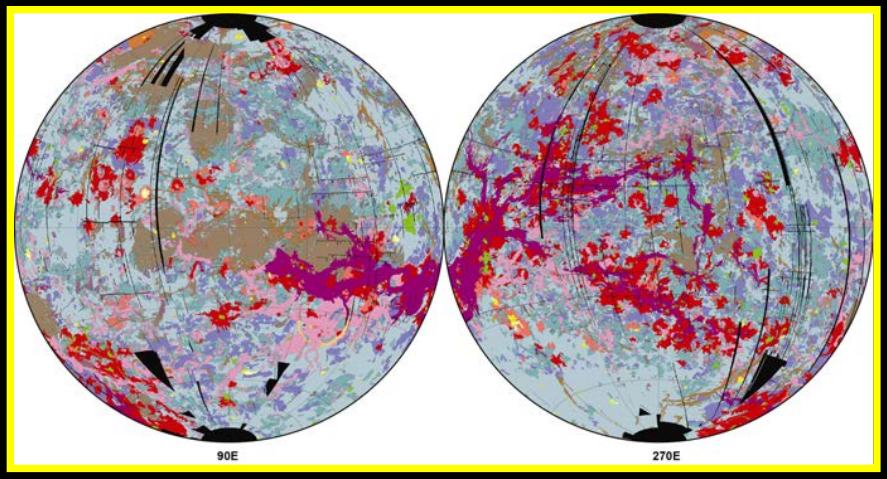
CONTRIBUTIONS OF VOLATILES TO THE VENUS ATMOSPHERE FROM THE OBSERVED EXTRUSIVE VOLCANIC RECORD: IMPLICATIONS FOR THE HISTORY OF THE VENUS ATMOSPHERE



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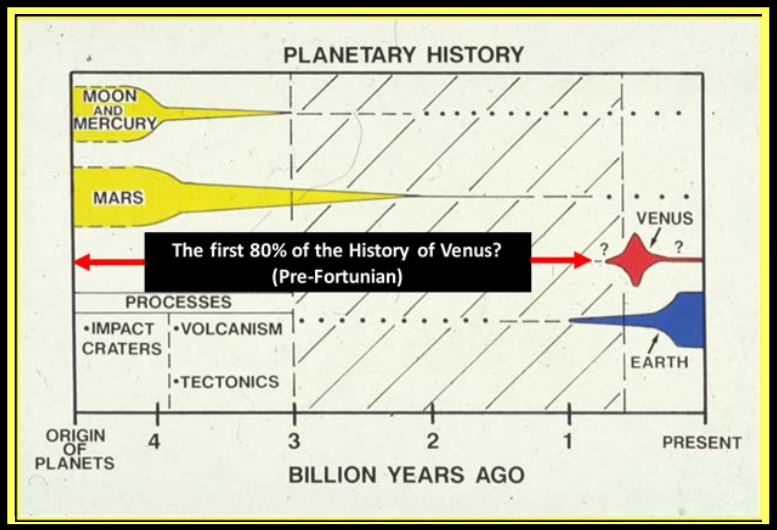
Questions that have perplexed planetary scientists since the early Space Age:

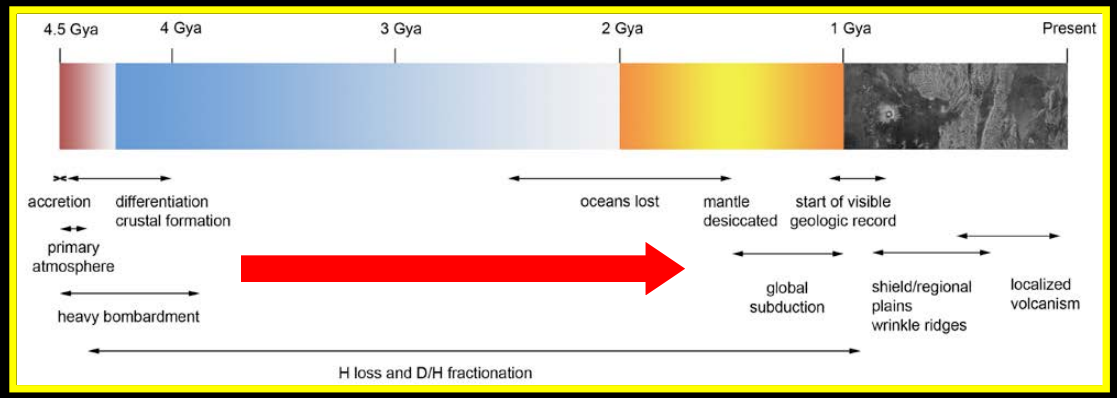
- 1. What is the *origin of the geologically recent Venus runaway greenhouse atmosphere?*
- 2. Why is it *so different from that of the Earth*?

