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# Variscan lithotectonic units in the Suchý massif of the Strážovské vrchy Mts, Western Carpathians – products of sedimentary, tectonometamorphic and granite forming processes

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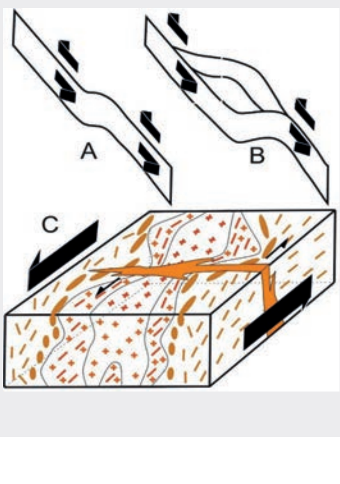
**Abstract:** The present geological investigation of the Pre-Alpine structure of the western part of Strážovské vrchy Mts (the Suchý massif; Western Carpathians) has distinguished three lithologically distinct Variscan lithotectonic units, which originated (1) in the deeper parts of oceanic basin (prevailingly metapelites with different content of organic matter, metabasalts, metacarbonates?); (2) sediments of the continental slope (flyschoid sediments with a predominance of greiwacke sediments; both VmD0); (3) a unit of continent basement primarily of pre-VmD0 granitic composition (orthogneiss). These rock sequences of differing geotectonic provenances were amalgamated and metamorphosed in the pre-intrusive (Pre-Mississipian) stage; pre-VmD2). Regarding the Variscan polyorogenic evolution, Variscan processes in Tatricum represent the Meso-Variscan evolution (VmD).

The maximum P-T conditions of orogenic (regional) metamorphism (up to 610 °C and 7.5–8.5 kbar) were not sufficient for more extensive anatexis. Field observations indicated that the production of a limited volume of granitoid melts occurred mainly at the contacts of amalgamated lithotectonic units. Probably due to the heat, produced by the hot line below the collisional orogen and contributing also to unroofing processes (in orogenic phase VmD2) there started new granitization process. This stage of Mississippian VmD2 granite formation is associated with the emplacement of various types of granitoid magma, encompassing the oldest granodiorites with frequent schliers, representing a poorly differentiated and poorly mobile crystal slurry (present in the SE part of the territory). In the highly evolved collision phase, masses of leucogranites intruded comformably with the deformation plan in the metamorphic complexes, interacting with surrounding metamorphic rocks in shallower crustal conditions and causing their contact metamorphic overprint (up to 590 °C and 3–4 kbar). The syn-deformation character of leucocratic granites is proved by the orientation of biotite flakes parallel to the deformation plane of surrounding metamorphites. Part of leucogranites, especially in the central parts of the bodies, is omnidirectional. The stress field acted not only during the intrusion of the leucogranite magma, but also in the subsolidus stage. The final stage of this process is the formation of large bodies of pegmatites in extensional VmD2 fractures oriented at a large angle to the main stress component. The texture of the grey blocky K-feldspar pegmatites and the lack of $H_2O$-bearing minerals point to pneumatolytic fracturing in a subsequently opened environment in VmD2. The final stage of VmD2 is represented by intrusions of I-type granodiorites with indications of magma mixing, or mingling. The chemical dating of monazites in granitoids allowed to date individual phases of granitization process in the range of 360–345 Ma, which youngest ages correspond with the formation of pegmatites. Dating of monazite in metamorphic rocks points to their thermal overprint during granitization process (360–350 Ma), having already earlier metamorphic overprint (380–370 Ma). The scenario of placement of granitoid intrusions is consistent with the decompression regime (in VmD2) after the end of VmD1c crustal thickening until the fracturing of the crustal block with of I-type magma intrusions of deeper origin. After this period, the exhumation of crystalline blocks, partial diaphtoresis and later surface erosion continue until the Lower Triassic. The re-submergence of the crystalline complexes is associated with a low degree of Alpine metamorphic reworking.

**Key words:** Western Carpathians, Strážovské vrchy Mts, Variscan lithotectonic units (LTUs), XD labelling, crystalline complexes, polymetamorphism, granite genesis

**Graphical abstract**




**Highlights**

- Three types of Meso-Variscan sequences (lithotectonic units; LTUs) were distinguished in the Tatric crystalline basement of the western part of Strážovské vrchy Mts (the Suchý massif), documenting its complicated Paleozoic geological evolution: (1) LTUs of the Lower Paleozoic riftogenic oceanic sedimentation, (2) flyschoid sediments (Paleozoic continental slope sediments; both VmD0) and (3) their basement crustal rocks – orthogneisses (originally pre-VmD0 granitoids). These complexes were amalgamated at collision VmD1c and later at granite forming processes VmD2. The VmD2 metamorphism has produced an initial melting. The formation of granitoids in decompression phase produced thermal overprint of the amalgamated complexes at the granite front. In the first stage, less mobile crystal slurries were formed, which inherit the structural characteristics of the surrounding metamorphites. In the second phase, the complexes were sheared and two-mica granites and pegmatites were formed; this additional thermal metamorphism overprinted also earlier metamorphosed complexes. In the last stage of VmD2 evolution, I-type granodiorites, tonalites and diorites indicating magmatic mixing have intruded. Chemical monazite dating indicates the age of granite formation of 360–345 Ma.

## Introduction

In 2015–2020 the State Geological Institute of Dionýz Štúr in Bratislava (Slovakia) carried out new geological mapping and regional geological research in eastern part of the Strážovské vrchy Mts, resulting in compilation of a new regional *Geological map of the Strážovské vrchy Mts (eastern part) at a scale of 1 : 50 000* in 2021 and explanatory notes to this map (currently edited). New map represents an update of a part of earlier geological map compiled by Maheľ et al. (1981). New research focused on Alpine tectonic units: Tatricum, Fatricum, Hronicum and younger geological formations (Paleogene, Neogene and Quaternary). This article is devoted to Variscan evolution and geological structure of the Tatricum crystalline basement of the western segment of mapped region, geographically belonging to the Suchý massif. Despite defining Meso-Variscan lithotectonic units (LTUs) in the Suchý massif, we briefly classify in studied area also those of Cadomian, Paleo-Alpine and Neo-Alpine orogenic cycles.

## General characteristics of crystalline basement and its previous researches in the Strážovské vrchy Mts

First and the most comprehensive research of the Strážovské vrchy Mts crystalline basement by A. Klinec, I. Lehotský and M. Ivanov (Klinec, 1956, 1958; Ivanov,

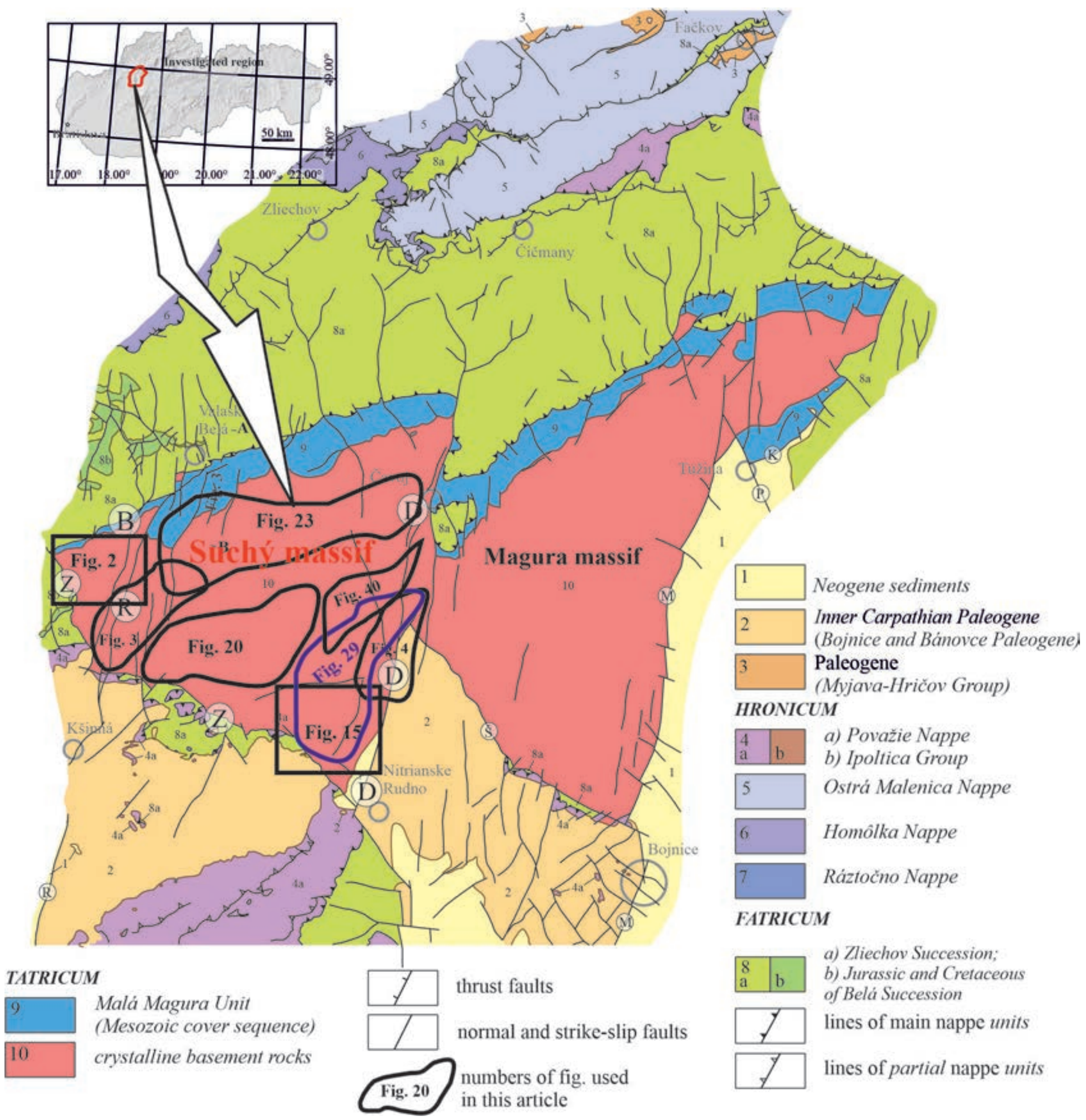



**Fig. 1.** Tectonic scheme of the Strážovské vrchy Mts, with tectonic blocks of Tatricum (crystalline basement and tectonically reduced Mesozoic sequences of the Malá Magura Unit), nappes of Fatricum and Hronicum, as well as Cenozoic sediments. The Meso-Variscan crystalline basement (VmD) is divided by N-S trending Neo-Alpine (AnD4) Diviaky fault (D) to Suchý and Magura massifs. The Suchý massif is tectonically rimmed by AnD34 Zdychava fault (Z) and Brekovský potok fault (B) and further segmented by intracrystalline Radiša fault system (R) with more pronounced Neo-Alpine deformation of crystalline formations.

1957) included geological mapping of this region in the 1950s for the purpose of compiling its first general geological map at a scale 1 : 200 000.

Ivanov (1957) parallelized the crystalline basement of Suchý and Malá Magura massifs with SW continuation of the Malá Fatra crystalline basement, formed of inhomogeneous sequence of crystalline schists and granitoids. Author correctly recognized the protoliths of metamorphites, as well as multi-stage magmatic granite genesis. The genesis of granitoid rocks he affiliated with Variscan (earlier used synonym by some authors Hercynian) late- to post-orogenic magmatic cycle. He considered the migmatites, present in paragneisses, mainly as thermodynamic product of granitoid intrusions.

Detail mapping and petrographic research of crystalline basement in the 1970s by Kahan et al. (1978) and Kahan (1979) distinguished several types of metamorphic and granitoid rocks, encompassing also their structural research.

Petrography and geochemistry of amphibolites and associated black schists (graphite gneisses) in Malá Magura and Suchý massifs were investigated by Ivan and Méres (2015). They equate them with effusive basalts, dolerites and gabbros as well as deep water sediments, rich in silica and carbon, being hydrothermally altered before orogenic metamorphism. These rocks represent upper part of ofiolite suite, equal with that, present in Upper Devonian Pernek Group of the Malé Karpaty Mts. The finding of distinctive Cr, V and Mn rich metamorphic rocks and Ca garnets in black schists in the Čierna Lehota area supports this opinion (Bačík et al., 2018). In the area of the Závada valley north of the Závada pod Čiernym vrchom village, the exploration activities were carried out for graphite raw material in black schists (Mikoláš et al., 1995).

Hovorka and Méres (1991) geochemically investigated paragneisses in both crystalline cores of the Strážovské vrchy Mts and also in the Malá Fatra Mts. They interpreted low K/Na lithologies of the continental crust as their source material (especially intermediate to acid magmatites of granodiorite-tonalite composition). The sedimentary maturity of the original material is the highest in the Suchý massif and manifested by a higher content of the clay component.

Putiš (1976) and Kahan et al. (1978) comprehensively evaluated the structural elements of the crystalline basement (Malá Magura and Suchý massifs) of the Strážovské vrchy Mts, including microstructural analysis. They distinguished secondary foliation planes s1 of metamorphic origin (crystallization schistosity), present in paragneisses and simultaneously forming biotite schliers in granitoids. The younger s2 planes, bearing retrograde facies minerals (sericite, chlorite, bauerite, albite, quartz), penetrated s1 planes. Planes s3 of retrograde metamorphism (according to Kahan et al., l.c.) were formed at arching of crystalline cores near the contact with Mesozoic and Cenozoic complexes. Work evaluates also fold structures in crystalline basement, mineral lineations and joints, identifying directional block displacements.

Based on microstructural research of preferred quartz orientation, P. Kováč (1986) demonstrated that in the Suchý massif granitoids the quartz elongations are trending NNE–SSW, correspondingly with the course of granitoids, as well as foliation in metamorphites, described by Kahan (1978). P. Kováč (l.c.) supposed that preferred orientation of granitoids, investigated in quartz and micas, represents a one-act process, manifested by recrystallization and rotation of quartz and mica minerals.

Based on drilling works and surface exploration trenches in the Čavoj area (Mikoláš et al., 1995), the synform and antiform geological setting of paragneisses was revealed with relatively steeply dipping fold planes. The intensive mylonitization of the crystalline basement in the wells increased N-ward, i.e. towards the contact of crystalline complexes with the Mesozoic cover (Malá Magura Unit), formed by quartzite at their contact. Stronger Alpine overprint along the margin of crystalline massif was proved by this way.

Based on relationship of metamorphic rocks, their metamorphic grade, granitization and migmatization, Kahan (1979, 1980) states two alternatives of thermal overprint – either by anatectic process, i.e. orogenic metamorphism producing anatexis, or by overheating of "supracrustal" metasedimentary series.

Investigating metamorphic zonality in Suchý massif, Korikovski et al. (1987) distinguished two metamorpic zones: staurolite-andalusite-biotite at the margin and sillimanite-biotite-muscovite in remaining part of crystalline basement. The petrogenetic grid revealed PT conditions of metamorphism 3 kbar (300 MPa) and 540–590 °C. Muscovite-sillimanite aggregates in peraluminous granites indicate their origin at the expense of magmatic feldspars and biotites through the loss of Mg, Fe, Na, partly K, which, according to authors, points to the process of high-temperature acid leaching. Simultaneously they separated this process from pervasive muscovitization in connection with granites. Authors (l.c.) consider this process to be a deeper analogue of greisenization with metasomatic origin of muscovite and andalusite.

The presence of the staurolite-sillimanite and garnet mineral association especially at the W margin of the Suchý massif Dyda (1988) explains by the premetamorphic protolith rich in clay schists. According to Dyda (1990), mineral balances indicate different metamorphic conditions in the Malá Magura and Suchý crystalline basements: In the first case their culmination reached 640 °C with pressure of 5 kbar and in the case of the Suchý paragneisses it was 560 °C and pressure of 4.5 kbar.

Hovorka and Méres (1991) distinguished two events in metamorphic overprint of the paragneisses of the Strážovské vrchy and Malá Fatra crystalline basements. The first event – found only in the Malá Fatra basement (garnets with pyrope content above 30 %) – took place in higher temperature amphibolite facies (sillimanite zone), second event – under lower conditions (staurolite and sillimanite zone) – was revealed in both basements.

High-temperature metamorphic conditions were determined by TERMOCALC software (Čík & Petrík, 2014) from migmatite and paragneiss of the Magura massif (Poruba valley). The peak conditions for migmatite – 782 ± 53 °C (resp. 670–760 °C), pressure 7.4 ± 1.7 kbar (resp. 6.9–7.4 kbar). For paragneiss it was – 668 ± 53 °C (resp. 700–770 °C) at pressure 5.5 ± 1.2 kbar (resp. 6.7–8.2 kbar). Younger low-temperature metamorphism was defined in the Magura massif (l.c.) by the presence of margarite and pumpellyite. Calculations of retrograde conditions in migmatite gave values of 480 °C and pressure of 4.6 kbar and in paragneiss 300 °C and a pressure of 2.9 kbar.

The composition and ages of granitoids and paragneisses from the Strážovské vrchy Mts were studied by Vilinovičová (1988, 1990). She divided tonalites, granodiorites and granites based on their petrochemical and mineral characteristics. Rocks of granodiorite composition dominate in the Suchý massif, less often are tonalites and granites. In the gneiss complex she (l.c.) investigated the fine-grained gneisses, banded gneisses and augen gneisses [in present geological map by Hraško & Kováčik (eds.) et al., 2021, being redefined to orthogneisses]. Vilinovičová (l.c.) investigated also chemical composition of the trace elements in feldspars and stated their structural arrangement. $Fe^{2+}$ biotites in all granitoid types with a relatively small compositional range, correspond by composition with biotites from gneisses. In garnets of granitoids, which are relatively non-zonal, the content of the spessartite molecule increases from leucogranites to granodiorites and tonalites. The normalized REE curves show the absence of Eu minimum in tonalites and enrichment of light REEs. The application of feldspar Plg-Kfs thermometry points to subsolidus equilibrium temperatures in granitoids (up to 550 °C). Leucogranites of the Strážovské vrchy Mts are frequently bearing garnets of several mm up to a few cm in size, which occur together with sillimanite, biotite, muscovite in the prevailing quartz–K-feldspar–plagioclase granite composition. Hovorka and Fejdi (1983) distinguished two types of garnets with very close composition. Garnets have prevailing almandine component (1. $Alm_{71}$, $Py_{9.5}$, $Spess_{18}$, $Gross_{1}$, $Andr_{0.5}$ and 2. $Alm_{75}$, $Py_{12}$, $Spess_{10}$, $Gross_{0.5}$, $Andr_{2.5}$). Authors interpreted this difference in composition to be the result of melt crystallization under different thermodynamic conditions – they crystallized before the emplacement of magma into higher crustal conditions.

Kráľ et al. (1987) investigated isotopic composition and age of granitoids based on $^{87}Rb/^{86}Sr$ isotopic system, including more types of granitoid samples and aiming to calculate the isochrone Rb/Sr age from the Suchý and Malá Magura massifs. Isochrone age was calculated to 393 ± 6 Ma, with inicial $^{87}Sr/^{86}Sr$ ratio 0.7060 ± 0.0002. According our opinion these samples were not genetically related. The dating of S-type granite sample (V-94) by Kráľ et al. (1997) using TIMS analysis provided the age of 356 ± 9 Ma.

More recent zircon dating based on SHRIMP analysis (concordia age) from sample of S-type muscovite-biotite granite with garnet (sample MM-29) performed by Kohút and Larionov (2021) from the Magura part of the Strážovské vrchy Mts, from the Porubský potok stream provided the age 360.9 ± 2.7 Ma.

The geological structure of the territory was comprehensively described in the monographs by Maheľ (1983, 1985).

## Used methodology

The field geological research was supported by detail petrography of mapped rock types. Chemical composition and BSEI images of rock-forming minerals were obtained by electron microprobe CAMECA SX 100, housed in the State Geological Institute of Dionýz Štúr (P. Konečný, V. Kollárová). In the laboratory, monazite dating methodology MARC (Monazite Age Reference Calibration) developed over past years by P. Konečný (2018 including further improvements) was applied to granitic rocks.

Monazites suitable for dating have to meet several conditions. A low concentration of Pb in the order of tenths of ppm can only be detected with the application of a strong analytical conditions (e.g long counting times and high beam current). Pb was acquired with accelerating voltage of 15 kV, long counting times of 300 s for peak and 150 s for two background points were applied and the high sample current of 180 nA was used. The electron beam diameter was adjusted to 3 µm. Under such conditions, the PbMα line is effectively excited and offers acceptable compromise between beam damage and counting efficiency. Th, U included in the age calculation and Y overlapping the PbMα were also precisely measured with an extended measurement time of 35 s, 90 s and 45 s, respectively. The following calibration standards (natural minerals or synthetic components) were used to calibrate the electron microprobe: apatite (P-Kα), wollastonite (Si-Kα, Ca-Kα), GaAs (As-Lα), baryte (S-Kα, Ba-Lα), $Al_2O_3$ (Al-Kα), $ThO_2$ (Th-Mα), $UO_2$ (U-Mβ), cerussite (Pb-Mα), $YPO_4$ (Y-Lα), $LaPO_4$ (La-Lα), $CePO_4$ (Ce-Lα), $PrPO_4$ (Pr-Lβ), $NdPO_4$ (NdLα), $SmPO_4$ (Sm-Lα), $EuPO_4$ (Eu-Lβ), $GdPO_4$ (Gd-Lα), $TbPO_4$ (Tb-Lα), $DyPO_4$ (Dy-Lβ), $HoPO_4$ (Ho-Lβ), $ErPO_4$ (Er-Lβ), $TmPO_4$ (Tm-Lα), $YbPO_4$ (Yb-Lα), $LuPO_4$ (Lu-Lβ), fayalite (Fe-Kα) and $SrTiO_3$ (Sr-Lα). UMβ overlapped by ThMζ, ThM3-N4, ThM5-P3 and PbMα overlapped by ThMζ1, ThMζ2 and PbMα overlapped also by YLγ2,3 as well as numerous other interferences among REE were corrected by correction coefficients obtained by measurement on calibration standards. Each analysis of monazite includes the complete set of elements of which it is composed. We are avoiding the methodology where only Th, U, Pb and Y are measured and the other elements are measured elsewhere in the same monazite zone. Such method creates inaccuracies depending on the homogeneity of the monazite and also on the matrix effect, where all elements are required for the ZAF correction. The age determined from the given analysis is only the apparent age. To find out the real age, it is necessary to combine measurements at several points (10-50). The age group plotted on the histogram can indicate whether it represents one or several age populations. The resulting age from the age of population is then calculated using the weighted average of the apparent ages. On the isochron (Pb vs. Th – including the contribution from U) the age population is spread around a linear relationship. The linear regression should ideally intersect the zero coordinate and thus represents an additional test of the correctness of the dating. The method of age calculating based on statistical evaluation was described by Montel et al. (1996). The methodology developed in the Electron Microanalysis Laboratory (ŠGÚDŠ) represents an improved methodology that is practiced only in this laboratory. It is based on a final correction using 7-9 monazite age standards, where the age is determined by more accurate isotopic dating methods – Th-U-Pb: SHRIMP, LA-ICPMS, ID-TIMS, etc. To sum up - the MARC methodology (Monazite Age Reference Calibration, P. Konečný et al., 2018) includes corrections for interferences, corrections for exponential background, an innovative method of determining the dependence between the composition of monazite (average atomic number) and the difference between the linear and exponential background for the PbMα line, determining the dependence between the measured Pb and the theoretically required (ΔPb) to reach the age of the monazite standard, determination of MARC coefficients, which will be used for final fine-tuning of the age calculation and others.

The pressure-temperature conditions of metamorphic overprint were determined by R. Demko (ŠGÚDŠ), using methodology of garnet-biotite-plagioclase-quartz (GBPQ) geobarometry in medium- to high-grade metapelites (Wu et al., 2004).

Cassification of lithotectonic units – **LTUs** – is based on orogenic (Wilson) cycles, being indicated by the **XD labelling method** in polyorogenic terrains by the prefix X (cf. Németh, 2021; Fig. 2 ibid), as well as by affiliation of individual orogenic phases of these cycles by a **number after D**: **XD0** – divergent process of riftogenesis; **XD1** – convergent processes of subduction (XD1s), obduction (XD1o) and closure of elongated oceanic space by collision (XD1c); **XD2** – post-collisional thermal / deformation processes, unroofing and metamorphic core complex evolution; **XD3** – intraplate consolidation – strike-slip faults preferably of NW–SE and NE–SW trends (cf. Németh et al., 2023), transpression, transtension, rotation of blocks, *etc*.; and **XD4** – regional extension (pure shear-type regional faults, dominantly of E–W and N–S courses, cf. l.c.). From **X prefixes** for orogenic cycles within Europe suggested by Németh (2021) in this paper we use: Cd – Cadomian, V - Variscan, Vm - Meso-Variscan, Ap – Paleo-Alpine (Mesozoic Alpine orogenic cycle) and An – Neo-Alpine (Cenozoic Alpine orogenic cycle; both represent complete orogenic cycles).

Similar principle of designation is used at metamorphic overprints – the **MX labelling** (e.g. MV0, MV1sc, MAp2, etc., l.c.)

## New characteristic of lithotectonic units of the pre-granite crystalline basement in the Suchý massif

Published geological map by Hraško and Kováčik (eds., 2021) for the reader of this paper is available on:

https://www.geology.sk/wp-content/uploads/documents/foto/geol_mapy_50k/58_StrazovskeVrchy_final.jpg.

Detail geological mapping of crystalline basement in the western part of Tatric occurrences in the Strážovské vrchy Mts (Suchý massif), research of structural and spatial relations acting before the granite-forming process and lithological pecularities, allowed to define three below stated main lithotectonic units (LTUs) of differing geotectonic provenience. Rock sequences of these LTUs were amalgamated during Meso-Variscan collision and later partial melting.

1. **LTU of deep-water euxinic facies (VmD0)**, in pre-metamorphic stage consisting mainly of fine-grained pelitic and quartzy sedimentary facies rich in organic matter, with preserved fragments of accompanying oceanic mafic volcanites;
2. **LTU of proximal sedimentay facies of continental slope (VmD0)** of Paleozoic basin, built mainly of flyschoid sediments of sandy-greiwacke composition. In the field, these can be distinguished by alternating of metamorphosed sandy vs. clayey-sandy beds (less Al-rich sediments), having lower content of organic matter and rare occurrence of small metabasite bodies;
3. **LTU of orthogneisses (CdD2)** is common in the Suchý massif. In smaller scale orthogneisses occur also in the W part of the Magura massif. They represent a crustal granitoid segment thrust at Meso-Variscan collision **(VmD1c)** on previously described **VmD0** LTUs. Later the originating thick skinned sequence was metamorphosed in **VmD2 / MVm2**. This LTU of orthogneisses crops out in upper structural position of fan structure with fan

axis trending ENE–WSW (shown in geological profile 1–2 in published geological map by Hraško & Kováčik, eds., 2021, l.c.).

These originally separated complexes were interconnected and submerged owing to convergence in zone of elongated Variscan basin. In the area of the lower part of the metamorphic packet and along shear faults, a partial melting of the protolith with an appropriate lithological composition took place in **VmD2**.

**General lithological and metamorphic characteristic of new lithotectonic units**

**1 Lithotectonic unit built of deep-water euxinic facies (VmD0).**

It is originally formed mainly of the fine-grained pelitic and quartzy sedimentary facies rich in organic matter, with preserved fragments of accompanying oceanic mafic volcanites;

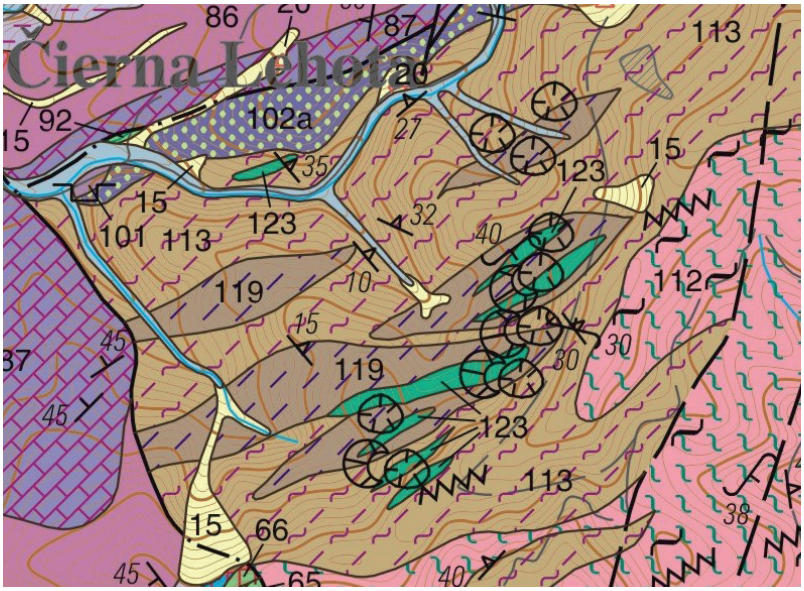
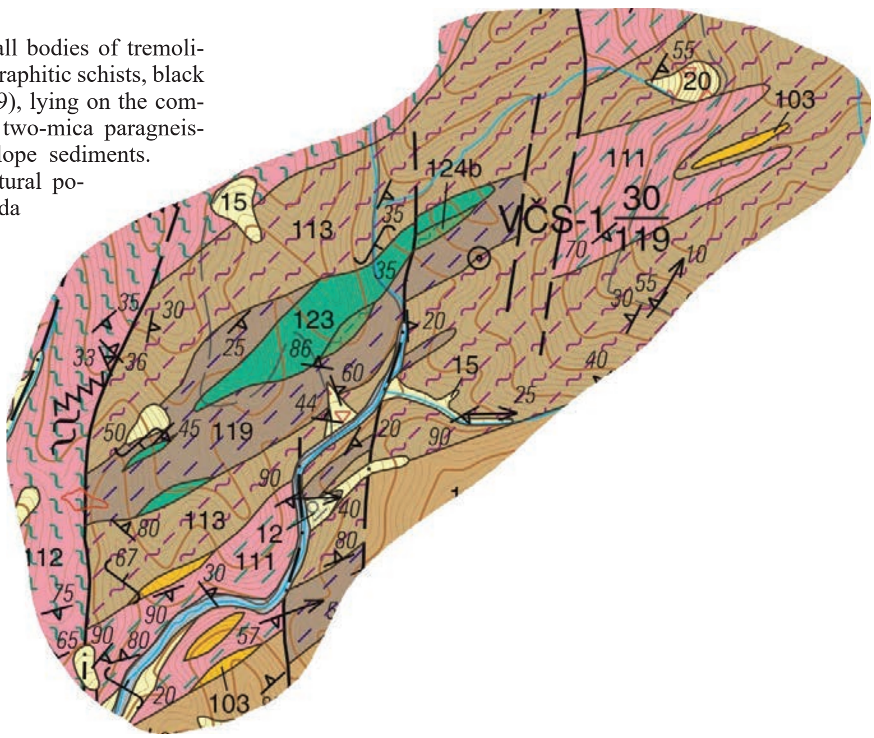



**Fig. 2.** Association of amphibolites (123) and black schists (119) SE of the Čierna Lehota village. Numerous mining works exploring possible sulphide mineralization are typical for this area.

