Executive summary

Over the five years long duration of the research grant the following main achievements have been reached related to the grant. 9 papers have been published in peer-reviewed journals. Out of these 3 are in D1, 2 in Q1, 2 in Q2 according to Scimago Journal Rank (scimagojr.com/journalrank.php) and 2 in journals without impact factors. The cumulated impact factor of these publications is 22.107. The known independent citations to these articles are 17. 4 extended and 29 conference abstracts have been published from which 17 and 12 were published related to domestic and international conferences respectively. Among the participating young scientists 1 obtained PhD, 2 MSc degrees whereas 1 young colleague is just about to finish his PhD studies. These young colleagues won all together 9 awards and grants during the tenure of the project. Two lecture series were organized at the Hungarian Academy of Sciences on the 20th of April 2017. and 16th of January 2019. to which our project contributed with several lectures.

1) Geoinformatics: a new holistic database and rock repository

More than 100 hand specimens were collected in this project form the Western and Eastern Volcanic Segment of the Carpathian-Pannonian region besides the rock collections from the Visegrád, Börzsöny and Mátra Mts. collected by Dávid Karátson.. The major scope during sampling was the detailed documentation of sampling localities and various related geological information (i.e. volcanic region/sub-region, lithostratigraphical unit, lithofacies). Consequently, handling of a large dataset including WGS84 coordinates and several tens of attributes from geochemical analyses and lithological descriptions were necessary. On this basis, a geodatabase was designed via Quantum GIS (qgis.osgeo.org) in order to store, analyze and visualize data.

Besides the 108 bulk- and trace element anlyses, former geochemical and age data as well as volcanological maps are also available, which were also introduced into our database (**Fig.1a**). 5 georeferenced and digitized volcanological/geological maps of the Visegrád Mts., Börzsöny Mts., Bükk Foreland Volcanic Area, Oas-Gutin Area, and from the CGH segment (including the Kelemen Mts., Görgényi Mts., Hargita Mts. and Csomád volcano from the Southern Hargita Mts.) were introduced into the geodatabase. Merged tiles of the SRTM (Shuttle radar Topography Mission; https://earthexplorer.usgs.gov/) digital surface model were used as a basemap. Both releases with 1 and 3 arc second resolutions were used; the later corresponds to ca. 30 m field resolutions (**Fig.1b**).

Such a geodatabase allows performing analyses on the relationship between volcanic region (i.e. Western vs. Eastern), lithostratigraphic units, lithofacies, radiometric age and geochemical character. Publication of this geodatabase in the near future is planned via using a web-based GIS frame in order to allow using our data publicly.

An important side project of the ’Water in fire’ project became the saving and of the samples from the Laboratory of Climatology and Environmental Physics in Institute for Nuclear Research at ATOMKI, Debrecen. The samples were formerly measured foremost with K-Ar and Ar-Ar techniques, often coupled with major and trace element data on whole rock and mineral samples and published by Zoltán Pécskay and his collaborators in about 65 high impact journal articles and reports.

The samples were taken from the Carpathian Pannonian Region (sensu lato) including sample places from Czech Republic, Poland and Serbia, the Balkans, including Bulgaria, Macedonia and Greece and as remote places as the Canary Islands or Antarctica. The majority of the samples are from locations, which are closely related to the 'Water in fire' project within the Carpathian Neogene Volcanic Arc but the capacity of the project did not allow us including these locations in the 2017 May field-campaign, such as the Tokaj Mts., Central Slovakian Volcanic field or Transcarpathia (Kárpátalja). The saving of these samples gives a unique opportunity to carry on with the geochemical research of the Carpathian-Pannonian Region Neogene volcanic rocks and interpret the results in the already well-established geochronological sequence.

We have sorted out 852 hand specimens that corresponded for the following criteria: a) size large enough to make thin sections of; b) sampling place is confirmed, c) field and laboratory id-numbers are available. The majority of the selected samples was already re-packed and transported to their intended final storage space at the Institute of Earth Physics and Space Science of Sopron (**Supplementary Table 1**).

Fig.1a. A representative image from the database showing bulk rock SiO_2 content of samples investigated in the project.

