UNIVERSITY OF COPENHAGEN

Seismic velocities – density relationship for the Earth's crust: effects of chemical compositions, amount of water and implications on topography

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Physical properties relationships

Thermo-chemical crustal structure

- formation and evolution
- role and distribution of fluids

In addition, **crustal models are essential** for:

- earthquakes localizations (velocity model)
- upper-mantle tomographic studies (velocity model)
- gravity modeling (density model)
- forward seismic wave propagation (velocity model)
- dynamic topography calculation (density model)

CRUST 1.0*

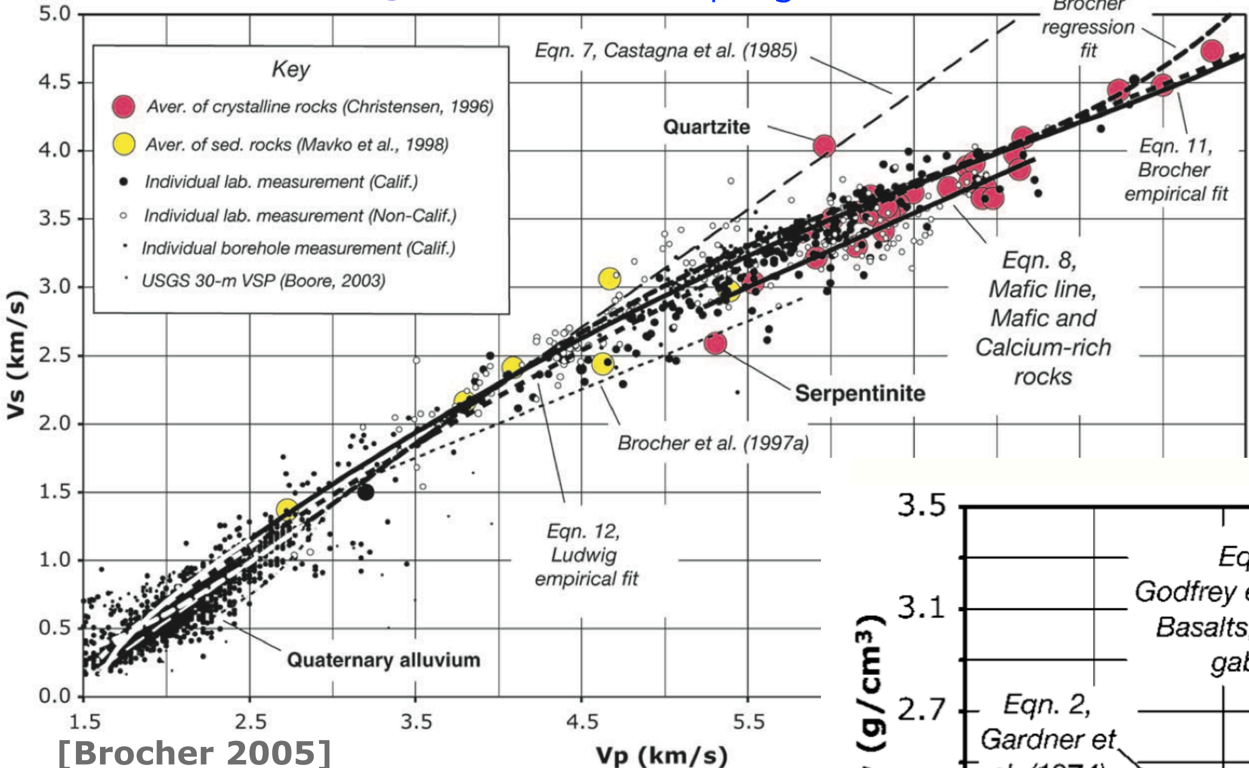
(Laske et al., 2013)

- Based on **active source seismic studies** and receiver function.
- **Gravity constraints** on areas where seismic data are missing.
- Subdivided in **crustal types** according to basement age or tectonic setting.
- Model tested against group velocity maps for Rayleigh and Love waves.
- **Scaling between Vp, Vs and density** validated against **Brocher (2005)**.

*** Free download at http://igppweb.ucsd.edu/~gabi/rem.html**

CRUST 1.0

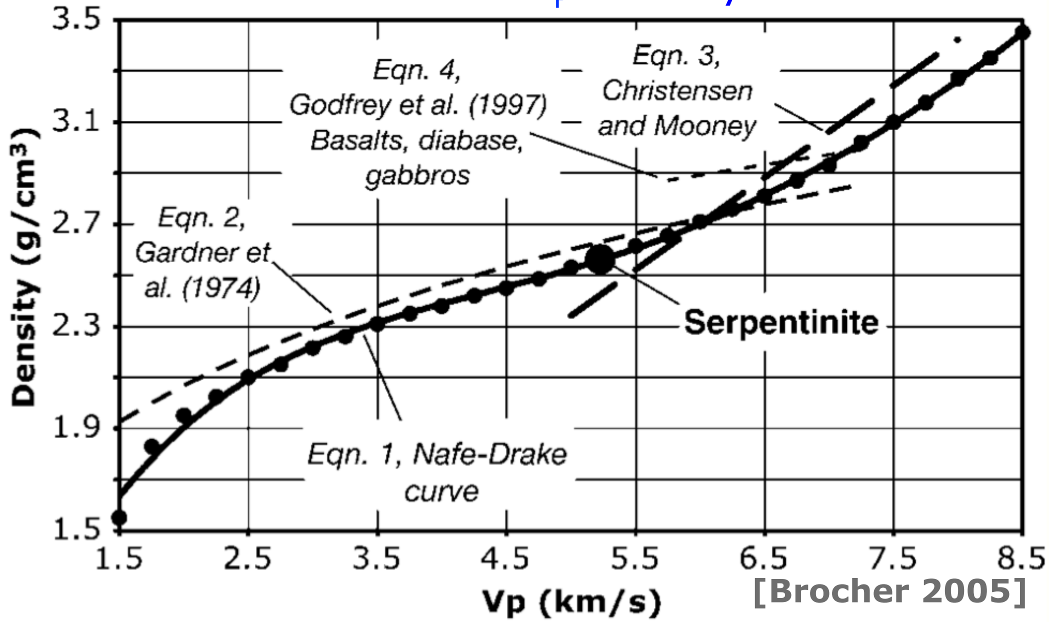
Brocher's regression fit, V_P-V_S relation



[Brocher 2005]

Data sources:
borehole logs
vertical seismic profiles
laboratory measurements
local tomography studies

