In the northeasternmost Bohemian Massif, there is a narrow belt of mica schists ca. 10 km wide, referred to as the Kamieniec Ząbkowicki Metamorphic Belt (KZMB); on the basis of zircon data collected from the adjacent units, it is assigned to the Saxothuringian microplates, Polish Academy of Sciences, Research Centre in Wroclaw, ul. Podwale 75, 50-449 Wroclaw, Poland; e-mails: mjasi@twarda.pan.pl, pansudet@pwr.edu.pl
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Abstract: The Kamieniec Ząbkowicki Metamorphic Belt (KZMB) is a narrow zone of mainly mica schists, subordinate acid metavolcanics and scarce eclogites, sandwiched between Brunovistulia and the northern tip of the Teplá-Barrandia microplates. Locally occurring high-pressure relics indicate subduction of the metasedimentary succession of the KZMB, the origin and provenance of which remain unclear. Laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) investigations of detrital zircons show that the metapelites represent an Ediacaran-Cambrian sedimentary basin, with a maximum depositional age of 561±9 Ma. This basin was filled with detritus from a source or sources, composed of rocks containing zircons that are mainly Cryogenian-Ediacaran and Palaeoproterozoic in age. No younger component was found in the zircon population studied. The isotopic U-Pb LA-ICP-MS and chemical U-Th-total Pb electron probe microanalysis (EPMA) monazite geochronology data indicate an important regional tectono-metamorphic event at ca. 330 Ma. Though these data do not permit determination of the peak pressure from the peak temperature stages, the event was part of a complex collision of the Saxothuringian plate with Brunovistulia.

Key words: U-Pb geochronology, LA-ICP-MS dating, U-Th-total Pb geochronology, EPMA dating, microplates of the Bohemian Massif, Kamieniec Ząbkowicki Metamorphic Belt, Variscan metamorphism.

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INTRODUCTION

In the northeasternmost Bohemian Massif, there is a narrow belt of mica schists ca. 10 km wide, referred to as the Kamieniec Ząbkowicki Metamorphic Belt (KZMB); on the basis of zircon data collected from the adjacent units, it is assigned to the Saxothuringian microplate (Obere-Dziedzic et al., 2018). The KZMB is positioned between the northwestern margin of the Brunovistulian terrane and the Góry Sowie Massif. The latter has been considered to be the northeast continuation of the Teplá-Barrandia/Bohemia Terrane (Matte et al., 1990; Franke and Żelaźniewicz, 2000; Obere-Dziedzic et al., 2015), the Central Sudetic Terrane (Cymerman et al., 1997) the Góry Sowie–Kłodzko Terrane (Mazur et al., 2006) or the Central Sudetic Accretionary Wedge (Mazur et al., 2015). In the regional subdivision, this narrow, N–S-trending belt belongs to the Fore-Sudetic Block and stretches from Kamieniec Ząbkowicki towards Wroclaw, though it is extensively hidden under the Cenozoic cover (Fig. 1A).

The mylonitized gneisses of the Góry Sowie Massif (e.g., Dziedzicowa, 1979; Żelaźniewicz, 1995), schistose rocks of the Niemcza Shear Zone (Dziedzicowa, 1975, 1985; Mazur and Puziewicz, 1995; Żelaźniewicz, 1995; Klimas
et al., 2003), mica schists of the Kamieniec Ząbkowicki Metamorphic Belt (e.g., Dziedzicowa, 1979; Mazur and Józefiak, 1999) and para- and orthogneisses of the Strzelin Massif (e.g., Oberc-Dziedzic et al., 2005; 2015) occur along a W–E transect (Fig. 1B). In the vicinity of Kamieniec Ząbkowicki, there are outcrops of porphyroblastic garnetiferous mica schists with high-pressure relics (Nowak, 1998; Szczepański et al., 2018) and lenses of eclogites, metamorphosed at ca. 13–15 kbar and 600°C (Achramowicz et al., 1997). The high-pressure (HP) signatures in these rocks emphasize the geodynamic importance of the whole belt in the eastern Variscides. However, so far neither the pre-Variscan nor the Variscan events recorded in these rocks have been constrained by isotopic geochronology.

Eclogites set in mica schists near Kamieniec Ząbkowicki are not unique in this part of the Bohemian Massif. However, such rocks are only confined to a broad, N–S-trending border area between the Saxothuringian and Moravo-Silesian (Brunovistulia) Zones. In the latter, the Velké Vrbno Dome contains eclogite (metamorphosed at 14–17 kbar, 600–700°C) lenses, associated with orthogneiss and embedded in a metavolcanic suite (Śtípská et al., 2006). On the other hand, gneisses of the Orlica-Śnieżnik Dome to the south of the Sudetic Marginal Fault (Fig. 1) that contain eclogites (15–30 kbar, 670–930°C) in the Śnieżnik area (e.g., Bakun-Czubarow, 1998; Štípská et al., 2012; Majka et al., 2019) are assigned to Saxothuringia (e.g., Franke et al., 1993; Franke and Zelaźniewicz, 2000).

The aim of this study of metapelites in the KZMB is to specify the provenance and terrane affiliation of this belt. The authors constrained the detrital zircon age spectrum and the maximum depositional age of the sedimentary protolith. Furthermore, timing constraints on the age of regional metamorphism in the KZMB were established using isotopic Laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) U-Pb dating and “chemical” U-Th-total Pb electron probe microanalysis (EPMA) dating. The age results obtained provided new data on the position and significance of the provenance, protolith and metamorphic age records in mica schists of the KZMB in pre-Variscan and Variscan times. These age data are of significant importance in refining knowledge of the evolution of the northeastern part of the Bohemian Massif and the Fore-Sudetic Block, in particular.

**GEOLOGICAL SETTING**

The KZMB occurs in the eastern part of the Fore-Sudetic Block. It emerges from beneath Cenozoic deposits in a N–S-trending belt, partly outcropping between Łagiewniki and Kamieniec Ząbkowicki (Fig. 1B). The belt is composed mainly of mica schists with minor intercalations of quartzo-feldspathic rocks, quartzo-graphitic schists, marbles, amphibolites (Dziedzicowa, 1979; Józefiak, 1998; Nowak, 1998) and eclogites localized only in its southern part (Achramowicz et al., 1997). Microfossils found in the quartzites and mica schists indicate their Ediacaran to earliest Cambrian protolith age (Gunia, 1979).

The KZMB underwent a polyphase tectonic history (Achramowicz, 1994; Nowak, 1998; Mazur and Józefiak, 1999; see Gurgurewicz and Bartz, 2011 for review), which was accompanied by regional metamorphism. The clockwise P-T path reconstructions, elaborated so far for the KZMB mica schists, are roughly comparable. In the mica schists, pseudomorphs after HP lawsonite (Nowak, 1998) occasionally have been observed. The conditions of the early HP episode were estimated as 11–12 kbar and 400–430°C (Nowak, 1998). Recent thermodynamic modelling indicates that the Kamieniec mica schists may have experienced pressures twice as high, reaching 20–25 kbar at 520°C (Szczepański et al., 2018). Peak temperature conditions in mica schists from different parts of the KZMB range from...
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500 °C to 640 °C with pressures of 3–10 kbar (see Józefiak, 1998; Nowak, 1998; Szczepański et al., 2018). Such a wide scatter of P-T estimates indicates a tectonic shuffling of rock units metamorphosed at different depths (Mazur and Józefiak, 1999). A series of thrust sheets with westward-increasing metamorphic grade was reported within the belt (Achramowicz et al., 1997; Nowak, 1998; Mazur and Józefiak, 1999).

An age of metamorphism of the KZMB was so far inferred indirectly from relationships with the adjacent units. In the northern part of the KZMB, some Niemcza granitoid bodies intruded the boundary zone between the Niemcza Shear Zone and KZMB at 335±2 Ma (U-Pb LA-ICP-MS zircon dating; Pietranik et al., 2013). Several other studies of the Niemcza granodiorites persistently indicate an age of ca. 340–330 Ma (Oliver et al., 1993; Kröner and Hegner, 1998; Kennan et al., 1999), interpreted as the time of their syntectonic intrusion.

ANALYTICAL METHODS

The mica schists cropping out near Kamieniec Ząbkowicki (50°31’06”N, 16°53’13”E) were sampled for this study (samples SUD24/1 and SUD24/2). The mica schists are porphyroblastic, coarse-grained rocks bearing large porphyroblasts of garnet (up to 1.0 cm in diameter) with chloritoid, quartz, muscovite, margarite and rutile inclusions. Rhomboidal pseudomorphs of phases that replaced lawsonite, similar to those described by Nowak (1998), occur in garnet cores in sample SUD24/1 (Fig. 2). Apart from relics of lawsonite, the rhomboidal inclusions contain paragonite, epidote, ilmenite, muscovite and kyanite. The rock matrix mainly consists of quartz, biotite, chlorite, staurolite and plagioclase. The parallel alignment of these minerals forms a penetrative schistosity. Zircon and monazite are accessory phases in each of the samples investigated.

Preliminary observations and sample selection for monazite dating were performed using a JEOL SuperProbe JXA–8230 Electron Probe Microanalyzer (EPMA) equipped with five wavelength dispersive spectrometers in the Laboratory of Critical Elements, AGH–KGHM (AGH University of Science and Technology, Kraków, Poland). A SUD24/1 mica schist sample containing monazite grains with sizes sufficient for placing laser ablation spots was selected for LA-ICP-MS U-Pb dating, whereas a SUD24/2 sample with smaller grains was selected for EPMA U-Th-total Pb dating. The composition of the monazites in both samples was measured using EPMA.

