Planetary Differentiation on Earth and Its Implications: From the Solar Nebula to Today.
Pd-Ag

Kevin Wheeler
Earth2Class
February 9, 2007

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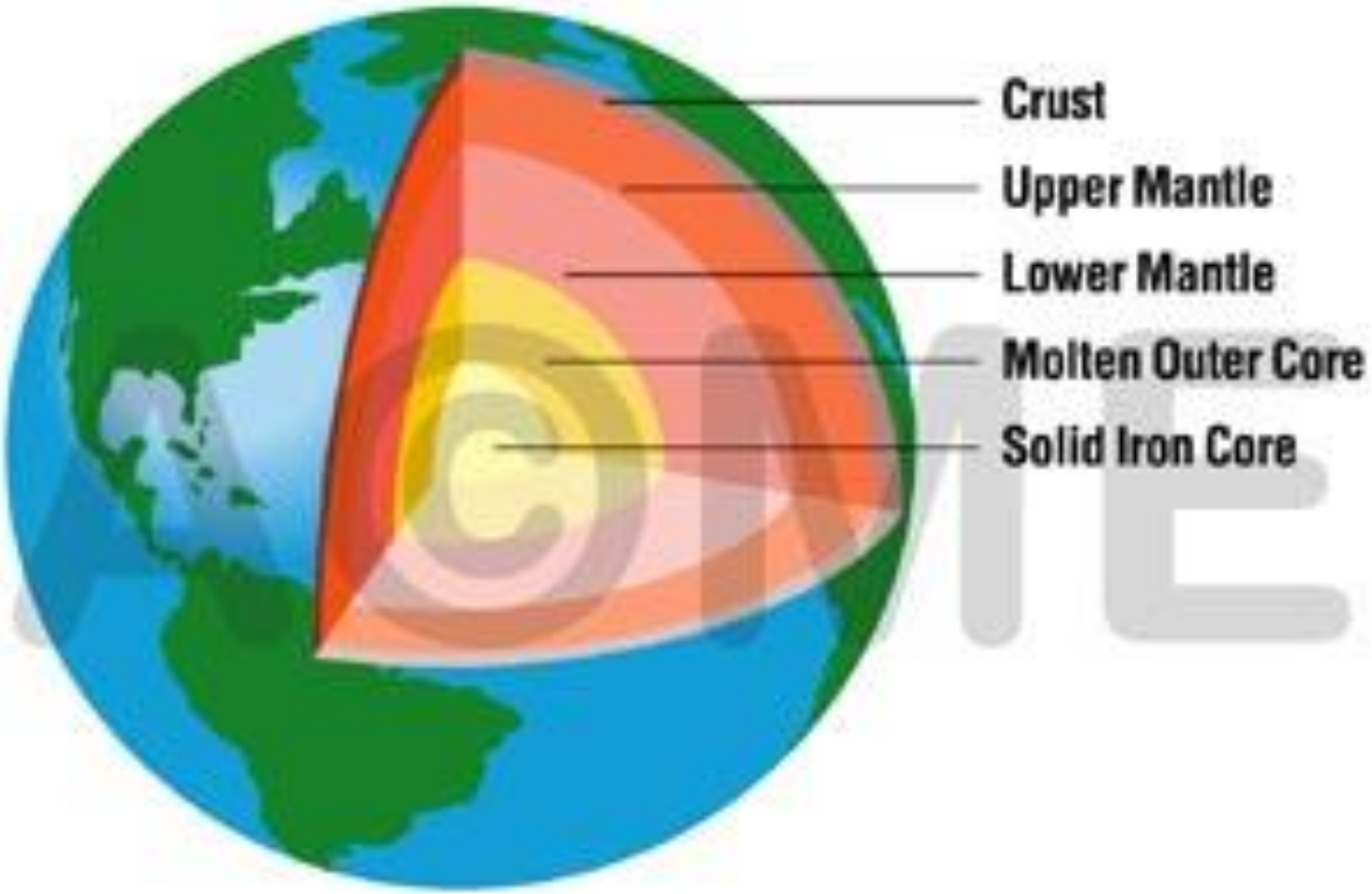
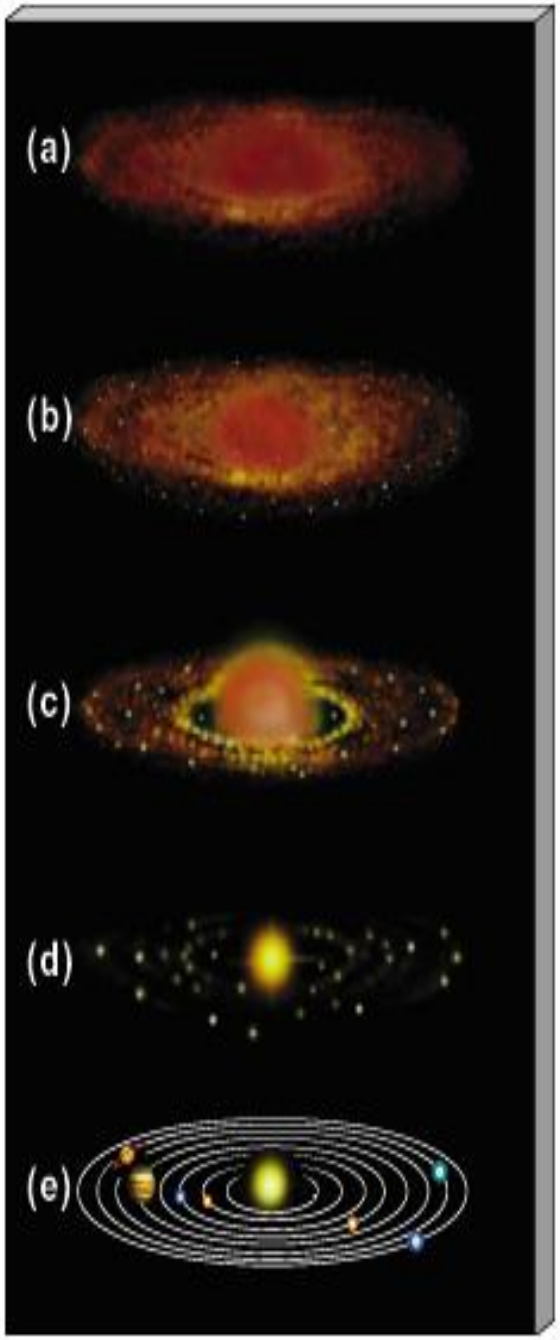
Thank you!

Pd Ag Outline

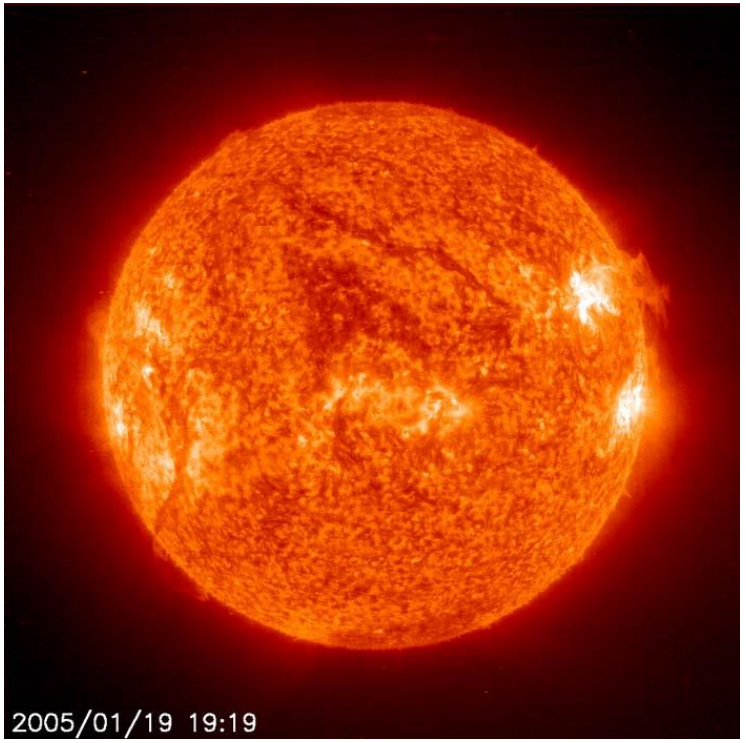
I. Planetary Accretion
II. Intro to the Siderophile Element Problem
III. Experimental Methods
IV. Semi-Resolution to Siderophile Element Problem
V. Uranium in the Core