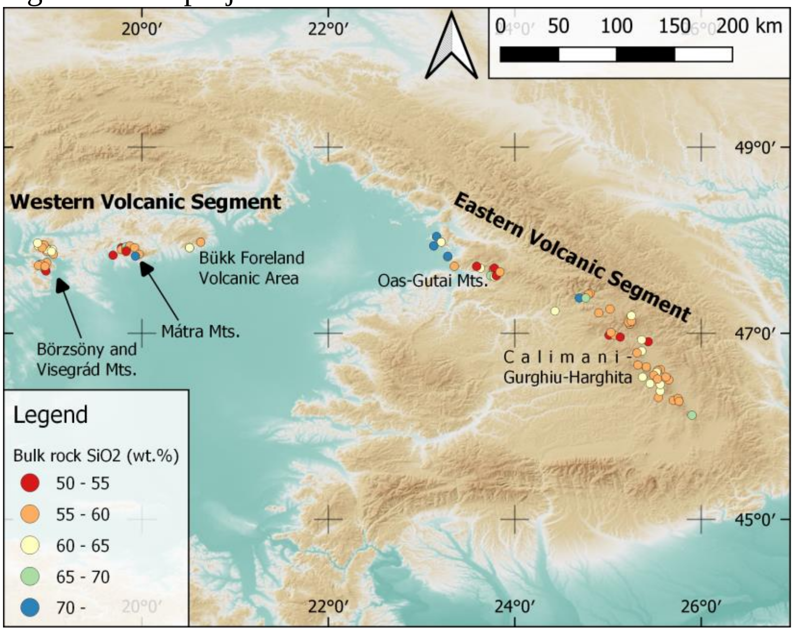
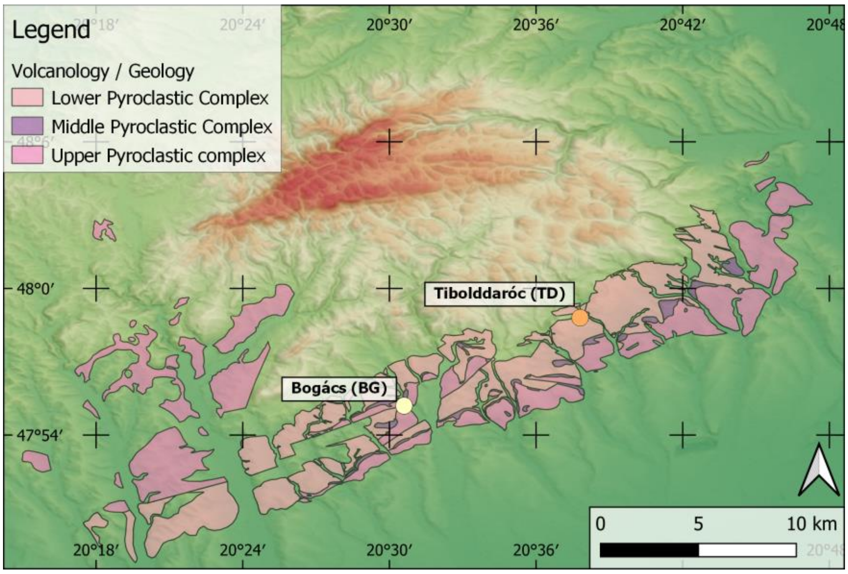


Fig.1b. A representative image from the database showing the two sampling localities from the Miocene Bükk Foreland Volcanic Area.



2) Systemic differences emerged between the "Western" and "Eastern Segment based on bulk rock geochemical analysis

We produced a new cohesive geochemical dataset for the Neogene calc-alkaline volcanic chain of the CPR which was analysed in the same laboratory with the same method to rule out interlaboratory variations. The measurements were carried out with a considerably wider array of trace elements measured than in most of the previous studies. For the main elements a Jobin Yvon Ultima 2C ICP-OES for the trace elements a Perkin–Elmer SCIEX ELAN DRC II ICP-MS were used, for detailed description of the techniques see Pálos et al. (2019).

The acquired data was organized into a database then illustrated on petrological diagrams based on the works of Chin et al. (2014), Mullen et al. (2017), Wattham et al. (2018) and Schmidt et al. (2017). Based on our observations and previous review studies (i.e., Seghedi et al. 2004) **we may divide our dataset into three geochemically distinct regions : the first group is Visegrád, Börzsöny, Mátra, Bükk (western); the second is Oas-Gutai Mts. (central) and the third is Calimani, Gurghiu, Hargita (eastern)** (**Fig.2, 3 and 4**). Note that originally the Western Segment in our terminology included both the aforementioned western and central segments besides the rock collections from the Visegrád, Börzsöny and Mátra Mts. collected by Dávid Karátson., but it become apparent that the central segment shows transitional and individual features.

In most of the figures the western and eastern group can clearly be distinguished from each other. The central region usually overlaps these and shows a transitional composition between the western and central region, but it is sometimes closer to any of these two. **The clearest distinction between the western and eastern segments is in their Na_2O concentrations, generally the eastern segment shows higher concentrations while the central overlaps mostly with the western** (**Fig.2**). On the K_2O vs. K_2O/Na_2O diagram which differentiates between continental and intra-oceanic calc-alkaline arcs (the higher K_2O/Na_2O ratios indicate fluid addition), the western segment showing the higher concentrations (**Fig 4**).

The explanation to the transition character in the case of the Oas-Gutai Mts. might be found in the origin of the Neogene calc-alkaline volcanincs in the CPR, currently the commonly accepted interpretation is that the western segment has an inherited subduction signature (e.g. Harangi and Lenkey 2007, Kovács and Szabó 2008), while the eastern segment was generated by a slab break off mechanism almost immediately after the subduction along the Eastern Carpathians (e.g. Seghedi et al. 2004). The Oas-Gutai situated between these two parts, relatively close to the assumed subduction and break-off but still above the ALCAPA microplate.

