Venera-D Landing Sites Selection and Cloud Layer Habitability Workshop 2019 Moscow, Russia

Site Selection for Geological Testing of Global Warming Models on Venus

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Collaboration on tesserae part of story: with P. Byrnes & R. Ghail

Outline

- INTRODUCTION
  - Climate transition from ambient to HOT (Way et al. 2016)
  - Transition in post tesserae time
- GEOLOGICAL EVIDENCE: EARTH-LIKE CONDITIONS DURING TESSERAE TIME
  - Primary surface in post-Tesserae BUT NOT during Tesserae time
  - Methodology: using tesserae margins that are partially flooded by plains lavas
  - Erosion required: evidence for water erosion (wind erosion also, glaciation can't be ruled out
- GEOLOGICAL EVIDENCE: SEARCH FOR CLIMATE TRANSITION IN EARLY BASALTS
  - Potential to identify from analysis of drill hole
  - Testing with Venus Conditions Chambers; e.g. with John's Hopkins Applied Physics lab (NOAM) or at Glenn Research Center (TIBOR)
- LANDING TARGET SUGGESTIONS

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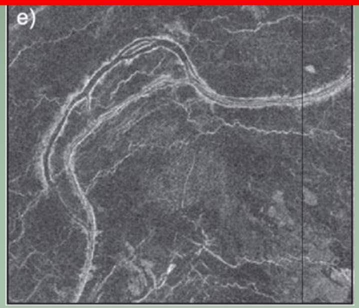
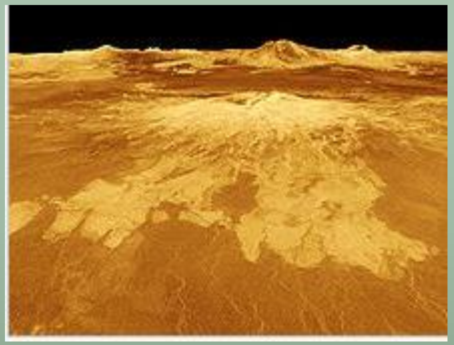
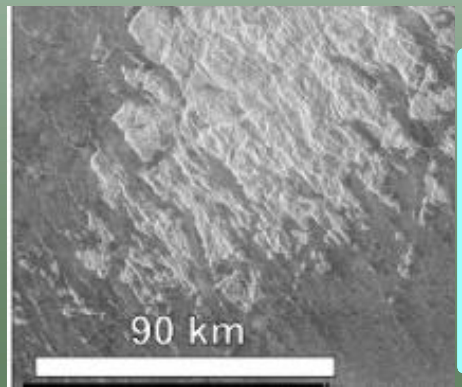
Hyper-Warming on Venus: is it preserved in the geology?

If warming starts with plains units, then
Tesserae (pre-plains) should be pre-warming,
Early basalts (plains units) should be early-warming &
Late basalts (volcanoes, coronae) should be high T-high P







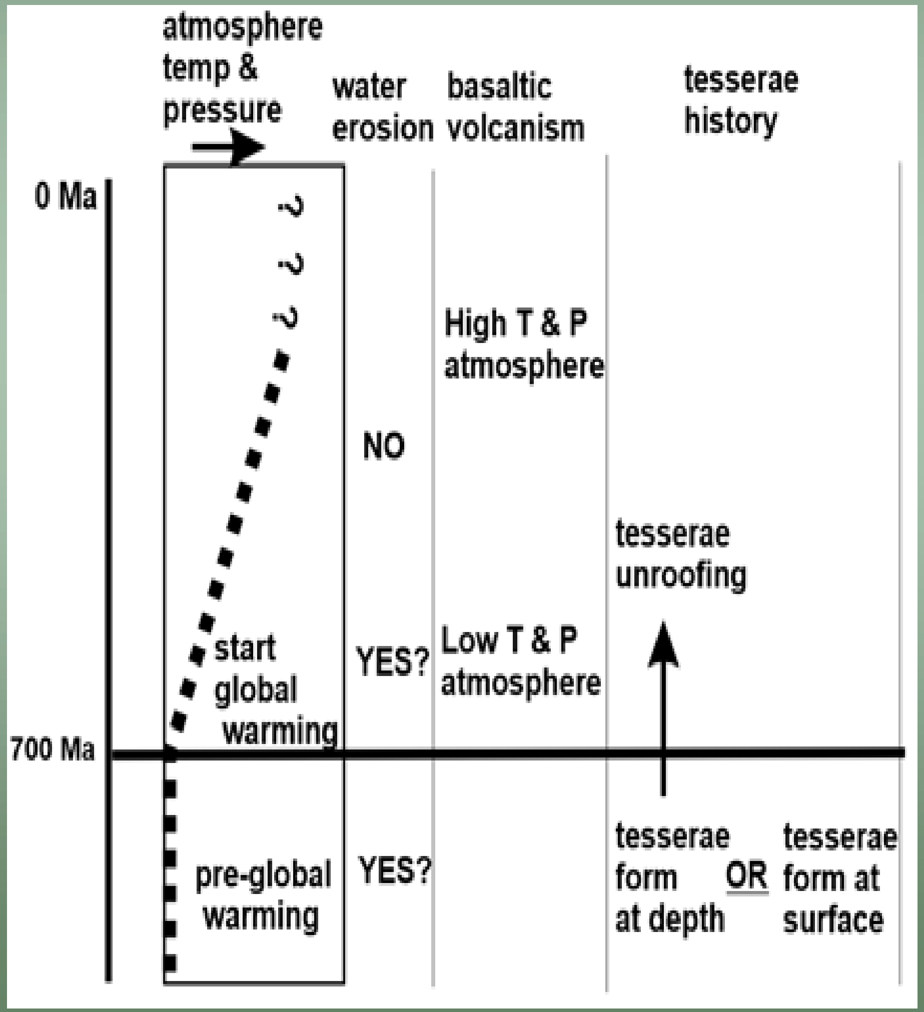
Younger

canali
volcanos,
coronae

Plains Units
missing basalts?

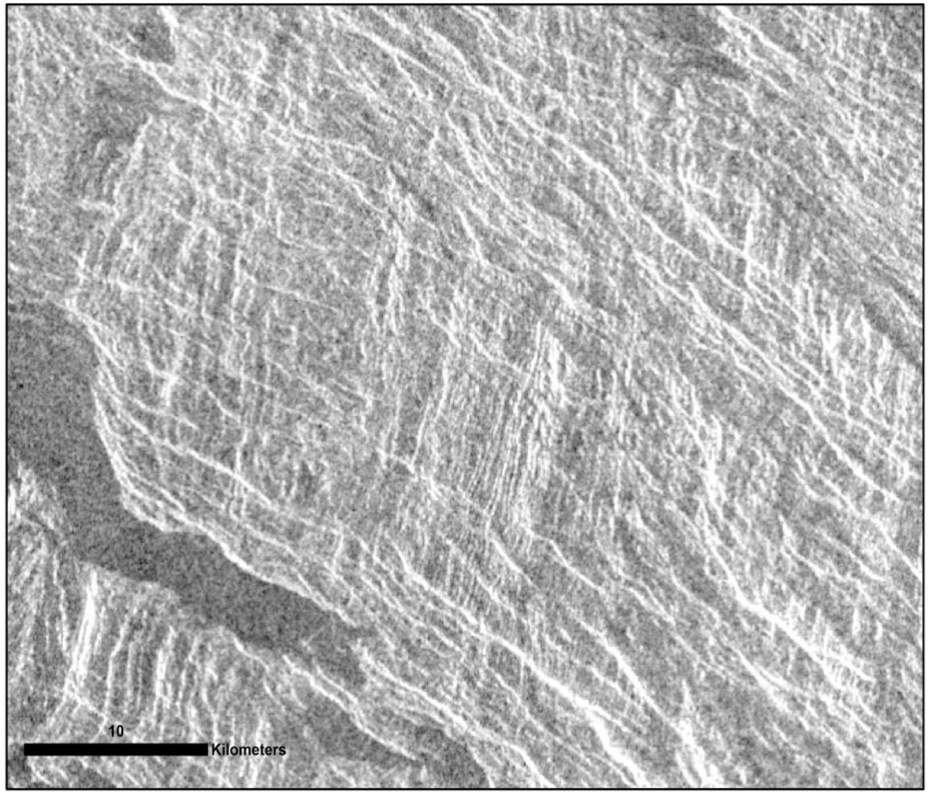
tesserae

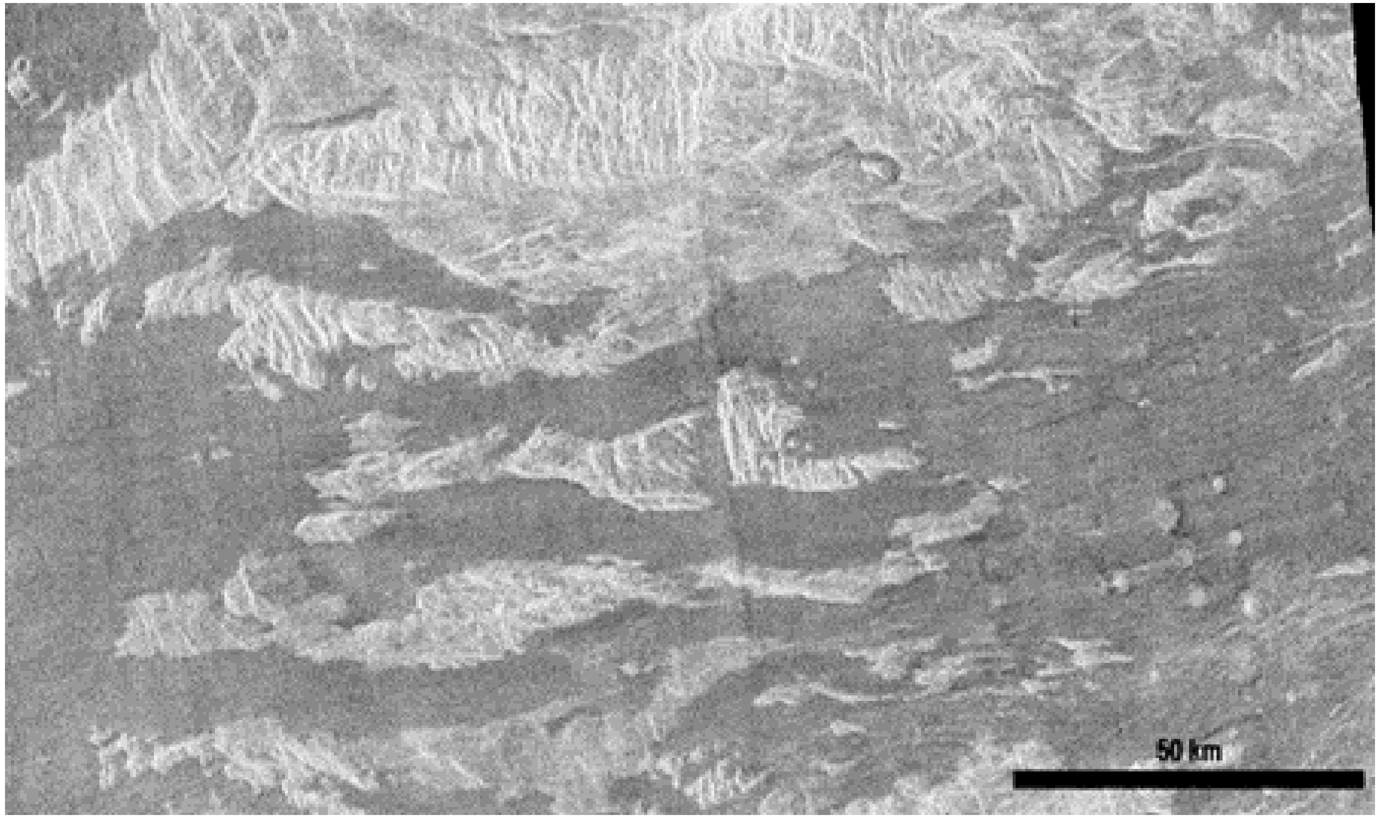
Older



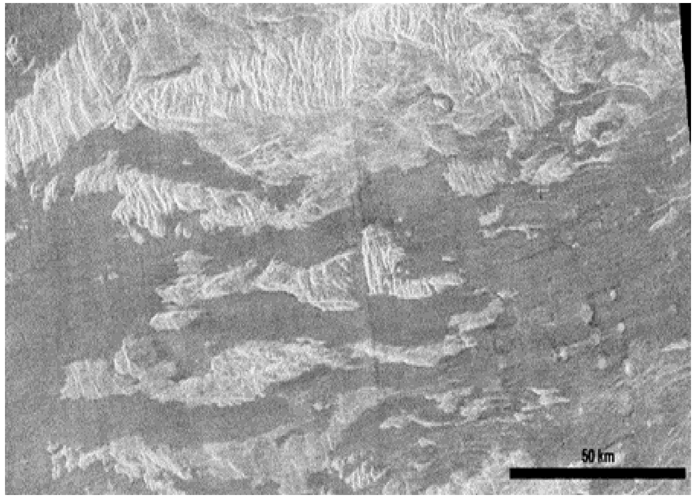
Methodology- partially flooded terranes

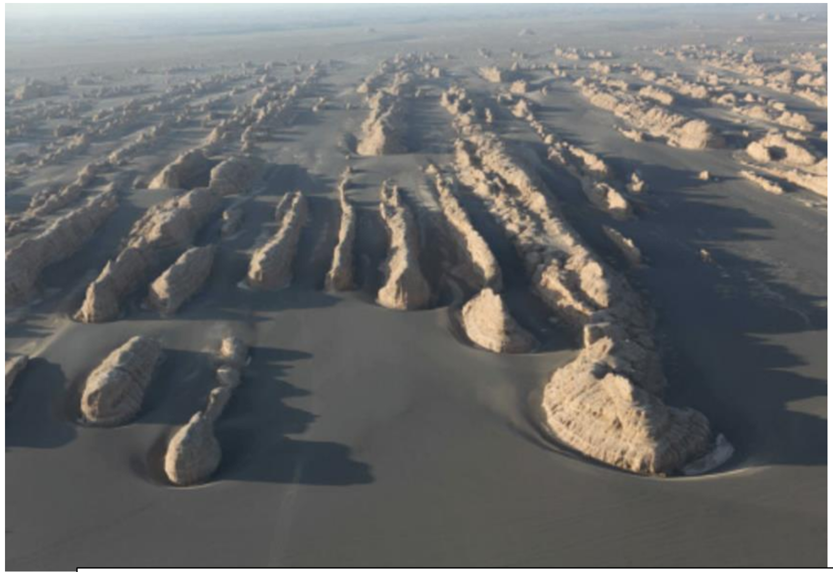
- Poor vertical and horizontal topographic resolutions
- Technique of using partially flooded portions of tesserae
- (to recognize local highs and valleys)





Analogues on Earth



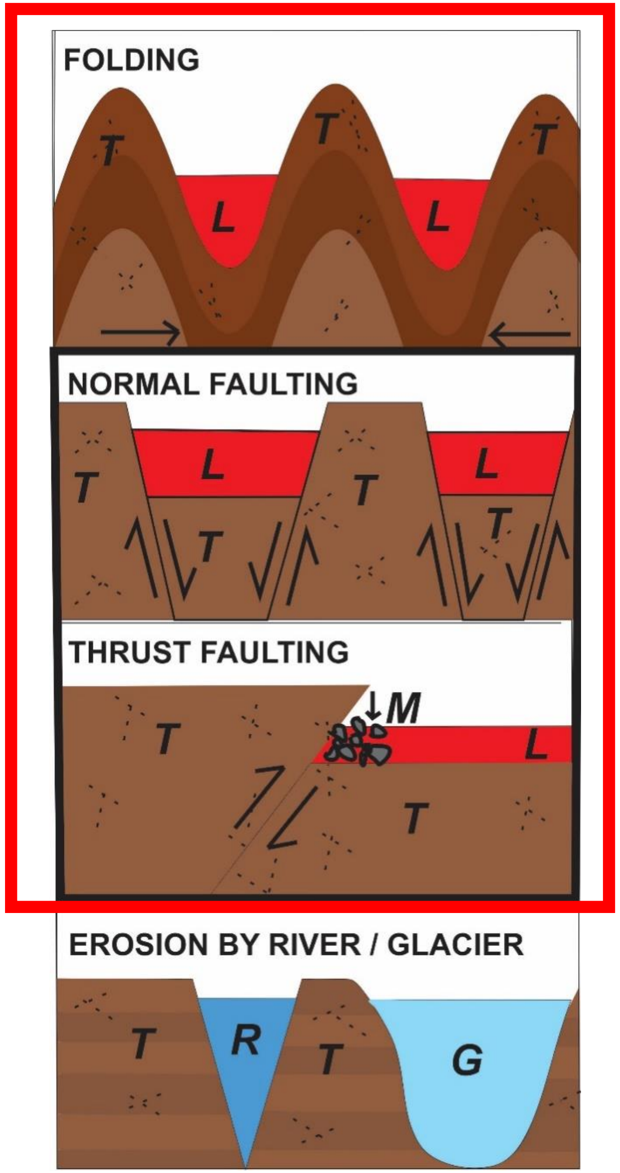


A) Flooded fjords located in Nain Labrador, Canada (Google maps)

B) Nunataks standing above a field of ice and snow

C) Yardang field bordering the arid desert of Kumtagh, China (Wang et al., 2011). With lengths that are hundred of meters long

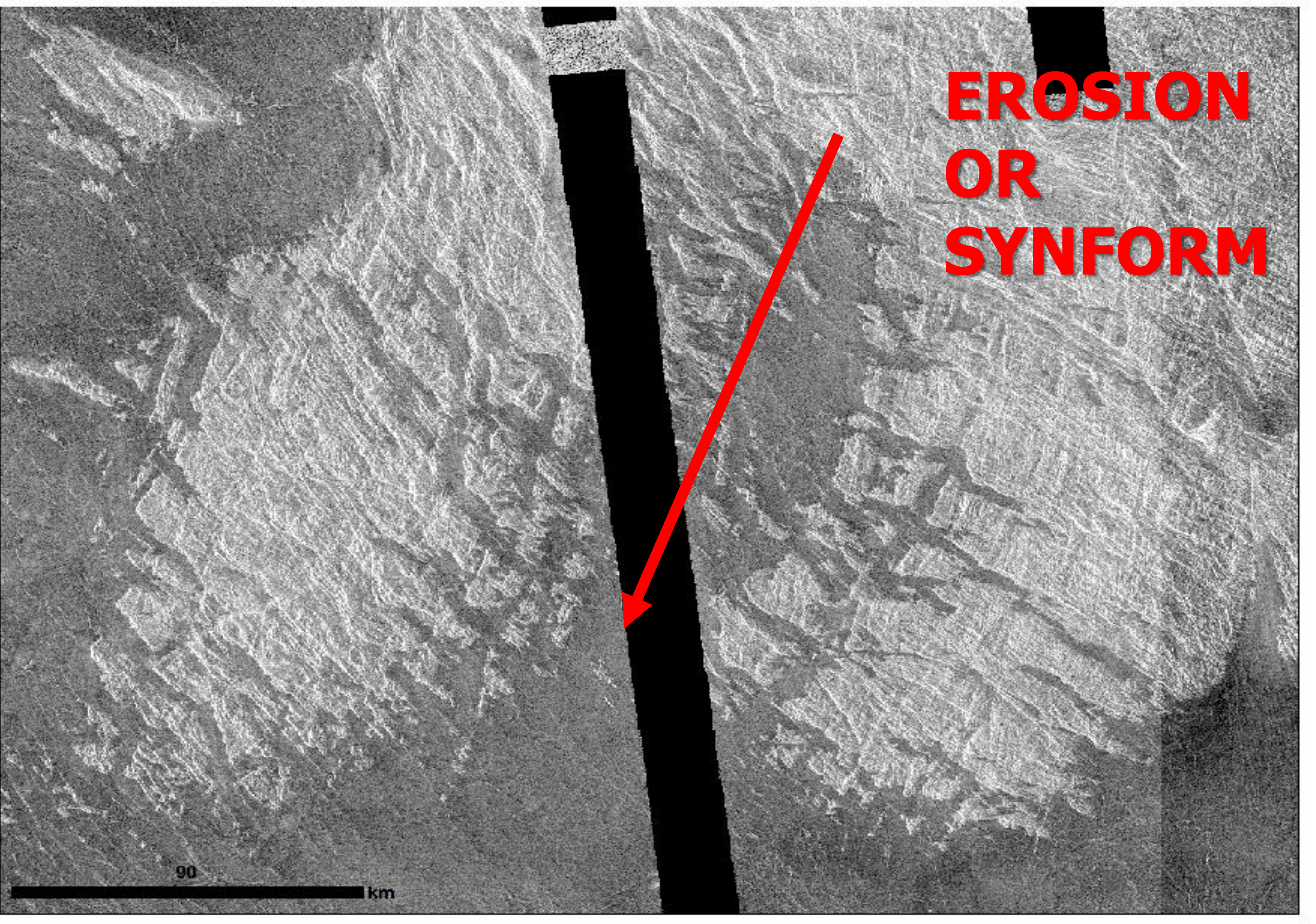
Models to Explain Topographic Variation in Tesserae

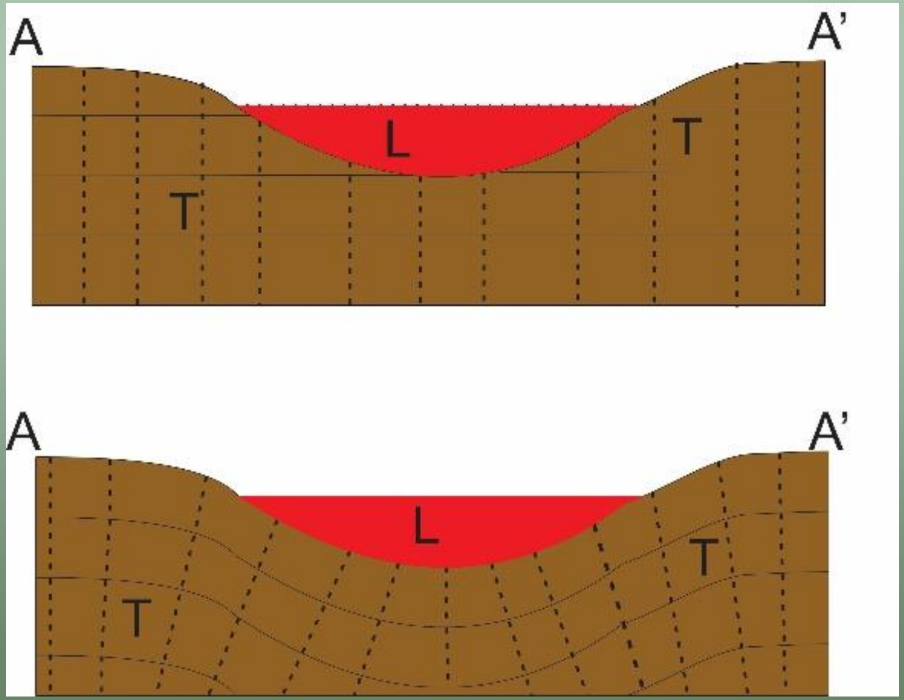


Schematic diagrams of three topographic models to explain topographic variations:
folding,
faulting (normal /thrust),

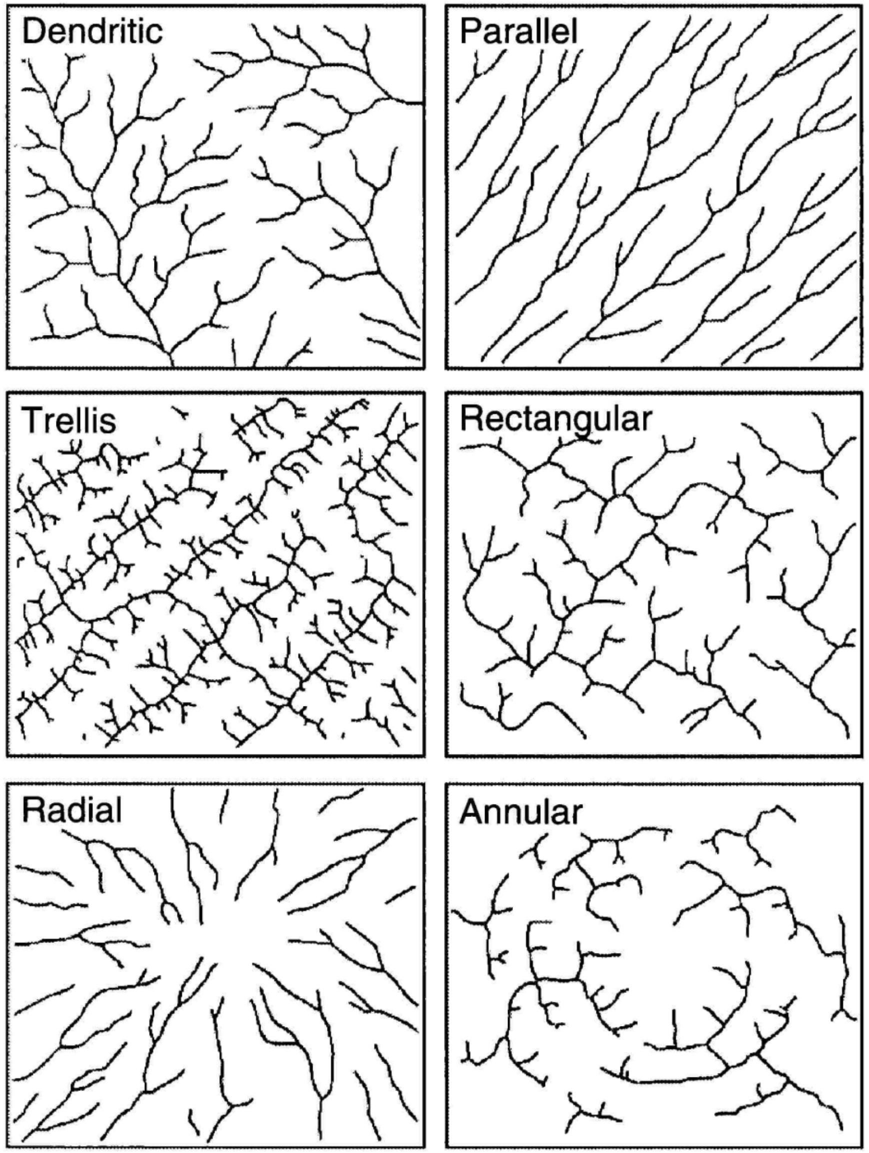
erosion. T = tessera, L = lava flooding, M = mass wasting, R = river erosion, G = glacial erosion

EVIDENCE AGAINST PURELY PRIMARY SURFACE





Types of Erosion: Water



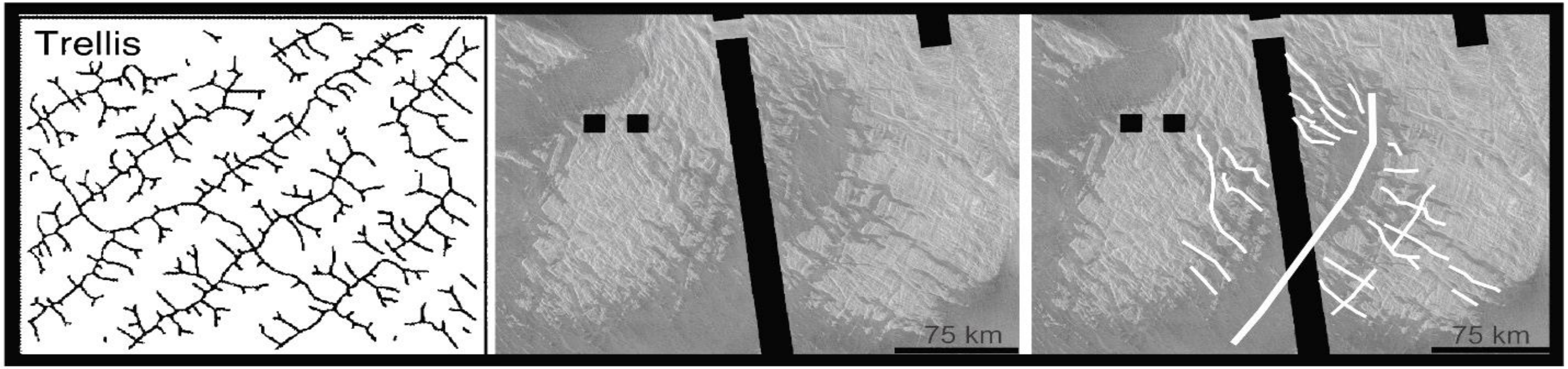
Terrestrial patterns of stream flow
(Howard (1967); Bridge and Demicco 2008)

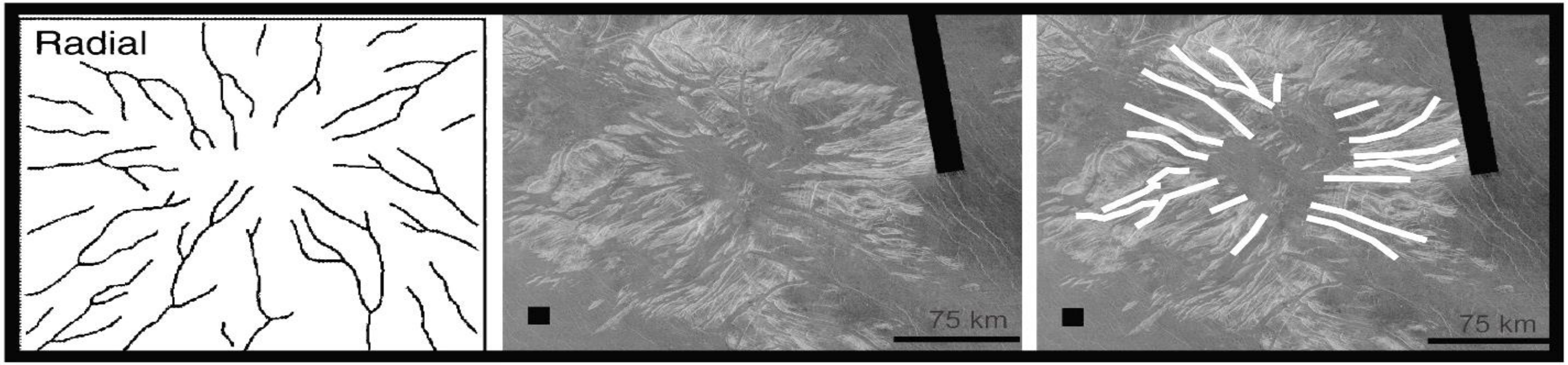
Compare with distribution of valleys revealed by lava partial flooding of tesserae

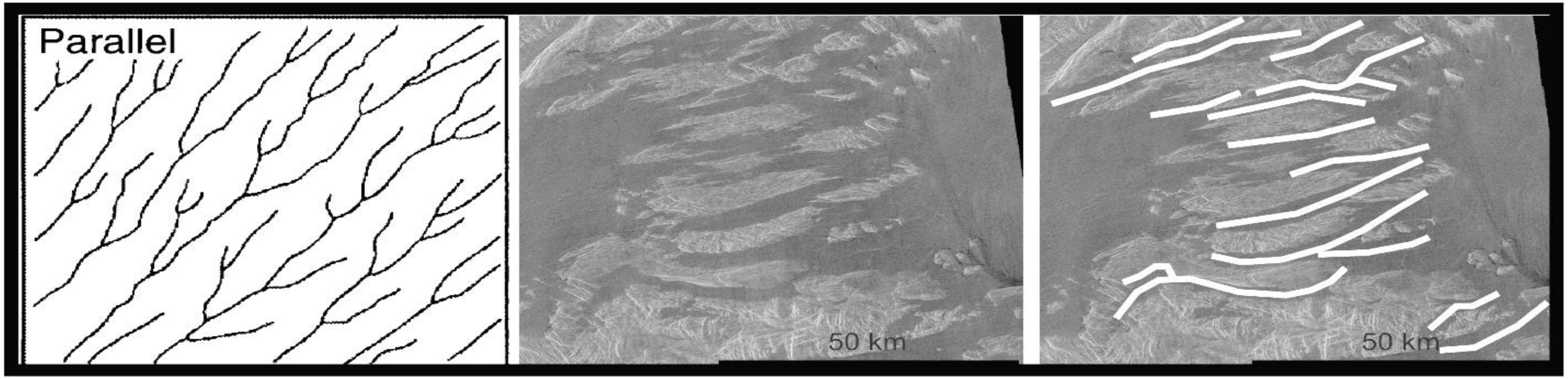
Tesserae- stream flow patterns:

