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Timescales from mixing to eruption in alkaline volcanism in the Eifel volcanic fields obtained from sanidine and olivine diffusion modelling

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Objectives:

(1) Determine the timing of recharge events prior to the Laacher See eruption (12.9 kyr BP) in the East Eifel volcanic field by...

(2) modelling diffusion profiles in sanidine from mafic to evolved phonolite and cumulate samples and

(3) in olivine from phonolite-basanite hybrid samples that formed after mafic recharge and before eruption.

(4) Additionally, olivine crystals from basanitic scoria cones were analyzed to identify Quaternary mafic parental magma compositions and determine their ascent times from mantle into the crust and to the surface.

Geological Setting

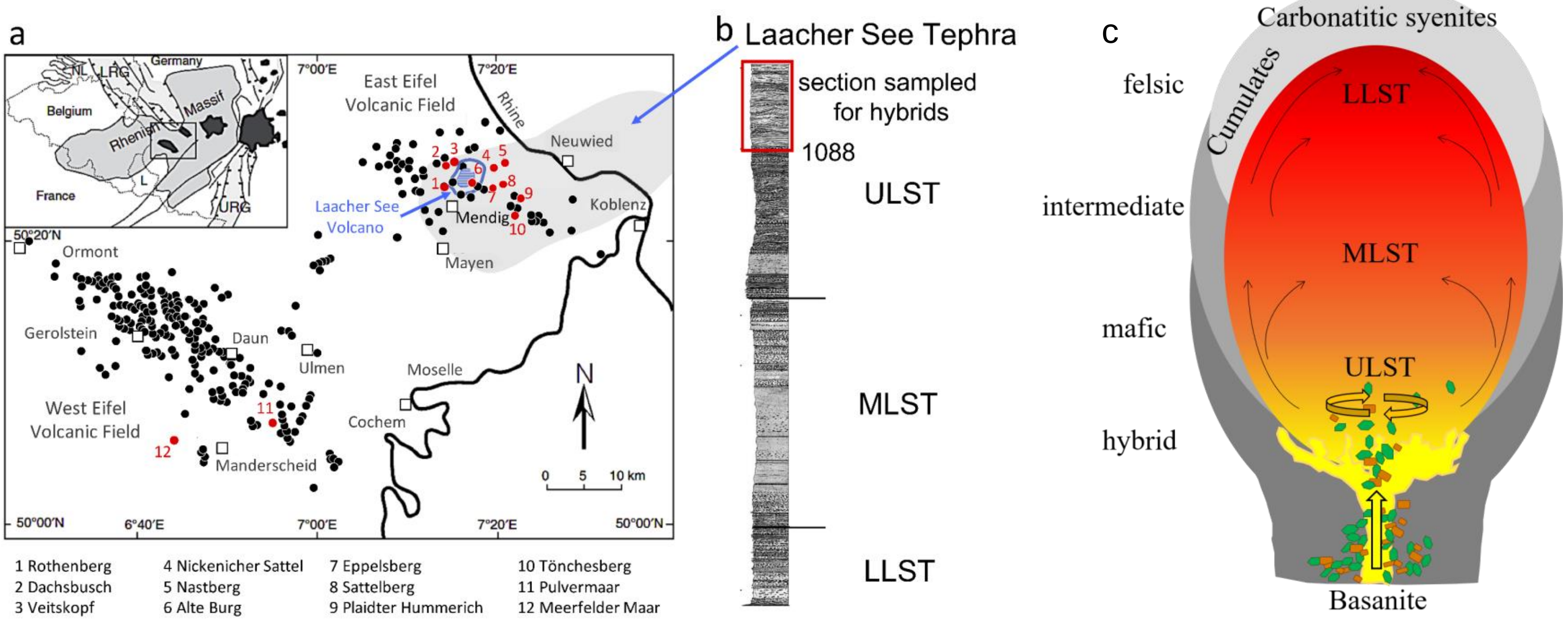


Fig. 1: Map of the Eifel volcanic field (western Germany, after Mertes 1983) showing eruptive centers (black dots). Red dots mark basanitic / nephelinitic scoria cones and maar deposits in the East and West Eifel which were here sampled for olivine analyses. (b) Laacher See tephra sequence. (c) schematic concept of the Laacher See magma chamber (after Wörner and Schmincke 1984b; Tait et al. 1989; Ginibre et al. 2004; Schmitt et al. 2010)

Laacher See volcano: The phonolitic Laacher See volcano belongs to the younger East Eifel volcanic field. Its most prominent eruption occured at 12.9 kyr BP and produced 6.3 km^3 of tephra (DRE).

