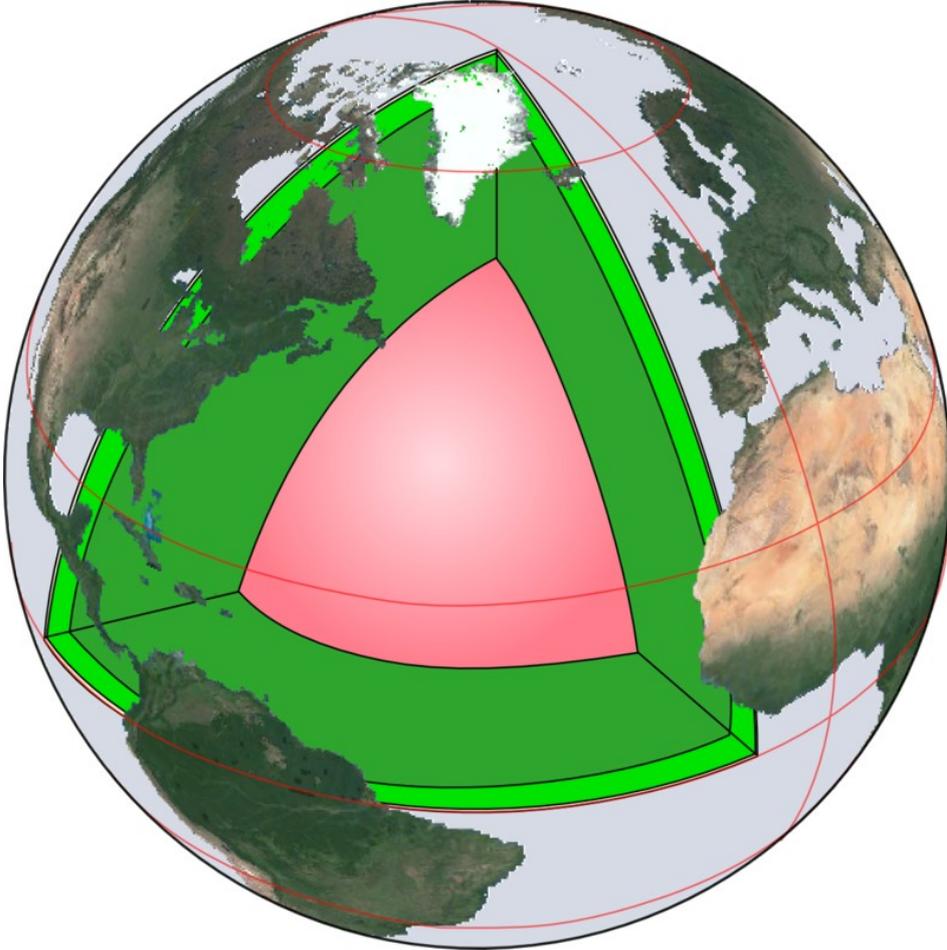


Sébastien Merkel

UMET, Université de Lille, France

Institut Universitaire de France



Convection dans le manteau Une question d'échelles...

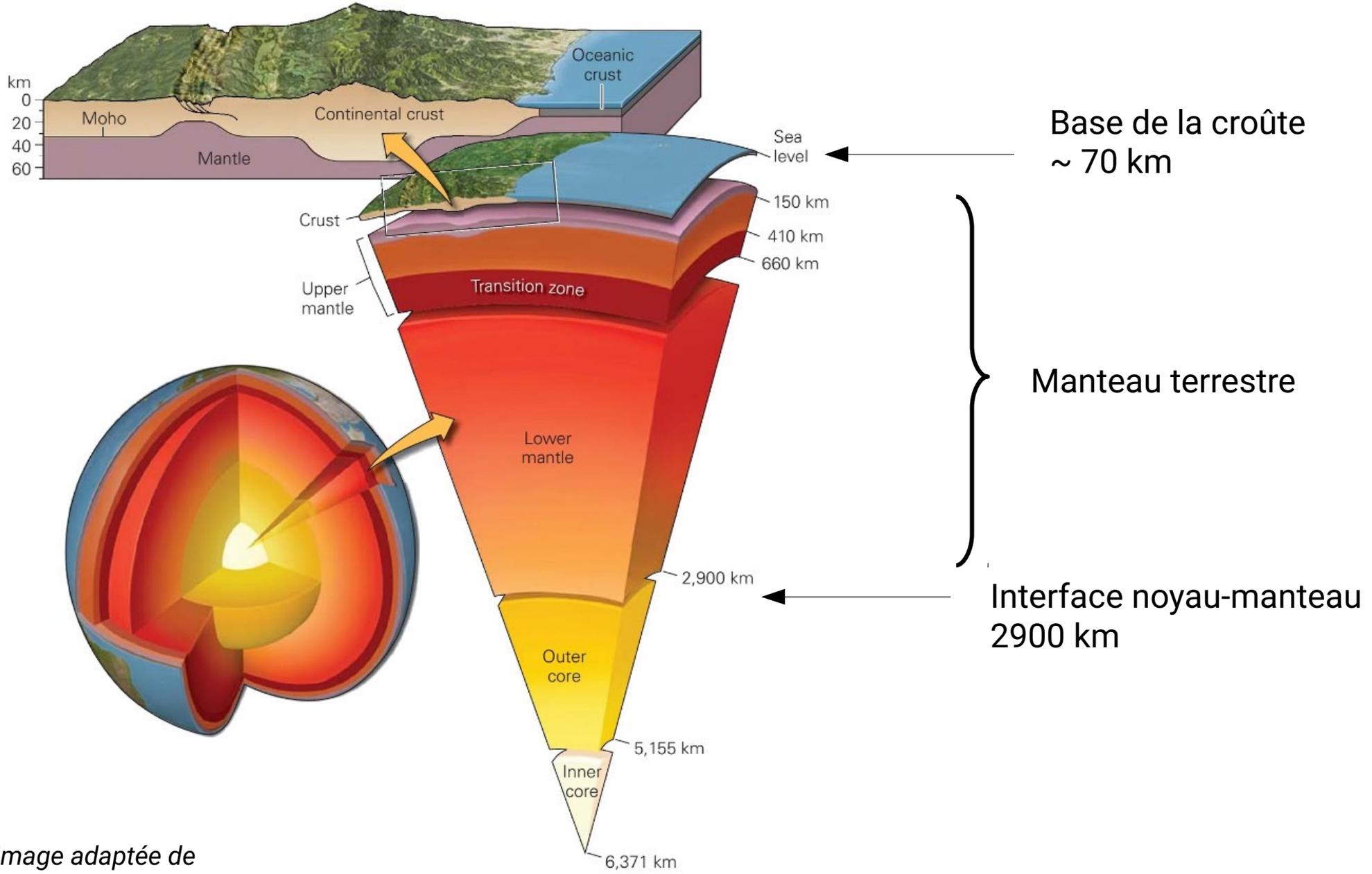
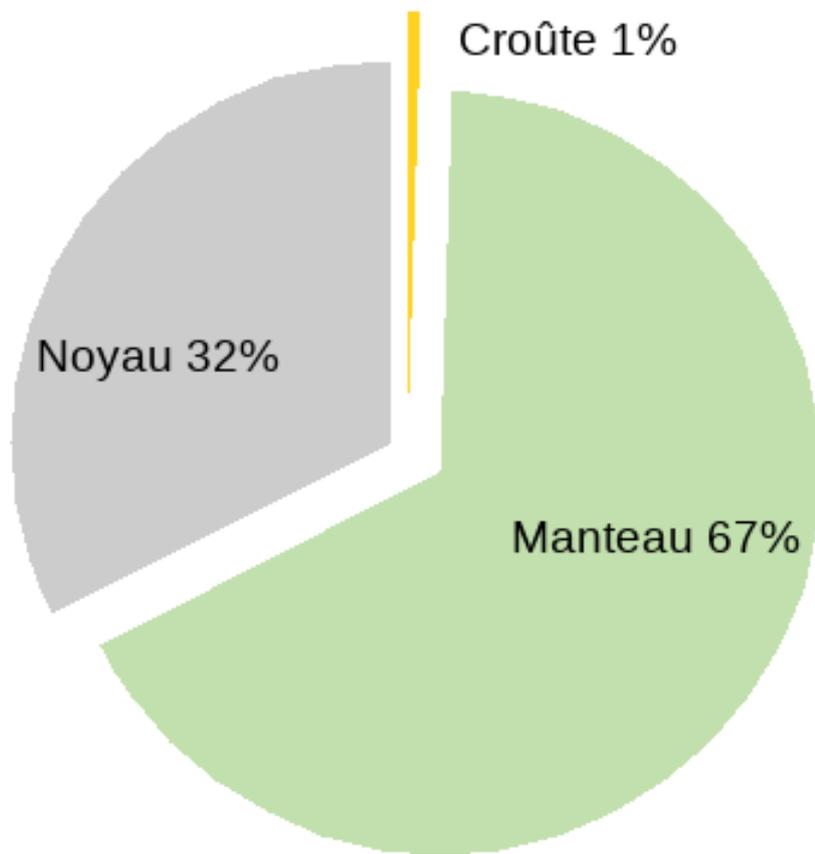
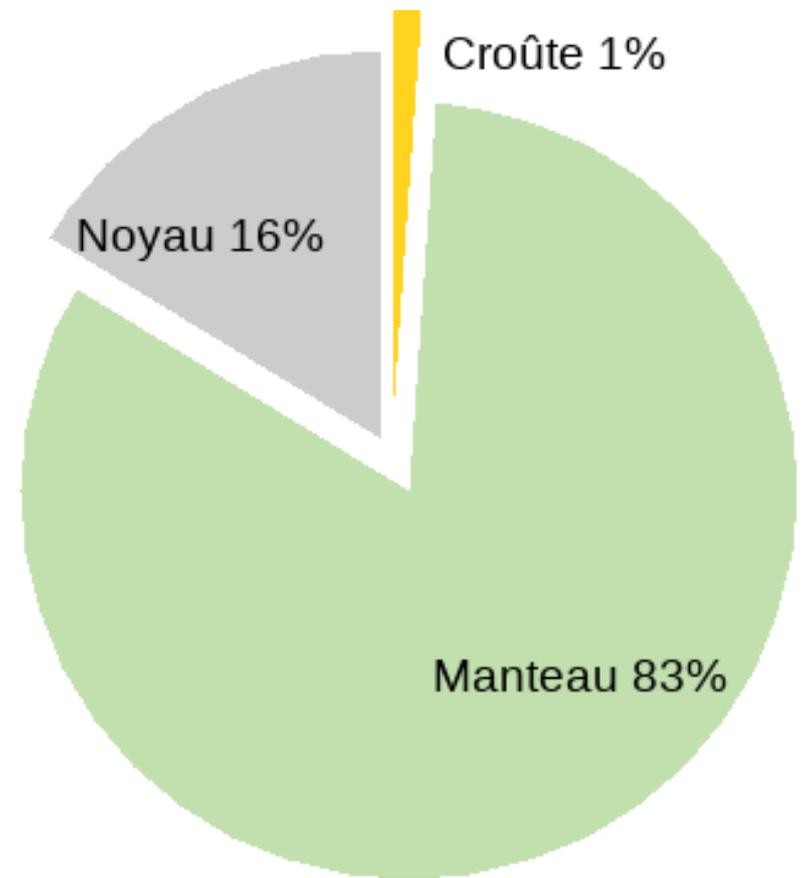


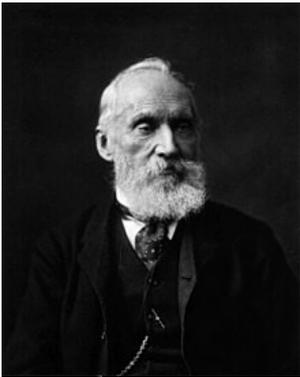
Image adaptée de <http://geologylearn.blogspot.com/>



En masse



En volume



Lord Kelvin

Refroidissement d'un
sphère par conduction
thermique

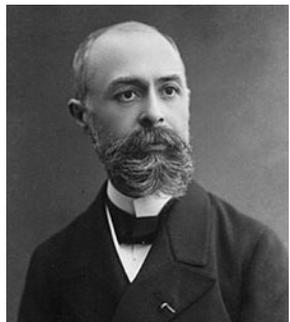
~100 Ma



James Hutton

Processus très lents
sur des observations
de terrain

Propose une terre
infiniment vieille



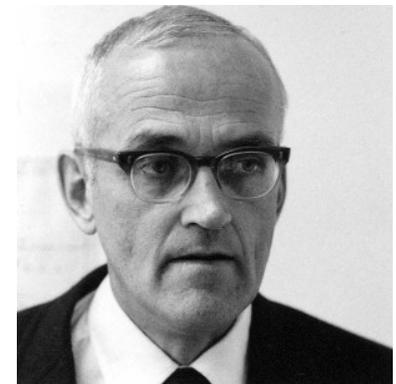
H. Becquerel

Resolution

Découverte de la radioactivité

Datation de roches et météorites

Age de la terre : 4.56 Ga



C. C. Patterson

Datation uranium plomb

Années 50

P. et M.
Curie

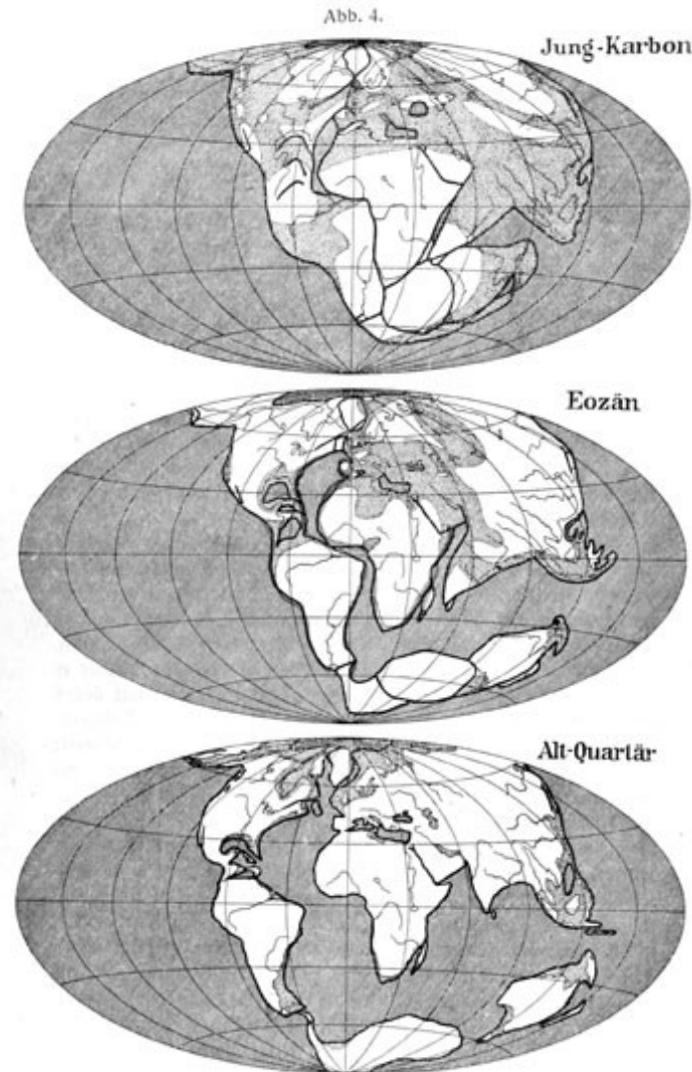




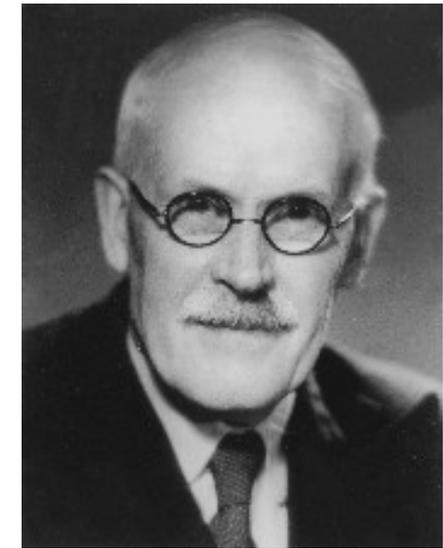
A. Wegener

Arguments géologiques,
paléontologiques,
climatiques

Les continents se
déplacent à la surface
du globe



Rekonstruktionen der Erdkarte nach der Verschiebungstheorie
für drei Zeiten.
Schraffiert: Tiefsee; punktiert: Flachsee; heutige Konturen und Flüsse nur zum Erkennen.
Gradnetz willkürlich (das heutige von Afrika).

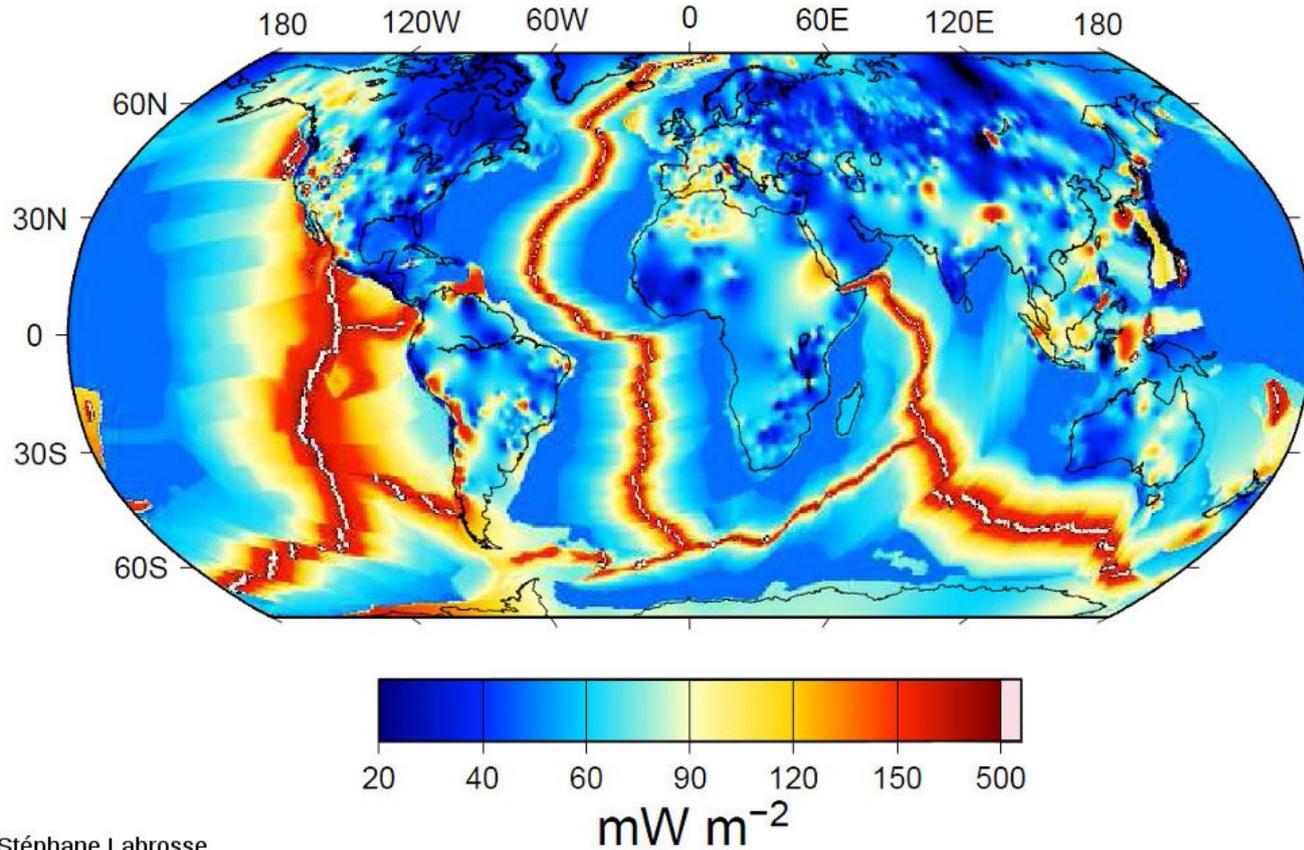


H. Jeffreys

Observations
sismiques : rigidité du
manteau et de la croûte

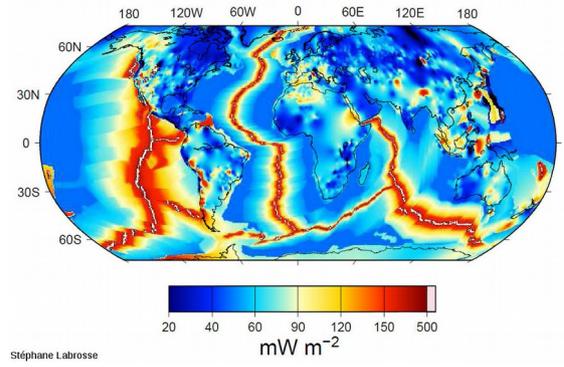
Absence de force
suffisante pour
déplacer les continents

Flux de chaleur en surface



Stéphane Labrosse

Flux de chaleur en surface



Âge des fonds marins

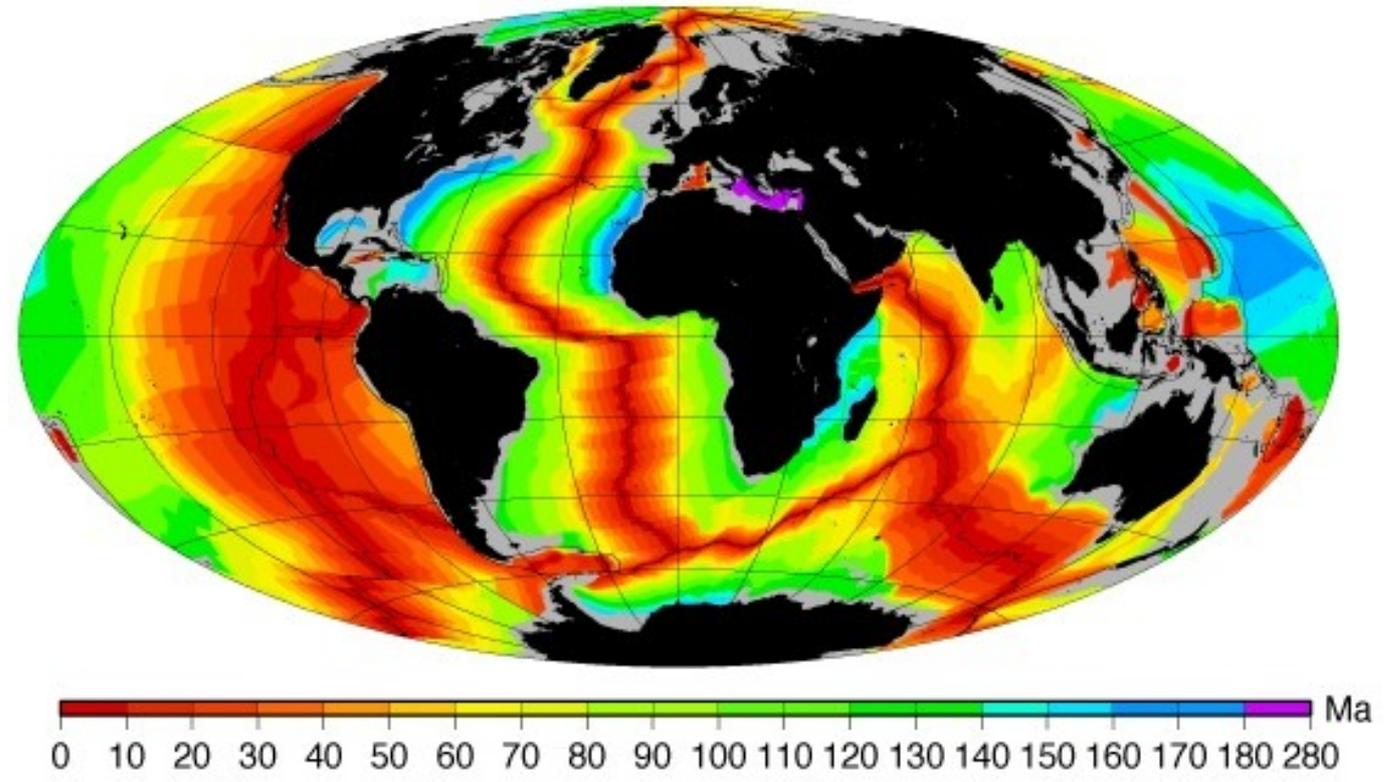
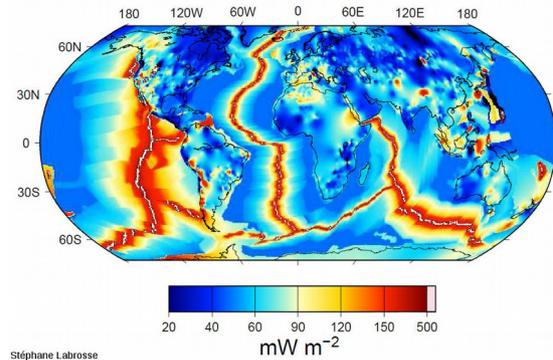
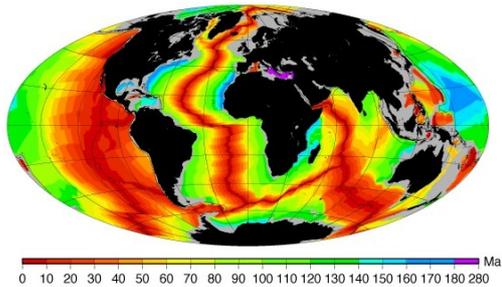