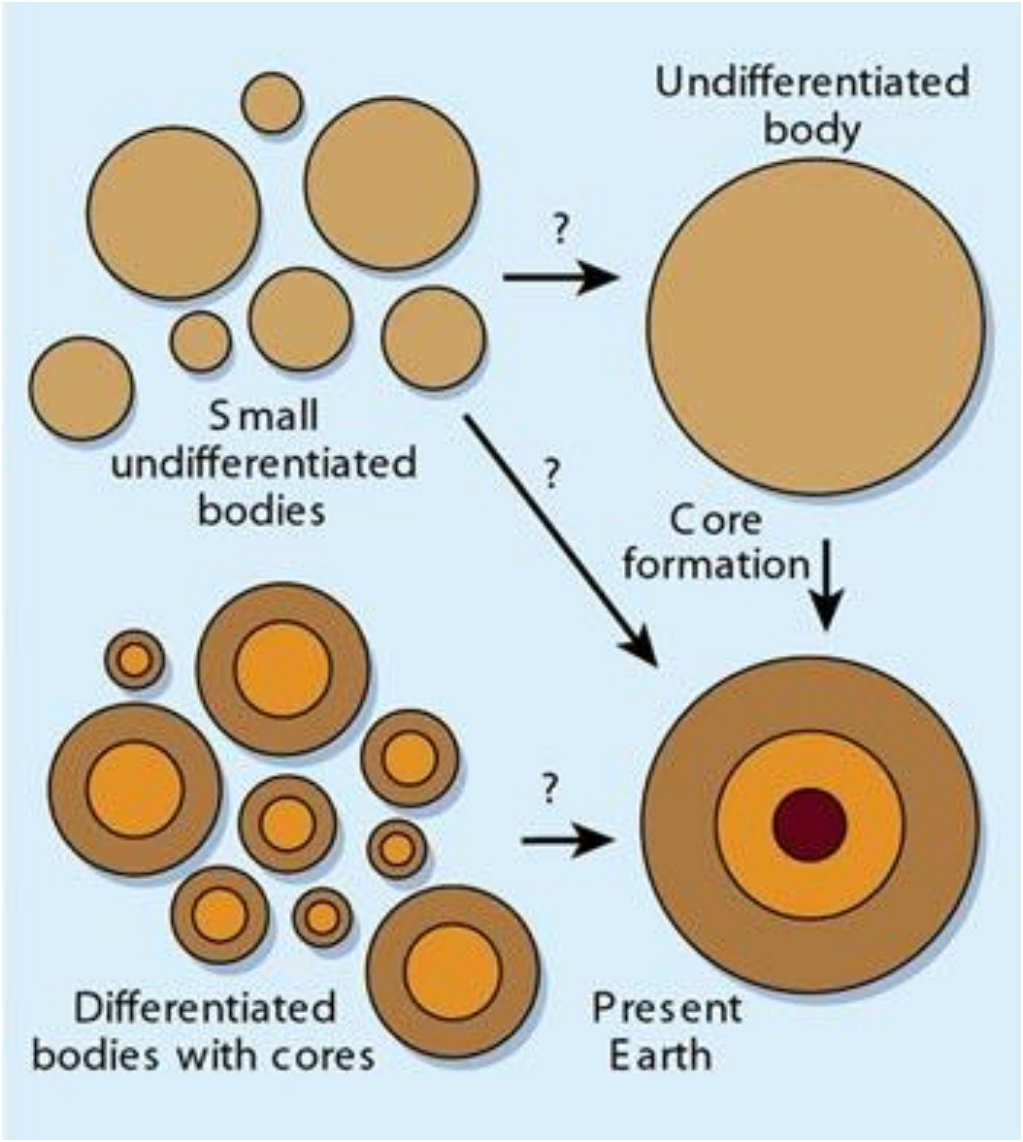

Crust
Upper Mantle
Lower Mantle
Molten Outer Core
Solid Iron Core

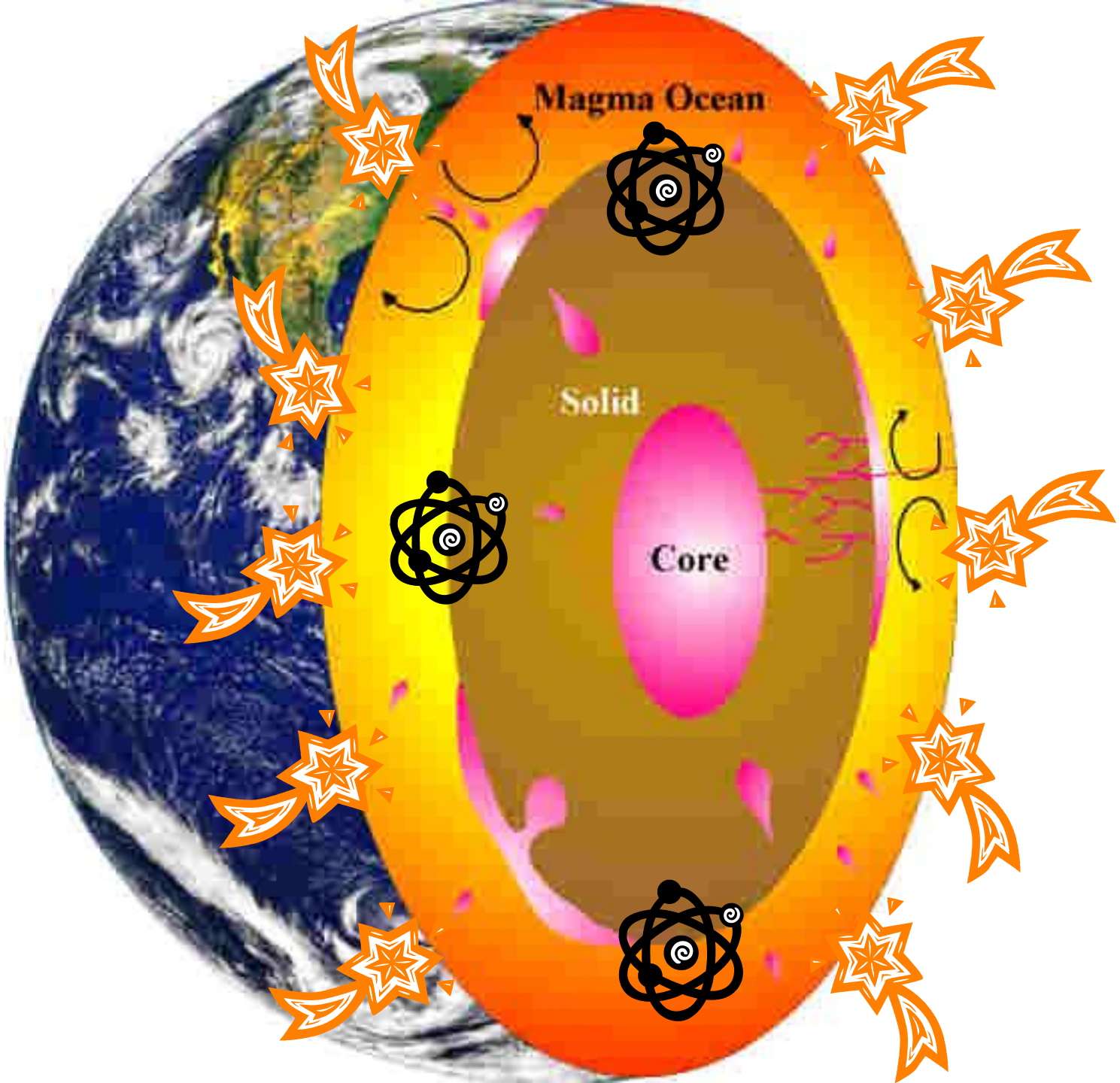

(a)
(b)
(c)
(d)
(e)

Nebular Condensate: Chondrite

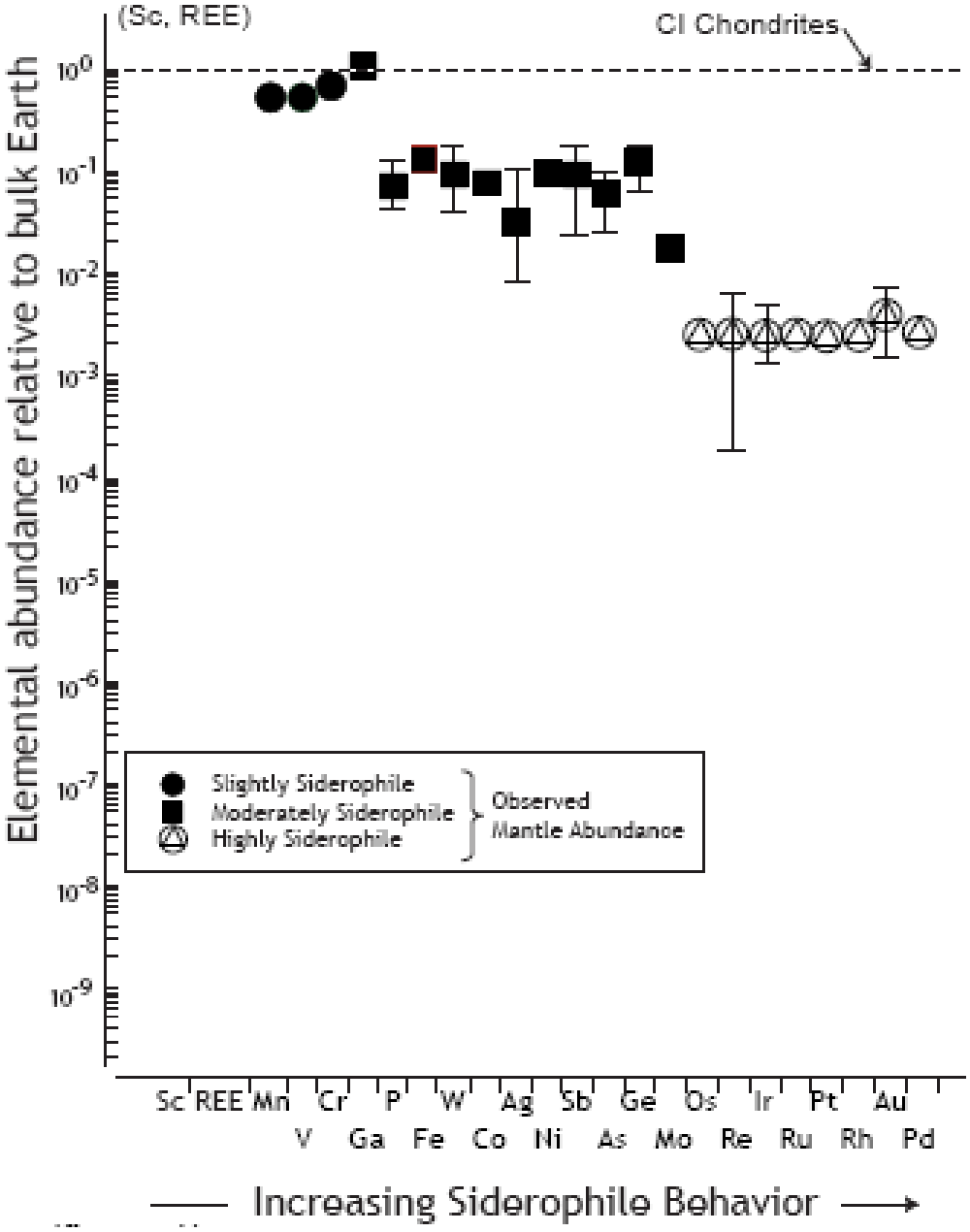
=


2005/01/19 19:19


Undifferentiated body
?
Small undifferentiated bodies
?
Core formation
?
Differentiated bodies with cores
Present Earth


Magma Ocean
Solid
Core

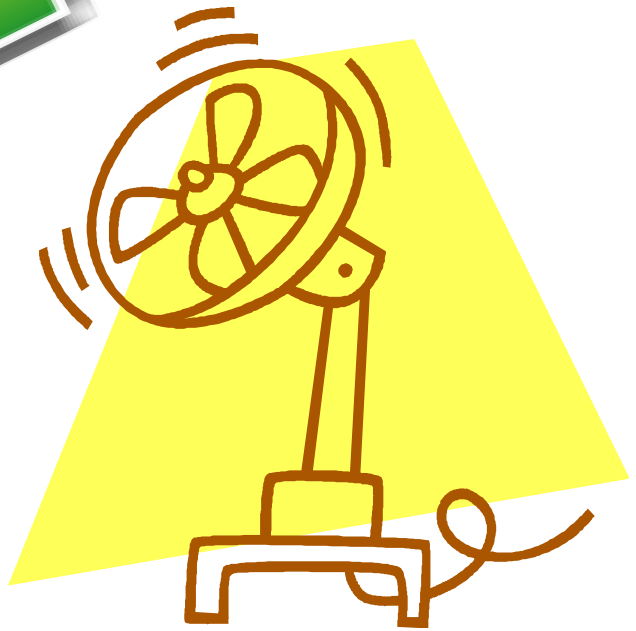
Key: Where did the elements go?
And who are they?