Our dataset complemented with the previously published data after a more robust statistical analysis (cluster analyses, multi variant regression analysis of different variables) will provide us with a more robust and refined insight into regional differences. The present results should be taken only as preliminary that certainly warrants further efforts. We would like to publish these new results in the Data in Brief online journal (journals.elsevier.com/data-in-brief).

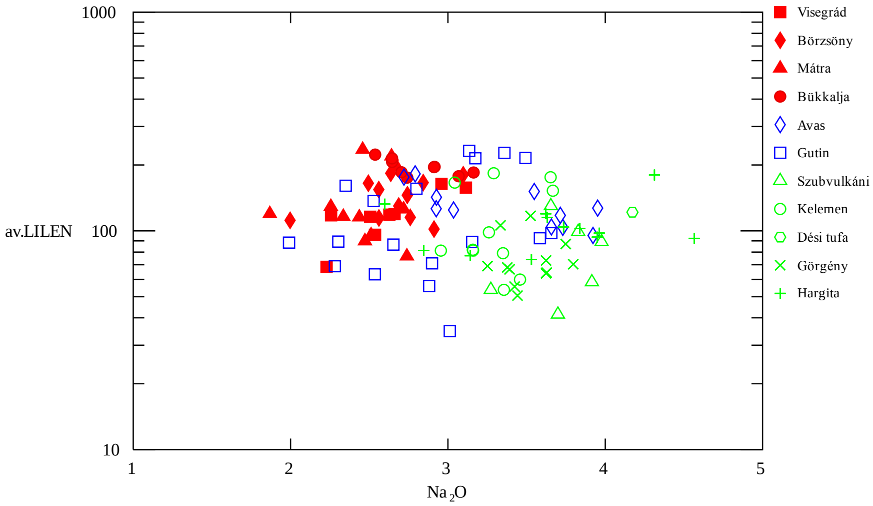


Fig.2. Average $LILE_N$ (expressed as the average of Rb_N, Ba_N, Th_N and U_N) vs Na_2O The av. $LILE_N$ is indicative of fluid additions while the Na_2O can also be derived from the mantle.

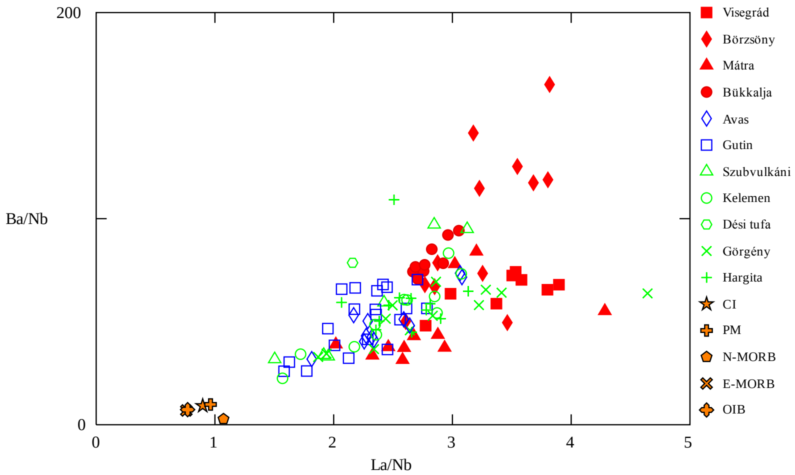


Fig.3. High **La/Nb** are linked to slab melts whereas both melts and fluids may increase **Ba/Nb** (Kelemen et al., 2014, and references therein). With orange the major geochemical end-members compositions are indicated for reference.

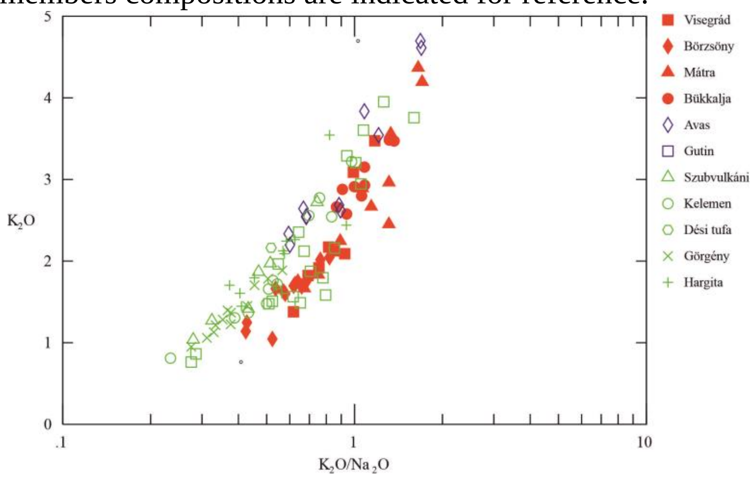


Fig.4. K_2O vs. K_2O/Na_2O: This diagram differentiates best between continental and intra-oceanic calc-alkaline arcs. Higher K_2O/Na_2O ratios indicate fluid addition. In the case of our samples it can be observed that the eastern segment shows a relatively lower K_2O/Na_2O ratio than the western segment and the main results from Oas-Gutai Mts.-based on Schmidt et al. (2017)..

