Metamorphic Processes: Metasomatism and geochemical cycling in subduction zone mélanges

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Metamorphic Processes: The inner workings of GeoPRISMS

Hacker, 2008

Bebout, 2007
Metamorphic Processes: The inner workings of GeoPRISMS

- Serpentinitized peridotite
- Anhydrous peridotite
- Eclogite
- Blueschist
- Greenschist

Beinlich et al. 2010

Kita et al., 2006; van Keken et al., 2010, AGU

Schumacher et al., 2010, AGU
Metamorphic Processes Participants

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1) Fluids, Magmas and Their Interactions
2) Geochemical Cycles
3) Plate Boundary Deformation and Geodynamics

After Bebout, 2007
Metamorphic Processes: Metasomatism and geochemical cycling in subduction zone mélange

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Why use Lithium?

- Li is a fluid mobile element
- Li partitions into fluid phase at high temperature \((K_{d\text{ min-fluid}}<1)\)
- For many minerals the heavier isotope fractionates into fluid phase \((\delta^7\text{Li}_{\text{fluid}} > \delta^7\text{Li}_{\text{min}})\)
- Lithium diffuses rapidly and can fractionate during diffusion

\[
\delta^7\text{Li} = \left( \frac{^{7}\text{Li}/^{6}\text{Li}_{\text{sample}} - ^{7}\text{Li}/^{6}\text{Li}_{\text{L-SVEC}}}{^{7}\text{Li}/^{6}\text{Li}_{\text{L-SVEC}}} \right) \times 1000
\]
**Diffusivity of Li**

- **Eclogite**
  - $\delta^7\text{Li} = -0.2\%_o$

- **Blueschist**
  - $\delta^7\text{Li} = 4.4\%_o$

- **Fluid flow**

- **Penniston-Dorland et al., 2010**

- **Marschall, unpub. data**

\[ \frac{D_T}{D_0} = \left( \frac{m_6}{m_7} \right)^\beta \]
Geochemical cycling of Li

-1 to +9‰ Sediments
-0.5 to +11‰ Serpentinite Diapir
-2 to +14‰ Altered Oceanic Crust

δ⁷Li

+1 to +8‰ Island Arc Basalt
+3 to +4‰ Mantle Wedge

~250km

after Zack et al., 2003; Tang, 2007
**P-T conditions**

Catalina Schist

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**Metamorphic facies**

**LOW**
- LA = Lawsonite-albite
- LBS = Lawsonite blueschist
- EBS = Epidote blueschist
- EA = Epidote amphibolite

**HIGH**
- AM = Amphibolite

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Bebout, 2007
Conceptual model for metasomatism and fluid flow in Catalina Schist

after Bebout et al., 1997
Metasedimentary rocks

No systematic change in Li concentration and $\delta^{7}$Li with grade

Contrasts with B, Cs, N all of which show dramatic losses with metamorphic grade

Dehydration reactions do not drastically affect Li
Metasedimentary rocks

Li concentration correlates with Chemical Index of Alteration (CIA)

Li reflects degree of weathering of source of protolith

\[
\text{CIA} = \frac{\text{wt}\% Al_2O_3}{\text{wt}\% Al_2O_3 + \text{wt}\% Na_2O + \text{wt}\% K_2O + \text{wt}\% CaO^*}
\]
Metamafic rocks

Mafic rocks have more Li than protolith

Suggests external source of Li

infiltration of Li-bearing fluid into block or diffusion of Li into block through grain boundary fluid.
Metasomatic features

Veins, conglomerate cobbles, and reaction rinds, all features indicative of fluid-rock interactions – wide range of Li compositions
Fluid compositions of metamafic rocks and metasomatic features largely overlap with fluid compositions calculated from metasedimentary rocks.

Local metasedimentary rocks as source of Li?

Calculated fluid $\delta^7\text{Li}$

Calculated using cpx-fluid fractionation of Wunder et al. (2006) [and mica-fluid fractionation of Wunder et al. (2007)]
**Diffusive Fractionation?**

Most block cores have significantly lower $\delta^7$Li than rinds suggesting diffusive fractionation.
Observations

• No systematic change in Li of metasedimentary rocks with grade

• Li of metasedimentary rocks correlates with CIA

Interpretations

• No significant effect of dehydration on Li – however some loss of Li during dehydration likely

• Li reflects weathering of source of protolith
**Observations**

- Mafic rocks have high Li compared to protolith
- Calculated fluid $\delta^7$Li for mafic rocks & most metasomatic features overlaps metasedimentary rocks of the same metamorphic grade
- Large difference in Li between block cores and rinds

**Interpretations**

- Mafic rocks interacted with fluids likely derived from metasedimentary rock
- Fluids are derived from local metasedimentary rocks
- Li may have diffused into blocks
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- Hydrothermal Alteration
- Oceanic Crust with Sediment
- Trench
- Accreted Sediment
- Volcanic Front
- Cross-Arc
- Continental Crust
- MOR Magmatism
- Hydration of Ultramafic Rocks?
- Melting induced by Fluids
- Mantle Wedge (hanging-wall)
- Dehydrating Ultramafic Rocks?
- Mixing Zone
- Mantle Wedge
- Zones of mechanical and metasomatic mixing, with hybridized compositions influencing "fluid" compositions
- Hydration by Aqueous Fluids Transitioning to Silicate Melts with depth

Possible Model for the Slab-Mantle Interface

Mafic blocks