Compositional analyses of monazite were conducted using a Cameca SX 100 EPMA equipped with 4 wavelength spectrometers, at the Laboratory of Electron Microanalysis, Geological Institute of Dionýz Štúr (Department of Special Laboratories, Bratislava, Slovak Republic). The analyzes were performed using 15 kV accelerating voltage, 180 nA sample current and 3 μm beam diameter (see Konečný et al., 2018 for analytical protocol and further details). The calculation of individual monazite dates in the SUD24/2 sample was processed using the in-house DAMON software (P. Konečný, unpublished); the mean age of the monazite population was calculated using Isoplot v. 4.16 (Ludwig, 2012).

The zircon and monazite for further LA-ICP-MS U-Pb analysis were separated from sample SUD24/1 using standard techniques and handpicking under a binocular microscope. Zircon and monazite grains were mounted in epoxy resin and polished. Cathodoluminescence (CL) of zircons and back-scattered electron (BSE) images of zircons and monazites were performed prior to the LA-ICP-MS measurements. A Thermo Scientific Element 2 sector field ICP-MS coupled to a 193 nm ArF excimer laser (Teledyne CETAC Analyte Excite laser) at the Institute of Geology of the Czech Academy of Sciences, Prague, Czech Republic, was used to measure the Pb/U and Pb isotopic ratios in zircon and monazite.

The laser was fired at a repetition rate of 5 Hz with fluence of 1.95 J/cm² and spot size of 10 microns for monazite analysis and 3.5 J/cm² and spot size of 25 microns for zircon analysis. The He carrier gas was flushed through the two-volume ablation cell at a flow rate of 0.85 L/min and mixed with 0.7 L/min Ar and 0.004 L/min N₂ prior to introduction into the ICP. The in-house glass signal homogenizer
(design of Tunheng and Hirata, 2004) was used for mixing all the gases and aerosol, resulting in smooth, spike-free signal. The signal was tuned for maximum sensitivity of Pb and U and low oxide level (below 0.1% as measured at the beginning of the analytical session). Typical acquisitions consisted of a 15 second measurement of blank followed by measurement of U, Th and Pb signals from the ablated phosphates for another 35 seconds. A total of 420 mass scans were acquired in time resolved – peak jumping – pulse counting / analogue mode with 1 point measured per peak for masses $^{204}$Pb + Hg, $^{208}$Pb, $^{207}$Pb, $^{232}$Th, $^{238}$U, and $^{235}$U. Owing to a non-linear transition between the counting and analogue acquisition modes of the ICP instrument and the fact that $^{238}$U is usually measured in “both” mode, the raw data were pre-processed using a Python routine for decoding the Thermo Element ICPMS data files (Hartman et al., 2017) and an in-house Excel macro. As a result, the intensities of $^{238}$U were left unchanged if measured in a counting mode and recalculated from $^{238}$U intensities if the $^{238}$U was acquired in an analogue mode, thus eliminating the non-linearity between pulse-counting and analogue-detecting modes. Data reduction then was carried out off-line using the lolite data reduction package version 3.4 with the VizualAge utility (Petrus and Kamber, 2012). Full details of the data reduction methodology can be found in Paton et al. (2010). The data reduction included correction for gas blank, laser-induced elemental fractionation of Pb and U and instrument mass bias. For the data presented here, blank intensities and instrumental bias were interpolated using an automatic spline function, while down-hole inter-element fractionation was corrected using an exponential function. No common Pb correction was applied to the data, owing to the high Hg contamination of the commercially available He carrier gas, which precludes accurate correction of the interfering $^{204}$Hg on the very small signal of $^{206}$Pb (common lead).

Residual elemental fractionation and instrumental mass bias of monazite analyses were corrected by normalization to the natural monazite sample from Jarasinga leptynite (India), with a TIMS U-Pb age of 953 ± 4 Ma (Aftalion et al., 1991). The monazites Manangoutry (Madagascar, 555 ± 2 Ma; Paquette and Tiepolo, 2007) and Itambe (Brazil, $^{208}$Pb/$^{235}$U age of 506.4 ± 0.7 Ma; Gonçalves et al., 2016) were periodically measured for quality control. The obtained values of $^{206}$Pb/$^{235}$U values of 553.1 ± 2.8 and 505.3 ± 2.3 Ma (2σ), respectively, are less than 1% within their published values. In line with the recommendations of Horstwood et al. (2016), the excess variance (Paton et al., 2010) of the reference Jarasinga monazite was calculated in Isoplot and quadratically added to the measurement uncertainties of all unknowns as well as to all pooled ages (weighted average and U-Pb Concordia age as it is called in Isoplot).

Residual elemental fractionation and instrumental mass bias of zircon analyses were corrected by normalization to the natural zircon reference material Plešovice (Sláma et al., 2008). The excess variance (Paton et al., 2010) of the primary Plešovice zircon was calculated in Isoplot and quadratically added to the measurement uncertainties of all unknowns including validation zircon reference materials GJ-1 [nr. 63] (Jackson et al., 2004) and 91500 (Wiedenbeck et al., 1995). These two were analysed periodically during the measurement for quality control. The obtained values (GJ-1: concordia age of 603 ± 4 Ma (2σ); 91500: concordia age of 1068 ± 5 Ma (2σ)) correspond perfectly and are less than 1% accurate within the published reference values (GJ-1: $^{206}$Pb/$^{238}$U age of 600.5 ± 0.4 Ma, Schaltegger et al., 2015 and $^{207}$Pb/$^{206}$Pb age of 608.53 ± 0.4 Ma, Jackson et al., 2004 respectively; 91500: $^{207}$Pb/$^{206}$Pb age of 1065.4 ± 0.3 Ma, Wiedenbeck et al., 1995).

The U-Pb ages are presented as concordia (pooled) age and probability density plots, generated with the ISOPLOT program v. 4.16 (Ludwig, 2012).

RESULTS

Zircon geochronology

The oscillatory zoning and Th/U ratios >0.1 (except for one analysis) indicate an igneous origin of the zircons investigated (cf., Rubatto, 2017). Nightly eight U-Pb analyses with <10% discordance, out of 140 analyses performed (one analysis per grain), yielded ages broadly ranging from 3.34 Ga to 504 Ma (sample SUD24/1; Appendix 1). The detrital population is dominated by Neoproterozoic and Palaeoproterozoic grains (Figs 3, 4). The two oldest zircon ages recognized are Archean: 3.34 and 2.61 Ga. They were determined for the oscillatory zoned cores of ca. 100 μm anhedral zircon grains. The Palaeoproterozoic is represented by 16 anhedral zircons, variously structured (homogeneous to oscillatory zoned) and sized (70 to 200 μm), with ages ranging from 2.33 to 1.81 Ga. A single age of ca. 1.42 Ga came from the core of a small (70 μm long) zonal zircon. A minor cluster of 1089–722 Ma is formed by 12 small ca. 100–120 μm anhedral grains, usually bright in CL and oscillatory zoned. The major age cluster is of Cryogenian-Ediacaran age (696—547 Ma; n = 65). The Cryogenian- Ediacaran zircons are subhedral to anhedral grains, 70 to 250 μm in diameter that exhibit predominantly oscillatory zoning and, occasionally, sector zoning. Two younger ages (521 and 504 Ma) have been obtained from small, subhedral zircons ca. 70–80 μm long, showing an oscillatory zoned structure (Figs 3A, C, D; Appendix 1). The maximum depositional age of the protolith of the investigated mica schist, calculated using five youngest $^{208}$Pb/$^{235}$U ages (discrepancy ≤ 3%) that overlap within error (2σ) with the youngest age, is 560.9±9.1 Ma (MSWD = 0.83, probability of concordance 0.36). No younger component has been found in the zircon population studied.

Monazite composition and age data

Monazite in both mica schists investigated (SUD24/1 and SUD24/2) is present as anhedral grains in the rock matrix, with sizes from several to ca. 60 μm and commonly forming aggregates. Individual monazite grains up to ca. 100 μm are present in the SUD24/1 sample. Rare, small inclusions of monazite in garnet also occur, but these are too small for accurate EPMA measurements. Monazite grains are homogeneous or, rarely, demonstrate growth or patchy zoning. The composition varies significantly within the monazite
Fig. 3. Results of U-Pb LA-ICP-MS zircon dating. A. Cathodoluminescence images and LA-ICP-MS ages of selected zircons from the Kamieniec Ząbkowicki Metamorphic Belt (sample SUD24/1). Scale bar under CL images (100 μm) refer to all zircon grains. Spot labels correspond to labels in Appendix 1. B. Concordia U-Pb plot. Analyses with discordance >10% are indicated by grey ellipses. C. Probability density plot; $^{206}\text{Pb}/^{238}\text{U}$ ages are given for data <1 Ga, $^{207}\text{Pb}/^{206}\text{Pb}$ ages are given for data >1 Ga. D. Concordia U-Pb plot in Neoproterozoic / Early Paleozoic range. Analyses with discordance <10%.

Fig. 4. Distribution of U-Pb ages vs. Th/U ratio in detrital zircons in mica schists SUD42/1.
population, including 1.58–9.44 wt.% ThO$_2$, 0.24–1.31 wt.% UO$_2$, 24.40–30.09 wt.% Ce$_2$O$_3$ in SUD24/1 and 3.07–16.37 wt.% ThO$_2$, 0.11–1.48 wt.% UO$_2$, 21.23–30.01 wt.% Ce$_2$O$_3$ in SUD24/2 (Appendix 2).

