The Growth of Garnet
&
The Chronology of Subduction Zone Dehydration

Ethan F. Baxter

TIMS FACILITY AT BOSTON UNIVERSITY

BOSTON UNIVERSITY

NSF

The Growth of Garnet
&
The Chronology of Subduction Zone Dehydration

Thanks to:	**Besim Dragovic**	**BU *(graduate student)***
	Leah Samanta	**BU *(graduate student)***
	Julie Barkman	**BU *(undergraduate)***
	Drs. Jason Harvey, Jeremy Inglis, & Denise Honn	**BU *(TIMS lab managers)***
	Prof. Jane Selverstone	**Univ. of New Mexico**
	Prof. Mark Caddick	**Virginia Tech**

Consumption & Production of

WATER

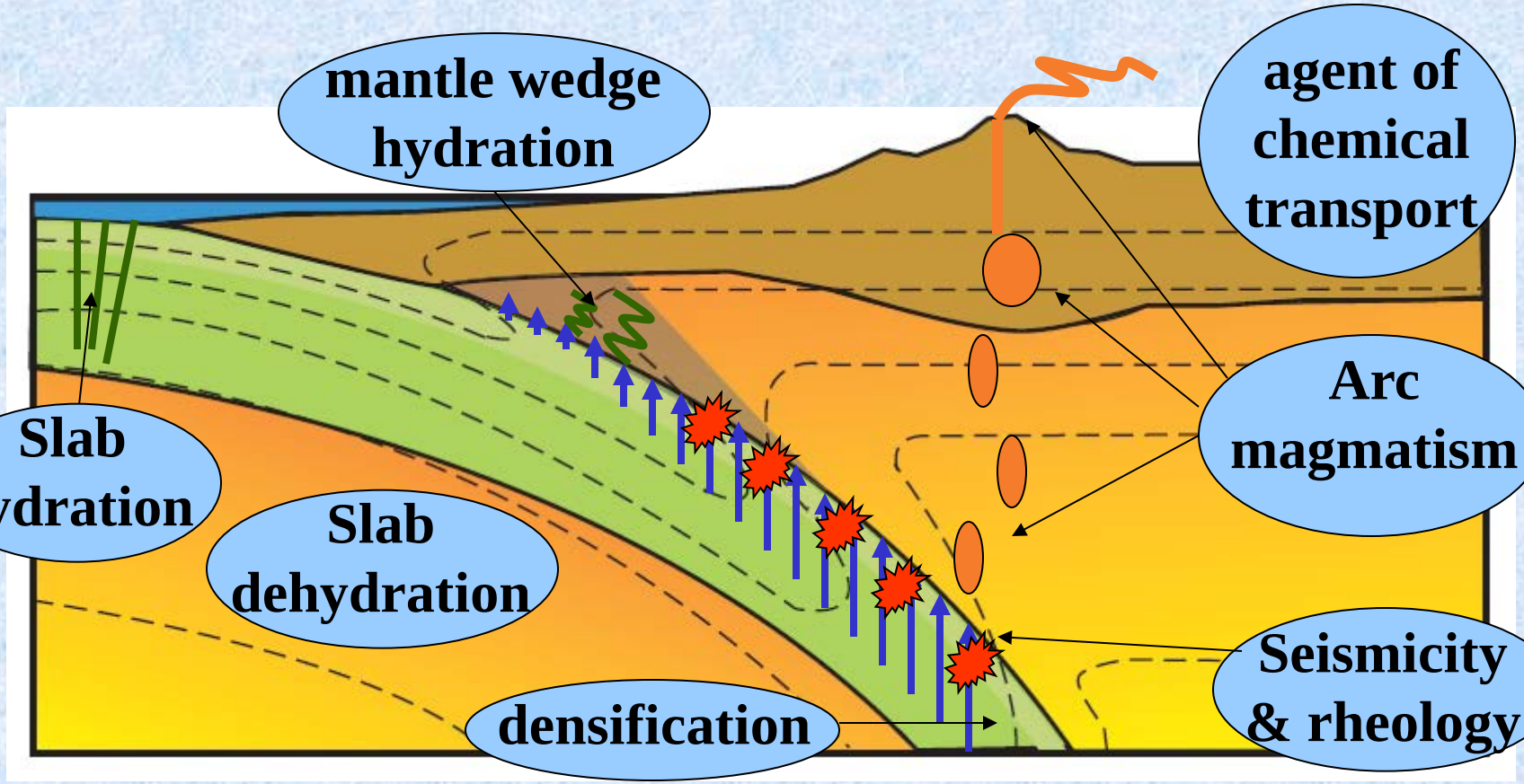


Figure modified from Rupke et al. (2004)

Consumption & Production of CO_2

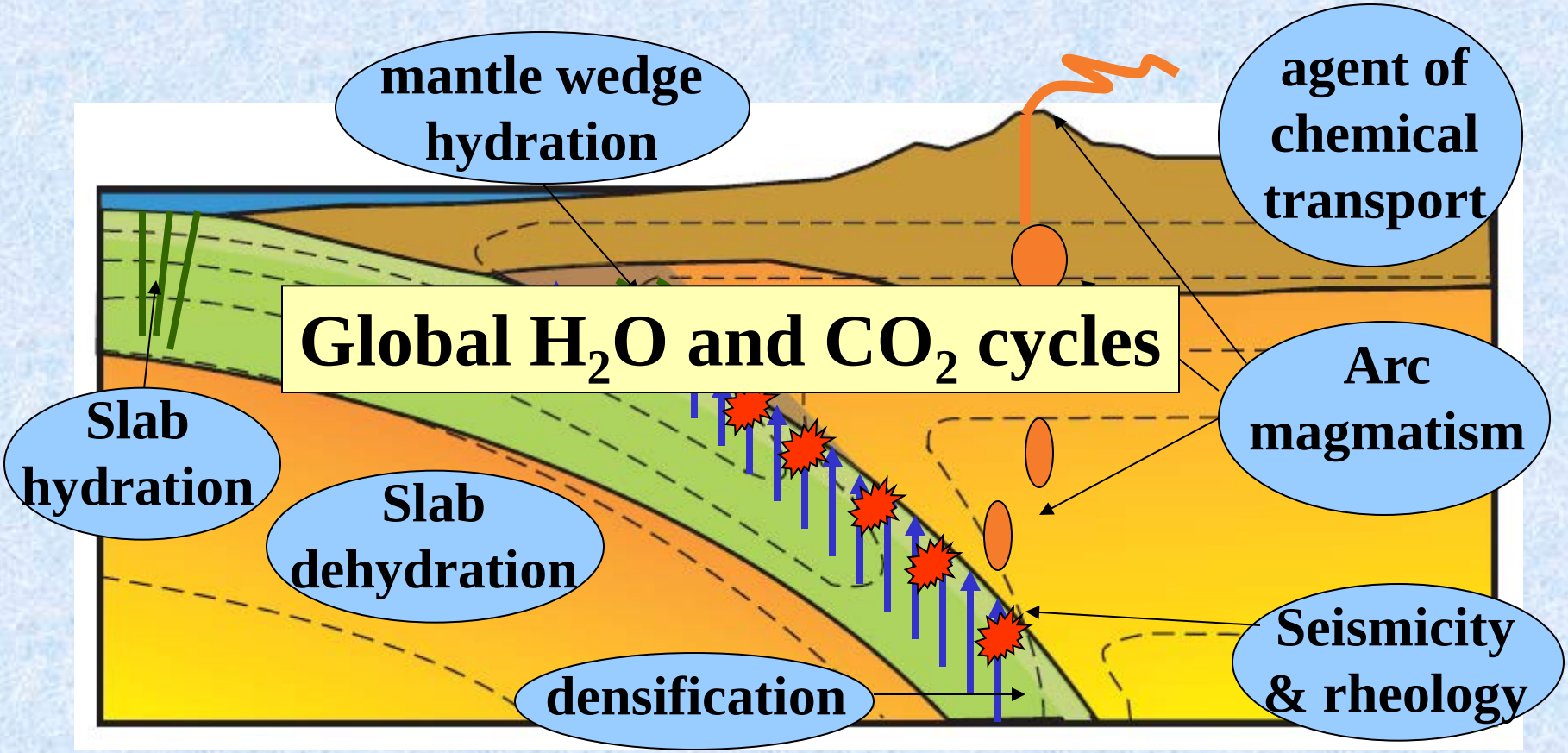
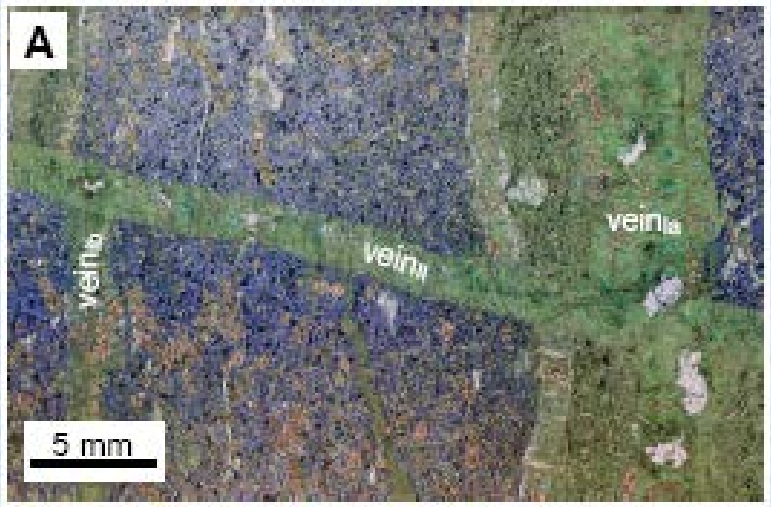


