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Footprints of past geological events recorded in the petrography and mineralogy of rocks from the Krucze Skały excavation (Karkonosze Mountains, SW Poland)

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Joanna Michalak

Nicolaus Copernicus University in Toruń, Poland

Correspondence: Nicolaus Copernicus University in Toruń, Poland. E-mail: asia.m@doktorant.umk.pl

https://orcid.org/0000-0002-1061-401X

Abstract. TThe Krucze Skały excavation is located within the Izera-Kowary Unit, which is a subdivision of the Karkonosze-Izera Massif. Traces of numerous geological events have previously been recognised and described in other locations within this unit. In this specific location only pegmatitic intrusions have been tested tested until now. This research considers the geological history recorded in the petrography and mineralogy of all remaining rocks. Samples collected along the excavation were analysed using a polarising microscope and the XRD method. During the examination, records of the magmatic genesis of these rocks protolith, as well as evidence of MP-LT and LP-HT metamorphism, metasomathosis and hydrothermal activity were found.

Key words:
Karkonosze-Izera Massif,
Kowary gneiss,
granite-gneiss,
metamorphism

Introduction

The Karkonosze-Izera Massif is part of the Bohemian Massif, located in Central Europe (Mazur *et al.* 2010). Its origin and, consequently, its present arrangement are strongly connected to Variscan orogeny (Kryza, Mazur 1995; Mazur et al. 2010; Mazur 1995; Mazur, Kryza 1996; Oberc-Dziedzic 1985; Słaby, Martin 2008; Zagożdżon 2008; Žák, Klomínský 2007; Žák et al. 2013). The Izera-Kowary Unit is part of the Karkonosze-Izera Massif, which consists of metamorphic rocks divided by the granitic Karkonosze Pluton into two parts: the northern (Izera Gneisses), which is bigger and better recognised, and the south-eastern (Kowary Gneisses). Although this geological unit is not highly diversified in terms of mineralogy, it is characterised by the multitude of textures and fabrics (Żaba 1982). Signs of the past geological events that created this geological unit are well preserved and described in the literature (Aleksandrowski, Mazur 2002; Mazur 1995; Mazur, Kryza 1996, Jeřábek 2016). A lot of attention has been given to changes induced by the placing of the adjacent Karkonosze Pluton. Oberc-Dziedzic (1985) and Żaba (1979) covered this topic for the Izera Gneisses and Zagożdżon (2008) described the Kowary Gneisses.

The Krucze Skały excavation is located within the Kowary Gneisses unit, close to the boundary with Karkonosze Granite, and therefore may reveal significant information about this region's geological history. In this excavation only the mineral composition of pegmatites has previously been tested (Szełęg *et al.* 2010; Kozłowski Sachabiński 2007). The purpose of this work is to find footprints left by past geological events recorded in other types of rocks occurring in Krucze Skały.

Study area

The Krucze Skały excavation is situated in the district of Wilcza Poręba, in Karpacz, SW Poland (Fig. 1A). According to the physico-geographical regionalisation of Poland (Kondracki 2002) the investigated area lies within the Karkonosze mountains mesoregion, which is a subdivision of the Western Sudetes macroregion. The excavation emerges from the western slope of Kowarski Grzbiet, which is in the eastern part of the Karkonosze Mountains. This natural excavation arose at the foot of a slope in the Płomnica river valley. It extends from north-west to south-east and is about 160 m long. It is a range of three rocks separated by gorges nearly perpendicular to the river valley. For the purpose of this work they were named the northern, central and southern rocks. The excavation's walls are nearly vertical and cut with numerous fractures. The height of these walls differs across the excavation and locally reaches almost 30 m.

Geological setting and history

According to the tectonic subdivision of Poland (Żelaźniewicz et al. 2011), the Karkonosze-Izera Massif belongs to the European Variscides, and the Western Sudetes are part of the Variscan internides. The Izera-Kowary Unit is the biggest and the most intrinsic metamorphic unit of the Karkonosze-Izera Massif (Mazur et al. 2010; Oberc-Dziedzic

