Mapping and structural analysis of faults network on Mars and Mercury: Implication for regional tectonic and magmatism

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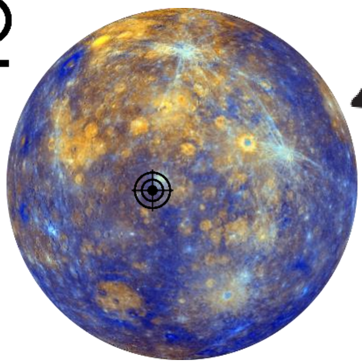
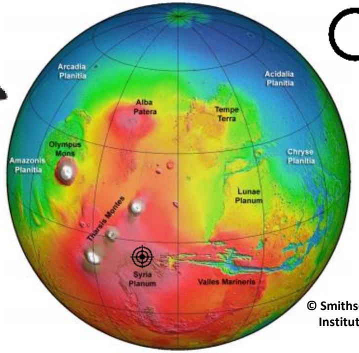
Supervisor: Prof.Matteo Massironi

Meeting for the admissions to the final exam - December 12, 2021 at 10:55

1.General context





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- Morpho-Stratigraphic map with 1:3M output scale
- Analysis of faults network and structural features
- Understand the tectonic kinematic on ½ Eminescu
- Study the volcanic activity
- Carry out a general tectonic and volcanic context on ½ Eminescu

- Structural map
- Analysis of faults spatial distribution and structural features
- Understand the tectonic kinematic on Noctis Labyrinthus
- Analysis of the Pit-chains and faults relationship
- Study faults geometrical attributes
- An evolutionary model for Noctis Labyrinthus

1.General context

Mercury

Clobal Contraction ?
Tidal despinning ?
Mantle convection ?

Faults kinematic and spatial distribution

Cross-cutting relationship, overlapping and faults phases ?

What driving processes behind the surface morphology in Eminescu?

Mars

How can we explain the distinct spatial distribution of fault systems over the N and S sectors in NL? How many are the faulting phases?

What is the relationship between joint PC and F?

Does the magmatic plumbing in SP helped creating the formational history in NL?

What is the possible scenario behind the formation of NL?

1.1 Noctis Labyrinthus

Terminology
Noctis Labyrinthus: it is a Latin word
Noctis means night
Labyrinthus is the Labyrinth

Quadrangle
Phoenicis Lacus (MC-17)

Coordinates
-6°86N_ 6°54S_267°48E_101°12W

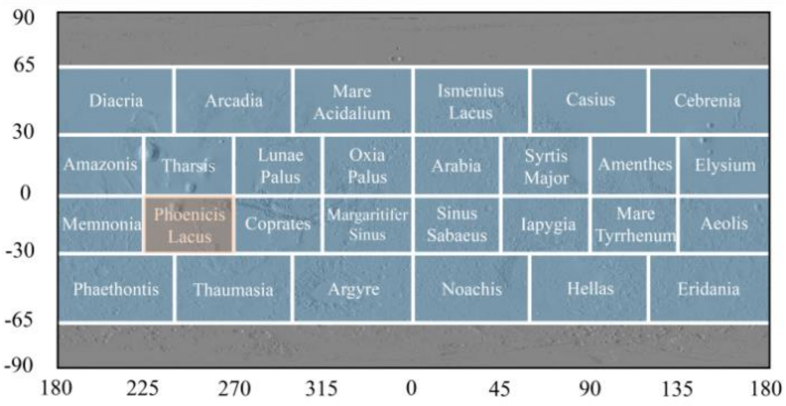


Figure 1. Mars Odyssey THEMIS-IR Global Mosaic, indicating the series of 30 quadrangles of Mars as defined by the USGS.
(Photos recognition: USGS (Modified)).

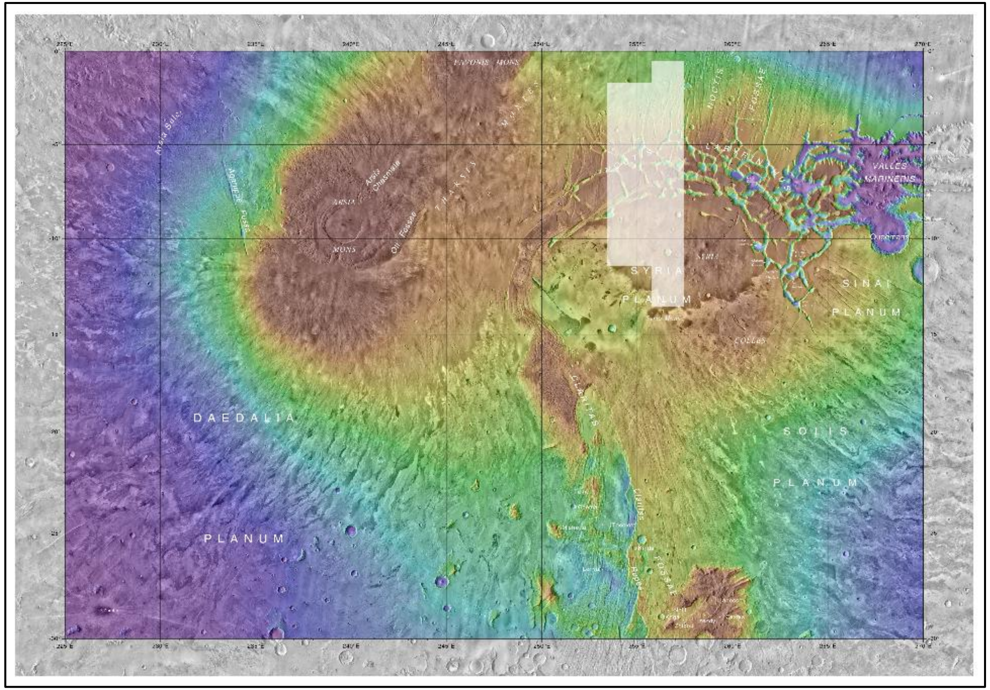


Figure 2. THEMIS IR Global Mosaic for Phoenicis Lacus, MC-17 covered by MOLA Elevation Model.
(Photo recognition: ASU, USGS (Modified)).

1.2.Structural map for Noctis Labyrinthus

Symbology

Feature	Attribute	Shapefile type
Large faults ≥40km	red line	Polyline
Medium faults ≥4km	orange line	Polyline
Small faults <4km	yellow line	Polyline
Pit_chains	dark red box	Polygon

Mapping scale
1:39,000

Coordinate system
Equirectangular_MARS

The total number of faults: 4247
The total number of faults covered with MOLA: 3340

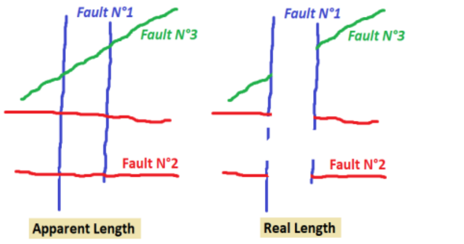


Figure 3. Faults length mapping mapping and difference between apparent and real measure

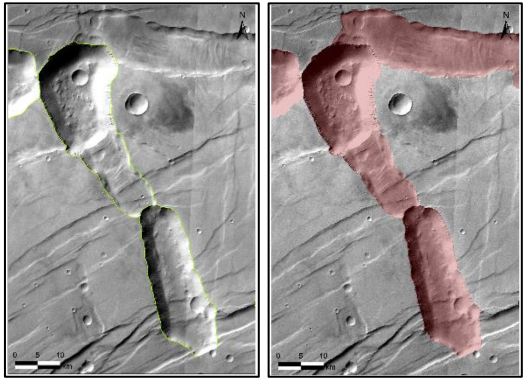


Figure 4. (A) Pit-chains full shape delineation using a polygon shapefile. (B) Pit-chains edge mapping by a polyline shapefile.

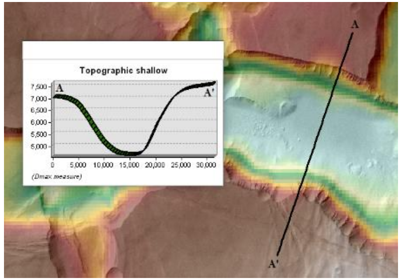
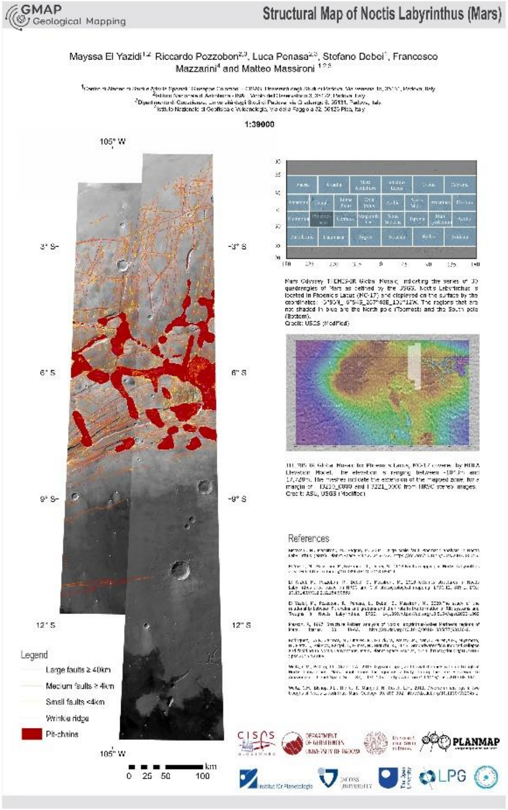


Figure 5. Cross-section across fault lineament for the vertical throw measurements



1.3. Study the faults spatial distribution

According to the faults mapping, we distinguish 3 systems of faulting:

1st system: NS and NNE-SSW
2nd system: EW and ENE-WSW
3rd system: NNW-SSE, and WNW-ESE

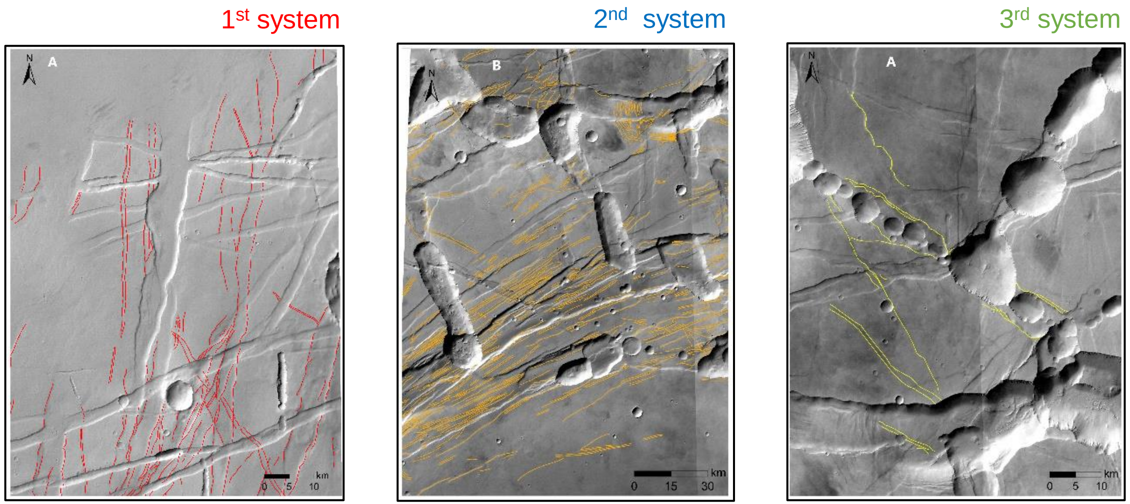
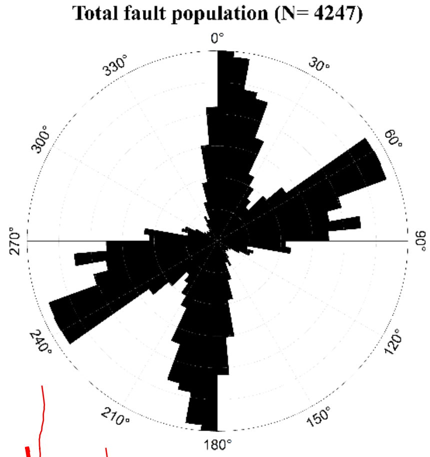


Figure 6. Overview of different fault systems.