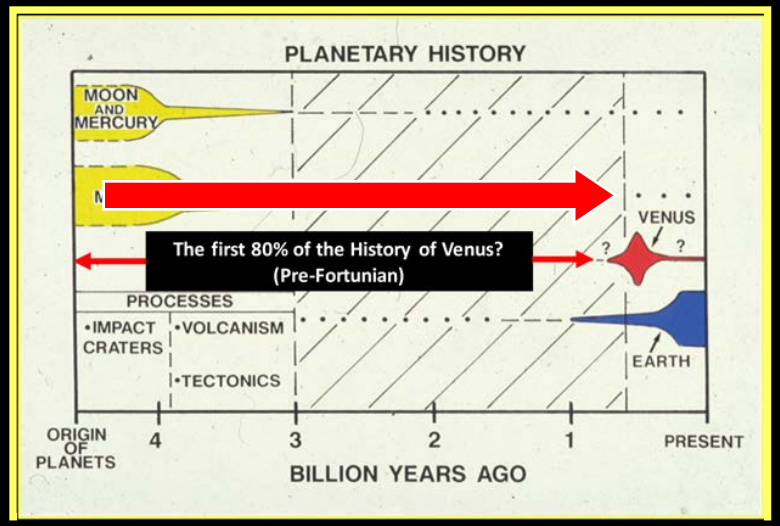


- 3. What is *its relation to the "observed" (<1 Ga) Venus geologic/geodynamic history?*
- 4. What is *its relation to the "cryptic/hidden" (>1 Ga; Pre-Fortunian) Venus geologic/geodynamic history?*

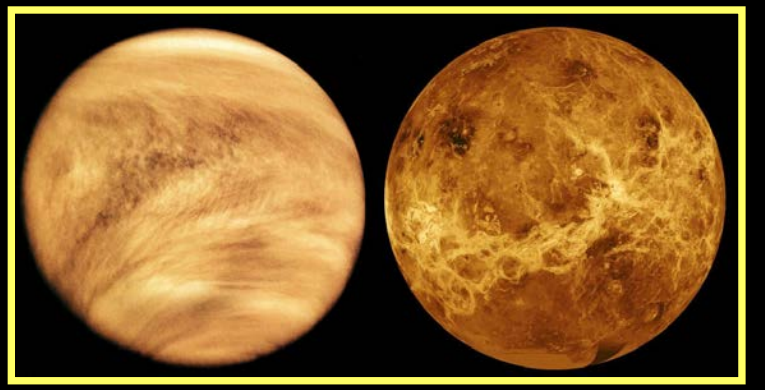
Forward-modeling:
The origin and evolution of the Venus atmosphere

- Define/assess nature and abundance of volatiles derived from interior and space.



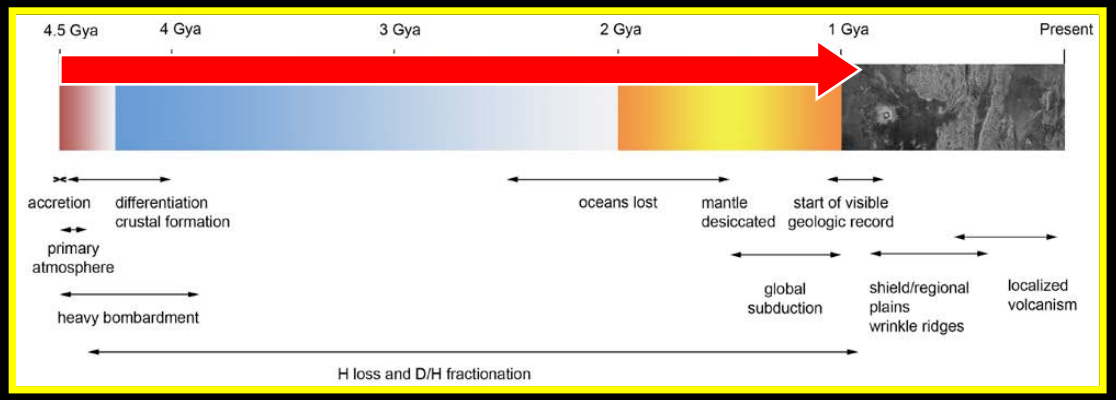


- Assess:
- 1. Their *influence on the evolving atmosphere.*
- 2. Their *interaction with the surface.*
- 3. Their *rates of their loss to space*
- *End-product* is current atmosphere.