**Fig. 3.** Amphibolite bodies (123) and small bodies of tremolite-plagioclase amphibolites (124b), black graphitic schists, black paragneisses and black metaquarzites (119), lying on the complex of schistose or massive biotite and two-mica paragneisses (113), representing the continental slope sediments. Orthogneisses (111) occur in upper structural position. Geological situation near the Závada stream.



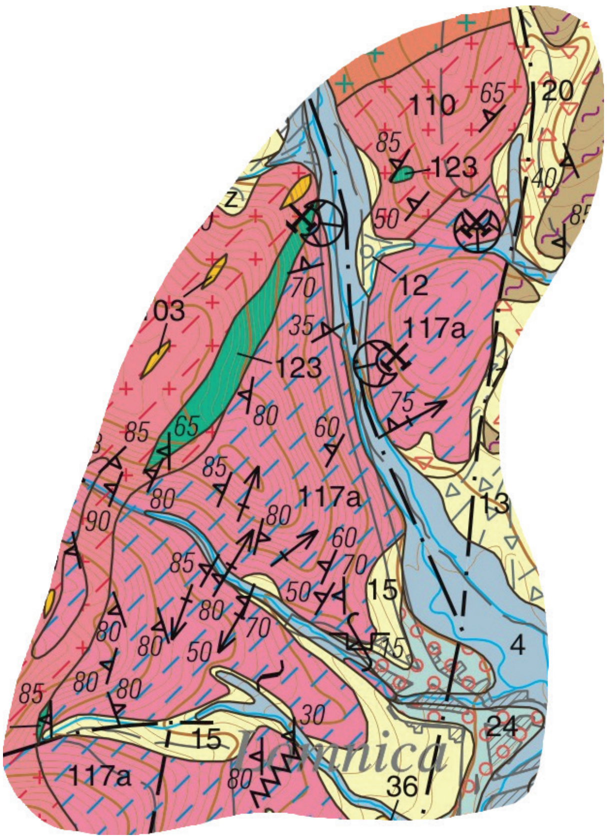



**Fig. 4.** The position of the largest amphibolite body (123), concordantly with the subvertical deformation structure, at the contact between migmatites with prevalence of stromatitic to ptygmatitic textures (117a) and massive to weakly oriented hybridic (schliered) granodiorite with frequent biotite schliers and xenoliths of paragneisses (110). No black schists were found, but according to presence of remnants of old mining in the northern part of body, their presence is probable. Amphibolite has signs of partial melting and intrusion of later leucogranites. Situation between Krstenica a Nitrica valleys.

Amphibolites and associated rocks (amphibolic and amphibole-biotite gneisses, quartzy massive paragneisses, graphitic metaquartzites, pyroxene amphibolites, amphibolites with garnet and tremolite-plagioclase amphibolites) are in earlier geological maps from this area (Kahan in Maheľ et al., 1982; Ivanov, 1957) shown in summary as amphibolites. Visualized are mainly large bodies at the Chvojnica area (Magura part), Liešťany (S part of the Krstenica valley) and in area north of the Závada pod Čiernym vrchom village (Závada valley, area of its right tributary – the Železná dolina valley). Amphibole-bearing rocks and associated sediments with prevailing pelitic, resp. quartzy composition represent common source of disseminated sulphidic mineralization, which is demonstrated also by numerous old mining works in their space. Based on the remnants of old mining we have identified such lithologies also in the westernmost termination of crystalline basement in the Suchý massif (SE of Čierna Lehota village, area of Závadská poľana hill).

Due to metamorphic overprint, it was not possible to express quite well the facies differences between the metapelitic and quartzy-pelitic, siliciclastic metasediments in cartographic visualization. Despite, in wider context in areas with higher presence of amphibolitic rocks, there was observable the presence of metasediments with higher content of Al-rich minerals – sillimanite and staurolite, as a reflection of more pelitic composition of metasediments. In the surrounding of smaller mafic bodies in area located SW and NW of Suchý vrch hill (altitude point 1028), there occur also metapelitic metamorphites with common macroscopic staurolite, representing an indicator of Al-rich protolith. At the contact zone of stromatitic migmatites (117a) and massive to weakly oriented schliered granodiorites (110) in the area of Nitrica river and Krstenica valley there were found two smaller and one big bodies of metamafites (123), which underwent interaction with leucogranitic melt (Fig. 11).

Amphibole occassionally occurs also in paragneisses, which can be in this case named as "amphibole-biotitite gneisses". These thin lithological intercalations we do not describe here, but in geological map their occurrences are visualized with a special hatch (122).

The amphibolite bodies occur in the Suchý massif concordantly with the structural elements of the surrounding metamorphites.

### *Amphibolitic rocks with calcareous-silicate component, loccally with garnet and clinopyroxene (124a)*

They are usually heterogeneous, often complexly deformed rocks, appearing in various green, greenish-grey shades in the area of larger amphibolite bodies of Suchý hill.


**Fig. 5.** Dark-grey amphibolic rock with thin light-grey interbed of diopside pyroxene (area of Železná dolina valley, sample SZN-32a).

Their affiliation to metamorphosed calcium-silicate rocks is evidenced by the increased proportion of epidote

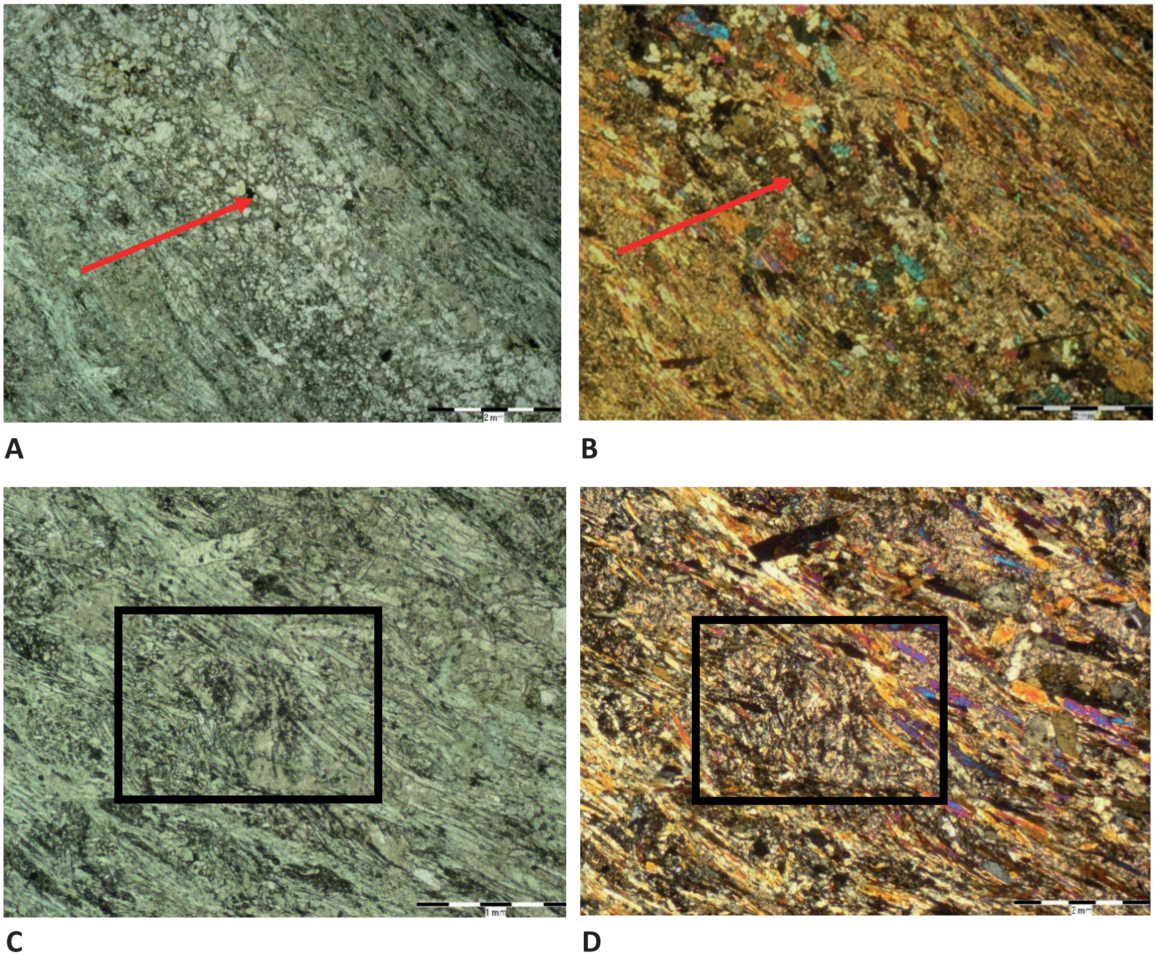



**Fig. 6.** Microphotographs of polymetamorpic clinopyroxene-amphibole amphibolite (sample SZN-32a, area of the Železná dolina valley, being a tributary to the Závada valley). A–B – granoblastic diopside (highlighted by red arrow) from Ca-rich, originally carbonate interbed in tuffitic sequence; C–D – dynamic deformation of older plagioclase (highlighted by black rectangle) with S-C setting represents younger deformation phase in the epidotic amphibolite facies.

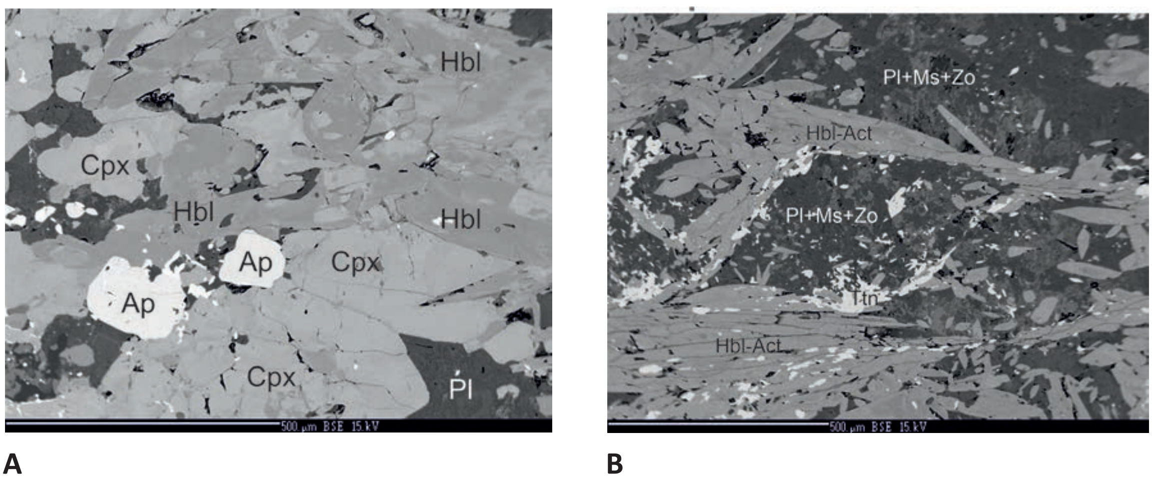



**Fig. 7.** BSEI of clinopyroxene-amphibole amphibolite, sample SZN-32a, the Železná dolina area. A – Assemblage of diopside (cpx) with amphibole (tschermakite and younger actinolite), accessoric apatite and chalcopyrite. B – Rotation of older plagioclase due to the decomposition of former plagioclase to Pl $X_{An}$ 40–48 %, muscovite, zoisite and rim, consisting of grey actinolite. Light phases represent titanite. Assemblage in part of this rock, consisting of prehnite, albite and actinolite belongs to the lowest thermal part of polymetamorphism.

(clinozoisite), the common presence of clinopyroxene phenocrysts and garnet rich in grossular component. The plagioclase-amphibole-dominated composition of the rocks and the loose spatial association with amphibolites indicate that the primary lithology consisted of pyroclastic (?) products of basic volcanism enriched with a calcareous admixture. Microscopically distinctive bright positions parallel to the metamorphic foliation are formed by diopside (Figs. 5 – 7).

The composition of clinopyroxenes corresponds to diopside with a content of 1.3 % jadeite component, older amphiboles correspond to tschermakite, while younger recrystallized amphiboles are of actinolite composition.

Plagioclase is usually recrystallized to form a new generation $X_{An}$ = 41–48 %. Based on the presence of clinozoisite, which was formed at the expense of plagioclase, the original plagioclases were more calcic. The lowest thermal part includes the albite-prehnite association, which is probably of Alpine age.

***Tremolite-plagioclase fine-grained pale amhibolites (124b)***

Rarely present light fine-grained rocks are part of the complex of amphibolites (metabasalts) and appear at the contact with black metaquartzites, irregularly rimming the southeastern part of the elongated body of amphibolite in the area of the Železné and Závada valleys north of the village of Závada pod Čierny vrchom.

Considering the mineral composition, they probably represented carbonate (dolomite) sedimentary inlays in black metaquartzites in contact with metabasalts. The alternative of altered ultramafite due to the lack of sedimentary textures is also possible (this would also be indicated by the position in the lower part of the amphibolite body, which could represent a fragment of the ophiolite suite). Another alternative is that the rock represented the acidic part of the ophiolite suite (keratophyre).


**Fig. 8.** Sample of tremolite-plagioclase rock with deficiency of dark minerals. In the field this rock resembles the fine-grained quartzitic rock (sample SZN-24).

The samples represent a light omnidirectional fine-grained rock (Figs. 8 and 9), without dark minerals. The microscopically visible metamorphic structure of the rock is formed by omnidirectional colorless strips of amphibole of tremolite composition. The basic material is composed of plagioclase ($An_{41–43}$). Younger metamorphic overprint is

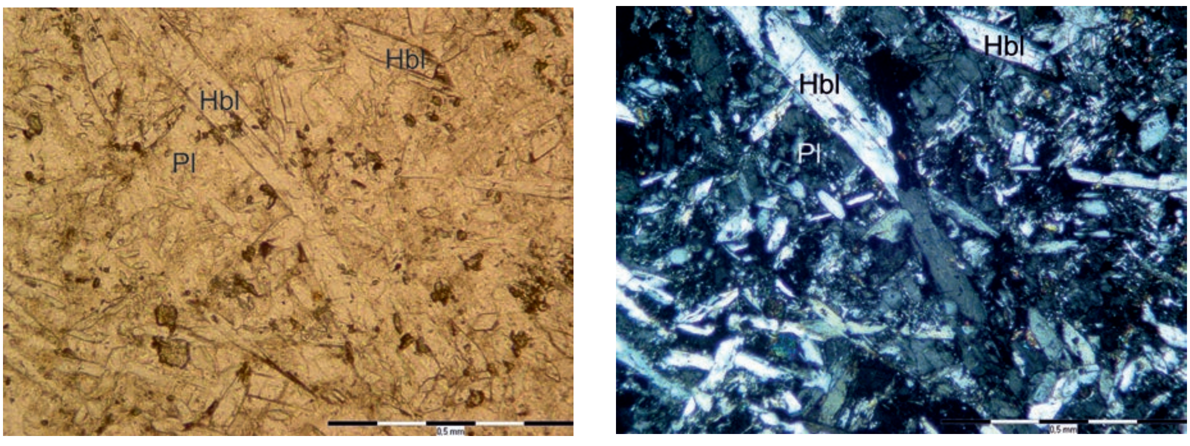
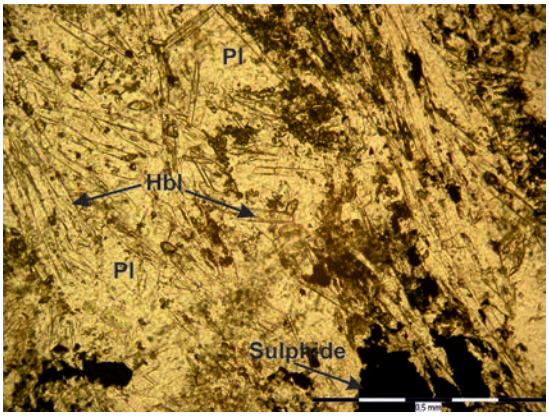



**Fig. 9.** A, B – Microphotographs of sample SZN-24 from the area between the Závada and its righ-side tributary from Železná dolina in western part of the Suchý massif. A rarely occurring amphibolic (tremolitic)-plagioclase fine-grained rock at first glance resembles metaquartzite. It contains a ground mass formed by plagioclase and phenocrysts of light amphibole of tremolite composition. The interstices between amphiboles of tremolite composition are formed by plagioclase. This rock occurs in marginal parts of large amphibolite bodies. A – parallel (N*II*) and B – crossed nicols (N*X*) of polarizing microskope.

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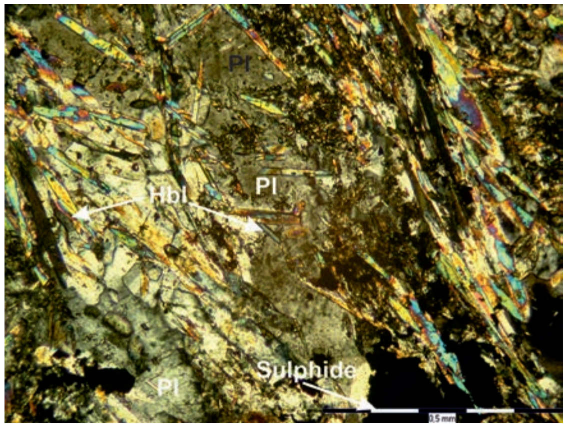


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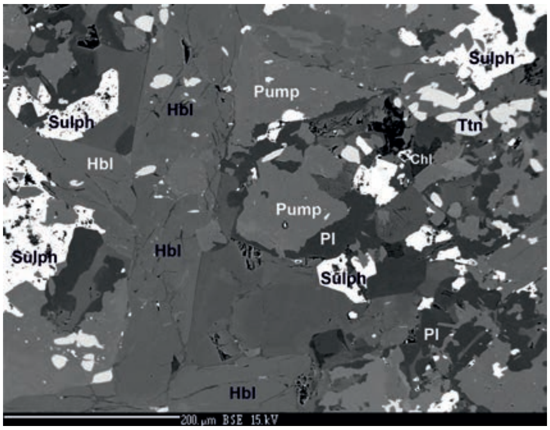


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**Fig. 10.** Microphoto of the sample LHS-261: A, B – nematoblastic structure of rock formed by trematolite to Mg-hornblende amphibole and plagioclase, N//, N*X*. C – BSEI – besides tremolitic to Mg-hornblende amphibole and plagioclase (An – 32, 46, 61 %) rock contains a great number of sulphides – pyrite, pyrhotite, chalcopyrite. Younger, lower temperature metamorphic association is formed by albite, chlorite and pumpellyite.

associated with formation of chlorite, barite, pompellyite and oligoclase ($An_{28}$).

A similar sample LHS-261 from the Suchý massif was taken from Závada and Železná dolina valleys area at the junction of paragneisses and black-graphitic schists in continuation of the amphibolite body above E side of the Závada valley. The rock resembling fine-grained light quartzite contains tremolitic-Mg-hornblende amphiboles, basic plagioclase of andesine-labradorite composition (max. An 61 %). The presence of sulphides is common.

***Amphibolites – olive-green-grey fine-grained foliated types (123)***

Amphibolite bodies were already considered by Ivanov (1957) to be part of the ophiolite (oceanic) suite of basic magmatites, which was confirmed by later geochemical research.

Amphibolites usually form several meters, max. the first 10 m thick bodies of dark green to grey fine-grained, detailed foliated rocks, mostly conformal with the surrounding paragneiss substrate. Tiny lenses of amphibolites are irregularly dispersed in the metamorphic substrate.

In the Suchý massif there are two to three more distinct bodies, or groups of bodies. The easternmost of them is located in the Liešťanská dolina valley (Krstenica valley), and like the body in the Chvojnica valley in the Magura part of the crystalline basement, it occurs at the junction of migmatites and granitoids, with exceptionally preserved higher-temperature paragneisses in the vicinity. From the point of view of the Variscan setting, this body occurs in the lower tectonic position at the contact of the lower part of the schist-like granodiorites near their contact with the migmatites (Fig. 4). These bodies are probably the relics of a larger set of metapelites, metapsammites, which, however, are found only rudimentarily in this position in the form of paragneisses. Only rarely is it possible, e.g. E from Nitrica to find amphibolite relics in association with paragneisses in hybrid granitoids. Such a lack of metasedimentary associating lithologies is very likely a consequence of the tectonic reduction of a significant part of the volcanic-sedimentary complex during the granitizing Devonian-Lower Carboniferous event. The second position of the amphibolites in the Suchý massif is the upper structural position of the amphibolites, which emerges both in the area of the Závada valley and its tributary Železná dolina valley, and on the other hand from the ridge of Závadská poľana towards the Čierna Lehota village, where the amphibolites are part of a complex of black schists (graphitic metaquartzites), graphitic and graphite-amphibole paragneisses. The association of amphibolic rocks with metapelitic rocks, which are characterized by Al-rich metamorphic minerals – sillimanite and staurolite, is striking in the western part of the territory. This structural position is spatially more remote from granitization processes.

**Fig. 11.** Banded amphibolite from the zone of granitization (sample LHS-153) above left side of the Krstenica valley (Liešťanská dolina valley) under the high voltage line. Rock in brittle regime is penetrated by aplitic leucogranite without mutual interactions, which proves intrusion of leucogranite in higher crustal level with more rapid crystallization of leucogranite magma.

The mineral content of amphibolites is usually characterized by a significant predominance of common amphibole with green pleochroism prevailing over plagioclase. In minor quantities, but characteristically represented minerals are titanite, epidote, or clinozoisite and opaque ore phases. As a rule, amphibolites are fine-grained (the average grain size reaches around 0.2 mm), amphibole in some places makes up to 90 vol. % of the mineral composition of the rock.

***Amphibole-biotite and amphibole-plagioclase gneisses (122)***

Due to the problematic differentiation of amphibolic gneisses and amphibolites at field mapping, these are usually cartographically included under the group of amphibolites (123). Only in some places do we highlight in the geological map with a special symbol the areas with a greater occurrence of paragneisses with amphibole, in which biotite and amphibole gneisses alternate, which often contain several cm thick positions richer in biotite and positions richer in amphibole. The marginal member is represented by amphibole-plagioclase gneisses, which originally probably represented intercalations of basic tuffites in the marine sediment. Plagioclases (from the

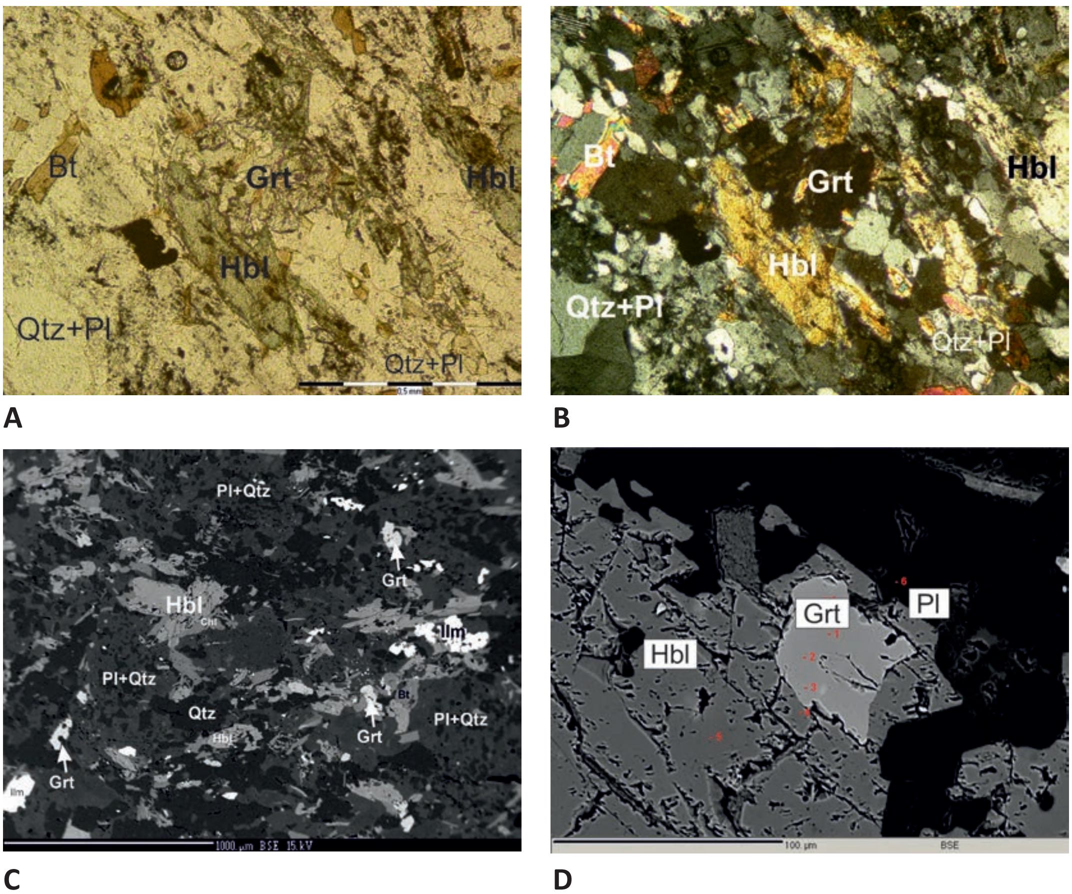
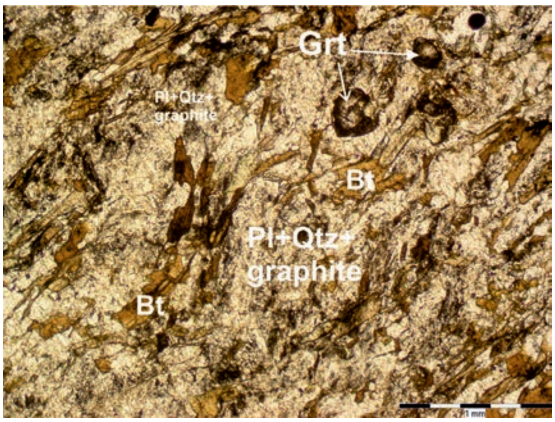



**Fig. 12.** Transitional type of paragneiss. Qtz–Plg–Hbl–Bt–Grt–Chl paragneiss in the vicinity of amphibolite bodies (sample SZN-57) contains often graphitic pigment. A – N//, B – N*X*: microphoto of lepidogranoblastic structure of paragneiss with often graphitic pigment. C, D – BSEI. D – Hornblend (Hbl) closes irregular garnet (Grt).

sample SZN-85 from the Závada valley area) correspond in composition to the oligoclase / andesine interface ($X_{An}$ = 31 %). Amphibole corresponds to tschermakite to magnesiohornblende, and the younger generation corresponds to actinolite.

