‘Water’ content as a tool to estimate rheological differences in the lithosphere of young extensional basins

Nóra Liptai[1,2], Thomas P. Lange[1,3], Levente Patkó[1,3,4], Márta Berkesi[1,3], Csaba Szabó[2,3], István J. Kovács[1,2]

[1]MTA CSFK Lendület Pannon LitH$_2$Oscope Research Group, Geodetic and Geophysical Institute, Research Centre for Astronomy and Earth Sciences, Hungarian Academy of Sciences, Sopron, Hungary

[2]Geodetic and Geophysical Institute, Research Centre for Astronomy and Earth Sciences, Sopron, Hungary

[3]Lithosphere Fluid Research Laboratory, Institute of Geography and Earth Sciences, Eötvös Loránd University, Budapest, Hungary

[4]Isotope Climatology and Environmental Research Centre, Institute for Nuclear Research, Debrecen, Hungary

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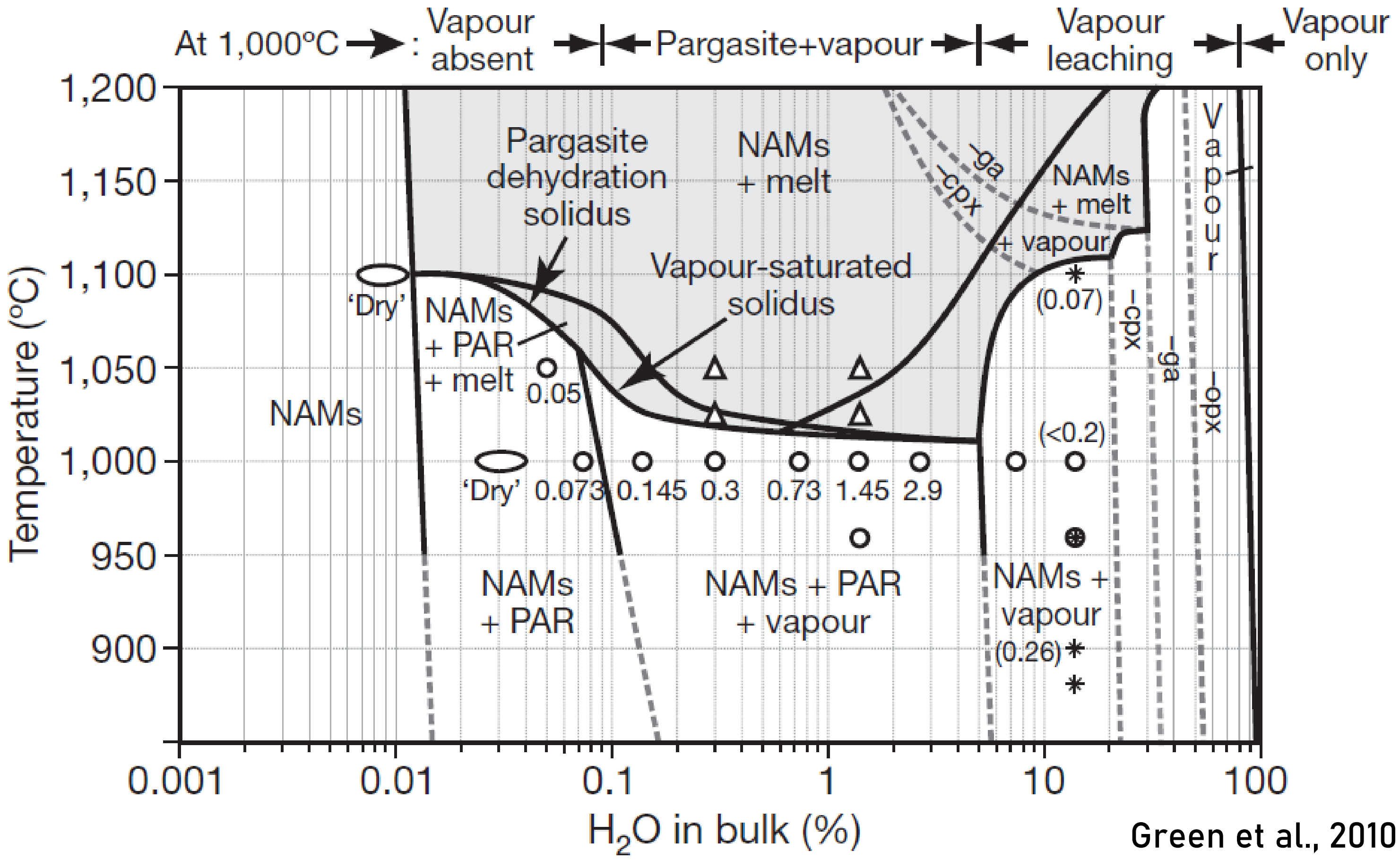
Presence of 'water' in the upper mantle