Image : EarthByte / Planet-Terre

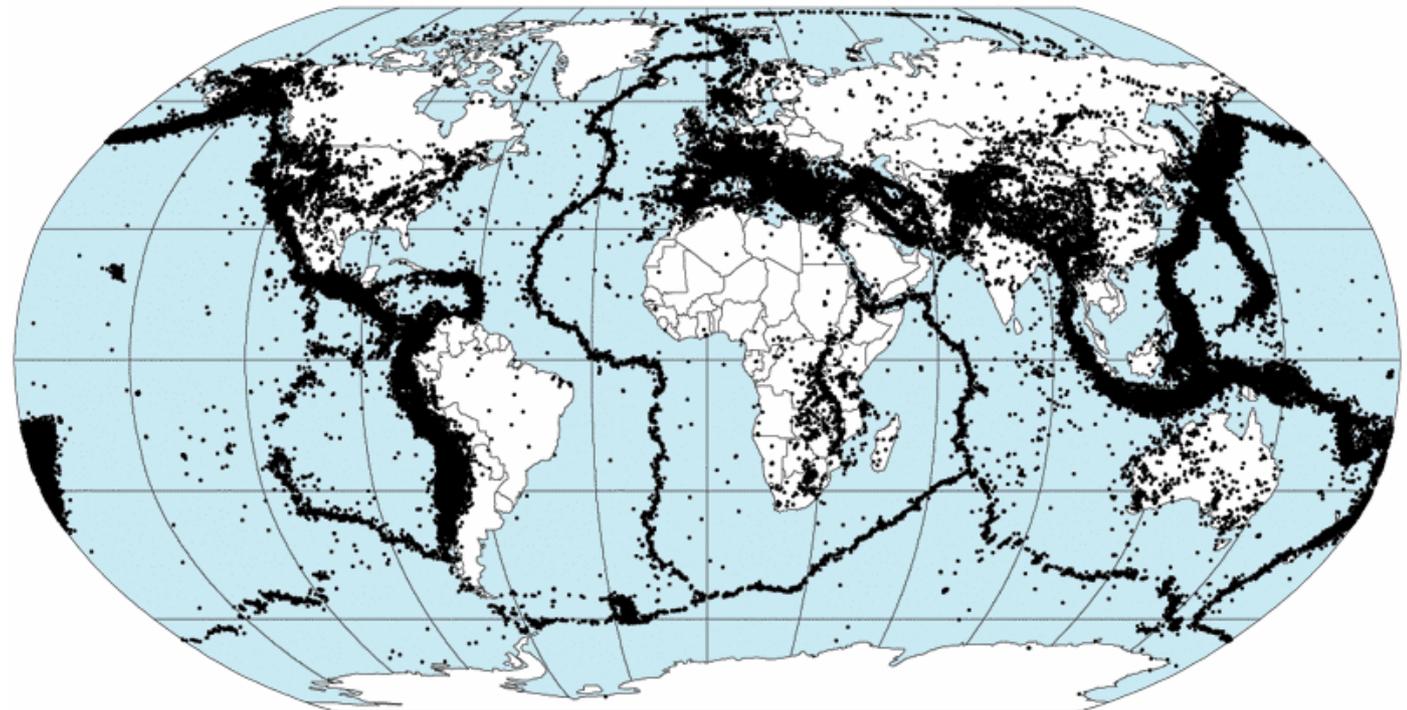
Flux de chaleur en surface



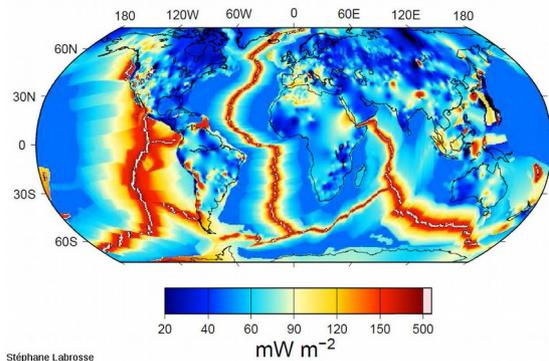
Âge des fonds marins



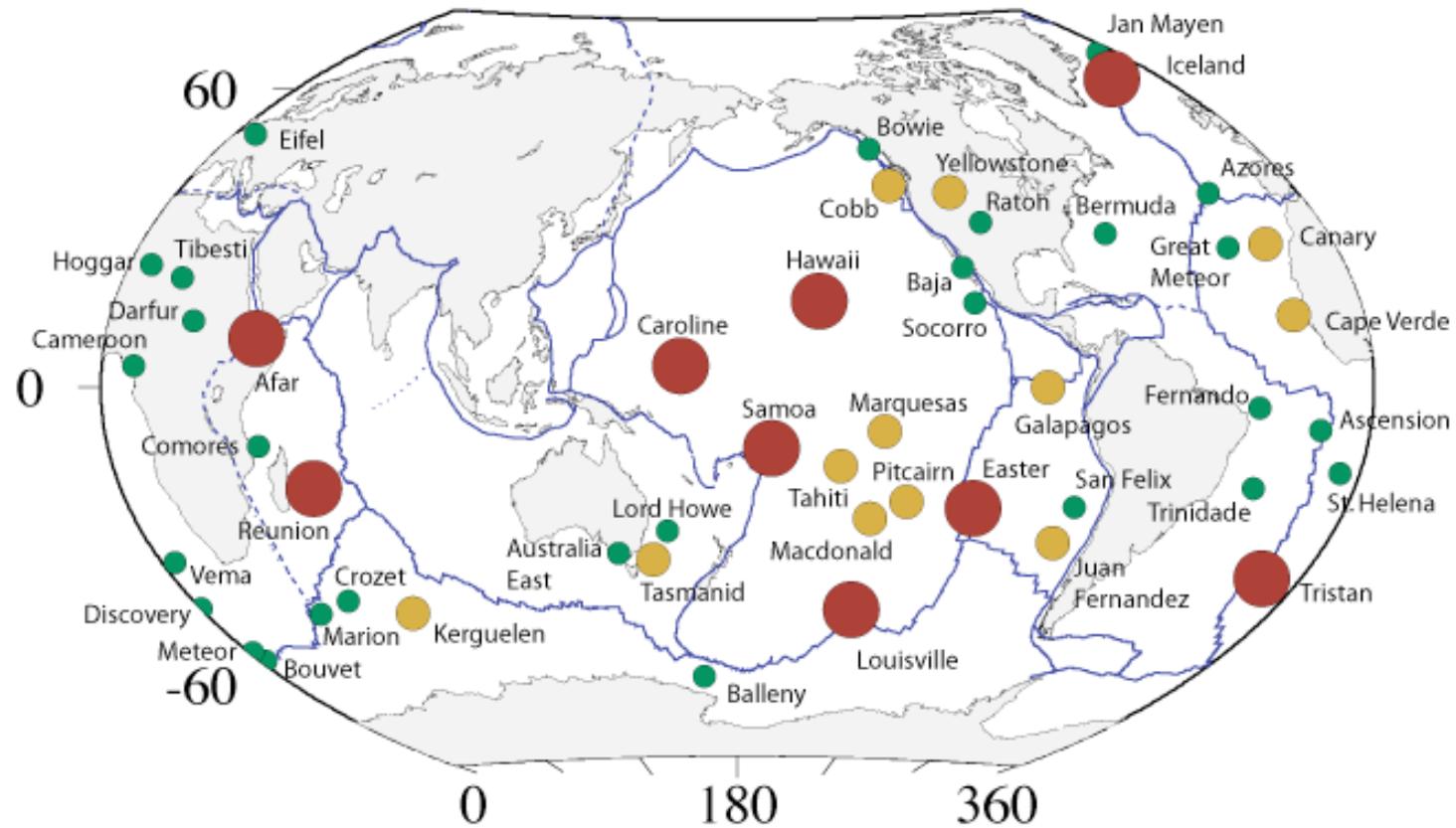
Localisation des séismes



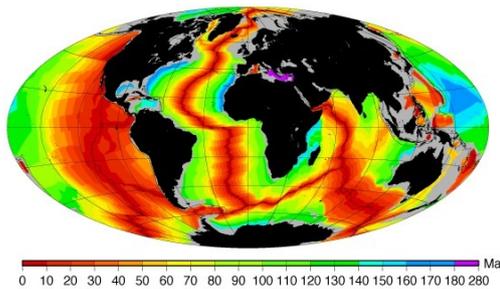
Flux de chaleur en surface



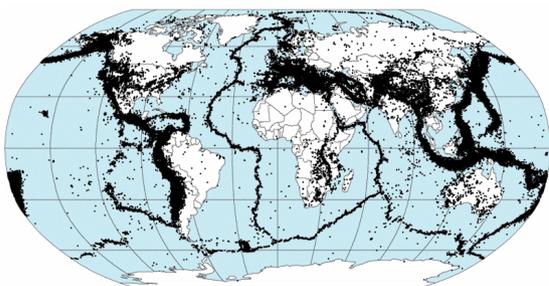
Identification des « points chauds »



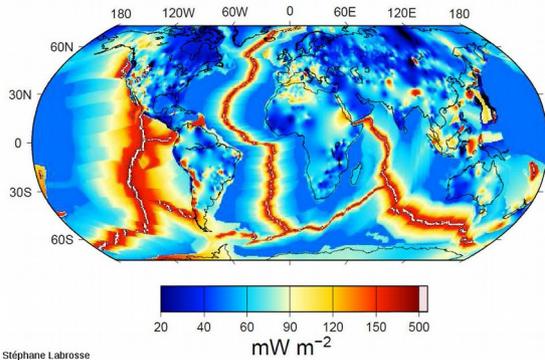
Âge des fonds marins



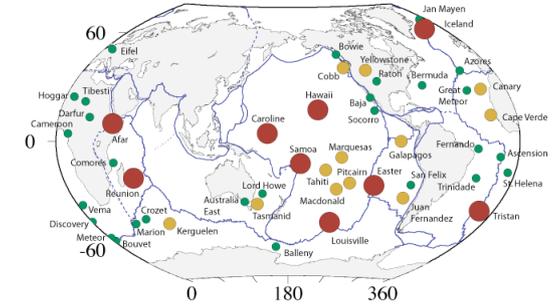
Localisation des séismes



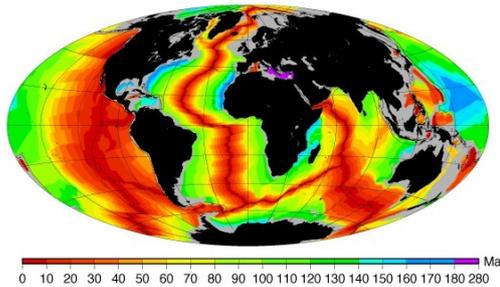
Flux de chaleur en surface



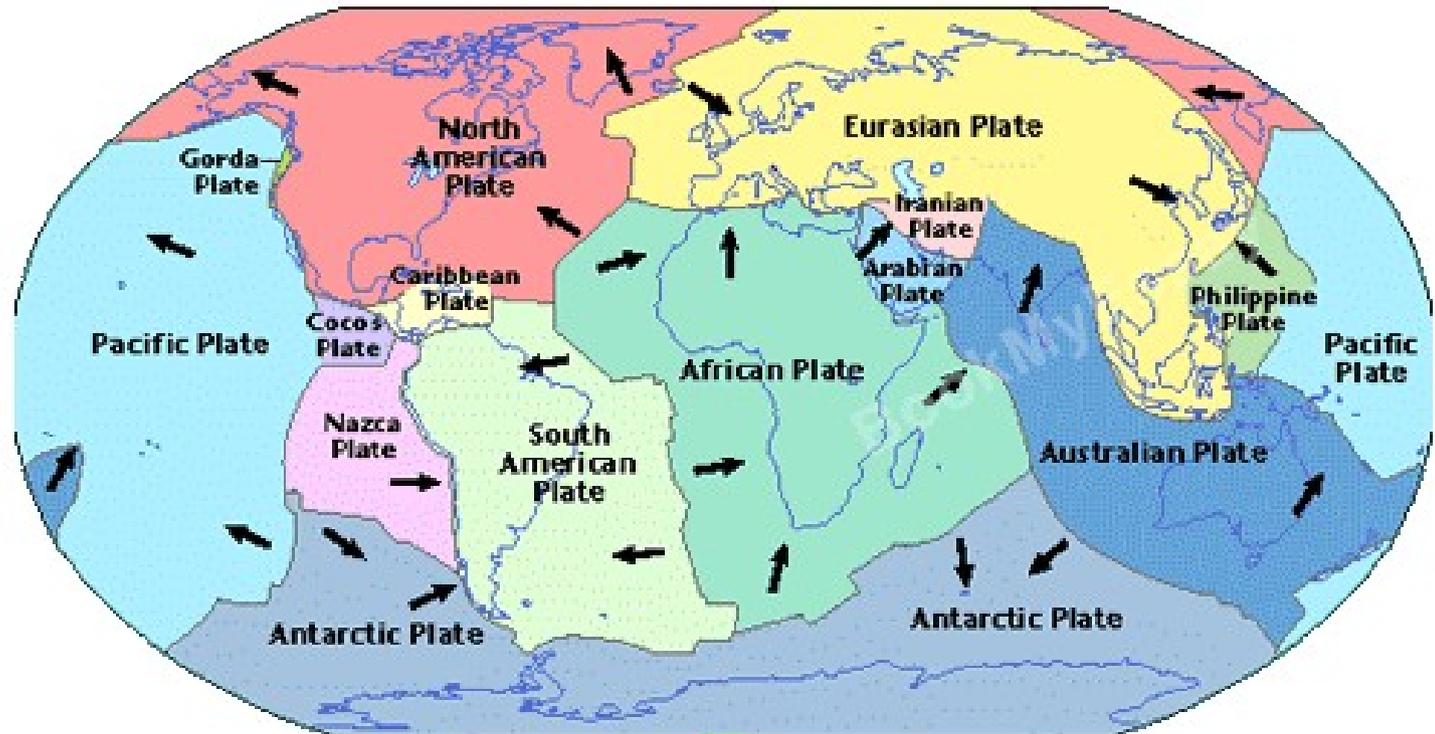
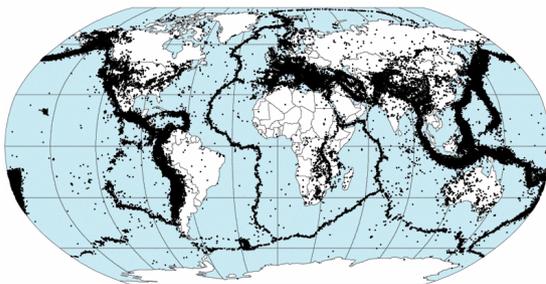
Identification des « points chauds »



Âge des fonds marins

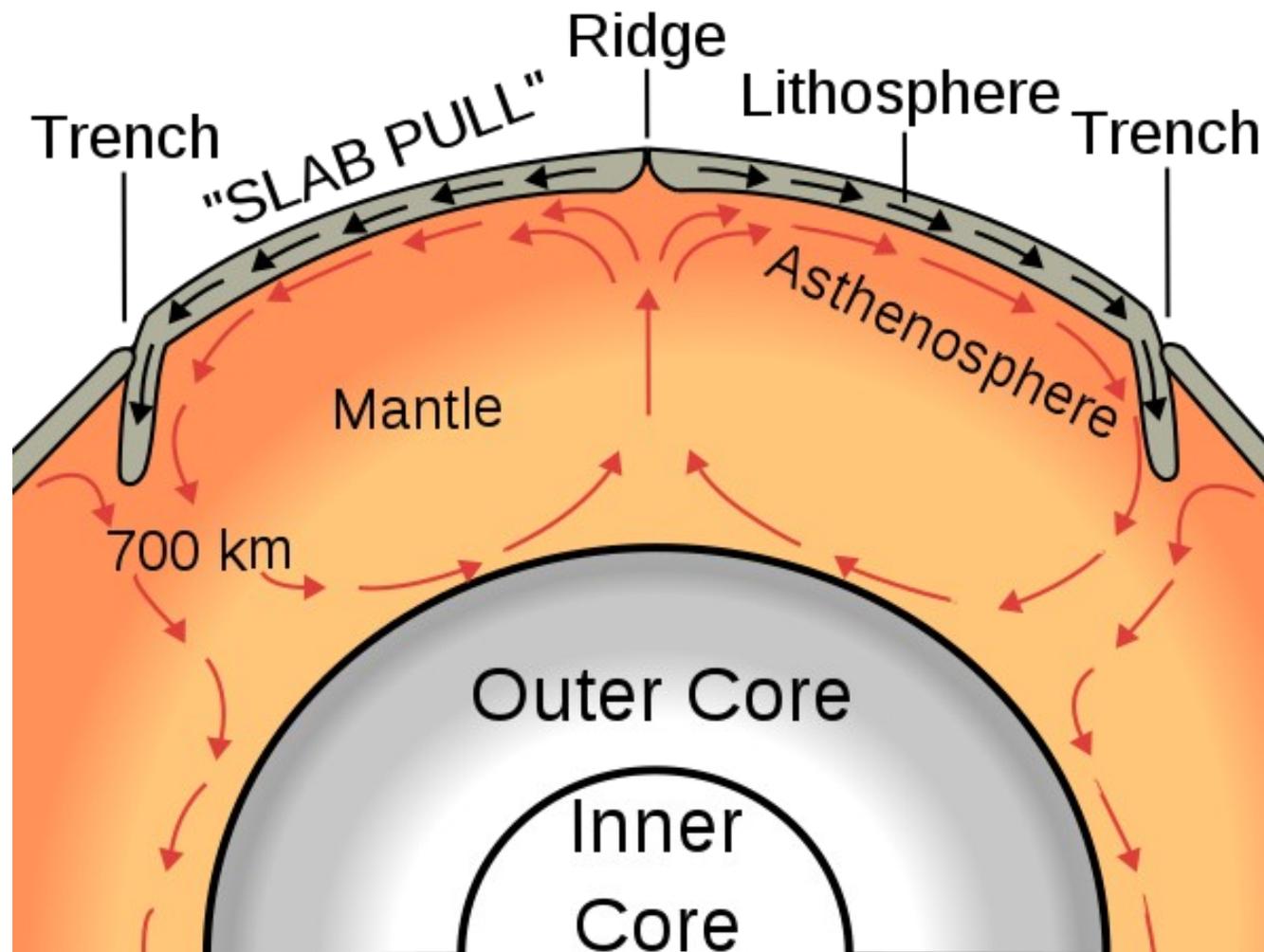


Localisation des séismes

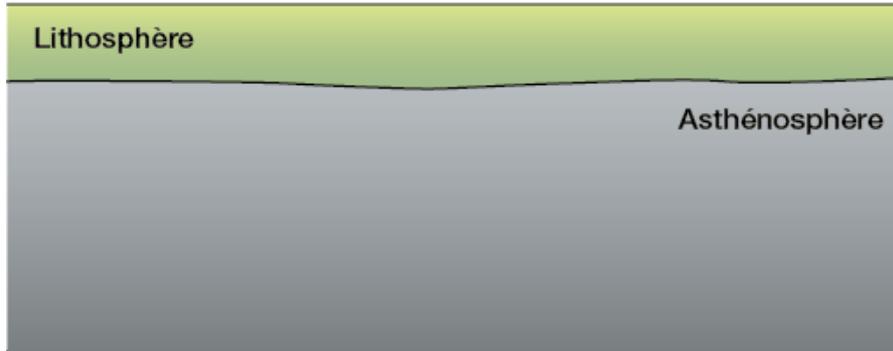


Tectonique des plaques

Vers la convection mantellique ?

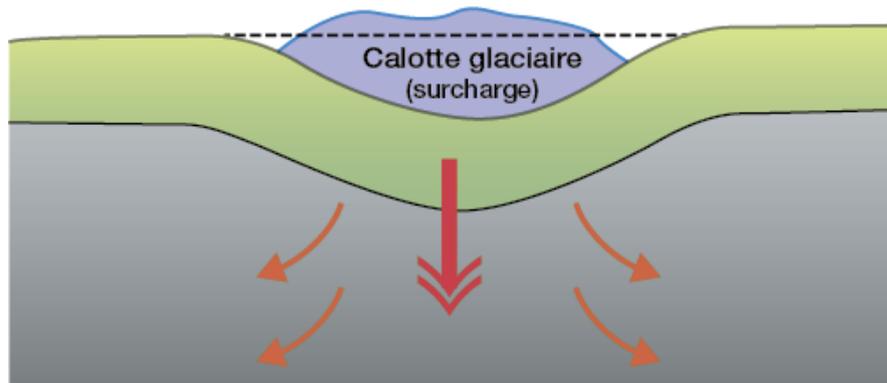


Modèle de convection mantellique ?



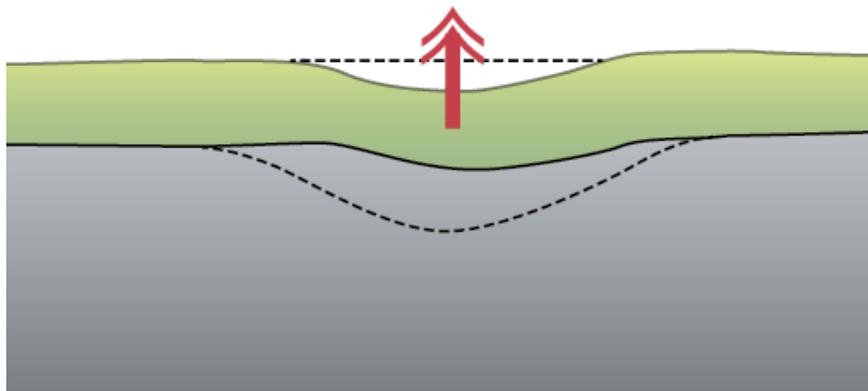
Période pré-glaciaire

Lithosphère en équilibre isostatique avec l'asthénosphère



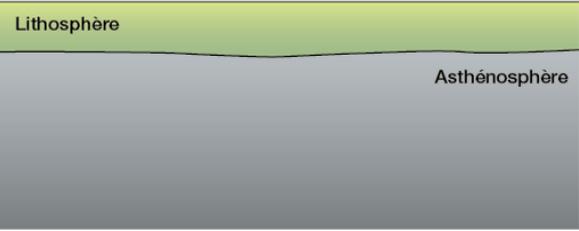
Glaciation

Nouvel équilibre isostatique lithosphère – asthénosphère après affaissement du au poids de la calotte glaciaire



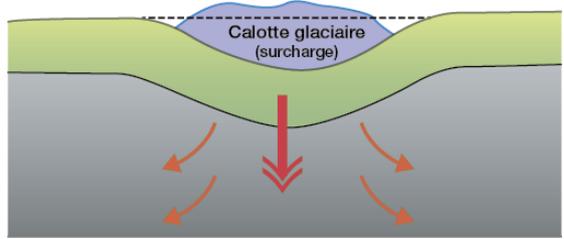
Période post-glaciaire

Fonte des glaces. Rebond isostatique vers un nouvel équilibre identique à l'ère pré-glaciaire

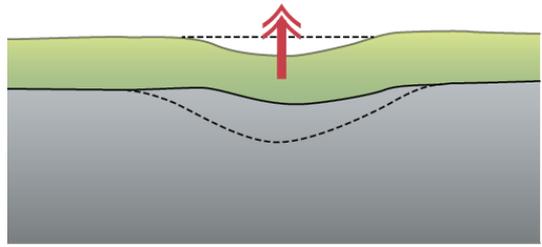


Observations aujourd'hui

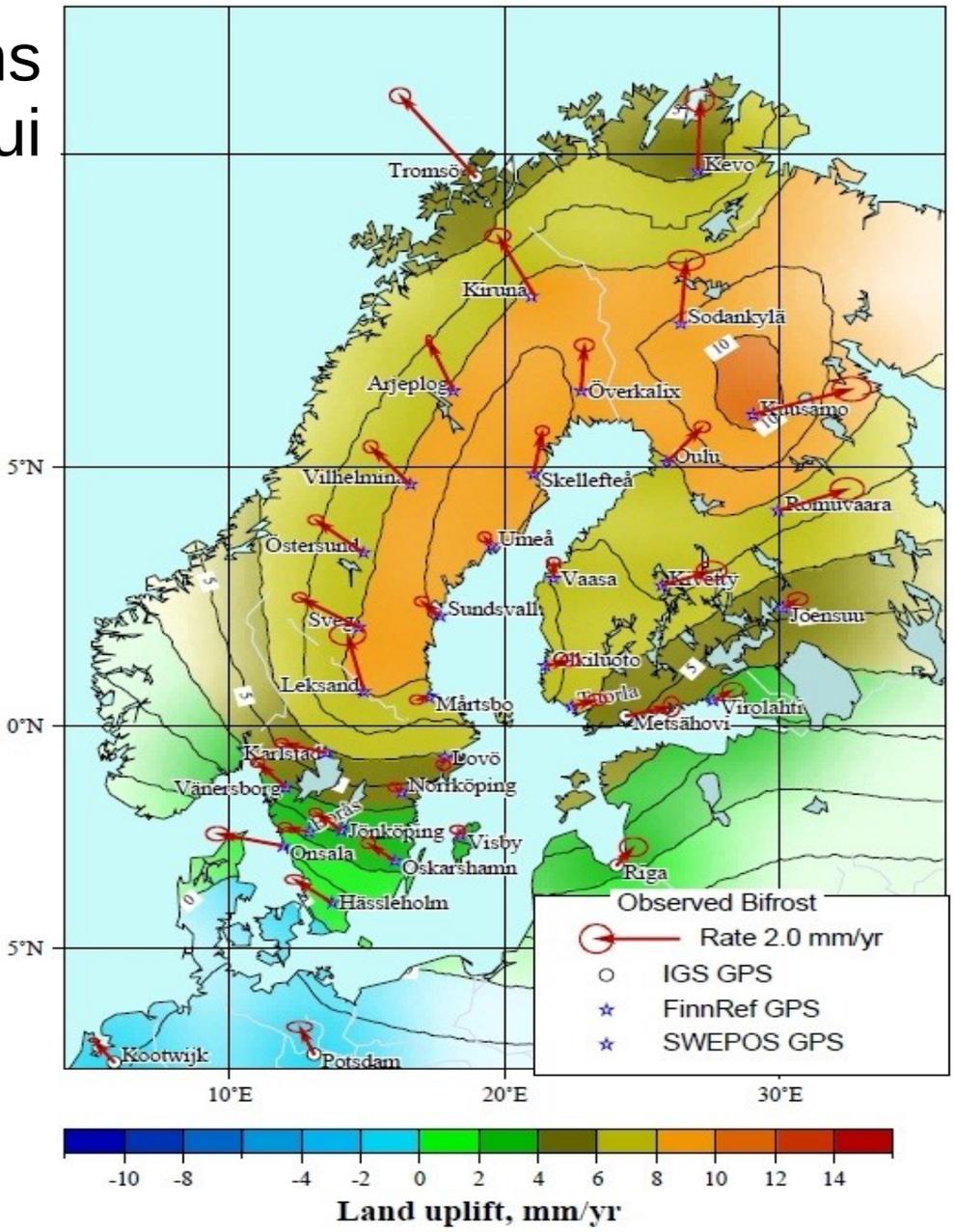
Période pré-glaciaire

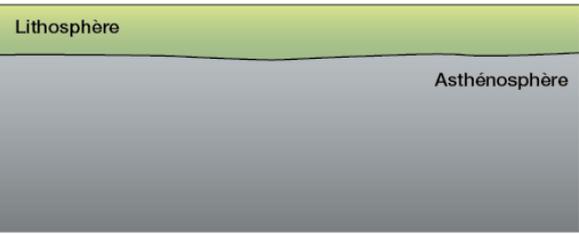


Glaciation



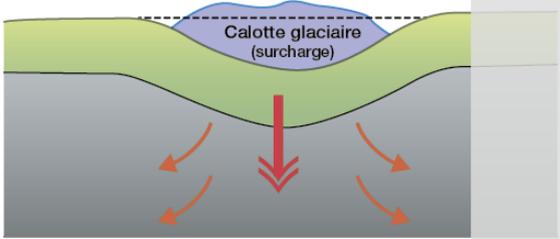
Période post-glaciaire



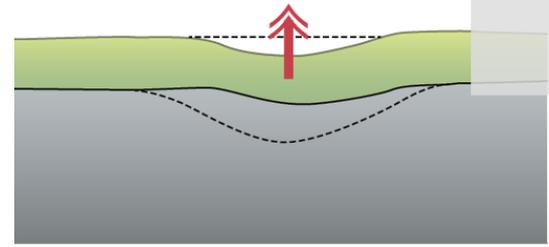


Observations
aujourd'hui

Période pré-glaciaire



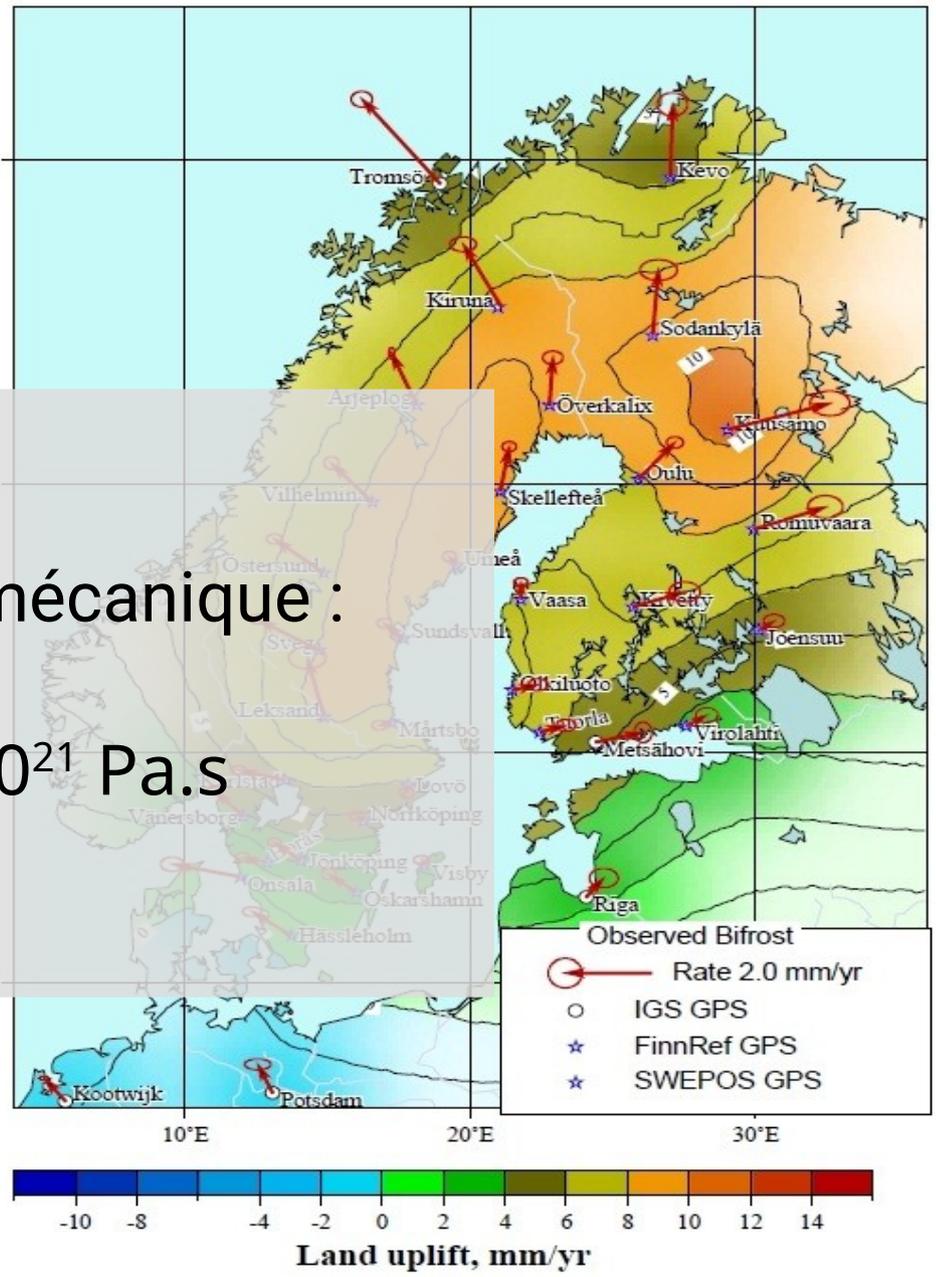
Glaciation



Période post-glaciaire

Modélisation mécanique :

