Earth's Core-Mantle Boundary: Results of Experiments at High Pressures and Temperatures

Knittle & Jeanloz,

Science, Vol. 251 (5000), 1991

- Observations

  The Core-Mantle boundary and the lowermost mantle exhibit radial and lateral heterogeneities in seismic velocities, velocity gradients, discontinuities and scattering.

- Previous interpretation

  The CMB is a ***thermal*** boundary layer which support a thermal gradient of *over 1000K* over ~200 Km.

Suggested model

- D'' is also a chemical boundary layer between the silicate mantle and the iron core

- May support the 1000K gradient, by allowing density variations to counteract the thermal buoyancy forces
- Can also explain lateral heterogeneities

Lab Experiments

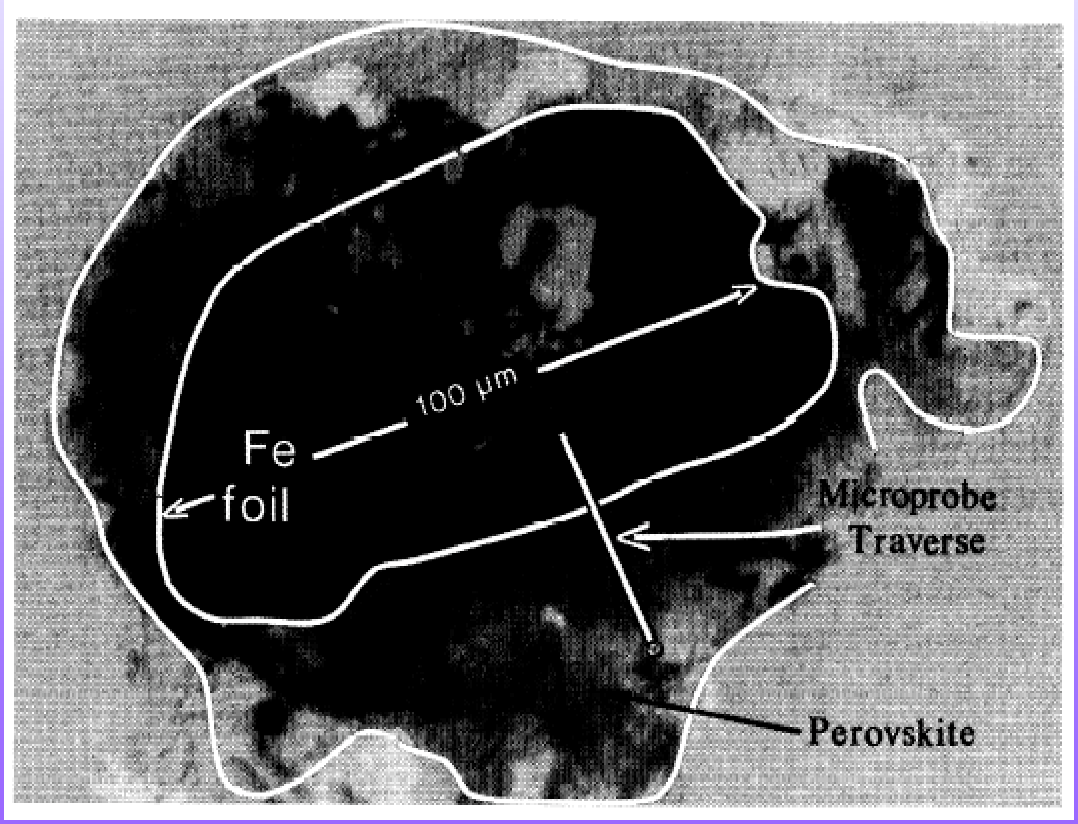
- Objective:

  Recreate the CMB in miniature, within a 200μm sample in a laser heated diamond-cell

- Tools:
  - Iron foils embedded in a silicate matrix (x4)
  - Laser heating melted the iron (not the silicates)
  - Pressure resemble CMB's (≥ 70 GPa)
  - Two comparison samples: one not heated and under pressure ; one heated and under low pressure.