Nafe-Drake curve
V_P-density relation

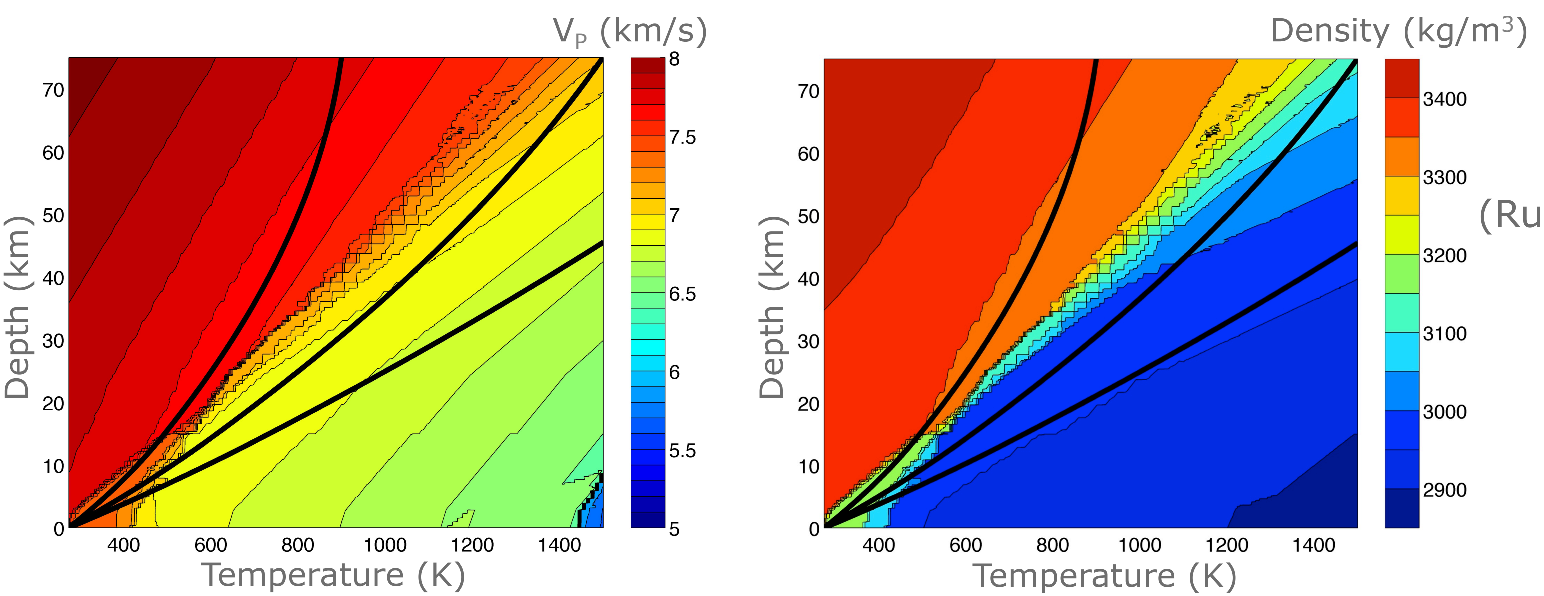


[Brocher 2005]

Not able to properly take into account the coupled effect of pressure and temperature on rocks physical properties.

Linking together VP, VS and density

- **Holland and Powell 1998** Thermodynamic data set: 154 mineral end-members, 13 silicate liquids end-members and 22 aqueous fluid species.
- Augmented by **shear moduli** for seismic velocity calculation *(Connolly and Kerrick, 2002)*.
- **Perple_X** (Connolly 2005): Calculation of phase equilibria and seismic velocities.



Lower crust composition
(Rudnick & Gao 2003)

Thermodynamic modeling: input compositions

Rudnick and Gao

[Rudnick and Gao 2003]

	1 Taylor (1964)	2 Ronov and Yaroshevsky (1967)	3 Holland and Lambert (1972)	4 Smithson (1978)	5 Weaver and Tarney (1984)	6 Shaw et al. (1986)	7 Christensen and Mooney (1995)	8 Rudnick and Fountain (1995)	9 Wedepohl (1995)	10 Gao et al. (1998a)	11 Taylor and McLennan (1985, 1995)	12 This study[a]
SiO_2	60.4	62.2	62.8	63.7	63.9	64.5	62.4	60.1	62.8	64.2	57.1	60.6
TiO_2	1.0	0.8	0.7	0.7	0.6	0.7	0.9	0.7	0.7	0.8	0.9	0.72
Al_2O_3	15.6	15.7	15.7	16.0	16.3	15.1	14.9	16.1	15.4	14.1	15.9	15.9
FeO_T[b]	7.3	6.3	5.5	5.3	5.0	5.7	6.9	6.7	5.7	6.8	9.1	6.71
MnO	0.12	0.10	0.10	0.10	0.08	0.09	0.10	0.11	0.10	0.12	0.18	0.10
MgO	3.9	3.1	3.2	2.8	2.8	3.2	3.1	4.5	3.8	3.5	5.3	4.66
CaO	5.8	5.7	6.0	4.7	4.8	4.8	5.8	6.5	5.6	4.9	7.4	6.41
Na_2O	3.2	3.1	3.4	4.0	4.2	3.4	3.6	3.3	3.3	3.1	3.1	3.07
K_2O	2.5	2.9	2.3	2.7	2.1	2.4	2.1	1.9	2.7	2.3	1.3	1.81
P_2O_5	0.24		0.20		0.19	0.14	0.20	0.20		0.18		0.13

Shaw et al.

Taylor and McLennan

Three compositions used: Rudnick and Gao (2003)
Shaw et al. (1986)
Taylor and McLennan (1985, 1995)

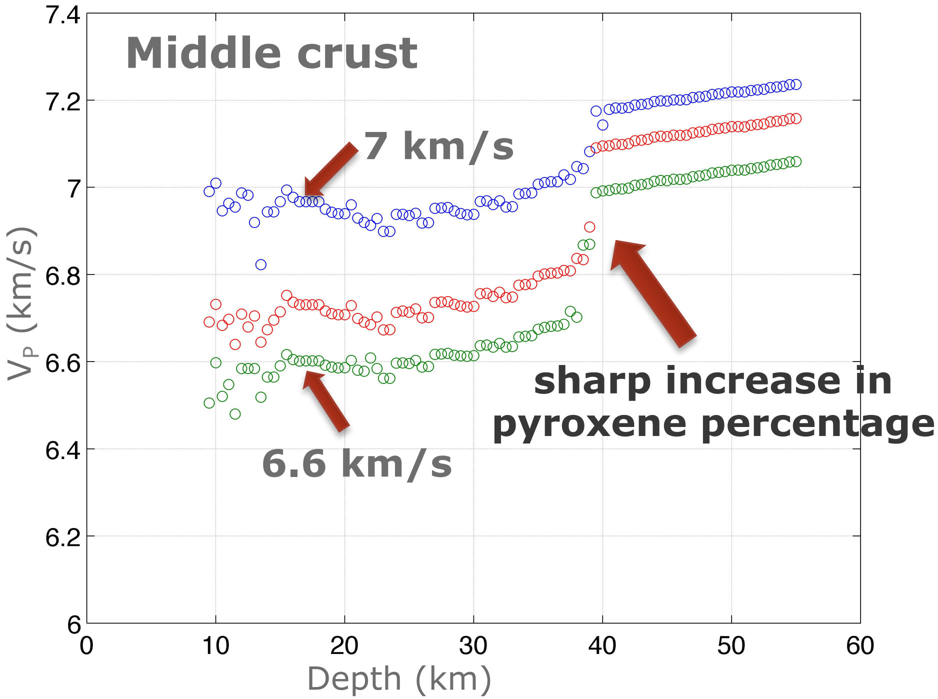
Oxides modeled: SiO2, Al2O3, FeO, MgO, CaO, Na2O, K2O

Rudnick and Gao composition tested adding 0.25 and 0.50 wt% of water

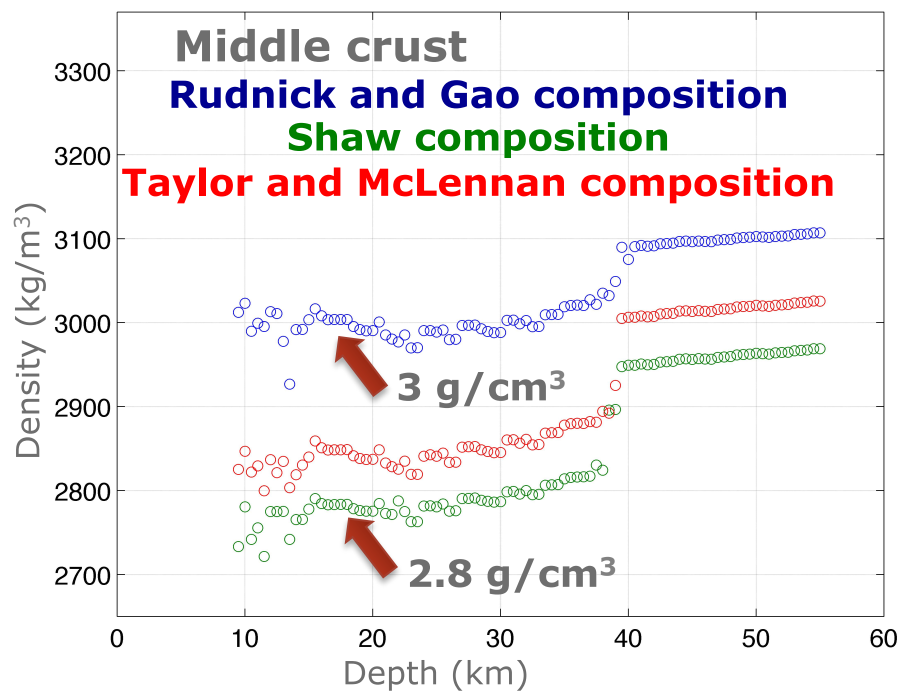
Major elements variation effects (mid. crust)