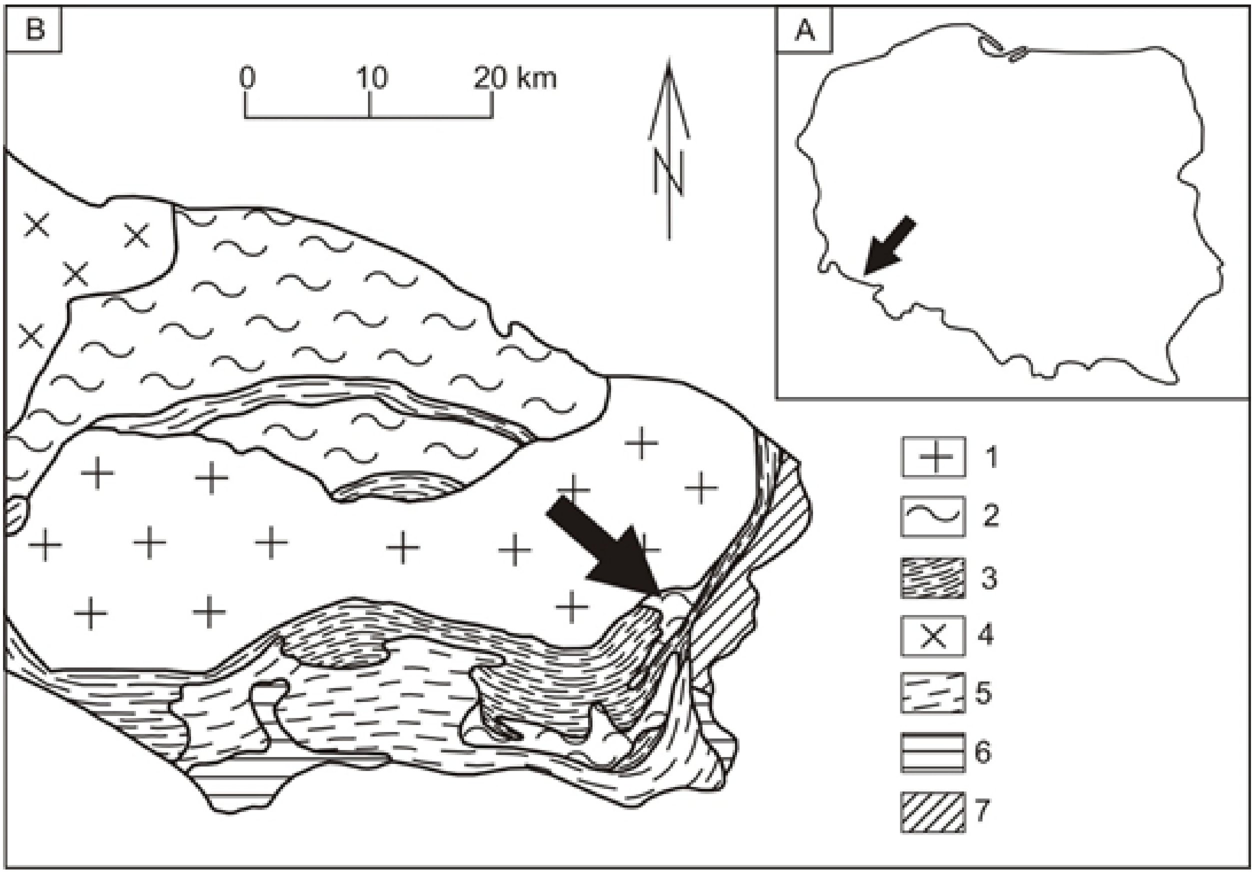

Fig 1. Location of the Krucze Skały excavation in Poland (A) and within the Karkonosze-Izera Massif, after Mazur et al. 2010 (B). 1 – Karkonosze granite, 2 – Izera/Kowary gneisses, 3 – mica schists, 4 – Lusatian granodiorites, 5 – phyllites, 6 – greenschists, 7 – metabasites and nerisses

et al. 2009). The research area lies in the western part of the Kowary gneiss (Szałamacha 1957; Fig. 1B), between mica schists and Karkonosze Granite (Teisseyre 1973). The location of the research area within the Karkonosze-Izera Massif is presented in Fig. 1B.

Magmatic bodies, which were protoliths of the examined orthogneisses, rose at the bottom of the Rheic Ocean (Mazur et al. 2010). According to Oberc-Dziedzic et al. (2010), U-Pb SHRIMP dating results show that protoliths of these gneisses and adjacent mica schists were formed at a similar time. The mica schists were considered a metamorphic envelope for the gneisses protolith (Oberc-Dziedzic 2003) but those two units adherence may also be an effect of later juxtaposition (Oberc-Dziedzic et al. 2010). The reason for the Cambrian magmatic bodies' uprising could be a continental crust rifting (Oberc-Dziedzic et al. 2005; Pin et al. 2007) or volcanic activity in the subduction zone (Kröner et al. 2001). Constituent parts of the Izera-Kowary unit – the Kowary, Izera and Karkonosze orthogneisses – are derived from one magmatic body, which is dated at 515–480 Ma by Borkowska et al. (1980, whole-rock Rb-Sr), Korytowski et al. (1993, U-Pb zircon), Kröner et al. (2001, single zircon vapour transfer and Sm-Nd whole-rock), Oliver et al. (1993, U-Pb zircon) and Żelaźniewicz (1994, U-Pb zircon). The Kowary orthogneiss exclusively was dated by Oberc-Dziedzic et al. (2010, U-Pb SHRIMP) at 487 ± 8 Ma and by Oliver et al. (1993, U-Pb zircon) at ~492–481 Ma.

