

Laboratory approaches to composition, origin, and evolution of the solid Earth

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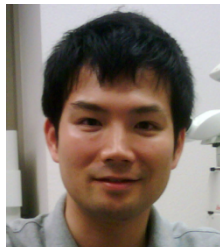
and

Earth-Life Science Institute, Ehime Satellite (ELSI-ES)

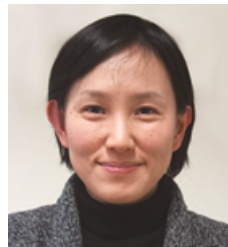
Current ELSI-ES members (to be expanded to 10-15 members soon)



T. Tsuchiya



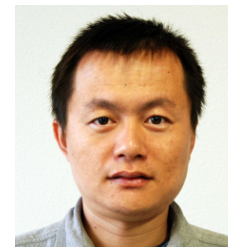
Y. Tange



J. Tsuchiya



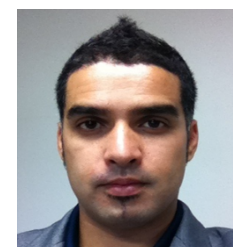
M. Nishi



X. Wang



H. Ichikawa



S. Great

Research targets at GRC



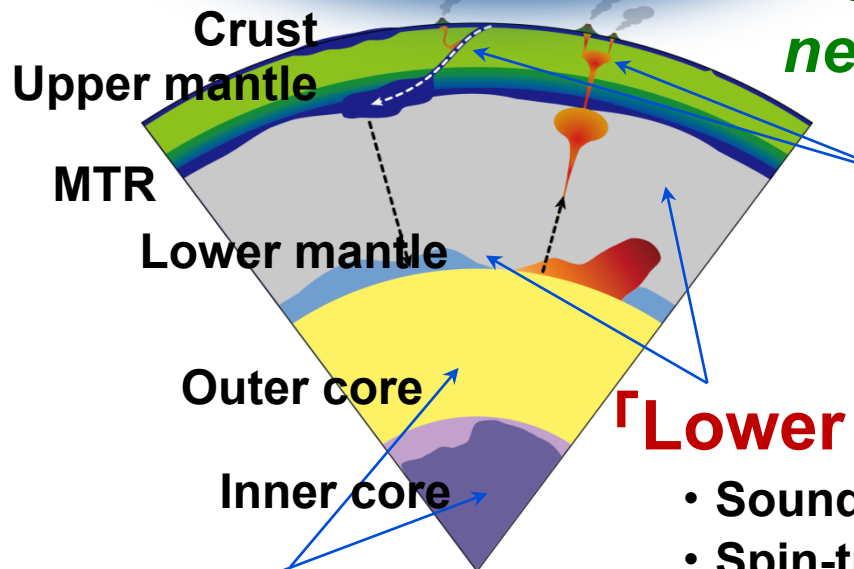
Global COE
DEEP EARTH MINERALOGY
EHIME UNIVERSITY JASRI, UNIV.TOKYO, SBU

prediction and interpretation

High-pressure
experiments

Numerical
simulations

new data



「Deep Earth Water」

- Structure of hydrous melts
- Phase transitions in hydrous minerals
- Symmetrization of hydrogen bond

「Lower Mantle」

- Sound velocities of lower mantle materials
- Spin-transitions in Fe and their implications
- Post-perovskite transition and mantle dynamics

「Core Materials」

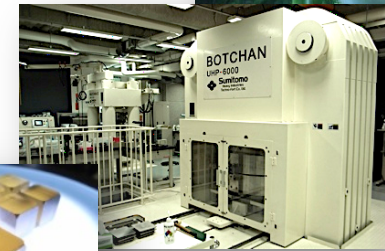
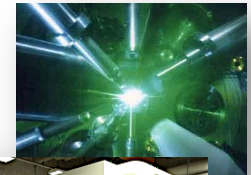
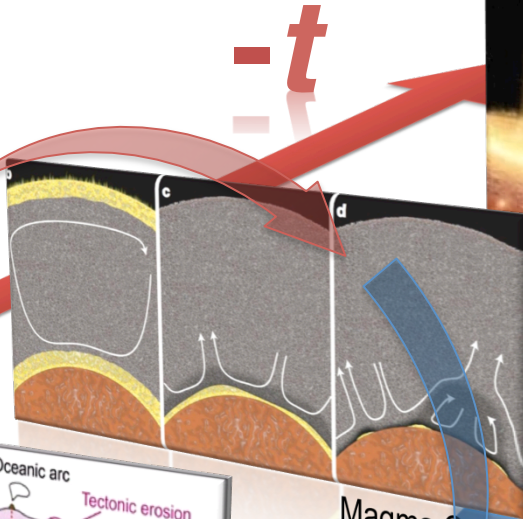
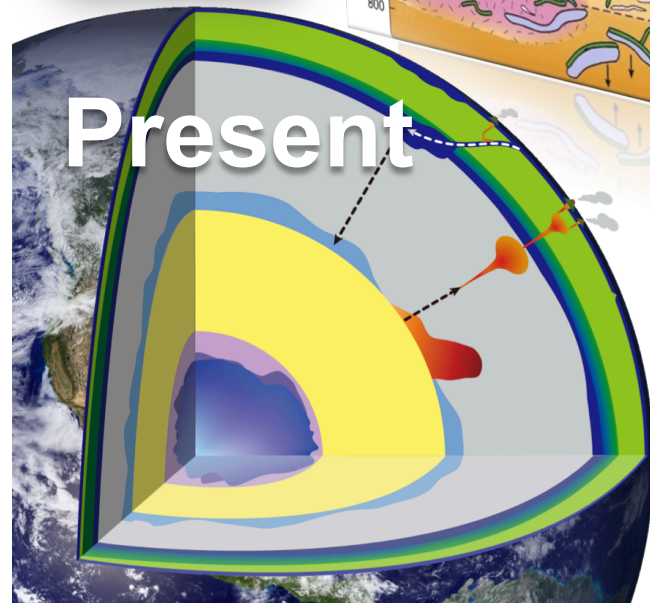
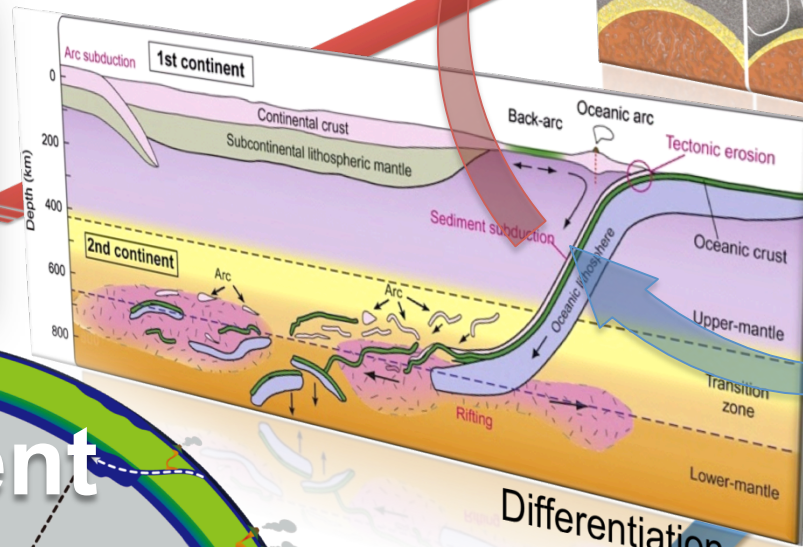
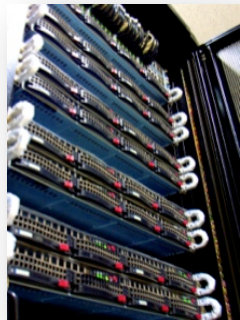
- Crystal structure of iron
- Effects of light elements
- Structure and dynamics of inner core

Phase transitions and structures of current Earth

Research concept at ELSI-ES

Clock-back

- Bulk Earth composition
- Distribution of volatile elements
- Dynamic behaviors

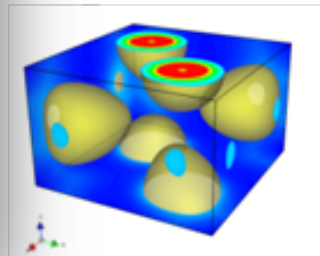
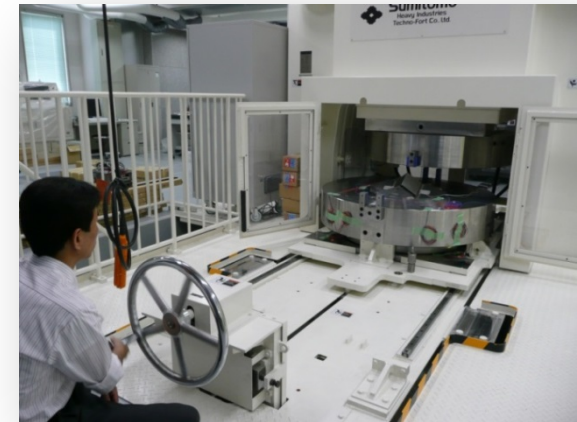


Forward modeling

- Early Earth environment
- Crystallization of primordial melt
- Properties of early Earth materials

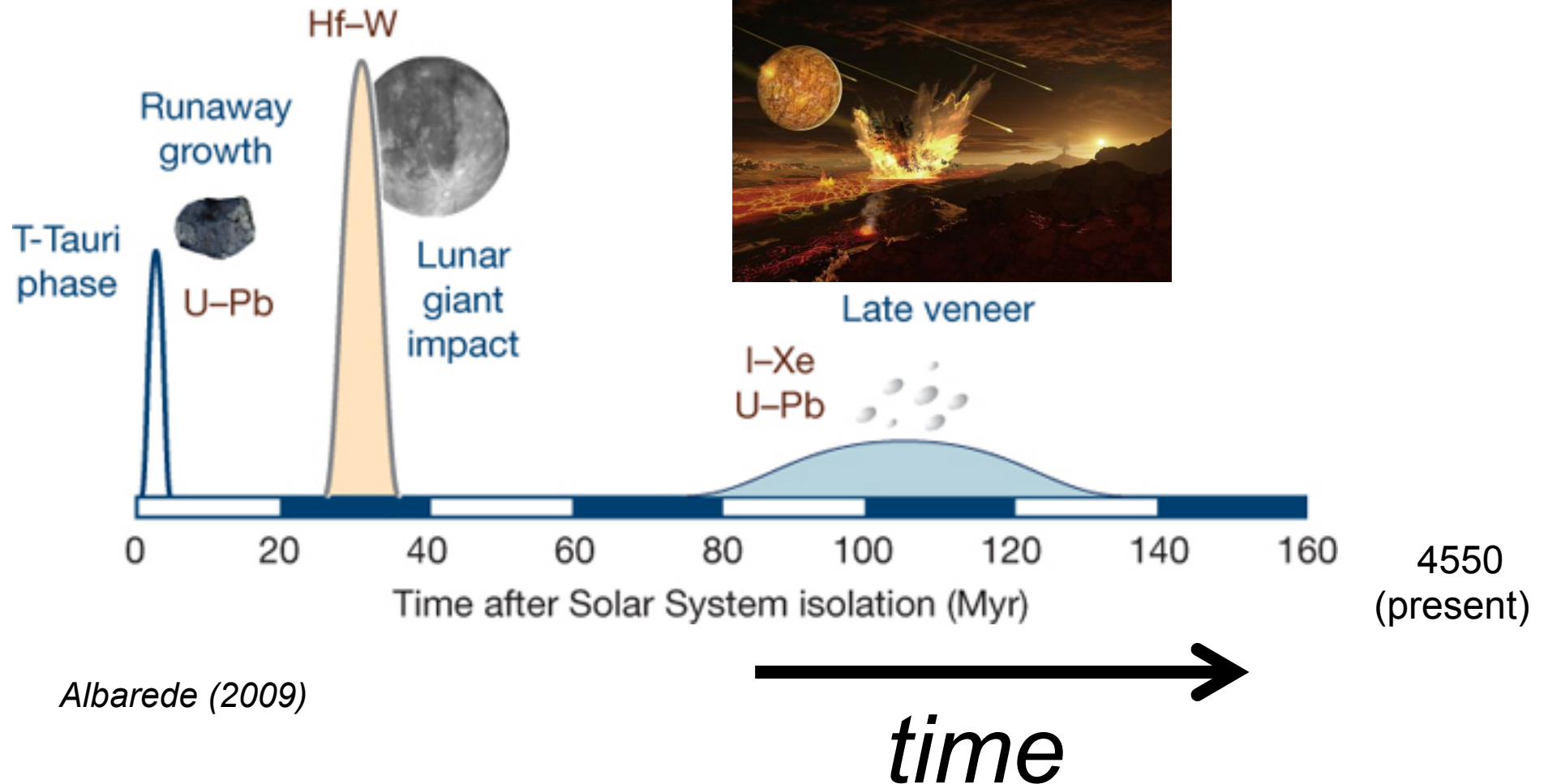
Research targets at ELSI-ES

- Chemistry of the lower mantle and bulk Earth
- Differentiation and element partitioning
- Distribution and circulation of water
- Thermal structure and evolution
- Laser shock and origin of life
 - ✓ *Large-pressure experiments*
 - ✓ *Ab initio computations*
 - ✓ *Quantum-beam applications*



