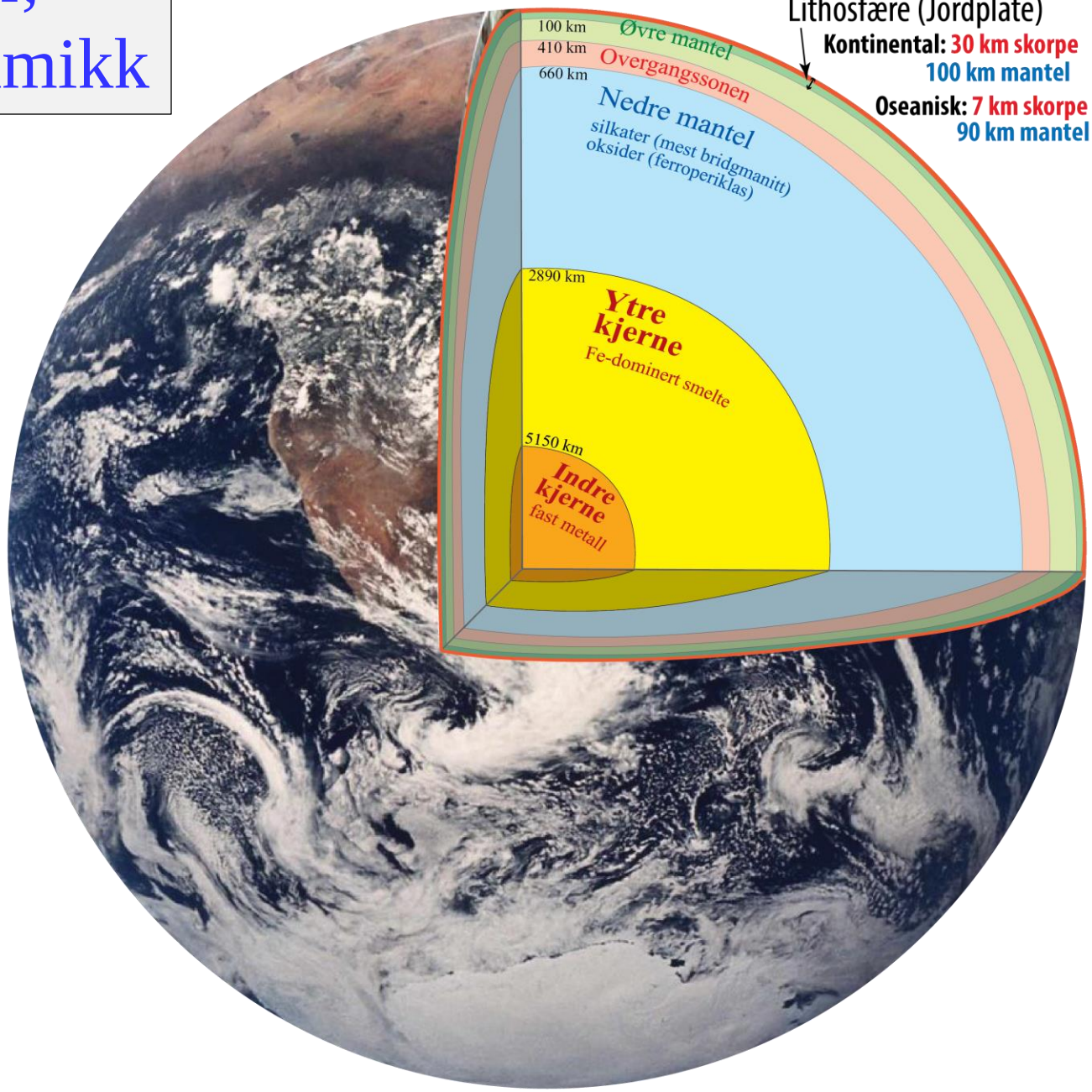
Jordas materialer, struktur og dynamikk



Jordas sammensetnnig

(bulk Jord, mantel, kjerne)

Planetære materialer

- mantel-prøver and basalts
- differensierte meteoritter (inkl. Måne, Mars og Vesta meteoritter)

Cosmochemistry

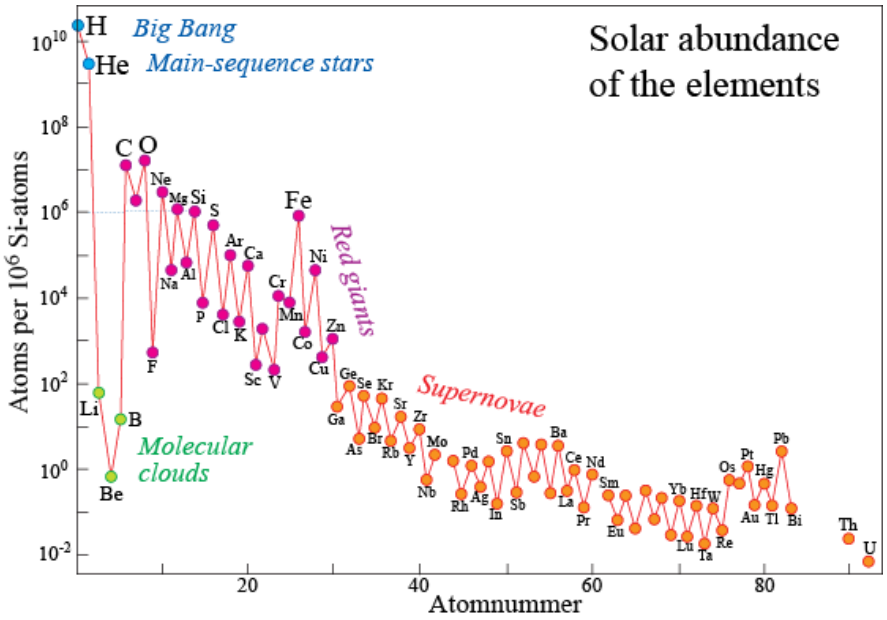
- Solas fotosfære
- primitive meteoritter