The isotopic U-Pb measurements in 8 grains (1–3 analyses per grain) from sample SUD24/1 demonstrated considerable discordance, indicating the presence of common Pb, which is rare for monazite (Fig. 5E;...
Appendix 3). The lower intercept at 329.8±4.3 Ma (MSWD = 0.21, n = 13; Fig. 5E) is the same as an U-Pb Concordia age of 329.6±9.6 Ma (2σ, MSWD = 0.15; Fig. 5F) yielded by four analyses with a discordance from -0.2 to +2.3%. Monazite in SUD24/2 sample yielded individual U-Th-total Pb dates from ca. 318 to 391 Ma (Appendix 4), with a mean age of 330±5 (2σ, MSWD = 0.57, n = 36, Fig. 6C). The Th*-Pb isochron trend indicates minor Pb loss within the monazite population, rather than the presence of common Pb (Fig. 6D). Because “chemical” age data were obtained mostly in small grains and there is no robust method to constrain the presence of common Pb or Pb loss in individual grains, these results should be viewed with caution. However, an agreement between the U-Pb Concordia and U-Th-total Pb mean ages partially suggest that the latter also can be used in further interpretations.

**DISCUSSION**

The zircon age data demonstrate that the detrital age spectra of the Kamieniec Ząbkowicki mica schists are dominated by two age clusters, Neoproterozoic and Palaeoproterozoic, with the predominance of Ediacaran ages (Figs 3, 4). The latter indicate that the protolith of the mica schists studied was deposited in a sedimentary basin with supply from source areas dominated by Ediacaran crystalline rocks.

The zircon data provide new insights into the provenance of the high-pressure mica schists of the KZMB. The source areas were composed mainly of Neoproterozoic, predominantly Ediacaran to Cryogenian, igneous rocks with a less common Palaeoproterozoic component. The zircon age spectrum is similar to those known from Saxothuringia, derived from the West African Craton in Gondwana (Linnemann et al., 2007, 2014; Fig. 7A). In the Sudetes, such detrital zircon age spectra were found in metasedimentary rocks of the Lusatian and Izera-Karkonosze massifs (e.g., Linnemann et al., 2007, 2014; Zelaźniewicz et al., 2009; Oberek-Dziedzic et al., 2010a; Žáčková et al., 2012), metavolcanosedimentary rocks of the Kaczawa Fold Belt (Kryza et al., 2007; Kryza and Zelasieczwicz, 2008; Tyszka et al., 2008), paragneisses, mica schists and quartzites of the Orlica-Śnieżnik Dome (Jastrzębski et al., 2010, 2015; Mazur et al., 2012, 2015), quartzites of the Staré Město Belt (Jastrzębski et al., 2015) and also in some paragneisses of the Strzelin Massif (Oberek-Dziedzic et al., 2018). Such zircon age characteristics are also very similar to that in the Erzgebirge region of the Saxothuringian plate (Collett et al., 2020 and references therein). In the adjacent northern part of Brunovistulia (the Strzelin Massif and Silesian Domain of the Moravo-Silesian Zone), rocks contain significant amount of 1.4 Ga zircons and for this reason they are expected to have been derived from the Amazonian part of Gondwana (Oberek-Dziedzic et al., 2003; Zelaźniewicz et al., 2005; Mazur et al., 2010).

In the Kamieniec Ząbkowicki metapelites, a single analysis of ca. 1418 Ma (Appendix 1) was obtained in the narrow core of a zoned grain (Fig. 3A). An interpretation that the KZMB sedimentary basin was located within the delivery reach of the detritus, ultimately derived from rocks similar to those of the Rondonia province in Amazonia, would not be well founded (Figs 3, 4).

Fig. 6. U-Th-total Pb EPMA monazite dating. A–B. BSE images of monazite grains from the mica schist SUD24/2. Analytical spot labels correspond to analysis labels in Appendix 4; dates are given in (Ma). C–D. Results of U-Th-total Pb dating. Th* values denote measured Th plus U converted to hypothetical Th with respect to production of the equivalent amount of radiogenic Pb (Konečný et al., 2018). Negative value of isochron intercept with Pb axis indicates minor Pb loss in monazite population.
However, a statistically more important group, defined by the 1089–722 Ma age cluster (n = 12), indicates a Grenvillian component, the presence of which cannot be easily reconciled with a source on the West African Craton. This requires seeking the Grenvillian or other source(s) with similar timing in nearby fragments of Rodinia/Gondwana. In Amazonia, anorogenic granites of Rondonia were emplaced at 990–900 Ma (Dall’Agnol et al., 1987). On the other hand, in southern Scandinavia, the Sveconorwegian (1.14–0.90 Ga) events were followed by the abortive breakup of Rodinia around 850 Ma (Paulsson and Andréasson, 2002), which corresponds to the Tonian group of zircons identified in the mica schists investigated. Clearly more work has to be done to expand the age dataset of detrital zircons and shed more light on the provenance of the region studied.

A West African Craton affinity of the KZMB rocks is still the most probable, as their zircon age spectra are practically without Mesoproterozoic ages. It has to be noted that a true depositional age of the protolith may be younger than the calculated maximum depositional age of 560.9±9.1 Ma (cf., Cawood et al., 2012). Sedimentation of the protoliths of the mica schists of the KZMB thus probably commenced in the Ediacaran, but the onset of deposition in the Cambrian cannot be excluded.

Most of the detrital zircons reveal Th/U ratio >0.1 characteristic for igneous rocks (e.g., Rubatto, 2017). Zircons with Th/U ratio <0.1 are scarce (Fig. 4), so that no distinct metamorphic episode in the source area of the sedimentary basin can be distinguished. Nevertheless, the presence of 30% of U-Pb ages highly (>10%) discordant (Fig. 3B; not considered and not shown in the histogram on Figure 3C) indicates partial Pb loss in the detrital zircon population. The zircons investigated demonstrate no record of post-depositional metamorphic regrowth (Figs 3, 4).

The LA-ICP-MS U-Pb isotopic and EPMA U-Th-total Pb dating revealed that all the monazites investigated represent a ca. 330 Ma Carboniferous thermal event with no inherited ages. In the NE Bohemian Massif, such Early Carboniferous ages are common in tectonostratigraphic units that belong to both the Saxothuringian Zone and also to the Moldanubian Zone. Compared to geochronological data from the Saxothuringian units adjacent to the KZMB, ages of about 330 Ma generally are related to cooling or later thermal overprints. In metamorphic rocks of the Orlica-Śnieżnik Dome, Ar-Ar mica ages point to more protracted cooling between ~340 Ma and 320 Ma (Marheine et al., 2002; Schneider et al., 2006; for most recent reviews of geochronology of this unit see Skrzypek et al., 2017; Walczak et al., 2017 and Jastrzębski et al., 2019). On the other hand, the ca. 330 Ma monazite-forming event in the KZMB is generally 10–30 Myr. older than the late Variscan thermal event in the NW Brunovistulia (Szczeperański, 2002; Schulmann et al., 2014). The monazite age of ca. 330 Ma also contrasts with Devonian ages obtained in the Góry Sowie Massif (Teplá-Barrandia), the tectothermal evolution of which was accomplished much earlier, i.e., before ca. 360 Ma (van Breemen et al., 1988; O’Brien et al., 1997; Bröcker et al., 1998; Kryza and Fanning, 2007).

The zircon and monazite data altogether indicate that the KZMB mica schists and eclogites cannot be assigned either to Brunovistulia or to Teplá-Barrandia. Instead, the KZMB is geotectonically more compatible with the Orlica-Śnieżnik Dome, although the relevant rock complexes cannot be correlated directly across the Sudetic Marginal Fault because the tectonostratigraphic units in its walls represent different erosional levels over a vertical distance of some five kilometres (e.g., Cwojdziński and Żelaźniewicz, 1995). Both the Orlica-Śnieżnik Dome and the KZMB most probably can be assigned to the Saxothuringian microplate (e.g., Franke and Żelaźniewicz, 2000; Chopin et al., 2012; Obere-Dzdziec et al., 2015). However, it should be noted that some geotectonic models consider these rocks as part of the Moldanubian microplate, which played an active role during the Variscan

Fig. 7. Position of the Kamieniec Ząbkowicki Metamorphic Belt during the Early and Late Palaeozoic on palaeogeographic schemes modified after Franke et al. (2017). A. Gondwana before the Early Ordovician fragmentation. B. Variscan terranes during the Early Carboniferous. AM – Amazonia, IB – Iberia, AR – Armorica, SX – Saxothuringia, KZMB – Kamieniec Ząbkowicki Metamorphic Belt, TB – Teplá-Barrandia, GSM – Góry Sowie Massif.
collision (e.g., Matte et al., 1990). Both Saxothuringia and Moldanubia have West African connections and were adjacent in pre-Variscan times (Zák & Sláma, 2018); thus, the Moldanubian affinity of the KZMB cannot be excluded entirely.

Given the tectonic shuffling of rocks with different P-T records (Józefiak, 1998; Nowak, 1998) within the KZMB, the data of the present authors confirm that the belt can be interpreted as part of the edifice stacked by collision that developed between the northern tip of the Teplá-Barrandian/Bohemian terrane and the Brunovistulian terrane, as observed along the W-E transect from the Góry Sowie Massif to the Strzelin Massif (Fig. 1B). The KZMB (10–20 km outcrop breadth) is a narrow strip of an accretionary prism forced between two microcontinents, of which Brunovistulia represents the lower plate. Saxothuringia and the structurally higher Teplá-Barrandian/Bohemian terrane are in the upper plate. The original contact of these two terranes was later strongly modified by sinistral strike-slip tectonics, localized mainly in the Niemcza Shear Zone (Mazur and Puziewicz, 1995; Želaźniewicz, 1995) that also embraced dismembered fragments of the Sudetic ophiolite (Fig. 1B).

