The Role of Carbon in Exotic Crust Formation on Mercury

Kathleen E. Vander Kaaden[1]

and

Francis M. McCubbin[2]

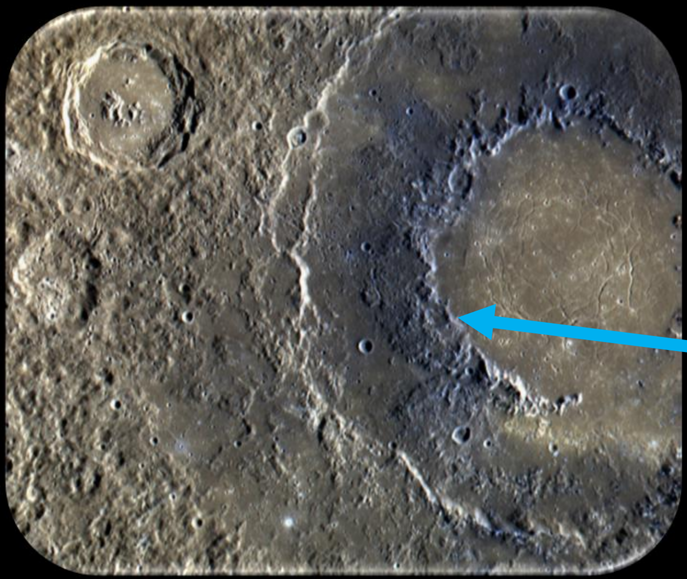
[1]Jacobs, NASA Johnson Space Center, Mail Code XI3, Houston, TX 77058

[2]NASA Johnson Space Center, Mail Code XI, Houston, TX 77058

Corresponding Author E-mail: Kathleen.E.VanderKaaden@nasa.gov

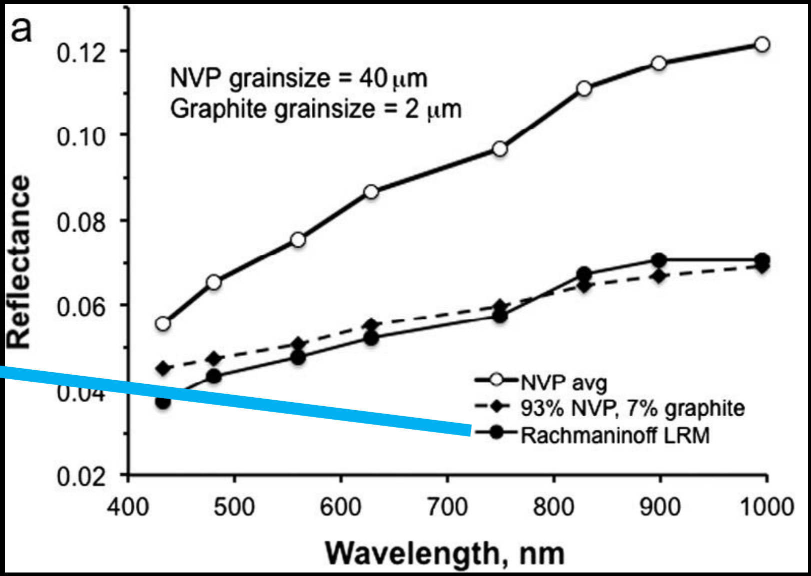
Evidence for C on Mercury

Peplowski et al. (2015)



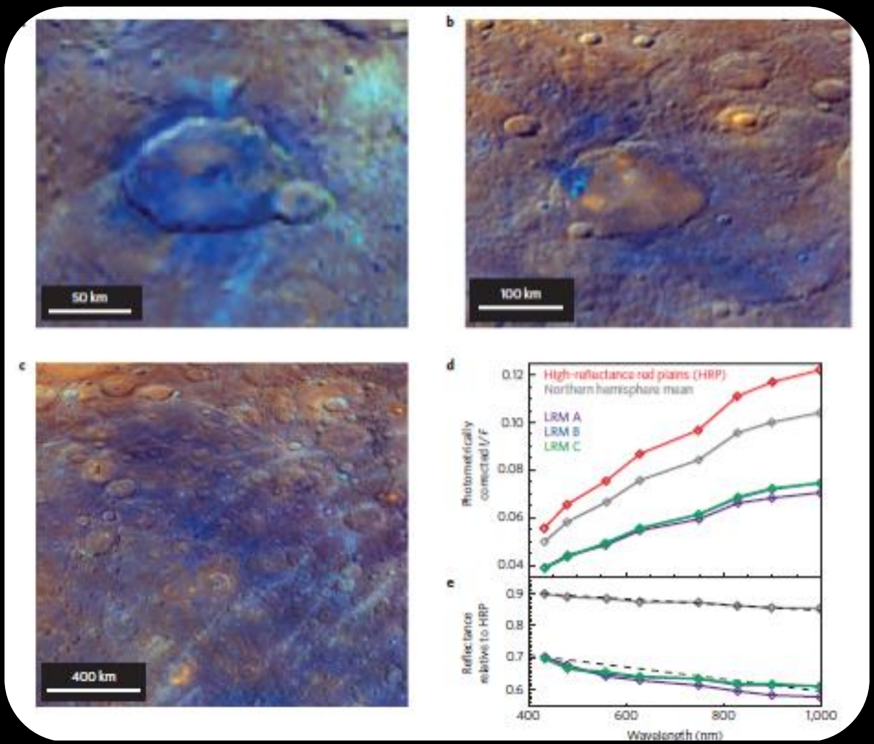
Average northern hemisphere C abundance of 1.4 ± 0.9 wt% C, corresponding to 0 – 4.1 wt% at 3σ

Murchie et al. (2015)



Coarse-grained graphite could darken HRP to LRM

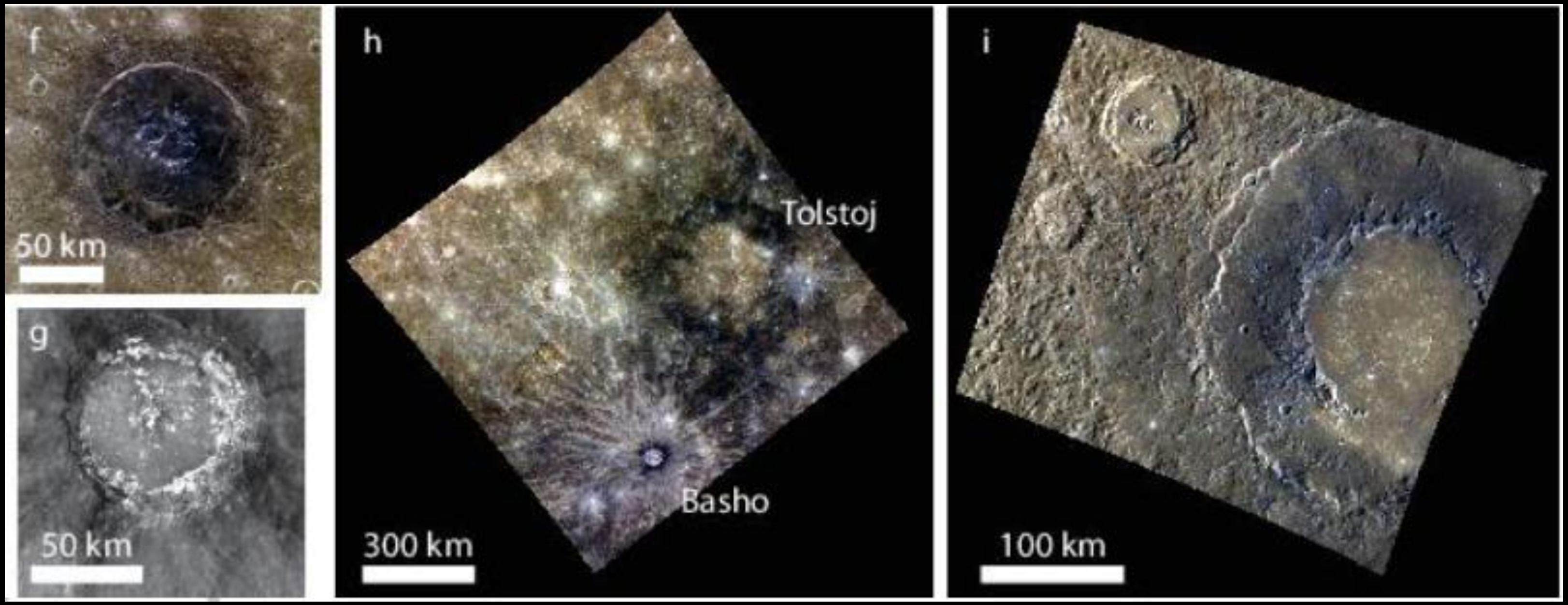
Evidence for C on Mercury

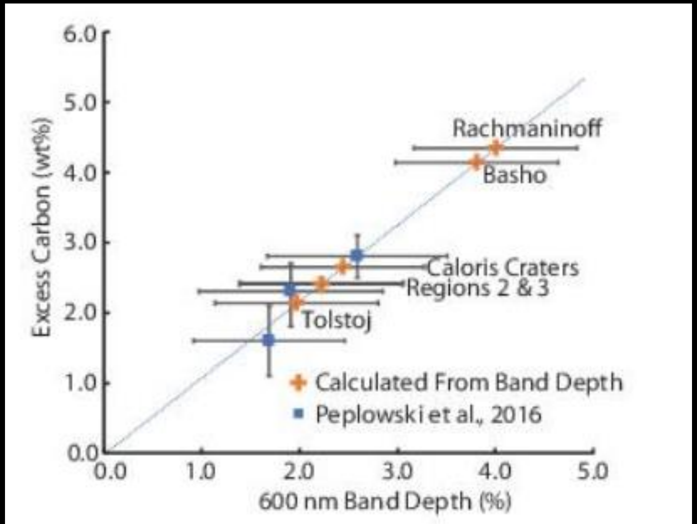


- The only element consistent with both the neutron measurements and visible to near-infrared spectra of low-reflectance material is carbon
    - abundance → 1–3 wt% greater than surrounding, higher-reflectance material.
- Infer → C is primary darkening agent on Mercury
- Infer → low-reflectance material samples carbon-bearing deposits within the planet's crust.