3) Structural hydroxyl content of phenocrysts strongly dependant on the volcanic facies

We studied diverse calc-alkaline rock facies and in them various NAM's phenocrysts as plagioclase, clino-, and orthopyroxene, quartz and garnet. Our goal was to understand the variation of structural hydroxyl content through various rock types, volcanic facies and different minerals and in addition, to uncover whether there is a systematic factor controlling the observed variations.

For this purpose from the studied minerals two have more prominent roles: plagioclase and clinopyroxene. Plagioclase is being one of the most common type of phenocrysts in calc-alkaline rocks, was selected due to its abundance and sufficient size for FTIR analyses. Nevertheless, for plagioclase one should also consider its tendency to weathering and alteration and the faster diffusivity of structural hydroxyl in it crystal lattice which can influence the accurate measurement of structural hydroxyl. The other important mineral is clinopyroxene, even if it is less common than plagioclase in calk-alkaline rocks, but it has a much slower rate of structural hydroxyl diffusion (Farver et al., 2010) and it is more resistant to weathering. In addition, based on the relative intensity of the main absorption bands in its FTIR spectra we can differentiate between original and modified water contents with a high probability (Patkó et al., 2019).

As can be observed in **Fig. 5** and **6** NAMs from various host rocks are characterized by very diverse structural hydroxyl contents. Generally, it implies that the clinopyroxenes have the highest average structural hydroxyl content, the second highest was observed in plagioclase and the lowest is quartz phenocrysts. This decreasing trend is in accordance with the decreasing number of potential crystallographic substitutions and vacancies from pyroxenes from clinopyroxene towards quartz. The terms "wet" and "dry" means that in those cases we could distinguish between a set of spectra with a large quantity of molecular water in the form of nano inclusions and those without (nano) inclusion barren molecular water. It is important to note that the 'real' hydroxyl content equilibrated under pre-eruptive conditions most probably lies somewhere between these two values.

Having a geochemically, stratigraphically and geochronologically well-characterized suite of volcanic rocks, the structural hydroxyl content of NAMs showed no correlation with either age or rock type only with the cooling and post-eruptive history of the studied outcrop. **Thus, one of the most important conclusions of this project is that phenocrysts in calc-alkaline rocks usually cannot be used to infer pre-eruptive magmatic water contents.** This is because structural hydroxyl content is tend to be modified by syn- and post eruptive processes.