### *Graphitic schists, graphitic paragneisses and black graphitic metaquartzites in association with amphibolites (119)*

Dark grey schists with an organic, graphite substance are sporadically scattered within the metamorphic substrate, conformly with its metamorphic schistosity. Distinctive beds of black schists have been identified near several amphibolite bodies, suggesting a genetic link between basic volcanism and euxinic facies sedimentation in deep-water conditions. Such rocks are also present in the SE region from the elevation Klin (769) towards the Jasenina stream, or, according to the drilling works, they are also part of the paragneiss complex, where amphibolites occur only rarely (area SW from the settlement of Gápel towards the settlement of Petriská). The spred of graphite-rich lithologies in the paragneiss complex is relatively frequent, but without detailed surface petrographic or geophysical research, it is difficult to visualize it spatially. Graphitic rocks are finer-grained, contain more quartz and muscovite, which are otherwise insignificantly represented in the metamorphic substrate in the primary metamorphic form. These rocks are generally poorer in plagioclase and biotite and primarily represented black schists. They can also be considered to be suitable carriers of disseminated sulphide mineralization, as indicated by remnants of old exploration activity in graphitic or silicified rock environments. At the scale of the geological map, identifiable occurrences of these lithological variations, similar to the gneisses with amphibole mentioned below, are marked with a special hatch. Dark grey biotite paragneisses are also an example (sample LHS-350 – Fig. 13) with an organic admixture in association with black graphitic schísts and amphibolic schists in the area of the westernmost termination of the basement above the right side of Brekovský potok valley (south from the Čierna Lehota village). Paragneisses have a lepidogranoblastic structure with a predominance of Qtz-Pl matter, Bt has metamorphic preferred orientation, associated in places with zonal Grt, which has cloudy edges (the poikilitic edge part is a consequence of new thermal metamorphism). Very fine organic matter is

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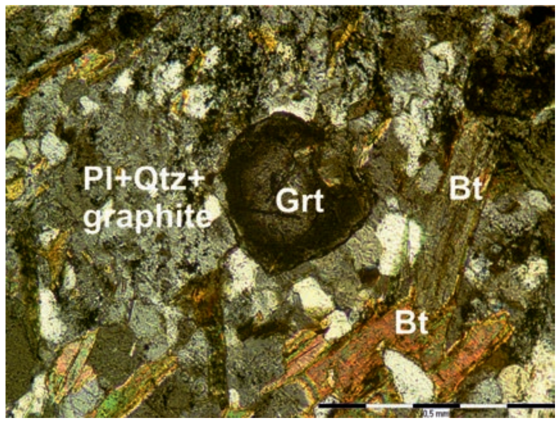


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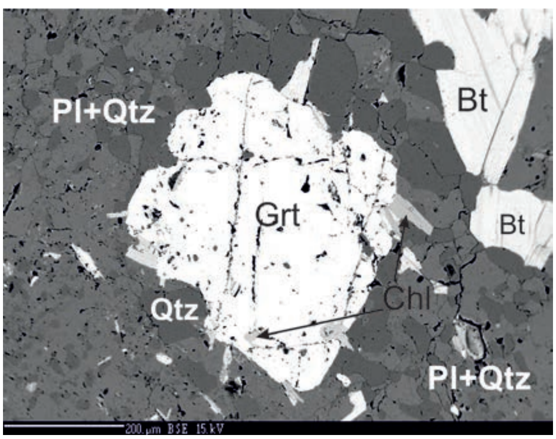



C

**Fig. 13.** A, B – Microphotograph at various magnifications (massif N, SSE of the Čierna Lehota village, sample LHS-350): A – view on structure of Bt paragneiss with fine disseminated graphite, bound mainly on plagioclase, N//; B – detail of association Qtz–Plg–Bt–Grt; C – BSEI of garnet in assemblage with Bt and Chl in plagioclase. Garnet closing poikilitically fine Qtz–Pl–Chl, inclusions are richer present in marginal part of garnet, what causes the cloudy character of the Grt edges.

irregularly dispersed in thin section. Rare there is present Chl in association with Grt. Pl has intermediate oligoclase composition ($An_{23}$), biotite and chlorite are probable coexisting minerals with roughly similar share of Fe/Mg. Grt is prograde zonal in the center with a predominance of the spessartine component over the almandine component, towards the edge with a predominance of the almandine molecule, a decrease in the grossulare component and an increase in the pyrope molecule.

We have revealed more significant beds of black graphitic paragneisses, black metaquartzites, which are in clear association with amphibolite bodies, in the area of Závada and Železná dolina valleys and in the area of Závadská poľana towards the Čierna Lehota village (Fig. 2). Impregnations of sulfidic minerals are typical for this group of rocks, which create light, graphite-rich cavernous rock during weathering. In the environment of graphitic paragneisses and black metaquartzites, there are frequent traces of field exploration works. In the past in the area of the Závada valley, a forecast area was set aside for graphite raw material.

*Chemical dating of monazite*

Chemical dating of monazite from the sample LHS-350 (Plt. 1-1) provided identical result as Mnz dating from samples of further paragneisses. Distribution and age diagram of chemically dated monazites (Plt. 1-1) and isochrone with the age of **366 ± 6.8 Ma** are typical for metamorphites of the Suchý hill. The data can be understood as a bimodal distribution corresponding to the peak of metamorphism around **380–370 Ma** and thermal reworking by granitization event **360–350 Ma**.

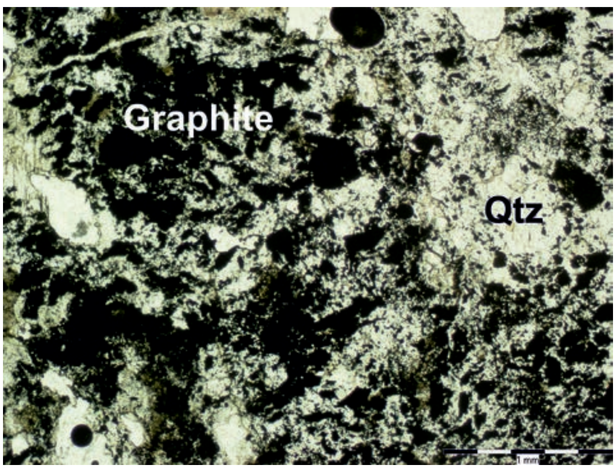



**Fig. 14.** Sample SZN-25 from the area of Železná dolina valley; Grey black fine-grained cavernous metaquartzite rich in graphite, porous after the weathering of sulphidic impregnation; N//. Thin section of the rocks composed of a substantial proportion of organic matter and quartz.

**2 Lithotectonic unit consisting of a complex of proximal sedimentary facies of the continental slope of the Paleozoic sedimentary basin (VmD0).**

This complex is built mainly by metamorphosed, flyschoid sediments of a sandy-loamy composition with a very small proportion of clayey-sandy facies and a very small representation of basic metavolcanites, or even their absence. Depending on the depth of the erosional cut, these lithologies are strongly metamorphosed.

***Schistose or massive biotite and two-mica paragneisses, locally with garnet and staurolite (113)***

Biotitic and two-mica paragneisses, locally with Al-rich metamorphic minerals, occur mainly in the W and N part of the Suchý massif. Between the area south of Valaská Belá and Čavoj villages these paragneisses form the footwall of Lower Triassic quartzites. Within the Variscan setting these paragneisses represent tectonic underlier of orthogneisses.

From the point of view of the granitization event, they were significantly less thermally reworked, which indicates their more external (shallower) position in the crustal package during the Devonian-Lower Carboniferous collision-granitization event.

The alternation of metapsammitic and metapelitic (more aluminous) mineral assemblages points to the flyschoid character of the protolith, without the presence of amphibolites. Several dm thick darker and lighter (feldspar-poorer / richer) sedimentary interbeds alternate here, or strongly siliceous dark paragneisses (metacherts) are present. The organic matter represents a rare constituent of paragneisses of the flyschoid complex without amphibolite bodies, being often dispersed throughout the rock, or bound to the interfaces of metamorphic quartz.

A very common ore pigment, predominantly of ilmenite is present. Prevailing rock-forming minerals are represented by quartz, plagioclase, biotite, less often are muscovite, garnet, sillimanite and staurolite (Fig. 15).

***Migmatitized paragneisses locally with stromatitic and ptygmatitic bodies of leucogranites (116)***

The migmatitized paragneisses represent a part of the lower tectonic unit. (It contains mainly metasediments of greywacke nature, which we affiliate with flyshoid sediments of the continental slope with the absence of amphibolite lithologies. They occur mainly in contact with hybrid granodiorites, with which they finger-like alternate and occur in a tight overburden of migmatites (Fig. 16). They typically occur in the Suchý massif in the area of the Bystrica valley closer to Rudnianska Lehota municipality, or in the area of the Krstenica stream (Liešťanská dolina valley) W of Liešťany village. These underwent initial partial melting and are a suitable lithology for tracing deformation structures in relation to granitoid formation.

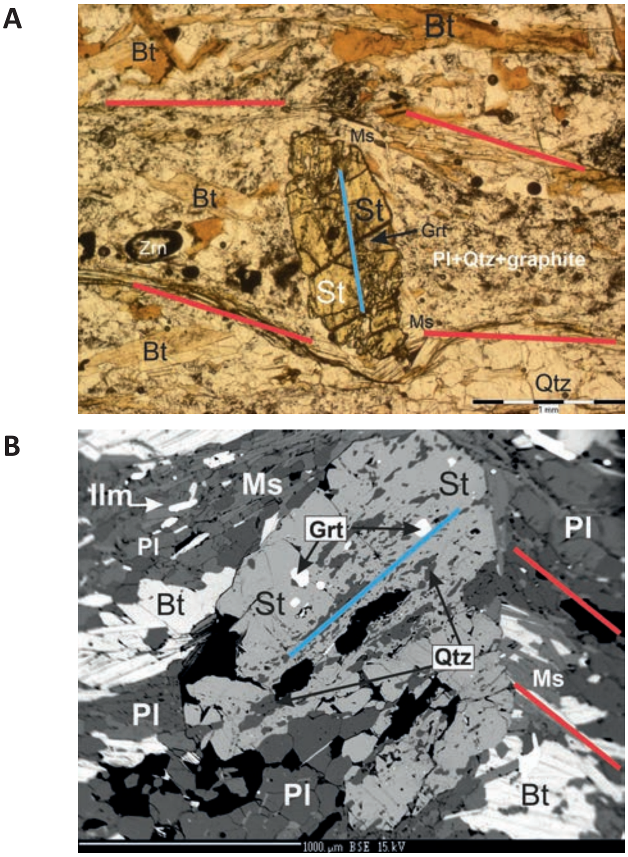



**Fig. 15.** Sample from the W part of the Suchý massif (SNZ-34) demonstrates polymetamorphic overprint of metapelite (Bt-Ms-St-Grt-Pl-Qtz paragneiss). Staurolite porphyroblasts with oriented quartz inclusions belong to older metamorphic phase. Rotation of staurolite is a product of shearing in new deformation-metamorphic event. A – Image from a polarizing microscope, N//, B – BSEI. The older metamorphic preferred orientation is shown by blue line. The red lines show the direction of the younger shearing deformation event.

Within this rock assemblage, the gneiss component significantly predominates over the leucogranite component, which is characterized by ductile granite structures manifested by bulging of granitoid material, which undoubtedly originated at different crustal levels (e.g. Figs. 17 and 18). Also from this example, it is possible to deduce the assumption that the main granitization process was more related to the contribution of heat from the intruding large granitoid masses, which is manifested by the different intensity of the migmatization process, than to deep crustal partial anatexis. At the same time, it is possible to state that the crustal thickening and melting in the deeper parts of the crust was followed by gradual decompression, the subsequent ascent of granitoid magmas into the metamorphic assemblage during the syntectonic regime and a change in the rheology of the metasediments from a ductile to a semi-ductile regime.

As is evident from the presence of leucogranite positions with melanosome rims, deeper crustal conditions of partial melting can be assumed through leucogranite ptygmatitic structures, without significant interaction with the gneiss substrate, to semiductile structures with transversal tabular veins. The mentioned structures are a consequence of the decompression of metamorphic complex. Larger bodies of hybrid (schlier) granodiorites that are associated with this complex could have formed as a product of segregation of granitoid material into suitable structures, but more likely represent independent pulses of granitoid magma into the metamorphic substrate.

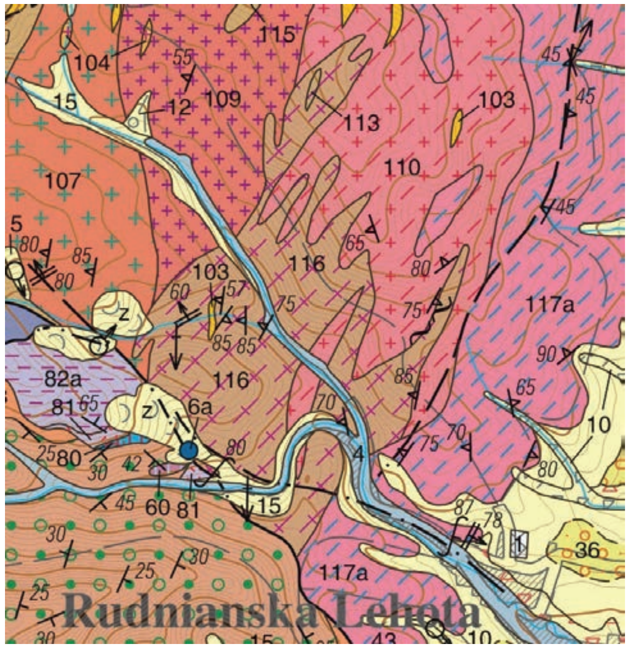



**Fig. 16.** Position of migmatitized paragneisses (116) with small content of ductile folded leucosome, neighbouring with migmatites (117a) and schliered-rich granodiorites (110).

*Monazite dating from leucocratic melts, associating with migmatitized paragneisses and hybridic granitoids*

Chemical dating of monazite indicates in high-metamorphic migmatitized paragneisses to presence of Mnz population, corresponding by age with pre-granite regional metamorphism, while all metamorphosed lithological members of the Suchý crystalline basement contain the Mnz population corresponding by age, where the chemical age approaches approximately **370–380 Ma** of the Upper Devonian. Origin of first melts relates with later thermal overprint with the age around **350–360 Ma**, which corresponds with the boundary of Upper Devonian / Mississippian. First leucocratic melts contain mixed population of monazites from older metamorphic phase as well as younger granitization stage. Following bigger volumes of hybridic tonalites and granodiorites contain only population of granitic stage (Plate 1–2, 3, 4).

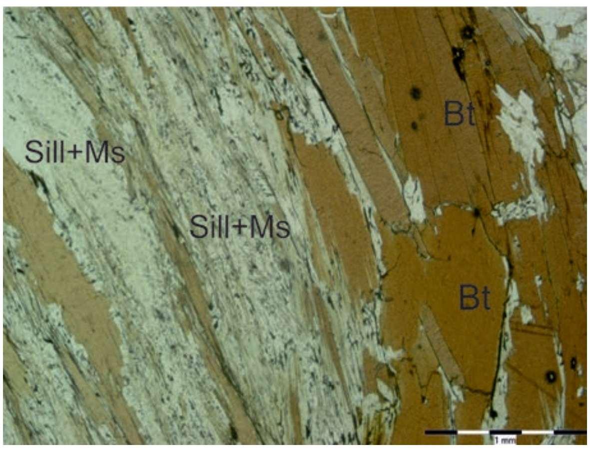
**Fig. 17.** Crossing off the older granite position during ductile deformation, resulting in origin of oblique ptygmatitic vein of granite (sample LHS-57)

**Fig. 18.** Migmatitized paragneiss with distinct primary "bedding of metasediment" s0 = s1, which is demonstrated with alternation of X cm thick light greiwacke-rich interbeds with more pelitic (rich in mica) beds. The multi-stage granitization process is distinct. Larger granite portions were formed in ductile stage of the thermal metamorphism of the rock, while thin veinlet (above hammer) is tied to semiductile flexure, originating in shallower conditions of the crust (sample LHS-42).

A


**Fig. 19.** A – Leucocratic melt at the boundary of granitoid part formed by hypidiomorphic plagioclase and quartz, containing relic biotite. Microphoto: melanosome composed of biotite and muscovite (after sillimanite) and chlorite. B – Detail melanosome formed of biotite and sillimanite, N//. C – Granite part formed of hypidiomorphic Plg and quartz. N*X* (sample LHS-114A).

B

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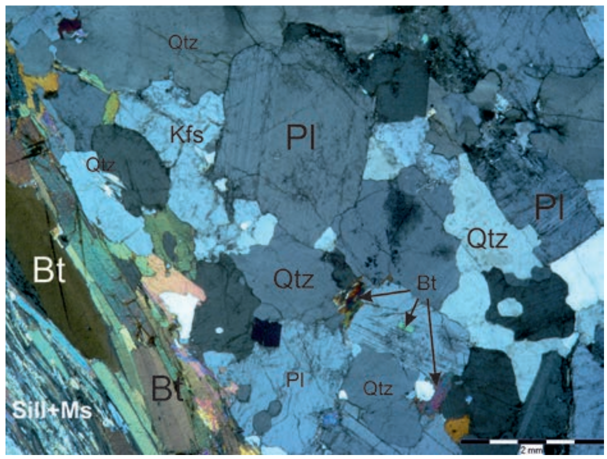



***Higher metamorphosed biotite to muscovite-biotite paragneisses with garnet, medium-grained, often with oriented secondary biotite (locally with sillimanite and staurolite) – distinctly injected with leucocratic granite (115)***

In geological map we separate complex of biotitic and two-mica paragneisses, very intensively injected by leucogranites, aplites and pegmatites. At the same time – in profiles the paragneisses are alternating with granitoid injections in distances of several meters and decameters.

Part of these rocks do not contain such leucocratic injection, but the presence of larger oriented and thermally induced biotite blasts, usually associates with nearby bodies of leucogranites in the footwall. The distinguishing


**Fig. 20.** Position of higher thermally overprinted paragneisses with thermally generated biotite II (115).

of a zone of paragneisses with blastesis of secondary, thermally induced biotite in conditions of dynamic emplacement of leucogranite magmas indicated the vicinity of larger bodies of leucogranites and pegmatites-aplites in nearby footwall. Locally paragneisses form larger xenoliths in leucogranites. The presence of ptygmatitic structures of leucogranites is absent, or is very rare, which indicates the higher crustal level of these lithologies during intrusion of leucogranite melt.

Thermal effect of granitoid intrusions produces larger flakes of biotite of 2nd generation, either in foliation planes of metamorphites, or growth of biotite II is characteristic for the whole rock. Blasts of biotite II have linear orientation and their arrangement corresponds with orientation of larger biotite flakes in leucogranites. Porphyroblasts of biotite II (Bt II) with flakes large up to 2–4 mm are characteristic for this type of gneisses (Fig. 21). They usually contain secondary garnet of contact thermic origin, reaching dimensions up to ca 0.1–0.2 mm (Fig. 22)

It is proved by concordance of the main component of the stress field of synintrusive deformation regime with emplacement of leucogranite veins. These simultaneously with emplacement and decompresion of the whole crystalline block rapidly solidified and behaved as dense crystal slurry.

They have corresponding mineral composition as following type of paragneisses, but slightly larger grains. In prevailing lepidogranoblastic structure the bands of biotite-plagioclase material alternate with cleaner quartz-rich lamina. Plagioclase grains usually connect by polygonal way and obtain hornfels structure. In comparison with the standard biotite gneisses, gneisses of this type were to some extent injected by leucocratic material. In the process of "thermic" metamorphic crystallization they acquired larger grain size, and probable there rarely crystallized also transversal muscovite.

A B

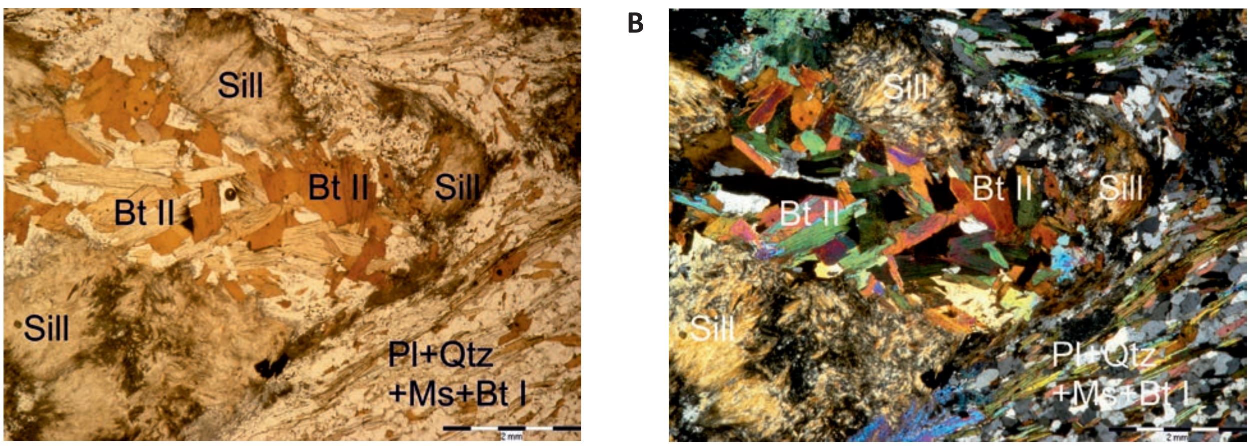



**Fig. 21.** Qtz–Pl–Bt–Ms paragneiss with older sillimanite-fibrolite (prevalence of Qtz over Pl). Sillimanite phenocrysts overreach 2 mm. At margin the fibrolite is replaced by Ms. Large blast of rotated sillimanite from regionally metamorphic phase is in later stage due to the intrusive leucogranitic thermic stage cataclased and fracture is filled with red-brown Bt, which has different position concerning the older Bt of subparallel metamorphic setting of two-mica paragness. A – N//, B – N*X* (sample LHS-197). Grey fine-grained paragneiss, overheated by thermic metamorphism in connection with deformation related to ingress of leucogranites. Synintrusive deformation is manifested by the formation of microfolds and formation of larger flakes of phyllosilicates. Metamorphic schistosity is subvertical of E–W direction.

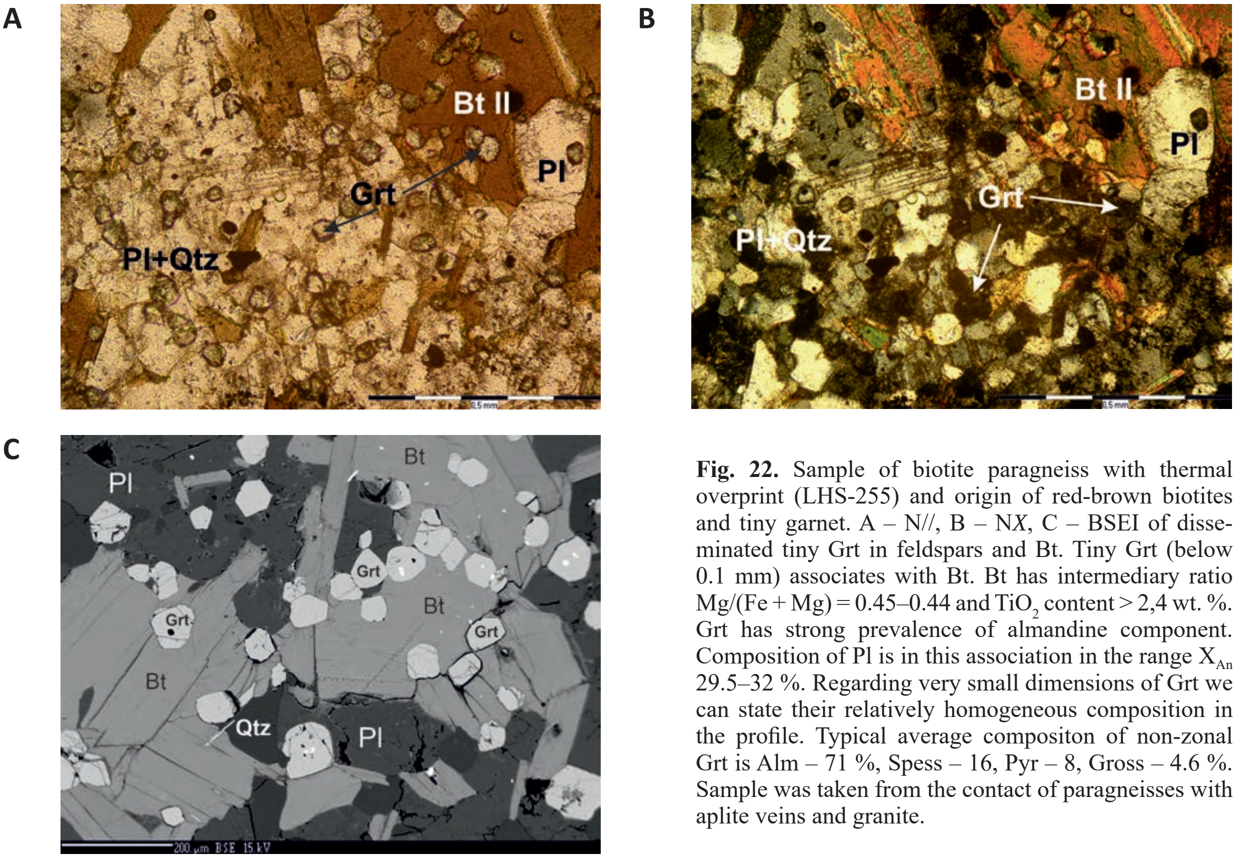



**Fig. 22.** Sample of biotite paragneiss with thermal overprint (LHS-255) and origin of red-brown biotites and tiny garnet. A – N//, B – N*X*, C – BSEI of disseminated tiny Grt in feldspars and Bt. Tiny Grt (below 0.1 mm) associates with Bt. Bt has intermediary ratio Mg/(Fe + Mg) = 0.45–0.44 and $TiO_2$ content > 2,4 wt. %. Grt has strong prevalence of almandine component. Composition of Pl is in this association in the range $X_{An}$ 29.5–32 %. Regarding very small dimensions of Grt we can state their relatively homogeneous composition in the profile. Typical average compositon of non-zonal Grt is Alm – 71 %, Spess – 16, Pyr – 8, Gross – 4.6 %. Sample was taken from the contact of paragneisses with aplite veins and granite.

*Chemical dating of monazite in metapsammitic paragneisses*

Monazite in biotitic paragneisses is relatively abundant mineral, often containing according the results of dating at least two separate populations. In paragneiss sample LHS-255 two temporal groups of monazite occur. Older group correpsonds to boundary of Silurian / Devonian (410 Ma) and probable can be correlated with the period of filling sedimentary basin with clastic material. Age **380–370 Ma** is significantly more distinct and probable relates with collision and metamorphic overprint in Upper Devonian. Following thermal metamorphism of Lower Carboniferous age was only indistinctly reflected by the origin of new generation of monazite (Plt 2-1).

### 3 Lithotectonic unit consisting of orthogneisses complex (granite protolith CdD2 with tectonometamorphic overprint in VmD1c and VmD2)

***Biotite, quartz-plagioclase (± K-feldspar ± muscovite), foliated and lineated orthogneisses (111)***

Quartz-, plagioclase-biotite orthogneisses with variable content of interstitial K-felddspar and muscovite crop out mainly in separate, distinctly limited zone with sharp contact with neighbouring biotite paragneisses. Main body of E–W direction is situated south of Valaská Belá village approximately W of the elevation point Capárka (924 m) through Okrúhly vrch (914 m) towards the confluence of the streams Jasenina and Nitrica (area at the crossing at the Motorest Klin). In this area the body of orthogneisses is areally reduced, which is caused by deeper erosion cut with higher degree of granitization, connected probable with the contribution of shear heat. This fact indicates the upper structural position of the body within Variscan tectonic setting (profile 1–2 in published geological map) in the footwall with the paragneiss complex. In this zone we interpret this position as fan structure, wedging into the deeper parts. Further this body follows in E–W to ENE direction towards the area of fault west of Temešská skala hill. Here it is intruded by younger leucogranites and biotite I-type granodiorites (106).

In the past, this lithology was considered as migmatites. However, the processes of migmatization in the rock are completely absent and are limited only to narrow zones, even in the deeper parts of the fan-shaped structure.

These are monotonous banded rocks, where quartz-feldspar bands alternate with biotite bands a few mm thick. The content of biotite and plagioclase slightly varies. The presence of spindle-shaped plagioclase is typical. The metamorphic foliations are steep, mainly in the E–W direction, with lineations mainly of biotite glomeroblasts

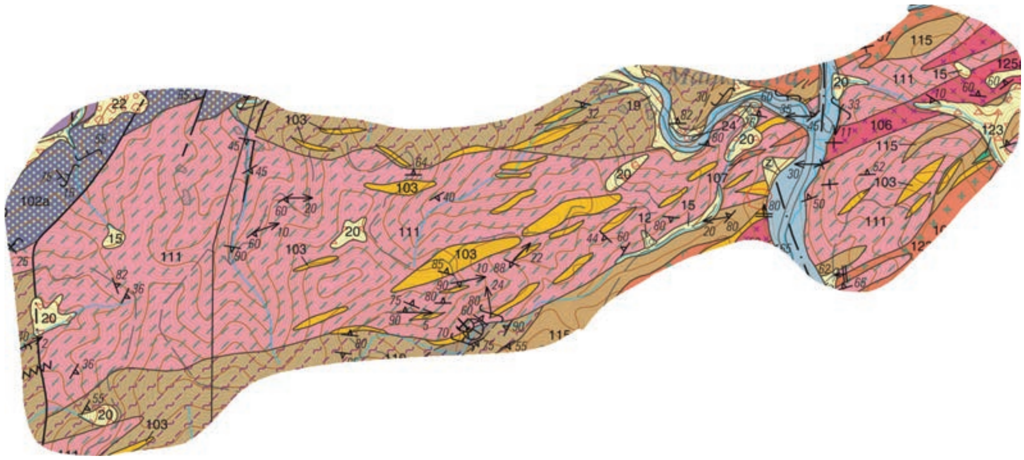


**Fig. 23.** Complex of orthogneisses (111) forms supreme structural level of pre-granite setting, which represents shallow deposited structural fan. Manifestations of a limited degree of partial melting occur only in its root part in the Nitrica river cuts, probably with the contribution of shear heat near the contact with the paragneiss complex.

