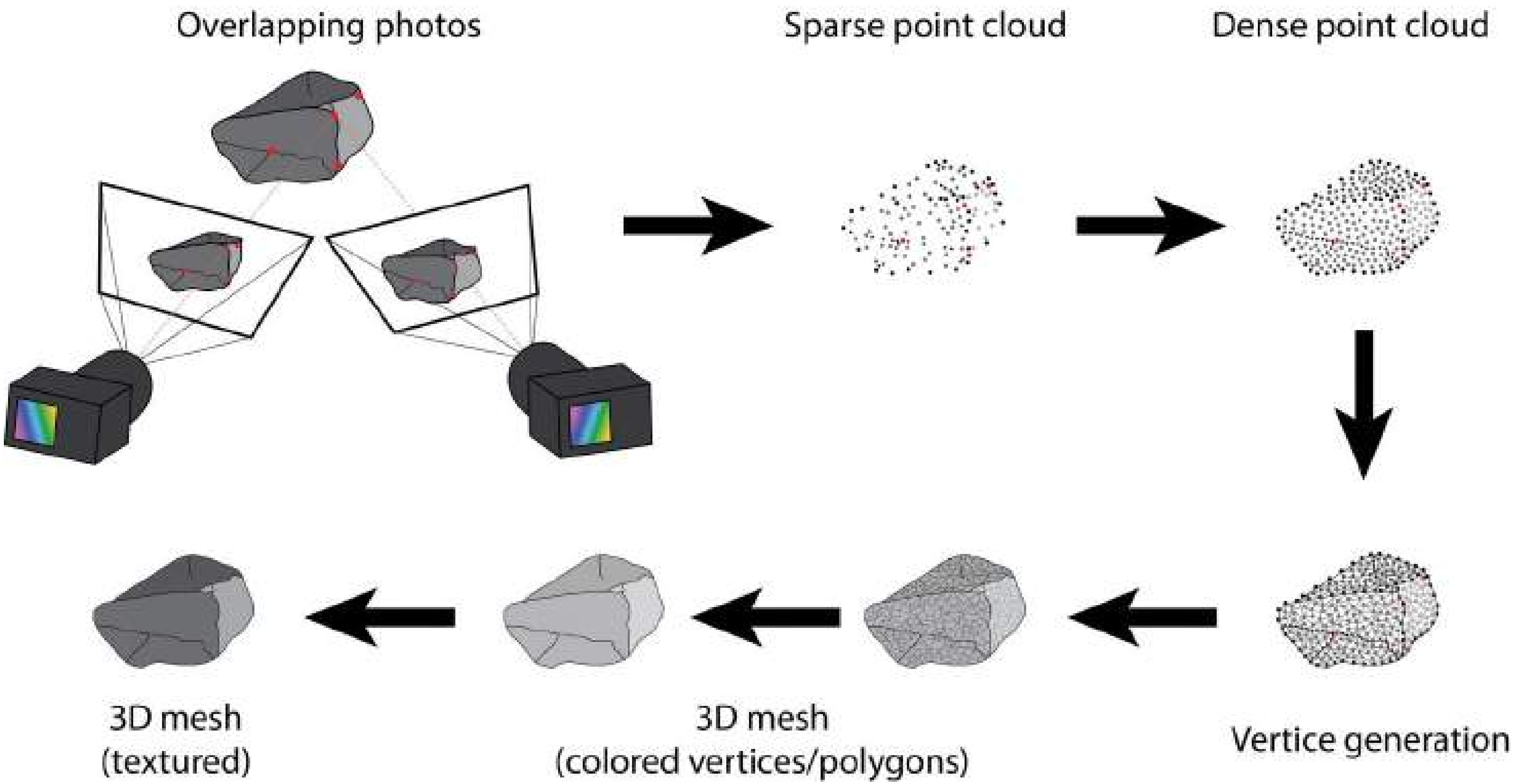


Estimating three-dimensional structures from two-dimensional image sequences that may be coupled with local

motion signals

Usually adjacent frames of an image sequence (possibly with geolocation)

SFM workflow



Aerial vs Terrestrial photogrammetry

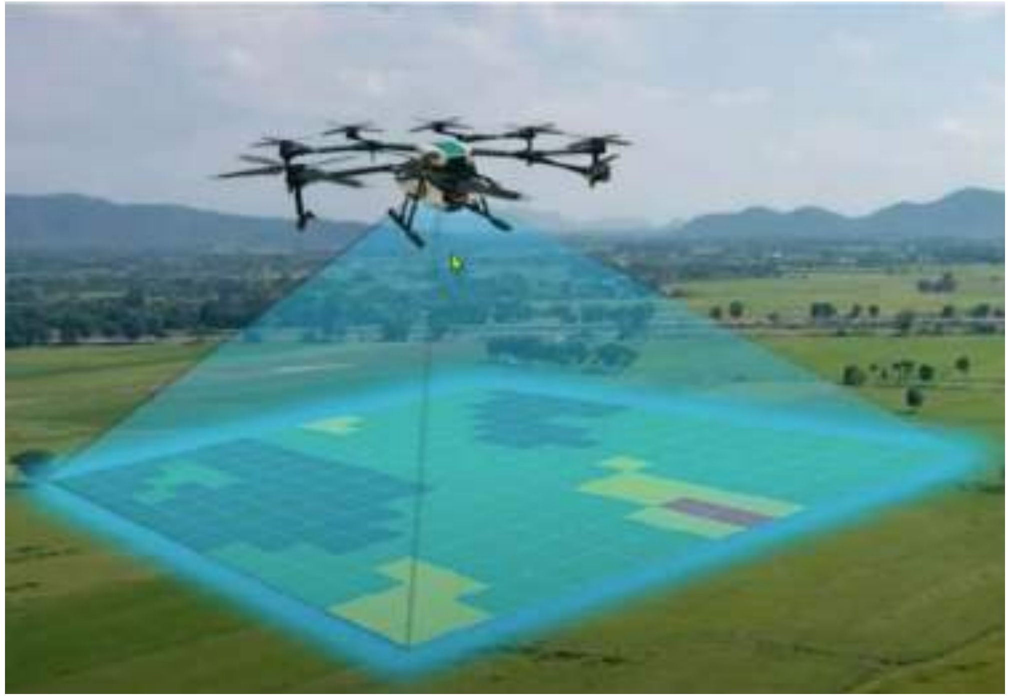
❑ **Aerial**

photographs ore taken by a camera mounted on an aircraft/airplane flying over the survey area.

❑ **Terrestrial**

photographs are taken from

a fixed position on or near the ground



Aerial: Pre-survey checklist

❑ **Equipment**

All equipment is flight-ready and the latest updates are installed across all software and hardware

❑ **Experience**

All drone operators are familiar with the hardware and software they will be using

❑ **Regulations**

Operators are aware of the local regulations regarding drone flying within their field area. Any flying license or permits have been obtained prior to flight. Drone exclusion zones have been identified and avoided (e.g. airports).