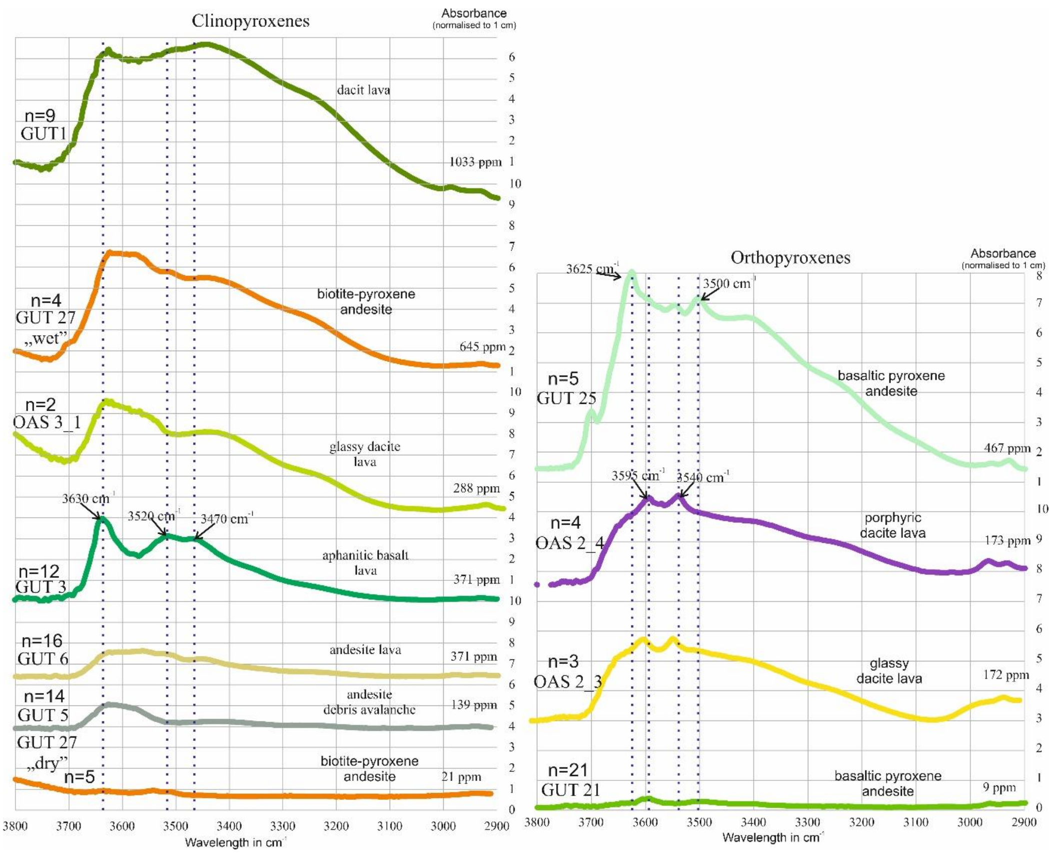


Fig. 5. Representative FTIR spectra from the Oas and Gutai Mts. for clinopyroxene and orthopyroxene crystals.

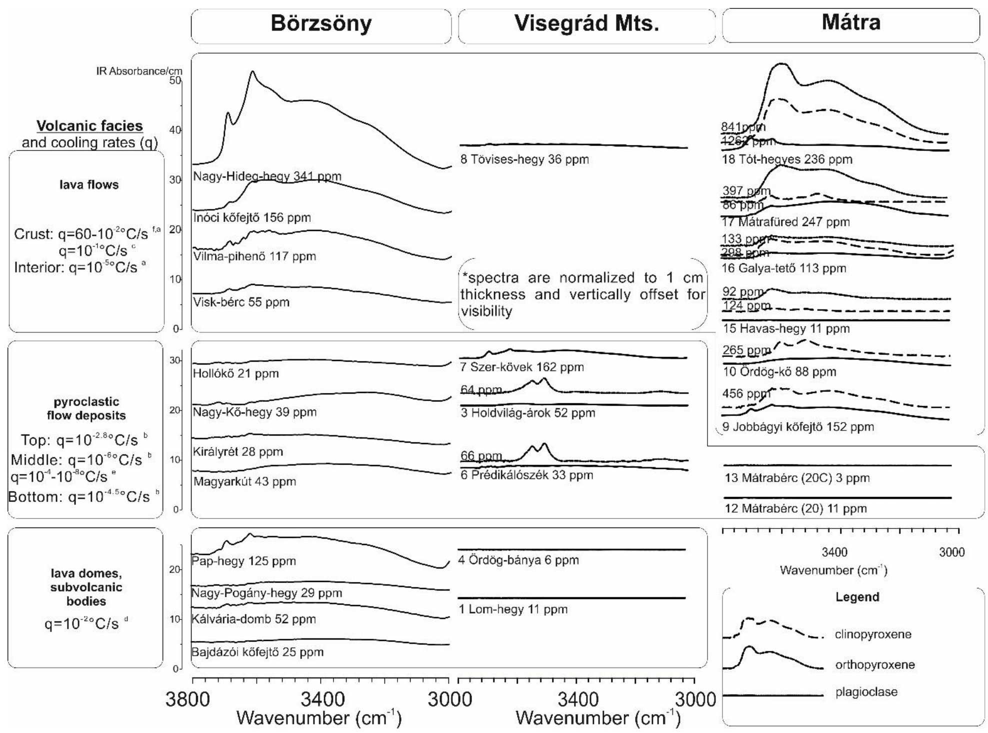


Fig. 6. Representative FTIR spectra from the Börzsöny, Visegrád and Mátra Mts. for clinopyroxene, orthopyroxene and plagioclase.

4) Quickly cooled phenocrysts may preserve original magmatic water content

Ignimbrite-hosted quartz phenocryst fragments contain much lower structural hydroxyl concentration than quartz in igneous rocks (Biró et al. 2016). Pre-eruptive and post-depositional loss of hydrogen were hypothesized as the main processes for lowering the initial magmatic concentrations of hydroxyl defects.

In our project, we examined the hydroxyl defect concentration of quartz phenocryst fragments from various vertical positions between 0.1 to 10.0 m above the base of pyroclastic density current (PDC; i.e. ignimbrite) deposits (Biró et al. 2017). Such sampling strategy aims to record the vertical variations of hydroxyl defect concentrations in order to have an insight into potential post-depositional hydrogen loss of PDC deposits. Ignimbrite-hosted quartz phenocryst fragments were examined from two different ignimbrites from Eger and Bogács in the Bükk Foreland Volcanic Area. Unpolarized micro-FTIR measurements on 23–35 unoriented crystal fragments from each sample were performed representing four different vertical positions above the base (i.e., lower contact of the ignimbrite) of each site. Present results imply that hydroxyl defect concentrations show a pronounced decrease upward from the base of the deposits. The initial ~12 ppm hydroxyl defect concentration decreases to <3 ppm within <10 m from the base.