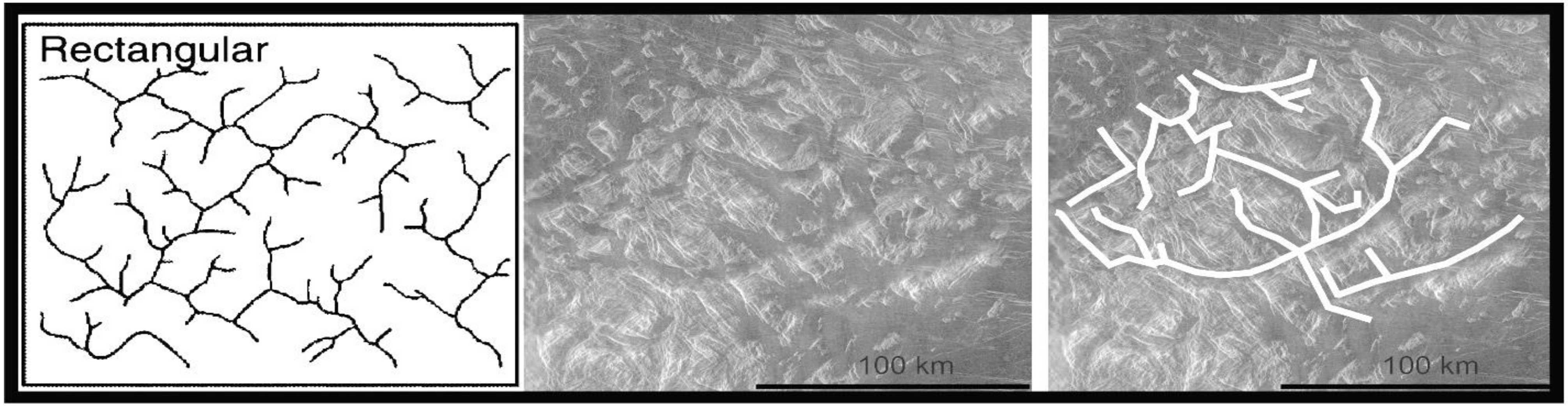
Match at least 3 of the terrestrial stream types;

Patterns reflect geology







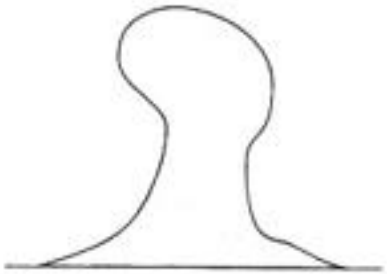


Tesserae- stream flow patterns:

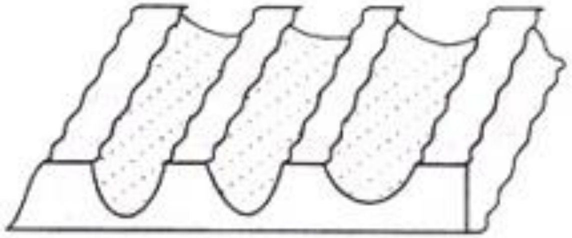
- Match at least 3 of the terrestrial stream types;
- Patterns reflect geology

Types of Erosion: Wind

A) Formation of Ventifact



B) Rock Pedestal



C) Zeugen

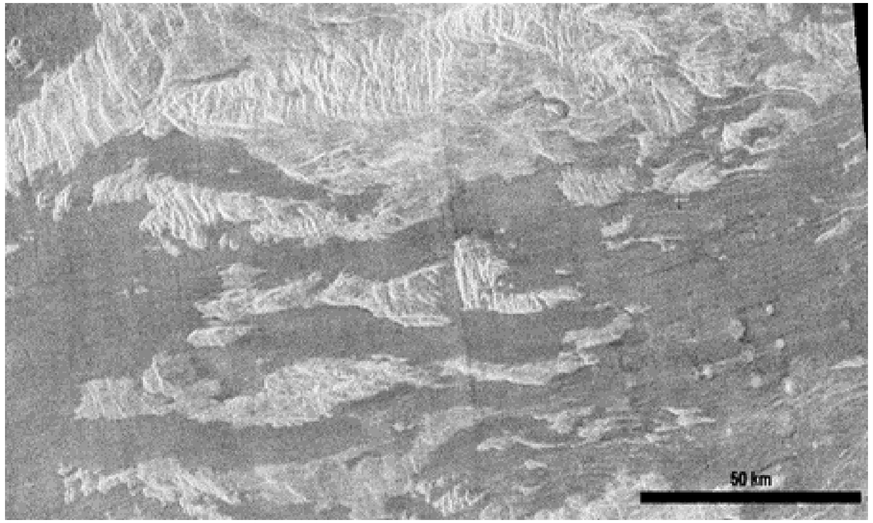
D) Yardangs

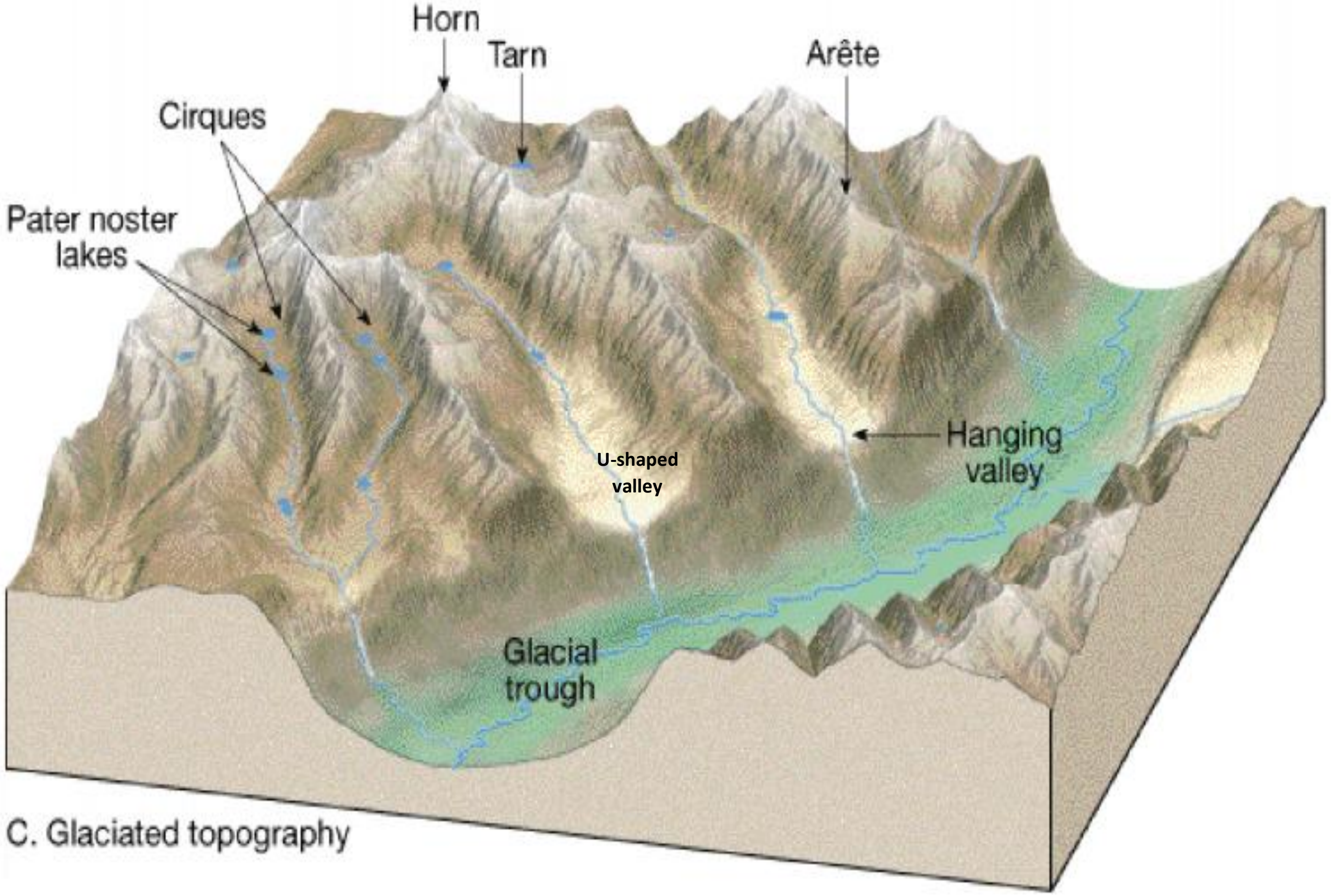
<u>Yardangs have been described on Venus</u>,

But these are linear features- but non-linear tesserae patterns are common; so Yardangs could only explain some tesserae

Also scale of features is 10s of m– smaller than the terrain relief in many local areas of tesserae

Types of Erosion: Glacial





Most significant glacial features are observed on peaks
Another characteristic is U-shaped valleys (vs. V shaped valleys for rivers)
Topographic resolution for peaks & valley shapes NOT IMPROVED through use of partial flooding

SO GLACIAL EROSION CANNOT BE RULED OUT

Erosion on Tesserae

- There are several reasons to expect erosional features in tessera terrains:

1. **Climate models suggest that Venus could have had Earth-like habitable conditions until about 700 Ma (Way et al. 2016). Therefore, the occurrence of water erosion would be expected up till that time**
2. Overall present-day topographic variations observed in tesserae are consistent with water erosion
3. **The tectonic complexity of tesserae (e.g., Hansen and Willis, 1996) would suggest deformation at depth followed by unroofing and exposure at the surface (Ernst et al. 2019)**
4. **Lineaments with irregular curvilinear patterns in tesserae may be indicative of shallow-dipping layers that follow undulating topography (e.g. examples in Alpha Regio; Byrne et al., 2019; see also Khawja et al., 2019)**

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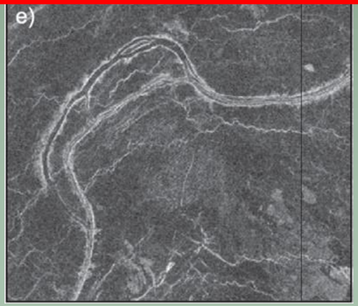

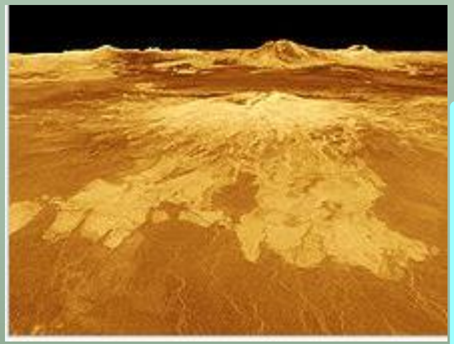

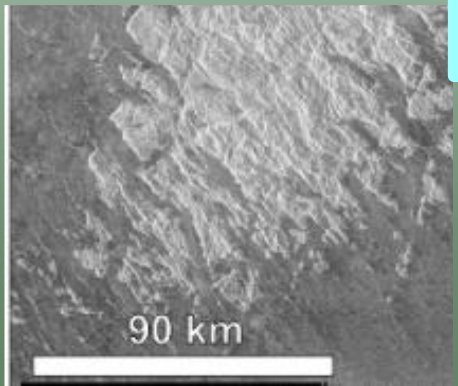

canali
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Younger

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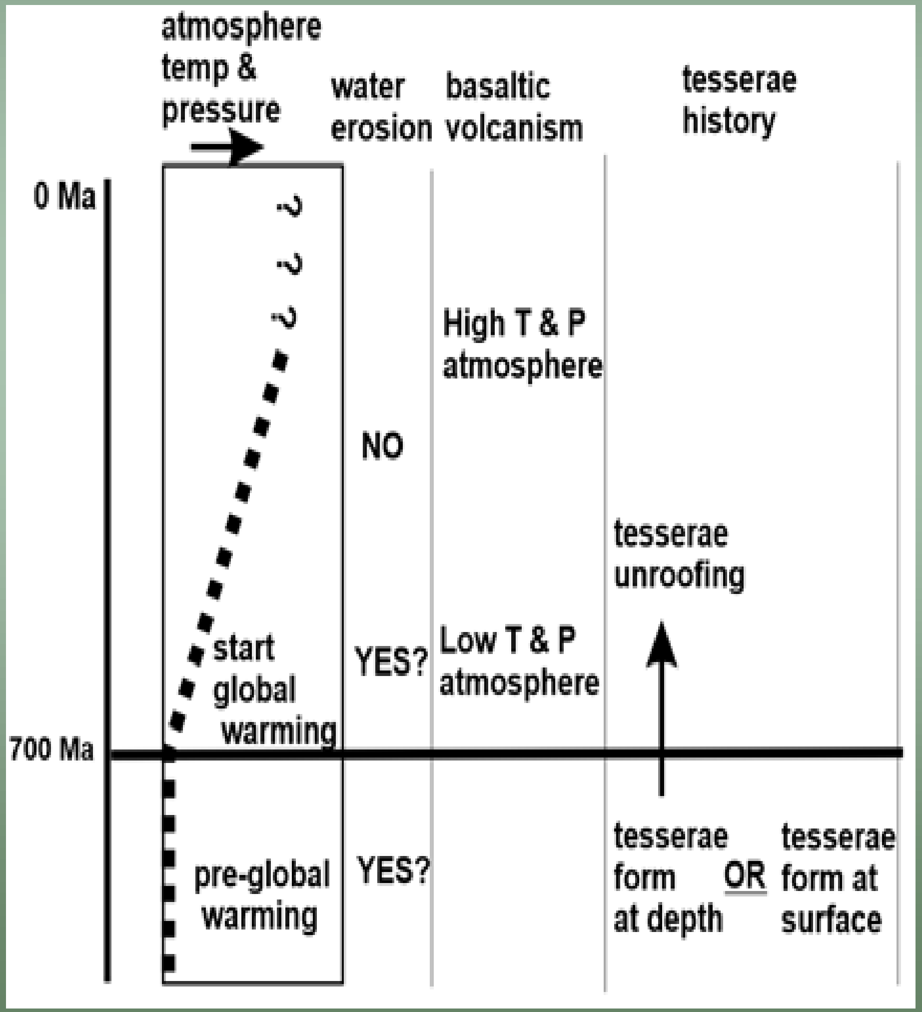
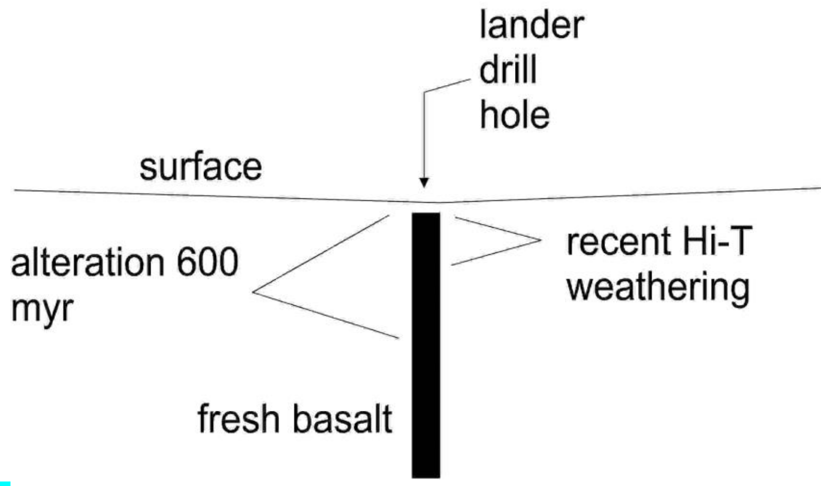


Drill in old plains flows to test for superimposed climates: relevant lab experiment



SCENARIO: old flow with this history

1) Emplaced in AMBIENT TIME (early flows): subaerial and subaqueous
2) Superimposed by present-day alteration in Venus's current atmosphere

QUESTION: can both stages be preserved in single drill core

- Will subaerial weathering or primary subaqueous alteration during emplacement extend deeper than later wreathing under Venus conditions

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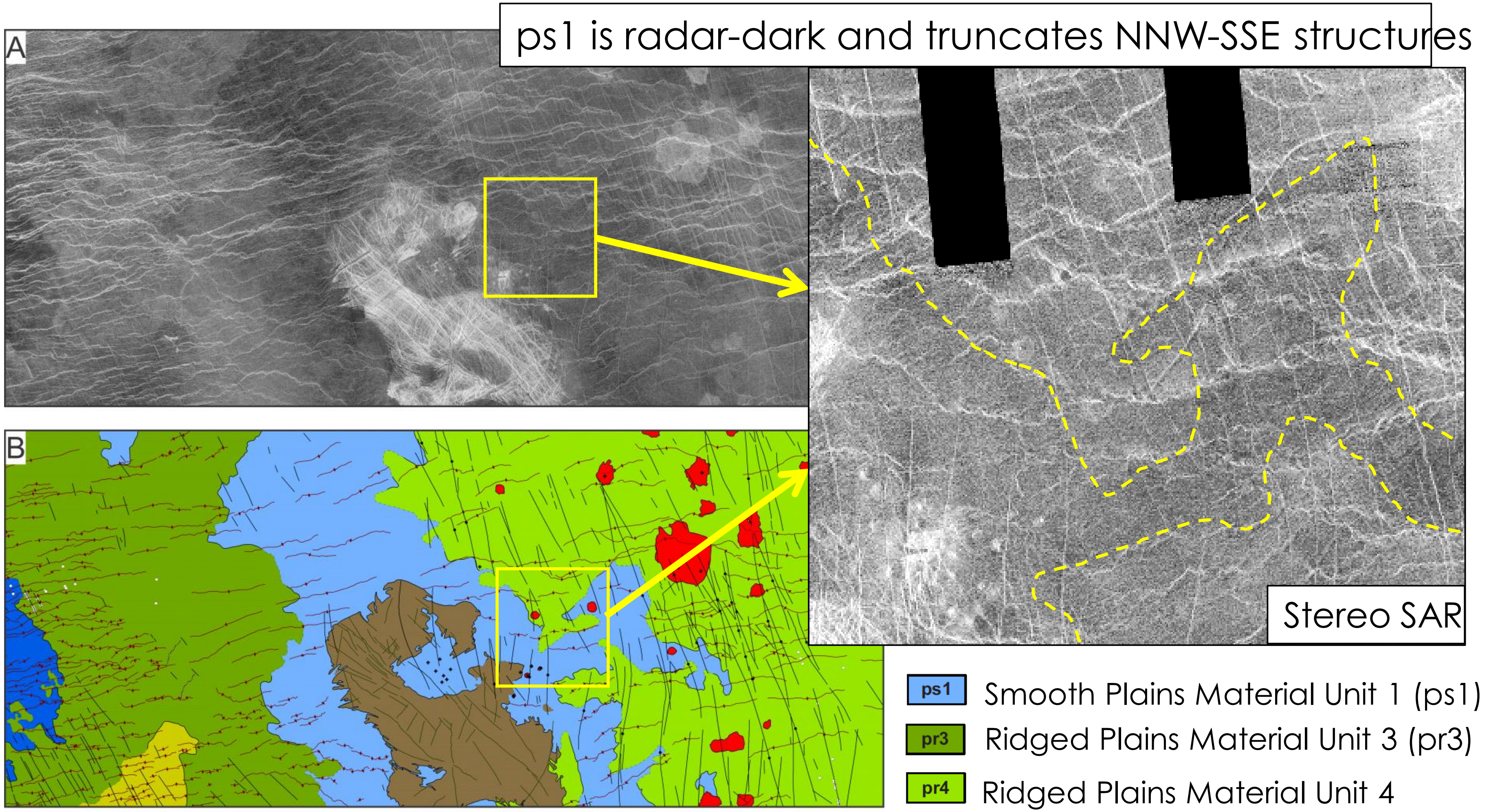
EXPERIMENTAL TESTS AT VENUS ATMOSPHERE FACILITY

<u>Take terrestrial basalt samples</u>:

- weathered in low latitudes (e.g. Deccan LIP basalts (laterites?)
- altered during undersea emplacement (e.g. pillow basalt)

<u>Then expose to present-day VENUS type conditions </u>–e.g. in labs like Applied Physics lab at Johns Hopkins (NOAM), or GEER lab (TIBOR)

Volcanic Plains – finding earliest flows



From Bethell et Alpha Regio V-32 Quadrangle map --- see poster

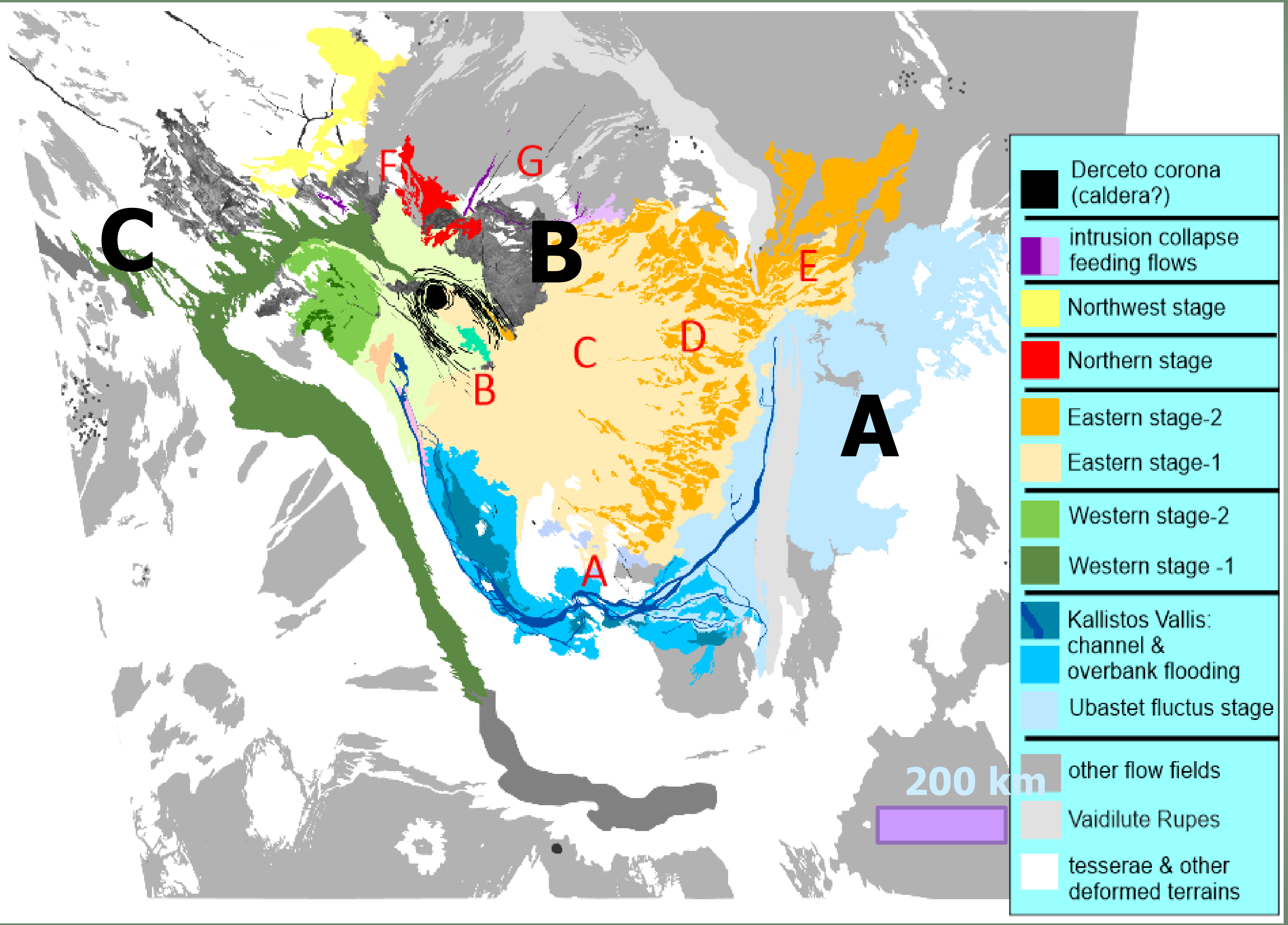
THE DERCETO-KALLISTOS LIP EVENT, NORTHERN LADA TERRA

Analyzed flows can be related to magmatic centres a long distance away

A= flow system Kallistos vallis (1300 km)

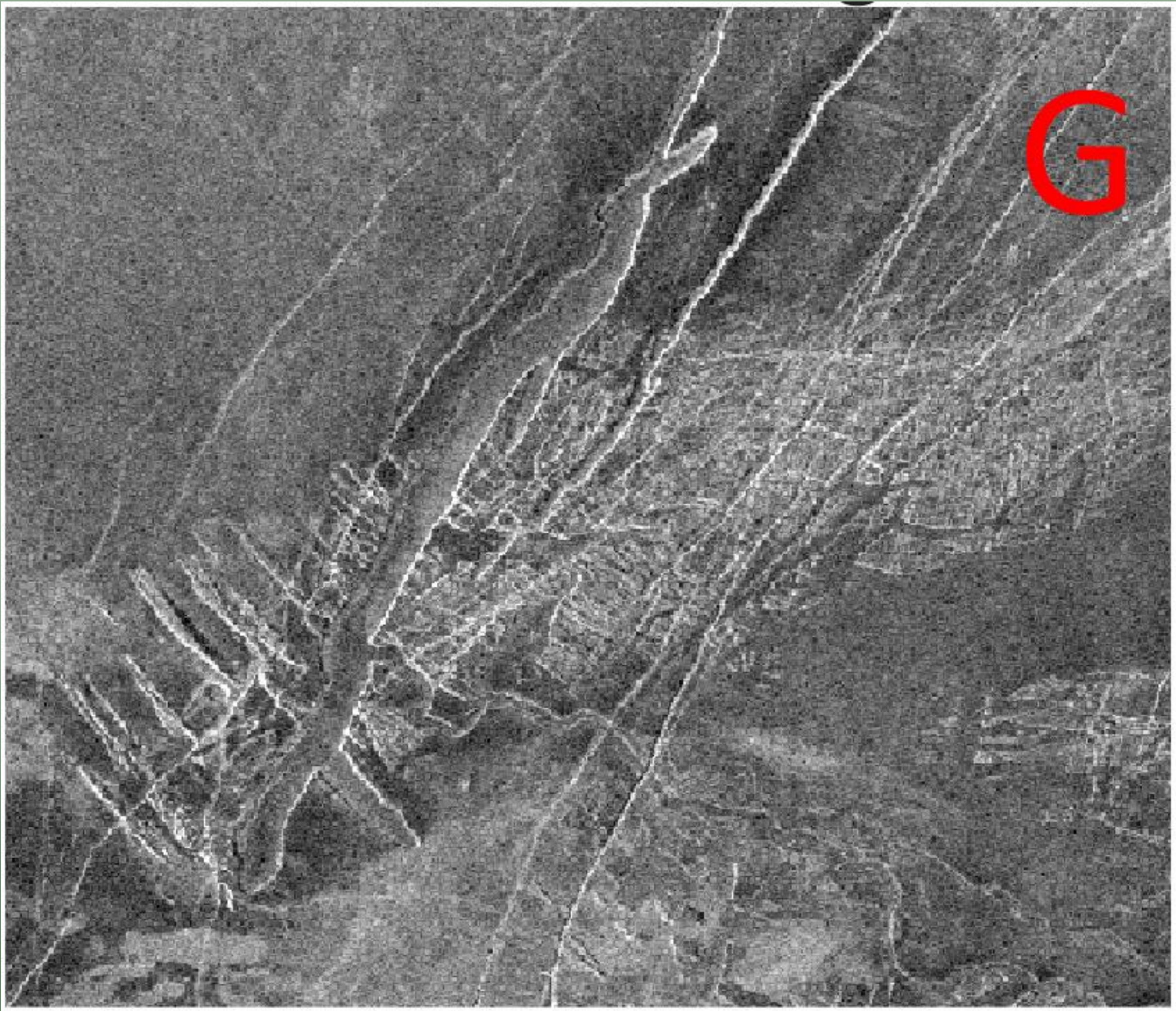
B= feeding from Great Dyke (400 km)

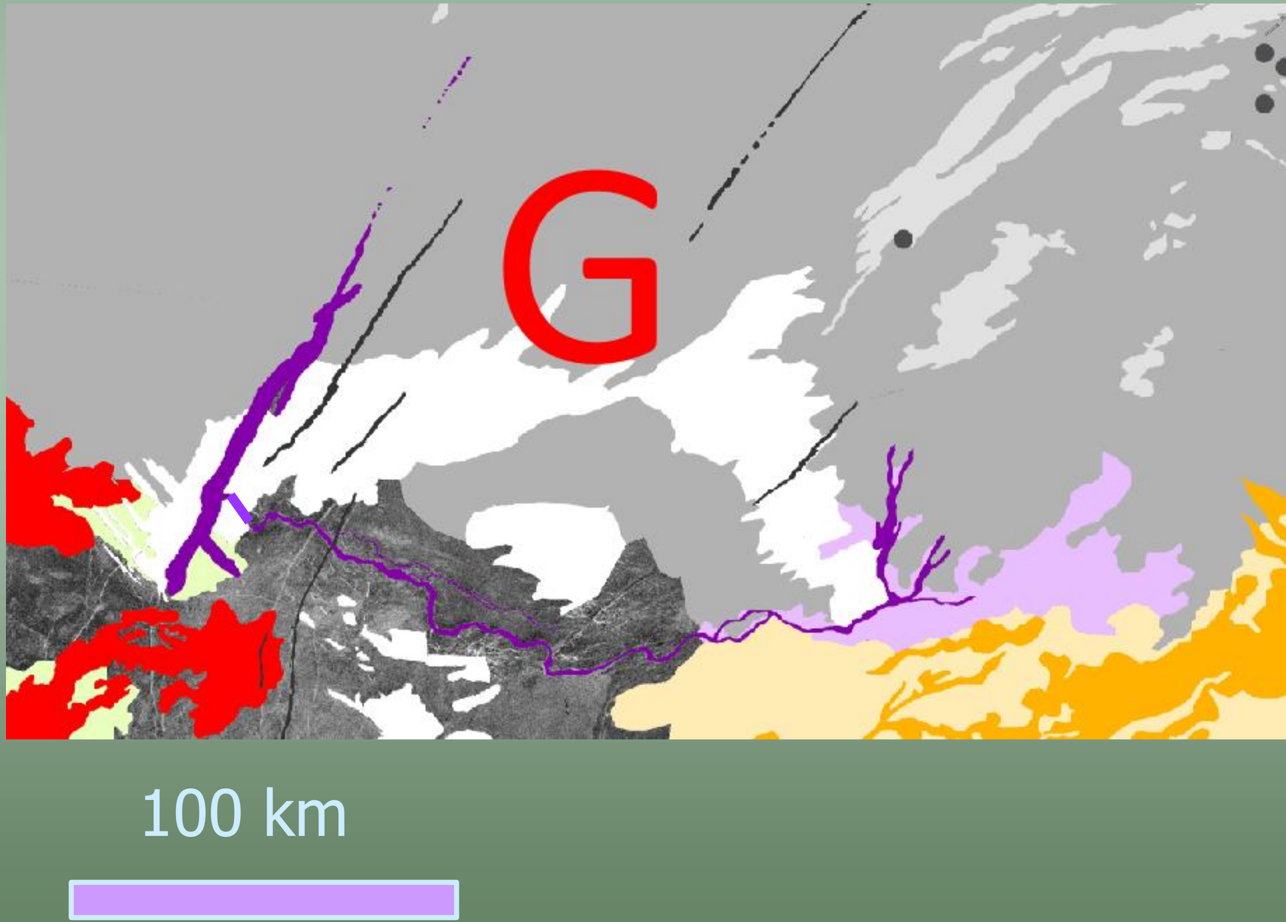
C= feeding from Selu corona (500 km away)



MacLellan and Ernst (in progress)---- see poster

Collapse above dyke-like layered intrusion "Great Dyke of Derceto-Kallistos LIP"; and feeding of channelized lava flow





LANDING TARGET SUGGESTIONS

TESSERAE, to test for:

- o Weathering profile during ambient temp time time followed by HOT temp regime overprint
- o Felsic composition,

VOLCANIC FLOWS:

Earliest flows (plains) to look for transition from ambient to hot

Note that flows can provide info about sources a long distance away

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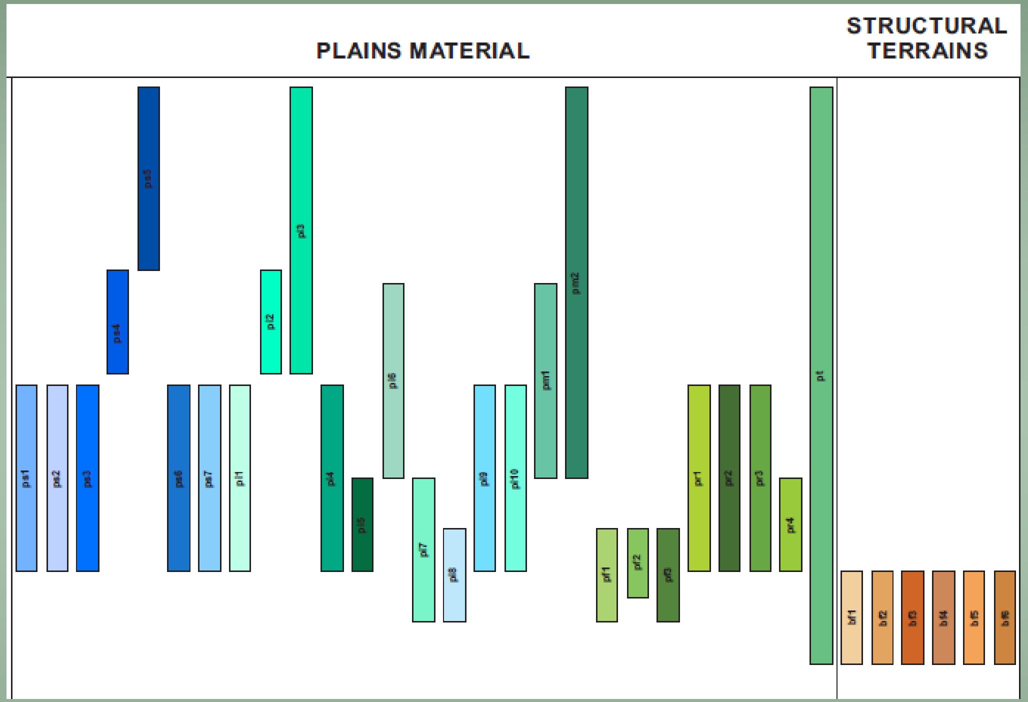
Potential insights from detailed mapping of plains units (early warming)

More difficult to map– subtle differences in radar brightness

Typically only a few plains units are mapped

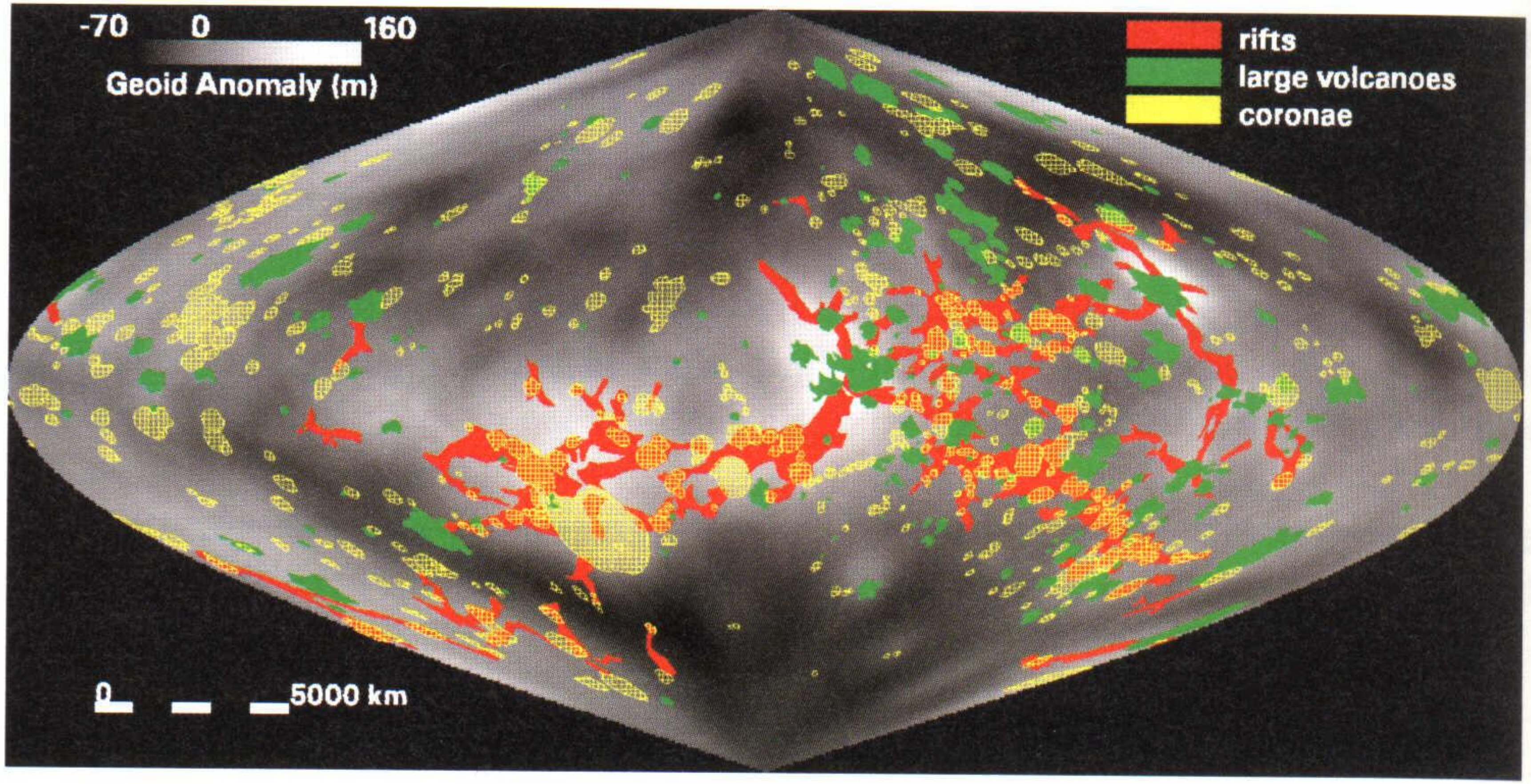
Recent detailed mapping is identifying sub-units.

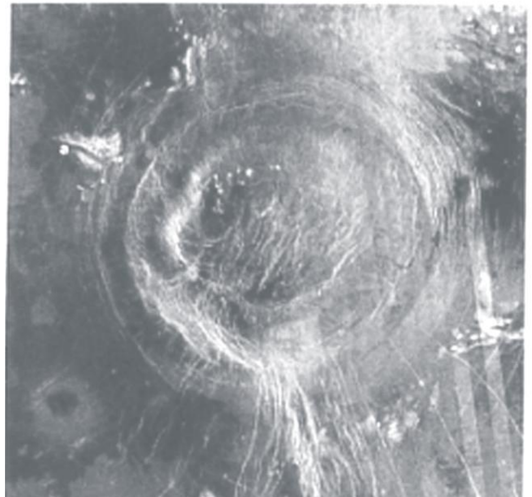
For instance Bethell et al. (2019; Alpha Regio Quadrangle) has identified 20 different plains sub-units (+3 with dense fracturing and 4 with wrinkle ridges)

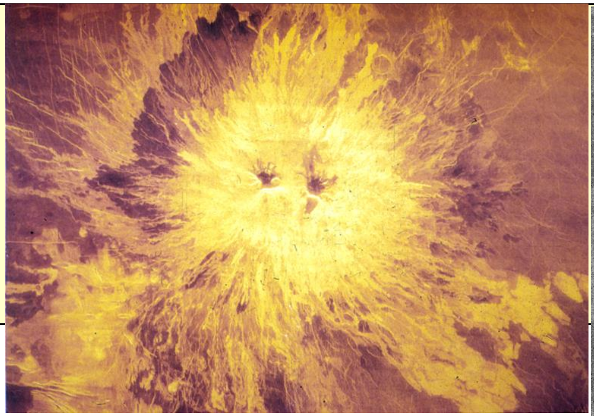


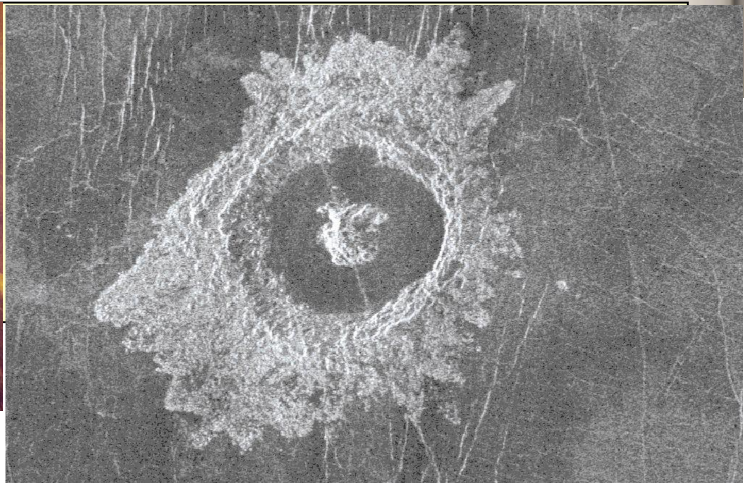
[Bethell et al. (2019) 1: 2,500,000 scale "GEOLOGICAL MAP OF THE ALPHA REGIO (V-32) QUADRANGLE, Journal of Maps (pending decision post-revision). See also Bethell #1462, earlier this session.]

Herrick
1999

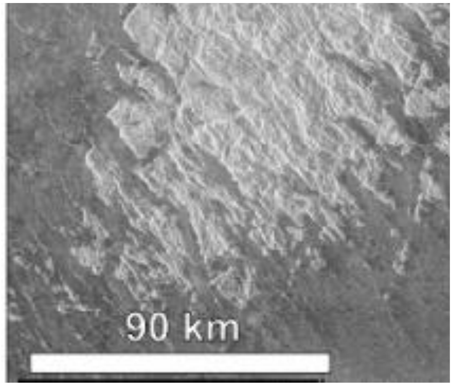








- **Plains units typically embay tesserae.**
- **Structures of tesserae typically DO NOT extend into plains.**
- **Unconformity.**
- **Potential missing sequence of key basalts**
- **<u>ASSOC. WITH EARLY GLOBAL WARMING</u>**



canali
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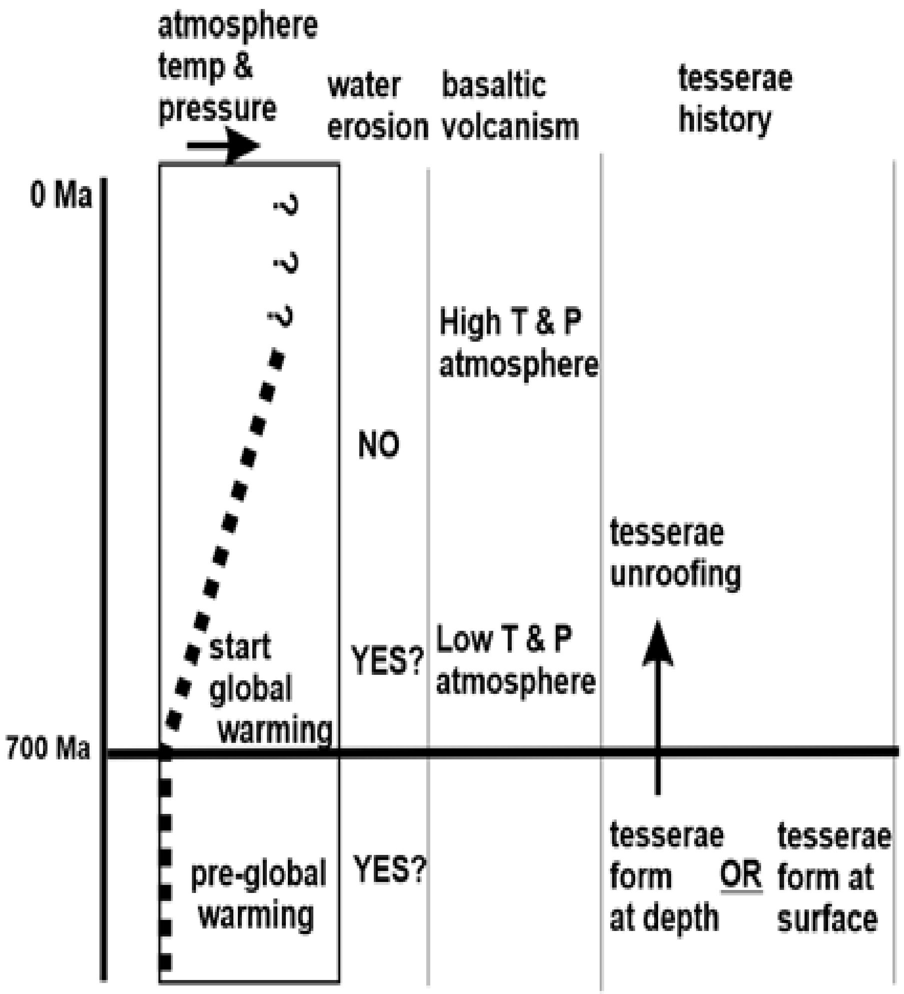
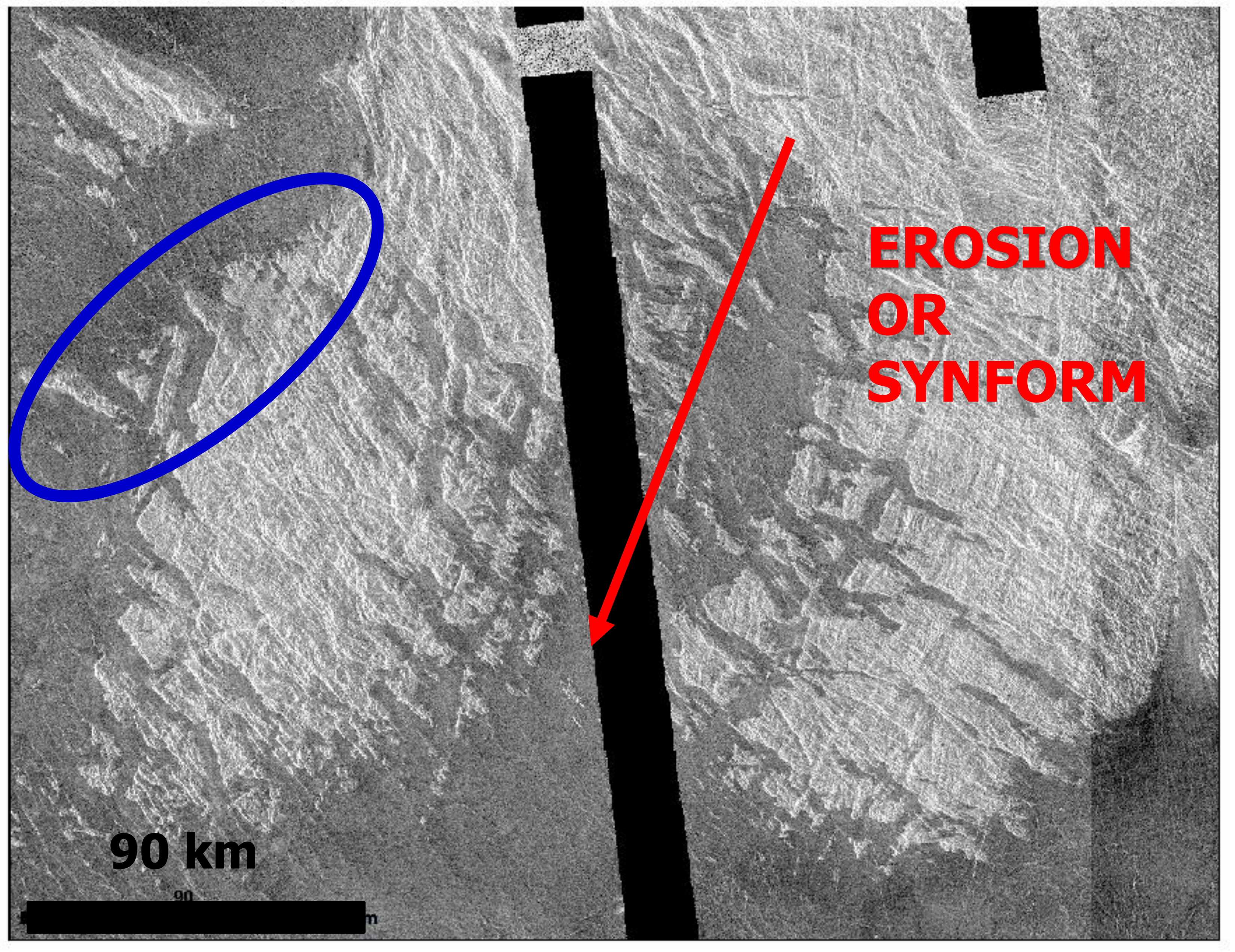
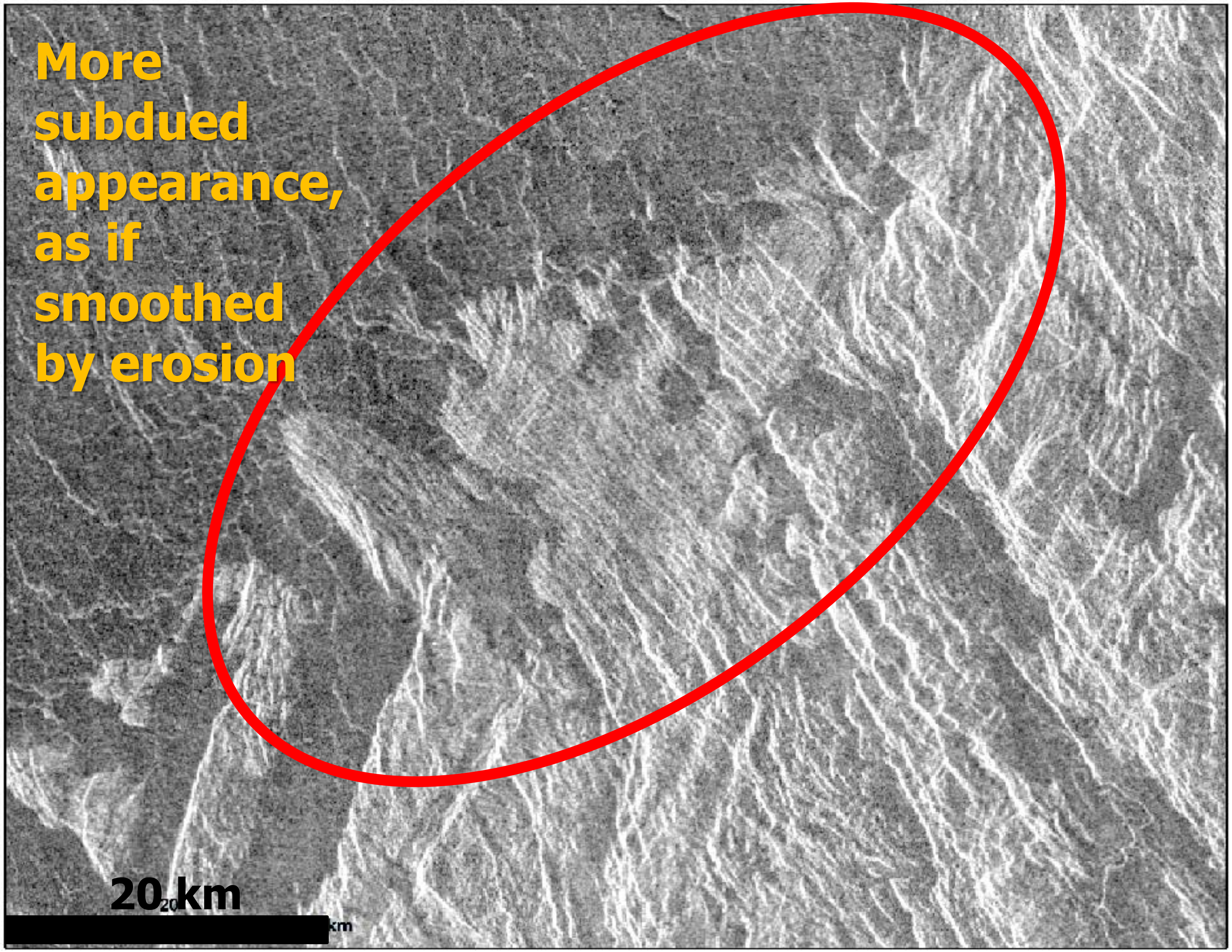
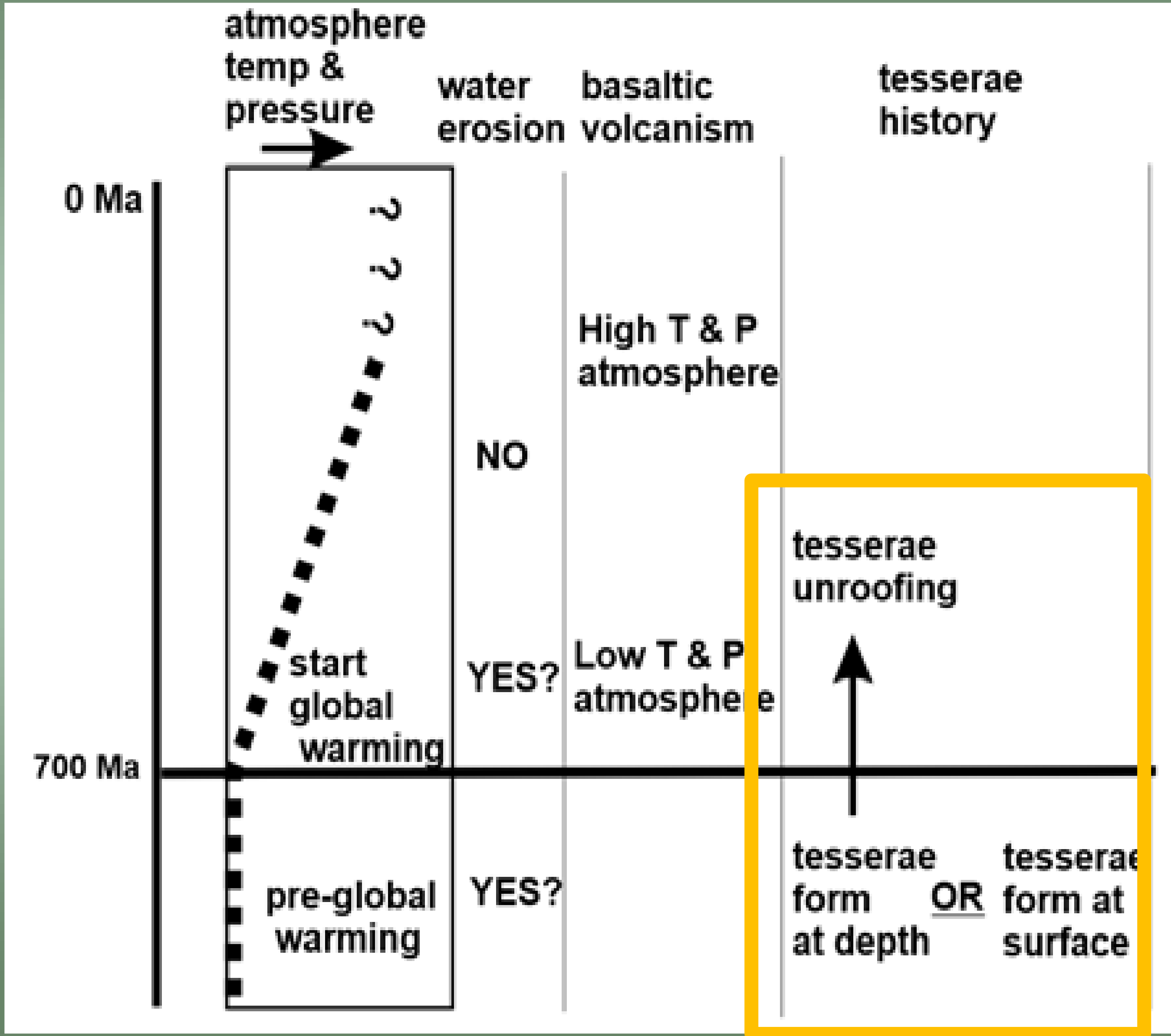



EROSION
OR
SYNFORM
90 km

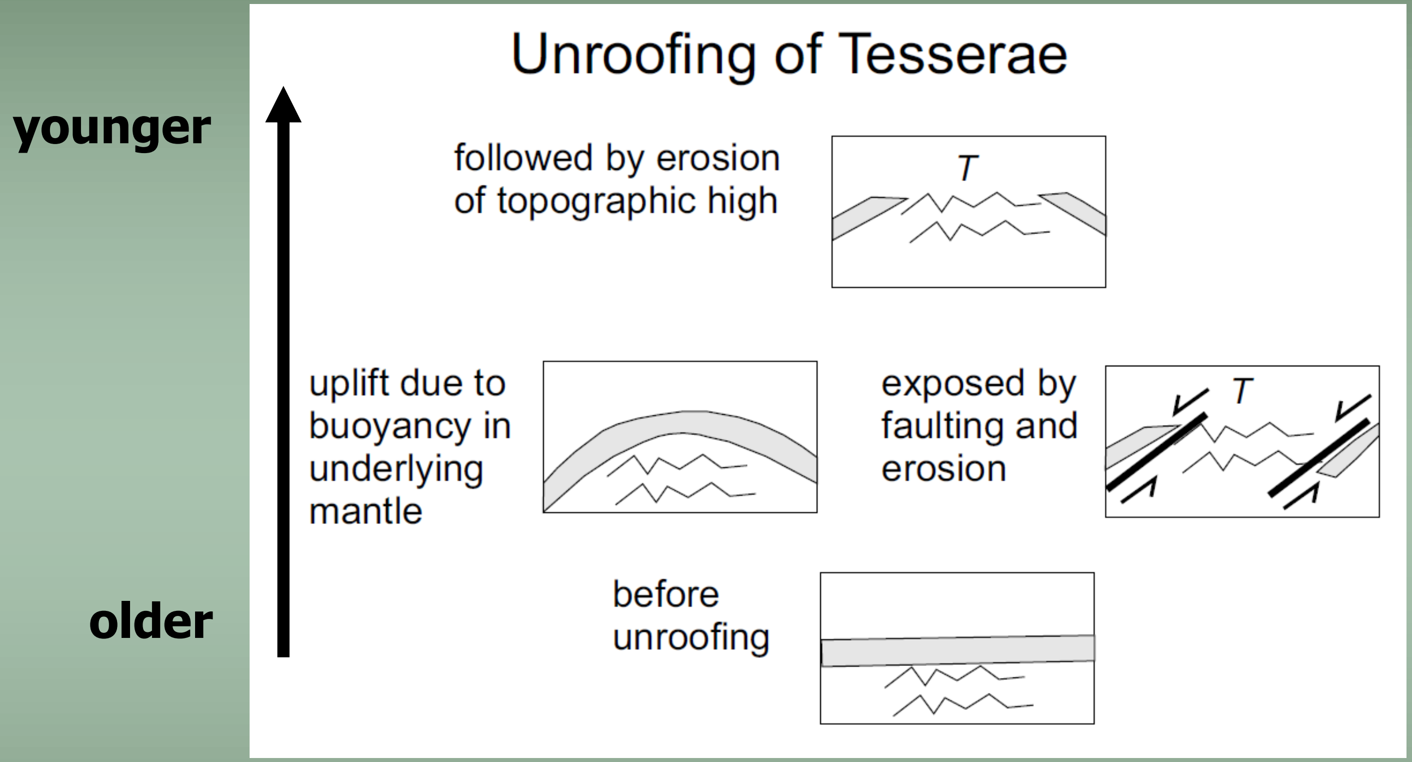

More subdued appearance, as if smoothed by erosion
20 km

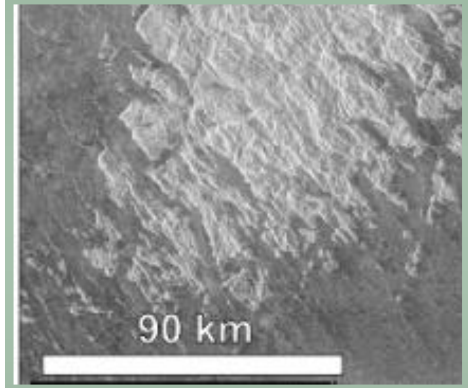
Tesserae (pre-warming):
Unroofing? Erosion?

- If tesserae formed at ambient conditions
- and given the apparent level of ductile deformation
- Then tesserae could have formed at depth
- If so then they must have been subsequently unroofed
- (by tectonics and/or by erosion)
- Particularly true if composition mafic, but also likely if felsic



Unroofing of Tesserae emplaced at depth



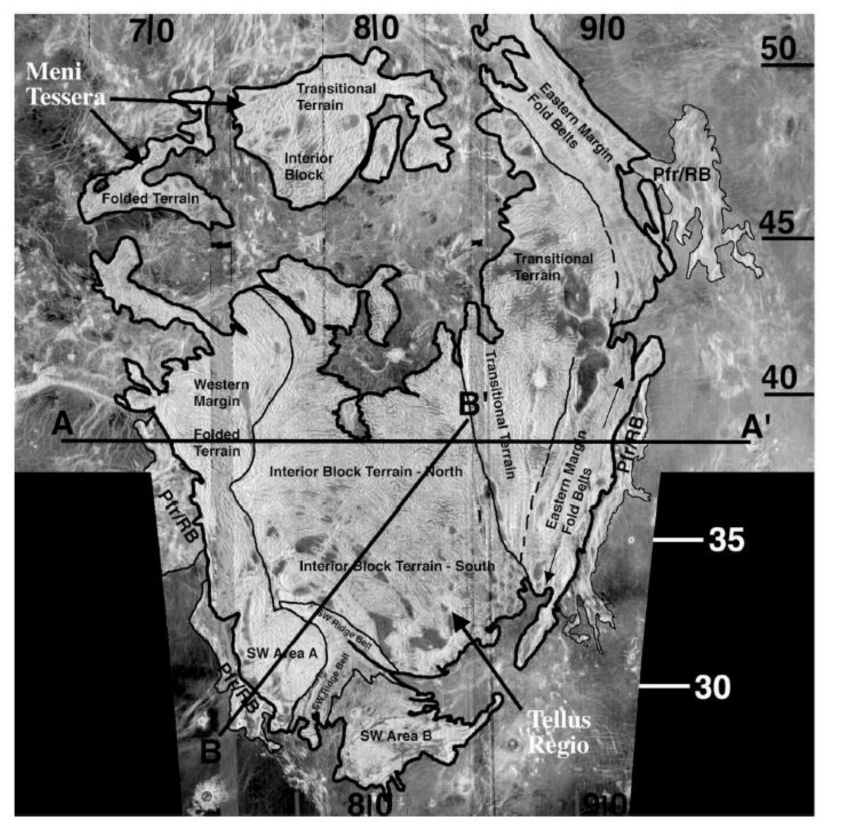


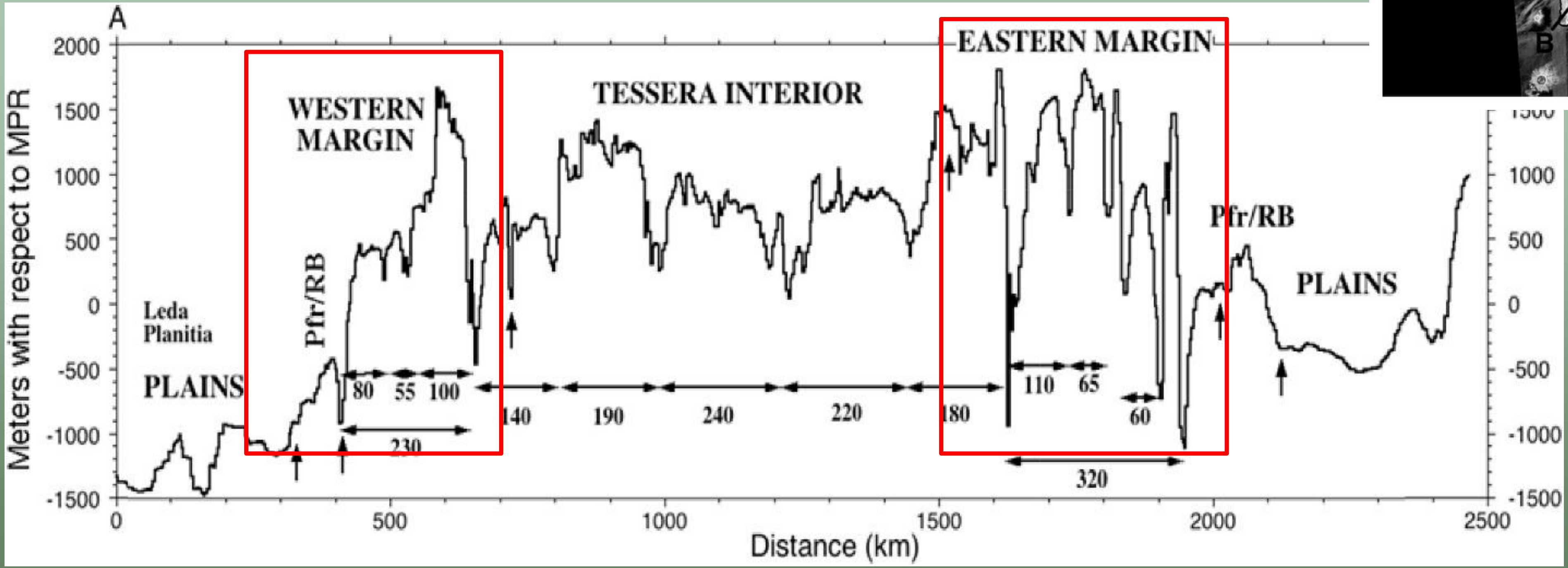
- **Particularly true if tesserae are mafic in composition, but also likely if felsic in composition**