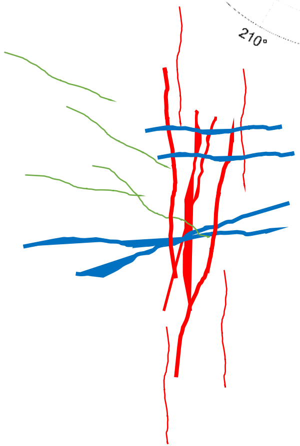


Figure 7. Polar plot for all mapped faults.

1. Mars

1.3. Study the faults spatial distribution

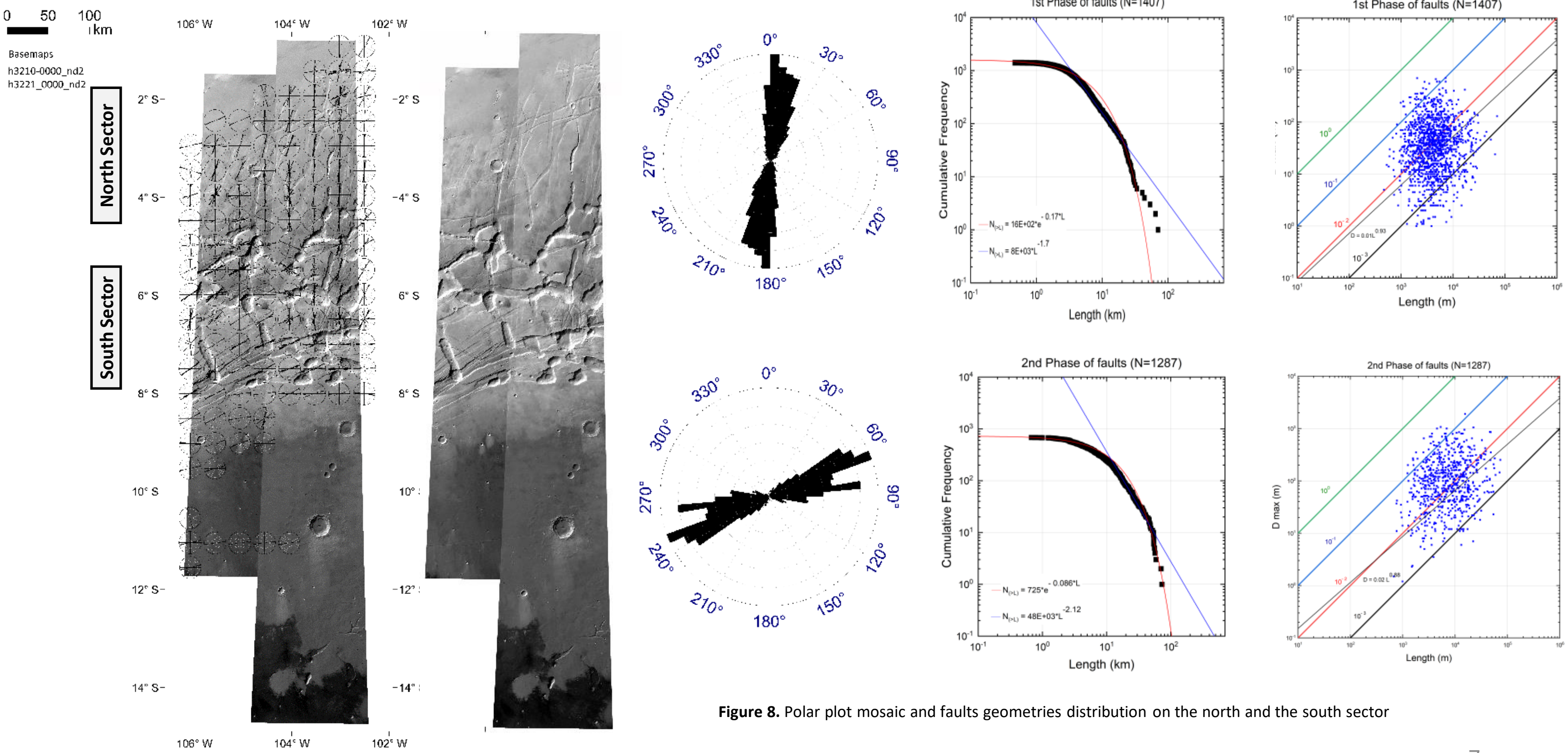


Figure 8. Polar plot mosaic and faults geometries distribution on the north and the south sector

1. Mars

1.3. Study the faults spatial distribution

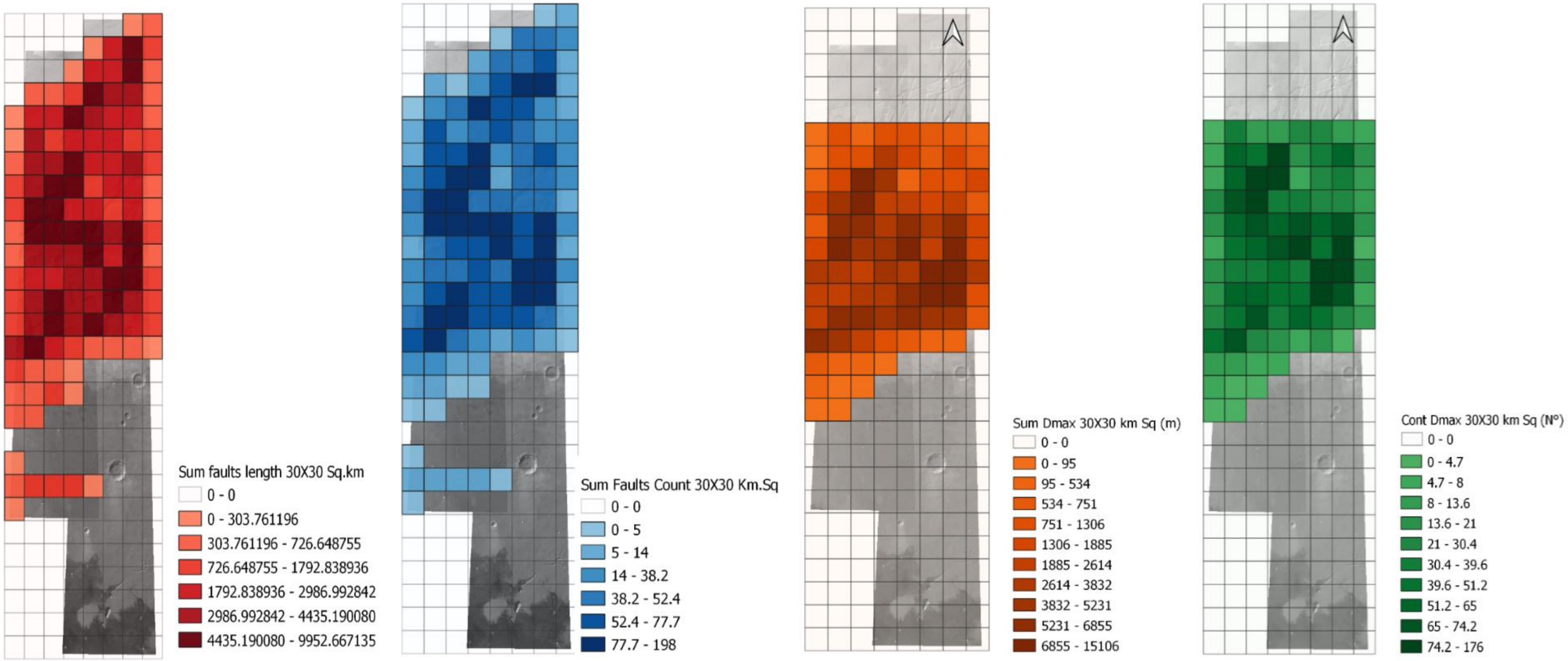


Figure 9. Faults length and vertical throw (Dmax) distribution over 30X30Sq.km grid.

1.4. Study the Pit-chains and faults relationship

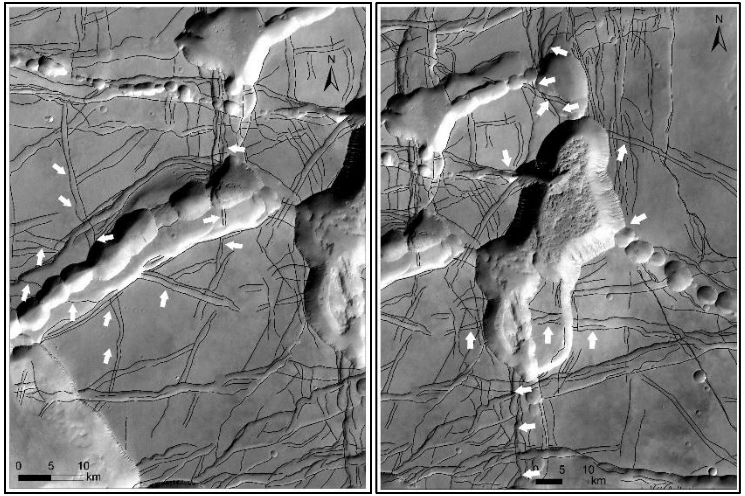


Figure 10. Overview for some fault systems, overlapped by pit-chains, indicating that the pit-chains formed just after the faulting systems.