Early Earth

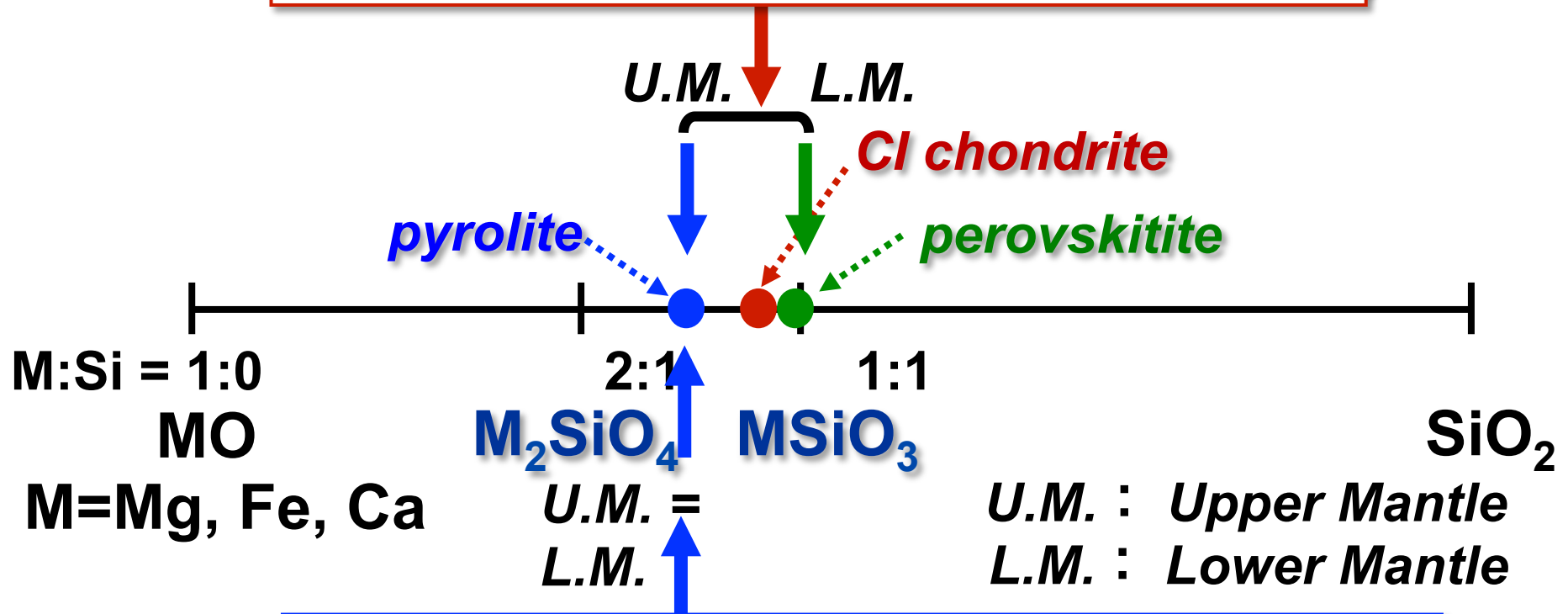
**Late veneer:
addition of volatile-rich
CI chondritic materials?**



Chemical models of Earth's mantle

1) *The Earth was made of CI chondrite (-volatile).*

Bulk mantle : CI chondritic (e.g. Liu, 1986)

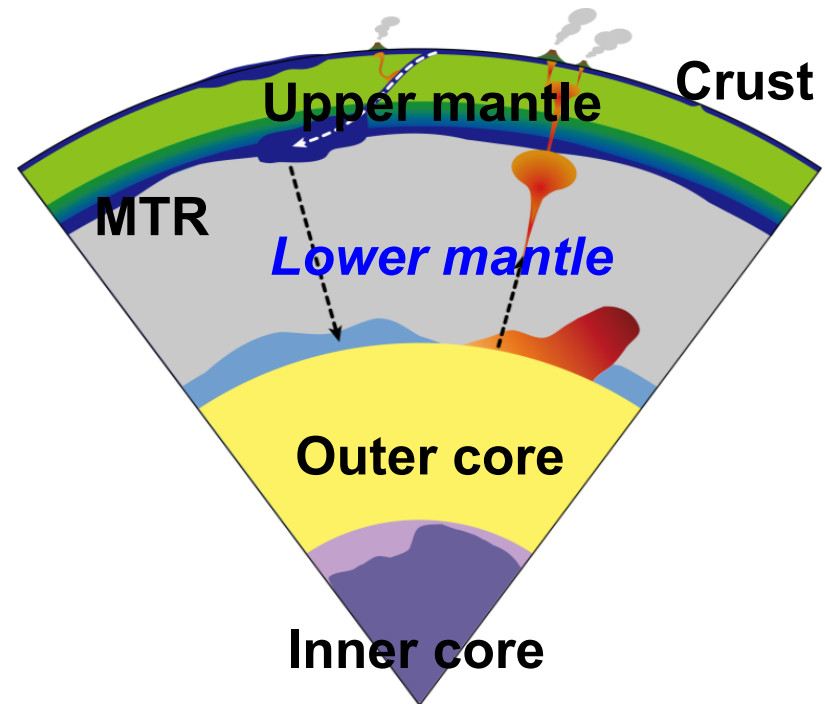
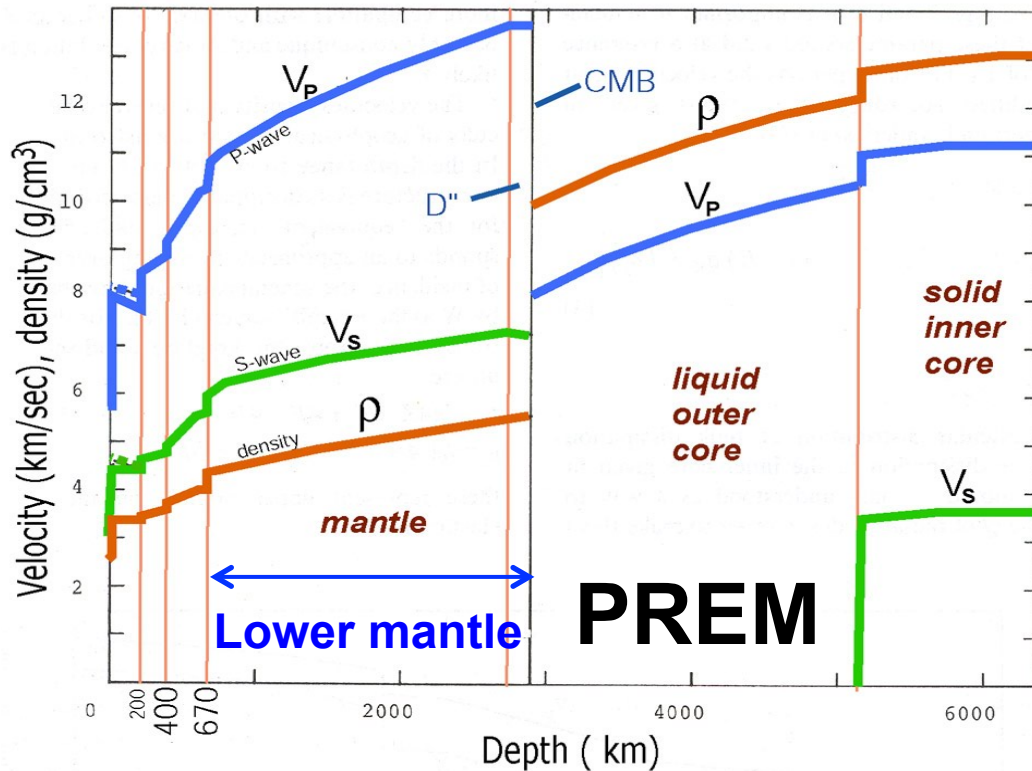


Bulk mantle : pyrolitic (e.g. Ringwood,

1979)

2) *The Earth was originally depleted in Si*

Mineral physics test



Lower mantle > half of the volume of the entire Earth

seismological models

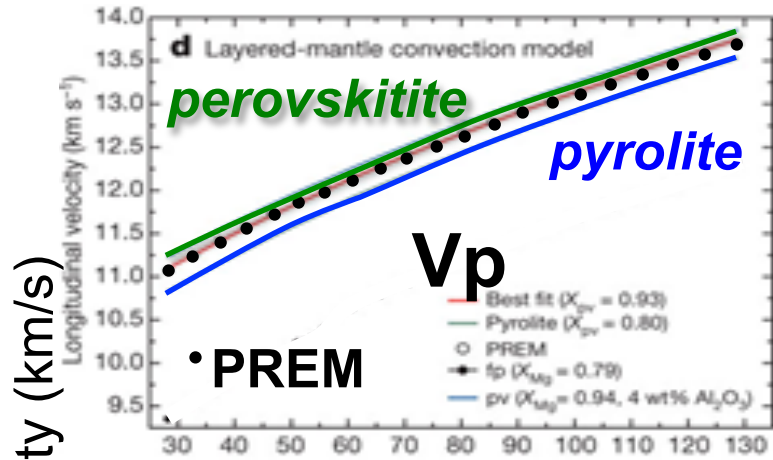


Lower mantle: pyrolite or perovskitite?

