Doctoral School of Geosciences

OPEN-SYSTEM IGNEOUS PROCESSES IN THE FELSIC ROCKS OF THE DITRĂU ALKALINE MASSIF (EASTERN CARPATHIANS, ROMANIA)

A Ditrói Alkáli Masszívum (Keleti-Kárpátok, Románia) felzikus kőzeteinek nyílt rendszerű magmás folyamatai

Theses of the PhD Dissertation

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I. Introduction and the aims of the study

The Ditrău Alkaline Massif (DAM; Eastern Carpathians, Romania) is a Middle–Late Triassic igneous complex (Pál-Molnár et al., 2021) that formed in an intra-plate, rift-related, extensional tectonic environment (e.g., Morogan et al., 2000; Pál-Molnár, 2000, 2010b; Batki et al., 2014; Pál-Molnár et al., 2015b). The massif is made up of a wide variety of rock types, ranging from ultramafic cumulates to granitoid rocks, crosscut by lamprophyre, syenite, and tinguaite dykes (Pál-Molnár, 2000; Batki et al., 2014; Pál-Molnár et al., 2015a, b). It is a remarkable natural site for studying the open- and closed-system magmatic processes of trans-crustal igneous systems. Rare earth element (REE) mineralization makes the massif one of the potential, economically viable deposits in Europe (Honour et al., 2018).

Numerous and often conflicting theories and genetic models have emerged during the 190-years-long scientific exploration of the massif (e.g., Streckeisen, 1938, 1960; Kräutner and Bindea, 1998; Morogan et al., 2000; Pál-Molnár, 2000). Researchers attempted to unravel the timing of the igneous event and to determine the emplacement sequence of the different magma batches (e.g., Streckeisen, 1952, 1954; Pál-Molnár and Árva-Sós, 1995; Kräutner and Bindea, 1998; Pană et al., 2000). Early on in the study of the massif, Streckeisen (1954), Kräutner and Bindea (1998) as well as Morogan et al. (2000) emphasized the importance of open-system igneous processes in the evolution of the DAM. Some details of these mechanisms have been unraveled by recent structural observations, bulk-rock and mineral-scale geochemical data (e.g., Batki et al., 2018; Heincz et al., 2018; Ódri et al., 2020). With a few exceptions (e.g., Streckeisen, 1954; Kräutner and Bindea, 1998; Morogan et al., 2000), the felsic rocks in the northern area of the DAM have generally been regarded as homogeneous, uniform units. Clinopyroxene antecrysts were described from diorite and syenite (Batki et al., 2018), raising the importance of re-examining the felsic rocks.

The PhD research focuses on the felsic suite exposed in the northern area of the DAM. The objectives were the following: (1) the revision of the previous geochronological data and to implement them with new K/Ar and U–Pb radiometric ages; (2) the detailed petrographic examination of the systematically collected and documented new set of felsic rock samples; (3) the whole-rock and mineral-scale geochemical analysis (including major and trace elements) of the samples; (4) to come up with a conceptual evolution model by integrating all recently obtained knowledge about the massif.

II. Applied methods

The most conventional methods (field observations, macroscopic and microscopic petrography, whole-rock and mineral-scale major and trace element geochemistry, K/Ar and U–Pb geochronology) were applied in the study of the felsic rocks cropping out in the northern part of the DAM.

Age determination was performed on a previously collected, archive set of samples. K/Ar geochronology was implemented on separated amphibole and biotite crystals by a digital flame photometer and a magnetic mass spectrometer at the HUN-REN Institute for Nuclear Research, Debrecen, Hungary. Titanite and zircon crystals were separated for U–Pb geochronology by standard gravity and magnetic separation methods. Backscattered electron (BSE) and cathodoluminescence (CL) imaging were performed at the Department of Petrology and Geochemistry, Eötvös Loránd University, Budapest, Hungary and at the Department of Geosciences, Johann Wolfgang Goethe University, Frankfurt, Germany. In situ U–Pb age determinations were carried out at the GÖochron Laboratories, Georg-August University of Göttingen, Göttingen, Germany, utilizing an excimer laser and a Thermo Finnigan Element2 sector field mass spectrometer.