V_P and density variation along a continental geotherm (45 mW/m^2)

Compressional wave velocity



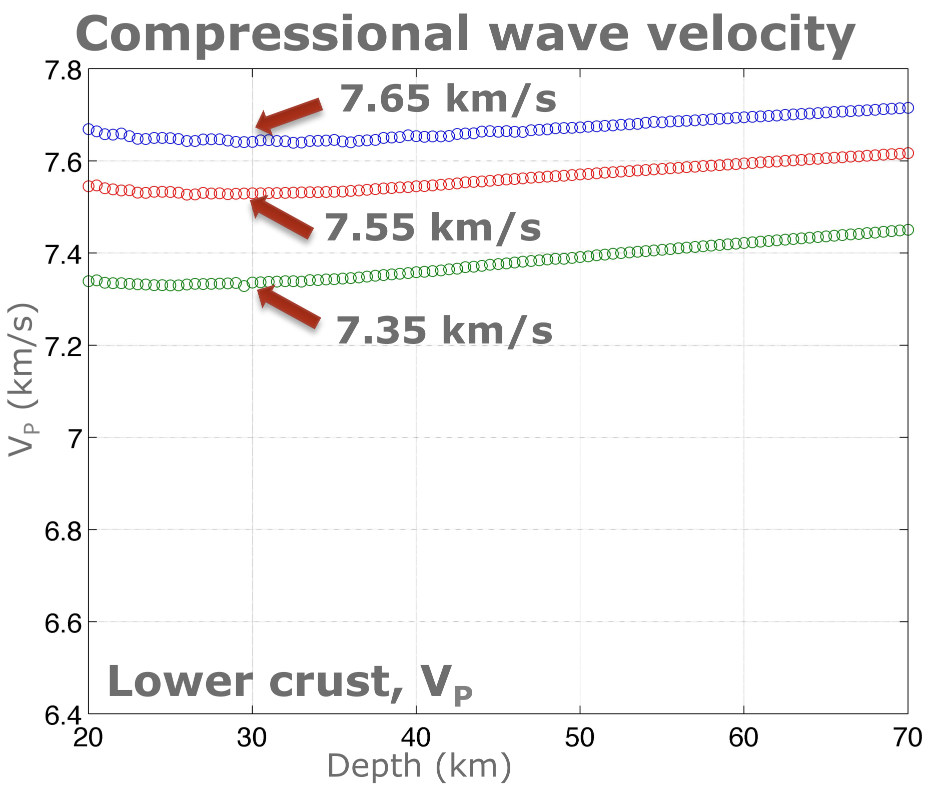
Density

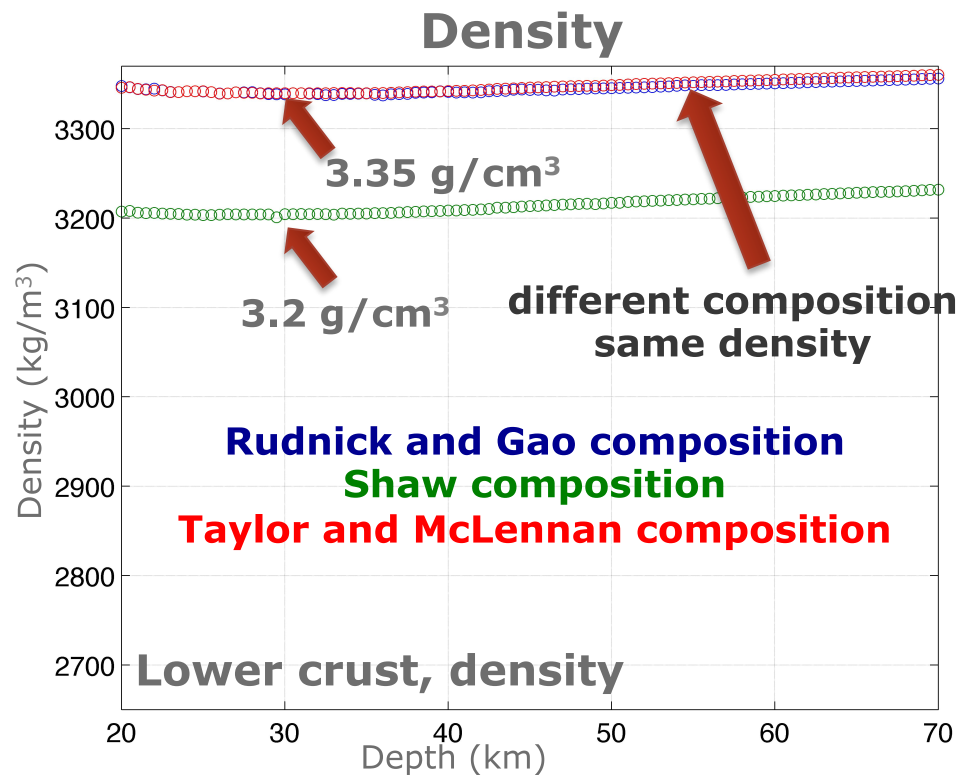


Variation in major element composition has a strong effect on both compressional wave velocity and density.

Major elements variation effects (low. crust)

V_P and density variation along a continental geotherm (45 mW/m^2)



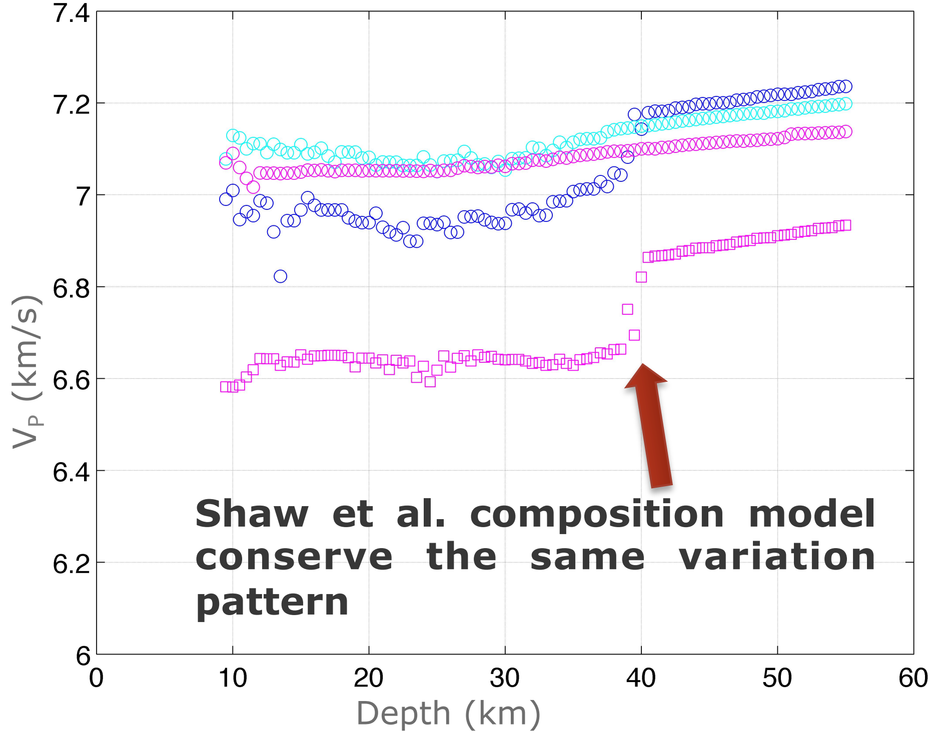


Different chemical compositions can result in the same density and yet present different seismic velocities.