Peplowski et al. (2016)

Evidence for C on Mercury

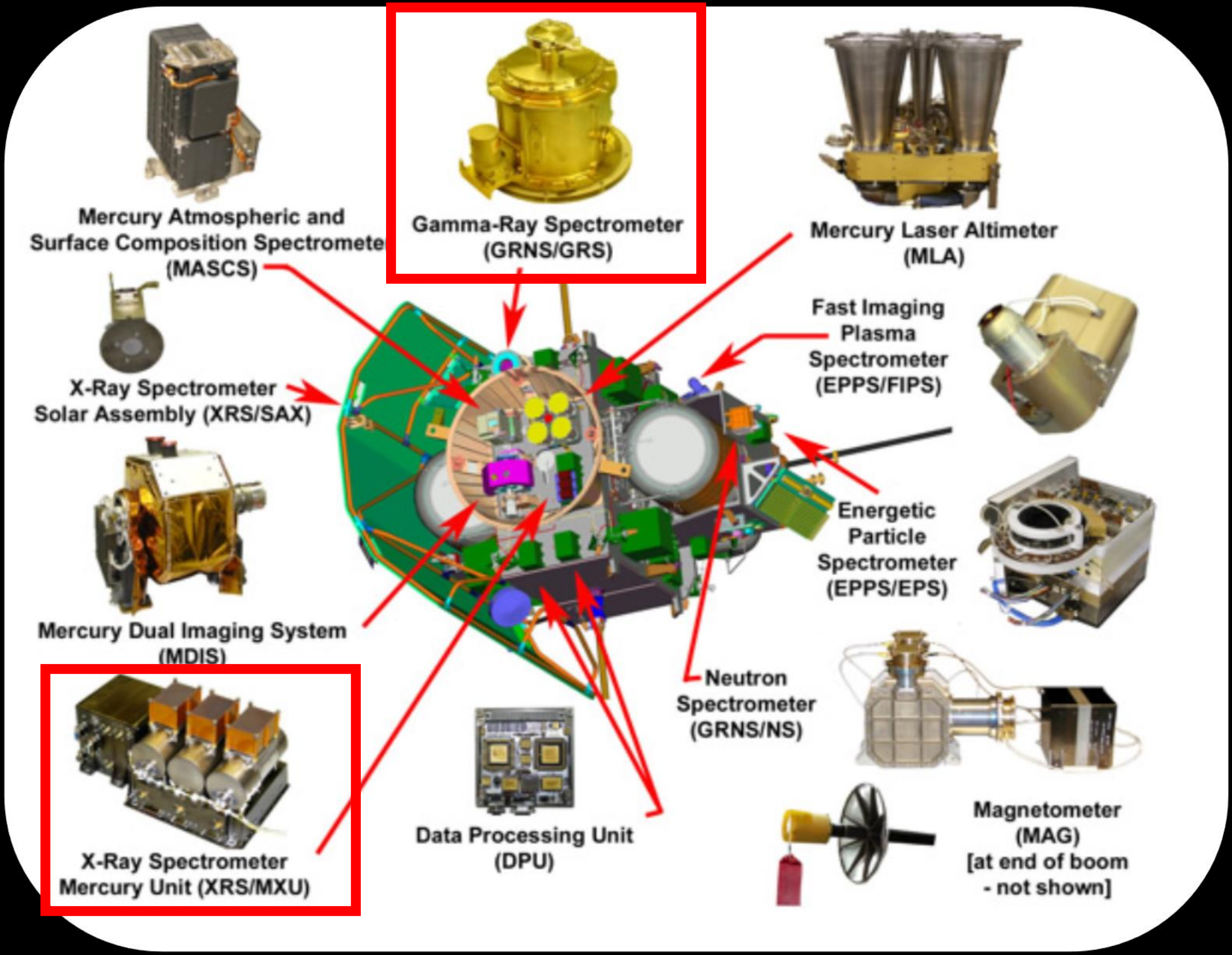




Klima et al. (2018)

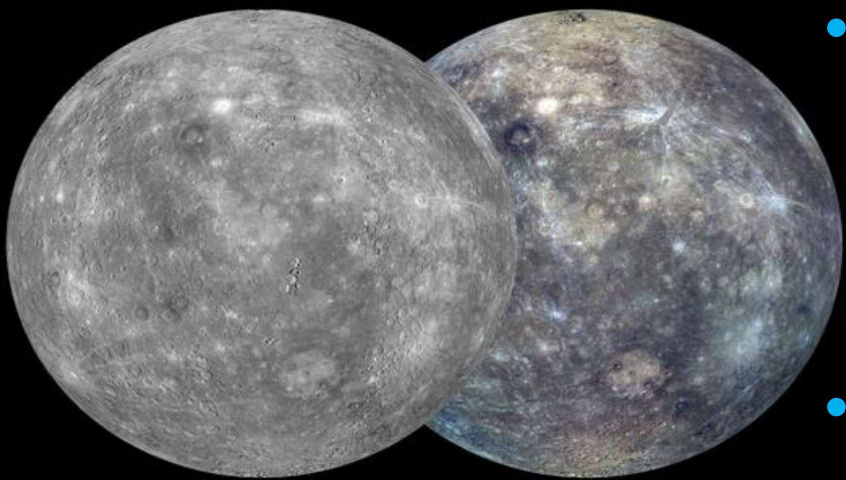
- LRM excavated from depth
- LRM may be enriched with as much as 4 wt% carbon over the local mean
- C is likely endogenic rather than exogenic

GRS Elements: K, Th, U, Si, O/Si, Fe/Si, S/Si, Ca/Si, Na/Si, Cl/Si, Al/Si



XRS Elements: Mg/Si, Al/Si, S/Si, Ca/Si, Ti/Si, Fe/Si, Cr/Si, Mn/Si

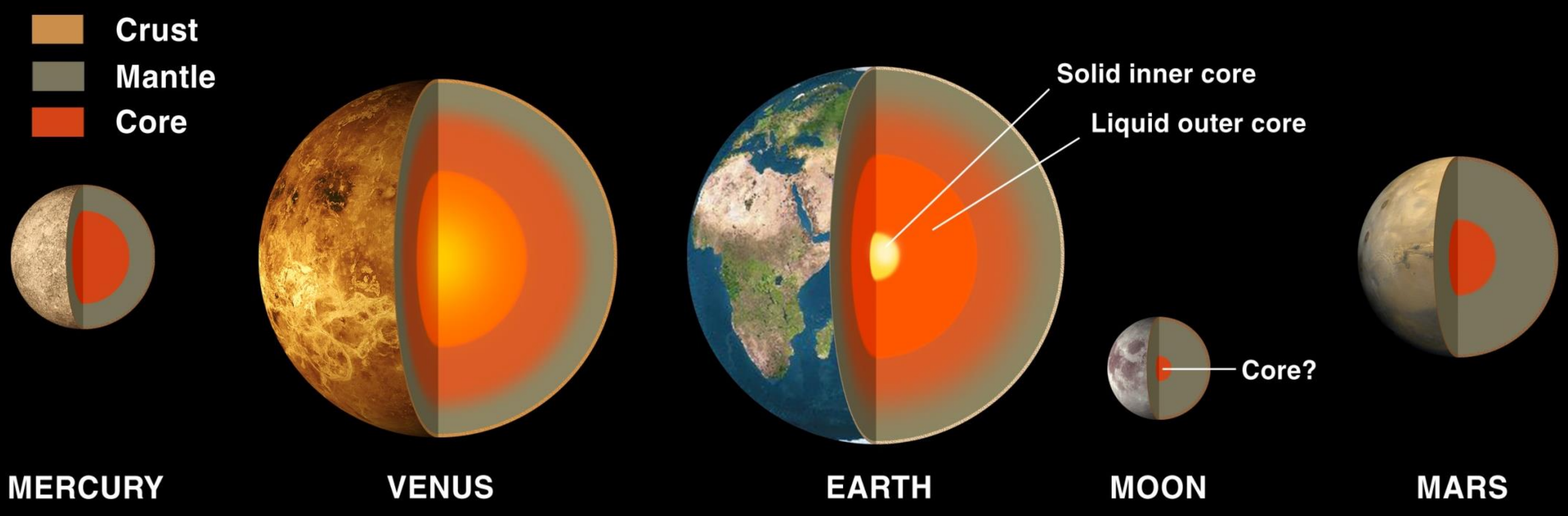
Mercury



Credit: NASA/Johns Hopkins University Applied Physics Laboratory/Carnegie Institution of Washington

Artist's impression of MESSENGER at Mercury.
Credit: NASA/JHUAL/Carnegie Institution of Washington

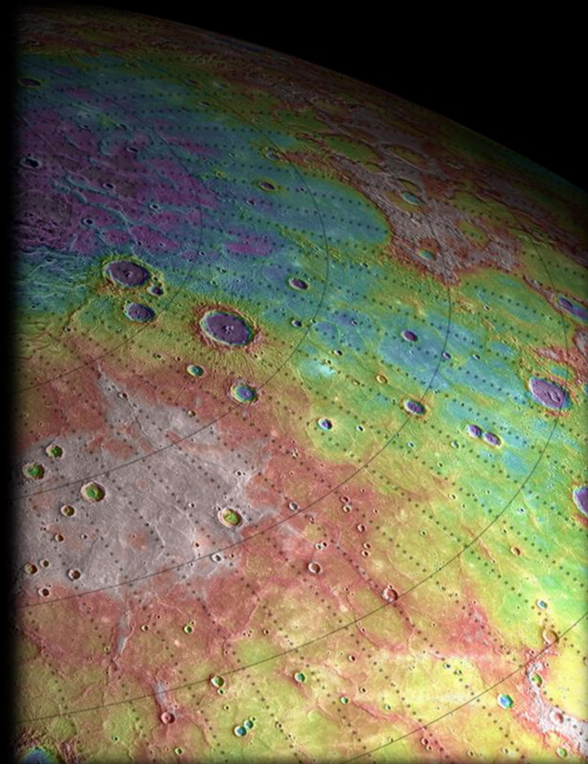
- Surface has:
  - high S abundance (4 wt%)
  - low FeO abundance (~2 wt%)
- Very low oxygen fugacity
  - -7.3ΔIW to - 2.6ΔIW
  - [Malavergne et al., 2010; Zolotov, 2011; McCubbin et al., 2012; Zolotov et al., 2013]
- Most reducing of the terrestrial planets



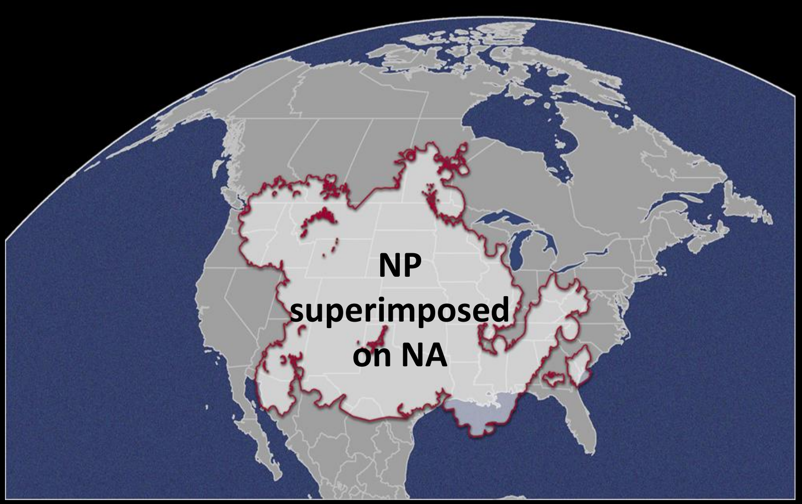
Goal: To experimentally determine the density and compressibility of a mercurian melt composition using sink-float experiments in order to assess its eruptability onto the surface of Mercury.

Northern Volcanic Plains (NP)

- Smooth Plains
- Less cratered than their surroundings
- Cover 12 % of the surface area in the northern hemisphere of Mercury
- No evidence of nearby impact basin → goes against impact origin



Credit: NASA/JHUAPL/CIW-DTM/GSFC/MIT/Brown University. Rendering by James Dickson and Jim Head



(Head et al., 2011)

- Most likely example of lavas that can be compositionally assessed from orbit.
- Best candidate to experimentally study magmas from the mercurian interior.

