Seismic Anisotropy

Introduction
- Shape Preferred Orientation
- Lattice Preferred Orientation

Theory
- Elastic constants $c_{ijkl}$ in isotropic and anisotropic media
- Transverse isotropy
- Anisotropic elasticity
- Shear wave splitting

Fast direction
Splitting time

Observations and Implications
- Crustal anisotropy (SPO)
- Anisotropy in the lithosphere and asthenosphere (LPO)
- Anisotropy of mineral crystals
- Anisotropy of mantle flow

Mid mantle (P660s and SKS)

Inner core anisotropy
- hcp iron ($\varepsilon$ phase)
- Aggregation mechanisms

Seismic velocity function of propagation/polarization direction.
- Anisotropic Minerals (Olivine)
- Lattice Preferred Orientation
- Deformation, Flow

Shear wave splitting (birefringence)
- Fast polarization direction follows flow/shear direction.
- Delay time is a measure of layer thickness.

Shape Preferred Orientation

Lattice Preferred Orientation

Seismic Waves in an Anisotropic Medium

Theory

Independent elastic constants
$3\times3\times3=27$

$6\times6=36$

$U=1/2(C_{ijkl} \varepsilon_{ik} \varepsilon_{jl})$

$(36-6)/2+6=21$
Transverse Isotropy

Azimuthal Anisotropy

Measurements of Seismic Anisotropy

Crustal Anisotropy (SPO)

Example of Shear-Wave Splitting

Anisotropy in the Lithosphere and Asthenosphere (LPO): Anisotropy of Olivine Crystals
LPO and Creeps

- Dislocation creep
  - Line defects
  - High stress and/or large grain size
  - Leads to an alignment of mineral grains. The resulting aggregate is seismically anisotropic

- Diffusion creep
  - Point defects
  - Lower pressure and/or small grain size
  - Leads to a random distribution of mineral grain orientations, resulting in an effectively isotropic aggregate

Seismic Anisotropy and Mantle Flow

- Lithosphere
  - Frozen LPO
  - Past plate motion

- Asthenosphere
  - LPO
  - Present plate motion

Anisotropy in the Lithosphere and Asthenosphere (LPO): Alignment of Crystals

SKS Splitting in the Eastern US

Anisotropy in the Mid-Mantle

Anisotropy in the D" Layer
IC composition and physical state

- **Composition:**
  - Fe
  - Light elements: Ni, S, O, Si
  - Radiogenic elements?
- **Physical state:**
  - Crystal structure:
    - Body-centered cubic (b.c.c)
    - Face-centered cubic (f.c.c)
    - Hexagon closed packet (h.c.p)
  - Temperature
- **Elastic properties:**
  - Seismic wave velocity
  - Anisotropy

Fe crystalline forms

Stixrude and Cohen, 1994

Anisotropic IC Growth

- Flow induced preferred orientation
  - Theory of Kamb 1959
  - Elastic constants of Steinle-Neumann et al.
- Strongest signal along rotation axis

Effects of Magnetic Fields

- Karato (Nature, 1993)
  - Argues that anisotropic magnetic susceptibility will cause Fe to become aligned as it freezes at the ICB
- Karato (Nature, 1999)
  - Argues that Maxwell stresses will align Fe crystals
  - Relies on magnetic pressure perturbation from IC toroidal B
  - How strong is $B_t$?
  - IC density stratification?
- Buffett and Wenk (Nature 413: 60–63, 2001)
  - How strong is $B_t$?
  - What is the IC viscosity?