Figure modified from Rupke et al. (2004)

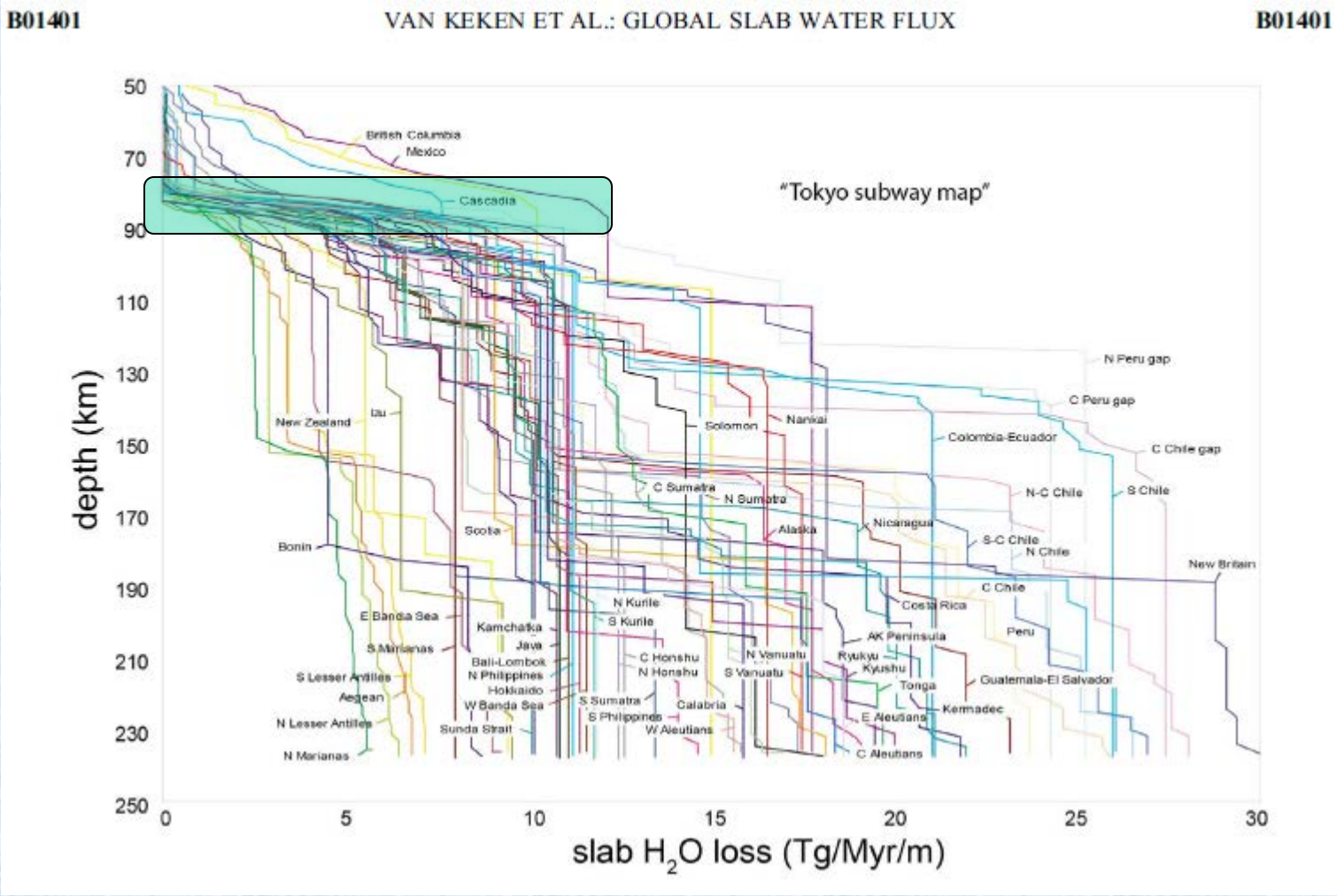
Pulsed or **Continuous**?

- Some models of metamorphism suggest slow, continuous, prolonged events lasting millions of years (e.g. England & Thompson 1984; Schmidt & Poli 1998)
- Other work suggests that metamorphic "events" – including fluid production and mineral growth - may be **short lived and/or episodic** for example….

- **Austrheim 1987** suggests eclogitization is localized and controlled by fluid flow
- **Baldwin & Lister 1998** show partial resetting of Ar ages indicates brief thermal events
- **Camacho et al. 2005** show evidence for "spasmodic" bursts of fluid flow; **$\Delta t = 10^3$ yrs**

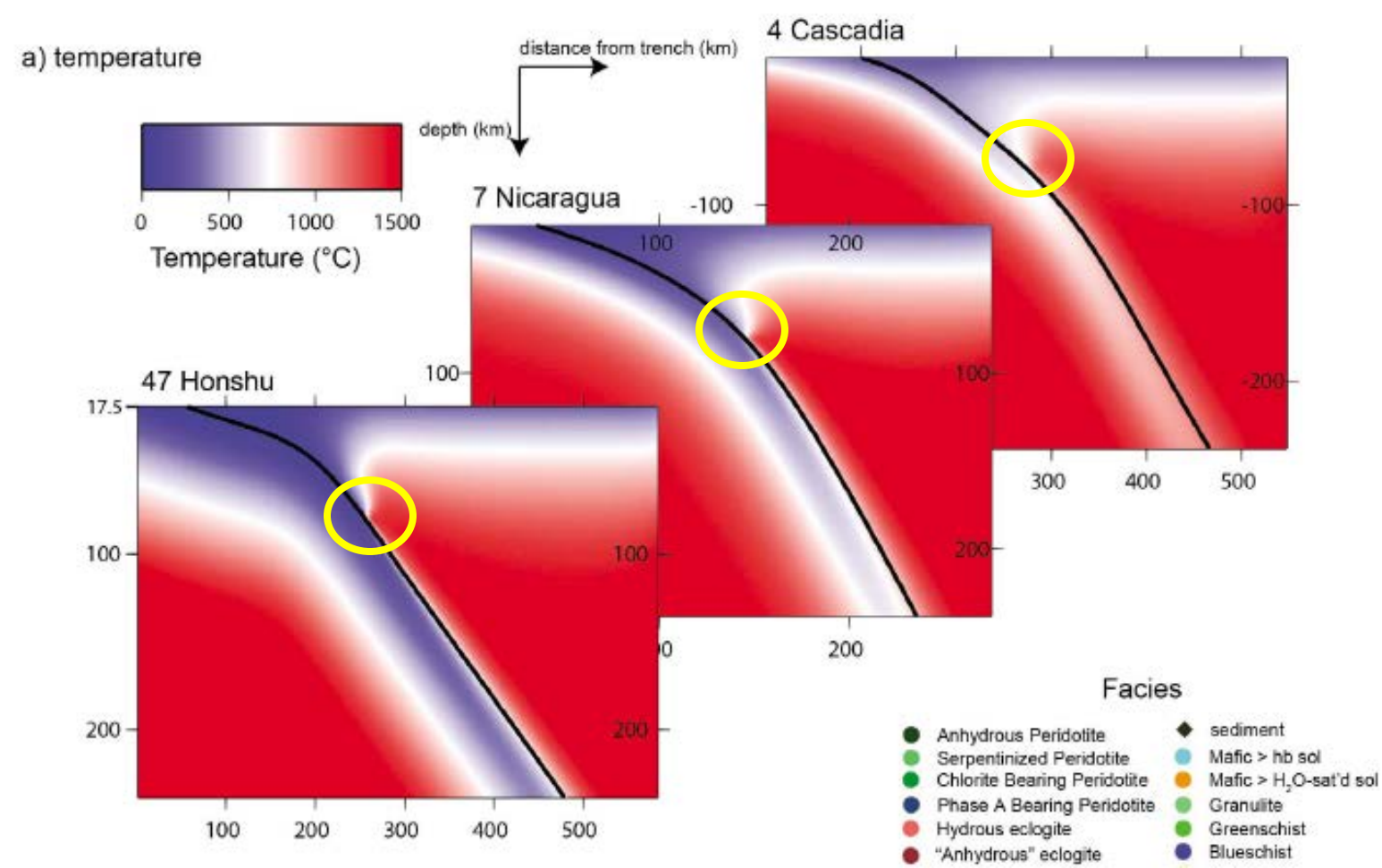


John et al. (2008, Lithos)



van Keken et al. 2011

“cold nose”



van Keken et al. 2011

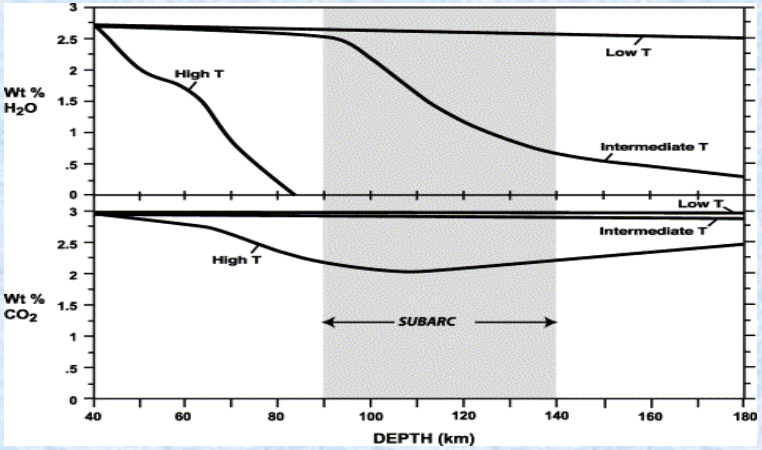
Why Study in Exhumed Terranes?