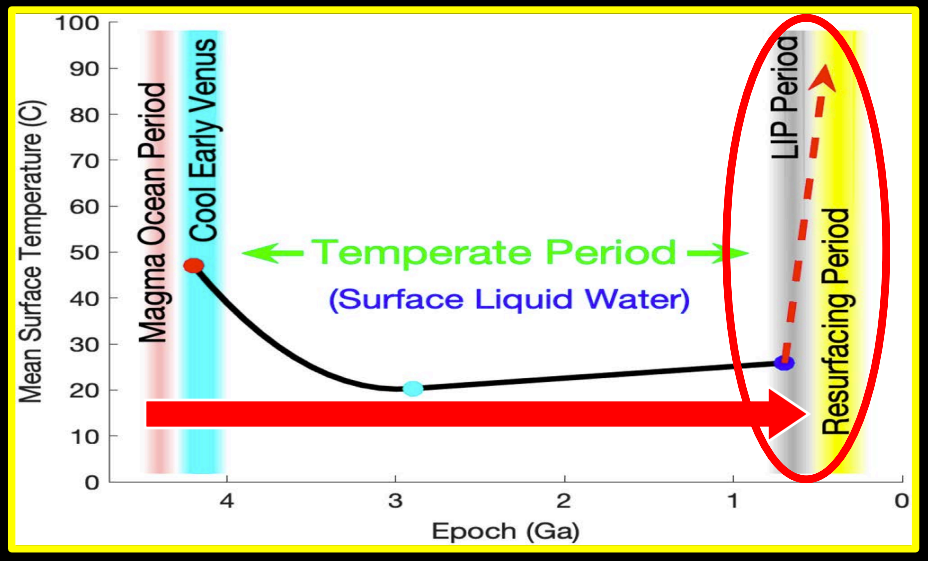
Several *Forward-Models* Have Found:

- More Earth-like clement conditions (Bullock & Grinspoon, 1996).



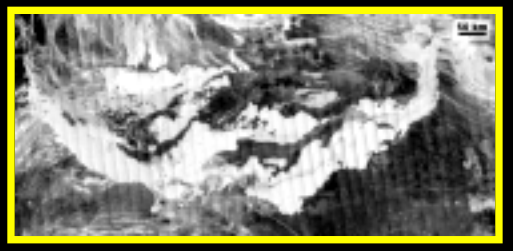
- Oceans and an N_2-dominant atmosphere (Way et al., 2016; Way & Del Genio, 2020).

-These may have carried into the last <20% of Venus' history (post crypto-history; <1Ga).

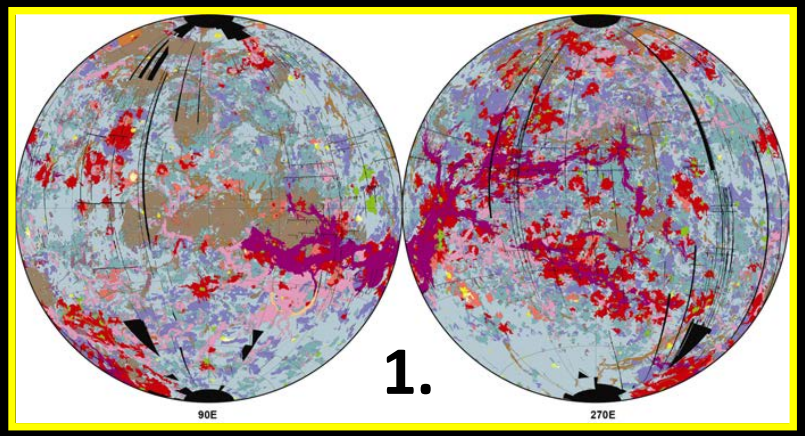


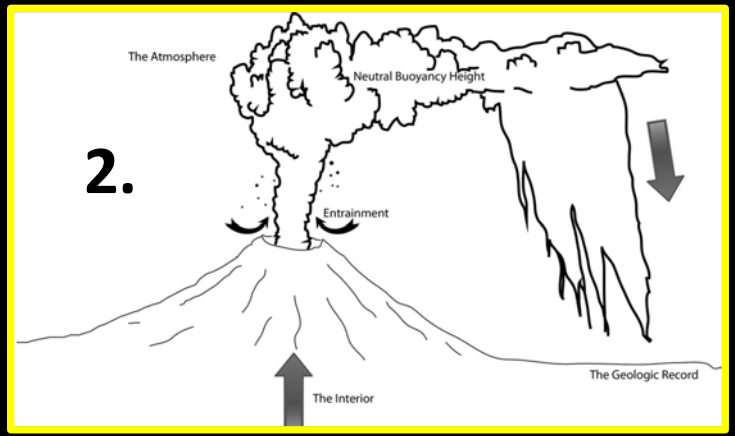
Volcanism: *Primary transfer process of volatiles from mantle to surface/atmosphere*

- We use the *current atmosphere as a baseline and work backward in time.*



- We assess:
- 1. The *nature and magnitude of the major phases of volcanism* seen in the geological record,
- 2. Their *style and the magnitude of volatile output.*
- 3. The *candidate effects of their volatile release on the observed atmosphere*.