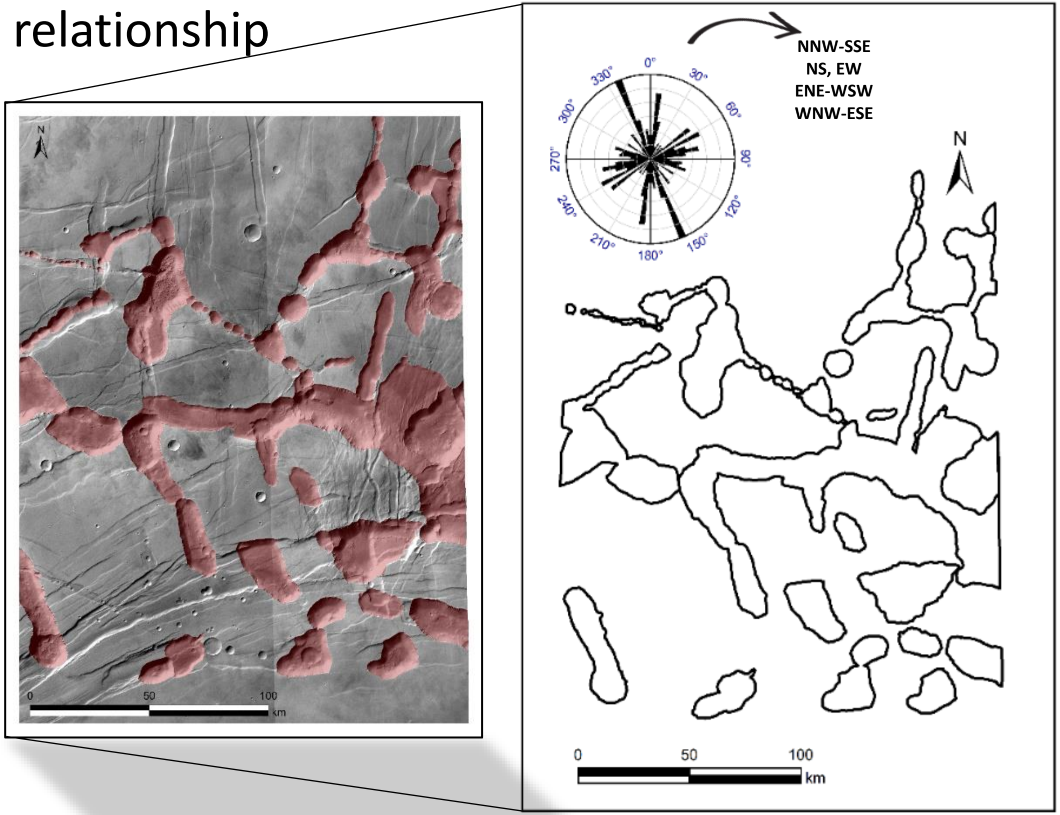


Figure 11. Pit-chains limits and orientations

1.4. Study the Pit-chains and faults relationship

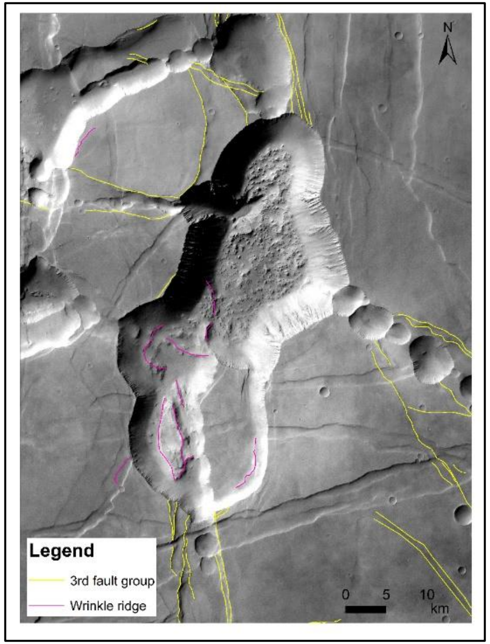


Figure 12. Overview of some pit-chains, connected to different size faults oriented NNW-SSE, and NW .

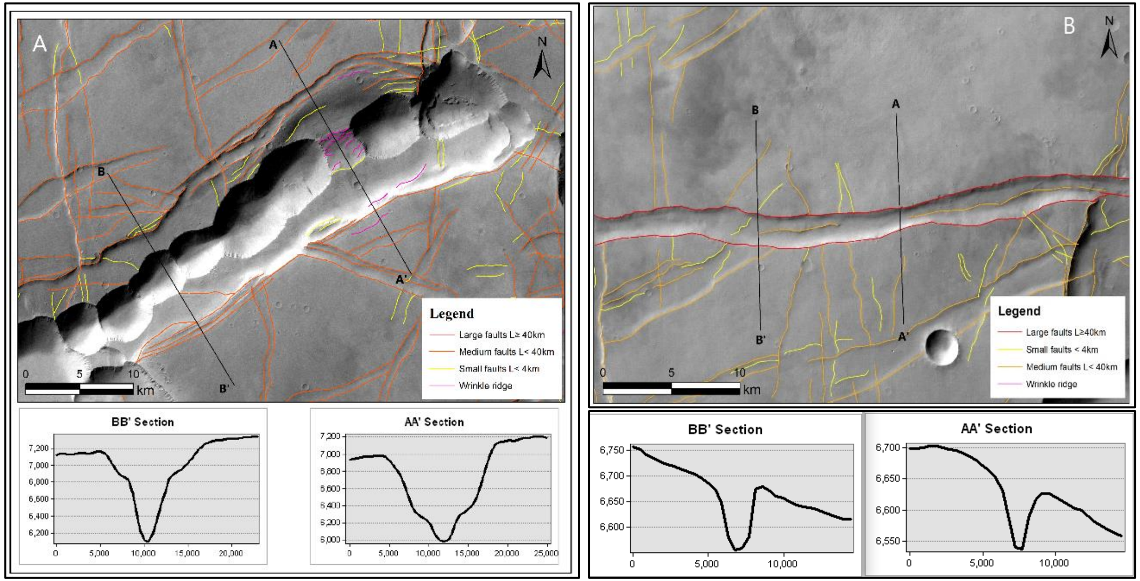
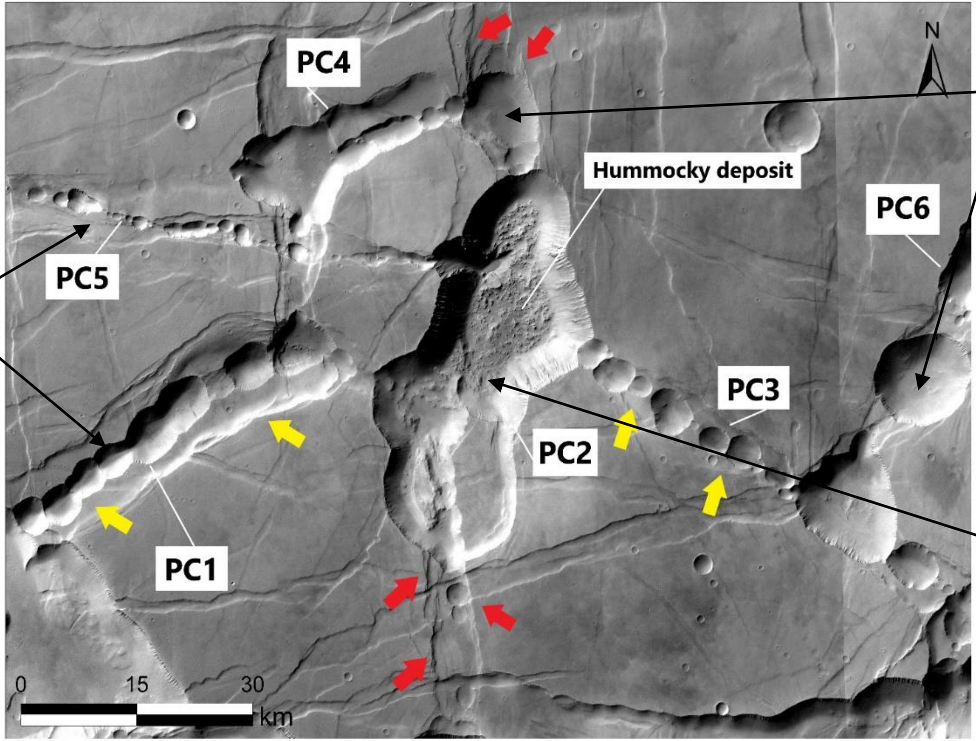


Figure 13. Maximum displacement measurement for a joint pit-chains and faults zone (A) and simple faulted zone (B). The topographic sections AA' and BB' show are showing the vertical throw for the joining pit-chains and graben feature.

1.4. Study the Pit-chains and faults relationship

Well rounded pit-chains, with smooth floor



Larger pit-chains, with an interconnection with other pits

Large pit-chains, with Hummocky materials on the floor

Figure 14. Overview of pit-chains (PC) intersection and extension.