$$\eta_{\text{manteau}} \approx 10^{21} \text{ Pa.s}$$

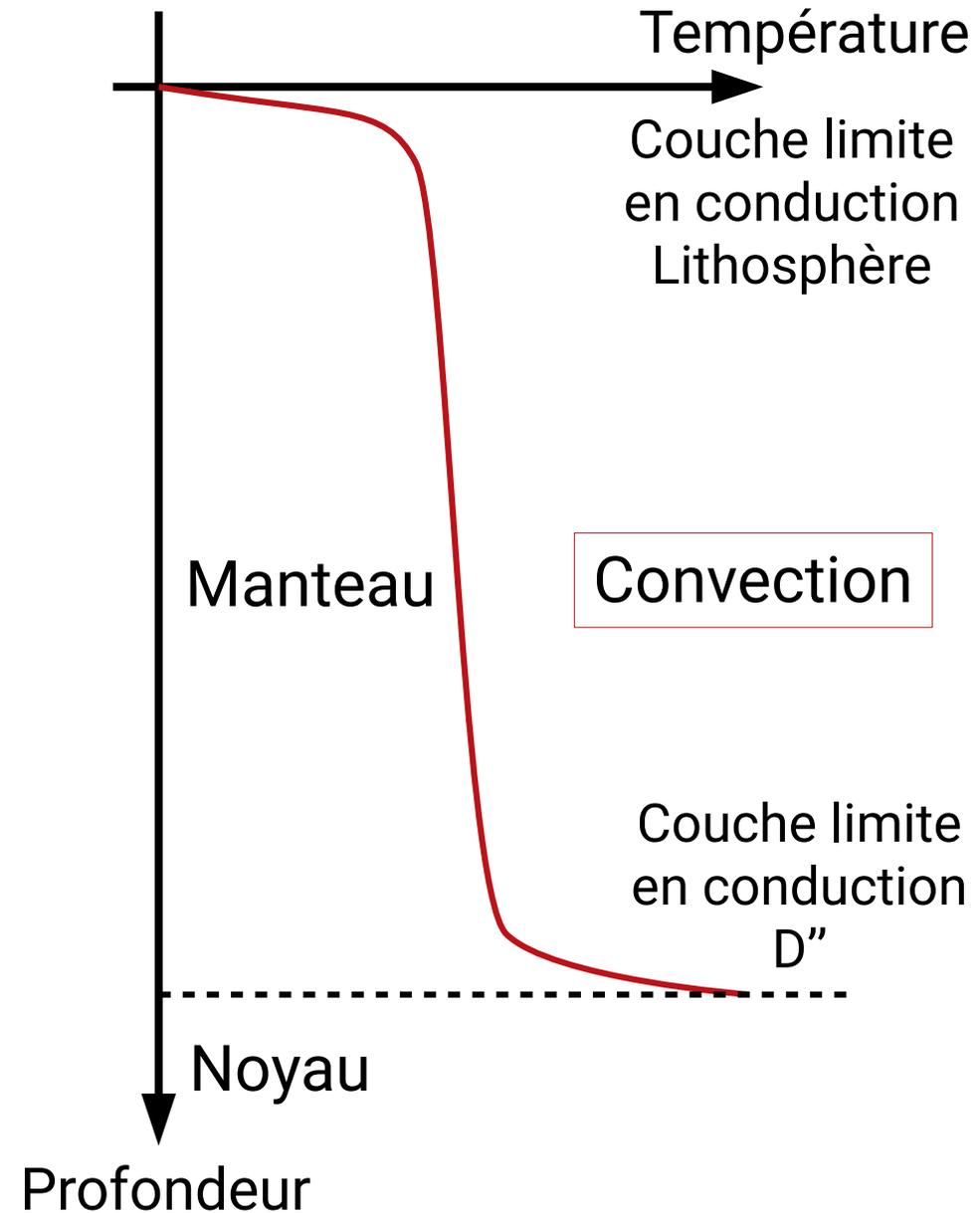
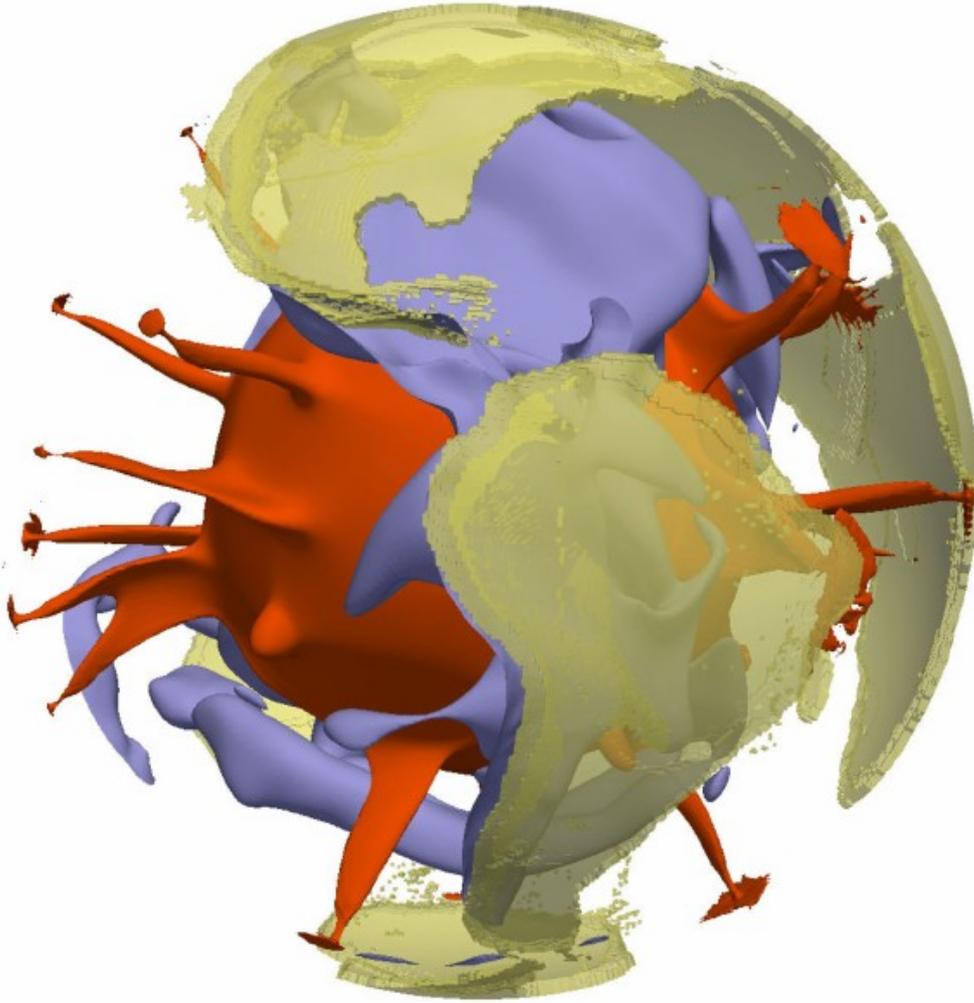


kirjo.

Archipelpe Kvarken Finlande

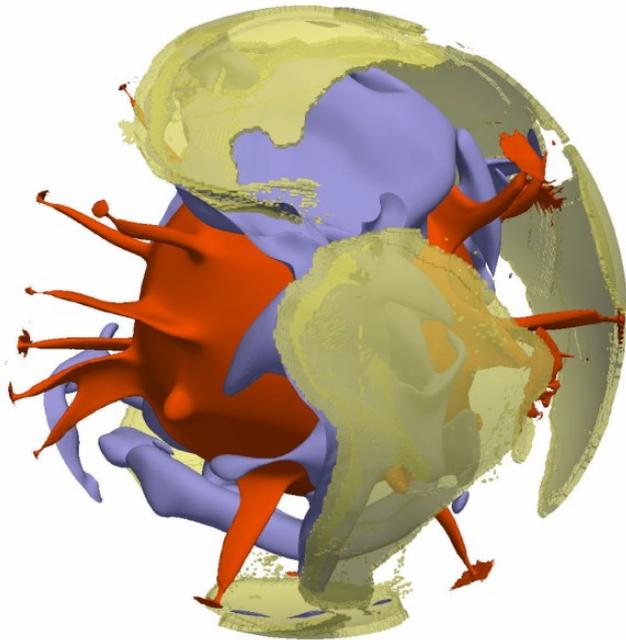


Le manteau terrestre Un fluide visqueux en convection ?

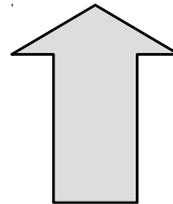
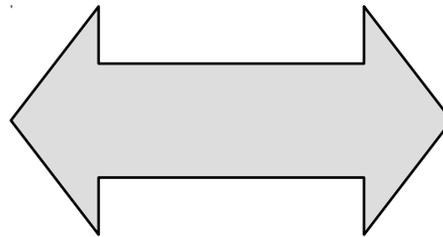


Modèles dynamiques
Convection mantellique

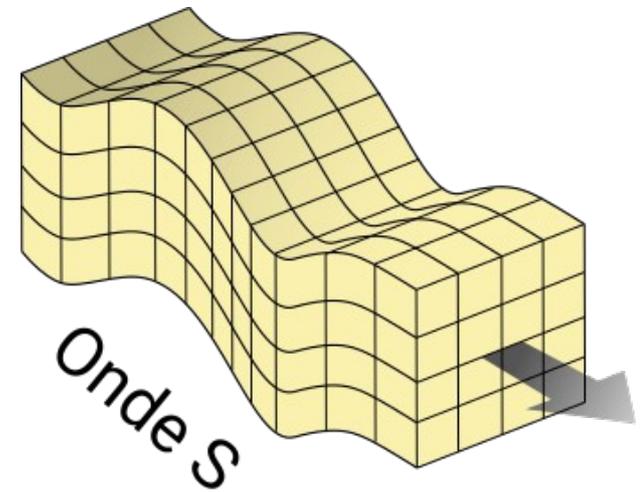
$$\eta_{\text{manteau}} \approx 10^{21} \text{ Pa.s}$$



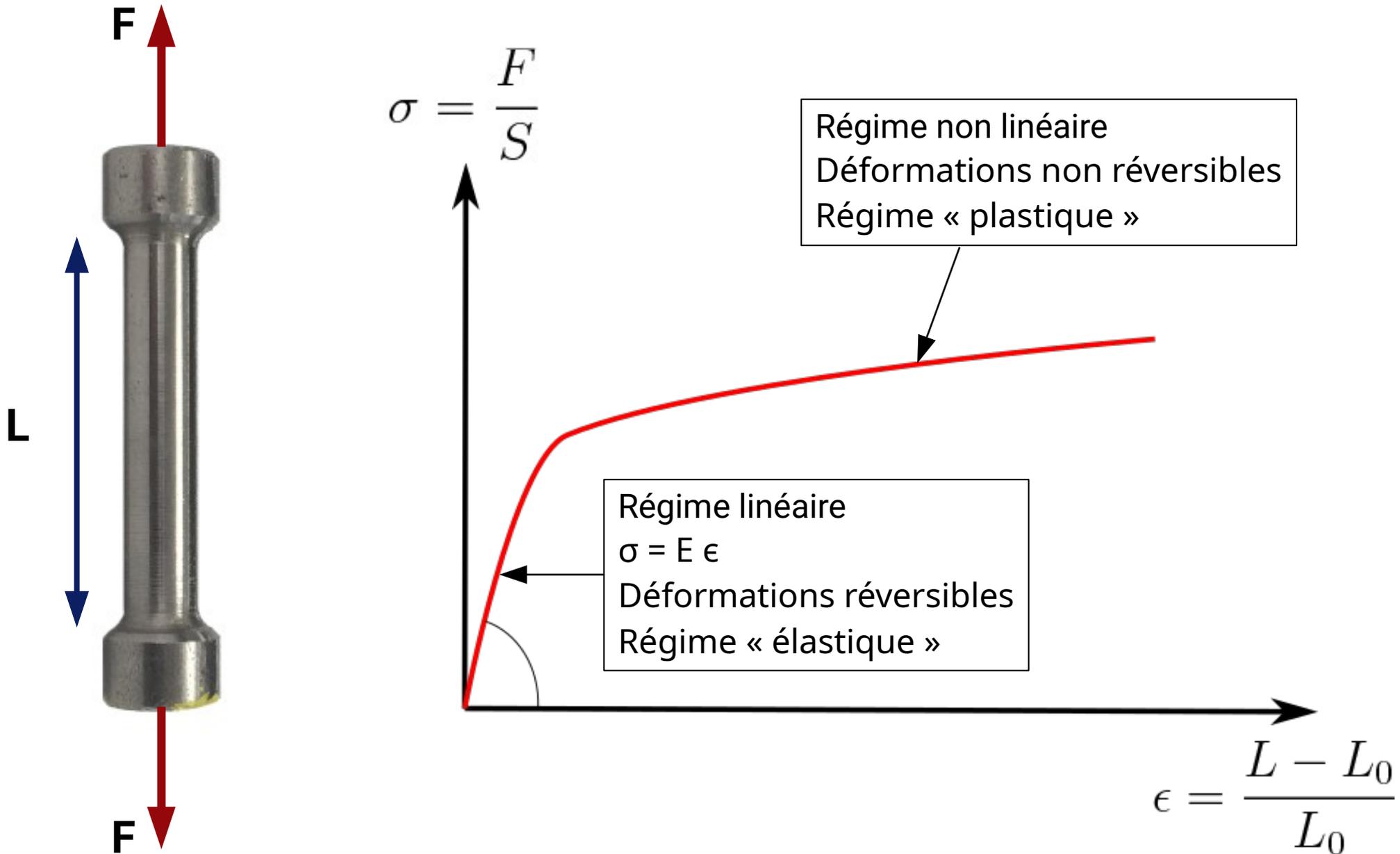
????

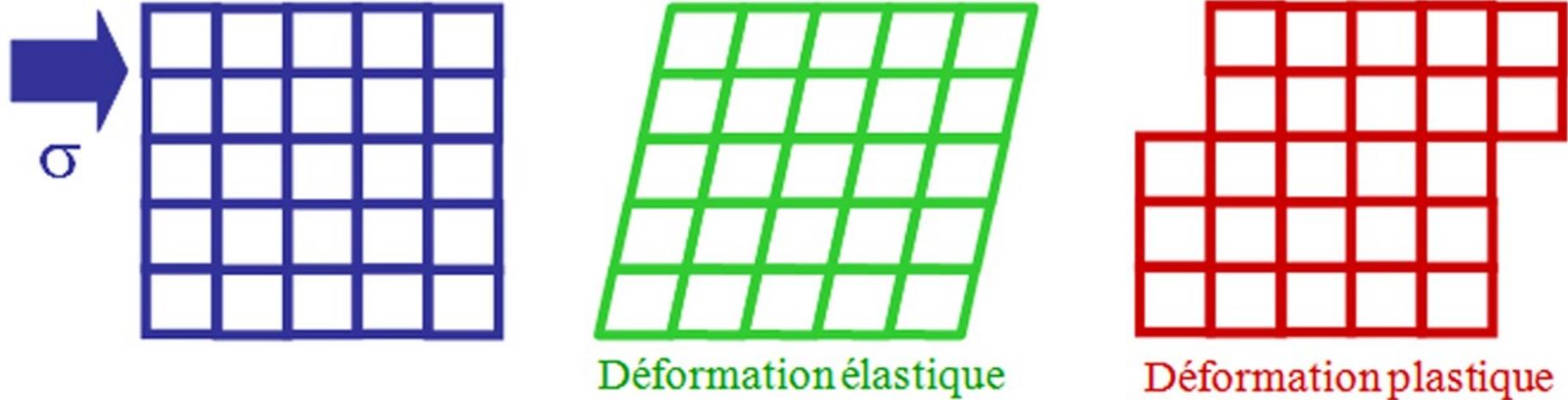


Observations sismiques
Ondes S
Manteau solide



Pendant ce temps ... en métallurgie





Déformation élastique :

- Réversible
- Les atomes restent proches de leurs positions d'équilibre
- Retour à la position d'équilibre après la l'application de contrainte

Déformation plastique :

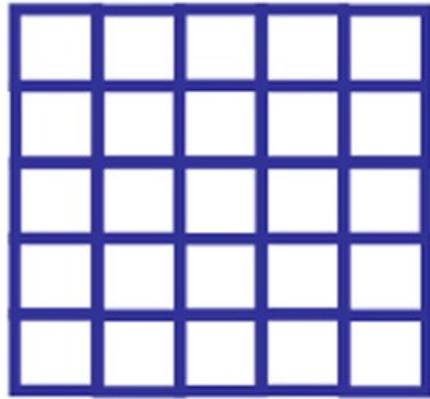
- Rupture de liaisons chimiques
- Ré-arrangement du cristal
- Pas de retour après l'application de contrainte



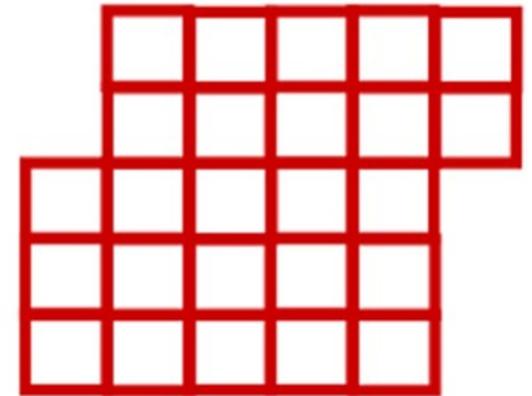
Épées de l'âge de bronze
Musée Denon
Chalon sur Saône



Controverse des années 30 Comment déformer des métaux ?

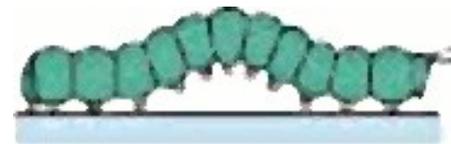
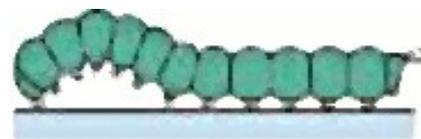


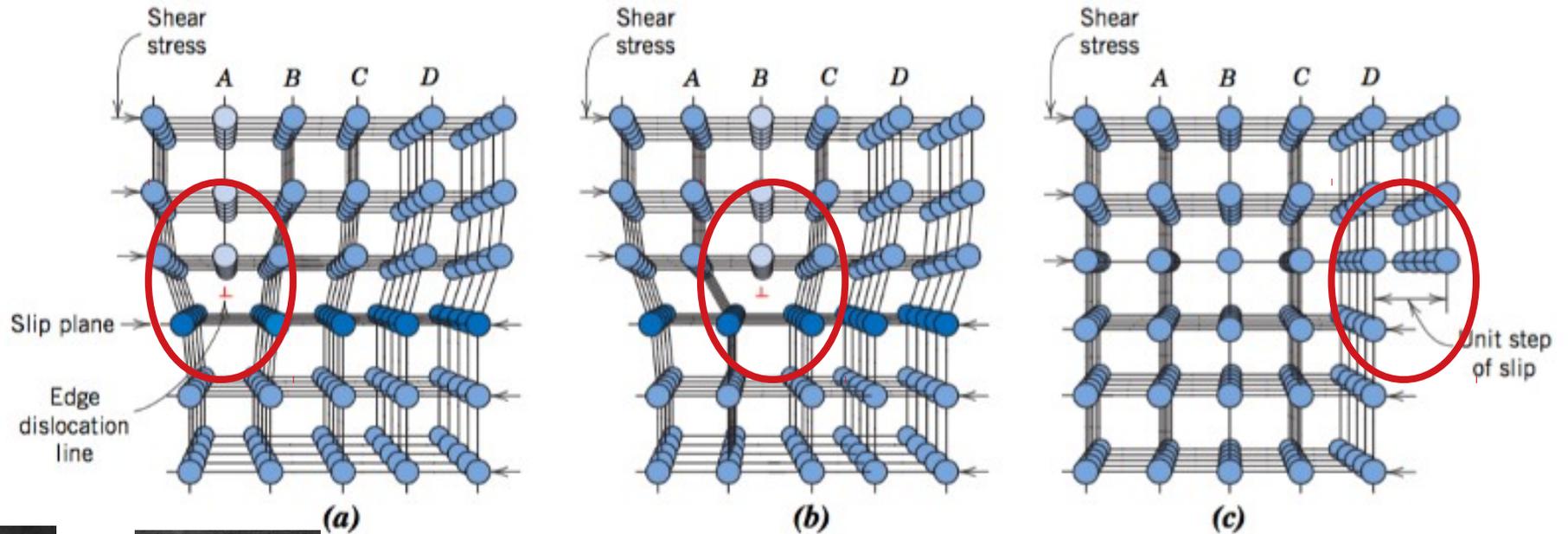
????



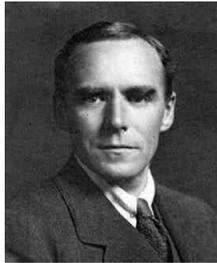
Mécaniquement :
très difficile

Une chenille en mouvement





V. Volterra



G. I. Taylor

Permet une déformation plastique moins énergétique

Concept théorique des années 30

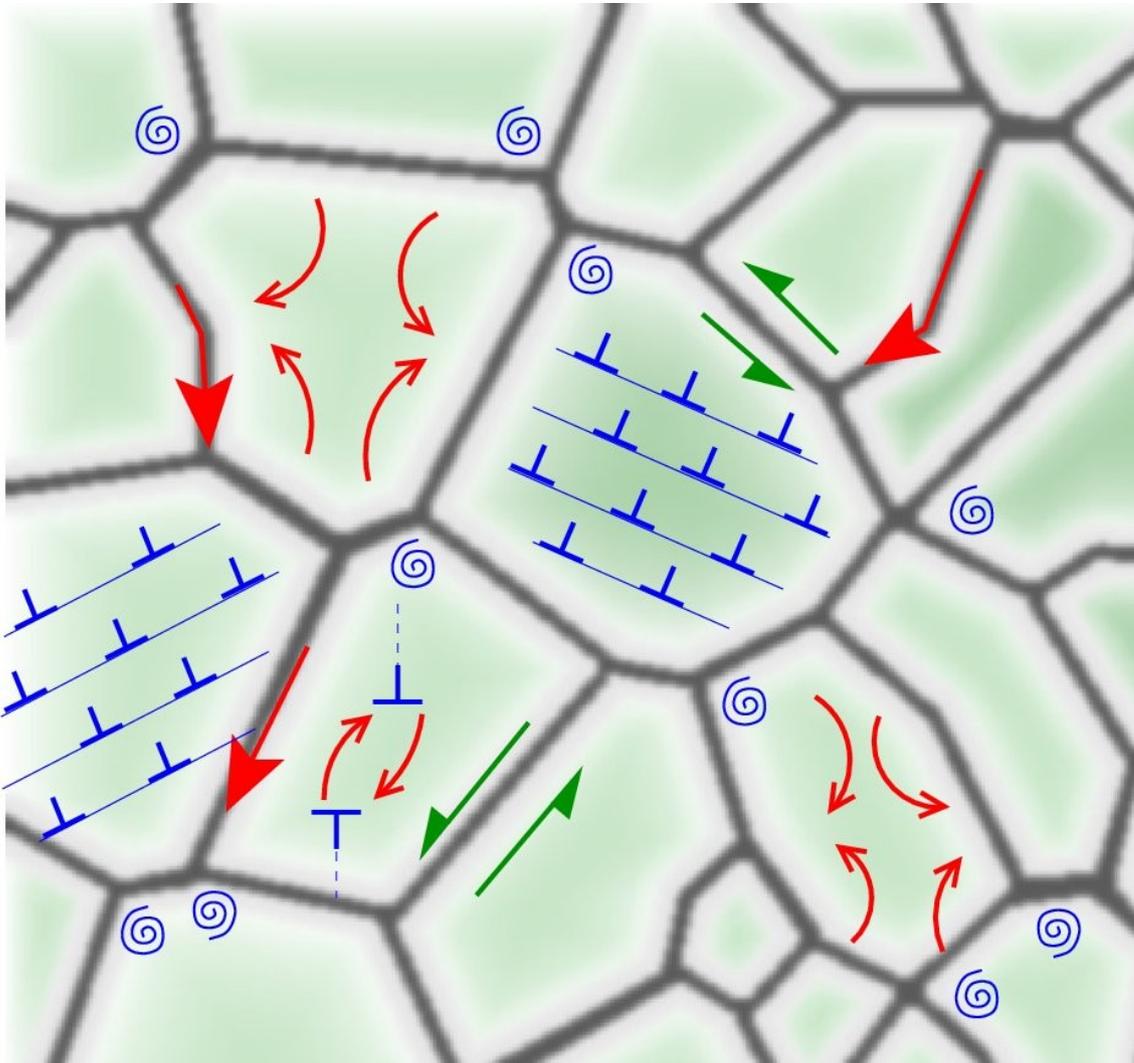


E. Orowan



J. M. Burgers

Observé expérimentalement dans les années 50
(microscope électronique)

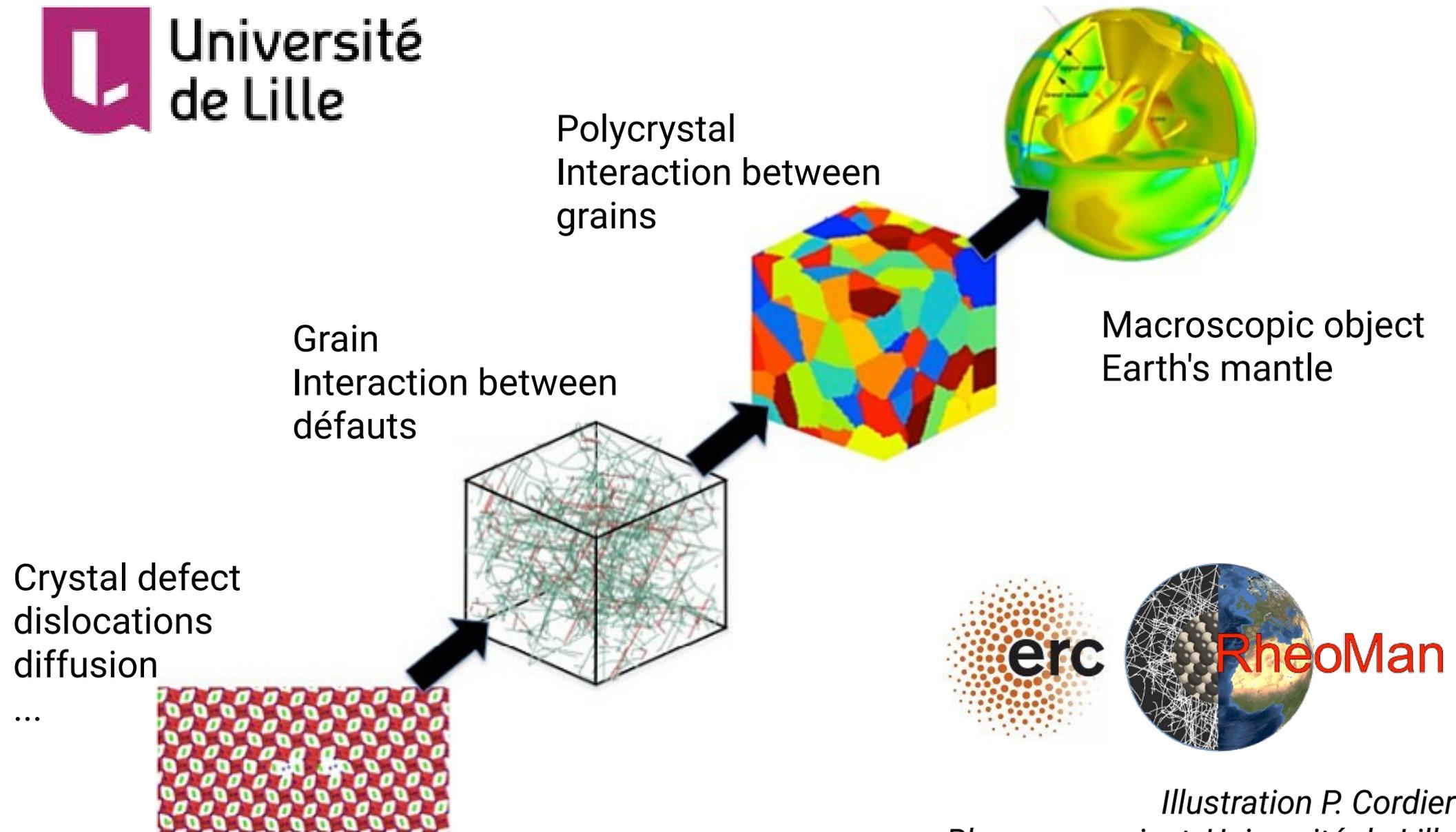


Le formage de métaux et la déformation plastique sont une affaire de défauts

- Glissement de dislocations
- Montée de dislocations
- Disclinaisons
- Diffusion
- Joints de grains
- Etc

Certains métallurgistes passent leur vie à étudier les défauts.