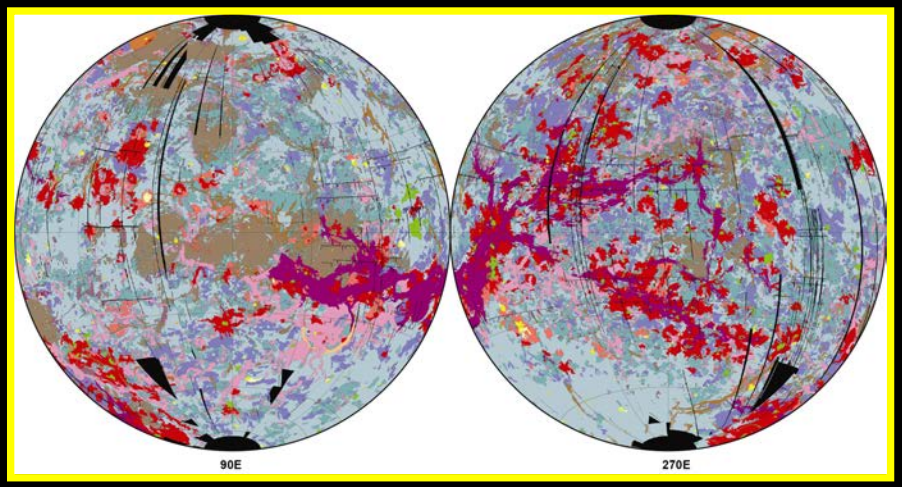


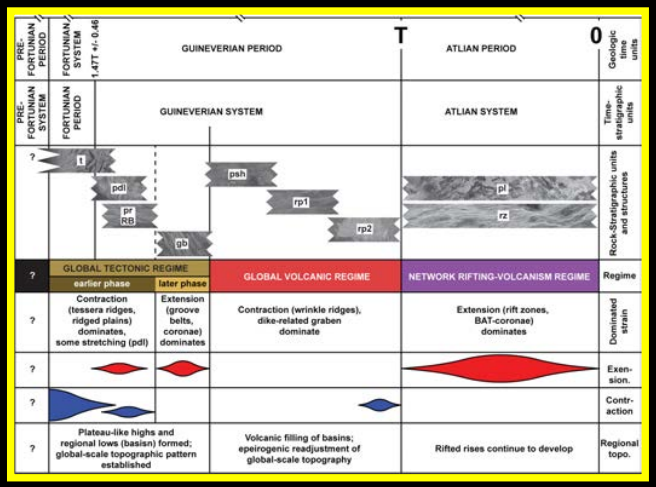


What questions do we address?:

- 1. How does the volume of the most recent phase of volcanism (lobate plains; large shield volcanoes) affect the interpretation that *observed atmosphere SO_2 levels are related to current ongoing volcanism?*

- 2. Does eruption of the *total volume of observed extrusive deposits contribute significantly* to the current atmosphere?