1.4. Study the Pit-chains and faults relationship

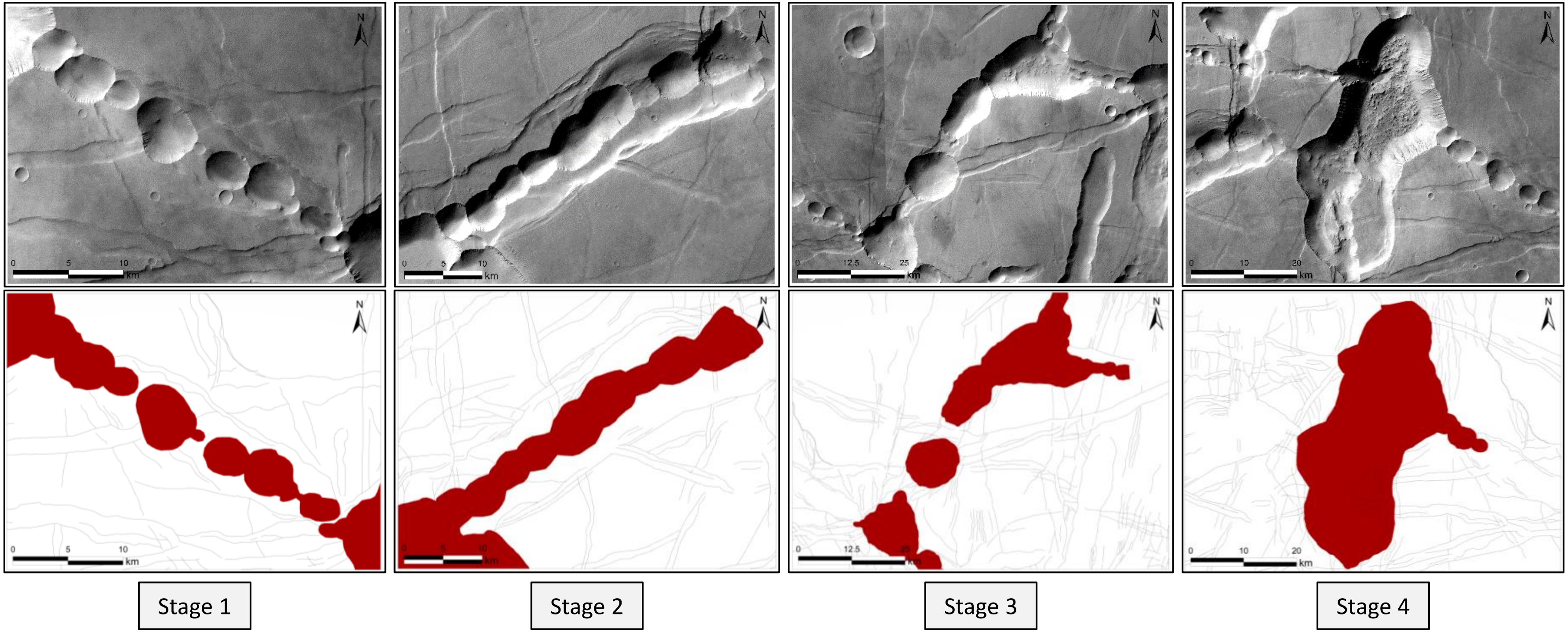


Figure 15 Pit-chains evolutionary stages

1. Mars

1.5.Study the faults system in North-South transect

Northward sector

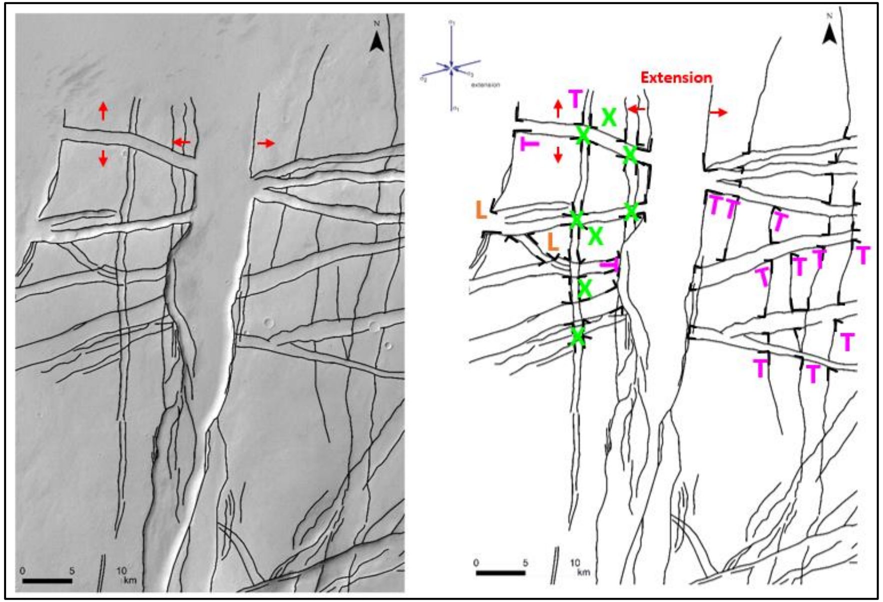
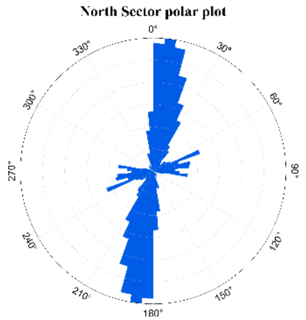
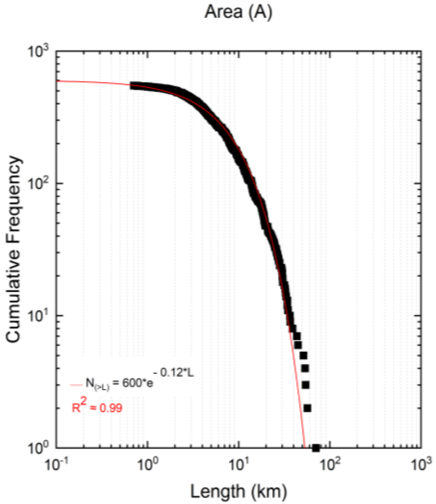
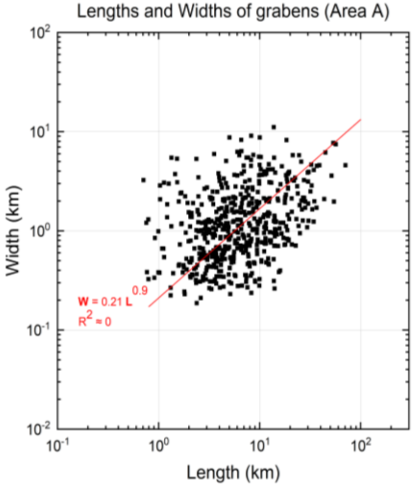


Figure 16. Faults intersection shapes and faults attributes distribution in the North sector.
The type of the intersections is indicated by letter (T= T-shaped, X for X-shaped and L for L-shaped).

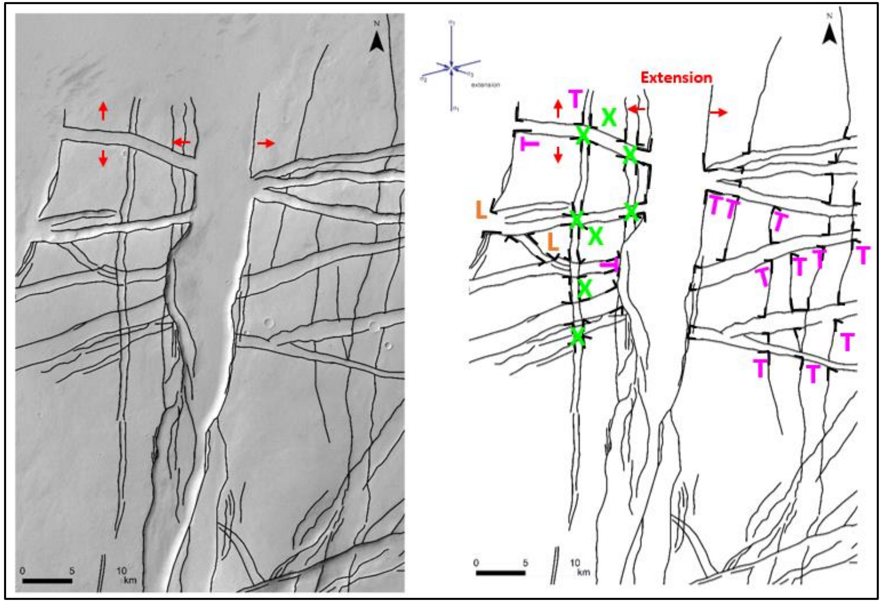






1.5. Study the faults system in North-South transect

Northward sector



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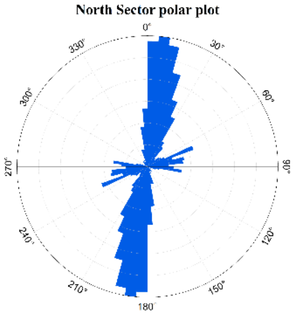
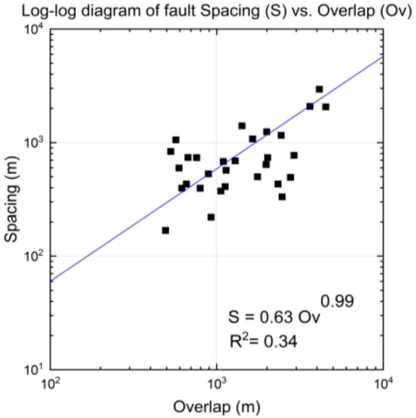
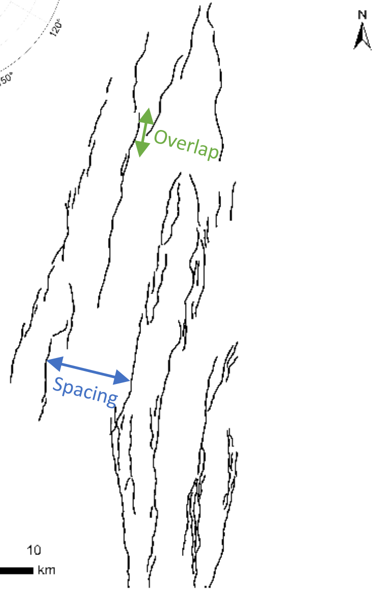






1.5. Study the faults system in North-South transect

Northward sector

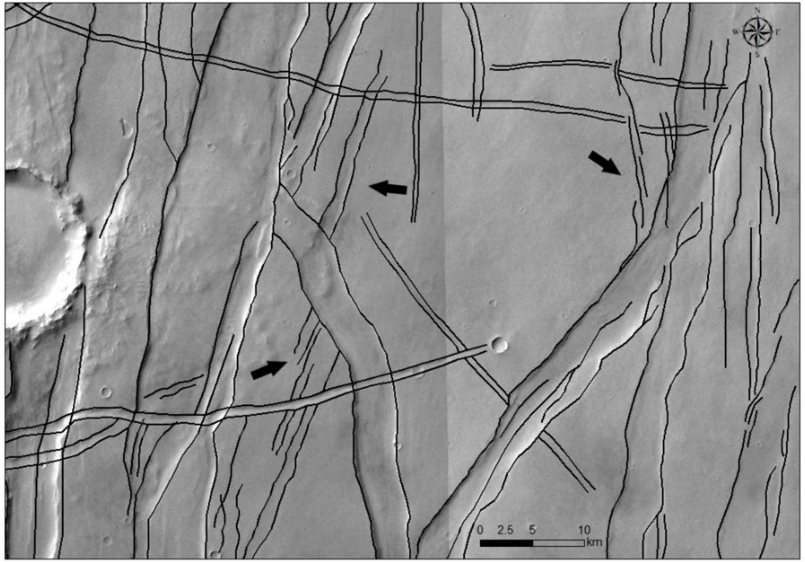
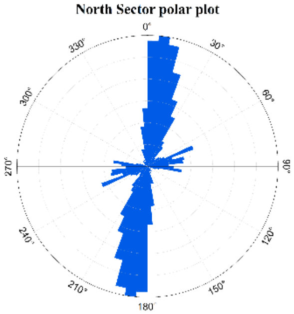
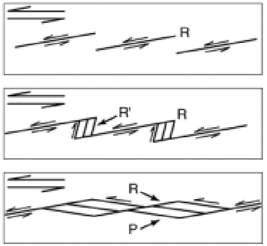


Figure 17. Riedel shear zones in the north sector.