Ignimbrites with contrasting degree of welding are characterized by different hydroxyl defect concentrations of quartz phenocryst fragments at the same height above the base. Thus, post-depositional dehydration as a function of cooling rate is supposed to be the main factor causing the observed vertical decreasing trend. The modeling of post-depositional dehydration by considering typical ignimbrite emplacement temperatures (300–700 °C) and thicknesses (20–50 m) revealed that neither different cooling rates nor different crystal diameters could cause the observed decrease in hydroxyl defect concentrations in ignimbrites. Other factors, such as contrasting pre-depositional thermal history, presence of melt- and fluid inclusion, and various crack density of crystals could also play an important role in affecting the final hydroxyl defect concentrations. The continuous decrease of structural hydroxyl concentration with height above the base of ignimbrites has two important further implications: Structural hydroxyl concentrations representing P,T and X conditions in the magma chamber just prior to the eruption could only be 'captured' by quartz crystals hosted in fallout deposits, where cooling rate is typically on the order of 10^1°C/s (Wallace et al. 2003).

An ignimbrite cooling unit should show a characteristic curve of structural hydroxyl concentrations in NAMs as a function of height above the base, with maxima at the lower and at the upper part of the ignimbrite and a depletion zone in the middle part. Consequently, the amount of erosion on ignimbrites could be calculated by revealing such curve and quantifying its missing part at the top of the ignimbrite. This will give information for paleo surface and erosion rate studies, but such applications need more detailed studies of the NAMs structural hydroxyl content's vertical distribution in well determined calc-alkaline volcano stratigraphic units.

5) Uniform water content in silica-rich magmas just prior to eruptions

During this research, structural hydroxyl content of volcanic quartz phenocrysts was investigated with unpolarized Fourier-transform infrared spectroscopy (FTIR) from five pyroclastic fallout deposits from the Bükk Foreland Volcanic Area (BFVA), Hungary (Bogács, Tibolddaróc, Eger, Ostoros, Sály), and two from the AD 1314 Kaharoa eruption (KH eruption), Okataina Volcanic Complex (Taupo Volcanic Zone), New Zealand. Both deposits were sampled at the lowermost part in order to avoid any significant thermal impact coming from the overlying ignimbrite. The quartz phenocrysts were prepared with the same technique. The measurements were carried out in a temperature-controlled laboratory at the HAS RCAES with a Bruker® Hyperion 2000 IR microscope attached to a Bruker® Vertex 70 spectrometer. We used unpolarized FTIR methodology in the light of indicatrix theory for unpolarized light (Kovács et al., 2008; Sambridge et al., 2008).

The calculated structural hydroxyl contents fit well in the range of earlier published values from quartz phenocrysts derived from different geological environments (granitic bodies, metamorphic rocks, detrital grains), including volcanic quartz phenocrysts. All investigated quartz populations contain structural hydroxyl content in a narrow range with an average of 9.3 wt. ppm (±1.7). The earlier correlated pyroclastic units in the BFVA had the same average structural hydroxyl content (within uncertainty). Thus, it can be concluded that the structural hydroxyl content does not depend on the geographical distance of outcrops of the same units from the source vent, nor the temperature or type of the covering deposit (i.e., relatively hot or cold ignimbrite). The rare outlier values and similar structural hydroxyl contents show that the fallout horizons cooled fast enough to retain their original structural hydroxyl content. The similarity of the structural hydroxyl contents may be the result of similar P, T and X (most importantly H_2O and the availability of other monovalent cations) conditions in the magmatic plumbing system just before eruption. Therefore, we envisage common physical-chemical conditions, which set the structural hydroxyl content in the quartz phenocrysts and, consequently, the water content of the host magma (~5.5 – 7 wt% H_2O) in a relatively narrow range close to water saturation. More occurrencesof large-scale silicic explosive volcanism worldwide need to be involved in future studies to prove this hypothesis. The preliminary results underline the importance of measuring water contents of NAMs in fallout pyroclastic layers originating from extension-related silicic explosive eruptions in various volcanic fields.

6) Water contents of alkaline basalts

Based on the structural hydroxyl content of clinopyroxene megacrysts from the Bakony-Balaton Highland Volcanic Field, the ‘water’ content of their host basalts is 2.0–2.5 wt.%, typical for island arc basalts. Likewise, the source region of the host basalts is ‘water’ rich (290–660 ppm), akin to the source of ocean island basalts. This high ‘water’ content could be the result of several subduction events from the Mesozoic onwards (e.g. Penninic, Vardar and Magura oceans), which have transported significant amounts of water back to the upper mantle, or hydrous plumes originating from the subduction graveyard beneath the Pannonian Basin.