Metapelites of the KZMB, with the revealed “Saxothuringian” detrital zircon age spectra, may be interpreted as a fragment of Ediacaran–Cambrian (?) successes, characteristic of the Saxothuringian margin (Oberc-Dziedzic et al., 2018 for review), which was subducted to a depth of 40–50 km and involved in the Variscan belt in front of the Brunovistulian sector of Laurussia (Fig. 7B). In the KZMB, the main monazite-forming event occurred during regional metamorphism around 330 Ma, yet whether this took place at the HP stage or during exhumation remains unknown. In the belt, regional metamorphism was enhanced by an increased heat flow, concurrent with Mississippian granitic intrusions in the neighbouring unit, namely granodiorites in the Niemcza Shear Zone (Oliver et al., 1993; Pietranik et al., 2013) and tonalites emplaced in the Neoproterozoic (Brunovistulian) basement of the Strzelin Massif (Oberc-Dziedzic et al., 2010b). The Niemcza granodiorite/monzodiorite crystallized from a magma within a temperature range of 850–730 °C and pressure of 4 ± 1 kbar (Puziewicz, 1992), thus at depths similar to those, at which the KZMB schists and eclogites re-equilibrated at the temperature peak on a clockwise P-T path (Dziedzicowa, 1979; Nowak, 1998; Szczepański et al., 2018). The new data in the present account show that a rather complex amalgamation of rock units with different grades, which belong to the tectonic stack of Teplá-Barrandia/Bohemia, Saxothuringia and Brunovistulia, in the NE corner of the Bohemian Massif, took place in Mississippian times, mainly during the Viséan.

CONCLUSIONS

1. The maximum depositional age for the protolith of the metasedimentary rocks of the Kamieniec Ząbkowicki Metamorphic Belt is 560.9±9.1 Ma.

2. The predominance of zircon ages clustering in 1.09–0.55 Ga and 2.16–1.81 Ga, with only scarce Mesoproterozoic and Cambrian zircon ages, indicates that the source areas for the KMB metapelites may have been in the West African Craton, as was the case for other parts of the Saxothuringia microplate.

3. The U-Pb and U-Th-total Pb monazite age data indicate that the metamorphism of the mica schists investigated occurred during the Viséan-earliest Serpukhovian (ca. 330 Ma) and can be related to tectonic extrusion of the Saxothuringian rocks along western Brunovistulia.

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Results of the U-Pb LA-ICP-MS analyses of zircon in the mica schist SUD24/1