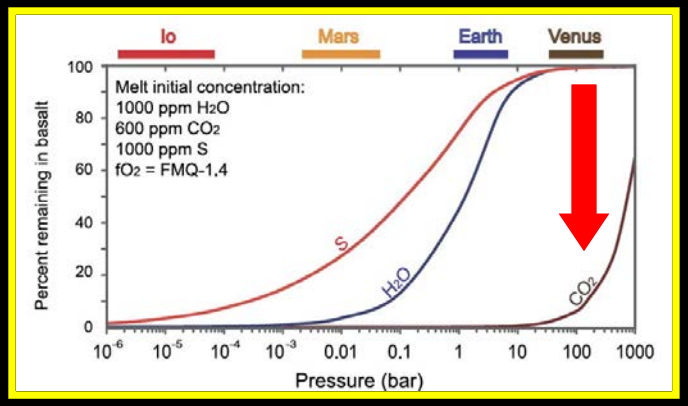




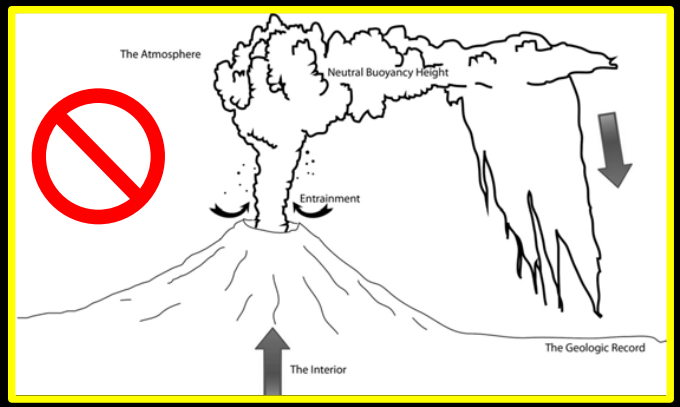
- 3. Could the period of near-global volcanic resurfacing (psh, $rp_{1,2}$) have *produced* the current atmosphere?

Volcanism: *Primary transfer process* of volatiles from the mantle to the surface and atmosphere

- We find that:
- -Current *very high Venus atmospheric pressure (~93 bars).*
- *-Sufficient to significantly inhibit exsolution of key volatile species during effusive eruptions.*
- -Sufficient to *preclude explosive volcanic activity that could deliver exsolved volatiles high into atmosphere.*
- *-Explosive volcanism requires volatile contents >several wt%*



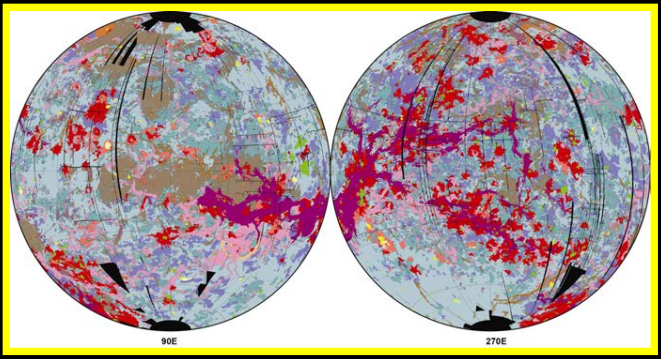
(Gaillard & Scaillet, 2014)



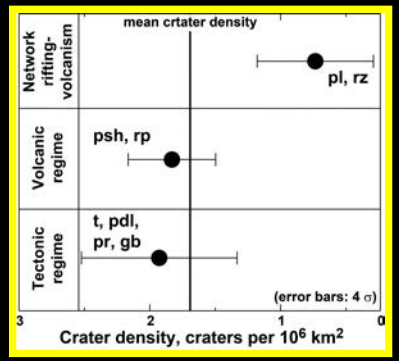
(Head & Wilson, 1986)

Geological Record of Venus Volcanism

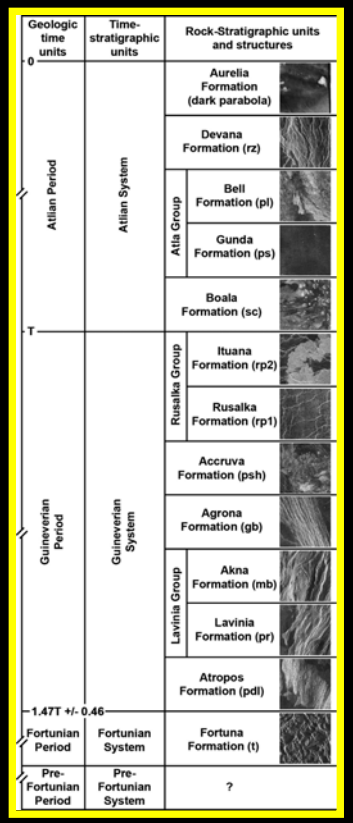
- *Global Geologic Map of Venus* (Ivanov & Head, 2011):
- Identifies *geologic units, stratigraphic relationships, origin*.
- Assessment of *nature/role of volcanism with time*.
- Estimates of the *total volume of individual volcanic units.*
- Estimates of the *absolute timescale of these events/units.*

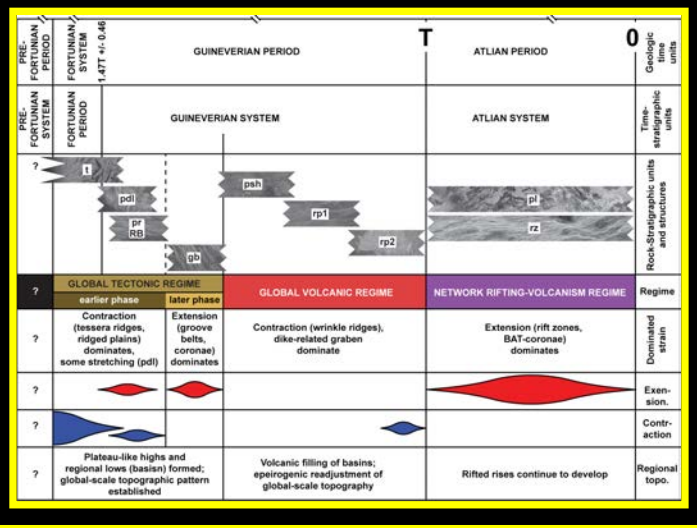


(Ivanov & Head, 2011)