During the Variscan orogeny, Izera-Kowary gneisses went through two stages of metamorphism (Mazur, Kryza 1996, Jeřábek 2016). The first stage – D1– was a compressional event encompassing overthrusting predated by the HP/LT metamorphism, and the second stage – D2– is an extensional event connected with uplift and exhumation (Mazur, Kryza 1996, Jeřábek 2016). The compressional stage can be connected to contraction during the Variscan orogeny and the extensional stage responds to extension during the late stage of the Variscan orogeny and after the end of it (Mazur et al. 2010, Jeřábek 2016). The extensional stage (D2), is when the Karkonosze Pluton occurred (Mazur and Kryza 1996). This post-orogenic magmatic activity may have been caused by the regional post-orogenic extension (Henk 1997) or by the delamination of thick crust under the Bohemian Massif (Finger et al. 2007). The Karkonosze Pluton consists of a few pulses of magma, whose emplacement is dated between 300 and 330 Ma (vide Mierzejewski 2007, and references therein).

Materials and methods

The first stage of research included field observations and sample collection. From the walls of excavation, 24 samples were taken. The location of sample collection is shown in the Fig. 2. Specimens were cut and described macroscopically. The next stage of work involved making thin sections and analysing them using a polarising microscope. Additionally, fragments of each sample were pulverised and examined using the XRD method. Examination was performed with an ARL X'TRA X-ray diffractometer from Thermo Electron Corporation, at the Faculty of Geographical and Geological Sciences of Adam Mickiewicz University in Poznań. The resultant diffractograms were processed with Win XRD software.

Results

Macroscopic description - petrography

The whole excavation consists of grey or slightly pinkish holocrystalline rocks. The main macroscopically observed minerals are quartz and feldspars. Features that differ across the excavation are: texture, grain size, fabric, and amount of dark minerals. Based on these distinctive attributes the collected samples were divided into four groups. Each of these groups is characterised in Table 1. Locations of sample collection are presented, with assigned groups, in Fig. 2.

Samples S01, S02, S03, S04, S09, S11 and S12 belong to group 1. They are non-foliated rocks with seriate texture. Occasionally oval quartz aggregates, of less than 1 cm in diameter occur. Grain size rarely exceeds 0.5 cm. The amount of dark minerals in this group is low compared to other groups. Sample

Table 1. Distinctive attributes of rocks from various groups

sample number		texture	grain size	fabric	amount of mafic minerals	type of rock
Group 1						
S01		seriate	< 0.5 cm	nonfoliated	+	Granitoids
S02					-	
S03			< 1 cm		+	
S04					-	
S09					-	
S11					+ +	
S12			< 1.2 cm		+	
Group 2						
S05		porphyritic	megacrysts up to 2.0 cm, groundmass up to 0.5 cm	poorly developed gneissose structure	+ +	granite-gneisses
S06					+ +	
S07					+ +	
S08					+	
S10					+ +	
S14					+ +	
S19					+	
Group 3						
S15		porphyritic	megacrysts exceeding 2.0 cm, groundmass <0.5 cm	well developed gneissose structure	+ +	Gneisses
S16					+ +	
S18					+ + +	
S20					+ + +	
S24					+ +	
Group 4						
A	S13	seriate	< 0.4 cm	nonfoliated	+ +	Aplite
	S21				+	
	S22				++	
B	S17	equigranular	< 1.0 cm		+	Pegmatite
	S23				+	

typical for this group is presented on Fig. 3A. Those rocks are granitoids and, as Fig. 2 shows, they occur mostly in the southern part of the excavation.