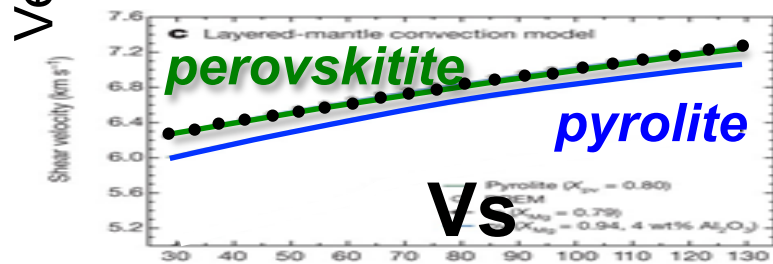
laboratory measurements

Sound velocities in the lower mantle

Brillouin scattering measurements



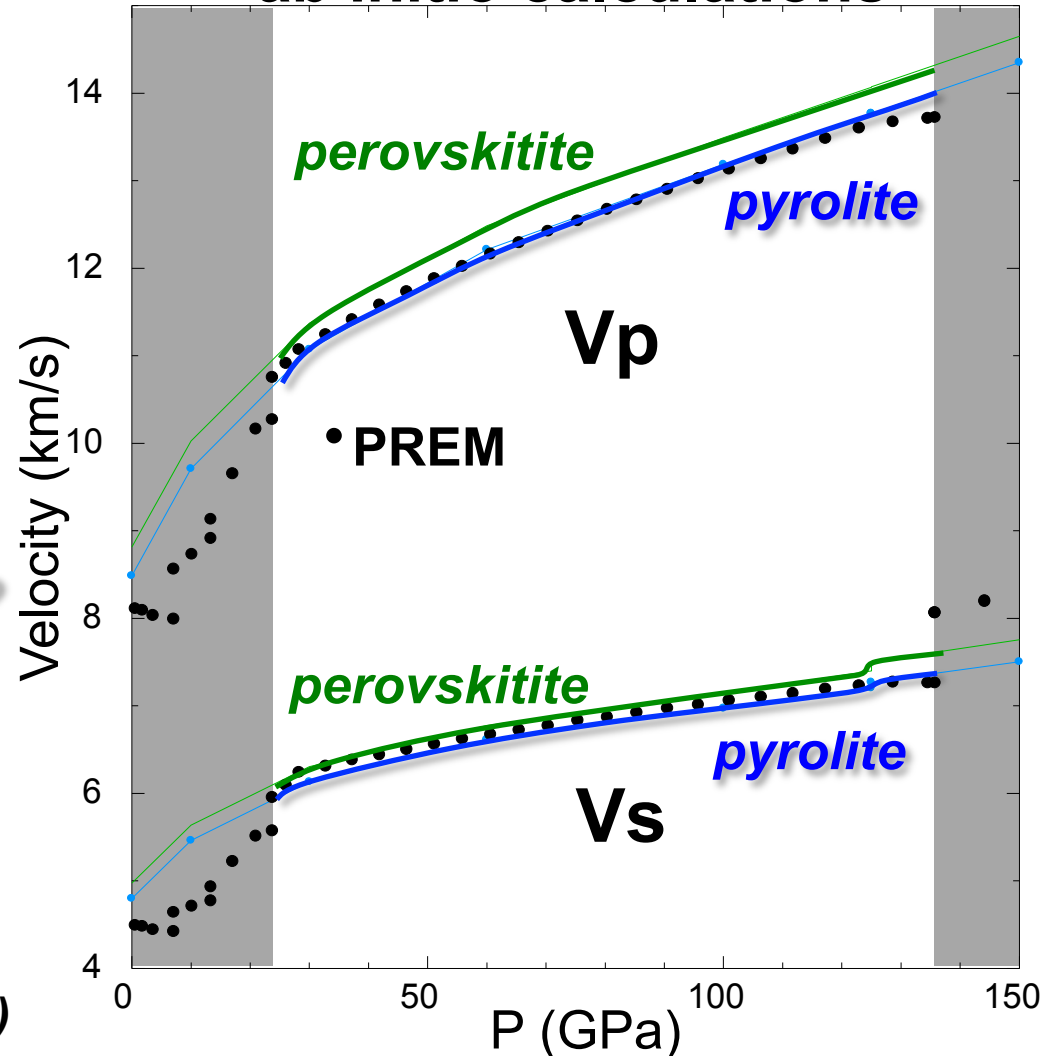
Perovskite: better model?



P (GPa)

Murakami et al. (2012)

ab initio calculations



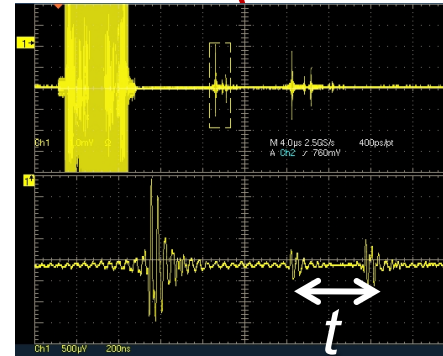
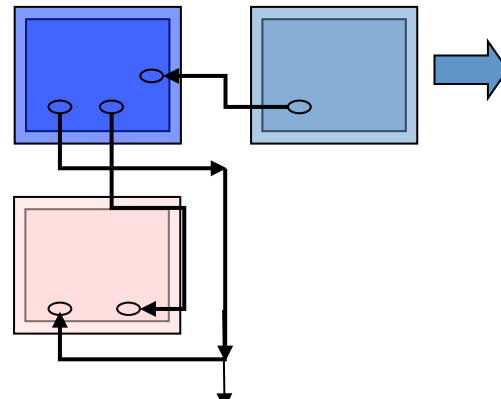
P (GPa)

Kawai & Tsuchiya (2013)

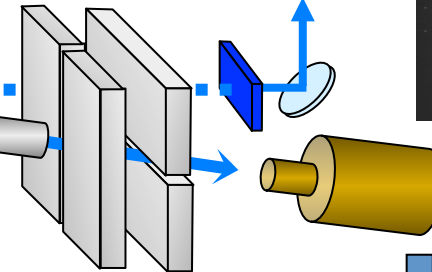
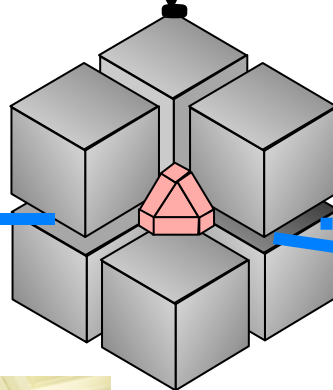
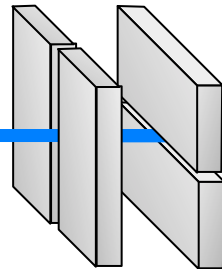
Theory: higher velocities for MgSiO₃-Perovskite

Ultrasonic set-up at SPring-8

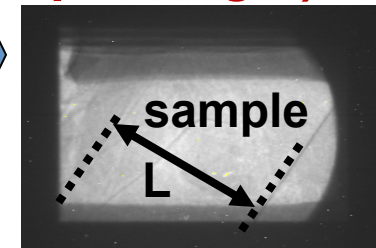
Ultrasonic (travel time)



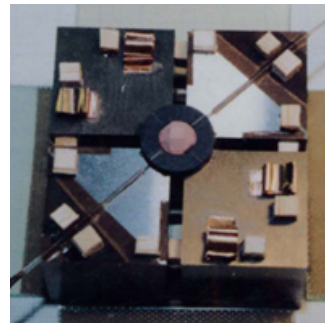
X-ray



Imaging (sample length)



*Diffraction
(phase, density, pressure)*

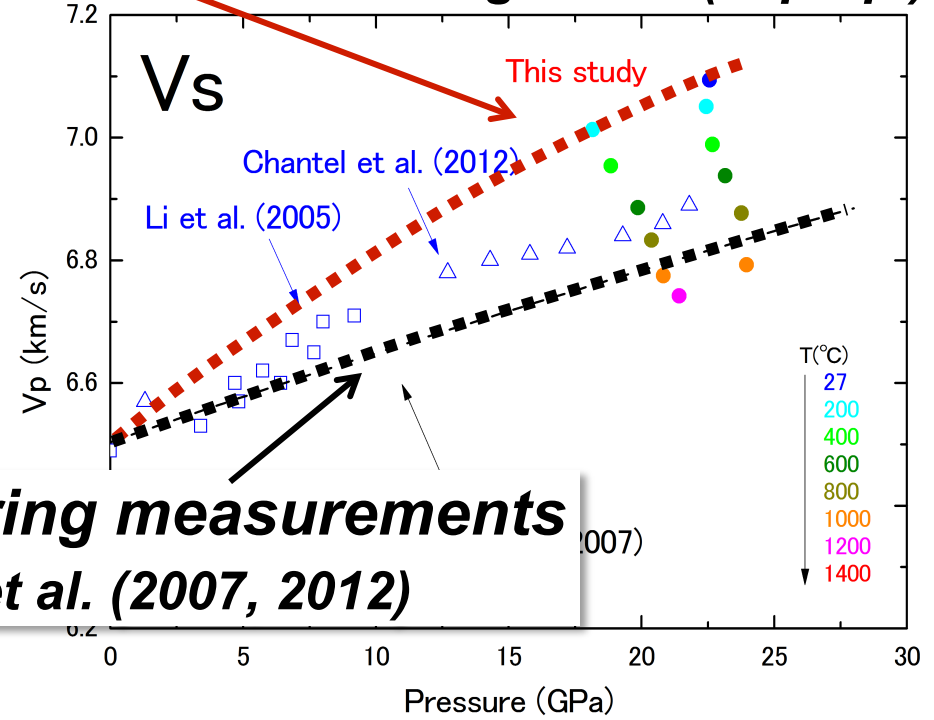
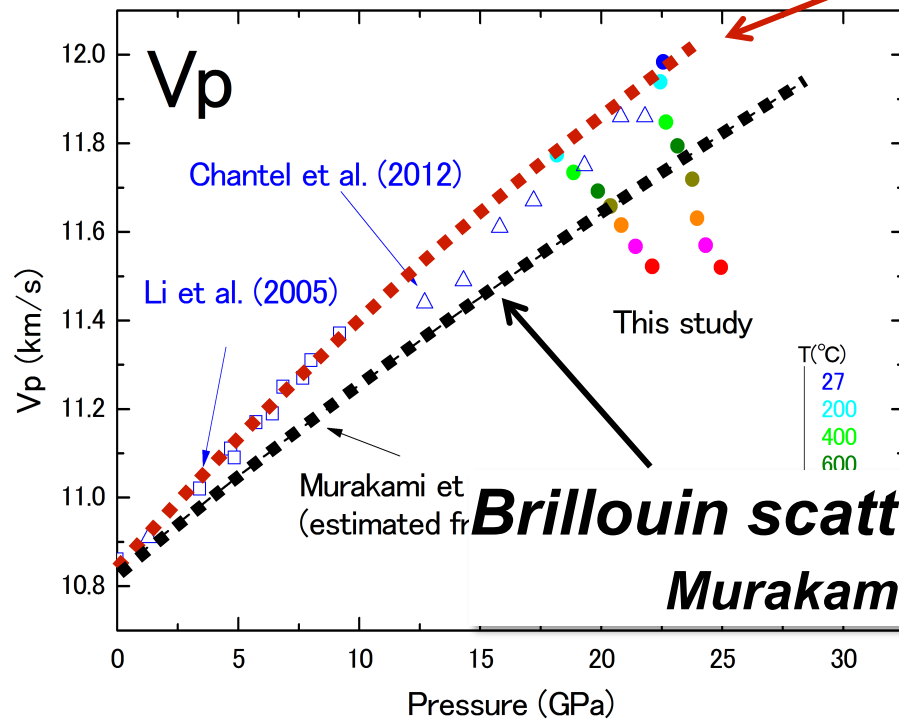


*Higo et al. (2008)
Irifune et al. (2008)*

Sound velocities of Mg-perovskite

ultrasonic measurements

Higo et al. (in prep.)