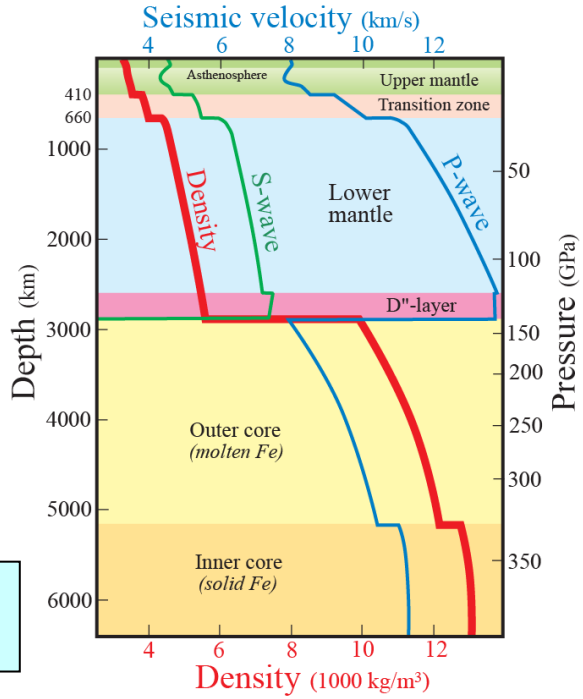
Eksperimentell geokjemi

Jordas struktur og mineralogi

Eksperimentell mineralfysikk

Seismologi

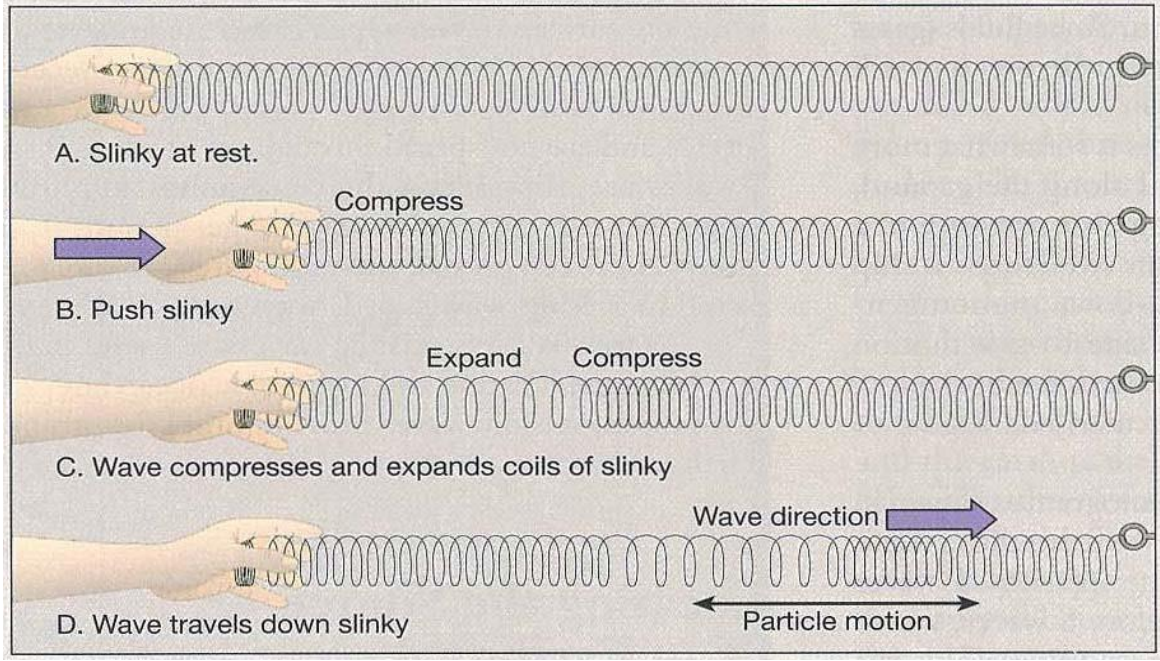




P-bølger

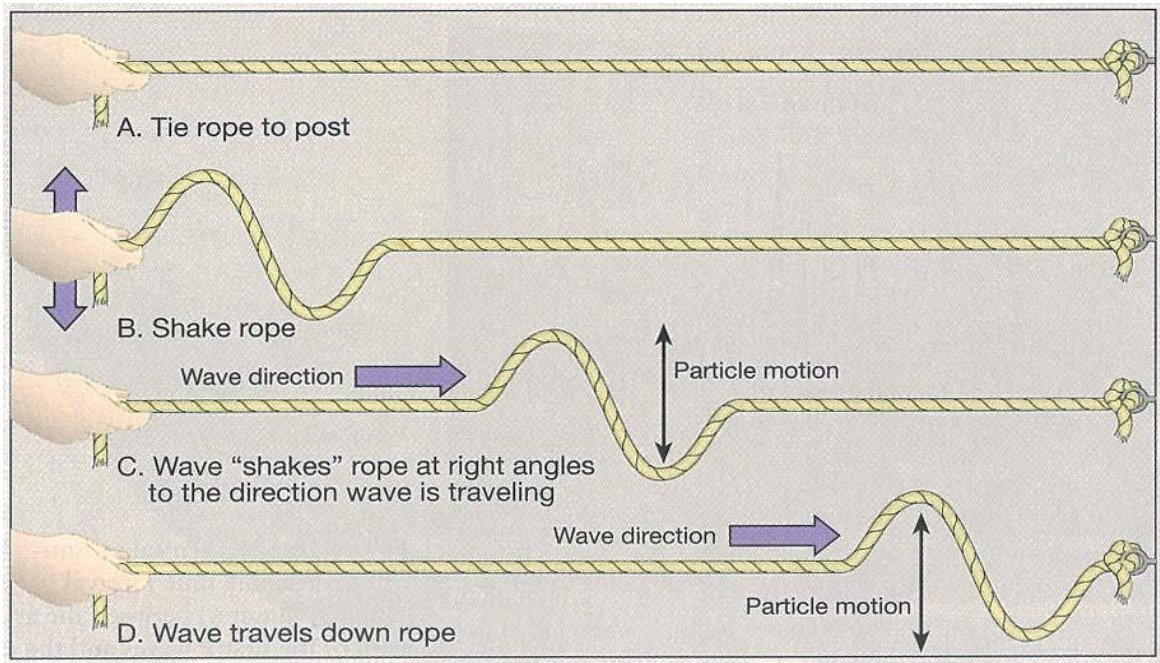
Trykkbølger, pressure waves

Eksempel: lydbølger i luft

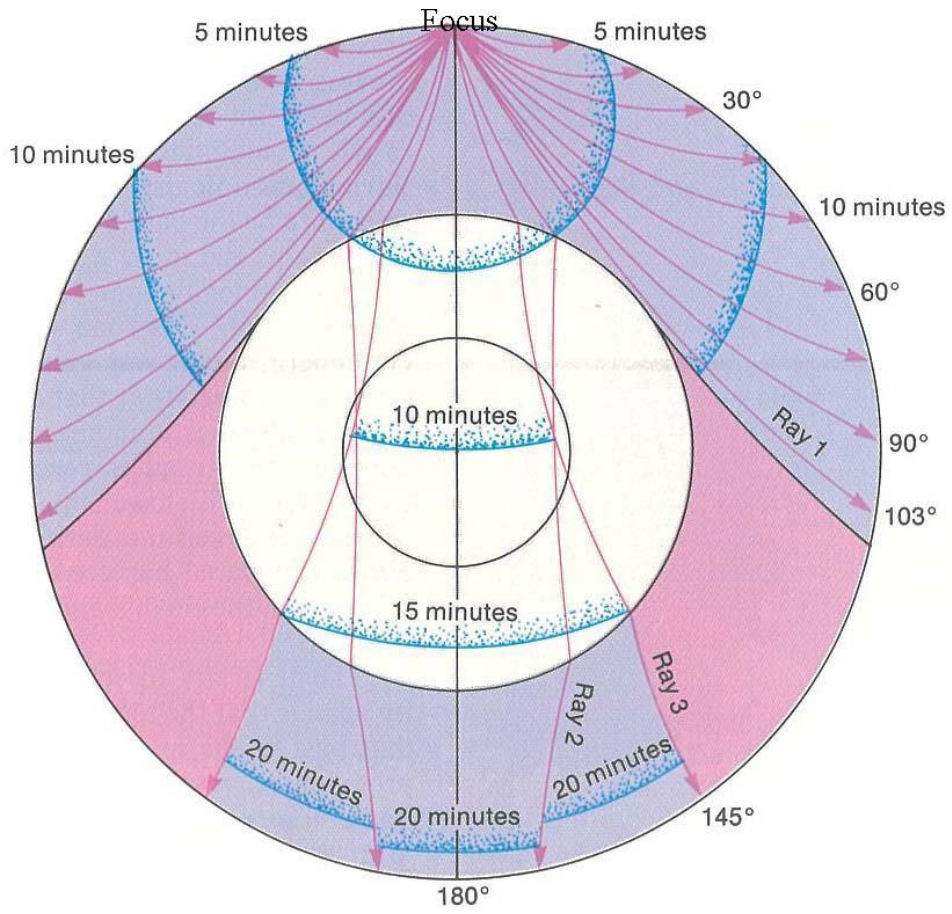


S-bølger

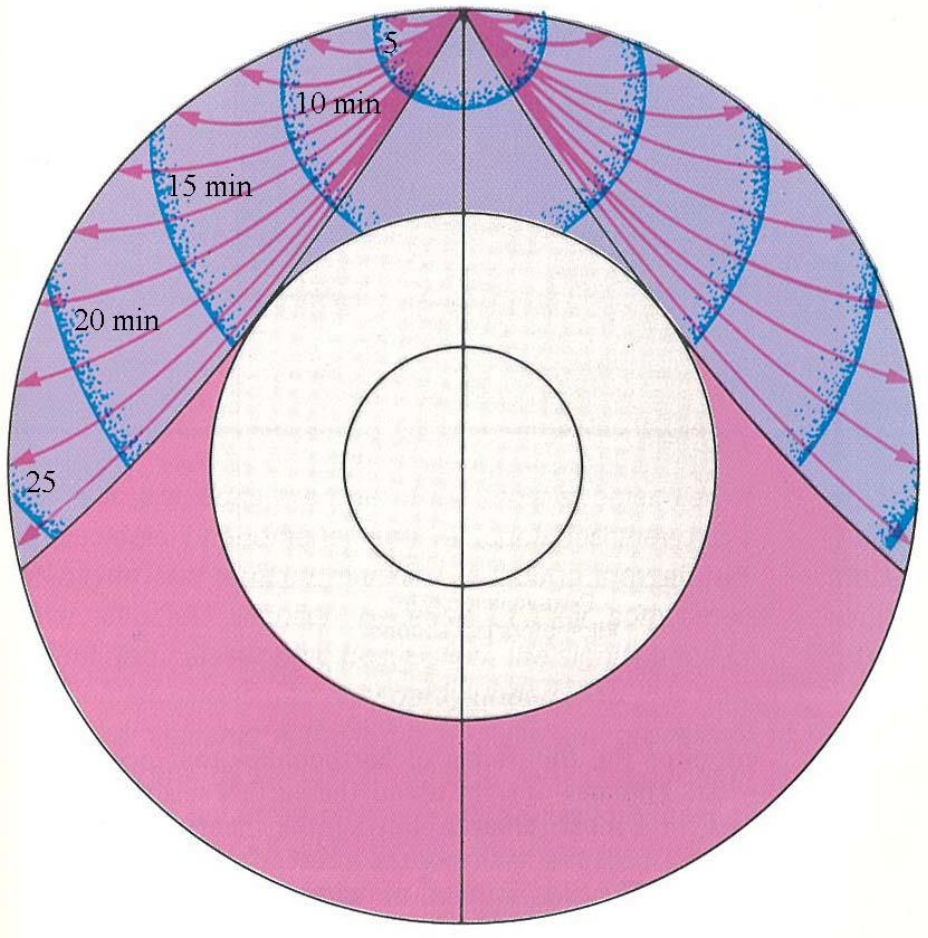
Skjærbølger, shear waves

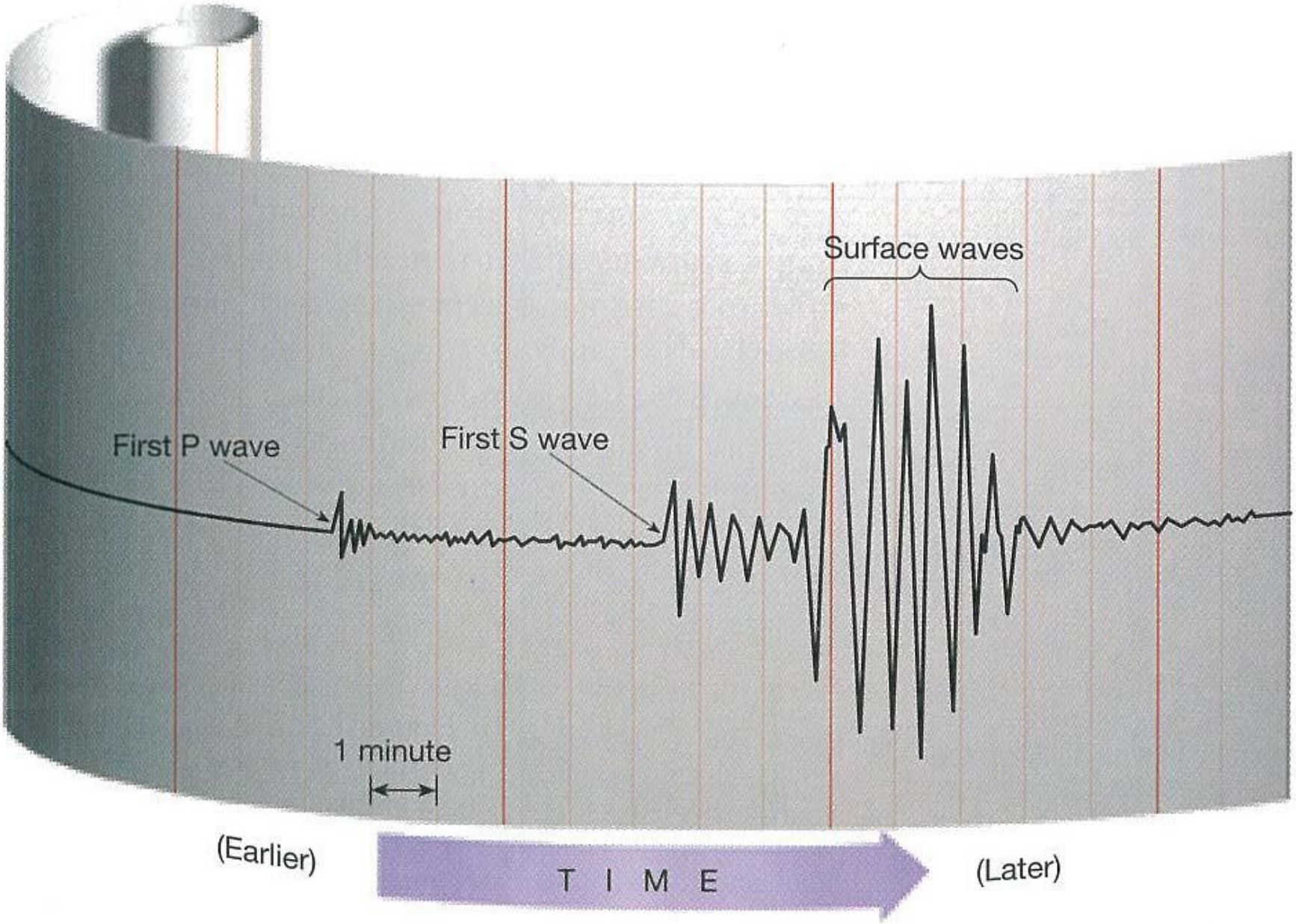


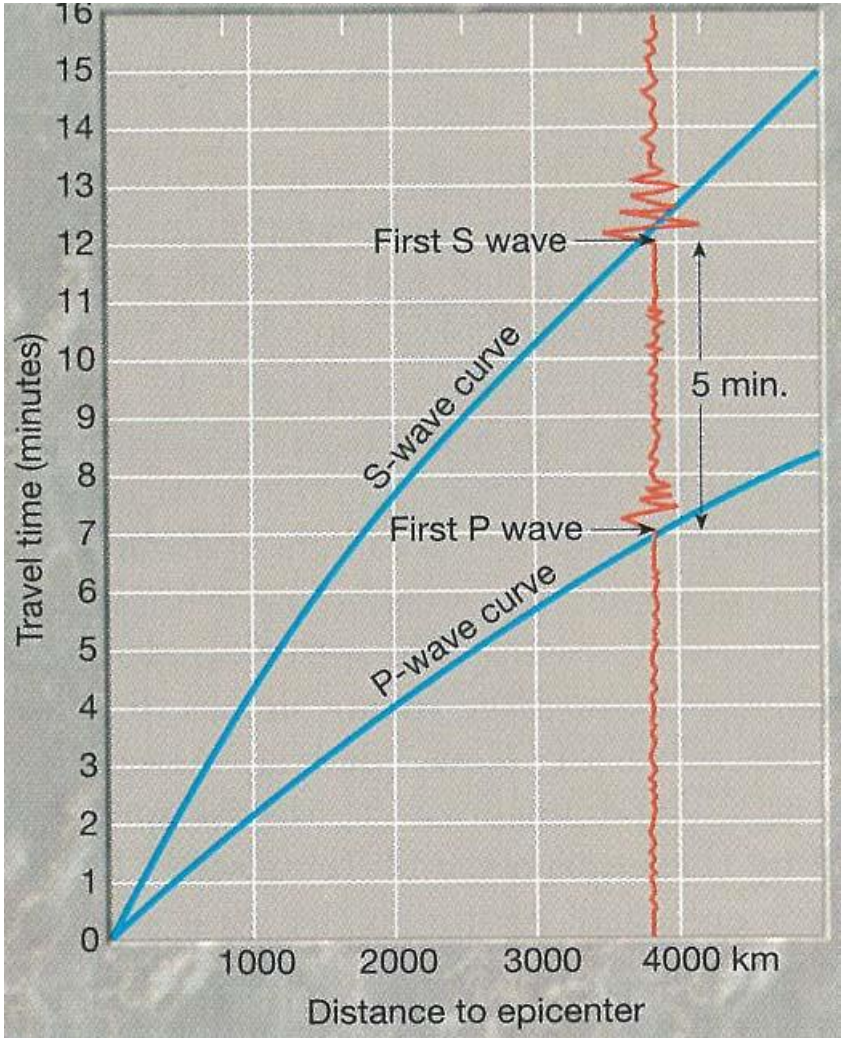
P-wave