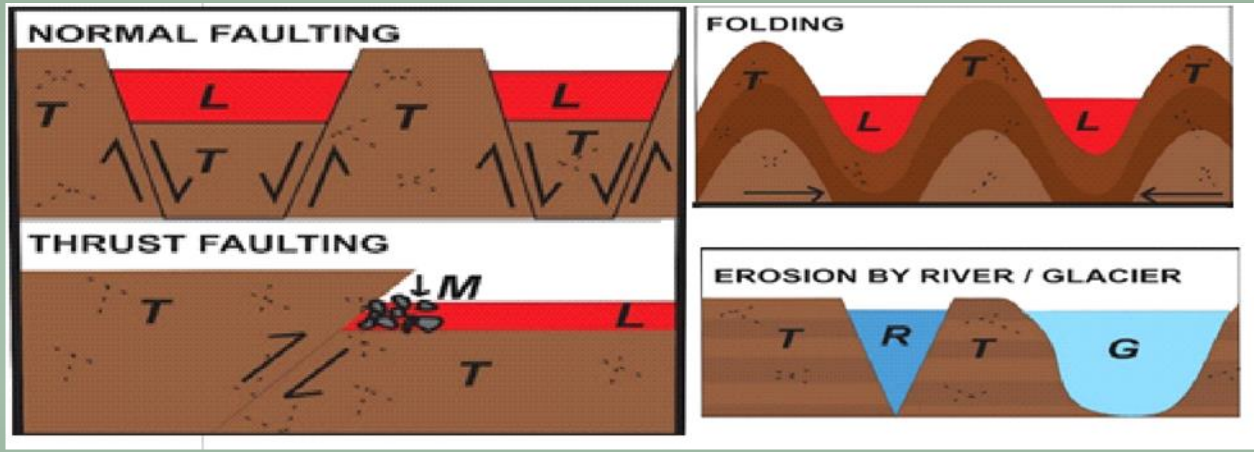
Tellus Regio
(Gilmore and Head 2018)

Western & Eastern margins potentially accreted terranes

(tectonic unroofing)







NORMAL FAULTING
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EROSION BY RIVER / GLACIER
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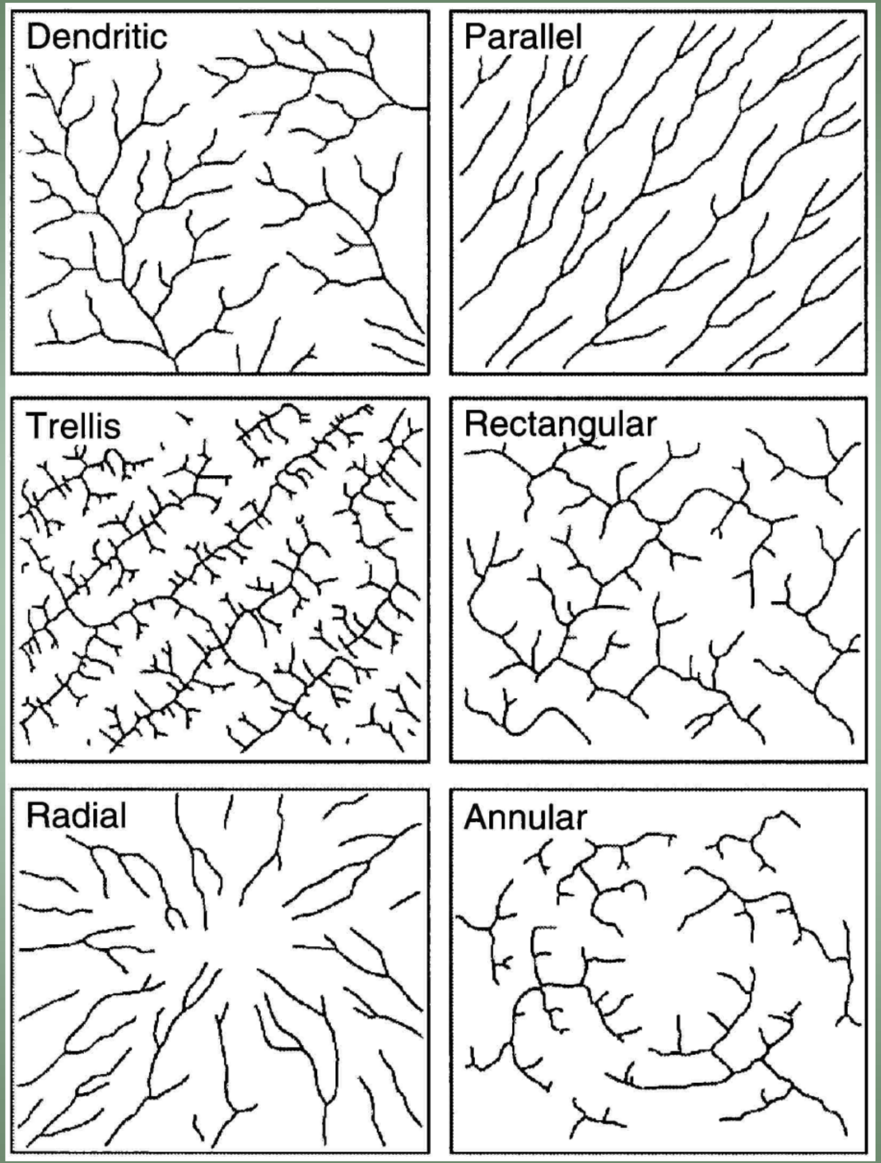
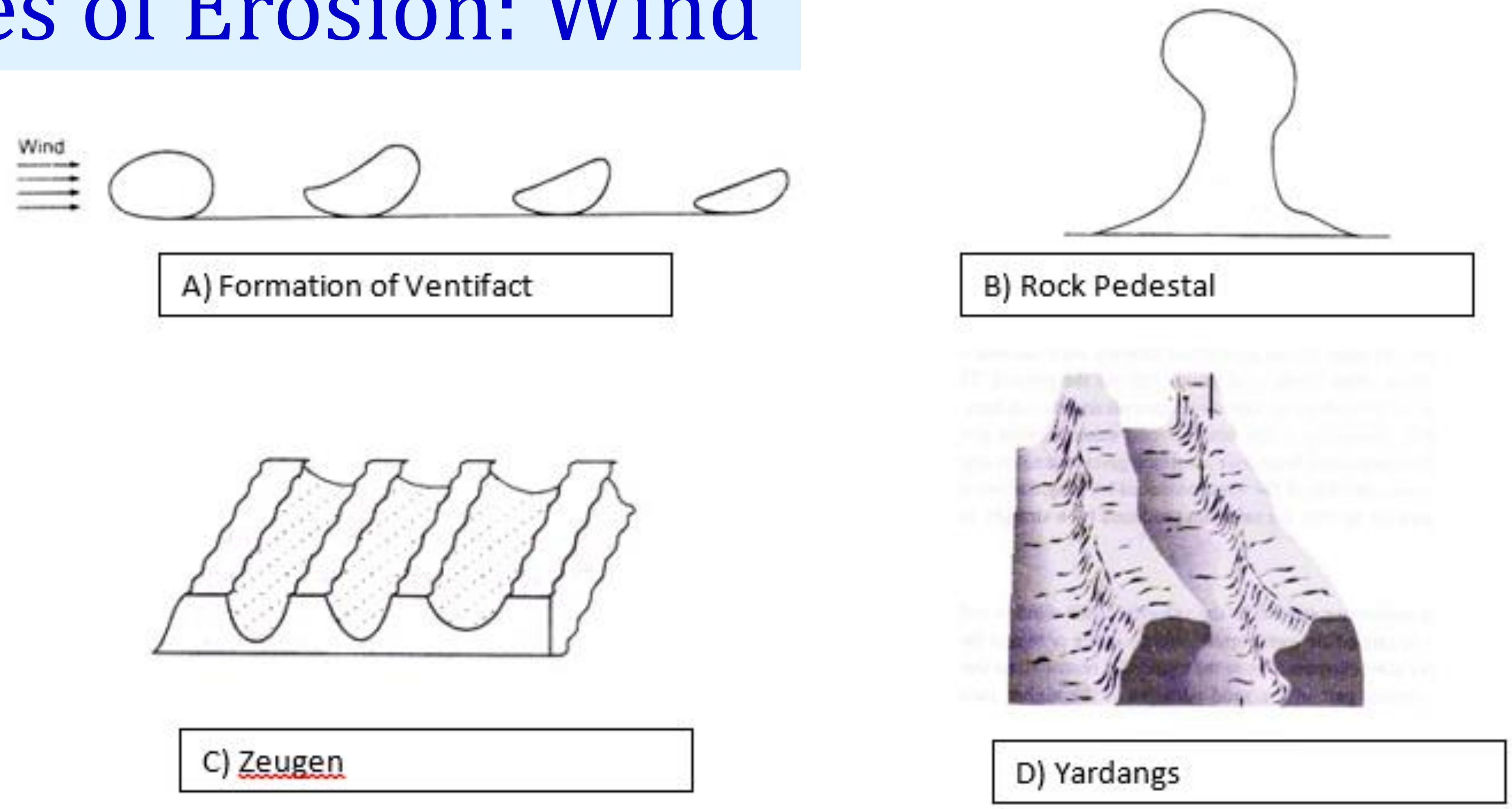
WATER EROSION
terrestrial stream types

after: Howard, 1967; Bridge and Demicco, 2008

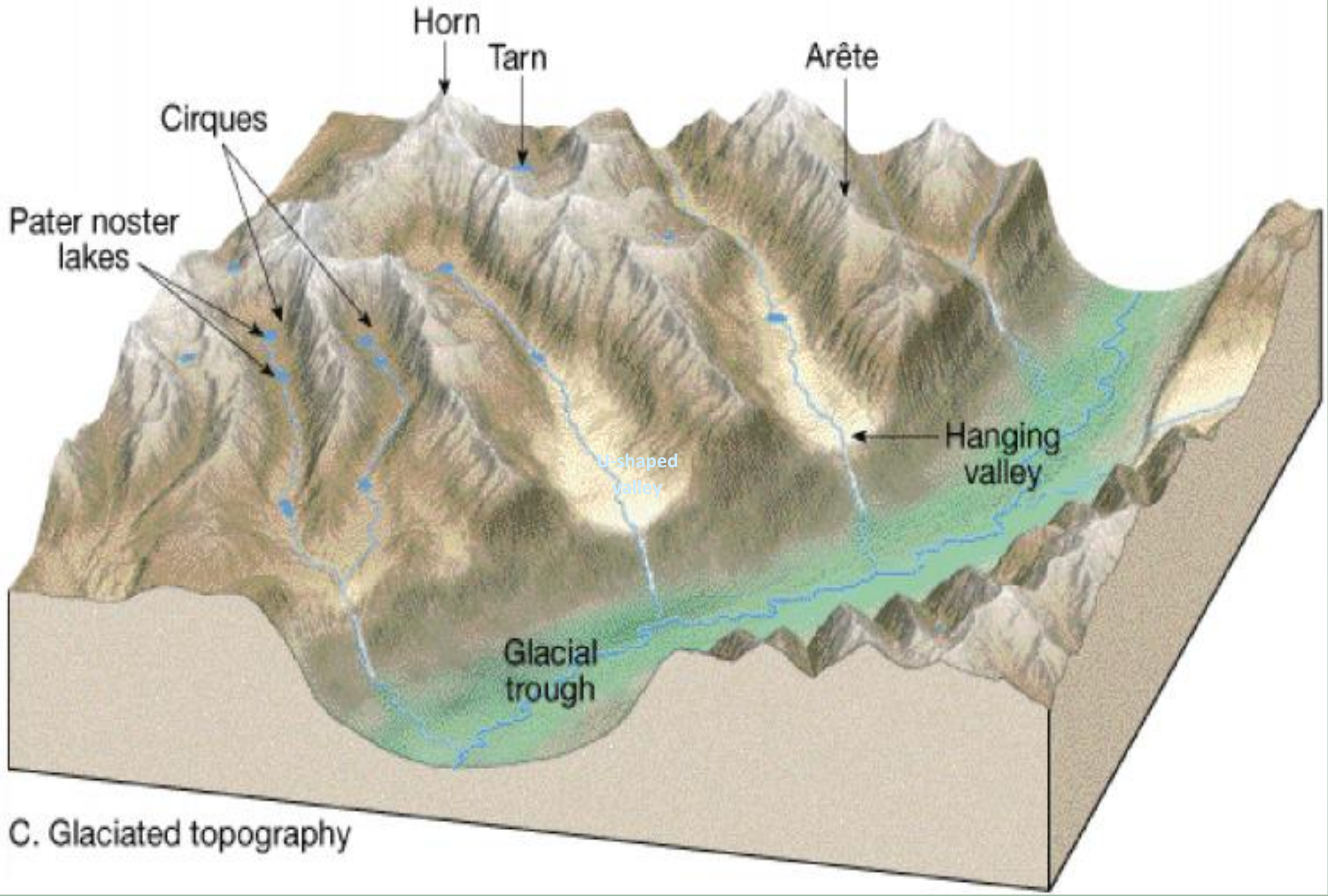


Types of Erosion: Wind



Dune fields exist on Venus and perhaps Yardings exist on Venus, but the scale of features is 10s of metres– smaller than the terrain relief in many tesserae (but question to answer is whether the thicker atmosphere on Venus has a more effective erosive effect than wind on Earth)

Types of Erosion: Glacial



C. Glaciated topography

Most significant glacial features are either on the peak (cirques, horns,, arete, etc.) but which we cannot interpret on Venus because of the uncertainty in the topography.

Another characteristic is U- shaped valleys (vs V-shaped valleys for river erosion). Again a topographic uncertainty problem. In this case the partial lava flooding does not help with distinguishing U-shaped vs. V-shaped valleys

Late basalts [volcanoes, coronae] (hot, high CO2 pressure)
Early basalts [plains units] (ambient)
is evidence preserved in the basaltic record?

canali
volcanoes,
coronae

Younger

plains
units
missing basalts?

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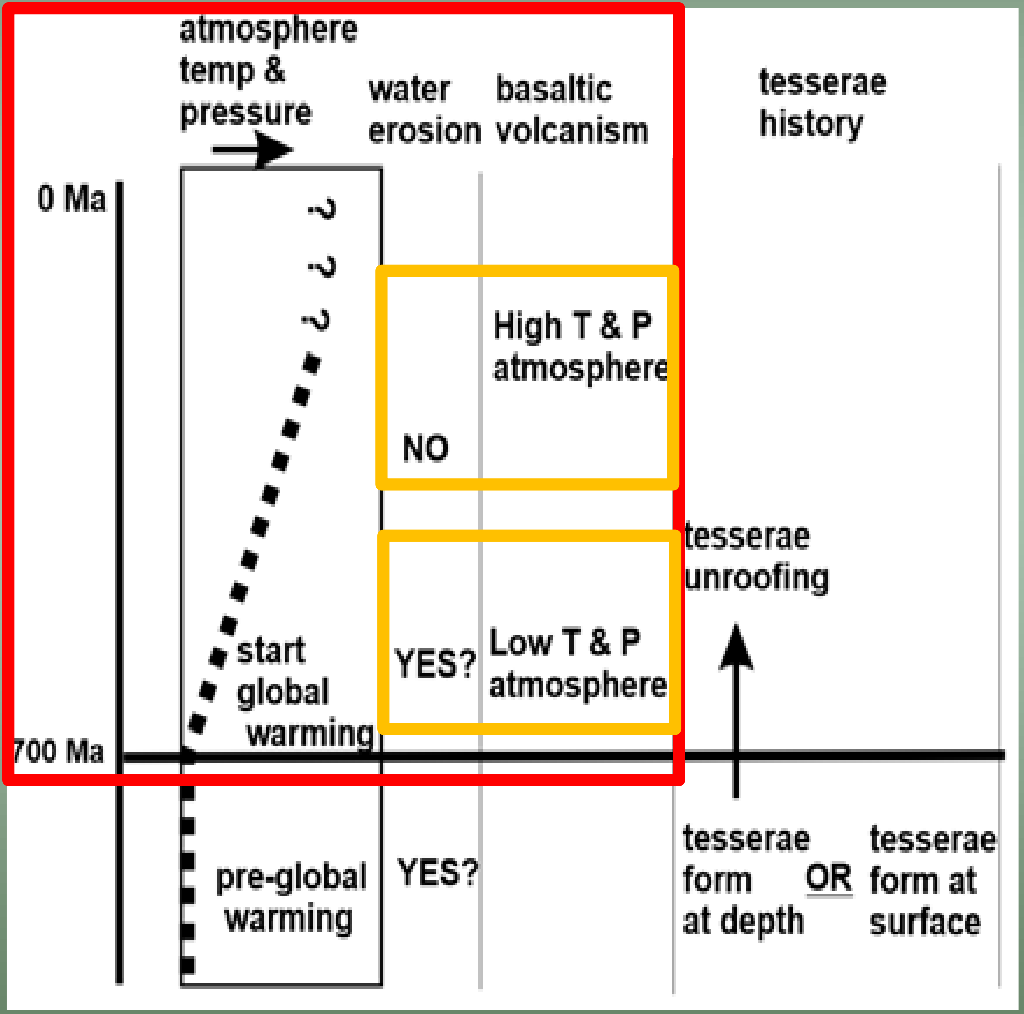
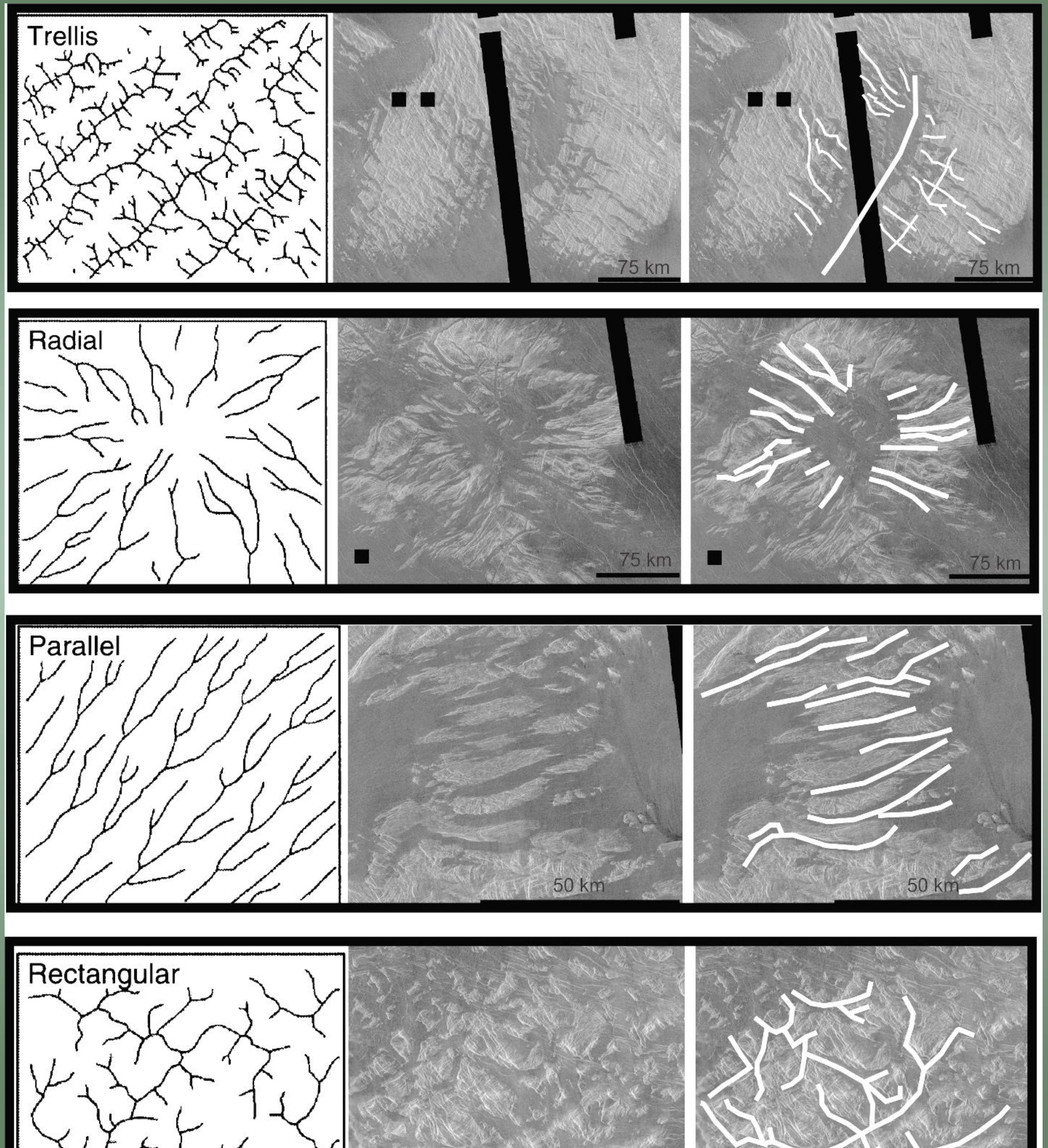
tesserae

Older





Trellis
75 km
75 km
Radial
75 km
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Parallel
50 km
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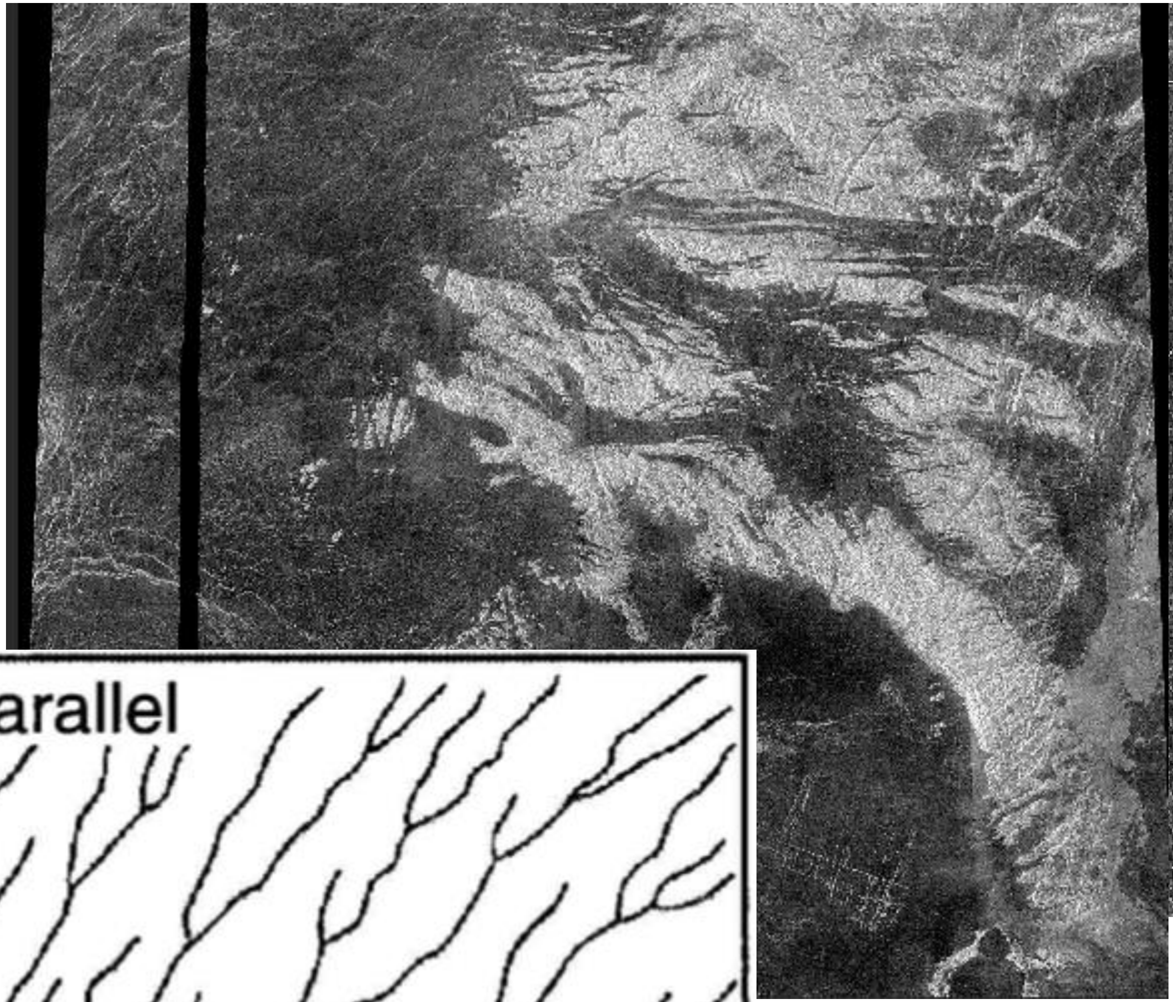

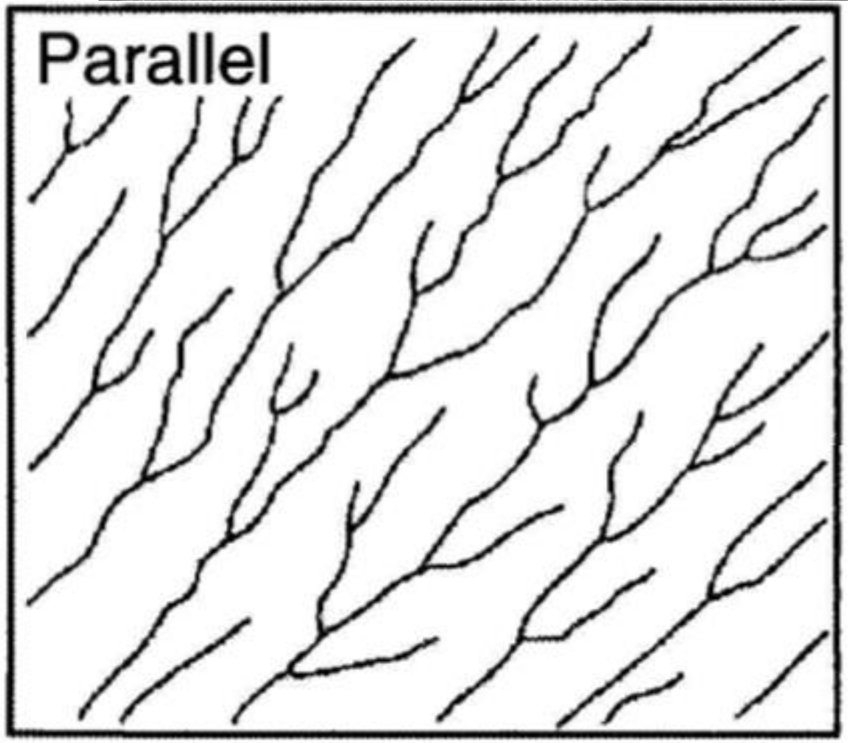
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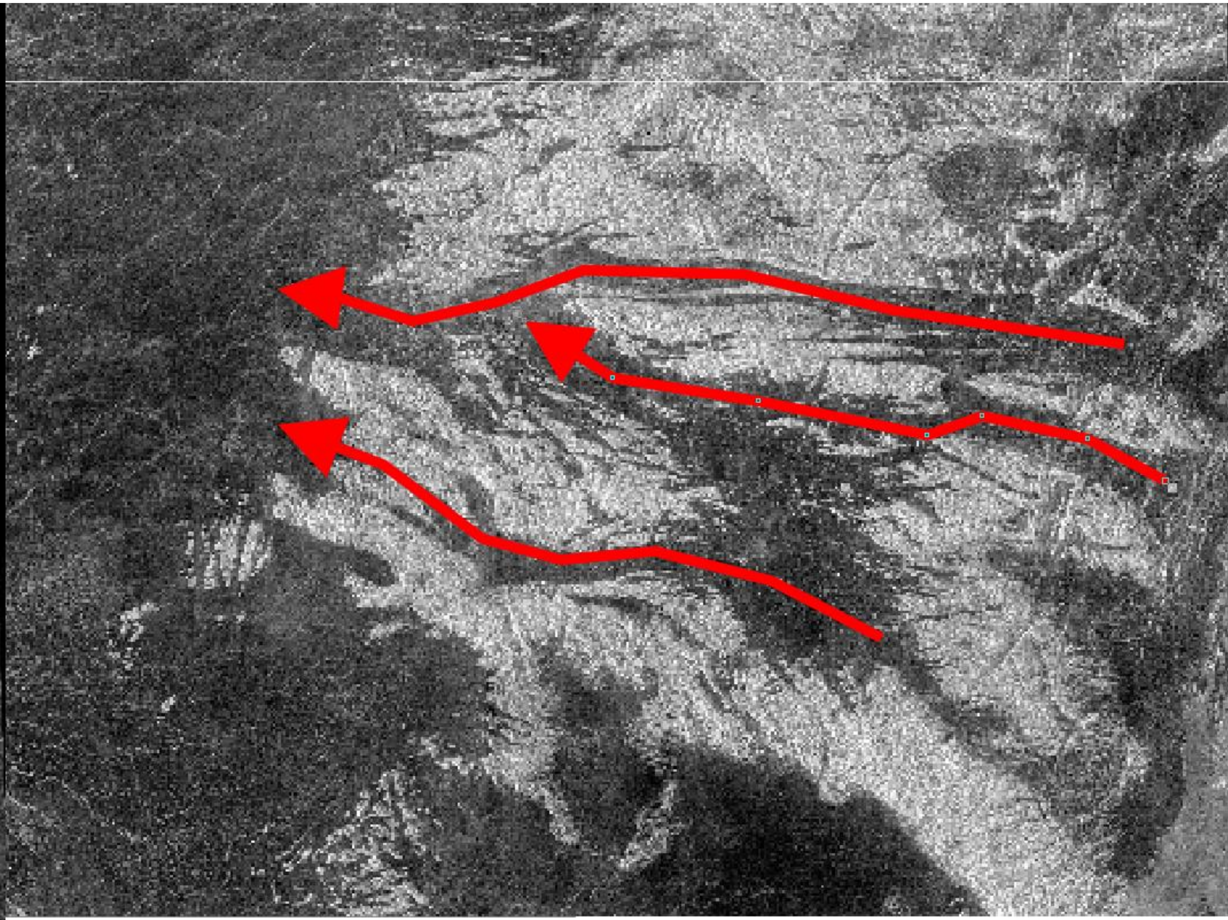


LATE: High T, high P = volcanoes, canali, corona

EARLY: Low T, low P = plains basalts (+ missing basalts)

Mafic volcanism

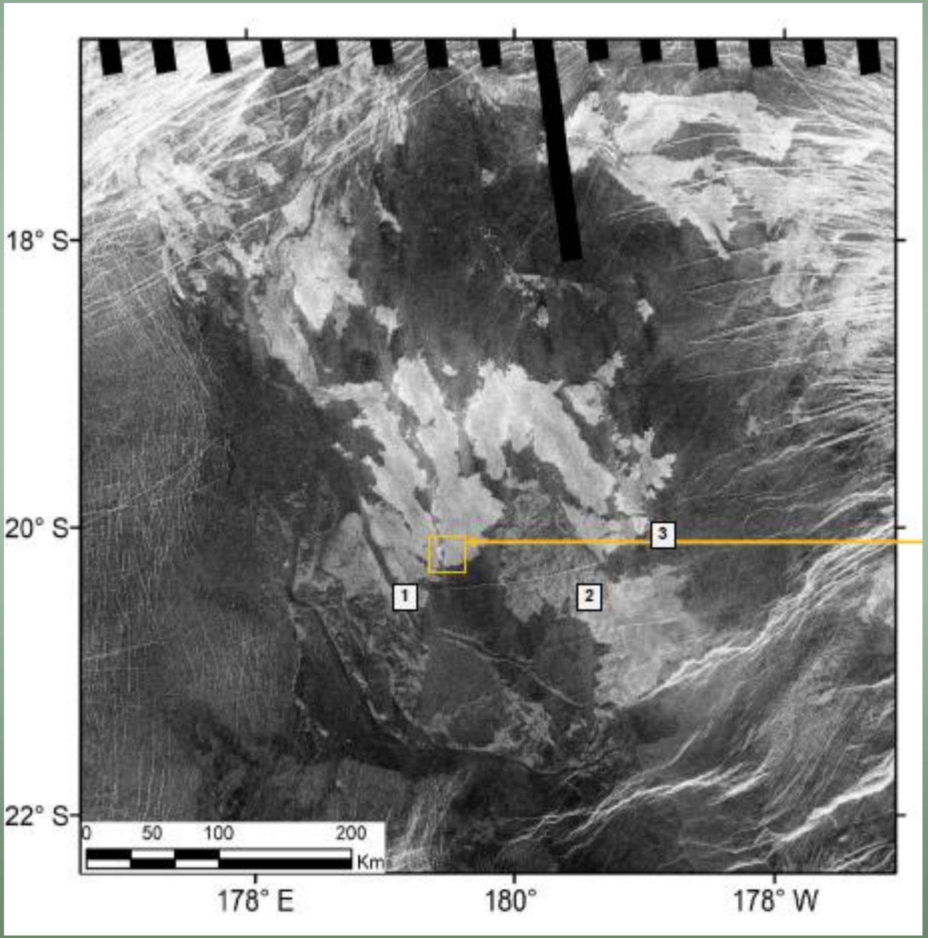
are there differences (e.g. in viscosity) in mafic flows emplaced under ambient conditions vs 450C & 90 atm.