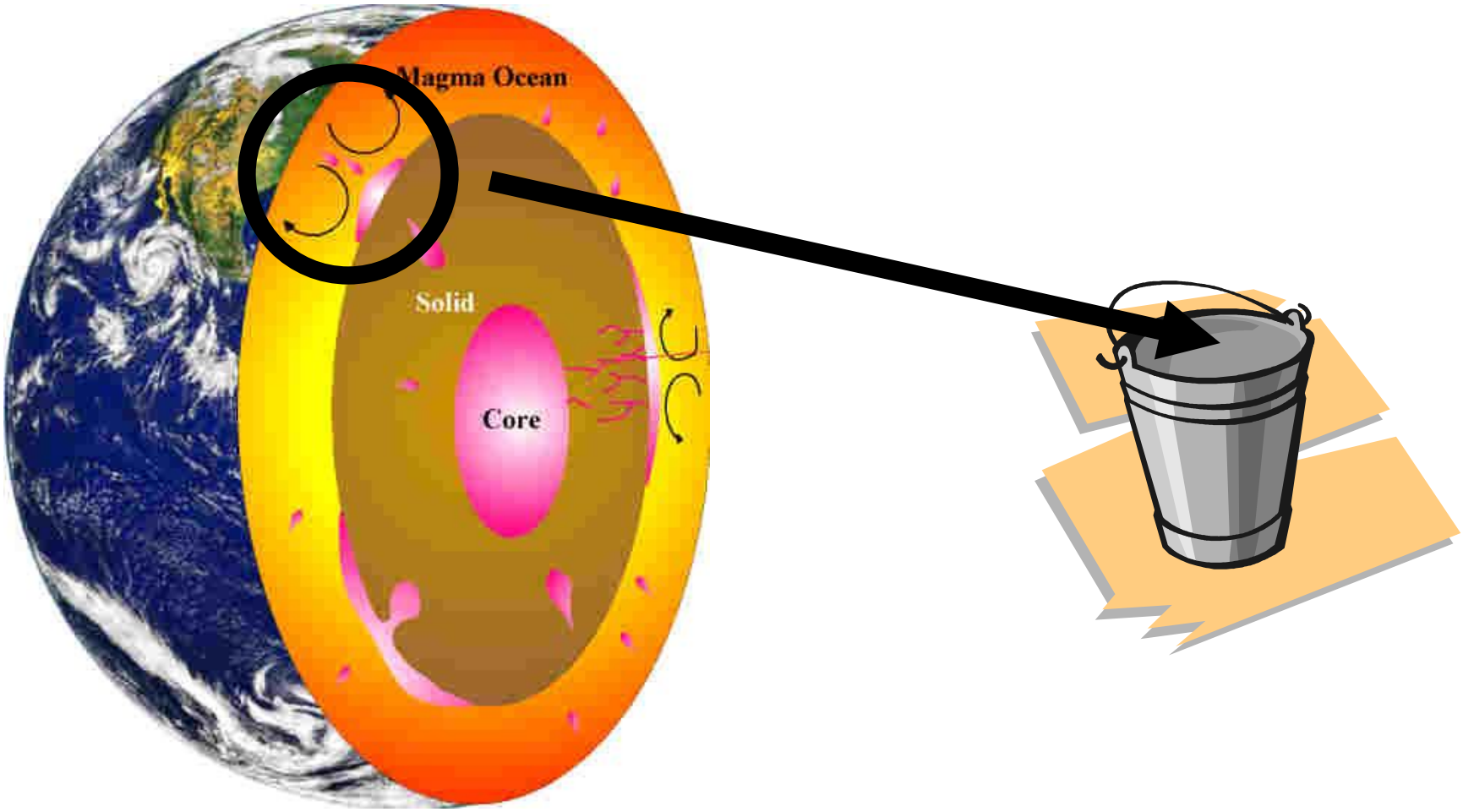

(Sc, REE)
CI Chondrites
Elemental abundance relative to bulk Earth
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
Slightly Siderophile
Moderately Siderophile
Highly Siderophile
Observed Mantle Abundance
Sc REE Mn Cr P W Ag Sb Ge Os Ir Pt Au
V Ga Fe Co Ni As Mo Re Ru Rh Pd
Increasing Siderophile Behavior

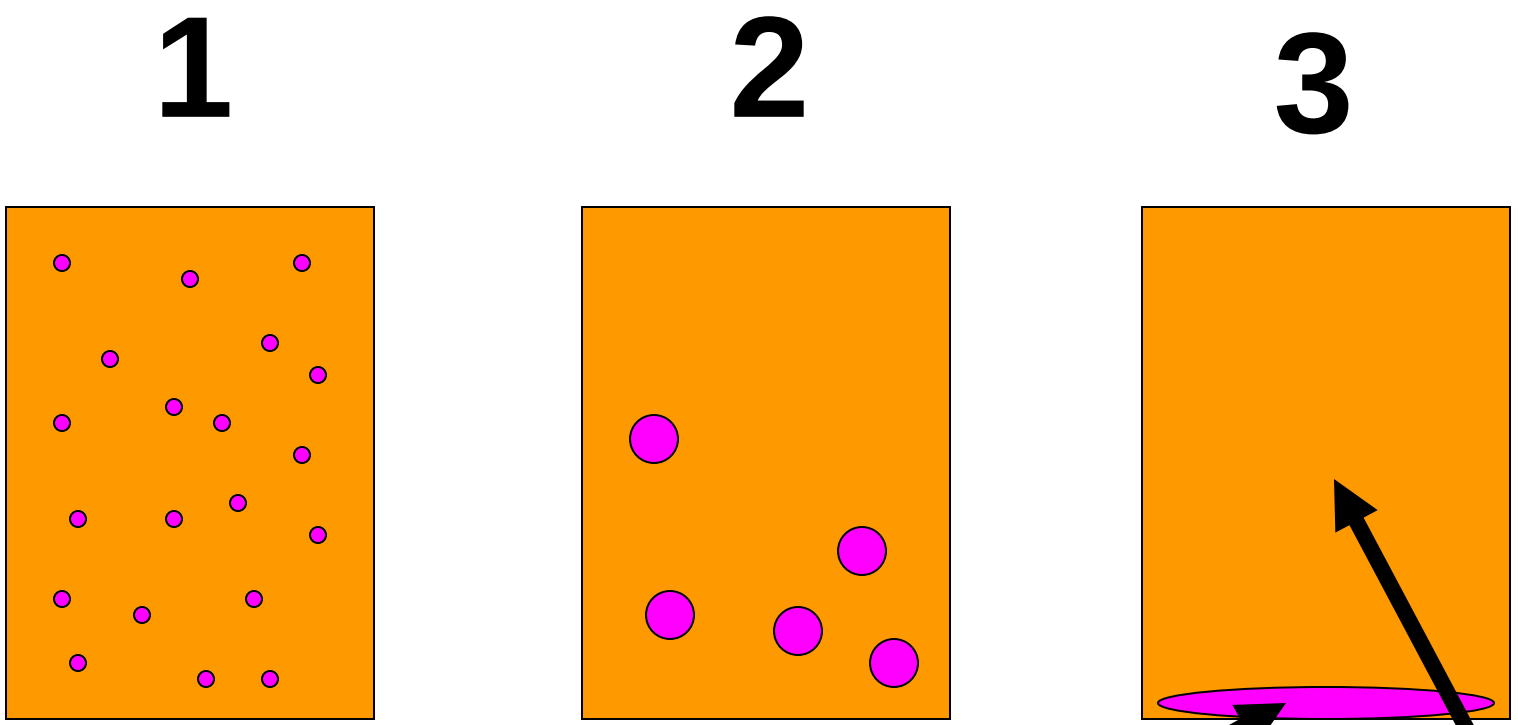
Experiments!

+S

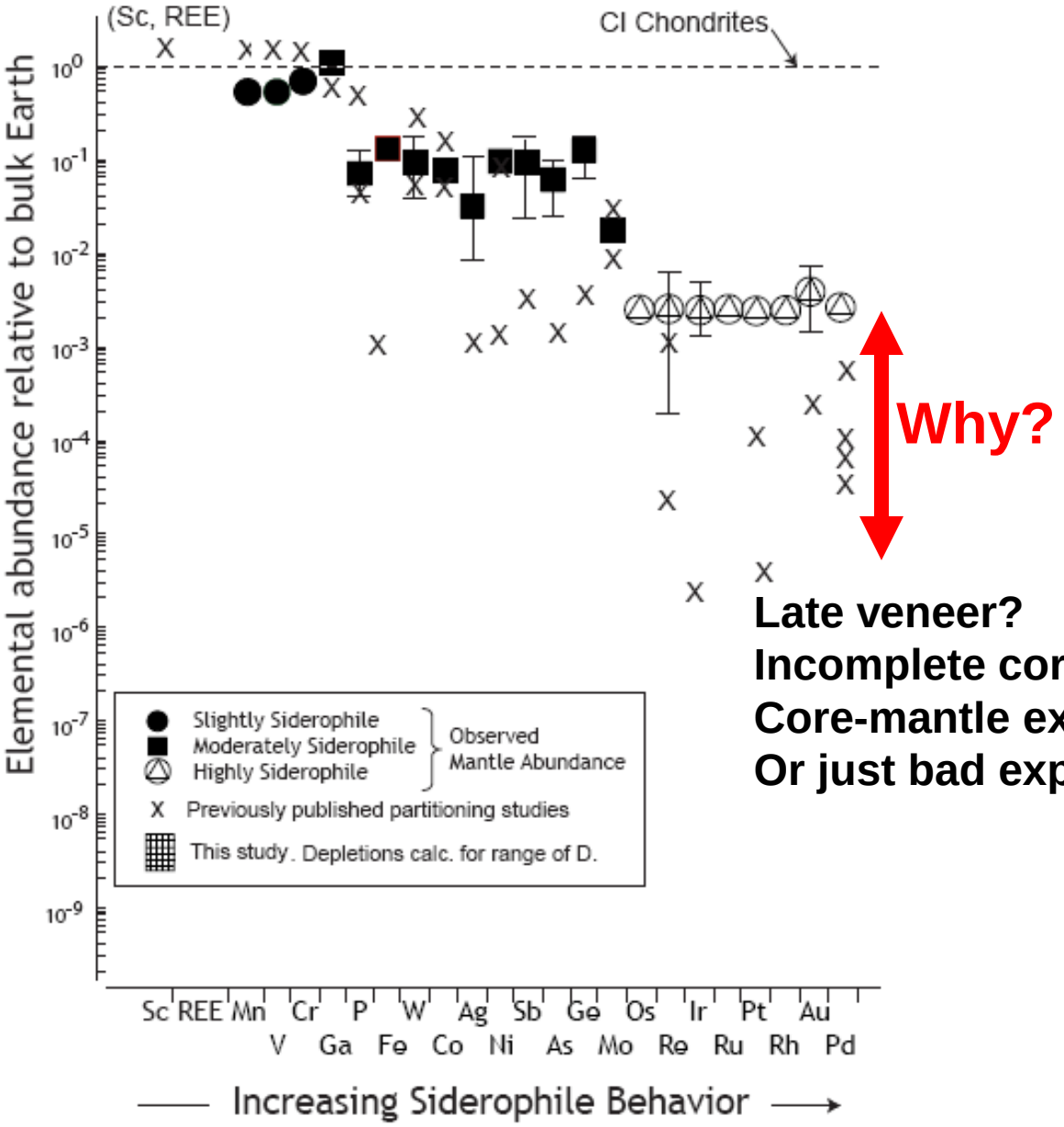
Trace Element




Magma Ocean
Solid
Core



D= Concentration in Metal/Concentration in Silicate



Late veneer?
Incomplete core formation?
Core-mantle exchange?
Or just bad experiments?

Let’s not give up on the MO and experiments just yet.