- Equilibrium model-based petrologic-geodynamic predictions require testing in natural systems
  - *Tatsumi 1986*
  - *Schmidt & Poli 1998*
  - *Kerrick & Connolly 2001 (figures shown)*
  - *Hacker, Abers & Peacock 2003*
  - *Rüpke et al. 2004*
  - *Hacker 2008*
  - *van Keken et al. 2011*
  - *And many more…*

We need a preserved prograde record of subduction zone dehydration…

The water is gone…

Need to find a solid residue that we can relate to the water that was released…



Garnet = n·Water

Garnet growth as a proxy for progressive subduction zone dehydration

Ethan F. Baxter[1] and Mark J. Caddick[2]
[1]Department of Earth & Environment, Boston University, 675 Commonwealth Avenue, Boston, Massachusetts 02215, USA
[2]Department of Geosciences, Virginia Tech, 5060 Derring Hall, Blacksburg, Virginia 24061, USA

GEOLOGY, June 2013; v. 41; no. 6; p. 643–646; Data Repository item 2013183 | doi:10.1130/G34004.1 | Published online 18 April 2013

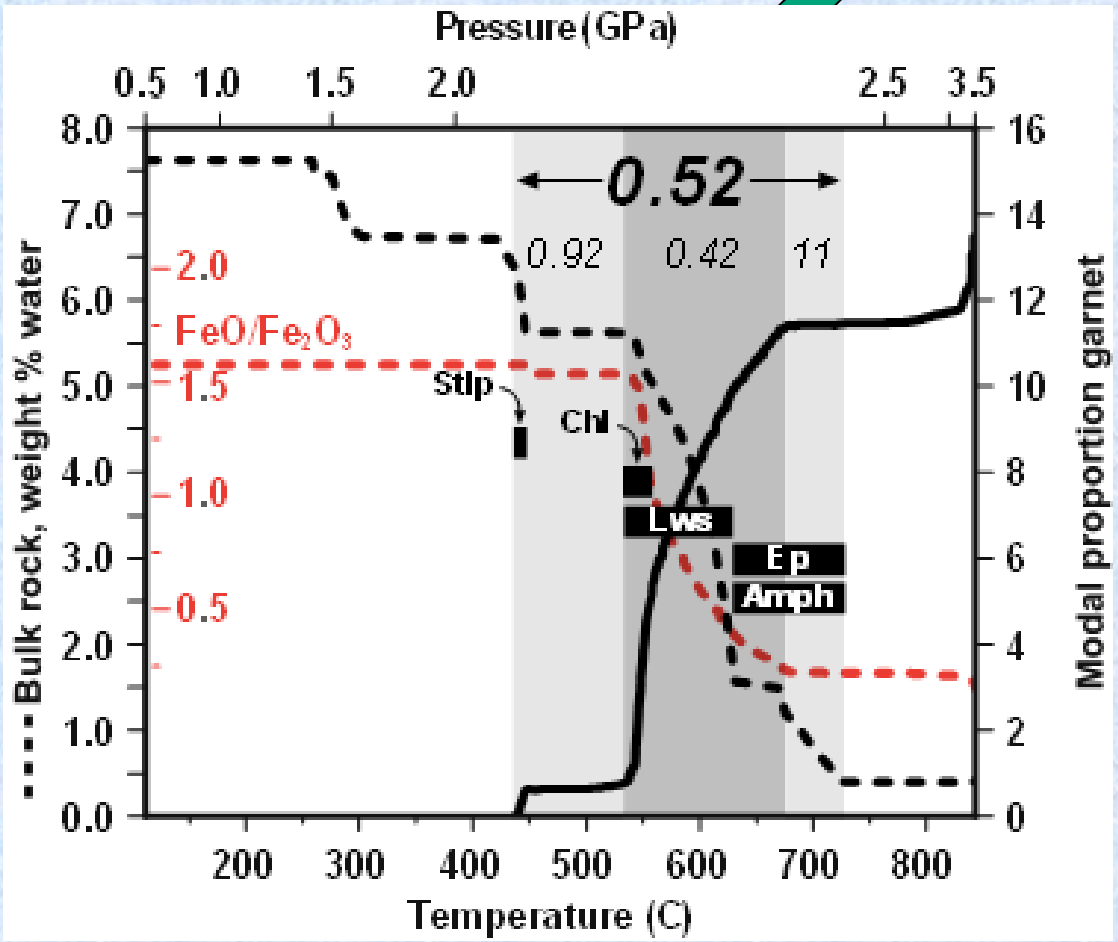
… we can constrain the rate, duration and net flux of devolatilization

chlorite + quartz = **GARNET + H_2O** ***(greenschist facies)***

mica + lawsonite
amphibole + carbonate = **GARNET** + pyroxene + **H_2O + CO_2** ***(blueschist to eclogite transition)***

Garnet:Water production ratio

thermodynamic modeling of garnet growth… *with fractionation*



Garnet fractionation effects can be significant

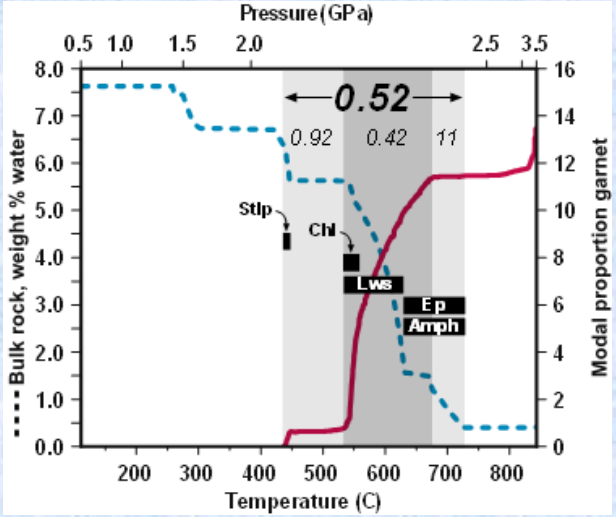
(e.g. Marmo et al. 2002 Konrad-Schmolke et al. 2008 Gaidies et al. 2008)

ferrous iron is depleted due to garnet growth

An example: hydrated MORB in Nicaragua model subduction geotherm ***(Baxter & Caddick, 2013 Geology)***

wt% water

Garnet:Water Reaction Stoichiometry



Overall

37 Amph + 0.64 Stlp + 134 Lws + 13 Sph =

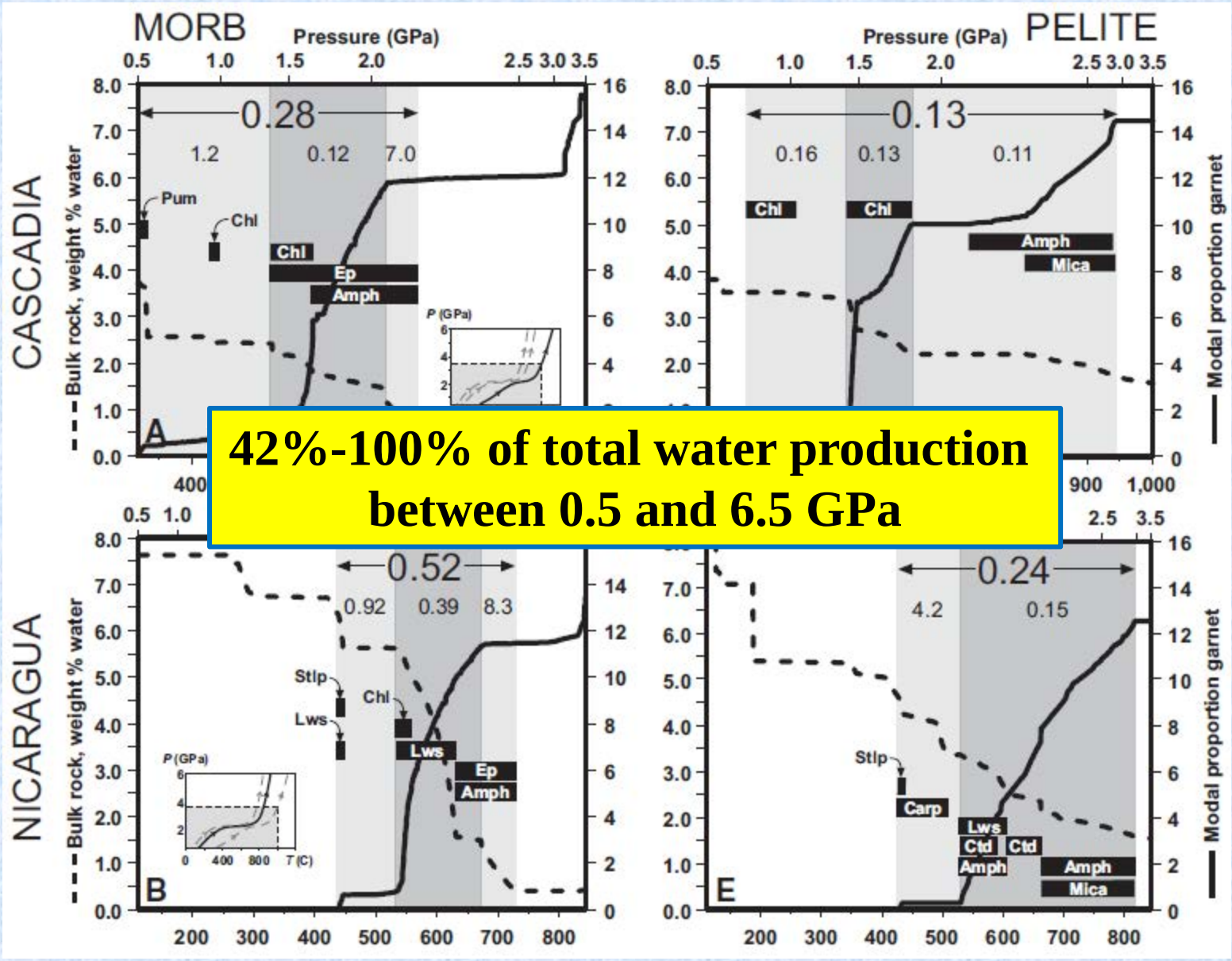
2.6 Cc + 4.2 Pheng + 170 Omph + 89 Qtz + 20 Ep + 79 Ky + 15 Rut + 32 Gt + 330 H_2O