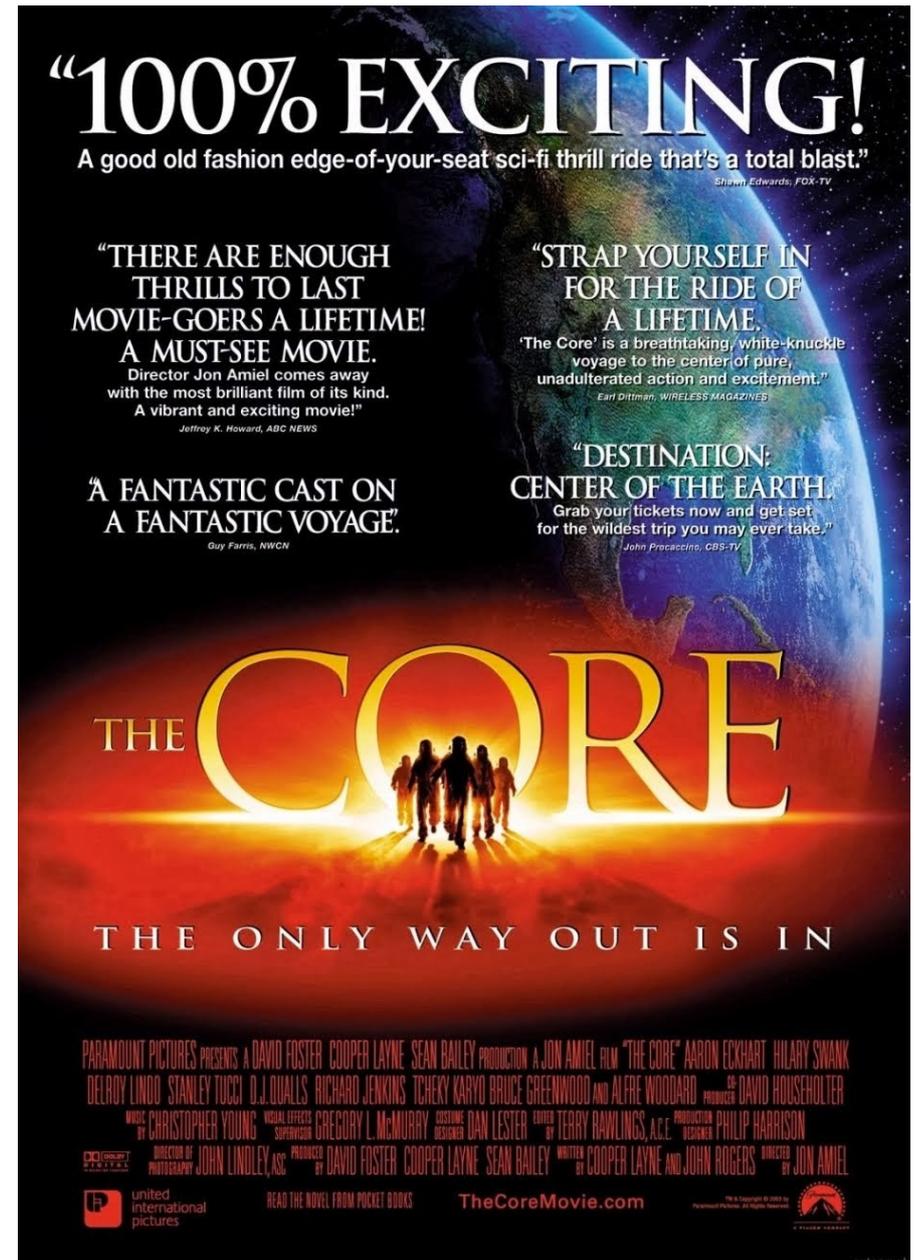
Certains minéralogistes aussi !

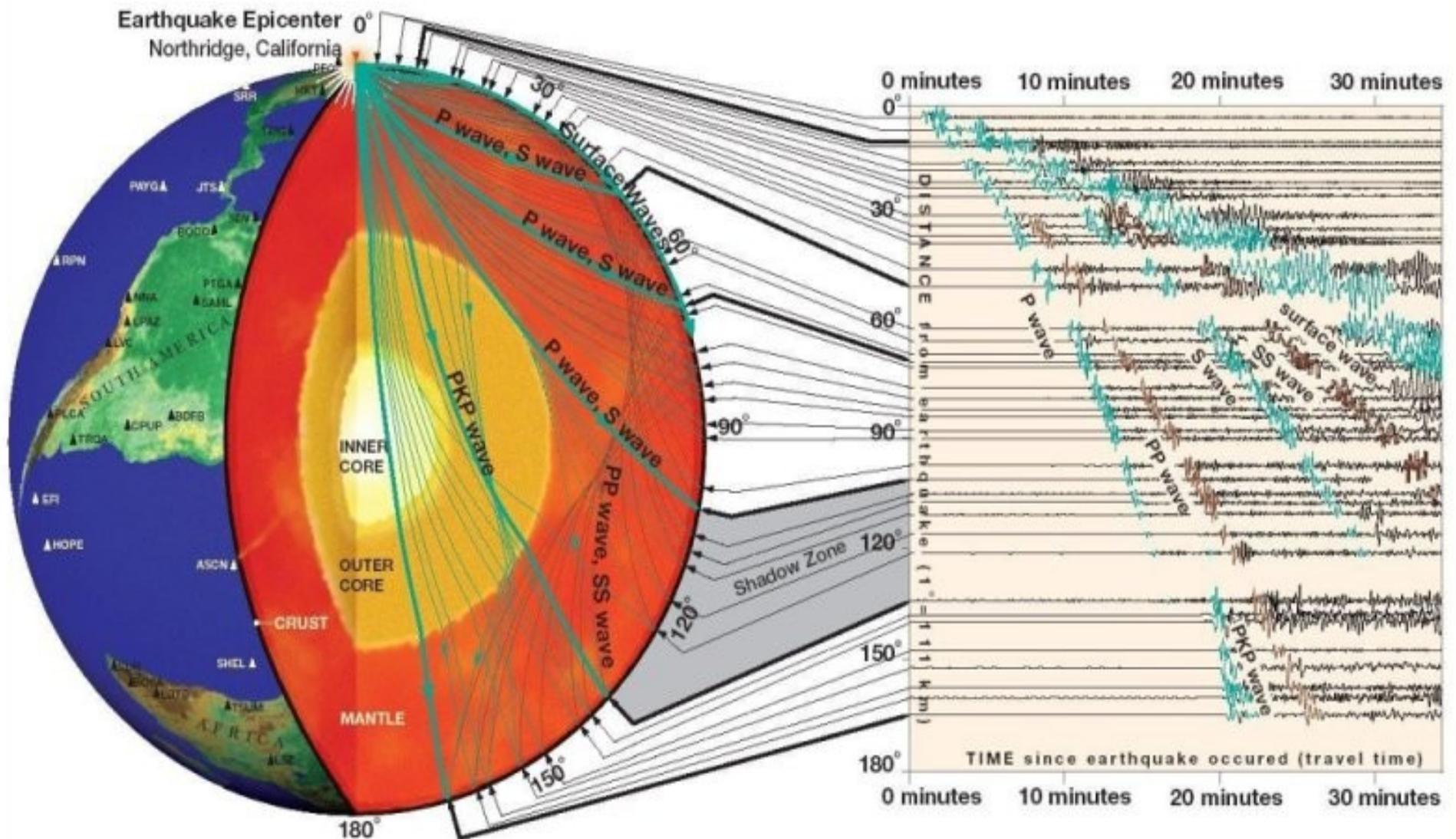


Des observables dans le manteau ?

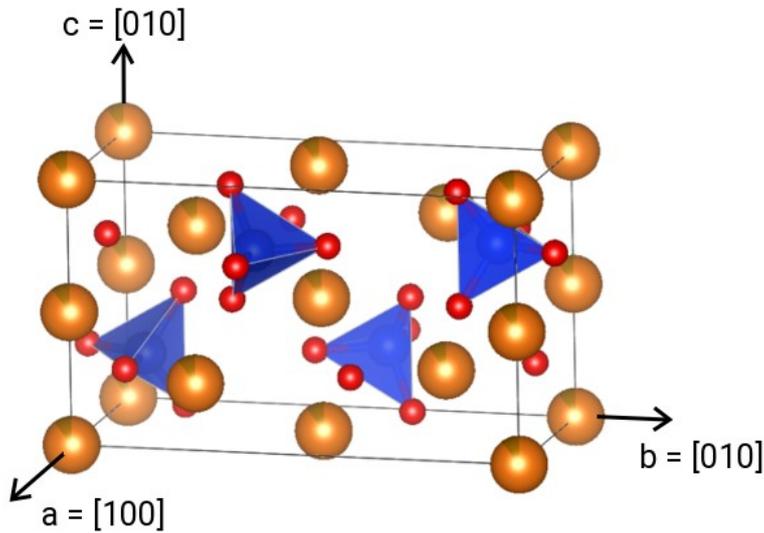


Forage record
Presqu'île de Kola (Sibérie)
Arrêté à 12 360 m
Une égratignure...



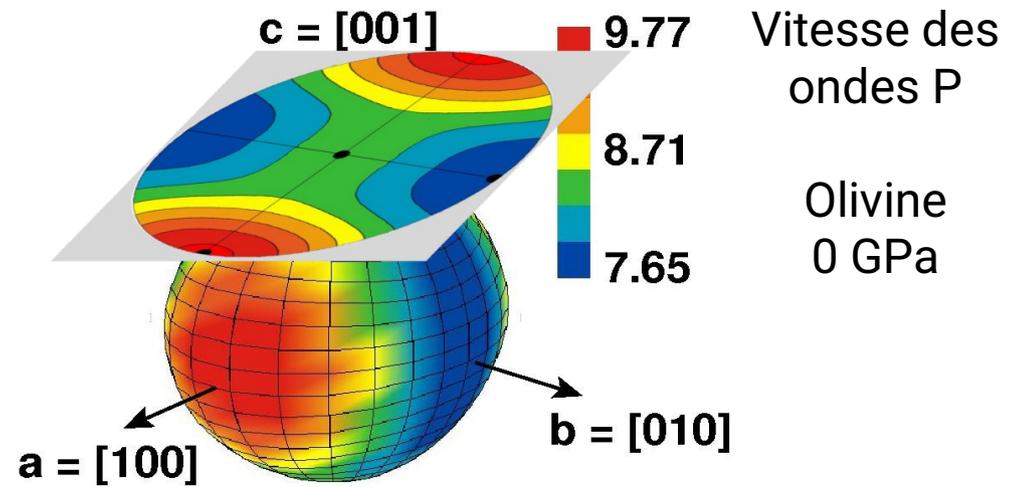


Vitesses des ondes sismiques

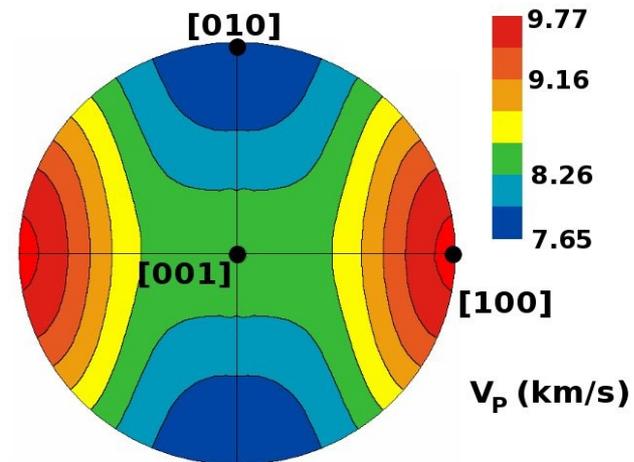


Olivine $(\text{Mg,Fe})_2\text{SiO}_4$

Illustrations : S. Merkel, Univ. de Lille



V_p (km/s)



Dans un cristal, la vitesse des ondes sismiques dépend de la direction de propagation

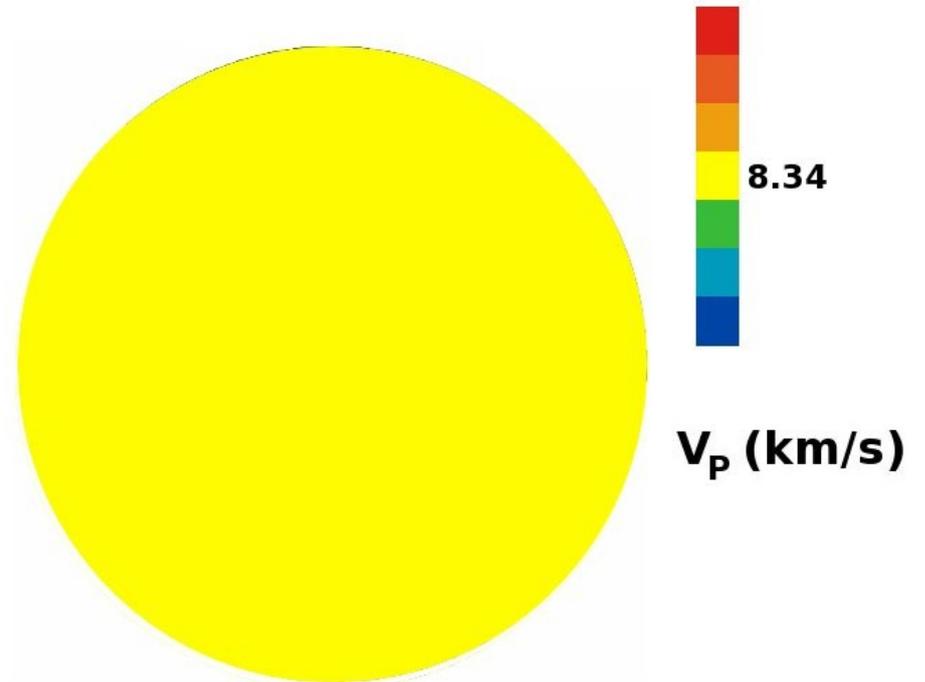


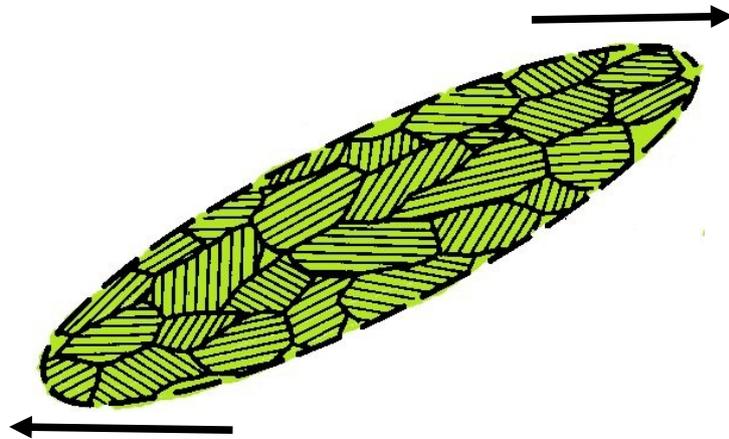
Roche

Assemblage de grains aléatoire

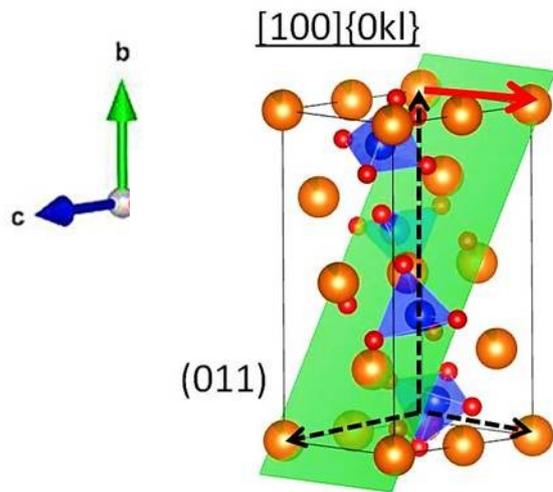
Les différents grains se compensent

Vitesse des ondes P = vitesse moyenne

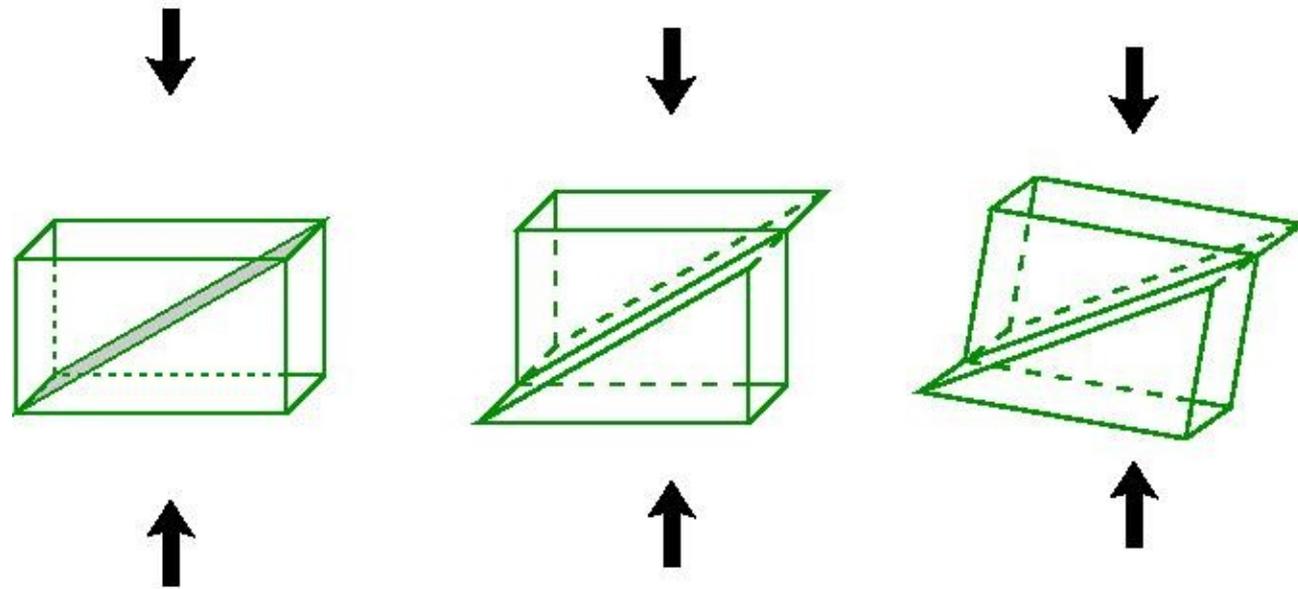




Plastic deformation
 Dislocation glide
 Grain rotations
 Non-random crystal orientations



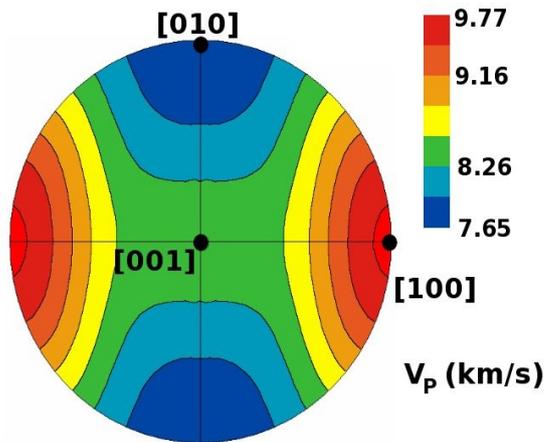
Olivine : sample of slip system



Vitesse des ondes sismiques

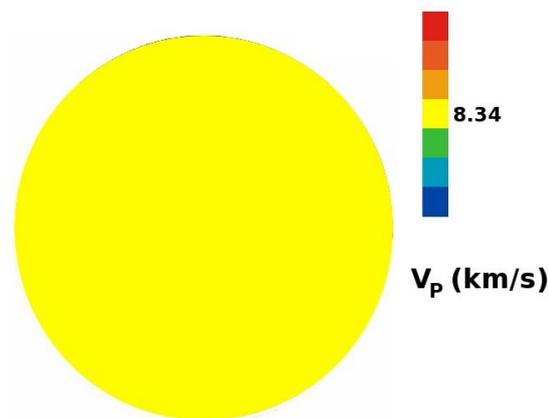
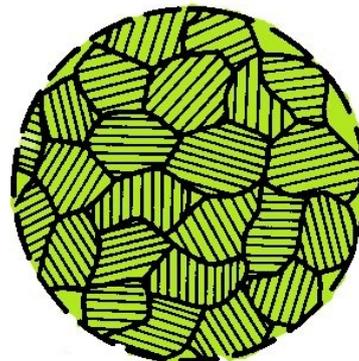
Roche déformée plastiquement

Monocrystal



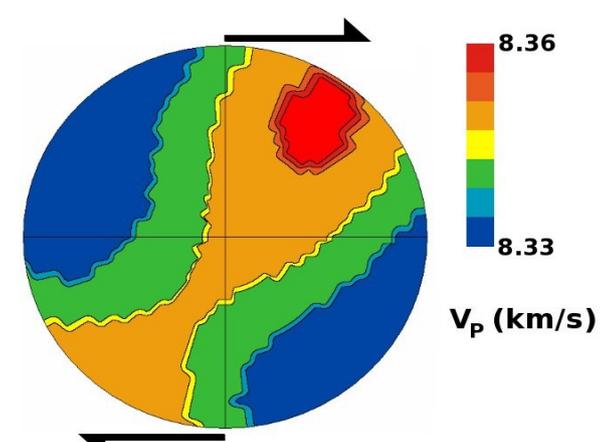
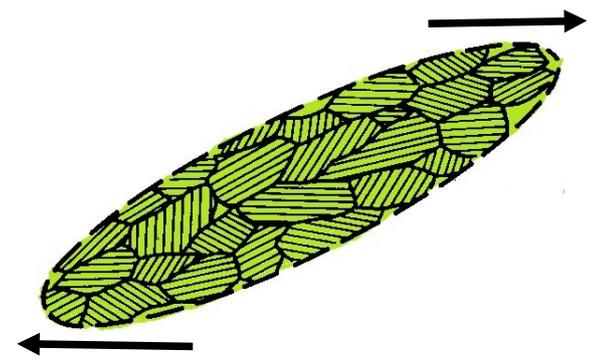
Anisotropie