(Ivanov & Head, 2013)

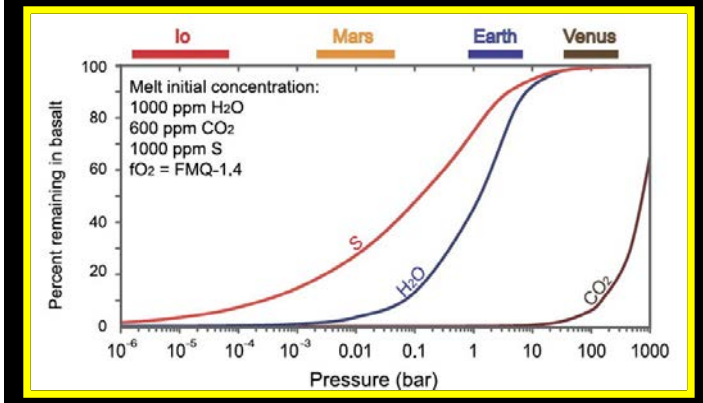


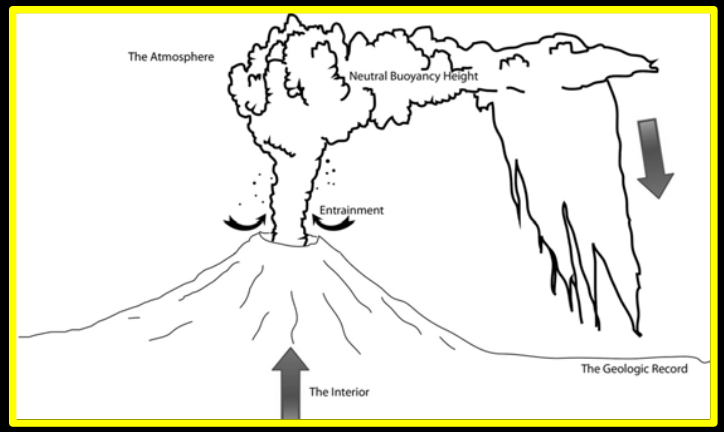


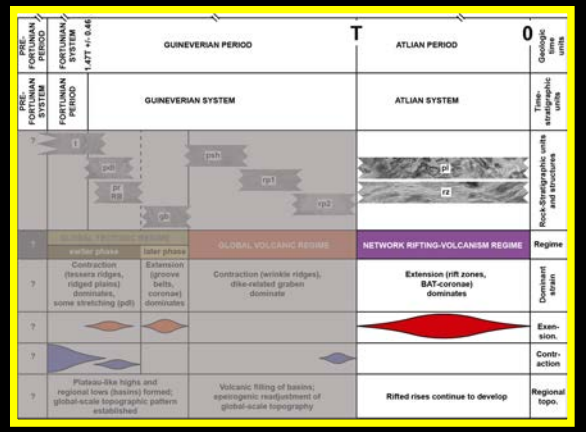
Unit	Exposed Area (10^6km^2)	Max Area (10^6km^2)	Mass (10^{20} kg) at specific thickness (km)					
			0.1	0.2	0.3	0.4	0.5	N/A
psh	84.5	320.3	0.96	1.92				
rp1	150.7	235.8				2.82	3.54	
rp2	44.8	85.1	0.27	0.51				
pl (lobate plains)	40.3	40.3			0.36		0.60	
pl (large volcanoes)[a]								0.255
pl (large volcanoes)[b]								0.51
total eruptives				2.43			4.14	0.765

Discussion and Conclusions:

- 1. The ***current high atmospheric pressure***:
  - ***Severely inhibits degassing of mantle-derived S, H_2O and CO_2*** brought to surface by volcanism and contributed to atmosphere.
  - ***Severely inhibits plinian explosive eruptions*** that can deliver volatiles directly into the atmosphere.



