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Electron microprobe dating of monazites from rhyolites of the Veľká Stožka Massif (Muráň nappe, Western Carpathians) – implications for the Permian volcanic evolution in Internal Western Carpathians

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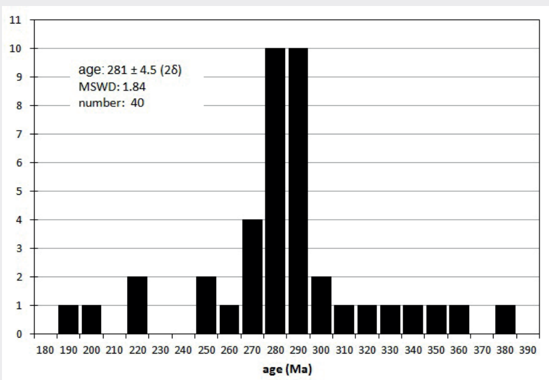
Abstract: New results of field research, as well as petrographical and geochronological studies are presented in the form of a geological map, tectonostratigraphic scheme and new magmatic age data of monazite crystallization from the rhyolite body located on SW slopes of the Veľká Stožka Massif, Dudlavka Valley (Muráň Plateau). The rhyolite bodies in the Veľká Stožka area are tectonically incorporated into the Lower Triassic formations at the base of the Muráň nappe. The electron microprobe dating of monazites yields magmatic / volcanic age 281 ± 4.5 Ma (Artinskian – Kungurian), which complements geochronological data from the same rhyolite body below the Veľká Stožka Massif, as well as other rhyolite bodies from Telgárt, Poniky and Tisovec, which, originally erupted in a Permian volcanically active fault zone (VAFZ) geodynamical setting. The comparison of geochronological data 281 ± 4.5 Ma and 269.5 ± 1.8 Ma from the studied locality suggest a geodynamic evolution, where not only one, but several separate volcanic eruption phases acted in the original domain of rhyolitic volcanism. The geochronological correlation of the rhyolite bodies in the Upper Hron Valley, active in time span 281–263 Ma, allowed to identify a volcanic hiatus between 280–271 Ma. Such eruptional pause correlates very well with other volcanic provinces such as Harnobis volcanogenic horizon of the North Veporic realm, the Petrova hora and Novoveská Huta Fm. of the Northern Gemericum, which erupted during hiatus of VAFZ and their activities have ended in during recovering rhyolite eruptions in VAFZ. Reactivation of rhyolitic volcanic activity in VAFZ 271–263 Ma is a result of paleostress reorganisation in Pangea lithosphere. The revealed paleovolcanic relationships highlight interconnection of paleotectonic and paleovolcanic events in the known paleotectonic units of Internal Western Carpathians during Permian.

Key words: EPMA, monazite magmatic age, Permian volcanic evolution, Muráň nappe

Graphical abstract



Highlights

- Dating of monazites from two samples gives a new magmatic age 281 ± 4.5 Ma (Artinskian – Kungurian) of the rhyolite eruption
- Permian rhyolitic bodies of the Internal Western Carpathians were generated and erupted along volcanically active fault zones (VAFZ)
- At least two different eruption phases can be recognized in the VAFZ: an older (ca. 281–280 Ma) and a younger (starting at ca 271–263 Ma) phase
- Reactivation of rhyolitic volcanic activity in VAFZ 271–263 Ma is a result of changed paleostress in Pangea lithosphere.

Introduction

The products of Permian acidic magmatic activity in the Internal Western Carpathians (volcanic detritus, rhyolite or granitic rocks) occur in several tectonic units. They are mostly connected with their coeval sedimentary complexes (Hronicum, Tatricum, Veporicum, Gemericum), but some of them, namely the rhyolite bodies Gregová near Telgárt, Veľká Stožka in the Muráň nappe, rhyolite bodies in the area of Poniky (usually assigned into Silicicum s.l., e.g. Plašienka et al., 1997) are tectonically amputated from their original environment and incorporated into geologically younger Lower Triassic sedimentary formations.

The presence of Permian rhyolites in the Internal Western Carpathians were already known since the 19th century (Stur, 1868; Oppenheimer, 1931; Kovářík, 1955; Grenar & Kotásek, 1956; Biely, 1956; Náprstek, 1958; Zorkovský, 1959a, b; Losert, 1963; Slavkay, 1965, 1971, 1981; Kravjanský, 1961, 1964, 1966; Kravjanský et al., 1966; Kusák, 1967; Rozložník et al., 1974; Orlický & Slavkay, 1979; etc.). Their study has a long geological tradition and has produced several lithostratigraphic correlations (see Havrila in Mello et al., 2000, p. 94), which results almost regularly consider them as Lower Triassic with an exception of some works that also considered the Permian age (Kusák, 1967, p. 37–42; Maheľ, 1986, p. 153; Plašienka, 1981).

Permian fault zones associated with active volcanism are a product of late Hercynian or even older tectonic processes and are not genetically bound to given Alpine tectonic units and their paleosedimentary environment. According to the character of the rhyolitic complexes, genetically bound to volcanically active fault zones (VAFZ), the paleovolcanic relation of these complexes to the hosting Alpine structural units remains problematic.

Some of mentioned tectonic models used the disputed rhyolitic rocks as a marker for assignment of whole sequences into overlying Mesozoic rocks (see Havrila, 1997; Hók et al., 2004). Due to our intention to avoid geological bias in the subdivision and definition of tectonic units (Hronicum, Vernaricum, Silicicum, etc.; for a recent discussion on this issue see, e.g., Hók & Olšavský, 2023), in the following text we will refer to the VAFZ of the Internal Western Carpathians.

The presented paper is focusing on the body of rhyolitic rocks on the western slopes of the Veľká Stožka Massif, Muráň Plateau, as one of the typical occurrences of Permian rhyolitic complexes tectonically incorporated into younger Triassic sedimentary formations.

Geological setting

The occurrence of the studied rhyolitic body in the Veľká Stožka Massif at the base of the Muráň nappe was for the first time reported during geological mapping by Kovářík (1955) and referred to as the *"Werfenian with melaphyres"*. The rocks were later petrographically characterized by Zorkovský (1959a, b). The position of the rhyolites in the studied area was usually described as an integral part of the Lower Triassic sequence (Slavkay, 1965; Bystrický in Slavkay et al., 1968, p. 61; Slavkay, 1971, 1981; Havrila in Mello et al., 2000, p. 94). More recent works have dealt with other aspects of the rhyolites (Uher et al., 2002; Ondrejka, 2004; Ondrejka et al., 2007). The Permian age of the rhyolites at the base of the Muráň nappe was proven by geochronological methods in the area of Gregová hill near Telgárt (Demko & Hraško, 2013) and from the vicinity of Tisovec and Veľká Stožka (Ondrejka et al., 2018). More recently, rhyolites in the Drienok nappe, which is usually correlated with the Muráň nappe, were also analysed (Ondrejka et al., 2022).