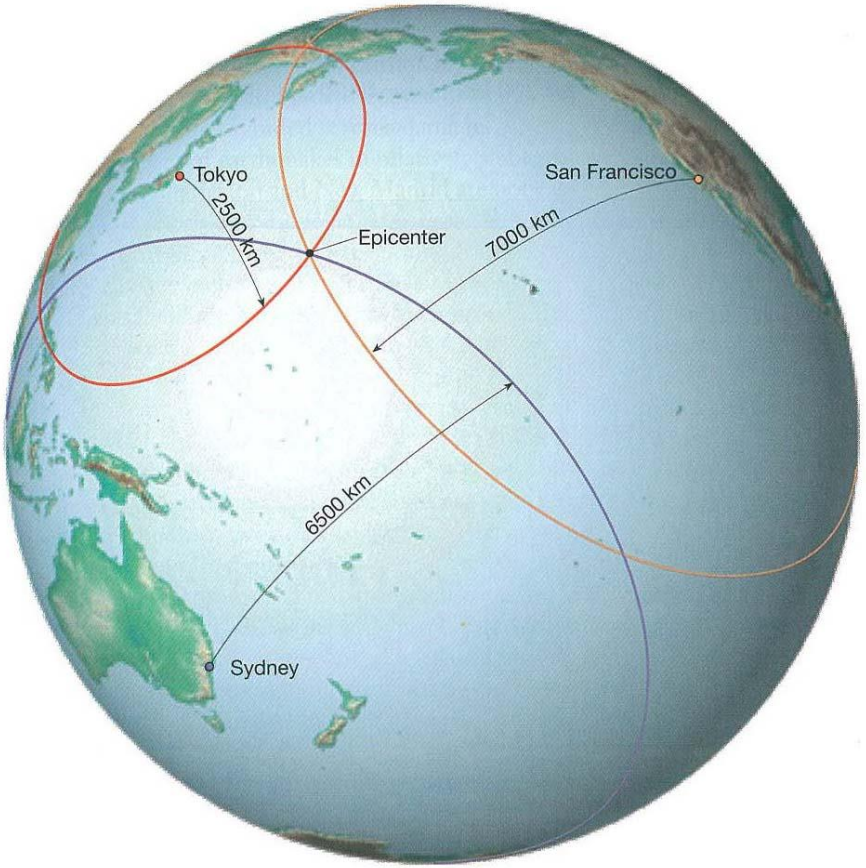

Focus
5 minutes
5 minutes
30°
10 minutes
10 minutes
60°
10 minutes
Ray 1
90°
103°
15 minutes
Ray 3
Ray 2
20 minutes
20 minutes
20 minutes
145°
180°

S-wave


5
10 min
15 min
20 min
25

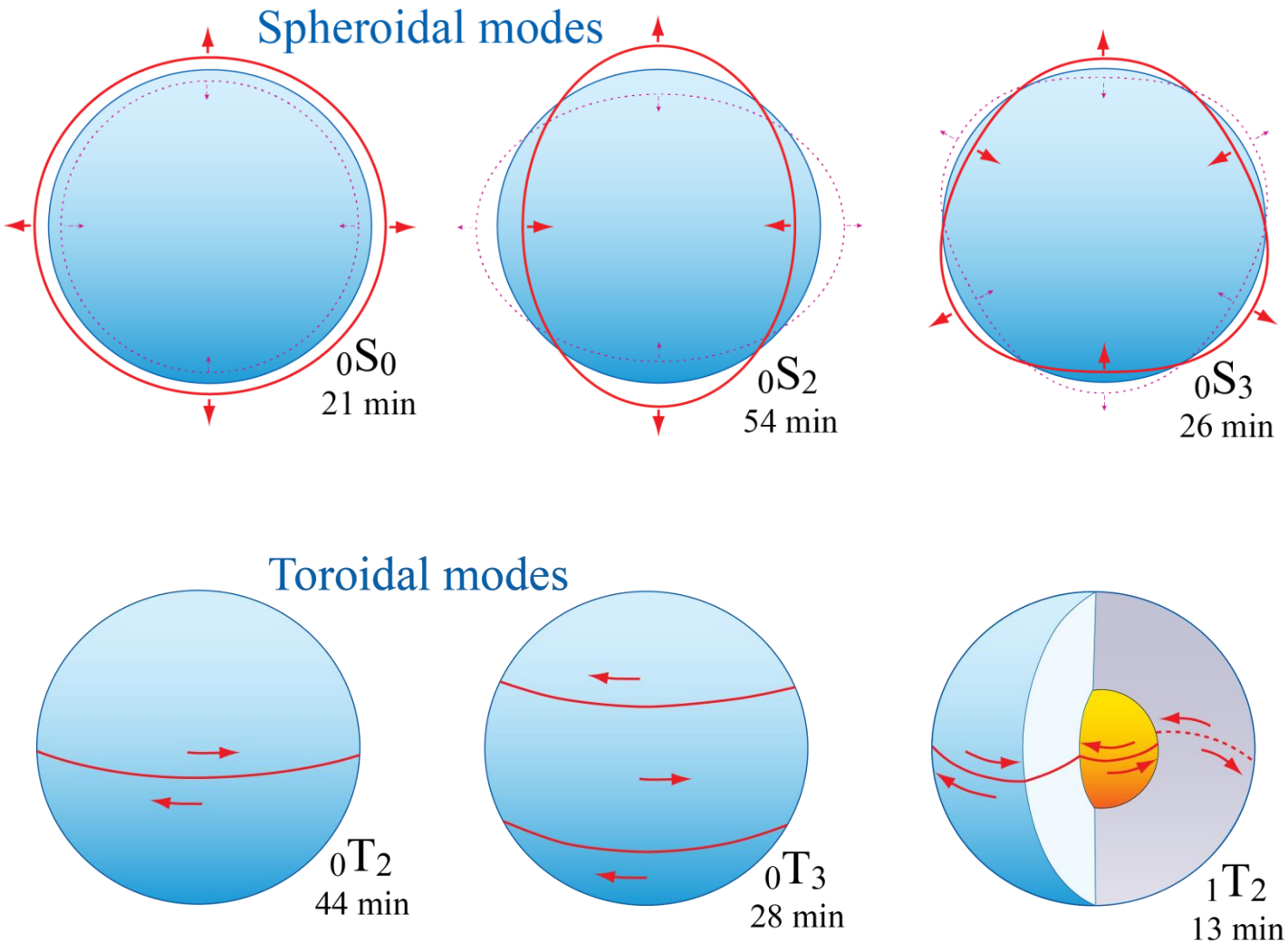

Surface waves
First P wave
First S wave
1 minute
(Earlier)
T I M E
(Later)


Travel time (minutes)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
First S wave
S-wave curve
5 min.
First P wave
P-wave curve
1000
2000
3000
4000 km
Distance to epicenter