Group 2 includes samples S06, S07, S08, S10, S14, S19 and a fragment of rock in sample S05. These rocks' gneissosity is poorly developed. Some of them have hardly noticeable foliation, some do not even have it throughout the whole sample. The texture of these rocks is seriate or porphyritic. Megacrysts are grains of feldspar that can reach 2 cm, whereas groundmass ingredients are usually less than 0.5 cm in diameter. In this group quartz aggregates were also observed. Usually these aggregates have an elongated shape with less than 0.5 cm width and up to 1 cm length. The amount of dark minerals here is visibly higher than in the previous group. Rocks from this group were classified as granite-gneisses, because they present features transitional between granites and gneisses. A sample typical for this group is shown in Fig. 3B. Most of the granite-gneisses were collected from the central rock, but they can also be found in smaller amounts in northern and southern rock (Fig. 2).

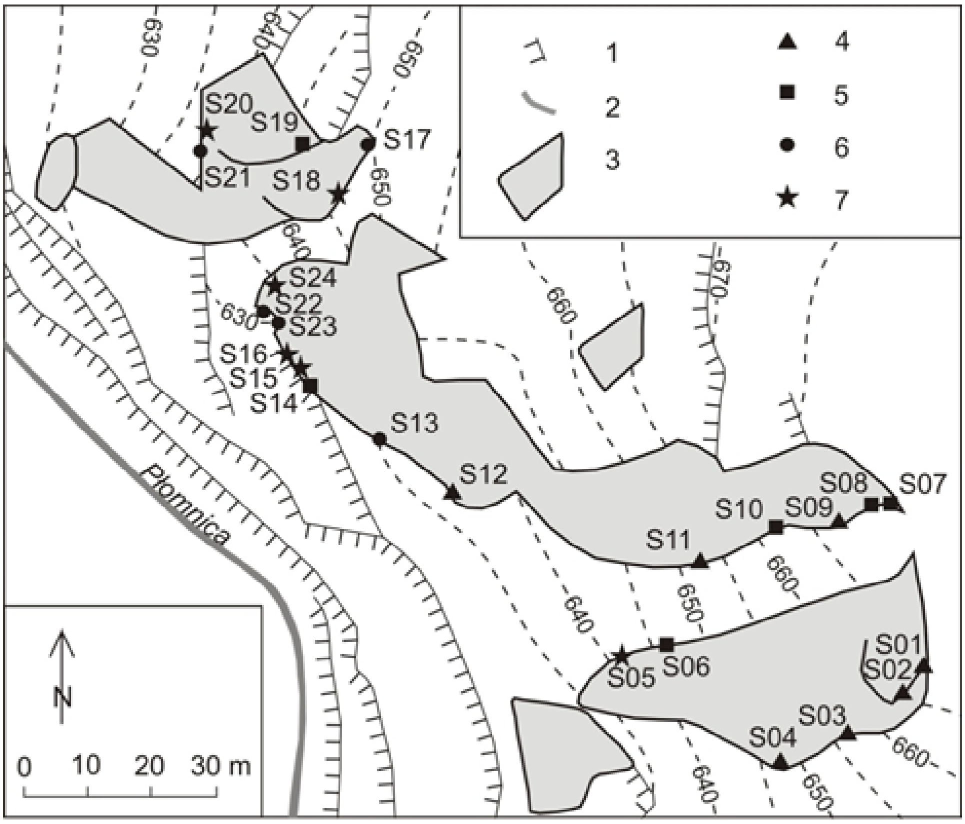

Fig. 2. Locations of sample collection with division into groups based on texture, grain size and fabric. 1 – scarps, 2 – stream, 3 – rocks, 4 – group 1 (granites), 5 – group 2 (granite-gneisses), 6 – group 3 (gneisses), 7 – group 4 (intrusive rocks); (explanations as in Table 1, Mapa zasadnicza; 1:500, arkusze: 461.441.1541, 461.441.1543.)

Group 3 consists of samples S15, S16, S18, S20 and S24. They have porphyritic texture. Megacrysts are bigger and more frequent than in the previous group. Their length usually exceeds 2 cm. Groundmass ingredients are even smaller than in previous groups and very rarely reach 0.3 cm. Quartz aggregates or ribbons are more widespread and longer. Their width, like in the previous groups, does not exceed 0.5 cm, but their length sometimes reaches more than 2 cm. These rocks have a well developed gneissose structure frequently emphasised by parallel arrangement of feldspathic megacrysts, quartz aggregates' longer axes and comparatively abundant strikes of dark minerals. Sample typical for this group can be seen in Fig. 3C. These rocks are classified as gneisses. They are most abundant in the northern part of the central rock, but they can also be seen in the northern rock (Fig. 2).

The Krucze Skały excavation consist mainly of these three types of rocks. Transitions between them are smooth, without pronounced boundaries. They change gradually along the excavation.