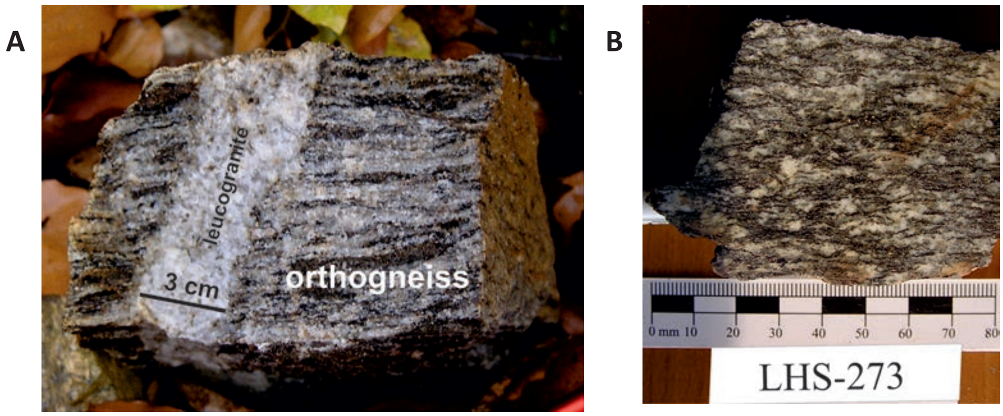
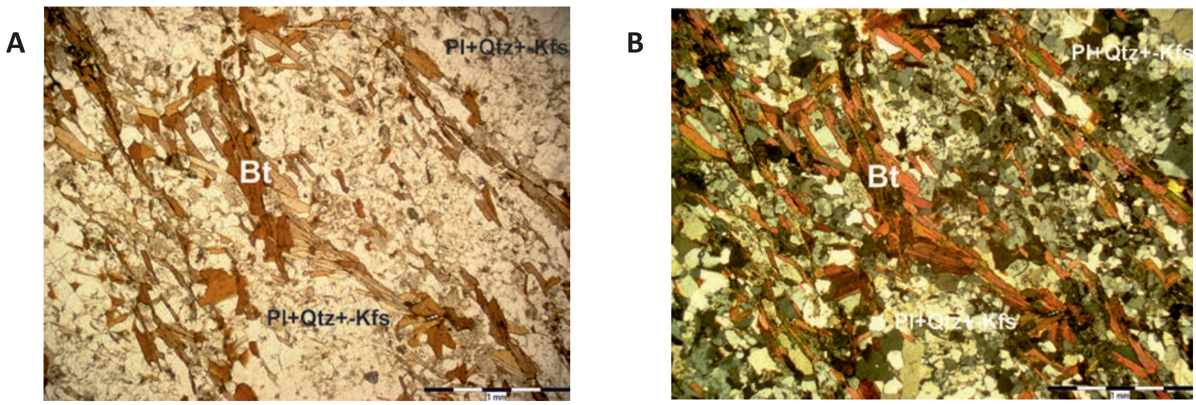



**Fig. 24**. A – Banded orthogneiss with transversal vein of leucocratic granite (sample LHS-207); B – ductile deformed relics of plagioclases in orthogneiss (sample LHS-273).



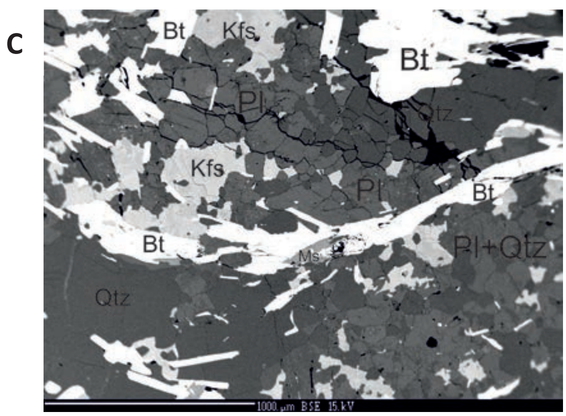




**Fig. 25.** Orthogneiss with plane-parallel setting, formed of chestnut-brown Bt (sample LHS-272). In Qtz-feldspar matrix moderately prevails Qtz over Pl and K-feldspar. The Ap and Zrn are frequent as accessory minerals, Mnz is present, too. The porphyroblasts in the rock occur in the form of quartz, plagioclase and Kfs aggregates.
Microphoto: A, B – N//, N*X*, C – BSEI of the orthogneiss structure.

of a subhorizontal direction, which contrast with the light quartz-feldspar mass. The position of orthogneisses during granitization processes was more external (higher), which is indicated by only very rare ductile deformations of orthogneisses associated with the presence of leucocratic melts. The aplite and pegmatite veins present in them are usually oriented at a high angle to the foliation of the orthogneisses.

The dominating foliation features indicate the presence of ductile shear folds with steep fold planes, shallow fold axes, and shallow lineations accentuated by elongation of biotite glomeroblasts. The pre-deformation origin of orthogneisses is not clear. Unlike the lighter, fine-grained paragneisses, the rock lacks graphitic pigment, which shifts our opinion to the assumption that it is an acidic, originally magmatic rock of granitic to granodiorite composition.

*Monazite chemical dating*

Chemical dating of monazite from orthogneiss (sample LHS-711) indicates an average age of 360 Ma, which, however, does not correspond to a real geological event. Dividing the data into two distinct peaks – into two separate events, where we interpret the older event (**400–380 Ma**) as the age of metamorphic event. The second significant maximum is the age of **355–345 Ma**, which corresponds to a younger thermal event associated with the formation of granitoids in the Strážovské vrchy area (Plt 2-2).

***Migmatites with prevalence of stromatitic, loc. ptygmatitic textures (117a)***

Migmatites form the lowest structural level of the crystalline massif from the point of view of the Variscan (pre-granite) setting. They emerge in the SE edge of the Suchý massif (so-called Liešťany migmatites). Pre-granitization, or syngranitizing fold planes and elements of metamorphic foliation have a steep to subvertical course in the NNE–SSW to NE-SW direction. The axes of the folds are predominantly subhorizontal.

In *stromatitic migmatites* there varies the content of the light quartz-feldspar component representing the neosome relative to the relict part, locally enriched with minerals rich in Fe and Mg (melanosome). The content of light and dark components varies from types with a predominance of the light component to the dark component in a ratio of approximately 70 : 30, to types with a slight predominance of the dark component over quartz-feldspar component. It points more to the variability of the composition of the substrate than to the intensity of the anatectic process. Smaller volumes of migmatized paragneisses are also present, where, in addition to granitoid injections, more or less numerous ptygmatitic granitoid melts appear.

**Fig. 26.** Ductile deformed migmatites with equal representation of light and dark component. Right beneath the hammer the boudins of quartz-feldspar pegmatite-type melt are visible (sample LHS-131 – the Krstenica valley).
Structure of the rock is grano-lepidoblastic to lepidoblastic with dominating plagioclase, biotite, K-feldspar, muscovite and sillimanite.

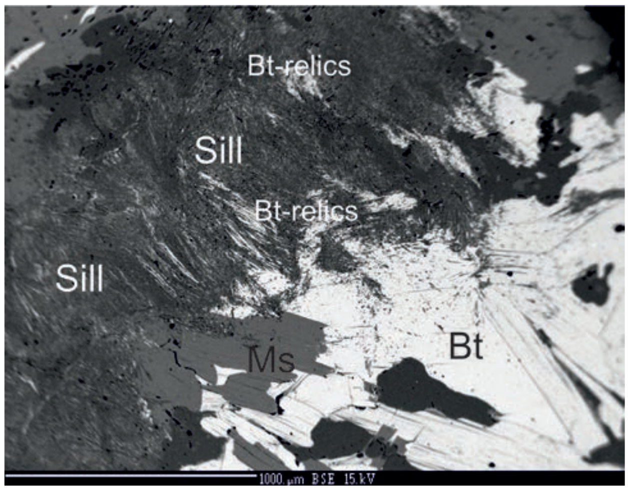



**Fig. 27.** Mineral association of melanosome from migmatite is formed by prevailing biotite, associated with Ms, Qtz and Pl, replaced Bt and Ms by sillimanite in the left side of the picture (sample LHS-137), BSEI.

In the Suchý massif, a strip of migmatites is adjacent from the western side to lighter schliered (hybrid) granodiorites (110), which represent an overlying complex to the migmatites. Although the contact is relatively sharp, larger migmatite septa are found parallel to the foliation elements in the migmatites and parallel to the inhomogeneities – schliers in granodiorite. Among the migmatites and hybrid granodiorites, amphibolite bodies that have undergone granitization occur. From a lithological point of view, this type of migmatites may correspond to the original composition of the orthogneiss material.

The composition of large flakes of biotite, characterized by a stable composition with Mg# = 0.38–0.40, is close to the composition of muscovite with Mg# = 0.43, which points to equilibrium conditions of association. Ms is often very intensively replaced by sillimanite by the reaction Ms + Qtz to form a melt, resp. Bt + Qtz to form a K-feldspar-rich melt (outside of the presented thin sections). Putiš (1976) reports the volume composition of mineral components from the more isotropic type of migmatite SW from Temeš village – quartz (19.2 vol. %), plagioclase-oligoclase (27.9 %), orthoclase-microcline (19.4 %), biotite (18.1 %), muscovite (2.5 %) and sillimanite (12.4 %).

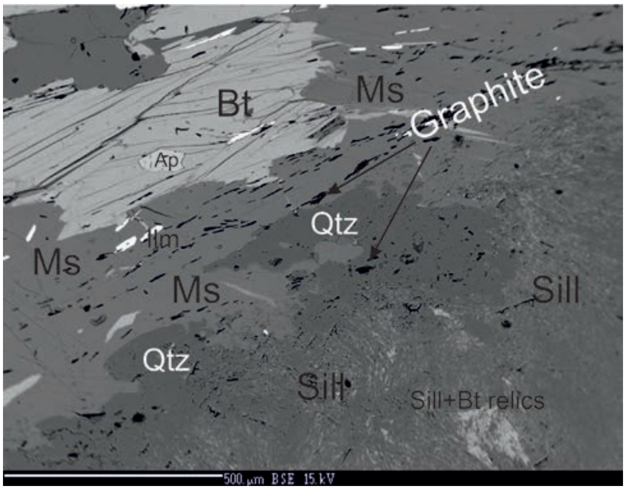



**Fig. 28.** Association Ms + Bt melanosome (apatite inclusion). Black subparallel flakes of graphite enclosed mainly in Ms. Subparalel arrangement of grafite flakes shows that this part represents former metamorphic assemblage. Chaotic arrangement of graphite right down points on flow arrangement due to melting of former consumed Bt (light relic right down). Ilmenite with content up to 5.61 wt.% of MnO crops as accessoric mineral together with plagioclase with $An_{18}$. Ilmenite and graphite are oriented parallel to metamorphic foliation surfaces (sample LHS-137). BSEI.

## Late Devonian-Mississippian granitoids (VmD2)

In the Suchý massif there is possible to distinguish several granitoid suites, which are close in time, but intruded at specific crustal conditions in decompression regime. In lower part of metamorphic packet there intruded the schliered granodiorites representing less mobile magma, which is proved by inhomogeneities parallel with those developed in migmatites. In shallower crustal conditions the transtension shearing applied with intrusions of S-type prevailingly two-mica granites (connected with distinct presence of transtension pegmatite intrusions), up to intrusions of I-type granodiorites, or even small diorite bodies.

### *Massive to weakly oriented hybrid granodiorites with common schliers and xenoliths of paragneisses and migmatites (110)*

Schliered granodiorites emerge to the west of the migmatite zone and their mutual relationship is relatively sharp, but blocks of underlying migmatites can be found quite commonly along the contact zone, about a few 100 m from the mapped border with migmatites. The contact is highlighted in places by smaller or larger bodies of amphibolites. The higher part of the complex is dominated by bodies of migmatized paragneisses and biotitic to two-mica paragneisses. These granitoids crop out in the zone of NNW direction from the Bystrica valley W of Rudnianska Lehota, where they alternate with migmatized paragneisses (116), through the localities Háj – Predné lazy – Prostredná dolina – Obory nad dolinou Krstenica (Liešťanská dolina valley) – Mihálová (where they are in contact with omnidirectional younger biotite granodiorite) – towards Nitrica and in the E this zone ends on fault zone of N–S direction.

The preferred orientation of foliation of NNE–SSW direction in migmatite and paragneisses blocks is identical

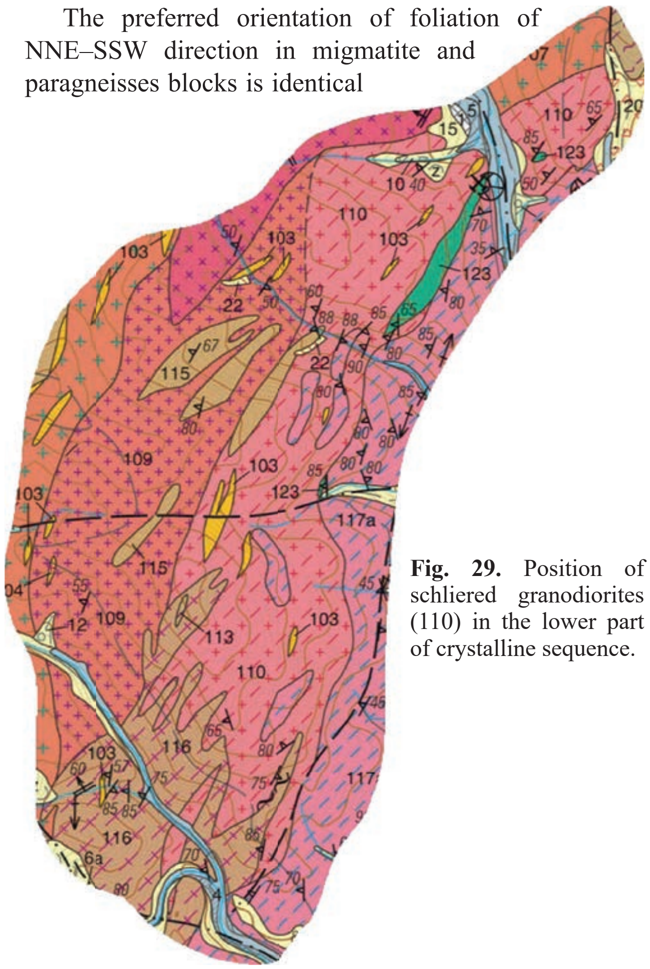



**Fig. 29.** Position of schliered granodiorites (110) in the lower part of crystalline sequence.

and corresponds with preferred orientation of dark biotite schliers in granodiorites.

Granodiorites represent medium-grained granitoids, where the quartz-feldspar component is more or less omnidirectional and the inhomogeneities are formed by biotite schliers, gneiss and migmatites xenolits, which setting indicates preferred orientation. However, there are also present varieties with a low content of inhomogeneities and omnidirectional biotite.

Xenoliths of paragneisses and migmatites range in size from a few cm to hundreds of meters in places. The composition of granitoid rocks varies from tonalite to granodiorite.

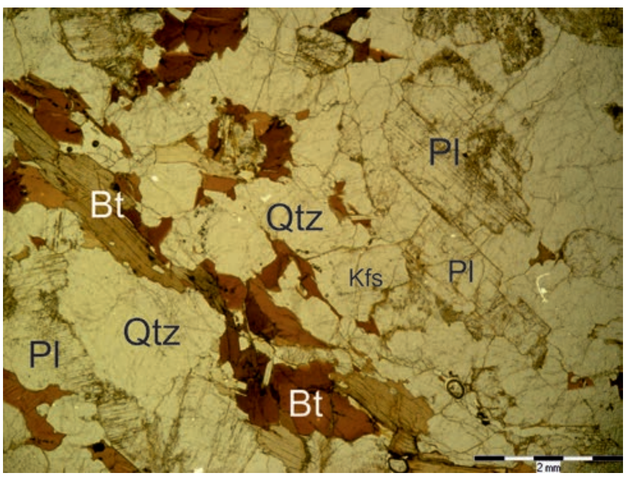
Schliered biotite granodiorite–tonalite (sample LHS-177-2) contains moderately zonal plagioclases of composition $An_{24–28}$ and biotite with Mg # = 0.41–0.44. Rare Ms developed in the structure later, which is indicated by different Mg # = 0.52. Zircon, monazite, apatite and ilmenite are rare present as accessoric minerals.

**Fig. 30. A** – Schliered granodiorite with xenoliths of migmatized paragneisses and oriented biotite.

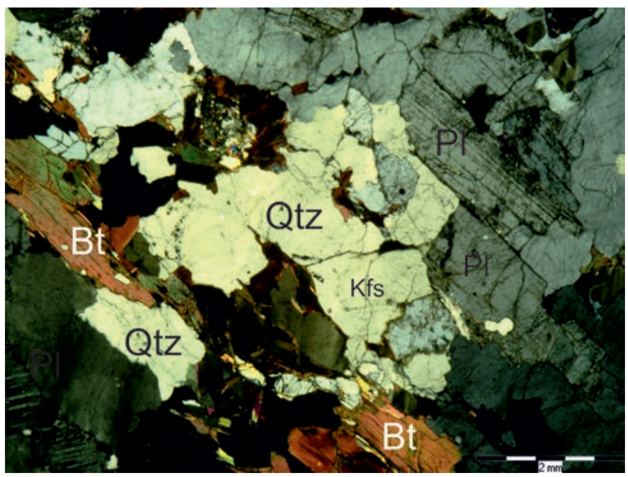
Mnz dating based on 27 values gave a fairly uniform distribution, where the age **348 ± 4.3 Ma** (sample LHS-177-2, Plt 2-3) can be considered as an age close to the thermal event that led to the emergence of melting rock and subsequent crystallization.

Schliered granodiorites represented the less mobile crystal slurry, which is associated with the underlying migmatites and was generated by ongoing thermal reworking of the metasediments. The rock is essentially a diatexite, i.e. a rock that has passed through the initial magmatic stage, which is evidenced by the zonality of plagioclase and biotite orientation, the presence of numerous schists, migmatite xenoliths and migmatized paragneisses. The separation of the K-feldspar component is only very limi-

**Fig. 30. B** – A schliered granodiorite with a substantial representation of inhomogeneously distributed components, subparallel, unevenly distributed laths and accumulations of biotite, which represent a redistributed melanosome. In some places, the biotite melanosome forms separate areas of biotite, separated by fuzzy pale stripes: The rock represents a higher degree of melting and mixing of granodiorite leucosome with melanosome in the form of a dense crystal slurry (sample LHS-185).




**A**




**B**

**Fig. 31.** Structure of the schliered granodiorite with oriented Bt laths, xenomorphic to hypidiomorphic weakly zonal Plg. Ms is rare and appears in the structure as late in origin (sample LHS-177-2).

ted and manifests itself in isolated positions parallel to the inhomogeneities in K-feldspar rich grey parts. Despite the rheological properties, the mobility of the crystal slurry can be observed in places, which is manifested by sharp contacts with the migmatites, which appear as septa in these granitoids.

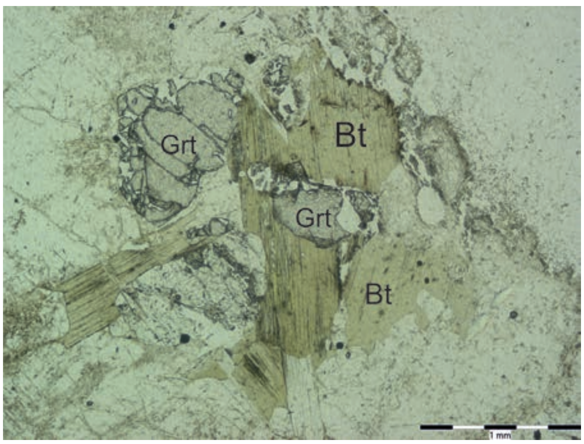
***Biotite or muscovite-biotite granites, locally leucocratic (109)***


**Fig. 32.** The medium-coarse-grained, more leucocratic types of granodiorite rocks with irregular spatially and size-distributed biotite.

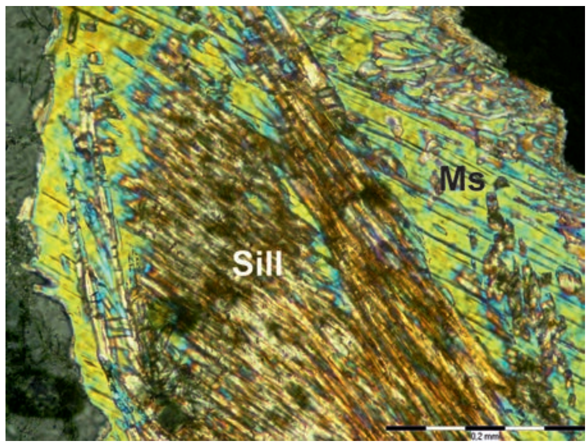
They form a strip emerging west of the rock type No. 110 and are spatially and genetically connected to it. They represent a band of granitoids dominated by more leucocratic types of granodiorites. They have a lower content of dark components.

The rocks have a slightly oriented biotite, which is generally inhomogeneous and size-distributed. But there are also varieties with omnidirectional Bt. The Bt dimensions sometimes exceed 1 cm. The different size and spatial characteristics of Bt indicate that only a small amount of the biotite crystallized from the magmas. They contain significantly fewer xenoliths of paragneisses as well as biotite schists compared to lithotype No. 110.

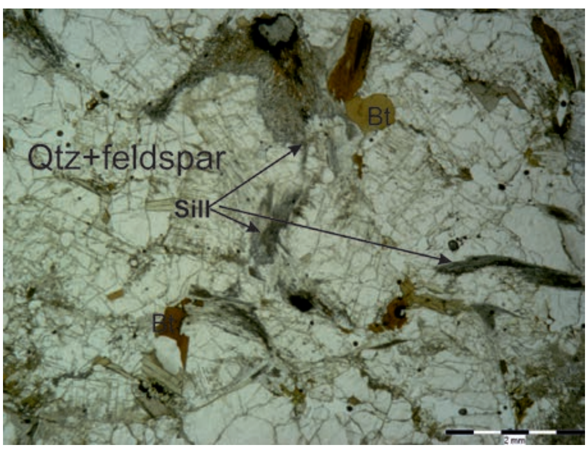
The structure is dominated by plagioclase (up to 7–8 mm in size), which is hypidiomorphic to xenomorphic, usually oriented in the direction of magmatic flow (or flow of crystal slurry), which is simultaneously parallel to the course of isolated schliers. Interstitial Kfs occurs relatively scarce. Rarely, Grt is macroscopically observable together with Bt. Sillimanite was observable only in thin sections. Grt is moderately zonal with a retrograde type of zonality from the center (Alm 74 – Pyr 12.3 – Spess 10.7 – Gross 3.0) towards the margin (Alm 73.1 – Pyr 8.5 – Spess. 15.2 – Gross 3.2). Biotite has a prevalence of Fe – Mg# = 0.38–0.40.




A

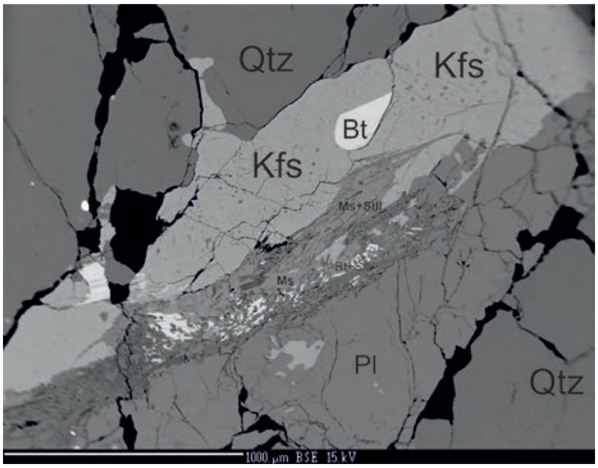



B

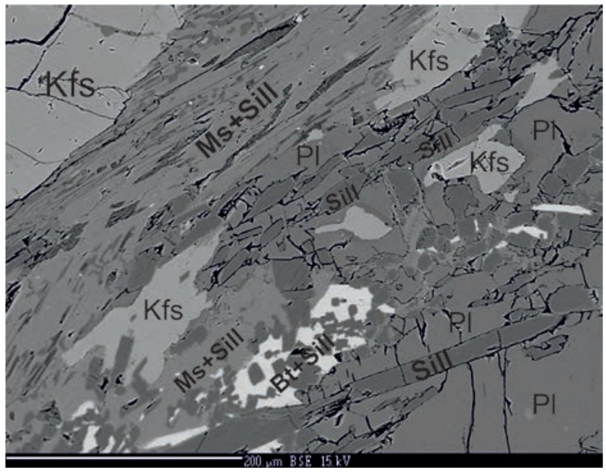



C

**Fig. 33.** Microphoto of the rock type in Fig. 32. A – association Bt–Grt–Ms from the schlier, B – muscovitization of sillimanite, C – association quartz–plagioclase–Bt–Sill (grey tufty objects), Ms. A, C = N//, B = N*X* (sample LHS-94 A).




A




B

**Fig 34.** BSEI of biotite schlier (A – general view, B – detail). Kfs (light grey phase in Fig. B upper left) due to its morphology is a product of the melting reaction of biotite or muscovite to form sillimanite + K-feldspar and garnet. The lightest phase represents a relict of decaying biotite with overgrown sillimanite, and the slightly grey phase represents decaying muscovite with inclusions of euhedral sillimanite (sample LHS-94A).

### *Leucocratic two-mica granites (107, 108)*

This type of granite is dominantly developed in the central zone of the Suchý massif. These subvertical intrusions of NE-SW direction are associated with a process of shear deformation. The importance of this deformation is manifested in the surrounding metasediments by opening of spaces for linear types of intrusions, in connection with their thermal effect. Shear deformation occurred continuously from the suprasolidus to the subsolidus stage, which is consistent with the scenario of decompression emplacement of granitoid intrusions.

### *Leucocratic syn-intrusive oriented two-mica granites (108)*

Leucocratic two-mica granites are the most widespread type in the Suchý massif, building mainly its central part. They are spatially connected dominantly with paragneisses (115), into which they intensively penetrate. However, they also form separate stocks and linearly oriented stocks, preferably trending NE–SW. From the point of view of the Variscan setting, they represent the upper part of a complex intrusive body, while the content of muscovite in the granitoids increases in the direction towards the overburden, i.e. to the NW. From the point of view of the genesis of pegmatites, it can be stated that only in these leucocratic granites there can be observed gradual transitions from zonal bodies formed at the margins by aplite and in the central part by pegmatites with an albite fine-grained zone and by blocky grey K-feldspar, quartz with occasional muscovite and biotite. Ms appears in the texture as primary, but also as later one, which is evidenced by the growth of Ms at the expense of sillimanite.

The majority of pegmatites can be associated with leucogranites of this type, where in the contraction zones they formed at a steep angle to the linear flow of leucogranite magma, cracks were formed in the high-temperature regime, being filled with pegmatite melt together with enrichment with a fluid component. The course of the pegmatite veins is dominantly N–S with variations the NNW or NNE direction.

The flow structure resulting from the magmatic flow direction is finally reflected from the early stages of crystallization up to the subsolid stage. It corresponds to the decompression stage of magma emplacement as well as the entire crystalline complex. The emplacement of these leucogranites took place partly even in the subsolid regime, while the foliated types of leucogranitoids were formed, which can be found in the footwall of injected gneiss complex (115) in the source area of the Krstenica stream (Liešťanská dolina valley). At the same time, the dynamic placement of leucogranites leads in the adjacent gneiss lithologies to the origin of preferred orientation, rotation of the former blasts of regional-metamorphic minerals (e.g. sillimanite, staurolite), the formation of larger lineated blasts of biotite of the second generation (Bt2).

The leucogranites are mostly medium-grained, with a small content of Bt. Their texture varies from omnidirectional to that with preferred orientation of newly formed minerals (lineated Bt), but also planar foliated. The structure is hypidiomophically granular. Rocks have a multi-stage crystallization history of rock-forming components.

Based on microprobe analyses, the plagioclase composition ranges from $An_2$ to $An_{17}$, K-feldspar – with max.

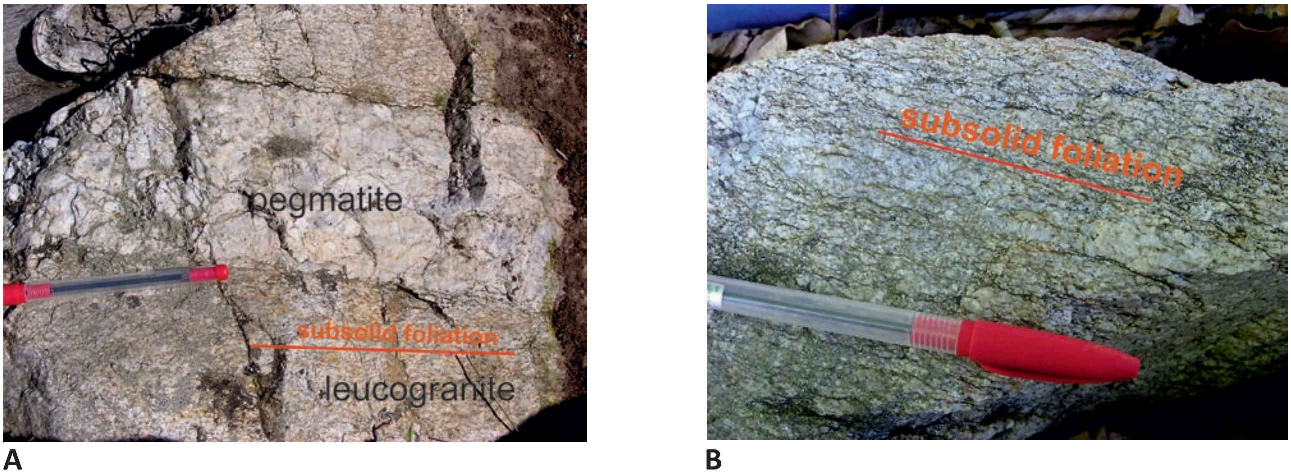



**Fig. 35.** Different types of planar oriented leucogranites: A – Planar oriented two-mica granite in the subsolid stage, with a pegmatite vein without deformation (sample LHS-626). B – Planar oriented two-mica granite with developed subsolid quartz bands (sample LHS-623).