Tokyo
San Francisco
2500 km
Epicenter
7000 km
6500 km
Sydney

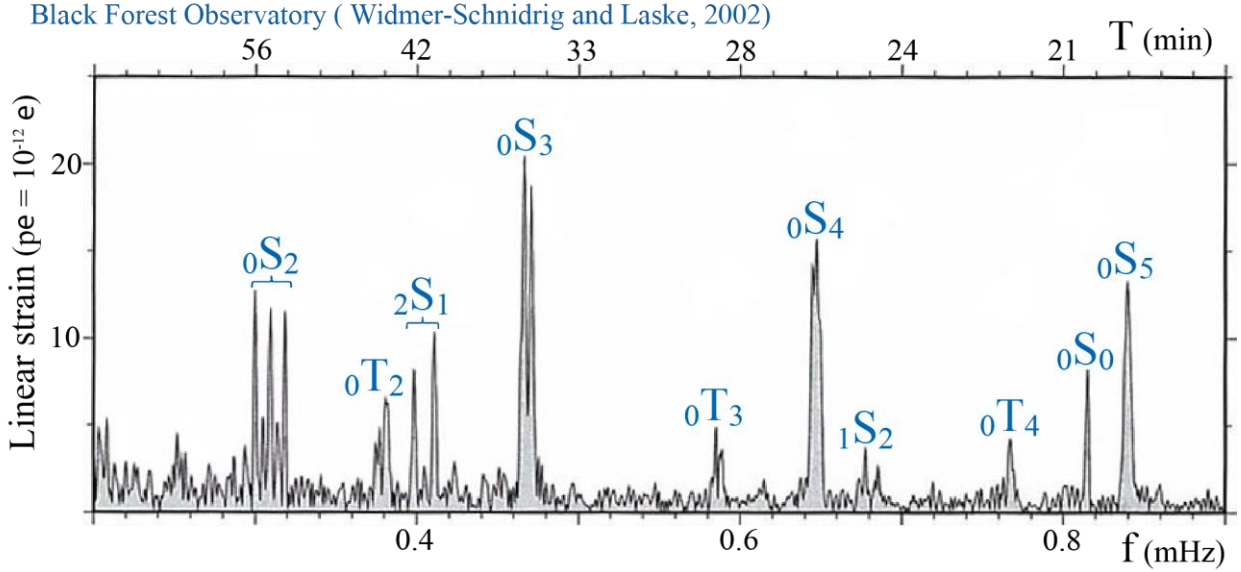
inger (normal modes)

Globale, lav-frekvente vibratsjoner av **hele** Jorda



Normal mode spectrum, 2004 Sumatra-Andaman EQ.

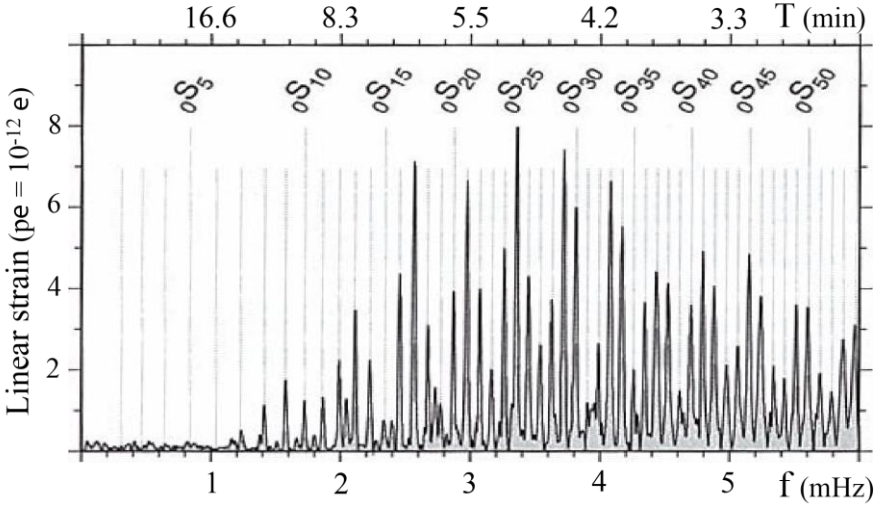
Black Forest Observatory (Widmer-Schnidrig and Laske, 2002)

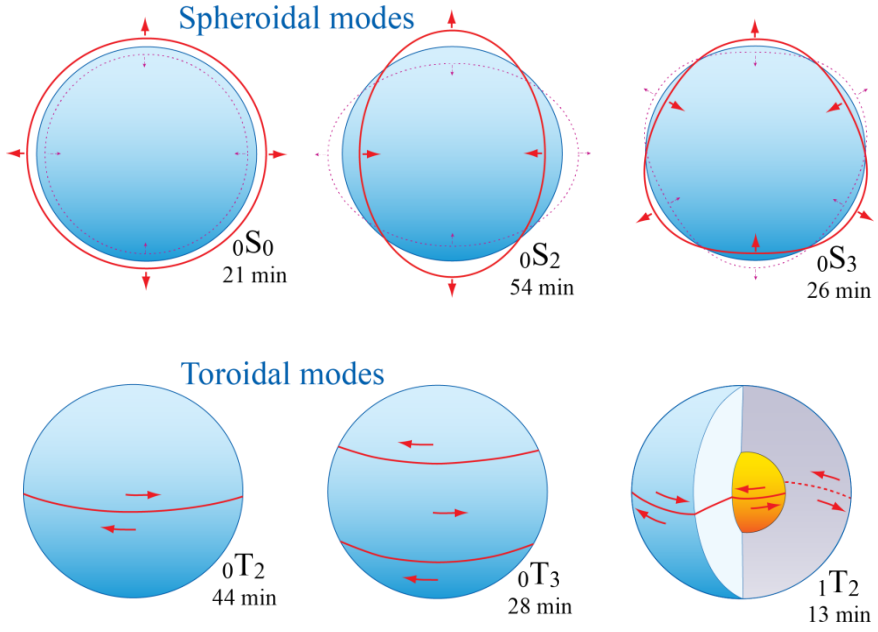


1 mHz =
1cycle / 17min

Normal mode spectrum, M_S-6.7 EQ south of Australia.

Black Forest Observatory (Widmer-Schnidrig and Laske, 2002)





Seismiske hastigheter $\leftrightarrow$ mineralfysiske egenskaper

Trykkstivhet (bulk modulus): K

Skjærstivhet (skjær-modulus): G

$G/\rho = v_s^2$

$\mathbf{K}/\rho = v_p^2 - 4/3 v_s^2 = v_\Phi^2$

v_Φ: "bulk lydhastighet", "bulk sound velocity"

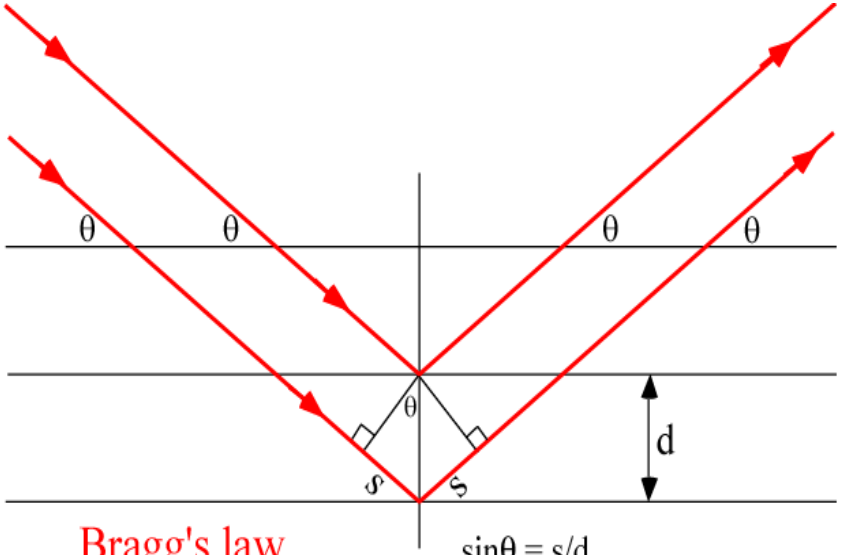
$v_s^2 = \mathbf{G}/\rho$

$v_p^2 = (\mathbf{K} + 4/3 * \mathbf{G})/\rho$

Vi kan enkelt

bestemme enhetscellens V og tetthet (ρ) som funksjon av trykket (p)

Røntgendiffraksjon av mineralene under høyt trykk ved hjelp av høy-intensitets synkrotron-stråling



Bragg's law

Positive interference:

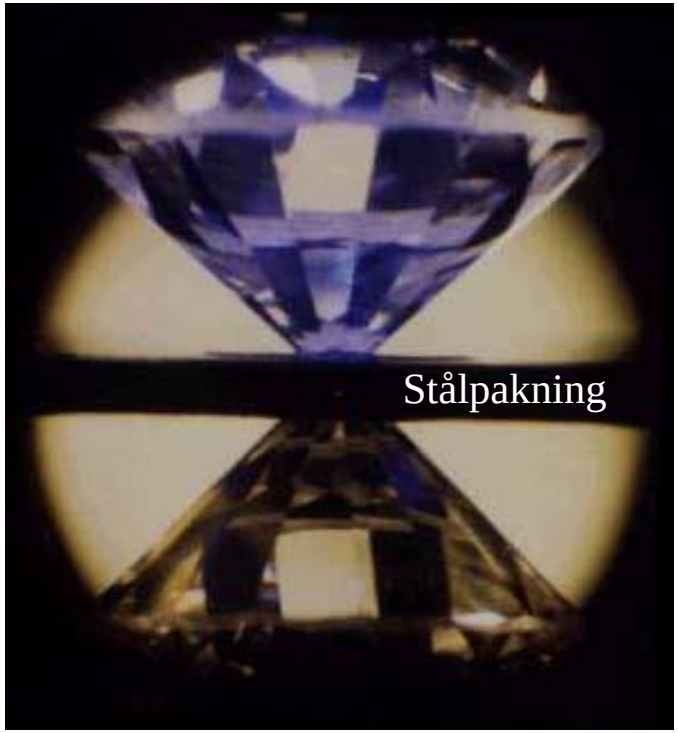
$2s = n\lambda$

$2d \sin\theta = n\lambda$

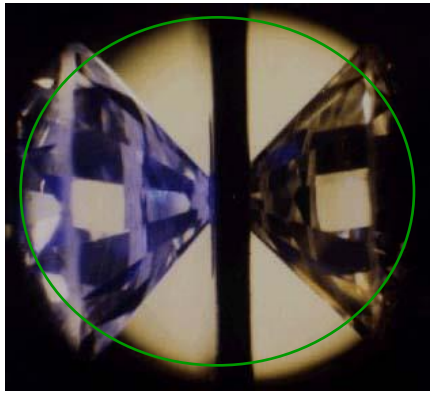
$\sin\theta = s/d$

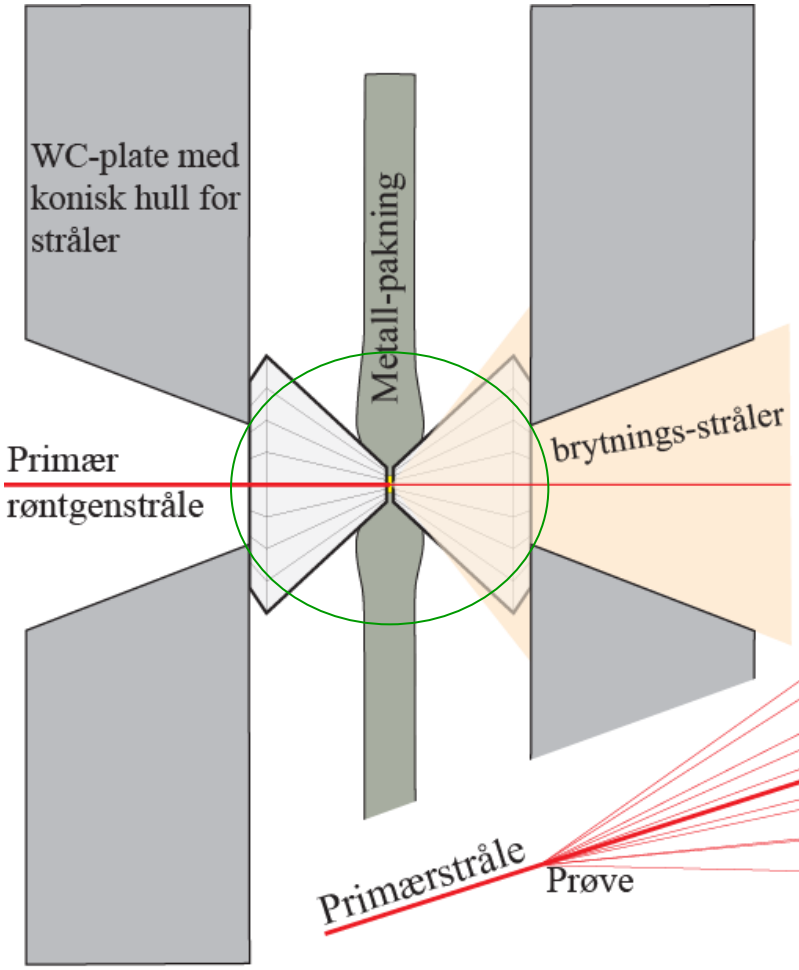
$s = d \sin\theta$

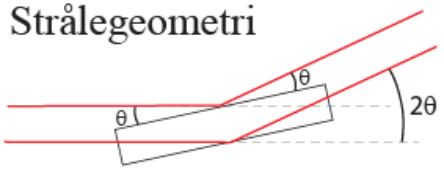
Diamantcellen



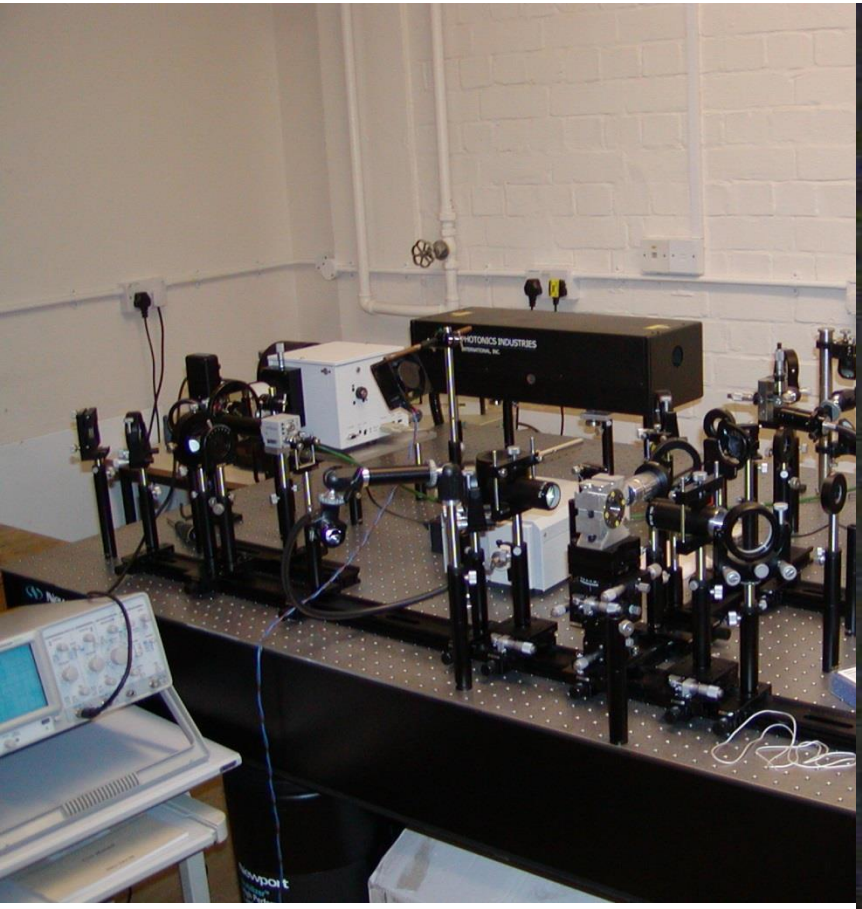
3 cm

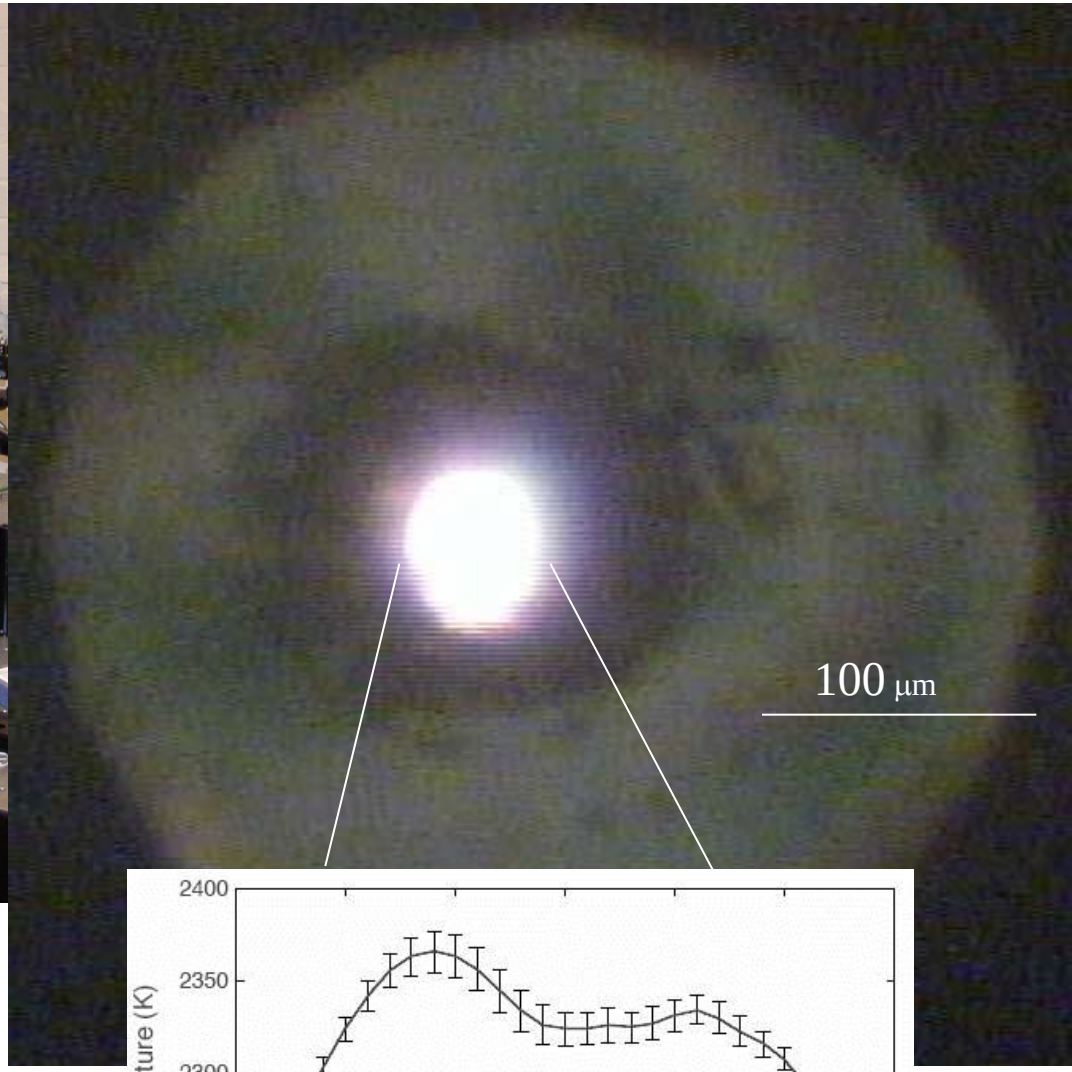



WC-plate med konisk hull for stråler
Metall-pakning
Primær røntgenstråle
brytnings-stråler
Primærstråle
Prøve
Primærstråle-skjold
Billedplate


Strålegeometri
θ
θ
2θ

Laser-varming av prøve i diamantcelle, Univ. of Bristol





High-pressure adjustments of crystal structures:

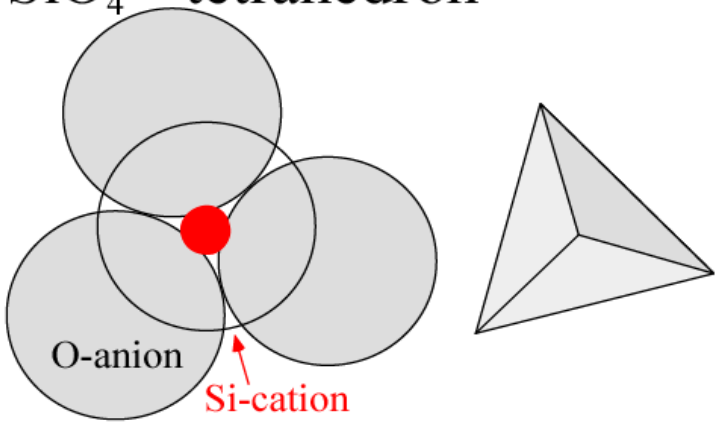
- anions compressed more than cations – decreasing size difference

➡ **may** lead to increasing coordination number

Building blocks for silicates

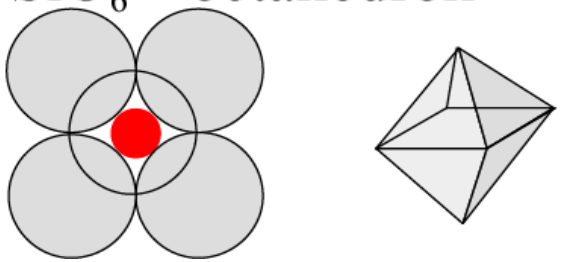
Crust and upper mantle (low p)

SiO_4^{4+}-tetrahedron



Lower mantle (high p)