The last, fourth, group contains samples picked from intrusions which cut the excavation. Samples belonging to this group are S13, S17, S21, S22 and S23. The two remaining fragments of sample S05 also belong to this group. These rocks are non-foliated and based on grain size can be divided into two types. The fine-grained type (group 4A in Table 1) is represented by samples S13, S21 and S22, and examples of the coarse-grained type (group 4B in Table 1) are S17 and S20. Grains in fine-grained type are of less than 1 mm in diameter, while in the coarse-grained type grain diameters can reach 1 cm. Sample S05, shown at Fig. 3D, apart from the first granite-gneiss piece with foliation perpendicular to the intrusion, consists of a coarse-grained layer and a fine-grained layer and it shows well pronounced boundaries between them. Rocks from this group have a relatively small amount of dark minerals, but in group 4A the size of crystals is bigger than in the other groups. Some grains of minor minerals – sheets of biotite (more common) and muscovite (less common) – can reach a few millimetres in length. Rocks from this group have seriate (coarse-grained type) or equigranular (fine-grained type) texture. Coarse-grained rocks in group 4A can also contain a fragmentary granophyric texture. These rocks were identified as pegmatites – coarse-grained type (group 4A) – and as aplites – fine-grained type (group 4B).

Figure 2 shows that samples of intrusive rocks were picked mainly from the northern part of the central rock. There intrusions are biggest and the most abundant. The biggest one is represented by samples S22 and S23. It is around 4 m wide near the ground and its visible part becomes more narrow with altitude. Its height reaches over 7 m above ground level. It is discordant – not parallel to the fractures in the rocks. More discordant intrusions can be seen in the central rock southward from the biggest pegmatitic body, but their visible parts are significantly smaller. All of these intrusions consist of a pegmatitic inner part with common granophyric texture and an aplitic layer with diversified thickness. Concordant intrusions are more widespread across the excavation. Their thicknesses vary from around 1 m next to the biggest pegmatite, through 20–30 cm in the northern rock, for example where the sample S17 was picked, to less than 5 cm in the northern part of the southern rock, for example in the location where sample S05 was found (Fig. 2). Those concordant intrusions are typically embedded in the most horizontal set of fractures. Their layered structure is more pronounced and more ordered than in discordant ones. The inner pegmatitic layer is surrounded by aplitic lay-