❑ **Local Area**

Remote reconnaissance of the local area has been undertaken using online satellite data prior to departure for the field area. Once in the field, in-person reconnaissance prior to the survey commencing is recommended

Aerial: Survey checklist

❑ **Survey Planning**

Identification of the survey target and desired level of detail (i.e. flight altitude or distance form subject)

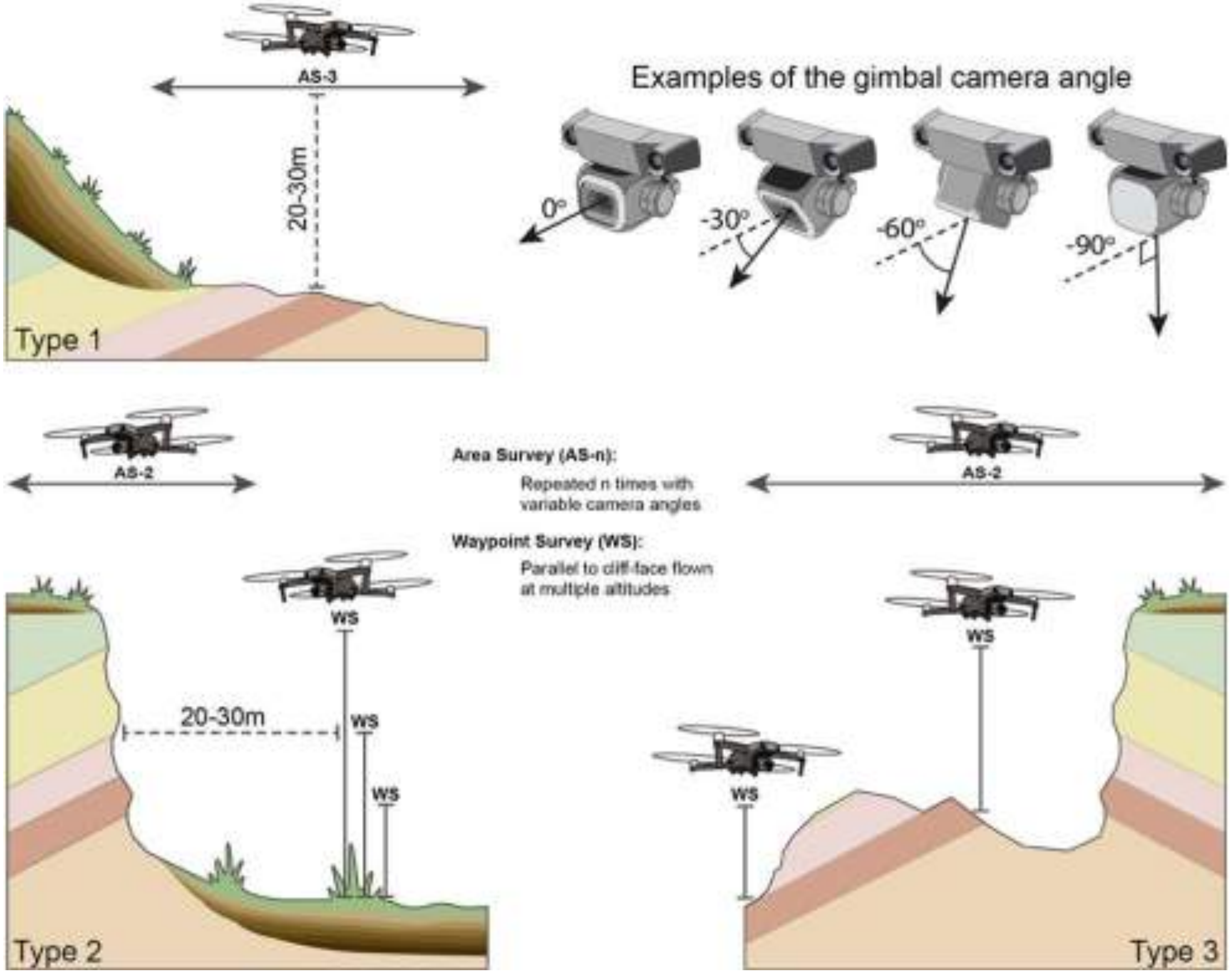
❑ **Data Collection**

Careful assessment of the survey area needs to be made in person and the flights plans adjusted and executed accordingly

❑ **Data Processing**

Image should be fed through photogrammetry software and the resulting model cleaned and exported