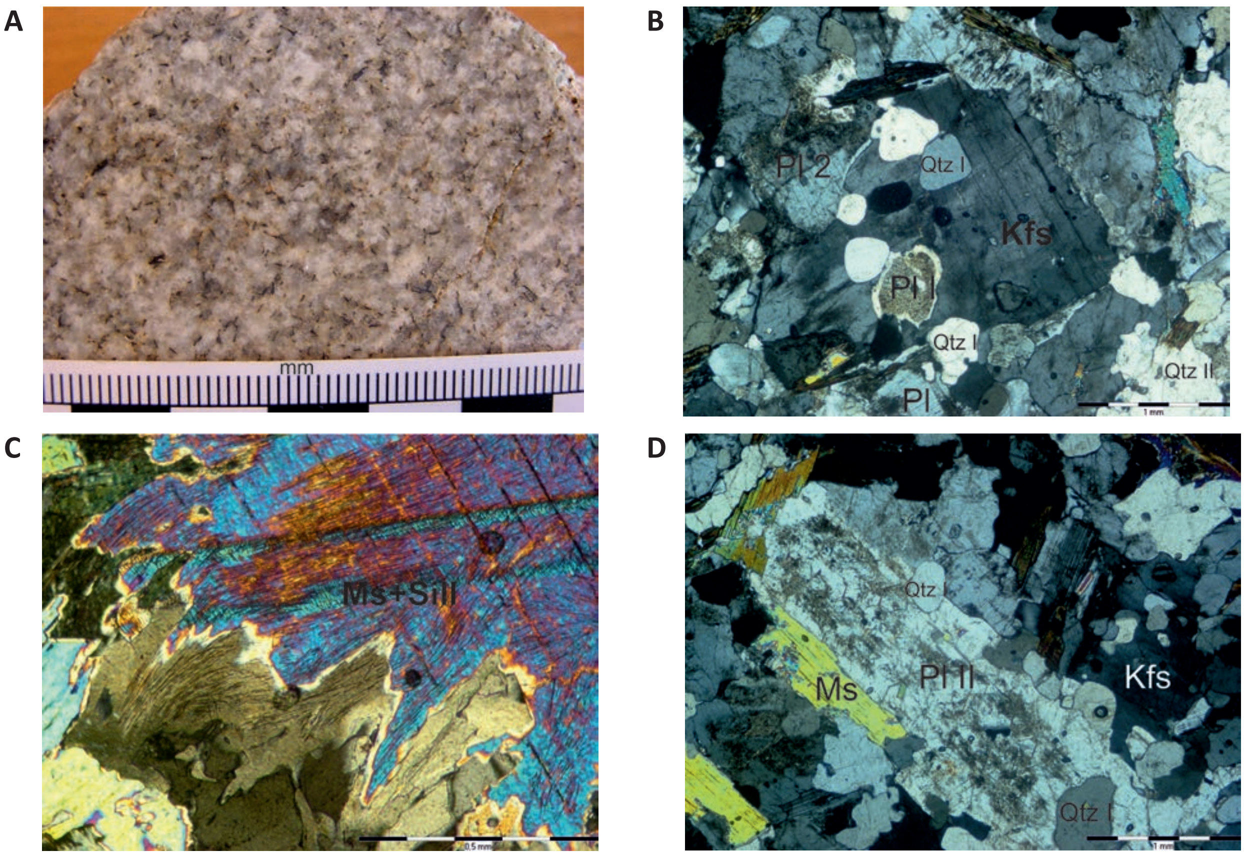



**Fig. 36.** A stock of muscovite-biotite granite that intruded into biotite paragneisses (sample taken about 100 m from the contact with them). The granite is fine- / coarse-grained leucocratic, sometimes containing Grt. Pegmatitoid granite with Grt is also common. Omnidirectional leucogranite has a predominance of Ms over Bt. It contains a microcline that poikilitically encloses oval Qtz I and Pl I (up to 0.2 mm in size; Fig. B). Fibrolitic sillimanites are present, being replaced by large flakes of Ms. But there is also present longer prismatic Na-richer Pl, which has a Ms shell in the vicinity without fibrolite. Pl encloses the oval Qtz I, which, due to the high content of Si in the melt, crystallized among the first minerals. Pl is composed of albite to Na-oligoclase ($X_{An}$ = 3–16) not revealed in the thin section, tiny pink Grt is macroscopically rarely present. The average grain size of the rock is 1–2 mm. A – texture of two-mica granite, where K-feldspar encloses Pl and Qtz of the 1st generation; B – An omnidirectional microcline closing Qtz I and Pl I; C – Fibrolitic sillimanite replaced by muscovite. D – Long-prismatic Pl, rimmed with Ms flakes, partially closing Otz I. *NX* (sample LHS-73).

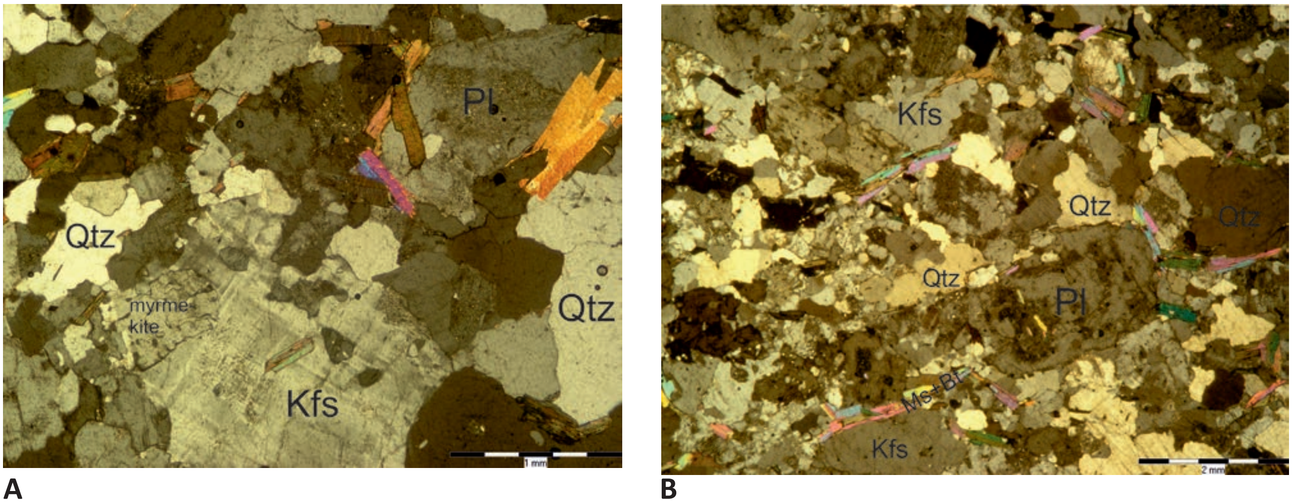



**Fig. 37.** Muscovite-biotite (Ms : Bt ratio about 1 : 3) equigranular omnidirectional granite. Bt and Ms, as well as Pl ± Qtz have weak preferred orientation, while the small Qtz and Kfs grains are without preferred orientation – omnidirectional. The myrmekites are developed in places among Kfs and sodic Pl. This indicates synintrusive deformation due to the flow direction. The average grain size of the Qtz-feldspar porphyroclasts is 1–2 mm, the average size of Ms flakes is up to 0.5 mm and Bt up to 0.1x0.4 mm (sample LHS-200).

content of albite component – 10 vol. %. Muscovite has content $TiO_2$ 0.15–0.75, which points to the fact that it probably did not crystallize within the magmatic stage, but is younger and partly formed at the expense of sillimanite and biotite. The rarely present garnet is rich in almandine component (Alm – 78, Pyr – 8.7–10.3, Spess – 9.2–11.5, Gross – 2.3–2.4). The Mg content of biotite is low – M # = 0.31–0.39, muscovite – 0.40–0.47. Content of $TiO_2$ in biotite varies from 2.2 to 3 wt. %.

### *Leucocratic omnidirectional to weakly oriented two-mica granites (107)*

They occur together with the previous type of more syndeformation oriented granitoids. Similar to the previous type of leucogranites, the deformation is caused by the magmatic flow, concordantly with the shear deformation in the surrounding metamorphites.

Dating of monazite from two-mica granites indicates a relatively narrow intrusive age range of **352–351 Ma** (sample LHS-73, Plt 2-4; sample LHS-482B, Plt 3-1 and sample LHS-482A1, Plt 3-2), which can be considered as the age of maximum granite forming process (intrusive phase in the shear regime). At the same time, the mentioned granites are characterized by the rapid dynamics of crystallization of mineral components. If the initial phases (crystallization of mainly plagioclase and coexisting micas) are oriented in the magmatic flow, the final phases are already more or less omnidirectional. However, already rheologically solidified rocks are still further deformed with the origin of planar structures in places (Fig. 35).

The whole process is thus related with the ongoing deformation of the rock complex and at the same time the decompression of the entire set of metamorphic and igneous rocks (rapid ascent to higher levels of the crust). Residual melts of aplites and pegmatites, associated with this complex, are bound to ongoing deformation in the semiductile to brittle stage of magma solidification and are placed in extensional structures that arise at a large angle to the main component of tectonic stress.

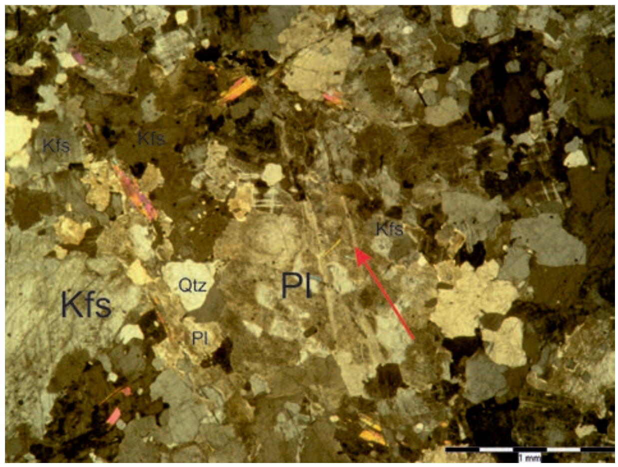
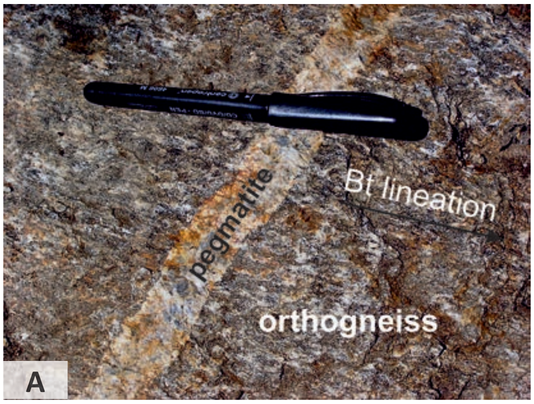



**Fig. 38.** Leucogranite. Manifestation of subsolid deformation in the solid state (zone in the middle of the image – red arrow), which is nearly parallel to the earlier crystallizing Pl (sample LHS-206).

### *Pegmatitic and aplitic veins (103)*

Pegmatites and aplites are genetically related to the development of the shear system and intrusions of two-mica leucogranites. As a rule, they fill transversally oriented semiductile to brittle structures, oriented at a large angle to the main stress component. In the Suchý massif, their course is usually oriented N–S (varying within NNE–NNW).

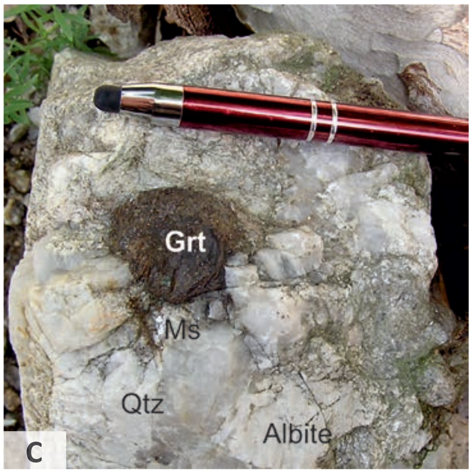
Pegmatites and aplites are genetically related, with aplites forming the external part of a complex pegmatite-aplite system. The marginal, aplite part is made up of fine-grained “sugary” aplite, whose mineral components, especially quartz and feldspar, are oriented omnidirectional, unlike it is in leucogranites. The macroscopic pink garnet that is often present in the aplite





A – Up to 3 cm thick transversal pegmatite veinlet with grey Kfs, forming tabular body with oblique orientation of ca 75° to course of lineation of biotite glomeroblasts in biotitic orthogneiss (sample LHS-415).

B – Wedging of the Ms pegmatite vein in Al-rich (metapelitic) paragneiss (Stau-Sill), at the time of intrusion the paragneiss was partially plastic (sample LHS-555).





C – Several cm large garnet in coarse-grained quartz-albite part of pegmatite (sample LHS-599).

D – Omnidirectional “sugar” aplite with small pink Grt on the edge of the Ms pegmatite (sample LHS-572).


E – Partially weathered pegmatite, where prominent blocks of grey K-feldspars are chaotically arranged in quartz-albite fine-grained mass. The texture is a result of subsolid (pneumatolytic?) fracturing (sample LHS-611).

**Fig. 39.** Typical present surface position of pegmatite and aplite bodies.

structure is striking, and can range from mm to several cm in size. Although the aplites crystallized together with the pegmatites as a final stage, some preferred orientation caused by magmatic flow in a dynamic environment is evident from the occasional linear arrangement of garnet phenocrysts (Fig. 39D). Pegmatites are coarse-grained and formed from the edge by a less coarse-grained zone with a predominance of albite feldspar, while inside they are formed by blocky quartz and grey K-feldspar, which sometimes reaches several dm to m in size (Fig. 39E). As a rule, pegmatites contain little mica, but there are varieties with large-scale Ms and, in places, Bt, which is preferably bound to the marginal part of the pegmatite bodies. The relation to the metamorphic rocks and older granitoids is sharp, and the aplite and pegmatite bodies occur in the form of sharply bounded tabular bodies. The only exception is the relationship to two-mica leucogranites, where in some places indistinct transitions from leucogranite and aplite to pegmatite are observable. This fact points to the genetic relationship of these lithologies.

The abundance of aplite and pegmatite veins is highest in the central part of the territory SE and ENE of Suchý vrch hill, while it is mainly linked to leucogranites and the overlying paragneiss complex, which is in contact with leucogranites. Injections of leucogranites and pegmatites – aplites often alternate in the paragneiss complex (115). In the direction to the SE – into the underlying formations, the number of pegmatite and aplite veins decreases, and the same occurs in the direction to the NW and to marginal (upper) parts of the crystalline basement. Pegmatite and aplite bodies are not always complexly developed in the zonality described above. In places, only separate swarms of aplites are present, or only swarms of pegmatites.

Regarding the cartographic visualization in the published geological map (Hraško & Kováčik, eds., 2021; web link available), from the genetic point of view we do not differentiate between pegmatites and aplites. The course of the bodies in the geological map does not always correspond to the actual course of the veins, but represents the concentration of vein swarms in the given area.

According to chemical dating of the monazite, as well as the geological position, these bodies represent younger magmatic stage of the shear emplacement of the granitoid magma – **345–343 Ma** (sample LHS-557, Plt 3-3; sample LHS-607, Plt 3-4).

Aplite garnets are almost non-zonal with high almandine content, in association with Fe-rich Bt with M/MF = 0.35–0.36.

Chemical dating of monazite from two selected aplite samples indicates consistently low ages in the given range of Lower Carboniferous ages. Age **345 ± 2.9 Ma** Ma up to **343 ± 2.9 Ma** can be reliably considered as the conclusion of magmatic processes associated with the shear emplacement of leucogranites and aplite-pegmatites.

**From the S-type highly orogenic granitoid stage (VmD1c) to the I-type late-kinematic granitoids (VmD2)**

A special type of I-type granitoids built mainly the NW edge of the crystalline basement area - to a limited extent in the Suchý massif, but especially the eastern area of the Magura part basement. From the point of view of monazite chemical dating, it was not possible to decide on the temporal relationship of the leucogranite and aplite-pegmatite intrusive stage (**350–345 Ma**), associated with the shear-deformation regime and the intrusion stage of I-type magmas. However, from the point of view of spatial relations, it is clear that I-type intrusions have a late kinematic character in relation to the shear deformation of the complexes.

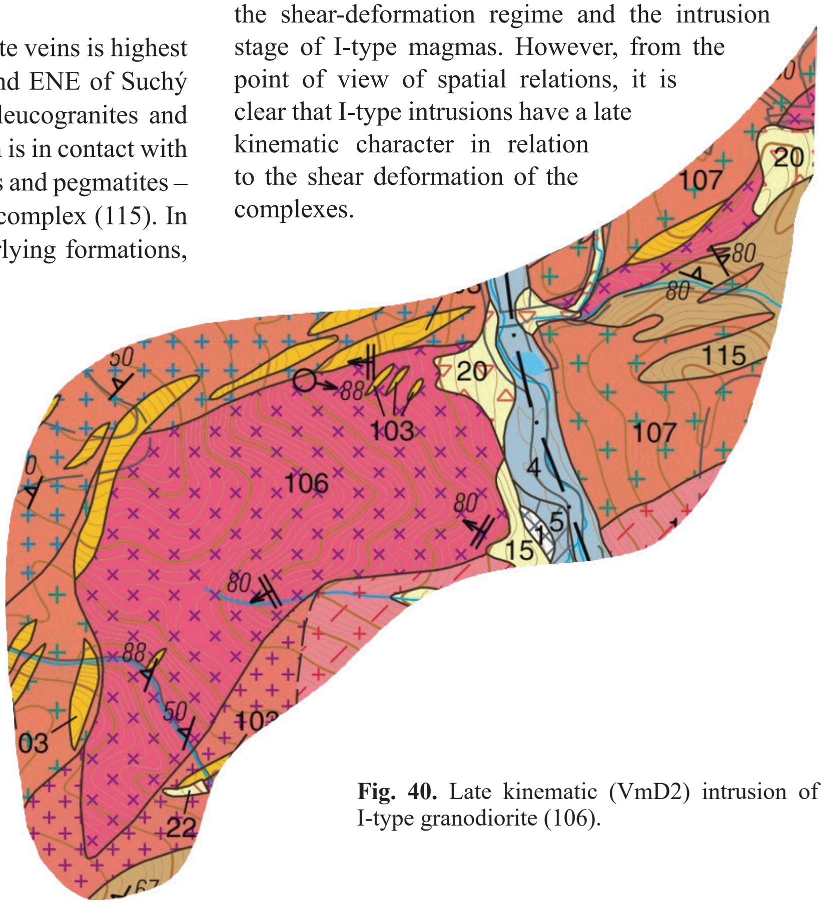



Fig. 40. Late kinematic (VmD2) intrusion of I-type granodiorite (106).

***Biotite granodiorites – tonalites, omnidirectional, only locally weakly oriented (106)***

Biotite granodiorites form several separate bodies of predominantly isometric shape, which points to their later age (VmD2) compared to the shear-deformation events of the Mississippian (VmD1c). They mainly penetrate older structures. Smaller bodies emerge on the E-oriented slope of the Suchý massif, W from Nitrica, and the larger body emerges in the area of Čavoj locality.

Granodiorites are conspicuous by their omnidirectional structure, fresh appearance and the lack, or the complete absence of pegmatite veins. This fact also points to their younger and deeper situated crystallization in the Variscan geological structure of the crystalline basement. In some places, several more mafic "globules" of omnidirectional granodiorites to tonalites can be observed, which interpenetrate each other in the form of loaf-like bodies of different grain sizes (Fig. 41). This indicates a good viscosity and a higher temperature of the magma.

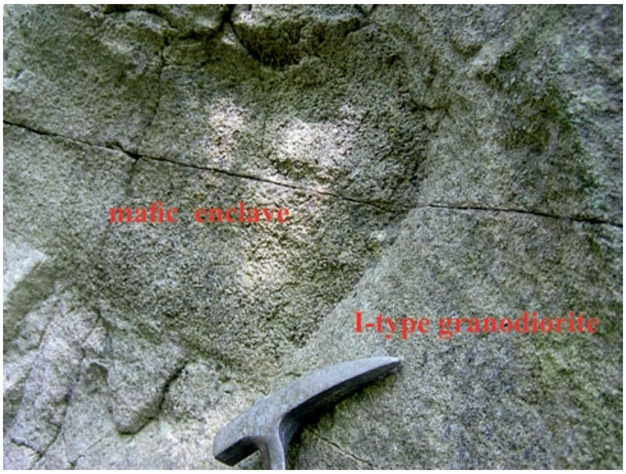



**Fig. 41.** Biotite granodiorites – tonalites – mixing of two types – block of more mafic part rich in plagioclase and the biotite rich part (above hammer) in more quartzy coarser-grained rock.

The Pl (up to about 50 %) rich granodiorite, which is also rich in Bt (up to 20 %), in some places may represent portions of more mafic magma in a lighter type (Fig. 41). Plagioclases usually 1 mm (rarely 2 mm) large are idiomorphic to hypidiomorphic, the intergranular spaces are filled mainly with Bt and Qtz.

Hypidiomorphic plagioclase is zonal, oriented in all directions, without inclusions, only in the final phase it crystallized together with quartz. Biotite with a content of 15 to 20 vol. % is reddish-brown in colour and appears usually along the edge of plagioclase, from the point of view of succession it is later than Pl. As a rule, quartz is interstitial and crystallized last in the succession. Accessory minerals, apatite (Ap) and also monazite (Mnz) are commonly present, which were chemically dated here. Magnetite is also present, which indicates a higher activity of water in the magma, as it points to an oxidation regime in the magma, which was a consequence of the dissociation of water vapor in the magmatic reservoir.


**Fig. 42.** Fine-grained omnidirectional, grey biotite-rich microgranodiorite-microtonalite, as one part of the biotite granodiorite-tonalite body (sample LHS-122 – Krstenica valley).

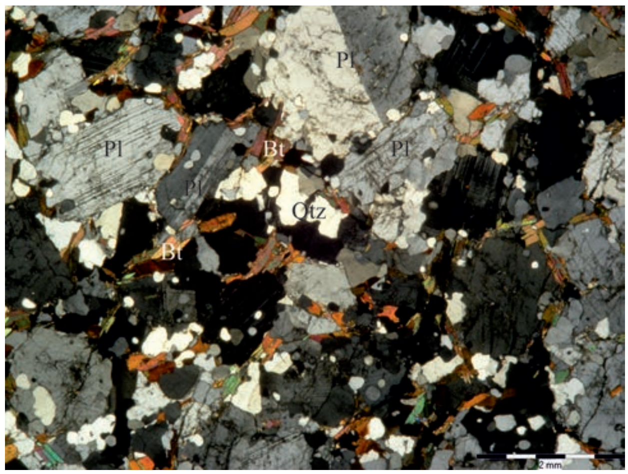



**Fig. 43.** Granite sample LHS-94B. Hypidomorphic plagioclases are zonal, crystallizing first in crystallization succession. Only rarely in their final phase of crystallization the interstitial K-feldspar crystallized. N*X*.

Mineralogy: Plagioclase, K-feldspar, biotite and rare muscovite were studied by microprobe analyser the granite in association with Bt. The composition of plagioclase is $An_{26}$ to $An_{36}$. The content of the albite component in K-feldspar reaches 10 vol. %. The BaO content is around 2.5 wt. %. The magnesium content of biotite (Mg#) varies in a narrow range of 0.51–0.52 and the $TiO_2$ content – 3.4–3.65 wt. %. The Mg content of Ms is around 0.57.

Chemical dating of monazite (Mnz) from a sample of omnidirectional granodiorite (sample LHS-94B, Plt 4-1) provided an age of **355 ± 5.5 Ma**, with the statistical distribution of the set points to one, homogeneous population of monazite.

***Coarse-grained amphibole diorite (125a)***

Such coarse-grained, to medium-grained omnidirectional, to weakly oriented amphibole-plagioclase rock was found in the environment of the previous type of omnidirectional granodiorites-tonalites of I-type (sample only in the scree).

The amphiboles correspond to the composition of magnesiohornblende, the plagioclase that fills the spaces between the amphiboles is of andesine composition. The association of ilmenite and titanomagnetite and then rutile and titanite is common, which indicates the oxidation regime in the magma. Sulfide minerals (pyrite, chalcopyrite?) are present. The stated oxidation conditions correspond to the conditions of magmatic crystallization of the intermediate magma. Therefore, we consider this lithology to be a part of the previous type of granodiorites to tonalites with features close to I-type granitoids, with higher temperature and water-rich magma.

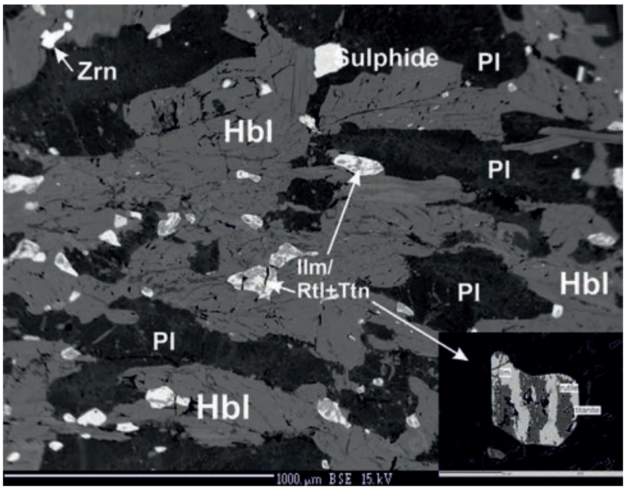



**Fig. 44.** BSEI of sample SZN-304 consisting of phenocrysts of magnesiohornblende and interstitial andesine. Former ilmenite is replaced by rutile and titanite aggregate due to postmagmatic oxidation.

## Discussion and conclusion

***Character of pre-granite lithotectonic units present in crystalline basement of the Suchý massif***

Pre-Alpine crystalline basement is built of variegated Paleozoic rock sequences. Regarding their position and depth in sedimentary basin, where they originated before they were amalgamated by Variscan tectonometamorphism there can be distinguished:

- Paleozoic deep water euxinic facies, formed originally mainly of fine-grained pelitic and psammitic sedimentary facies rich in organic matter, with preserved fragments of accompanying oceanic basic volcanites. At field research these associations are relatively well detectable;
- Proximal sedimentary facies of continental slope of Paleozoic sedimentary basin, represented mainly by flyschoid sandy-greywacke sediments. They contain almost no bodies of basic rocks and pelitic lithologies are very rare;
- The upper part of present Variscan setting is built of orthogneiss complex (less in W part of Magura massif and more extensive in the Suchý massif). During Variscan collision VmD1c and related tectonometamorphic overprint the orthogneiss complex, probable as Cadomian crustal granitoid segment was thrust on two above described rock sequences and later again (in VmD2) metamorphosed together with them (Fig. 45).

*Relations of metamorphic complexes and granitoid intrusions*

Due to the Alpine tectonic rotation of the blocks of crystalline basement and cover Mesozoic sequences, the Suchý massif provides a more comprehensive profile through the basement, indicating an increase of regional overprint from NW to SE. The highest degree of ductile deformation reworking is present in stromatitic migmatites, which typically crop out in the valley of the Krstenica stream (NW from Lieštány municipality), up to the area of Rudnianska Lehota. Biotite dehydration melting processes were also observed here. At the same time, intense granitization processes are present in this SE part, which are getting weaker towards the W–NW. For this reason, there were analysed the p-T metamorphic conditions from the W part of the crystalline basement, with minimum presence of granitization processes. On the other hand, to determine the pressure-temperature conditions due to the influence of intruding granitoids, samples were selected from the area of intense manifestations of granitizing activity.

Regional (orogenic; MVm1c) metamorphism, acting in crustal levels on metamorphosed rocks (presently sampled and investigated from the surface), reached 570–620 °C at pressures of about 6–8 kbar. Conversely, mineral associations of younger, contrasting thermal metamorphism MVm2 indicate the approximate temperatures of 550–600 °C and pressure of 3–4 kbar (p-T calculations of metamorphic events were carried out by R. Demko, ŠGÚDŠ, Slovakia, Tab. 1).

These different p-T conditions indicate a rapid uplift of the complex at the simultaneous intrusion of leucocratic granites in a shear regime of VmD1c. Due to the consistent directional relationship of deformation structures in leucocratic granitoids and surrounding metamorphites (concordant lineations of biotite schliers in leucogranites and thermally induced flakes of biotite II in the surrounding metamorphites), it is obvious that the

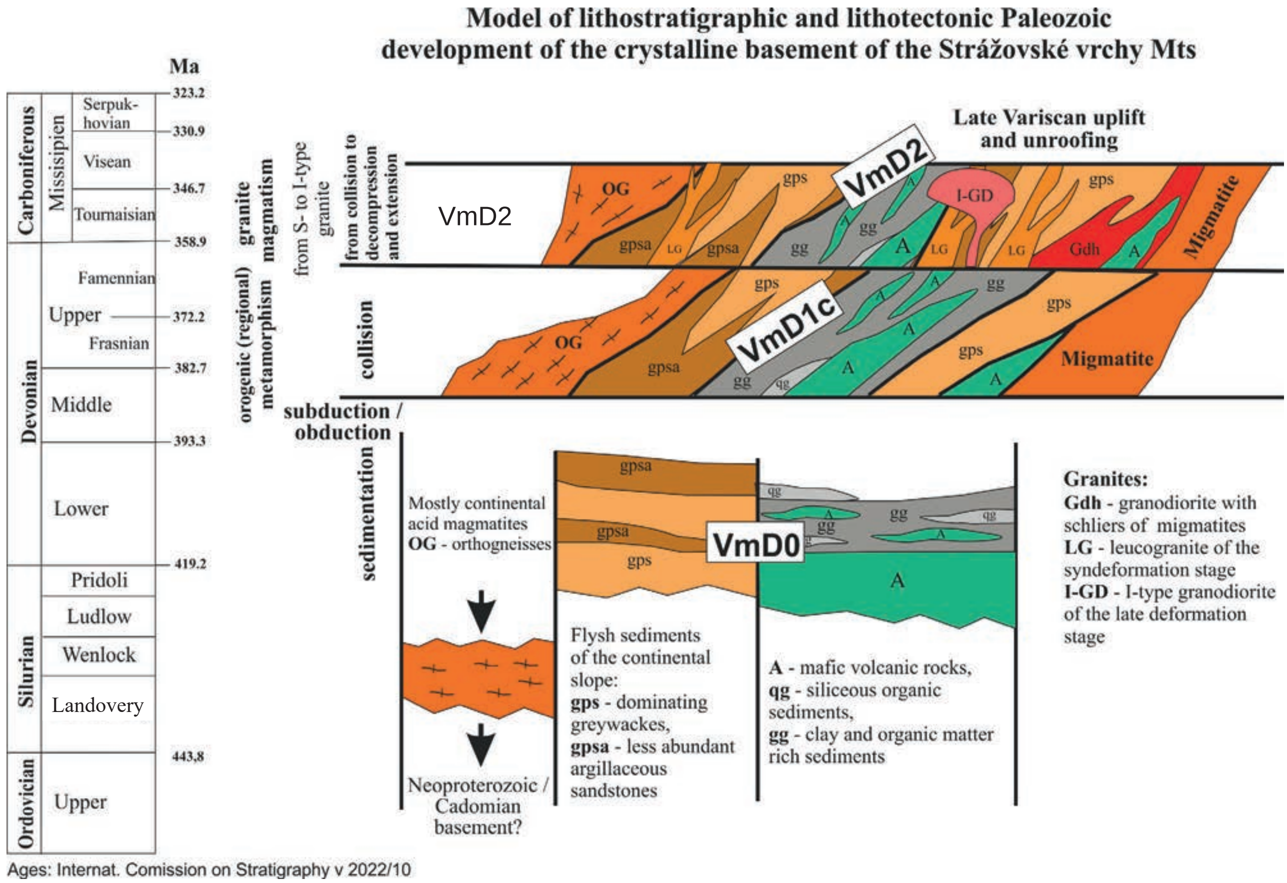



**Fig. 45.** Lithostratigraphic and lithotectonic column with indicated position of protolith in sedimentary basins of various crustal provenience, their following amalgamation at VmD1c collision, metamorphic overprint and syn-kinematic up to late-kinematic (VmD2) granite forming phase. Subsequent post-kinematic unroofing relates with orogenic collapse and ascent of crystalline basement to higher crustal levels (used ages are from actual International chronostratigraphic chart).