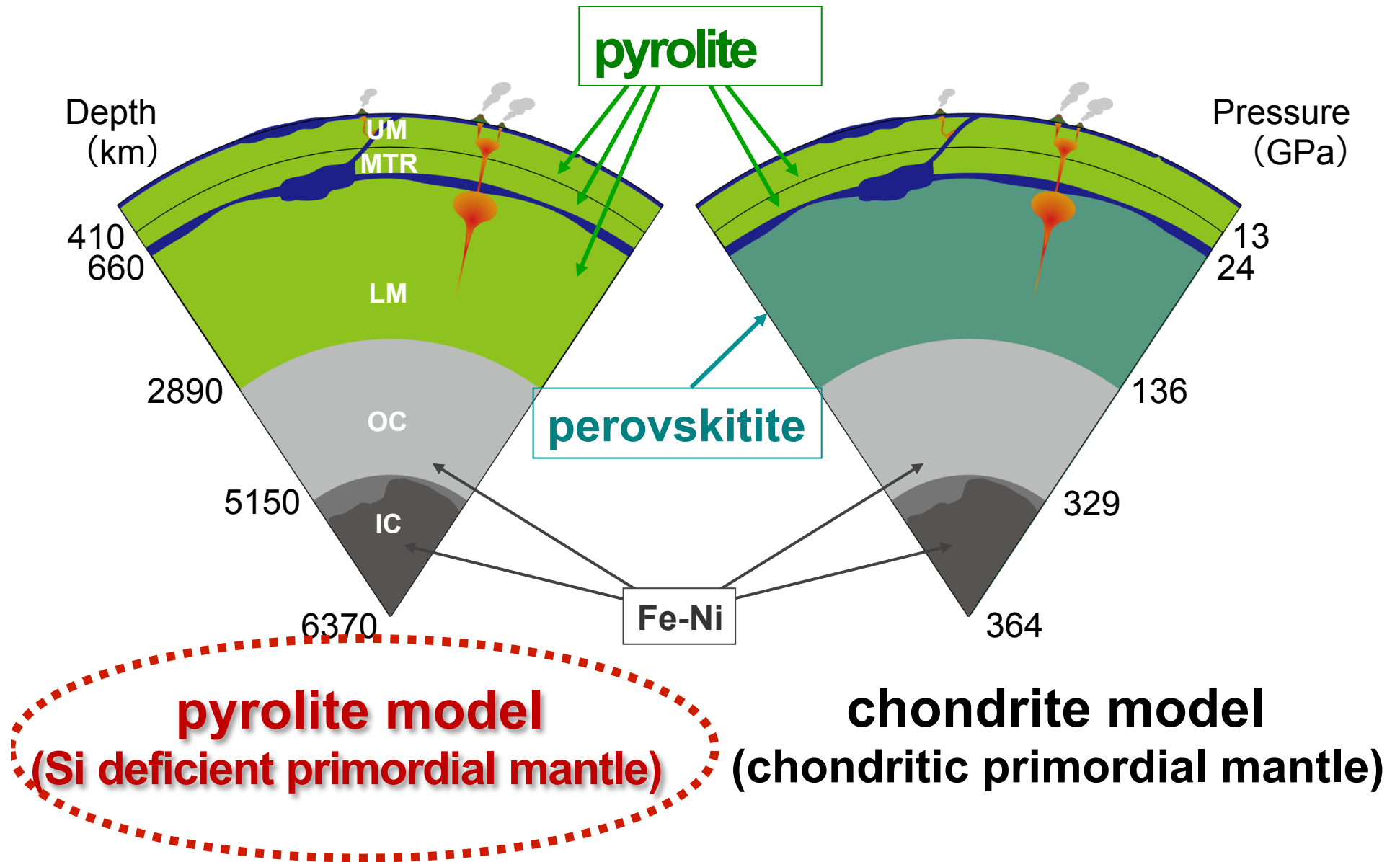


Brillouin scattering measurements

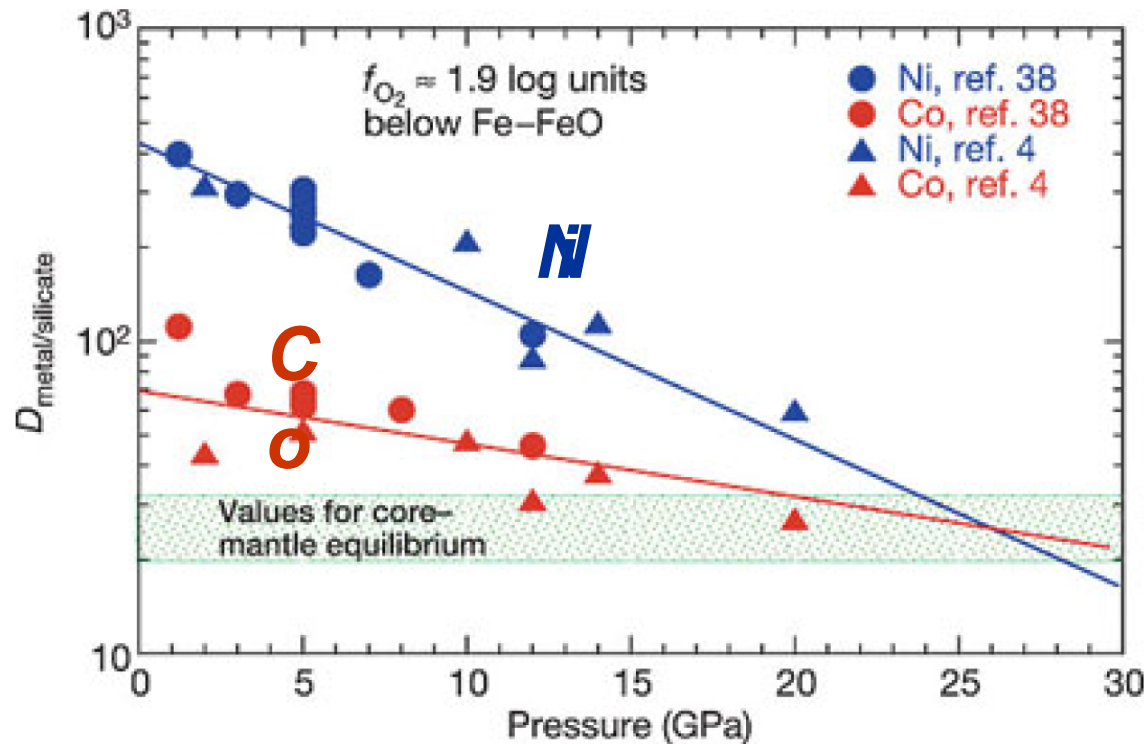
Murakami et al. (2007, 2012)

*consistent with ab initio calculations...
pyrolitic lower mantle?*

Composition of the lower mantle

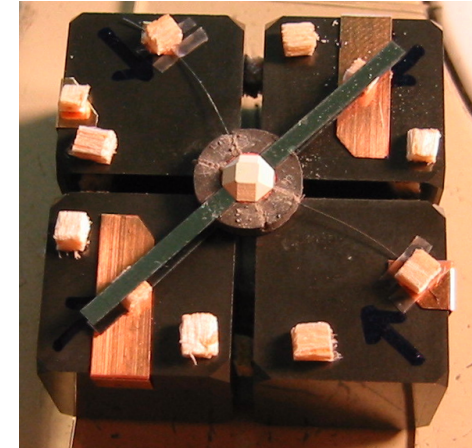


Partitioning in lower mantle (Irifune)

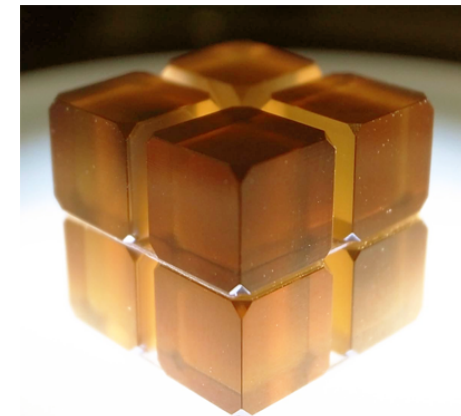


Wood et al. (2006)

Concept of “lithophile”, “siderophile” may not be valid any more ...needs laboratory studies under LM conditions

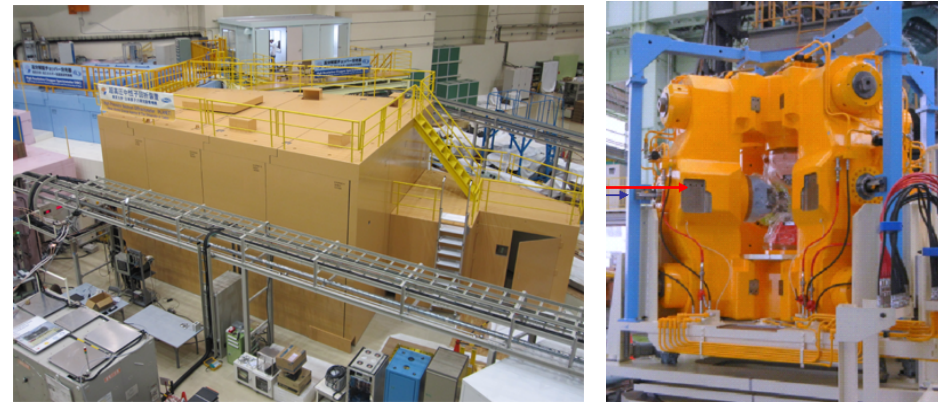
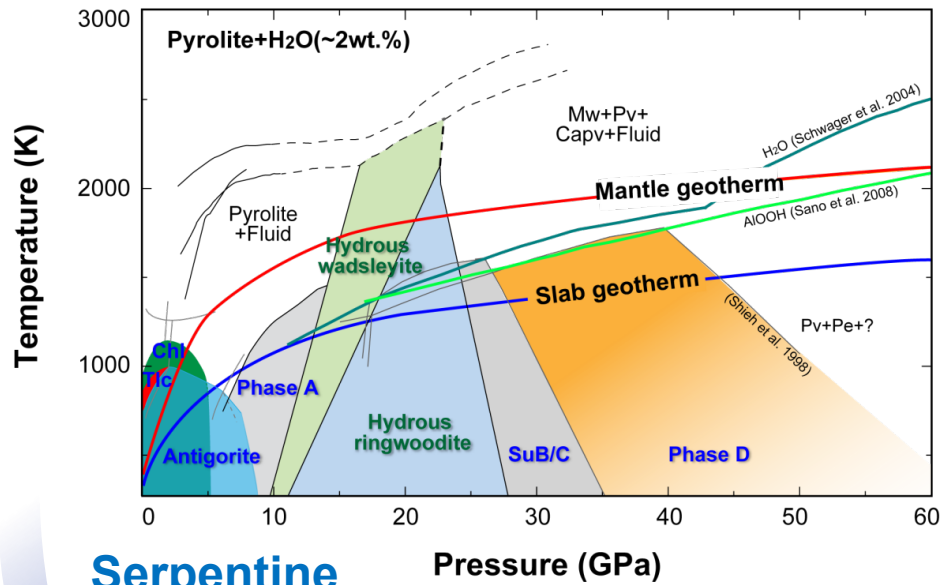


Sintered diamond anvils



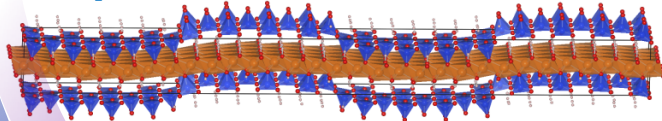
Nano-polycrystalline diamond anvils

Distribution of water (J. Tsuchiya)