Laacher See reservoir: The Laacher See magma chamber is located below 3-6 km depth (Wörner and Schmincke 1984b). The Laacher See tephra sequence (Lower, Middle and Upper Laacher See tephra) represents the inverted sequence of a chemically zoned magma chamber with evolved, crystal poor phonolite at the top that was erupted and deposited first (LLST) towards the final erupted, crystal-rich mafic phonolite from the bottom of the reservoir (ULST).

Samples and Analytical Methods

Sanidine: Zoned sanidine crystals were analyzed in samples from (1) phonolitic cumulates that are genetically directly related to the Laacher See phonolite magma and (2) from compositionally distinct phonolite pumice from the MLST and ULST. Measurements were done with an electron microprobe for quantitative measurements (at 15 keV, 15 nA, and 10 µm beam diameter). Back scattered electron (BSE) images were taken at 20 keV, 20 nA.

Olivine: Olivine crystals occur only in the uppermost section of the ULST, which represent the final mafic hybrid products after mixing between the phonolite and the intruding, olivine-bearing basanite. Olivine analyses were performed as line profiles by electron microprobe using a trace element program (20 keV, 300 nA, a focused beam, and a step size of 3-5 µm).

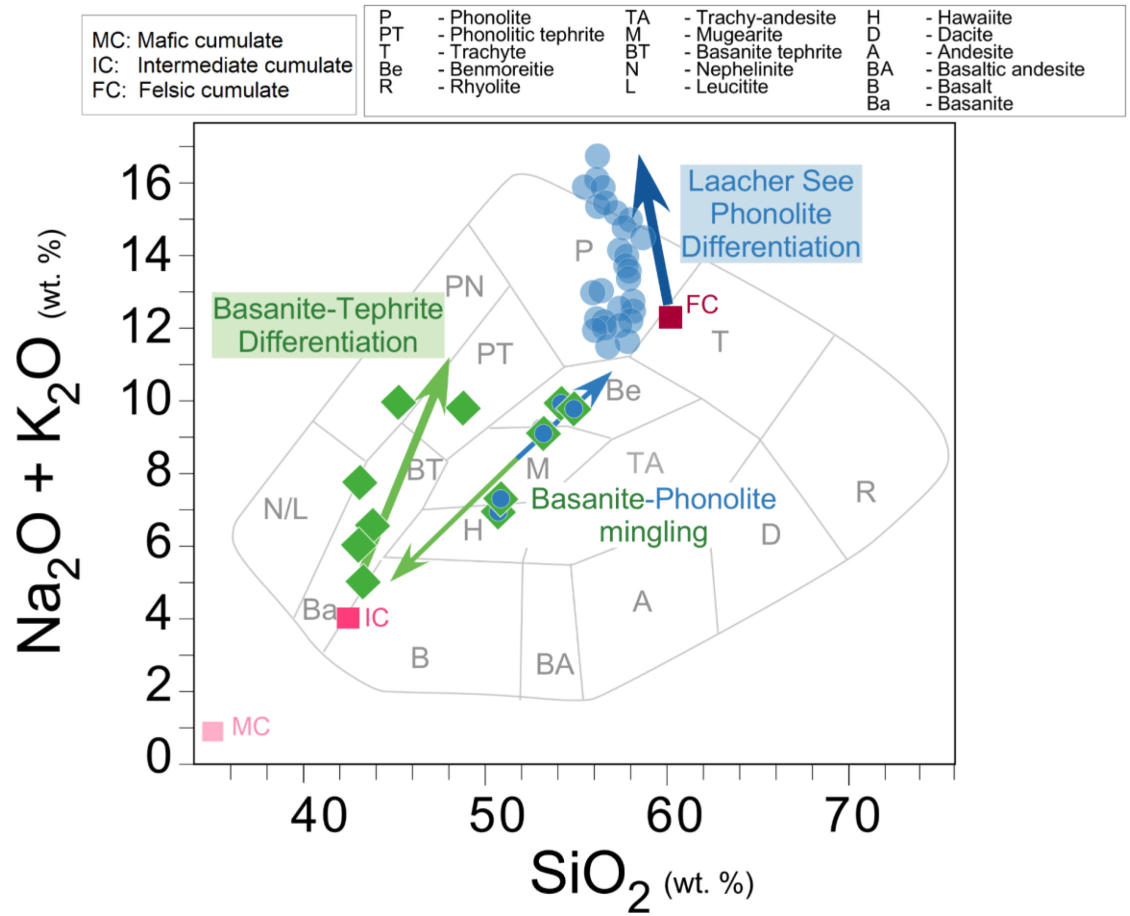
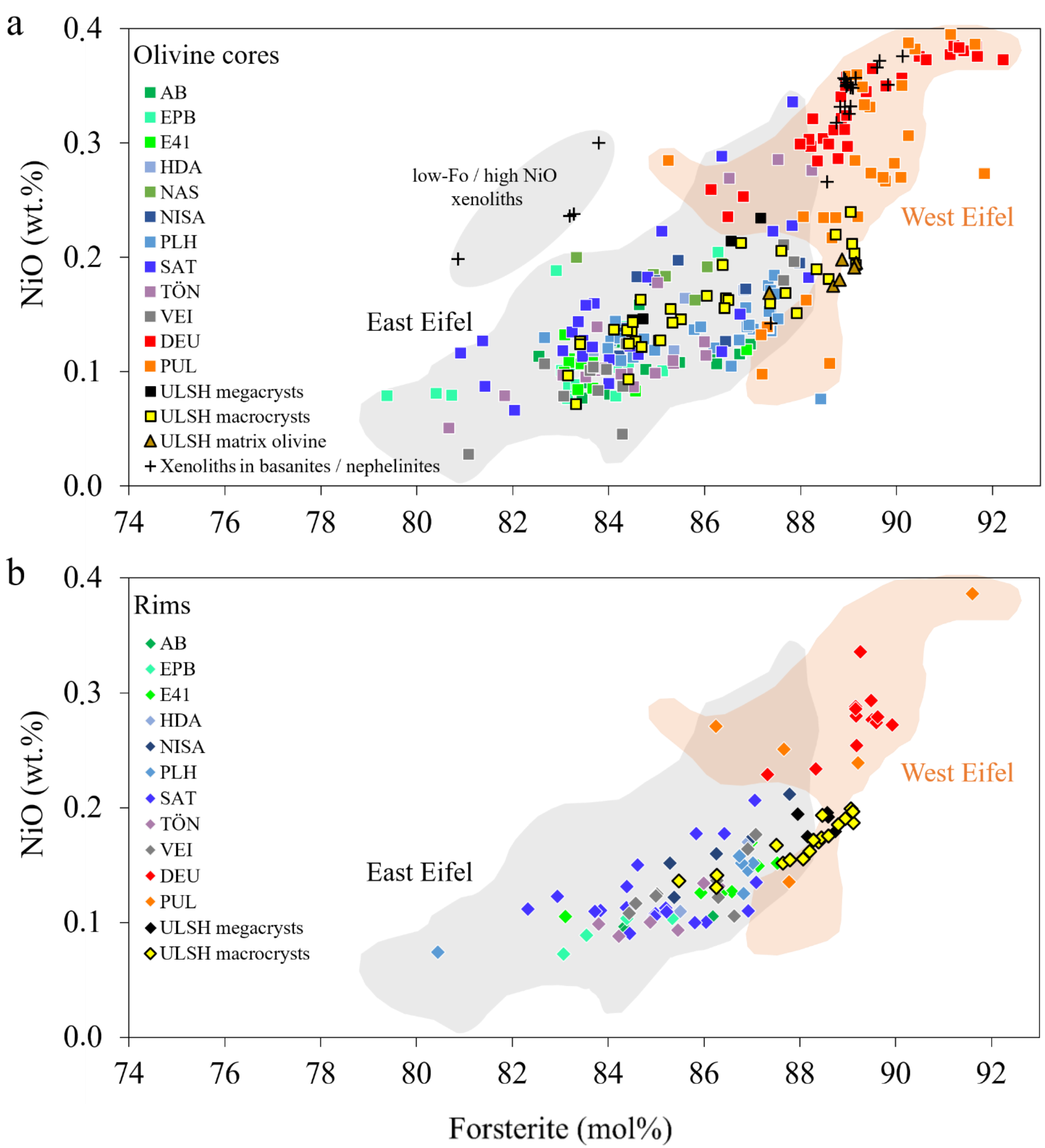


Fig 2: Volcanic samples (including phonolitic pumice, basanite and hybrid samples) and three representative cumulate compositions plotted on a alkali- SiO_2 diagram. Plot also shows distinct phonolite differentiation, basanite-tephrite differentiation and basanite-phonolite mingling trends.