(Ahlgren, 2001)

1.5. Study the faults system in North-South transect

Southward sector

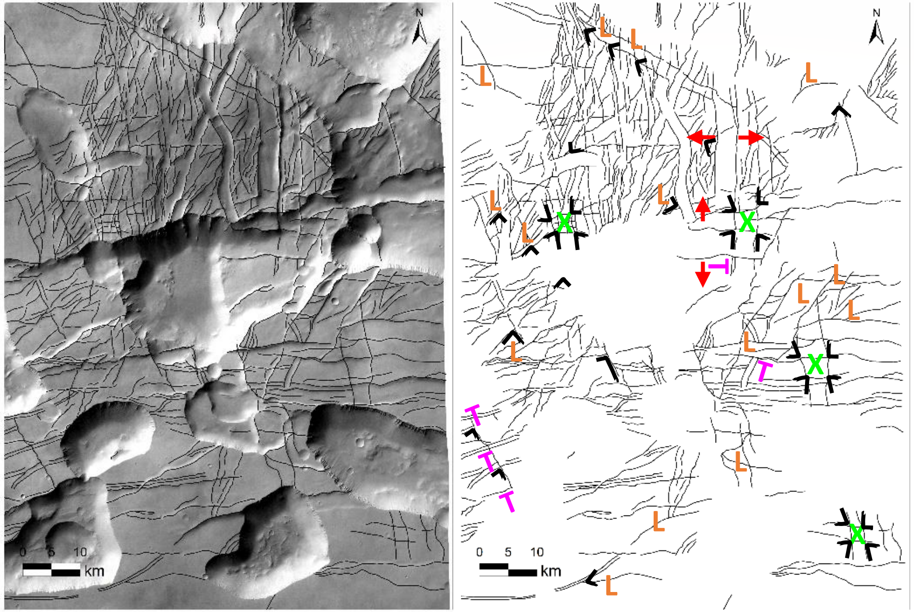
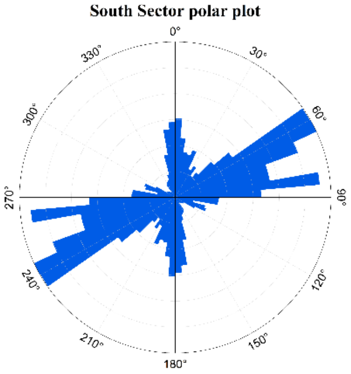
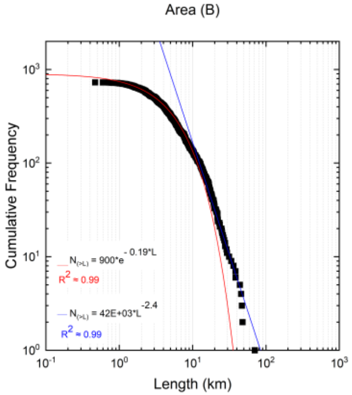
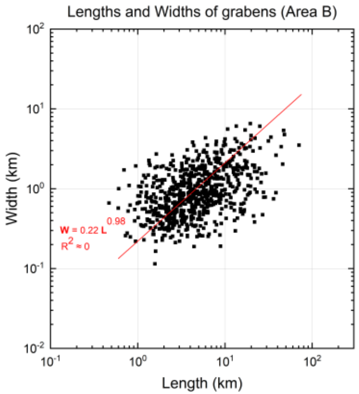


Figure 18. Faults intersection shapes and faults attributes distribution in the North sector.
The type of the intersections is indicated by letter (T= T-shaped, X for X-shaped and L for L-shaped).







1.6 Bi-directional extension: 2 ϕ of bidirectional deformation

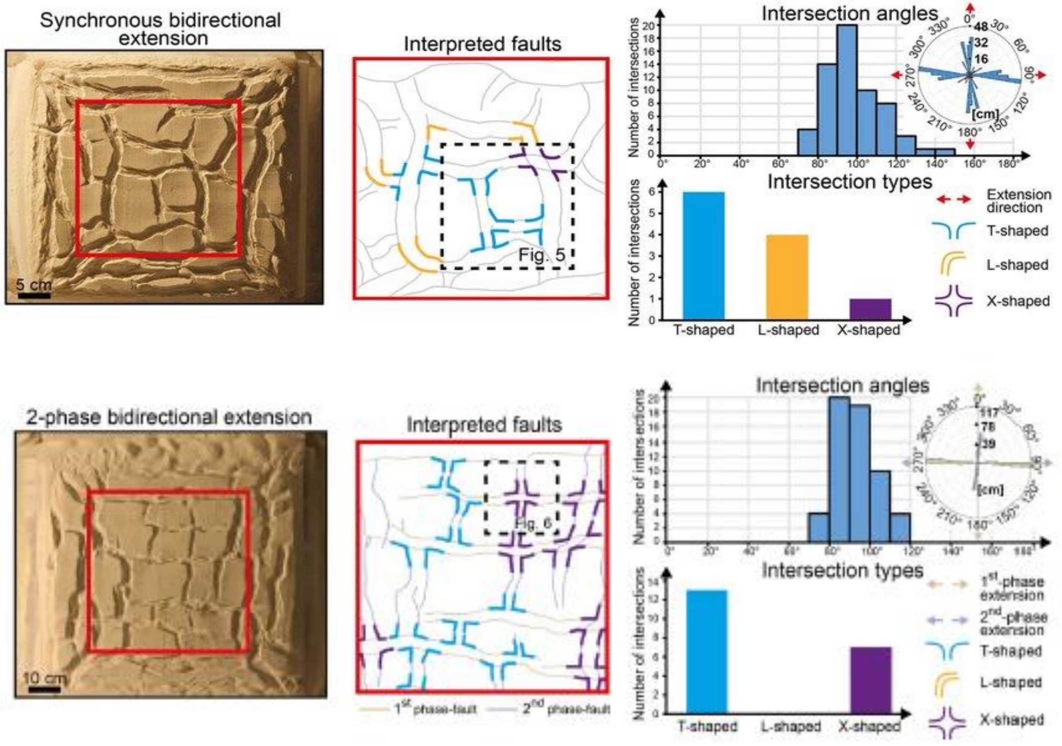
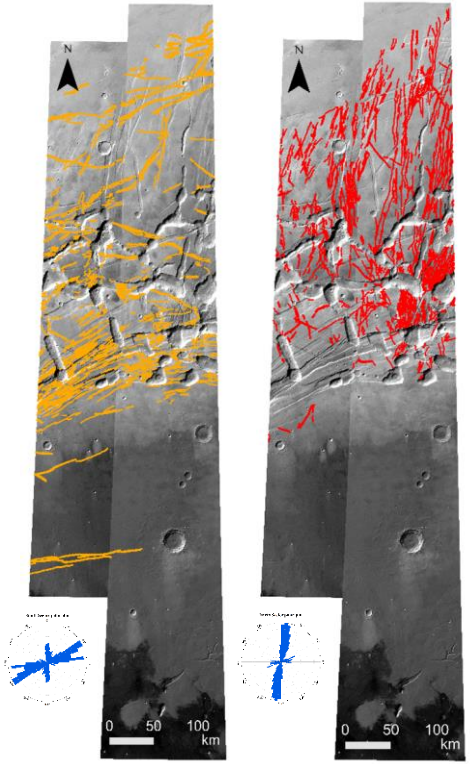
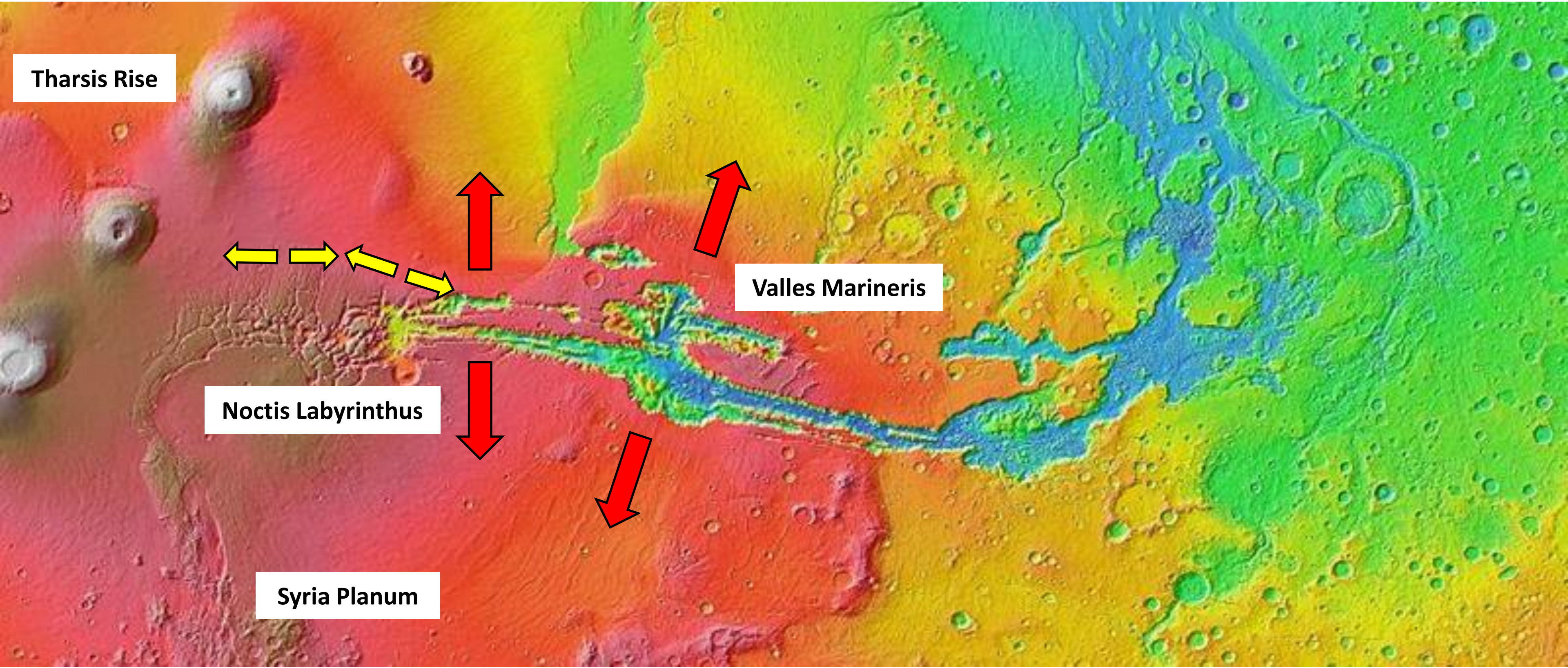


Figure 19. Different types of Bi-directional extension, according to the faults intersections shapes.