NP Composition

Composition of NP

Oxide	Weight Percent
SiO_2[a]	55.09
MgO[b]	14.52
CaO[b]	5.33
S[b]	1.54
Al_2O_3[b]	12.84
K_2O[c]	0.22
Na_2O[d]	2.78
FeO[a]	4.97
TiO2[a]	1.29
Cr_2O_3[a]	0.75
MnO[a]	0.66
Total	100

Composition of Starting Material

Oxide	Weight Percent
SiO_2	57.51
MgO	14.64
CaO	5.34
Al_2O_3	14.61
FeO	5.23
TiO_2	1.24
Cr_2O_3	0.74
MnO	0.69
Total	100

[a]Nittler et al. (2011), [b]Weider et al. (2012), [c]Peplowski et al. (2012), [d]Evans et al. (2012)

NP Composition

Composition of NP

Oxide	Weight Percent
SiO_2[a]	55.09
MgO[b]	14.52
CaO[b]	5.33
S[b]	**1.54**
Al_2O_3[b]	12.84
K_2O[c]	**0.22**
Na_2O[d]	**2.78**
FeO[a]	4.97
TiO2[a]	1.29
Cr_2O_3[a]	0.75
MnO[a]	0.66
Total	100

Composition of Starting Material

Oxide	Weight Percent
SiO_2	57.51
MgO	14.64
CaO	5.34
Al_2O_3	14.61
FeO	5.23
TiO_2	1.24
Cr_2O_3	0.74
MnO	0.69
Total	100

[a]Nittler et al. (2011), [b]Weider et al. (2012), [c]Peplowski et al. (2012), [d]Evans et al. (2012)

NP Composition

Composition of NP

Oxide	Weight Percent
SiO_2[a]	55.09
MgO[b]	14.52
CaO[b]	5.33
S[b]	**1.54**
Al_2O_3[b]	12.84
K_2O[c]	**0.22**
Na_2O[d]	**2.78**
FeO[a]	4.97
TiO2[a]	1.29
Cr_2O_3[a]	0.75
MnO[a]	0.66
Total	100

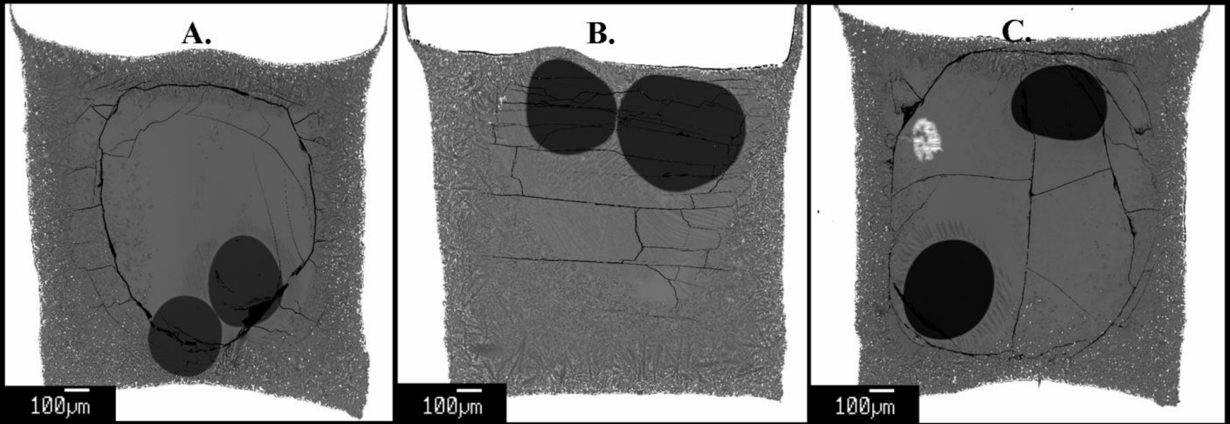
Composition of Starting Material

Oxide	Weight Percent
SiO_2	57.51
MgO	14.64
CaO	5.34
Al_2O_3	14.61
FeO	**5.23**
TiO_2	1.24
Cr_2O_3	0.74
MnO	0.69
Total	100

[a]Nittler et al. (2011), [b]Weider et al. (2012), [c]Peplowski et al. (2012), [d]Evans et al. (2012)

Experimental Methods

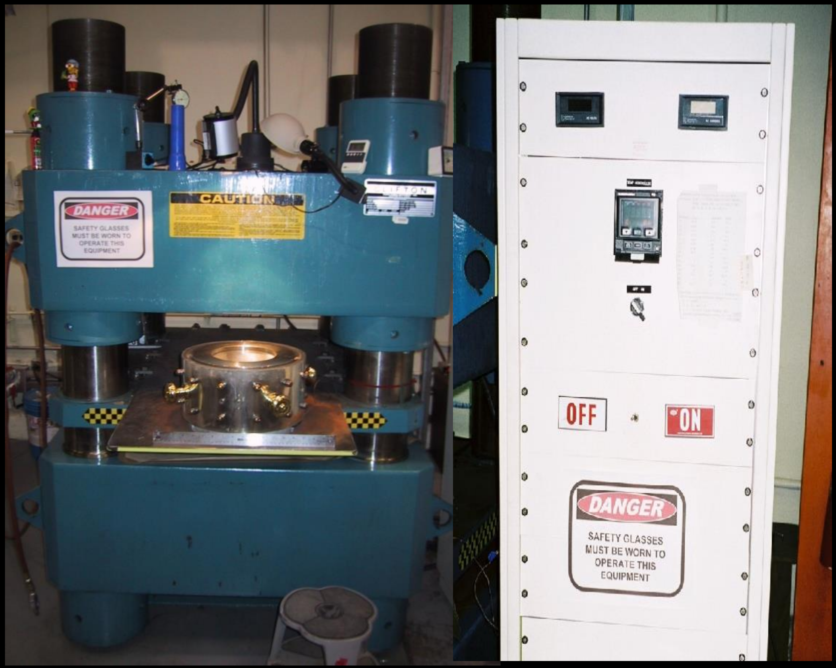
- Sink-Float Experiments
  - Density markers (Fo_{100}) to monitor the density of the melt throughout the experiment
  - Used in the past to successful bracket the density of ultrabasic silicate liquids [Agee and Walker, 1988], melts of the lunar volcanic glasses [Circone and Agee (1996), Smith and Agee (1997), Van Kan Parker et al. (2011), Vander Kaaden et al. (2015)] , CO_2 rich magmas [Duncan and Agee, 2011], hydrous magmas [Agee, 2008], etc…

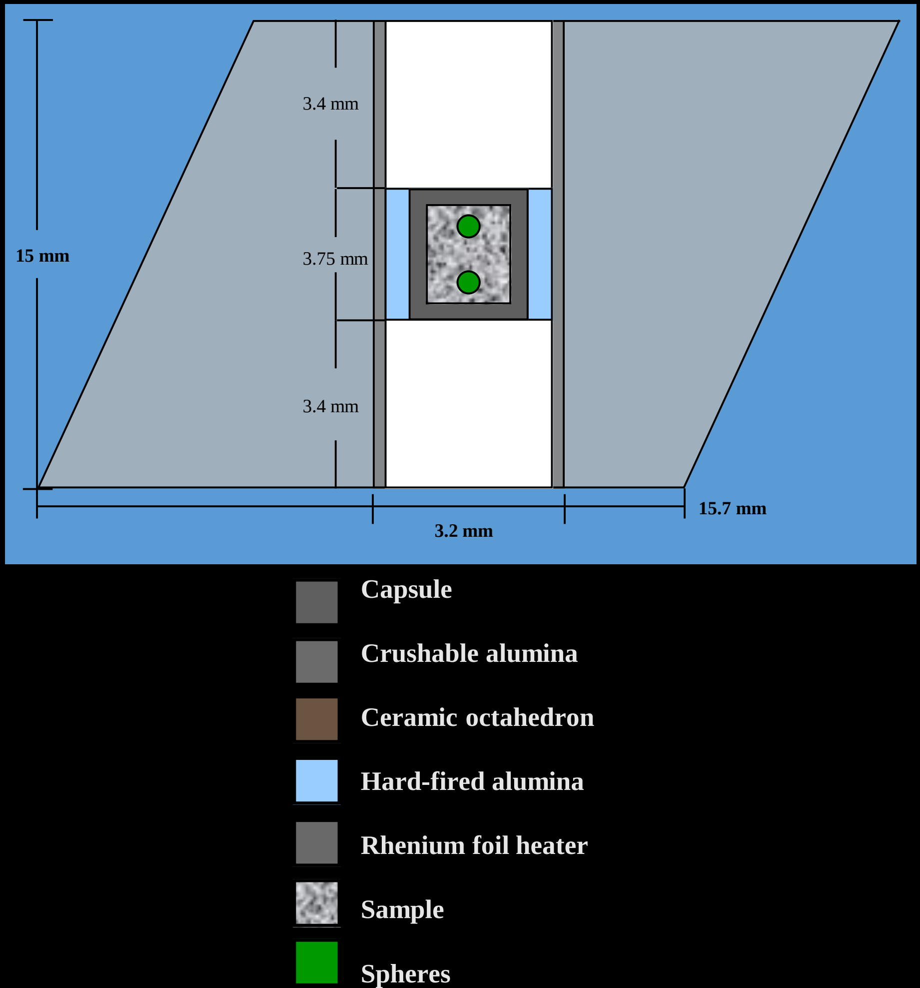


Vander Kaaden et al. (2015)

Experimental Methods

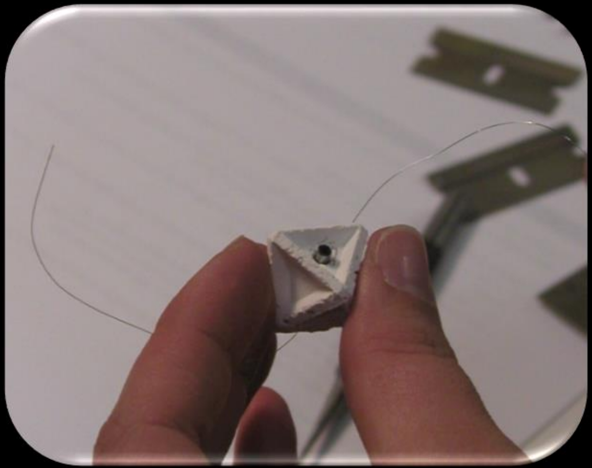
- 2.5-6 GPa
  - Multi-Anvil (MA)





[http://epswww.unm.edu/highp/gear.html]

Experimental Methods

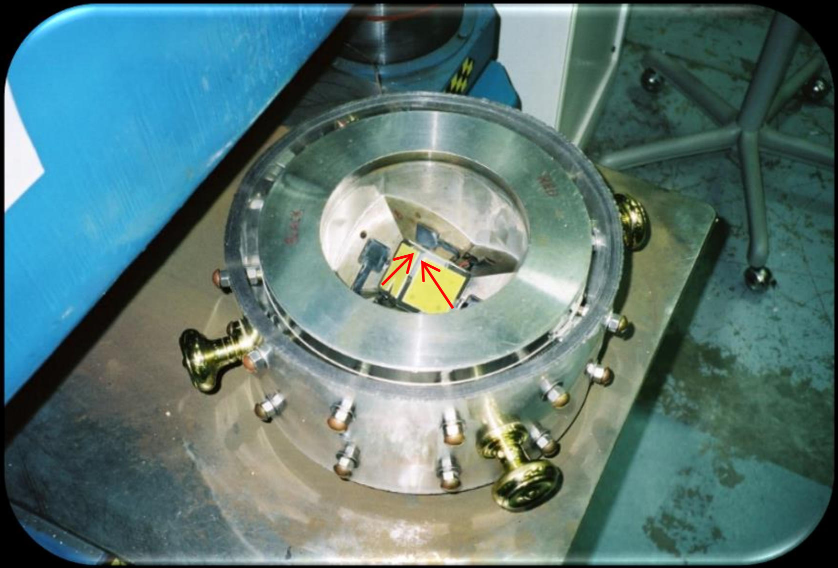


Pressurize: 1 oil bar/min

Ramp Rate: 300 deg/min

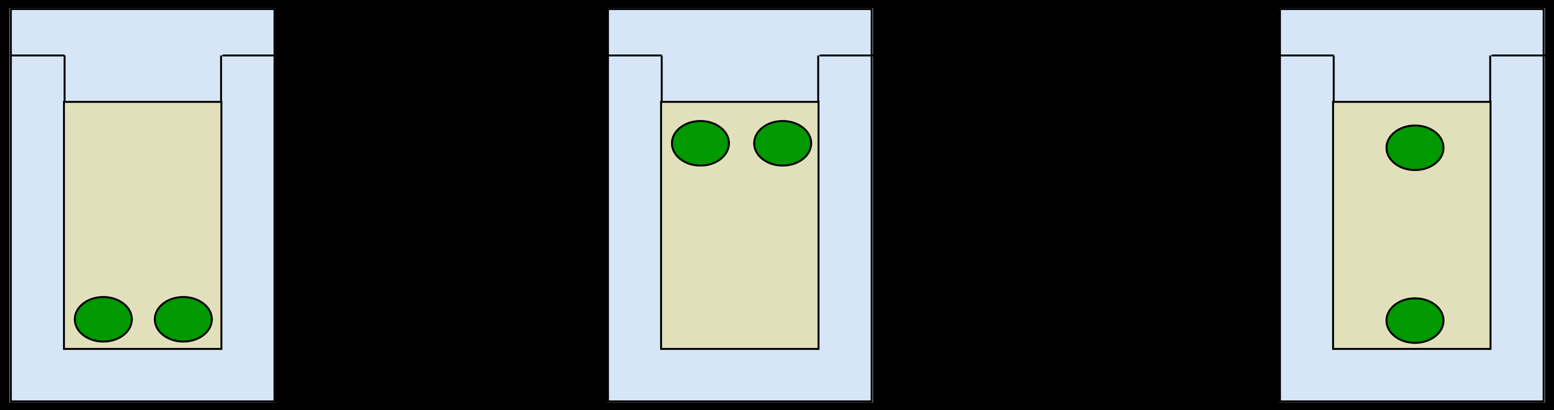
Hold at target P,T conditions 30 seconds