Composition of parental basanite magma



Chemical compositions of olivine from basanite and nephelinite samples were measured to track primitive parental magmas, which may be compositionally similar to the basanite recharging the Laacher See magma chamber.

Fig. 3 (left) shows that olivine core compositions from Laacher See hybrid samples (ULSH) and East Eifel basanites (AB to VEI samples) are similar. However, olivine rims, which likely were in equilibrium with the recharging magmas, do not exceed Fo_{88} in basanite samples from scoria cones, but are distinctly more forsteritic in the LS hybrids ($Fo_{87.5-89}$).

This indicates that the basanite recharging the Laacher See magma chamber was more mafic than any of the East Eifel basanites analyzed in this study.

Fig 3 : NiO-Fo diagrams for (a) cores and (b) rims of all olivine crystals analyzed in this study. Bright grey and reddish fields mark the measured core compositions from West- (orange and red symbols) and East-Eifel (green to blue symbols) samples.

Diffusion Modelling

Sanidine

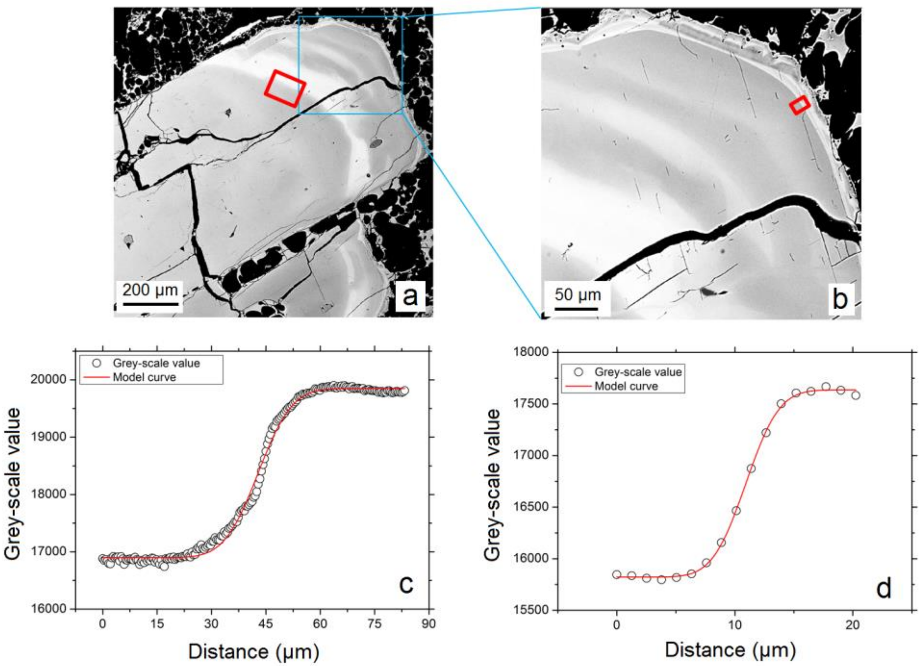


Fig 4: (a) accumulated BSE image of a selected sanidine grain [sanidine 2 in sample 1088-1H (a hybrid sample)]. Grey-scale profiles are modelled as a proxy for Ba-profile after a correlation check. The solid red rectangle encloses the area over which the grey-scale swath profile (c) for inner boundary is taken. (b) the zoomed-in view of (a); the solid red rectangle covers the area of the swath profile (d) across the outer-most boundary. The red curves in (c) and (d) are the model curves obtained through a least square fitting.

Zoning and composition: Sanidine phenocrysts from mafic and intermediate phonolite are nearly homogenous in major element composition. Observed zonation are only due to variation in Ba and Sr. Each sanidine grain has 2 to 4 significant, well-identified growth bands that are characterized by a change of at least 0.5 wt% in Ba content. 60 – 70% of the sanidine phenocrysts from the hybrid samples have an additional very thin (2 – 10 µm wide) Ba-rich (at least 1.8 – 2.5 wt%) overgrowth (Fig 4) with 60 – 70% change in Ba compared to the preceding zone. This kind of overgrowth is never observed in the sanidine phenocrysts from non-hybrid samples.