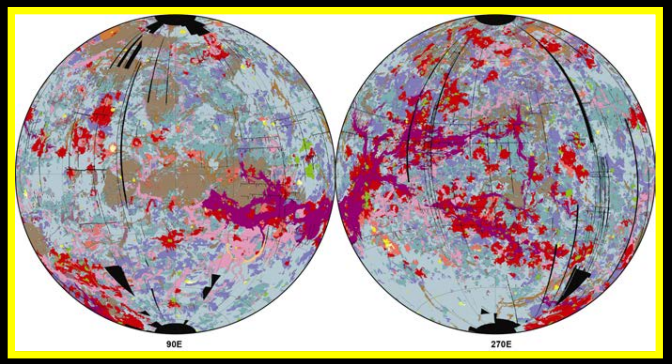


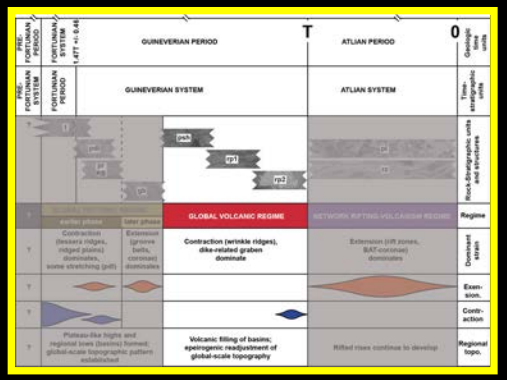


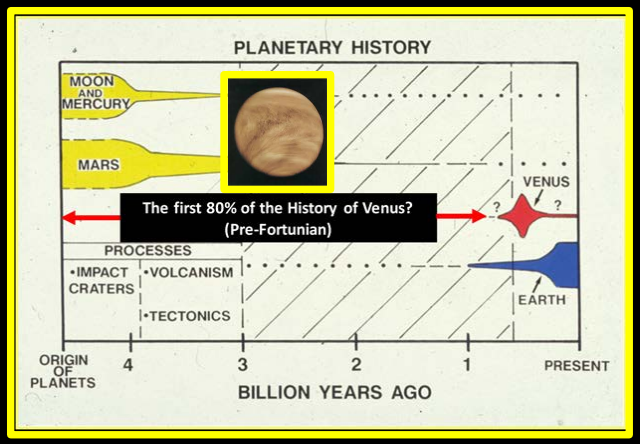
- 2. The **total volume of lava erupted in the stratigraphically youngest period** of the observed record (pl, rift-related, volcanic edifices):
  - ***Insufficient to account for current atmosphere SO_2 abundance.***
  - Thus, ***highly unlikely that current/recent ongoing volcanism could be maintaining observed 'elevated' levels of atmospheric SO_2.***

Discussion and Conclusions:

- 3. The *total volume* of lava erupted in the period of *global volcanic resurfacing* (psh, rp_1, rp_2):
  - *Insufficient to produce the CO_2 atmosphere observed today!*
  - True even if the ambient atmospheric pressure was 50% of today.
  - Therefore, *a very significant part of the current CO_2 atmosphere must have been inherited from a time prior to the observed geologic record, sometime in the first ~80% of Venus history.*