| Analysis | Isotope ratio | Age (Ma) and discordance (%) | Concentration (ppm) |
|----------|---------------|-------------------------------|---------------------|
|          | $^{206}$Pb/$^{238}$U | $2\sigma$ (abs) | $^{207}$Pb/$^{206}$Pb | $2\sigma$ (abs) | $^{207}$Pb/$^{206}$Pb | $2\sigma$ (abs) | Disc.1 $\%$ | $^{207}$Pb/$^{206}$Pb | $2\sigma$ (abs) | $^{207}$Pb/$^{235}$U | $2\sigma$ (abs) | $^{206}$Pb/$^{238}$U | $2\sigma$ (abs) | Disc.2 $\%$ | Th | U | Pb | Th/U |
| 1        | 6.410 0.350 | 0.353 0.019 | 0.78 0.1296 | 0.0051 | 2018 49 | 1939 90 | 3.9 2068 | 70 6.2 | 158 319 | 472 0.5 |
| 3        | 6.060 0.310 | 0.339 0.014 | 0.71 0.1270 | 0.0045 | 1980 45 | 1879 66 | 5.1 2049 | 64 8.3 | 111 343 | 319 0.3 |
| 4        | 0.750 0.017 | 0.092 0.002 | 0.61 0.0594 | 0.0010 | 567 10 | 564 11 | 0.5 578 | 33 2.4 | 632 783 | 509 0.8 |
| 6        | 0.854 0.022 | 0.101 0.002 | 0.54 0.0620 | 0.0012 | 625 12 | 620 13 | 0.8 656 | 40 5.5 | 353 399 | 351 0.9 |
| 8        | 0.916 0.025 | 0.109 0.003 | 0.59 0.0608 | 0.0013 | 657 13 | 666 16 | -1.4 608 | 46 9.5 | 136 287 | 147 0.5 |
| 9        | 0.744 0.022 | 0.089 0.003 | 0.52 0.0609 | 0.0014 | 565 13 | 547 15 | 3.2 615 | 49 11.1 | 512 2001 | 492 0.3 |
| 11       | 0.772 0.019 | 0.093 0.002 | 0.60 0.0602 | 0.0011 | 581 11 | 577 13 | 0.7 594 | 40 2.9 | 459 728 | 427 0.6 |
| 12       | 0.947 0.024 | 0.112 0.003 | 0.50 0.0616 | 0.0013 | 676 12 | 686 15 | -1.4 634 | 44 8.2 | 310 422 | 365 0.7 |
| 14       | 0.787 0.019 | 0.096 0.002 | 0.53 0.0595 | 0.0010 | 590 11 | 588 12 | 0.3 573 | 39 -2.6 | 466 644 | 437 0.7 |
| 17       | 3.118 0.081 | 0.250 0.006 | 0.36 0.0899 | 0.0024 | 1435 20 | 1439 32 | -0.3 1418 | 48 -1.5 | 51 139 | 97 0.4 |
| 19       | 8.190 0.260 | 0.399 0.014 | 0.40 0.1495 | 0.0047 | 2250 29 | 2160 63 | 4.0 2330 | 54 7.3 | 493 1009 | 409 0.5 |
| 20       | 0.787 0.021 | 0.094 0.003 | 0.47 0.0613 | 0.0014 | 588 12 | 579 15 | 1.5 623 | 49 7.1 | 97 153 | 253 0.6 |
| 21       | 6.710 0.280 | 0.369 0.016 | 0.68 0.1315 | 0.0042 | 2071 37 | 2024 74 | 2.3 2112 | 57 4.2 | 439 745 | 312 0.6 |
| 23*      | 0.741 0.019 | 0.091 0.002 | 0.67 0.0593 | 0.0010 | 562 11 | 558 12 | 0.7 572 | 36 2.4 | 58 76 | 82 0.8 |
| 24       | 1.693 0.055 | 0.168 0.005 | 0.60 0.0730 | 0.0018 | 1001 20 | 999 25 | 0.2 973 | 52 -2.7 | 72 101 | 215 0.7 |
| 26       | 5.270 0.180 | 0.325 0.011 | 0.58 0.1181 | 0.0033 | 1856 28 | 1814 55 | 2.3 1923 | 48 5.7 | 269 622 | 218 0.4 |
| 27*      | 0.723 0.019 | 0.089 0.002 | 0.61 0.0594 | 0.0013 | 550 11 | 547 12 | 0.6 550 | 45 0.5 | 219 456 | 189 0.5 |
| 29       | 0.819 0.022 | 0.098 0.003 | 0.58 0.0612 | 0.0013 | 606 12 | 599 15 | 1.1 622 | 45 3.7 | 131 344 | 130 0.4 |
| 30       | 0.814 0.022 | 0.098 0.003 | 0.63 0.0604 | 0.0013 | 602 12 | 603 15 | -0.2 588 | 46 -2.6 | 169 135 | 187 1.3 |
| 31       | 0.983 0.031 | 0.114 0.003 | 0.54 0.0626 | 0.0016 | 690 16 | 696 19 | -0.9 657 | 54 -5.9 | 330 246 | 1388 1.3 |
| 32       | 0.888 0.027 | 0.105 0.003 | 0.62 0.0612 | 0.0014 | 643 14 | 645 17 | -0.3 620 | 47 -4.0 | 39 380 | 34 0.1 |
| 35       | 24.880 0.700 | 0.652 0.019 | 0.79 0.2760 | 0.0049 | 3301 27 | 3233 74 | 2.1 3337 | 28 3.1 | 257 226 | 203 1.1 |
| Analyze | Age (Ma) | Th/U | Pb | 207Pb/206Pb | 206Pb/238U | 207Pb/235U | 206Pb/238U | Rho | 207Pb/206Pb | 2σ (abs) | 2σ (abs) | 2σ (abs) | 2σ (abs) | Concentration (ppm) |
|---------|--------|-----|----|-------------|------------|-------------|------------|-----|-------------|---------|---------|---------|---------|-------------------|
| 40      | 0.879  | 0.023 | 0.096 | 0.0671     | 0.0013     | 0.13        | 13         | 7.6 | 8.24       | 41      | 28.5    | 327     | 397     | 275               |
| 41      | 6.470  | 0.330 | 0.361 | 0.1294     | 0.0034     | 2035        | 12         | 599 | 2.6        | 13      | 2.6     | 89      | 128     | 322               |
| 42      | 0.790  | 0.022 | 0.095 | 0.0602     | 0.0001     | 590         | 12         | 585 | -0.2       | 15      | 1.4     | 61.3    | 49      | 7.7               |
| 43      | 0.919  | 0.033 | 0.108 | 0.0617     | 0.0019     | 659         | 17         | 660 | 15         | 15      | 6.1     | 312     | 123     | 262               |
| 44      | 1.719  | 0.039 | 0.122 | 0.0611     | 0.0014     | 651         | 14         | 640 | 11         | 11      | 6.1     | 410     | 208     | 348               |
| 45      | 0.772  | 0.018 | 0.094 | 0.0601     | 0.0011     | 581         | 10         | 578 | 12         | 12      | 0.6     | 664     | 1138    | 577               |
| 46      | 0.889  | 0.023 | 0.105 | 0.0614     | 0.0017     | 1014        | 19         | 1026| 25         | 25      | -1.2    | 785     | 41      | 1255              |
| 47      | 0.802  | 0.028 | 0.106 | 0.0622     | 0.0021     | 643         | 12         | 644 | 12         | 12      | -0.1    | 626     | 48      | 3.6               |
| 48      | 0.754  | 0.029 | 0.107 | 0.0662     | 0.0022     | 623         | 17         | 626 | 17         | 17      | 1.1     | 666     | 48      | 9.2               |
| 49      | 0.806  | 0.019 | 0.095 | 0.0603     | 0.0011     | 581         | 10         | 592 | 14         | 14      | 1.0     | 592     | 41      | 0.0               |
| 50      | 0.885  | 0.026 | 0.104 | 0.0618     | 0.0014     | 641         | 15         | 636 | 17         | 17      | 0.8     | 648     | 48      | 1.9               |
| 51      | 11.950 | 0.200 | 0.573 | 0.1763     | 0.0040     | 2596        | 33         | 2564| 8.3        | 8.3     | 1.2     | 2608    | 38      | 1.7               |
| 52      | 0.812  | 0.020 | 0.090 | 0.0622     | 0.0013     | 602         | 11         | 557 | 13         | 13      | 7.5     | 776     | 42      | 28.2             |
| 53      | 0.851  | 0.026 | 0.095 | 0.0614     | 0.0011     | 598         | 10         | 592 | 14         | 14      | 1.0     | 592     | 41      | 0.0               |
| 54      | 0.685  | 0.019 | 0.095 | 0.0608     | 0.0008     | 633         | 16         | 638 | 18         | 18      | 0.8     | 586     | 56      | 8.9               |
| 55      | 0.818  | 0.026 | 0.095 | 0.0616     | 0.0016     | 623         | 17         | 626 | 17         | 17      | 0.8     | 648     | 48      | 1.9               |
| 56      | 4.490  | 0.100 | 0.378 | 0.1316     | 0.0055     | 4095        | 23         | 4062| 23         | 23      | -1.2    | 2108    | 34      | 1.8               |
| 57      | 4.680  | 0.190 | 0.292 | 0.1129     | 0.0025     | 1720        | 24         | 1677| 24         | 24      | -1.7    | 1805    | 24      | 8.4               |
| 58      | 1.267  | 0.022 | 0.095 | 0.0653     | 0.0017     | 726         | 16         | 722 | 16         | 16      | 0.6     | 745     | 56      | 3.1               |
| 59      | 1.355  | 0.038 | 0.095 | 0.0668     | 0.0018     | 532         | 11         | 521 | 11         | 11      | 0.3     | 752     | 56      | 3.1               |
| 60      | 0.693  | 0.021 | 0.095 | 0.0631     | 0.0018     | 1009        | 49         | 706 | 46         | 46      | 2.6     | 806     | 1161    | 564               |
| 61      | 0.732  | 0.019 | 0.095 | 0.0640     | 0.0014     | 577         | 11         | 521 | 13         | 13      | 6.5     | 760     | 46      | 2.6               |
| 62      | 1.520  | 0.040 | 0.095 | 0.0628     | 0.0014     | 577         | 11         | 521 | 13         | 13      | 6.5     | 760     | 46      | 2.6               |
| 63      | 1.472  | 0.022 | 0.095 | 0.0669     | 0.0014     | 590         | 13         | 588 | 13         | 13      | 6.1     | 612     | 47      | 3.9               |
| 64      | 0.803  | 0.023 | 0.096 | 0.0602     | 0.0002     | 596         | 13         | 588 | 13         | 13      | 6.1     | 612     | 47      | 3.9               |
| AGE | Constraint | Temperature | Plane | Radiometric | Geological | Hydrodynamic | 2D | 3D |
|-----|------------|-------------|-------|-------------|------------|--------------|-----|-----|
| 70  | 0.804      | 0.023       | 0.96  | 0.003       | 0.68       | 0.0608       | 0.0013| 598 | 13 |
| 72  | 0.742      | 0.019       | 0.90  | 0.002       | 0.55       | 0.0599       | 0.0012| 562 | 11 |
| 73  | 6.840      | 0.200       | 0.387 | 0.011       | 0.76       | 0.1295       | 0.0025| 2080| 26 |
| 76  | 0.881      | 0.032       | 0.103 | 0.003       | 0.51       | 0.0622       | 0.0019| 642 | 16 |
| 77  | 0.927      | 0.037       | 0.109 | 0.003       | 0.56       | 0.0619       | 0.0020| 657 | 19 |
| 78  | 1.172      | 0.032       | 0.129 | 0.003       | 0.63       | 0.0665       | 0.0014| 783 | 15 |
| 80  | 0.824      | 0.033       | 0.098 | 0.004       | 0.68       | 0.0618       | 0.0018| 608 | 18 |
| 81  | 0.793      | 0.027       | 0.097 | 0.003       | 0.57       | 0.0604       | 0.0016| 594 | 15 |
| 82  | 0.989      | 0.052       | 0.108 | 0.005       | 0.47       | 0.0673       | 0.0029| 691 | 27 |
| 84  | 1.094      | 0.037       | 0.124 | 0.003       | 0.49       | 0.0636       | 0.0018| 746 | 18 |
| 85* | 0.748      | 0.031       | 0.092 | 0.003       | 0.39       | 0.0588       | 0.0022| 566 | 18 |
| 86  | 0.926      | 0.024       | 0.110 | 0.003       | 0.60       | 0.0615       | 0.0012| 665 | 13 |
| 87  | 0.869      | 0.027       | 0.104 | 0.003       | 0.73       | 0.0611       | 0.0013| 633 | 15 |
| 91  | 0.809      | 0.023       | 0.097 | 0.003       | 0.60       | 0.0606       | 0.0013| 599 | 13 |
| 93  | 0.939      | 0.031       | 0.112 | 0.004       | 0.61       | 0.0613       | 0.0016| 668 | 16 |
| 94  | 7.470      | 0.220       | 0.399 | 0.011       | 0.73       | 0.1350       | 0.0025| 2168| 25 |
| 95  | 0.871      | 0.029       | 0.105 | 0.003       | 0.60       | 0.0611       | 0.0015| 632 | 15 |
| 97  | 0.824      | 0.026       | 0.095 | 0.003       | 0.48       | 0.0640       | 0.0019| 607 | 14 |
| 99  | 1.366      | 0.048       | 0.133 | 0.004       | 0.53       | 0.0750       | 0.0022| 868 | 21 |
| 100 | 0.777      | 0.022       | 0.094 | 0.003       | 0.55       | 0.0598       | 0.0014| 580 | 13 |
| 105 | 0.855      | 0.022       | 0.101 | 0.002       | 0.63       | 0.0617       | 0.0012| 625 | 12 |
| 107 | 0.789      | 0.026       | 0.096 | 0.003       | 0.55       | 0.0607       | 0.0016| 588 | 16 |
| 108 | 6.500      | 0.190       | 0.365 | 0.009       | 0.77       | 0.1287       | 0.0023| 2037| 25 |
| 110 | 0.966      | 0.036       | 0.108 | 0.004       | 0.70       | 0.0650       | 0.0018| 684 | 19 |
| 111 | 5.920      | 0.210       | 0.341 | 0.010       | 0.44       | 0.1284       | 0.0040| 1959| 32 |
| 112 | 0.825      | 0.026       | 0.098 | 0.003       | 0.48       | 0.0615       | 0.0015| 607 | 15 |
| 113 | 0.921      | 0.029       | 0.110 | 0.003       | 0.62       | 0.0608       | 0.0013| 658 | 15 |
| 114 | 0.935      | 0.029       | 0.111 | 0.003       | 0.61       | 0.0615       | 0.0014| 672 | 15 |
| 115 | 4.820      | 0.150       | 0.316 | 0.009       | 0.58       | 0.1117       | 0.0027| 1778| 27 |
| Analysis | Isotope ratio Age (Ma) and discordance (%) Concentration (ppm) |
|----------|---------------------------------------------------------------|
|          | $^{207}$Pb/$^{235}$U $2\sigma$ $^{206}$Pb/$^{238}$U $2\sigma$ ($\text{abs}$) $^{207}$Pb/$^{206}$Pb $2\sigma$ ($\text{abs}$) $^{207}$Pb/$^{235}$U $2\sigma$ ($\text{abs}$) $^{206}$Pb/$^{238}$U $2\sigma$ ($\text{abs}$) Disc. $^1$ § $^{207}$Pb/$^{206}$Pb $2\sigma$ ($\text{abs}$) Disc. $^1$ § $\text{Th}$ $\text{U}$ $\text{Pb}$ $\text{Th}/\text{U}$ |
| 117      | 5.630 0.170 0.344 0.009 0.62 0.1186 0.0026 1918 26 1904 44 0.7 1927 40 1.2 | 383 736 1223 0.5 |
| 118      | 0.816 0.026 0.100 0.003 0.74 0.0600 0.0014 605 16 612 18 -1.2 576 50 -6.3 |
| 120      | 0.892 0.031 0.106 0.003 0.49 0.0618 0.0019 641 16 647 18 -0.9 609 64 -6.2 |
| 121      | 5.340 0.170 0.330 0.010 0.73 0.1178 0.0017 1056 22 1037 28 1.8 1089 46 4.8 |
| 123      | 1.836 0.059 0.175 0.005 0.66 0.0763 0.0014 622 12 597 15 4.0 708 47 -6.3 |
| 124      | 0.808 0.028 0.097 0.003 0.63 0.0610 0.0016 598 16 593 18 0.8 603 54 1.7 |
| 125      | 0.847 0.022 0.097 0.003 0.52 0.0635 0.0014 617 16 622 19 -0.8 588 63 -5.8 |
| 126      | 0.819 0.030 0.094 0.003 0.60 0.0634 0.0018 607 17 579 19 4.6 691 59 16.2 |
| 127      | 0.936 0.029 0.107 0.003 0.59 0.0641 0.0016 668 15 651 18 2.5 722 51 9.8 |
| 128      | 0.852 0.030 0.101 0.003 0.73 0.0605 0.0013 620 16 619 18 0.2 594 45 -4.2 |
| 129      | 0.894 0.022 0.103 0.002 0.56 0.0625 0.0011 647 12 633 12 2.2 683 38 7.3 |
| 130      | 5.970 0.190 0.358 0.009 0.35 0.1210 0.0036 1960 28 1970 42 -0.5 1939 54 -1.6 |
| 131      | 0.793 0.025 0.097 0.003 0.65 0.0596 0.0013 590 14 594 16 -0.7 577 48 -2.9 |
| 132      | 0.835 0.027 0.100 0.003 0.53 0.0607 0.0016 615 15 615 17 0.0 581 56 -5.9 |
| 133      | 0.813 0.025 0.096 0.003 0.72 0.0611 0.0012 602 14 594 16 1.3 620 44 4.2 |
| 134      | 1.459 0.044 0.151 0.004 0.54 0.0703 0.0017 911 18 904 23 0.8 927 48 2.5 |
| 135      | 0.827 0.025 0.101 0.003 0.68 0.0596 0.0013 609 14 621 16 -2.0 566 48 9.7 |
| 136      | 1.453 0.035 0.149 0.003 0.55 0.0707 0.0013 909 15 895 19 1.5 941 38 4.9 |