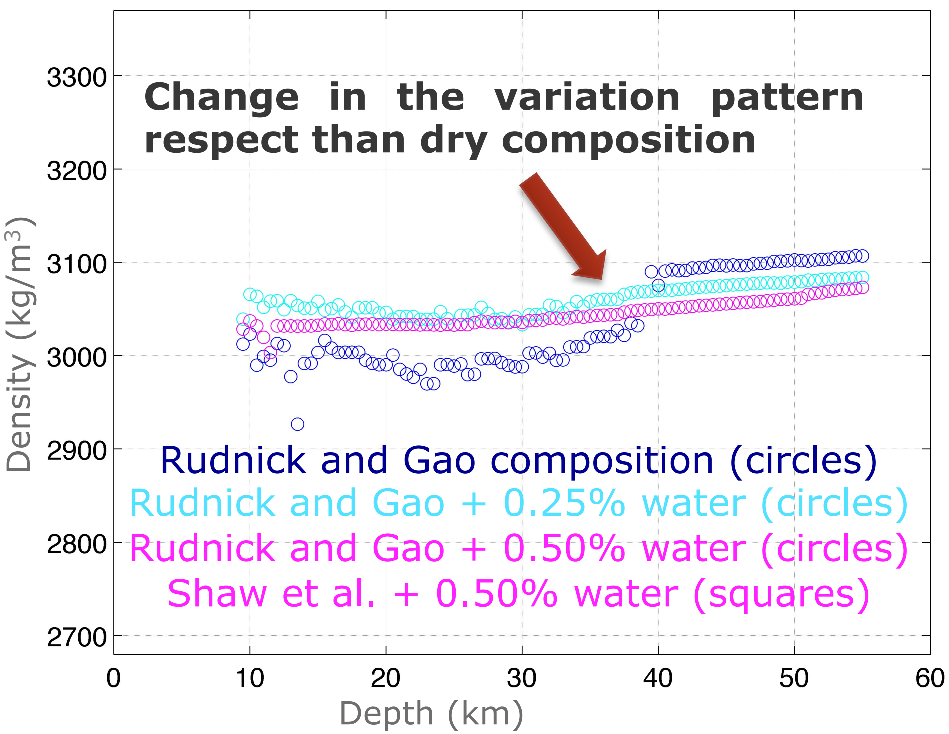
Effects of water (mid. crust)

V_P and density variation along a continental geotherm (45 mW/m²)

Middle crust
Compressional wave velocity



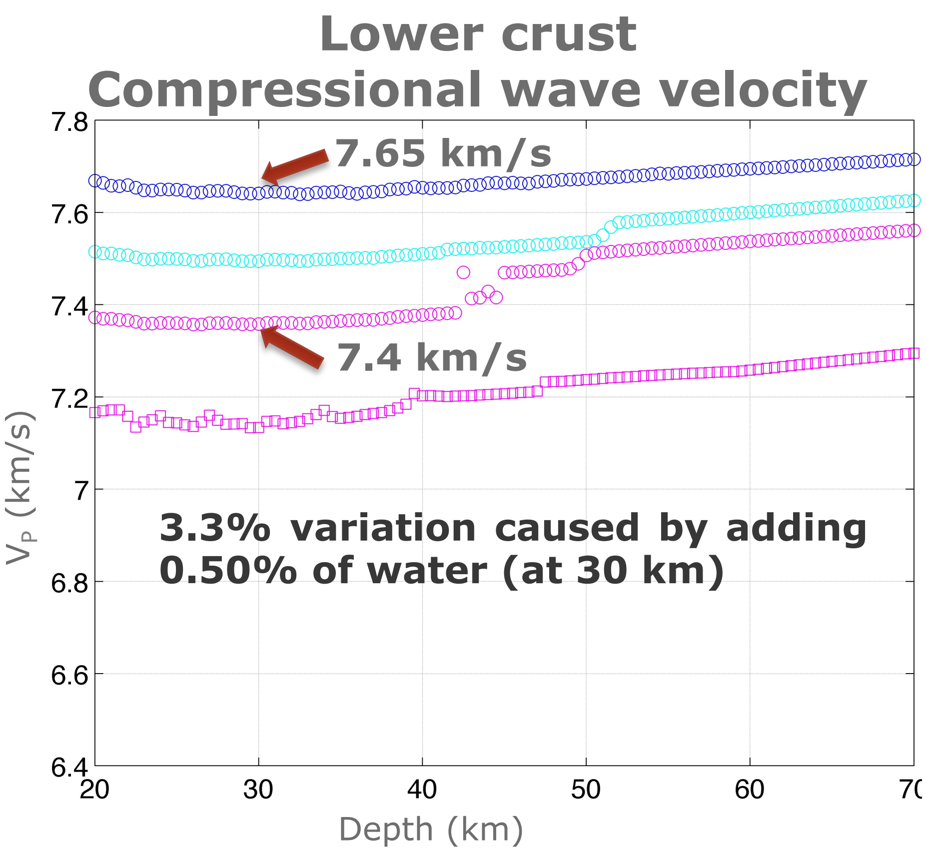
Middle crust
Density

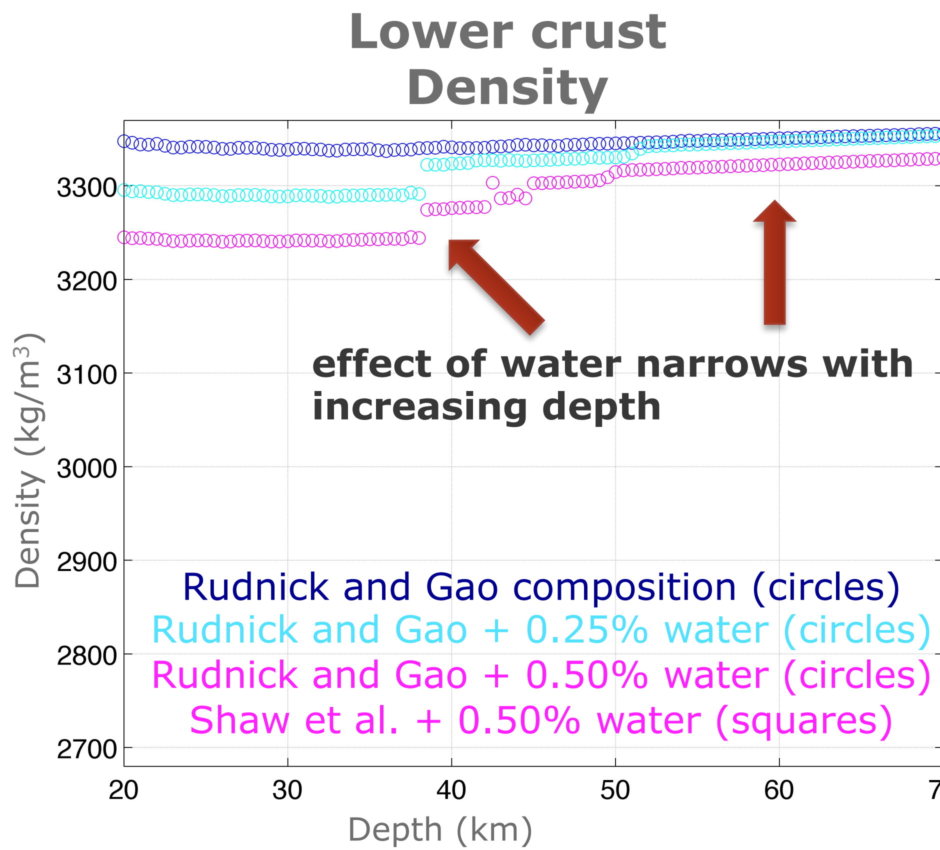


Water affects values of V_P and density and also (for Rudnick and Gao composition) the variation pattern along increasing P-T.