A new set of samples was collected in two sampling campaigns in 2019 and 2021. Documentation involved the registration of GPS coordinates and the relationship of the felsic rocks with other rock types (e.g., country rocks, dykes, mafic rocks). Thin sections were prepared at the Department of Petrology and Geochemistry, Eötvös Loránd University, Budapest, Hungary. Petrographic observations were performed using Brunel SP300P and Olympus BX41 optical microscopes at the Department of Mineralogy, Geochemistry and Petrology, University of Szeged, Szeged, Hungary. A THERMO Scientific DXR Raman microscope was also utilized to determine certain mineral phases. Compositional zonation and microtextural relations were revealed by BSE imaging, using an AMRAY 1830 SEM equipped with an EDAX PV 9800 EDS detector at the Department of Petrology and Geochemistry, Eötvös Loránd University, Budapest, Hungary.

The samples selected for bulk-rock geochemistry were prepared and analyzed at the Bureau Veritas Mineral Laboratories (ACMELabs) in Vancouver, Canada. Major element concentrations were determined by ICP-ES; whereas, trace elements (including rare earth elements) were analyzed by ICP-MS.

The major and trace element compositions of single minerals were determined from polished thin sections of 30 μm thickness. Amphibole, clinopyroxene, and plagioclase were selected for analysis since they occur in nearly all rock types in the northern part of the massif. Amphibole and clinopyroxene from lamprophyre and plagioclase-bearing pyroxene

hornblendite were also analyzed for comparison. To determine whether there are any compositional variations, ferromagnesian and felsic minerals in various textural positions [including aggregated minerals and single crystals occurring in the "groundmass" (the phaneritic, holocrystalline, felsic mineral-rich domain of the so-called host rock)] were investigated. Major- and minor-element compositions of minerals were analyzed at the Institut des Sciences de la Terre d'Orléans – Centre National de la Recherche Scientifique (ISTO-CNRS), Orléans, France, utilizing a Cameca SX Five electron microprobe. The same spots were measured during the trace element (including rare earth elements) analyzes as for the EMPA. Trace element concentrations were also determined at the Institut des Sciences de la Terre d'Orléans– Centre National de la Recherche Scientifique (ISTO-CNRS), Orléans, France by LA-ICP-MS, using a RESOlution SE laser ablation system connected to an Agilent 8900 QQQ inductively coupled plasma mass spectrometer.

III. New scientific results

The integrated investigation of the felsic rocks cropping out in the northern part of the Ditrău Alkaline Massif has provided significant novel results regarding the age, time span, and paleotectonic environment of the igneous event, the textural heterogeneity of the felsic rocks, the complex history of the constituent mafic and felsic minerals, the evolution of the felsic suite, and the genesis of the massif.

T1 Felsic rocks of the Ditrău Alkaline Massif were formed by a short-lived igneous event in the Middle–Late Triassic.

The age and time span of the felsic magmatism were specified by new K/Ar (amphibole: nepheline syenite and granite; biotite: granite) and U–Pb ages (titanite and zircon: nepheline syenite and syenite), combined with the thoroughly revised archive age data. Titanite and zircon from syenite yielded U–Pb ages of 225.3 ± 2.7 Ma and 232.4 ± 3.3 Ma, respectively. Amphibole from nepheline syenite formed at 216.0 ± 8.1 Ma; whereas, U–Pb ages of titanite and zircon are 230.6 ± 3.5 and 230.6 ± 2.4 Ma, respectively. K/Ar ages of amphibole and biotite from granite range from 196.3 ± 7.4 to 197.3 ± 7.4 and 198.3 ± 7.5 to 201.4 ± 7.6 Ma, respectively. Considering new and previous (post-1990) K/Ar and U–Pb data, there is no resolvable age difference between the early emplaced mafic cumulates and the felsic rocks. These findings disprove the age and time span of the previous, multi-phase evolution theories (e.g., Pál-Molnár and Árva-Sós, 1995; Kräutner and Bindea, 1998; Morogan et al., 2000; Pál-Molnár, 2000, 2008) and infer that the Ditrău Alkaline Massif is the product of a relatively short-lived igneous event.