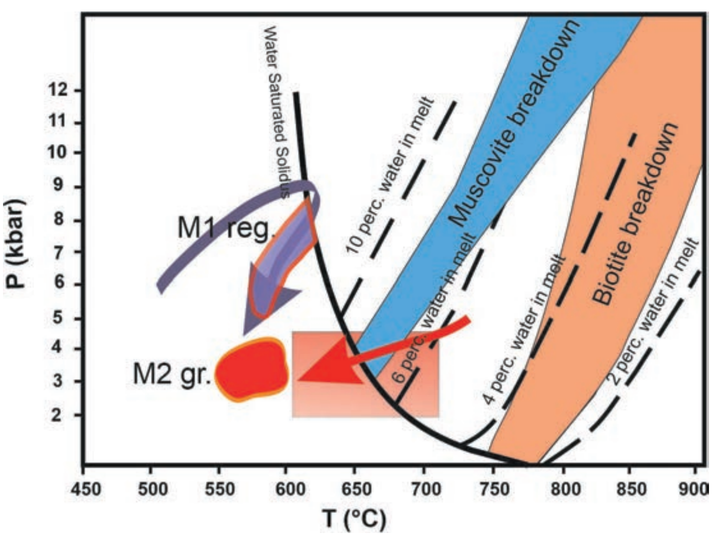



**Fig. 46.** Presentation of conditions of Variscan regional metamorphism (M1 reg., MVm1c) in the upper part of the metamorphic pile (blue arrow). Melting reactions must have taken place mainly with the participation of muscovite melting. However, the speed of the process was not sufficient for more extensive melting and segregation of granitic magma. Granitic magma was generated from deeper parts under the influence of new thermal input (red arrow) and caused (M2 gr., MVm2) thermal metamorphism in higher crustal levels. The pink rectangle shows the near solid placement of the leucocratic magmas. (Fields of water-saturated granitic solid, mica melting fields and amounts of water provided during melting processes in metasediments are according to Vielzeuf & Montel, 1994).

leucocratic granites were emplaced simultaneously with the VmD1c deformation of the metamorphites.

At the same time, it is obvious that the emplacement of leucocratic granites also took place in the subsolid stage, which is manifested in field conditions by the plate disintegration of leucogranites and deformation microstructures. In the subsolid stage, pegmatite bodies were also placed in the same deformation regime. Their composition (lack of water-bearing minerals) as well as textures indicate open structures and leakage of fluids into the higher parts of the metamorphic packet.

**Tab. 1**

Determination of petrogenetic parameters according White et al. (2014) and applying garnet-biotite-plagioclase-quartz thermobarometry (GBPG) after Wu, Chun-Ming et al. (2004)

| Sample | Temperature [°C] | Pressure [kbar] | Comment |
|---|---|---|---|
| M2 (MVm2) induced thermal overprint | | | |
| LHS-204 | 593 ± 10 | 2.9 ± 0.2 | thermal decomposition of muscovite to Kfs |
| LHS-356a | 571 ± 13 | 3.4 ± 0.3 | Bt, Ms, St, Grt (inclusion in St), Pl, Qtz |
| LHS-356b | 578 ± 4 | 3.4 ± 0.1 | |
| SZN-34a | 580 ± 9 | 3.6 ± 0.3 | Grt as inclusion in St, Sill and Kfs (product of high thermal decomposition) |
| LHS-329 | 561 ± 14 | 3.7 ± 0.7 | cellular, poikilitic garnet, towards rim |
| LHS-255 | 585 ± 6 | 4.0 ± 0.2 | enormous thermal blastesis o small Grt crystals |
| SZN-34c | 591 ± 8 | 4.2 ± 0.2 | |
| M1 (MVm1c) regional metamorphism preceeding granitic intrusions | | | |
| LHS-350 | 561 | 5.4 | |
| LHS-329 | 581 ± 5 | 5.6 ± 0.5 | cellular, poikilitic garnet, central part |
| SZN-34b | 582 ± 2 | 6.7 ± 0.1 | |
| SZN-66 | 608 ± 15 | 7.5 ± 0.8 | garnet I, in the centre of garnet II |
| LHS-350 | 569 | 8.5 | |

The temperature of regional metamorphism in the western part of the territory (the Suchý massif) did not generally reach the temperature of partial melting, but the granitization manifestations were mainly caused by the combination of the heat supply of granitoid masses in the peak stage of the syncollision event with simultaneous deformation. In the eastern part of the Strážovské vrchy Mts (Magura massif) crystalline basement, the processes of migmatitization were more distinct, because this part represented a deeper structural segment.

*Deformation and magmatic structures in granitoids and surrounding metamorphites*

The oldest Variscan structures are observable only in a microscale as oriented porphyroblasts of quartz within younger and larger blasts, especially staurolite. The blastesis of staurolite originated in metapelitic assemblages at the peak stage of orogenic (regional) metamorphism MVm1c, before the beginning of a younger deformation event, which caused the origin of the most prominent metamorphic foliation connected with shear deformation, thermal metamorphism under lower pressure conditions, being a reflection of granitoid intrusion in the shear-deformation event.

This younger deformation, which led to the rotation of older blasts together with their inclusions, is macroscopically and microscopically the best structurally defined phenomenon. It led to the formation of steeply (up to subvertically) built structures of metamorphic schist, which were used in parallel syntectonic leucogranite intrusions in extensional regime of unroofing kinematics (**VmD2**) in the time range of **355–345 Ma**. It is supposed that primary foliation was not so steep and their present spatial position was completed by Alpine (Cenozoic) **AnD3** shearing. Dominant structural elements represent metamorphic foliations generally trending NE–SW (with variability in the NNE–SSW to ENE–WSW trend; Fig. 47) with rarely identified fold axes of the same direction and mineral lineations of metamorphic minerals with a shallow orientation on foliation surfaces (Fig. 48). From this, it is possible to infer the shear origin of the fold structures, or to the maximum component of the deformation stress, close to the direction of the fold axes. Based on the dating of monazites in paragneisses and orthogneisses, it can be concluded that the maximum metamorphic overprint of rock complexes was around **380 Ma**, which corresponds to the Middle to Upper Devonian boundary and process above the subduction zone (**VmD1s**).

Shear deformation in the ductile conditions of the amphibolite facies led, depending on the position of the rock complex in the continental crust, to the tectonic separation of leucogranite melt located in fold closures of migmatized paragneisses (Figs. 17 and 18), through the boudinage of leucogranitic bodies situated in fold limbs still in supersolid to subsolid state up to the placement of thin leucogranite interbeds in semiductile flexures (Fig.

18). This indicates the decompresion of the whole complex and gradual change of rheological conditions from ductile, to semiductile up to brittle conditions. Orogenic metamorphism, leading maximally to first manifestations of local melting of metamorphic complexes, was followed by decompression and intrusion of thicker leucogranite volumes in shear regime. Granitoid melts were placed to higher crustal levels in ductile state, which is indicated by structures of magmatic flow, defined by position of dark minerals, but also feldspars. In more extreme conditions along the contact of leucogranite intrusions with metamorphic mantle there occurred also synintrusive deformations of leucogranite, being manifested by origin of higher temperature foliation in conditions close to solidus, but also in subsolidus stage (this phenomenon was observed mainly NE of the Suchý vrch peak). These tectonites were distinguished also in geological map as syntectonic leucogranites with preferred orientation.

The structural analysis indicates that only part of inhomogeneities in granitoids can be derived from relic "pre-granitoid" setting of metamorphites and greater part corresponds to own dynamics of magmatic flow of leucogranites, which is moderately counter-clockwise rotated with respect to older metamorphic foliation (Fig. 49).

Regional metamorphic structures (**VmD1c**) were overprinted by the heat of intruding granite masses (**VmD2, MVm2**). This overprint produced large macroscopically decipherable biotite II porphyroblasts (Bt of 2nd generation), though also these crystallized with preferred orientation due to acting stress field. Thermal effect of close leucogranite intrusions is manifested in microscale by the origin of red-brown biotite and formation of numerous small garnets.

Chemical dating of monazite revealed the age **355–345 Ma** of maximum intrusive activity and calculation of its PT conditions indicates pressure 3–4 kbar (for the stage of syntectonic S-type leucogranites of the age of **352–351 Ma**).

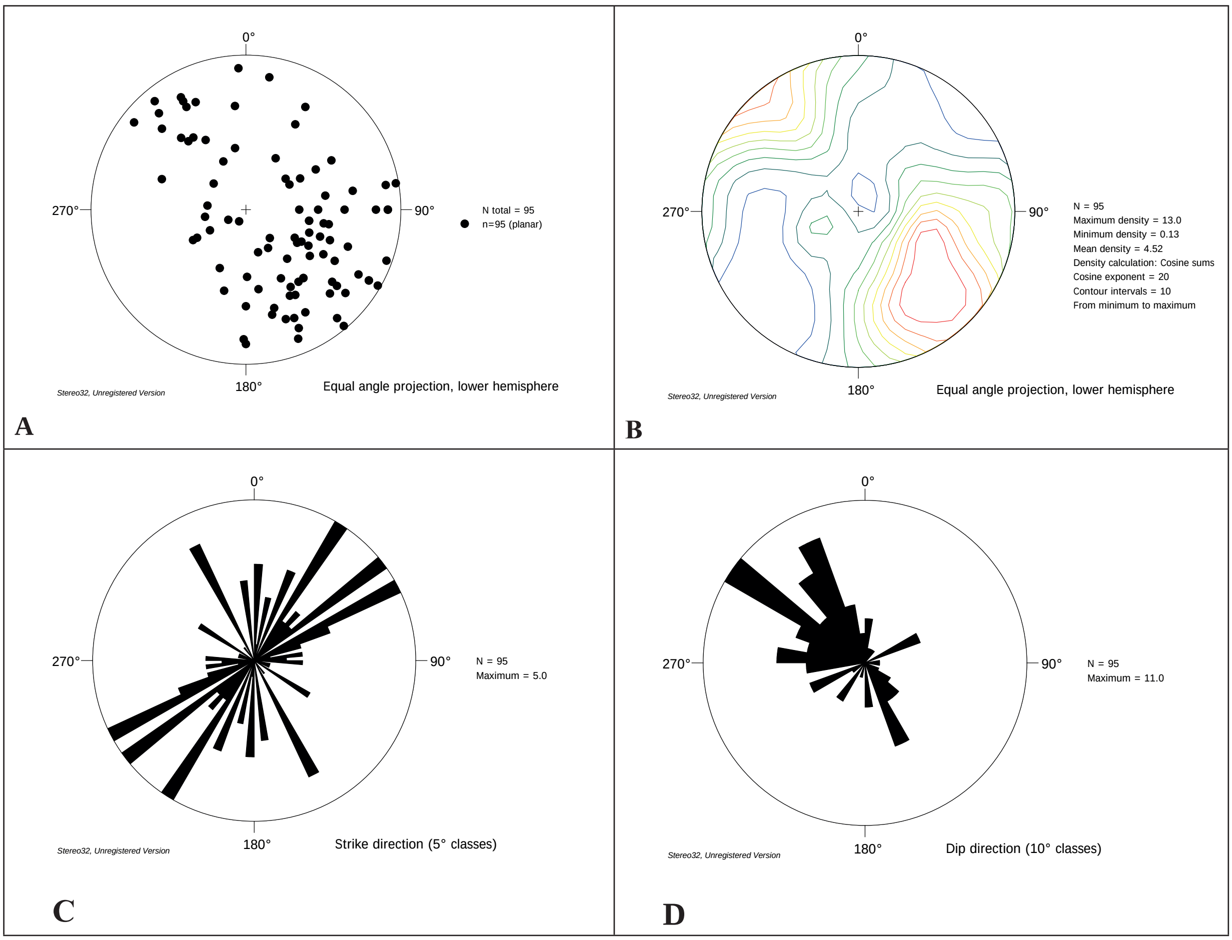



**Fig. 47.** Courses of metamorphic foliation in paragneisses (prevailingly the Suchý massif – 96 measurements): A – poles of planes, B – contourogram of the poles of the planes, C – prevailing trends of planes, D – dips of planes in paragneisses. Dominating foliations have NE–SW trend with steep dip to NW.

The shear emplacement of S-type leucogranite intrusions under decompression regime conditions (**VmD2**) was followed with later opening of deeper crustal structures used by the intrusion of I-type omnidirectional biotitic granodiorites. They contain fine-grained mafic globules (currently not examined further; Fig. 43), corresponding with mafic portions of the magma, as well as rare rocks of (gabro-)dioritic composition (Fig. 44). This type of intrusion has a linear course (**VmD4?**) and crops out oblique to older structures in NE part of Suchý massif. By this way the transition from S-type granite intrusions of exclusively crustal origin to more mafic intrusions of I-type reflects **the increase of thermality of granite melt towards the end of granite magmatism**. It indicates the deeper crustal, resp. subcrustal genesis of later magmatic melts by adding additional heat from the hot line. Such time succession, where the I-type granitoid intrusions in short time sequence followed after previous S-type granites was already demonstrated in granitoids of the Malé Karpaty Mts (Kohút et al., 2009).

In our work we used U-Th-Pb chemical dating of monazite, applying methodology by Konečný et al. (2018), which after statistic processing of its results can provide results close to zircon dating. It is valid especially at rapidly cooling magmatic systems without additional influence on the Mnz crystals by the fluid regime. With respect to proved Meso-Variscan decompression in the crystalline basement of the Suchý massif it is probable that Mnz dating provided data close to real intrusive age of granites. It is valid mainly for leucogranites, connected with the phase of their rapid shear emplacement (**352–351 Ma**) and formation of pegmatite veins, finishing magmatic regime of VmD1c phase (**343–345 Ma**; Tournaisian / Visean boundary).

At I-type granodiorites, which finish magmatic process from geological and structural viewpoints, their generation age is probable influenced by the presence of older monazites, reflecting the mixed origin of the monazite crystals.

The group of S-type granitoids, indicating the contamination with surrounding paragneisses, the mixed origin of monazites, reflects the age of intrusion as well as the age of formation of older monazites, analogical with those in paragneisses – which probable reflect the age of orogenic (regional) metamorfic process and in smaller scale also the age of protolith.

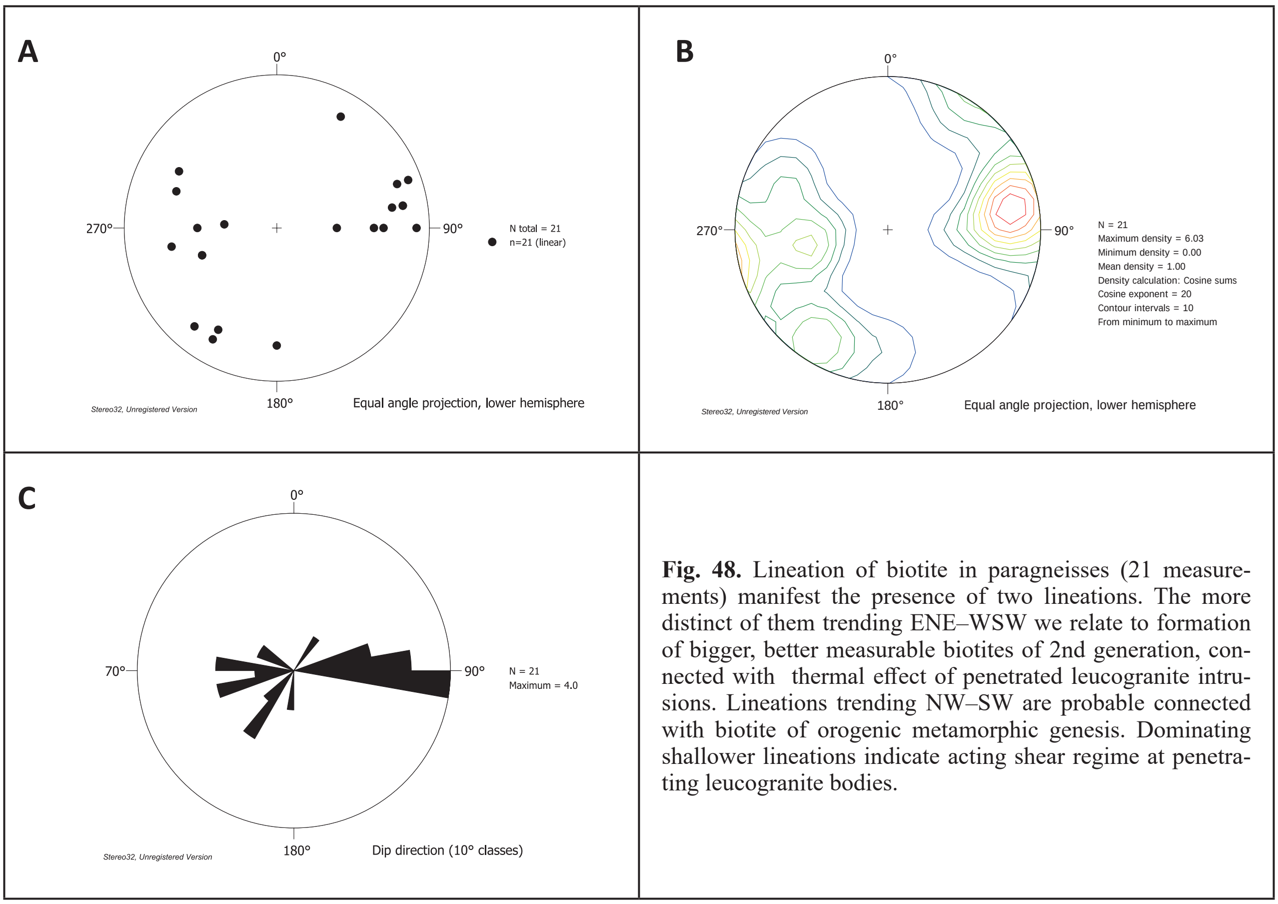



**Fig. 48.** Lineation of biotite in paragneisses (21 measurements) manifest the presence of two lineations. The more distinct of them trending ENE–WSW we relate to formation of bigger, better measurable biotites of 2nd generation, connected with thermal effect of penetrated leucogranite intrusions. Lineations trending NW–SW are probable connected with biotite of orogenic metamorphic genesis. Dominating shallower lineations indicate acting shear regime at penetrating leucogranite bodies.

SHRIMP dating of zircon of S-type two-mica granite from Magura part of the Strážovské vrchy Mts (Kohút & Larionov, 2021) has shown two age modal groups of zircons (sample MM-29 – older), with Neoproterozoic (Cadomian) age **568–551 Ma** and younger **365–361 Ma** (Devonian / Lower Mississippian) with Concordia age **360.9 ± 2.7 Ma**.

Older assumptions and measurements, indicating that I-types granitoids in Tatricum are significantly younger (310–303 Ma; Bibikova et al., 1990; Broska et al., 1990) than S-types, in the W. Carpathians were not confirmed by subsequent zircon dating. The LA-ICP-MS zircon dating from Krivánska Fatra (Broska & Svojtka, 2020) indicated only a small age difference among zircons from S-type granites (**342 ± 3 Ma**) and zircons from I-type granitoids (cores with magmatic age of **353 ± 3 Ma** and rims **342 ± 3 Ma** – this age was probably influenced by fluid regime?), so the I-type granitoids should be slightly older.

On the contrary, the SHRIMP zircon dating (Kohút et al., 2009) in S-type granites of the Bratislava massif (**355 ± 5 Ma**) and I-type tonalites of the Modra massif (**347 ± 4 Ma**) in Malé Karpaty Mts pointed out a small age difference between two large groups of granitoids of W. Carpatians, however, I-type granitoids appear younger. Just like in the Malé Karpaty Mts (Kohút et al., 2009), also in the Strážovské vrchy Mts, it is confirmed that S-types and I-types of granitoids were produced in the same collision event, but they represent different stages of decompression – shearing regime (**S-types; VmD1c**) until the opening of the space in the final, extensional phase of the orogenic cycle (**VmD2**), which was associated with the output of higher thermal, deeper-based magmas of I-type, with manifestations of hybridization, with accompanying diorite magmas of small volumes.

According to the chemical dating of the monazite in the Strážovské vrchy Mts, the age of I-type granites intrusion is older than the age of the monazite of the S-type granites associated with the shear-deformation regime. Geological relationships, however, indicate the opposite. I-type intrusives penetrate mainly in the E-W direction (ENE–WSW; i.e. at a small angle) through older deformation structures, which are associated with the emplacement of S-type granites in the NE–SW direction in a shear regime. Thus, I-type granodiorites can be considered late- to post-tectonic in relation to shear deformation associated with syntectonic intrusions of leucogranites.

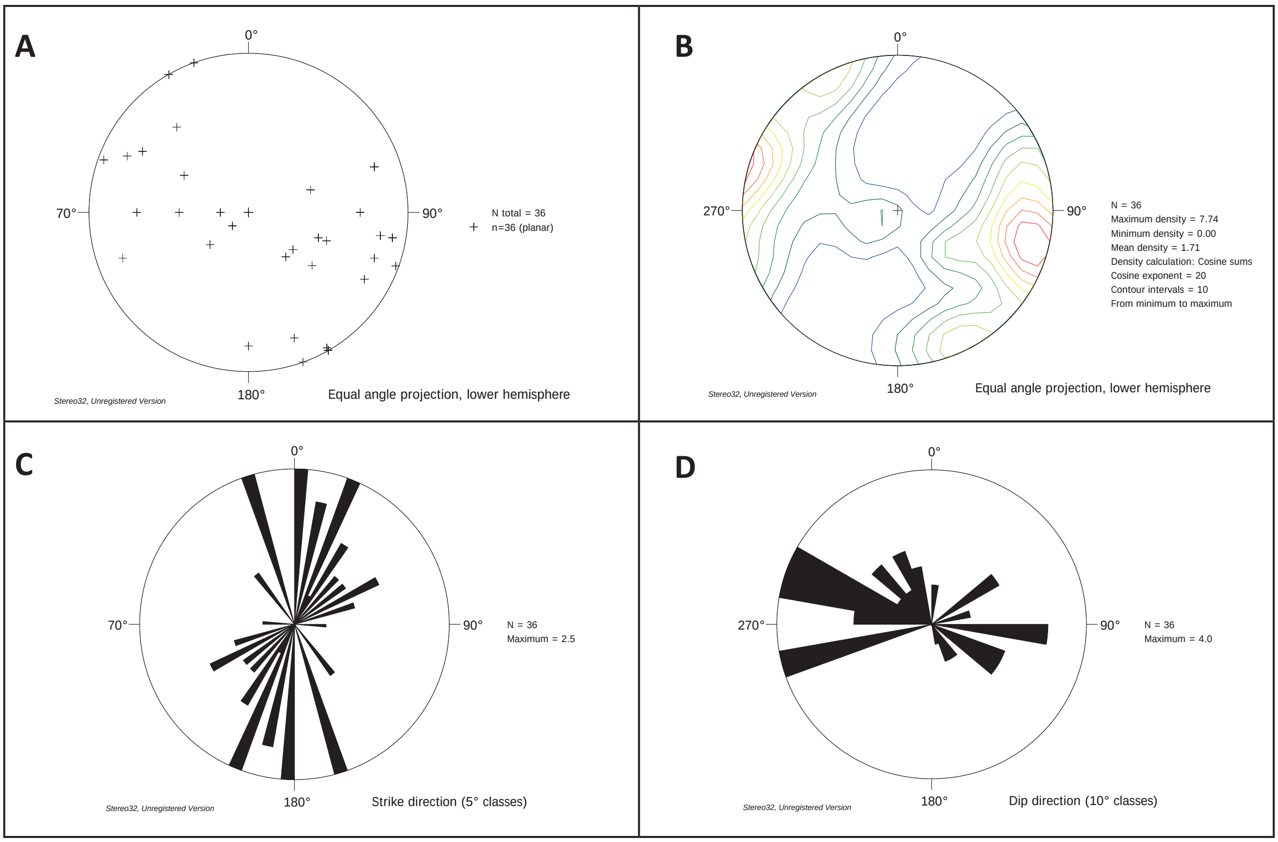



**Fig. 49.** Foliations (schliers – planar orientation of biotite, eventually feldspars) in granitoids (36 measurements): A – poles of planes, B – contourogram of the poles of planes, C – prevailing trends of planes, D – dips of inhomogeneities in granitoids. The contour diagram of planes poles (B) shows two distinct maxima, more often corresponding to planes trending NNE–SSW with steep dip to WNW, resp. ESE. Second, less distinct maximum corresponds to planes trending ENE–WSW with steep dip to SSE resp. NNW. While second, less distinct maximum probable represents relict structures connected with metamorphic rim of intrusion, first – very distinct maximum reflects the penetration dynamics of leucogranite magma.

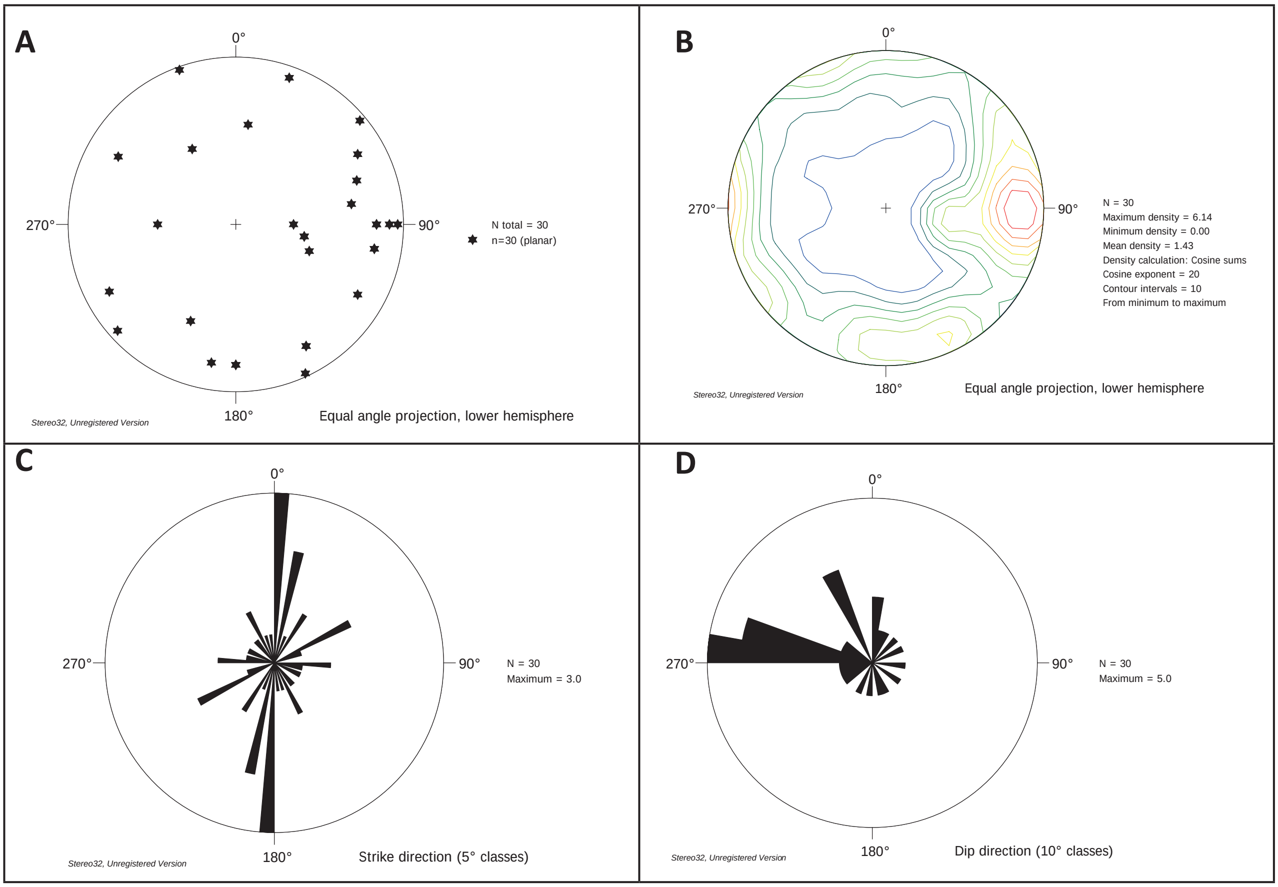



**Fig. 50.** Prevailing courses of planar structures, filled with pegmatite and aplite-pegmatite melt (30 measurements), representing the last stage of leucogranite intrusions. They have prevailing N–S course with steep dip to W, less NE–SW and E–W. Relatively steep disjunctive structures formed in the final extension phase of the generating of granitoids. A – poles of planes, B – contourogram of the poles of the planes, C – prevailing trends of planes, D – dips of pegmatite and aplite veins.