- H_2O in fluid/melt inclusions
- Structurally bound hydroxyl in mineral structures
  - Volatile-bearing mantle minerals (e.g., pargasite, phlogopite) – ~2 wt.%
  - Nominally anhydrous mantle minerals (olivine, pyroxenes) – tens to hundreds of wt. ppm



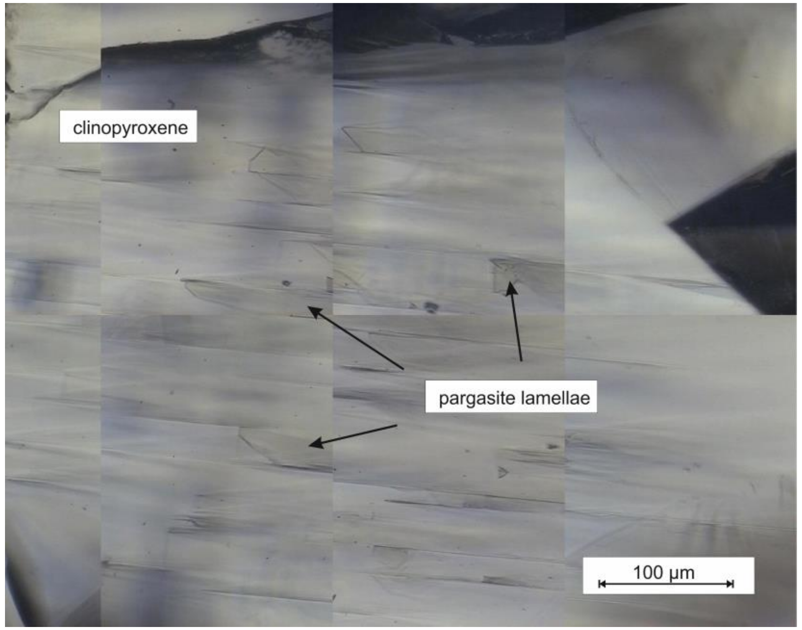
Green et al., 2010

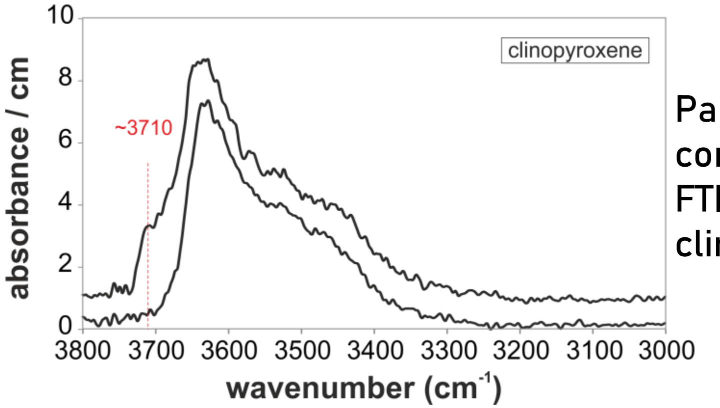
The upper limit of pargasite stability:

1050-1150°C or ~90-100 km depending on the lithospheric composition (fertility)

Pargasite stability

- Interstitial grains
- Lamella in pyroxenes (exsolving upon entering stability)