SiO_6^{8+}-octahedron

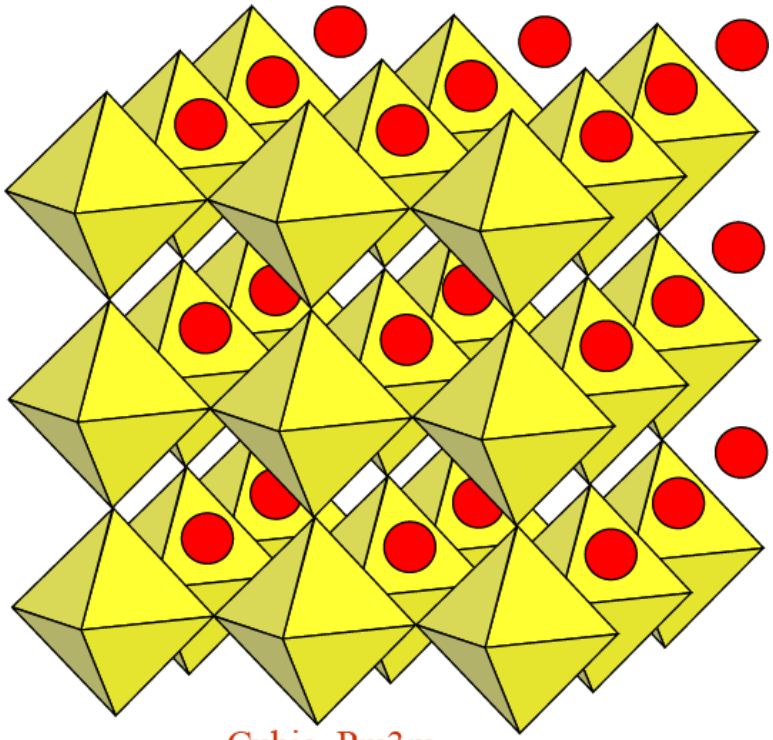


Perovskite-structured minerals: high coordination numbers - **high entropy**

The perovskite structure: $A^{[12\text{-}8]}\ B^{[6]}\ O_3$

"Ideal", undistorted structure with larger divalent cation (Ca) in 12-coordination