(Collanega et al, 2020)

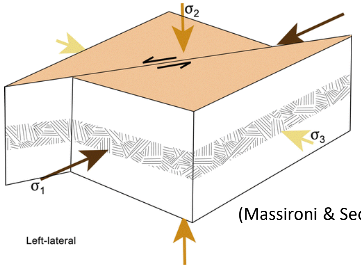
1.6. Processes involved in the formation of Noctis Labyrinthus



1.7. A possible scenario for the formation of Noctis Labyrinthus

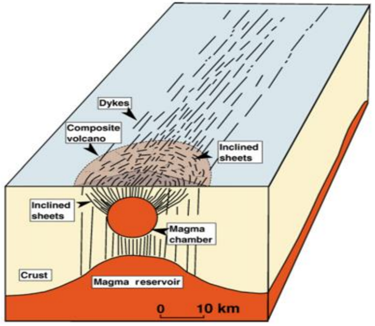
We suggest the following scenario behind this work:

1st event (Tectonic):
- Synchronous bidirectional extension: generate the formation of two fault systems with NS and NNE-SSW trends
- Dextral and sinistral Strick-slip



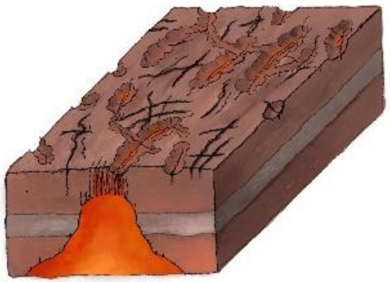
(Massironi & Seog Kim., 2015)

2nd event (Magmatic):
Magma plumbing in Syria Planum, generate the formation for arctic fault system that starts in ENE-WSW and turn to EW (On the bottom part), interpreted as an inclined sheet
On the north side, the ENE-WSW and EW they follow w linear trend



(Gudmundsson.,2006)

3rd event:
<u>Stage1:</u>
Reactivation of faults from event 1 and event 2
<u>Stage 2:</u>
Oblate strain generates the formation of NNW-SSE, and WNW-ESE
<u>Stage 3:</u>
Pit-chains formation



2.1. Eminescu

Terminology
Named after the Eminescu crater
In honor of the Romanian poet Mihai Eminescu

Quadrangle
Eminescu H-09

Coordinates
72°E_144°E_22,5°N_-22,5°S

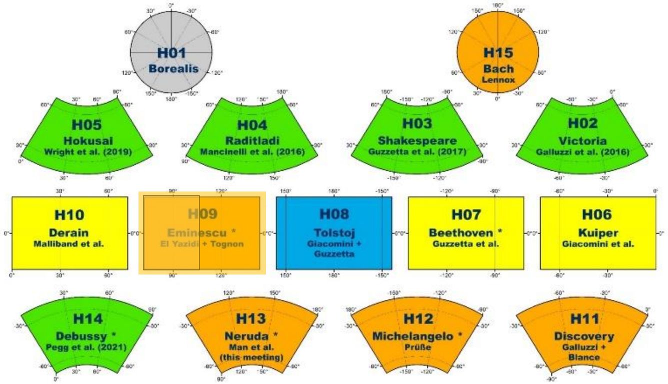


Figure 20. Global Mosaic for Mercury quadrangles with new names and boundaries as defined by the MESSENGER team.
(Photo recognition:Galluzzi., 2021).

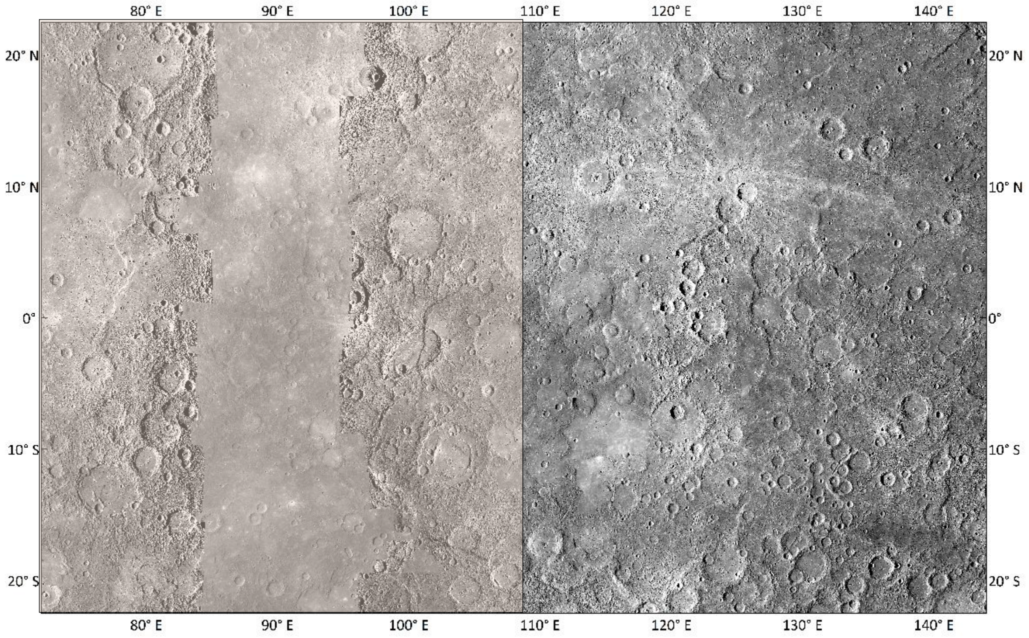


Figure 21. Eminescu H-09 over MESSENGER BASEMAP_MDIS_BDR2_256PPD.
(Photo recognition: PDS Geosciences Node Orbital Data Explorer (ODE)).

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2. Mercury

2.2. Data

Basemaps

- Monochrome mosaic Basemap Reduced Data Record (BDR, ~166 mpp)
- Monochrome mosaics Low-Incidence Angle Basemap RDR (LOI, ~166 mpp)
- Global Monochrome Map of reflectance at high-incidence angle, Illuminated from East RDR (HIE, ~166 mpp)
- Global Monochrome Map of reflectance at high-incidence angle, Illuminated from WEST RDR (HIW, ~166 mpp)
- Enhanced-color global mosaic (665 mpp)
- RGB-color global mosaics (665 mpp)

Topography: USGS Global DEM (665mpp)

Scale and Symbology

Output Scale: 1:3M
Mapping scale: 1:400K

Symbology:
Based on the Federal Geographic Data Committe (FGDC) and United States Geographic System (USGS) recommendations with appropriate revisions.

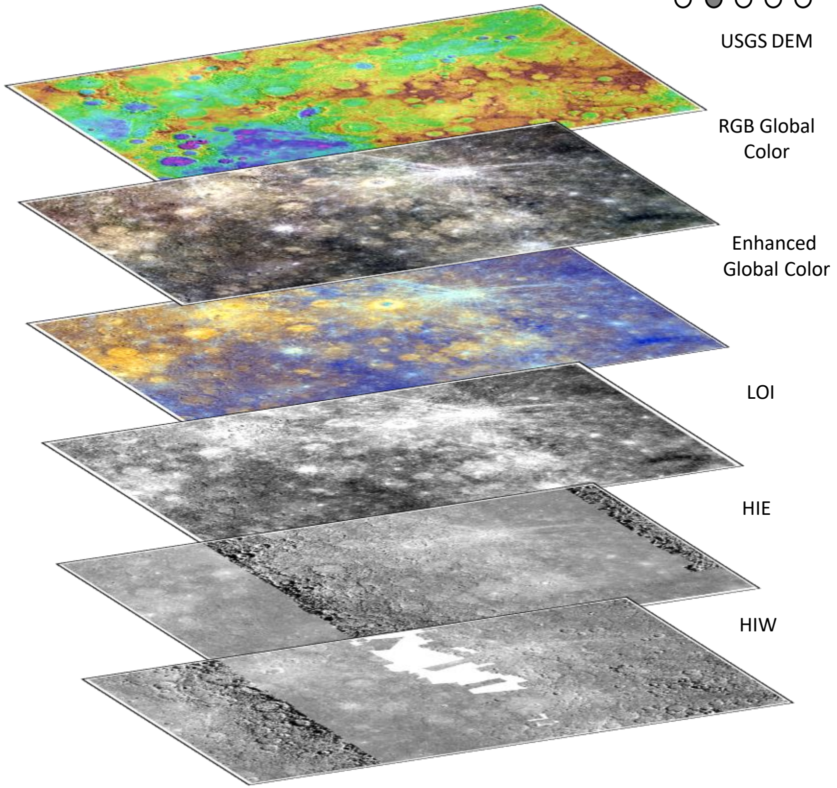


Figure 22. The Various basemaps used for Eminescu mapping

2.3. Mapping status

Coordinates:
72°E - 144°E, 22,5°N - 22,5°S

Projection System:
Equirectangular_Mercury

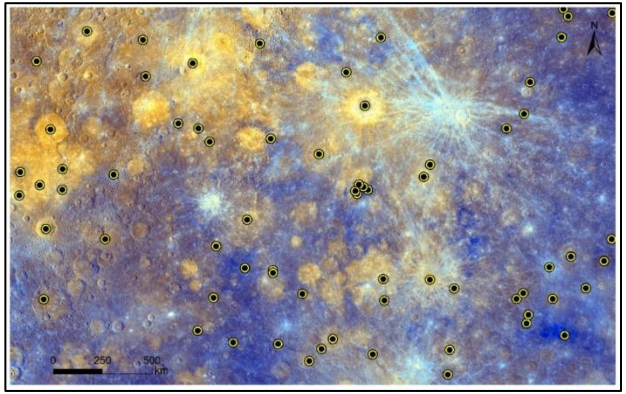
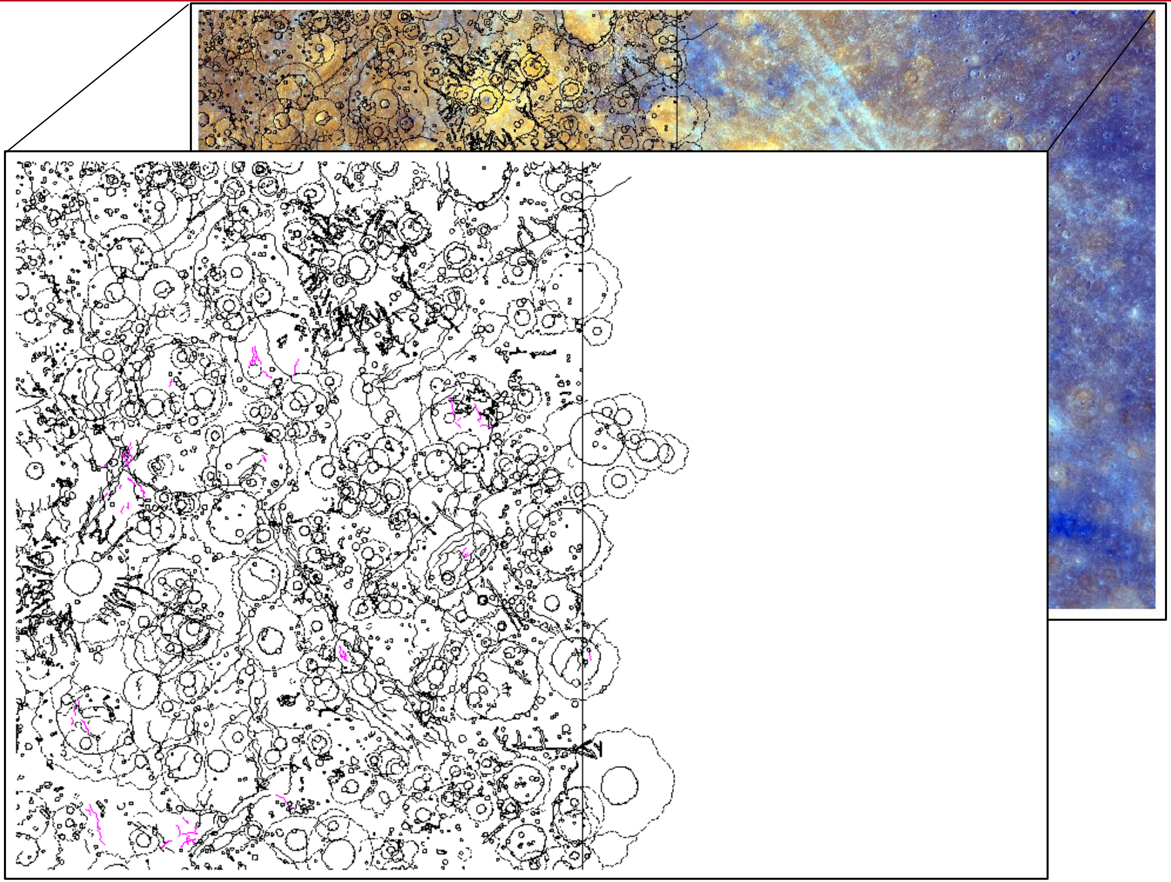
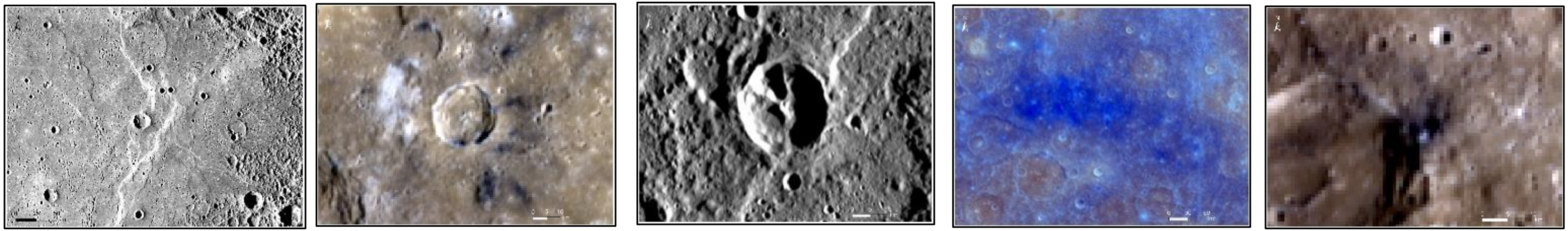