Polycristal aléatoire

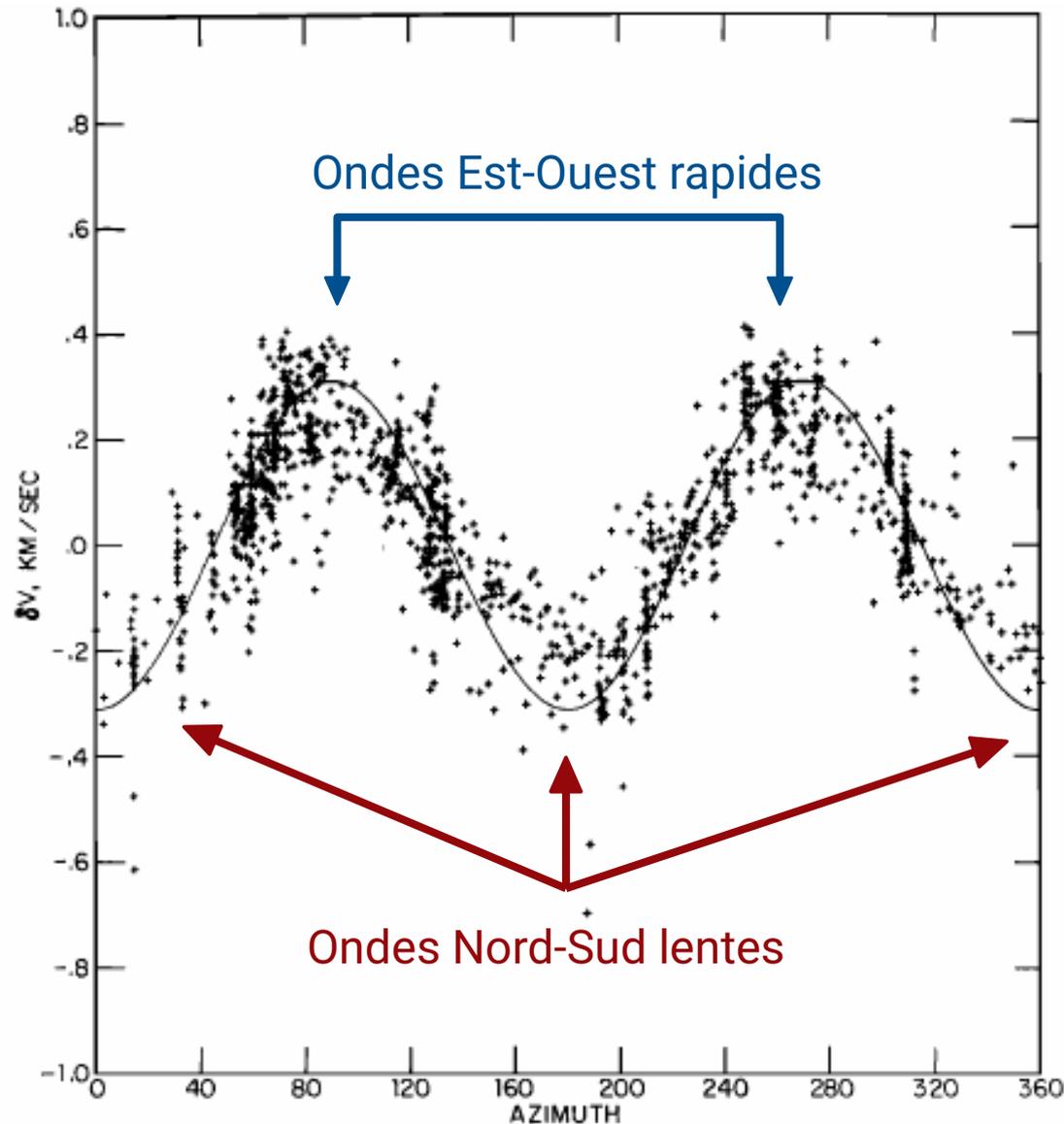


Pas d'anisotropie

Polycristal déformé



Anisotropie



Velocity Anisotropy and Delay-Time Maps of the Mantle near Hawaii^{1, 2}

G. B. MORRIS, R. W. RAITT, AND G. G. SHOR, JR.

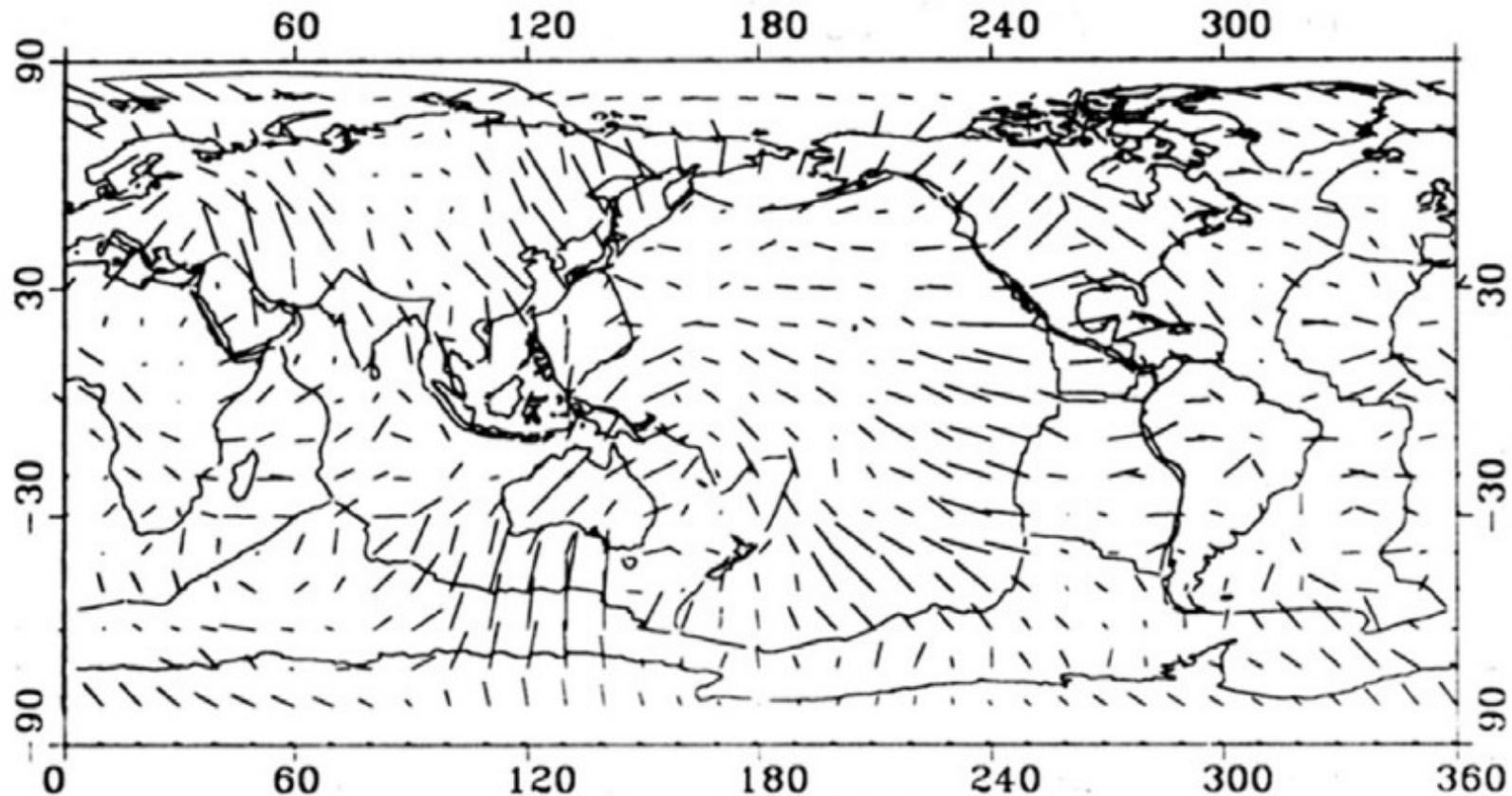
Vitesses des ondes P sous Hawaii

Changent avec la direction de propagation

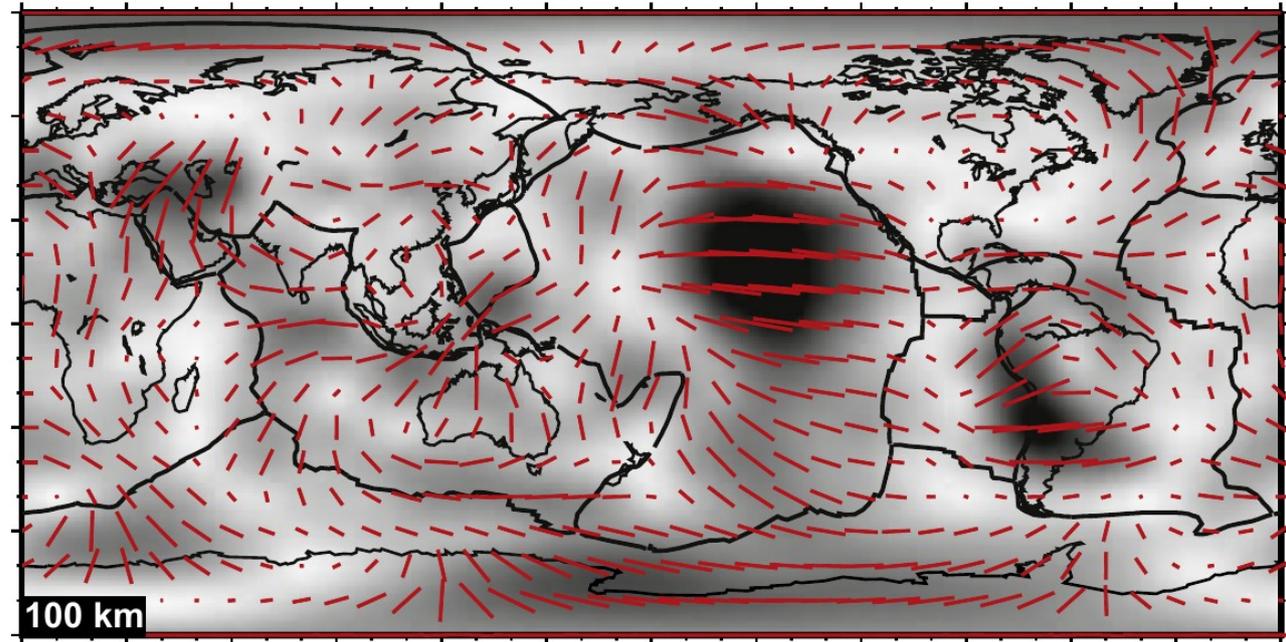
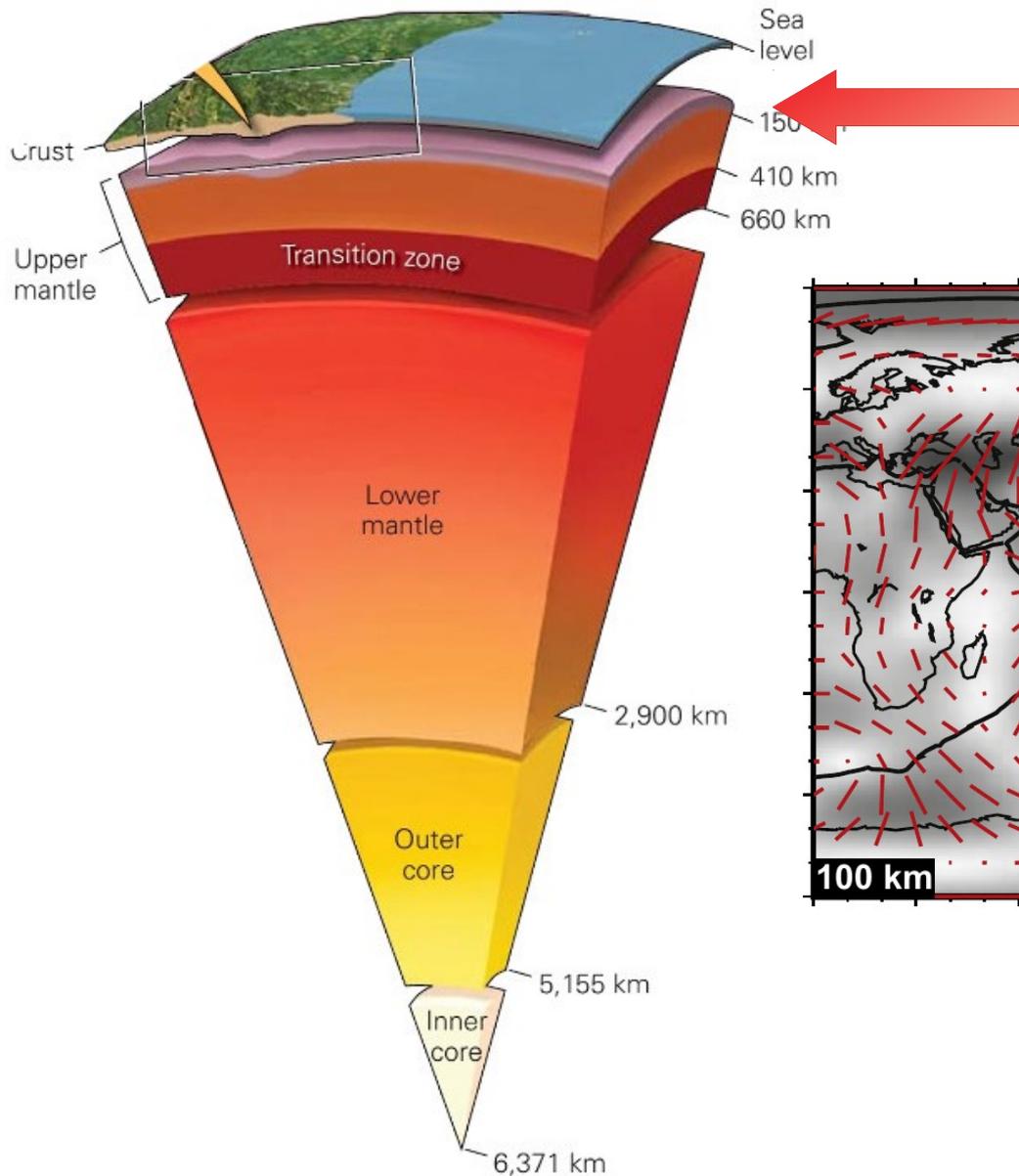
Observation de 1969

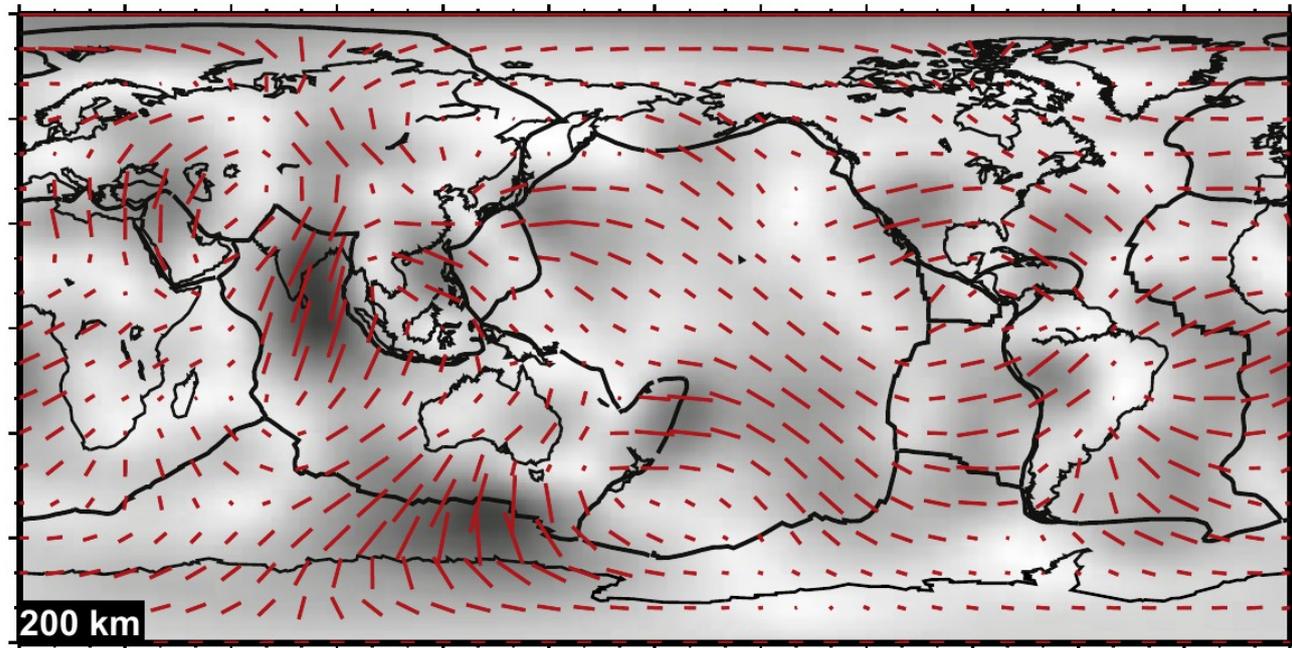
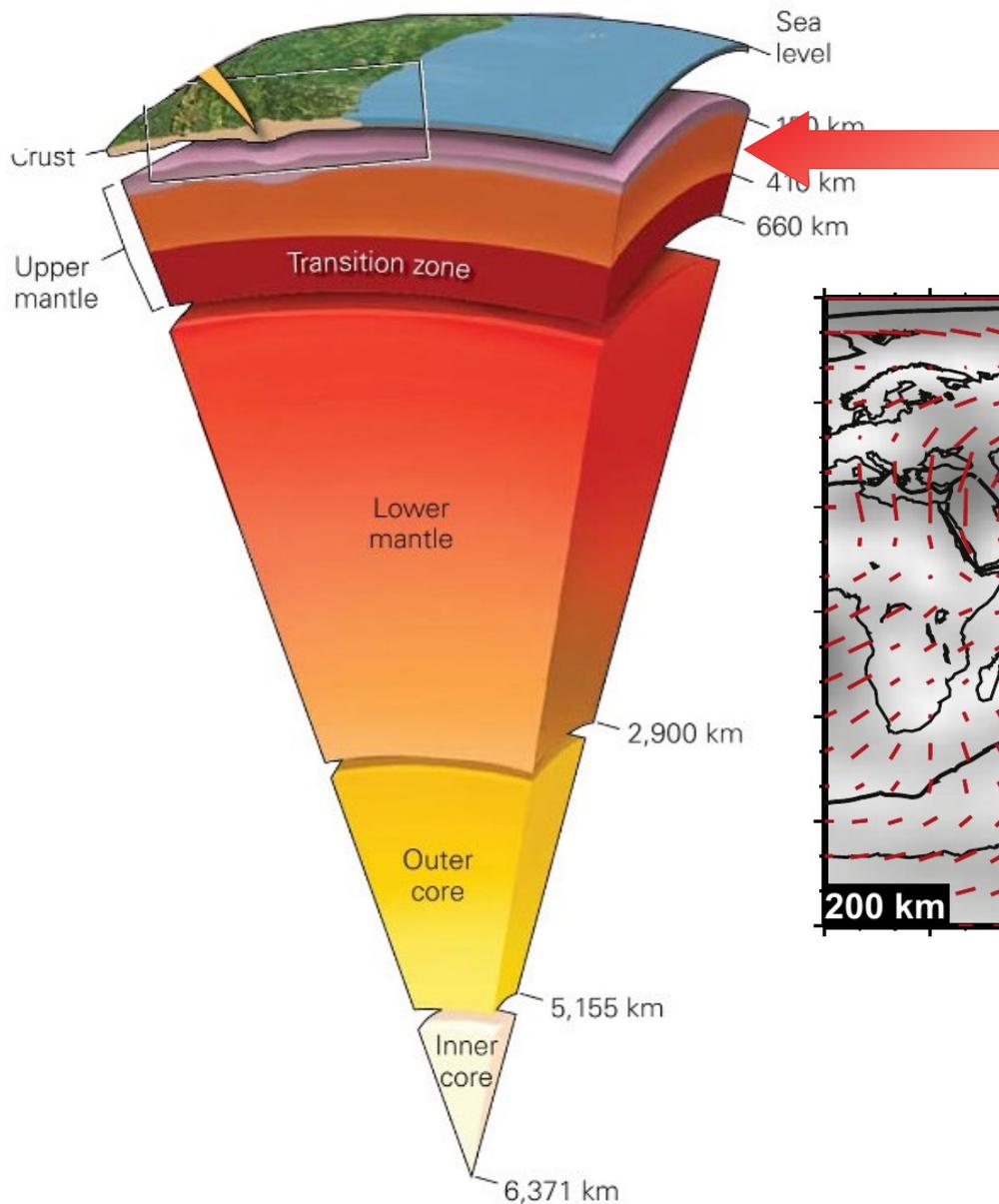
Fig. 12. Velocity anisotropy given as deviations from mean velocity of 8.159 km/sec plotted as a function of azimuth. Combined data are from Hilo and Show expeditions.

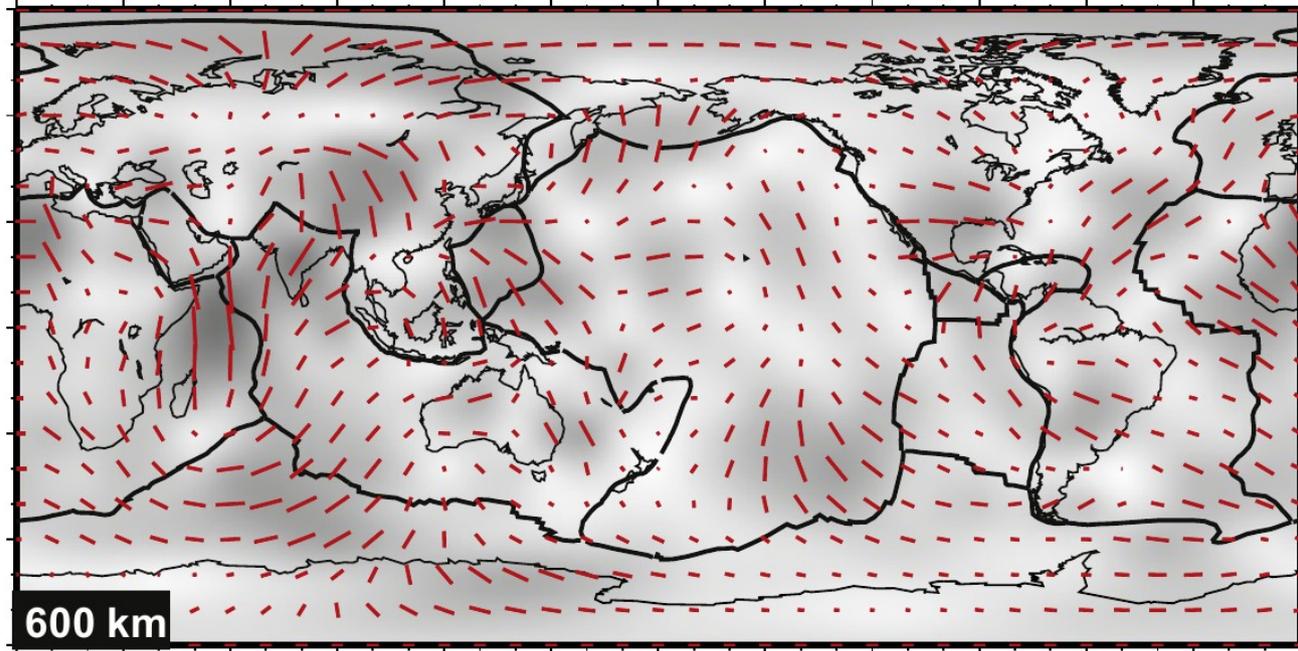
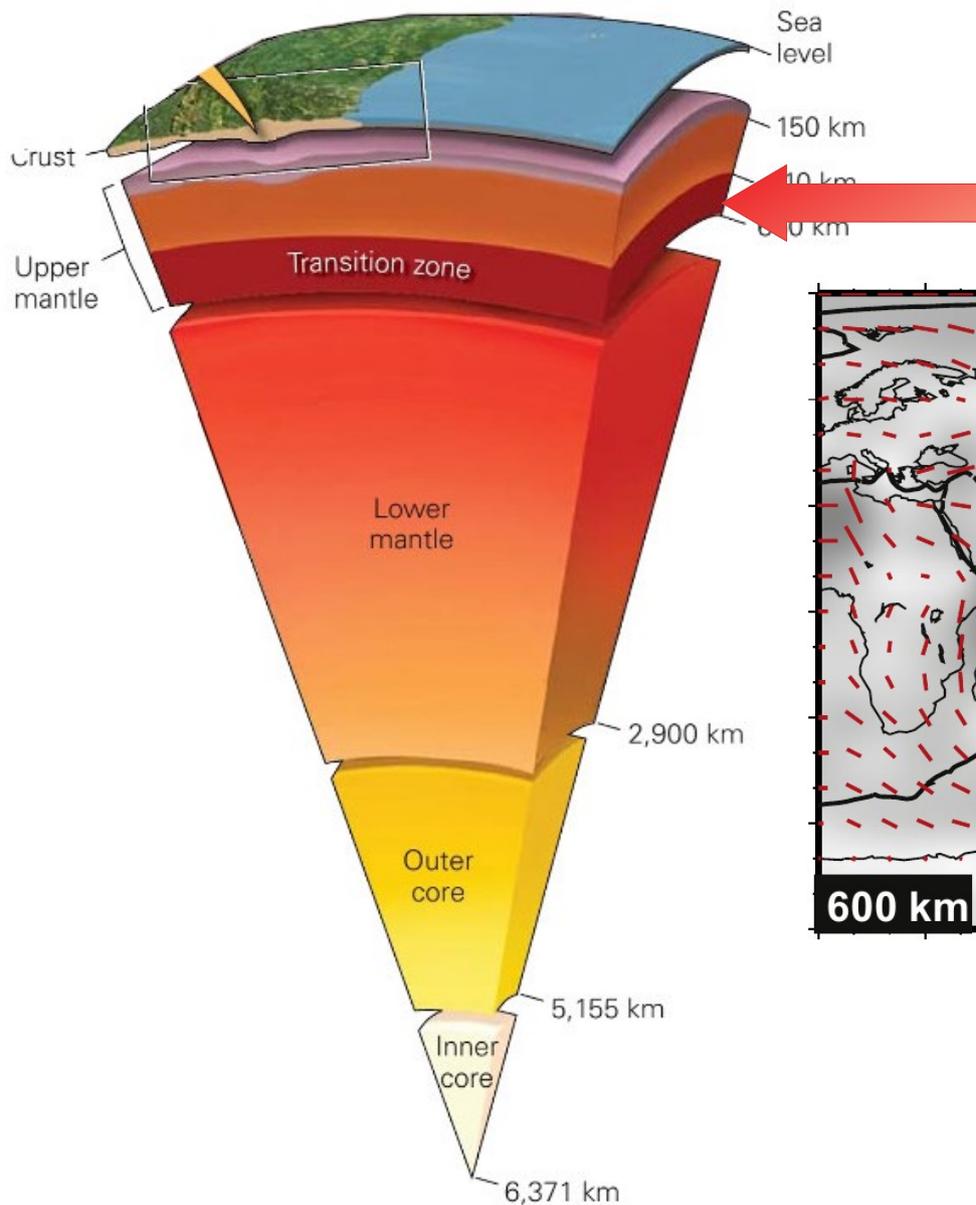
Anisotropie sismique dans le manteau terrestre
Montagner and Tanimoto, 1991