	Stlp	*Chl*	*Lws*	*Amph*	*Ep*	*Pheng*	*Water*	*Garnet*
Overall	***39***	***x***	***268***	***37***	***-10***	***-4***	***330***	***32***
Lt Gray 1	*39*	*-25*	*21*	*9*	*x*	*-3*	*40*	*2.1*
Dk Gray	*x*	*25*	*247*	*-7*	*-32*	*-1*	*229*	*29*
Lt Gray 2	*x*	*x*	*x*	*35*	*25*	*-<1*	*60*	*0.75*

Table DR-2. *Water balance summary for Nicaragua MORB, presented as moles of water released (+) or consumed (-) by each phase per 100 kg of rock. Moles of garnet per 100 kg also shown for reference*

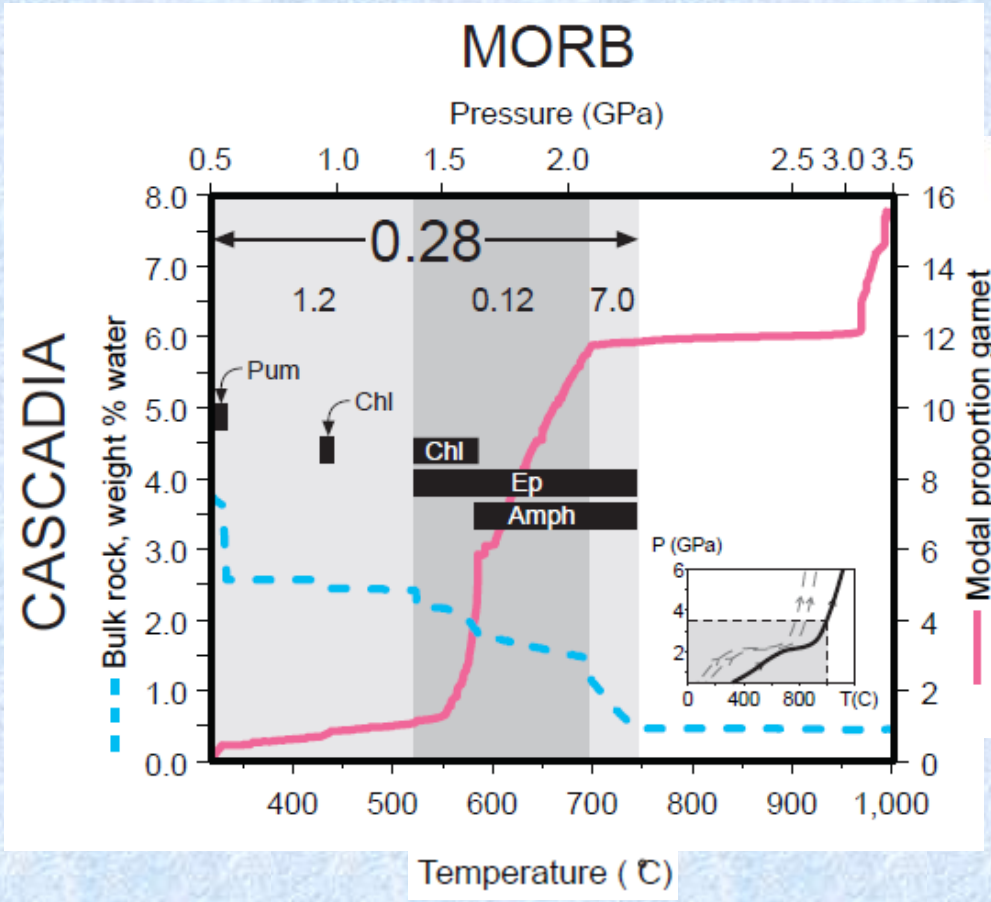
Baxter & Caddick 2013

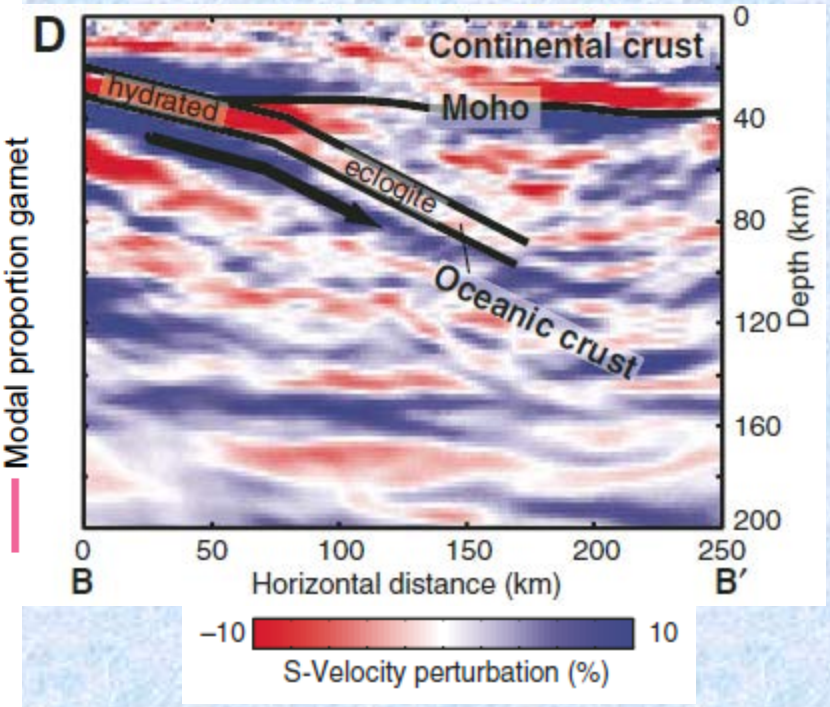
Water:Garnet Production Ratios range from 0.13 to 0.52



Baxter & Caddick 2013

Water (and garnet?) in Seismic Data





Baxter & Caddick 2013, Geology

Rondenay et al. 2008

Chemical Geology 314-317 (2012) 9–22

Contents lists available at SciVerse ScienceDirect

Chemical Geology

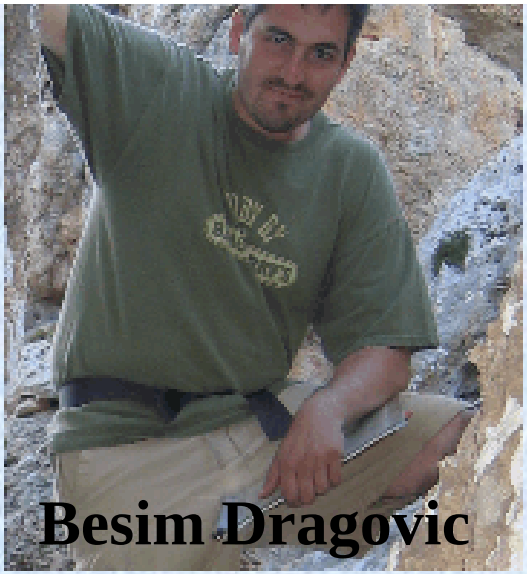
journal homepage: www.elsevier.com/locate/chemgeo