Quench: shut off power, slowly decompress → 150°/second



[http://epswww.unm.edu/highp/gear.html]

Sink-Float Results

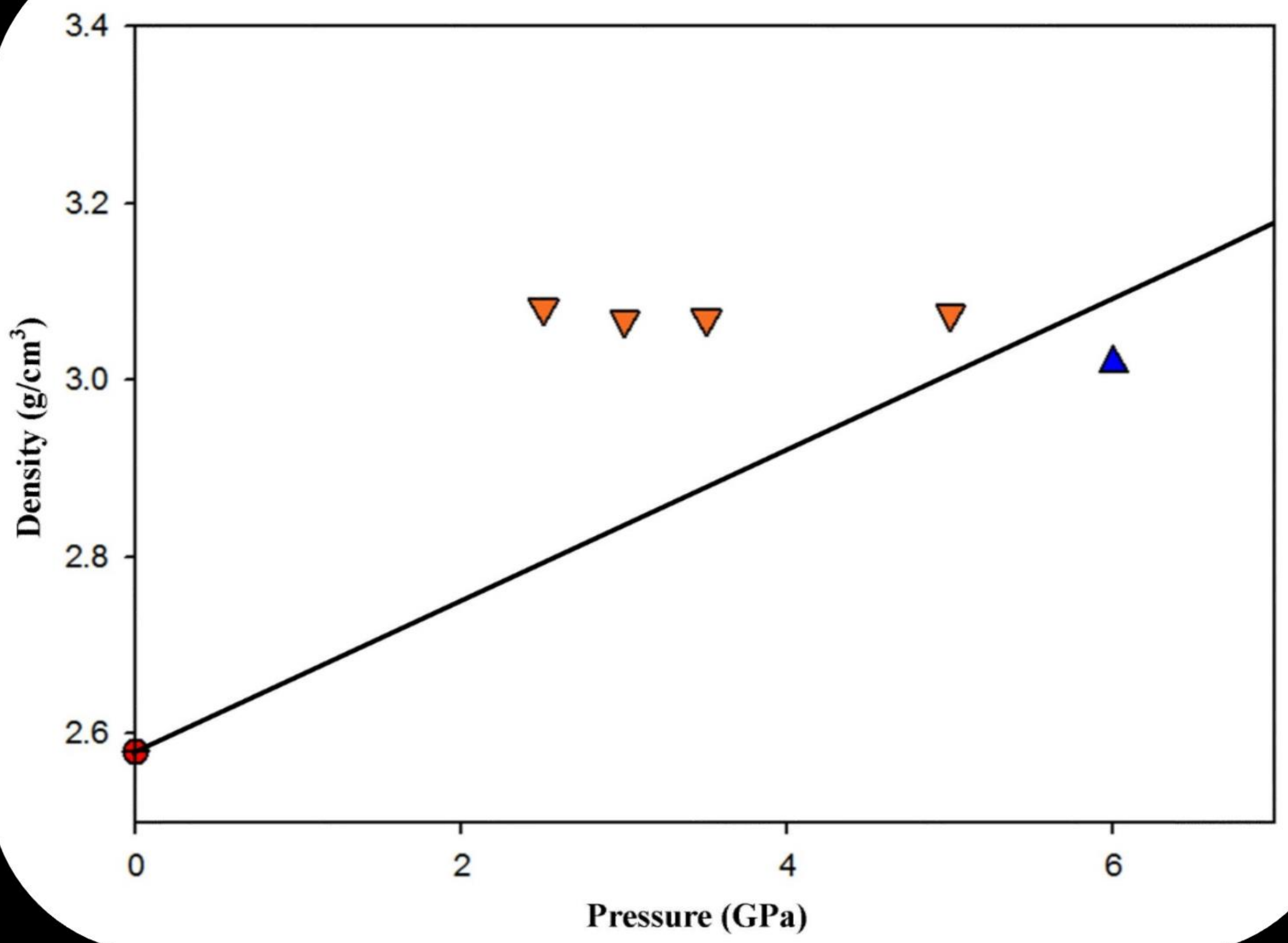


Sink	Float	Neutral Buoyancy
Spheres:	Spheres:	Spheres:
More dense than melt	Less dense than melt	Equivalent to density of melt