UAV: Acquisition techniques



Type 1: Mostly horizontal outcrop

Type 2: Mostly vertical outcrop

Type 3: mixture of type 1 and 2

Data collection on the field

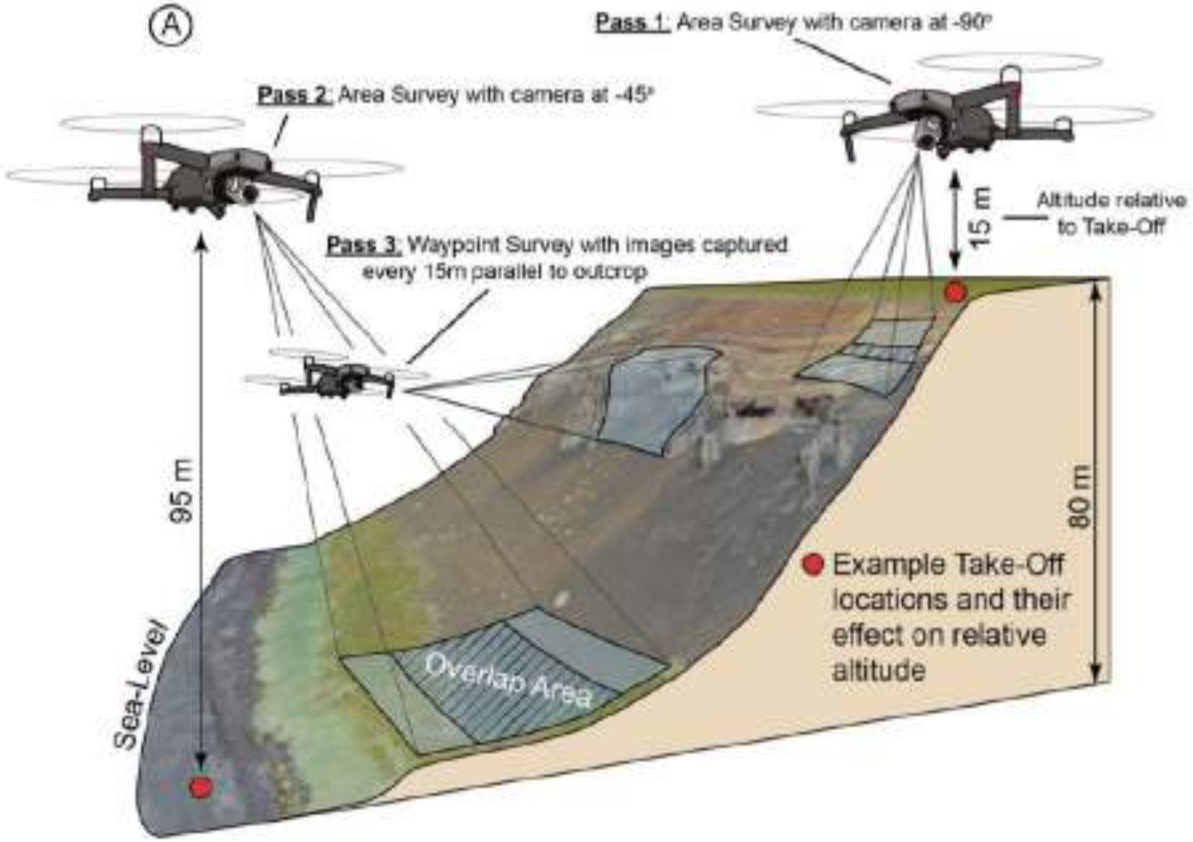
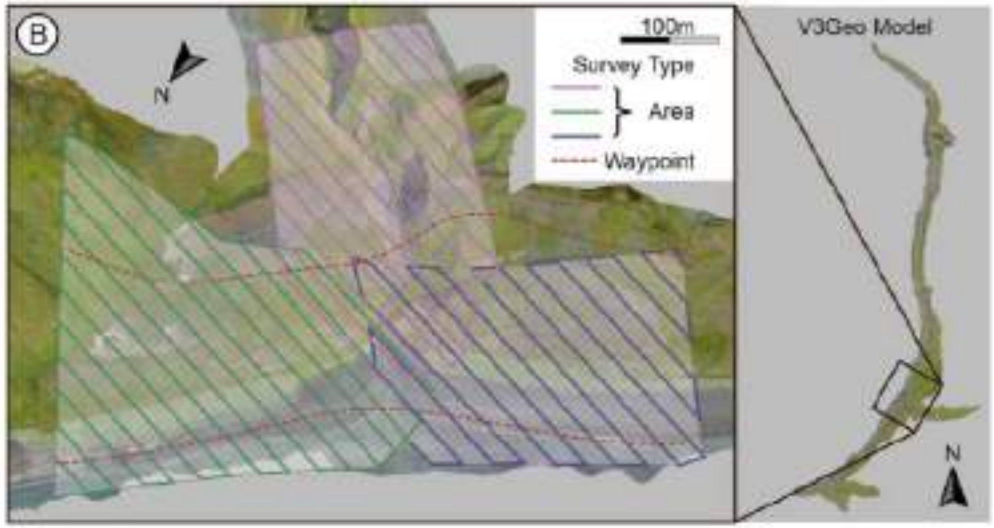


Image size and overlap variation according to topography

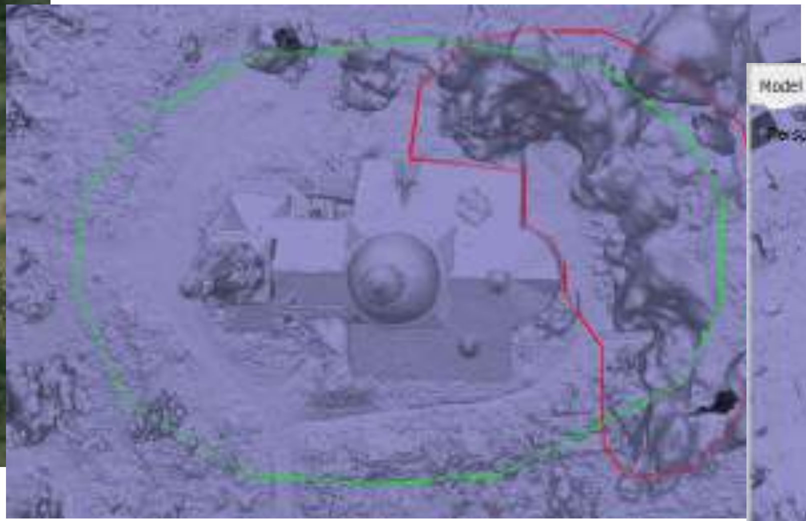


Multiple surveys

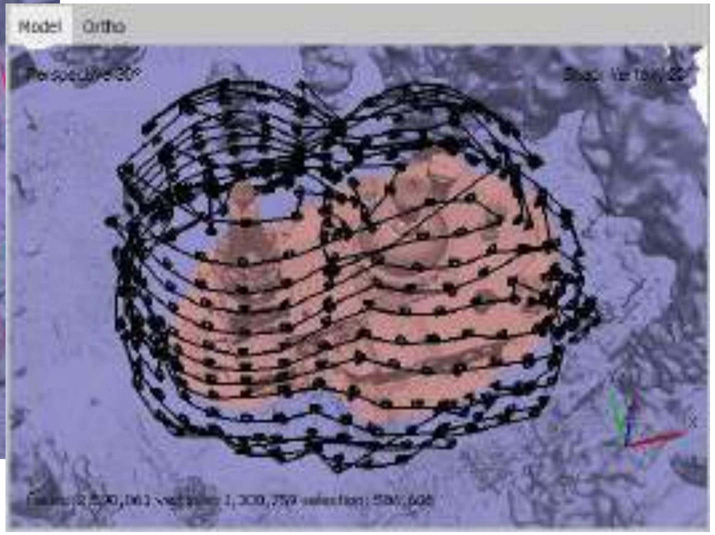
Mission Plan with existing rough model

Horizontal flight (or vertical)

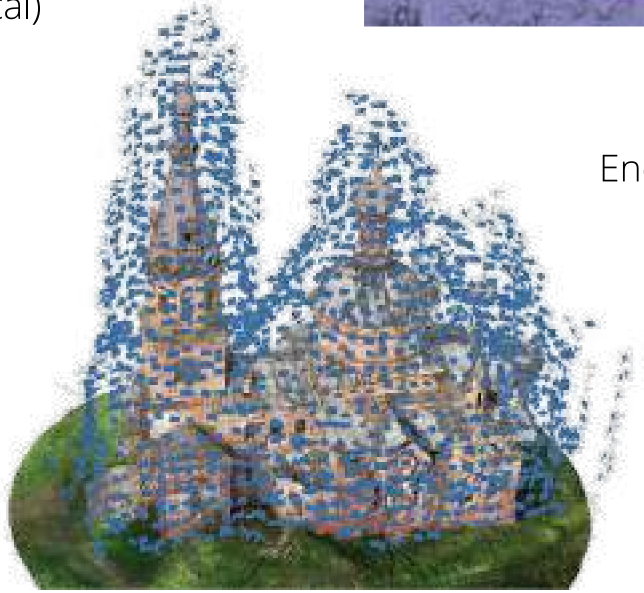
Rough model creation
Region of interest and no fly zones definition