Pargasite contribution on FTIR spectrum of clinopyroxene

Outside pargasite stability

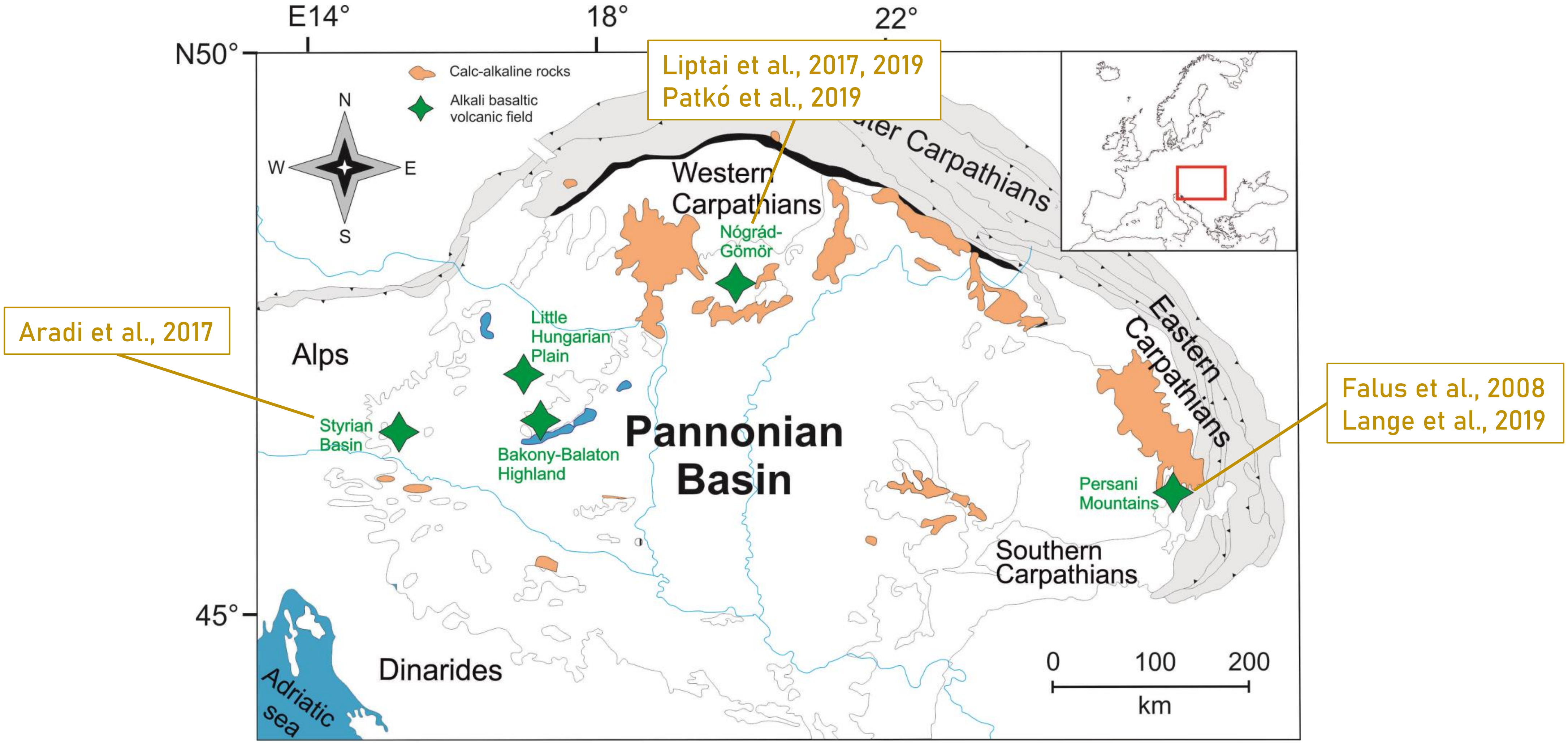
'Water' appears as:

- Aqueous phase (e.g., in fluid inclusions)
- Dissolved in incipient melt
- Partitioning in nominally anhydrous minerals (NAMs) as H^+ in cation vacancies

Influence on rheological properties (hydrolitic weakening):

- Partial melting temperature
- Effective viscosity
- Electrical conductivity / resistivity

Water in the xenoliths of the Carpathian-Pannonian region



Late Miocene – Pleistocene xenolith-bearing alkali basalt localities:

'Marginal' locations: Styrian Basin, Perşani Mountains (in the vicinity of subduction zones)