Research paper

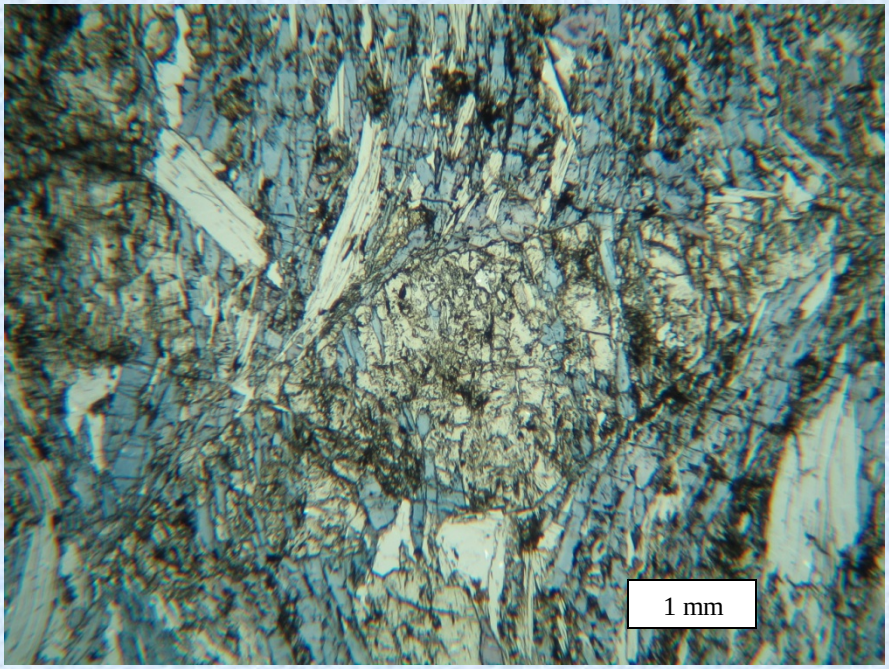
Using garnet to constrain the duration and rate of water-releasing metamorphic reactions during subduction: An example from Sifnos, Greece

Besim Dragovic [a], Leah M. Samanta [a], Ethan F. Baxter [a,*], Jane Selverstone [b]

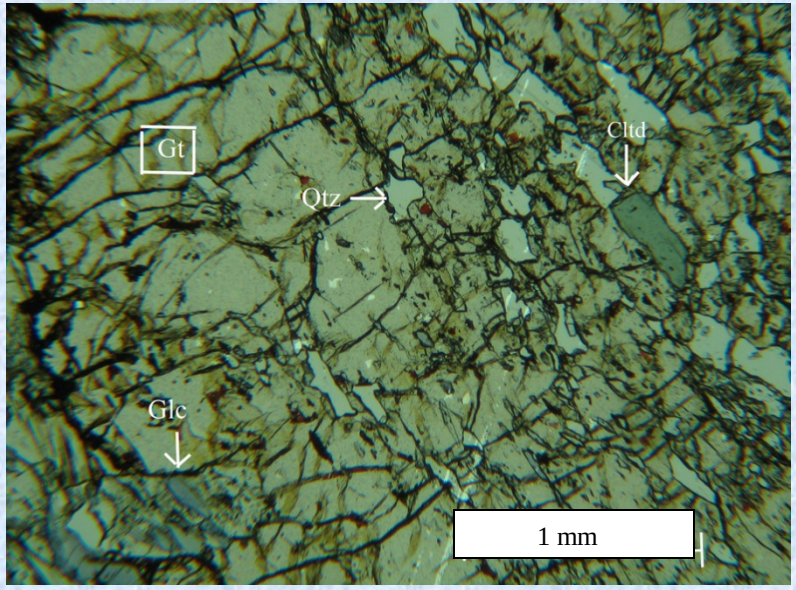
[a] Department of Earth Sciences, Boston University, 675 Commonwealth Ave., Boston, MA 02215, USA
[b] Department of Earth & Planetary Sciences, University of New Mexico, MSC03 2040, Albuquerque, NM 87131-0001, USA



Garnet-epidote blueschist



Matrix:
glaucophane, epidote, paragonite, phengite, quartz, rutile, jadeite, & garnet

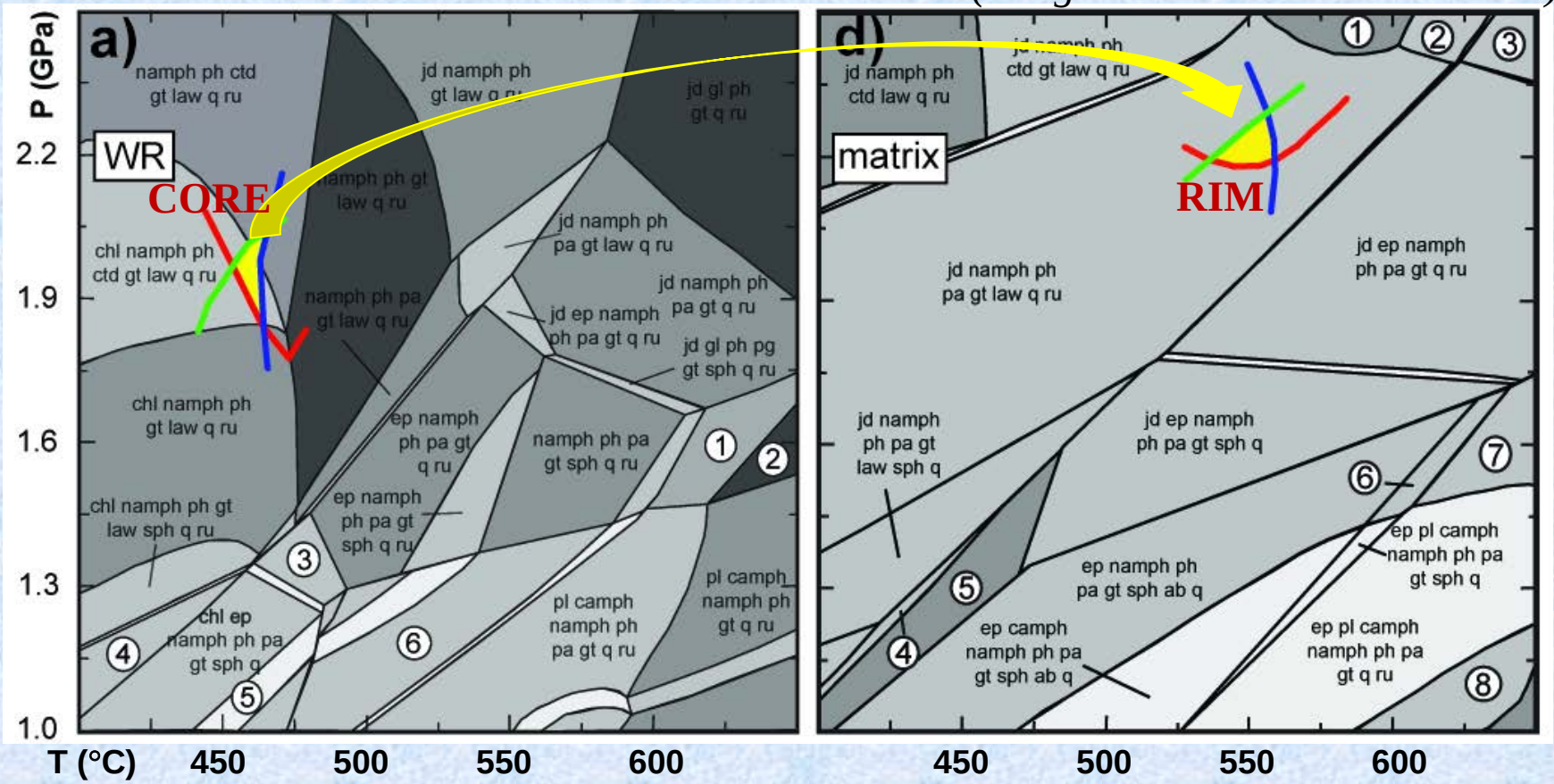


~1.5cm Garnet:
Inclusions of quartz, jadeite, glaucophane, chloritoid, & lawsonite (mostly replaced by epidote)

Garnet:Water production ratio

from pseudosection analysis

(Dragovic et al. 2012 Chem Geol)