All samples analyzed on JEOL 8200 Superprobe at UNM

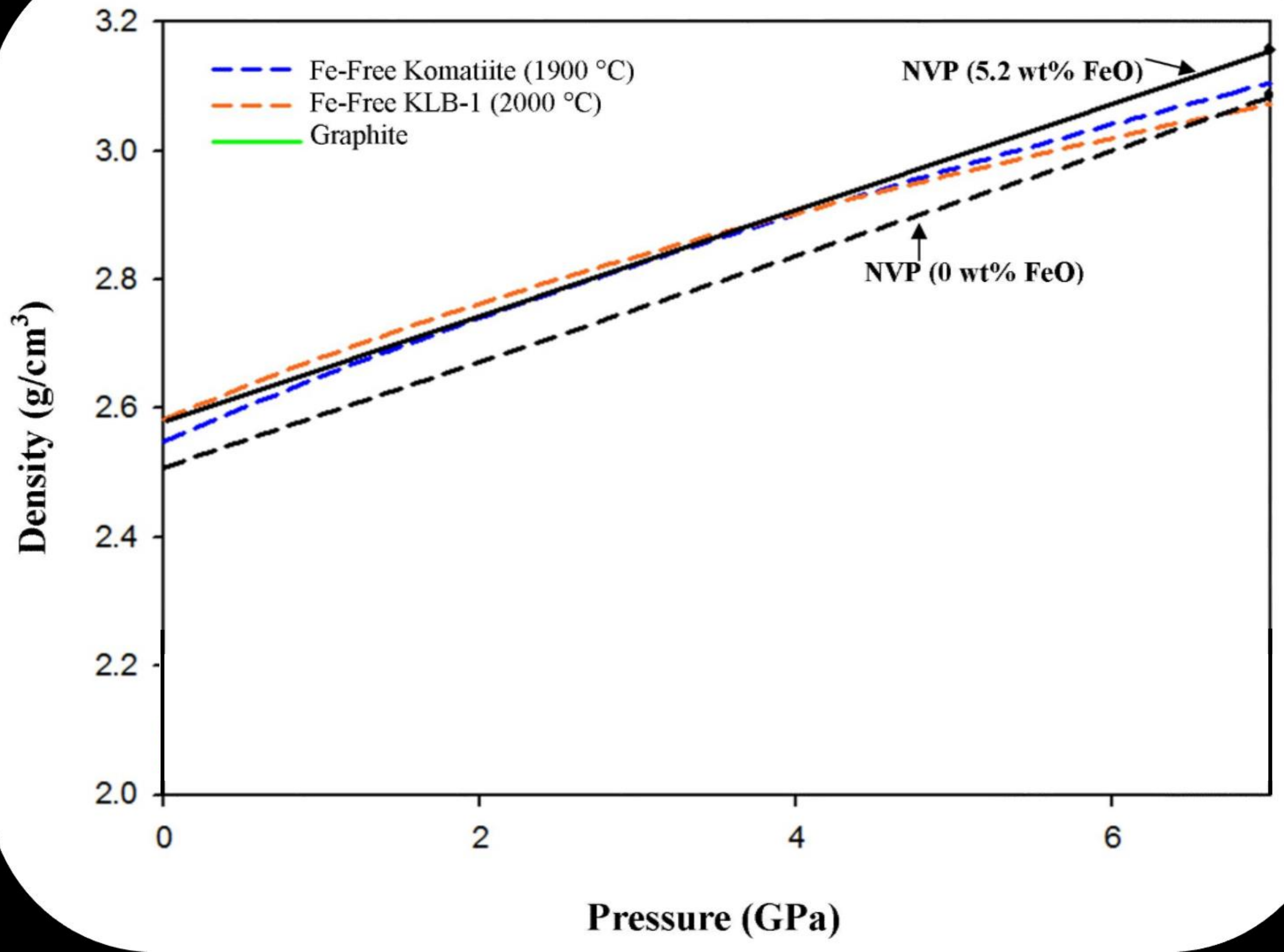
Results

Vander Kaaden and McCubbin (2015) JGR: Planets



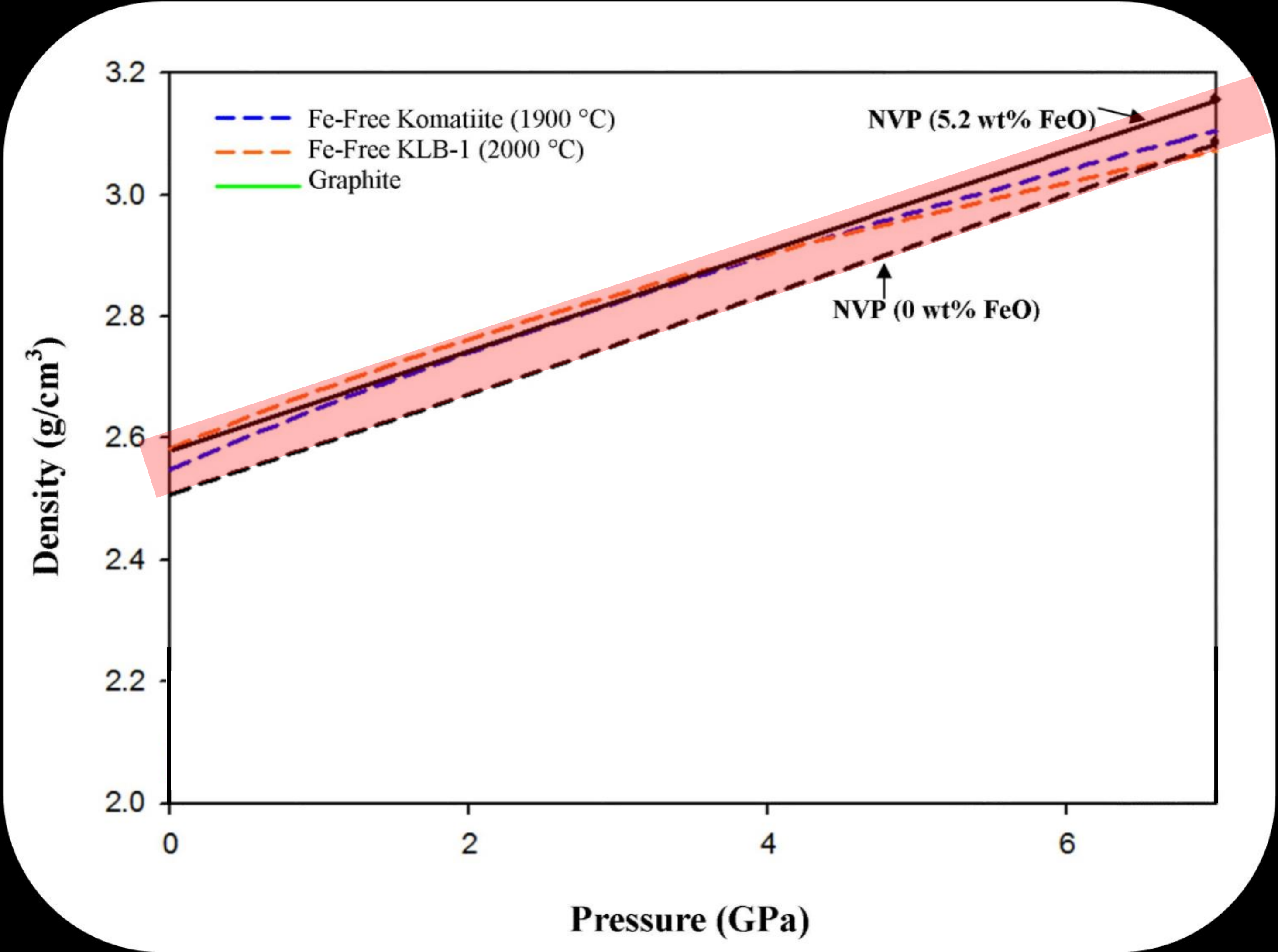
Comparison to Terrestrial Melts

Vander Kaaden and McCubbin (2015) JGR: Planets



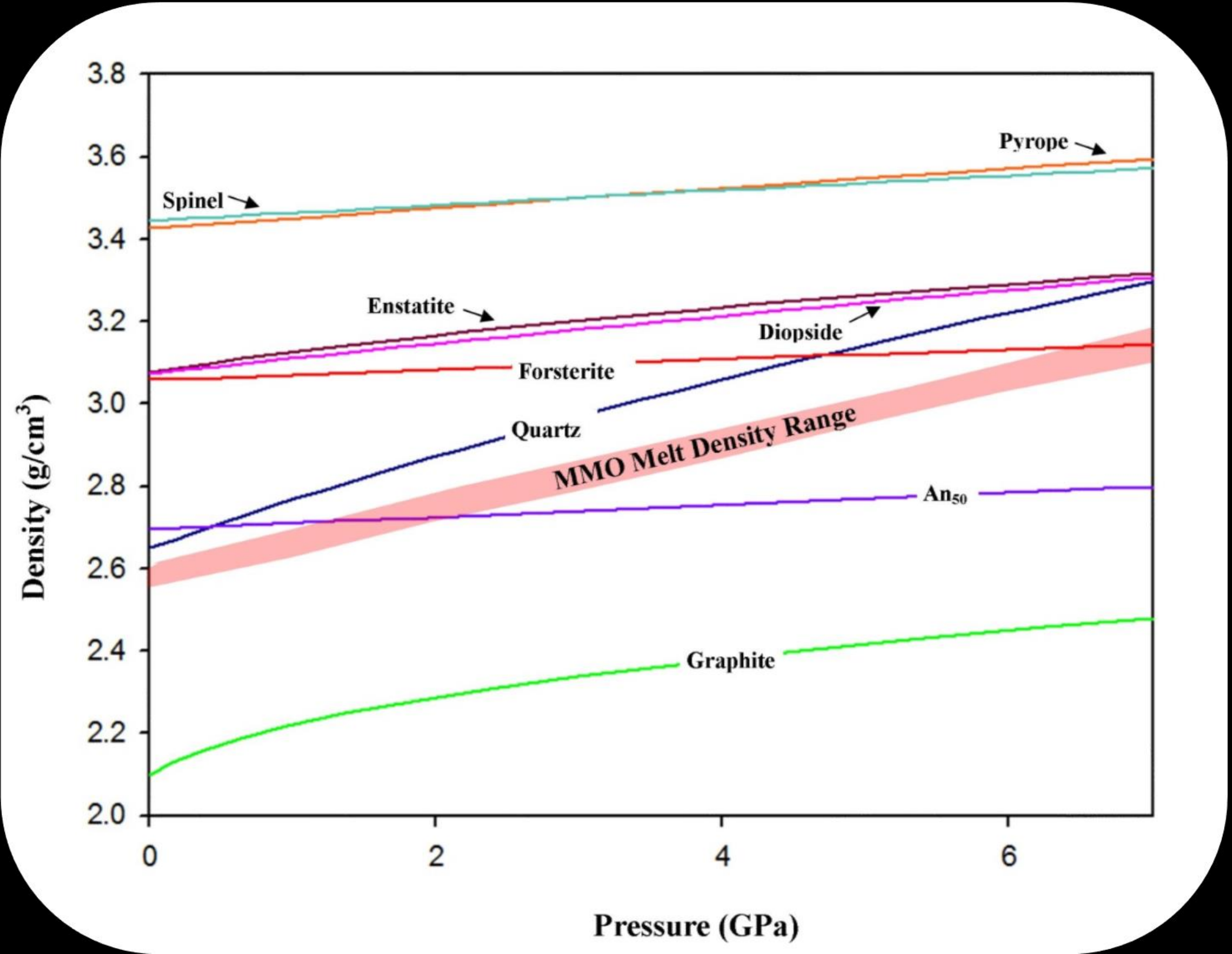
Comparison to Terrestrial Melts

Vander Kaaden and McCubbin (2015) JGR: Planets



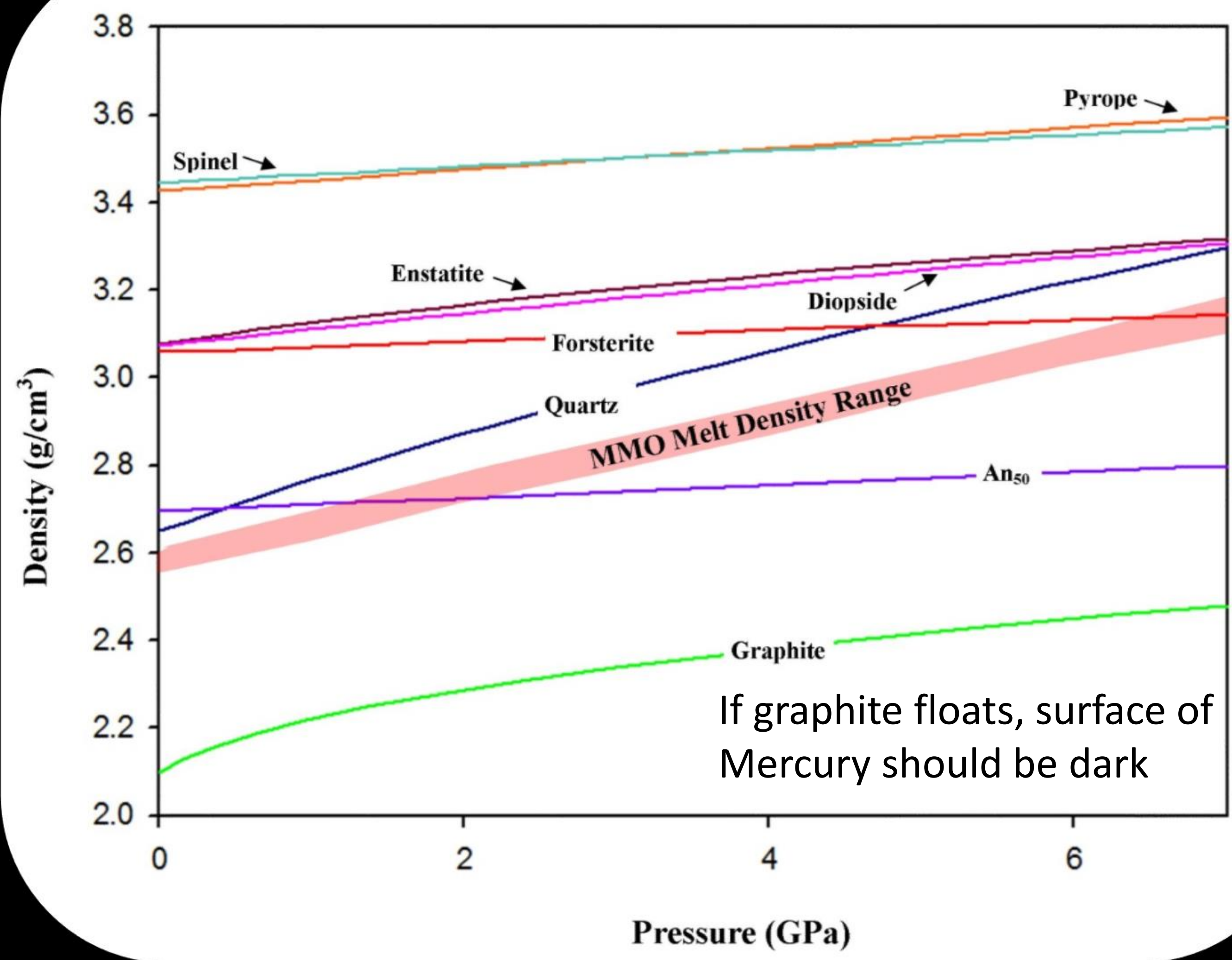
Comparison to Common Minerals

Vander Kaaden and McCubbin (2015) JGR: Planets



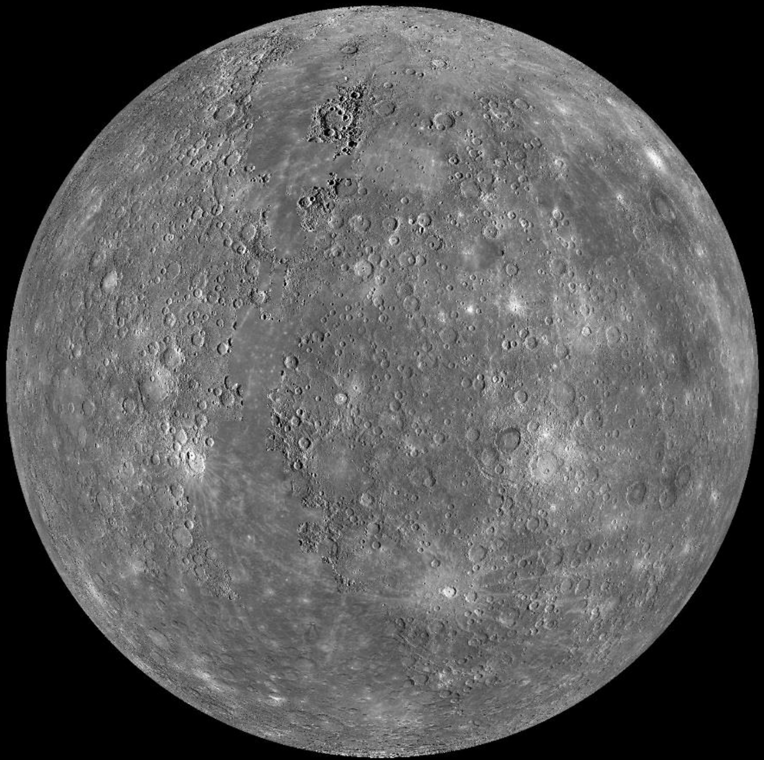
Comparison to Common Minerals

Vander Kaaden and McCubbin (2015) JGR: Planets



