Valles Marineris

The Grandest Canyon in the Solar System

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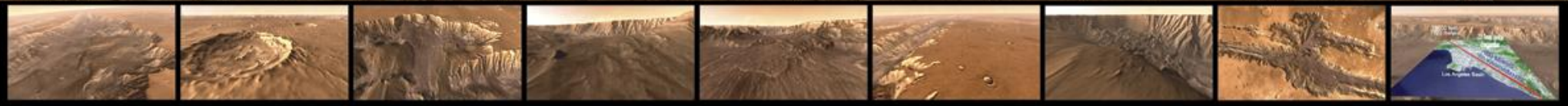
EARTH 438: Mars
3/6/17

http://www.space.com/20446-valles-marineris.html

THEMIS

THERMAL EMISSION IMAGING SYSTEM



MARS ODYSSEY

JPL Lockheed Martin Raytheon

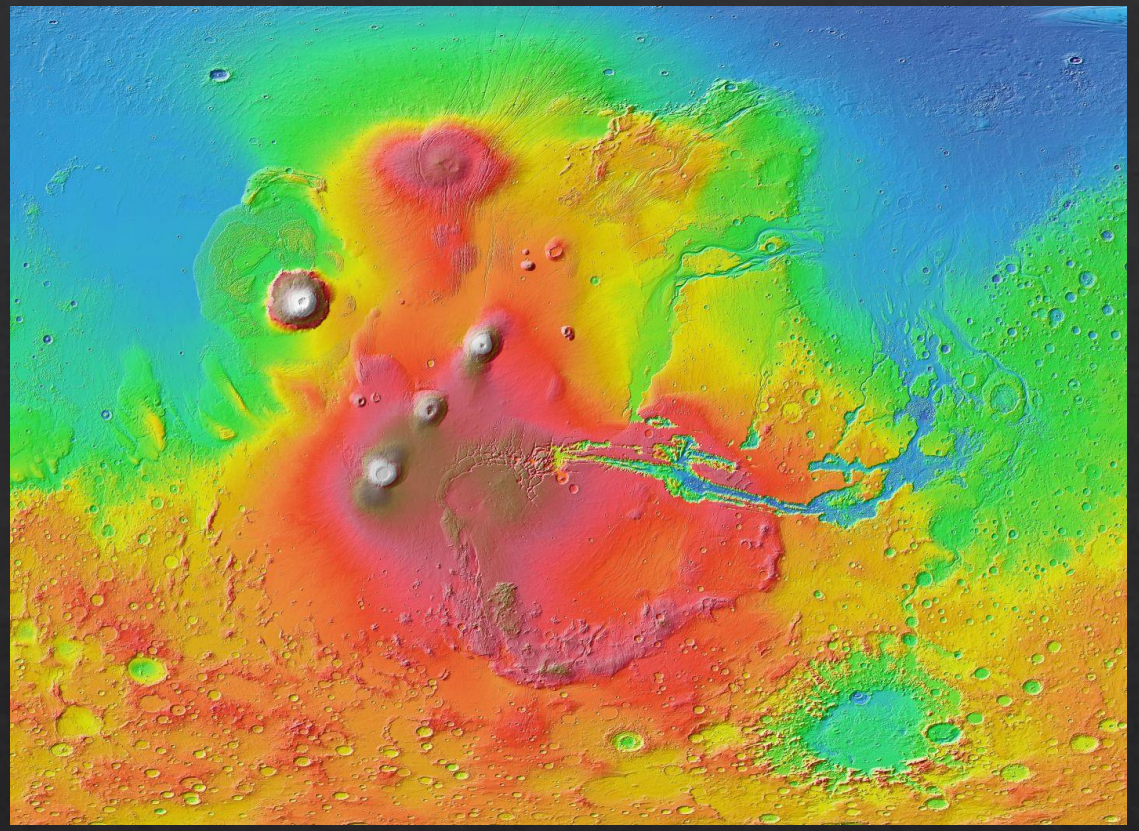
Flight Into Mariner Valley: The Movie

A movie by Arizona State University and the Jet Propulsion Laboratory's Digital Image Animation Laboratory using THEMIS infrared mosaics.

ASU Arizona State University

Introduction

- Valles Marineris is a vast system of interconnected canyons and troughs on Mars
- Latin for Mariner Valley, named after the Mariner 9 orbiter that discovered it in 1971
- East-west trending just south of the Martian equator
- Largest canyon in the Solar System
- 4000 km long, up to 11 km deep, and up to 700 km wide (Fueten et al., 2014)
- Spans more than one fifth of the equatorial circumference of Mars



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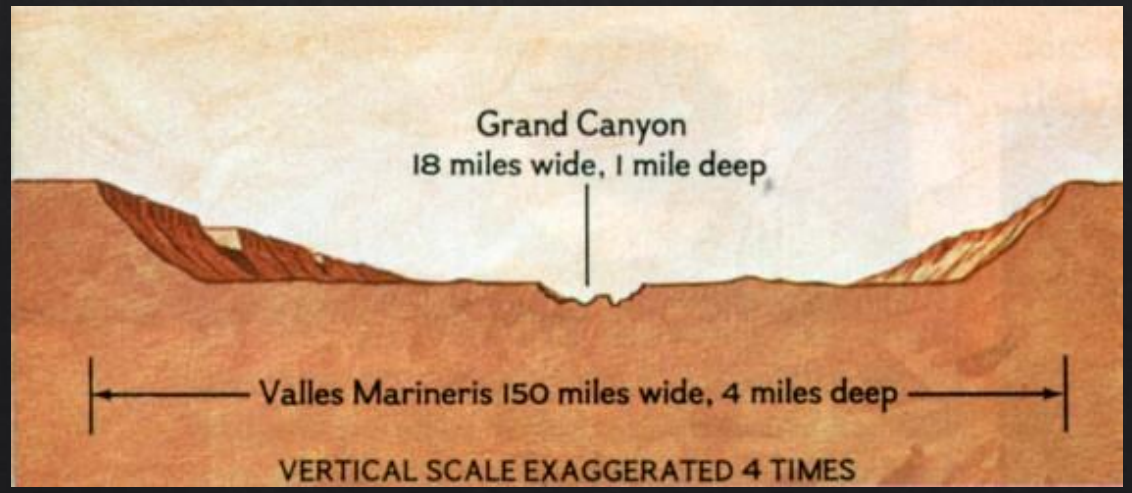