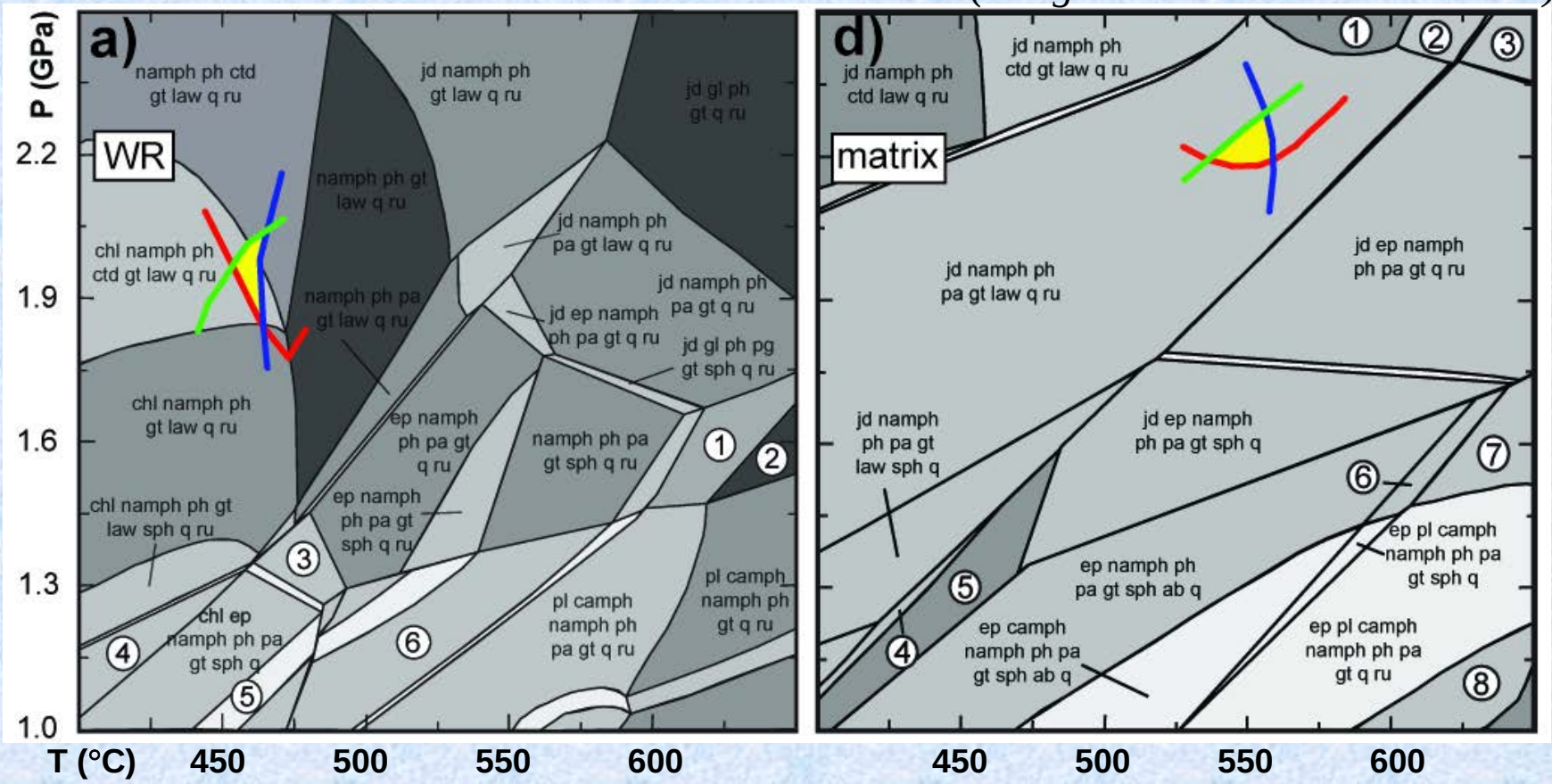


Important to account for fractional crystallization of garnet in effective bulk composition

Garnet:Water production ratio

from pseudosection analysis

(Dragovic et al. 2012 Chem Geol)

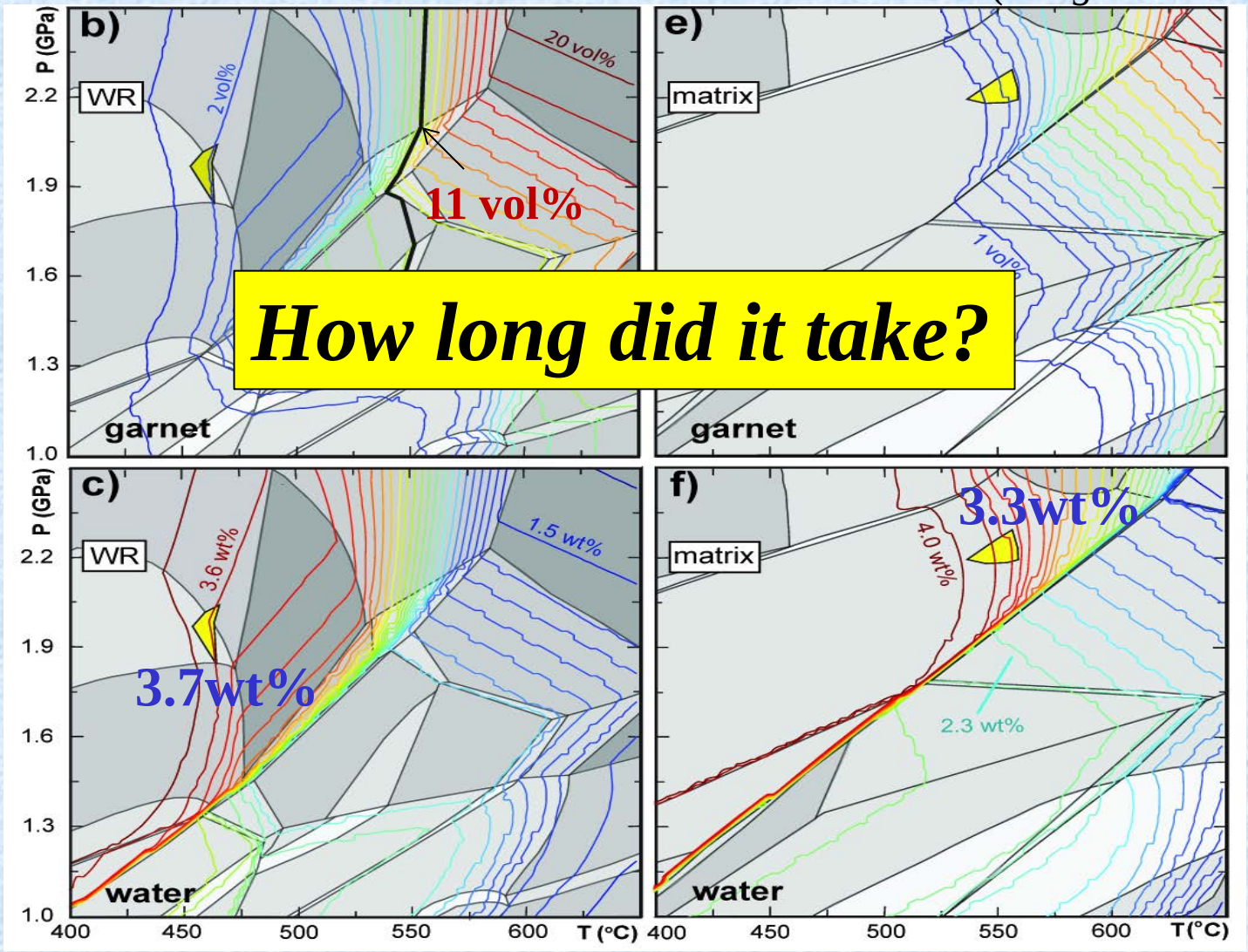


0.02 chlorite + 0.97 glaucophane + 0.10 phengite + 0.06 chloritoid + 0.10 rutile = 1.07 omphacite + 0.18 paragonite + 0.16 lawsonite + 1.36 quartz + 1.00 garnet + 0.69 water

Garnet:Water production ratio

from pseudosection analysis

(Dragovic et al. 2012 Chem Geol)



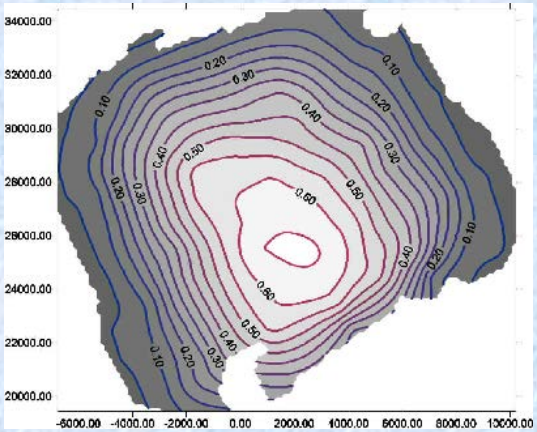
How long did it take?

GARNET vol%
contoured

WATER wt%
contoured

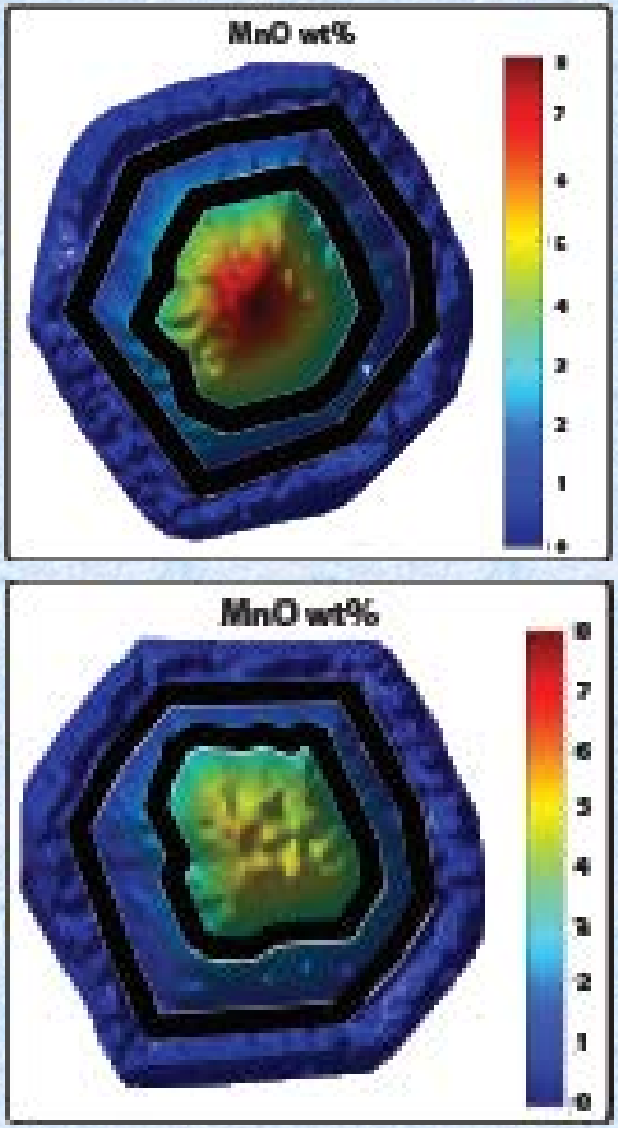
Zoned Garnet Geochronology

- Potentially provides longest continuous record of tectonic and metamorphic processes
  - Provides P-T-X-t info
  - Rate, duration of growth **& dehydration**