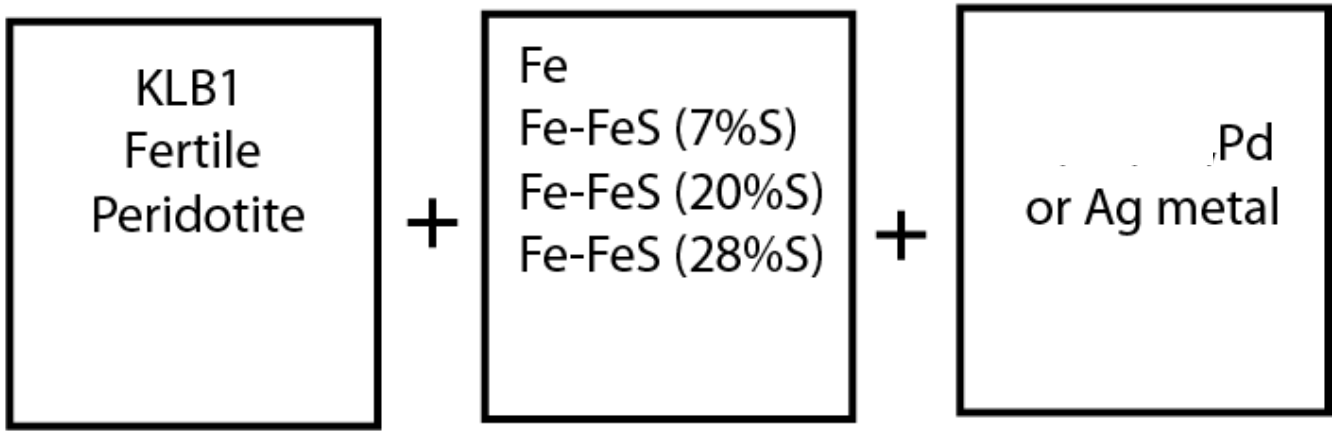
- **Lots of shortcuts** (analysis, physical constraints)
- **Selectively gloss over some parameters** (P, T, silicate comp, S, fO2)
- Shortcuts will always exist (physical model imperfect)
- Have to make the right shortcuts-play with certain parameters.

Key Experimental Issues

- Chemical conditions
- Physical Conditions

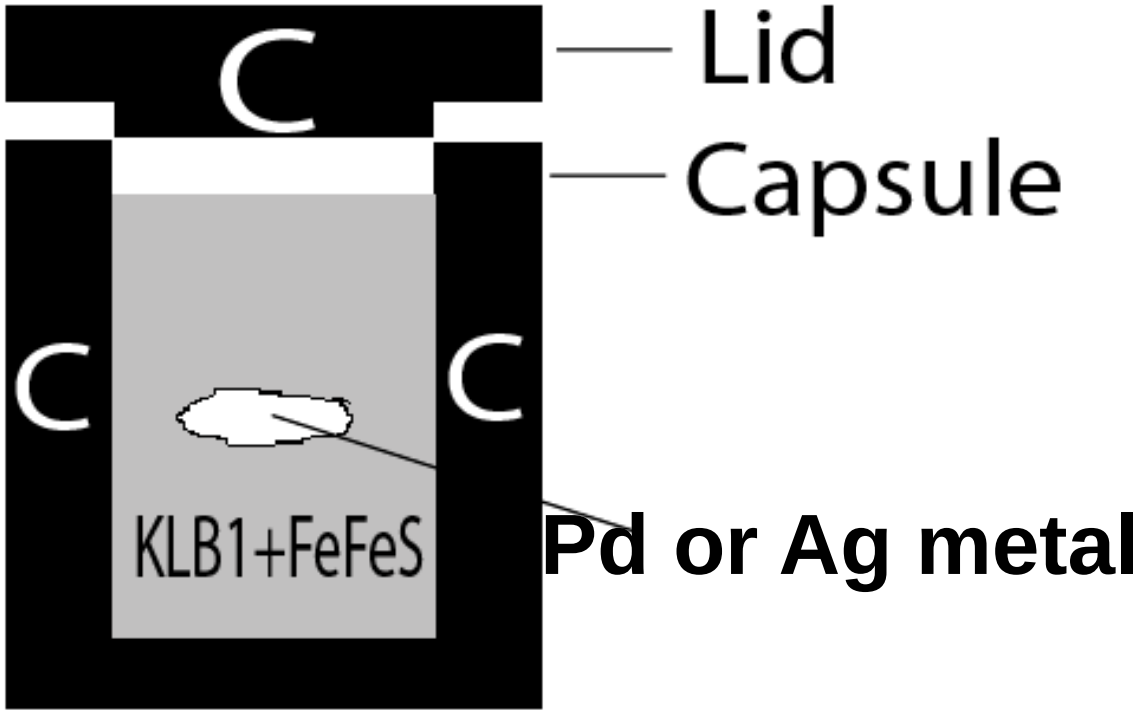
Experimental Methods

Starting Material:

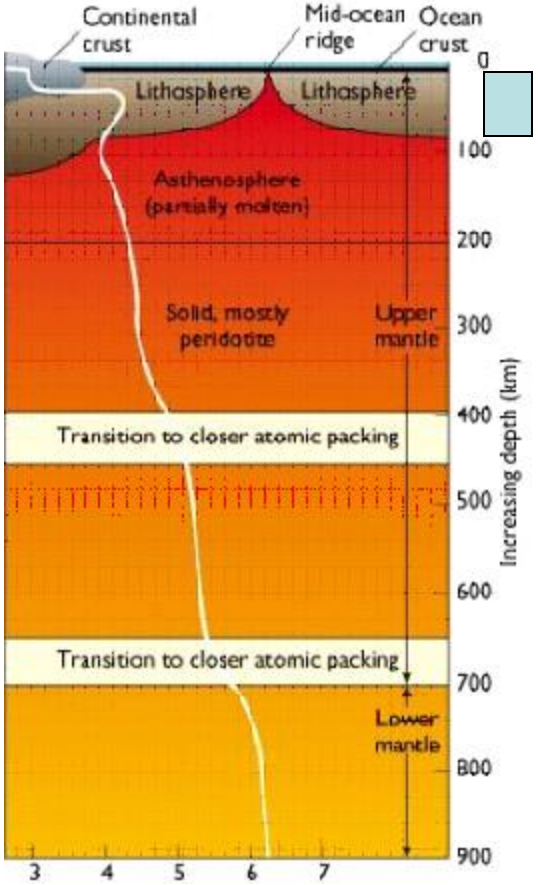


Fe/Si ~1.75

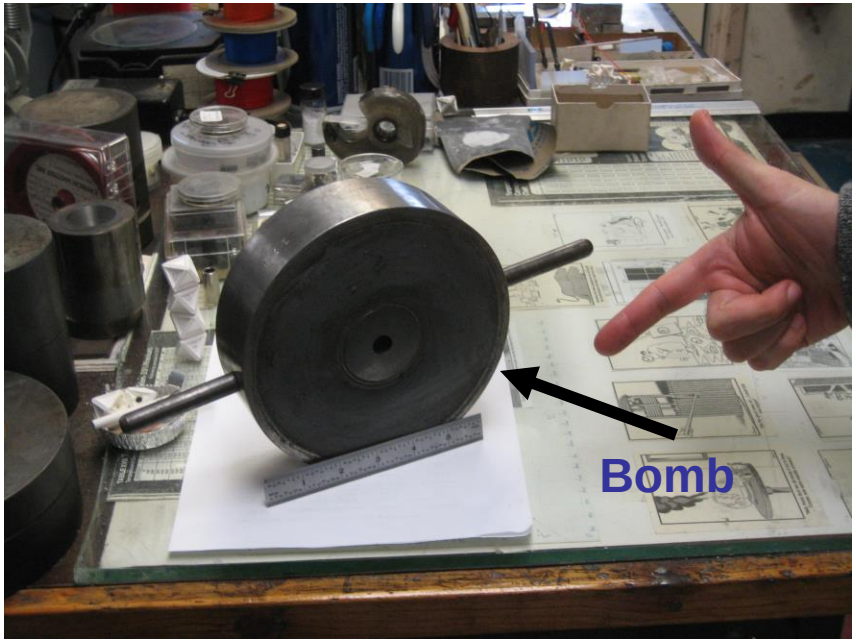
Graphite capsule to keep low oxygen fugacity (fO2)