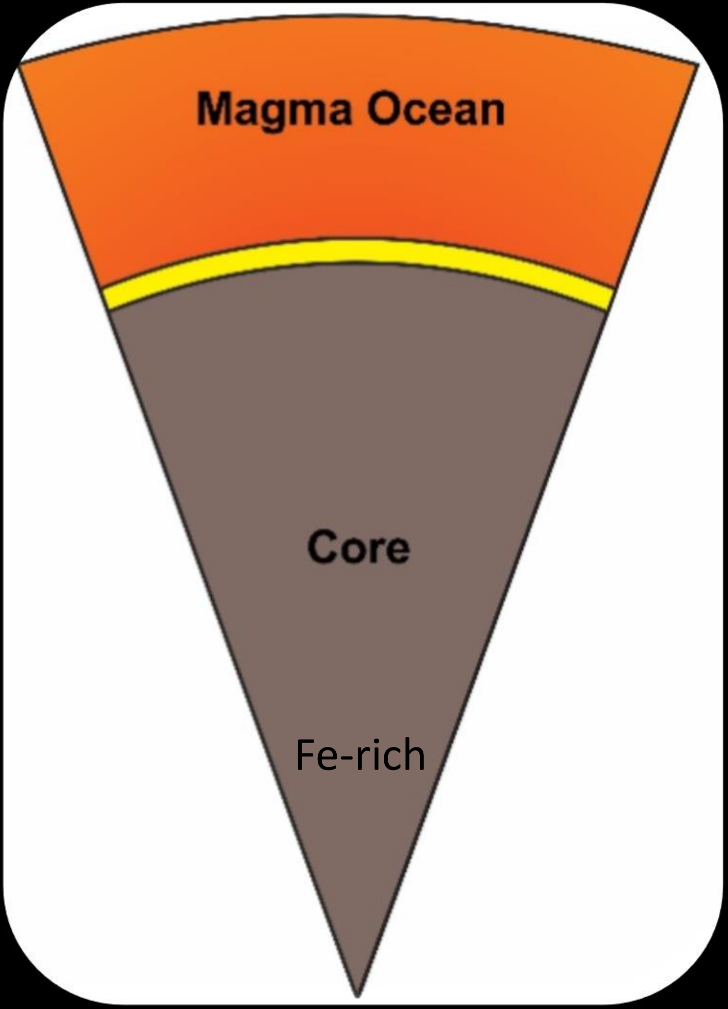
Graphite → Darkening Agent on Mercury

Mercury



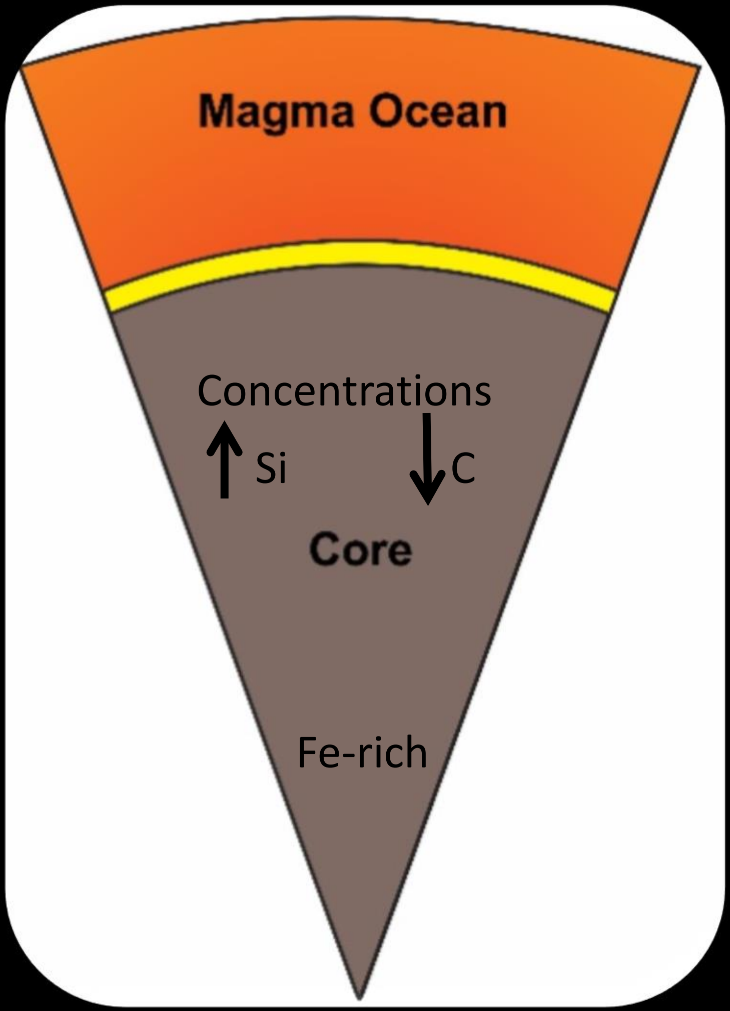
Moon

Thermal and Magmatic Evolution of Mercury



- Mercurian magma ocean → highly reducing conditions → large, Fe-rich core

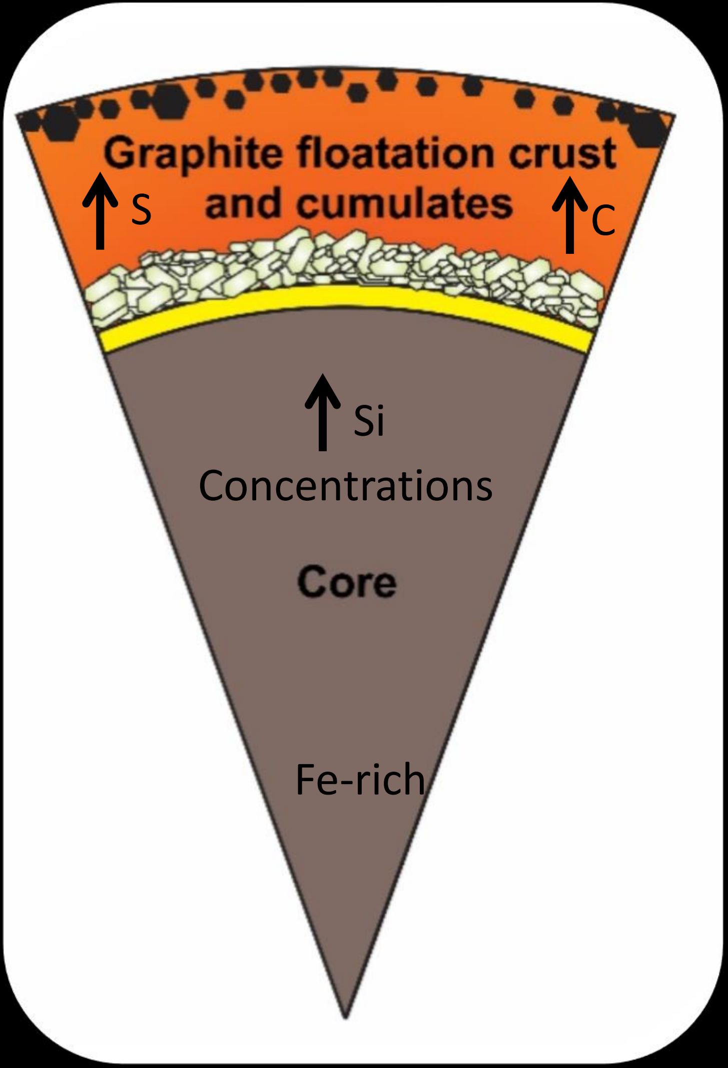
Thermal and Magmatic Evolution of Mercury



- Increase Si in core → results in low C in core

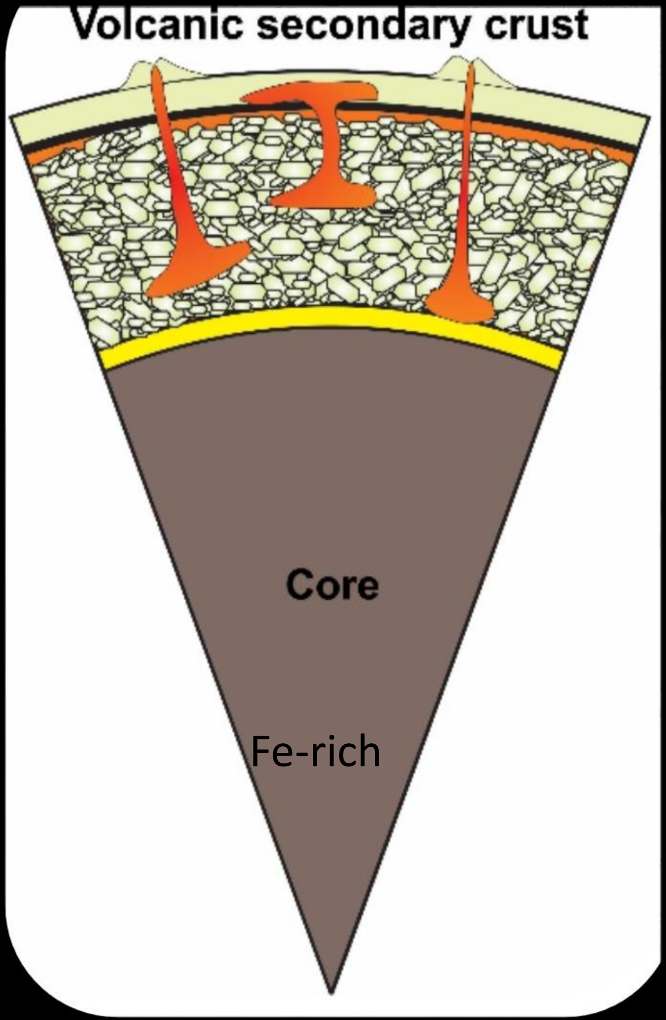
Vander Kaaden et al. (2016) LPSC

Thermal and Magmatic Evolution of Mercury



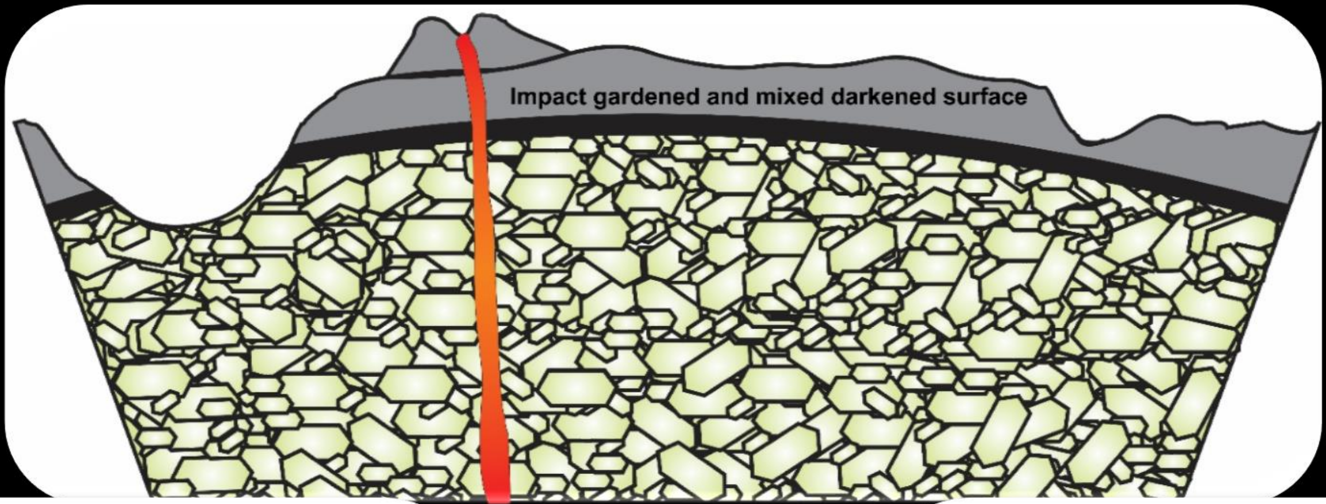
- Increase S in silicate portion accompanied by buoyant rise of C