Great care must be taken when selecting suitable clinopyroxene grains for estimating the ‘water’ content equilibrated in their basaltic host melt. The geochemistry, infrared spectra and structural hydroxyl content of clinopyroxenes, as well as their pre- and post-eruptive history must be examined to ensure that their structural hydroxyl concentration represents equilibrium conditions with their host melt. The selected clinopyroxene phenocryts from Szentbékkálla and Szigliget have been in the range of 391–476 ppm wt. structural hydroxyl content. This is in line with the ‘general’ trend shown by other clinopyroxenes in equilibrium with their host magma, where the ~3630 cm^{-1} band is the most intensive and the other bands at lower wavenumbers show gradually lower absorbance.

While basaltic partial melts have been present in such wet asthenosphere for a long time, they were not channeled to the surface in the syn-rift phase, but were only emplaced at the onset of the subsequent tectonic inversion stage at ~8–5 Ma. We propose that the extraction has been facilitated by evolving vertical foliation in the asthenosphere as a response to the compression between the Adriatic indenter and the stable European platform. The vertical foliation and the prevailing compression effectively squeezed the partial basaltic melts from the asthenosphere. The overlying lithosphere may have been affected by buckling in response to compression, which was probably accompanied by formation of deep faults and deformation zones. These zones formed conduits towards the surface for melts that were squeezed out of the asthenosphere.

Not only the alkaline basalts from the Bakony-Balaton Highland Volcanic Field show high water contents. We can assume that clinopyroxenes from the calc-alkaline basalt Firiza basalt from the Gutai Mts. retained their original hydroxyl contents based on their FTIR spectra. Based on this assumption we can calculate the original water content of this basaltic magma which is around 5.2 wt.% H_2O.

7) Deviation from the original work plan, overlapping research and future research activities

The major 'failure' of the project was, that the original calc-alkaline magmatic water contents in the Western and Eastern Segments could not have been compared. This is due to several objective factors: First of all, our results made it clear that only quartz and clinopyroxene phenocryst from fallout deposits and basal zones of ignimbrites characterized by quick cooling can be used to infer original magmatic water contents. At the beginning, this information was not known and our sample pool was included mainly samples from lava domes, lava flows and internal part if ignimbrites where the preservation of the original and equilibrium water content is very unlikely due to relatively slow cooling. In the future we have to focus on investigating phenocrysts from suitable phenocrysts from both segments. The research was also hampered by the SARS-CoV-2 disease because a lot of laboratory measurements become impossible or must be postponed. In addition, one PhD student Zsófia Pálos has departed the research group, which also slowed down the realization of measurements and data processing.

Two papers have been published on upper mantle xenoliths from the Styrian Basin (Aradi et al., 2017) and the Nógrád-Gömör Volcanic Field (Patkó et al., 2019) which are seemingly unrelated to the present project. In fact, these papers were among the first, even at international levels, which directed the attention to the volcanic facies of the host enclosing alkaline basalt. The results imply that the preservation of the original structural hydroxyl contents in upper mantle xenoliths is more likely especially in phreatomagmatic pyroclastic successions than massive lava flows. Thus, our discoveries indirectly contribute a lot to find suitable host basalts and their upper mantle xenoliths from which the original water content of the upper mantle can be reconstructed.

There are two other papers by Biró et al. (2020 JVGR) and Hencz et al. (2021 Geol. Carpath.) which directly does not include relevant information to the present proposal. At least a part of the samples in these studies were collected in the framework of the present proposal and the physical volcanological observations, geochemistry and paleomagnetic data in these studies were all indispensable to the interpretation of structural hydroxyl data from phenocrysts.

The most important future work is to publish the significant geochemical database, that we produced during the project in a review paper. In addition, we want to complete our FTIR database with the samples from the Eastern Segment which could not be analysed so far and compared to those of the Western Segment. Thus, the fact that this has not been achieved in the duration of this project does not mean that we give up ouroriginal intentions.

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Nyilvános idéző összesen: 12, Független: 5, Függő: 7, Nem jelölt: 0

2) Biró, T., Kovács I.J., Karátson D., Stalder, R., Király E., Falus Gy., Fancsik T., Sándor-né K.J. (2017): **Evidence for post-depositional diffusional loss of hydrogen in quartz phenocryst fragments within ignimbrites.**, American Mineralogist, https://doi.org/10.2138/am-2017-5861 SJR Scopus - Geochemistry and Petrology: Q1, IF: 3.003, Angol nyelvű

Nyilvános idéző összesen: 13, Független: 4, Függő: 9, Nem jelölt: 0

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4) Biró T., Hencz M., Karátson D., Mártonné Szalay E., Szalai Z., Bradák B.: **Egy összetett robbanásos kitörés üledékei a Bükkalján - a Bogácsi Ignimbritre települt tefrasorozat / The products of a complex explosiveeruption at tephra layers on Bog**, Új vulkanológiai, geokémiai és geomorfológiai eredmények az NKFIH-OTKA K115472. és K128122. számú kutatási pályázatából/New results in volcanology, geochemistry geomorphology of NKFIH-OTKA research projects no. K115472. and K128122., 2019