Mission plan around model



End result



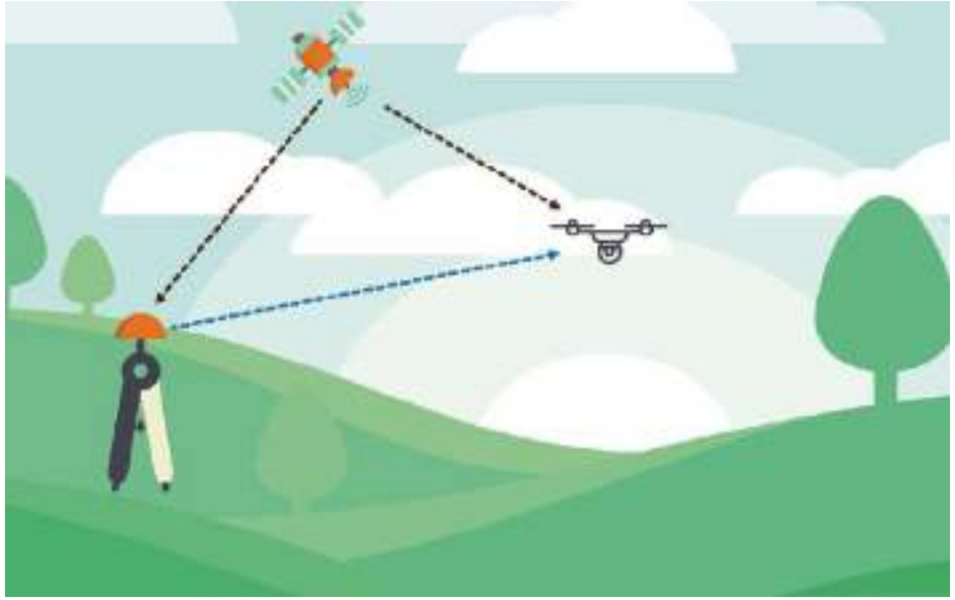
Source: Agisoft Metashape

Drone and RTK

RTK stands for Real Time Kinematics

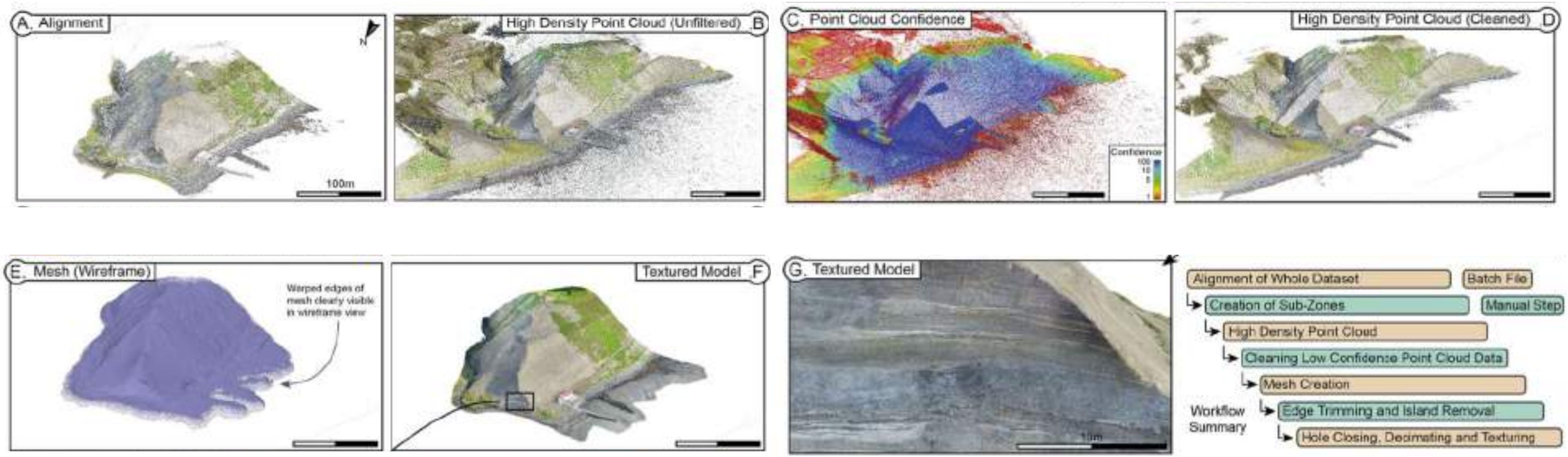
It is often mounted on professional drones or can be a standalone instrument

Photogrammetric models can be tied to RTK points in order to ensure highest possible accuracy