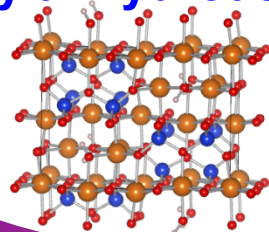


J-PARC neutron facility

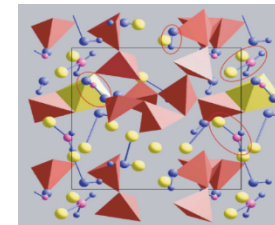
Serpentine



Nominally anhydrous minerals



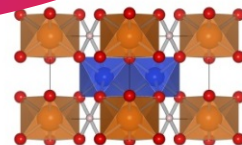
Hydrus magma



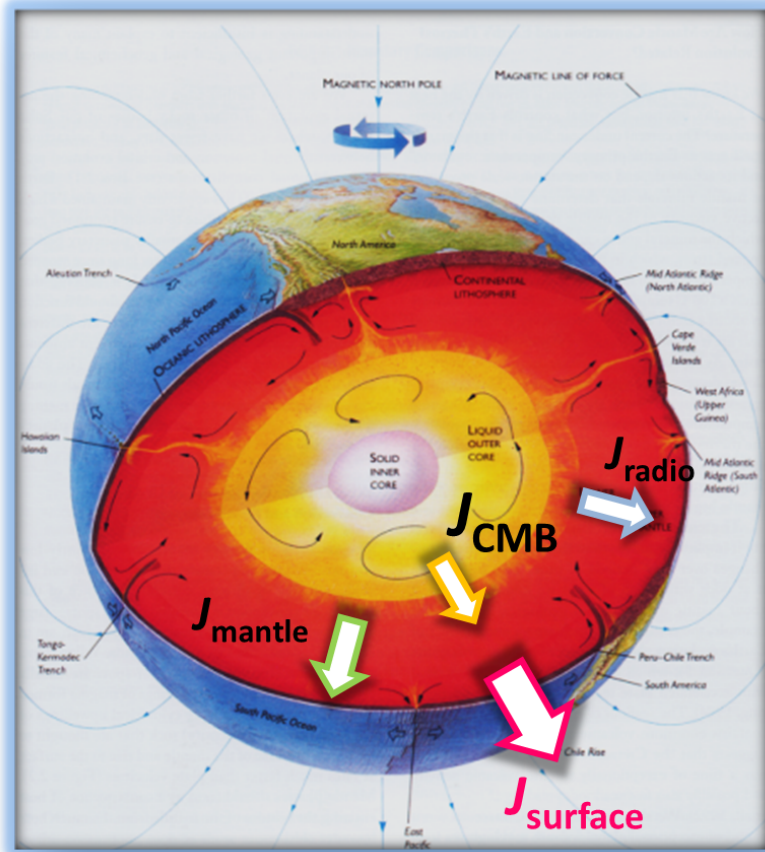
• Water storage capacity

Estimation of current water inventory

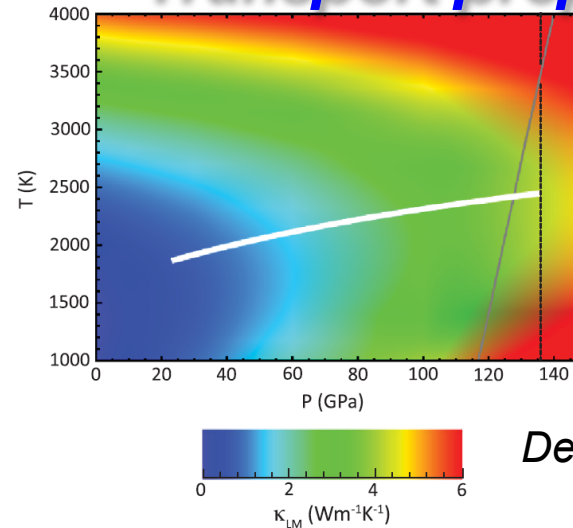
Dense hydrus minerals



Thermal evolution of Earth (T. Tsuchiya)

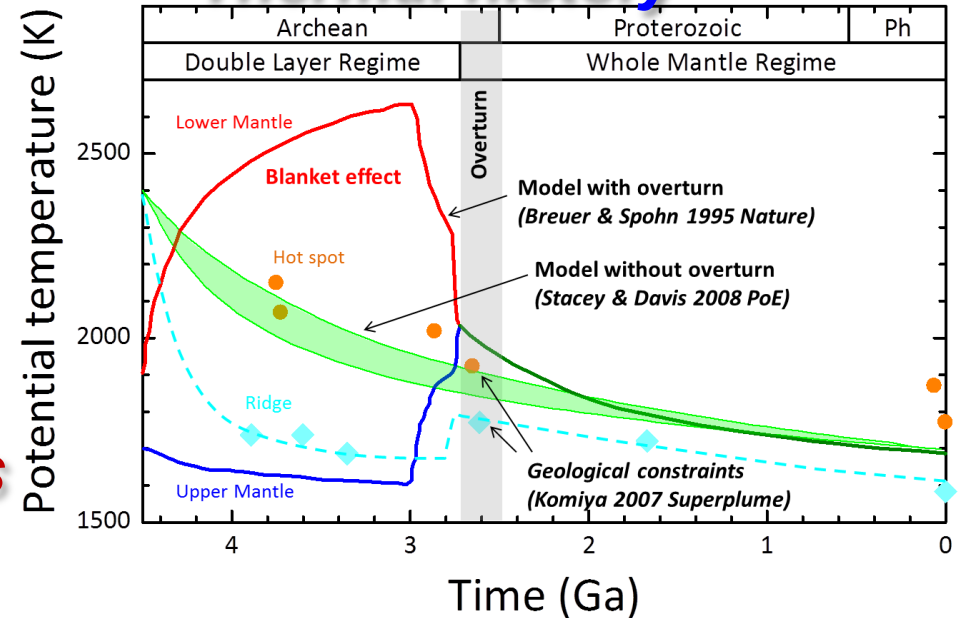


• Transport properties



Dekura et al. (2013)

• Thermal history



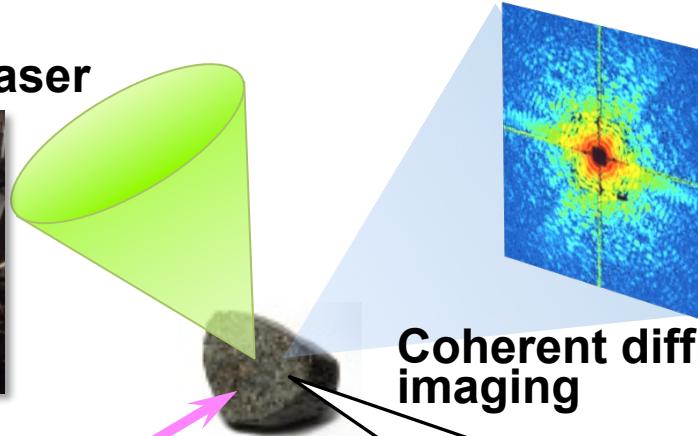
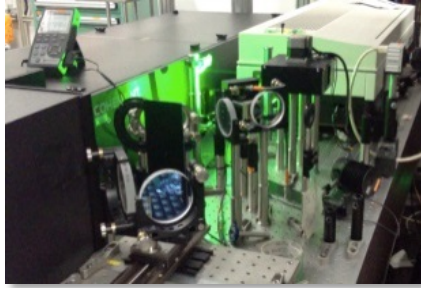
$J \downarrow CMB \uparrow From\ core \gg J \downarrow CMB \uparrow To\ mantle$

???

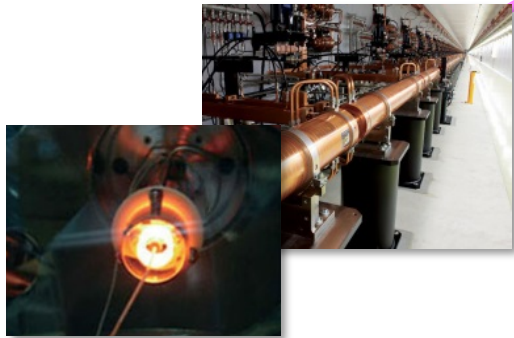
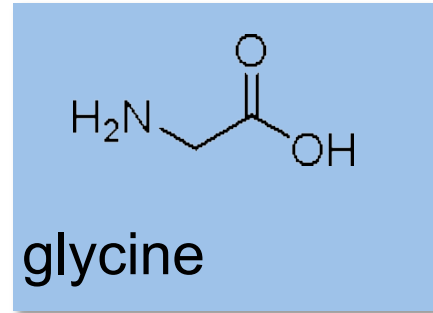
How affect interior dynamics & surface environment?

Laser shock with X-FEL (Tange)

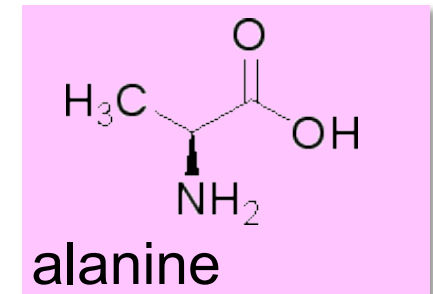
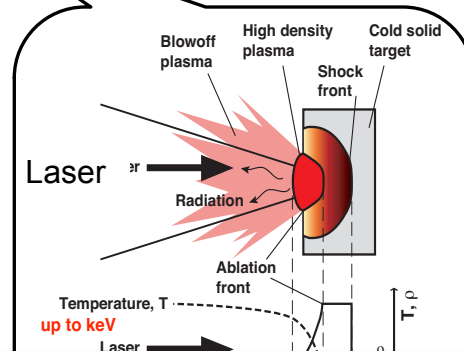
Synchronized pump laser



Coherent diffraction imaging



SACLA XFEL-proton



Challenges to the origin of

- **life**
- **Laser-shock on primordial materials**
- **Ultrafast time-resolve observations**
- **Survival rates of amino acids**



Origin of life on the early Earth

(1) Endogenous production (e.g. Miller & Urey, 1959)

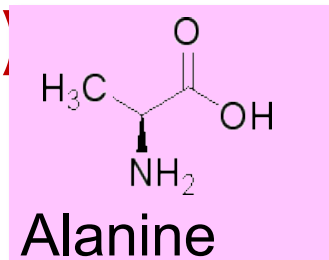
- Electrical discharges in the atmosphere
- Heating at submarine hydrothermal vents

(2) Impact-shock synthesis (e.g. Gilvarry & Hochstim, 196

- Shock heating of atmosphere by meteoroid impact
- Meteoritic impacts to the ocean

(3) Exogenous Delivery (e.g. Chyba et al., 1990)

- Asteroids
- Comets
- Interplanetary dust particles



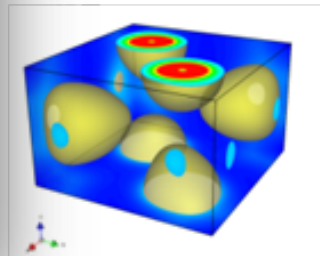
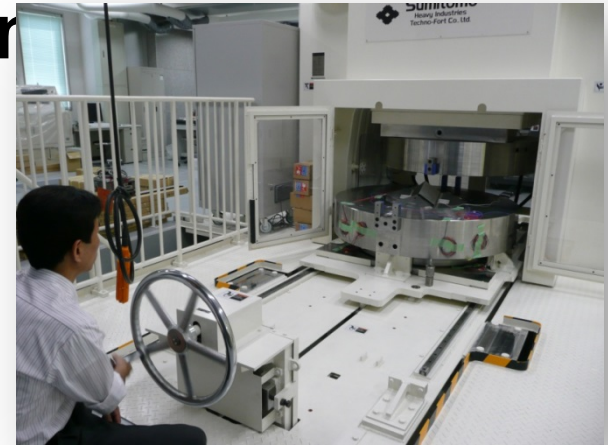
Survival of amino acids?