T2 The felsic suite, cropping out in the northern part of the Ditrău Alkaline Massif, is more heterogeneous at the micro-scale than previously presumed.

Felsic rocks have been mostly regarded as homogeneous, uniform units of the magmatic complex. However, a detailed textural study has revealed that the felsic rocks occurring north of the Jolotca Creek valley exhibit considerable micro-scale heterogeneity. The studied rocks were categorized into two groups based on their field occurrence and microtexture: Group 1 – lacking or containing scant ferromagnesian minerals, spatially associated with mafic rocks and Group 2 – containing mafic minerals and clusters, spatially unassociated with mafic rocks. All rocks of Group 1 and some of Group 2 bear micro-scale traces of the gravitational accumulation of felsic minerals and the compaction of the crystal mush [e.g., feldspar lamination, feldspar-rich aggregates (chain structure), mutually impinging crystals].

T3 The mafic minerals of Group 2 rocks generally occur in different types of clots comprising multiple grains of either identical or disparate ferromagnesian phases.

The microtextural heterogeneity of the rocks from Group 2 partly derives from the presence of different types of mafic mineral clusters with various petrographic features. Monomineralic (green amphibole-, blue amphibole-, biotite-, and epidote-rich) and polymineralic (green amphibole + biotite; blue amphibole + biotite; amphibole + clinopyroxene + titanite + opaque minerals ± biotite) aggregates were distinguished in the studied felsic rocks. Some of the clots are made up of replacive minerals after a precursor phase (antecryst and/or xenocryst) and the different clusters exhibit distinct stages of substitution of the entrained materials. The presence of aggregates contributes significantly to the increased modal proportion of ferromagnesian minerals in the host rocks. Clots associated with mafic microgranular enclaves have not been observed; however, certain types are associated with metamorphic country rock xenoliths. The amount of isolated mafic minerals is rather limited.

T4 The accumulation of both mafic and felsic crystals played a significant role in the formation of the Ditrău Alkaline Massif.

T4a A new mafic cumulate type was revealed by the trace element composition of cumulus clinopyroxene.

Clot-forming clinopyroxenes with a convex REE pattern have previously been reported as antecrysts, among others, in diorite and syenite. Clinopyroxenes of identical composition were described for the first time as cumulus minerals (autocrysts) from plagioclase-bearing pyroxene hornblendite, which represents the cumulate phase of the parental melt of nepheline syenite. Mobilization and redistribution of clinopyroxene crystals of this type resulted in the formation of mafic mineral clusters in the felsic rocks, some of which still preserve relics of antecrystic clinopyroxene.

T4b Two types of felsic cumulates of different origins were distinguished by their whole-rock major and trace element composition.

Certain monzonite and monzodiorite samples of Group 2 are characterized by a high Eu/Eu^{*} value (2.5–6.7), low ΣREE (125–206 ppm) as well as elevated La and Sr concentrations. These features, combined with the high abundance and microtexture of plagioclase (e.g., chain structure, impingement), suggest that these rocks are less differentiated, early felsic cumulates. Based on their mineralogy, microtexture, and geochemical properties, the felsic xenoliths of the Tarnița Complex were previously described as felsic cumulates. Nevertheless, the whole-rock composition of these enclaves differs from that of the Group 2 monzonite and monzodiorite, implying that they are felsic cumulates of different parental magmas.

T5 A nomenclature based on the bulk-rock composition of the studied rocks can be misleading due to cumulate formation and the incorporation of exotic materials.