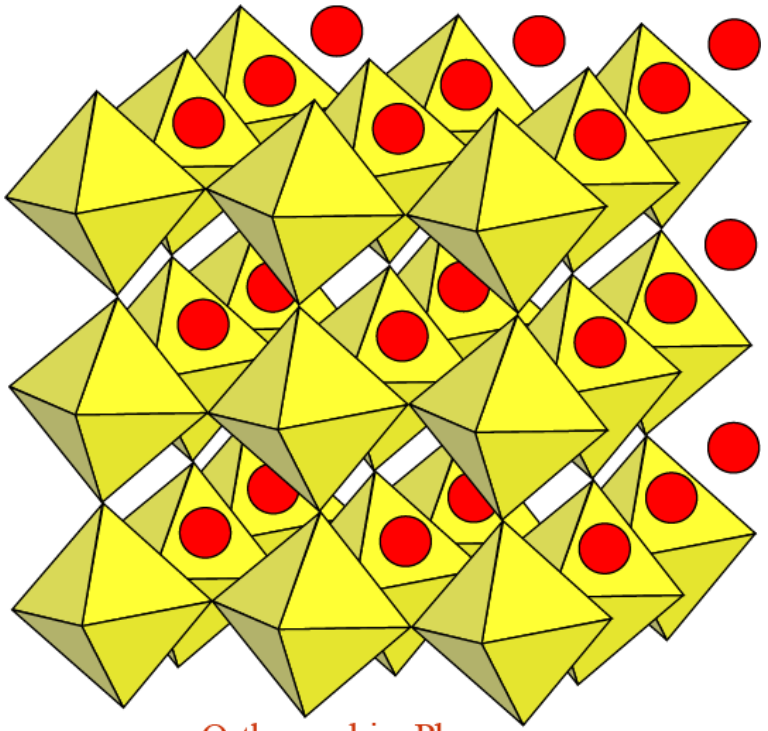
$Ca^{[12]}\ Si^{[6]}\ O_3$



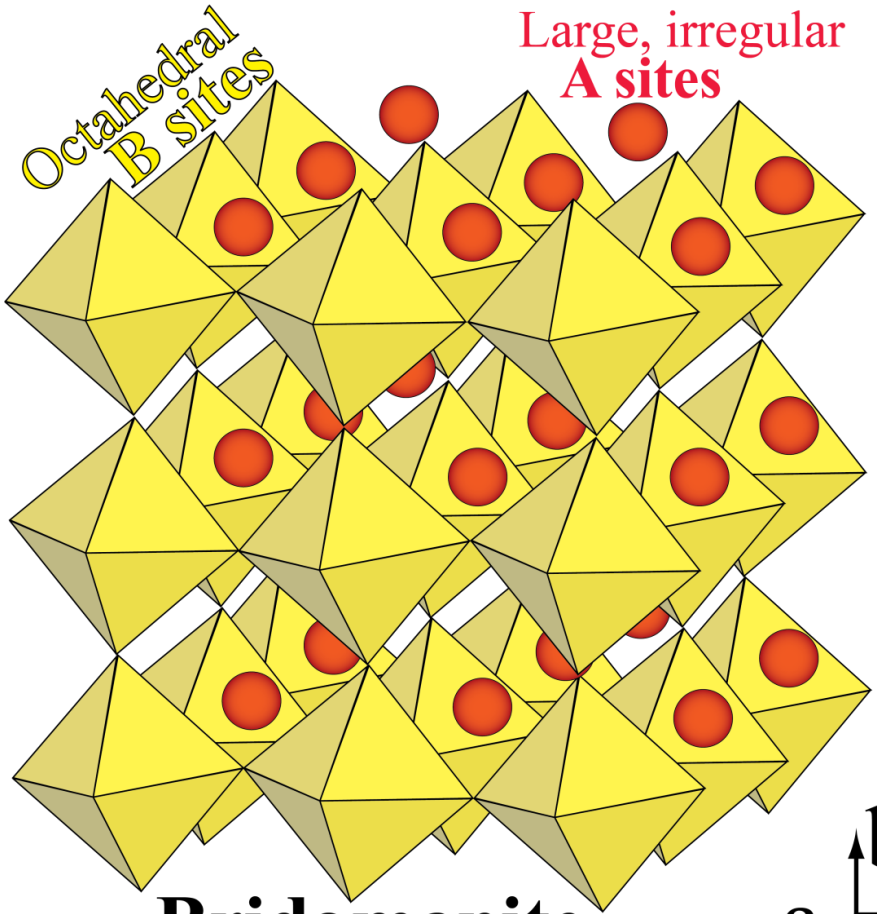
Cubic, Pm3m

Distorted structure with smaller divalent cations (Mg, Fe) i 8-coordination

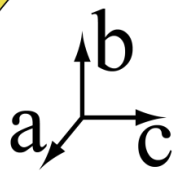
$Mg^{[8]}\ Si^{[6]}\ O_3$

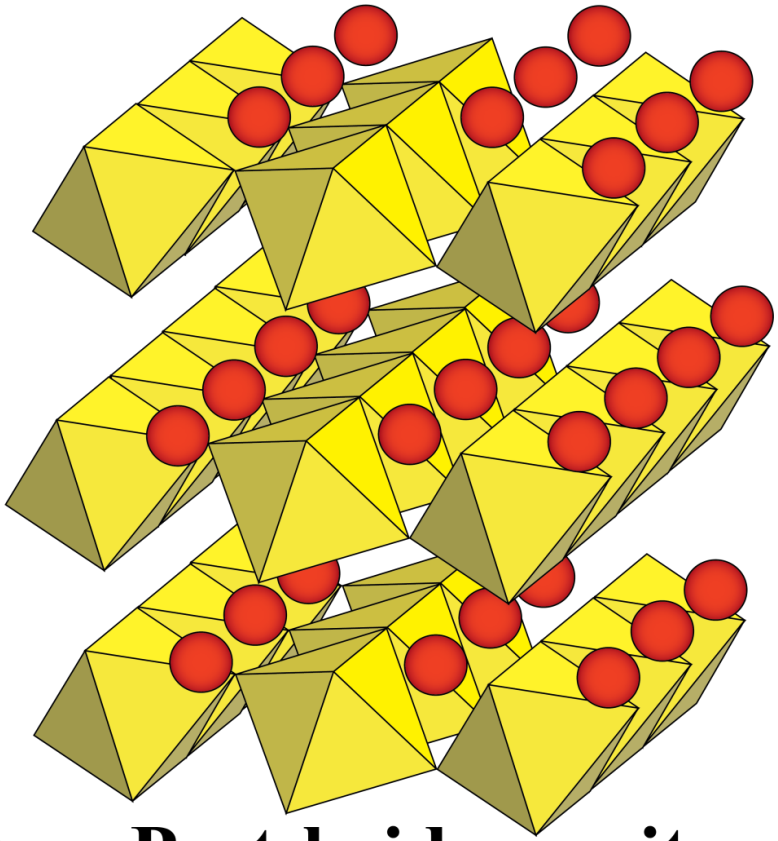


Orthorombic, Pbnm



Bridgmanite





Post-bridgmanite

Orthorombic, Pbnm

Higher entropy and slightly lower density than post-bm

Corner-linked O-octahedra in all three directions

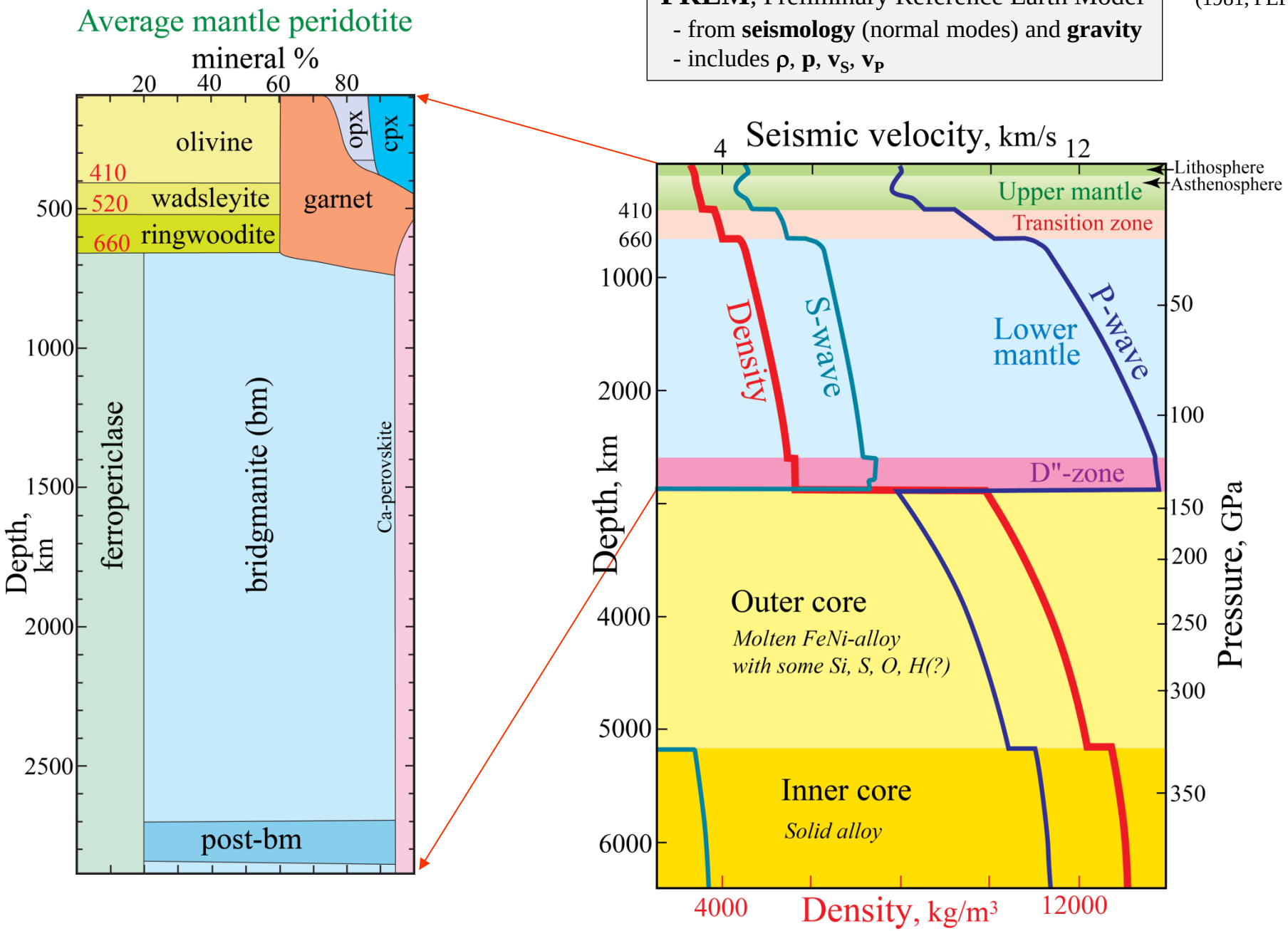
Orthorombic, Cmcm

- edge-linked O-octahedra along the a-axis
- a-c sheet-like units with a more compressible b-axis

First-order Earth structure

PREM, Preliminary Reference Earth Model
- from **seismology** (normal modes) and **gravity**
- includes **ρ**, **p**, $\mathbf{v_S}$, $\mathbf{v_P}$

Dziewonski & Anderson (1981, PEPI)

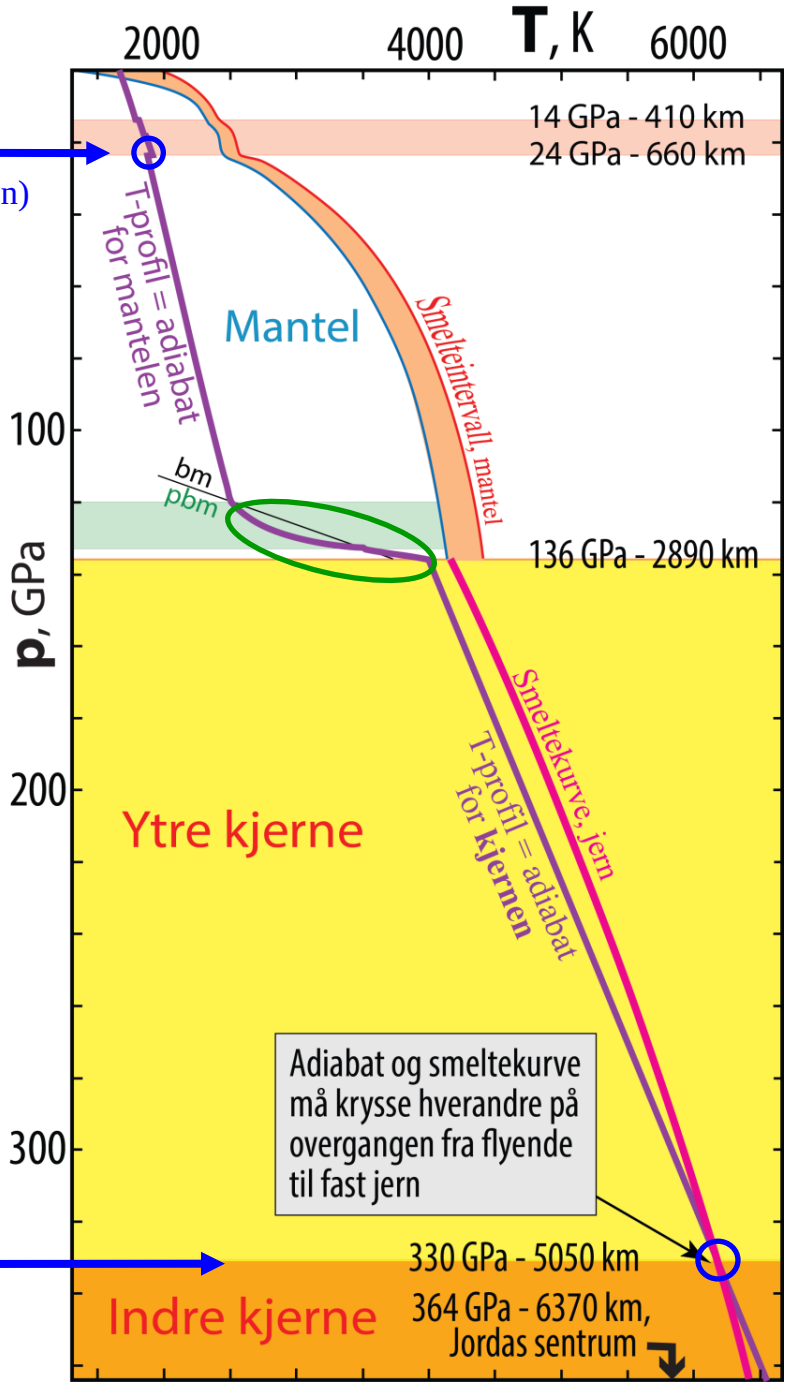


First-order constraints on temperature

660 km: Reaksjonen **ringwooditt = bridgmanitt+ferroperiklas**
ved 24 GPa, 1900 K (endotermisk faseovergang: adiabatisk T-reduksjon)

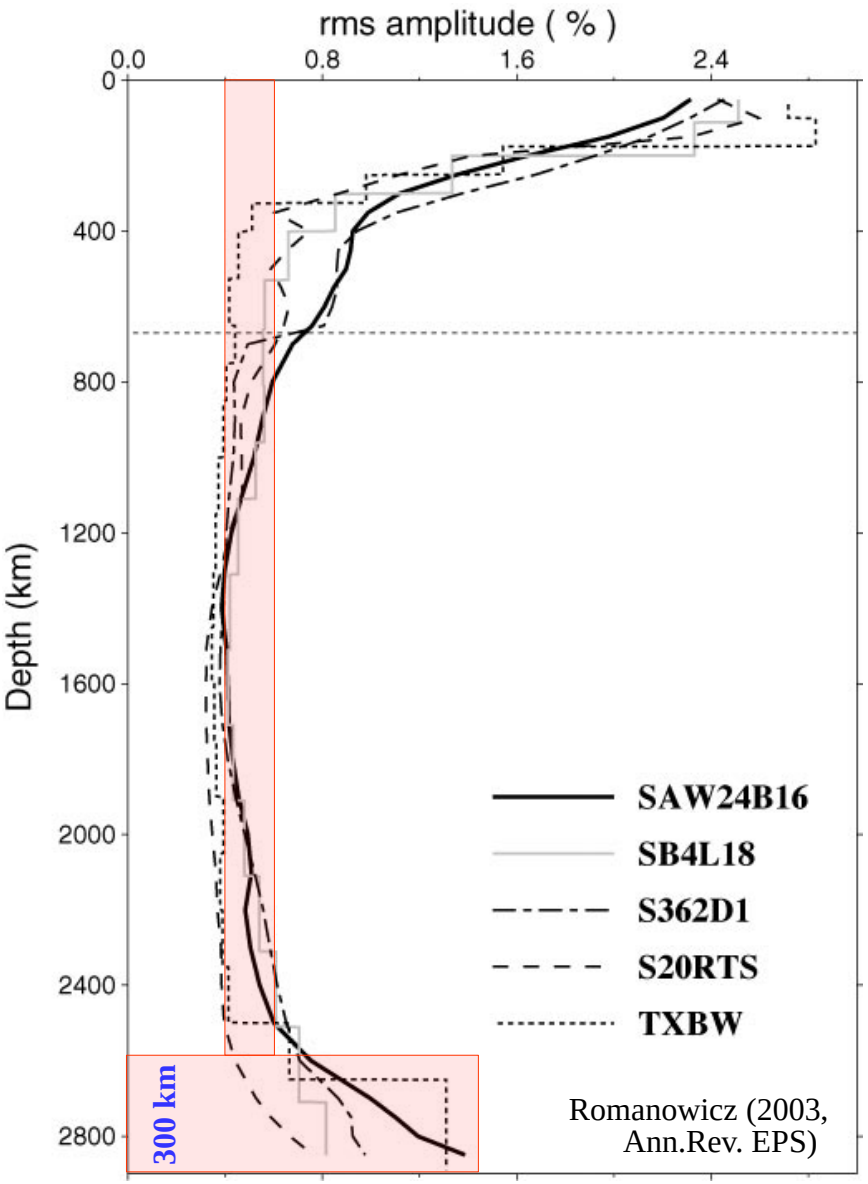
CMB: extreme thermal boundary layer !
2500 - 3800 K ! (ΔT: 1300K)

Indre-ytre kjernegrensen, 330 GPa / 5150 km:
Smelte-temperaturen til FeNi-legering