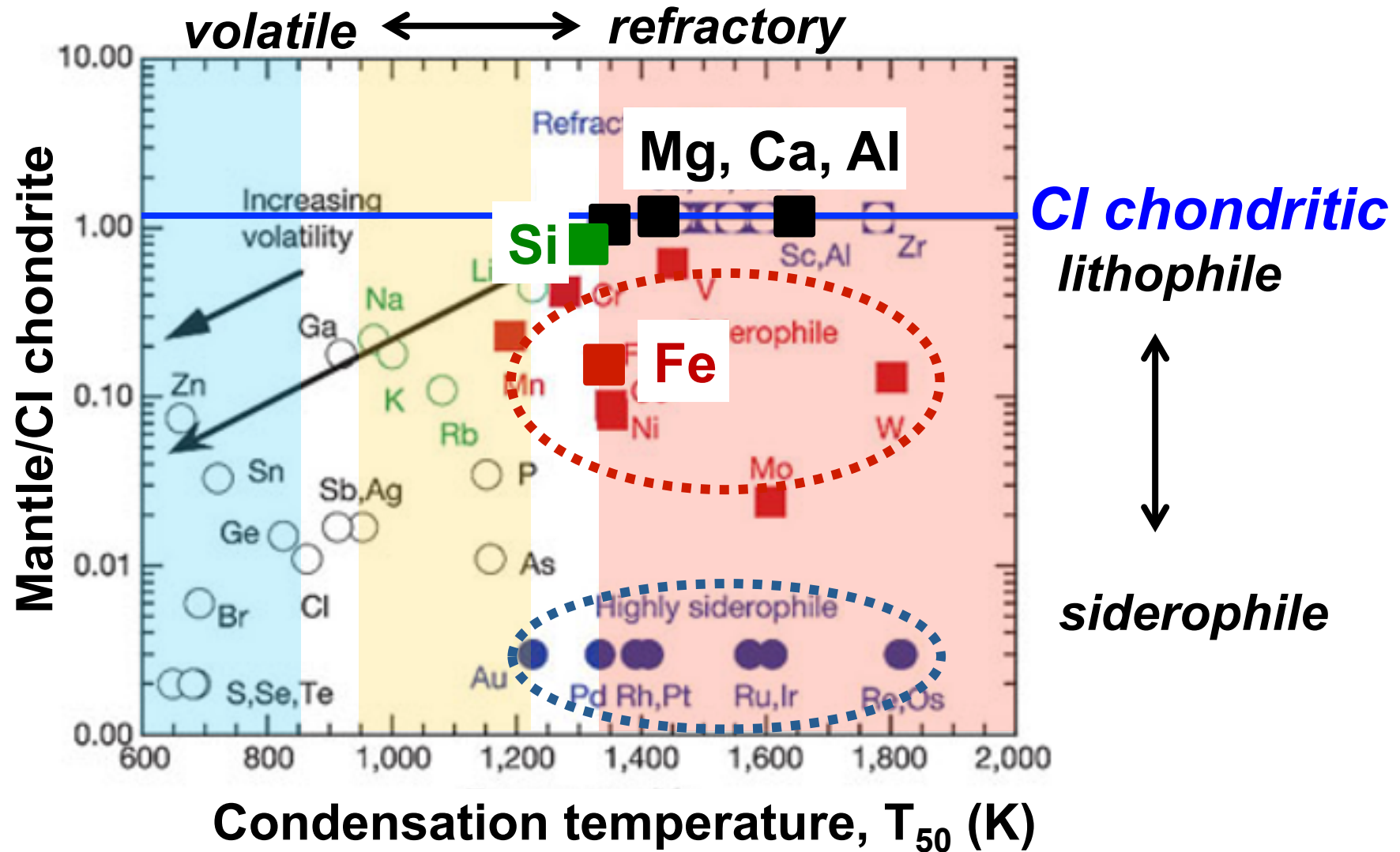
...may be solved by FEL+ laser shock experiments?

Research targets at ELSI-ES

- Chemistry of the lower mantle and bulk Earth
 - Differentiation and element partitioning
 - Distribution and circulation of water
 - Thermal structure and evolution
 - Laser shock and origin of life
- ✓ *Large-press experiments*
 - ✓ *Ab initio computations*
 - ✓ *Quantum-beam applications*

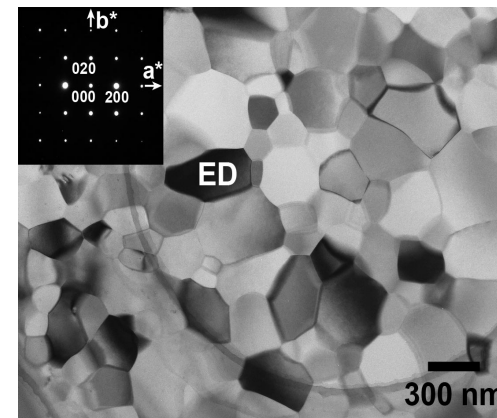
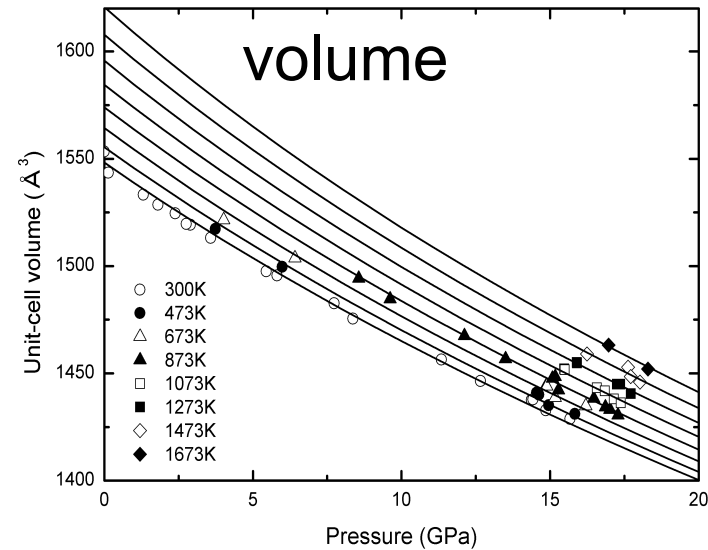
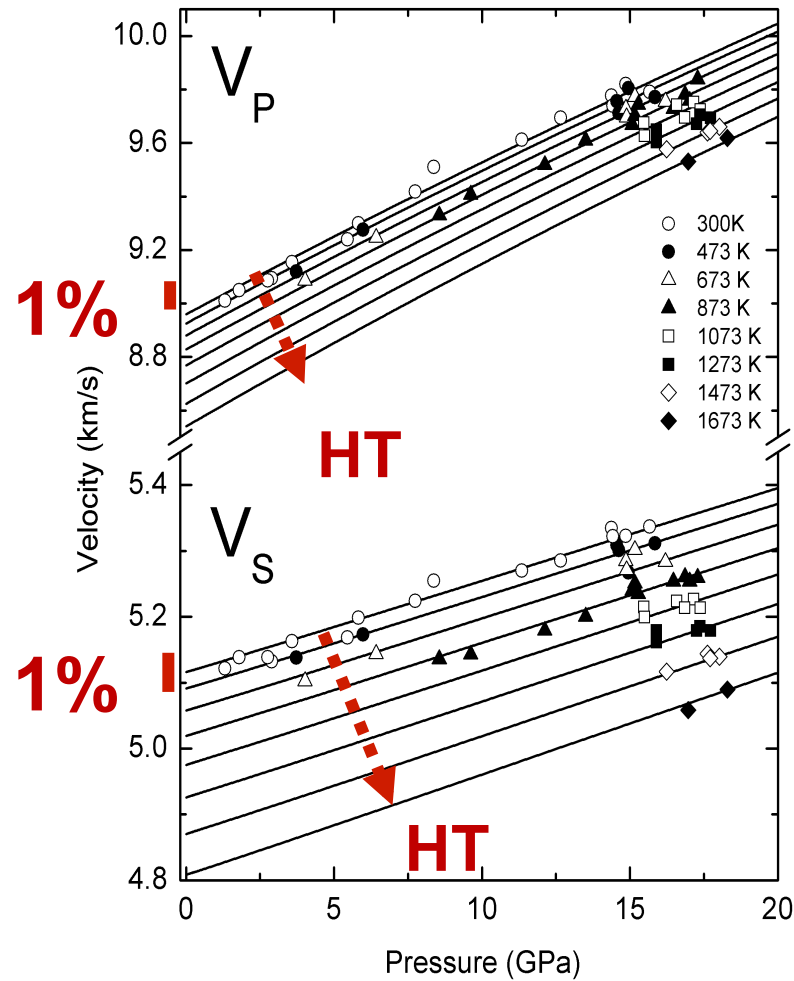


Element abundances in the Earth's mantle



Wood et al. (2006)

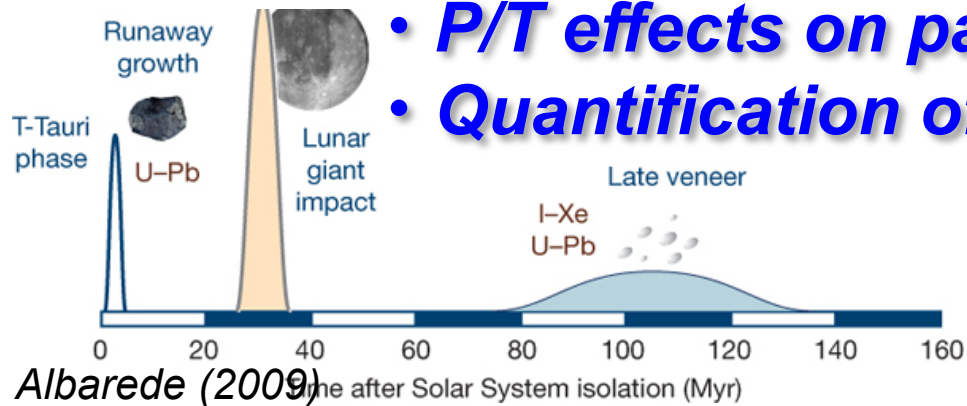
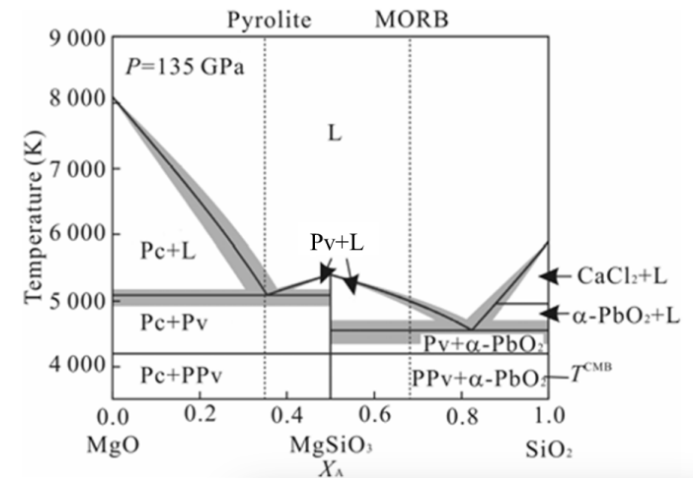
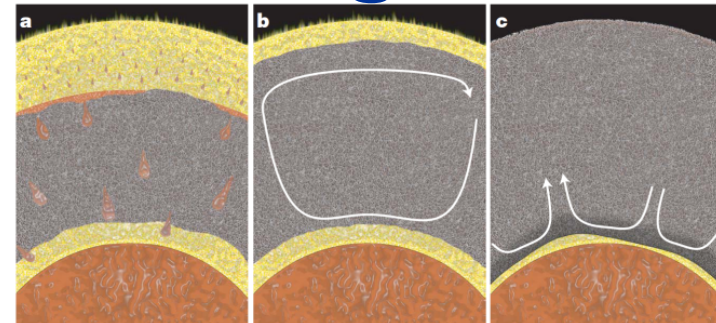
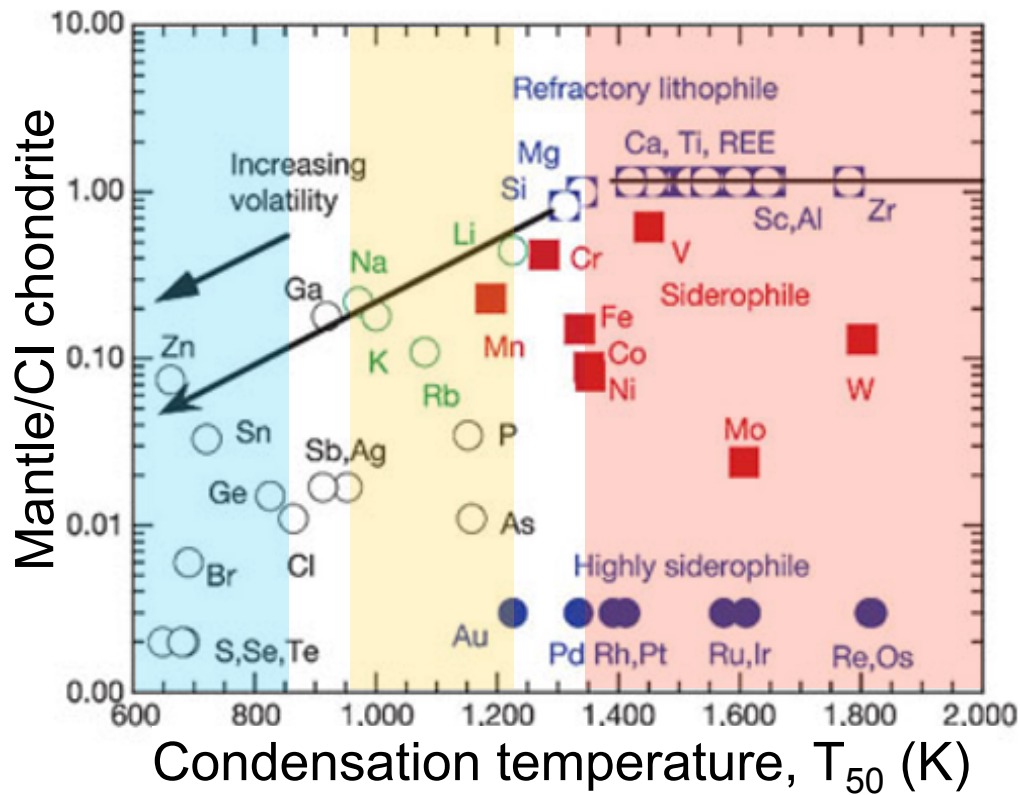
Sound velocities of pyrolitic majorite