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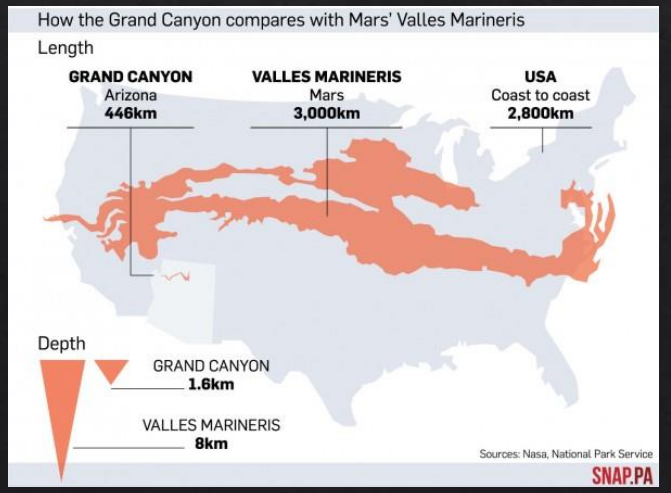
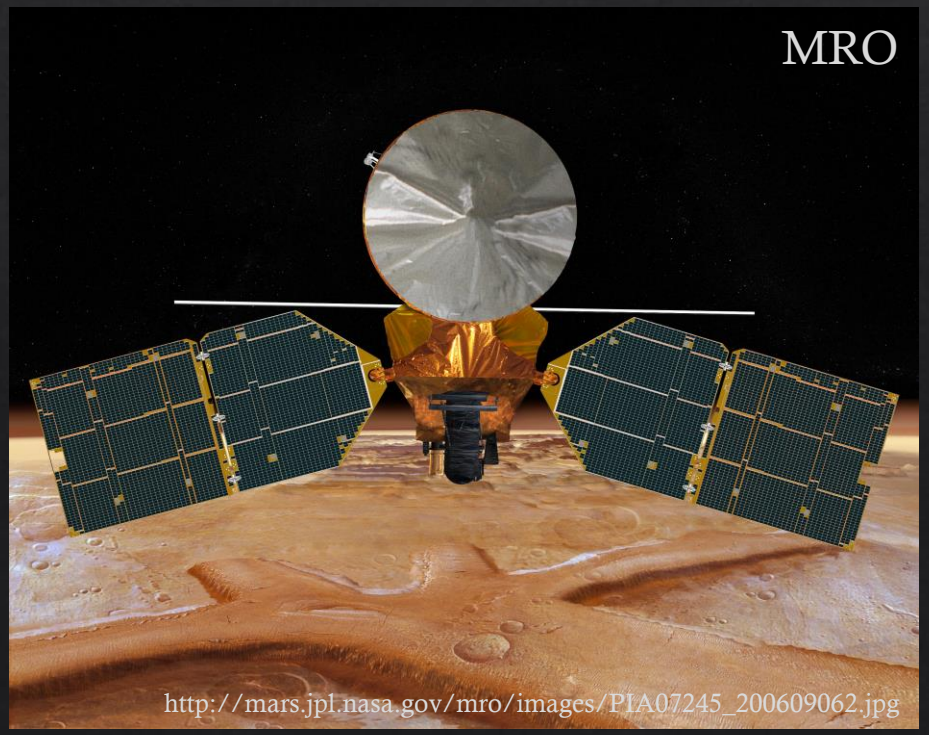


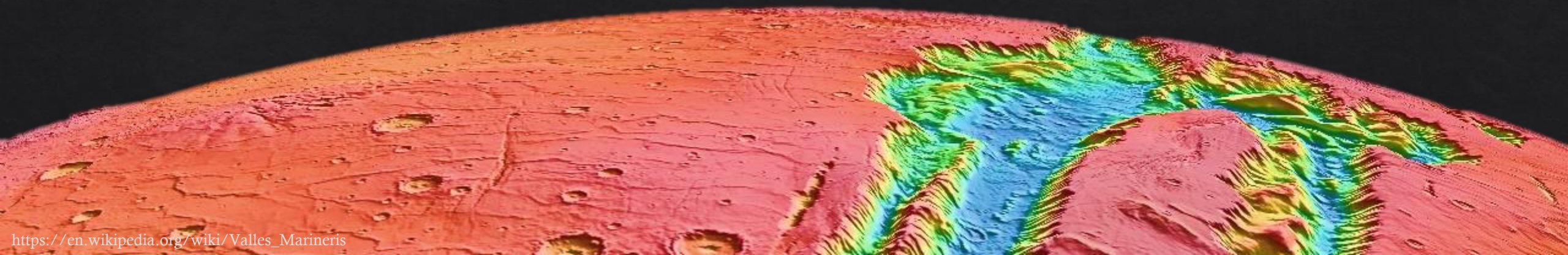
Satellite Data

- (1971 – 1972) Mariner 9 → Mariner Valley/Valles Marineris
  - Variations in terrain morphology and coloration: 1 – 1.5 km/pixel
- (1976 – 1980) Viking 1 and 2
  - Vertical displacements along faults, scarps, fractures, dunes, sedimentation patterns, etc.: 100 – 150 m/pixel
- (1997 – 2006) Mars Global Surveyor
  - Mars Orbiter Camera (MOC): 0.3-5 m/pixel
- (2001 – ?) Mars Odyssey Mission
  - Thermal Emission Imaging System (THEMIS): 18 m/pixel
- (2003 – ?) Mars Express
  - High-Resolution Stereo Camera (HRSC): 13 m/pixel
- (2006 – ?) Mars Reconnaissance Orbiter Mission
  - Context Camera (CTX): 5 m/pixel
  - High-Resolution Imaging Science Experiment (HiRISE): 25-60 cm/pixel



But how did it form?

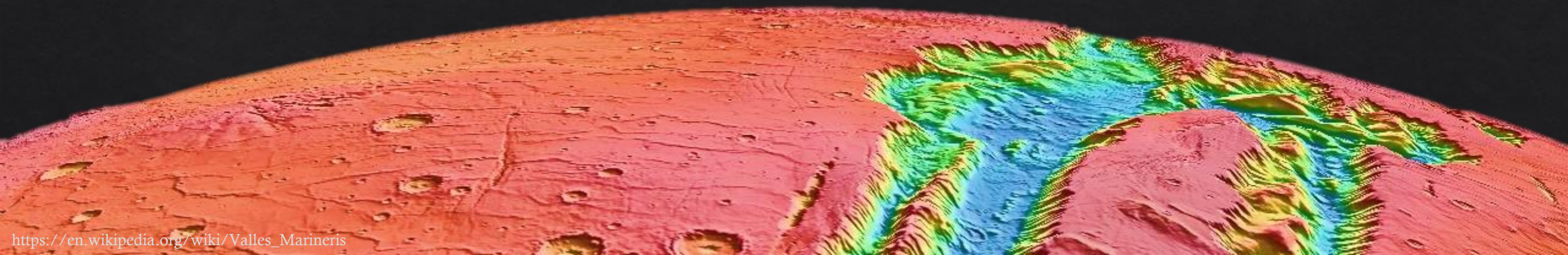
- For over four decades – since its discovery in 1971 – Valles Marineris has been the topic of numerous regional and tectonic studies
- Even though it is the longest canyon system in the solar system, its origin and evolutionary history remains enigmatic
- Ongoing debate over the relations, if any, between the Tharsis volcanic province and the opening of Valles Marineris
- A wide range of hypotheses has been proposed:
  - Rifting, subsurface removal of dissolvable materials or magma withdrawal, massive dike emplacement causing ground-ice melting and thus catastrophic formation of outflow channels, interaction among Tharsis-driven activity and an ancient Europe-sized basin, large-scale right-slip or left-slip faulting related to plate tectonics, lateral extrusion, continental-scale megalandslide emplacement, or some combination of these
- "The origin of the Valles Marineris remains unknown, although a leading hypothesis holds that it started as a crack billions of years ago as the planet cooled." – nasa.gov



https://en.wikipedia.org/wiki/Valles_Marineris

All hypotheses can be divided into:

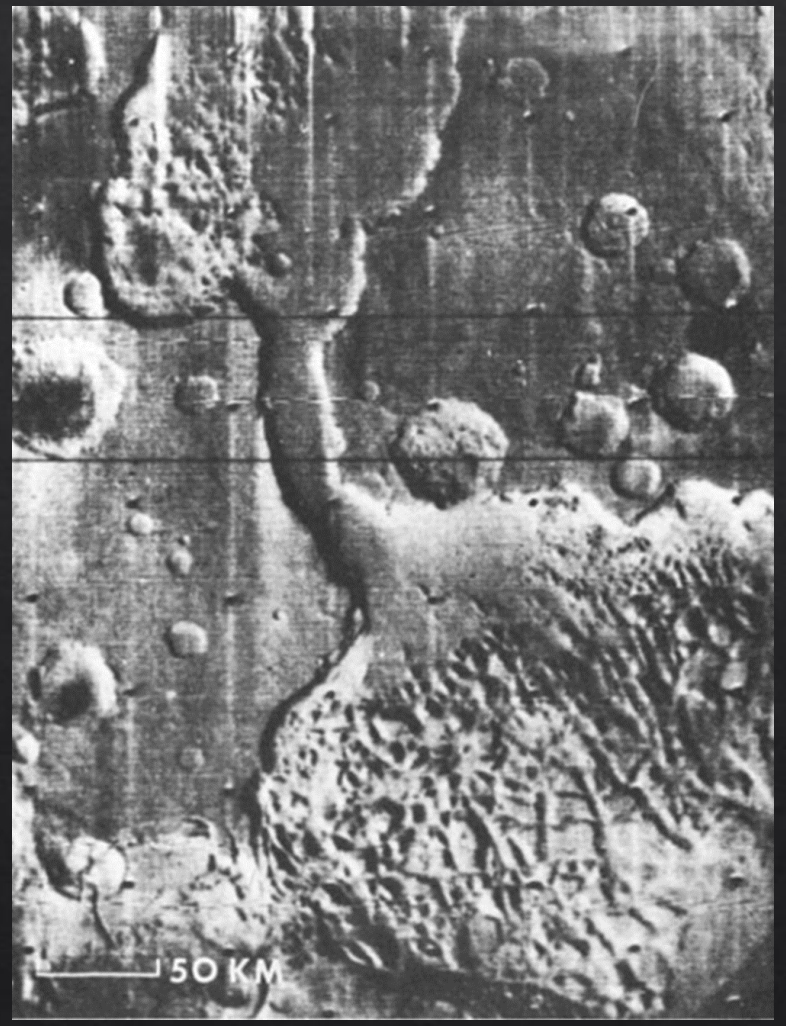
- Those related to erosion
  - Induced by surface collapse via mass withdrawal from below (either magma, ice, or carbonate rocks) or the development of an antecedent drainage system (Sharp, 1973; Adams et al., 2009)
- Those related to tectonic processes
  - Right-slip (dextral) model (Anguita et al., 2001)
  - Left-slip (sinistral) model (Webb and Head, 2002; Montgomery et al., 2009; Yin, 2012)
  - Simple rift model (Blasius et al., 1977; Peulvast and Masson, 1993; Schultz, 1998)
  - Complex rift model (Schultz, 1998)
- Those related to gravity driven processes
  - Thick-skinned gravitational spreading (Webb and Head, 2002)
  - Thin-skinned megalandslide model (Montgomery et al., 2009)



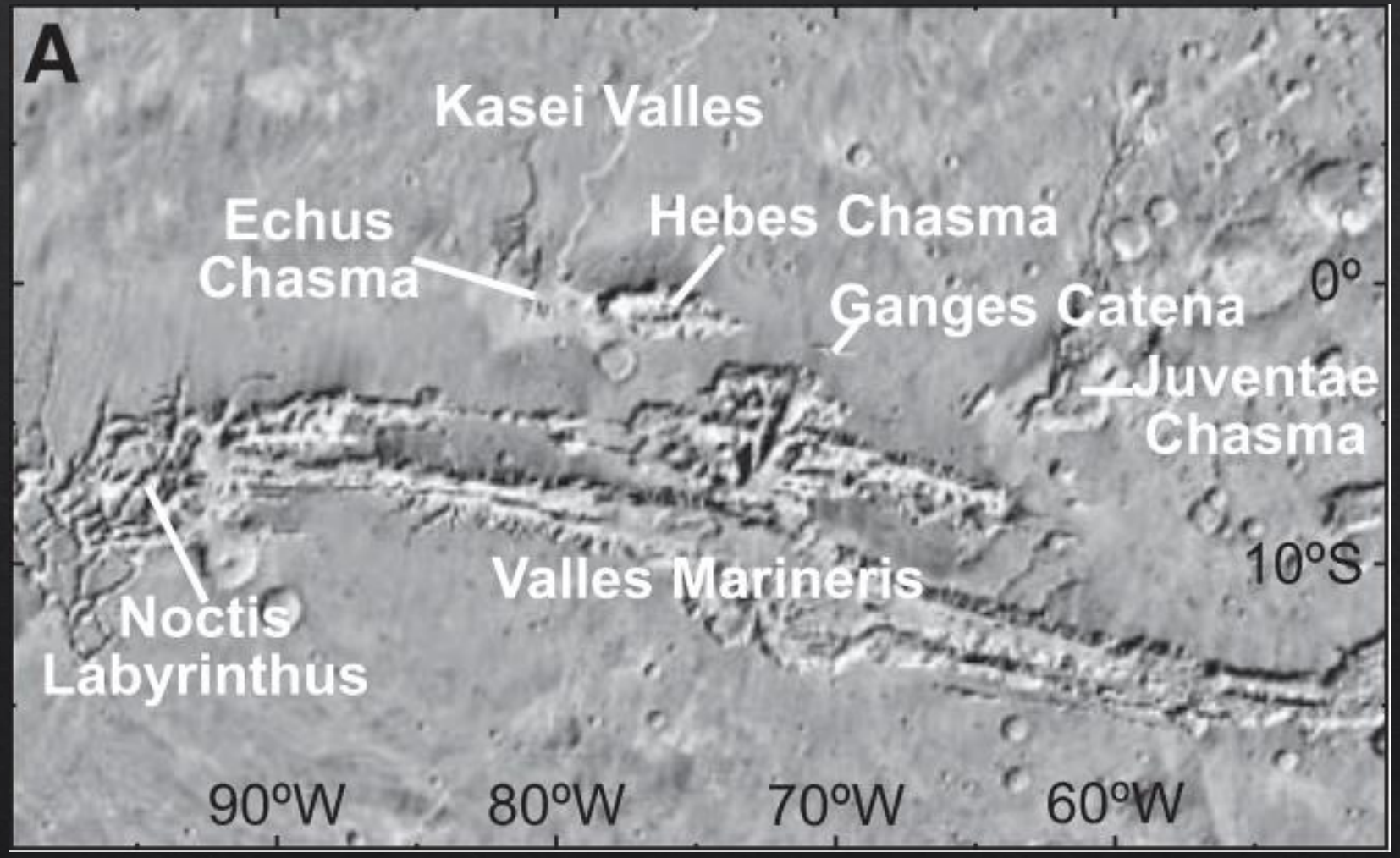
https://en.wikipedia.org/wiki/Valles_Marineris