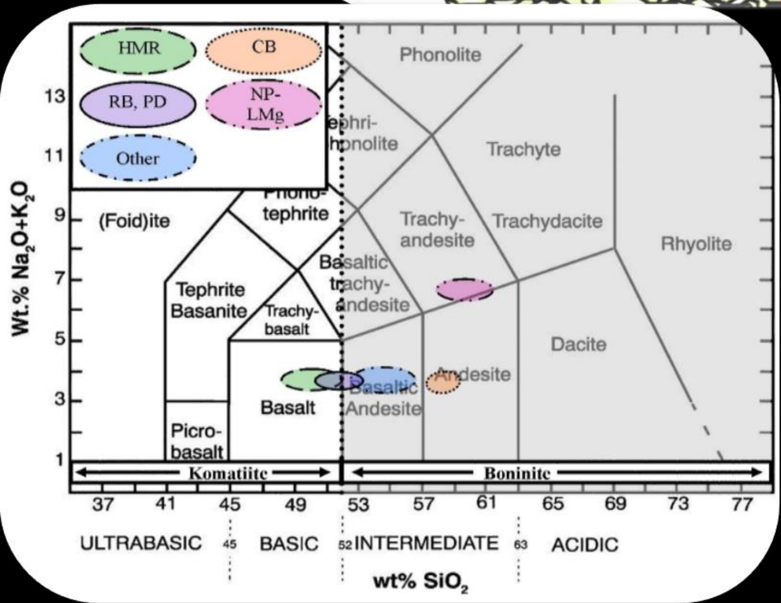
Thermal and Magmatic Evolution of Mercury

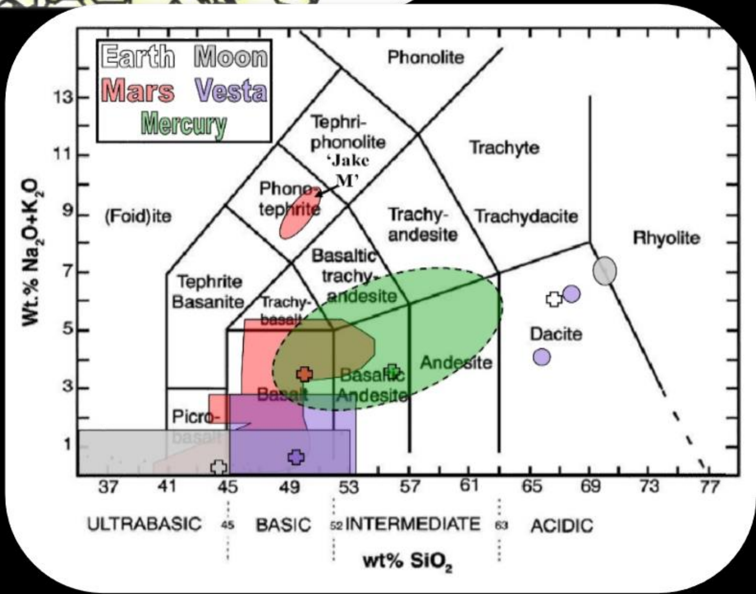


- Continued volcanism resurfaced the planet and buried LRM

Thermal and Magmatic Evolution of Mercury





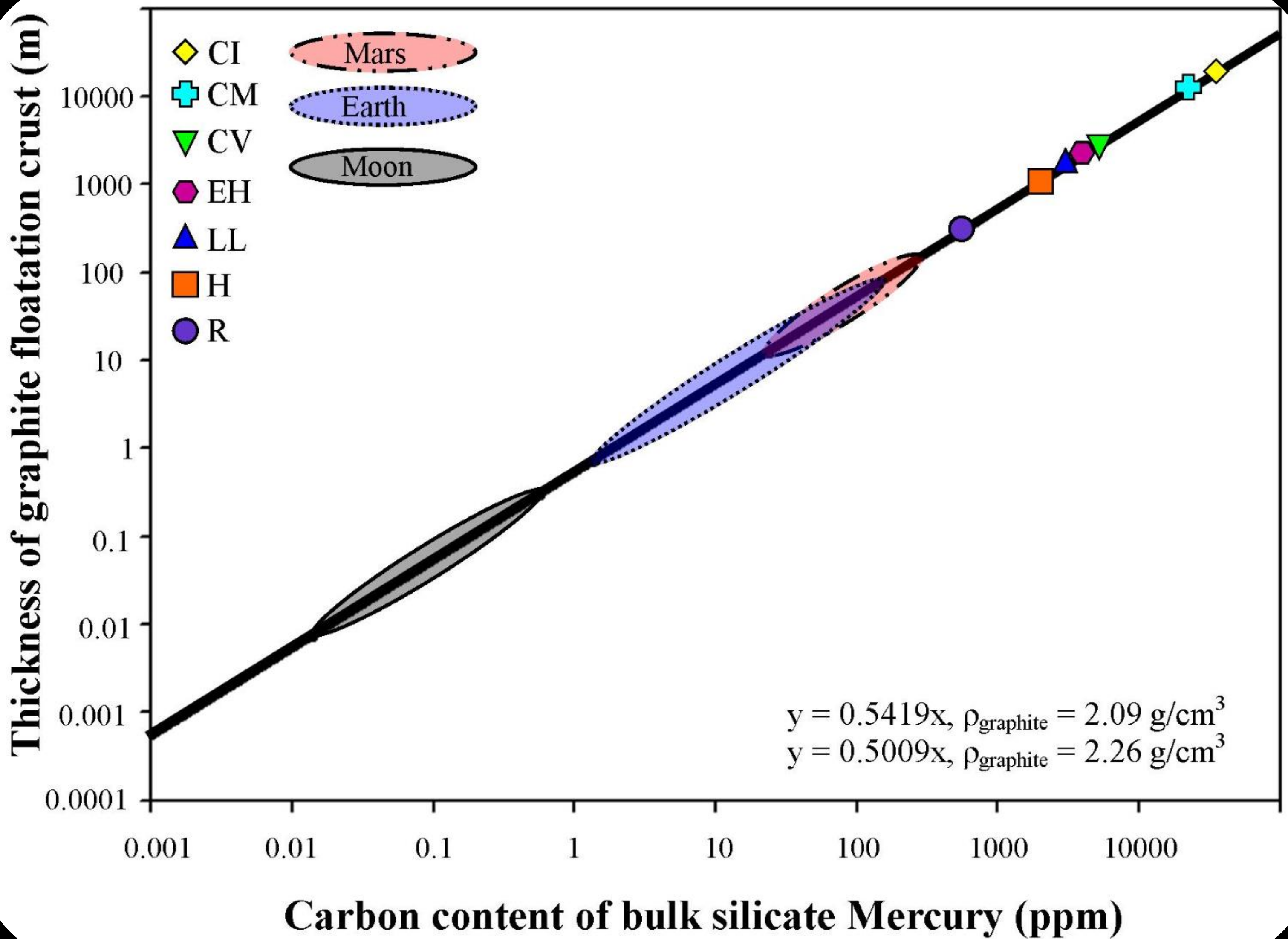


- LRM mixed and exposed through continuous impacts
- Results in chemically diverse surface