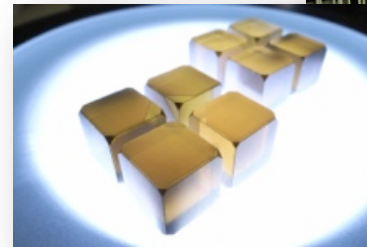
Irifune et al. (2008)

**Upper mantle and mantle transition region:
Pyrolitic (Irifune et al., Nature 2008)**

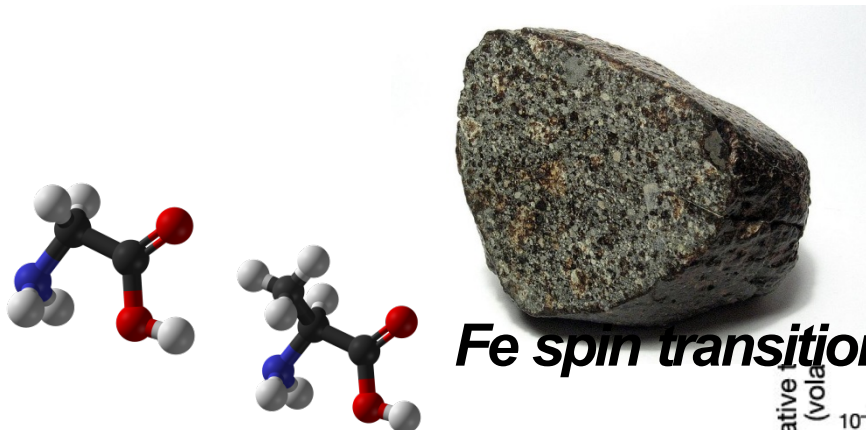
Melting and element partitioning



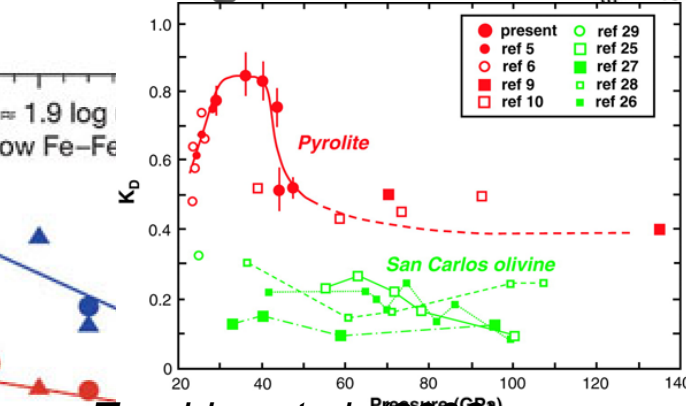
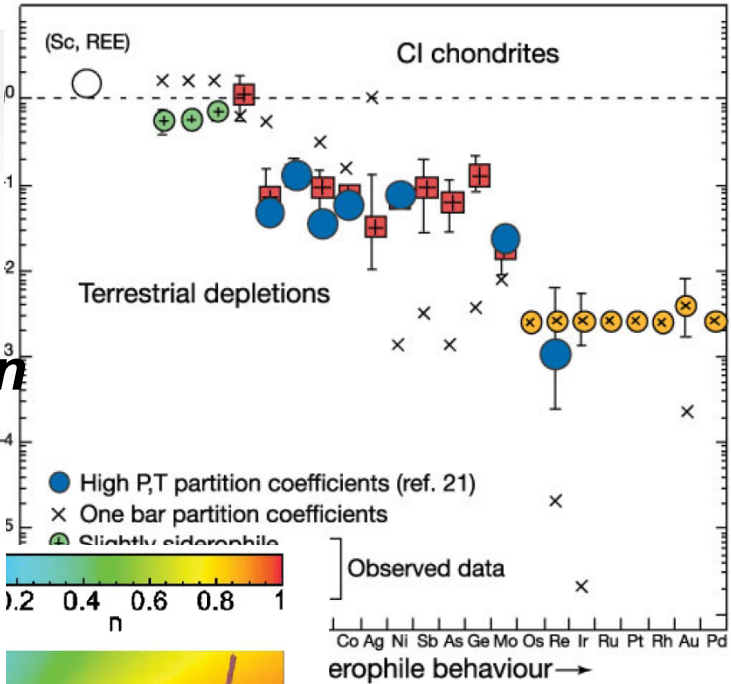
- *P/T effects on partitioning*
- *Quantification of "late veneer"*



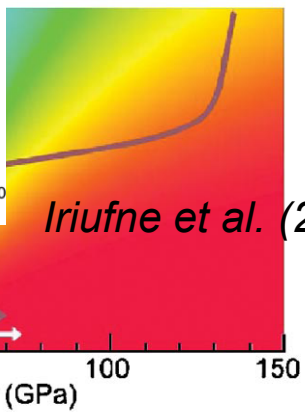
Albarede (2009)



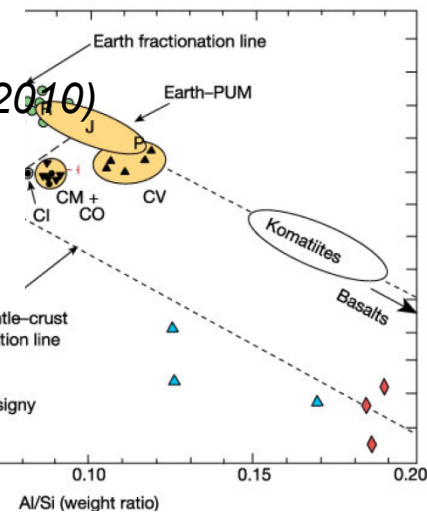
Fe spin transition

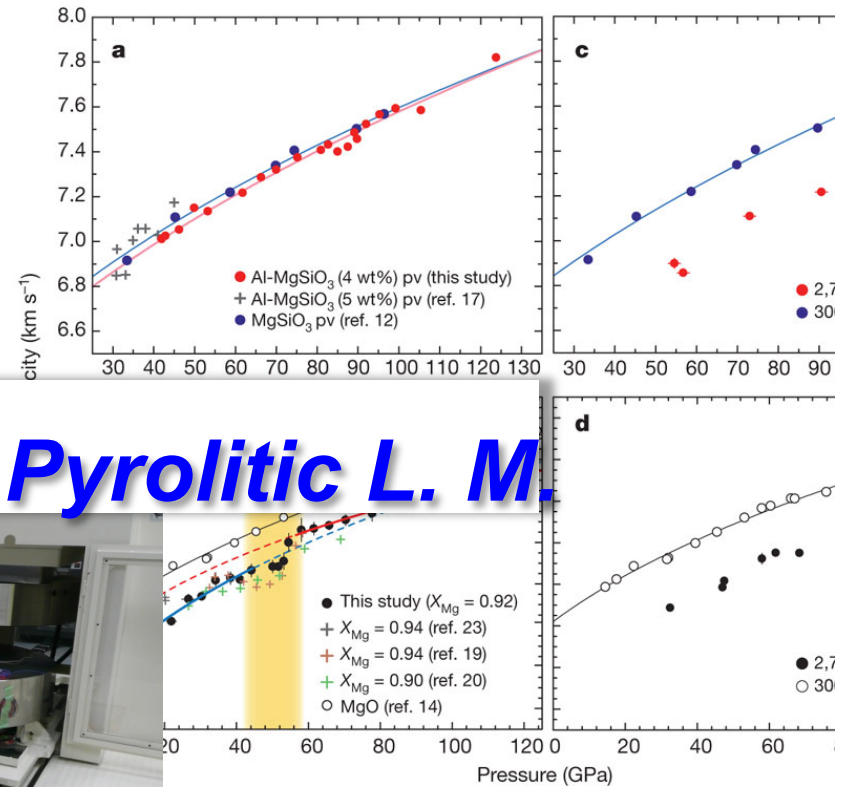
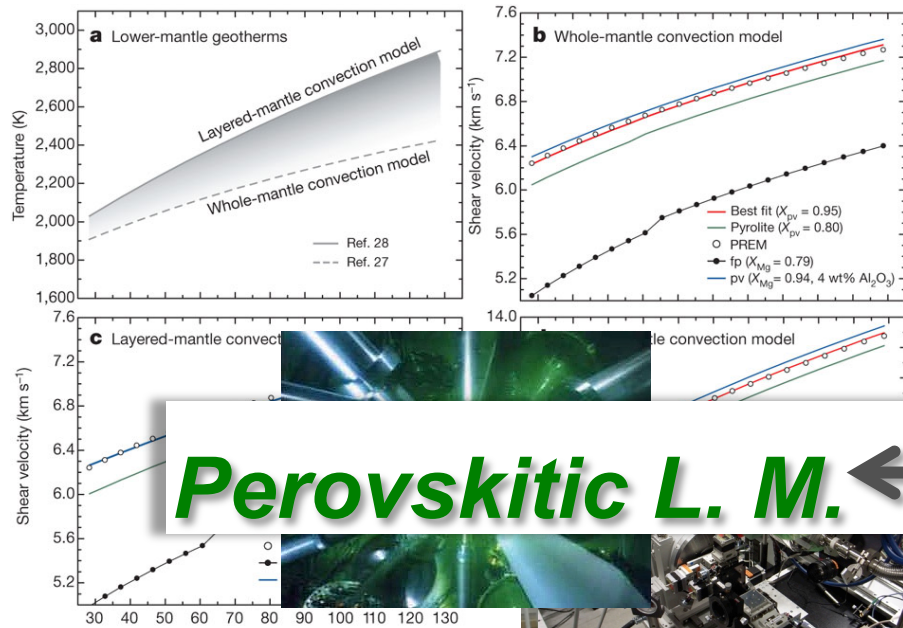


Tsuchiya et al. (2006)



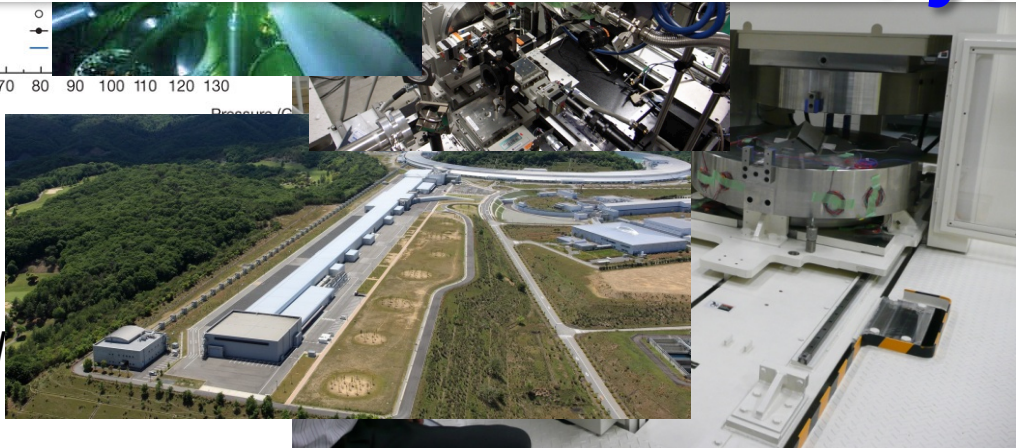
Irfune et al. (2010)