Effects of water (low. crust)

V_P and density variation along a continental geotherm (45 mW/m²)





Adding even small amount of water results in a strong effect on physical properties, also this effect is not constant changing P-T.

crustal physical properties computation

Input composition

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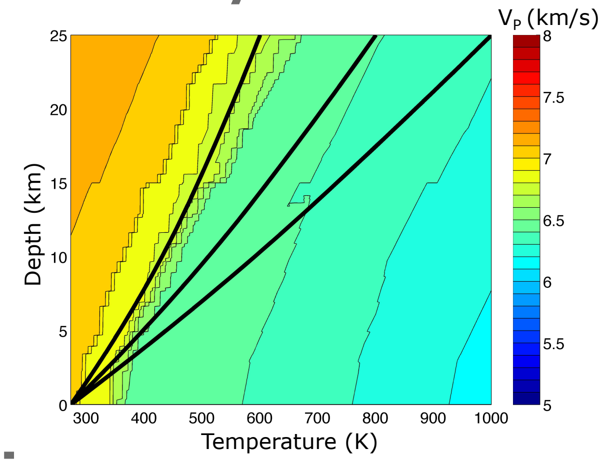
Thermodynamic modeling



Seismic velocities - density relations

CRUST 1.0 (Laske et al. 2014) as reference model

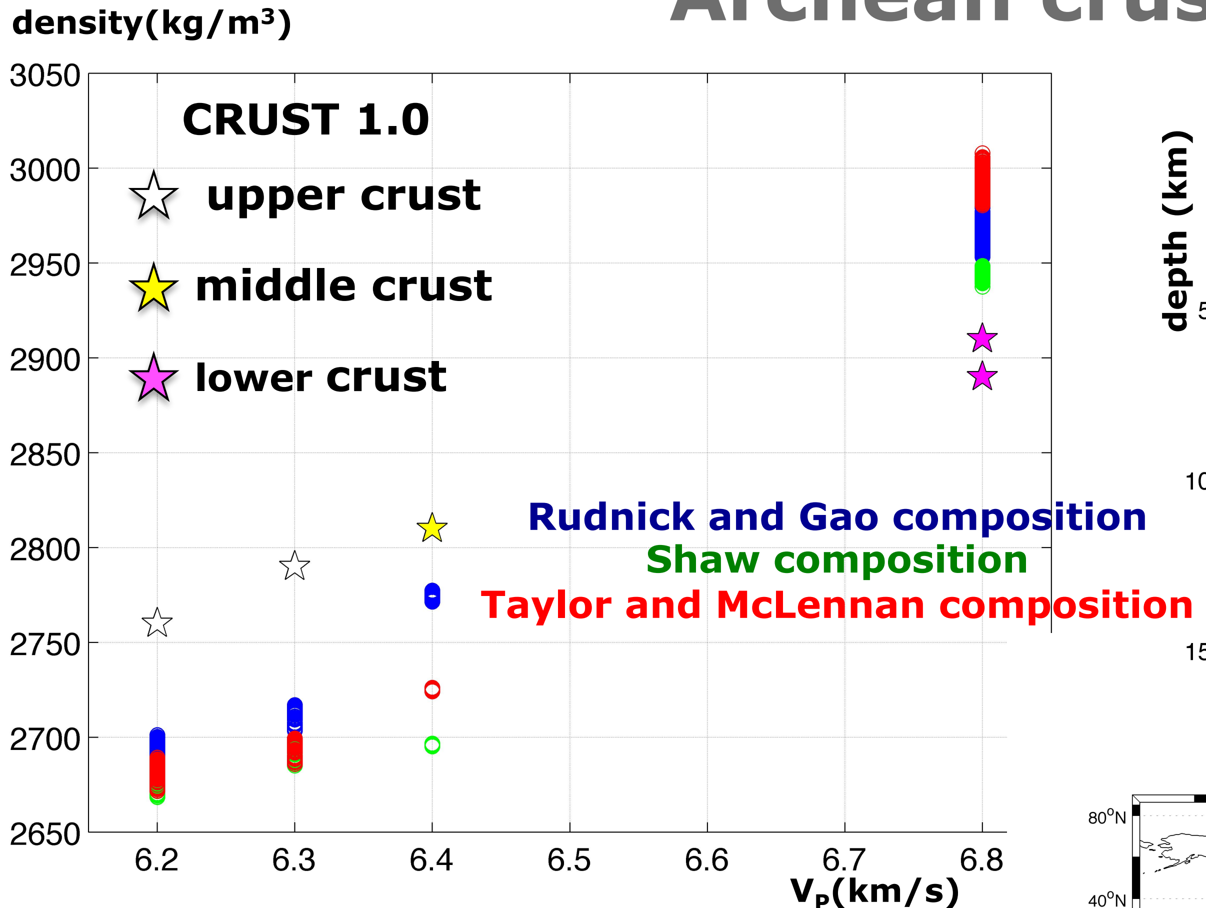
2 different approaches:

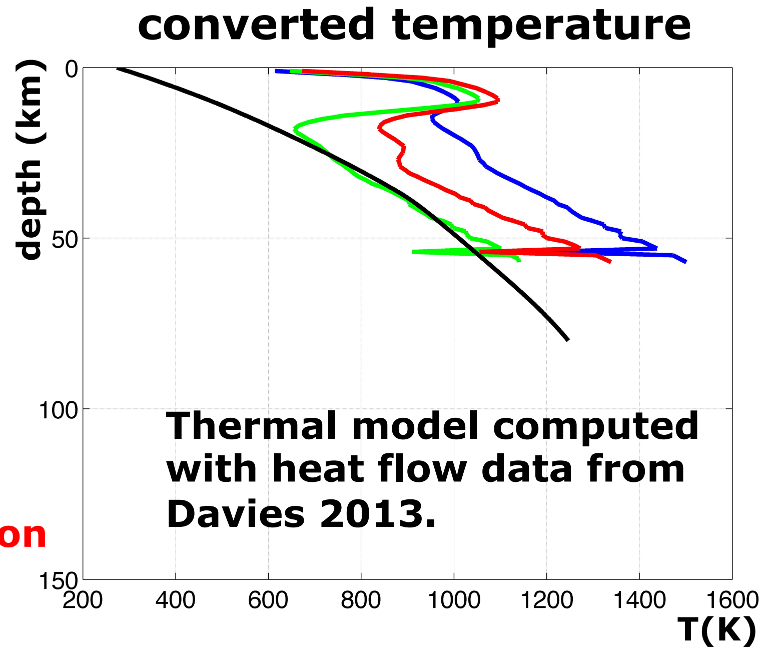
1) Convert CRUST 1.0 V_P model in a density, temperature and V_S model
2) Forward computation of V_P, V_S and density considering CRUST 1.0 thicknesses and a thermal model (from Davies 2013).