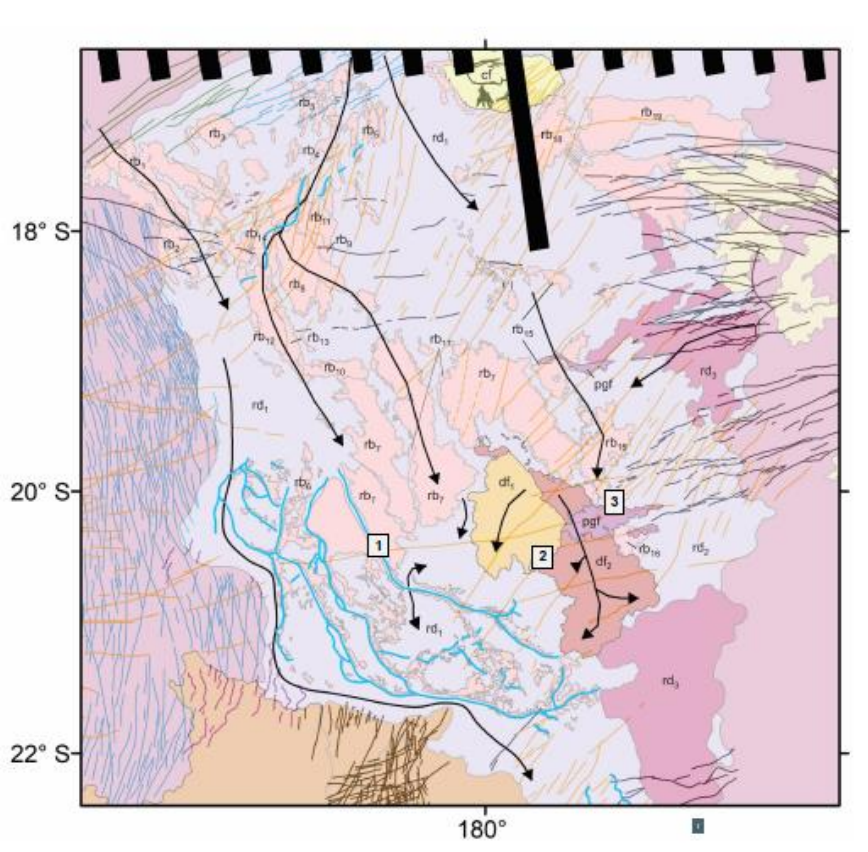
POSSIBLE PARAMETERS THAT MIGHT VARY

- **Length of flows (mean flow length)**
- **A’a vs. pahoehoe distribution**
- **Level of vesiculation (related to atmospheric pressure, volatile abundance and composition)**
- **Other?**

Potential insights from detailed mapping of flow fields (post-hyper-warming)

>26 flow units/subunits distinguished in Henwen fluctus (Lee et al., in prep.)





(see Lee et al. #2224, Thursday poster session)

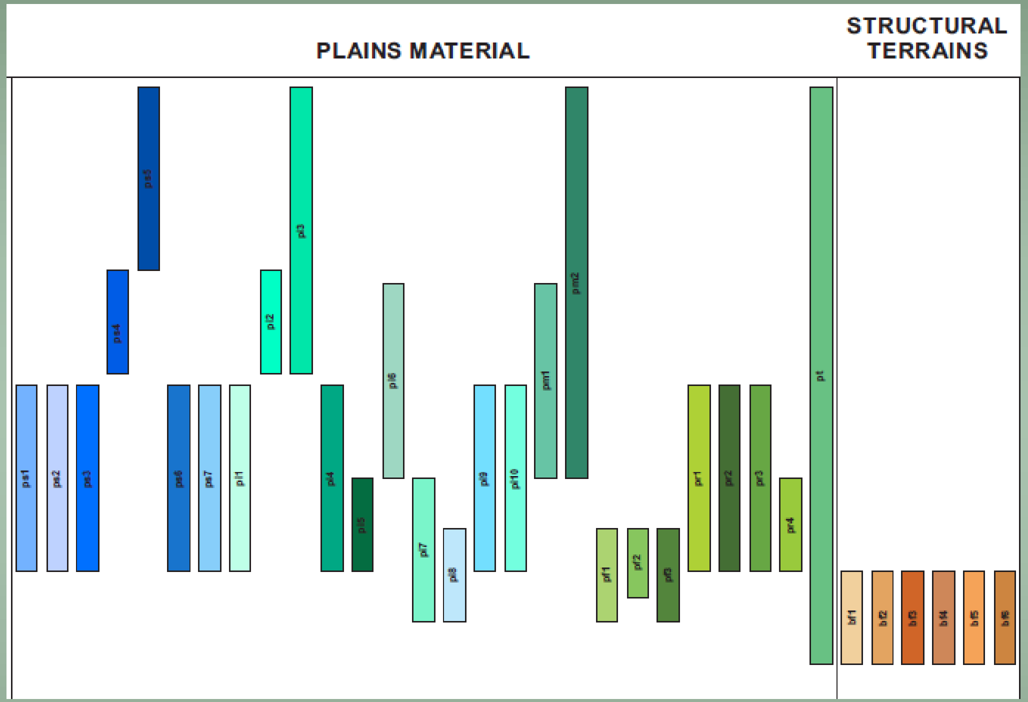
Potential insights from detailed mapping of plains units (early warming)

More difficult to map– subtle differences in radar brightness

Typically only a few plains units are mapped

Recent detailed mapping is identifying sub-units.

For instance Bethell et al. (2019; Alpha Regio Quadrangle) has identified 20 different plains sub-units (+3 with dense fracturing and 4 with wrinkle ridges)



[Bethell et al. (2019) 1: 2,500,000 scale "GEOLOGICAL MAP OF THE ALPHA REGIO (V-32) QUADRANGLE, Journal of Maps (pending decision post-revision). See also Bethell #1462, earlier this session.]

SUMMARY

Hyper-Warming event (450C, 90 atm) on Venus: Potential to recognize in the geological record

geological evidence in basalt: for differences between:

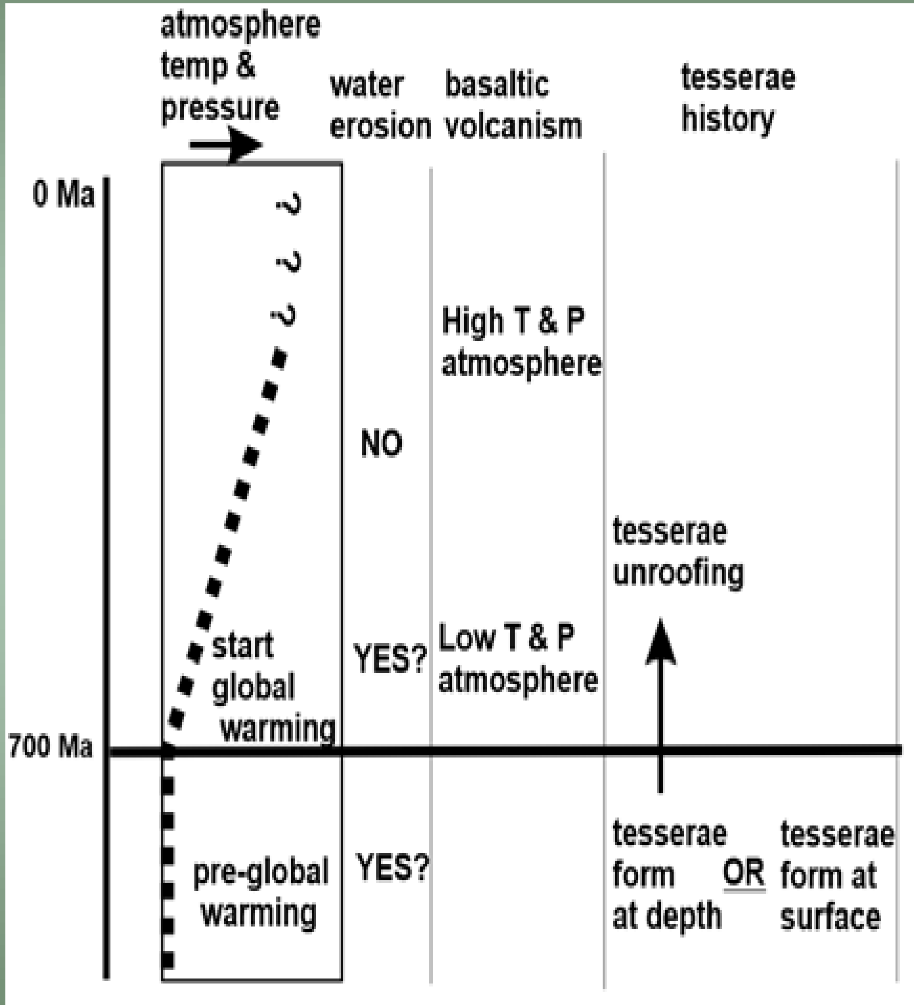
later basalts emplaced in high T high P conditions)
vs
early basalts emplaced in ambient conditions
tesserae formed in ambient conditions (and at depth?)
UNROOFING, EROSION?

Younger

canali
volcanoes,
coronae

plains
units
(+ missing basalts?)
----
tesserae

Older



Erosion on Tesserae

- There are three major reasons to expect erosional features in tessera terrains:

1. **Climate models suggest that Venus could have had Earth-like habitable conditions until about 700 Ma (Way et al. 2016). Therefore, the occurrence of water erosion would be expected up till that time**
2. **The tectonic complexity of tesserae (e.g., Hansen and Willis, 1996) would suggest deformation at depth followed by unroofing and exposure at the surface (Ernst et al. 2019)**
3. **Lineaments with irregular curvilinear patterns in tesserae may be indicative of shallow-dipping layers that follow undulating topography (e.g. examples in Alpha Regio; Byrne et al., 2019; see also Khawja et al., 2019)**
4. Overall present-day topographic variations observed in tesserae seem consistent with water erosion

Models to Explain Topographic Variation in Tesserae

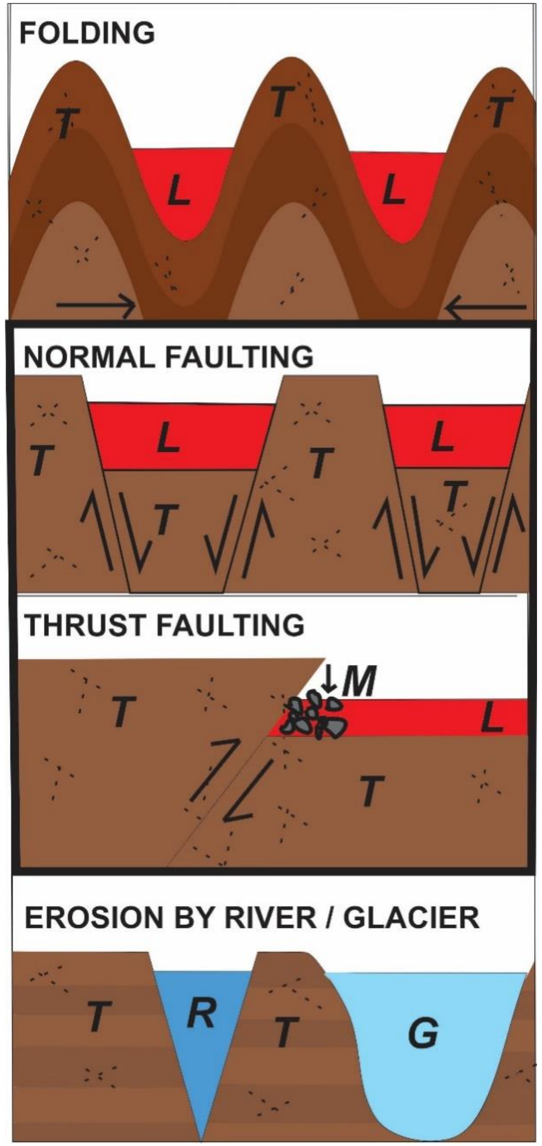


Figure 8: Schematic diagrams of three topographic models to explain topographic variations: folding (A), faulting (normal (B)/thrust (C)), and erosion by river/glacier (D). T = tessera, L = lava flooding, M = mass wasting, R = river erosion, G = glacial erosion

Types of Erosion

In the previous section we concluded that:

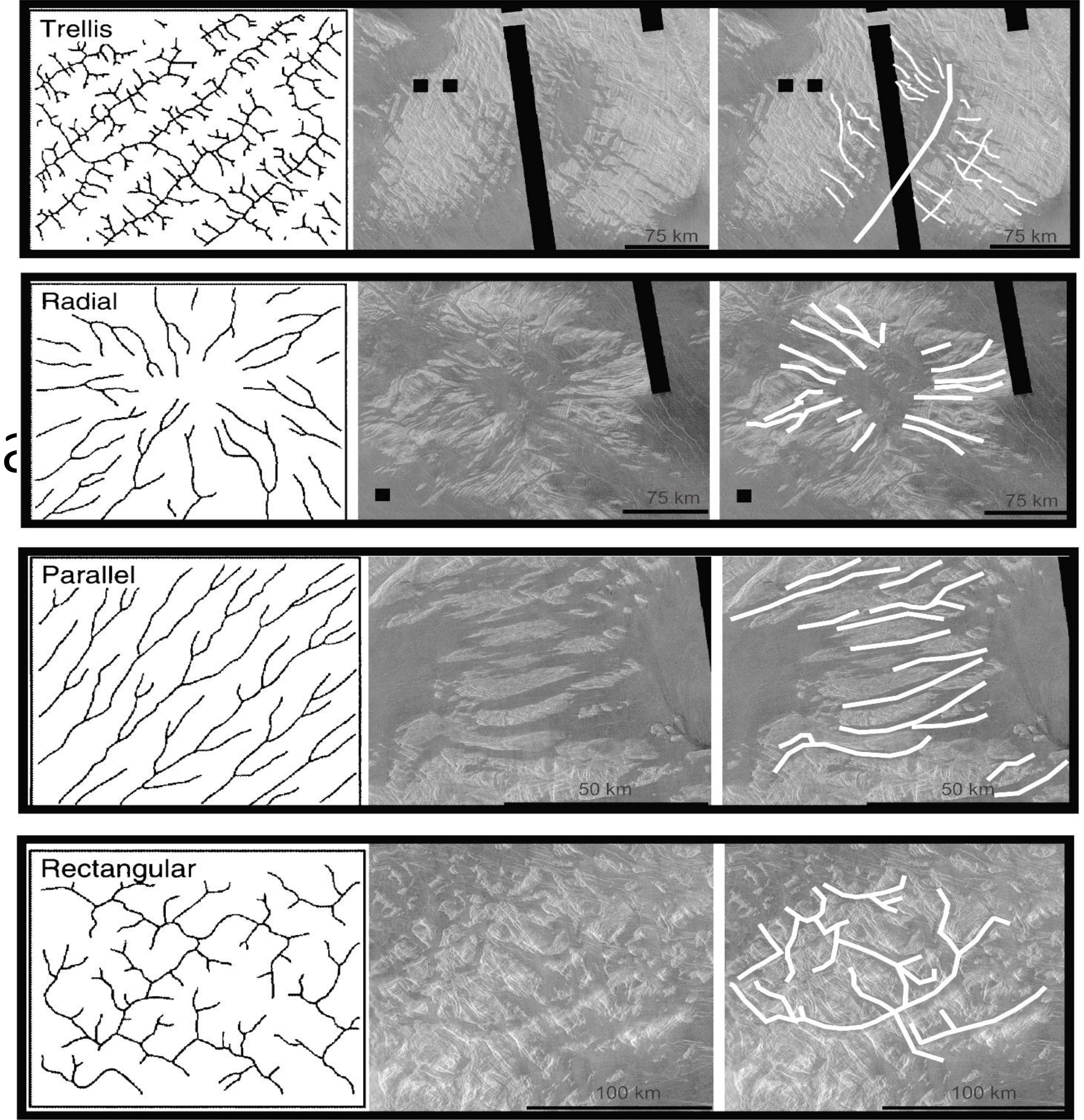
- tesserae which have been partially flooded, exhibit patterns of elevated areas (peaks and ridges) and valley (flooded areas)
- that can only partially be addressed by primary features (folding and faulting) and that there must be a considerable erosion component.

- We next consider wind, ice and water erosion to explain the observed topographic patterns of partially flooded tesserae

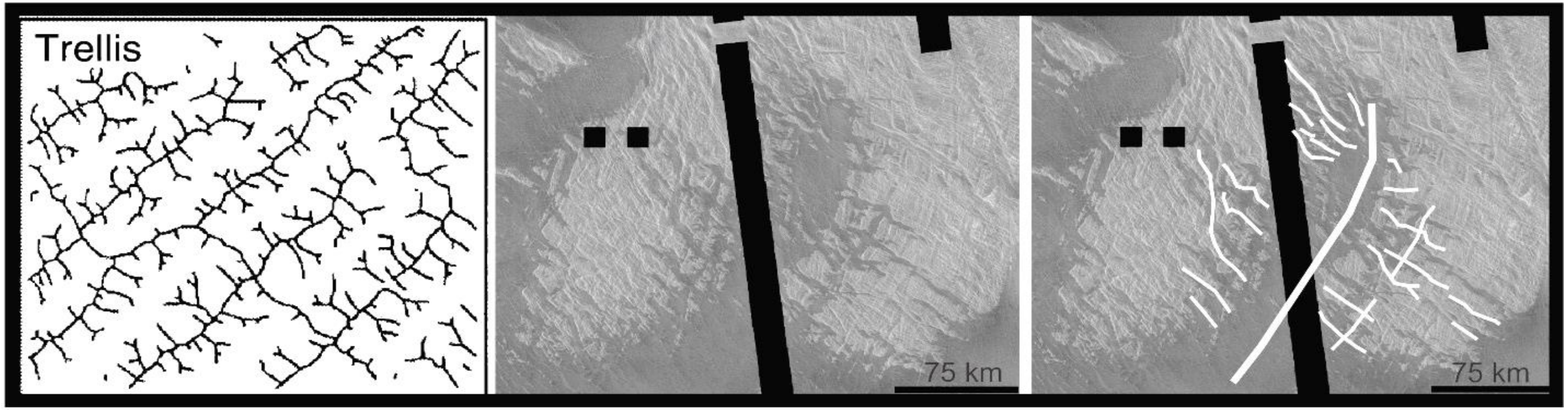
Tesserae- stream flow pattern

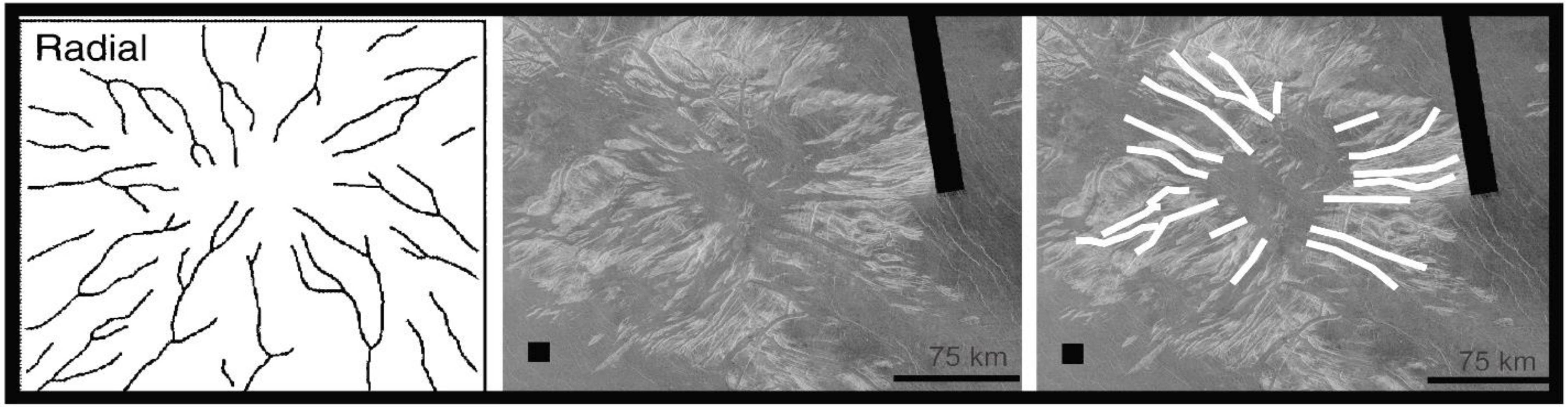
Match at least 3 terrestria[l] types

Patterns reflect geology



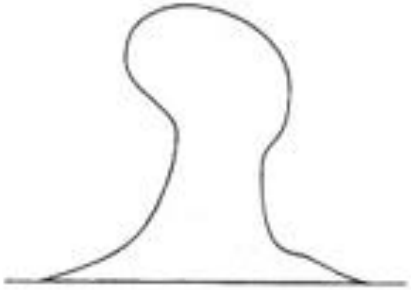
Tesserae- stream flow patterns
Match at least 3 terrestrial types
Patterns reflect geology



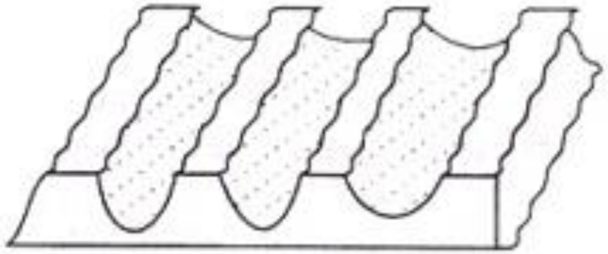


Types of Erosion: Wind

A) Formation of Ventifact



B) Rock Pedestal

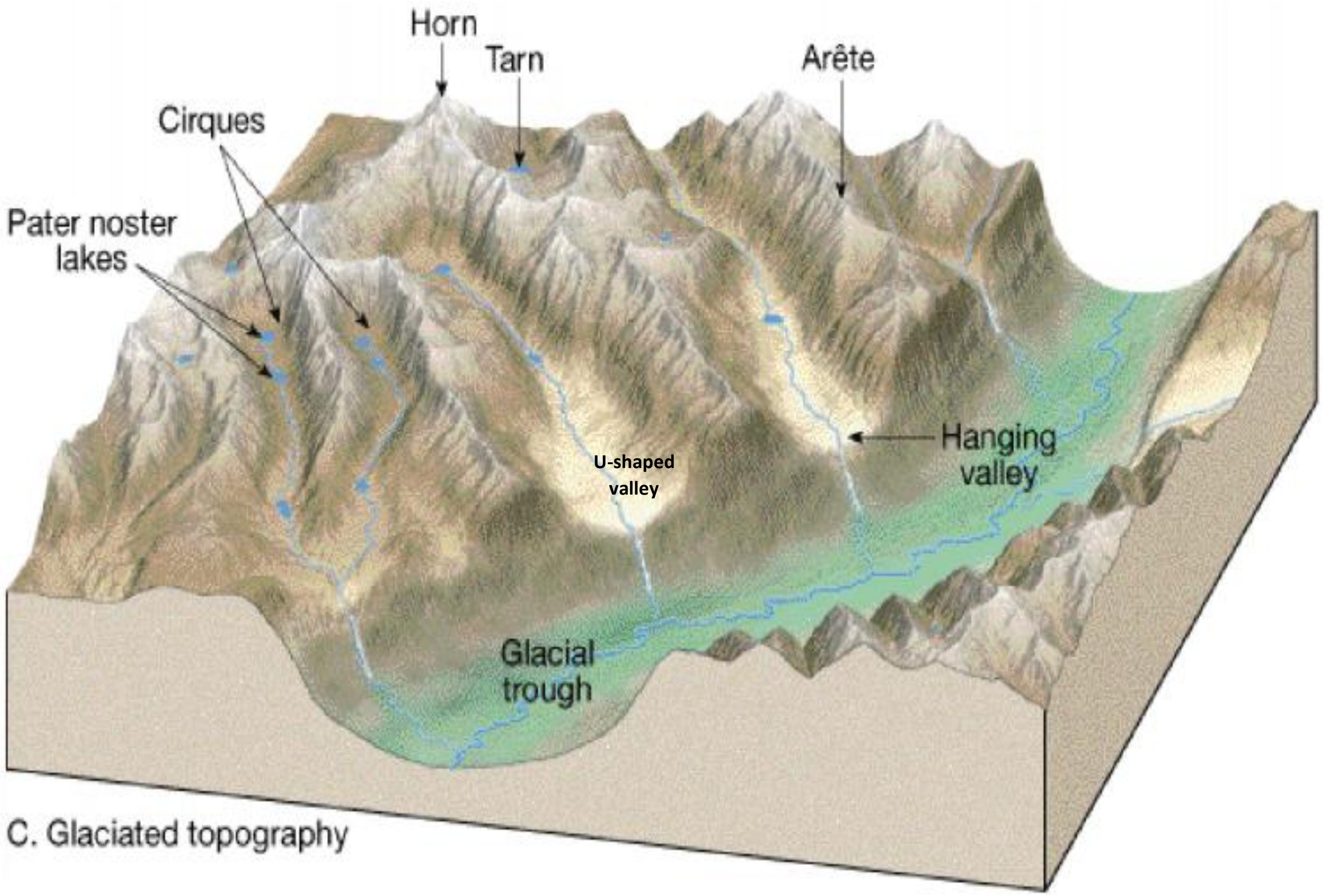


C) Zeugen

D) Yardangs

Dune fields exist on Venus and perhaps Yardings exist on Venus, but the scale of features is 10s of metres– smaller than the terrain relief in many tesserae
(but question to answer is whether the thicker atmosphere on Venus has a more effective erosive effect than wind on Earth)

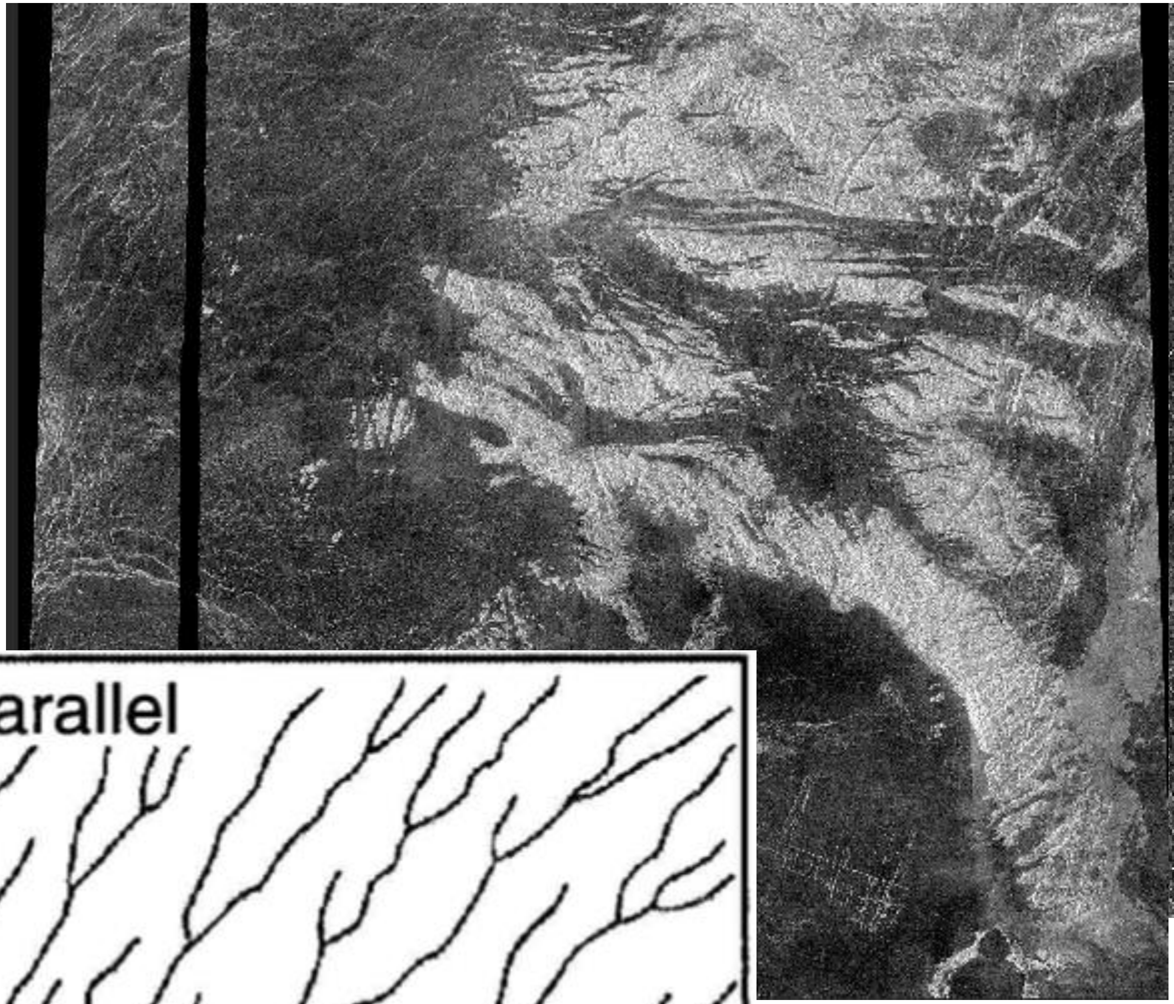
Types of Erosion: Glacial

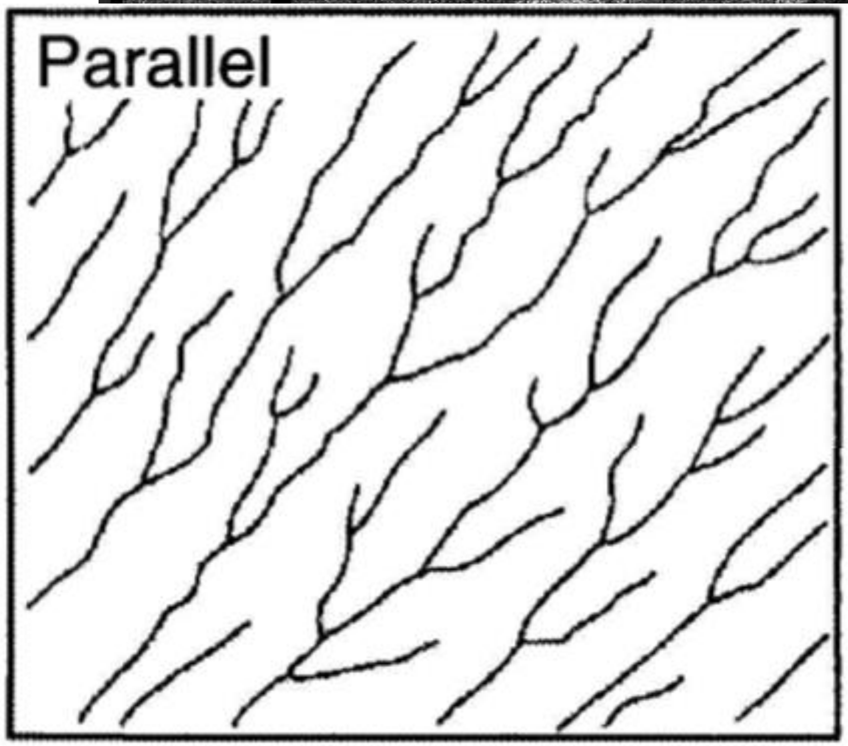


C. Glaciated topography

Most significant glacial features are either on the peak (cirques, horns,, arete, etc.) but which we cannot interpret on Venus because of the uncertainty in the topography.