Erosion – Sharp, 1973

- One of the first interpretations of the Mariner 9 images
- Doesn't call it Valles Marineris, but instead used the term "troughed terrain" to describe the region:
  - "Huge, steep-walled troughs, up to several hundred kilometers long and possibly 5 km deep, integrated into a belt 2700 km long and 500 km wide, wall side slumps, intratrough ridges, orthogonal and dendritic wall scars"
- Proposes that some regions of Mars are frozen to a depth of about 1-2 km
  - As frozen groundwater is exposed along the escarpments and melts or evaporates, it allows the rack to crumble causing recession
- Alternatively, frozen ground and significant quantities of ground ice may have developed under the Martian surface to a depth of 10 km
  - Sublimation or melting of the ground ice (presumably also due to igneous activity) could cause 2 km of collapse
  - Could also be dissolution of rock material, deterioration of ground ice, or evacuation of magma by volcanism



Erosion – Adams et al., 2009



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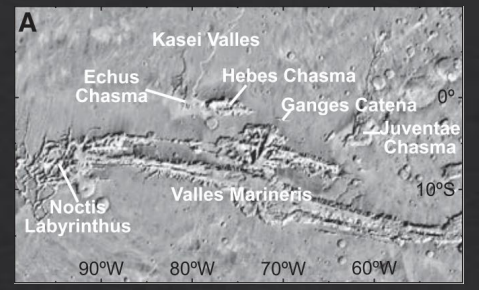
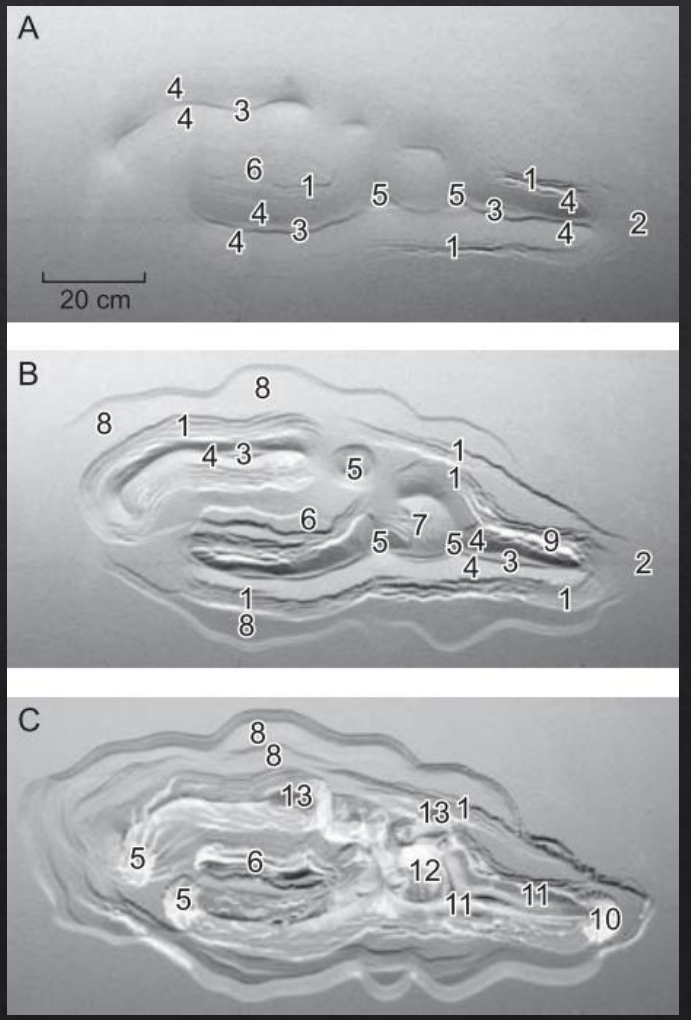


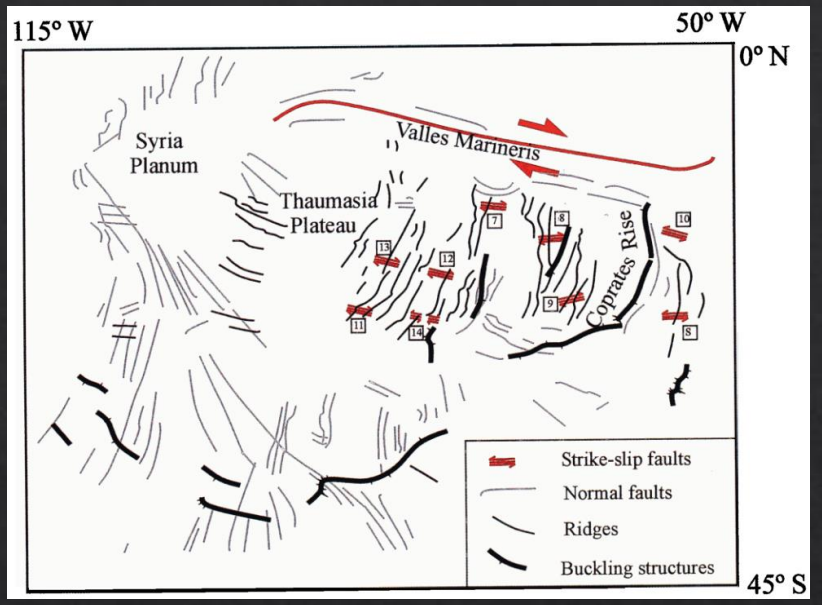
- Used a combination of photogeological mapping and physical modeling
- Hebes Chasma lacks many of the same features of Valles Marineris as a whole:
  - No surface outflow channel, therefore the flood hypothesis can be eliminated
  - Surface excavation does not explain where the missing 10^5 km^3 of material went
  - A purely tectonic origin can't explain its irregular elliptical shape, blunt ends, and absence of surrounding grabens
- Tested the hypothesis of subsidence due to subsurface brine fluid flow using 2 new tests:
  - Photogeological mapping revealed a lack of a fluvial outlet, layers that dip towards the pits and troughs, and extensive mass flows into the pits with a lack of accumulation
  - Scaled (1:500,000) physical modeling revealed all stages of the collapse, not just the end result
- Results are consistent with the hypothesis that material was evacuated through drains in the floor, while an origin of pure extension fails to explain many properties of Hebes Chasma
- While it's unlikely that all of Valles Marineris evolved the same way, this suggests that salt tectonics was important in shaping the regions topography