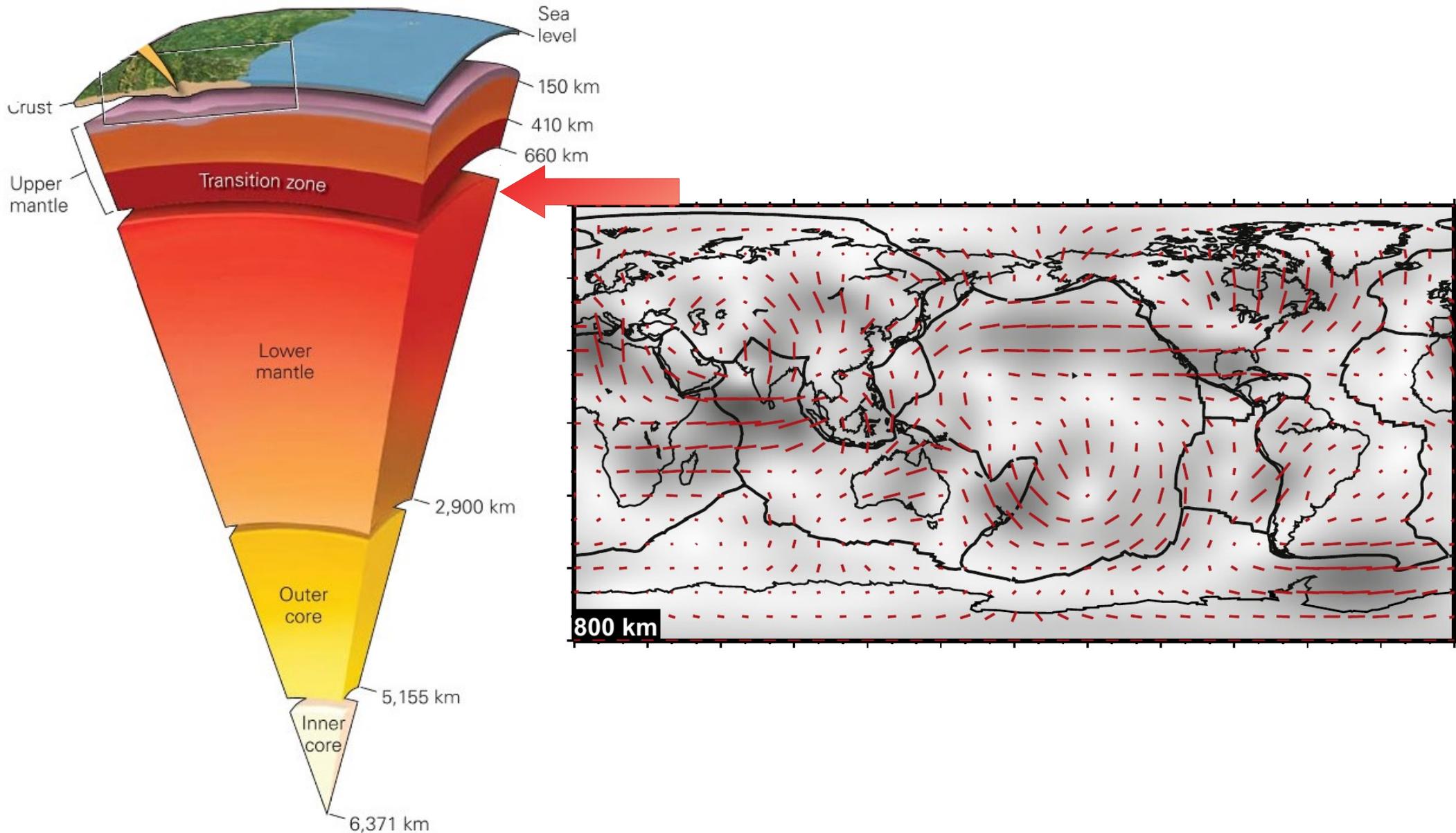


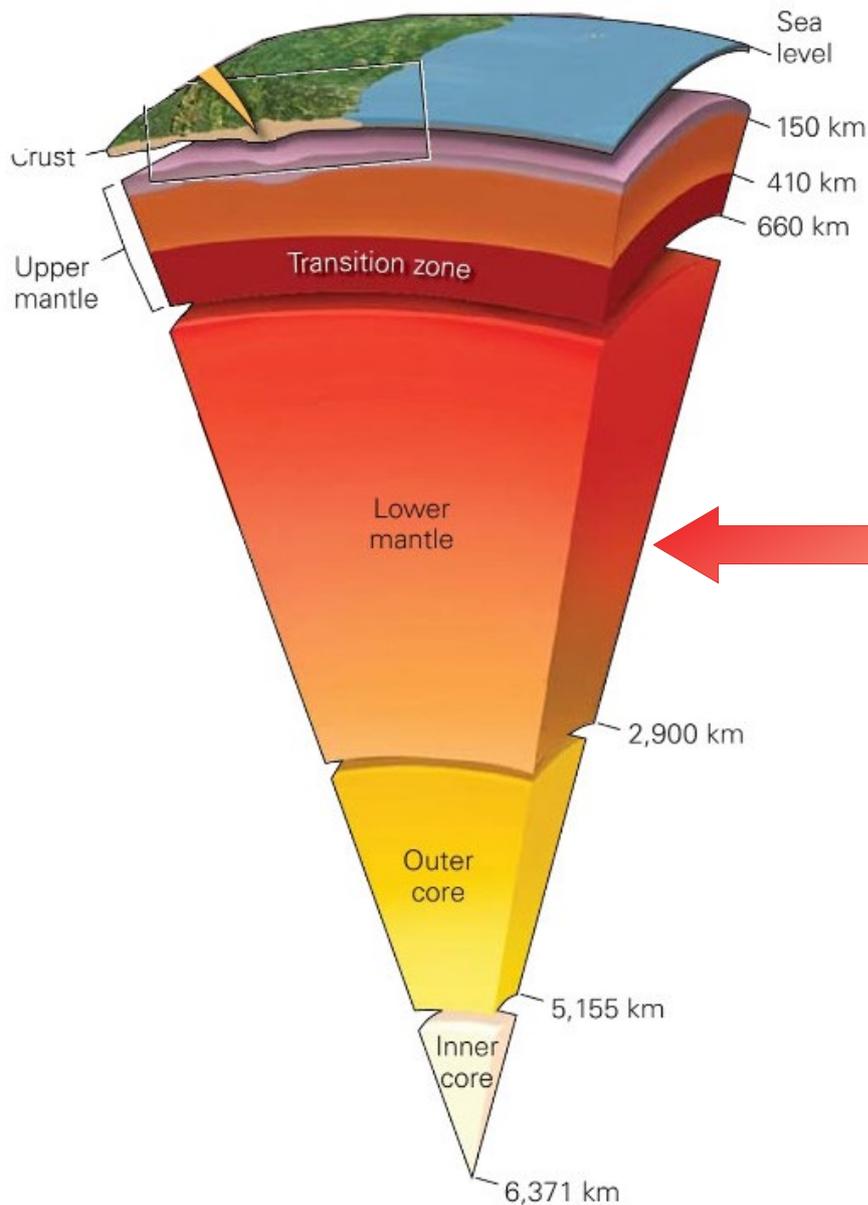
Orientation des battons : directions de propagation rapides



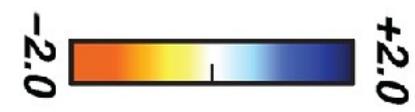
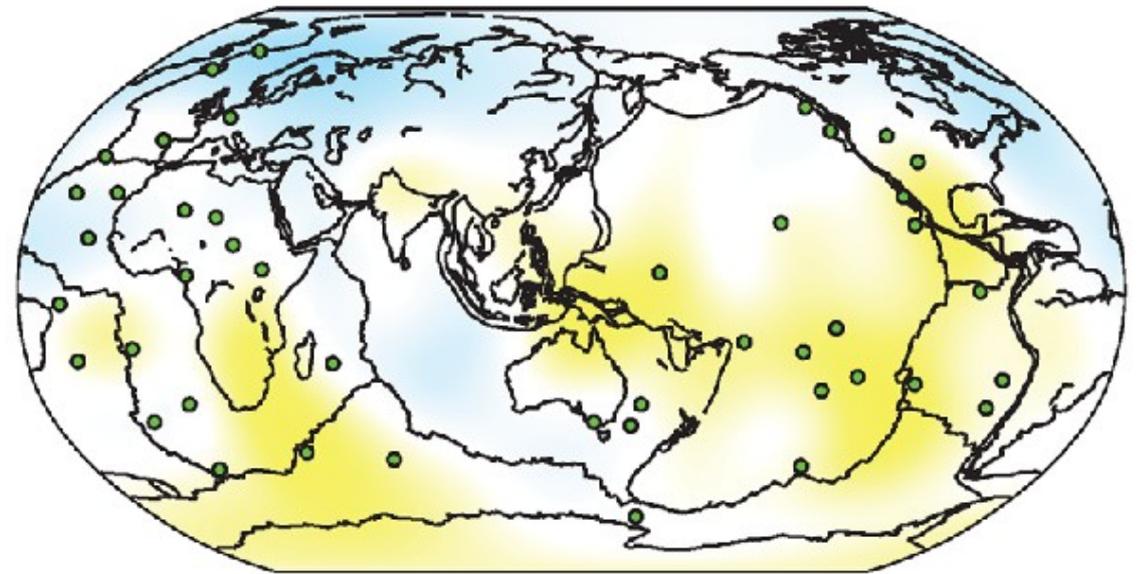


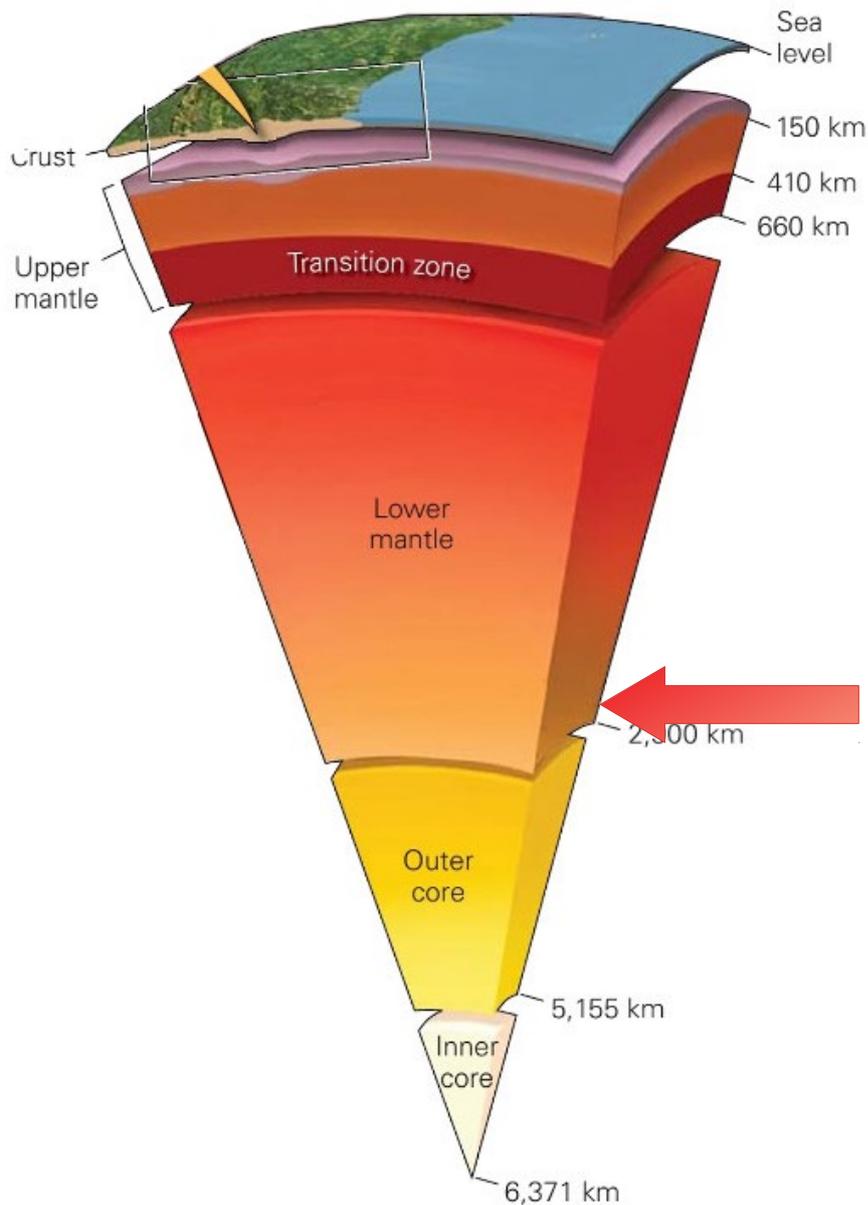




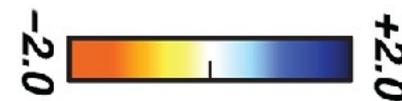
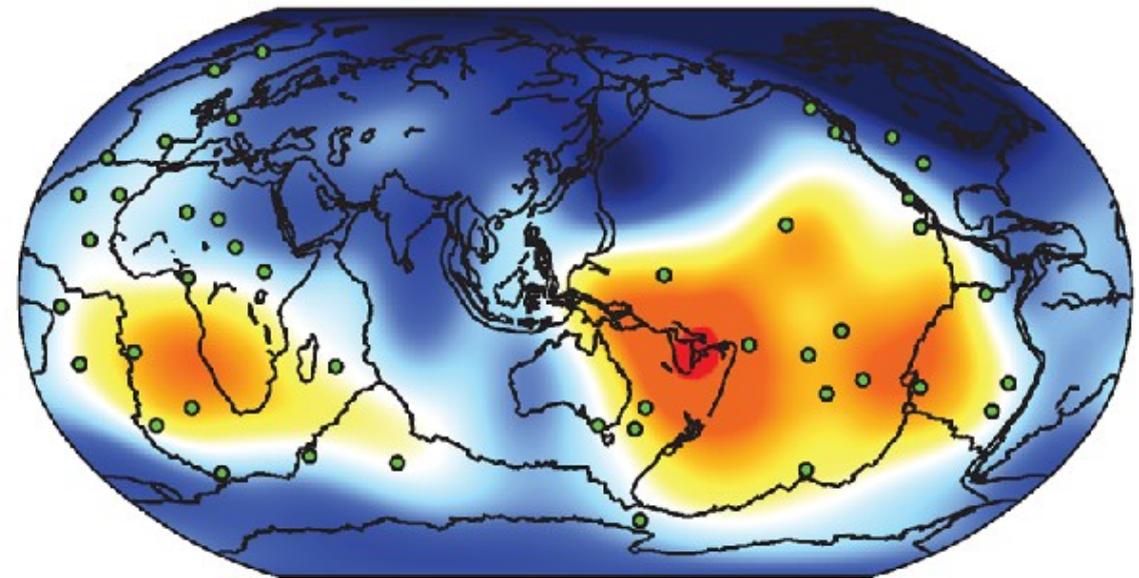


-0.5 / +0.6



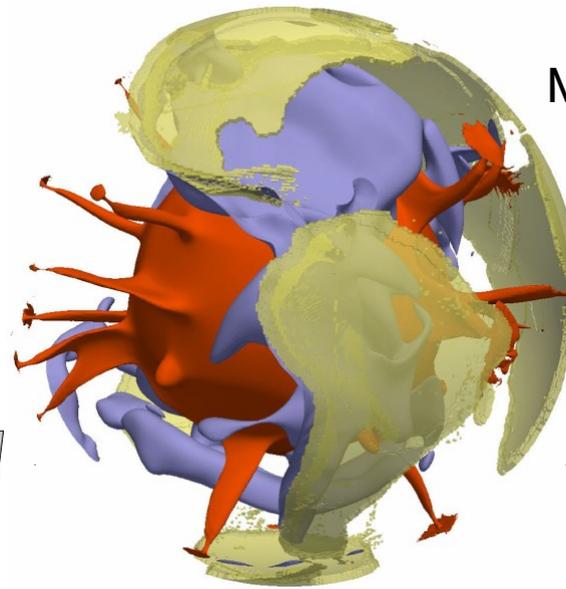


-2.1 / +2.8

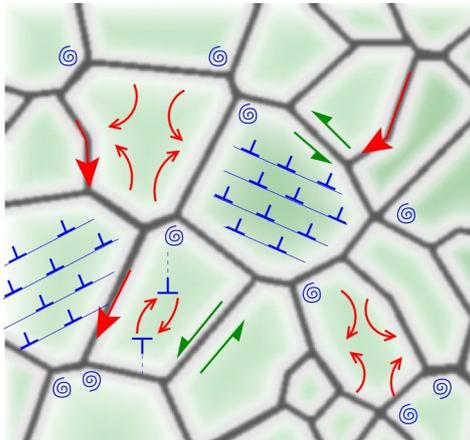
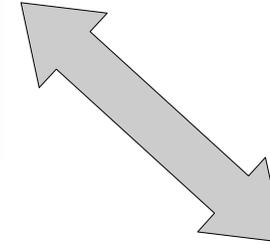
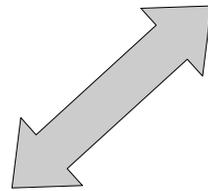


Dynamique du manteau profond

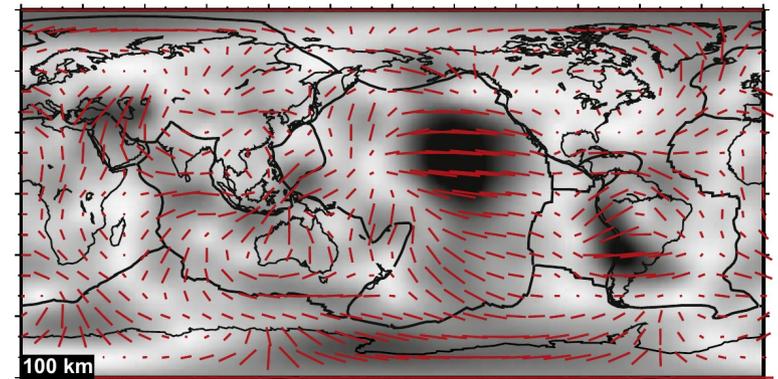
Un cercle vertueux



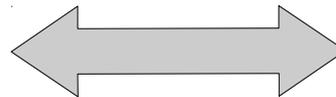
Géodynamique
Modèles de du manteau



Minéralogie
Plasticité de minéraux



Sismologies
Observables vérifiables

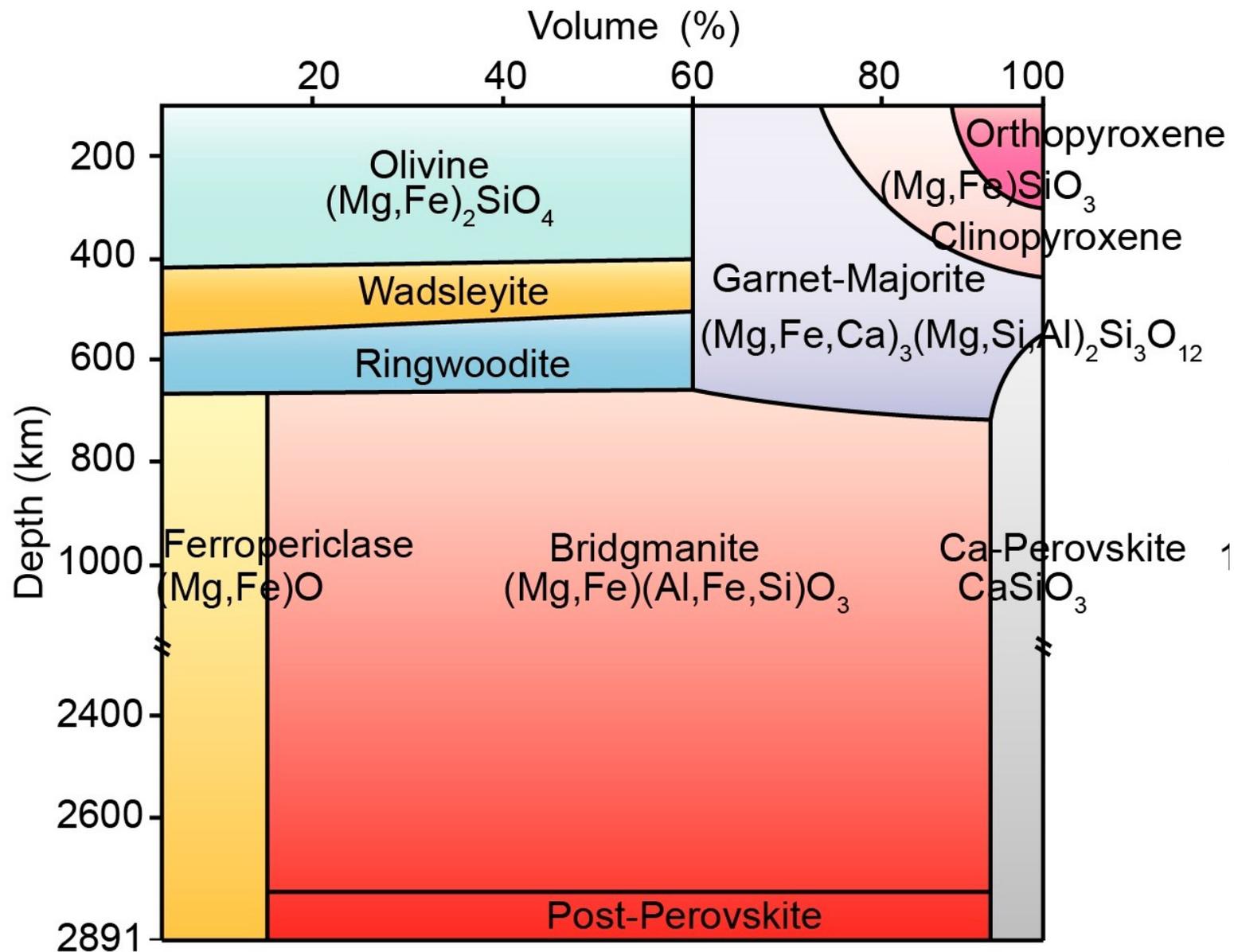


Robustesse des observations d'anisotropie sismique ?

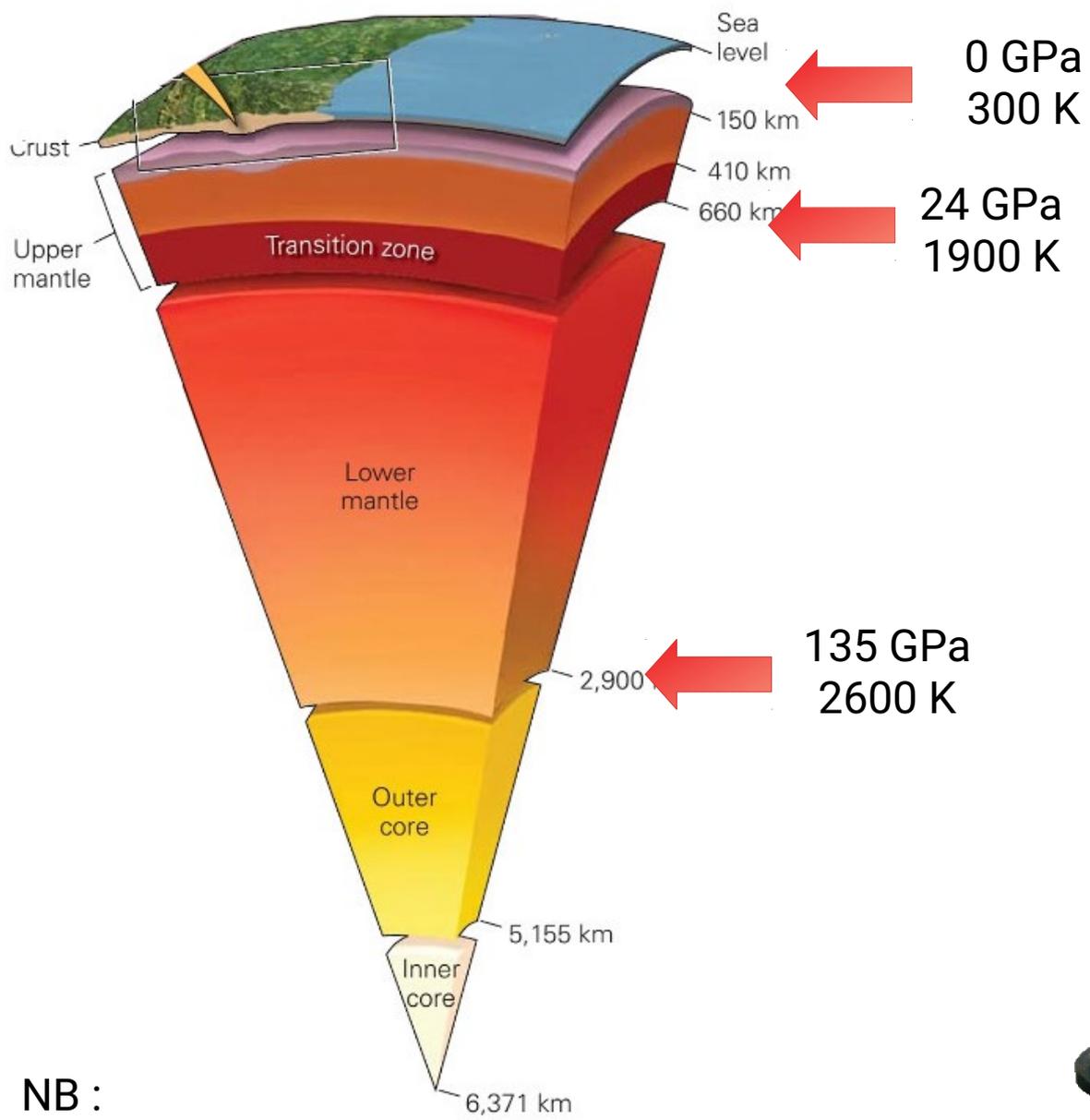
- Effet des algorithmes d'inversion ?
 - Reproductibilité des mesures
- reste encore un débat de spécialistes

Interprétation des observations

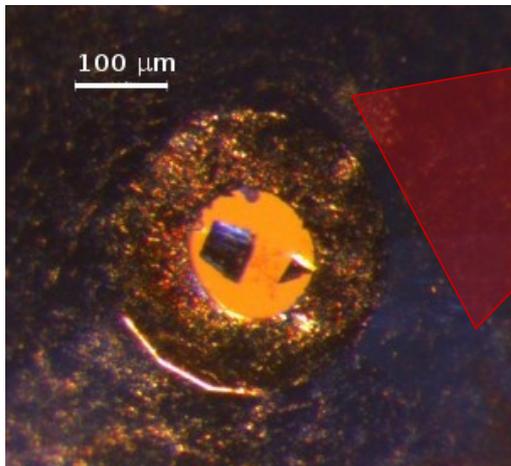
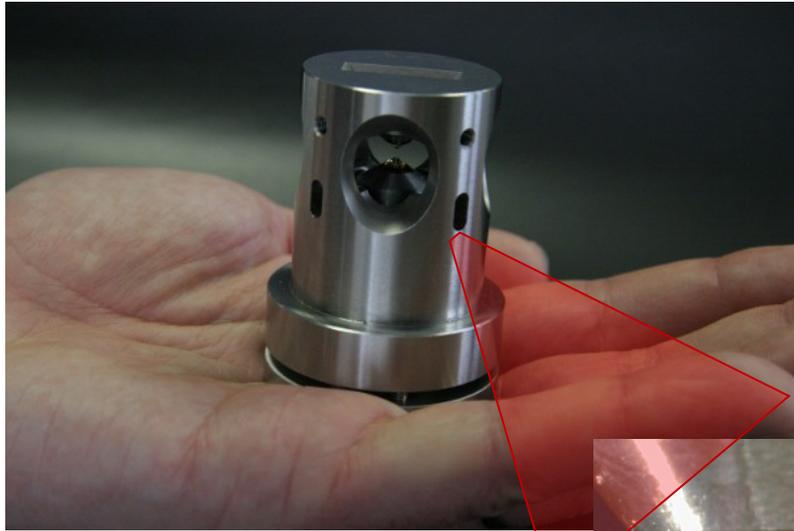
- Lien entre direction rapide et direction de déformation dans le manteau ?
 - Effet des changements de minéralogies ?
 - Effet des conditions de P / T / déformation ?
- encore beaucoup de travail



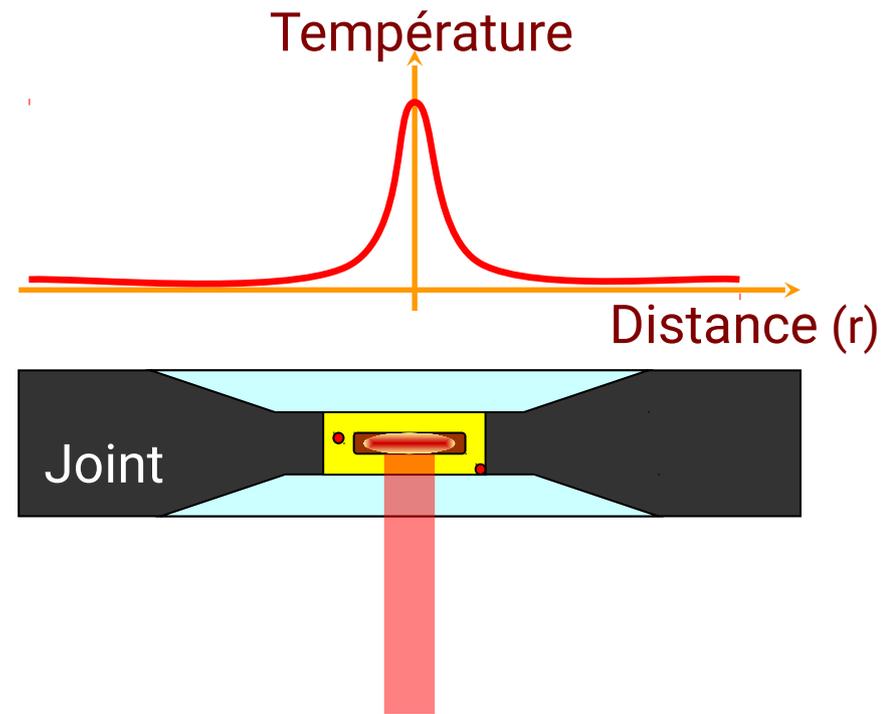
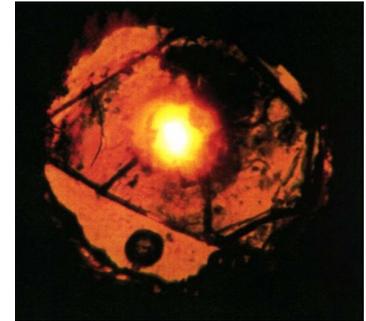
La convection du manteau en minéralogie