5) Hencz M., Kovács I.J., Biró T., Pálos Zs., Kesjár D., Karátson D.: **Névlegesen vízmentes ásványok víztartalma egy bükkaljai pliniuszi (sensu lato) piroklasztit-sorozatban / Nominally anhydrous minerals' water contentin a 'sensu lato' Pli**, Új vulkanológiai, geokémiai és geomorfológiai eredmények az NKFIH-OTKA K115472. és K128122. számú kutatási pályázatából/New results in volcanology, geochemistry, geomorphology of NKFIH-OTKA research projects no. K115472. and K128122., 2019

6) Mártonné Szalay E., Karátson D., Biró T., Hencz M.: **Észak-magyarországi miocén ignimbritek korrelációja paleomágneses vezérszintek és polaritás alapján: új eredmények a Mátra és a Bükkalja területéről / Correlation origin** Új vulkanológiai, geokémiai és geomorfológiai eredmények az NKFIH-OTKA K115472. és K128122. számú

kutatási pályázatából/New results in volcanology, geochemistry, geomorphology of NKFIH-OTKA research projects no. K115472. and K128122., 2019

2017.04.20.

A víz potenciális hatása a Kárpát-Pannon térség tercier vulkanizmusára

Kovács István PhD - Biró Tamás - Karátson Dávid, az MTA doktora - Pálos Zsófia - Szabó Csaba PhD - Falus György PhD - Király Edit PhD - Török Kálmán PhD - Fancsik Tamás, a műszaki tudomány kandidátusa - Sándorné Kovács Judit

Kvarc fenokristályok víztartalma a bükkaljai miocén ignimbritekben - új lehetőségek a magmás rendszerek vizsgálatában

Biró Tamás - Kovács István PhD - Király Edit PhD - Karátson Dávid, az MTA doktora - Roland Stalder PhD - Falus György PhD - Fancsik Tamás, a műszaki tudomány kandidátusa – Sándorné Kovács Judit

Díjak és ösztöndíjak/Awards and grants

Mátyás Hencz.: 3rd price in oral talks category, 10th Petrology and Geochemistry Assembly, Mátraháza, Hungary, 2019

Mátyás Hencz.: 3rd place in the theoretical category, Special Award of the Biocentrum Ltd., Audience Award (best presentation) 50th Meeting of Young Geosicentists, Ráckeve, Hungary, 2019

Ákos Kővágó.: Special award of the Hungarian Geological Survey at the 50th Meeting of Young Geoscientists, Ráckeve, Hungary, 2019

Ákos Kővágó.: 1st place at the XXXIV. National Scientific Conference of Students held at college of Eger, Eger, Hungary, 2019

Ákos Kővágó.: Special award at the XXI. Conference on Mining, Metallurgy and Geology, Nagybánya/Baia Mare, Romania, 2019

Zsófia Pálos.: 1st poster award for young scientists at the 9th Petrology and Geochemistry Assembly, Szentkút, Hungary, 2018

Zsófia Pálos.: ÚNKP-17-2 New National Excellence Program of the Ministry of Human Capacities research scholarship for master students for 10 months, ELTE/12421/98, 2017

Zsófia Pálos.: 2nd poster award for young scientists at the 8th Petrology and Geochemistry Assembly, Szihalom, Hungary, 2017

Zsófia Pálos.: Special Award of the Hungarian Defensive Forces Geoinformation Service at the Scientific Conference of Students (OTDK) held at University of Debrecen, Debrecen, Hungary, 2017

Disszertációk/Dissertations

Biró, T.: **Új eredmények a Bükkalja miocén tűzhányótevékenységéről - fizikai vulkanológiai és geokémiai megközelítés.** / New results on the Miocene volcanic activity of the Bükkalja – physical volcanological and geochemical approach. – Doktori értekezés / PhD dissertation; ELTE TTK, Doctoral School of Earth Sciences, Course of Geography and Meterology, 151 p. Date of Defense: 16.04.2018. .https://doktori.hu/index.php?menuid=193&lang=HU&vid=18434

Kővágó, Á.**: Felzikus és mafikus kőzetzárványok vizsgálata a „Laleaua Alba" („Fehér Tulipán") kompozit dácit dómból (Gutin-hegység, Erdély, Románia) / Felsic and mafic xenolith studie**, MSc thesis, Eötvös University Department of Petrology and Geochemistry Budapest Hungary Eötvös University Department of Petrology and Geochemistry p. 102, 2019

Pálos, Zs.: **Olvadékzárványok vizsgálata kvarc fenokristályokban a bükkaljai egri Tufakő bánya pliniuszi szórt rétegéből / Water content in quartz-hosted silicate melt inclusions from** University Department of Petrology and Geochemistry MSc thesis,Budapest, 2018. december 17. Eötvös Hungary Eötvös University Department of Petrology and Geochemistry p. 64, 2019