Experiment Results

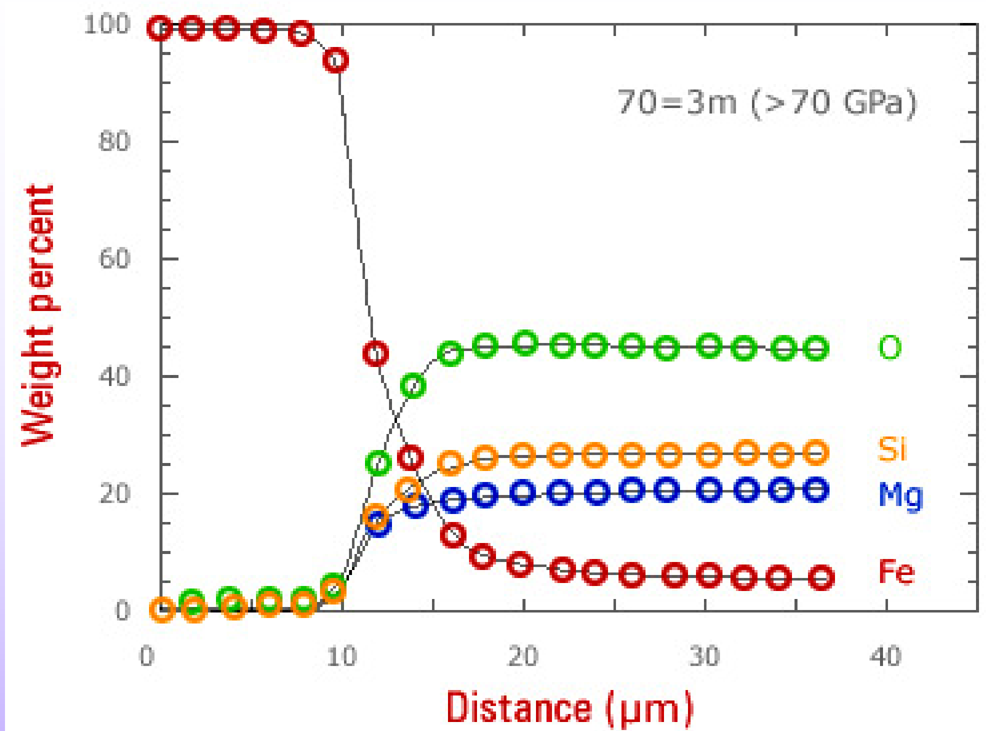
- All 4 samples had reaction zones between iron and silicates



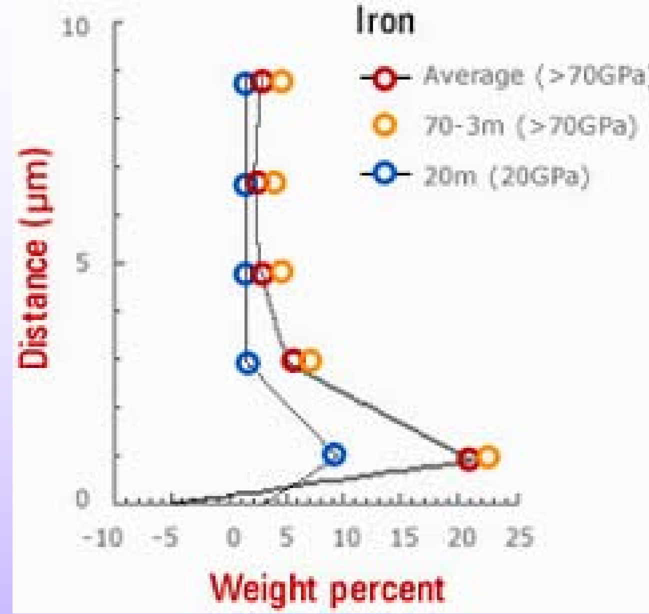
Experiment Results – Contd.

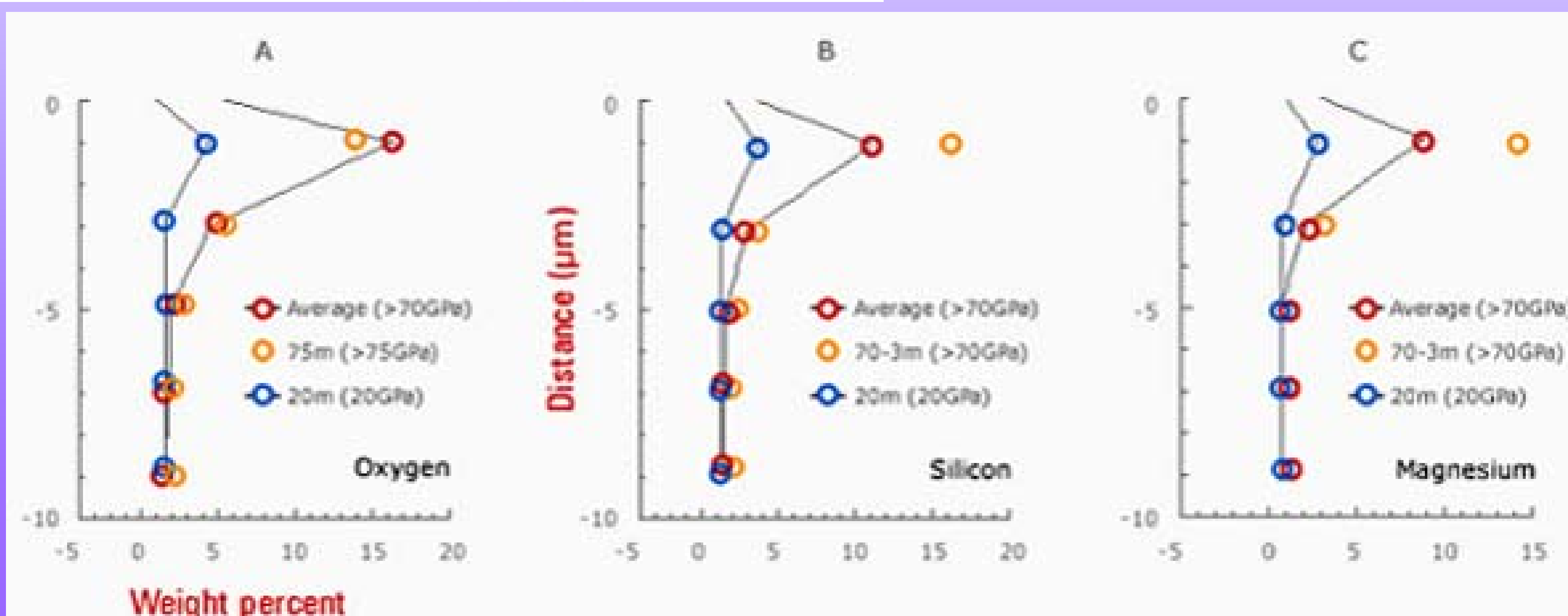
- Resolution of microprobe readings ≤ 2μm (determined using the pressure-only sample).
- Observed composition gradients:
  - Diffusion of O, Mg, Si : 4-7μm
  - Diffusion of Fe: at least 12 μm
- Migration of elements much stronger under higher pressures