Temperature: Based on experimental data by Berndt et al. (2001), 760±10 °C for intermediate phonolite, 840±10 °C for mafic phonolite and 870±10 °C for the hybrid were used. For the post-mixing outermost rims in the hybrid samples, we used the highest liquidus temperature documented for upper ULST sanidines i.e. 890±10 °C (Wörner 1982; Berndt et al. 2001).

Diffusion Modelling

Olivine

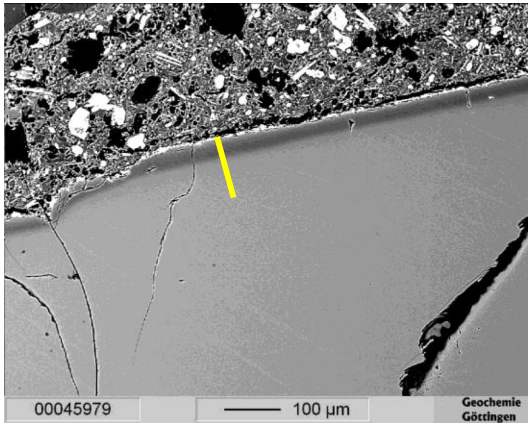


Fig 5: BSE image of an olivine (LSH-1-1) from Laacher See hybrids with the measured profile in yellow.

Zoning and composition: Olivine megacrysts from Laacher See hybrid samples show exclusively reverse-normal zoning that is restricted to the outermost 100 µm of the crystals. They have variable core compositions (Fo_{83-89}), but more uniform rims ($Fo_{87.5-89}$). The grain boundary composition is $Fo_{86.5-87.5}$.

Olivine crystals from East Eifel basanite samples have similar reverse zoning and core compositions (Fo_{80-88}), but are less forsteritic rim compositon (Fo_{83-88}) than olivine from Laacher See hybrids.

Olivine from West Eifel nephelinites are normal zoned and have high-Fo cores (Fo_{88-92}) and rim compositions similar to those from Laacher See ($Fo_{87.5-90}$).

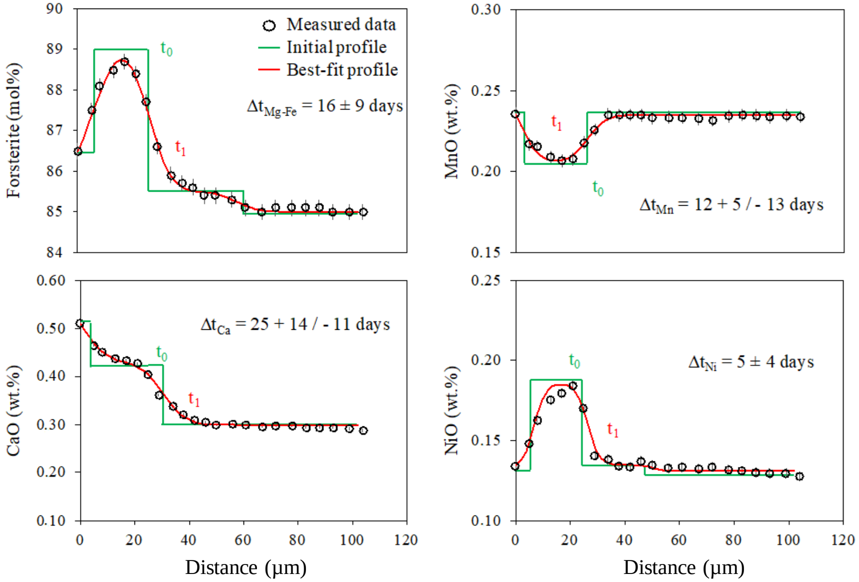


Fig 6: Diffusion profiles for Mg-Fe, Mn, Ca, and Ni from a representative olivine crystal from Laacher See hybrid samples (LSH-1-1). Profiles were modelled using a numerical approach with fixed boundary compositions (DIPRA; Girona and Costa 2013).

Temperaturen and pressure: The profiles were modelled with an estimated pressure of 2 kbar and for two different temperatures: (1) an intermediate T = 1120 °C to consider cooling of the recharging basanite (= 1170 °C) during mixing with lower-T phonolite and cumulate disaggregation and (2) a minimum T = 1000 °C calculated for the hybrid after mixing between basanite and phonolite (880 °C; Berndt et al. 2001).