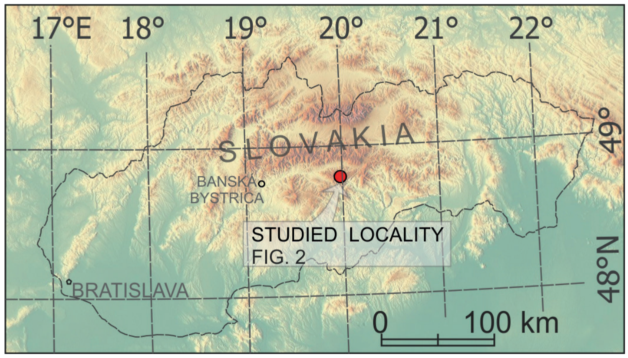


Fig. 1. Location of studied locality in the territory of Slovakia.

The studied area of the Veľká Stožka Massif is located within the Vepor Belt (Klinec, 1976; Vass et al., 1988; Vojtko et al., 2000). The wider area is composed of the (South) Veporic crystalline basement, with locally preserved Triassic sedimentary cover and overlying allochthonous Triassic sedimentary rocks of the Muráň nappe (Kronome et al., 2019; Figs. 1–2). The Veporic crystalline basement rocks are represented by granites and migmatites of the so-called Kráľova hoľa Complex (Klinec, 1966). The South Veporic cover rocks are mostly metamorphosed quartzites and phyllites, with locally preserved metamorphosed and often tectonized crystalline limestones, locally reworked into rauhwackes (Figs. 2–3). The Veporic rocks are overthrust by the Muráň nappe built mostly of Mesozoic carbonates. The basal décollement zone of the Muráň nappe is characterized by imbricated tectonic slices of Lower Triassic rocks with pink and grey rhyolites which are the main subject of this paper. The hanging wall of rhyolites is represented by Lower Triassic red/variegated sandy shales of the Hronsek Beds (upper part of the Benkovo Formation sensu Olšavský et al., 2010) and orange to yellow fine grained sandy marls of the Šuňava Formation. The Middle Triassic part of overlying sequence is composed of Anisian Gutenstein limestones and dolomites, Steinalm, Raming and Ráztoka limestones. The highest part of the Veľká Stožka Massif is formed of light grey Ladinian Wetterstein limestones (Kronome et al., 2019; Figs. 2–3).

Overall, three rhyolite bodies are located on the northern and western slopes of the Veľká Stožka Massif (Fig. 2). We were able to verify two of the bodies south of Závadka nad Hronom during our geological mapping:

1. Larger elongated body in the Dudlavka Valley, SE slopes of the Veľká Stožka Massif (48.768428° N, 19.946801° E) which is analysed in this paper;

2. Smaller body above the cottages on the western slope of the Veľká Stožka Massif; the rhyolite body is not exposed, its material is present only as a rock debris, not suitable for further analysis due to its low quality and volume;
3. The third rhyolite body was not visualized in the published map of the region (Klinec, 1976). Its presence was mentioned by Uher et al. (2002) and Ondrejka et al. (2015) at the end of Teplá dolina Valley, where it was not verified during the geological mapping.

Methods

Rhyolite rock samples were studied microscopically applying polarizing microscope for the purpose of basic petrographic description and obtaining data enabling the reconstruction of solidification during syn- to post-eruptive history. Subsequently, the samples were analysed using an electron microanalyzer "EPMA" in the Laboratory of electron microanalysis at the Dionýz Štúr State Geological Institute in Bratislava, cooperation with the analyst RNDr. Viera Kollárová, PhD.

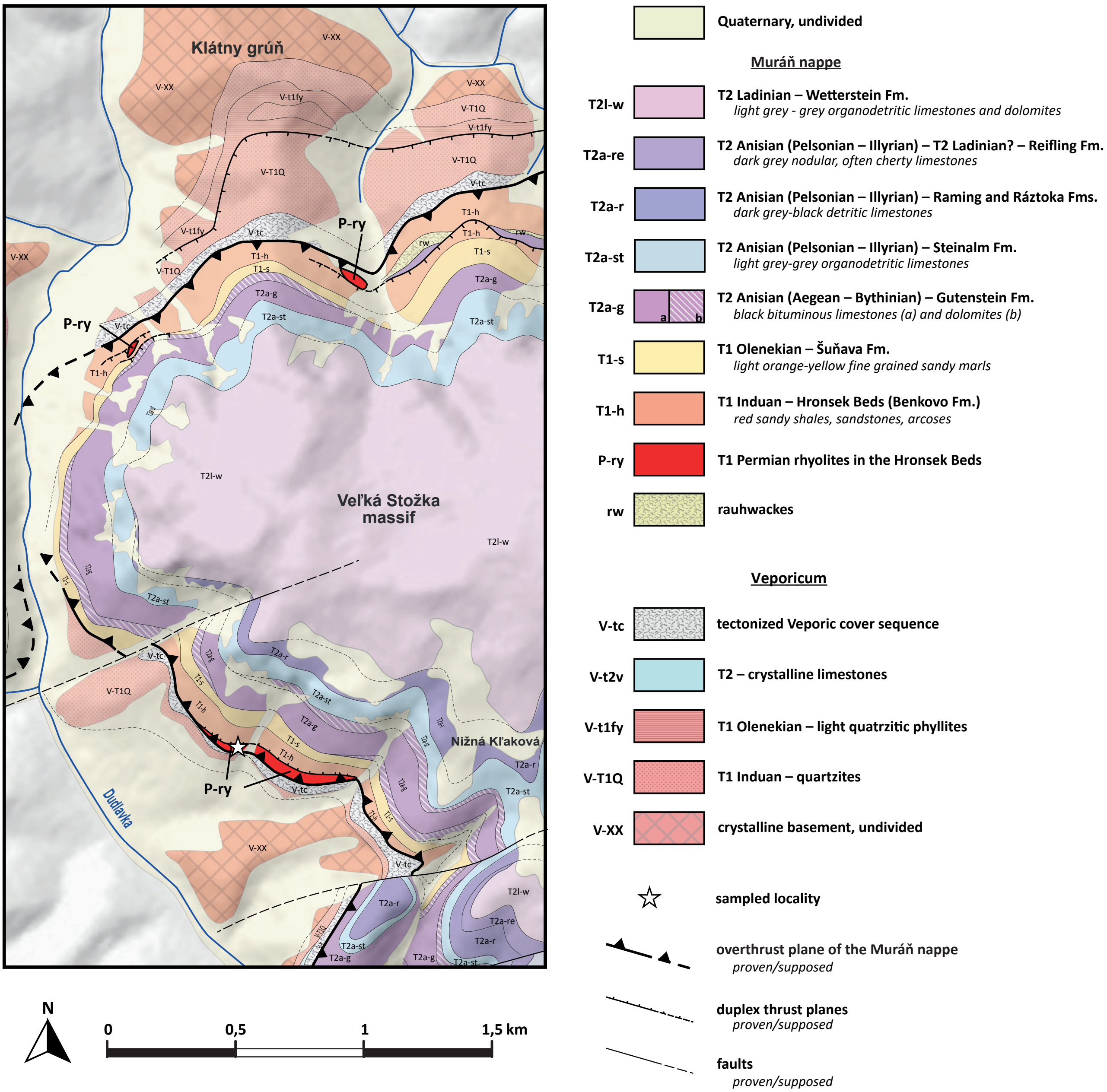


Fig. 2. Geological map of the studied area of the Veľká Stožka Massif (Kronome et al., 2019, modified). Permian rhyolites are marked by red colour. Location of the studied samples from the Dudlavka valley (48.768428° N, 19.946801° E).