Most of the examined rocks are cumulates or partial cumulates, characterized by the accumulation of felsic minerals in varying modal proportions. In addition, some of the samples contain polycrystalline clusters of mafic minerals with antecrysts. It has been pointed out that the whole-rock data should be treated with caution, as cumulate formation (both mafic and felsic) and the incorporation of crystals of different origins have a significant impact on the modal mineralogy and subsequently on the overall composition of the rocks. These findings challenge the conventional use of nomenclature based on the bulk-rock composition and demonstrate that the integration of microtextural investigations and mineral-scale geochemical analyzes is crucial for selecting an appropriate nomenclature for the studied rocks and also for understanding the processes that occur during pluton emplacement.

T6 A conceptual evolution model was created by integrating all available knowledge about the Ditrău Alkaline Massif.

The rocks of the DAM were formed by the emplacement and interplay of multiple magma batches derived from two different parental magmas in an open-system magmatic environment (Fig. 1).

Two types of felsic cumulates with distinct whole-rock compositions were formed in regions where convection was limited (Fig. 1C, I). Not only felsic but also (ultra)mafic cumulates were produced (Fig. 1A–C). The latter can be distinguished by the composition of cumulus clinopyroxene; however, cumulus amphibole crystals exhibit overlapping geochemical features. Orbicular inclusions with primitive clinopyroxene crystals in their core occur in plagioclase-bearing pyroxene hornblendite, suggesting that the two parental magmas have already interacted in the deeper part of the igneous system (Fig. 1C, D). Whereas, tinguaite with ijolite enclaves was formed by mingling of the fractionated derivatives of the parental magmas (Fig. 1E–G).

The syenitic magma was formed by crustal assimilation of the parental melt of nepheline syenite during its emplacement (Fig. 1H).

Bulk-rock compositions of the recently analyzed felsic rocks partially overlap with and connect the trends of the syenite–granite series and those of the rocks formed by magma mingling in the Tarnița Complex [diorite (*s.l.*), monzodiorite, and monzonite]. Amphibole and plagioclase crystals are characterized by variable intra-crystalline zoning patterns and element contents (particularly Ba, Sr, and TiO_2 as well as MgO, FeO, TiO_2, Sr, Ba, La, and Ce, respectively) and are diverse in terms of their size. These features imply that the studied felsic rocks have a hybrid origin and were formed by mixing of the syenitic magma and the fractionated (most likely intermediate) derivative of the basanitic parental magma. The interaction between magmas of comparable temperature, rheological properties, and composition favored thorough mixing rather than mingling (Fig. 1K). This explains the lack of outcrop-to-macro-scale evidence (e.g., mafic microgranular enclaves) of open-system magmatic processes in the northern part of the DAM (between the Tarnița and Turcului Creeks).

Further fractionation of the hybrid magma and simultaneous crustal assimilation resulted in the formation of granite (Fig. 1K).

The last stage of the igneous event was marked by the intrusion of lamprophyre, ijolite, tinguaite, and (nepheline)syenite dykes.