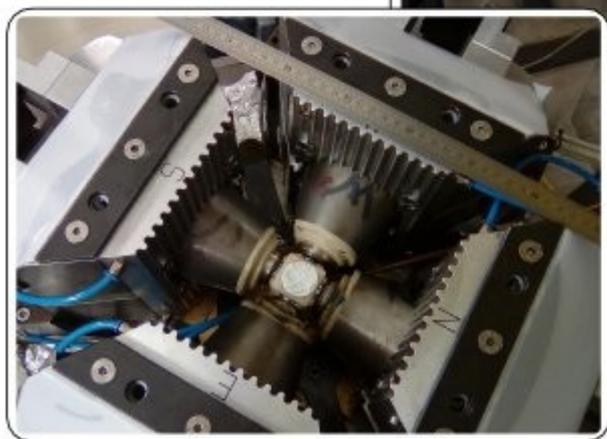
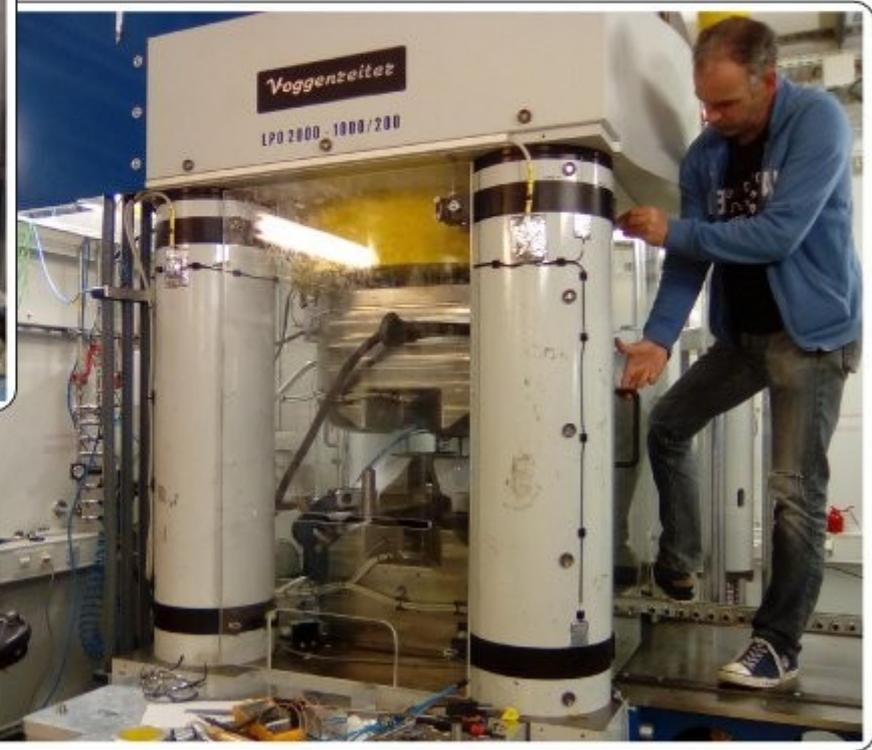
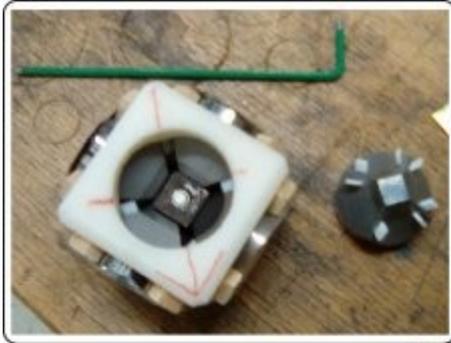
NB :
100 GPa = 10^6 atm



Chauffage des
échantillons
par laser

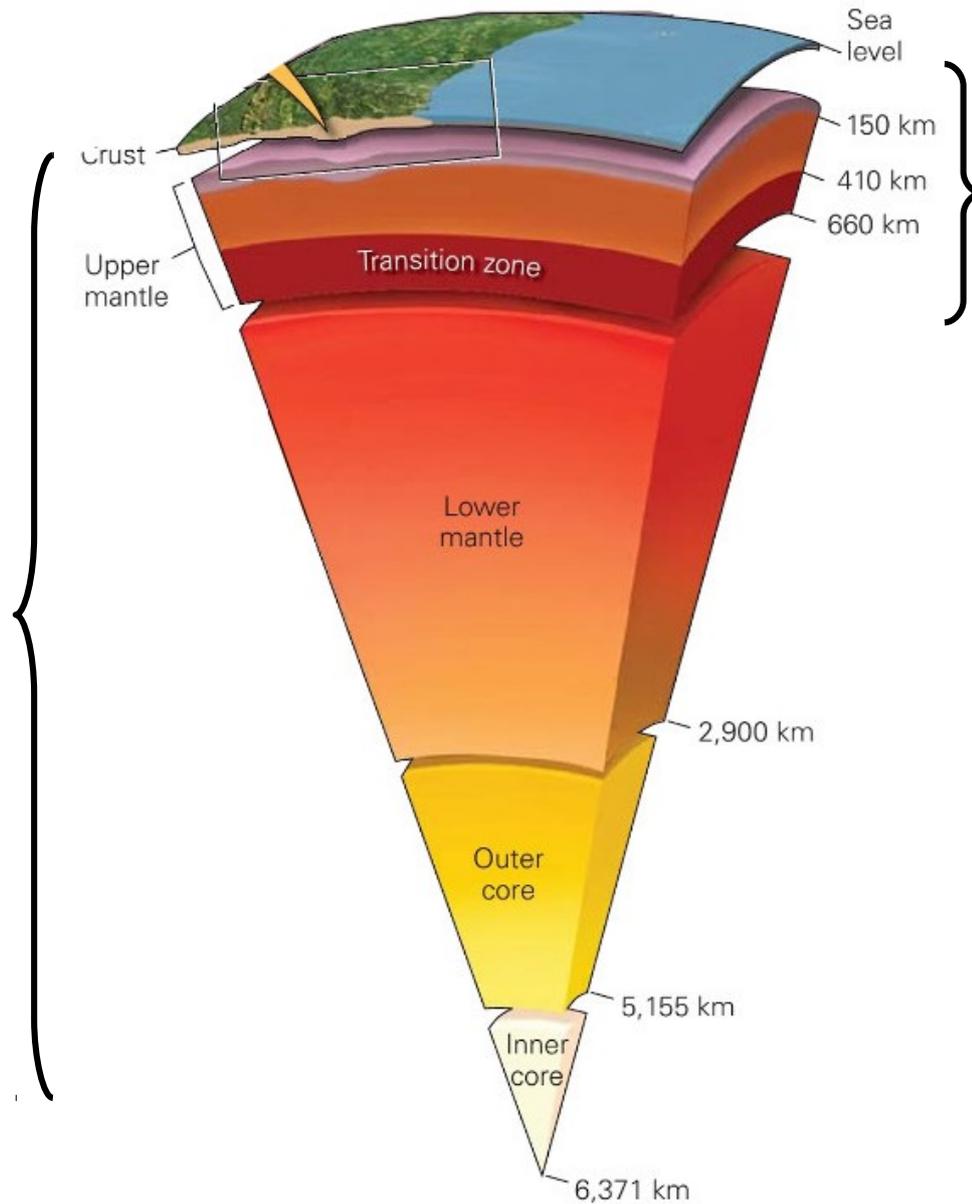
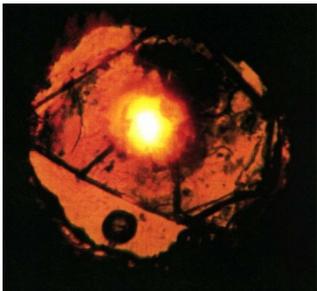


Large volume press
sample loading
at ESRF@ID06





Cellules à enclumes de diamant
Chauffage laser



Presses
« gros volume »



Synchrotron ESRF, Grenoble



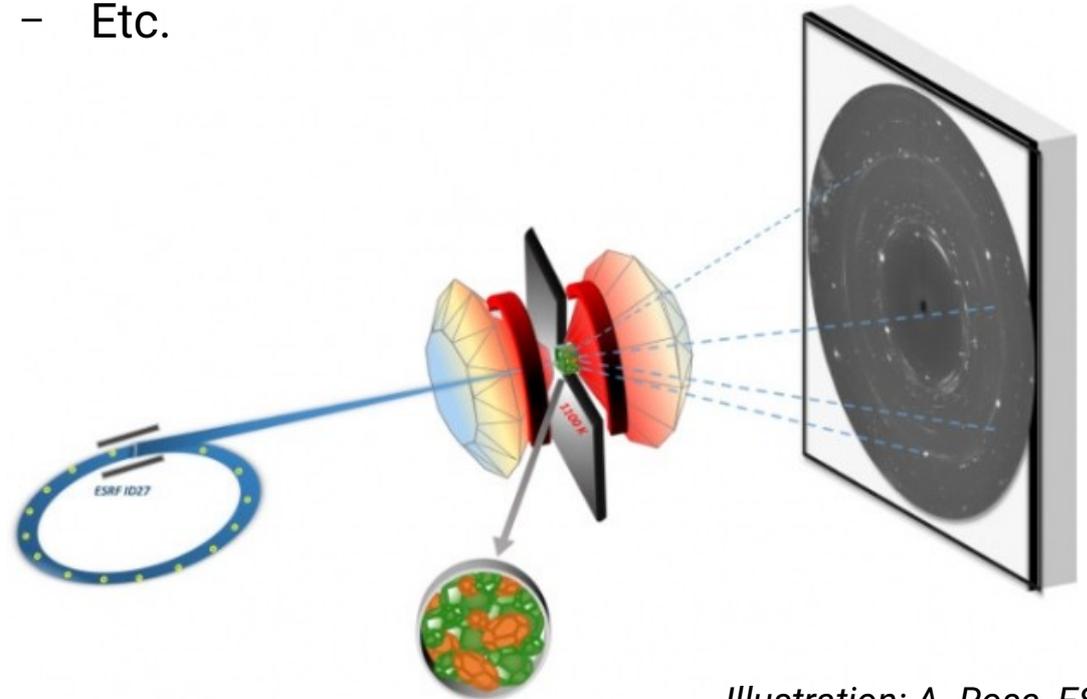
Lignes dédiées sur grands instruments internationaux

Sources de rayons X très intenses, très focalisés

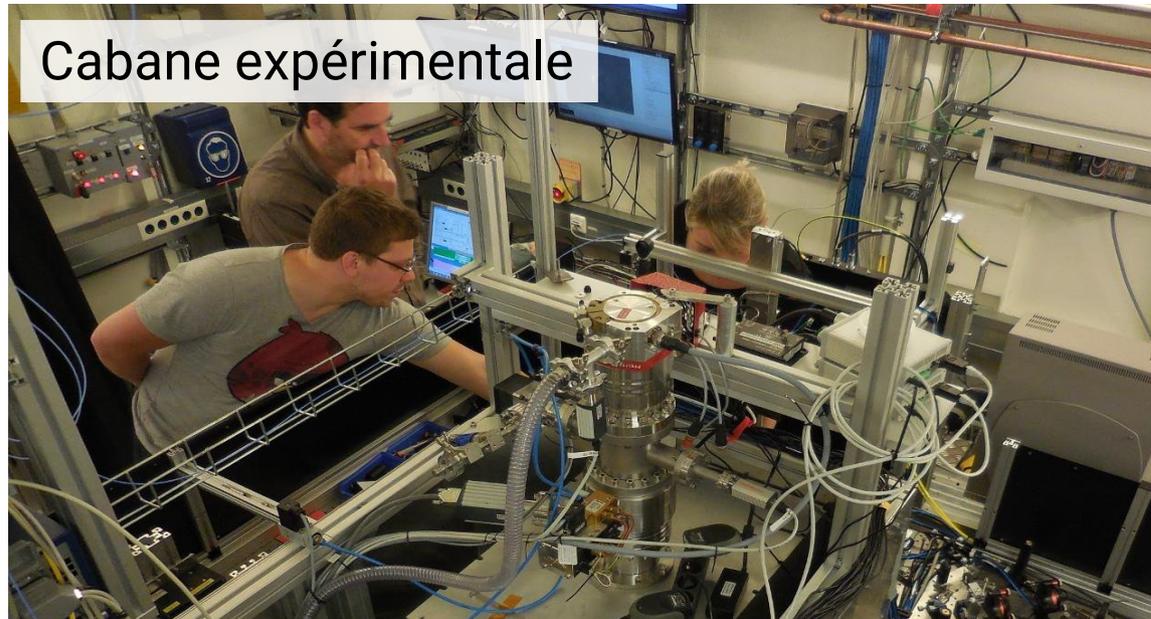
Mesures :

- Diffraction des rayons X ;
- Radiographie ;
- Tomographie ;
- Etc.

Synchrotron Soleil, près de Paris



Cabane expérimentale



Cabane de pilotage

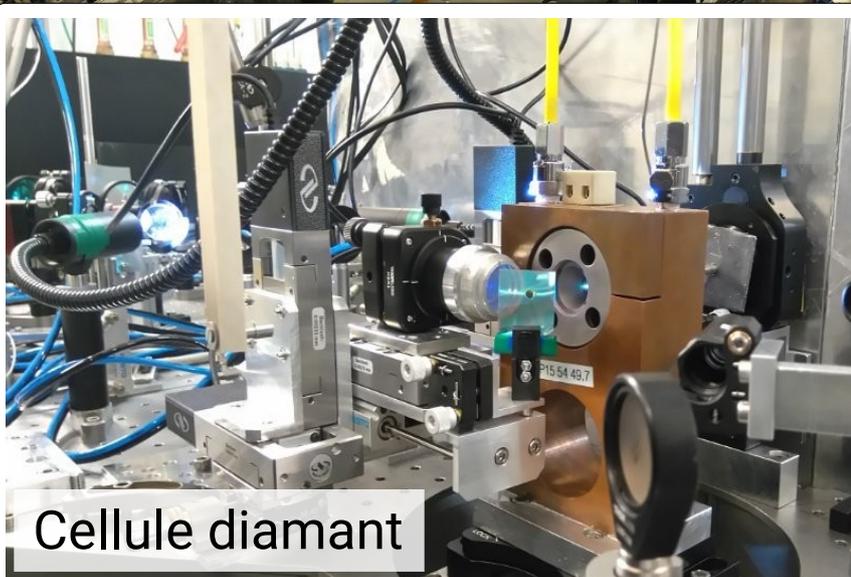


Ligne d'expérimentation
cellule diamant

Synchrotron PETRA III

Hambourg

Cellule diamant



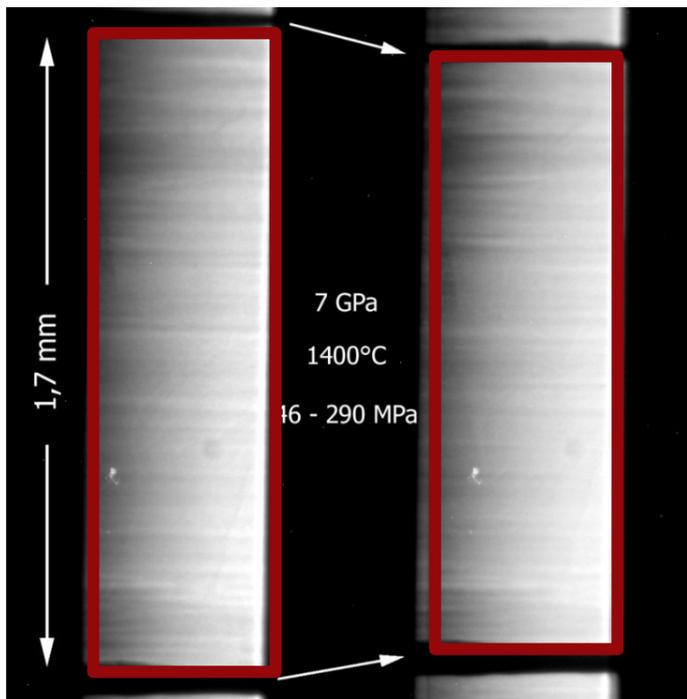
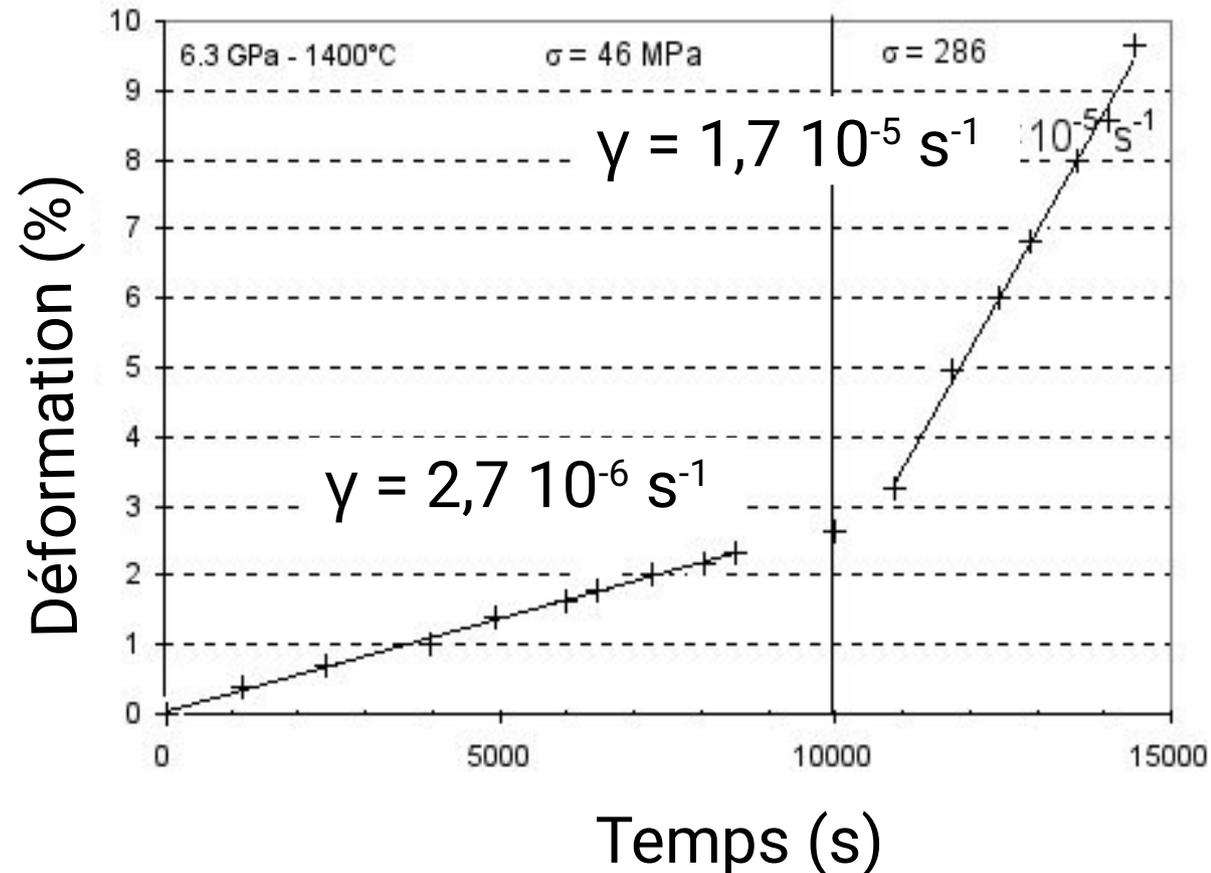


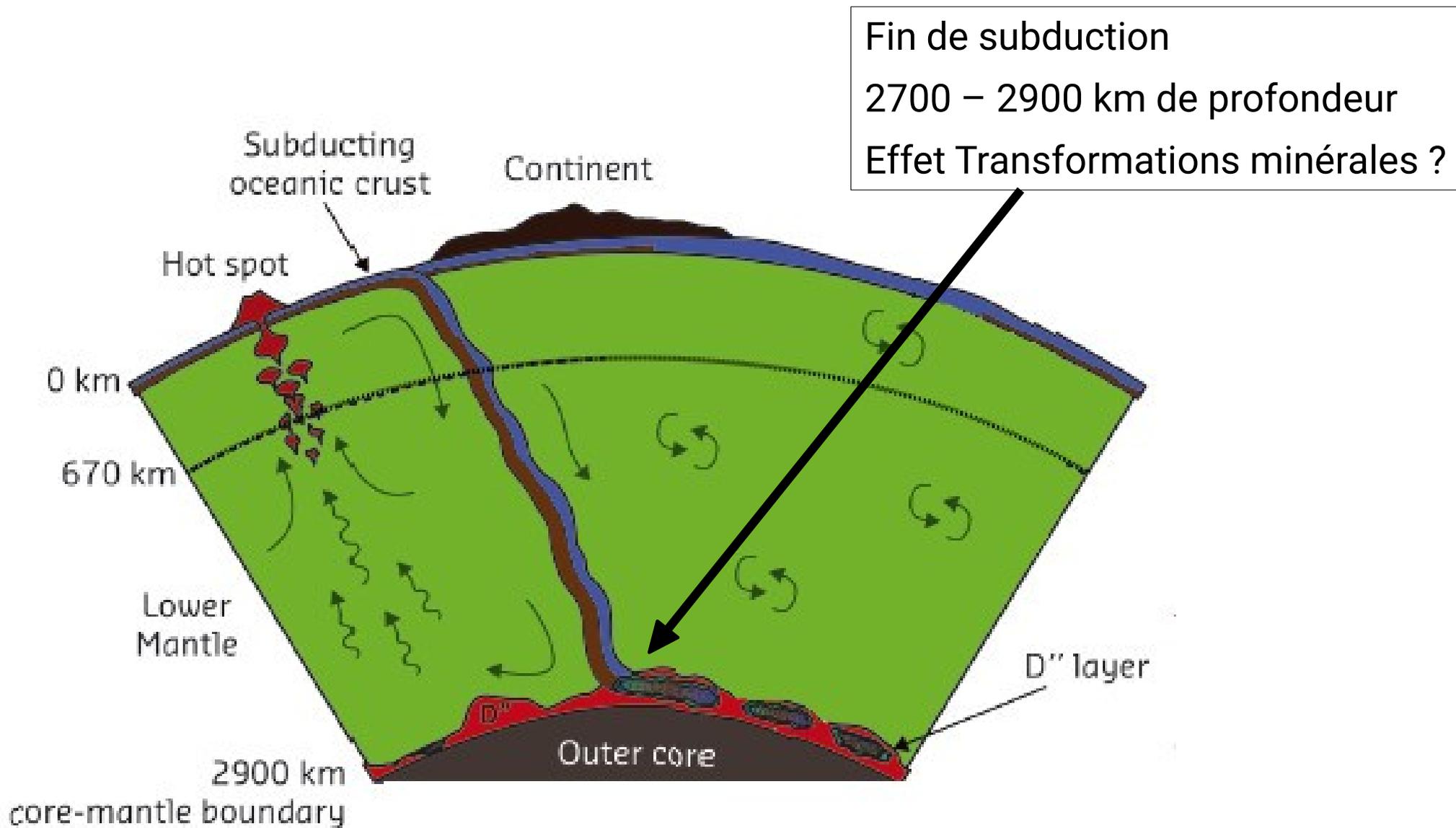
Image en radiographie
 Échantillon d'olivine déformé
 7 GPa – 1673 K (~ 220 km)
 Mesure de longueur
 d'échantillon en fonction du temps

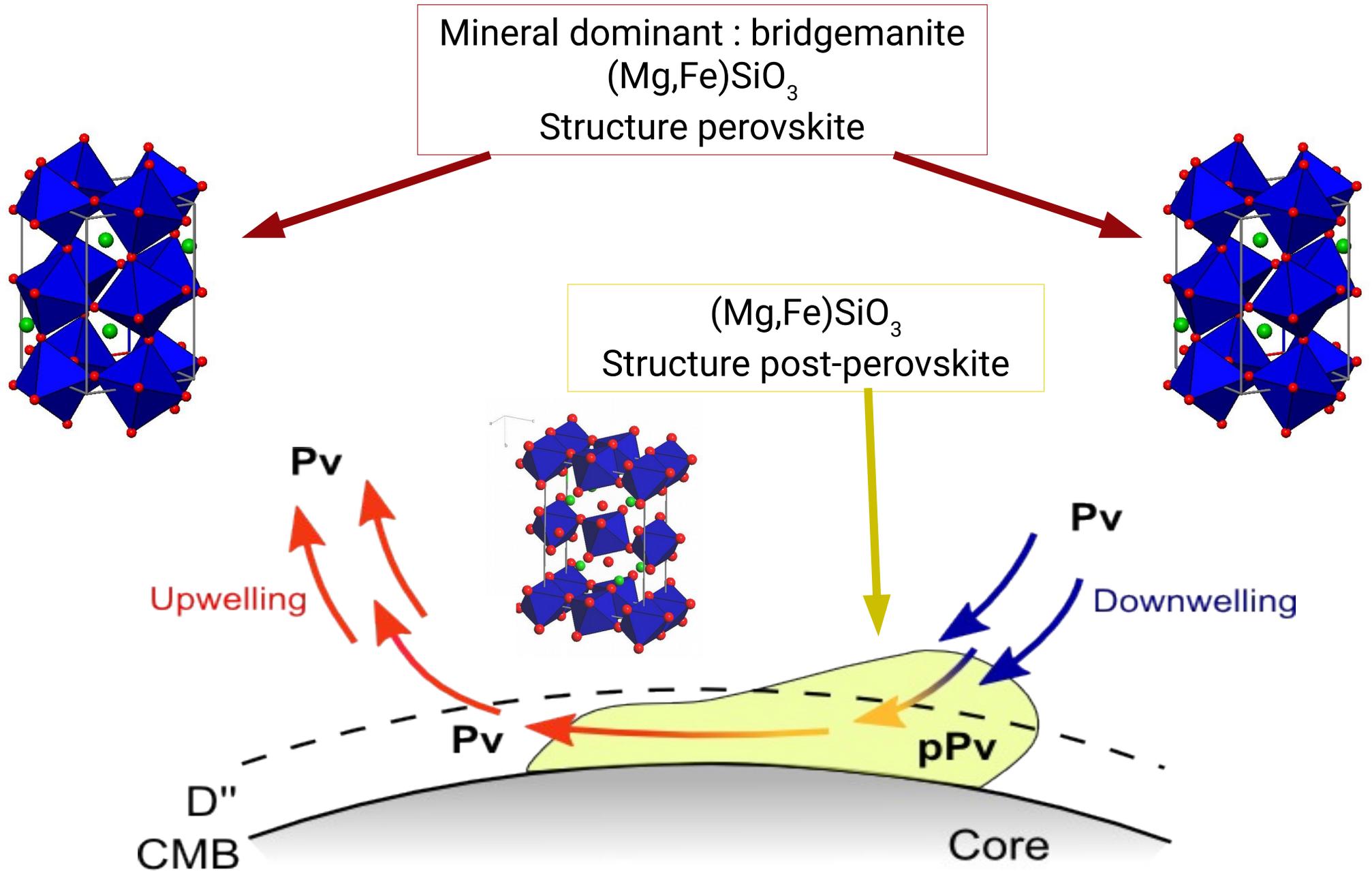


Ajustement de lois du type

$$\dot{\epsilon} = A \sigma^n d^{-p} e^{\frac{-E^*}{RT}}$$

→ viscosité

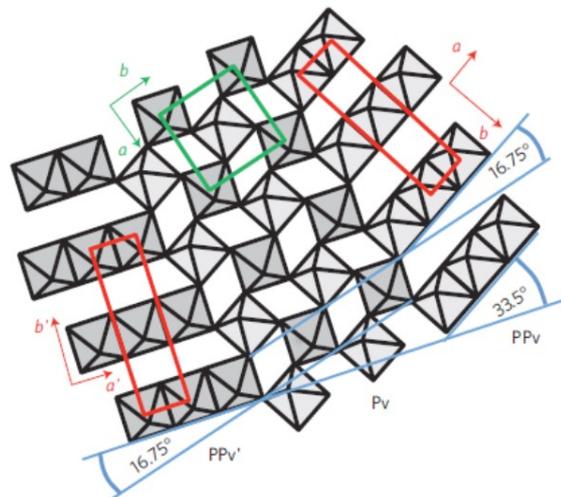
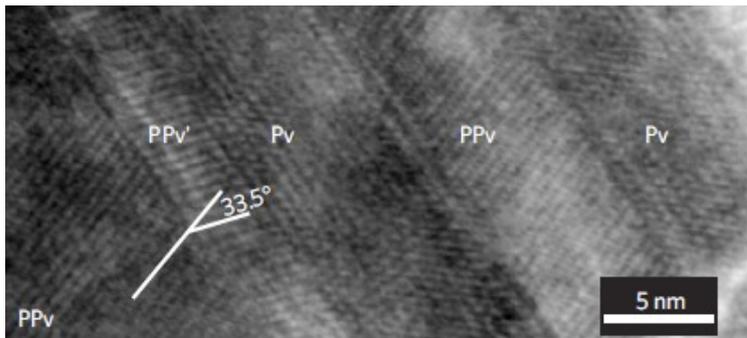




Strong inheritance of texture between perovskite and post-perovskite in the D'' layer

David P. Dobson^{1,2*}, Nobuyoshi Miyajima³, Fabrizio Nestola⁴, Matteo Alvaro⁴, Nicola Casati⁵,
 Christian Liebske², Ian G. Wood¹ and Andrew M. Walker⁶

NATURE GEOSCIENCE | VOL 6 | JULY 2013

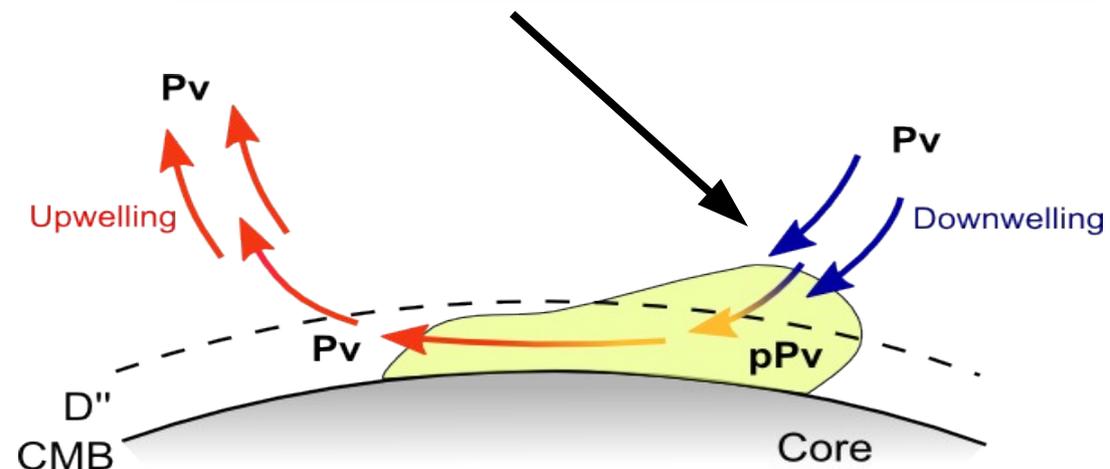


Transformation de phase

- Effet de mémoire ?
- Orientations de cristaux préservées ?