Chemical gradient across the interface



Compositional profiles (Variations from the unreacted sample)





- Note – penetration of Fe into ***unmelted*** silicate matrix:
  - migration along grain boundaries?
  - Soret diffusion of heaviest component?

Thermodynamics

Proposed balanced equation:

$$Mg_xFe_{1-x}SiO_3 + 3[(1-x)-s]Fe = xMgSiO_3 + sSiO_2 + [3(1-x)-2s]FeO + [(1-x)-s]FeSi$$

By assuming amount of $FeSi$ equal to SiO_2

$$Mg_{0.9}Fe_{0.1}SiO_3 + 0.15Fe = 0.9MgSiO_3 + 0.2SiO_2 + 0.05FeO + 0.05FeSi$$

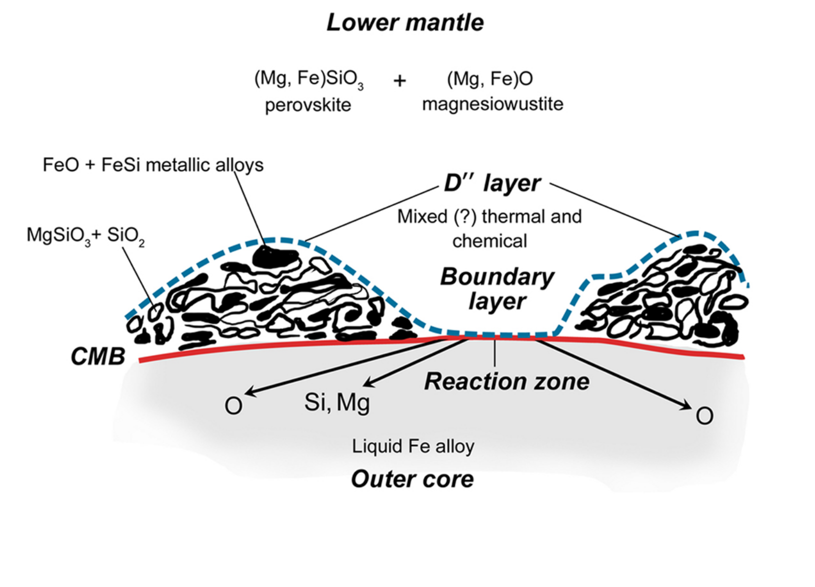
Sign of thermodynamic driving force:

- By calculating the volume change
- By experiments with higher Fe content

Result: the reaction is **favored** under high pressure and higher Fe content (See Fig 8-9)

Implications on the CMB

- The proposed reaction inevitably takes place in D''
- Can cause strong heterogeneity in density, elastic properties and electrical conductivity



- Implications on the magnetic field –due to lateral variations in electric conductivity (Secular variations?)

  See Buffet, 1996; Busse&Witch, 1992

- Implications on mantle dynamics due to variations in thermal conductivity (Manga&Jeanloz, 1996)

Length and time scales

- Short time/length scale:
  - Mantle rocks in direct contact with core iron react rapidly.
  - The reaction zone will penetrate upwards on order of 10^1-10^2 meters, based on capillary rise along grain boundaries

- Long time/length scales:
  - The reaction zone will be swept upwards by slow mantle convection. Will expose fresh rock to reaction.
  - Reacted material is denser – cannot rise very high → will form the D'' layer

Implications on outer core

- Reaction products, mainly Oxygen, swept into the core by the rapid outer convection.
- May explain why the density is lower by 10% of pure liquid iron

Conclusions

- Preferred model –
  - Vigorous chemical reaction between liquid iron of the outer core and the crystalline silicates of the lower mantle.
  - Dissolving of mantle O, Mg and Si into the core
  - Dissolving of core Fe into the mantle.