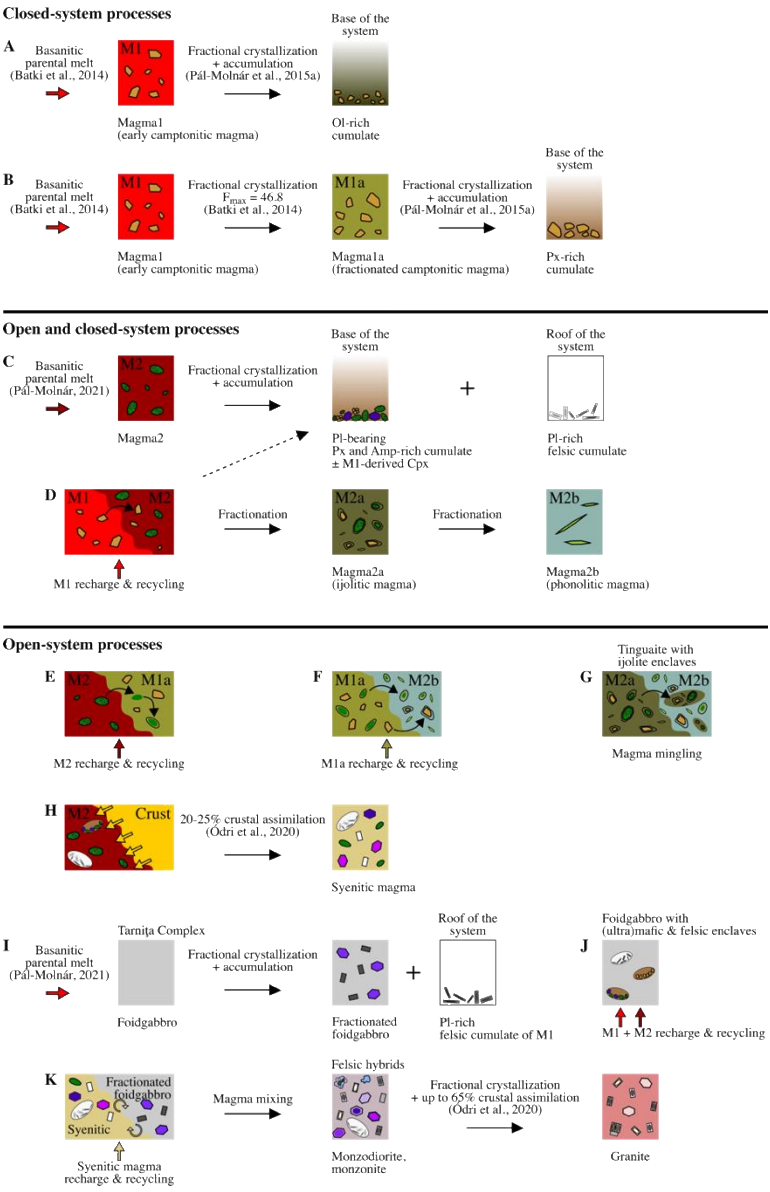

Fig. 1. Schematic emplacement model for the Ditrău Alkaline Massif. The relative size of the structural and textural elements is not illustrated to scale. See text for details

IV. Összefoglalás

Az értekezés a Ditrói Alkáli Masszívum (DAM) északi részén felszínre bukkanó felzikus kőzeteket vizsgálja integrált terepi, kőzettani (szerkezeti és szöveti), geokémiai és geokronológiai módszerekkel. A tanulmány célja a felzikus kőzetsorozat szerkezeti- és (mikro)szöveti bélyegeinek feltárása, teljes kőzet geokémiai (fő- és nyomelemek), valamint ásványkémiai vizsgálata, a kőzetek keletkezési korának pontosítása, továbbá eddigi ismereteink alapján a DAM keletkezési modelljének felvázolása.

Az archív mintaanyag felzikus kőzeteiből (gránit, nefelinszienit, szienit) szeparált amfibol és biotit kristályok kormeghatározása K/Ar, míg a cirkon és titanit szemcséké U–Pb módszerrel történt. A terepbejárások során rögzítettem az új mintagyűjtési pontok GPS koordinátáit, valamint a begyűjtött kőzetek településviszonyait és makroszkópos szerkezeti-szöveti tulajdonságait. Az újonnan begyűjtött minták mikroszöveti bélyegeinek vizsgálatát vékonycsiszolatokon végeztem. Az ásványfázisok azonosításához Raman mikroszkópot, az összetételi zonáció feltárásához pásztázó elektronmikroszkópot (SEM) alkalmaztam. A kőzetminták főelem összetételének meghatározása ICP-ES, a nyomelem összetételé ICP-MS technikával történt. Az ásványok (amfibol, klinopiroxén és plagioklász földpát) fő- és nyomelem összetételét elektronmikroszonda, illetve LA-ICP-MS segítségével vizsgáltam.