New models of crustal physical properties

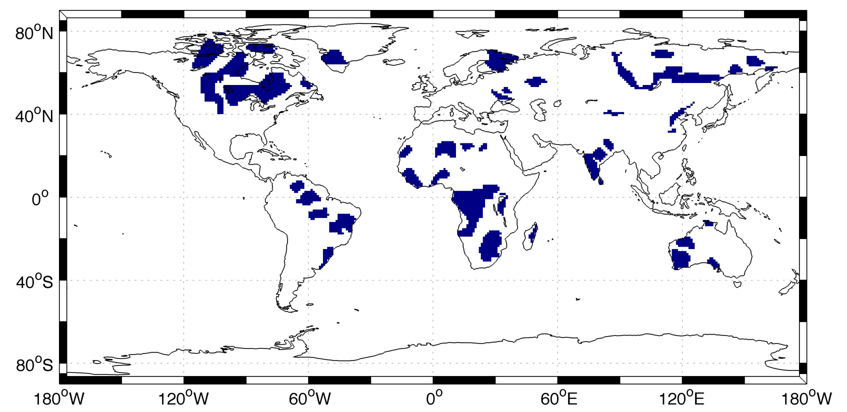
Converted crustal models

Archean crust

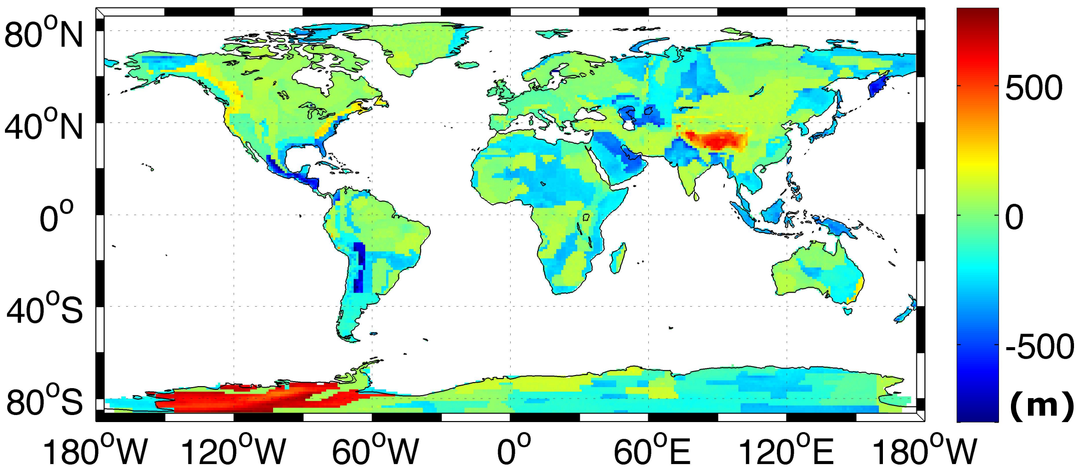




Archean crust



Effects on isostatic topography



Converted model **Rudnick and Gao dry composition**

–

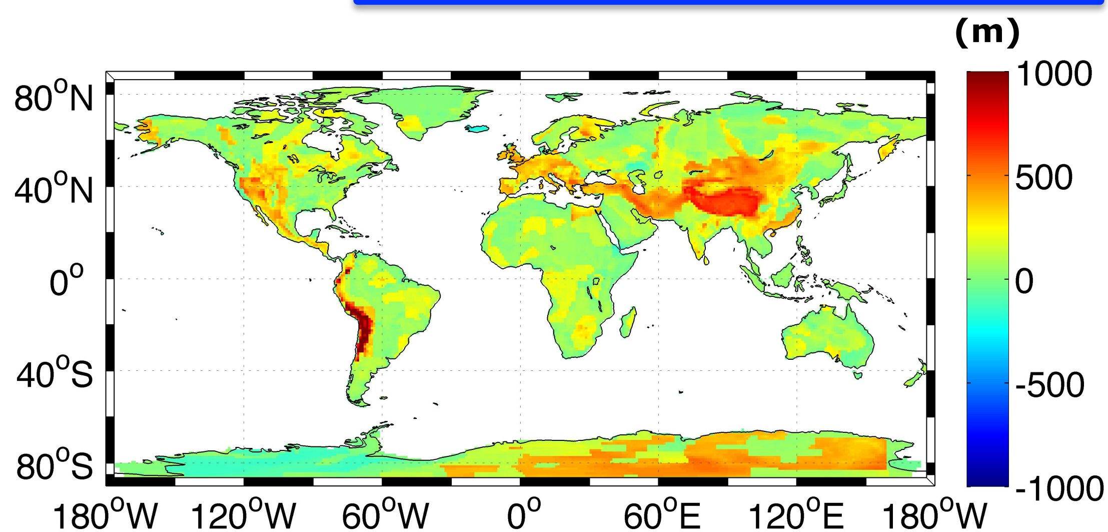
crust 1.0

Difference in isostatic topography computed considering models obtained using various compositions.

converted model **Shaw et al. dry composition**

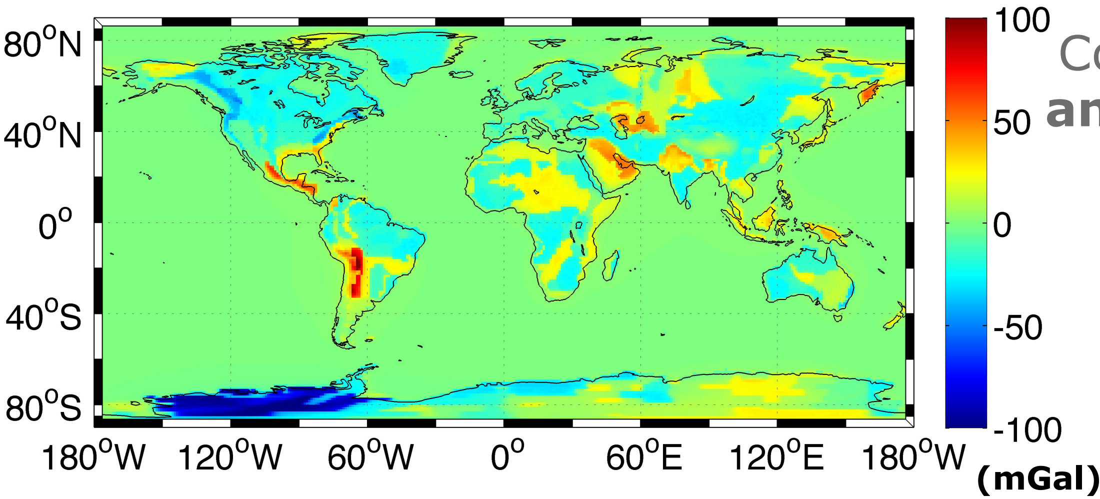
–

converted model **Rudnick and Gao dry composition**



Effects on gravitational field

Difference in the grav. fields computed with various crustal models



Converted model **Rudnick and Gao dry composition**

–

crust 1.0

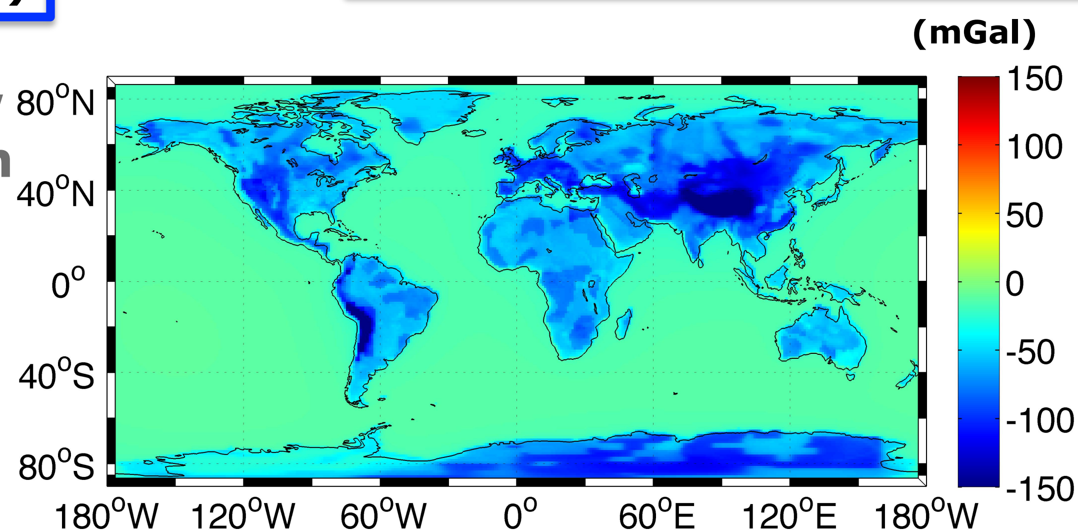
Difference in gravitational attraction computed considering models obtained using various compositions.

Gravity modeling performed with Tesseroids (Uieda, 2013).

converted model **Shaw et al. dry composition**

–

converted model **Rudnick and Gao dry composition**



Conclusions

- Variations in **major elements composition** have a strong impact on **crustal physical properties**, and our methodology is suitable to understand it properly.
- Crustal physical properties result to be extremely sensitive also to **small amounts of water** because of its effect in the **stable mineralogical assemblage**.
- Variations in density between the various models obtained considering **different compositions** and **amount of water** have a strong effect on the predicted **isostatic topography** and **gravitational fields**.