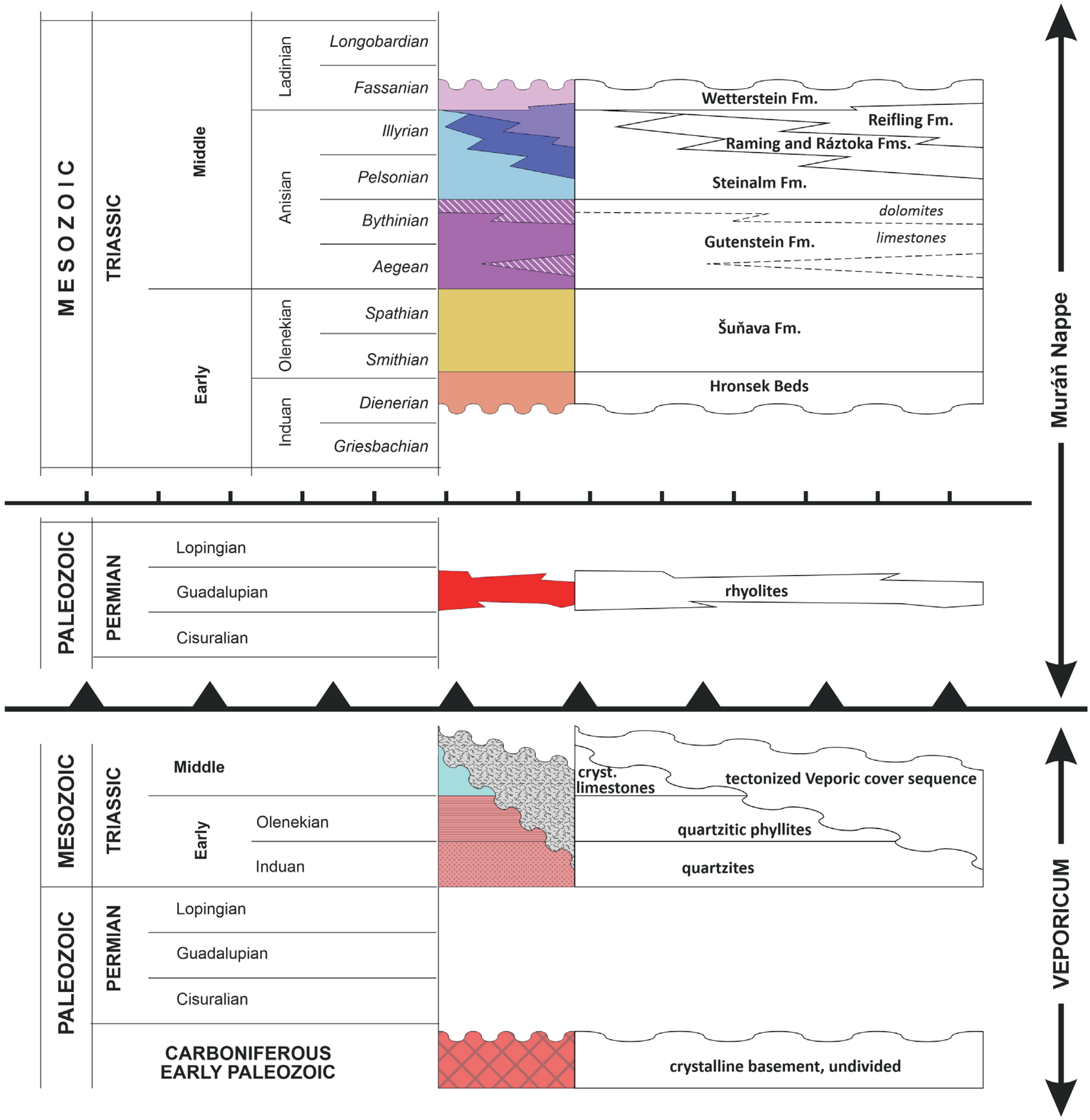


Fig. 3. Lithotectonic scheme of the studied area of the Veľká Stožka section, showing the relations of the South Veporic complexes and the Muráň nappe, including the rhyolite body tectonically incorporated into the base of the nappe. The thickness of the rhyolite body does not exceed 15–20 m.

Analyses of monazite crystals for geochronological dating purposes were done by Cameca SX-100 electron microanalyzer at analytical conditions of 15 kV accelerating voltage, analytical current of 80–150 nA, with 165 s a measurement time for Pb, Th, U, Y analysis and 25 s for other elements, and 3–5 µm defocused electron beam.

The principles of measuring method, analytical conditions and the method of result processing are presented in the work of Konečný et al. (2018). Individual magmatic ages for every measurement were calculated by methods described in Montel et al. (1996, 2017). The MONDAT program (P. Konečný) was used for the final software processing. The electron microanalyser was calibrated using the following standards and spectral lines shown in parentheses: Pb-PbS (Mα, LPeT), U-UO_2 (Mβ, LPeT), Th-ThO_2 (Mα, LPeT), Y-YPO_4 (Lα, LPeT), Ce-