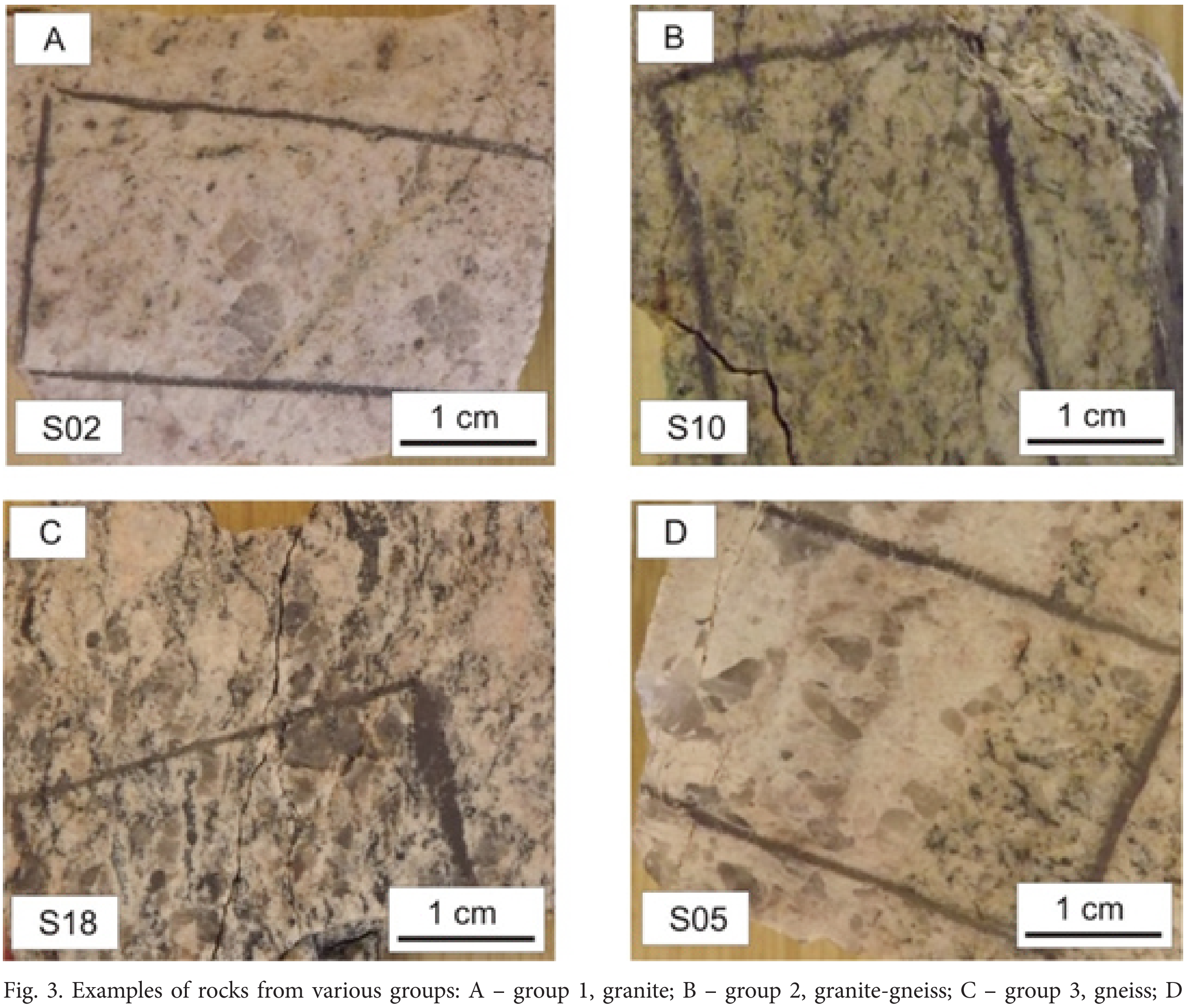

Fig. 3. Examples of rocks from various groups: A – group 1, granite; B – group 2, granite-gneiss; C – group 3, gneiss; D – group 4, intrusive rocks

ers of comparatively constant thickness. The lower aplitic layer is typically thicker than the upper one.

Microscopic description

Main minerals

For microscopic description, samples were divided into the same four groups as during macroscopic analyses. In all samples the main minerals are quartz and feldspars. Most abundant is plagioclase with narrow polysynthetic twinning. The measured extinction angle in intersections perpendicular to the x axis was low (7–15°). That indicated Na-rich plagioclase (albite or oligoclase). Cross-hatched twinning present in some feldspar grains indicate that microcline is also common. Simple twinning was rare. In terms of main minerals, almost all grains are xenomorphic. The only exceptions are a few individual plagioclase grains with diameters of less than 0.1 cm, which are automorphic or hipautomorphic.

Example of rock from the first group can be seen in Fig. 4. Quartz grains in this group have uneven, often embayed boundaries with some cases of bulging. Undulose extinction is very common. Quartz aggregates are composed of grains of usually 1 mm in diameter (Fig. 5). Feldspars have ragged or embayed boundaries. Sericitisation of plagioclase is also a common feature. Sometimes even sheets of sericite with vibrant interference colour can be seen. A small number of plagioclase grains has zonal structure with normal zoning, which manifests in stronger sericitisation in the inner parts of grains. In some plagioclase grains, kinking was observed – their polysynthetic twinning was curved.

In the second group megacrysts are made of feldspars, mainly plagioclase with polysynthetic twinning. Antiperthites are very common. Megacrysts are changed by sericitisation, which is strongest in external parts of grains. Their inner parts are cloudy while, on the edges and along the cracks, sericite sheets are big enough to show their vibrant interference colours. They frequently contain round inclusions of quartz.

In groundmass, quartz displays effects of grain boundary migration such as embayed boundaries or bulging. Undulose extinction is also very common. Quartz aggregates, just as in the previous group, are made of grains measuring around 1 mm or less. Most feldspars present in groundmass are sericitised. They are almost always cloudy and some of them contain sheets of sericite with vibrant interference colour. More intense sericitisation in some grains inner parts indicates that they are normally zoned.

In the third group megacrysts, as in the previous group, are made of feldspars, mainly plagioclase. They contain antiperthites. They are also sericitised, and this process is more intense along the boundaries of grains. Very common are round quartz inclusions, which are concentrated mainly near the edges of megacrysts.

Besides megacrysts, rocks from this group are made of three types of laminae. The first type of laminae are quartz ribbons or aggregates. They are usually have less than 5 mm in width and are made entirely of quartz grains with comparable straight boundaries. Foam structure occasionally appears. Grain size in these laminae can reach 3 mm. Undulose extinction and subgrains are common. The second type of laminae is made of quartz and feldspars. Grain size rarely exceeds 0.5 mm. Grain boundaries are relatively straight and quite pronounced. Sericitisation in feldspars is weakly developed. The third type of laminae also consists of quartz and feldspars, but here quartz is distinctly less abundant. The size of grains is more diversified here. They can reach 1 mm, but most of them are less than 0.2 mm in diameter. Feldspars here are clearly more sericitised. More advanced sericitisation in central parts of most grains indicates that normal zoning is common.