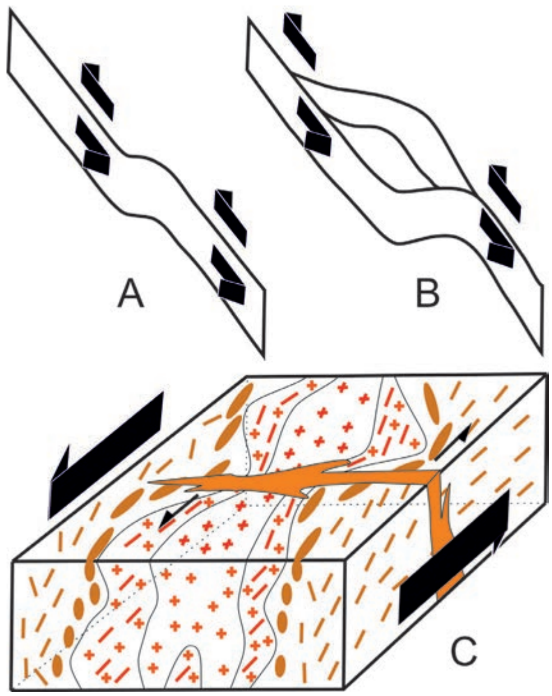



**Fig. 51.** Diagram of the opening of space for leucogranite intrusions (VmD2). A – the beginning of the shear regime with the deformation of the metamorphic complex; B – diagram of space opening in a more advanced stage of shear deformation; C – block diagram of syn-deformation leucogranite intrusions (omnidirectional up to indistinct preferential orientation of minerals – red crosses; and syn-intrusively oriented marginal parts of intrusions – red crosses and dashes). Formation of thermally induced biotite II (brown ellipses). Thermally (granite thermal effects) slightly, or no affected complex of paragneisses is indicated by dashes. Transversely steep structures filled with aplites and zonal pegmatites, formed from leucogranite magma (orange). Black arrows show the sense of tectonic shear transport.

Therefore, we assume that the intrusions of I-type granodiorites-tonalites and rarely diorites should be close in age to the formation of pegmatites, or follow them (within the Tournaisian / Visean interface). For this reason, it is necessary to carry out a geochronological investigation of zircon in I-type granitoids from this area.

The interpretation of the late emplacement of I-type granodiorites and small diorite bodies in the Strážovské vrchy Mts is in agreement with the statement by Kohút and Larionov (2021): "The peak at ca 342–340 Ma, representing probably the main period of the collisional granites production / emplacement, was in part accompanied by intrusions of dioritic syn-plutonic dykes."

We determined the age of the change in deformation conditions in metamorphic complexes from ductile to semi-ductile and brittle conditions, based on monazite dating to approximately 345 Ma, which is the typical age of emplacement of aplite and pegmatite veins in brittle structures. Aplite and pegmatite veins are steeply dipping (mainly N–S dip) and their trend is generally oriented at a large angle to the main shear stress component (dominantly E–W direction), as was found in the eastern part of the Suchý massif.

The mechanism of emplacement of granites in shear zones during the extensional regime has received more attention since the 1990s (Hutton et al., 1990). It is a mechanism when thickened continental crust is decompressed with the simultaneous ascent of granites in shear zones parallel with the axis of the orogen (orogen-parallel extension). Such placement mechanism is known e.g. in Caledonides (Braathen et al., 2000), Variscides (Oberc-Dziedic et al., 2015), or in "younger" ranges, e.g. from Greater Himalaya (Xu et al., 2013), or nearby Alpine Periadriatic line with several intrusive complexes (Márton et al., 2006). In the environment of the Variscan shear zone, a transition from metatexites to diatexites accompanied by

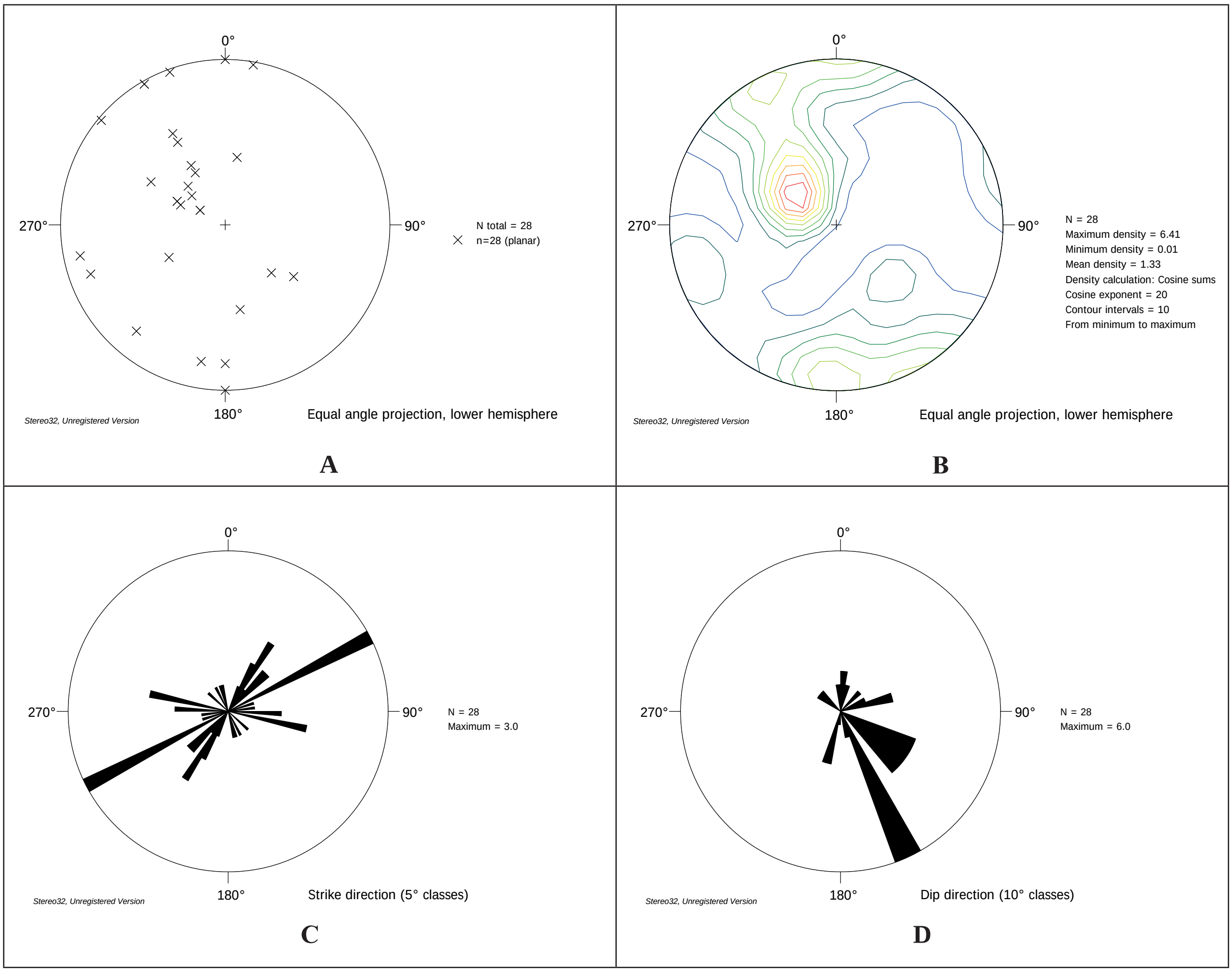



**Fig. 52.** Planar elements in orthogneisses (28 measurements): A – poles of plains, B – contourogram of poles of plains, C – prevailing trend of planes, D – dips of metamorphic schistosity of orthogneisses.

an increase in the volume of granite mobilized up to the placement of peraluminous granodiorite in the shear zone was demonstrated (De Luca et al., 2023).

Later intrusions of I-type granitoids are evidence of the increase in thermality of the granitoid process at the end of the decompression granitogenic stage. A suitable mechanism for such process is a model of the subsidence of a relict block of oceanic crust after a collision into the asthenosphere (slab breakoff), thermal ascent of mantle masses, acceleration of decompression of crustal parts, its melting associated with the ascent of deeper-seated intrusions (e.g. von Blanckenburg & Davies, 1995). For granitoids of the Low Tatra Mts, such a model is discussed by Maraszewska et al. (2022).

**Orthogneisess** represent a special phenomenon within the Suchý crystalline basement. Less significantly they occur also in the western part of the Magura massif. From the viewpoint of Variscan collisional setting we consider them as the upper structural element. On the older geological map of Maheľ (1982) they were considered as migmatites. The presence of spindle-shaped polycrystalline glomeroblasts composed of feldspars and quartz, which are a manifestation of ductile deformation of older phenocrysts and the absence of leucosome formation, testify against such interpretation. This crustal element, which, due to the monotonous character, composition and dating of the metamorphic reworking, we consider to be a pre-Varicsan granitoid (**pre-VmD0**), within Variscan collision being obducted (**VmD1o**) onto those parts of crystalline basement that primarily sedimented on the Paleozoic continental slope, or even on the ocean floor.

Orthogneiss lithologies were identified as a common component within the Western Carpathian crystalline basement. Several authors have investigated their age characteristics based on zircon dating. In the Western Tatras, they were dated from the upper and lower tectonic units using the method LA-MC-ICP-MS method by Burda and Klötzli (2011) to 534 Ma, which authors considered to be the age of the protolith, while the age of 387 Ma they considered as the age of highly metamorphic Eo-Varican event. The age of the protolith of the Veporic orthogneisses from Muráň (Gaab et al., 2005) was determined to 464 ± 34 Ma (later redefined by Putiš et al., 2008 to Cadomian). Isochrone age of zircons from orthogneiss from the Low Tatra Mts (sample NTJ-1) was determined by Putiš et al. (2003) to 381 Ma, whereas model ages for different size fractions of zircons vary for isotopic system $^{207}Pb/^{235}U$ = 466.2–576.6 Ma and for isotopic system $^{206}Pb/^{238}U$ = 441.2–526.4 Ma. From this, it can also be concluded that the age of 381 Ma represents the high-temperature metamorphic overprint of the protolith. Later dating of orthogneisses, but also banded amphibolites from W. Carpathians (Putiš et al., 2008) provided wider Neo-Proterozoic–Cadomian age extent (640–530 Ma) at larger group of orthogneisses. Our chemical dating of monazite from orthogreisses with a distinct peak of 390 Ma can undoubtedly be considered as the metamorphic age of monazite, while ages in the range of 340–350 Ma represent the age of a subsequent thermal event associated with leucogranite intrusions.

The metamorphic schistosity of orthogneisses is trending dominantly ENE–WSW with steep to moderate dip to SSE, NNW. The field configuration indicates the shallow fan-like setting of orthogneiss body. The presence of distinct biotite lineations indicates a significant stress field acting at emplacement of orthogneisses in the Variscan setting. The more external (higher) position in the Variscan setting is emphasized by the absence, or the rarity of granitization manifestations, while transversal brittle structures in orthogneisses are filled only with aplitic and pegmatite veins (Figs. 24A and 39A).

When analysing the structural elements of the crystalline basement in megascale, it is necessary to state that these very probably demonstrate Alpine-modified directions, which can be indicated by the variable and often steep dips of the Mesozoic cover of Tatricum (Malá Magura cover succession) towards the NW. The Alpine tilting of the crystalline basement in the NW direction would indicate that the structures in crystalline basement were significantly more gently dipping to the NW in the pre-Alpine period.

Regarding the configuration of the entire structure of the Magura and Suchý massifs, it is necessary to point out again that the western part of the Strážovské vrchy crystalline basement – the Suchý massif represents more external and less granitized part of Variscan setting, manifested mainly by sharp intrusive contacts of granitoids with metamorphites. In the western part of the Suchý massif, approximately from the Radiša valley, surfaces of metamorphic foliation have shallower dip, being accompanied with diaphtoresis of former metamorphic minerals from the greenschists facies. In microscale it is manifested by cataclasis of garnet phenocrysts, its new rotation, chloritization along cataclastic fractures, forming of actinolite at the expense of hornblende in metabasites and replacement of original Al silicates in metapelites by glomeroblasts of fine-grained muscovite. We associate new metamorphic schistosity and retrograde mineral replacements with Late Variscan unroofing in shallow crustal levels.

### *Alpine metamorphic overprint*

Alpine overprint (**ApD, AnD**) is not always reliably distinguishable from the Meso-Variscan unroofing (**VmD2**), however, there are some diagnostic signs that distinguish them. Fission-track dating of zircon from the

Tatric crystalline basement (Marko et al., 2017) indicates that this basement during Alpine cycle was not overprinted by temperature higher than 320 °C (zircon closure temperature), which is valid also for Mesozoic sediments of the Malá Magura unit. Younger, Alpine low temperature metamorphism in the Magura massif (Čík & Petrík, 2014) was characterized by the presence of margarite and pumpellyite. Calculations of Alpine association in the Poruba area in migmatite provided values 480 °C at pressure 4.6 kbar and in paragneiss 300 °C at pressure 2.9 kbar. Radial arranged pumpellyite crystals can occasionally be found in granite fractures also in the Suchý massif and often in thin sections from metabasites, mainly from the western margin if the Suchý massif.

Planes of Alpine cleavage in crystalline basement have prevailing trends ENE–WSW (55–65°) with dominant dip to SE, less to NW. The linear kinematic indicators show mainly to horizontal shifts (strike-slips) related to the Alpine thrusts of higher units (**ApD1c, AnD3**), mainly of the Fatricum, which was partially reflected also in the Tatric basement.

Thermal modelling (Marko et al., 2017) based on fission-track dating of zircon (ZFT ages, reflecting thermal transition between 230–250–max. 320 °C) indicated ages corresponding to gradual ascent of Paleozoic consolidated crystalline block, while the absence of Late Paleozoic sediments in Tatricum reflects denudation of Tatric segment down to the level of crystalline basement in the lowest Triassic. Youngest ZFT ages (245, 239 and 222 Ma) reflect gradual, but irregular cooling of crystalline blocks in the Middle to Upper Triassic, possibly repeated uneven submergence of the crystalline basement during the Lower to Middle Jurassic (ages 198 and 168 Ma).

The distinguishing criterion for Late Variscan unroofing (**VD2**) and Alpine metamorphism (**MAp**) is mainly Alpine mineral metamorphism with the formation of pumpellyite facies minerals in metabasites, indicating lower metamorphic conditions in comparison with the Late Variscan diaphtoresis. From the spatial view, the Alpine metamorphism is often bound with marginal parts of the massif in contact with sediments of Mesozoic Malá Magura unit, which are also strongly tectonically reduced. This is manifested by narrow mylonite zones parallel with the margins of the massif, which, in the case of binding to sediments with black schists (e.g. in the Čavoj area), are a source of metals remobilized into veins or stockworks in these narrow zones. During later Alpine updoming of crystalline basement after the completion of formation of the nappe setting (**post-ApD1**), probably in the Upper Cretaceous or Paleogene (**ApD2**), there locally started in upper crustal conditions the origin of zones of low-temperature utracataclasis (kakiritization), demonstrated by origin of dark afanitic zones thick up to several cm. At a later stage (**AnD34**) during the continuing structuring of the crystalline blocks, wider zones of ultracataclasis were formed in the granitoids and quartzites, which are mainly present in the area of the Radiša fault (more appropriate name – Radiša fault zone), Závadka fault, Šútovo fault, possibly also Diviaky fault (more appropriate name – Diviaky fault zone; Fig. 1). The final stage is the **AnD4** disintegration of the crystalline massif along the E-W trending faults with the subsidence of the southern blocks, as well as faults and fault zones with regard the N–S direction (e.g. Diviaky fault and Radiša fault; **AnD4**).

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# Variské litotektonické jednotky v masíve Suchého v Strážovských vrchoch, Západné Karpaty – výsledok sedimentárnych, tektonometamorfných a granitizačných procesov

Západná časť tatrického kryštalinika Strážovských vrchov vystupuje v masíve Suchého západne od rieky Nitrica a jej okolia. Kryštalinické jadro má zachovaný mezozoický, tektonicky redukovaný obal (tzv. malomagurskú obalovú jednotku) len v severnej a severozápadnej časti. Z východnej a juhozápadnej strany je jadro ohraničené popaleogénnymi zlomami. V dôsledku viacetapovej alpínskej tektogenézy sa vytvorilo asymetrické jadro, ktoré z hľadiska variskej tektogenézy predstavuje menej metamorfovaný segment v porovnaní s východným jadrom, ktoré patrí k magurskej časti Strážovských vrchov. V dôsledku alpínskej tektogenézy sa v masíve Suchého obnažili bloky patriace vo variskom období k rôznej kôrovej úrovni.

Na základe zhodnotenia starších prác a nových poznatkov sme v predalpínskej štruktúre západnej časti Strážovských vrchov (masív Suchého) vyčlenili tri litologicky odlišné variské litotektonické jednotky: 1. sedimenty, ktoré majú pôvod v hlbšom oceánskom bazéne (prevažne metapelity s rôznym obsahom organickej hmoty, metabazalty, metakarbonáty?); 2. sedimenty kontinentálneho svahu (flyšoidné sedimenty s prevahou drobových sedimentov bez prítomnosti alebo so vzácnou prítomnosťou metabazaltov); 3. jednotku kontinentálneho pôvodu blízku granitovému zloženiu (ortoruly), ktorá má pravdepodobne predvariský (kadómsky) pôvod. Tieto komplexy rôznej geotektonickej proveniencie boli amalgamované a metamorfované pred granitizačným štádiom (štádium *pre-VmD2* pred obdobím misisipu). Z pohľadu variskej polyorogenetickej evolúcie variské procesy v tatriku reprezentujú mezovariskú evolúciu *(VmD)*.

Maximálne tlakovo-teplotné podmienky orogénnej (regionálnej) metamorfózy (do 610 °C a 7,5 – 8,5 kbar), ktorá korešponduje s maximálnym zhrubnutím kôrového segmentu počas variskej kolízie, neboli dostatočné na rozsiahlejšie prejavy anatexie v podstatnej časti územia. Z terénnych pozorovaní vyplýva, že k produkcii obmedzeného objemu granitoidných tavenín dochádzalo najmä pri kontaktoch amalgamovaných litotektonických jednotiek, pravdepodobne s prispením strižného tepla.

Pravdepodobne vplyvom dodatočného tepla produkovaného pod akrečným klinom spolu s dekompresným režimom nastala etapa tvorby a umiestňovania granitoidov v orogenetickej fáze *VmD2*.

Etapa tvorby granitov počas misisipu (štádium *VmD2*) je spojená s umiestňovaním rôznych typov granitoidných magiem, pričom ako geologicky najstaršie vystupujú granodiority s častými šlírmi. Predstavujú málo diferencovanú a málo mobilnú kryštálovú kašu (jv. časť územia).

V hlavnom deformačnom štádiu strižného charakteru súhlasne s deformačným plánom v metamorfovaných komplexoch intrudovali masy leukogranitov, ktoré interagovali s okolitými metamorfovanými horninami v plytších kôrových podmienkach a spôsobili kontaktnú premenu staršej metamorfnej asociácie (do 590 °C a 3 – 4 kbar). Syndeformačný charakter leukokratných granitov je preukázaný usmernením lupeňov biotitu v okrajových častiach intrúzií, paralelne s deformačným plánom v okolitých metamorfitoch. Časť leukogranitov najmä v centrálnych častiach telies je všesmerná. Deformačné pole pôsobilo nielen počas intrúzie leukogranitovej magmy, ale aj v subsolidovom štádiu. Prejavuje sa to planárnym usmernením časti leukogranitov za vzniku vyššieteplotných mylonitických štruktúr, ktoré sú staršie ako intrúzie pegmatitov. Chemické datovanie monazitov z pegmatitov poukázalo na pomerne úzky diapazón vekov, 345 – 343 mil. rokov. Záverečnou etapou tohto procesu bola teda tvorba veľkých telies pegmatitov v extenzných fraktúrach štádia *VmD2*, orientovaných pod veľkým uhlom k hlavnej zložke napätia. Textúra pegmatitov so sivým blokovým K-živcom veľkým niekoľko desiatok centimetrov a nedostatok minerálov obsahujúcich vodu (sľudy) poukazujú na pravdepodobnú pneumatolytickú frakturáciu v následne otvorenom prostredí štádia *VmD2*.

Záverečnou etapou štádia *VmD2* sú intrúzie granodioritov typu I so znakmi miešania magiem (*mixing*, resp. *mingling*). Tieto granodioritové až tonalitové (miestami aj dioritové) magmy typu I mali hlbšie založenie a vyšší obsah vody, ktorý sa následne prejavil v oxidačnom režime záverečných štádií magmatického procesu.

Chemické datovanie monazitu v granitoidoch umožnilo datovať jednotlivé fázy granitizačného procesu približne medzi 355 – 345 mil. rokov, pričom najmladšie veky korešpondujú so vznikom pegmatitov. Chemické datovanie monazitu v metamorfovaných horninách poukazuje na termálne ovplyvnenie granitizačným procesom (okolo 350 mil. rokov) a zároveň indikuje staršie regionálne metamorfné prepracovanie prevažne v období 370 – 380 mil. rokov. Staršie reliktné údaje, ktoré je problematické interpretovať, môžu byť sčasti odvodené od veku protolitu metamorfovaných hornín.

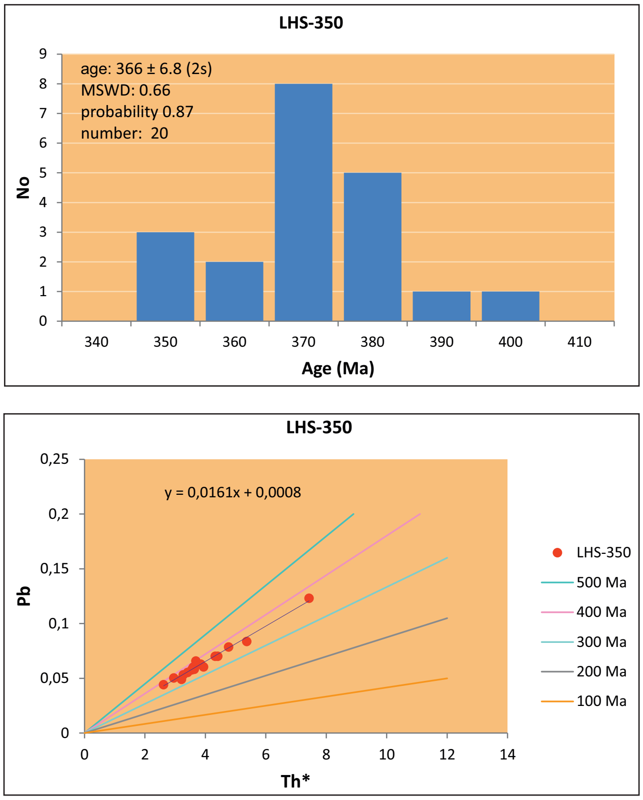
Scenár umiestňovania granitoidných intrúzií je súhlasný s dekompresným režimom (v štádiu *VmD2*) po závere kôrového zhrubnutia (v štádiu *VmD1c*) až po frakturáciu kôrového bloku s intrúziami magiem typu I hlbšieho pôvodu.

Po tomto období pokračovala exhumácia blokov kryštalinika, čiastočná diaftoréza a neskôr povrchová erózia až do spodného triasu.

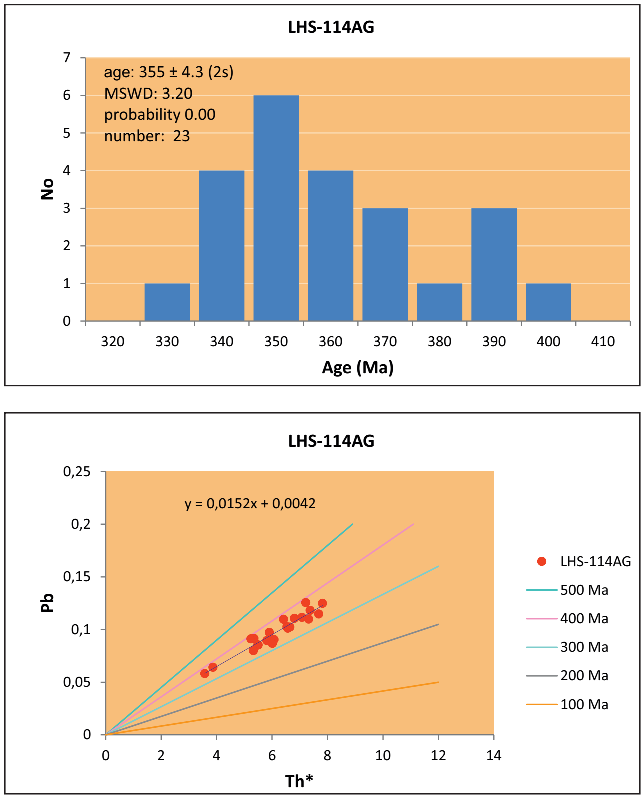
Opätovné ponorenie kryštalinických komplexov je spojené s nízkym stupňom alpínskeho metamorfného prepracovania.

Na klasifikáciu litotektonických jednotiek bola použitá nová metodika, tzv. *XD labelling*, postavená na geodynamických princípoch a definovaní rozšíreného orogenetického (Wilsonovho) cyklu. Táto metodika (Németh, 2021) vznikla vďaka dlhoročnému detailnému spoznávaniu polyorogenetického vývoja v regióne Západných Karpát – variského *(VD)*, paleoalpínskeho *(ApD)* a neoalpínskeho *(AnD)* – s ich rozčlenením na jednotlivé orogenetické fázy. Novodobý výskum regiónu Strážovských vrchov a terajší článok (Hraško et al., 2024) rozširujú súčasné poznanie geodynamiky Západných Karpát o nové informácie o prítomnosti produktov kadómskej orogenézy *(CdD)* v tomto regióne a variskú orogenézu delia na dva samostatné, aj keď vzájomne sa prelínajúce variské orogenetické cykly – mezovariský (*VmD*; odlíšený v tatriku Strážovských vrchov) a neovariský (*VnD*; štandardne definovaný v gemerickej zóne ako variský).