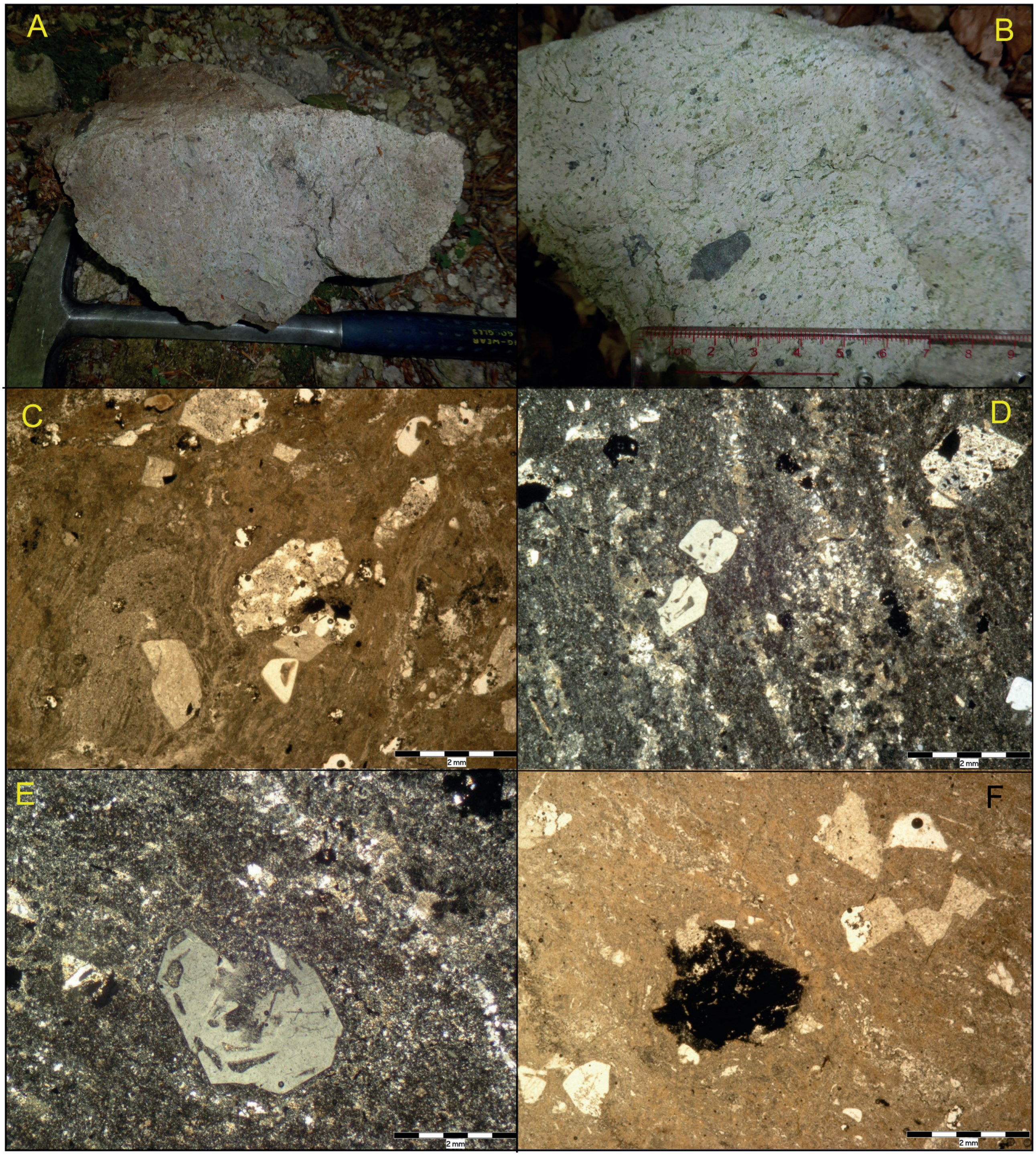


Fig. 4. Macroscopic and microscopic documentation of rhyolite rock samples from the Veľká Stožka Massif used for the geochronological study of chemical U-Th-Pb dating of monazites. A – rhyolite rock with reddish-white stripes created a fluidal structure; B – light rhyolitic rock with small microxenoliths of older rhyolite; C – porphyric rhyolite with phenocryst association formed by altered feldspar and magmatically corroded quartz. Red fluidal matrix and synvolcanic alteration of phenocrysts are typical features of extrusive and some subvolcanic rhyolite bodies (transmitted light); D – porphyric rhyolite with phenocrysts of corroded quartz, K-feldspar and Fe-Ti oxides. The allotriomorphic matrix with fluidic texture contains a parallel network of cracks as a result of shear deformation during the flow of a highly viscous rhyolitic magma. The crack network is filled by a low-temperature association of quartz and sericite; E – phenocryst of magmatically corroded quartz with partial transition to a skeletal habit as a consequence of intense thermodynamic parameters oscillation controlling SiO_2 saturation (crossed pollars); F – porphyritic rhyolite with phenocrysts of altered feldspar and quartz. The dark aggregate of Fe-Ti oxides in the central part is product of opacitization of mafic minerals, probably amphibole.

$CePO_4$ (Lα, LliF), La-$LaPO_4$ (Lα, LliF), Gd-$GdPO_4$ (Lα, LliF), Yb-$YbPO_4$, (Lα, LliF), Sm-$SmPO_4$ (Lβ, LliF), Pr-$PrPO_4$ (Lβ, LliF), Er-$ErPO_4$ (Lβ, LliF), Nd-$NdPO_4$ (Lβ, LliF), Lu-$LuPO_4$ (Lβ, LliF), Ho-$HoPO_4$ (Lβ, LliF), Dy-$DyPO_4$ (Lβ, LliF), Tb-$TbPO_4$ (Lα, LliF), Al-Al_2O_3 (Kα, TAP), wollastonite for Si and Ca (Kα, TAP), apatite for P (Kα, LPET).

Results

Petrography of analysed rhyolite rocks

The rhyolite rock samples are macroscopically porphyritic of mottled and striped structures with typical alternating reddish and light zones. In part of samples, microxenoliths of different structures occur (Fig. 4B). The phenocryst mineral association consists of feldspars, magmatically corroded β-quartz and Fe-Ti oxides (Fig. 4D, E, F). Part of the Fe-Ti oxides replaces the original mafic minerals, probably amphiboles (Fig. 4F). Intense alteration is manifested by feldspars sericitization, which are transformed into a mixture of light mica aggregate mixed with quartz and albite. The matrix has fluidal and holocrystalline allotriomorphic texture preceded into axiolitic, graphic, micropoikilitic to granophyric development.

The matrix is deformed locally by invasion of parallel network of deformation ruptures, which were originated as a result of cracks opening during shear deformation of the viscous rhyolitic magma stressed during flowing.

The opening cracks were cemented by low-temperature quartz and clay minerals during deformation accompanied by synvolcanic subsolidus alteration (Fig. 4D, E).

The observed interactions between association of magmatic minerals, mechanism of synvolcanic alteration linked to stage of highly viscous magma flowing, indicate a dynamic alteration associated with final stages of solidification, ductile deformation and controlled decompression devolatilization, i.e. conditions associated with eruptions of rhyolite extrusions or solidification of subvolcanic bodies. The intense alteration of the rhyolite body, which results in the decomposition of magmatic feldspars and the cementation of a matrix deformed in ductile conditions, is clearly related to the processes of the final stage of rhyolite solidification associated with devolatilization and eruptive emplacement of rhyolite. Rhyolites do not contain any signs associated with metamorphism, as a result of burial of the rhyolite body accompanied by with progressive increase in temperature and pressure.

Monazite dating

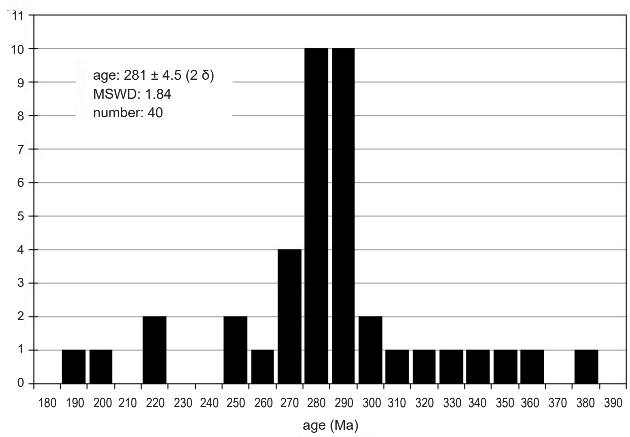


Fig. 5. Histogram of calculated ages for individual analyses of monazite crystals from rhyolite rock samples from Veľká Stožka. The weighted average of the calculated ages gives result of monazite magmatic crystallization in time 281 ± 4.5 Ma. The calculated ages create a sharp central maximum of 280–290 Ma, where the arithmetic mean (280 Ma) = median (280), based on which the result is considered correct.

