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An Fe-Si-Ni solidification model for the Earth's layering

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1. Are you interested in ...

- Inner core structure?
- Core's light element?
- D" layer oddities?
- Chemical layers in the mantle?
- Other rocky planetary bodies?

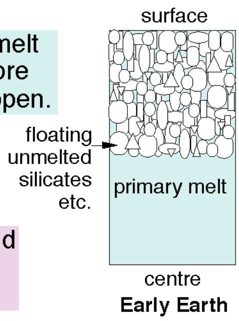
Have a look how solidification from a multicomponent fluid produces layers!

2. What fluid?

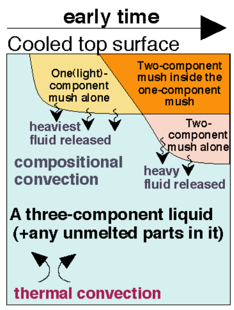
The primary partial melt which allowed the core differentiation to happen.

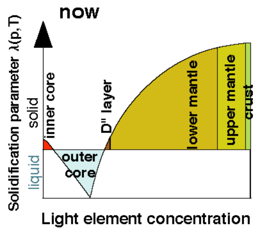
What are its main components?

Fe and **Ni** to descend to the core but also **Si** to rise up.



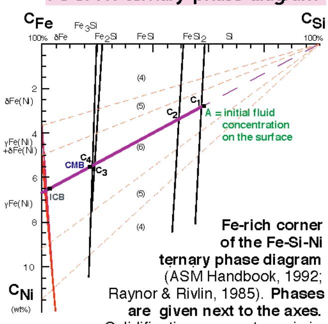
3. What layers?





A schematic presentation of the **two solidification fronts** inside the Earth. The **solidification parameter** combines the effects of **pressure and temperature**.

4. Layers' chemistry from the Fe-Si-Ni ternary phase diagram



Fe-rich corner of the Fe-Si-Ni ternary phase diagram (ASM Handbook, 1992; Raynor & Rivlin, 1985). **Phases are given next to the axes.** Solidification parameter axis is perpendicular to the concentration plane.

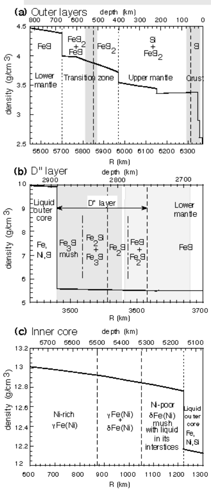
A narrow peritectic region in the Fe-Ni axis has been linearly continued to the point (Si,Ni)=(0.04,0.11) where it changes to be a cotectic line. The residual fluid concentration evolves from A along the **tie line** towards C_1 as the Si-mush is solidifying. **At C_1 a cotectic mixture of Si and $FeSi_2$ is solidifying. Ni/Fe ratio is assumed to stay constant due to convection. Thus after C_1 the residual fluid evolves along the same tie line** towards C_2, **C_3, C_4 and on to the CMB (core-mantle boundary), solidifying between them a mushy compound and on each C_j a cotectic mixture of the neighbouring phases**. The **inner core** has been assumed to have **started to solidify from the other end of this same line** and the residual fluid concentration on its solidification front **has now crossed the peritectic region and has reached the ICB (inner core boundary)**. **The liquid line of descent through A corresponds to an Ni/(Ni+Fe) ratio of 0.067.**

For different planetary bodies the slope of the liquid line of descent (Ni/(Ni+Fe) ratio) could vary and the five possible regions are separated by dotted lines with different selections of the crossed phase boundaries, the number of them being shown in brackets.

5. Model:

- Phase boundary equations (k_j and b_j from the graph): $C_{Ni} = k_j\, C_{Si} + b_j$, j=1,2,3,4
- **C_{Ni}/C_{Fe} is constant:** $C_{Ni} = k\,(1 - C_{Si})$
- Si-concentration $C_{Si} = a\,R^2$ where R is the distance from the centre
- **a is solved numerically** by changing **k** in steps of 0.001 and finding the **best fit** by using the **four** cotectic lines.

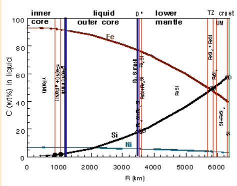
6. R-value interpretation from PREM's density discontinuities:



Shaded R-regimes are used to guide the numerical fit. Dashed lines are the **results** from the fit (a and b) or **predictions** from this model (c). Dashed-dotted lines (in b) are only estimates.

7. Results:

Fluid concentrations C_{Si}, C_{Ni} and C_{Fe} versus the radius.



The **open circles** are the Si-concentrations on the four cotectic lines with their R-value interpretations from PREM. The **two solid dots** indicate the Si-concentrations and **radii of the structure change predicted by this model inside the inner core**. The fronts at the present time are marked with bolder lines.

The data lie on the **parabola** $C_{Si} = a\,R^2$ with

$a = (1.437 \pm 0.007) \times 10^{-8}\ km^{-2}$ and **k = 0.067±0.001** (= Ni/(Ni+Fe)). Ni/Fe ratio is **0.072**. The **initial fluid Si-**concentration is **58.3 wt%** of the surface fluid.

13 chemically different layers form just via the **solidification process from this three-component melt**.

D" layer is **132 km thick** (same as from Vidale & Benz, 1993). It has **four sublayers**. Deepest of them is made of Fe_3Si-mush and is growing inwards.

The fluid **Si**-concentration is **2.1 wt%** at the **ICB** and **17.4 wt%** at the **CMB**. Its average in the outer core is about **11 wt%**.

Inner core has **three layers**:

- **From centre up to R = 870 km** it has **Ni-rich Fe**.
- **From R = 1050 km to the surface** it has **Ni-poor Fe-mush** (having Si-enriched melt in its interstices).
- **Between them** it has an **inhomogeneous mixture of Ni-rich and Ni-poor Fe**.

8. Conclusions:

The solidification process from a three-component fluid offers a **unified reasoning for the Earth's layers**.

It gives **more precise predictions for the core** structure and its concentration than any other model before. The seismically observed **anisotropy** may be generated by the **differing Ni-content in the inner core layers** and the presence of fluid in the surface layer. **Si trapped** into the interstices would **reduce the inner core density** as expected. The observed **hemispheric asymmetry** follows if **Ni/Fe-ratio varies locally**.

This model does not consider the recycling which has happened in the upper layers. **Rich crust and mantle chemistry** comes from the **unmelted original material**. Still, it does not seem to have much effect on the main layers, here generated by the solidification of the primary melt, but it could create extra layers if melted and resolidified.