Rejected data (disc. >10%)

| Analysis | Isotope ratio Age (Ma) and discordance (%) Concentration (ppm) |
|----------|---------------------------------------------------------------|
|          | $^{207}$Pb/$^{235}$U $2\sigma$ $^{206}$Pb/$^{238}$U $2\sigma$ ($\text{abs}$) $^{207}$Pb/$^{206}$Pb $2\sigma$ ($\text{abs}$) $^{207}$Pb/$^{235}$U $2\sigma$ ($\text{abs}$) $^{206}$Pb/$^{238}$U $2\sigma$ ($\text{abs}$) Disc. $^1$ § $^{207}$Pb/$^{206}$Pb $2\sigma$ ($\text{abs}$) Disc. $^1$ § $\text{Th}$ $\text{U}$ $\text{Pb}$ $\text{Th}/\text{U}$ |
| 2        | 0.924 0.037 0.094 0.003 0.59 0.0718 0.0015 663 14 566 45 12.5 973 44 46.4 |
| 5        | 0.376 0.149 0.247 0.008 0.61 0.1223 0.0023 1877 22 1774 39 5.5 1983 33 10.5 |
| 7        | 0.284 0.069 0.176 0.005 0.66 0.0843 0.0023 1199 22 1041 28 13.2 1492 46 38.2 |
| 10       | 0.284 0.057 0.195 0.008 0.76 0.0853 0.0022 1199 31 1139 41 4.3 1283 54 11.2 |
| 13       | 10.210 0.250 0.405 0.010 0.62 0.1049 0.0030 2449 22 2186 43 40.7 2663 27 17.9 |

Rejected data (disc. >10%)
AGE CONSTRAINTS ON THE THERMAL EVENTS
| Analysis | 207Pb/235U 2σ (abs) | 206Pb/238U 2σ (abs) | Rho 207Pb/206Pb 2σ (abs) | 207Pb/235U 2σ (abs) | 206Pb/238U 2σ (abs) | Disc. 1 § | Disc. 2 § |
|----------|----------------------|----------------------|--------------------------|----------------------|----------------------|------------|------------|
| 106      | 1.271                | 0.040                | 0.113                    | 0.0021               | 0.57                 | 0.0816     | 0.0024     |
| 109      | 0.270                | 0.011                | 0.380                    | 0.0062               | 0.290                | 0.01536    | 0.0065     |
| 116      | 0.750                | 0.130                | 0.408                    | 0.0029               | 0.615                | 0.0167     | 0.0029     |
| 119      | 0.770                | 0.110                | 0.408                    | 0.0054               | 0.697                | 0.02625    | 0.0058     |
| 122      | 4.447                | 0.110                | 0.407                    | 0.0024               | 5.05                 | 0.0167     | 0.0028     |
| 127      | 0.559                | 0.039                | 0.408                    | 0.0019               | 0.676                | 0.02625    | 0.0058     |
| 132      | 0.770                | 0.110                | 0.408                    | 0.0023               | 4.939                | 0.02625    | 0.0058     |
| 140      | 0.911                | 0.040                | 0.407                    | 0.0027               | 5.05                 | 0.02625    | 0.0058     |

Comments: * – analysis used for calculations of maximum depositional age; § disc. 1 = \(1 - \left(\frac{206\text{Pb}}{238\text{U}}\right) / \left(\frac{207\text{Pb}}{235\text{U}}\right)\) × 100 for zircon younger than 1 Ga; disc. 2 = \(1 - \left(\frac{206\text{Pb}/238\text{U}}{207\text{Pb}/206\text{Pb}}\right)\) × 100 for zircon older than 1 Ga.
## AGE CONSTRAINTS ON THE THERMAL EVENTS

The EMMA presenting composition of the monazite in the mica schist samples SUD24/1 and SUD24/2.

| Monazite | U | Th | K | Pb | Total |
|----------|---|----|---|----|-------|
| mzn1-1   | 30.32 | 0.56 | 7.23 | 0.47 | 99.83 |
| mzn1-2   | 30.78 | 0.47 | 7.23 | 0.47 | 99.83 |
| mzn2-1   | 30.26 | 0.56 | 7.23 | 0.47 | 99.83 |
| mzn2-2   | 30.47 | 0.47 | 7.23 | 0.47 | 99.83 |
| mzn3-1   | 30.45 | 0.56 | 7.23 | 0.47 | 99.83 |
| mzn3-2   | 30.89 | 0.47 | 7.23 | 0.47 | 99.83 |
| mzn4-1   | 31.14 | 0.47 | 7.23 | 0.47 | 99.83 |
| mzn4-2   | 30.12 | 0.56 | 7.23 | 0.47 | 99.83 |
| mzn5-1   | 30.05 | 0.56 | 7.23 | 0.47 | 99.83 |
| mzn5-2   | 30.34 | 0.47 | 7.23 | 0.47 | 99.83 |
| mzn6-1   | 30.77 | 0.56 | 7.23 | 0.47 | 99.83 |
| mzn6-2   | 30.56 | 0.47 | 7.23 | 0.47 | 99.83 |
| mzn7-1   | 30.29 | 0.56 | 7.23 | 0.47 | 99.83 |
| mzn7-2   | 30.56 | 0.47 | 7.23 | 0.47 | 99.83 |
| mzn8-1   | 30.89 | 0.56 | 7.23 | 0.47 | 99.83 |
| mzn8-2   | 30.56 | 0.47 | 7.23 | 0.47 | 99.83 |
| mzn9-1   | 30.34 | 0.56 | 7.23 | 0.47 | 99.83 |
| mzn9-2   | 30.56 | 0.47 | 7.23 | 0.47 | 99.83 |
| mzn10-1  | 30.77 | 0.56 | 7.23 | 0.47 | 99.83 |
| mzn10-2  | 30.56 | 0.47 | 7.23 | 0.47 | 99.83 |
| mzn11-1  | 30.34 | 0.56 | 7.23 | 0.47 | 99.83 |
| mzn11-2  | 30.56 | 0.47 | 7.23 | 0.47 | 99.83 |
| mzn12-1  | 30.77 | 0.56 | 7.23 | 0.47 | 99.83 |
| mzn12-2  | 30.56 | 0.47 | 7.23 | 0.47 | 99.83 |
| mzn13-1  | 30.34 | 0.56 | 7.23 | 0.47 | 99.83 |
| mzn13-2  | 30.56 | 0.47 | 7.23 | 0.47 | 99.83 |
| mzn14-1  | 30.77 | 0.56 | 7.23 | 0.47 | 99.83 |
| mzn14-2  | 30.56 | 0.47 | 7.23 | 0.47 | 99.83 |
| mzn15-1  | 30.34 | 0.56 | 7.23 | 0.47 | 99.83 |
| mzn15-2  | 30.56 | 0.47 | 7.23 | 0.47 | 99.83 |
| mzn16-1  | 30.77 | 0.56 | 7.23 | 0.47 | 99.83 |
| mzn16-2  | 30.56 | 0.47 | 7.23 | 0.47 | 99.83 |
| mzn17-1  | 30.34 | 0.56 | 7.23 | 0.47 | 99.83 |
| mzn17-2  | 30.56 | 0.47 | 7.23 | 0.47 | 99.83 |
| mzn18-1  | 30.77 | 0.56 | 7.23 | 0.47 | 99.83 |
| mzn18-2  | 30.56 | 0.47 | 7.23 | 0.47 | 99.83 |