Microprobe EPMA study of monazites identified small subhedral monazite crystals up to 20 µm in size in two rhyolite samples. Analytical data corrected for interference together with calculated ages for individual analyses are processed using the MONDAT ver. 5.5 program (P. Konečný) and listed in Tab. 1. Statistical processing of 40 measured analyses in the form of a weighted average for two separately analysed samples RY-01 and RY-02 gives the age of the rhyolite eruption of 281 ± 4.5 Ma. The identified crystallization age of the accessory monazite crystals corresponds to the magmatic age, which is practically identical to eruption age. Statistically processed results from individual measurements are presented in the form of a histogram in Fig. 5, where showed results are grouped into a sharp central maximum, corresponding to the interval of 280–290 Ma, where arithmetic mean (280 Ma) = median (280 Ma). The determined magmatic age of monazite crystallization, or age of rhyolite magma eruption 281 ± 4.5 Ma is partially different from 269.5 ± 1.8 Ma magmatic age, obtained by precise in-situ SIMS analysis of zircon crystals from the rhyolites of Veľká Stožka (Ondrejka et al., 2018). A partial 11 Ma difference between magmatic ages obtained by two different methods may not have analytical significance, since the identical age of 280 Ma is also captured by a separate analysis of euhedral core of an older zircon by U-Pb in-situ SIMS analysis No. 8 (Ondrejka et al., 2018). Considering practically ideal distribution with a sharp central maximum of 280–290 Ma, see Fig. 5, we assume a statistically identified age of 281 ± 4.5 Ma as correct and real.

Tab. 1

Th-U-Pb-Y data of measured monazite crystals, corrections for analytical interferences and magmatic ages, calculated by equations listed in Montel et al. (1996).

Grey boxes indicate samples after reduction for low analysed thorium and high absolute age deviation. A reduced statistical set of analyses (n = 30) gives the same age of 281 ± 4.7 million years.

Analysis	Th	U	Pb	Y	Th corr	U corr	Pb corr	Th ± 2δ	U ± 2δ	Pb ± 2δ	Age Ma	Abs. dev.
mnz2-1	1.191	0.053	0.020	0.562	1.168	0.039	0.012	0.020	0.011	0.005	212.1	-69.0
mnz3-1	1.640	0.078	0.027	0.392	1.607	0.058	0.021	0.023	0.012	0.005	256.1	-24.9
mnz4-2	3.068	0.082	0.046	0.097	3.007	0.048	0.040	0.032	0.012	0.005	280.3	-0.7
mnz5-1	0.681	0.056	0.029	1.824	0.667	0.047	0.010	0.017	0.011	0.005	271.0	-10.0
mnz6-1	0.851	0.079	0.030	1.214	0.834	0.068	0.016	0.018	0.011	0.005	347.2	66.1
mnz7-1	6.890	0.247	0.103	0.538	6.752	0.168	0.089	0.054	0.012	0.006	273.0	-8.0
mnz7-2	6.831	0.220	0.101	0.540	6.694	0.142	0.086	0.054	0.012	0.006	270.4	-10.6
mnz8-1	1.920	0.042	0.022	0.228	1.882	0.022	0.016	0.025	0.011	0.005	184.3	-96.8
mnz9-1	5.423	0.132	0.085	0.599	5.315	0.072	0.072	0.046	0.012	0.006	289.8	8.8
mnz10-1	1.409	0.029	0.020	0.269	1.381	0.014	0.014	0.022	0.011	0.005	219.7	-61.3
mnz11-1	1.236	0.051	0.016	0.208	1.211	0.037	0.011	0.021	0.011	0.005	191.8	-89.2
mnz11-2	0.667	0.041	0.017	0.346	0.654	0.033	0.012	0.016	0.011	0.005	338.3	57.2
mnz12-1	2.876	0.086	0.047	0.511	2.819	0.054	0.037	0.030	0.011	0.005	280.2	-0.8
mnz12-2	2.450	0.068	0.049	0.468	2.401	0.041	0.040	0.028	0.011	0.005	353.3	72.2
mnz12-3	3.651	0.102	0.052	0.534	3.578	0.061	0.042	0.035	0.012	0.005	247.4	-33.6
mnz13-1	3.376	0.185	0.070	1.049	3.308	0.145	0.055	0.034	0.012	0.006	324.8	43.8
mnz14-1	1.887	0.123	0.040	1.420	1.849	0.100	0.024	0.025	0.012	0.005	246.7	-34.3
mnz15-1	1.425	0.051	0.031	0.280	1.396	0.035	0.025	0.022	0.011	0.005	375.4	94.3
mnz16-1	1.437	0.034	0.022	0.061	1.408	0.019	0.018	0.021	0.011	0.005	279.9	-1.1
mnz17-1	5.087	0.110	0.076	0.434	4.985	0.054	0.064	0.043	0.011	0.005	279.8	-1.2
mnz17-2	5.078	0.107	0.074	0.467	4.976	0.051	0.063	0.043	0.012	0.005	273.5	-7.6
mnz17-3	3.946	0.098	0.061	0.585	3.867	0.054	0.050	0.037	0.012	0.005	276.2	-4.8
mnz17-4	4.041	0.092	0.059	0.405	3.960	0.048	0.049	0.038	0.012	0.005	266.5	-14.5
mnz17-5	3.962	0.102	0.064	0.660	3.882	0.058	0.052	0.037	0.012	0.006	284.3	3.2
mnz18-1	4.182	0.112	0.064	0.640	4.099	0.066	0.052	0.038	0.011	0.005	268.5	-12.5
mnz18-2	4.810	0.125	0.074	0.567	4.714	0.072	0.062	0.042	0.012	0.005	279.1	-1.9
mnz18-3	4.266	0.102	0.067	0.459	4.180	0.056	0.056	0.038	0.011	0.005	287.9	6.9
mnz18-4	4.129	0.134	0.071	0.958	4.046	0.088	0.056	0.038	0.012	0.005	289.0	8.0
mnz18-5	3.918	0.089	0.058	0.425	3.839	0.046	0.049	0.036	0.011	0.005	272.7	-8.3
mnz18-6	3.976	0.094	0.069	0.556	3.897	0.050	0.058	0.037	0.011	0.005	319.8	38.8
mnz19-1	6.751	0.168	0.102	0.524	6.615	0.093	0.088	0.054	0.012	0.006	283.9	2.8
mnz19-2	6.729	0.178	0.104	0.510	6.595	0.103	0.090	0.053	0.012	0.006	291.9	10.9
mnz19-3	6.657	0.173	0.104	0.540	6.524	0.099	0.090	0.053	0.012	0.006	294.2	13.2
mnz19-4	6.746	0.177	0.102	0.526	6.611	0.102	0.088	0.053	0.012	0.006	282.4	1.4
mnz20-1	4.148	0.100	0.064	0.510	4.065	0.055	0.053	0.038	0.012	0.006	280.8	-0.3
mnz21-1	4.279	0.097	0.065	0.402	4.193	0.050	0.055	0.039	0.012	0.006	282.0	0.9
mnz21-2	4.266	0.104	0.064	0.429	4.181	0.057	0.053	0.038	0.011	0.005	274.4	-6.6
mnz21-3	5.170	0.131	0.074	0.445	5.066	0.073	0.062	0.044	0.012	0.005	263.2	-17.9
mnz22-1	4.010	0.095	0.060	0.511	3.930	0.051	0.049	0.037	0.011	0.005	267.1	-13.9
mnz22-2	3.682	0.103	0.063	0.561	3.608	0.062	0.052	0.035	0.012	0.005	304.6	23.6