Another characteristic is U- shaped valleys (vs V-shaped valleys for river erosion). Again a topographic uncertainty problem. In this case the partial lava flooding does not help with distinguishing U-shaped vs. V-shaped valleys

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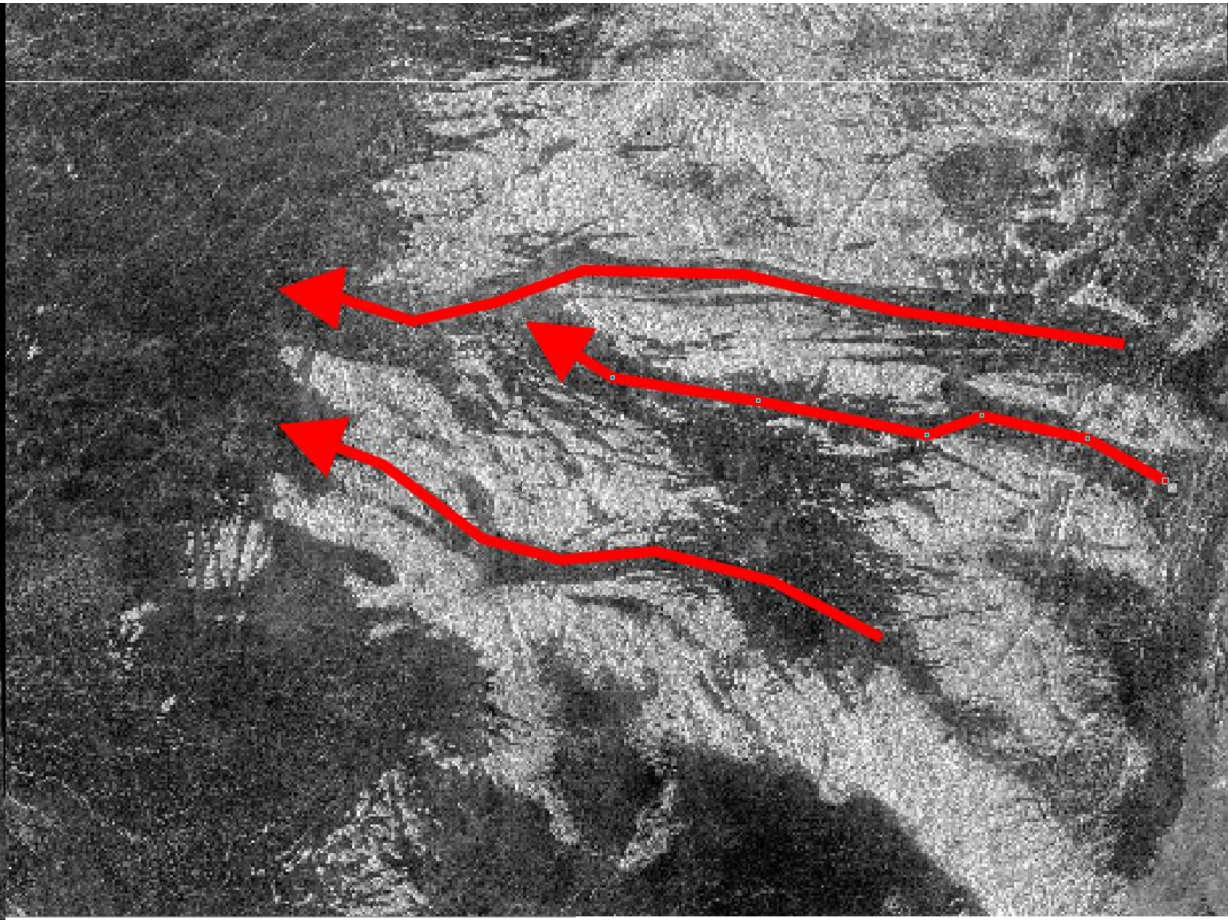

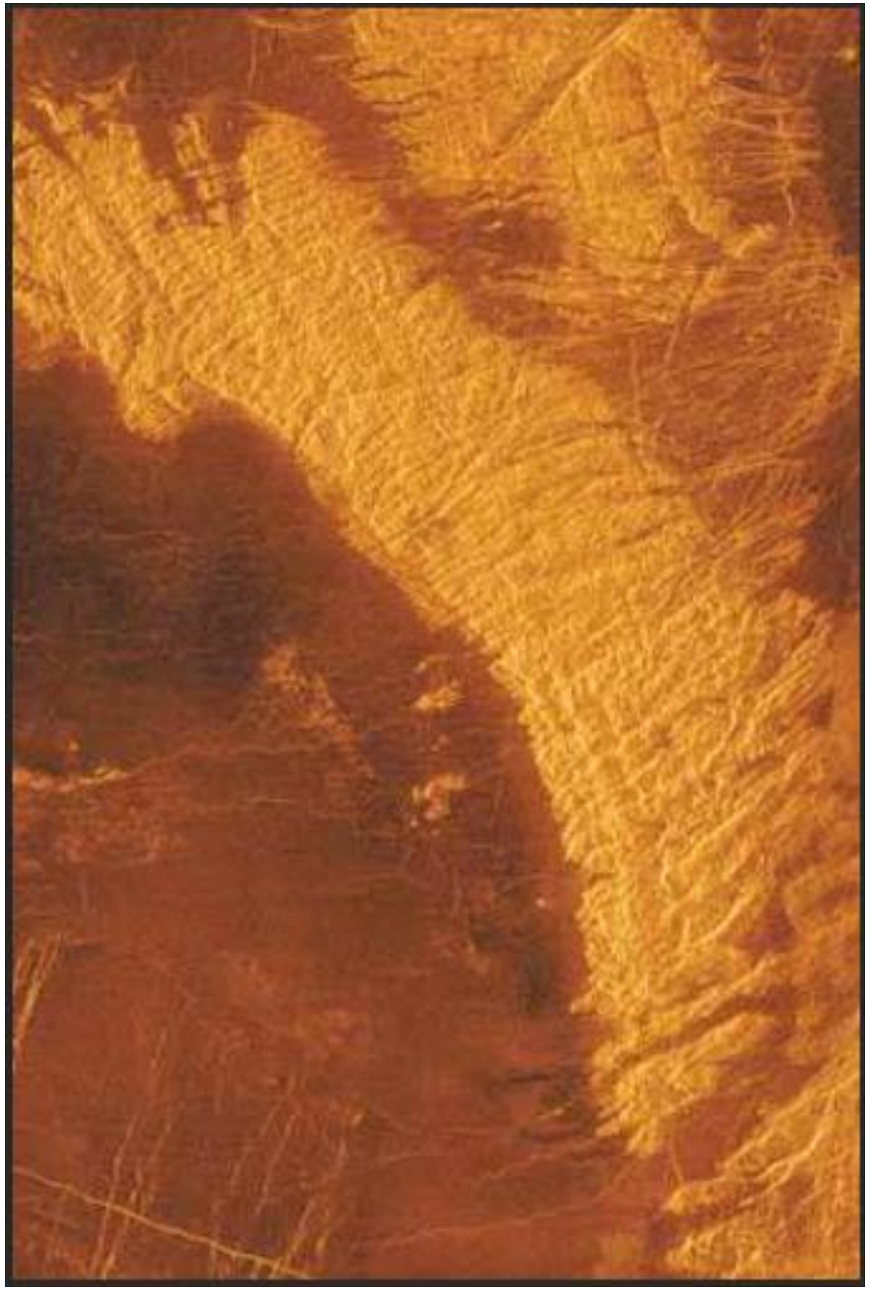

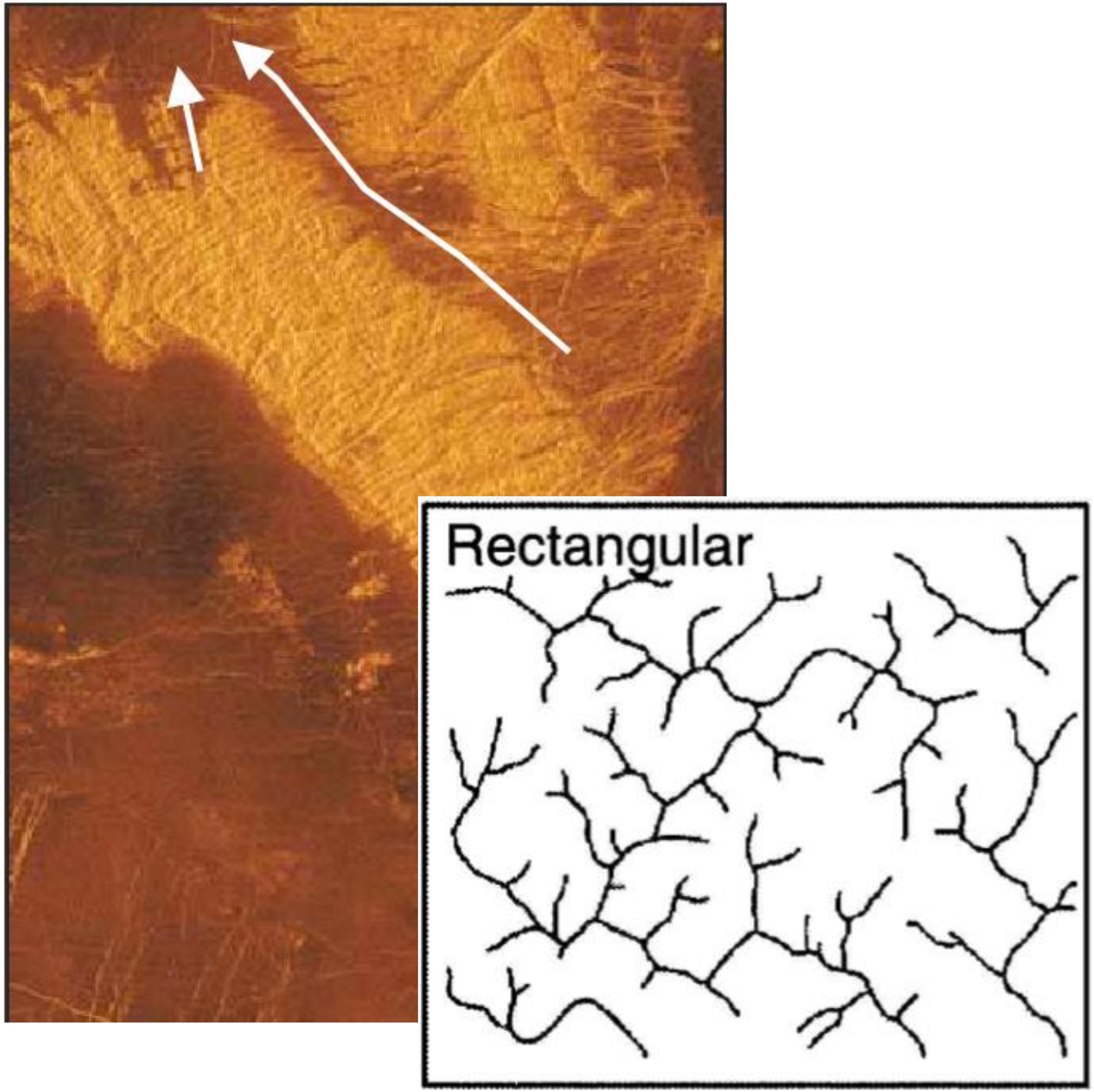
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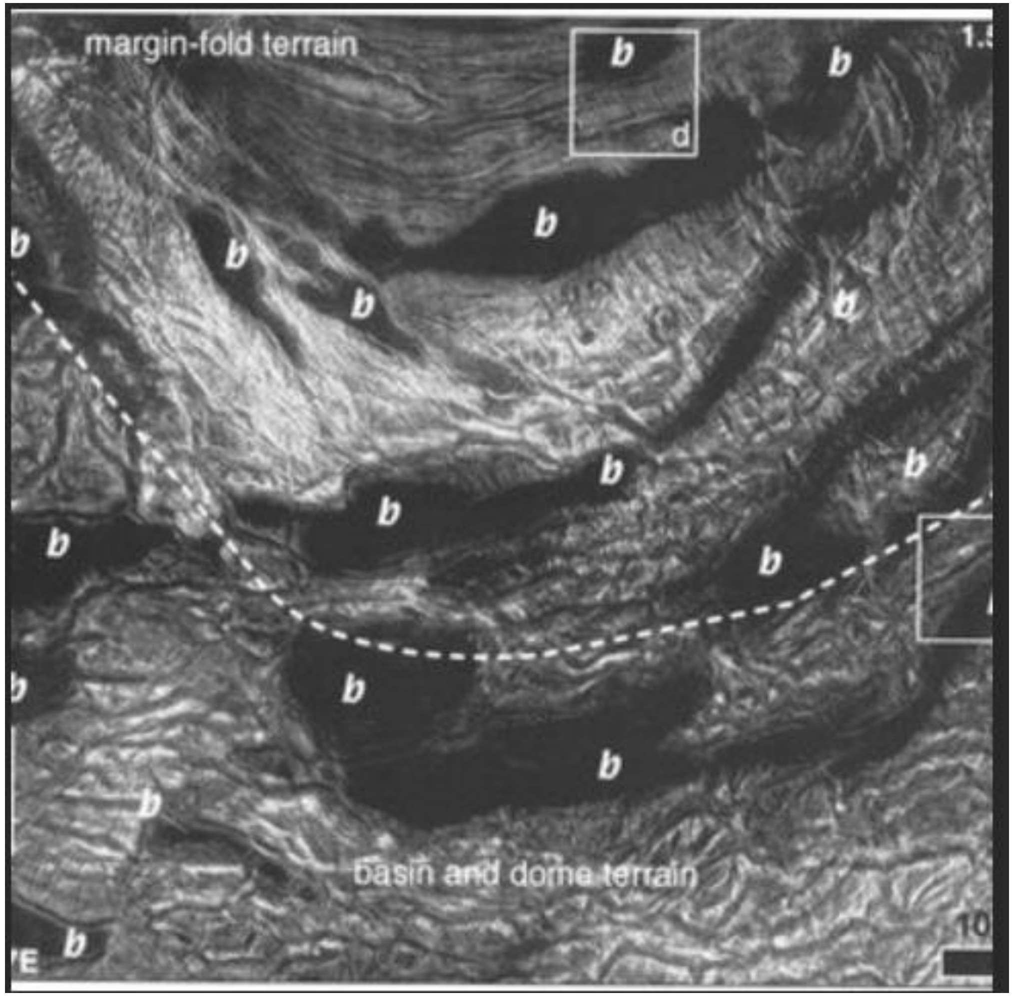
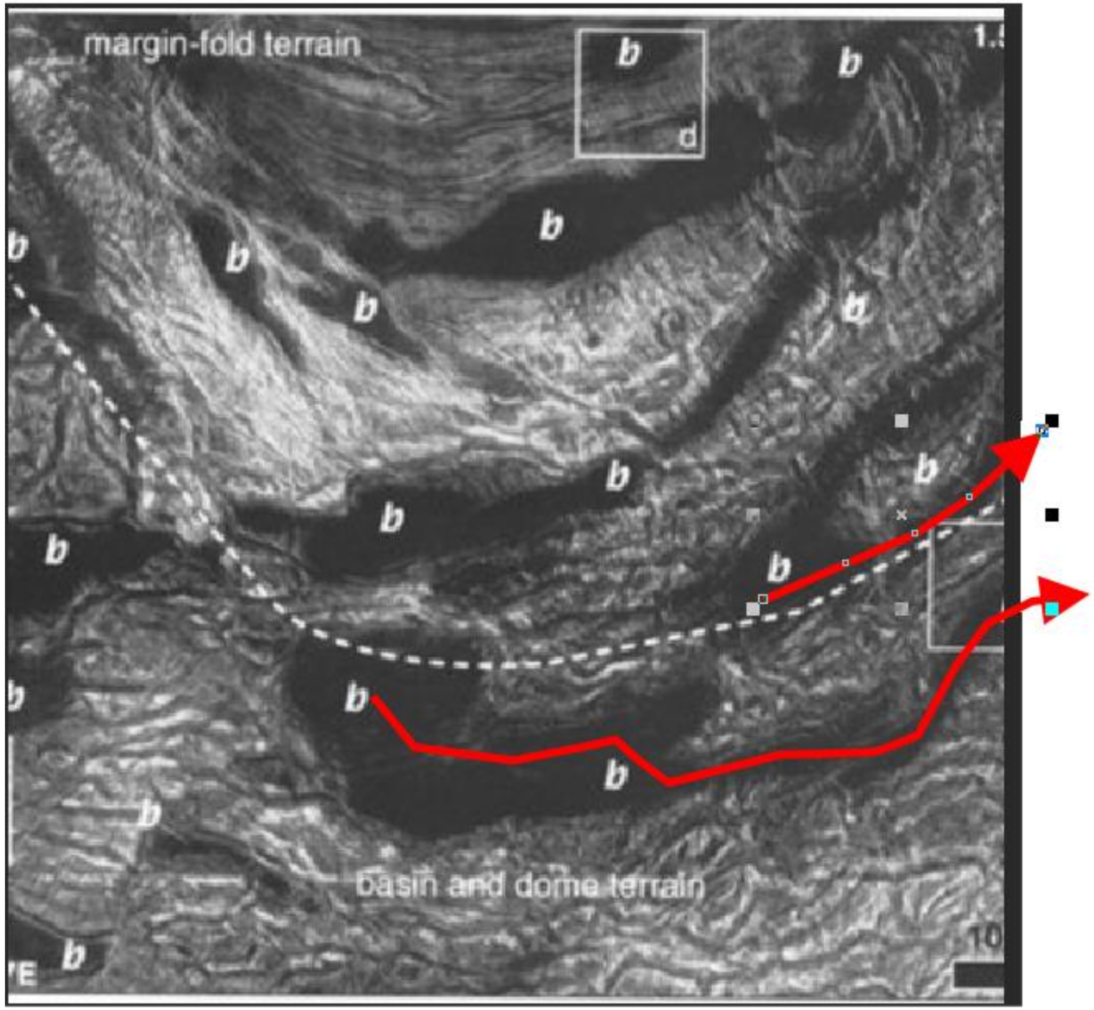
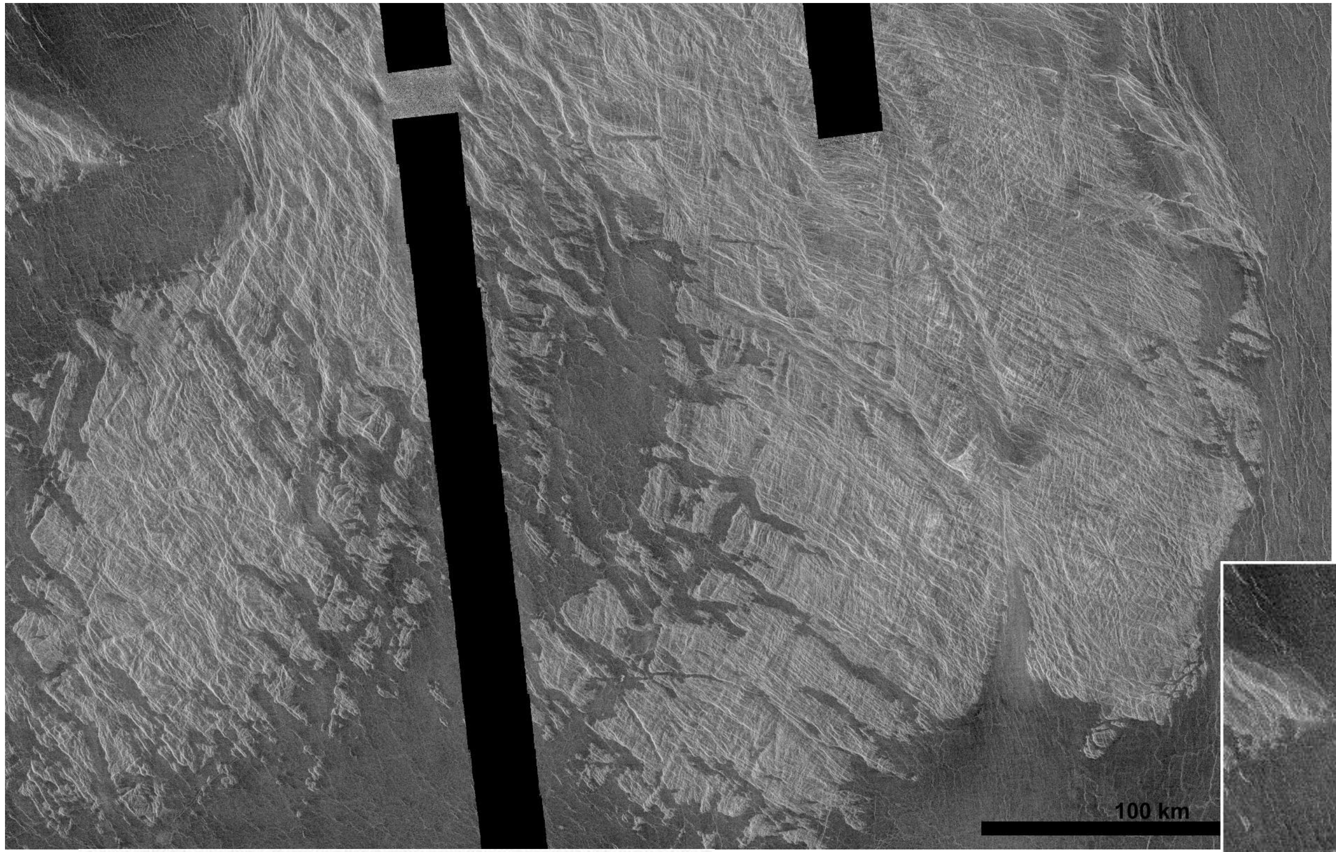
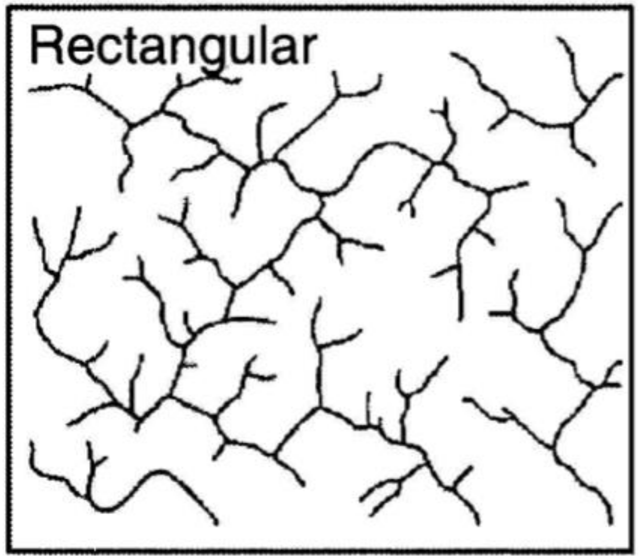

margin-fold terrain
b
d
basin and dome terrain


margin-fold terrain
b
d
basin and dome terrain


100 km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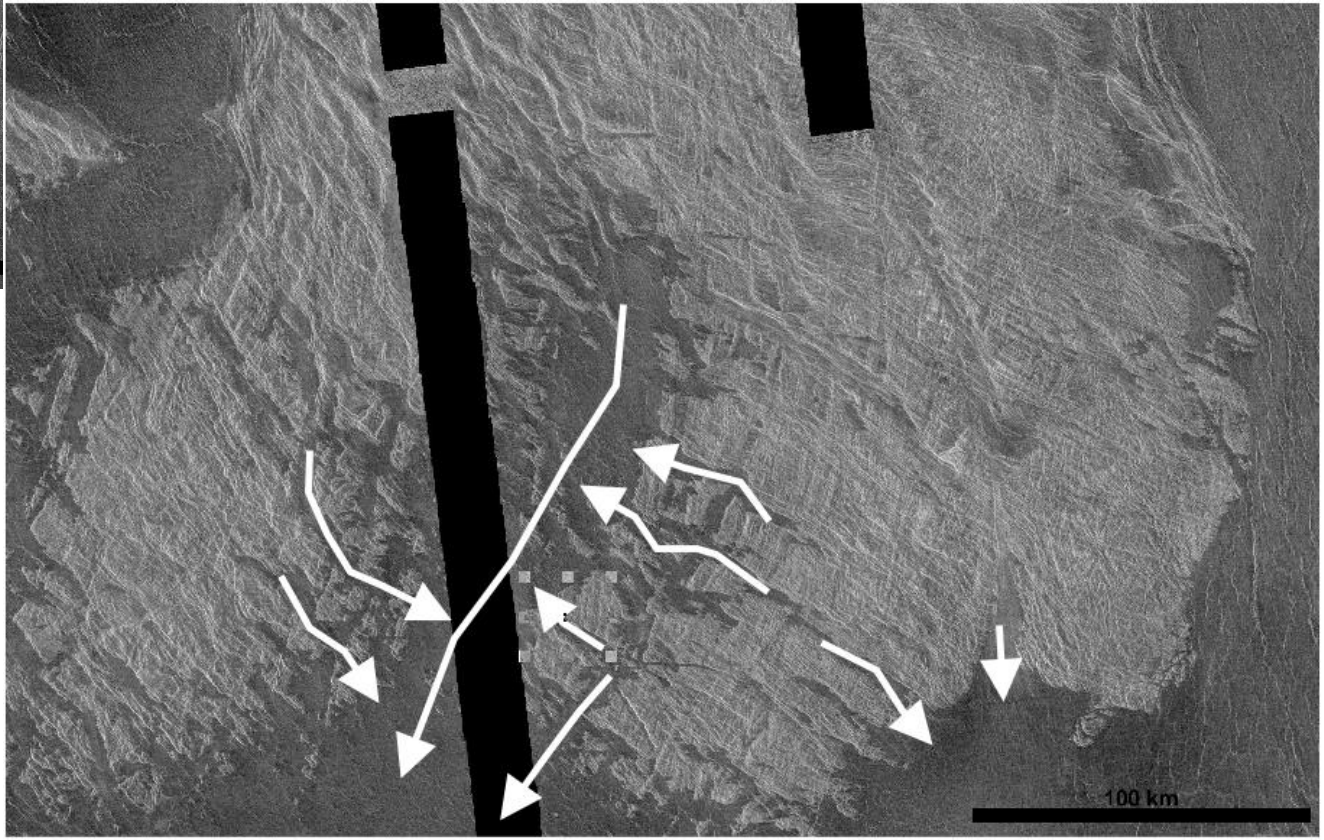
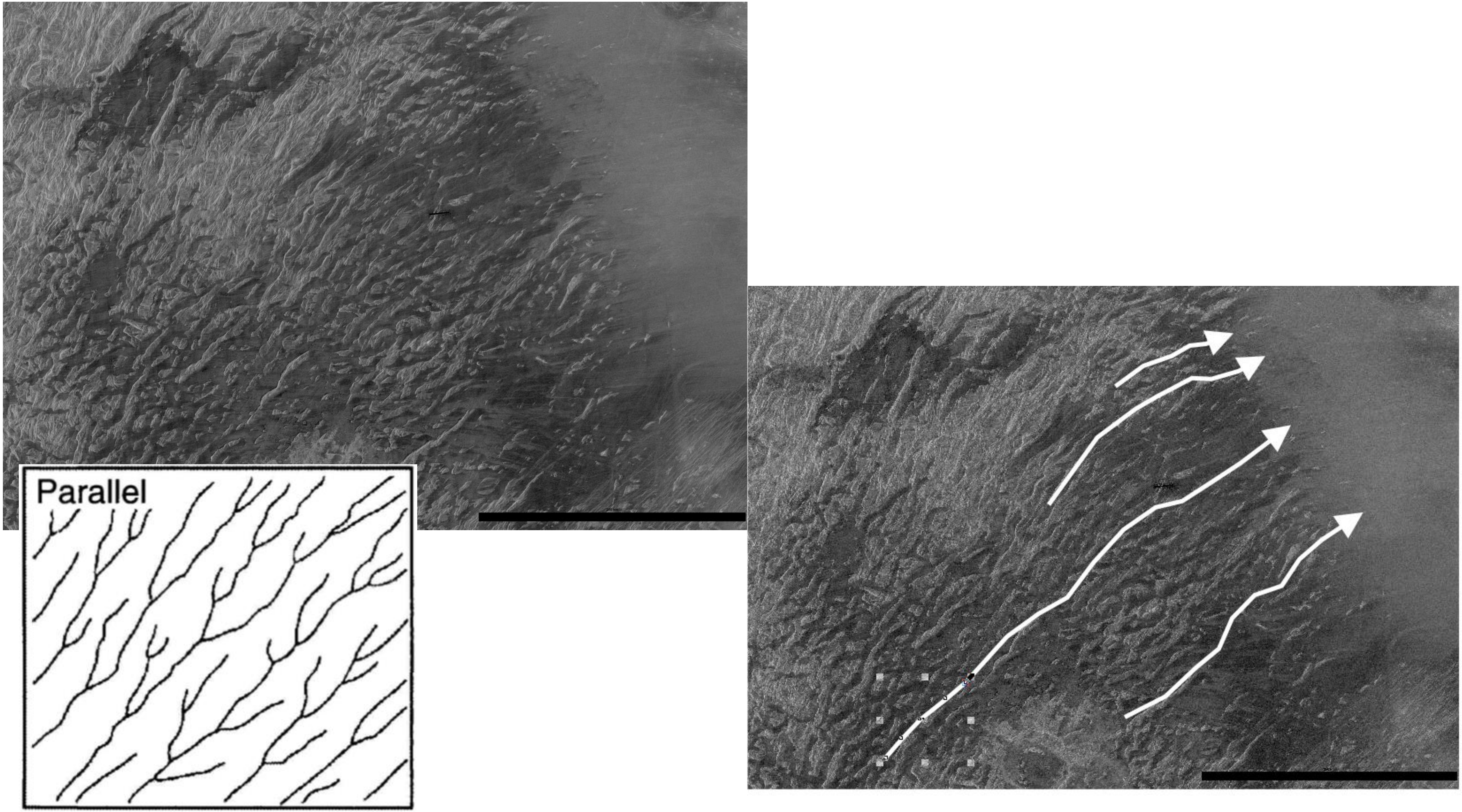

100 km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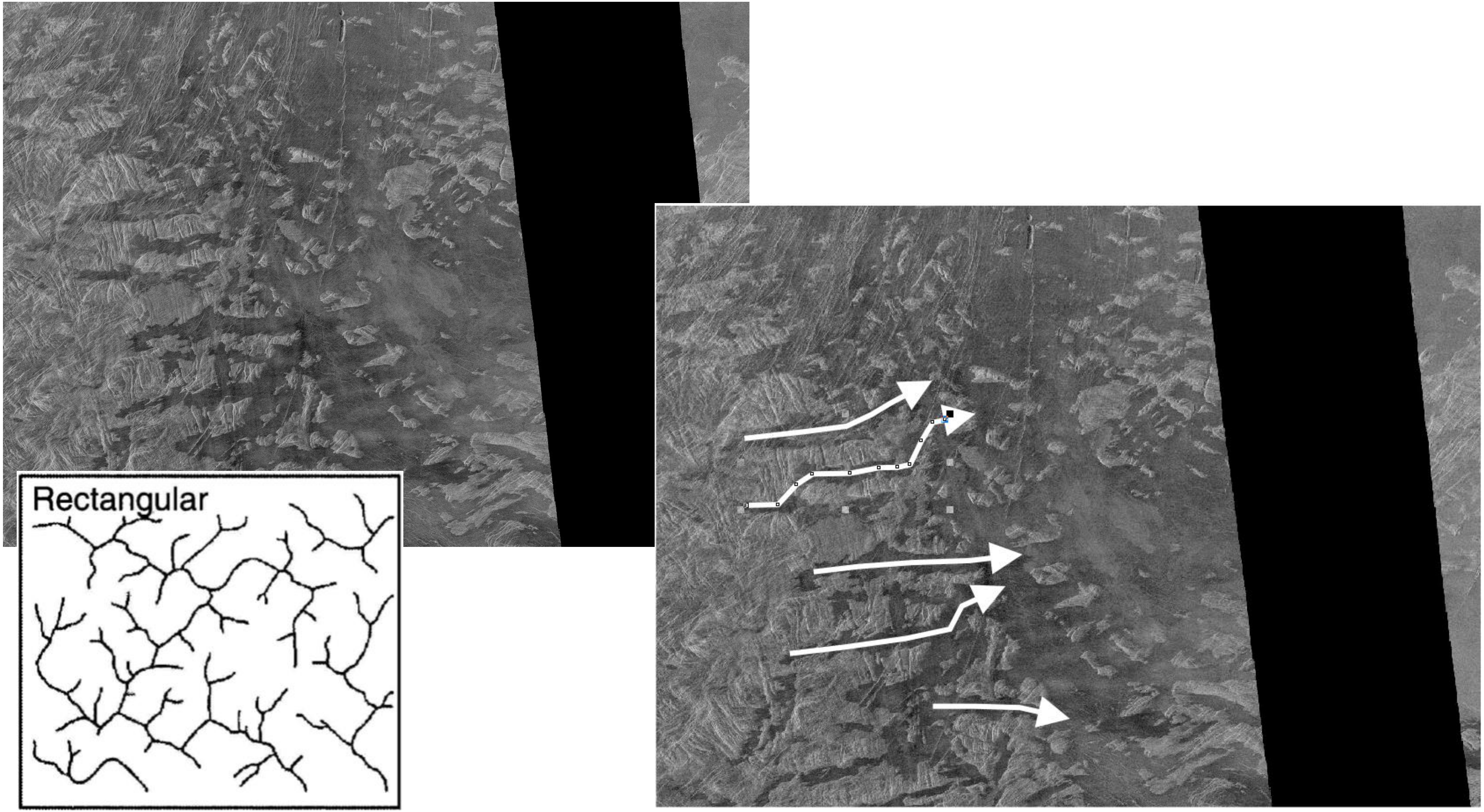
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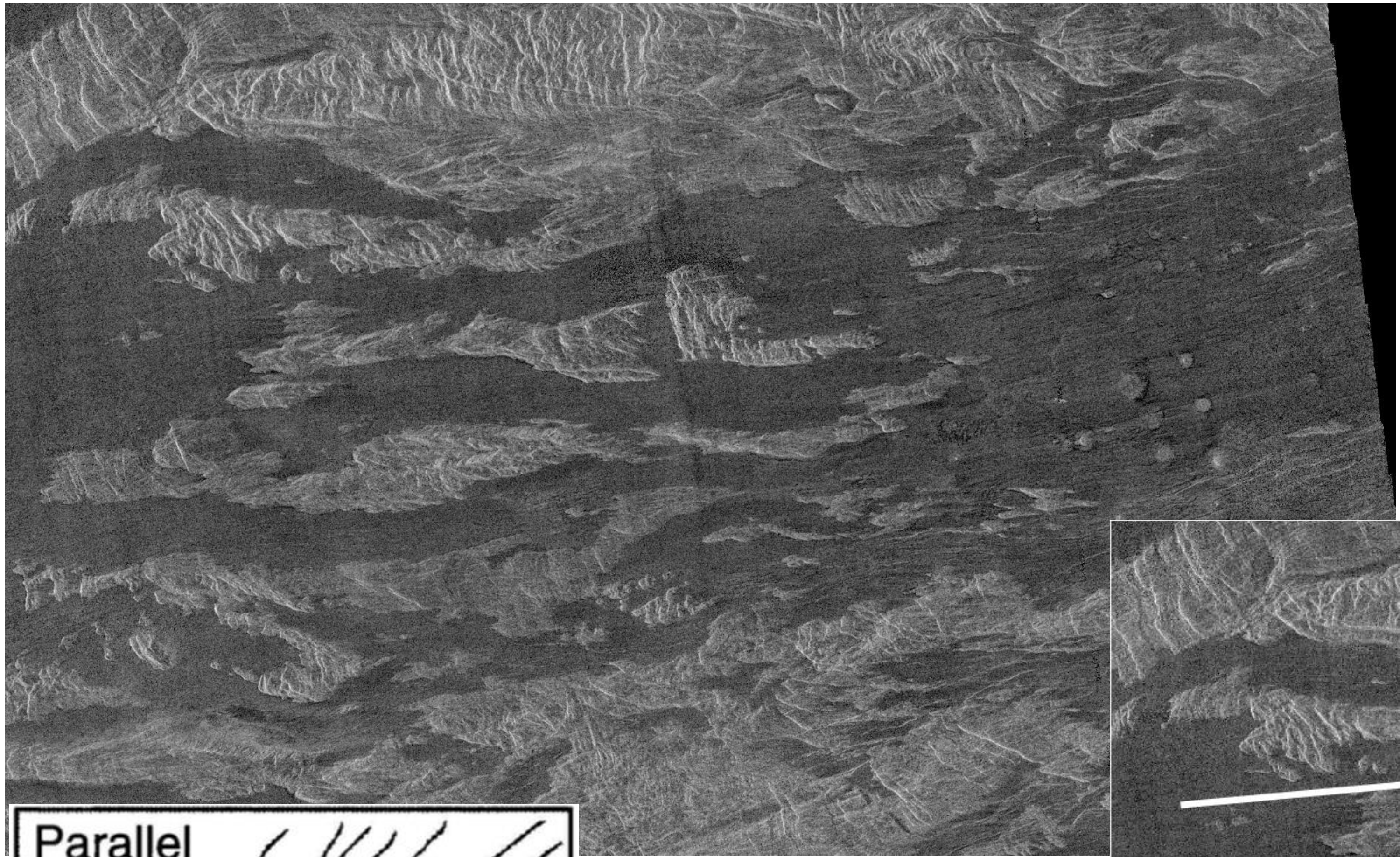