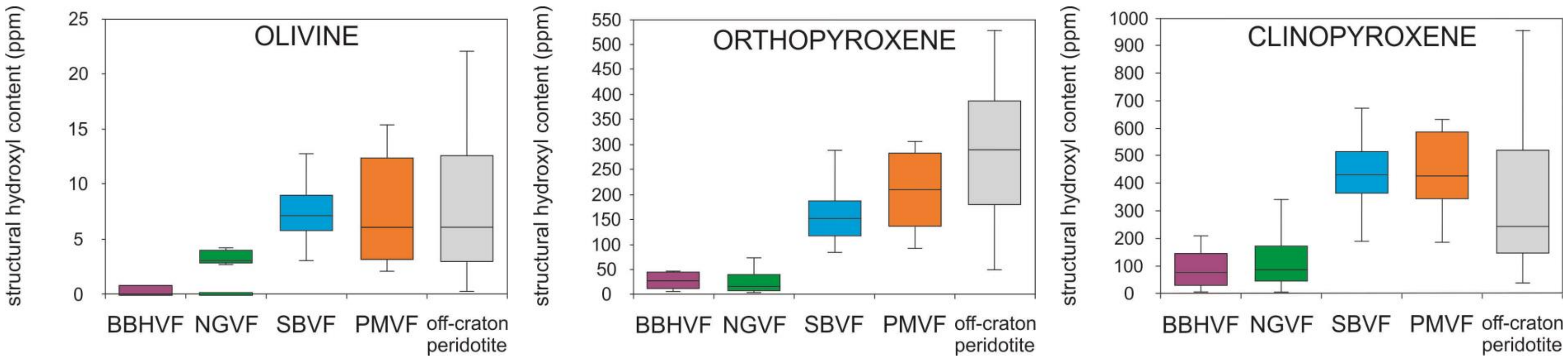
'Central' locations: Bakony-Balaton Highland, Little Hungarian Plain, Nógrád-Gömör

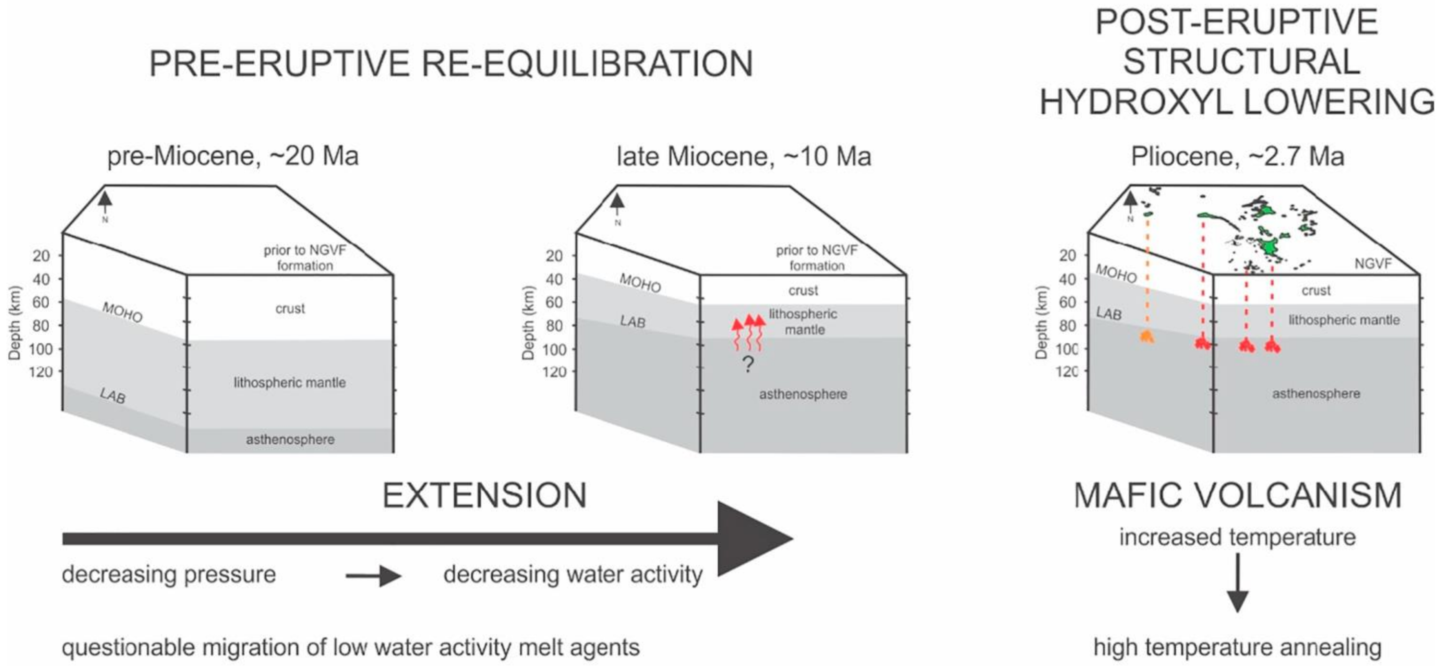
Water in the xenoliths of the Carpathian-Pannonian region

NAMs of xenoliths from Bakony-Balaton Highland (**BBHVF**) and Nógrád-Gömör (**NGVF**) have significantly **lower water content than** those from Styrian Basin (**SBVF**) and Perşani Mountains (**PMVF**)