Top-down view of evolving laboratory model

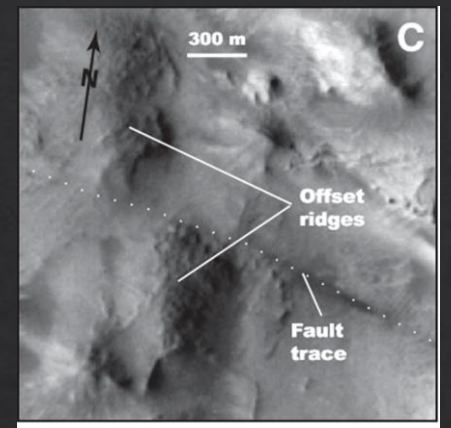
Right-Slip Model – Anguita et al., 2001

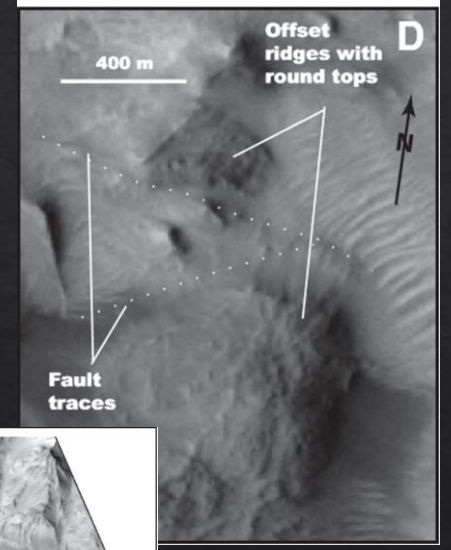
- Interprets many dextral strike-slip faults, and considers the Thaumasia Plateau more decisive in the inception of Valles Marineris
- Relied on a reorientation of the rotational axis by as much as 30° to produce the stresses high enough to initiate faulting
- Goes against previous explanations of pure extension, stating it is a right-lateral transtensive megashear, supported by:
  - Valles Marineris' curved geometry
  - Strong negative Valles Marineris gravity anomaly
  - Structural differences between north and south Tharsis, such as distribution of wrinkle ridges and buckling structures
- Initial formation of Valles Marineris is believed to have occurred at Late Noachian, contemporaneous to the lithospheric buckling in Thaumasia
- Claims that geometrical, geophysical, geomorphological, and structural observations support right lateral deformation.

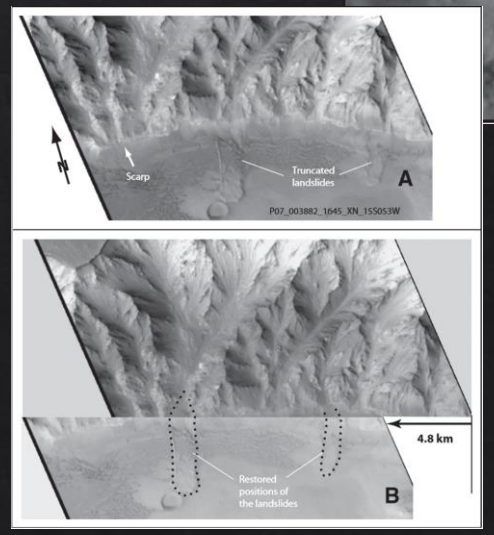


Left-Slip Model – Yin, 2012

- Focuses mainly on trough-wall and trough-floor structures from photogeologic mapping
- Formation of Valles Marineris started in Late Noachian (Dohm, 2001) and lasted after the end of the Hesperian (Schultz, 1998) or as late as the Late Amazonian (younger than 0.7 Ga) (Witbeck et al., 1991).
- Finds clear evidence of left-lateral strike-slip faulting
- Recent faults cut through late Hesperian drainage activity, meaning left-slip faulting was active and could postdate it
- Occurrence of continuous linear scarps over 10s of km to >100 km along the base of the trough walls strongly supports a tectonic origin
- Fault zone is observed to extend beyond the required boundaries set by the megalandslide model of Montgomery et al. (2009) and the gravitational-spreading model of Webb and Head (2002)
- All of this begs the question of why such a structure, typically associated with plate tectonics on Earth, was developed on Mars