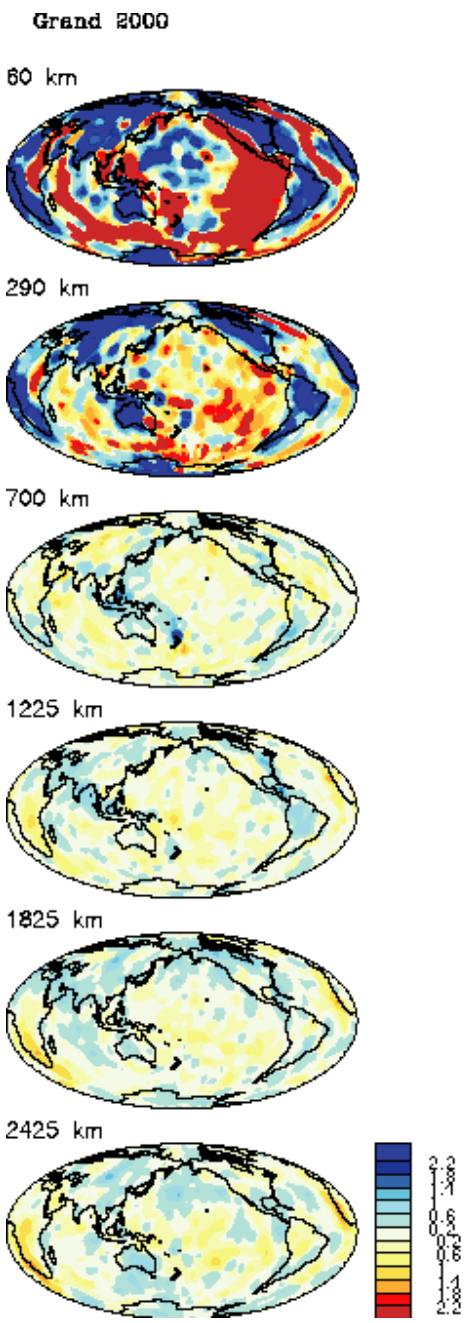


Seismic tomography models

Large v_S-amplitudes at the **top** and **bottom** of the mantle

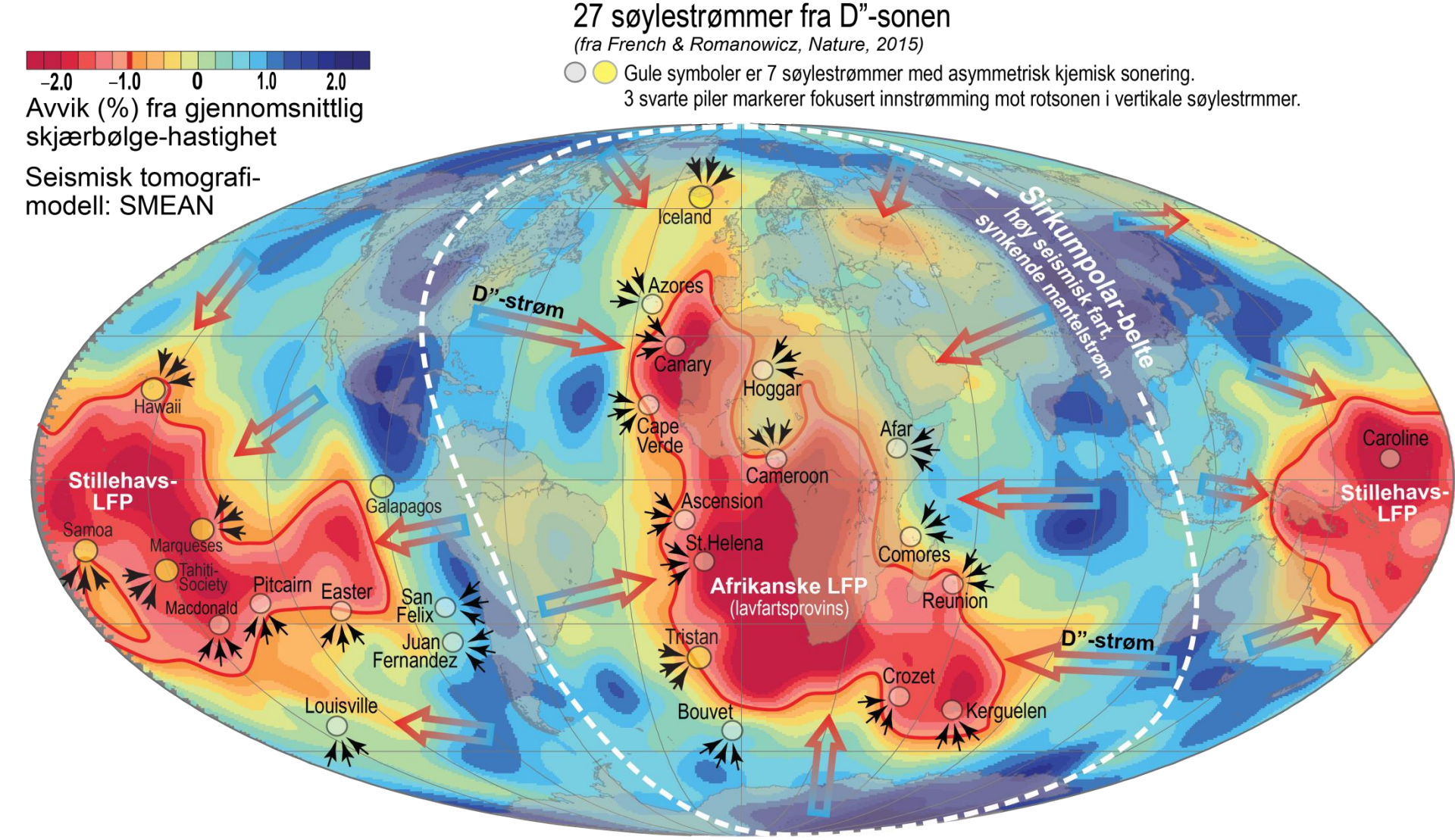


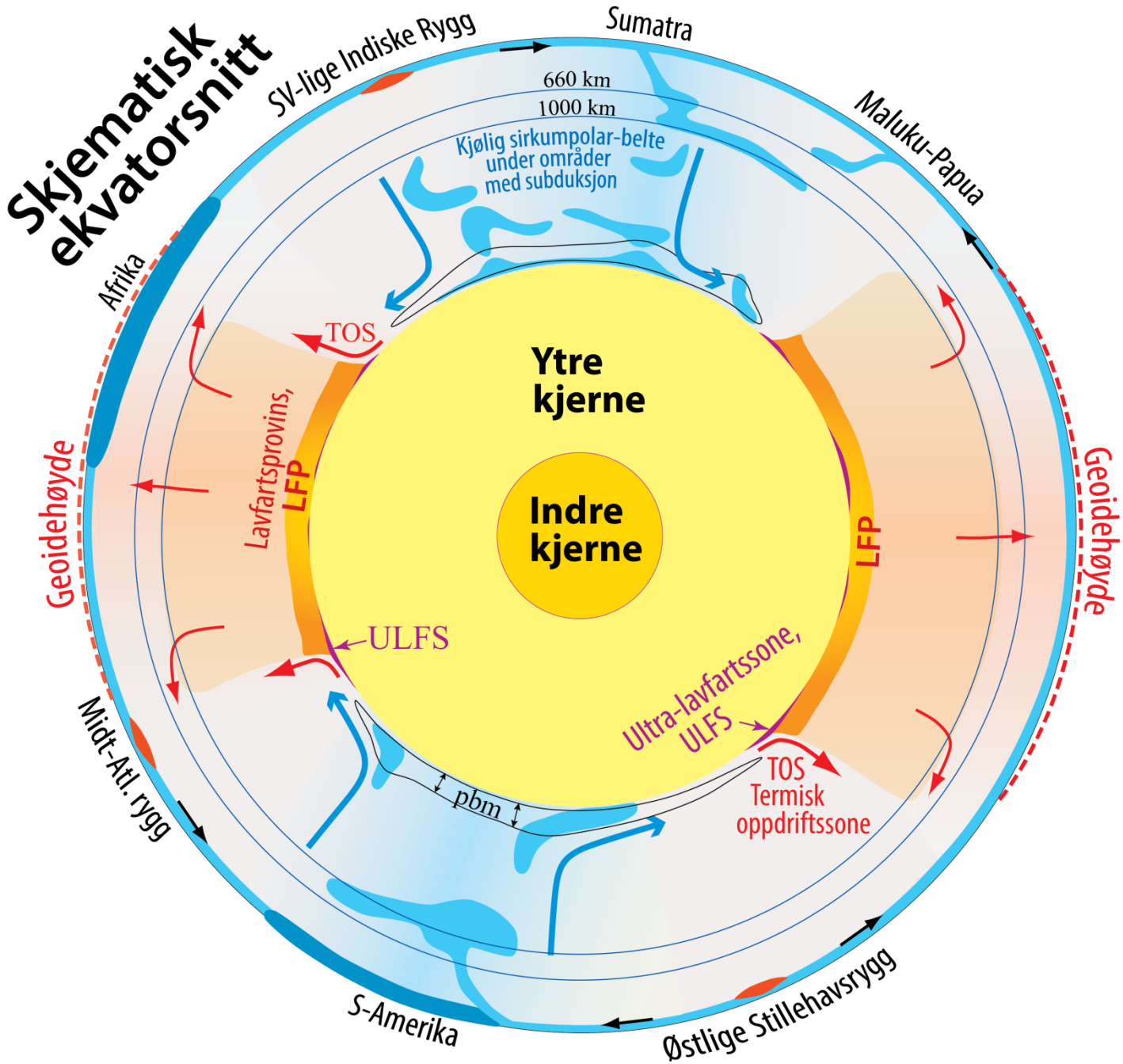
Romanowicz (2003, Ann.Rev. EPS)



465 km above CMB

120 km above CMB


27 søylestrømmer fra D”-sonen
(fra French & Romanowicz, Nature, 2015)
Gule symboler er 7 søylestrømmer med asymmetrisk kjemisk sonering.
3 svarte piler markerer fokusert innstrømming mot rotsonen i vertikale søylestrmmer.
−2.0
−1.0
0
1.0
2.0
Avvik (%) fra gjennomsnittlig skjærbølge-hastighet
Seismisk tomografi-modell: SMEAN
Sirkumpolar-belte
høy seismisk fart,
synkende mantelstrøm
D”-strøm
D”-strøm
Iceland
Azores
Canary
Hoggar
Cape Verde
Afar
Cameroon
Hawaii
Stillehavs-LFP
Galapagos
Ascension
St.Helena
Comores
Reunion
Afrikanske LFP
(lavfartsprovins)
Samoa
Marqueses
Tahiti-Society
Pitcairn
Easter
Macdonald
San Felix
Juan Fernandez
Tristan
Crozet
Kerguelen
Bouvet
Louisville
Caroline
Stillehavs-LFP


Skjematisk ekvatorsnitt
SV-lige Indiske Rygg
Sumatra
Maluku-Papua
660 km
1000 km
Kjølig sirkumpolar-belte under områder med subduksjon
Afrika
TOS
Ytre kjerne
Indre kjerne
Lavfartsprovins, LFP
LFP
Geoidehøyde
Geoidehøyde
ULFS
Ultra-lavfartssone, ULFS
TOS
Termisk oppdriftssone
pbm
Midt-Atl. rygg
S-Amerika
Østlige Stillehavsrygg