Vander Kaaden et al. (2017) Icarus

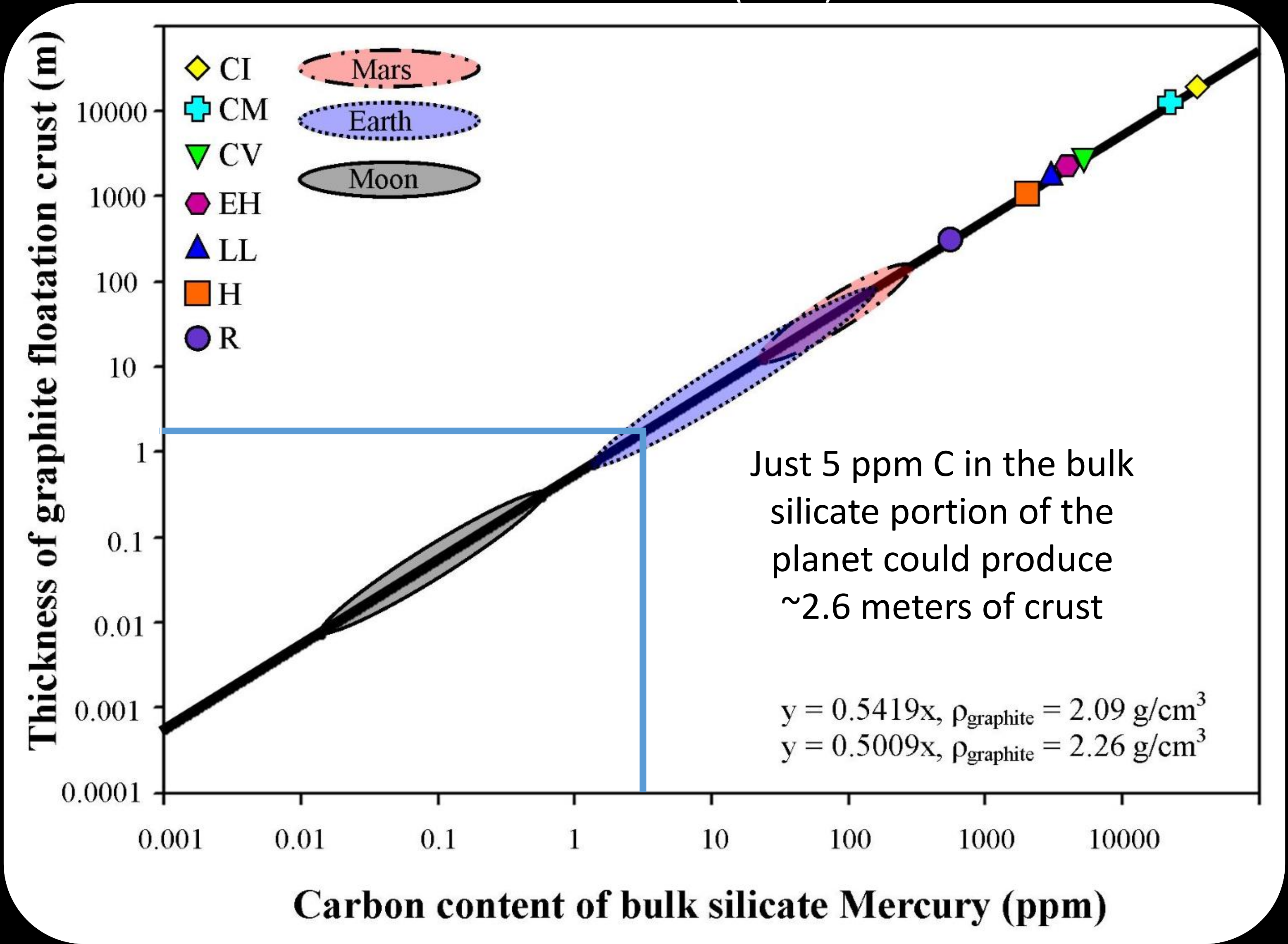
Implications for Mercury

Vander Kaaden and McCubbin (2015) JGR: Planets

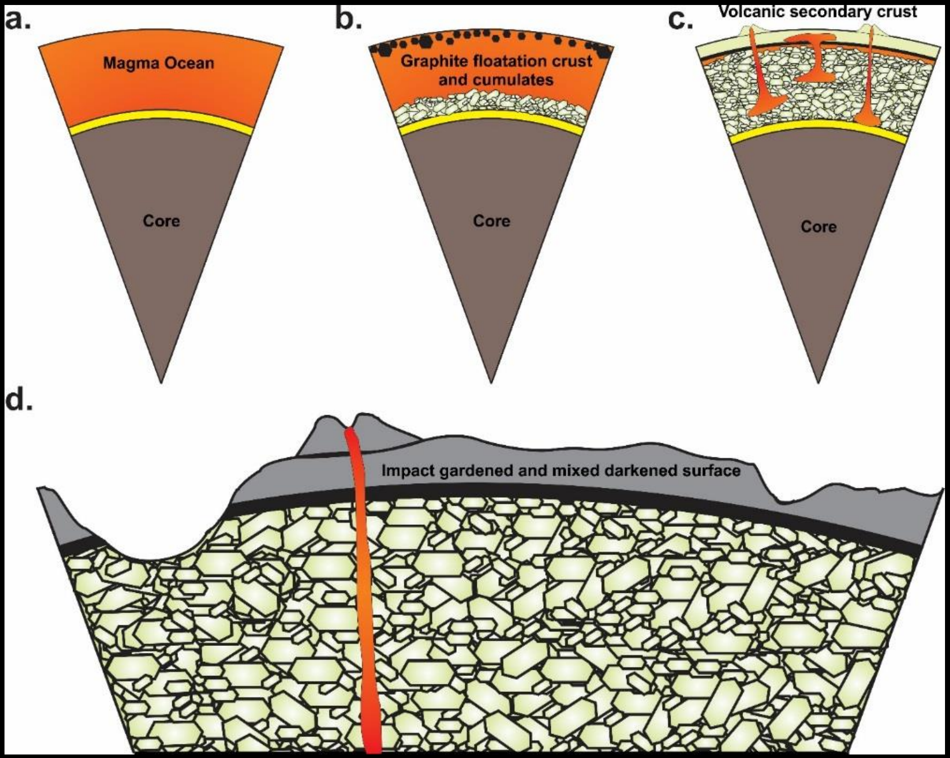


Implications for Mercury

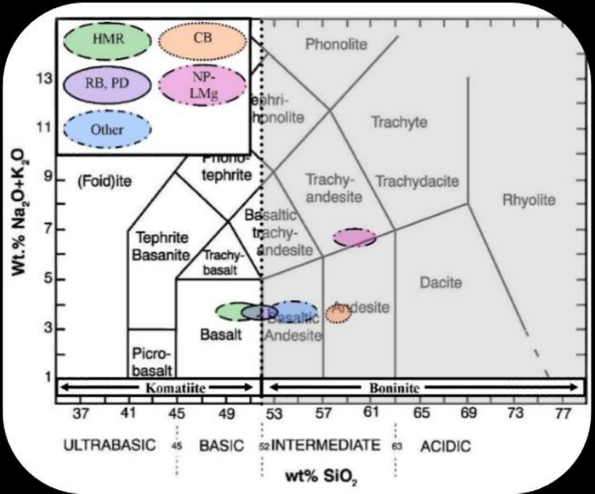
Vander Kaaden and McCubbin (2015) JGR: Planets

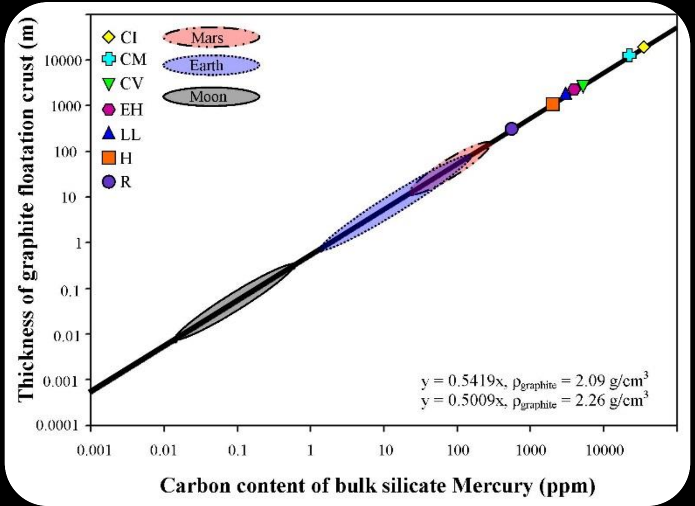


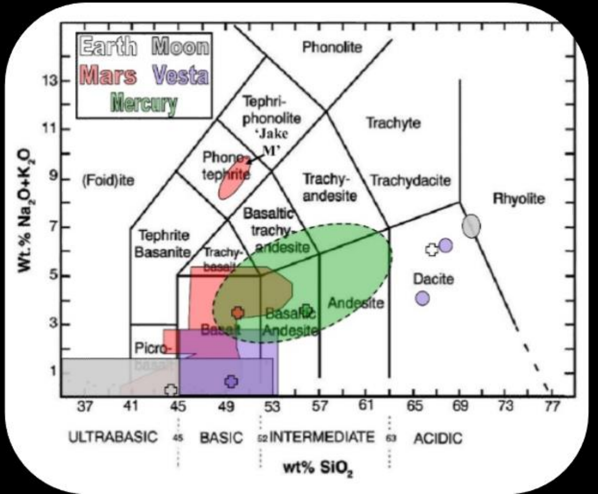
Thank you!



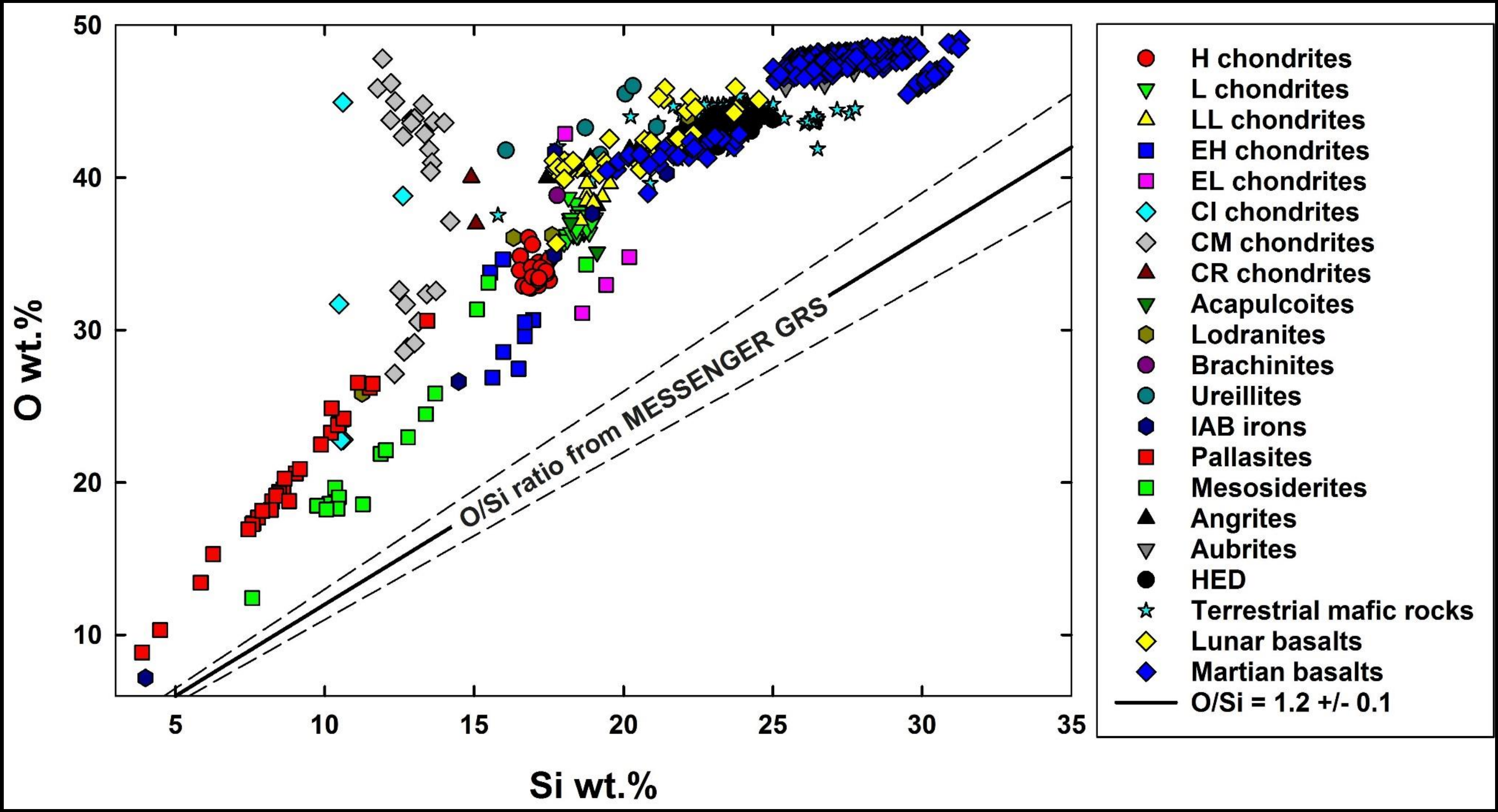
Questions?





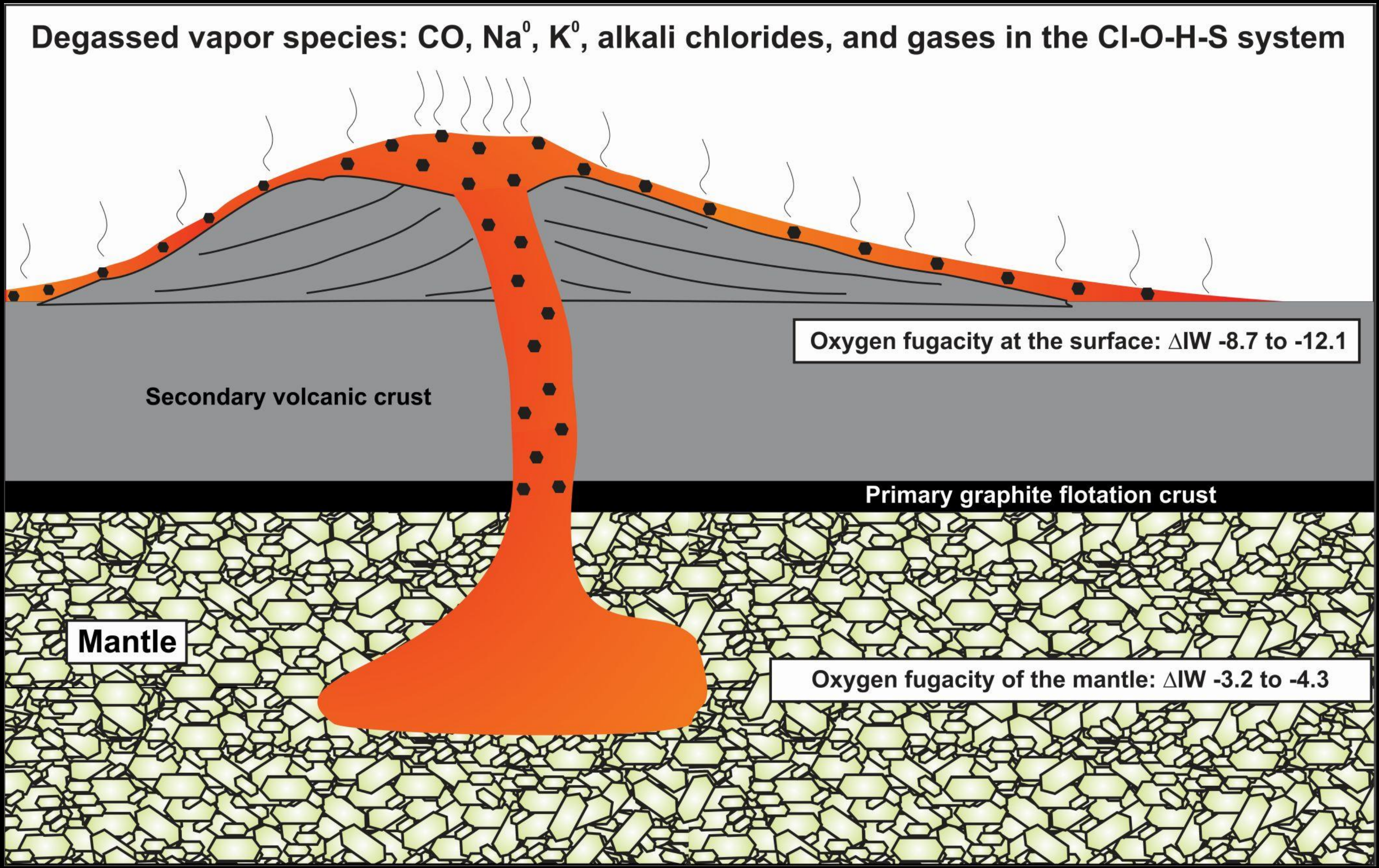


O/Si ratio of Mercury



McCubbin, Vander Kaaden, et al. (2017) JGR: Planets

O/Si ratio of Mercury



McCubbin, Vander Kaaden, et al. (2017) JGR: Planets