Rocks from group 4A and samples S23 and S05 from group 4B are quite similar. Boundaries between grains are comparably straight and well pronounced. Quartz shows very intense undulose extinction and sometimes contains subgrains. Sericitisation is not as strong as in previous groups. Stronger sericitisation in central parts of some plagioclase grains indicates normal zoning. Granophyric texture is very common here. In this group, perthites are more common than antiperthites. Some cases of myrmekites were observed, but they are quite scarce. The difference between those two groups is in grain size, which was marked in the macroscopic description.

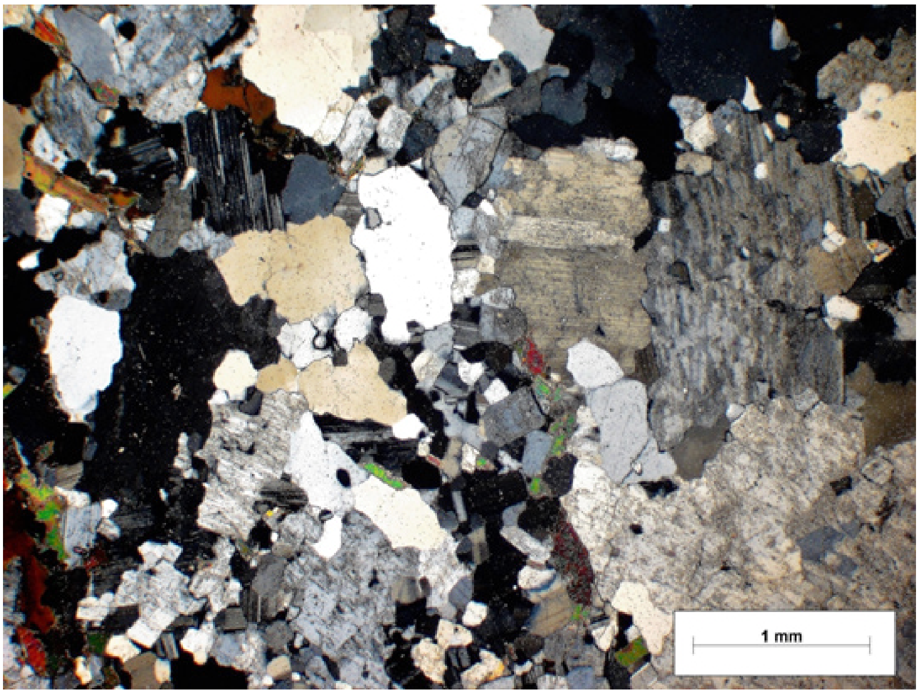

Fig 4. Example of rock from group 1 – granitoid with seriate texture and nonfoliated fabric