Thanks for your attention

more details, feedbacks, questions:

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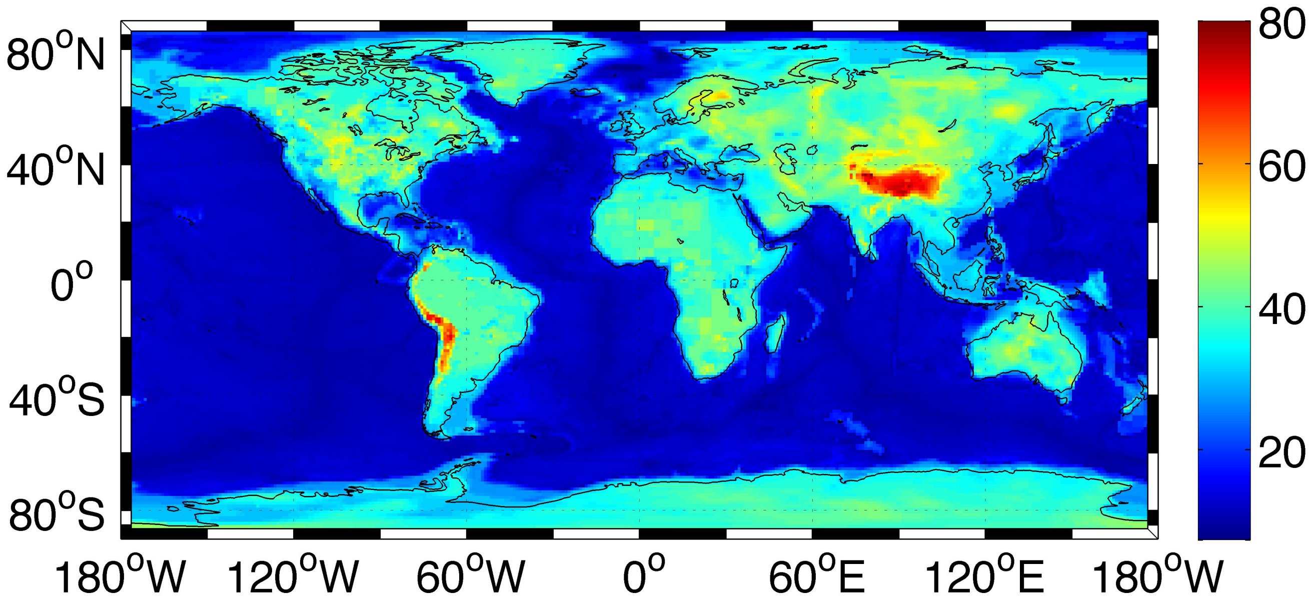
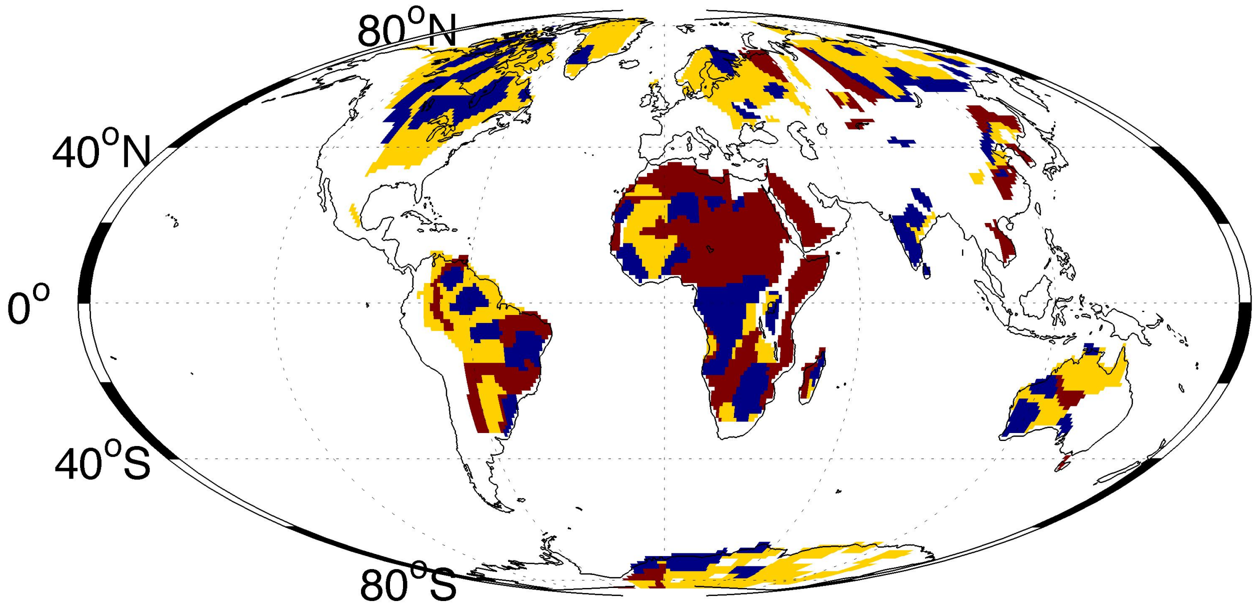
Some supporting material