Reasons for lower water content in xenoliths from areas more affected by lithospheric thinning:

- Pre-eruptive re-equilibration
- Post-eruptive hydrogen loss during cooling





Patkó et al., 2019

Effective viscosity

Expressed from stress and strain rate: $\eta_{eff} = \sigma/\dot{\varepsilon}$

Strain rate is calculated with an Arrhenius equation containing a term related to water content (water fugacity or concentration)

$$\dot{\varepsilon} = A_{cre}\sigma^{n_1} f^{r}_{H_2O} \exp\left(-\frac{Q + PV_{cre}}{RT}\right)$$

$$\eta_{\mathrm{eff}} = \dot{\varepsilon}^{(1-n)/n} f_{\mathrm{H_2O}}^{-r/n} \left(A \exp^{-(H^*/RT)}\right)^{-1/n}$$

Dixon et al., 2004

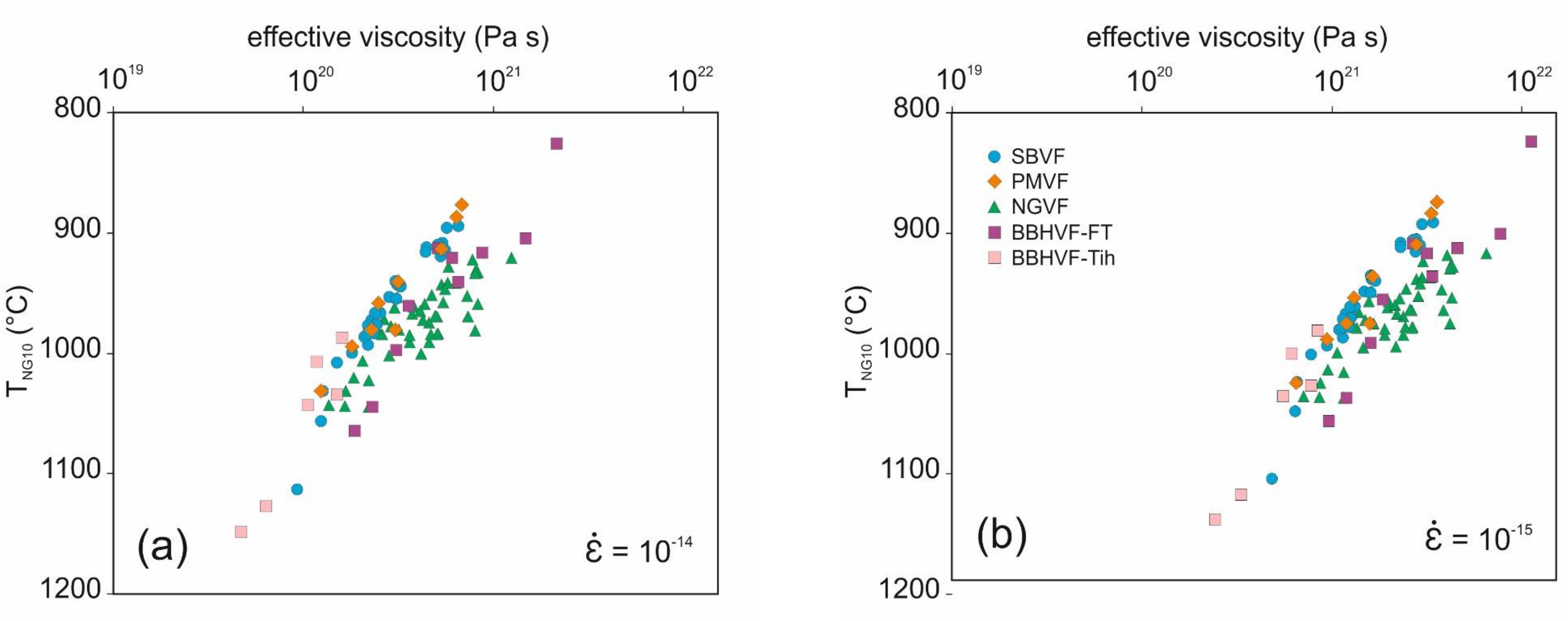
Material constants $H^* = Q^* + PV^*$

	A	Q^* (J/mol)	V^* (m^3/mol)
Dry dislocation	1.1×10^5 $(MPa)^{-n}/s$	5.30×10^5 (± 0.04)	20×10^{-6}
Wet dislocation (constant f_{H_2O})	1600 $(MPa)^{-(n+r)}/s$	5.20×10^5 (± 0.4)	22×10^{-6}
Wet dislocation (constant C_{OH})	90 $(MPa)^{-(n+r)}/s$	4.80×10^5 (± 0.4)	11×10^{-6}

n (stress exponent) = 3.5, r (fugacity exponent) = 1.2 for wet dislocations [40].