Discussion – Permian magmatic activity in the area of the Internal Western Carpathians

Based on results of previous research, focused on the Gregová rhyolite extrusion near Telgárt village and identification of its Permian age, it was assumed that allmost all rhyolite bodies in Silicicum (sensu Plašienka et al., 1997), previously considered as Triassic, may be of Permian age (Demko & Hraško, 2013). This assumption was later confirmed by Ondrejka et al. (2018, 2022). The originally raised questions (Demko & Hraško, 2013), whether it is a single massive rhyolite province active in one time period and later tectonically fragmented, or a rhyolite volcanism active during a longer time with migrating activity in time and space, can be answered using the synthesis of new geochronological data (Fig. 6).

A set of Permian rhyolite bodies (Gregová, Veľká Stožka, Poniky), which are located in the Upper Hron Valley assigned to the Silicicum (sensu Plašienka et al., 1997) are tectonically amputated from their basement and incorporated into a complex of Lower Triassic sediments at the base of these nappes (Demko & Hraško, 2013; Ondrejka et al., 2018, 2022). A comparison of geochronological data (Demko & Hraško, 2013; Ondrejka et al., 2018, 2022 and Demko et al., this work) shows a separate age of each body, in chronological sequence Veľká Stožka (281 ± 4.5) → Poniky, Piesky (271 ± 1.5) → Veľká Stožka, (269.5 ± 1.8) → Poniky, Žiarec (267 ± 1.6) → Tisovec-Rejkovo (266.6 ± 2.4) → Gregová (263 ± 3.5; 263.3 ± 1.9), while in the rhyolite body on the western slopes below Veľká Stožka Massif, two age-separate volcanic pulses are identified (this work). The situation indicates a rhyolitic volcanic activity in the wide time span between 281–263 Ma, which took place in the form of separate volcanic pulses migrating in time and space. In the present tectonic structure rhyolite bodies are tectonically amputated from their sedimentary and volcanic environment. Tectonic and erosional activity caused their volume reduction, when mainly the rigid cores of extrusive bodies were preserved. Traces of pyroclastic volcanic activity remained preserved only to a limited extent. These are relics of ignimbrites at the Gregová hill (Demko & Hraško, 2013) and relics of lithoclastic and lapilli tuffs at the Poniky area (Slavkay, 1965, 1981). Migrating eruptions of rhyolite magmas in the period 281–263 Ma in the geochronological synthesis (Fig. 6) show hiatus or cessation of magmatic activity (after 280 Ma) for a time span 9 Ma between 280–271 Ma. This cessation in volcanic activity (280–271 Ma) was followed by next incoming separate magmatic episodes 271 → 269 → 267 → 263 Ma. The identified magmatic hiatus is fundamental for the understanding of wider magmatic and volcanic events and relationships in the realm of the Permian magmatic provinces in the Internal Western Carpathians.

Activity of rhyolitic volcanic centres in the studied area of VAFZ is synchronous in time with andesite volcanic activity (267 Ma) of the Čierna hora Mts. (Vozárová et al., 2021), acid volcanism 268–267 Ma was recorded in the Rožňava Fm. in the Southern Gemericum (Vozárová et al., 2009), basic volcanism of Veporicum (267 Ma) in the Tribeč Mts. (Vozárová et al., 2020), acid volcanism in the Infratatricum 267–262 Ma (Putiš et al., 2016) and also with basic magmatic activity in the Tatric unit in time 260 Ma (Pelech et al., 2017) and 263 Ma (Spišiak et al., 2018). Time-synchronous volcanic activity is assumed in the space of the Permian sedimentary area of the Hronicum unit (Vozár, 1977; Vozárová & Vozár, 1988). The termination of magmatic activity in the VAFZ in the Internal Western Carpathians (263 Ma) is highlighted by the production of basaltic lavas recorded in the Permian of Tribeč Mts. (Vozárová et al., 2020) and intrusive activity of S-type granites placed in Gemericum domain 265 Ma (Poller et al., 2000), 265–263 Ma (Kohút & Stein, 2005) and 263 Ma (Finger et al., 2003). The magmatic activity in the VAFZ overlaps in time interval between 281–263 Ma with the magmatic activity of several units of the Internal Western Carpathians, but their synchronicity and petrogenetic causality may be purely coincidental. It is precisely in these contexts that the magmatic hiatus of volcanic activity in the VAFZ of the Internal Western Carpathians appears to be fundamentally important. It is marginally synchronous with the volcanic activity of the Northern Gemericum, namely rhyolite tuff 278 Ma (Rojkovič & Konečný, 2005) and zircon detritus 281–276 Ma (Vozárová et al., 2019), 275–272 Ma andesite-rhyolite volcanism occurred in Petrova hora Fm. (Vozárová et al., 2012) and the most important dacite-trachyandesite volcanism of the Northern Veporic 279–273 Ma was recorded in the Harnobis volcanogenic horizon of Brusno Fm. – 279–273 Ma (Vozárová et al., 2016). The sharp, time-limited concurrence of volcanic activity in original space of the Harnobis volcanogenic horizon accompanied by cessation of magmatic activity in VAFZ, discussed in this work is most probably not coincidental.

The specific paleovolcanic situation can be explained by the wider geodynamic relationship between terrains of the Internal Western Carpathians during the Permian, when the dacite-trachyandesite volcanic activity (279–273 Ma) of the Harnobis volcanogenic horizon (Vozárová et al., 2016) reflected the release of tectonic stress in the continental crust of the Northern Veporic domain, where the adjacent continental crust remained in tectonic stress shadow.