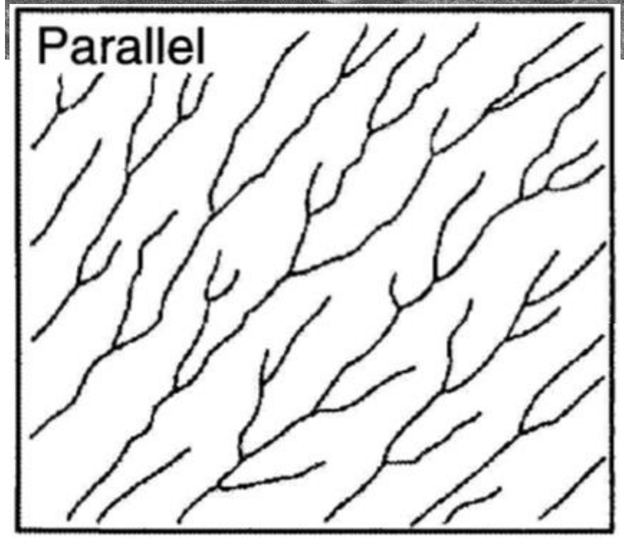
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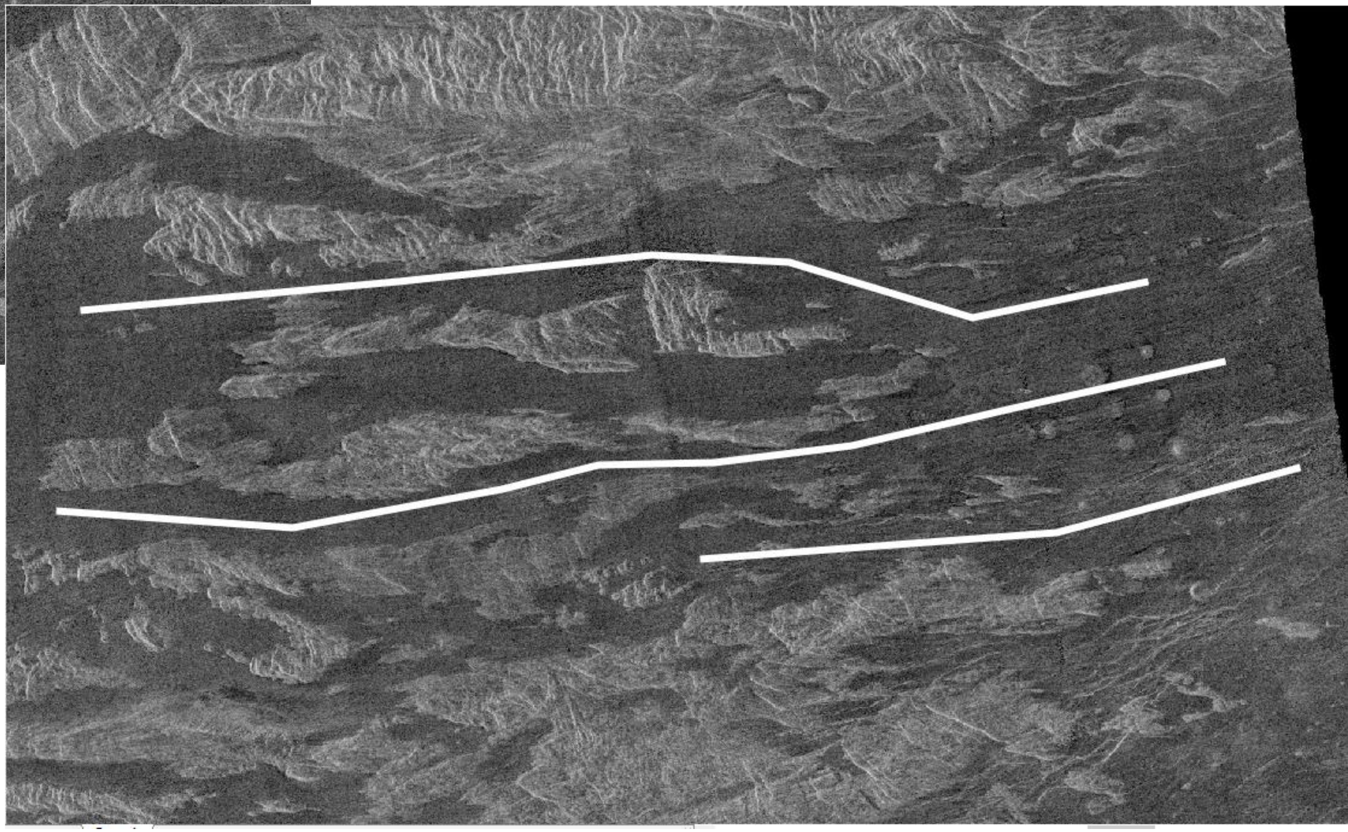

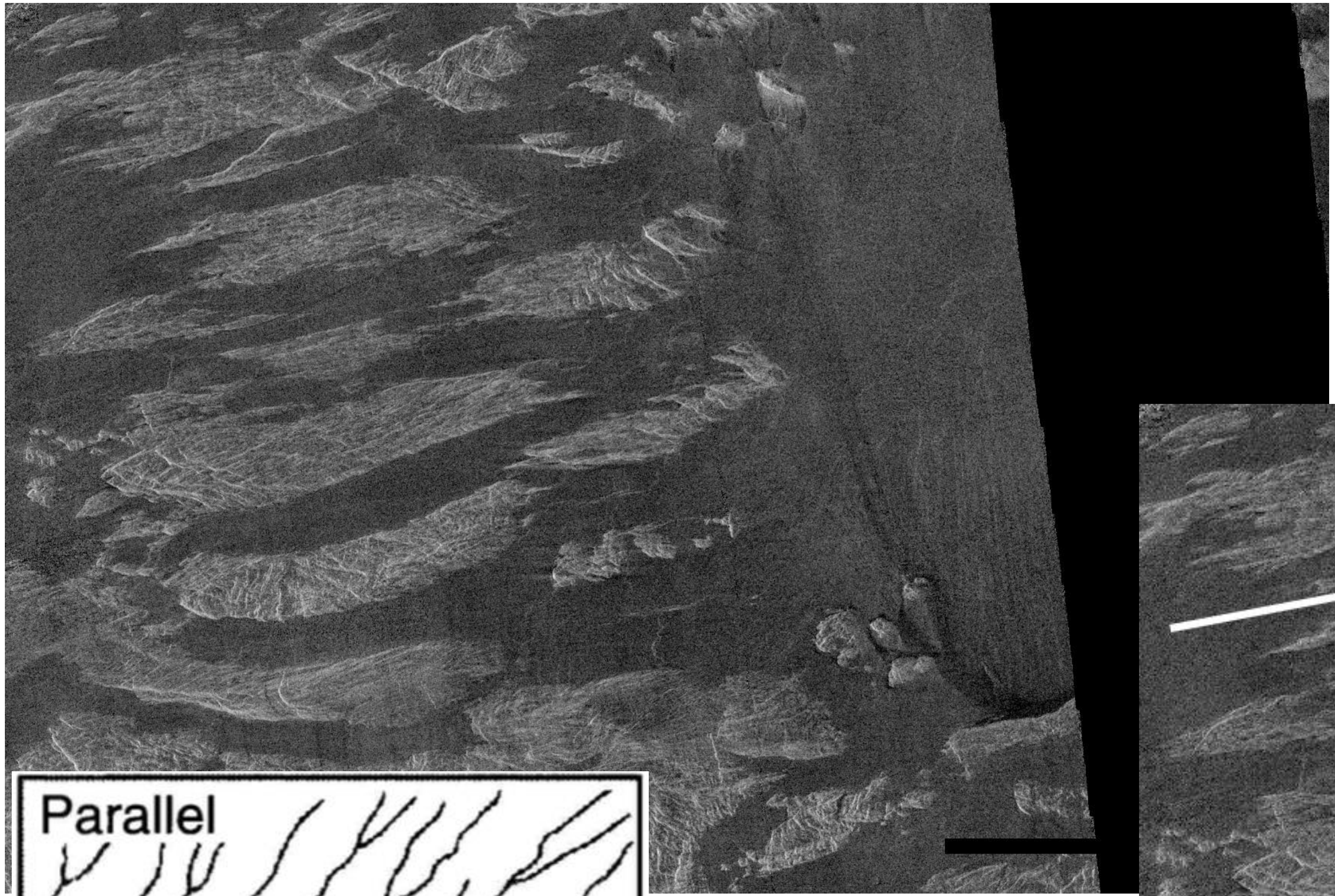

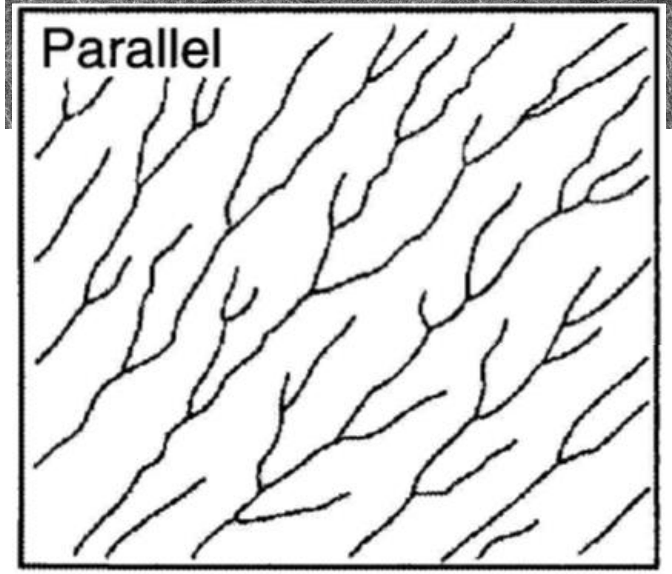
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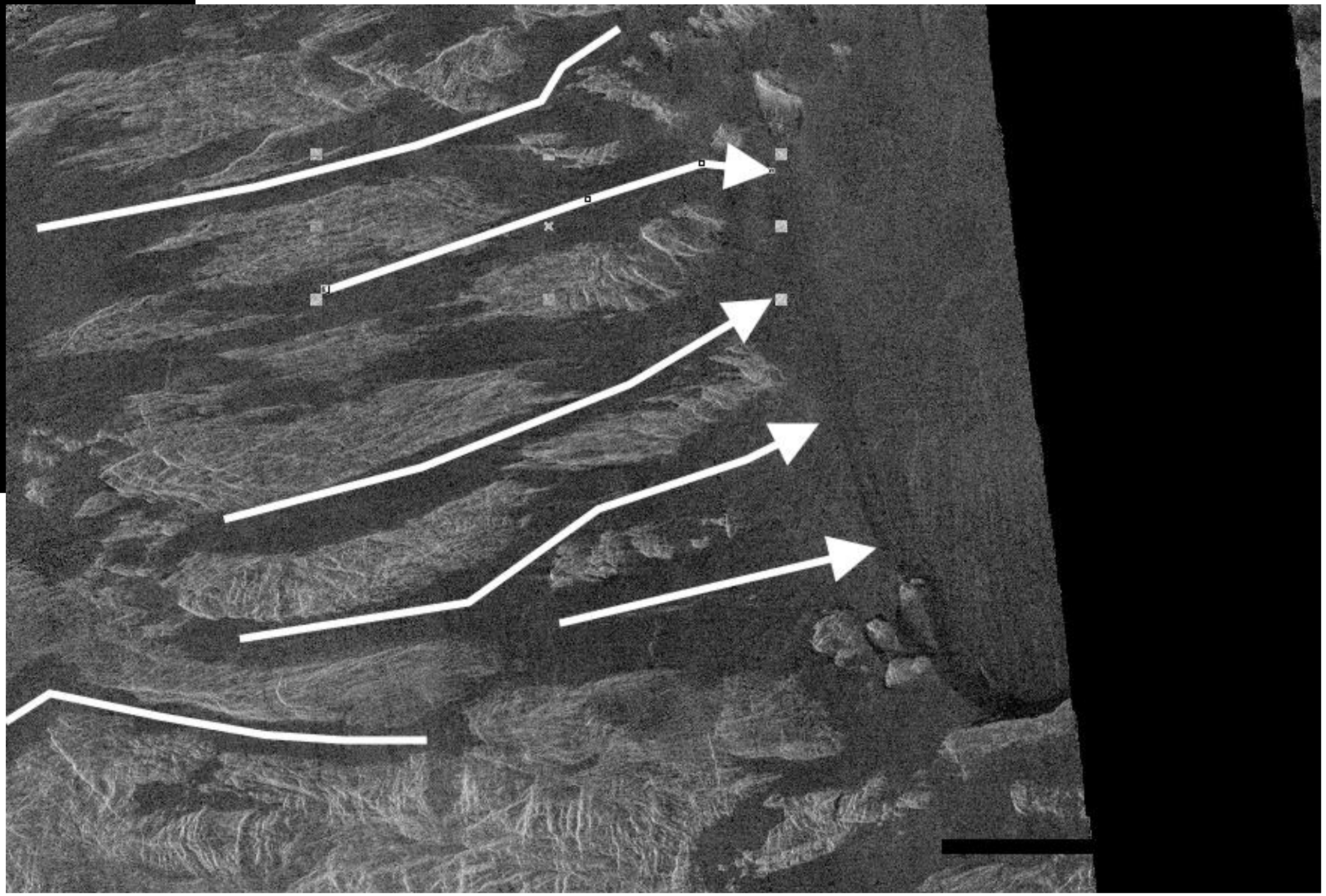
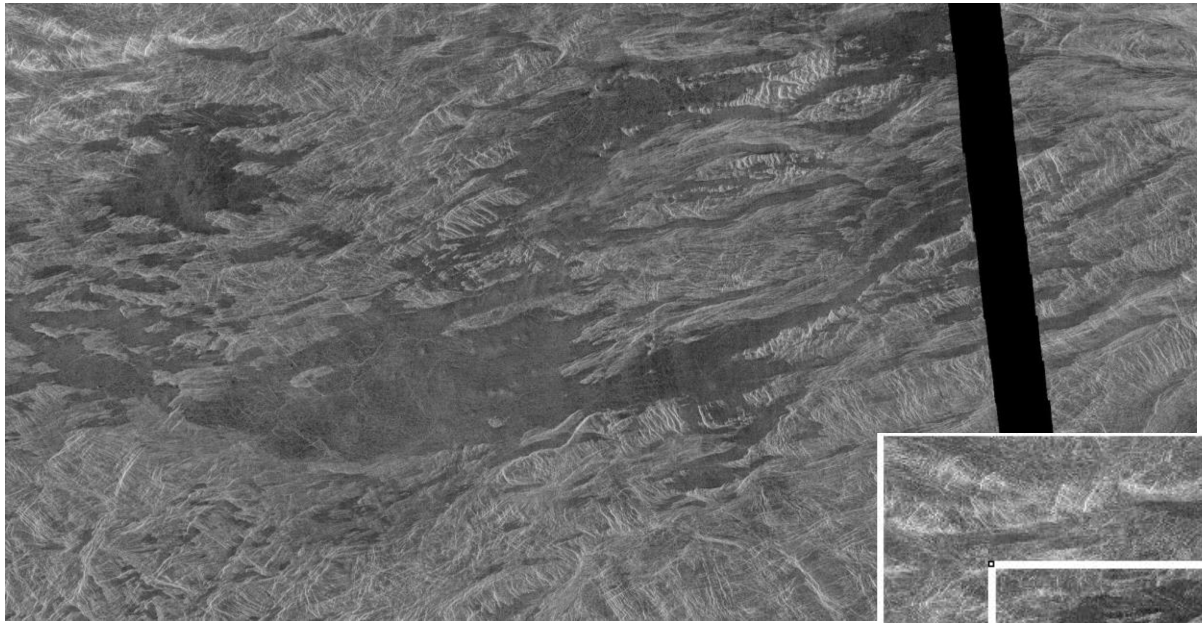
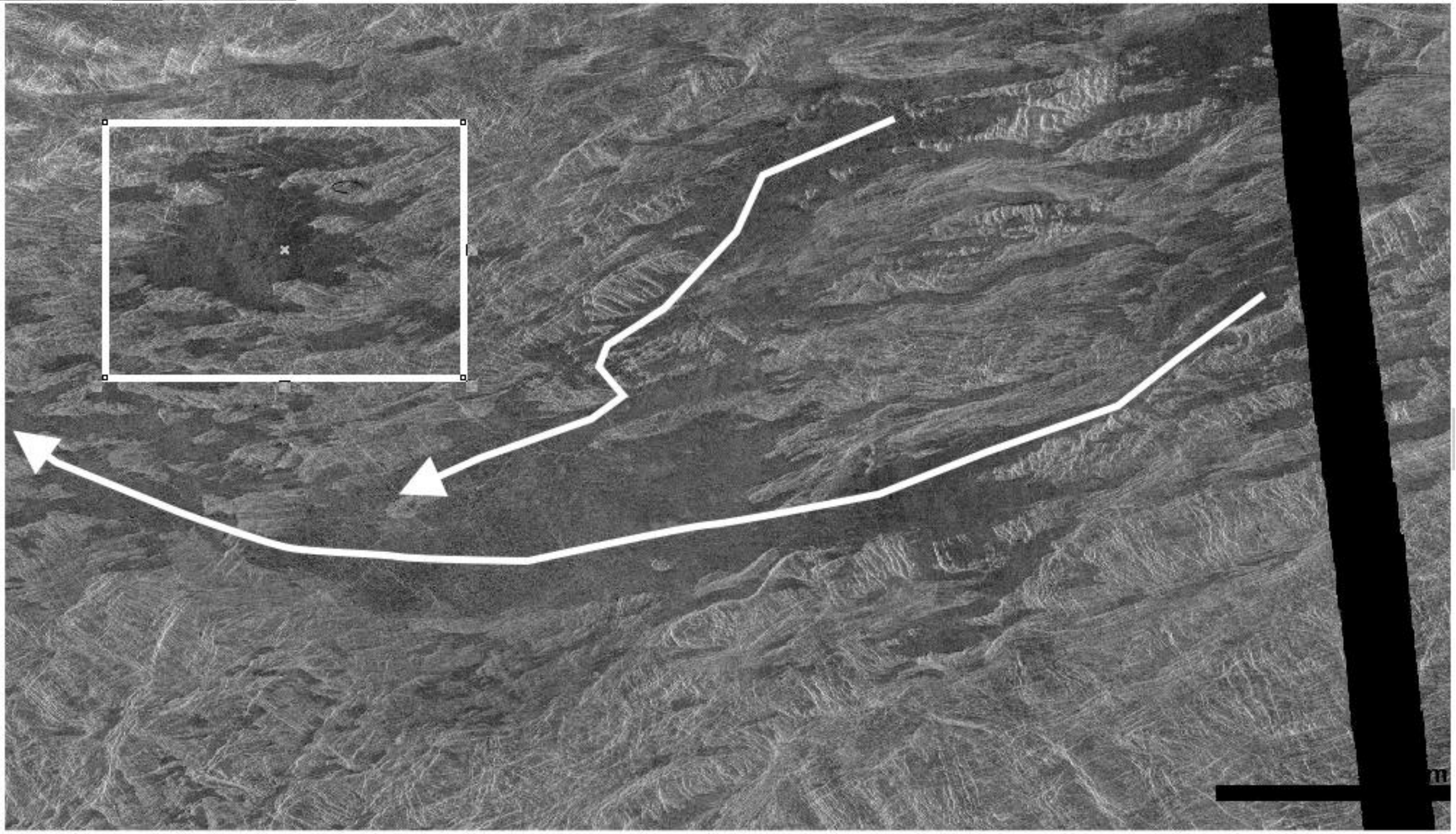
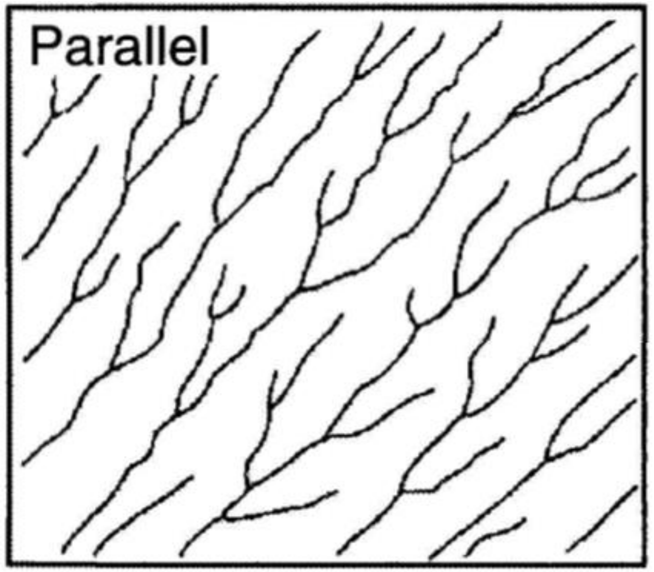







Parallel

Conclusions

- Tesserae terrain are enigmatic in terms of their tectonics and complexity. An impediment to their full understanding is due to the assumption that they did not experience erosion, a case that is better made for younger mafic volcanism
- Here we use partial lava flooding along the margins of tesserae as a local datum to reveal the pattern of local topographic highs (peaks and ridges) and “valleys”
  - We consider these patterns against models in which topography could only be due to primary folds and faults. That interpretation fails and we are left with the necessity of erosion affecting tesserae
- We consider the role of wind, glacial and water erosion
  - The scale of wind erosion on Earth would not be sufficient to explain the erosional patterns on Venus
  - Topographic resolution of Venusian topography is not sufficient to recognize the essential features of glacial erosion (u-shaped valleys, cirques, hanging valleys)
  - Water erosion can produce the appropriate “valley” patterns and thus represents a viable explanation for local topographic variation in tesserae on Venus

QUESTIONS?

7th LIP Conference 2019, Tomsk State University

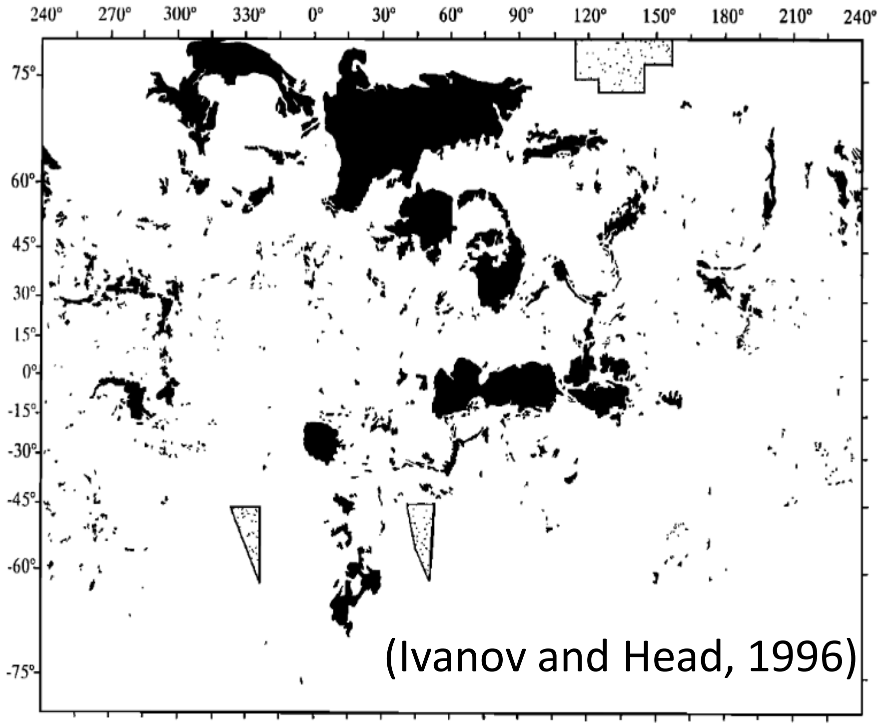
QUESTIONS?

S. Khawja[1], R. E. Ernst[1,2], C. Samson[1,3]

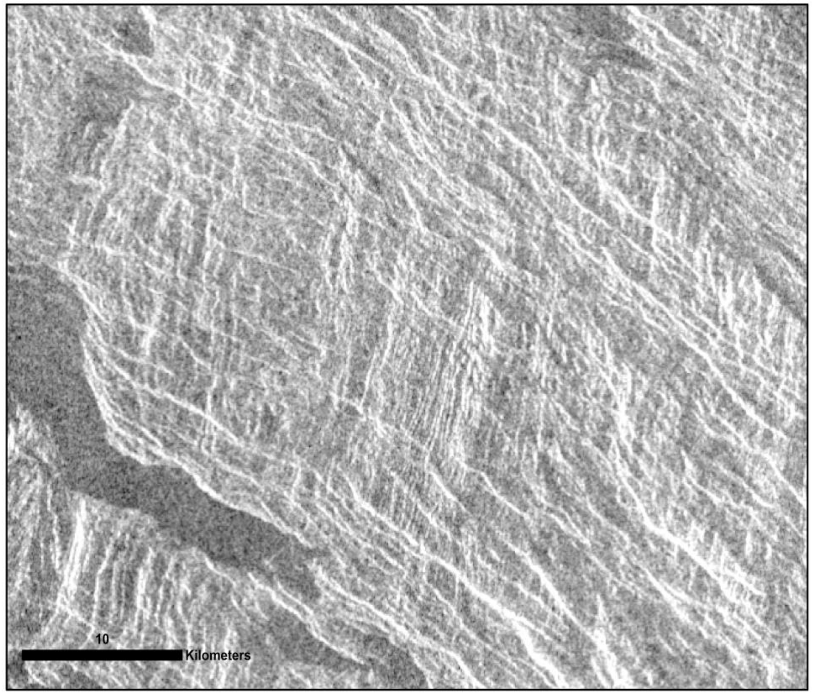
[1] Department of Earth Sciences, Carleton University, Ottawa, Canada
[2] Faculty of Geology and Geography, Tomsk State University, Tomsk, Russia
[3] Department of Construction Engineering, École de Technologie Supérieure, Montréal, Canada

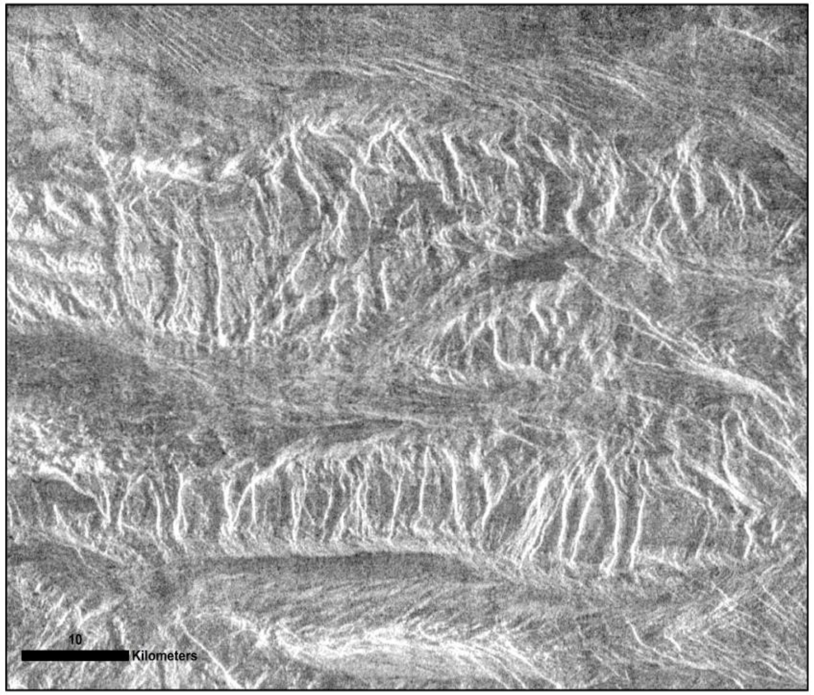
Tesserae

- Occupy approximately 8% of Venus's surface, forming continent-like units (crustal plateaus) embayed by adjacent volcanic plains
- **Consist of at least two sets of intersecting lineaments (e.g. ridges and grooves) and are a result of tectonic deformation of a precursor terrain**
- **Thought to represent oldest structures on Venus (based on crater counting)**



(Ivanov and Head, 1996)





Erosion on Tesserae

- **It has been commonly interpreted that the surface of Venus is primary suggesting that it has not suffered erosion**
- This observation makes sense in view of the high surface temperatures (ca. 450 C) observed on Venus and the absence of free water and therefore the absence of water erosion. However, the assumption of the absence of erosion on tessera can be questioned

AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER
10.1002/2016GL069790

Key Points:
- Venus may have had a climate with liquid water on its surface for approximately two billion years
- The rotation rate and topography of Venus play crucial roles in its surface temperature and moisture
- Young Venus-like exoplanets may be considered candidates for the search for life beyond Earth

Was Venus the first habitable world of our solar system?