Az új K/Ar és U–Pb koradatok, valamint a relevánsnak tekintett szakirodalmi eredmények alapján nincs jelentős időbeli eltérés a korai mafikus kumulátumok és a felzikus kőzetek kialakulása között, ami a masszívum viszonylag rövid, középső–késő triászban végbemenő magmás evolúciójára utal. A koradatok ellentmondanak Pál-Molnár és Árva-Sós (1995), Kräutner és Bindea (1998), Morogan et al. (2000), valamint Pál-Molnár (2000, 2008) időben elhúzódó, többfázisú keletkezési elméletének.

A vizsgált kőzetek makroszkóposan homogénnek tűnnek, mikroszkópi léptékben azonban jelentős heterogenitást (pl. mafikus és felzikus ásványaggregátumok, különböző zonációjú amfibol és plagioklász kristályok) mutatnak. Szöveti bélyegeik, valamint teljes kőzet fő- és nyomelem geokémiai és ásványkémiai összetételük alapján felzikus kumulátum képződéssel és nyílt rendszerű magmás folyamatokkal (pl. kristály recirkuláció, mellékkőzet asszimiláció és magmaelegyedés) jellemzett, dinamikus magmás környezetben keletkeztek.

A masszívum felzikus kőzeteinek kialakulása különböző, nyílt rendszerben fejlődő „magmacsomagok” (*magma batches*) ismétlődő benyomulásához és fizikai-kémiai kölcsönhatásához köthető.

V. References

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VI. List of publications

Luca Kiri (MTMT author ID: 10064115)

VI.1. Articles used in the PhD Dissertation

Pál-Molnár[*], E., **Kiri[*], L.**, Lukács, R., Dunkl, I., Batki, A., Szemerédi, M., Almási, E.E., Sogrik, E., Harangi, Sz. (2021). Timing of magmatism of the Ditrău Alkaline Massif, Romania – A review based on new U-Pb and K/Ar data. Central European Geology, 64(1), 18–37 (Impact Factor in 2021: 0.73; Scimago Journal Rank in 2021: 0.172).

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[*]The first two authors have contributed equally to this work.

VI.2. Other publications

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Pál-Molnár, E., Batki, A., Kiss, B., Jankovics, M.É., Almási, E.E., Heincz, A., **Kiri, L.**, Szemerédi, M., Lukács, R., Mészáros, E. (2019). Nyílt rendszerű magmás folyamatok a Ditrói Alkáli Masszívumban (Open-system igneous processes in the Ditrău Alkaline Massif). 10th Assembly of Petrology and Geochemistry, Mátraháza, Hungary, pp. 21–33 (in Hungarian).

Walter, H., Pál-Molnár, E., Fintor, K., **Kiri, L.** (2018). Fluid inclusions in post-magmatic diopsides of Jolotca ore field (Ditrău Alkaline Massif). XXI International Congress of the Carpathian Balkan Geological Association (CBGA), Salzburg, Austria, p. 183.

Walter, H., Pál-Molnár, E., **Kiri, L.** (2018). Fluidumzárvány vizsgálatok a Ditrói Alkáli Masszívum telérkitöltő ásványfázisaiból (Fluid inclusion studies of the vein-filling minerals from the Ditrău Alkaline Massif). Spring Wind Conference, Győr, Hungary, pp. 390–399 (in Hungarian).

Kiri, L., Pál-Molnár, E., Batki, A., Kiss, B. (2018). Evidences of magma mixing/mingling in syenites of the Ditrău Alkaline Massif. Meeting of Young Geoscientists, Hajdúszoboszló, Hungary, pp. 24–26.