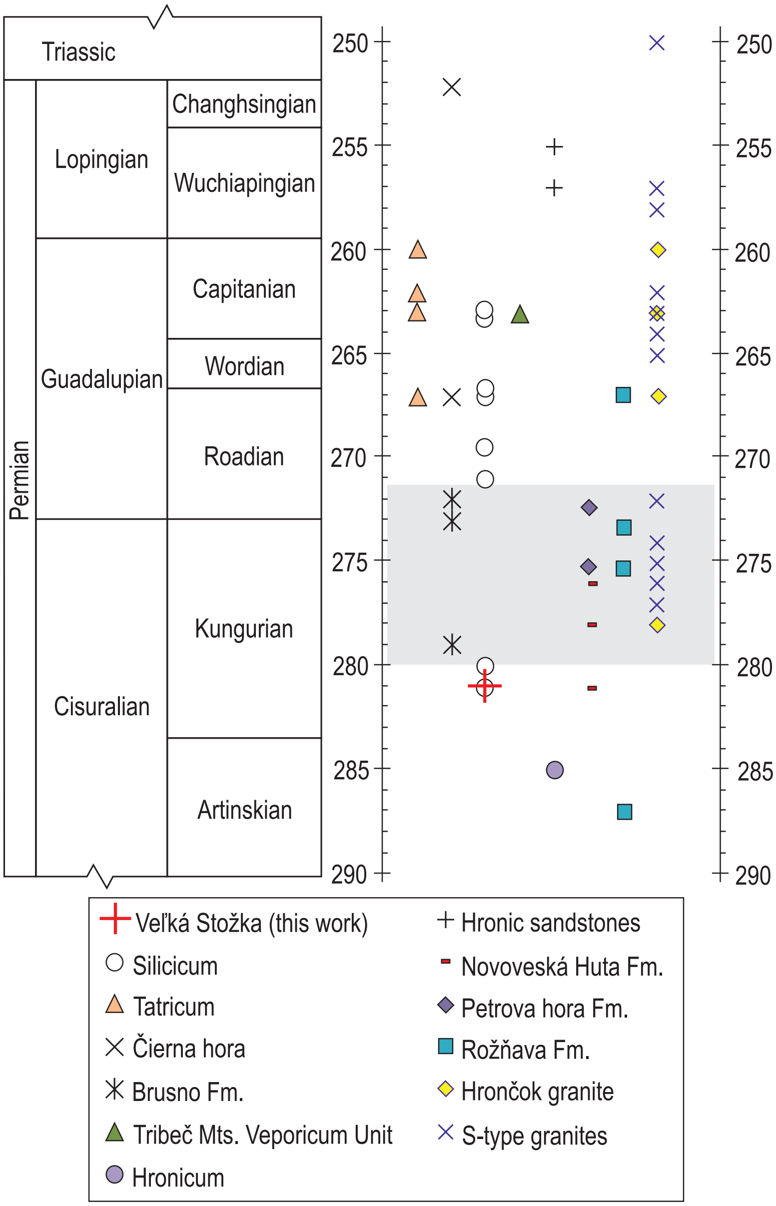


Fig. 6. Graphically presented synthesis of geochronological results of magmatic events in the Permian of Tatricum, Veporicum and Gemericum of the Internal Western Carpathians. The grey marked area is determined by the magmatic hiatus identified by the absence of geochronological data from VAFZ rhyolite volcanism between 280–271 Ma (based on data by Demko & Hraško, 2013; Ondrejka et al., 2018, 2021, 2022 and Demko et al., this study). The sources used in the synthesis from Tatricum (Putiš et al., 2016; Pelech et al., 2017; Spišiak et al., 2018), Veporicum (Čierna hora Mts.: Vozárová et al., 2021; Tribeč Mts.: Vozárová et al., 2020; Harnobis volcanogenic horizon: Vozárová et al., 2016), Hronicum (Vozár, 1977; Vozár et al., 2015; Vozárová & Vozár, 1988; Vozárová et al., 2014; Demko & Olšavský, 2007; Demko & Olšavský, 2007); Northern Gemericum (Vozárová et al., 2019; Novoveská Huta Fm.: Rojkovič & Konečný, 2005; Petrova hora Fm.: Vozárová et al., 2012); Southern Gemericum (Rožňava Fm.: Vozárová et al., 2009). Data sources from Veporic Hrončok granite (Cambel et al., 1977; Kotov et al., 1996; Ondrejka et al., 2021; Finger et al., 2003; Putiš et al., 2000) and Gemeric S-type granites (Finger & Broska, 1999; Poller et al., 2000; Finger et al., 2003; Kohút & Stein, 2005; Radvanec et al., 2009; Kubiš & Broska, 2010; Villaseňor et al., 2021).

The termination of geodynamic stress compensation (for example, by subduction termination gradually changing into collision) in the area of the Northern Veporic domain caused a tectonic stress migrating to more southern zones, where it is evidenced by the initiation of pulsating volcanic activity in the VAFZ (from 271 Ma). The discussed VAFZ volcanic activity between 271–263 Ma are clearly results of stress compensation from area of wedged terrain continental blocs to free space along deep seated crust-mantle fault zones as a result of the relaxation of the transferred stress. In other words, centers of rhyolitic volcanic activity in VAFZ during the Permian in the realm of the Internal Western Carpathians were located in the fault zones of the continental crust, along which stress relaxation took place. The presented tectonic processes of a transpressional-transtensional tectonics induced melting of the mantle, whose magmas intruded the continental crust and created discussed rhyolite magmas by anatectic and fractionation mechanisms. Current paleomagmatic reconstructions based on correlations of Permian magmatic activity link the discussed Permian "Silicic" rhyolitic volcanism (sensu Ondrejka et al., 2018, 2021, 2022) with intrusions of mantle magmas into the continental crust, where they induced melting of quartz-feldspar rocks to form rhyolitic magmas in the extensional tectonic regime as part of the "disintegration of the Pangea supercontinent during the Permian – Triassic period" (Ondrejka et al., l. c.).

Our different view on tectono-magmatic processes associated with the formation of rhyolite magmas in the VAFZ is the active participation of transpressional-transtensional tectonics, in contrast to the extension supported concept by the aforementioned authors. The centres of volcanic activity in domain of rhyolite volcanism were definitely located on the VAFZ, because the faults provide ideal structures for transport of acidic magmas to the Earth's surface. However, we favour transpressional-transtensional tectonic processes (as opposed to extensional tectonics), since no basic eruptive rocks are observed with rhyolites in VAFZ. Active extension destabilizes crustal filter allowing blocking of intruded mantle magmas into continental crust, reduces volume of crustal rocks anatexis and practically supports straight eruptions of basalts to Earth's surface, which were not observed. We observe exactly opposite situation of what was discussed, namely due to the petrographic and compositional homogeneity of VAFZ rhyolitic rocks without basic rocks in association in time and space (Veľká Stožka, Gregová, Tisovec, Poniky).