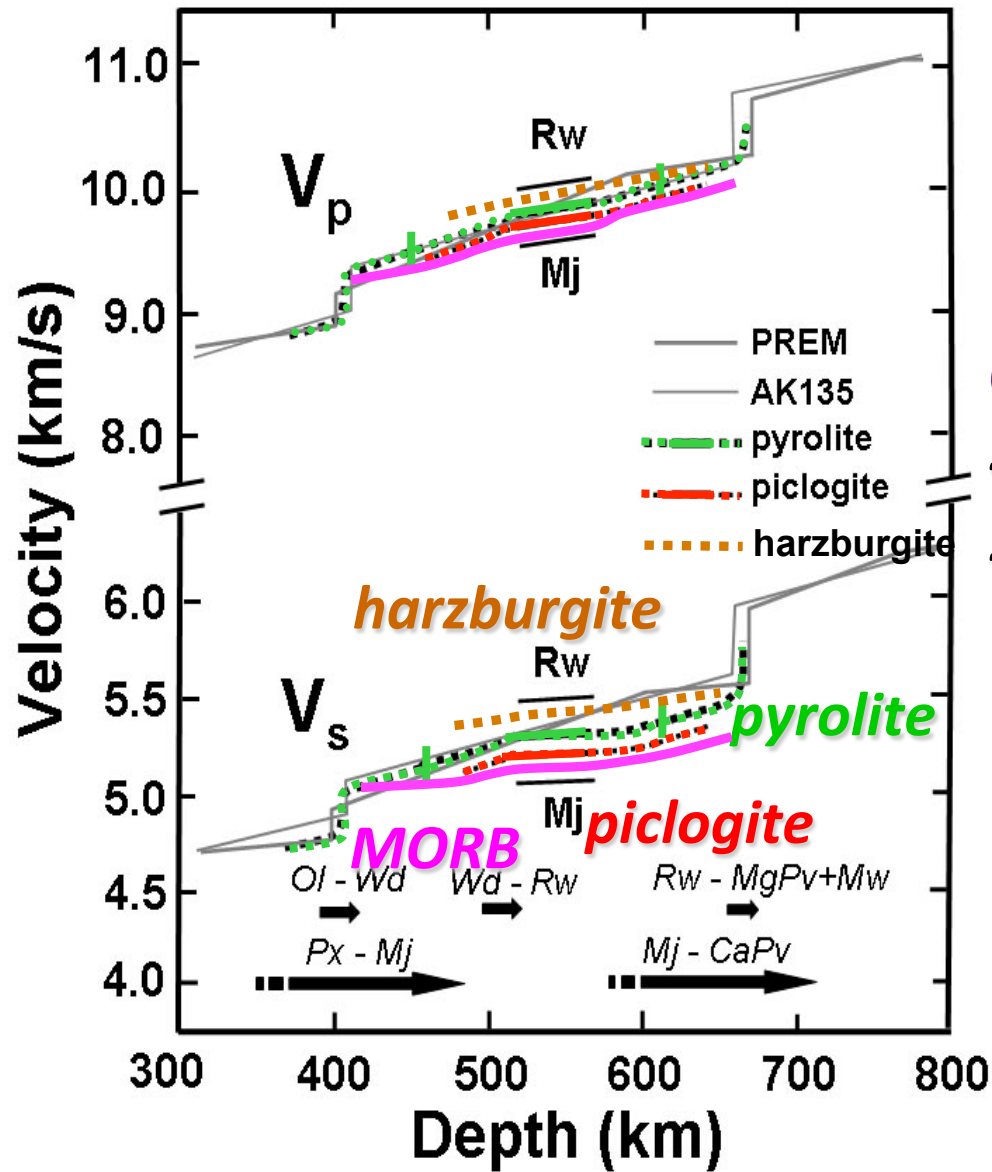


Perovskitic L. M. ↔ **Pyrolitic L. M.**

Albared



Pyrolite vs piclogite vs harzburgite vs MORB

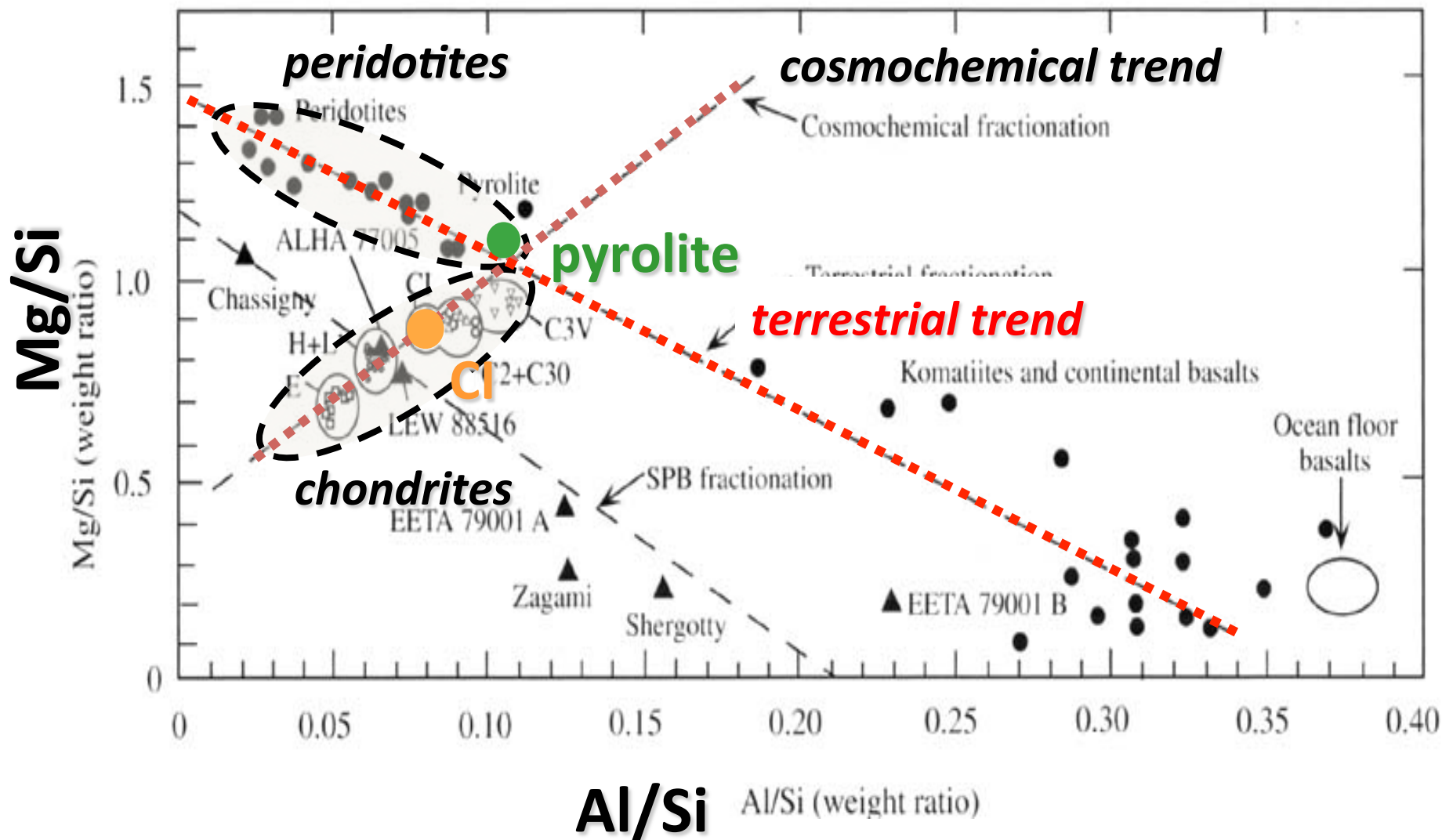


Composition of MTR

- upper to middle: *pyrolite*

- bottom: *harzburgite*

Terrestrial & cosmochemical fractionations



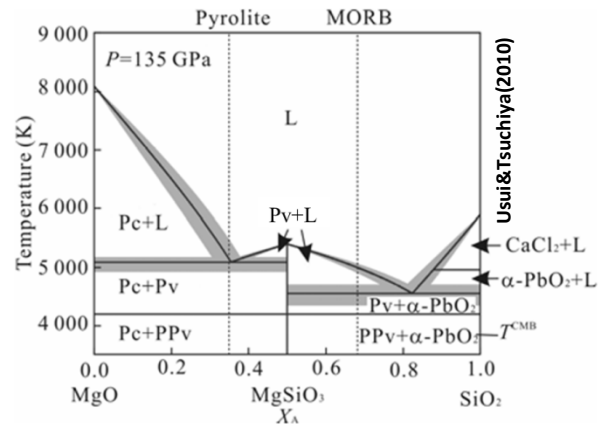
Taylor (2001)

Evolution of the mantle

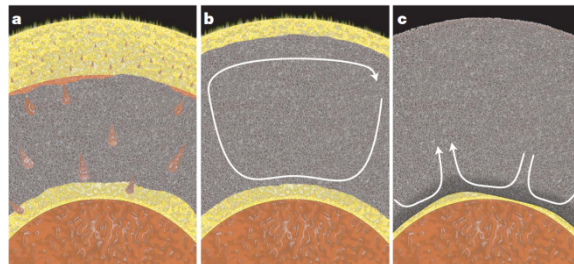
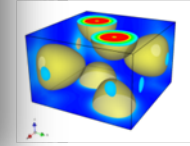
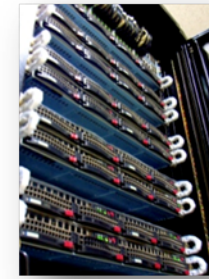
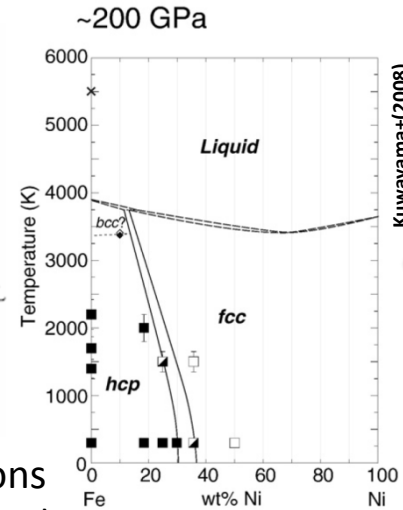
Magma ocean



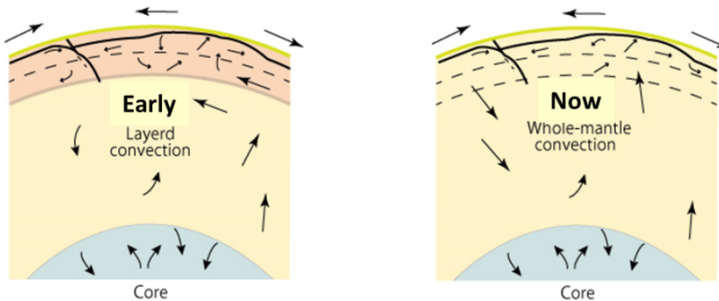
Late veneer



- ◆ Melting phase relations
- ◆ Melt properties $\rho(P, T, X)$



Solidification



Change in convection style

How to make the present pyrolitic mantle?