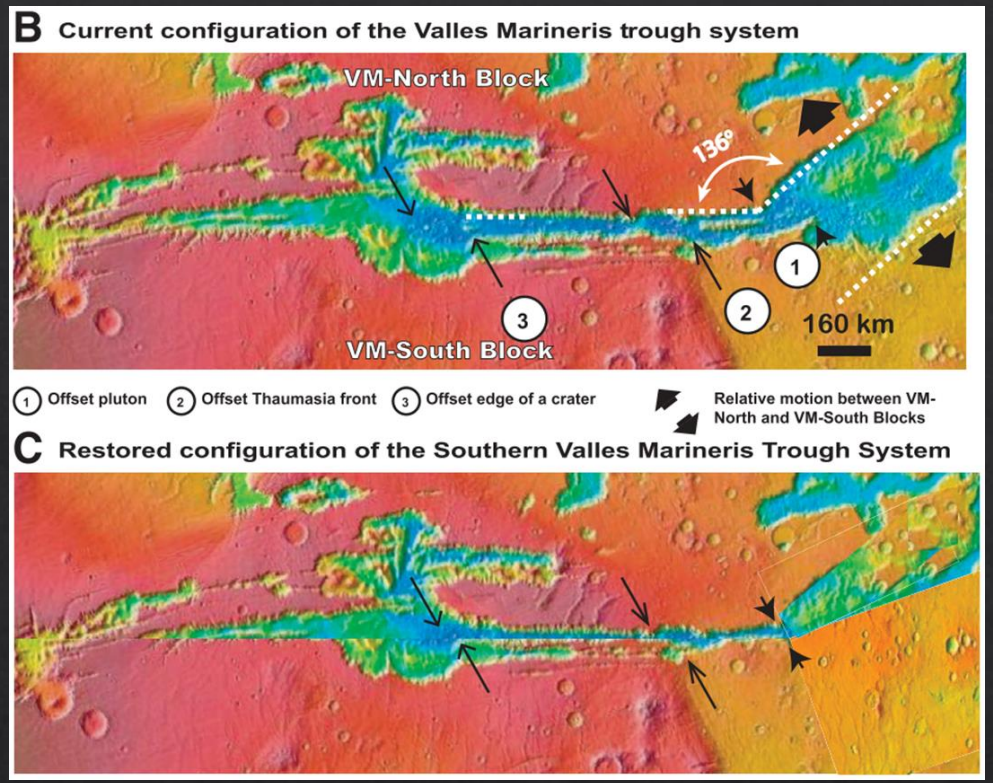


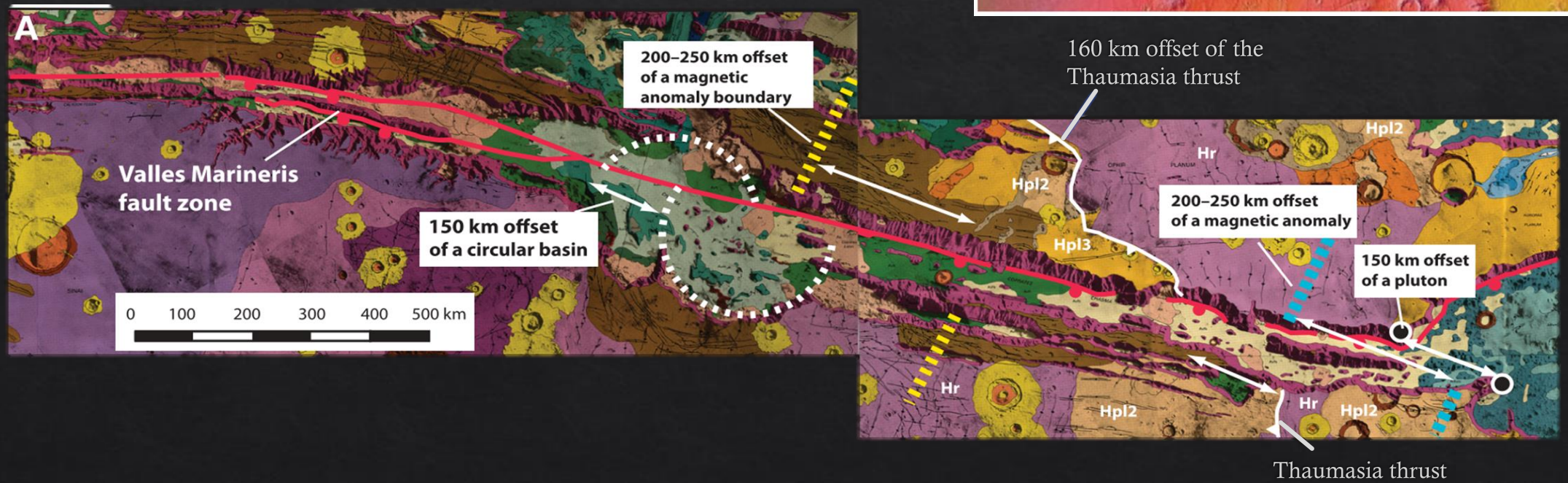




Left-Slip Model – Yin, 2012

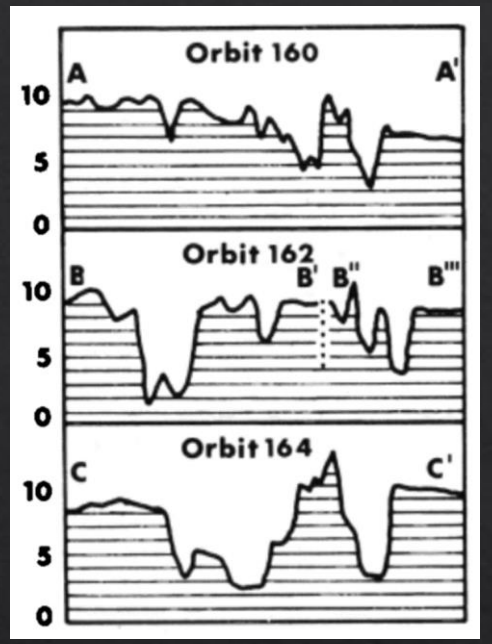
- Estimated 160 ± 50 km of left-slip displacement
- Timing of deformation:
  - Left-slip structures all involve late Amazonian (<200 Ma) units, suggesting that deformation has occurred recently or is still active today
  - Main fault zone cuts the Late Hesperian upper Syria Planum Formation, so its initiation must be younger than the emplacement of that unit.
  - Tharsis Rise experienced two drastically different tectonic events:
    - Hesperian E-W compression, expressed by the development of the Thaumasia topographic front
    - Late Amazonian NW-SE extension linked by large-scale left-slip faulting
- Difficult to generate a fault system with this much offset purely through flexural loading of the Tharsis Rise.