VII. Co-author statements

I, *Elemér Pál-Molnár*, hereby declare that the role of **Luca Kiri**, the doctoral candidate, in the publication of

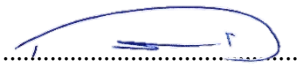
Pál-Molnár, E., Kiri, L., Lukács, R., Dunkl, I., Batki, A., Szemerédi, M., Almási, E.E., Sogrik, E., Harangi, Sz. (2021). Timing of magmatism of the Ditrău Alkaline Massif, Romania – A review based on new U-Pb and K/Ar data. Central European Geology, 64(1), 18–37.

Kiri, L., Szemerédi, M., Pál-Molnár, E. (2022). Petrographic evidences of open-system magmatic processes in the felsic rocks of the northern part of the Ditrău Alkaline Massif (Eastern Carpathians, Romania). Central European Geology, 65(1), 49–76.

Kiri, L., Szemerédi, M., Erdmann, S., Batki, A., Pál-Molnár, E. (2023). Bulk-rock and mineral-scale geochemical evidence of open-system magmatic processes in the felsic rocks of the northern part of the Ditrău Alkaline Massif (Eastern Carpathians, Romania). Geologica Carpathica, 74(4), 297–323.

was decisive and that I have not used it to obtain a scientific degree and will not do so in the future.

Szeged (Hungary), 15 November 2023



Elemér Pál-Molnár

I, *Máté Szemerédi*, hereby declare that the role of **Luca Kiri**, the doctoral candidate, in the publication of

Pál-Molnár, E., Kiri, L., Lukács, R., Dunkl, I., Batki, A., Szemerédi, M., Almási, E.E., Sogrik, E., Harangi, Sz. (2021). Timing of magmatism of the Ditrău Alkaline Massif, Romania – A review based on new U-Pb and K/Ar data. Central European Geology, 64(1), 18–37.

Kiri, L., Szemerédi, M., Pál-Molnár, E. (2022). Petrographic evidences of open-system magmatic processes in the felsic rocks of the northern part of the Ditrău Alkaline Massif (Eastern Carpathians, Romania). Central European Geology, 65(1), 49–76.

Kiri, L., Szemerédi, M., Erdmann, S., Batki, A., Pál-Molnár, E. (2023). Bulk-rock and mineral-scale geochemical evidence of open-system magmatic processes in the felsic rocks of the northern part of the Ditrău Alkaline Massif (Eastern Carpathians, Romania). Geologica Carpathica, 74(4), 297–323.

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Szeged (Hungary), 9 November 2023

Dr. Szemerédi Máté

.....

Máté Szemerédi

I, *Anikó Batki*, hereby declare that the role of **Luca Kiri**, the doctoral candidate, in the publication of

Pál-Molnár, E., Kiri, L., Lukács, R., Dunkl, I., Batki, A., Szemerédi, M., Almási, E.E., Sogrik, E., Harangi, Sz. (2021). Timing of magmatism of the Ditrău Alkaline Massif, Romania – A review based on new U-Pb and K/Ar data. Central European Geology, 64(1), 18–37.

Kiri, L., Szemerédi, M., Erdmann, S., Batki, A., Pál-Molnár, E. (2023). Bulk-rock and mineral-scale geochemical evidence of open-system magmatic processes in the felsic rocks of the northern part of the Ditrău Alkaline Massif (Eastern Carpathians, Romania). Geologica Carpathica, 74(4), 297–323.

was decisive and that I have not used it to obtain a scientific degree and will not do so in the future.

Swansea (United Kingdom), 15 November 2023

Batki Anikó

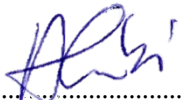
Anikó Batki

I, *Enikő Eszter Almási*, hereby declare that the role of **Luca Kiri**, the doctoral candidate, in the publication of

Pál-Molnár, E., Kiri, L., Lukács, R., Dunkl, I., Batki, A., Szemerédi, M., Almási, E.E., Sogrik, E., Harangi, Sz. (2021). Timing of magmatism of the Ditrău Alkaline Massif, Romania – A review based on new U-Pb and K/Ar data. Central European Geology, 64(1), 18–37.

was decisive and that I have not used it to obtain a scientific degree and will not do so in the future.