Figure 23. Mapping status and targets selection .



2.4. Targets selection (SIMBIO-SYS)

BepiColombo



Tectonic | Craters | Volcanic | Terrains | Other feature

Figure 24. Different categories of targets that was selected in the frame to support BepiColombo mission goals.

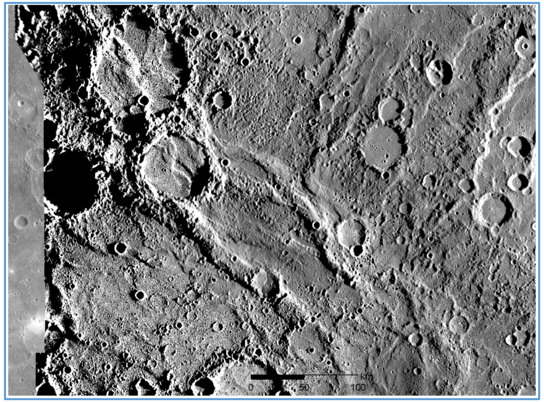
2.4. Preliminary result

Two principle features:
Craters and lobate thrust fault (Fig.25)

Two stages of compressive deformation by two distinct sets of tectonic structures following NE–SW and NW–SE directions (Fig.27) .

Sveinsdóttir crater, and Beagle rupes: A complex and distinctive feature on Mercury's landscape (Fig.26).

Fig.25. View of part of densely cratered and tectonized terrain in the southern part. Image centered at 94.36°E, -10.14°N



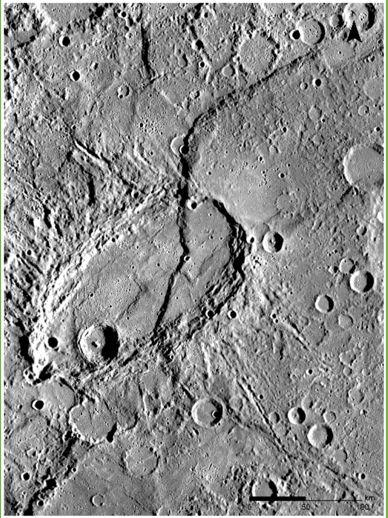


Figure 26. Sveinsdóttir crater cut by Beagle rupes, generate the creation of complex feature. Image at 100.91°E, -2.36°N

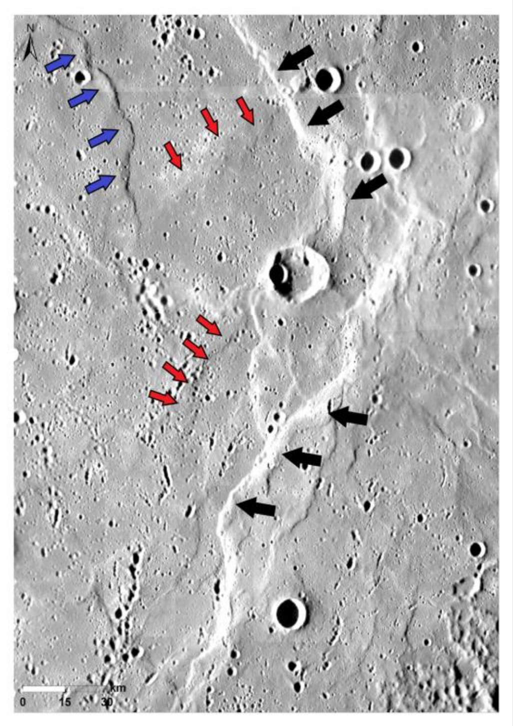


Figure 27. Low relief ridges (red arrows) crossed by wrinkle ridge (blue arrows) and by the large lobate scarps (black arrows). Image centered at 4.77°N, 1.61°N Lat and 78.77°E, 77.91°E Lon

2.4. Preliminary result

NS trending segment

Asymmetric topographic profile with a steep western slope, would indicate a westward motion (‘top up to the west’ kinematics)

Given the EW shortening direction required by the NS arcuate frontal scarp, it is unlikely that either of the lateral ramps can represent pure compression.

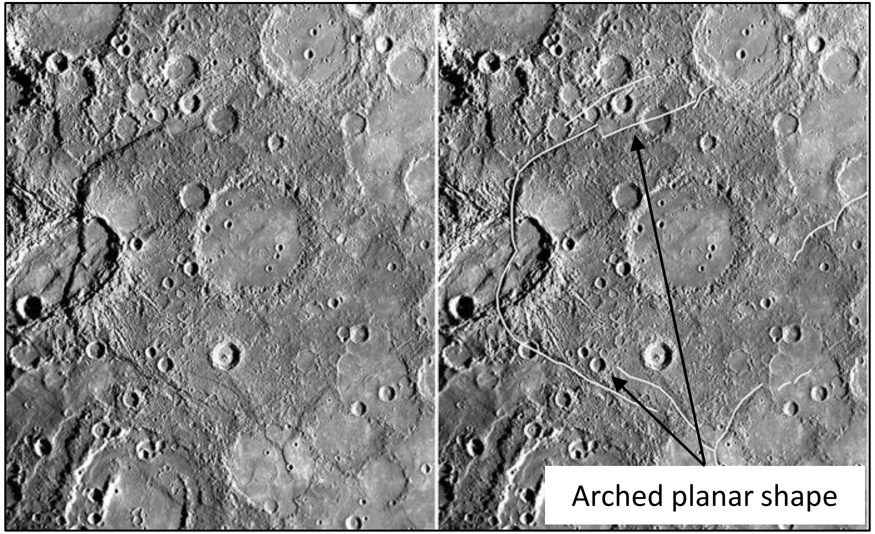


Figure 28. MESSENGER basemaps showing the area of Beagle Rupes, with and without lines interpretations.

(Rothery and Massironi, 2010)

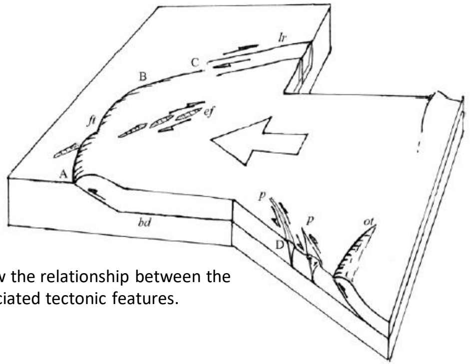
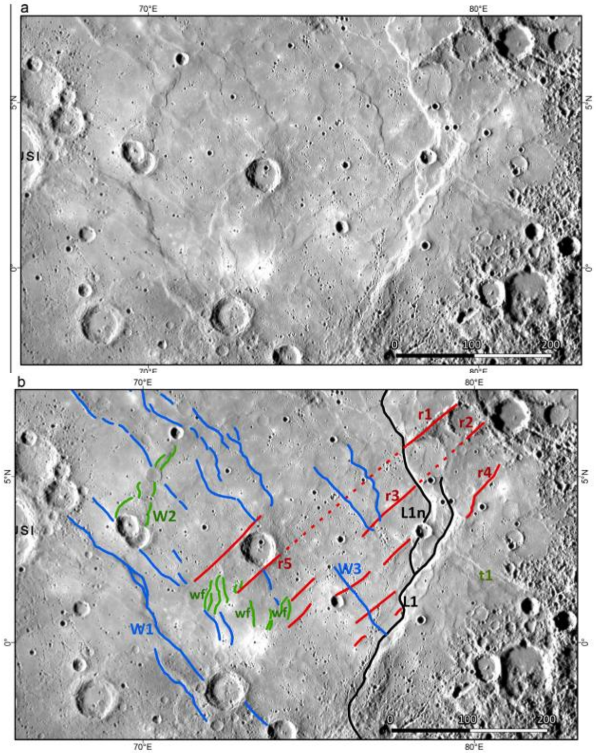


Figure 29. Schematic block diagram to show the relationship between the Beagle Rupes frontal scarp and associated tectonic features.

2.4. Preliminary result



(López et al, 2015)

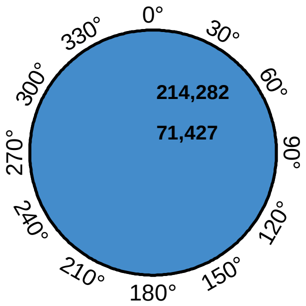
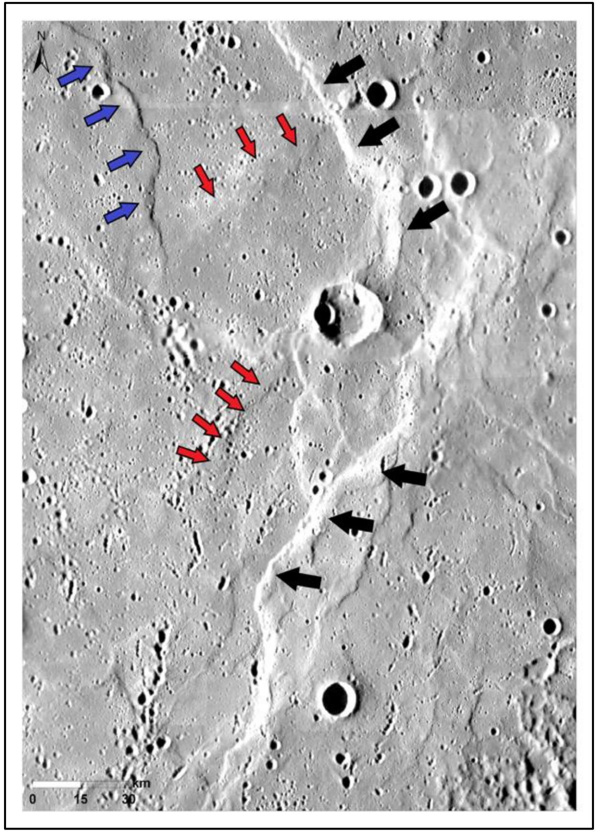


Figure 29. Different families of tectonic features observed in the studied basin. Black lines indicate a lobate scarp (labeled L1) superimposed on the east/southeast of the basin rim.