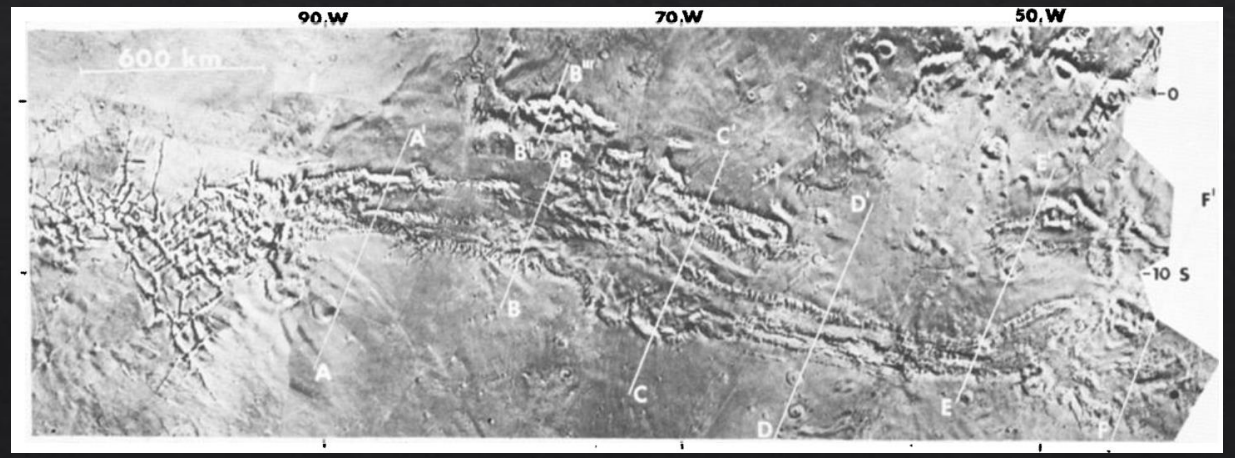




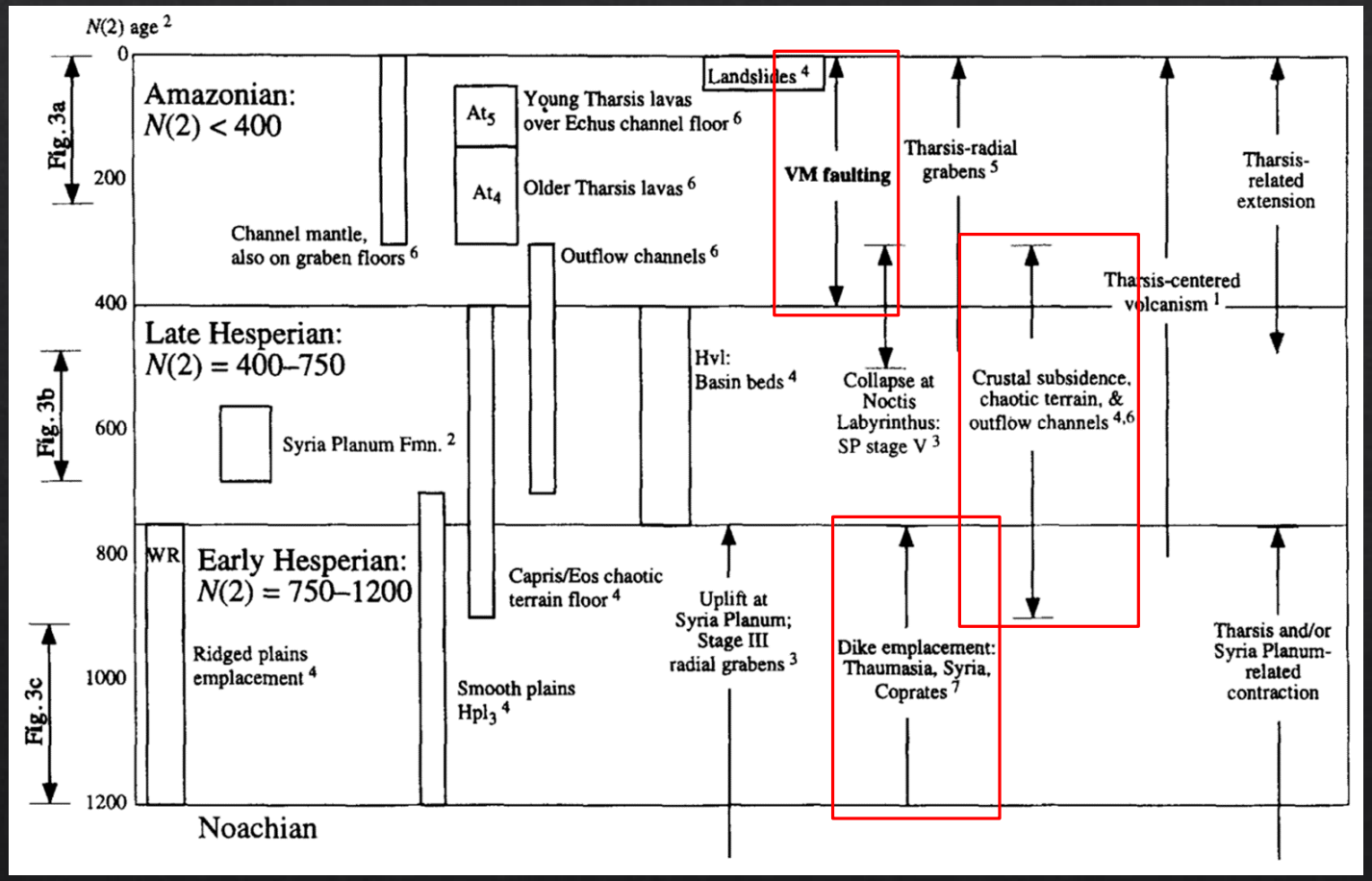
Simple Rift Model – Blasius et al., 1977

- First analysis done using the images from Viking Orbiters
- Proposes that tectonic control is the main influence on canyon form and evolution, but the style and intensity is regionally variable
- Primary N-S and secondary E-W extension played a big role in the west and central canyons, while the eastern canyon appears to reflect a lesser amount of extension
  - Much of the erosion can be attributed to mass wasting by either Aeolian of fluvial processes
- Scarps cut erosional features, indicating that the driving force for enlargement of the valley continues to be downfaulting
- Because the influence of extensional tectonics in the Valles Marineris is so pervasive, they doubt that decay of ground ice or volcanism is needed
- Underlying issue in putting together an erosional and depositional history is its relationship with activity in the Tharsis Rise region to the west
- Propose that tectonic activity persisted over the entire region and controlled the Tharsis volcanism while continuing to deepen the canyons of Valles Marineris