Szeged (Hungary), 30 October 2023



.....

Enikő Eszter Almási

I, *István Dunkl*, hereby declare that the role of **Luca Kiri**, the doctoral candidate, in the publication of

Pál-Molnár, E., Kiri, L., Lukács, R., Dunkl, I., Batki, A., Szemerédi, M., Almási, E.E., Sogrik, E., Harangi, Sz. (2021). Timing of magmatism of the Ditrău Alkaline Massif, Romania – A review based on new U-Pb and K/Ar data. Central European Geology, 64(1), 18–37.

was decisive and that I have not used it to obtain a scientific degree and will not do so in the future.

Moab (USA), 16 October 2023

.....

István Dunkl

I, *Saskia Erdmann*, hereby declare that the role of **Luca Kiri**, the doctoral candidate, in the publication of

Kiri, L., Szemerédi, M., Erdmann, S., Batki, A., Pál-Molnár, E. (2023). Bulk-rock and mineral-scale geochemical evidence of open-system magmatic processes in the felsic rocks of the northern part of the Ditrău Alkaline Massif (Eastern Carpathians, Romania). Geologica Carpathica, 74(4), 297–323.

was decisive and that I have not used it to obtain a scientific degree and will not do so in the future.

Orléans (France), 9 November 2023

.....

Saskia Erdmann

I, *Szabolcs Harangi*, hereby declare that the role of **Luca Kiri**, the doctoral candidate, in the publication of

Pál-Molnár, E., Kiri, L., Lukács, R., Dunkl, I., Batki, A., Szemerédi, M., Almási, E.E., Sogrik, E., Harangi, Sz. (2021). Timing of magmatism of the Ditrău Alkaline Massif, Romania – A review based on new U-Pb and K/Ar data. Central European Geology, 64(1), 18–37.

was decisive and that I have not used it to obtain a scientific degree and will not do so in the future.

Budapest (Hungary), 16 October 2023

Harangi Szabolcs Tamás

Digitally signed by Harangi Szabolcs Tamás
Date: 2023.10.16 16:39:04 +02'00'

.....

Szabolcs Harangi

I, *Réka Lukács*, hereby declare that the role of **Luca Kiri**, the doctoral candidate, in the publication of

Pál-Molnár, E., Kiri, L., Lukács, R., Dunkl, I., Batki, A., Szemerédi, M., Almási, E.E., Sogrik, E., Harangi, Sz. (2021). Timing of magmatism of the Ditrău Alkaline Massif, Romania – A review based on new U-Pb and K/Ar data. Central European Geology, 64(1), 18–37.

was decisive and that I have not used it to obtain a scientific degree and will not do so in the future.

Budapest (Hungary), 31 October 2023

.....
Réka Lukács

I, *Edina Sogrik*, hereby declare that the role of **Luca Kiri**, the doctoral candidate, in the publication of

Pál-Molnár, E., Kiri, L., Lukács, R., Dunkl, I., Batki, A., Szemerédi, M., Almási, E.E., Sogrik, E., Harangi, Sz. (2021). Timing of magmatism of the Ditrău Alkaline Massif, Romania – A review based on new U-Pb and K/Ar data. Central European Geology, 64(1), 18–37.

was decisive and that I have not used it to obtain a scientific degree and will not do so in the future.

Paris (France), 18 October 2023

Sogrik
.....
Edina Sogrik

VIII. Declaration of the supervisor

I, *Elemér Pál-Molnár*, hereby confirm that the content of the dissertation is based on the independent work of **Luca Kiri**, the doctoral candidate, and that she has contributed decisively to the results through her independent creative activity. I consider the entire dissertation to be eligible for support from a professional and academic point of view and recommend its acceptance.

Szeged (Hungary), 15 November 2023

.....

Elemér Pál-Molnár, DSc
PhD supervisor