Conclusions

- The rhyolite body located on the SW slope of Veľká Stožka Massif is one of several examples of Permian rhyolites tectonically displaced and incorporated into the younger Triassic sedimentary formations at the base of the Muráň nappe.
- Electron microprobe dating of monazite crystals from Veľká Stožka rhyolite body provides new information on the Permian age of rhyolitic volcanism.
- The presented geochronological result 281 ± 4.5 Ma complements previous in-situ zircon U-Pb SIMS age 269.5 ± 1.5 Ma of Ondrejka et al. (2018) and suggests not a single rhyolite eruption in the original volcanic area but several eruptional pulses repeating in time.
- According to geochronological data from similar tectonically amputated rhyolitic bodies of VAFZ (Volcanically Active Fault Zones; Gregová, Veľká Stožka, Poniky, Tisovec) a hiatus is observed in eruptive activity between 280–271 Ma.
- Using actual geochronological data of the Permian volcanic rocks in the tectonic units of the Internal Western Carpathians, we suggest important correlation of eruptive events between observed hiatus of VAFZ rhyolitic group and the Permian volcanic activity in the Harnobis volcanogenic horizon of the Northern Veporicum (279–273 Ma; Vozárová et al., 2016), Permian volcanism in the Northern Gemeric Petrova hora Fm. (275–272 Ma; Vozárová et al., 2012) and Novoveská Huta Fm. (281–276 Ma; Rojkovič & Konečný, 2005; Vozárová et al., 2019).
- The cessation of Permian eruptive activity in the present day Northern Veporic and/or Northern Gemeric area as well as the resuming of the interrupted rhyolitic volcanism in the VAFZ suggest change, reorganisation and transfer of tectonic stress during the Permian in Internal Western Carpathian before 272/271 Ma.

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Datovanie monazitu z masívu Veľkej Stožky (muránsky príkrov, Západné Karpaty) – význam pre poznanie vývoja permského vulkanizmu Vnútorných Západných Karpát

Produkty permskej acidnej magmatickej činnosti Vnútorných Západných Karpát (ryolity, granitoidy alebo vulkanický detrit) sa nachádzajú vo viacerých tektonických jednotkách. Aj keď sú väčšinou viazané na ich súveké sedimentárne komplexy (hronikum, tatrikum, veporikum, gemerikum), niektoré z nich, konkrétne ryolitové telesá Gregová pri Telgárte, telesá vo svahoch pod Veľkou Stožkou na Muránskej planine a ryolitové telesá v oblasti Poník (zvyčajne zaraďované do silicika s. l.; napr. Plašienka et al., 1997), sú tektonicky amputované z pôvodného prostredia a začlenené do geologicky mladších sedimentárnych útvarov spodného triasu.

Skúmané územie masívu Veľkej Stožky sa nachádza vo veporskom pásme (Klinec, 1976; Vass et al., 1988; Vojtko et al., 2000). Širšie územie je tvorené (juho)veporským kryštalinickým fundamentom s lokálne zachovaným triasovým sedimentárnym obalom a nadložnými mezozoickými komplexmi muránskeho príkrovu (Kronome et al., 2019; obr. 1 – 2). Veporské kryštalinikum zastupujú granitoidy a migmatity tzv. kráľovohoľského komplexu. Prekrývajú ho prevažne metamorfované kvarcity a fylity, lokálne sa zachovali metamorfované a tektonizované kryštalické vápence, lokálne prepracované na rauvaky (obr. 2 – 3). Veporikum tektonicky prekrýva muránsky príkrov. Bázu muránskeho príkrovu tvoria na mnohých miestach imbrikované tektonické šupiny. Tvoria ich obvykle spodnotriasové súvrstvia, miestami s tektonicky inkorporovanými ružovými a sivými ryolitmi, ktoré sú hlavným predmetom tejto práce. Nadložie ryolitov zastupujú prevažne spodnotriasové pestré piesčité bridlice hronseckých vrstiev (vrchná časť benkovského súvrstvia, sensu Olšavský et al., 2010) a pestré bridlice a piesčité vápence šuňavského súvrstvia. Strednotriasovú časť sledu na tejto lokalite tvoria gutensteinské vápence a dolomity, steinalmské, raminské a ráztocké vápence. Najvyššiu časť masívu Veľkej Stožky tvoria svetlosivé ladinské wettersteinské vápence (Kronome et al., 2019; obr. 2 – 3).

Ryolitové horniny v masíve Veľkej Stožky sú tektonicky amputované zo svojho pôvodného geologického prostredia. Mikrosondové U-Th-Pb datovanie monazitových kryštálov ryolitových hornín zo svahov masívu Veľkej Stožky na Muránskej planine poskytlo magmatický vek 281 ± 4,5 mil. rokov, ktorý je prakticky totožný s vekom ryolitovej erupcie. Identifikovaný permský vek guadalup je podobný ako zistený vek ďalších ryolitových telies – Gregová pri Telgárte (Demko a Hraško, 2013; Ondrejka et al., 2018), Tisovec-Rejkovo, Poniky-Piesky, Poniky-Žiarec alebo Veľká Stožka (Ondrejka et al., 2018; Ondrejka et al., 2022). Porovnanie geochronologických údajov (Demko a Hraško, 2013; Ondrejka et al., 2018; Ondrejka et al., 2022 a táto práca) ukazuje samostatný vek každého telesa v chronologickej postupnosti Veľká Stožka (281 ± 4,5) → Poniky-Piesky (271 ± 1,5) → Veľká Stožka, (269,5 ± 1,8) → Poniky-Žiarec (267 ± 1,6) → Tisovec-Rejkovo (266,6 ± 2,4) → Gregová (263 ± 3,5; 263,3 ± 1,9), pričom v prípade ryolitového telesa v masíve Veľkej Stožky sú identifikované dva vekovo samostatné vulkanické pulzy, konkrétne 281 ± 4,5 mil. r. a 269,5 ± 1,8 mil. r. Situácia ukazuje na širokú vulkanickú aktivitu ryolitového vulkanizmu v rozpätí 281 – 263 mil. r.

Tektonická a erozívna činnosť spôsobila objemovú redukciu ryolitových telies, z ktorých ostali zachované predovšetkým rigidné jadrá extruzívnych telies. Stopy po pyroklastickej vulkanickej aktivite sa zachovali len obmedzene (Telgárt, Poniky). Migrujúce erupcie ryolitových magiem v období 281 – 263 mil. r. ukazujú na hiát vulkanickej aktivity v období medzi 280 – 271 mil. r. v trvaní 9 mil. r., ktorý je synchrónny s vulkanickou aktivitou severogemerickej jednotky – ryolitový tuf 278 mil. r. (Rojkovič a Konečný, 2005) a zirkónový detrit 281 – 276 mil. r. (Vozárová et al., 2019), s andezitovo-ryolitovým vulkanizmom petrovohorskej formácie 275 – 272 mil. r. (Vozárová et al., 2012), a predovšetkým s dacitovo-trachyandezitovým vulkanizmom severného veporika 279 – 273 mil. r., ktorý je zaznamenaný vo vulkanogénnom horizonte Harnobisu (Vozárová et al., 2016).

Ryolitové horniny sú produktom extruzívnej erupčnej aktivity situovanej na hlboko založených zlomoch transpresno-transtenznej tektonickej povahy „VAFZ“, ktoré po reaktivácii slúžili na kompenzáciu tektonického napätia zmeneného v období od 271 mil. r., t. j. po skončení vulkanickej aktivity budúceho severného veporika a severného gemerika.

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