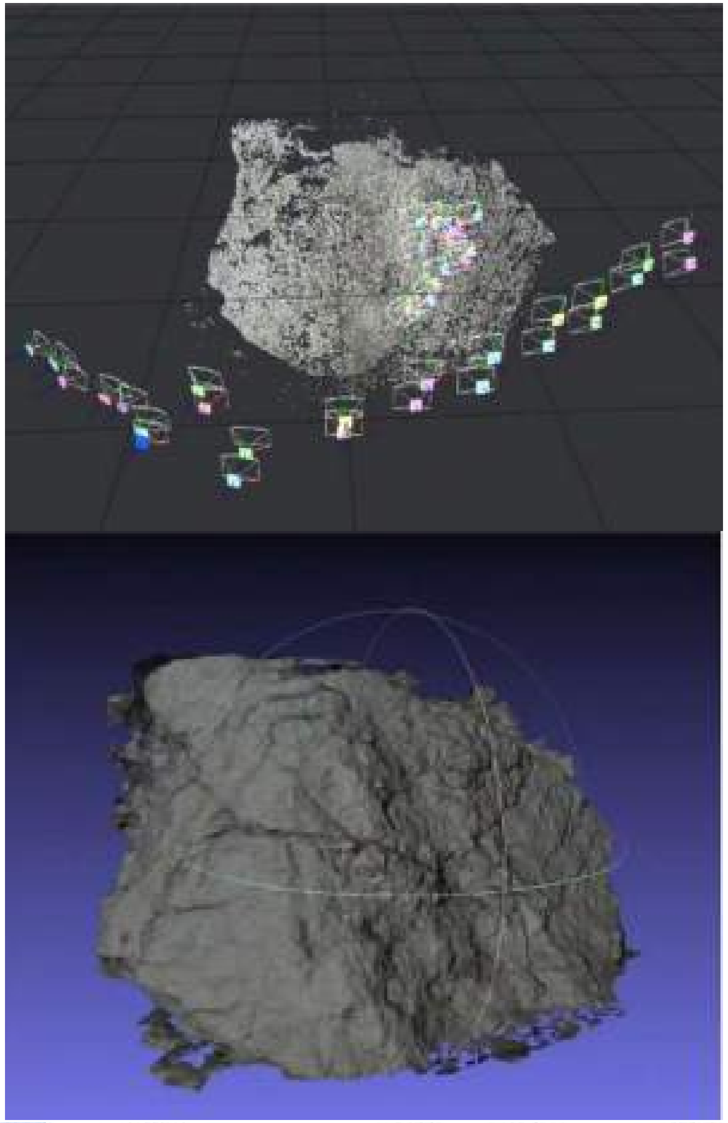


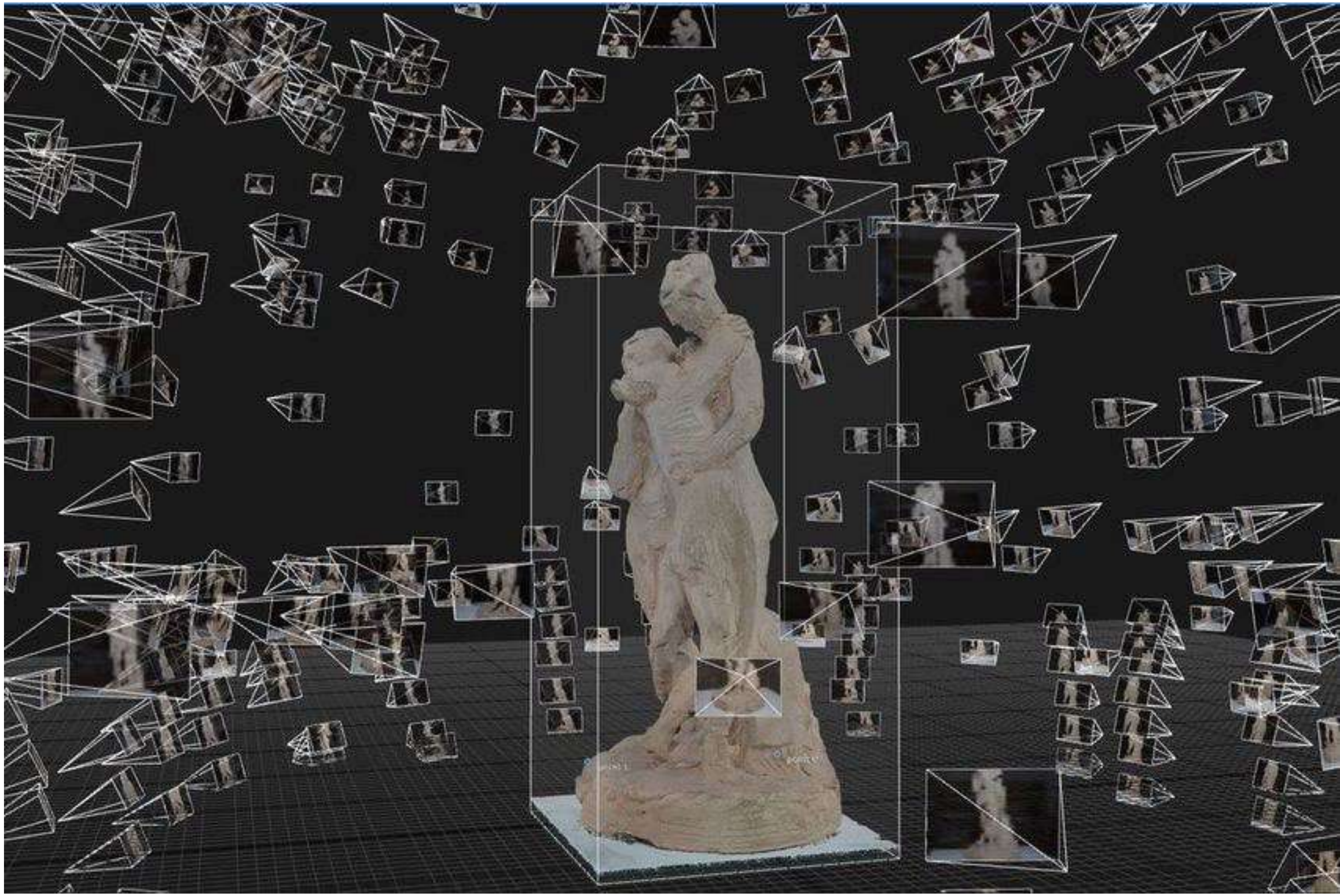
Source: italdron

Typical photogrammetric workflow



Terrestrial (or hand-held) photogrammetry

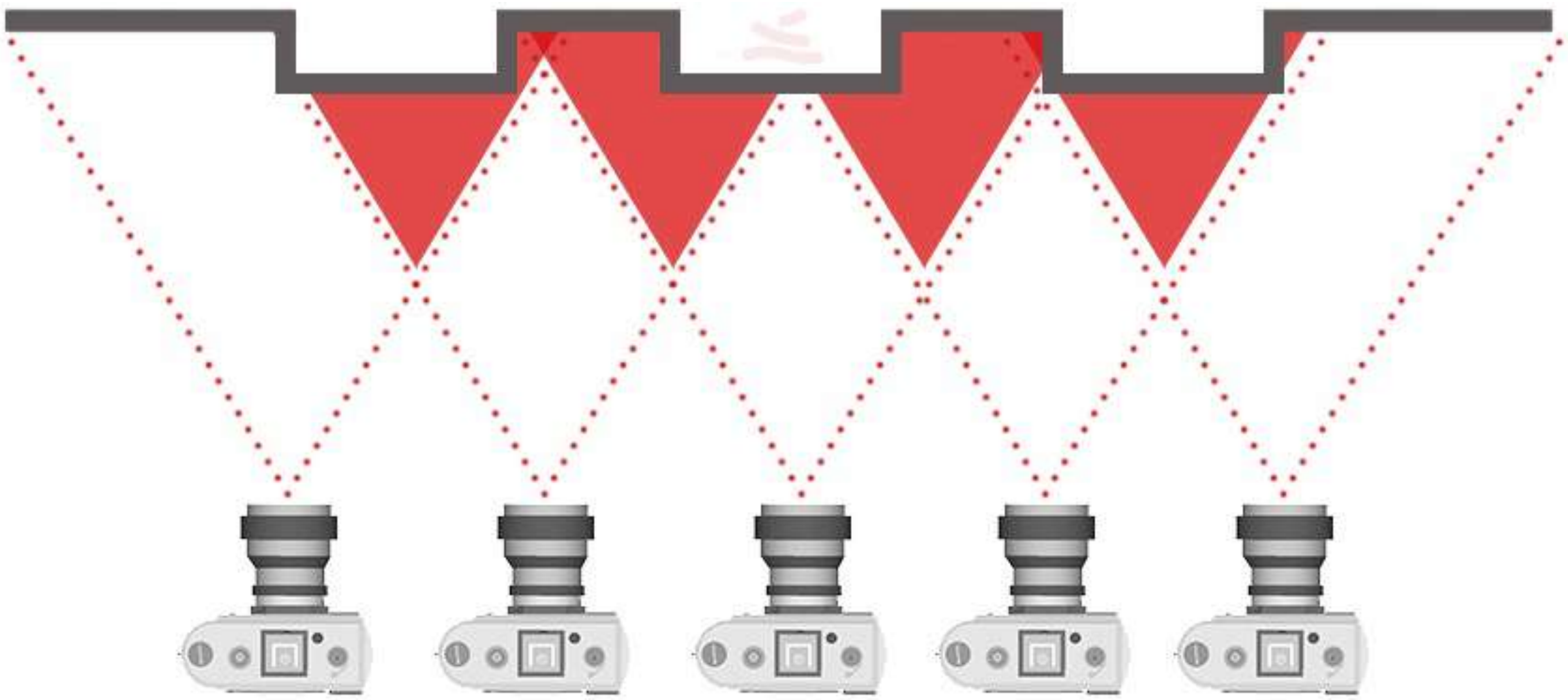




Best practices

Know your subject:

Walls, vertical objects, sub-planar objects

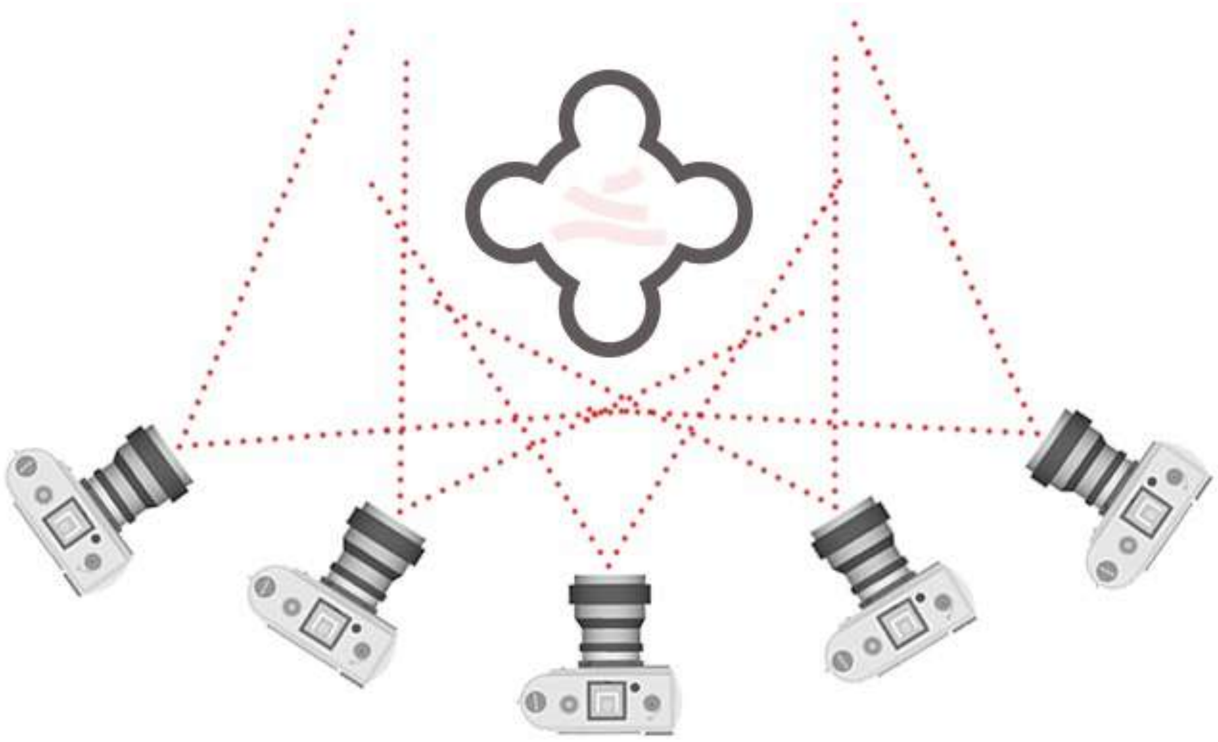


Source: 3D Zephyr

Best practices

Know your subject:

Outcrop, boulder, sample, metric size objects

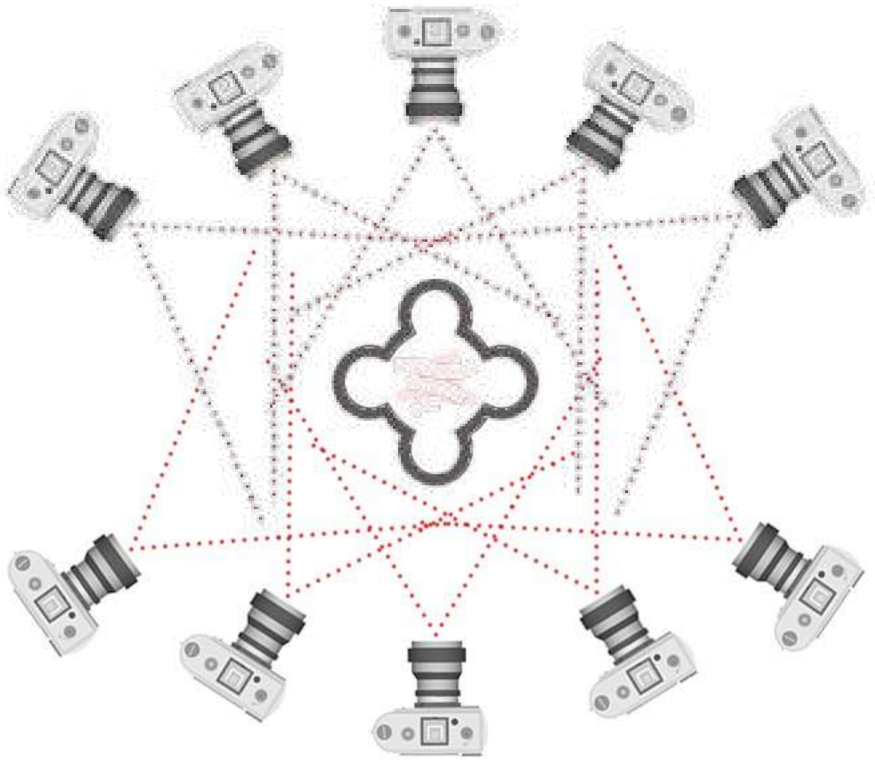


Source: 3D Zephyr

Best practices

Know your subject:

Small objects with 360 photography possibility around them



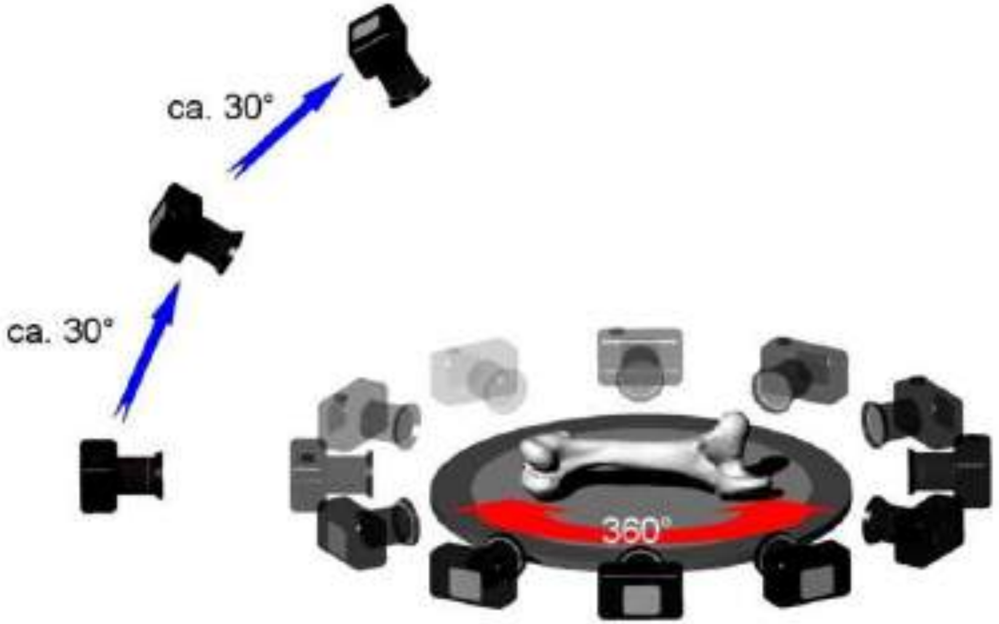
Source: 3D Zephyr

Best practices

Small objects (i.e. small samples)

Camera fixed on a tripod and rotating platform with object produces best results

Alternative: rotate around your subject with fixed height of the camera



Source: https://dinosaurpalaeo.wordpress.com/

Dos and Don’ts - 1

- ❑ **Avoid direct sunlight on the subject**

Shadows will mask parts of the details

Shoot in cloudy days or diffused light

- ❑ **Avoid high ISO**

Noise can degrade the sfm matching result

- ❑ **Use high depth of field**

Use high values of aperture (ideally from f/8 to f/16)

- ❑ **Avoid the use of flashlight**

- ❑ **Use high shutter speed or tripod**

Dos and Don'ts - 1

❑ **Avoid reflecting or transparent surfaces**

❑ **Do NOT crop images or correct lens distortion**

The software uses the EXIF information and the camera parameters to create the final model

❑ **Take a LOT of pictures – superposition between 60-80% between photographs**

Use the RULE OF 3: each object in the scene must appear in at least 3 photos from different point of views

❑ **NEVER adjust or modify the zoom level**

This is the worst thing you can do and it will severely affect the result

Use fixed focal length

Software list

(not comprehensive)

Application	License	Platform	Standalone / plugin	Automatic modelling	Scalability	Type of photogrammetry	Data source	Inception	Vendor / creator	Guide price	Online service	Free tier or trial period
3DF Zephyr	Proprietary	Microsoft Windows[1]	Standalone[1]	Yes[1]	Yes, multiple images[1]	Aerial, close-range, UAS	Images, video, laser scan[1]	2013[citation needed]	3DFLOW[1]	Free-US$4,260[1]	No	Yes, Free Edition[2] and Free Trial[3]
Ames Stereo Pipeline	Apache v2	Linux and OSX	Standalone	Yes	Yes, can run on a cluster in parallel	Satellite, aerial, close-range	Images		NASA		No	
IMAGINE Photogrammetry	Proprietary	Microsoft Windows	Standalone	Semi-automatic	Yes, multiple images	Aerial, satellite, UAS	Images	2009	Hexagon Geospatial	Unknown		
Metashape (former PhotoScan)	MPLv2	Linux, macOS, Microsoft Windows	Standalone	Yes	Yes, multiple images, cluster distributed processing	Aerial, close-range, UAS, satellite	Images, video, laser scan	2010	Agisoft	$179–3,499 educational $59–549, $4/hour on GeoCloud, Free Demo mode, Free Trial mode	Yes Agisoft Cloud (requires license)	Yes Unlimited featured 30 days trial or free demo mode with limited features.
OpenDroneMap	AGPLv3	Linux, macOS, Microsoft Windows	Standalone	Yes	Yes, multiple images	Aerial, close-range, UAS	Images	2013	OpenDroneMap	Free	WebODM Lightning Network	
PhotoModeler	Proprietary	Microsoft Windows	Standalone	Yes	Yes, multiple images	Aerial, close-range, UAS	Images, video, laser scan	1994	Eos Systems - PhotoModeler	$995-$2995 or from $49/month, edu discounts[4]		Yes Free no-save demo mode, or free 30 day all features trial.
Photosynth	Unknown	Microsoft Windows	Standalone	No	Yes, multiple images	Close-range	Images	2008	Microsoft Live Labs, University of Washington	Free		
Pix4Dmapper	Proprietary	Linux, macOS, Microsoft Windows	Standalone	Yes	Yes, multiple images	Aerial, close-range, UAS	Images, video	2011	Pix4D	License from $350/month	Pix4D Cloud	New customers are entitled to 25 days of free access to Pix4Dmapper.
Qlone	Proprietary	iOS, Android, macOS	Standalone	Yes	Yes, multiple images	Aerial, close-range, UAS	Images	2017	EyeCue Vision Technologies LTD.	Free Demo mode	No	
RealityCapture	Proprietary	Microsoft Windows	Standalone	Yes	Yes, multiple images	Aerial, close-range, UAS	Images, video, laser scans	2014	Capturing Reality	699-15000 (Free Demo)		
SOCET SET	Proprietary	Microsoft Windows	Standalone	No	Yes, multiple images	Aerial, close-range, satellite	Images		BAE Systems	Unknown		