M. J. Way[1,2], Anthony D. Del Genio[1], Nancy Y. Kiang[1], Linda E. Sohl[1,3], David H. Grinspoon[4], Igor Aleinov[1,3], Maxwell Kelley[1], and Thomas Clune[5]

[1]NASA Goddard Institute for Space Studies, New York, New York, USA, [2]Department of Astronomy and Space Physics, Uppsala University, Uppsala, Sweden, [3]Center for Climate Systems Research, Columbia University, New York, New York, USA, [4]Planetary Science Institute, Tucson, Arizona, USA, [5]Global Modeling and Assimilation Office, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA

Introduction: MAGELLAN MISSION

- As the planet with the closest approach to Earth, Venus has been a prime target for early interplanetary exploration
  - Difficult with thick atmosphere
- Magellan Mission Launch: May 4th, 1989
- Venus orbit insertion: August 10th, 1990
  - By the end of its mission, Magellan had mapped over 98% of Venus at a resolution of 100 meters or better using Synthetic Aperture Radar (SAR). Images were acquired over three "cycles" at different geometries, permitting stereoscopic views of parts of the surface. Magellan also acquired topography (4 km/pixel), slope, and radiometry measurements of the surface over a mission spanning five years.

Magellan Timeline

04 May 1989	Launch
10 Aug 1990	Venus orbit insertion and spacecraft checkout
15 Sep 1990	Cycle 1: Radar mapping (left-looking)
15 May 1991	Cycle 2: Radar mapping (right-looking)
15 Jan 1992	Cycle 3: Radar mapping (left-looking)
14 Sep 1992	Cycle 4: Gravity data acquisition
24 May 1993	Aerobraking to circular orbit
03 Aug 1993	Cycle 5: Gravity data acquisition
30 Aug 1994	Windmill experiment
12 Oct 1994	Termination experiment - loss of signal
13 Oct 1994	Presumed loss of spacecraft

Source: NSSDC

Introduction: VENUS

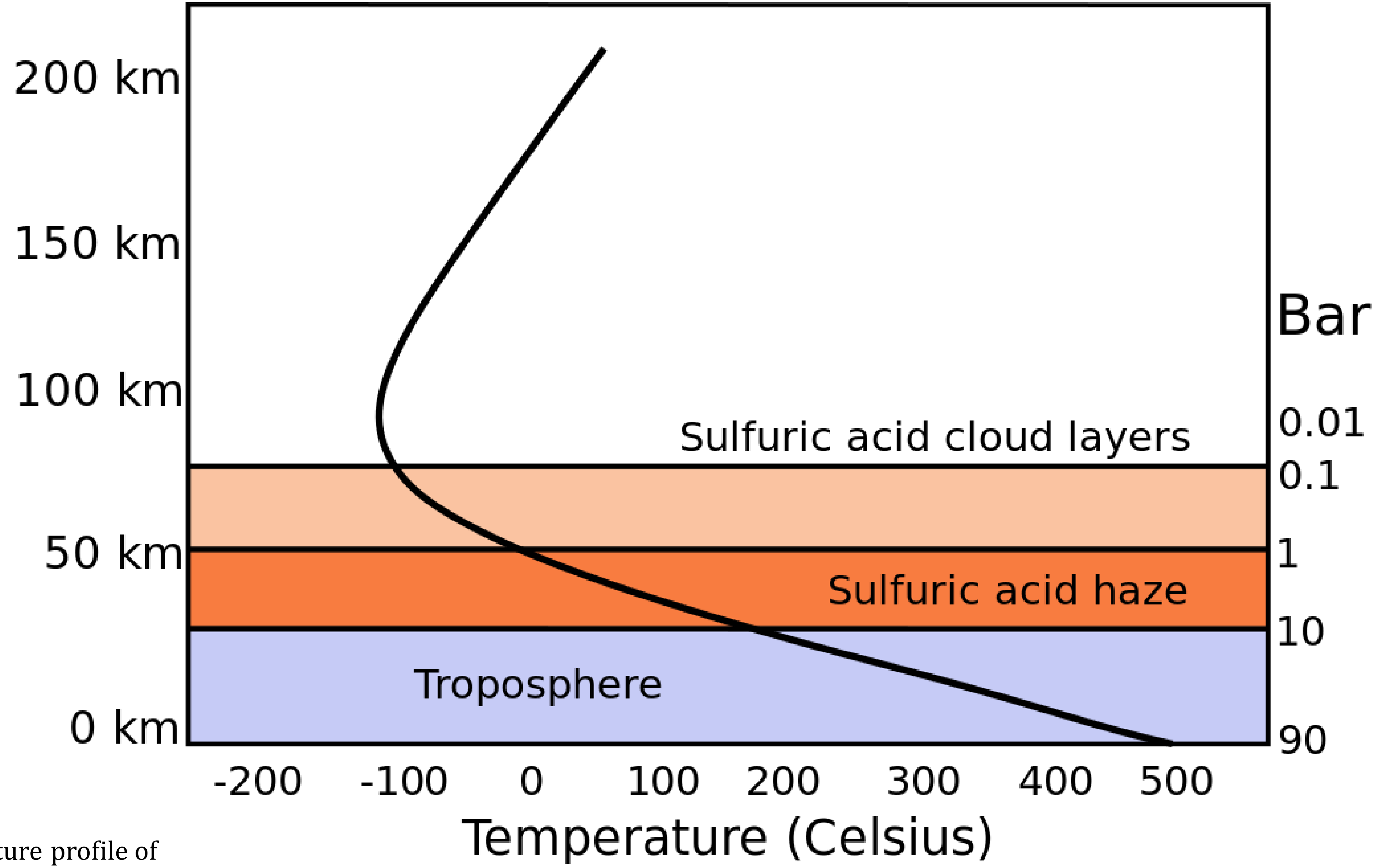


Figure 2: Temperature profile of Venusian atmosphere (Smith, 2012)

Introduction: VENUS

- Second planet from the Sun, and third brightest celestial object in the sky
- Venus is known as Earth's sister planet because they both have similar size, mass, and density
  - Volume: 9.28 x 1011 km3 (0.857 times Earth volume)
  - Mass: 4.87 x 1024 kg (0.815 times Earth mass)
  - Mean density: 5.24 x 103 kg/m3 (0.951 times Earth mean density)
  - Surface gravity: 8.87 m/s2 (0.905 times Earth surface gravity)

Similar but also quite different!

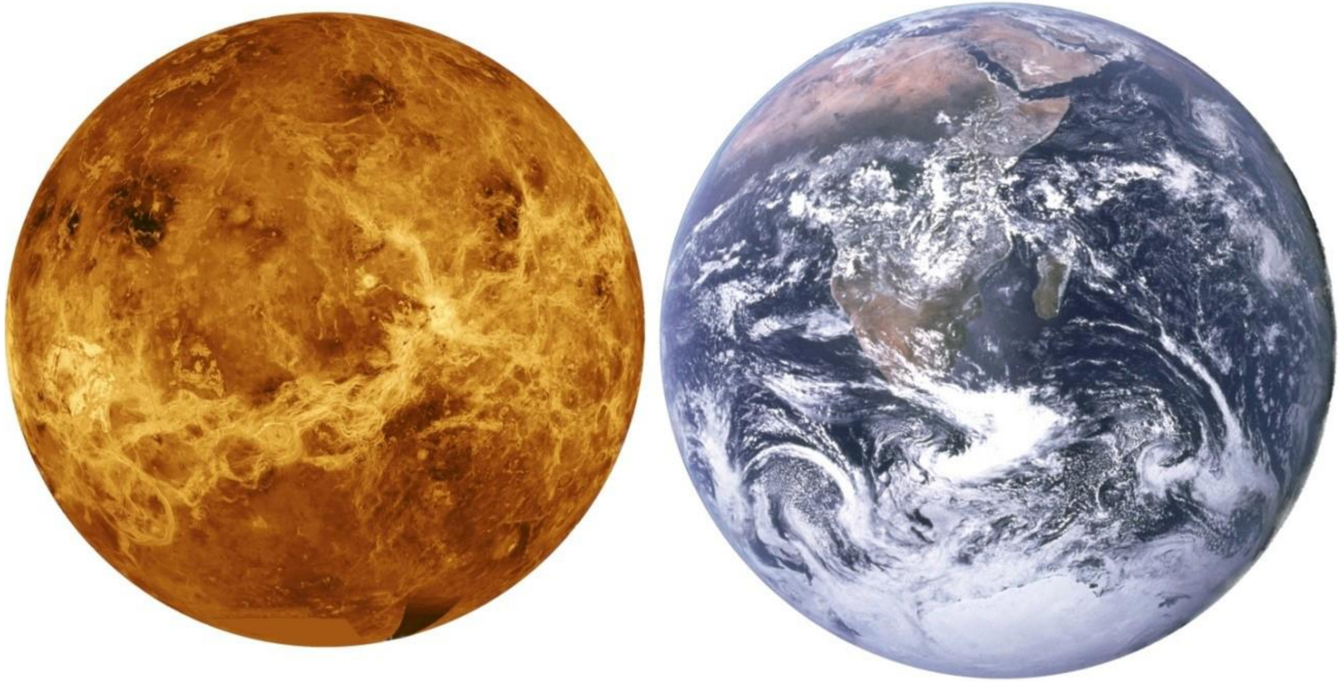


Figure 1: Size comparison of Venus and Earth. Venus (6051 km mean radius) shown on the left, imaged using the microwave spectrum; Earth (6371 km mean radius) on the right, imaged at the visible spectrum.

Introduction: OVERVIEW OF GEOLOGY

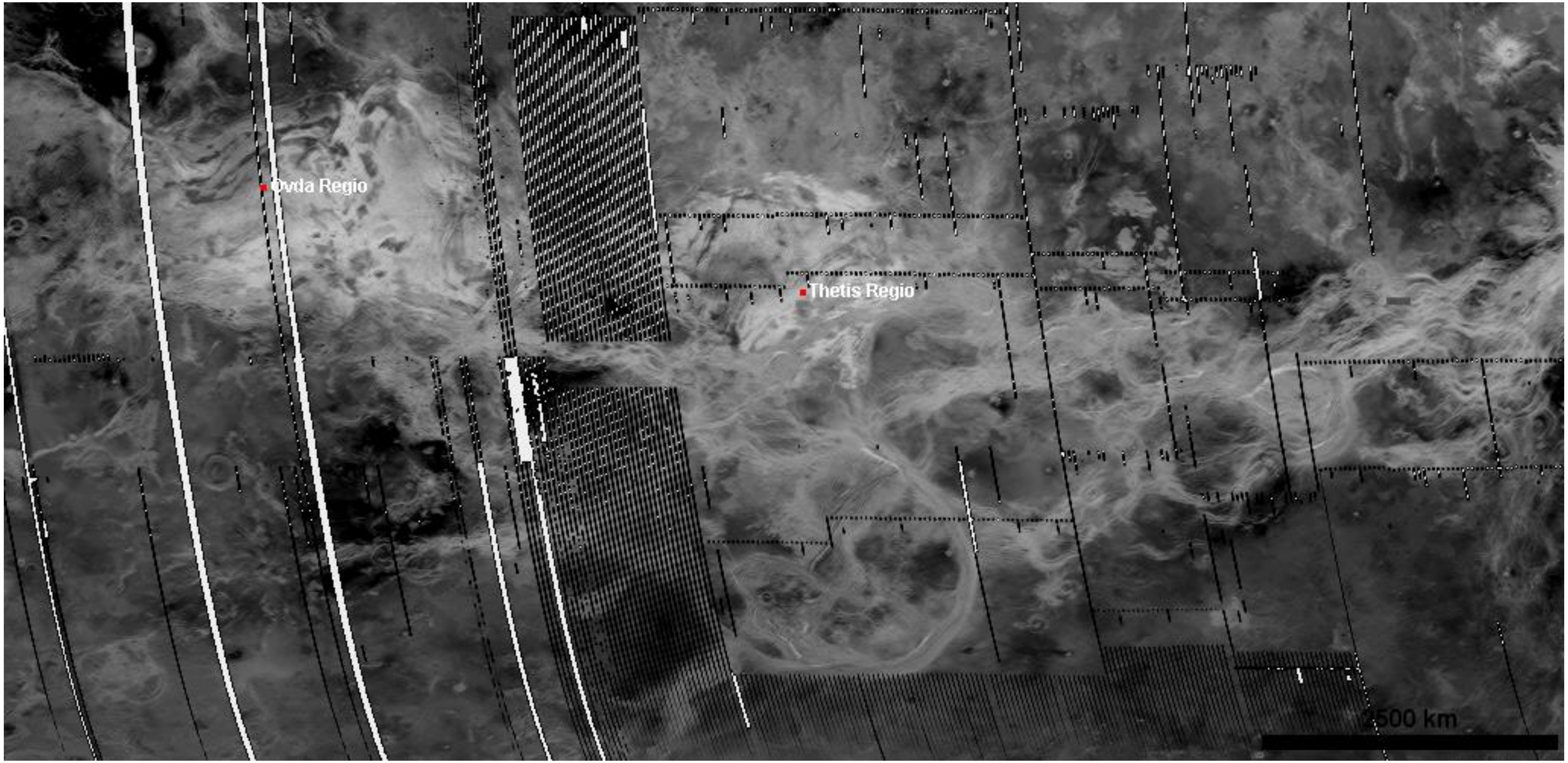
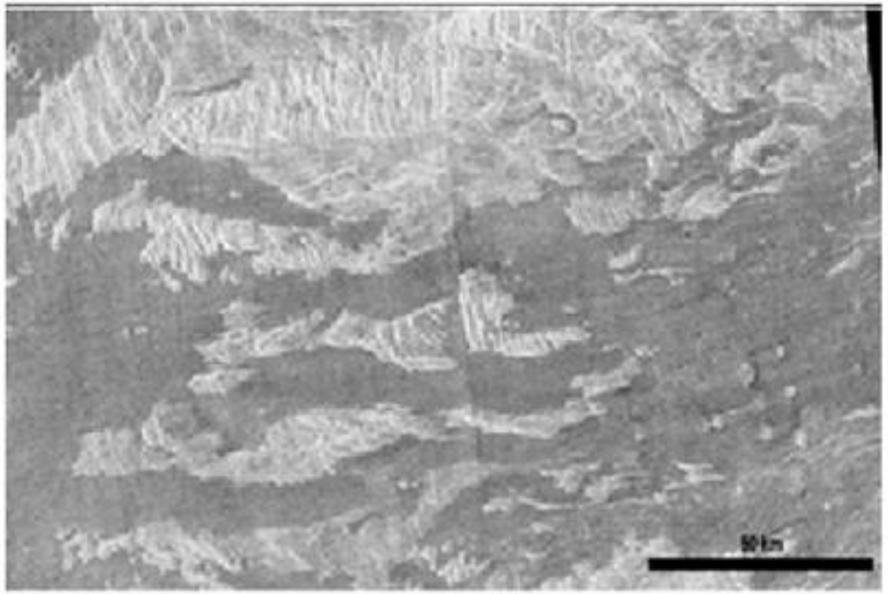
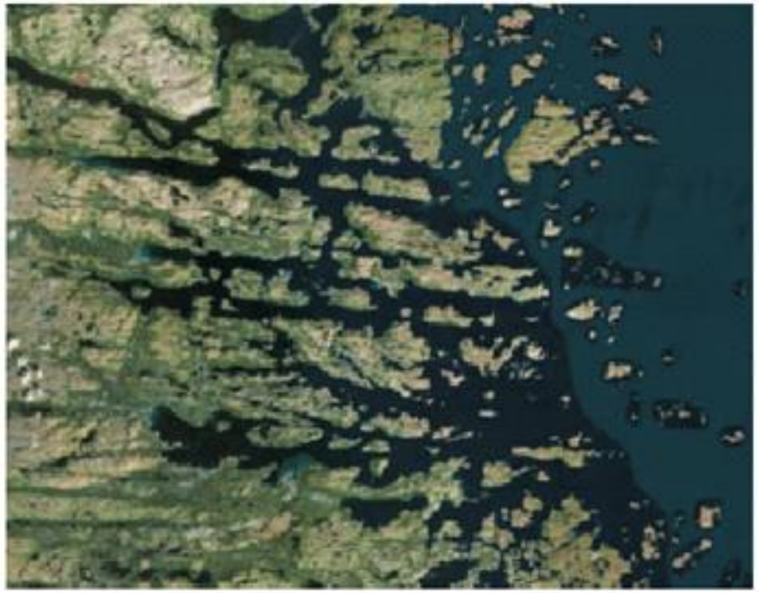


Figure 6: Thetis and Ovda Regio, equatorial highlands on Venus.
Lat, Long: 129.5°E, 10.4°S

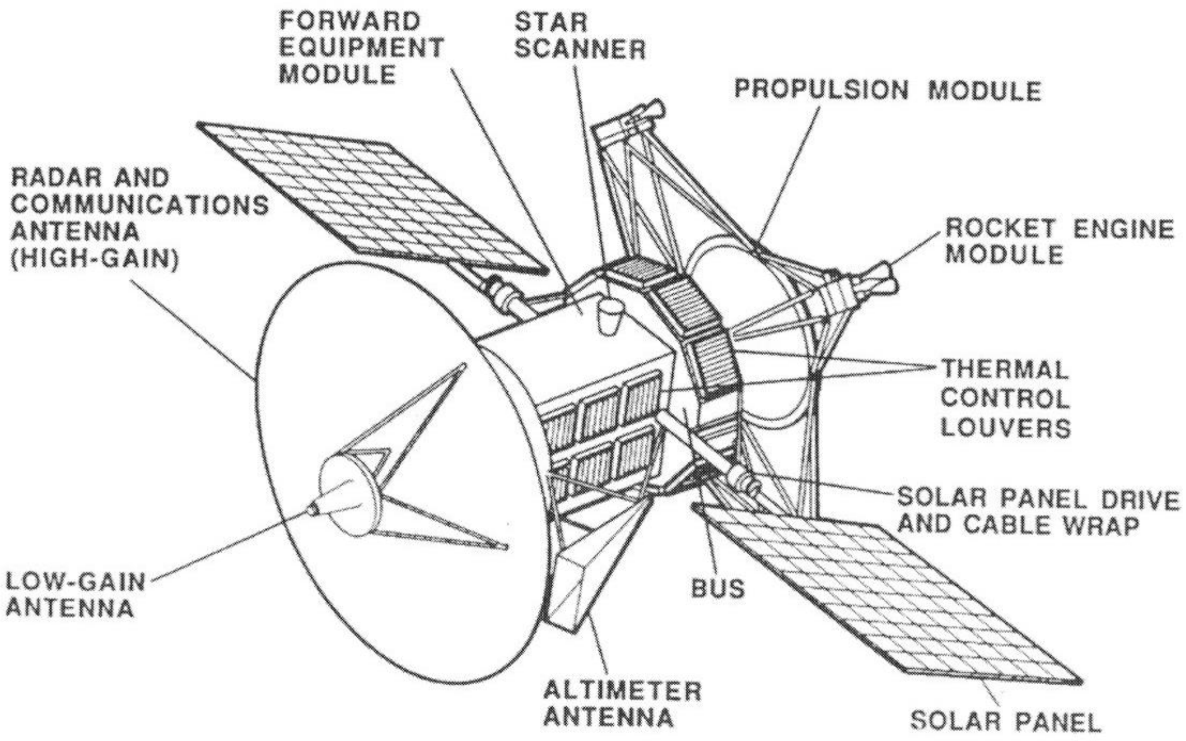


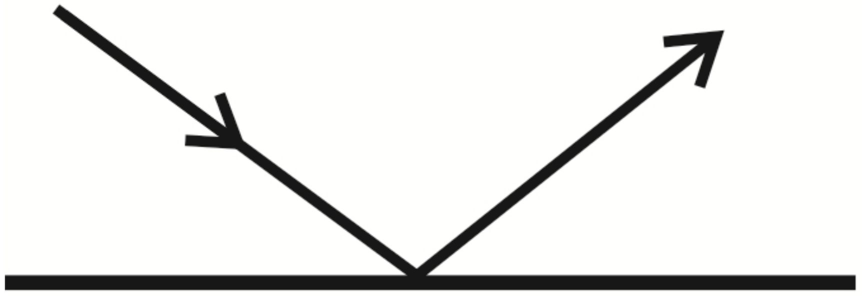


Introduction: VENUS

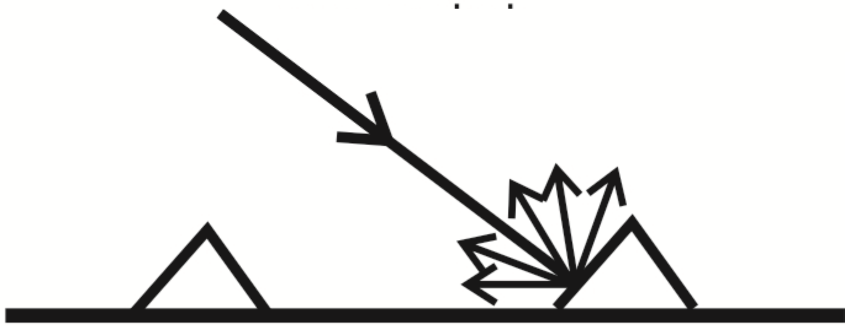
- Dense atmosphere results in surface pressures of approximately 9.2 MPa, about 90 times greater than the Earth
  - Pressure found 3,000 ft underwater on Earth
- Venus is the hottest planet in the Solar System, with a mean surface temperature of 735 K (462 °C)
  - *Even though Mercury is closer to the Sun*
- Venus has a global cloud cover composed of 75% sulphuric acid, with lesser quantities of nitrogen gas (N2), hydrogen sulphide (H2S), and low-lying cloud layers of sulphuric acid (H2SO4) droplets
- Abundance of these gases creates a runaway greenhouse effect by trapping nearly all of the Sun`s incoming radiation, in addition to any internal heat dissipated from the planetary interior

Introduction: MAGELLAN MISSION



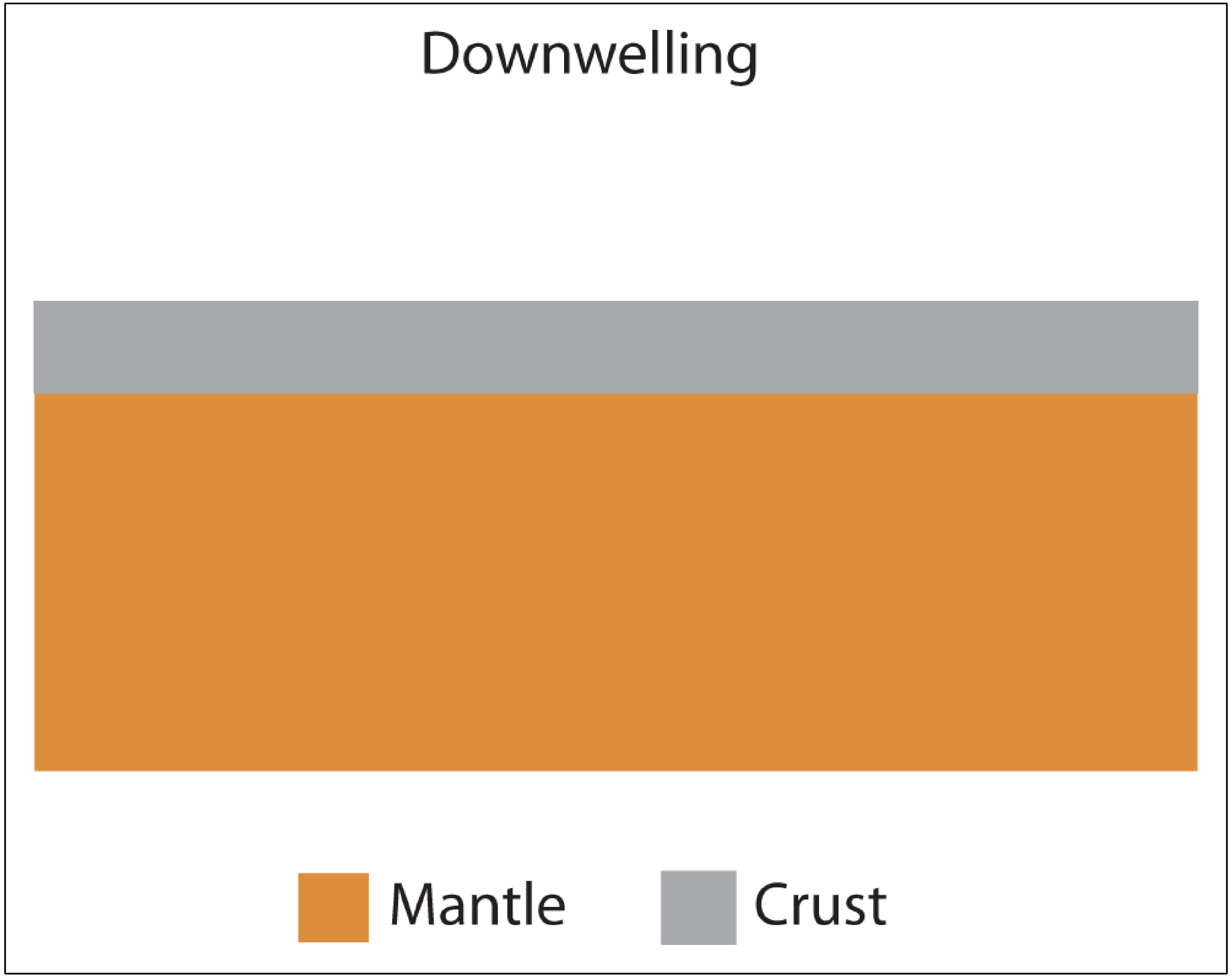


Smooth: Radar signal reflects away from spacecraft, no reflections detected by receiver; image



Rough: Radar signal scatters against rough or uneven surfaces, reflections detected by receiver; image appears bright.

Introduction: TESSERAE



Source: Gilmore, 1998

Introduction: TESSERAE

- Tesserae are thought to represent an ancient time of globally thin lithosphere on Venus
- It was thought by many researchers that the tesserae might form an "onion skin" and extend beneath the plains, however more research is coming forth in support of regional formation
- Many models have been put forward to explain the formation of tesserae
  - Mantle downwelling (Gilmore, 1998) is currently the most accepted model

- Downwelling
  - Mantle downwelling (mantle convection?) causes compression and thickening of the crust and compression structures that are seen on tesserae
  - Isostatic rebound occurs due to crustal thickening and delamination within the mantle produces extensional features seen on tesserae

Introduction: OVERVIEW OF GEOLOGY

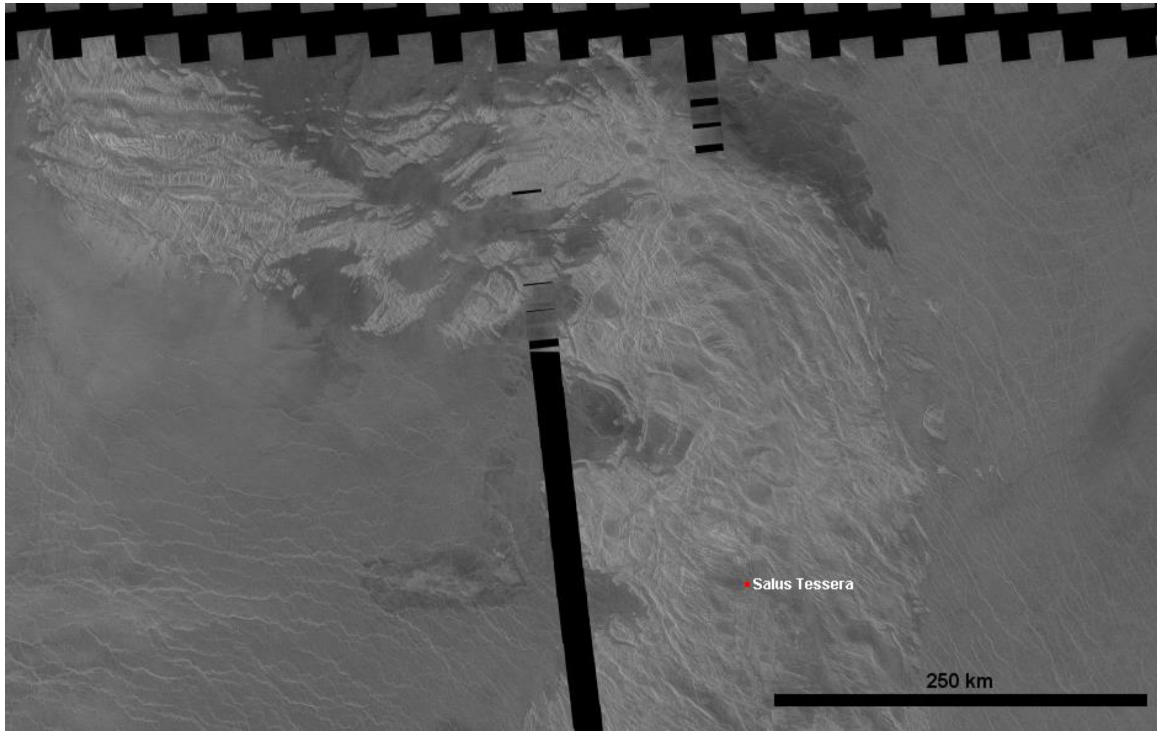


Figure 4: Salus tessera surrounded by volcanic flooding. Other features seen include wrinkle ridges.
Lat, Long: 46.7°E, 1°N

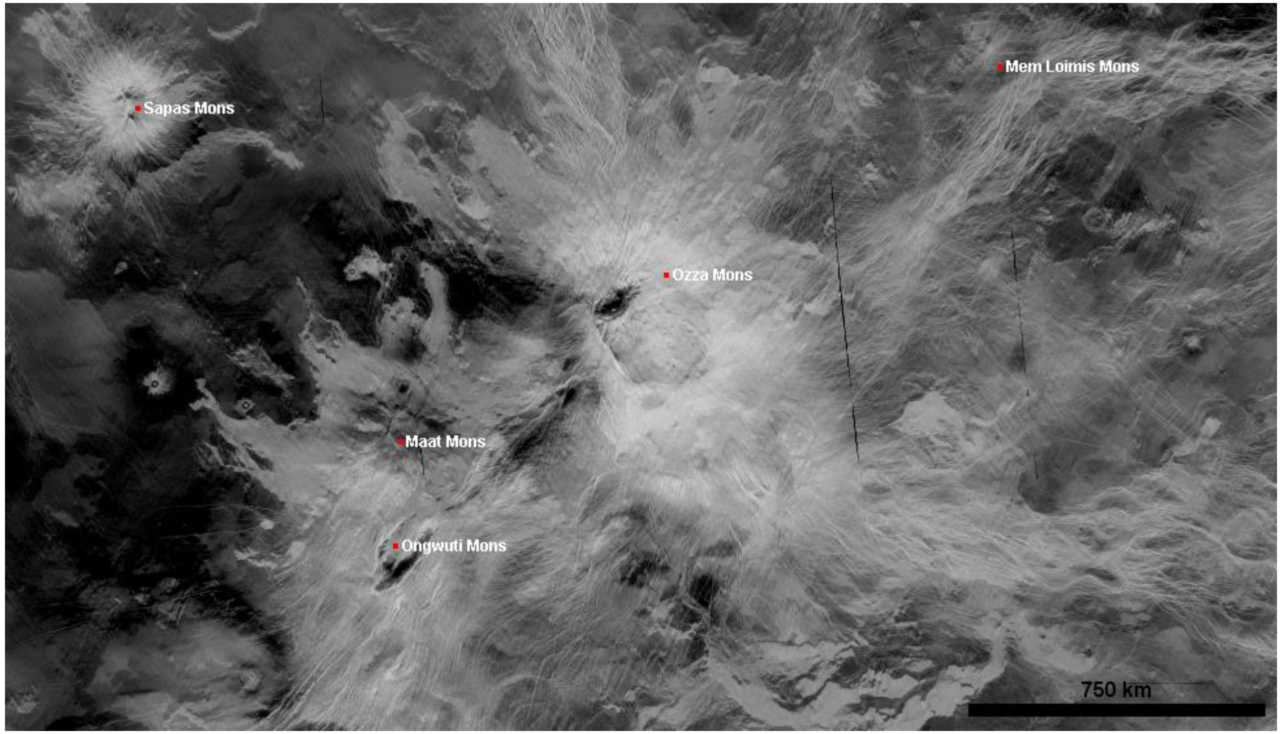


Figure 5: Biggest volcanoes on Venus: Maat mons, Ozza Mons, Ongwuti Mons, Sapas Mons and Mem Loimis Mons
Lat, Long: 194.6°E, 5°N

Introduction: OVERVIEW OF GEOLOGY

- **From crater counting, the age of Venus' surface is interpreted to be only 500 – 700 Ma, supporting the well-accepted idea that Venus experiences global resurfacing events as a primary method of global heat loss**
- **The exact style of global resurfacing is still under debate as to whether it occurs via catastrophic or steady-state processes**
- **Following the Magellan mission, many tectono-magmatic structures on Venus have been readily observed and studied from the analysis of SAR images**
- Features include large volcanoes and volcanic rises; graben-fissure systems and rift zones created as a result of local and regional extensional deformation; lava flooded plains material featuring clusters of shield volcanoes; densely packed extensional lineations, and contractional groove belt structures; coronae; pit crater chains; and major highland mountain belts and heavily deformed ***tessera terrain***