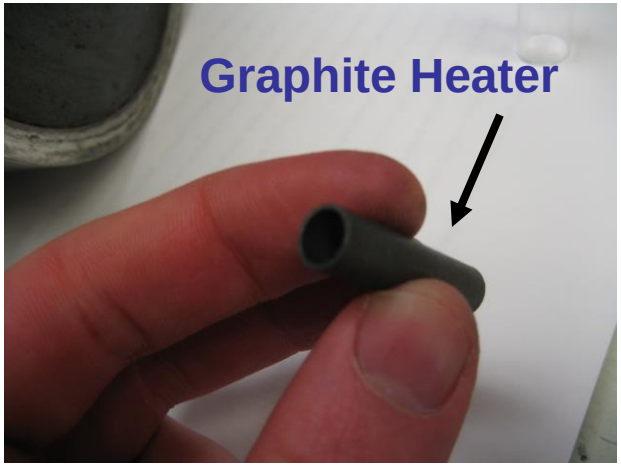


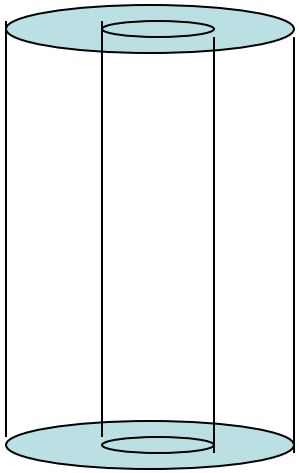
Piston Cylinder

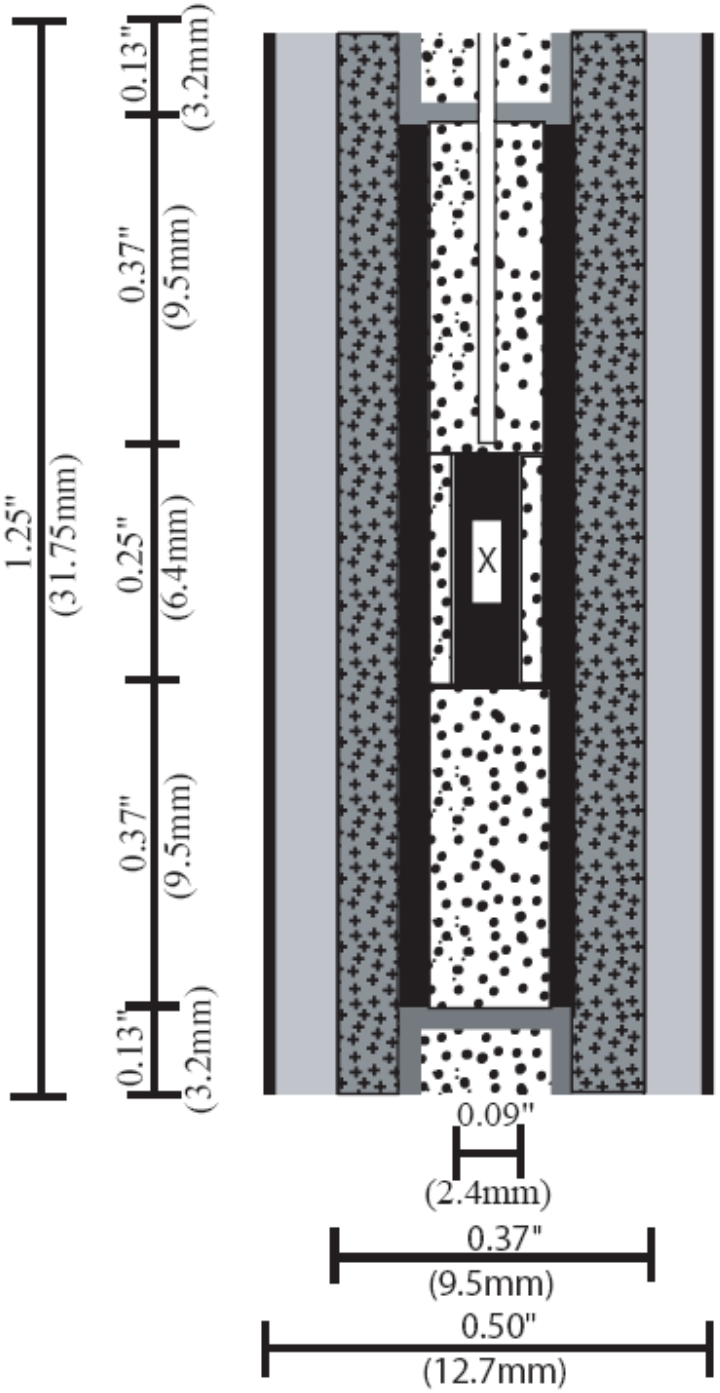


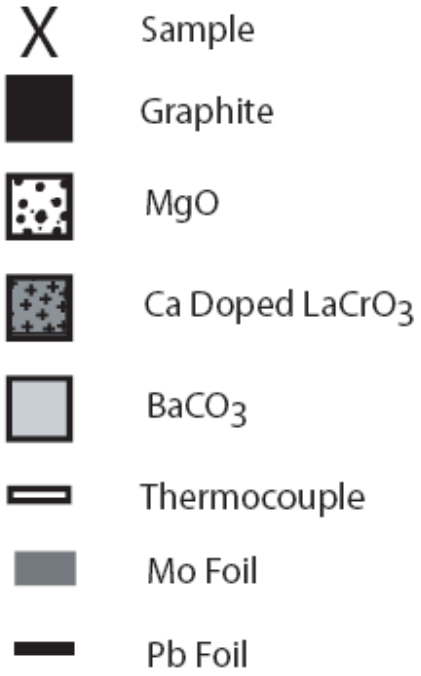
Piston Cylinder Bomb



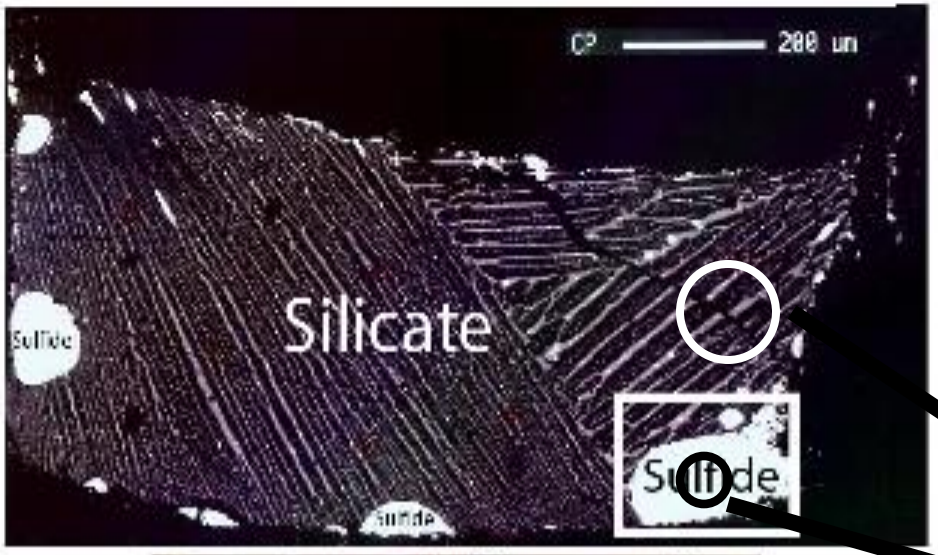


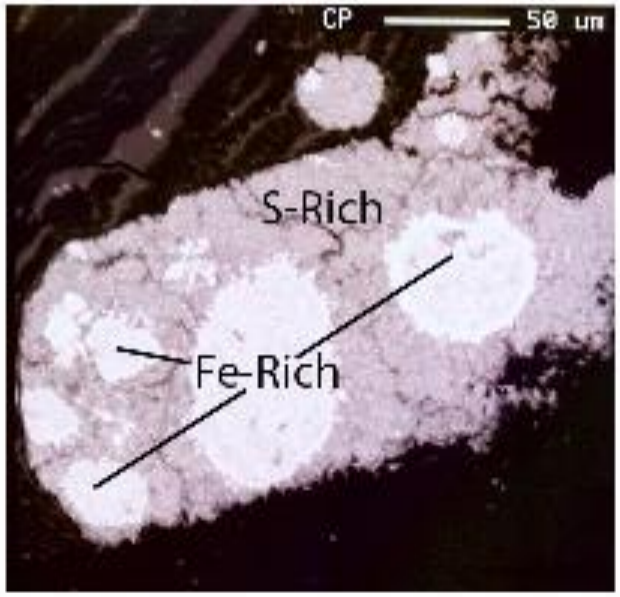



1.25"
(31.75mm)
0.13"
(3.2mm)
0.37"
(9.5mm)
0.25"
(6.4mm)
0.37"
(9.5mm)
0.13"
(3.2mm)
X
0.09"
(2.4mm)
0.37"
(9.5mm)
0.50"
(12.7mm)