**Note:** The table above provides a summary of the age constraints on the thermal events based on the analysis of monazite in mica schist samples. Each monazite is represented by its specific U, Th, K, Pb, and total values, indicating the age constraints for each event.
| Sample | Mn | Fe | Zn | Cu | Co | Ni | Cr | Al | Si | K | Ca | Mg | Mn | Fe | Zn | Cu | Co | Ni | Cr | Al | Si | K | Ca | Mg |
|--------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Mnz1-1 | 30.51 | 0.15 | 3.07 | 0.55 | 0.11 | 0.33 | 2.78 | 17.68 | 29.81 | 3.06 | 9.50 | 1.17 | 0.30 | 0.78 | 0.11 | 0.33 | 0.26 | 0.18 | 0.07 | 0.03 | 99.70 |
| Mnz1-2 | 30.57 | 0.46 | 3.97 | 0.66 | 0.12 | 0.35 | 13.33 | 28.57 | 3.43 | 12.35 | 2.52 | 0.16 | 1.22 | 0.20 | 0.36 | 0.12 | 0.13 | 0.10 | 0.06 | 0.04 | 100.15 |
| Mnz1-3 | 30.90 | 0.36 | 3.98 | 0.72 | 0.12 | 0.36 | 13.53 | 28.76 | 3.43 | 12.45 | 2.52 | 0.16 | 1.22 | 0.20 | 0.36 | 0.12 | 0.13 | 0.10 | 0.06 | 0.04 | 100.15 |
| Mnz1-4 | 29.69 | 0.19 | 2.83 | 0.45 | 0.09 | 0.26 | 14.29 | 31.01 | 3.22 | 10.82 | 1.17 | 0.17 | 0.24 | 0.04 | 0.42 | 0.11 | 0.18 | 0.04 | 0.07 | 0.10 | 00.96 |
| Mnz1-5 | 30.18 | 0.33 | 4.23 | 0.66 | 0.14 | 0.37 | 13.58 | 28.62 | 3.43 | 12.45 | 2.52 | 0.16 | 1.22 | 0.20 | 0.36 | 0.12 | 0.13 | 0.10 | 0.06 | 0.04 | 100.15 |
| Mnz1-6 | 29.75 | 0.19 | 2.83 | 0.45 | 0.09 | 0.26 | 14.29 | 31.01 | 3.22 | 10.82 | 1.17 | 0.17 | 0.24 | 0.04 | 0.42 | 0.11 | 0.18 | 0.04 | 0.07 | 0.10 | 00.96 |
| Mnz1-7 | 29.86 | 0.35 | 4.12 | 0.66 | 0.14 | 0.37 | 13.58 | 28.62 | 3.43 | 12.45 | 2.52 | 0.16 | 1.22 | 0.20 | 0.36 | 0.12 | 0.13 | 0.10 | 0.06 | 0.04 | 100.15 |
| Mnz1-8 | 29.68 | 0.41 | 2.83 | 0.45 | 0.09 | 0.26 | 14.29 | 31.01 | 3.22 | 10.82 | 1.17 | 0.17 | 0.24 | 0.04 | 0.42 | 0.11 | 0.18 | 0.04 | 0.07 | 0.10 | 00.96 |
| Sample | Value 1 | Value 2 | Value 3 | Value 4 | Value 5 | Value 6 | Value 7 | Value 8 | Value 9 | Value 10 | Value 11 | Value 12 | Value 13 | Value 14 | Value 15 | Value 16 | Value 17 | Value 18 | Value 19 |
|--------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| mzn21-2 | 30.48 | 0.60 | 6.82 | 0.41 | b.d.l. | 0.75 | 11.82 | 26.44 | 3.28 | 13.17 | 2.60 | 0.25 | 1.32 | b.d.l. | 0.24 | b.d.l. | 0.40 | 0.10 | 0.16 | b.d.l. |
| mzn21-3 | 29.79 | 1.01 | 9.53 | 0.43 | b.d.l. | 0.60 | 11.39 | 25.47 | 3.16 | 12.08 | 2.53 | b.d.l. | 1.27 | 0.12 | 0.23 | b.d.l. | 0.43 | b.d.l. | 0.18 | b.d.l. |
| mzn22-1 | 30.53 | 0.42 | 3.49 | 0.98 | 0.04 | 0.77 | 12.86 | 28.51 | 3.45 | 12.78 | 2.50 | 0.18 | 1.12 | b.d.l. | 0.31 | b.d.l. | 0.29 | b.d.l. | 0.11 | b.d.l. |
| mzn22-2 | 30.63 | 0.53 | 4.59 | 1.12 | b.d.l. | 0.68 | 10.91 | 26.55 | 3.63 | 14.57 | 3.16 | 0.24 | 1.67 | b.d.l. | 0.31 | b.d.l. | 0.20 | b.d.l. | 0.89 | 0.28 | b.d.l. |
| mzn22-3 | 30.11 | 0.36 | 3.17 | 0.97 | b.d.l. | 0.50 | 13.00 | 29.09 | 3.58 | 12.55 | 2.37 | 0.15 | 1.11 | b.d.l. | 0.10 | b.d.l. | 0.48 | b.d.l. | 0.11 | b.d.l. |
| mzn23-1 | 29.34 | 0.97 | 9.88 | 1.36 | b.d.l. | 0.62 | 10.57 | 24.60 | 3.10 | 12.34 | 2.53 | 0.23 | 1.16 | b.d.l. | 0.22 | b.d.l. | 0.44 | b.d.l. | 0.19 | b.d.l. |
| mzn23-2 | 29.99 | 0.56 | 6.67 | 0.76 | b.d.l. | 0.61 | 11.41 | 27.03 | 3.41 | 13.36 | 2.67 | 0.24 | 1.32 | b.d.l. | 0.20 | b.d.l. | 0.45 | 0.11 | 0.10 | b.d.l. |
| mzn23-3 | 29.78 | 0.50 | 4.62 | 0.39 | b.d.l. | 0.46 | 12.62 | 28.51 | 3.47 | 12.93 | 2.47 | b.d.l. | 1.04 | b.d.l. | 0.19 | b.d.l. | 0.39 | b.d.l. | 0.17 | b.d.l. |
| mzn23-4 | 29.63 | 0.63 | 6.65 | 1.48 | b.d.l. | 0.84 | 11.13 | 25.67 | 3.24 | 13.09 | 2.68 | 0.24 | 1.47 | 0.12 | 0.24 | b.d.l. | 0.34 | 0.13 | 0.22 | b.d.l. |
| mzn23-5 | 29.87 | 0.46 | 4.26 | 0.51 | b.d.l. | 0.54 | 11.96 | 27.77 | 3.56 | 13.30 | 2.73 | 0.22 | 1.27 | b.d.l. | 0.25 | b.d.l. | 0.29 | b.d.l. | 0.14 | b.d.l. |
| mzn23-6 | 30.01 | 0.26 | 3.69 | 1.14 | b.d.l. | 0.86 | 11.82 | 27.28 | 3.48 | 13.53 | 2.71 | 0.23 | 1.40 | 0.10 | 0.28 | b.d.l. | 0.30 | b.d.l. | 0.16 | b.d.l. |
| mzn23-7 | 30.21 | 0.43 | 5.09 | 0.69 | 0.14 | 0.77 | 11.05 | 26.47 | 3.46 | 13.91 | 3.01 | 0.18 | 1.54 | 0.08 | 0.31 | b.d.l. | 0.42 | b.d.l. | 0.17 | b.d.l. |
| mzn23-8 | 30.05 | 0.29 | 3.83 | 1.26 | b.d.l. | 0.95 | 11.42 | 26.86 | 3.50 | 13.62 | 2.85 | 0.18 | 1.53 | 0.09 | 0.36 | b.d.l. | 0.44 | b.d.l. | 0.15 | b.d.l. |
| mzn23-9 | 30.39 | 0.39 | 4.30 | 0.62 | b.d.l. | 0.74 | 11.36 | 27.01 | 3.48 | 14.19 | 2.98 | 0.23 | 1.56 | 0.13 | 0.23 | b.d.l. | 0.41 | b.d.l. | 0.15 | b.d.l. |
| mzn23-10 | 29.94 | 0.54 | 3.90 | 1.26 | b.d.l. | 0.62 | 11.91 | 28.06 | 3.45 | 13.66 | 2.72 | b.d.l. | 1.29 | b.d.l. | 0.33 | 0.09 | 0.17 | b.d.l. | 0.82 | 0.28 | b.d.l. |
| mzn23-11 | 29.79 | 0.61 | 3.82 | 0.89 | b.d.l. | 0.59 | 12.00 | 27.74 | 3.53 | 13.55 | 2.69 | 0.18 | 1.30 | 0.11 | b.d.l. | 0.31 | b.d.l. | 0.17 | b.d.l. |
| mzn23-12 | 30.03 | 0.45 | 4.26 | 0.76 | 0.14 | 0.77 | 11.05 | 26.47 | 3.46 | 13.91 | 3.01 | 0.18 | 1.54 | 0.08 | 0.31 | b.d.l. | 0.42 | b.d.l. | 0.17 | b.d.l. |
| mzn23-13 | 30.03 | 0.45 | 4.26 | 0.76 | 0.14 | 0.77 | 11.05 | 26.47 | 3.46 | 13.91 | 3.01 | 0.18 | 1.54 | 0.08 | 0.31 | b.d.l. | 0.42 | b.d.l. | 0.17 | b.d.l. |