Observations sismiques

- Mesure de la déformation (convection) locale ?
- Effet de l'histoire de la subduction ?

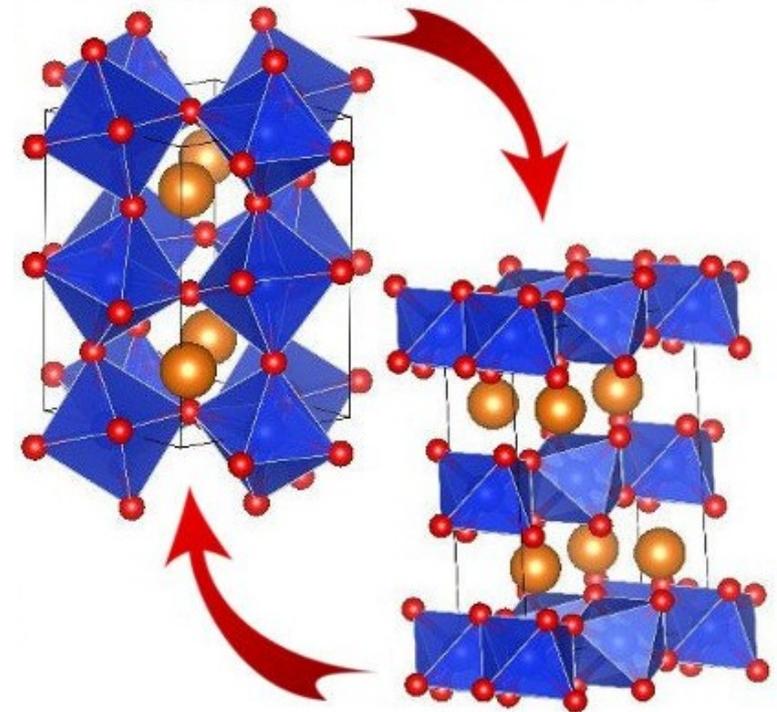
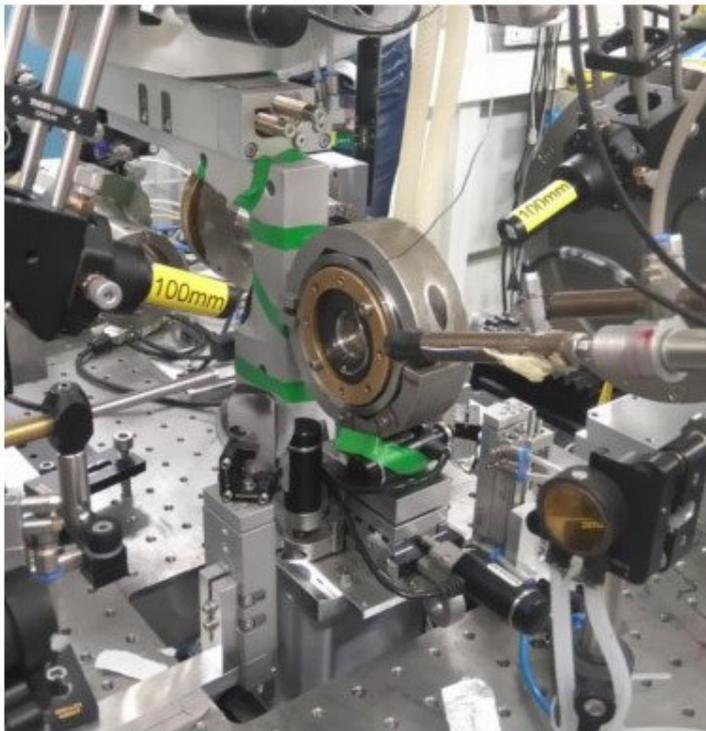


Expérience en cellules à enclume de diamant

4 campagnes de diffraction des rayons X sur synchrotron ESRF (Grenoble) sur 2 ans

Tests de transformation

- Perovskite → post-perovskite
- Post-perovskite → perovskite

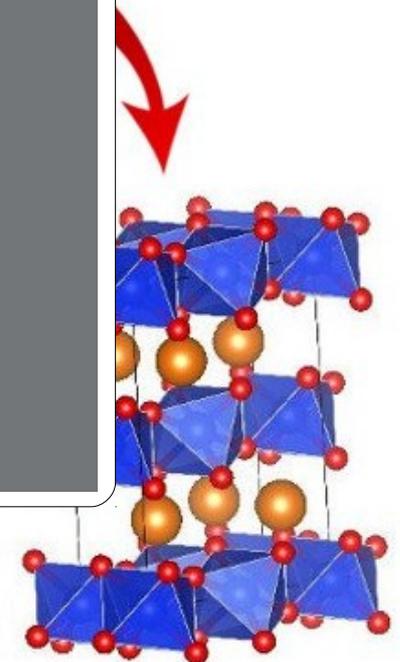
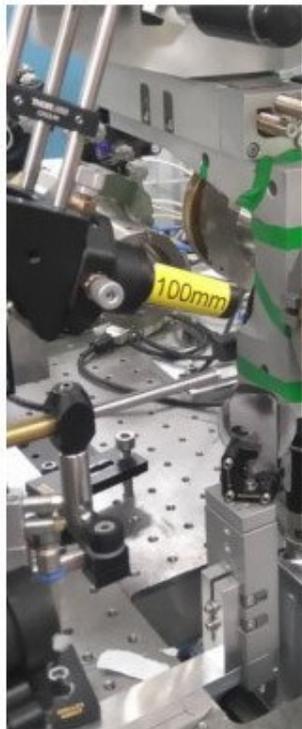


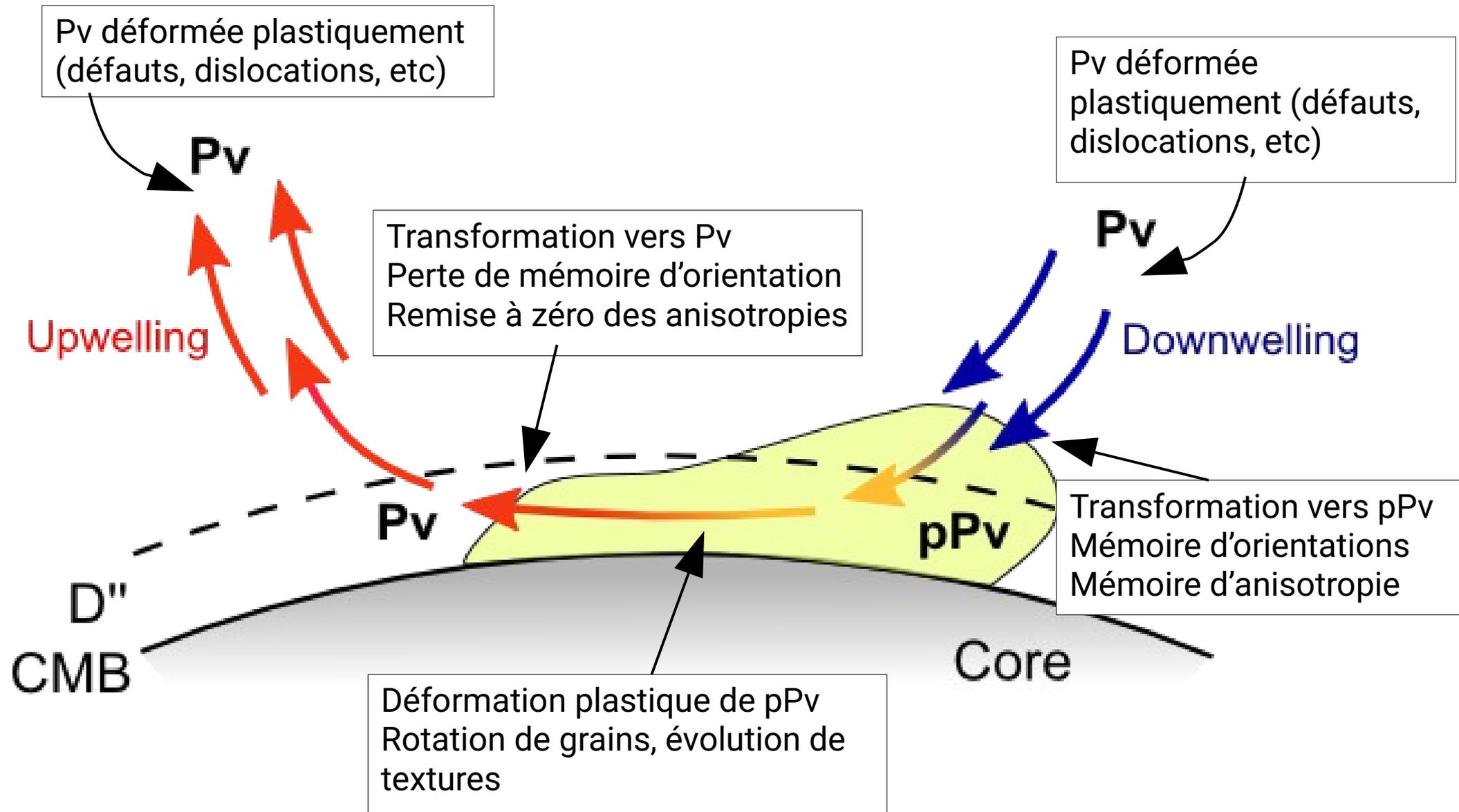
Expérience en cellules à enclume de diamant

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Tests de transfo

- Perovskite
- Post-perov





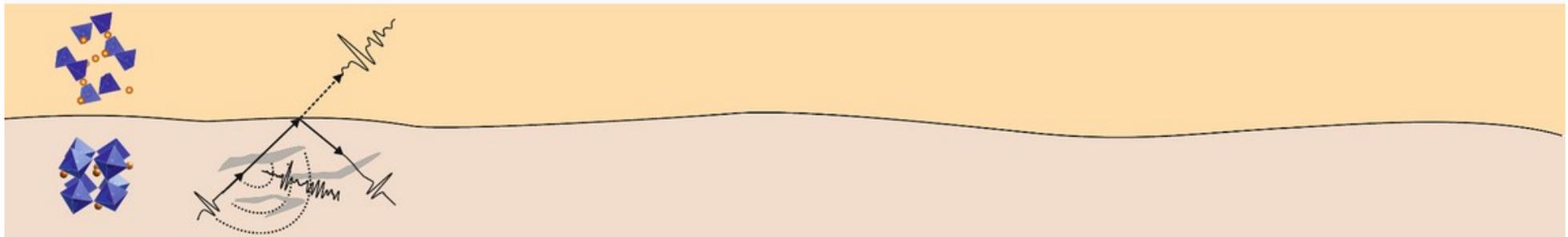
TIMEleSS

Phase Transformations, MicrostructurEs, and their Seismic Signals from the Earth's mantle

TIMELESS ▾

SCIENTIFIC OUTPUT ▾

OUTREACH ▾



TIMEleSS

The TIMEleSS project aims at studying interfaces in the Earth's mantle combining observations from seismology, mineral physics experiments, microstructures, and wave propagation modeling. It is supported through a bilateral grant, from the [ANR in France](#) and the [DFG in Germany](#). The project is led by Sébastien Merkel and Nadège Hilairet at the [Université de Lille](#), Christine Thomas and Carmen Sanchez-Valle from the [Westfälische Wilhelms-Universität, Münster](#), and Sergio Speziale from the [Deutsche GeoForschungsZentrum, Potsdam](#).

Project launch: March 2018

Duration: 36 months

Total ANR-DFG funding: 700 000 €

TIMELESS ON TWITTER

Tweets by [@DeepTransitions](#)



TIMEleSS

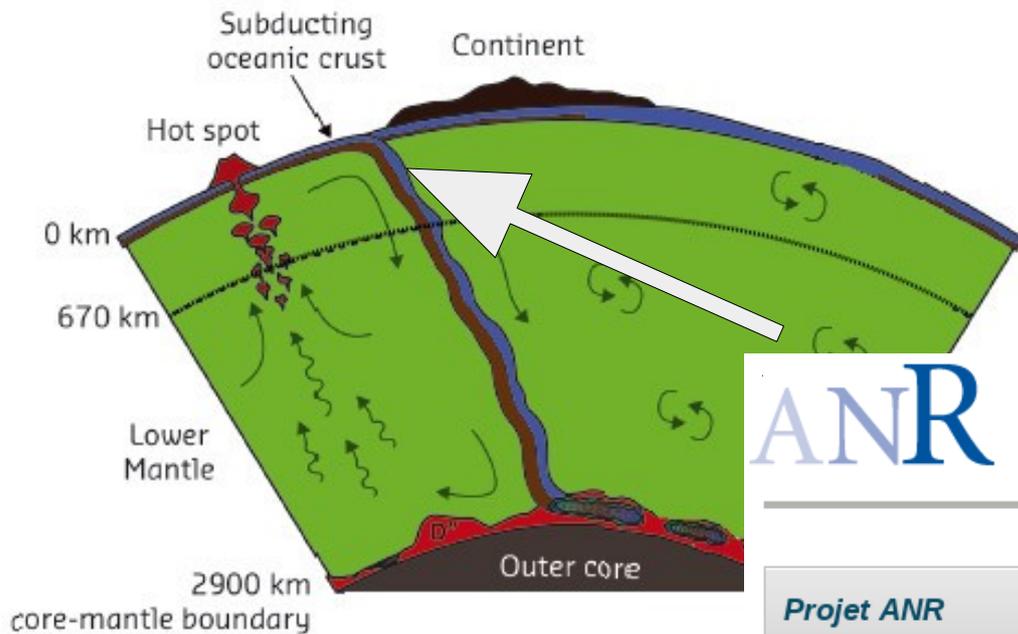
@DeepTransitions

Federica Rochira and Estelle Ledoux, PhD students for the TIMEleSS project are attending the Doctoral training on internal Earth in Les Houches. Great opportunity for advanced classes and meeting world experts!
epti.isterre.fr/?lang=en/

Projet collaboratif franco-allemand

Couplage transitions de phase dans le manteau, observations sismiques, et dynamique

Kick-off meeting mardi 30 octobre 2018



L'Agence nationale de la recherche
Des projets pour la science



Projet ANR

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- Portail thématique >
- Financer votre projet >
- Documents >
- Page précédente >

Défi des autres savoirs (DS10) 2017

Projet *MADISON*

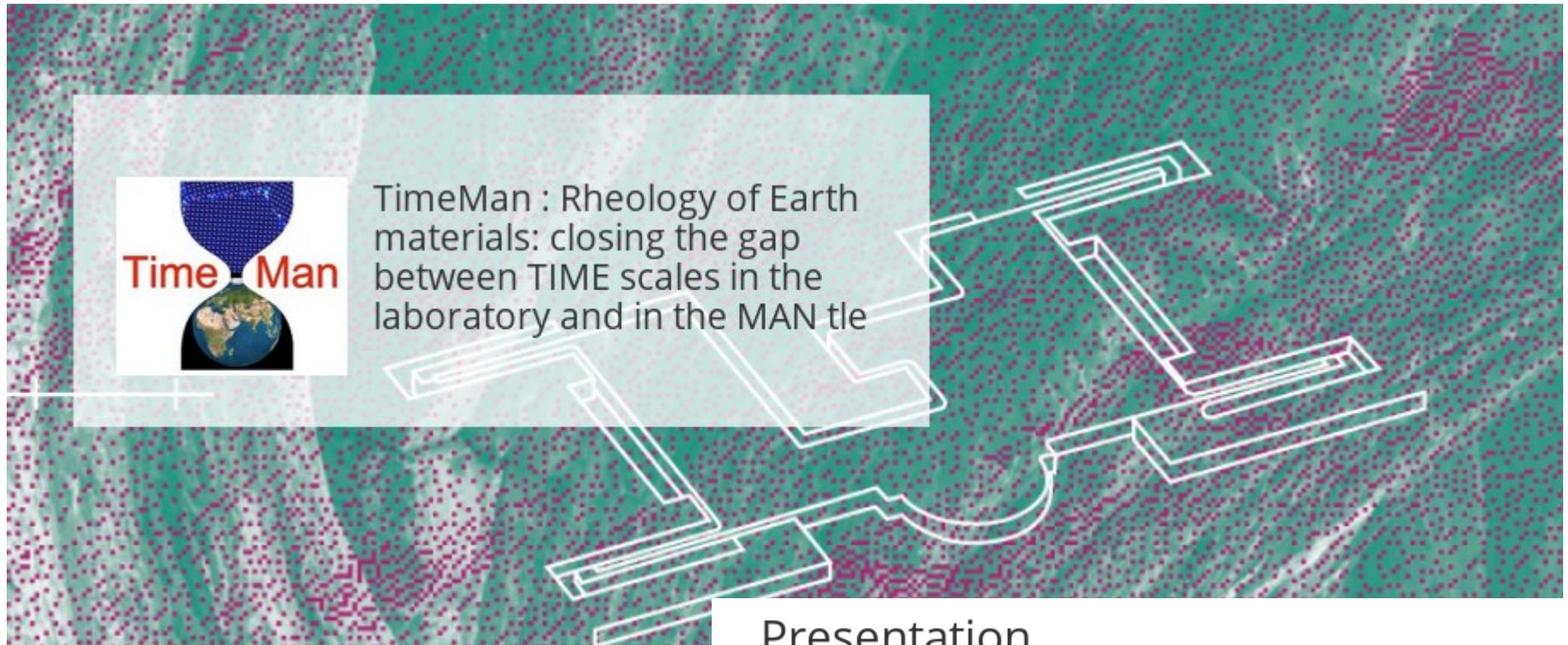
Deformation des roches multiphasées des zones de subduction

Les zones de subduction sont des régions de la Terre extraordinairement complexes, où deux plaques tectoniques convergent, l'une plongeant sous l'autre. Elles concentrent la majeure partie des activités sismiques et volcaniques. Elles sont un aspect majeur de la tectonique des plaques, la partie descendante la convection terrestre, et l'un des styles de dynamique des planètes de notre système solaire. Les zones de subduction sont donc un objet crucial pour comprendre la machine terre aux échelles de temps géologique et humaine. Modéliser l'évolution de la terre à travers les temps géologiques, comprendre comment fonctionne la subduction à l'échelle régionale et planétaire, sa mécanique depuis les séismes jusqu'à la convection, nécessite de quantifier la viscosité des roches.



N. Hilairet
Chercheuse CNRS
UMET Univ. Lille

Projet Agence Nationale de la Recherche
Début des thèses en octobre 2018



Presentation



P. Cordier
Professeur
UMET Univ. Lille



TimeMan

ERC Advanced Grant 2017 (Call ERC-2017-ADG)

RHEOLOGY OF EARTH MATERIALS: CLOSING THE GAP BETWEEN
TIMESCALES IN THE LABORATORY AND IN THE MANTLE

Principal investigator (PI): Patrick Cordier

PI's host institution : Université de Lille

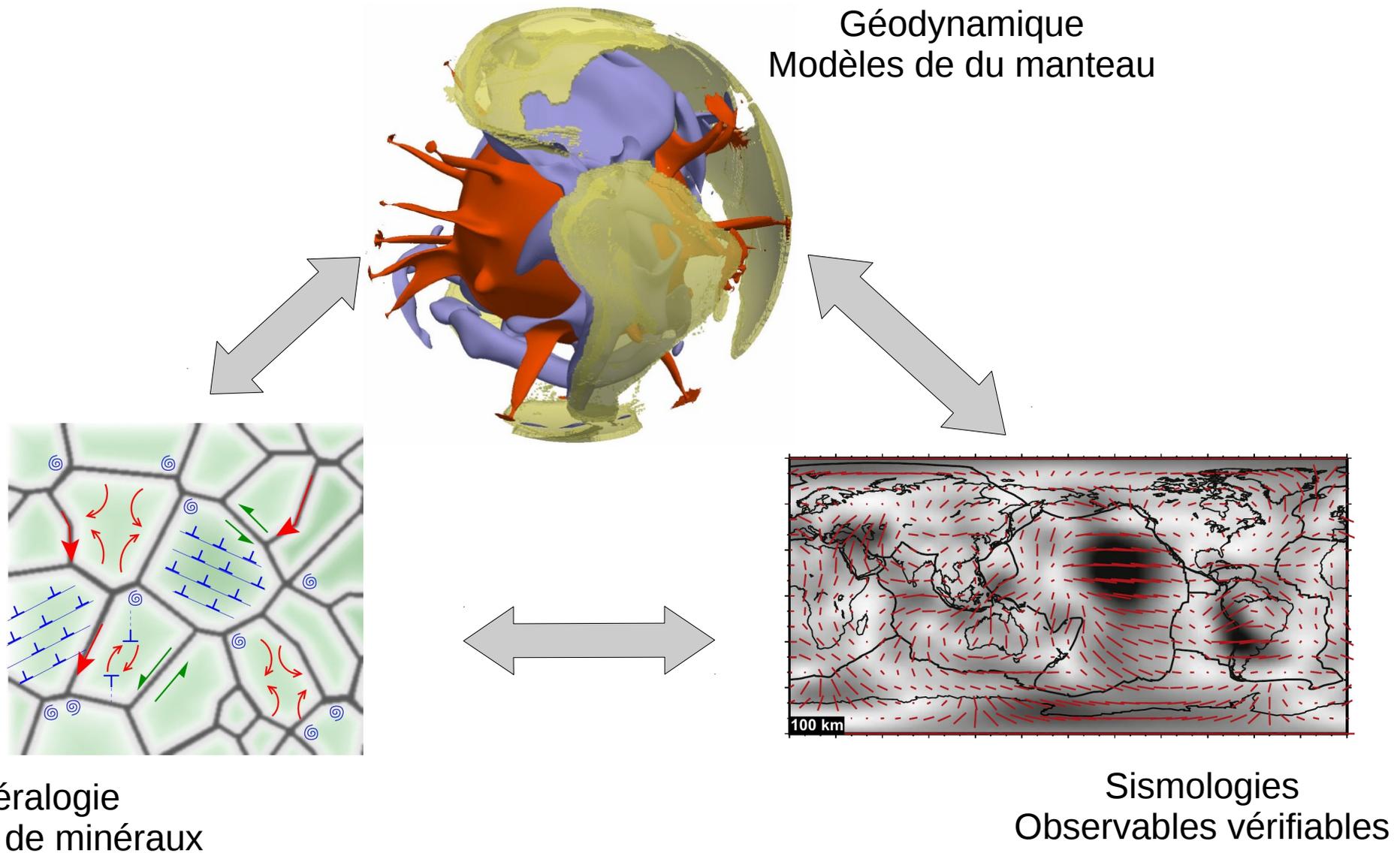
Duration: 60 months

Starting date: April 2019

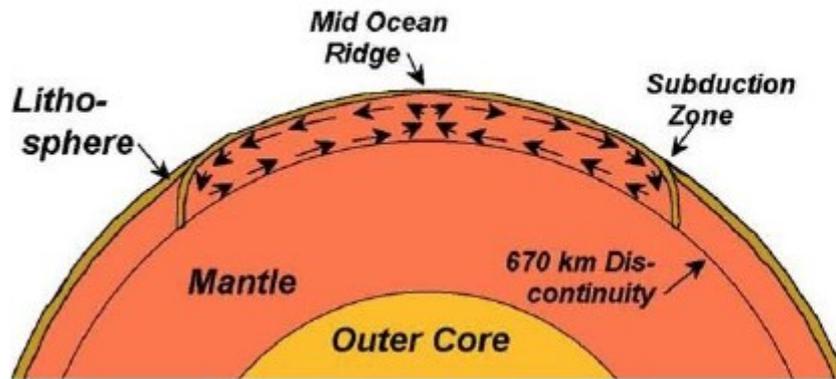
Project ID: 787198

Début en 2019

La convection dans le manteau terrestre ?

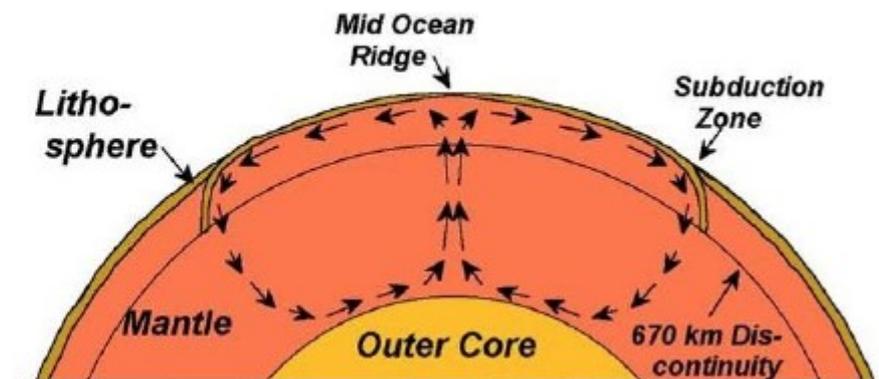


Upper Mantle Convection



VS.

Whole Mantle Convection



Resolution

Images de tomographie sismique

Certains plaques en subduction passent dans le manteau inférieur

Les panaches ont des sources profondes