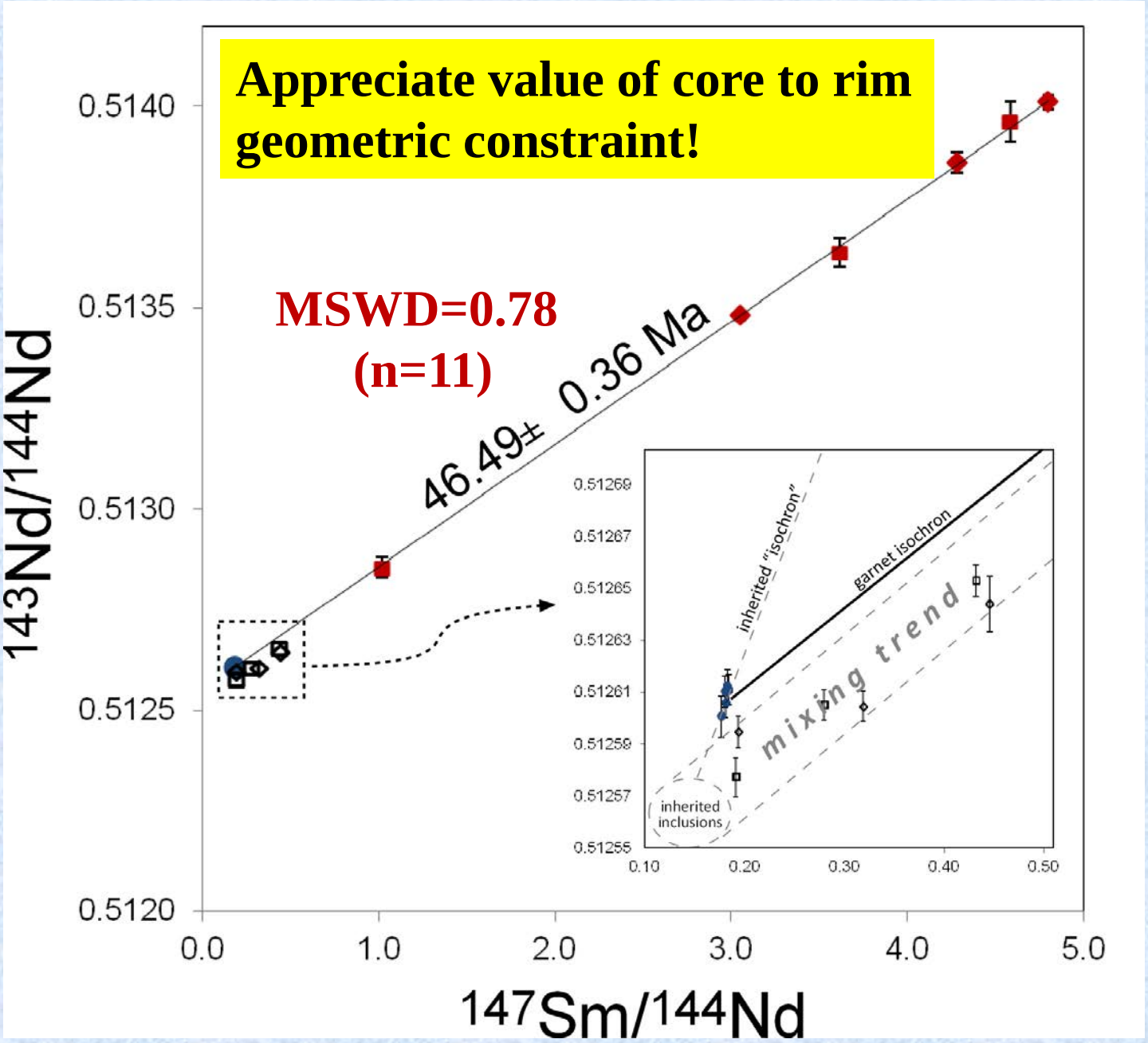


=

Sifnos, Greece *(Dragovic et al., 2012 Chem Geol)*



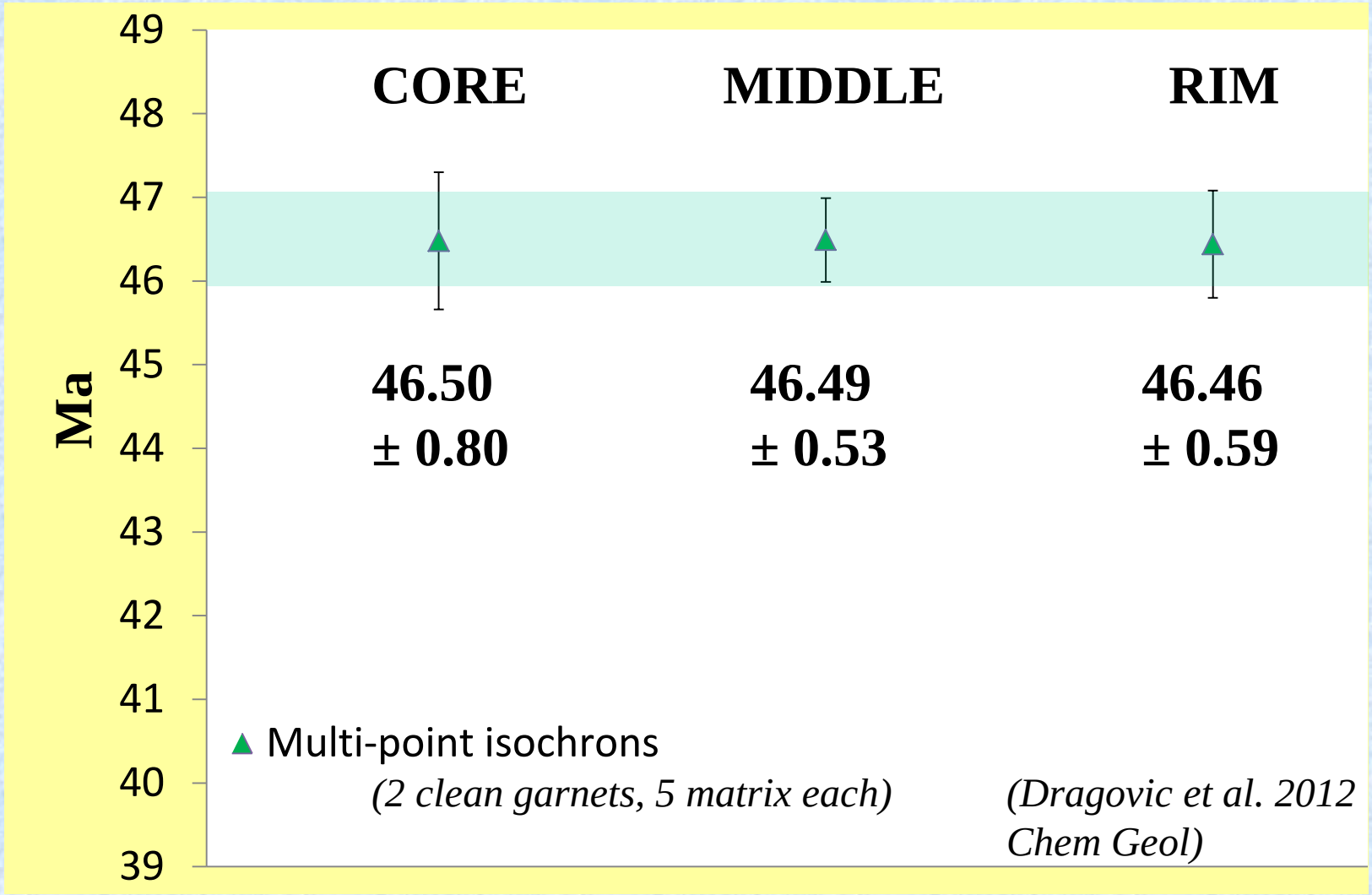
- 53 to 135mg of garnet per zone
- 0.8 to 1.9 ng of Nd per zone
- ±0.7 to 1.8 Ma age precision; one at ±4.8 Ma



(Dragovic et al. 2012, Chem Geol)