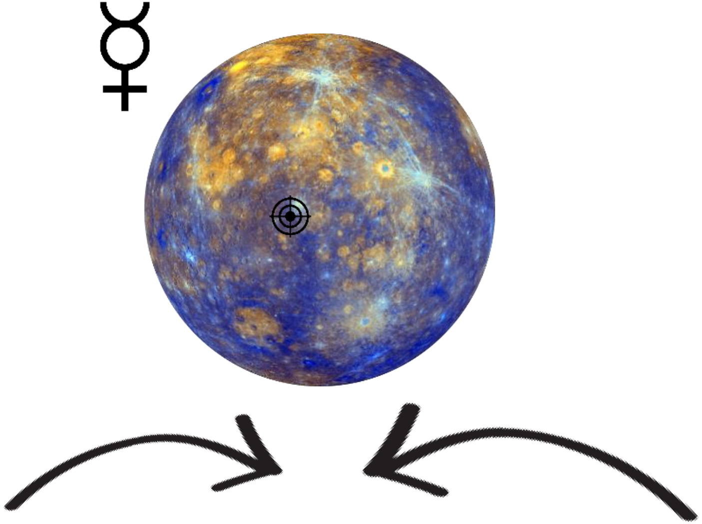
Blue lines: a set of wrinkle ridges of orientation NW–SE that have the same approximate orientation than the wrinkle ridges and lobate scarps deforming the surrounding terrains

Red lines indicate an oldest set of tectonic structures consisting of subtle, subparallel, quasi-rectilinear and low-relief ridges, NE–SW oriented and regularly spaced. Green lines indicate a wrinkle ridge.

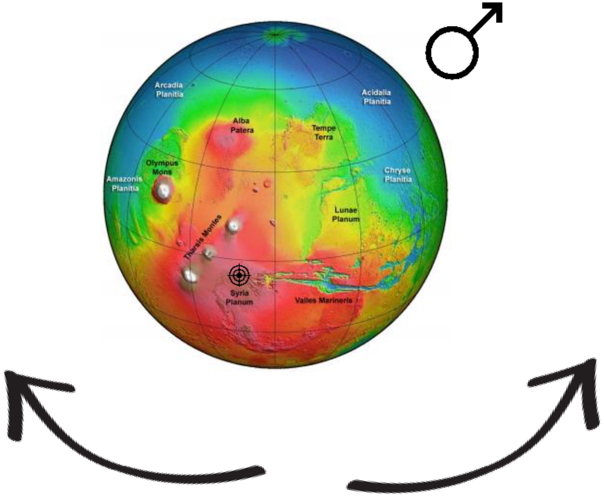


2. Mercury

Conclusion



- Complete the Morpho-Stratigraphic map with 1:3M output scale
- Analyse and study the tectonic features
- Identified all interesting surface features on the area



- Possible Bi-directional extension
- At least two phases of faulting plus possible reactivation of some previous faults system
- The pit-chains formation are the last event happened
- A Volcano-Tectonic activity involved in the creation of Noctis Labyrinthus

3. Conference papers

El Yazidi, M., Pozzobon, R., Penasa, L., Debei, S & Massironi, M. (2021). A Volcano-tectonic activity: Possible scenario beyond the formation of the rift systems in Noctis Labyrinthus (Mars). *90th Conference of the Italian Geological Society*. Poster Presentation.

El Yazidi, M., Tognon, G., Galluzzi, V., Giacomini, L & Massironi, M. (2021). Geology of the Eminescu (H-09) quadrangle: Mapping status. *Europlanet Science Congress*. Poster Presentation.

Galluzzi, V., Rothery, D.A., Giacomini, L., Guzzetta, L., **El Yazidi, M.**, Ferranti, L., Lennox, A.R., Malliband, C., Man, B & Massironi, M. (2021). European quadrangle mapping of Mercury: Status Report. Annual Meeting of Planetary Geologic Mappers. Poster Presentation.

Galluzzi, V., Rothery D. A., Giacomini, L., Guzzetta, L., **El Yazidi, M.**,Ferranti L., Lennox A. R., Malliband C., Man B.,Massironi, M.,Palumbo P., Pegg D. L.,Tognon, G, Wright J.(2021).European quadrangle mapping of Mercury: status report.Geologic Mappers 2021.Poster Presentation.

El Yazidi, M., Pozzobon, R., Penasa, L., Debei, S & Massironi, M. (2020). The study of the relationship between Pit chains and grabens and their role in the formation of Rift systems and Troughs in Noctis Labyrinthus. *Europlanet Science Congress*. Oral Presentation.

El Yazidi, M., Pozzobon, R., Penasa, L., Debei, S & Massironi, M. (2020). Structural analysis of grabens, Pit Chains and rifting in Noctis Labyrinthus (Mars) based on data derived from HRSC and MOLA. *16th National Congress of Planetary Sciences*. Poster Presentation.

El Yazidi, M., Pozzobon, R., Debei, S & Massironi, M. (2018). Tectonic structures in Noctis Labyrinthus area based in HRSC and CTX photogeological mapping. *Europlanet Science Congress*. Poster Presentation.

El Yazidi, M., Pozzobon, R., Debei, S & Massironi, M. (2018). Faults mapping in Noctis Labyrinthus area. *1st Electronic Conferenec on Geosciences*. Poster Presentation.

4. Personal training Plan

EDUCATIONAL ACTIVITIES ACTIVATED BY THE STMS PHD COURSE						
Interdisciplinary Module/Activity	**Lecturer**	**Expected credits**	**Frequency (YES/NO)**	**Exam (YES/NO) ***	**Date of exam**	**Attained credits**
Aerospace propulsion	Prof.Marco Manente	4 ECTS	Yes	Yes	1st year	4 ECTS
Exploring the Solar System and its environment	Prof.Lucchetti/ Prof.Marzari /Prof.Pajola	4 ECTS	Yes	Yes	1st year	4 ECTS
Space optics and detectors	Prof.Naletto/ Prof.Pelizzo	4 ECTS	Yes	Yes	1st year	4 ECTS
Astrophysics of the Solar System	Prof.Monica Lazzarin	6 ECTS	Yes	Yes	1st year	6 ECTS
Space systems and their control	Prof.Francesconi/ Prof.Lorenzini	0.8 ECTS	Yes	No	1st year	0.8 ECTS
Introduction to computational fluid dynamics	Prof.Francesco Picano	0.4 ECTS	Yes	No	1st year	0.4 ECTS
Geologia ed esplorazione dei corpi planetari	Prof.Matteo Massironi	1.6 ECTS	Yes	No	1st year	1.6 ECTS
Research Project Proposal/Preparing a Scientific Paper	Prof.Naletto	2 ECTS	Yes	Yes	1st year	2 ECTS
Presentation of Doctoral Activities	-	1.5 ECTS	-	-	1st year	0.5 ECTS
A Polarimetric View of Astrophysical Jets, 4th-13th December 2019. Department of Physics and Astronomy (DFA), University of Padova. (10 h)	Ulisses Barres de Almeida	0.4 ECTS	YES	NO Exam	No Exam	0.4 ECTS
Curriculum oriented seminars	**Lecturer**	**Expected credits**	**Frequency (YES/NO)**	**Exam (YES/NO) ***	**Date of exam**	**Attained credits**
09 Seminars activated by STMS PhD course	-	3.6 ECTS	Yes	Yes	1st year	3.6 ECTS
Seminar "Space Technologies"	Giampaolo Preti	0.06 ECTS	Yes	No	1st year	0.06 ECTS
XVI Congresso Nazionale di Scienze Planetarie, 3rd-7th Febbraio 2020 (Centro Culturale Altinate San Gaetano, Padova)	Many	1.6 ECTS	YES	No Exam	No Exam	1.6 ECTS
03 European Planetary Science Congress (EPSC)	Many	0.18 ECTS	Yes	No Exam	1st +3rd year	0.18
SIMBIO-SYS Team meeting	Many	0.3 ECTS	Yes	No exam	3rd year	0.3
Seminar "Galileo: The European infrastructure for global navigation satellites system services"	Giuditta Montesanti	0.06 ECTS	Yes	No	1st year	0.06 ECTS

4. Personal training Plan

UNIVERSITÀ DEGLI STUDI DI PADOVA

OTHER EDUCATIONAL ACTIVITIES							
Title of the activity (Date/Period/University)	**Lecturer**	**Duration of activity**	**Expected credits**	**Frequency (YES/NO)**	**Exam (YES/NO)**	**Date of exam**	**Attained credits**
Educational support for Planetary Geology Mapping-INAF-IAPS di Roma.	Dr. Valentina Galluzzi	40 hours	1.6 ECTS	Yes	No	1st year	1.6 ECTS
Workshop "Planetary Mapping and Virtual Observatory "	Many	24 hours	0.96 ECTS	Yes	No	1st year	0.96 ECTS
School "Detectors and Electronics for High Energy Physics, Astrophysics, Space applications and Medical Physics "Legnaro (Laboratori Nazionali di Legnaro dell'INFN)	Many	40 hours	1.6 ECTS	Yes	No	1st year	1.6 ECTS
Padova Excellence School of physics of the Universe, focused on Multimessenger Astrophysics 2020, 14th- 23th January 2020 (Astronomical Observatory of Asiago)	Many	10 days	3 ECTS	Yes	YES	2nd year	3 ECTS
GeoPlaNet analogue field school "Fluid-Rock interactions in the Solar System, 23th September to the 1st of October (France-Spain)	Many	48 hours	1.94 ECTS	Yes	No Exam	No Exam	1.94 ECTS
PLANMAP winter school on planetary geologic mapping and 3D geological modelling	Many	44 hours	1.76 ECTS	Yes	No Exam	No Exam	1.76 ECTS
Tutoring and educational support (Scuola di Ingegneri, Scienze Tecnologie e Misura Spaziali)	Prof.Stefano Debei	30 hours	2.4 ECTS	Yes	No Exam	No Exam	2.4 ECTS
53rd Annual Meeting of the Division for Planetary Sciences	Many	20 hours	0.8 ECTS	No	No Exam	No Exam	0.8 ECTS
Tutoring and educational support (Scuola di Ingegneri, Scienze Tecnologie e Misura Spaziali)	Prof.Stefano Debei	30 hours	2.4 ECTS	Yes	No Exam	No Exam	2.4 ECTS
Total of expected ECTS credits attainable in educational activities (>30):			**45.96 ECTS**	**Total of credits attained in educational activities (at date 30 June 2020):**			**45.96 ECTS**

Thank you for your attention