Water fugacity (f_{H2O}) can be replaced with water concentration (C_{OH})

Effective viscosity



Effective viscosity decreases with depth due to increasing T

- 'Marginal' localities have similar trends
- 'Central' localities show higher viscosity on average

Beside water content, strain rate also has an important effect

T_{NG10}: Ca-in-opx thermometer of Brey and Köhler (1990) modified by Nimis and Grütter (2010)

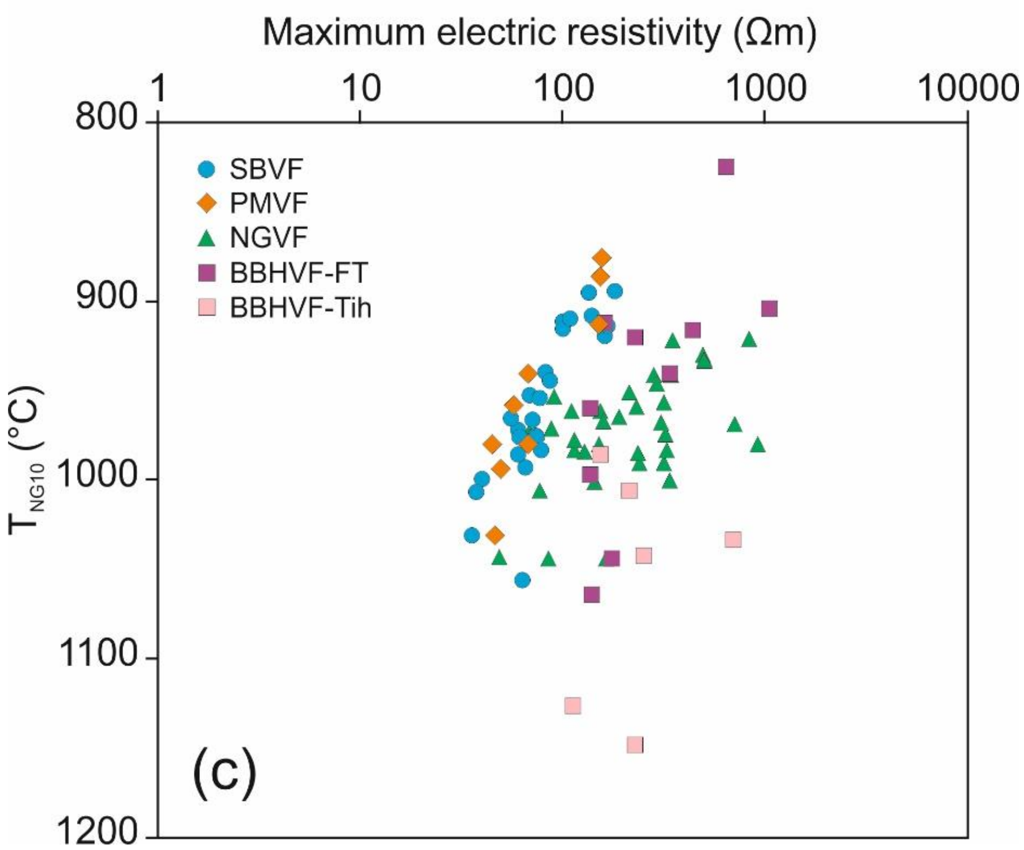
BBHVF-FT and –Tih are the youngest and oldest xenolith locality of the volcanic field, respectively

Electrical conductivity / resistivity

Model of Fullea, 2017

- Includes pyroxenes and their proportion alongside olivine
- Used parameters: modal ratio, composition (Fe-content), and structural hydroxyl concentration of olivine and pyroxenes

Higher resistivity of 'central' localities → lower water content (no significant difference in Fe-content)
Presence of melts/fluids can have a significant effect



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Conclusions

- In the Carpathian-Pannonian region, xenoliths from the 'marginal' localities are more water-rich compared to those from 'central' localities
- Water content has an effect on rheological properties (effective viscosity, resistivity) → central areas are more rigid than marginal areas
- This may be similar in subduction – back-arc basin systems worldwide
- Additional effects (change in strain rate, presence of melts/fluids) need to be taken into account
- Comparable with geophysical observations (e.g., deep MT soundings)

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