Comments: all values are given in wt.%; b.d.l. – below detection limit.
Results of the LA-ICP-MS measurements of monazite from the mica schist SUD24/1

| Analysis | Isotope ratio | Concentration (ppm) |
|----------|---------------|---------------------|
|          | $^{206}\text{Pb}/^{238}\text{U}$ | $\pm 2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $\pm 2\sigma$ | $^{206}\text{Pb}/^{235}\text{U}$ | $\pm 2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $\pm 2\sigma$ | $^{208}\text{Pb}/^{206}\text{Pb}$ | $\pm 2\sigma$ |  |
| 1        | 0.447         | 0.016               | 0.054 | 0.002 | 0.42   | 0.0602 | 0.0012 | -22000  | 375    | 11  | 339   | 10 | 590 | 42 | 9.4   | 46300  | 12250 | 410  |
| 2        | 0.474         | 0.016               | 0.053 | 0.002 | 0.49   | 0.0646 | 0.0011 | -65000  | 393    | 11  | 335   | 9  | 740 | 37 | 14.7  | 87200  | 9540  | 759  |
| 3        | 0.572         | 0.021               | 0.054 | 0.002 | 0.48   | 0.0765 | 0.0016 | -105000 | 457    | 13  | 341   | 9  | 1084 | 41 | 25.5  | 88500  | 9910  | 787  |
| 4        | 0.508         | 0.020               | 0.054 | 0.002 | 0.31   | 0.0677 | 0.0018 | -40000  | 415    | 14  | 340   | 10 | 816 | 57 | 18.0  | 125400 | 4320  | 1078 |
| 5        | 0.471         | 0.021               | 0.054 | 0.002 | 0.29   | 0.0646 | 0.0021 | -24000  | 391    | 14  | 338   | 11 | 720 | 70 | 13.6  | 163600 | 6070  | 1359 |
| 6        | 0.396         | 0.016               | 0.052 | 0.002 | 0.44   | 0.0548 | 0.0013 | -100000 | 337    | 11  | 330   | 10 | 374 | 54 | 2.3   | 101900 | 5010  | 861  |
| 7        | 0.475         | 0.016               | 0.054 | 0.002 | 0.39   | 0.0643 | 0.0011 | -40000  | 394    | 11  | 337   | 9  | 728 | 38 | 14.5  | 89600  | 10390 | 799  |
| 8        | 0.459         | 0.016               | 0.053 | 0.002 | 0.41   | 0.0628 | 0.0011 | -130000 | 383    | 11  | 335   | 9  | 680 | 38 | 12.7  | 127900 | 21470 | 1122 |
| 9        | 0.500         | 0.017               | 0.054 | 0.002 | 0.51   | 0.0673 | 0.0012 | -42000  | 411    | 12  | 340   | 9  | 830 | 36 | 17.3  | 95800  | 11180 | 869  |
| 10       | 0.560         | 0.019               | 0.054 | 0.002 | 0.43   | 0.0749 | 0.0013 | -55000  | 451    | 13  | 342   | 10 | 1046 | 36 | 24.1  | 110500 | 11710 | 990  |
| 11       | 0.381         | 0.014               | 0.052 | 0.002 | 0.40   | 0.0728 | 0.0010 | -54000  | 328    | 10  | 328   | 9  | 302 | 42 | -0.2  | 43910  | 7380  | 383  |
| 12       | 0.383         | 0.014               | 0.052 | 0.002 | 0.33   | 0.0532 | 0.0011 | -38000  | 329    | 10  | 330   | 9  | 314 | 46 | -0.2  | 54800  | 9010  | 469  |
| 13       | 0.384         | 0.013               | 0.052 | 0.002 | 0.30   | 0.0535 | 0.0011 | -15000  | 329    | 10  | 328   | 9  | 330 | 45 | 0.3   | 45200  | 7750  | 386  |

Comments: § disc. = $\{1 - \left( {^{206}\text{Pb}/^{238}\text{U}} \right) / \left( {^{207}\text{Pb}/^{235}\text{U}} \right) \} \times 100$ for monazite younger than 1 Ga; disc. = $\{1 - \left( {^{206}\text{Pb}/^{238}\text{U}} \right) / \left( {^{207}\text{Pb}/^{206}\text{Pb}} \right) \} \times 100$ for monazite older than 1 Ga.
Results of the monazite EPMA dating in the mica schist SUD24/2 with concentrations of Th, U, Pb and Y

| Analysis | 2σ | 2σ | 2σ | 2σ | 2σ | 2σ | Age  |
|----------|----|----|----|----|----|----|------|
|          | Th | U  | Pb | Y  | Th*| Age |      |
| mzn1-1   | 3.71| 0.04| 0.61| 0.01| 0.08| 0.01| 5.73 | 328 | 46 |
| mzn1-2   | 3.49| 0.04| 0.61| 0.01| 0.07| 0.01| 5.50 | 306 | 48 |
| mzn1-3   | 4.02| 0.04| 0.67| 0.01| 0.09| 0.01| 6.23 | 342 | 42 |
| mzn2     | 11.10| 0.08| 0.66| 0.01| 0.20| 0.01| 13.37| 342 | 22 |
| mzn3     | 12.27| 0.09| 0.68| 0.01| 0.22| 0.01| 14.62| 342 | 21 |
| mzn5-1   | 10.74| 0.08| 0.62| 0.01| 0.18| 0.01| 12.86| 318 | 23 |
| mzn5-2   | 11.19| 0.08| 0.67| 0.01| 0.20| 0.01| 13.47| 329 | 22 |
| mzn5-3   | 10.79| 0.08| 0.85| 0.02| 0.20| 0.01| 13.67| 335 | 22 |
| mzn5-4   | 10.24| 0.08| 0.80| 0.01| 0.19| 0.01| 12.95| 329 | 23 |
| mzn6-1   | 12.81| 0.09| 0.97| 0.02| 0.24| 0.01| 16.11| 338 | 19 |
| mzn6-2   | 14.38| 0.10| 0.89| 0.02| 0.26| 0.01| 17.43| 339 | 18 |
| mzn7-1   | 5.50| 0.05| 0.64| 0.01| 0.11| 0.01| 7.64  | 331 | 35 |
| mzn7-2   | 6.28| 0.05| 0.71| 0.01| 0.13| 0.01| 8.65  | 335 | 31 |
| mzn9     | 2.69| 0.03| 0.50| 0.01| 0.07| 0.01| 4.36  | 344 | 59 |
| mzn12    | 4.59| 0.04| 0.98| 0.02| 0.11| 0.01| 7.83  | 329 | 34 |
| mzn18-1  | 3.82| 0.04| 1.29| 0.02| 0.11| 0.01| 8.05  | 313 | 34 |
| mzn18-2  | 3.02| 0.03| 1.15| 0.02| 0.10| 0.01| 6.78  | 332 | 40 |
| mzn18-3  | 3.25| 0.03| 0.57| 0.01| 0.07| 0.01| 5.11  | 323 | 51 |
| mzn20-1  | 4.02| 0.04| 0.14| 0.01| 0.07| 0.01| 4.51  | 342 | 57 |
| mzn21-1  | 4.67| 0.04| 0.75| 0.01| 0.10| 0.01| 7.17  | 310 | 37 |
| mzn21-2  | 6.00| 0.05| 0.40| 0.01| 0.11| 0.01| 7.35  | 326 | 37 |
| mzn21-3  | 8.37| 0.07| 0.43| 0.01| 0.15| 0.01| 9.84  | 350 | 29 |
| mzn22-1  | 3.06| 0.03| 0.93| 0.01| 0.09| 0.01| 6.12  | 317 | 43 |
| mzn22-2  | 4.04| 0.04| 1.02| 0.02| 0.11| 0.01| 7.40  | 321 | 36 |
| mzn22-3  | 2.79| 0.03| 0.88| 0.01| 0.08| 0.01| 5.68  | 314 | 46 |
| mzn23-1  | 8.69| 0.07| 1.25| 0.02| 0.19| 0.01| 12.85 | 334 | 23 |
| mzn23-2  | 5.87| 0.05| 0.71| 0.01| 0.11| 0.01| 8.23  | 307 | 33 |
| mzn23-3  | 4.06| 0.04| 0.37| 0.01| 0.07| 0.01| 5.32  | 290 | 49 |
| mzn23-4  | 5.84| 0.05| 1.35| 0.02| 0.15| 0.01| 10.28 | 329 | 27 |
| mzn23-5  | 3.74| 0.04| 0.48| 0.01| 0.08| 0.01| 5.33  | 329 | 49 |
| mzn23-6  | 3.24| 0.03| 1.03| 0.02| 0.09| 0.01| 6.62  | 316 | 40 |
| mzn23-7  | 4.47| 0.04| 0.65| 0.01| 0.09| 0.01| 6.62  | 303 | 40 |
| mzn23-8  | 3.37| 0.03| 1.15| 0.02| 0.10| 0.01| 7.12  | 325 | 37 |
| mzn23-9  | 3.77| 0.04| 0.58| 0.01| 0.08| 0.01| 5.71  | 319 | 46 |
| mzn23-10 | 3.43| 0.04| 1.14| 0.02| 0.10| 0.01| 7.18  | 324 | 37 |
| mzn23-13 | 3.36| 0.03| 0.81| 0.01| 0.09| 0.01| 6.04  | 323 | 43 |

Comments: Th* values denote measured Th plus U converted to hypothetical Th with respect to production of the equivalent amount of radiogenic Pb (Konečný et al., 2018)