X
Sample
Graphite
MgO
Ca Doped $LaCrO_3$
$BaCO_3$
Thermocouple
Mo Foil
Pb Foil

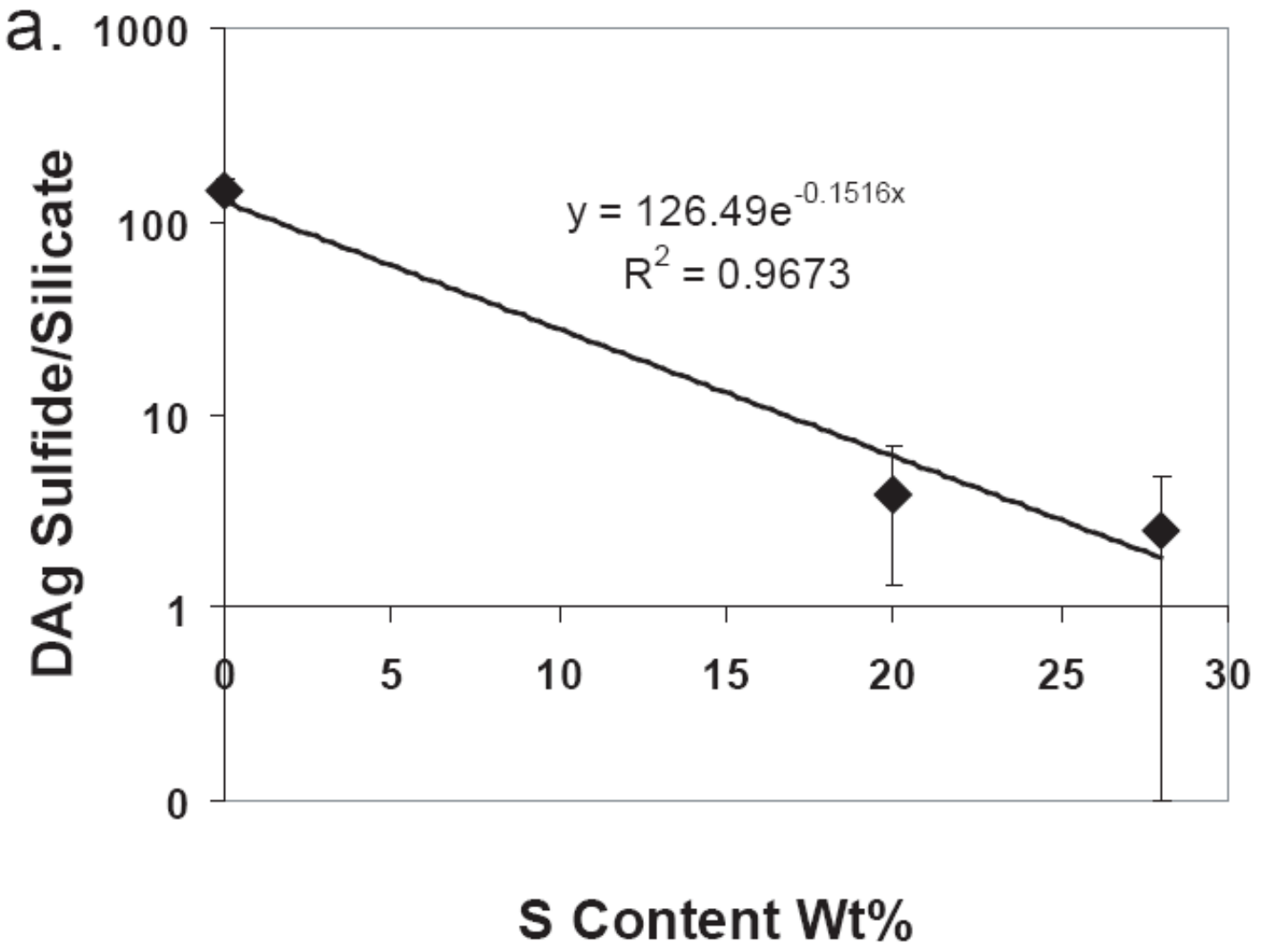
The Product

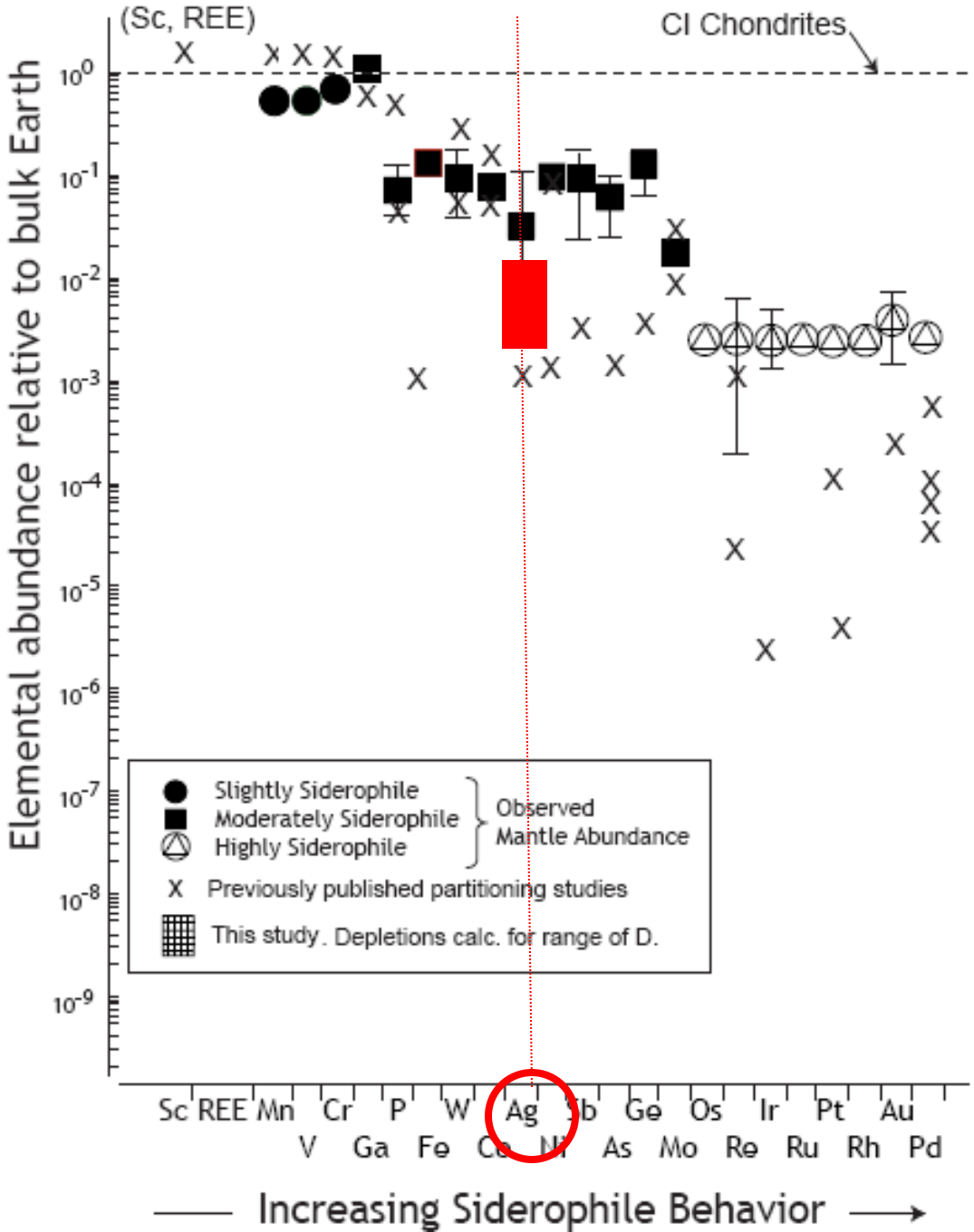




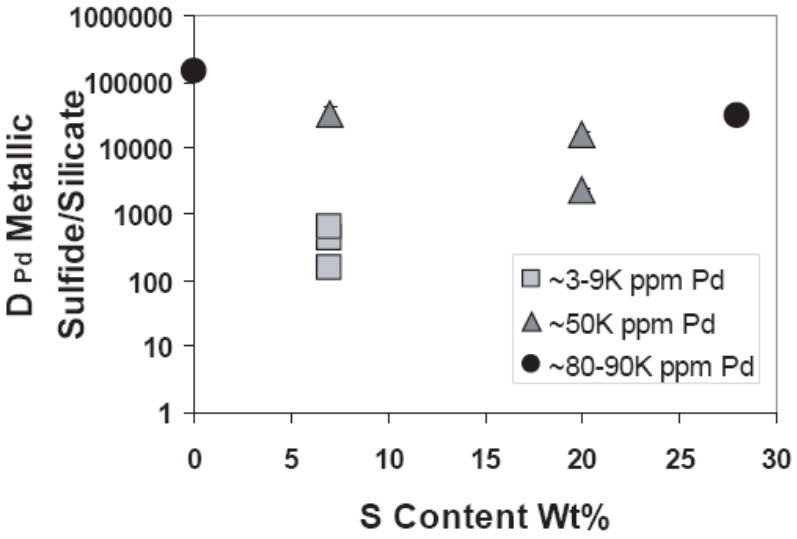
D = X metal/X sil

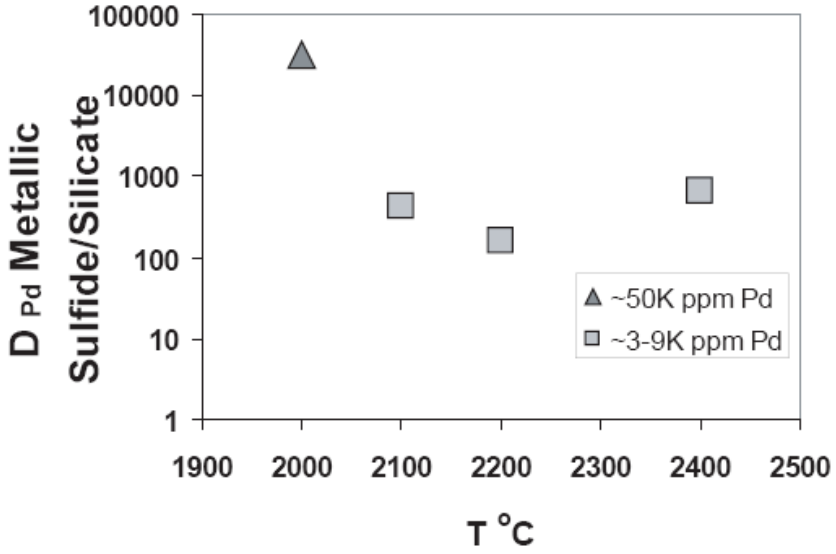
The Resuts (Ag)

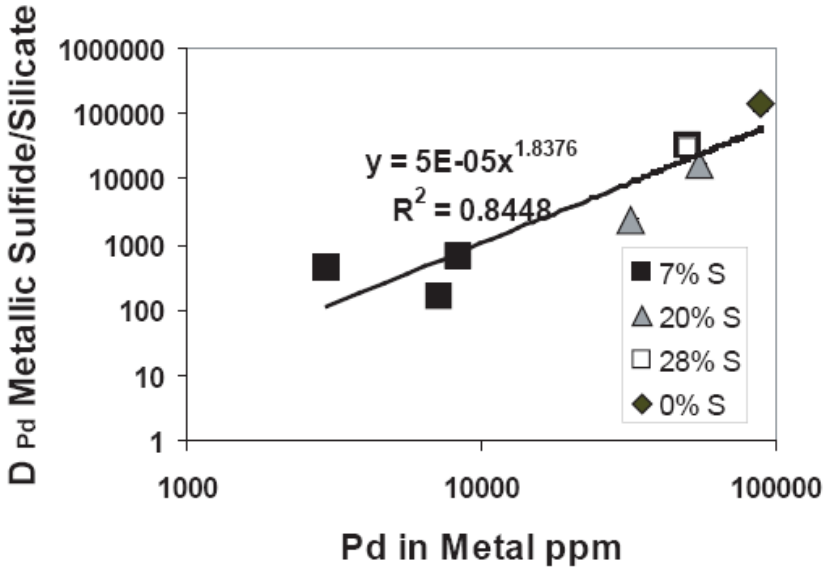


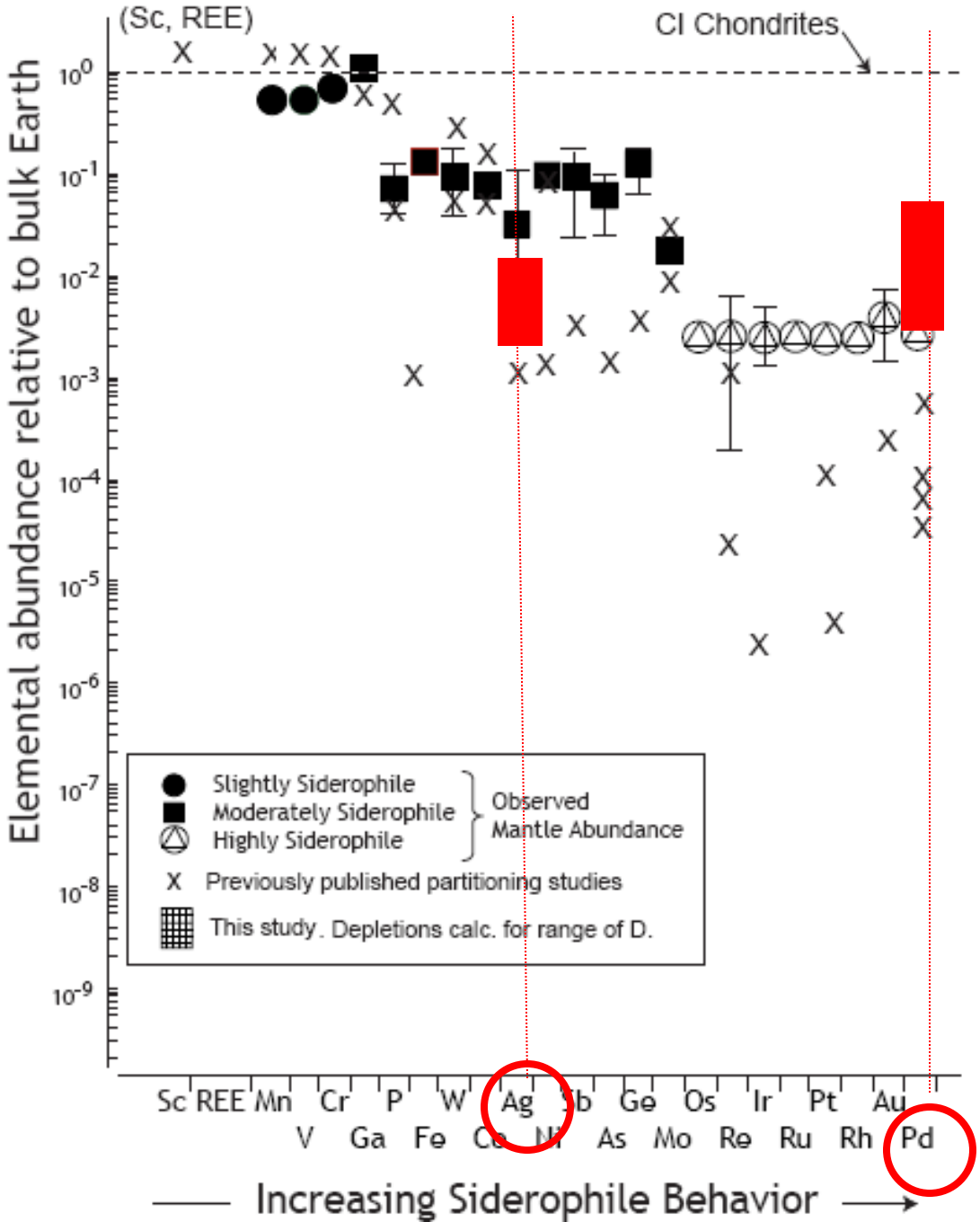

(Sc, REE)
CI Chondrites
Elemental abundance relative to bulk Earth
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
Slightly Siderophile
Moderately Siderophile
Highly Siderophile
Observed Mantle Abundance
Previously published partitioning studies
This study. Depletions calc. for range of D.
Sc REE Mn Cr P W Ag Sb Ge Os Ir Pt Au
V Ga Fe Co Ni As Mo Re Ru Rh Pd
Increasing Siderophile Behavior