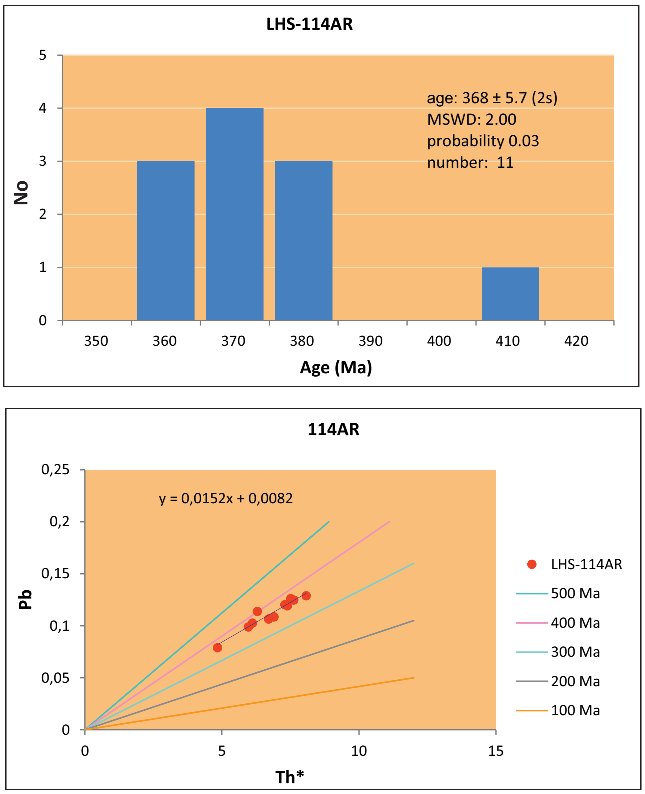
Metodika *XD labelling* (Németh, 2021) umožňuje prehľadné označovanie jednotlivých orogenetických cyklov a ich fáz a je aplikovaná aj v tomto článku. V nej premenná *X* označuje konkrétny orogenetický cyklus (v podmienkach Západných Karpát: *Cd* – kadómsky, *Vm* – mezovariský, *Vn* – neovariský, *Ap* – paleoalpínsky a *An* – neoalpínsky). Jednotlivé orogenetické fázy v rámci týchto orogenetic-



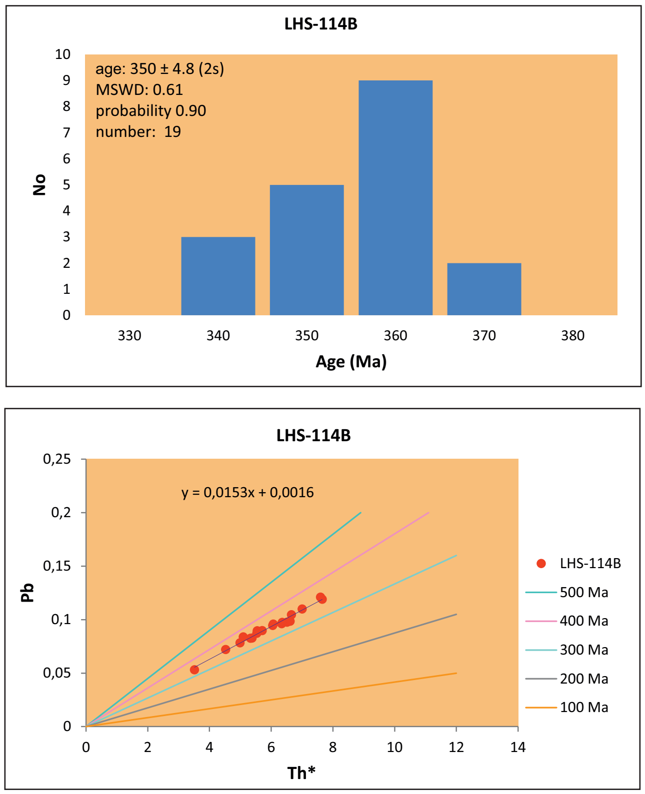

Plt 1-1: Bt paragneiss with graphite




Plt 1-2: Migmatite-granite / granite part

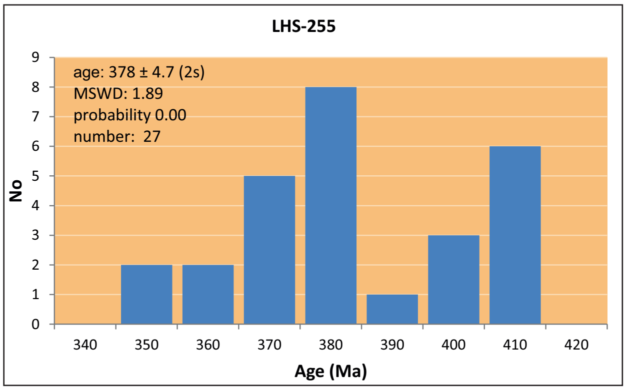


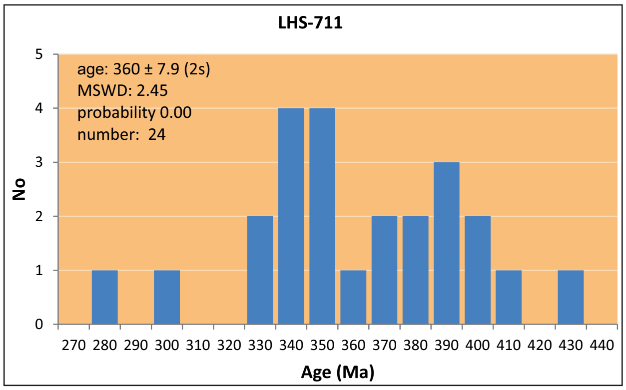

Plt 1-3: Migmatite-granite / gneissic part

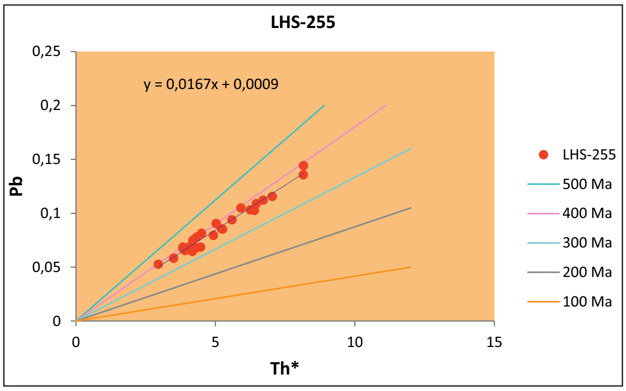


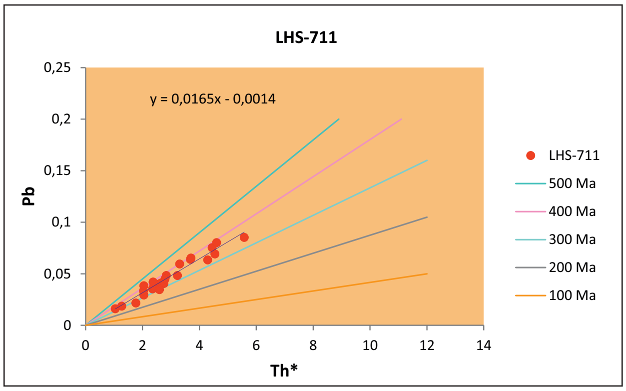

Plt 1-4: Schliered granite - granodiorite

**Plate 1: Chemical monazite dating**



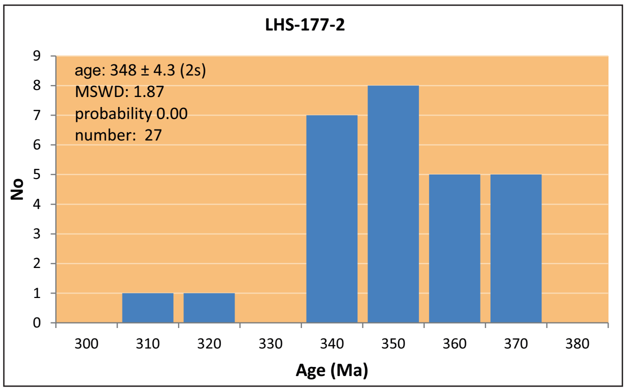



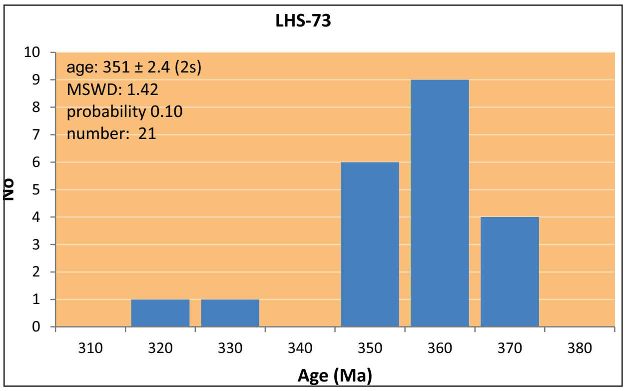



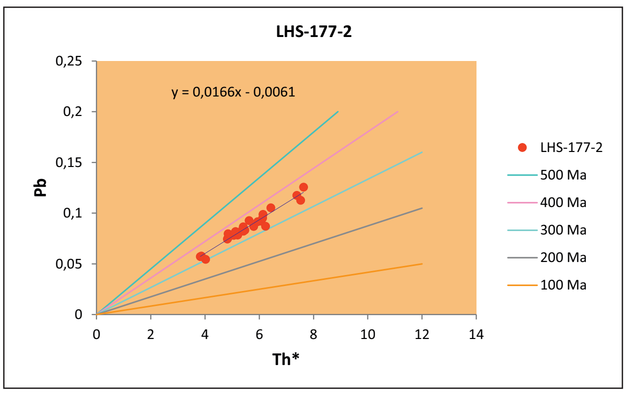



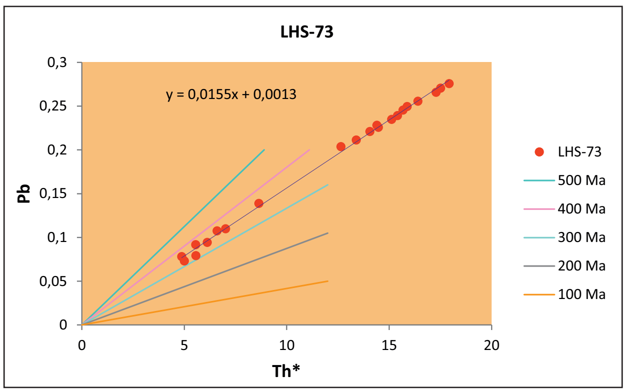

Plt 2-1: Bt paragneiss with graphite

Plt 2-2: Bt orthogneiss



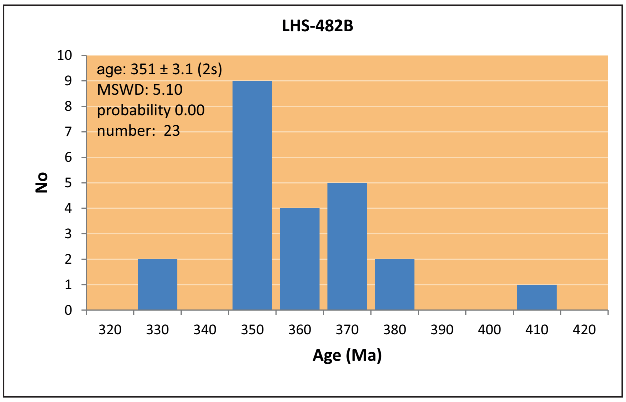



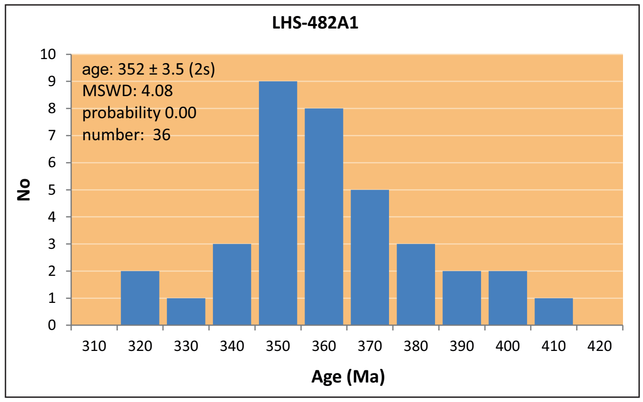



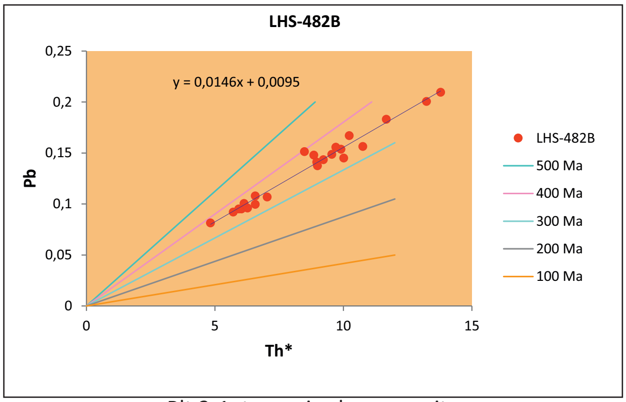

Plt 2-3: Schliered granodiorite

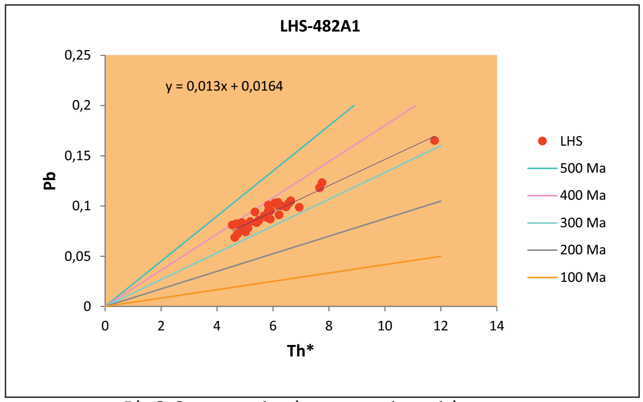
Plt 2-4: Two-mica leucogranite

**Plate 2: Chemical monazite dating – continuation**



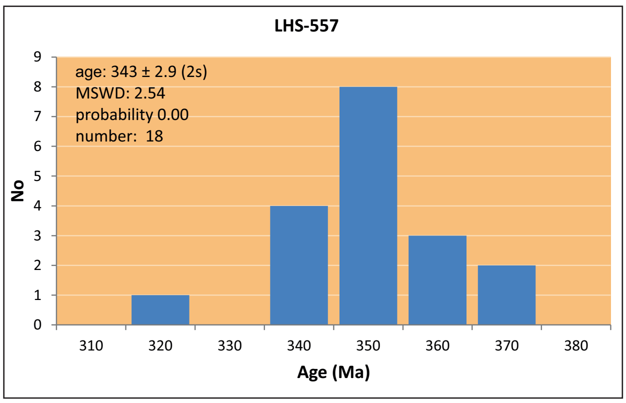



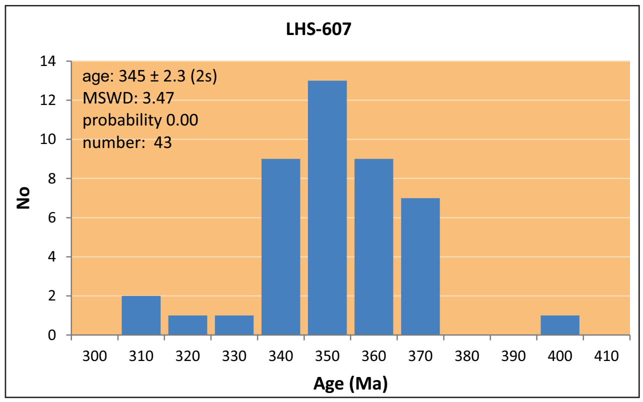



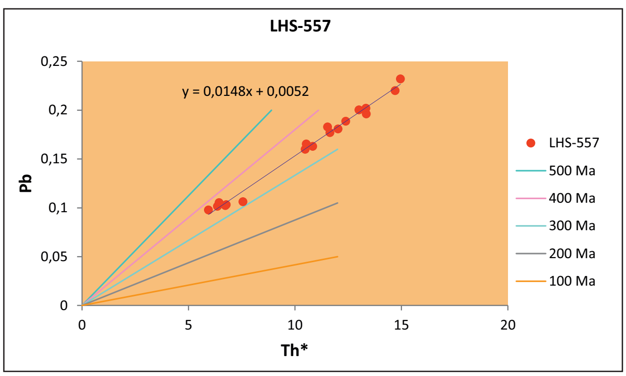



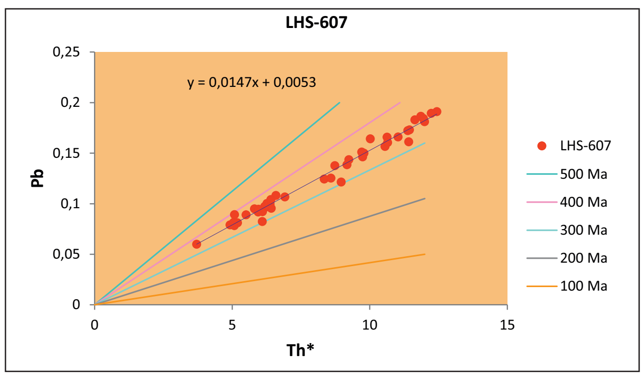

Plt 3-1: two-mica leucogranite

Plt 3-2: two-mica leucogranite with garnet



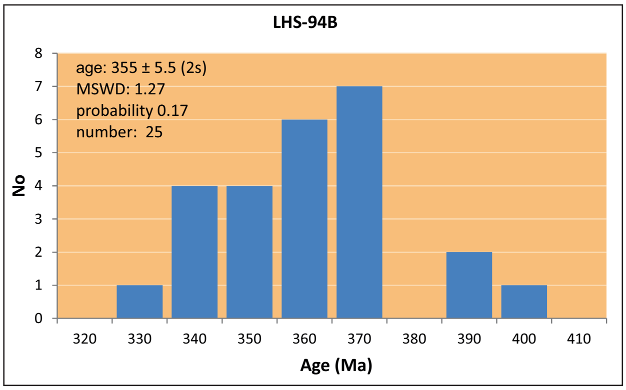



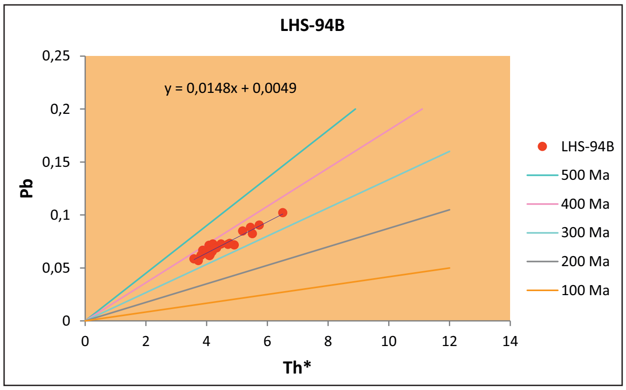




Plt 3-3: aplite to pegmatite in two-mica leucogranite

Plt 3-3: aplite to pegmatite in two-mica leucogranite

**Plate 3: Chemical monazite dating – continuation**




Plt 4-1: I-type omnidirectional granodiorite

**Plate 4: Chemical monazite dating – continuation**

kých cyklov indikuje číslo, prípadne ďalšie symboly za indexom *XD*: *XD0* – divergentné štádium riftogenézy, rozpad kontinentálnej kôry, vznik kôry oceánskeho typu, *XD1* – konvergentné štádium končiace sa kolíziou a uzavretím bazénu s oceánskou kôrou, ktoré sa detailnejšie člení na subdukčnú fázu vývoja *XD1s*, obdukčnú fázu *XD1o* a finálnu kolíznu fázu *XD1c*. Orogenetický (Wilsonov) cyklus v klasickom chápaní bol vďaka detailnému spoznaniu polyorogenézy Západných Karpát rozšírený o ďalšie tri orogenetické fázy: *XD2* – označuje pokolízny vývoj orogénnej zóny, spojený predovšetkým so zvyšovaním teploty v zóne novej kontinentálnej kôry zhrubnutej kolíziou *(metamorphic core complex)*, súvisiacu metamorfózu hornín, granitizačné procesy a metalogenézu, *XD3* – označuje obdobie vyrovnávania vnútroplatňových napätí predovšetkým bočne posuvnou aktivitou na strižných zónach párového systému s priebehom v smere SZ – JV a SV – JZ. Záverečná fáza orogenetického cyklu je extenzným obdobím, ktoré neskôr prechádza do začiatku nového orogenetického cyklu $X^{+1}D$. Vyznačuje sa tvorbou regionálnych zlomov (lineamentov) s generálnym priebehom v smere V – Z a S – J. Orogenetické fázy *XD3* a *XD4* spolu súvisia a ich produktom býva vertikálny pohyb blokov hornín ohraničených zlomami (cf. Németh et al., 2023).

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## Appendix

Table of sample basic field characteristic and coordinates

| Sample | Field characteristics | WGS-84 coordinates | | SJTSK coordinates | |
|---|---|---|---|---|---|
| | | φ | λ | X | Y |
| LHS-42 | Contact of Bt paragneiss and pegmatite with grey blocky Kfs. Metamorphic schistosity 320/85. | 48.820 482 | 18.416 903 | 1 214 869.74 | 470 428.22 |
| LHS-57 | Metamorphically differentiated Bt paragneiss with small interbeds of granitic material, subvertical metamorphic schistosity in N–S direction. | 48.816 606 | 18.441 510 | 1 215 450.29 | 468 663.70 |
| LHS-73 | Stock of the Ms-Bt massive granite. | 48.838 813 | 18.433 411 | 1 212 940.00 | 469 050.00 |
| LHS-94A | Medium-grained schliered granitoid with moderate preferred orientation of Bt-Plg, Kfs, contains planes rich in Bt. | 48.839 33 | 18.448 381 | 1 212 974.39 | 467 950.35 |
| LHS-94B | Small body of Plg-rich (up to 50 %) granodiorite with abundant Bt. Idiomorphic Plg large up to 1–2 mm. Interstices are filled with Bt. | 48.839 33 | 18.448 381 | 1 212 974.39 | 467 950.35 |
| LHS-114 | Alternation of migmatites with predominant metamorphic schists with the direction of dip 300/85°. 2 generations of granites are present in them: 1. granite – ductile folded, parallel to the metamorphic schist. 2. In the fold cores there are coarse-grained Ms-Bt granites, with idiomorphic feldspars. This 2nd type is hybridized at the edges, finer-grained. The presence of Bt schists indicates low magma mobility. This 2nd type probably segregates into large volumes, so that granitoids predominate in the western flank of the outcrops. | 48.837 475 | 18.464 977 | 1 213 281.35 | 466 753.53 |
| LHS-131 | Ductile folded migmatites with a ratio of leucosome and melanosome of 1 : 1. In these, the concordant positions of medium-grained leucogranites with inhomogeneously distributed Bt are placed, in them the Bt is parallel to that in the migmatites. | 48.837 114 | 18.465 415 | 1 213 323.96 | 466 724.77 |
| LHS-137 | Stromatitic migmatite with 1 cm thick parallel granite positions. | 48.831 848 | 18.467 765 | 1 213 921.89 | 466 601.54 |
| LHS-153 | Fine-grained amphibolitic rocks, containing positions of leucogranite veins parallel to the metamorphic foliation, a few cm thick, up to a younger generation of transversal granite veins, which branch intricately. Veins of pegmatitic granites are also present. | 48.840 364 | 18.462 299 | 1 212 944.81 | 466 922.69 |
| LHS-177-1<br>LHS-177-2 | 177-1 light-grey Bt paragneisses without foliation planes with Bt2, but Bt is lineated; 177-2 hybridic medium- to coarse-grained granodiorites with irregularly spatially and dimensionally arranged Bt (together with 177-1) light-grey Bt paragneisses without foliation planes with Bt2, Bt is lineated. | 48.819 231 | 18.456 915 | 1 215 253.67 | 467 512.06 |
| LHS-185 | Schliered granitoids with xenoliths of fine-grained Bt paragneiss. | 48.836 248 | 18.459 216 | 1 213 382.14 | 467 186.30 |
| LHS-197 | Grey, fine-grained paragneiss, schistose, which is affected by new thermal reworking, with the formation of larger Bt2 flakes. Metamorphic schistosity is subvertical in E–W direction. | 48.836 381 | 18.397 549 | 1 212 988.88 | 471 695.77 |
| LHS-200 | Tectonized, partially diaphtorized? medium-grained Bt + Ms leucogranites without paragneisses. | 48.842 981 | 18.400 166 | 1 212 273.72 | 471 442.73 |
| LHS-204 | Grey, metamorphically foliated fine–grained Bt paragneisses, with new thermal reworking, with 1–2 mm Bt2 flakes, parallel with new foliation surfaces. | 48.828 532 | 18.389 932 | 1 213 811.65 | 472 326.31 |

Appendix – continue

| Sample | Field characteristics | WGS-84 coordinates | | SJTSK coordinates | |
|---|---|---|---|---|---|
| | | φ | λ | X | Y |
| LHS-206 | Medium- to coarse-grained pegmatite leucogranite with transition to pegmatite. Several hundred m thick vein, cropping out in N side of the valley, where large blocks fall down to the stream. Locally present tiny Grt and grey Kfs. Grt forms subparallel interbeds, which proves the zonality. Ms in larger flakes usually forms nests. | 48.828 998 | 18.432 599 | 1 214 022.56 | 469 200.63 |
| LHS-207 | Banded gneisses with metamorphic differentiation with straight flat alternating of 1 mm thick light and dark bands. Foliation planes are covered with larger Bt flakes. Transversally to metamorphic foliation penetrating fine to medium-grained veinlets of leucogranite. | 48.826 465 | 18.402 749 | 1 214 119.71 | 471 407.99 |
| LHS-255 | Paragneiss to micaschist with the formation of chlorite, in contact with aplite also with garnet, metamorphic schistosity has the dip 320/15°. | 48.829 517 | 18.378 054 5 | 1 213 629.24 | 473 186.11 |
| LHS-261 | Grey aphanitic omnidirectional rock originally supposed to be metaquartzite. Contains Hbl. | 48.846 793 | 18.378 087 0 | 1 211 715.29 | 473 021.80 |
| LHS-272 | Porphyroblastic orthogneiss with 5 mm porphyroblasts of rotated feldspars. | 48.849 538 | 18.385 927 0 | 1 211 459.60 | 472 422.79 |
| LHS-273 | Porphyroblastic orthogneiss. | 48.853 505 | 18.387 930 0 | 1 211 032.43 | 472 239.20 |
| LHS-329 | Dark and light grey, fine-grained banded paragneiss. | 48.858 451 | 18.342 786 | 1 210 204.72 | 475 493.36 |
| LHS-350 | Dark grey Bt paragneiss with graphitic admixture, associated with black graphitic schists, schistosity dip 50/35°. | 48.860 370 | 18.344 089 | 1 210 000.00 | 475 380.00 |
| LHS-356a | Micaceous Bt paragneiss, metamorphic foliated structure, micas approx. 1 mm large (metapelite), contact with aplite. | 48.837 683 | 18.367 388 | 1 212 658.42 | 473 889.70 |
| LHS-356b | Micaceous Bt paragneiss, metamorphic foliated structure, micas approx. 1 mm large (metapelite), contact with aplite. | 48.837 683 | 18.367 388 | 1 212 658.42 | 473 889.70 |
| LHS-415 | Oriented Bt-rich orthogneiss on the road base, metamorphic foliation, oblique pegmatite vein with grey Kfs. | 48.863 594 | 18.423 373 | 1 210 132.55 | 469 553.65 |
| LHS-482A | Bt grey paragneisses with steep metamorphic schistosity. In foliation planes large Bt2 occur, system is penetrated in shear regime by granites – leucocratic fine-grained with rare oriented Bt in magmatic flow, the same system is followed with coarse-grained to blocky pegmatites with grey blocky feldspars and rare Ms. | 48.865 501 | 18.456 219 | 1 210 122.58 | 467 134.79 |
| LHS-482B | Bt paragneisses with metamorphic schistosity, Bt2, interbeds of leucogranite with inhomogeneously distribued Bt. The weakly bordered pegmatite is present in them, being zonal, thick to 10 m, in the middle with grey Kfs and Ab at the margin. | 48.865 812 | 18.455 568 | 1 210 084.14 | 467 179.50 |
| LHS-557 | Two-mica granite with prevailing Ms and pegmatite. | 48.837647 | 18.421309 | 1 212 995.11 | 469 946.15 |
| LHS-572 | Bt paragneisses with Bt2, the grey to light-grey pegmatites frequently occur with sugar-type aplitic zone and often tiny Grt, central zone with Ms, Bt, Gtr, Kfs, Ab, Qtz. | 48.849 571 | 18.407 010 | 1 211 585.96 | 470 880.79 |
| LHS-599 | Large blocks of pegmatites with blocky grey Kfs, aplites with garnet. Rock contains only Bt, Ms is missing. Vein crops our in the environment of two-mica granites. | 48.830 616 | 18.434 235 | 1 213 853.53 | 469 066.00 |

Appendix – continue

| Sample | Field characteristics | WGS-84 coordinates | | SJTSK coordinates | |
|---|---|---|---|---|---|
| | | φ | λ | X | Y |
| LHS-607 | Two-mica leucogranite with irregularly distributed, oriented Bt, and omnidirectional Ms, present are not sharply bordered pegmatites. | 48.842 982 | 18.423 083 | 1 212 414.87 | 469 766.75 |
| LHS-611 | Large blocks of pegmatites with grey blocky K-feldspar in environment of leucogranites with oriented Bt. | 48.827 868 | 18.424 823 | 1 214 100.00 | 469 780.00 |
| LHS-623 | Light deformed granites in subsolidic regime, planar orientation in outcrop, Bt with preferred orientation. | 48.849 214 | 18.441 503 | 1 211 837.30 | 468 361.74 |
| LHS-626 | Light leucogranite with oriented Bt and feldspars, Kfs is large up to 2–3 mm. | 48.849 991 | 18.434 700 | 1 211 709.53 | 468 852.01 |
| LHS-650 | Migmatite with a predominance of felsic component. | 48.847 407 | 18.476 226 | 1 212 249.59 | 465 839.11 |
| LHS-711 | Orthogneiss with oriented biotite. | 48.862 027 | 18.370 590 | 1 209 981.00 | 473 427.10 |
| SZN-24 | Light fine-grained rock, omnidirectional keratophyre? | 48.841 015 | 18.368 883 | 1 212 298.32 | 473 749.04 |
| SZN-25 | Black metamorphosed schist, folded. | 48.840 181 | 18.381 699 | 1 212 469.97 | 472 819.50 |
| SZN -32a | Alternation of grey to black metamorphosed shales and metasandstones. | 48.844 398 | 18.365 499 | 1 211 902.50 | 473 964.71 |
| SZN-34a | Dark metapelitic paragneiss with biotite, staurolite and garnet. | 48.842 115 | 18.369 983 | 1 212 183.26 | 473 658.27 |
| SZN-34b | Dark metapelitic paragneiss with biotite, staurolite and garnet. | 48.842 115 | 18.369 983 | 1 212 183.26 | 473 658.27 |
| SZN-34c | Dark metapelitic paragneiss with biotite, staurolite and garnet. | 48.842 115 | 18.369 983 | 1 212 183.26 | 473 658.27 |
| SZN-57 | Dark-grey paragneiss with graphitic pigment. | 48.861 108 | 18.354 930 | 1 209 985.55 | 474 580.53 |
| SZN-66 | Dark-grey to black paragneiss. | 48.864 038 | 18.369 480 | 1 209 751.09 | 473 489.36 |
| SZN-85 | Fine-grained amphibolite. | 48.845 178 | 18.374 989 | 1 211 874.84 | 473 263.40 |

Used abbreviations:

**Minerals:** Pl – plagioclase (Ab – albite, An – anortite), Kfs – K-feldspar, Hbl, Amf – hornblende, Cpx – clinopyroxene, Grt – garnet (Alm – almandine, Spess – spessartine, Pyr – pyrope, Gross – grossular), Qtz – quartz, Bt – biotite, Ms – muscovite, Sill – sillimanite, Stau, St – staurolite, Chl – chlorite, Ep – epidote, Ap – apatite, Zrn – zircon, Mnz – monazite, Mag – magnetite, Ilm – ilmenite

Mg # – ionic ratio $Mg/(Fe_{total} + Mg)$

BSEI – back scatterred electron image

TIMS – Thermal Ionization Mass Spectrometry

SHRIMP – Sensitive High Resolution Ion Micro-Probe

LA-ICP-MS – Laser Ablation Inductively Coupled Plasma Mass Spectrometry

**Lithotectonic units – orogenic cycles, orogenic phases:** VD – Variscan orogenic cycle, VmD0 – Meso-Variscan divergent orogenic phase, VmD1c – Meso-Variscan collisional phase, VmD2 – Meso-Variscan post-colllisional phase with thermal overheating over hot line, extensional and unrooging kinematics, AD – Alpine orogenic cycle, AnD3 – Neo-Alpine orogenic phase characteristic with subhorizontal shearing kinematics, AnD4 – Neo-Alpine orogenic phase characteristic with regional extension and origin of pure shear-type faults preferably of E–W and N–E course.