Sifnos, Greece

Brief growth duration in subduction zone… 0.04 ± 1.0 Myr



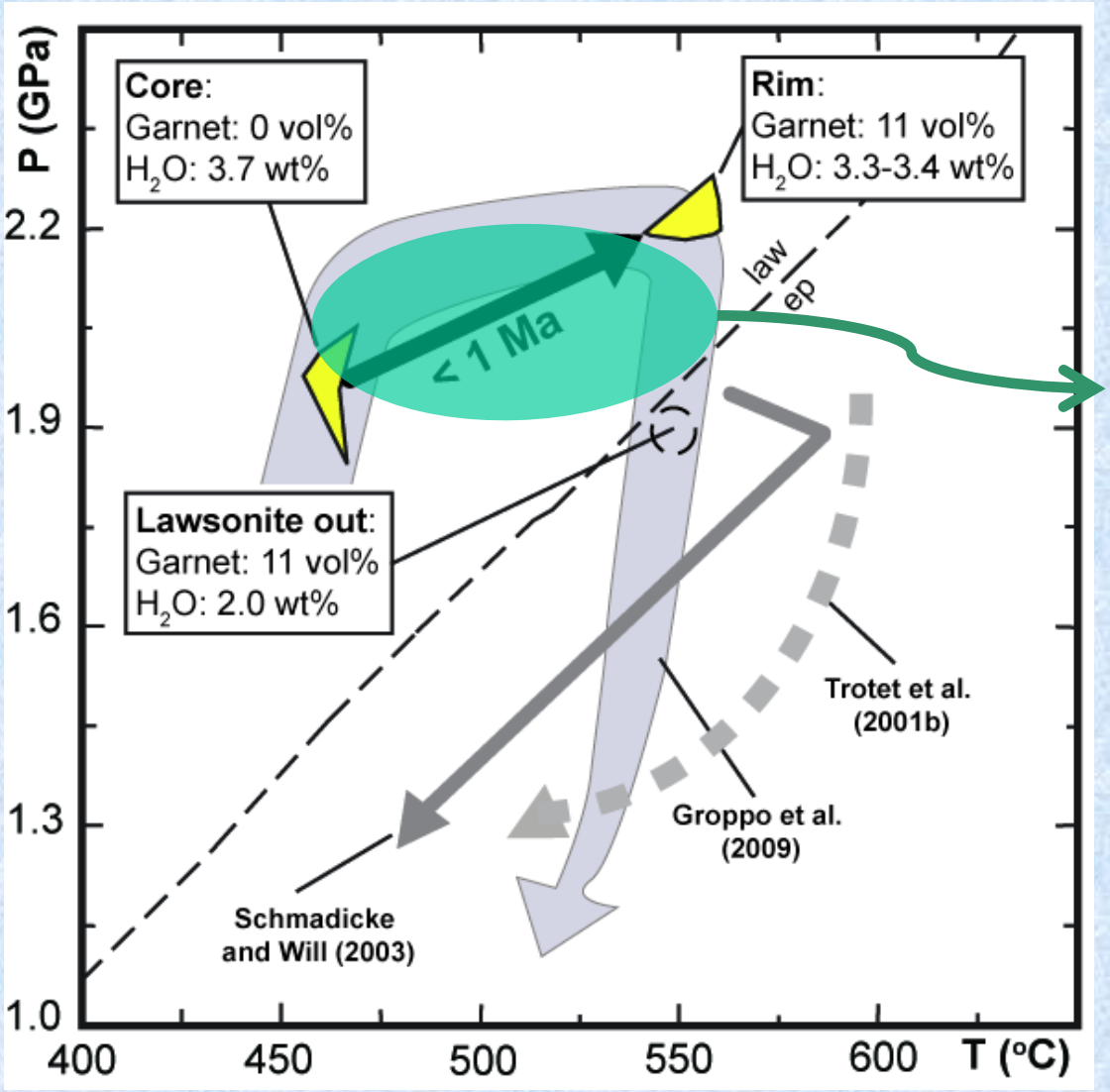
Dehydration Rate

(Dragovic et al., 2012 – Chemical Geology)

- 11% (volumetric) garnet produced in <1.0 million years duration
- >9 x 10^{-10} moles garnet/ cm^3 rock/ year
- **>5 to 7 x 10^{-10} moles water/ cm^3 rock/ year**

- **0.3 to 0.4 wt% water produced from THIS rock during garnet growth in 0.04 ± 0.99 Myr**

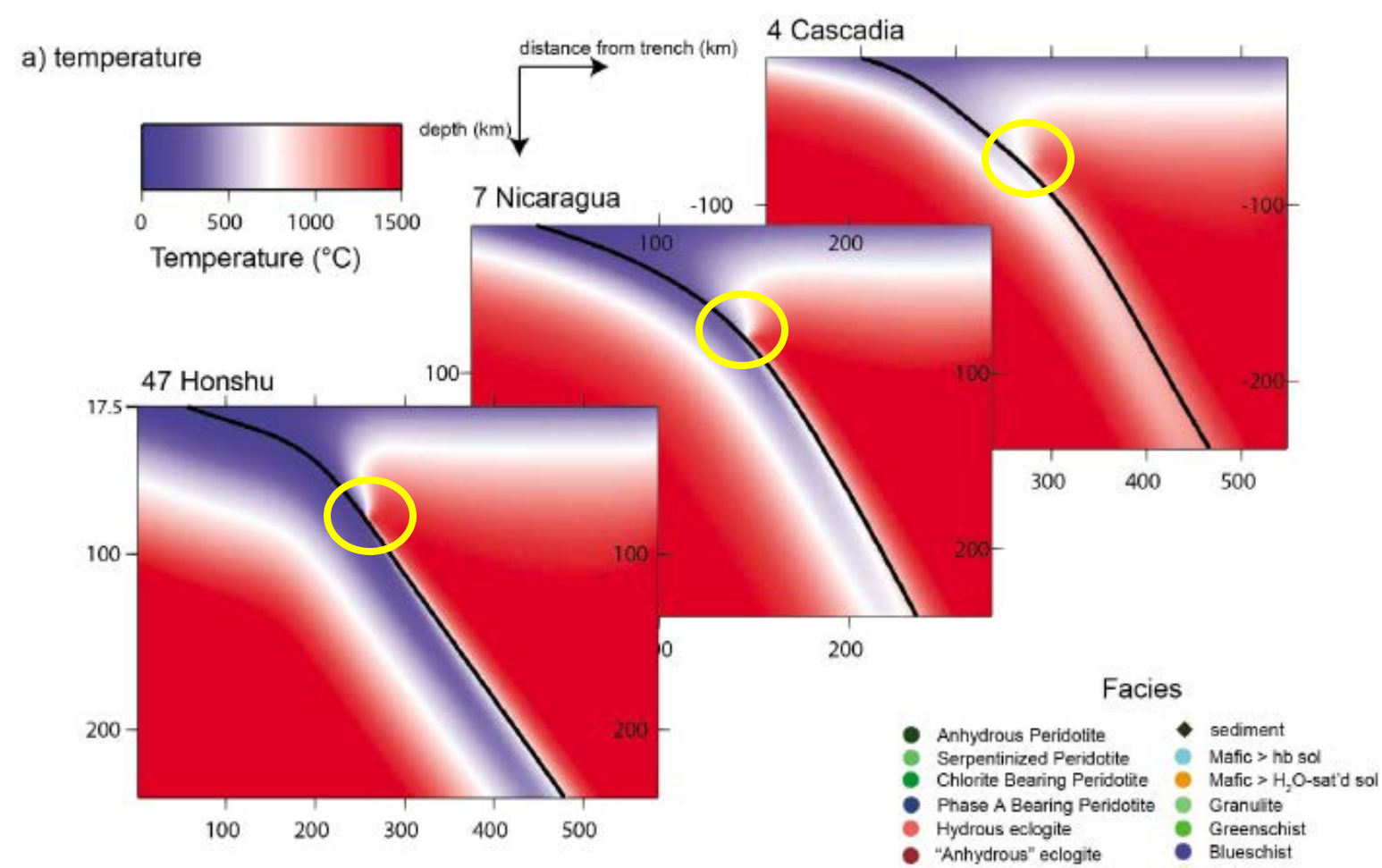
Dehydration (and heating) pulse from a Sifnos blueschist



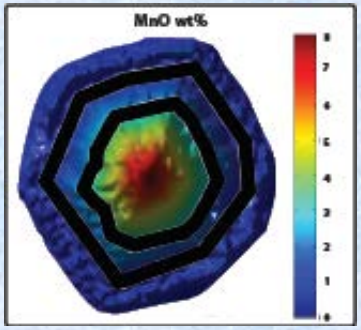
Approx. depth of slab-mantle decoupling (e.g. 70-80km Wada & Wang 2009; Van Keken et al. 2011)

(Dragovic et al. 2012 Chem Geol)

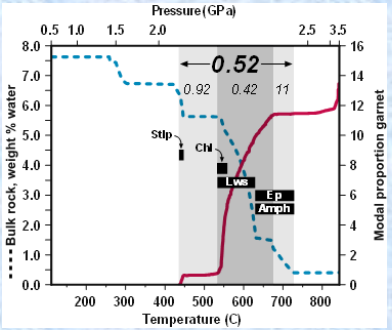
Dehydration & Heating Pulse consistent with “cold nose” models



van Keken et al. 2011



Conclusions



- Garnet forming reactions are generally dehydration reactions
- Thermodynamic analysis (including fractionation effects) quantifies garnet:water production ratio which is focused between 1.4 and 3.0 GPa
- Garnets growth may be dated as a direct proxy for dehydration
- Focused pulse(s) of dehydration and heating < 1Ma duration have been resolved in Sifnos rocks at ca. 46 Ma
  - *This supports a "cold nose" geodynamic thermal model (e.g. Wang & Wada 2009; Van Keken et al. 2011)*