Diffusion times

Sanidine: Diffusion times of sanidine phenocrysts (MLST) indicate several recharge events at a frequency of 1500-3000 yr^{-1} for the 20,000 yrs prior to the eruption. In contrast, sanidine phenocrysts from the ULST give Ba-diffusion times of only 4-8 yrs**.** Diffusion between the exsolution lamellae in sanidine from the cumulates also give rather short (and maximum) times of 1.5-3 yrs, which likely represent a last heating event prior to eruption.

Olivine: Diffusion times of olivine in the Laacher See hybrids are <50 days (modelled at T = 1120 °C) to maximum 410 days (modelled at the minimum T = 1000 °C). These timescales correspond to those obtained from cumulate sanidines for the last heating event. Olivine zoning can be related to basanitic recharge and cumulate disaggregation (reverse zoning) and basanite-phonolite mixing (outermost normal zoning).

Olivine in basanitic samples: Diffusion times of olivine in basanite samples from two East Eifel scoria cones are longer (up to 490 days) than the times calculated for olivine crystal within Laacher See hybrid samples.

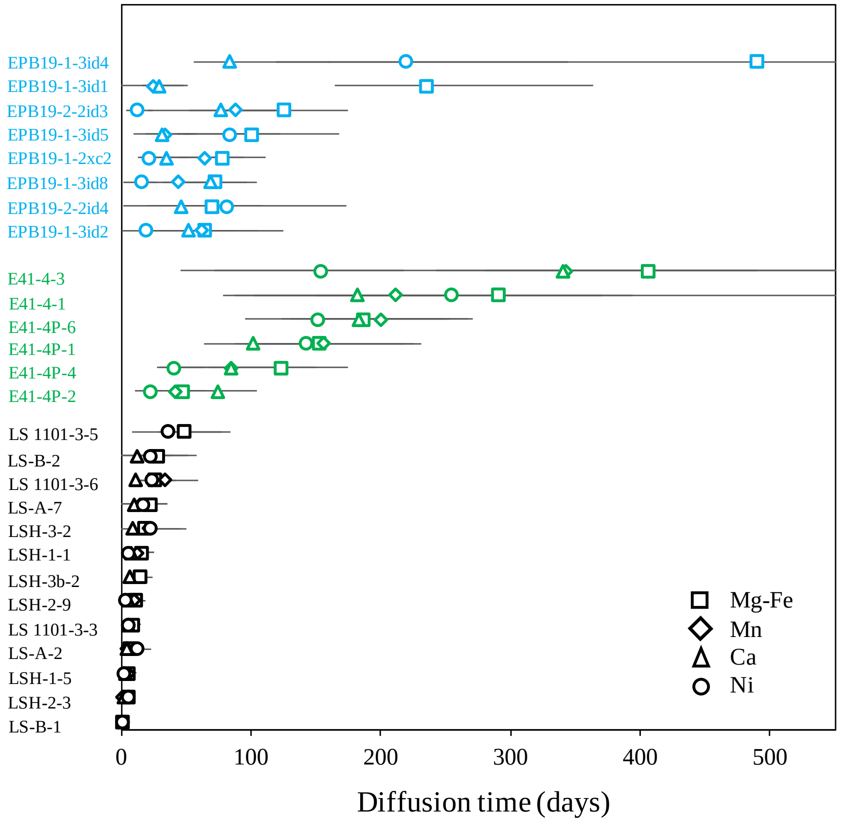


Fig 7: Diffusion times of olivine crystals from Laacher See (LS) and basanite samples (E41, EPB19).

Conclusions

- The basanite that intruded into the Laacher See magma chamber and mixed with the phonolite prior to eruption was more mafic than any of the basanites that erupted at scoria cones in the surrounding area previous to activity of the Laacher See volcano.
- Diffusion times obtained from Ba diffusion modelling in sanidine indicate recharge events every 1500-3000 yrs within the 20,000 year history of storage and phonolite differentiation within the Laacher See magma system.
- Timescales from diffusion modelling in sanidine and olivine show, that the last basanite recharge occurred months to maximum 3 yrs prior to the eruption and may have therefore acted as a triggering mechanism.

References

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