CRUST 1.0 crustal thickness



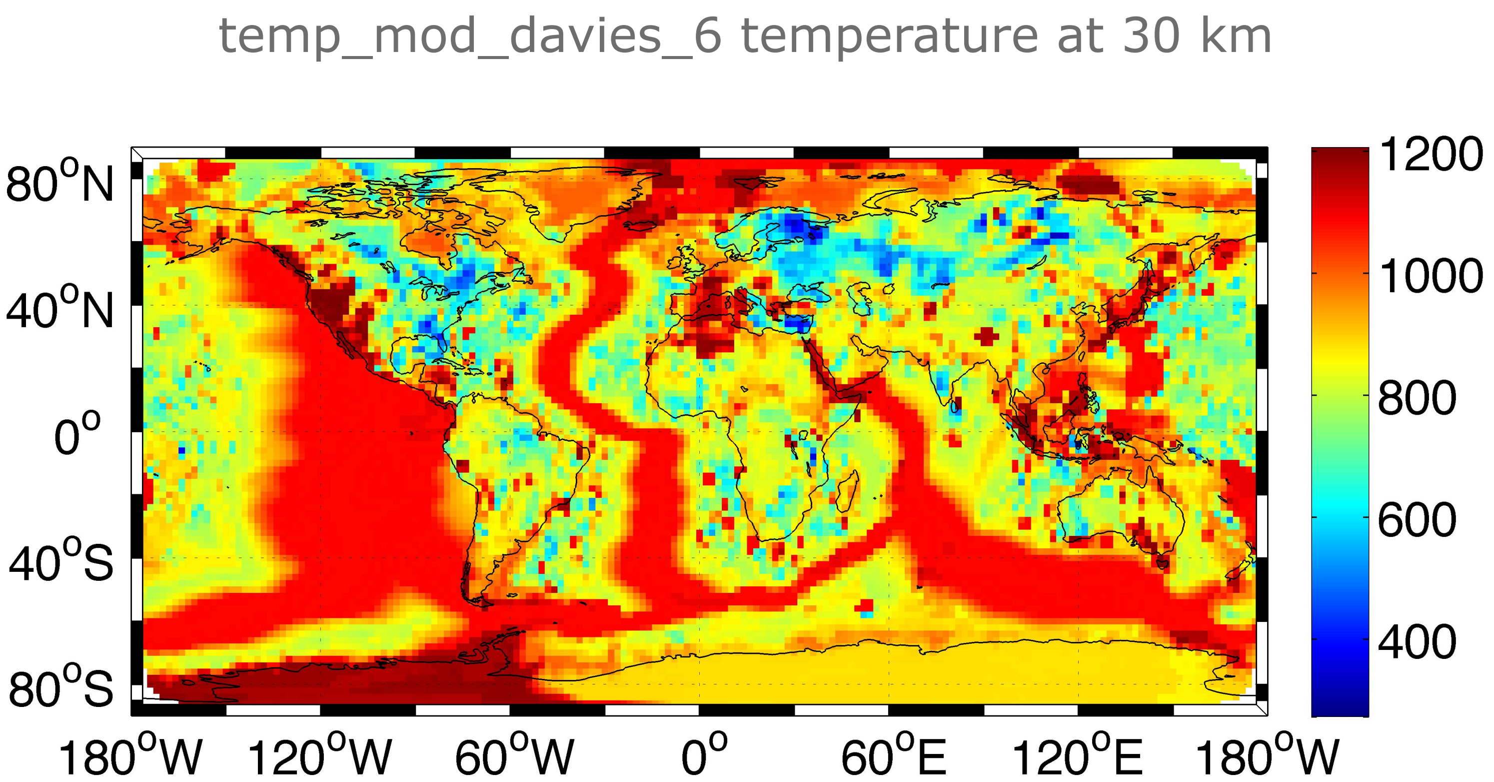
Some supporting material

CRUST 1.0 cratons



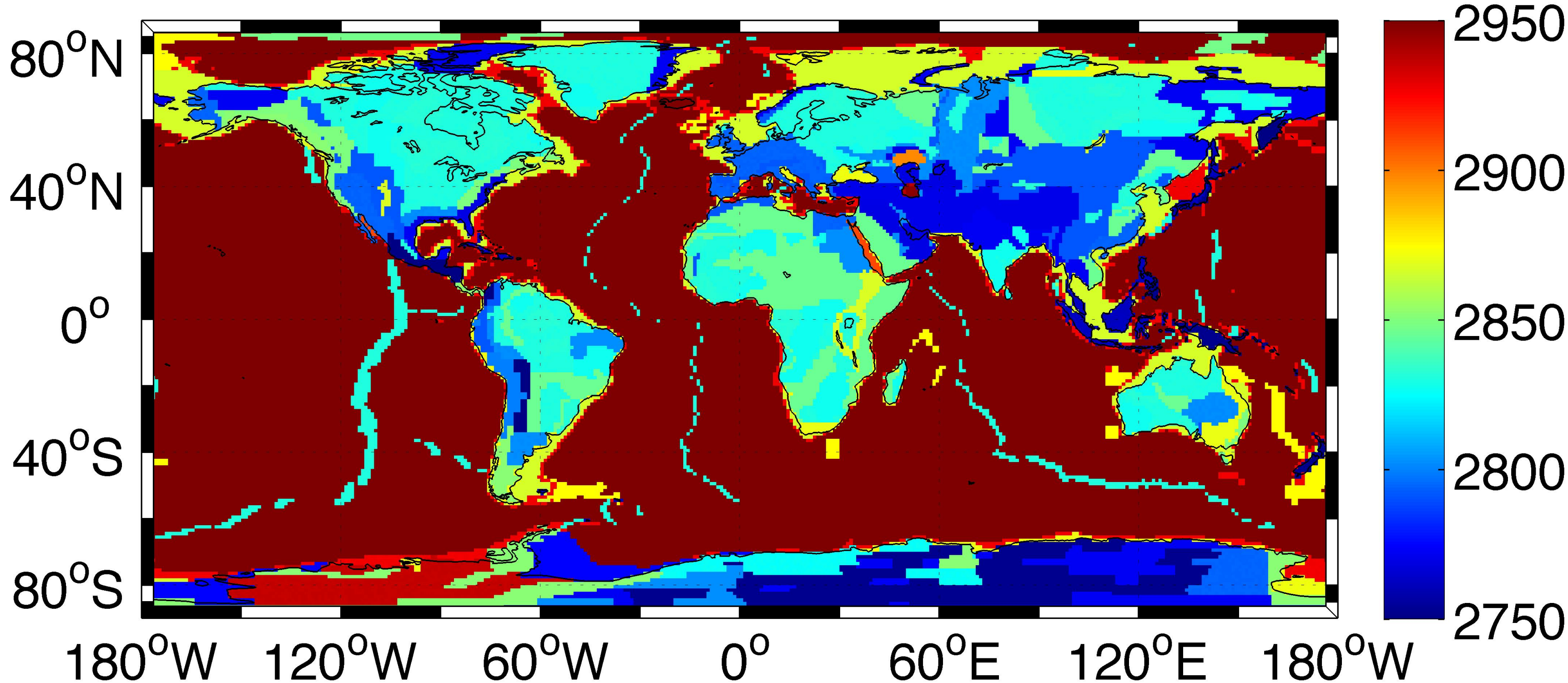
Archean **early-mid Prot.** **mid/late Prot.**

Some supporting material



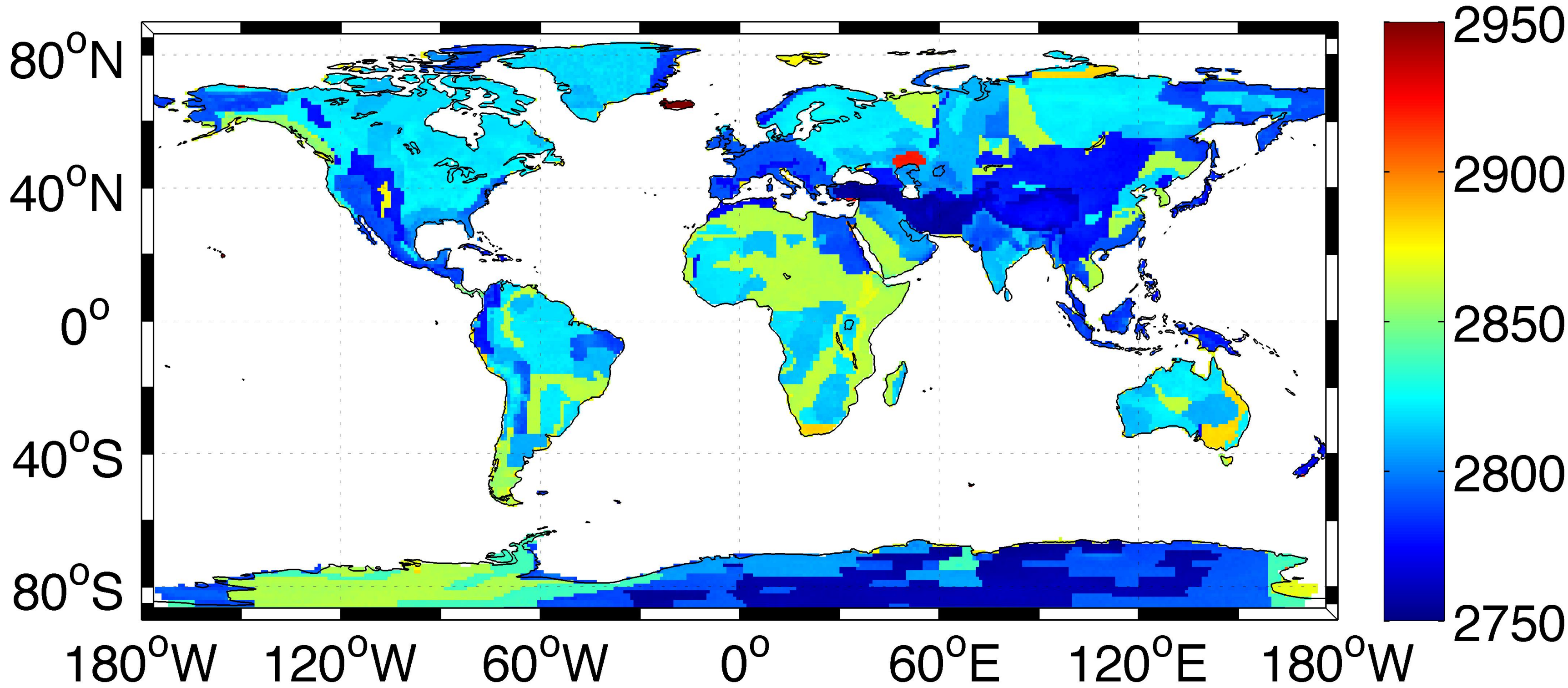
Some supporting material

average density model CRUST 1.0



Some supporting material

average density model conv. anhyd. RG



Some supporting material

difference
average density model conv. anhyd. RG
-
average density model crust 1.0