Pd Results


D Pd Metallic Sulfide/Silicate
1000000
100000
10000
1000
100
10
1
0
5
10
15
20
25
30
S Content Wt%
~3-9K ppm Pd
~50K ppm Pd
~80-90K ppm Pd


D Pd Metallic Sulfide/Silicate
100000
10000
1000
100
10
1
1900
2000
2100
2200
2300
2400
2500
T °C
~50K ppm Pd
~3-9K ppm Pd


D Pd Metallic Sulfide/Silicate
1000000
100000
10000
1000
100
10
1
1000
10000
100000
Pd in Metal ppm
y = 5E-05x^1.8376
R^2 = 0.8448
7% S
20% S
28% S
0% S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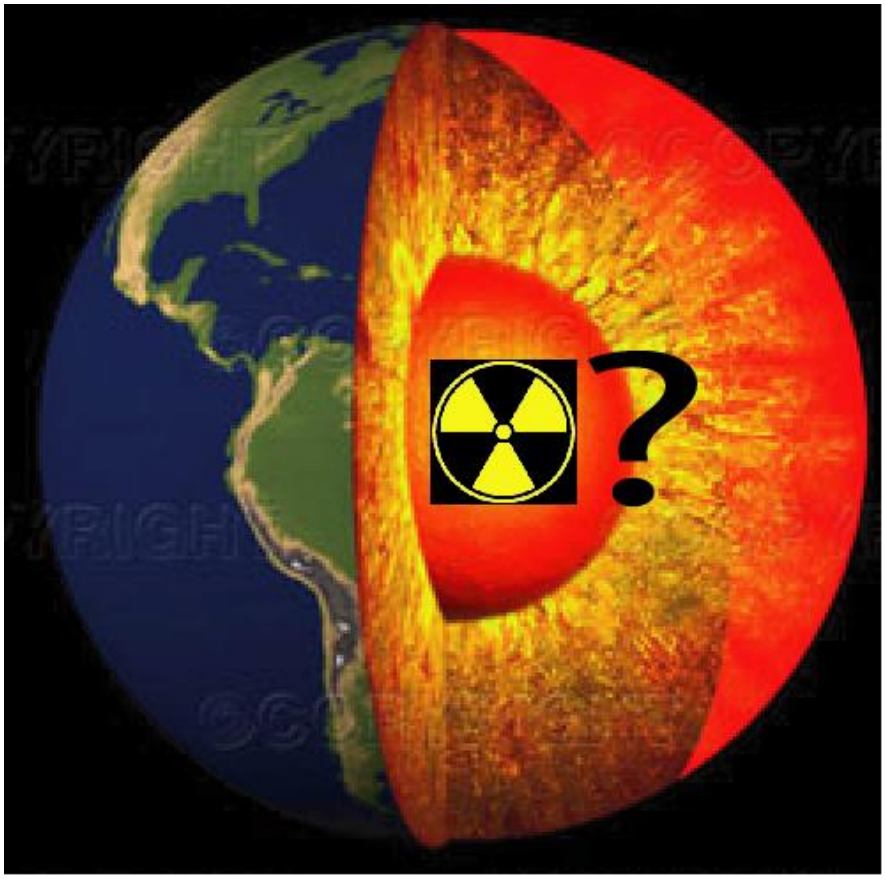
Sc REE Mn Cr P W Ag Sb Ge Os Ir Pt Au
V Ga Fe Co Ni As Mo Re Ru Rh Pd
Increasing Siderophile Behavior

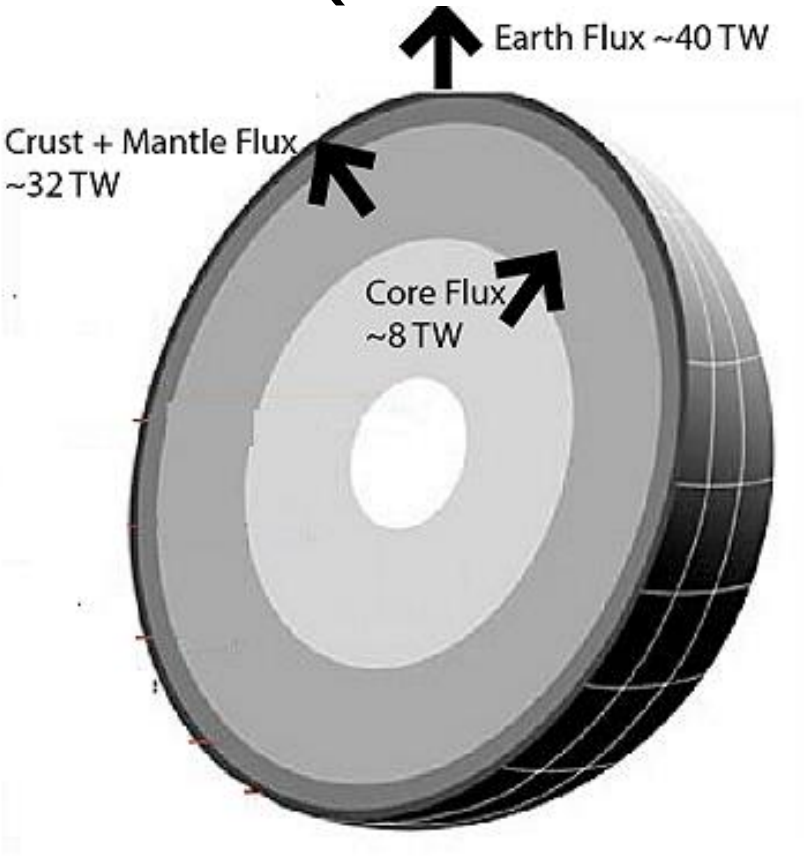
Conclusions I

- Metal-Silicate Equilibrium in Magma Ocean Sufficient!

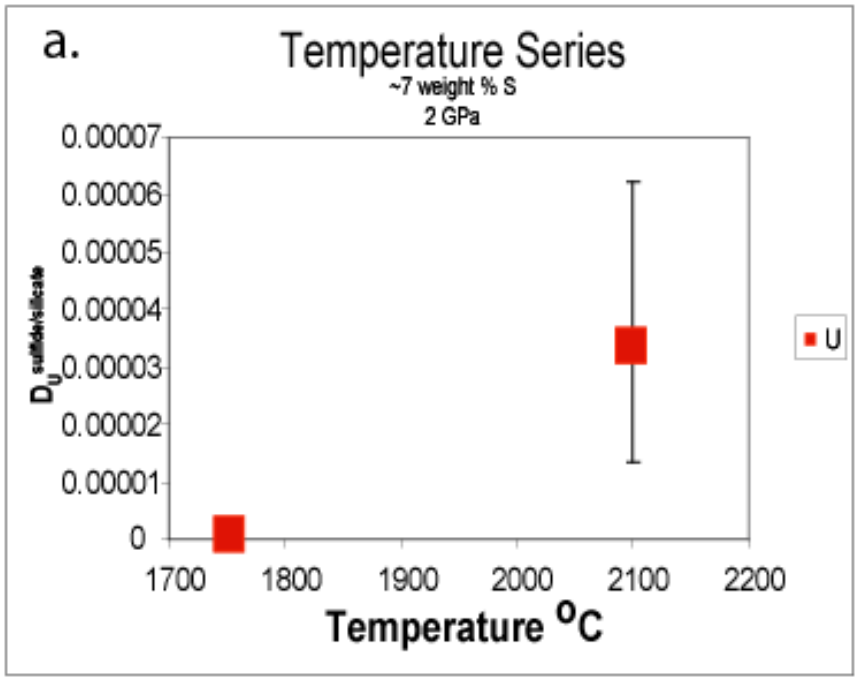
Application II: Radioactivity in the Earth's Core? An Experimental Study.