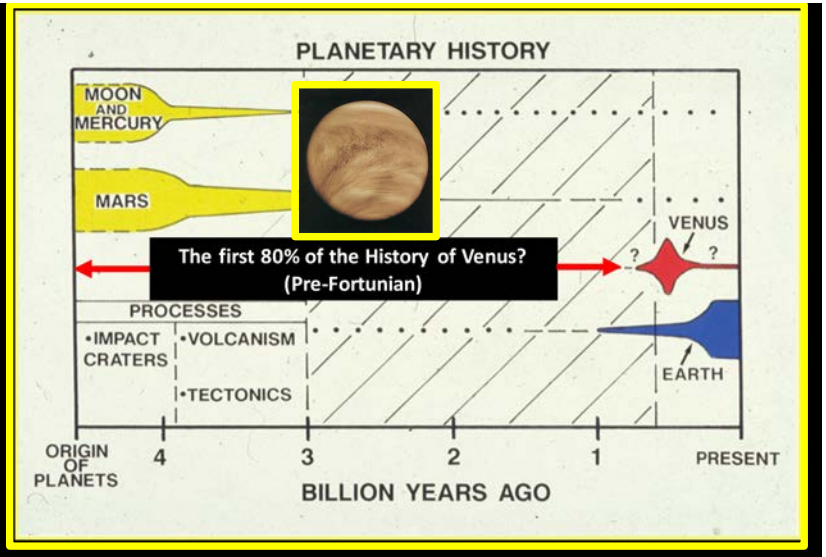




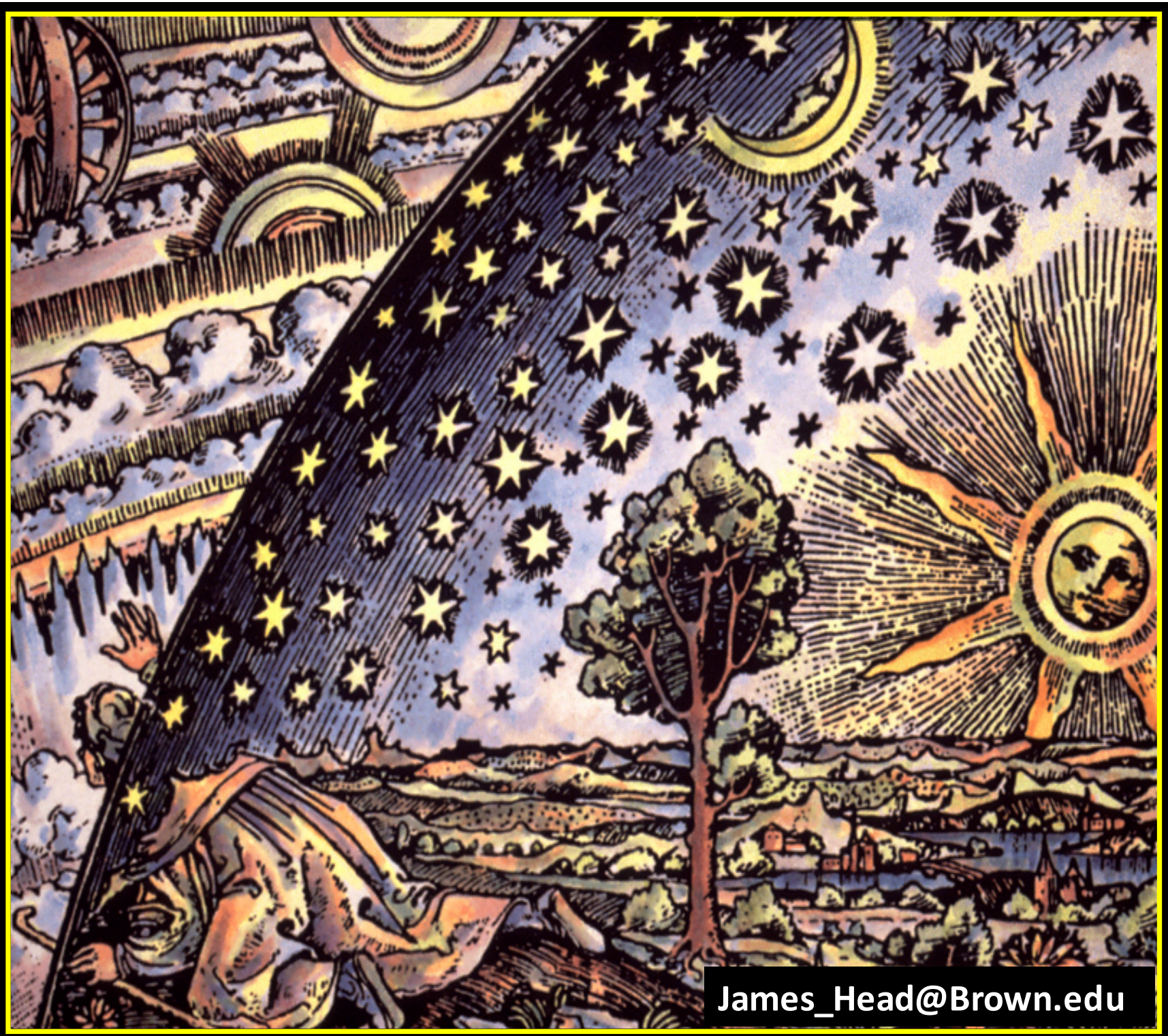


- 4. The amount of water degassed to the atmosphere during the period of *global volcanic resurfacing:*
  - *Would have been minimal*, even if the atmospheric pressure was only 10% of what it is today.
  - The current low atmospheric water content *may be an inherent characteristic of the ambient atmosphere* and *not require enhanced loss rates to space in the last 20% of Venus history.*

Discussion and Conclusions:



- 5. Current Venus atmosphere:
  - May be a *"fossil atmosphere".*
  - Largely *inherited from a previous epoch in Venus history.*
  - May provide *insight into conditions in first 80% of Venus history!*
- 6. If episodic periods of *global volcanic resurfacing built up the "fossil atmosphere":*
  - Assuming an initial 1 bar atmosphere, *more than 90 similar global volcanic resurfacing periods would be required to produce the currently observed CO_2 atmosphere.*
- 7. A critical question:
  - *What was the atmospheric pressure/water content/solar insolation 'tipping point'* that led to the general stabilization of this "fossil atmosphere"?



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