Something Amazing:
Despite the apparent complexity of the mantle wedge dynamics, the wedge exhibits robust characteristics.
Competition between slab-driven flow and ...

- Along-arc variations in slab geometry [Kneller and van Keken, 2007] (keynote by Peter van Keken)
- “Cold plumes” [Gerya and Yuen, 2003, Gerya et al., 2006]
- Slab edge [Jadamec and Billen, 2010]
- Foundering of arc lower crust [Behn et al., 2007]
- Slab rollback [Long and Silver, 2008]
- ...
Robustness of Processes in the Mantle Wedge

Location of the Arc

- The arc tends to form where the slab is 100–120 km deep [England et al., 2004; Syracuse et al., 2008].

Hot Backarc

- Shallow part of the mantle is hot [Currie and Hyndman, 2006]
Water in Mafic Arc Magmas: Olivine Melt Inclusions

Compilation by Katie Kelley

“Why mafic arc magmas contain 4 wt% water on average?” – T. Plank et al. at Goldschimdt 2011
Cold to Hot Thermal Transition: Surface Heat Flow

Northern Cascadia

[Wada and Wang, 2009]

E.g., Honda [1985], Furukawa [1993], Kincaid and Sacks [1997], van Keken et al., [2002], Currie et al. [2004], Conder [2005]
Cold to Hot
Thermal Transition: Seismic Attenuation

1. Transition from cold to hot is sharp.

2. Transition tends to occur where the slab is at 70-80 km depth.
Maximum depth of decoupling (MDD) of 70-80 km
[Wada and Wang, 2009; Syracuse et al., 2010]

Factors that affect the mantle-interface strength contrast

- T- dependence of the mantle rheology [Wada et al., 2011]
- Rheology of the interface material
- Metamorphic changes of the interface material or the mantle
- Variations in fluid and melt content
- Hot backarc – heat supply
- …
1. Location of fluid release/influx
   • Dehydration reactions in the slab and in the hydrous layer at the wedge base [e.g., Tatsumi, 1986; Peacock, 1990; Davies and Stevenson, 1992; Grove et al., 2009]

2. Volatile transport to the hot region
   • Plumes/diapirs [Hall and Kincaid, 2001; Gerya and Yuen, 2003; Currie et al., 2007; Behn et al., 2011]
   • Porous fluid migration within the wedge [Arcay et al., 2005; Iwamori, 1998, 2007; Cagnioncle et al., 2007; Hebert et al., 2009]
• Fluid migration occurs through interconnected pores between grains.

• Grain-scale permeability ($k$) depends on grain size ($d$) and fluid fraction ($\phi$):

$$k = \frac{d^2 \phi^3}{270}$$  

[Cagnioncle et al., 2007]
Grain Size Evolution Model

[Austin and Evans, 2007, 2009; Behn et al., 2009]

Laboratory-derived model for wet olivine

\[
\frac{\dot{a}}{p_g} = \left[ \frac{G_0}{p_g} \exp\left( -\frac{E_g}{RT} \right) a^{1-p_g} \right] + \left[ -\frac{\lambda \sigma \varepsilon_{\text{dis}}}{c \gamma} d^2 \right]
\]

- The model does not account for brittle deformation and is valid only for creeping regions (> 600° C).

Poster:
“Grain size distribution in the mantle wedge”
[Wada et al., JGR, in press]
Steady State Grain Size Distribution

Slab age 100 Ma
Subduction rate 4 cm/yr
Slab dip 30°

Grain size increases downdip from 10-100 μm to a few cm, by > 2 orders of magnitude, independent of subduction parameters.

Poster:
“Grain size distribution in the mantle wedge”
[Wada et al., JGR, in press]
Effect of Grain Size Variations

Fluid migration model in progress [I. Wada, M. Behn., and E. M. Parmentier]

\[ S = -k \Delta \rho g + \nabla P \]

Fluid velocity

\[ \frac{r}{V_f} = V_m + \frac{S}{\phi} \]

Darcy’s flux

Permeability

\[ k = \phi^3 d^2 / 270 \]
Effect of Grain Size Variations

Fluid migration model in progress [I. Wada, M. Behn., and E. M. Parmentier]

- Time at 300 Kyr
- Time at 600 Kyr

Fluid influx (10^{-12} m^2/s)

- H_2O (wt%)
  - 0.001
  - 0.01
  - 0.1
  - 1

Distance (km)

Depth (km)

Temperature (°C)

Subduction Interface

Moho

4 cm/yr
Conceptual Model for Fluid Migration

Updip fluid migration along the interface?

Downdip fluid transport by the flowing mantle?

Lower $k$, less $H_2O$

Higher $k$, more $H_2O$

Melt

High temperature ($>1200^\circ C$)

Conceptual model

Upward fluid migration where $k$ is high enough
Concluding Remarks

Despite complex dynamic processes, the mantle wedge exhibits robust features – Clues to understanding the mantle wedge dynamics.

• Maximum depth of slab-mantle decoupling – Disappearance of mantle-interface strength contrast
• Cold wedge nose (<70-80 km depth) – No significant mantle flow
• Hot region – Enough flow to bring heat for melt generation; Competition among viscous coupling and other flow drivers.
• Relatively high water content of mafic arc magmas – Water transfer mechanism.
• Arc location relative to the slab – Focusing of melt where slab is ~110 km deep: Grain size variations may help regulate upward fluid flow.
• Hot backarc – Small scale convection; heat supply regulator?
Robust Feature: Hot Mantle (> 70-80 km depth)

Formation of hydrous phases

- Thin hydrous boundary layer above the subducting slab [Kawakatsu and Watada, 2007; Grove et al., 2009] – weakening effect

Melting

- Anhydrous melting via adiabatic decompression [e.g., England and Katz, 2010]
- Hydrous melting [e.g., Grove et al., 2006] – Fluid availability
Fluid migration

- Grain size, dynamics pressure gradients due to mantle shear and compaction, variations in fluid influx
- Shear induced melt bands [Spiegelman, 1993; Katz et al., 2006; Butler, 2009]
- Anisotropic permeability of serpentinites [Kawano et al., 2011]
Variable direction of fast direction and magnitude of delay time

What does seismic anisotropy indicate?

- Crystal-preferred orientation (CPO) of olivine: A type vs. B type \([\text{Jung and Karato, 2001; Kneller et al., 2007}]\).
- CPO of serpentine \([\text{Katayama et al., 2009; Jung, 2011}]\).
- Fluid filled cracks or melt lenses \((e.g., \text{Holtzman et al. [2003]})\).
- ...
Large Variability in Observables

Seismic Anisotropy

Trench-\(//\) to trench-normal

Trench-normal to trench-\(//\)

“Not clear cut”

Little anisotropy

[Long and Silver, 2008]
Cold Wedge Nose & Mantle Wedge Serpentinization

Alaska

- Slab age: 46 Ma
- Subduction rate: 47 mm/yr
- Frictional heating: 0-40 km depths

Central Aleutians

- Slab age: 55 Ma
- Subduction rate: 54 mm/yr
- Frictional heating: 0-20 km depths

[Wada and Wang, 2009]