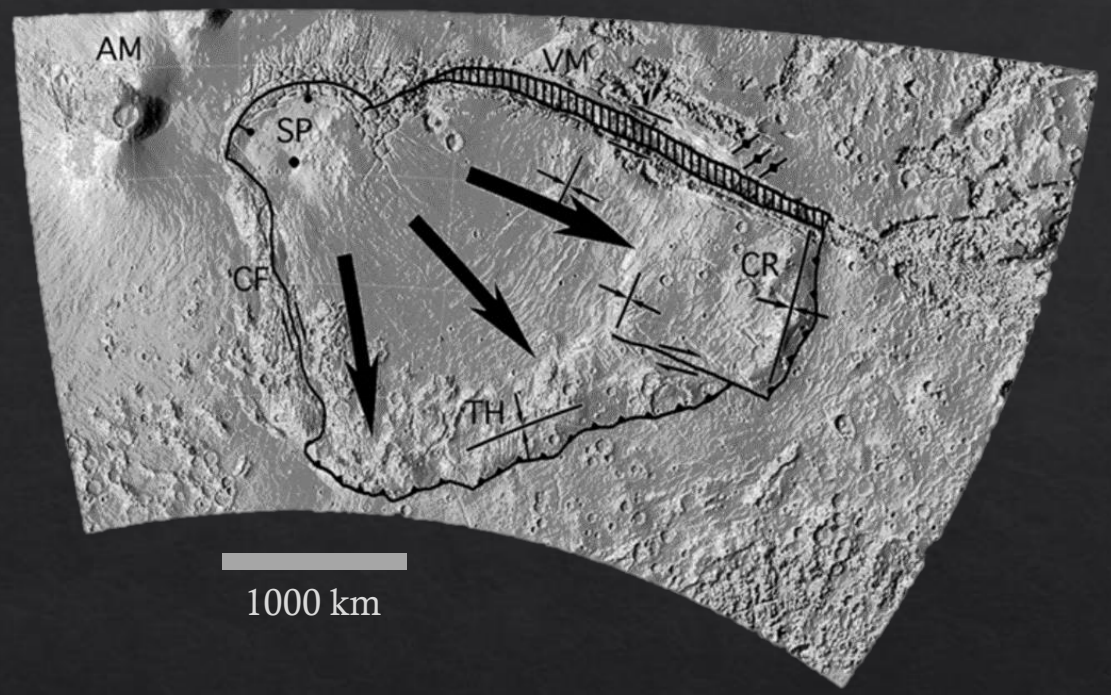
Complex Rift Model – Schultz, 1998



- 3 key stages of Valles Marineris Formation:
  - Dike emplacement radial to Syria Planum during Late Noachian to Early Hesperian time
  - Localized subsidence of crustal rocks during post-Early Hesperian time, forming ancestral basins such as Hebes Chasma
  - Regional normal faulting that overprints the ancestral basins and forms the structural troughs such as Coprates Chasma, principally during Amazonian time
- Previous studies either thought it was collapse and only focus on Hebes Chasma, or tectonic and focus on the main Chasmata
  - A single process appears to be insufficient to account for the full range of characteristics observed in the system
- Also find cross-cutting relations indicating localized crustal extension or rifting has occurred primarily in recent times

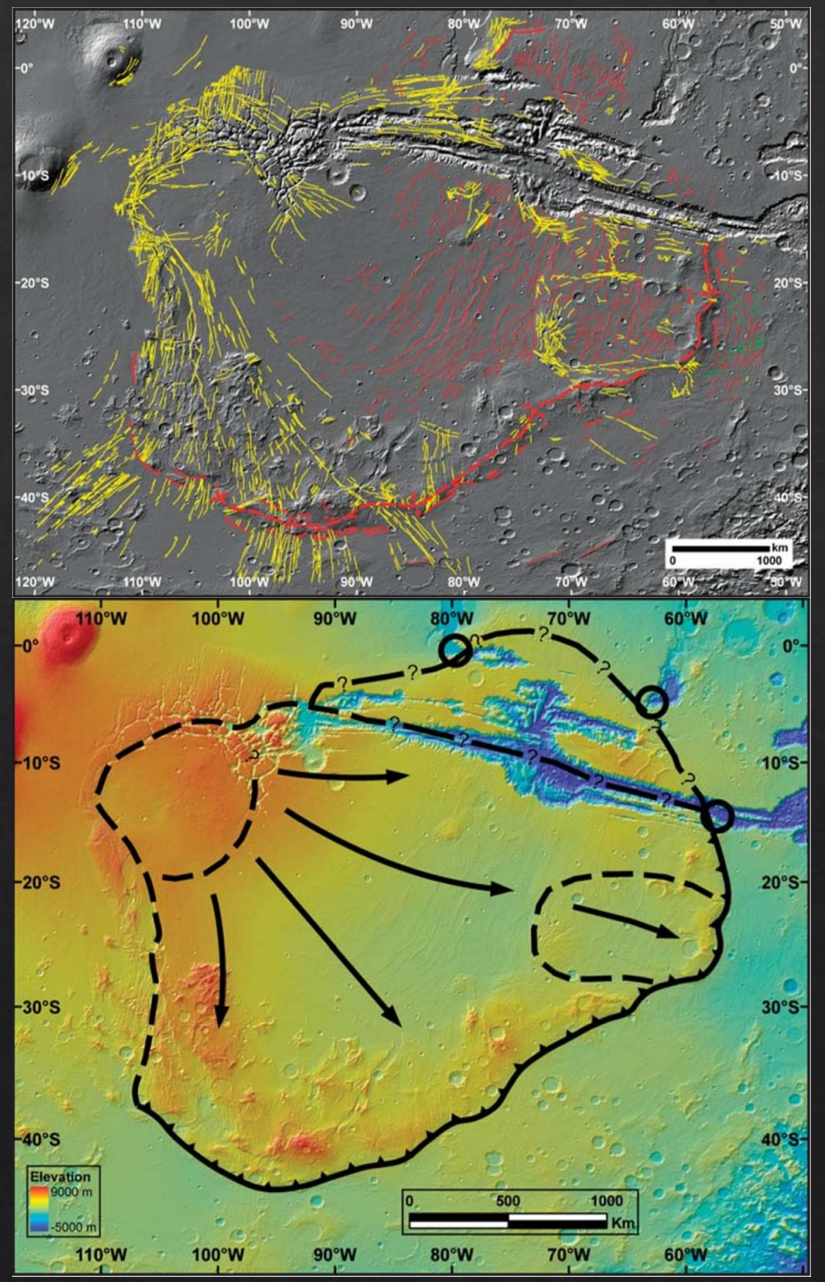
Thick-Skinned Gravitational Spreading – Webb and Head, 2002

- Valles Marineris forms the northern boundary of the Thaumasia Plateau and opened in Early Hesperian
- This model suggests that the gravity-driven movement of the Thaumasia Plateau produce the tectonic features which later controlled Valles formation
- Requires 3 elements:
  - A sufficiently massive volcanic center
  - Adequate heat input (e.g. magma intrusion)
  - A weak basal layer
- Propose large-scale weak basal layer such as thick, weak lithosphere in the southern hemisphere



Thin-Skinned Megalandslide Model – Montgomery et al., 2009

- The generally linear chasmata of Valles Marineris reflect extension, collapse, and excavation along fractures radial to Tharsis
- Either initiated or reactivated as part of the Thaumasia gravity-spreading system
- Hypothesis includes several episodes:
  - Extensive salt deposits accumulate before the growth of Tharsis, perhaps in Early Noachian lakes or shallow water bodies, or through regional groundwater flow
  - Rise of Tharsis, increasing both the regional heat flux and local topographic slope, loading the region with ash and lava flows and producing radial extension cracks
  - Layered salts, ice, and volcanic debris provided multiple detachments for the gravity spreading southeastward
  - Finally, fractures cut through an aquifer, which found ready outlets along radial fractures such as Valles Marineris, carving the outflow channels
- Provides a unifying explanation involving the location, linearity, and depth of the Valles Marineris chasmata



Thoughts and Ongoing

- It's clear that this is still not a completely settled matter
- Sense of motion in Valles Marineris is left-lateral and appears to still be active today
- Doesn't make sense to limit the formation of Valles Marineris to a single mechanism
  - Hypotheses that include a combination of forces and factors fill more gaps in our understanding than single method hypotheses
    - Schultz (1998), Montgomery et al. (2009), and Yin (2012)
- Debate is moving towards understanding the influence of/relationship with the Tharsis Rise, as the proximity of these two large scale Martian features is clearly not coincidental
- Next step is to gain a deeper structural and tectonic understanding of the Tharsis Rise

http://news.softpedia.com/news/Unprecedented-Tectonics-Explain-Mars-039-Strange-Landscape-100231.shtml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