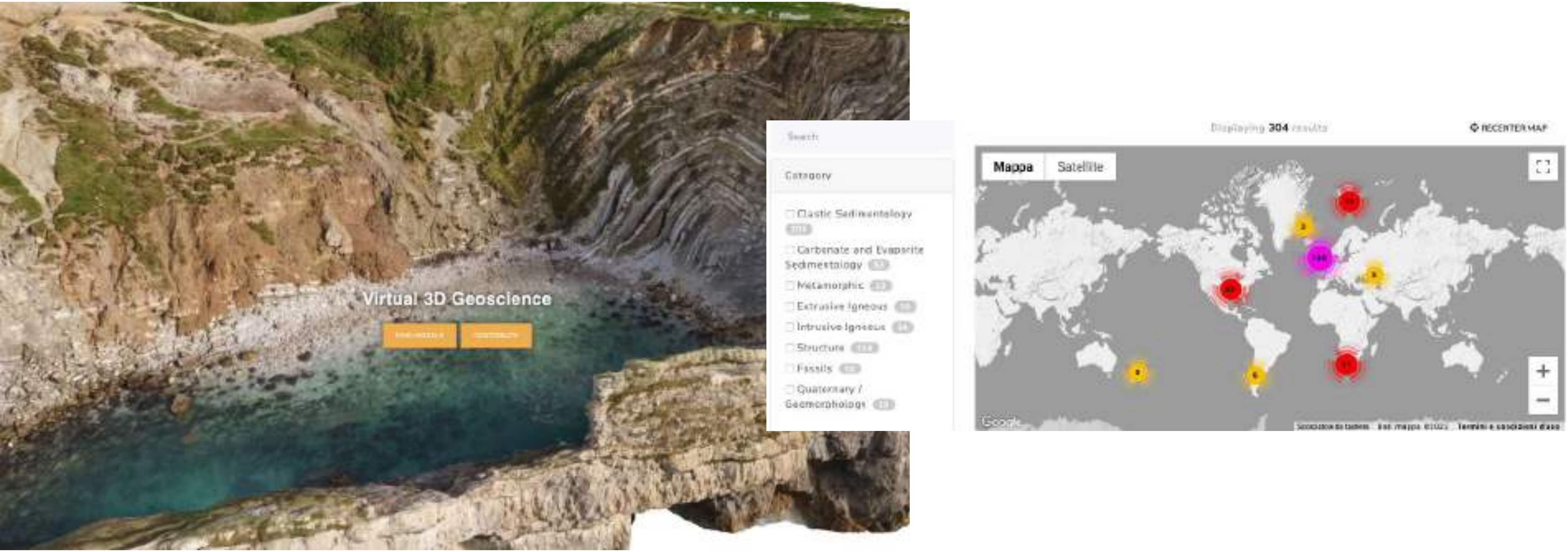
Source: https://en.wikipedia.org/wiki/Comparison_of_photogrammetry_software

Guide to DOM creation and open source alternatives for Earth and Planetary Science

https://www.europlanet-gmap.eu

https://www.europlanet-society.org/wp-content/uploads/2021/09/D9.4.pdf

Online DOM resources



https://v3geo.com

VR – Virtual Reality

- Virtual Reality is a term used for computer-generated 3D environments that allow the user to enter and interact with alternate realities
- The users are able to "immerse" themselves to varying degrees in the computers artificial world which may either be a simulation of some form of realitv 26 or the simulation of complex data
- The use of the term "virtual reality" was first used in the mid-1980s when Jaron Lanier founder of VPL Research began to develop the gear, including goggles and gloves, needed to experience what he called "virtual reality."

VR technology

The focuse is to reproduce an alternate reality using

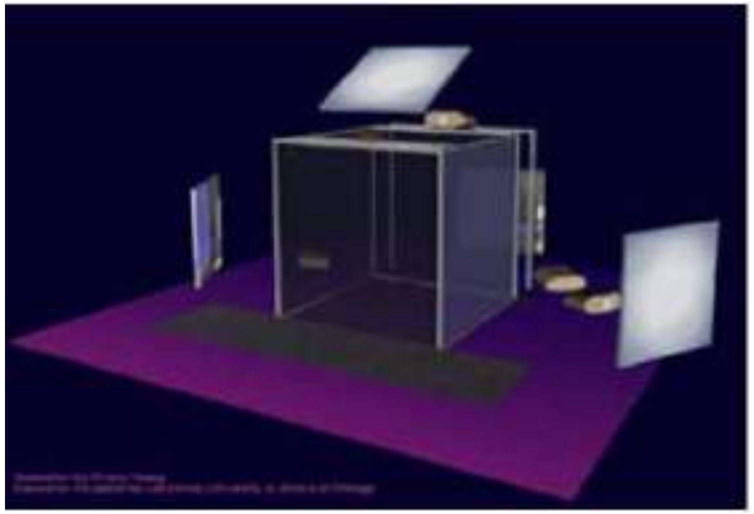
3D immersive stereoscopy

3D sound

Force feedback

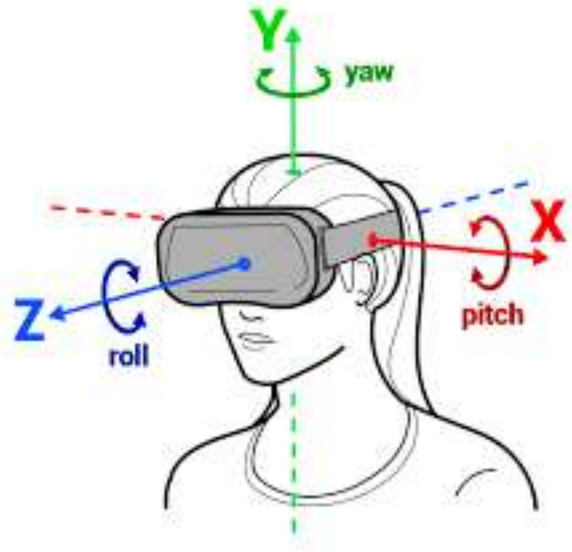
HMD (Head Mounted Displays)

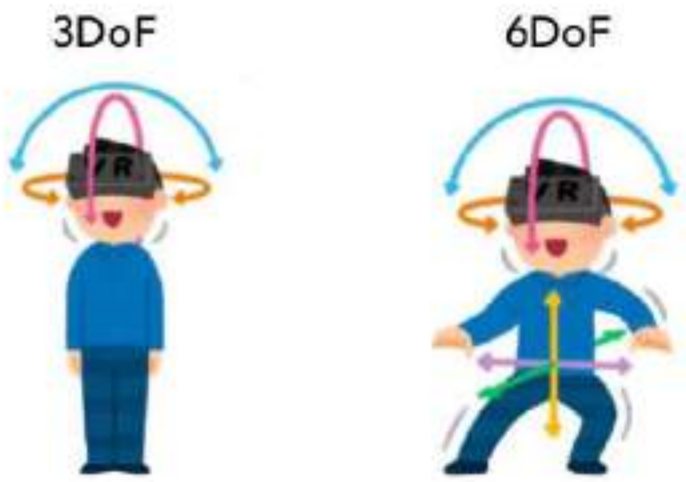
Cyberpuck for motion control in 6 degrees of freedom



CAVE

VR technology





The head tracking and eye tracking for parallax is mandatory

Stereoscopic view and large FOV is also mandatory to have the immersion

VR in geosciences

- ❑ Enhance the perception of outcrops and features
- ❑ Map and exploit unreachable locations
- ❑ Having shared experiences
- ❑ Return to previously visited locations with UAV
- ❑ Didactic purposes (i.e. pandemic, mobility impairment)
- ❑ Augmented mapping tools

VRGS – Virtual Reality Geological Studio