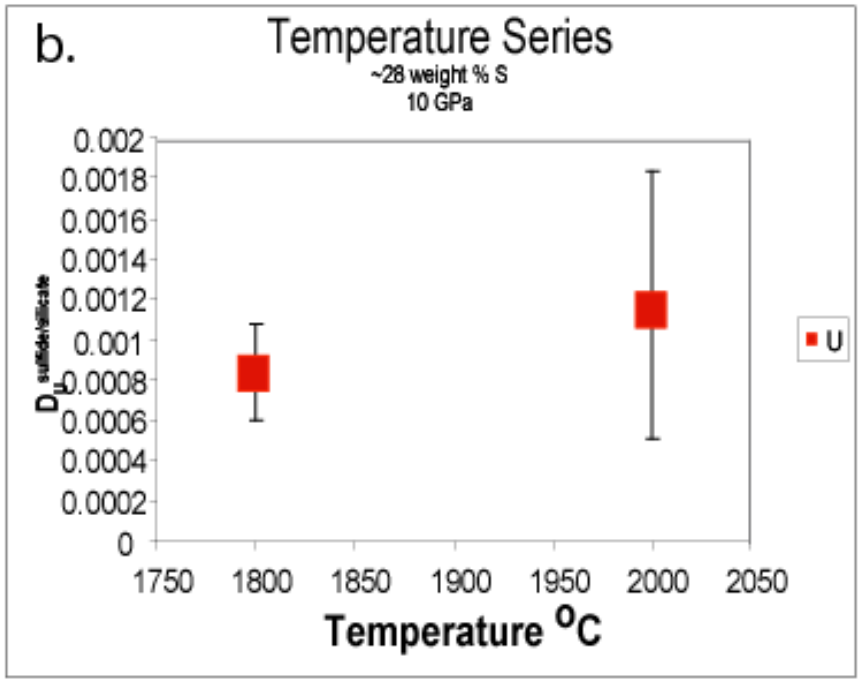


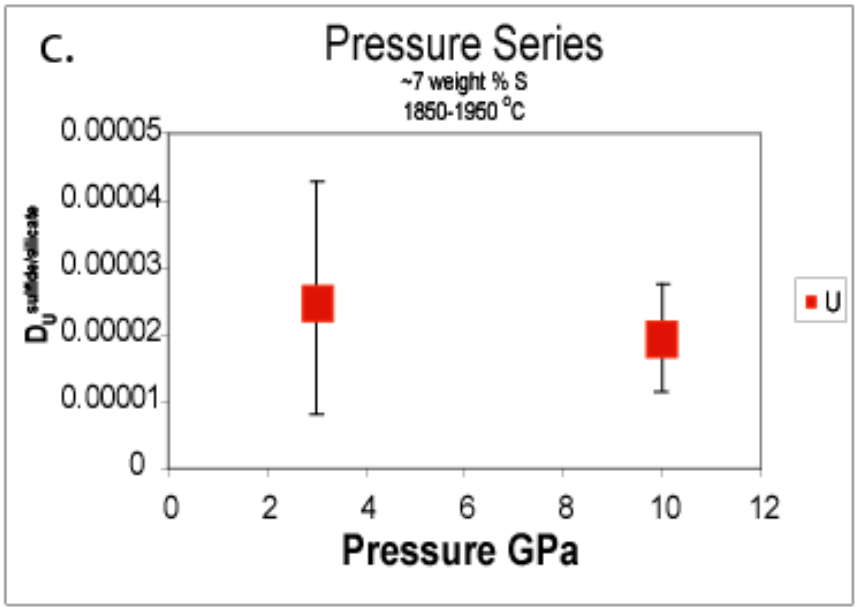
The Uranium (and Thorium) Story

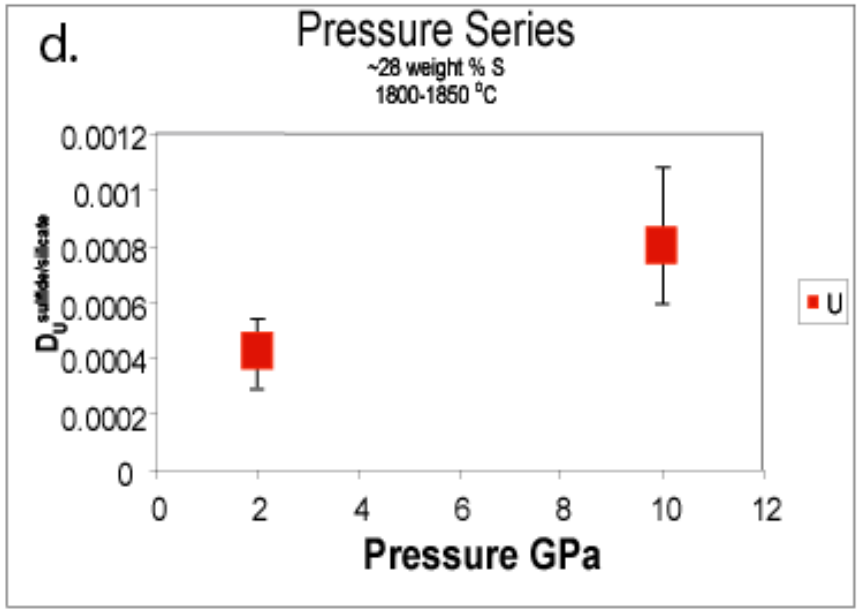


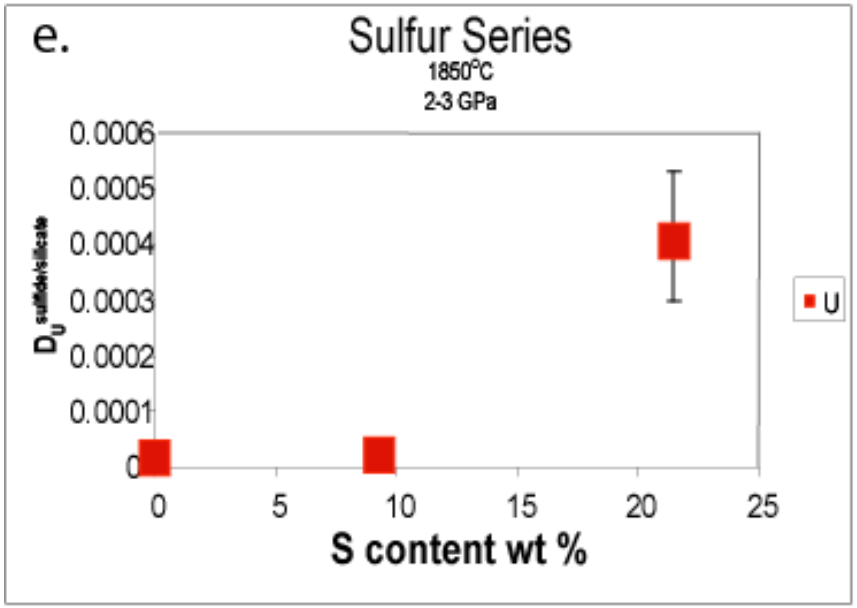
Possible Core Heat Producers:
1) Secular Cooling
2) Freezing of the Inner Core
3) Radioactive Element Recay

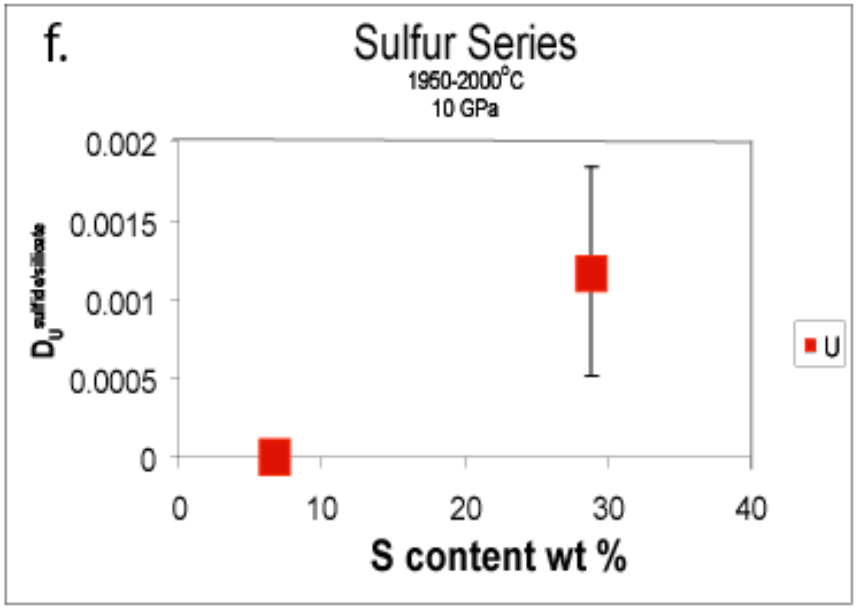

a.
Temperature Series
~7 weight % S
2 GPa
0.00007
0.00006
0.00005
0.00004
0.00003
0.00002
0.00001
0
1700
1800
1900
2000
2100
2200
Temperature °C
U

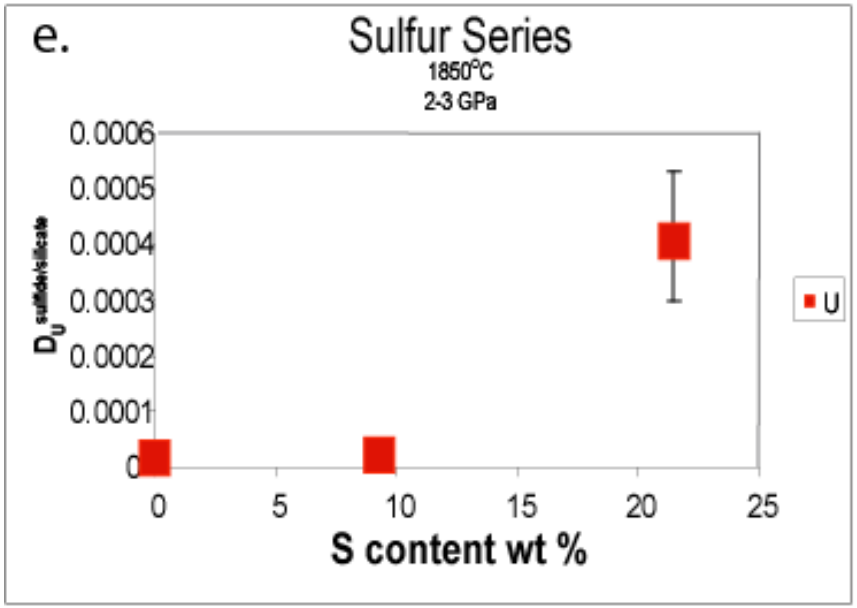

b.
Temperature Series
~28 weight % S
10 GPa
0.002
0.0018
0.0016
0.0014
0.0012
0.001
0.0008
0.0006
0.0004
0.0002
0
1750
1800
1850
1900
1950
2000
2050
Temperature °C
U

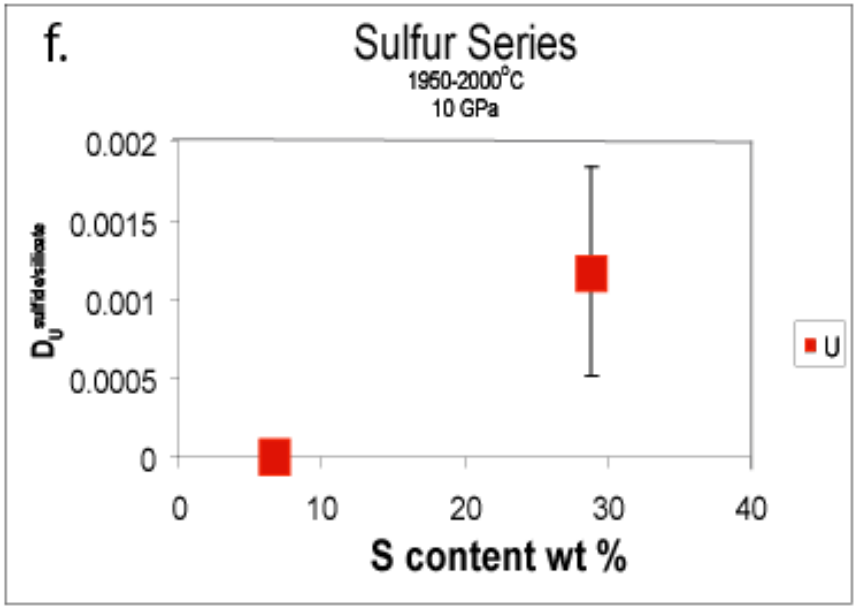

c.
Pressure Series
~7 weight % S
1850-1950 °C
0.00005
0.00004
0.00003
0.00002
0.00001
0
D_U sulfide/silicate
0
2
4
6
8
10
12
Pressure GPa
U


d.
Pressure Series
~28 weight % S
1800-1850 °C
0.0012
0.001
0.0008
0.0006
0.0004
0.0002
0
D_U sulfide/silicate
0
2
4
6
8
10
12
Pressure GPa
U


e.
Sulfur Series
1850°C
2-3 GPa
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0
$D_U^{sulfide/silicate}$
0
5
10
15
20
25
S content wt %
U


f.
Sulfur Series
1950-2000°C
10 GPa
0.002
0.0015
0.001
0.0005
0
$D_U^{sulfide/silicate}$
0
10
20
30
40
S content wt %
U


e.
Sulfur Series
1850°C
2-3 GPa
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0
$D_U^{sulfide/silicate}$
0
5
10
15
20
25
S content wt %
U


f.
Sulfur Series
1950-2000°C
10 GPa
0.002
0.0015
0.001
0.0005
0
$D_U^{sulfide/silicate}$
0
10
20
30
40
S content wt %
U

Uranium Conclusions

- No variation of U partitioning behavior with P and T.
- There is variation with S content.
- No significant U in the core.
- Very hi T might coax U into the metal phase.
- Th experiments are awaiting analysis.