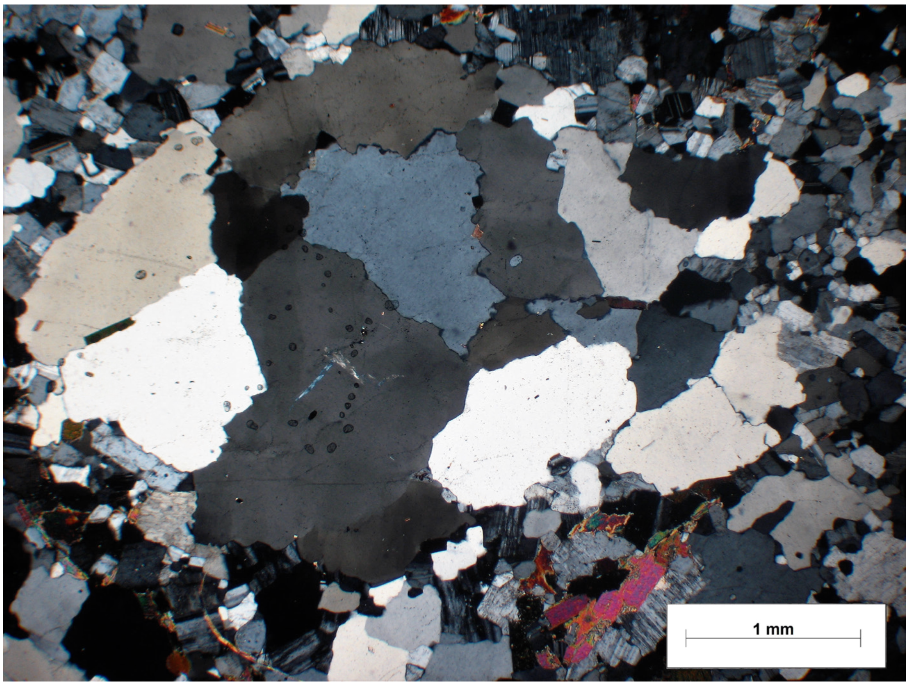

Fig. 5. Example of quartz aggregate present in rock from group 1

Sample S17 differs significantly from other samples in the group 4B. It has very common poikilitic texture. Grains of feldspars, which measure up to 7 mm, are filled with xenomorphic intergrowths of feldspar, often plagioclase, and chloritised biotite.

Minor rock components

Biotite is the most abundant of minor rock components. It is usually concentrated in groups or streaks, but in intrusive rocks it occurs as single, dispersed sheets. Biotite grains are often hipautomorphic and can reach over 1 mm in size. Degree of chloritisation varies within samples. Some biotite sheets are entirely chloritised, while some of them are chloritised only locally, or hardly even touched by this process. Chloritisation starts on edges and along cleavage plains. Some chlorite grains show a subnormal, blue interference colour. In group 3, where three types of laminae were distinguished, biotite is completely chloritised in the third type of laminae, and very weakly chloritized in the second type. The second minor rock component is muscovite, that appears only as a single, dispersed sheets in intrusive rocks.

Accessory minerals

In sample groups 1–3, accessory minerals are concentrated in clusters (in non-foliated rocks) or in streaks (in rocks with foliation).

The most common of accessory mineral is rutile. It usually appears near biotite sheets as xenomorphic grains of less than 500 μm in diameter. It is most abundant in samples from the first group. In the second group, rutile is more rare, and in the third group appears only occasionally. In rocks from groups 1 and 2, near these xernomorphic grains there also occur sporadic needles of rutile of less than 10 μm long.

Together with chloritised biotite and rutile, xenomorphic grains of opaque minerals and automorphic or hipautomorphic grains of zircon surrounded by a pleochroic halo occur. Opaque minerals can reach 200 μm in diameter, while the size of zircon grains rarely exceeds 50 μm.

Other, more rare accessory minerals are: apatite, tourmaline, pyroxene and corundum. They usually appear around biotite or biotite concentrations. Apatite occurs as xenomorphic grains or automorphic hexagonal prisms. Its diameter rarely exceeds 100 μm. Tourmaline appears as hipautomorphic prisms of less than 100 μm in length and strong pleochroism from transparent to dark brown. Pyroxene and corundum grains are always xenomorphic, and of less than 100 μm in diameter.

X-ray powder diffraction

Diffractograms obtained for all samples are quite similar in all types of rocks. The minerals that are always present are: quartz, plagioclase, alkali feldspar and muscovite (Fig. 6). This examination indicates that the occurring plagioclase is Na-rich albite, and the present potassium feldspar is microcline. The reflections typical of muscovite that frequently appear on the diffractograms may be an effect of common sericite occurrence. Examination proved the presence of chlorite and biotite in some samples, although they are not present on all diffractograms. This may be caused by the limited occurrence of these minerals in sample volumes.

Discussion

In terms of main mineral composition, all rocks from Krucze Skały excavation are quite similar. Those are: feldspars (mostly Na-rich plagioclase and microcline) and quartz. According to existing sources these rocks can be named quartzofeldspathic rocks (Oberc-Dziedzic et al. 2008). A few of the present plagioclase grains show more intense sericitisation in the central part of the grains, which may indicate normal zoning. That means a high rate of cooling. This agrees with the prevalent opinion that the protolith of present Kowary gneisses was igneous and formed from magma that raised as a consequence of partial melting of the continental crust (Żelaźniewicz et al. 2003; Oberc-Dziedzic 2003).

Minor rock components and accessory minerals are often concentrated in assemblages. Some of them, that have magmatic genesis are: biotite, apatite and zircon. Rarely occuring pyroxene is not accompanied by cordierite or andalusite therefore it may probably also have magmatic genesis, but it needs further study. Biotite crystals with a reddish tint, occuring together with grains of apatite may probably suggest that the protolith of the present gneisses is an S-type granite (Chappell and White 2001), which is confirmed in existing publications (Oberc-Dziedzic et al. 2005; Pin et al. 2007).

The origin of corundum-rich bodies measuring up to 40 cm within pegmatite from Krucze Skały

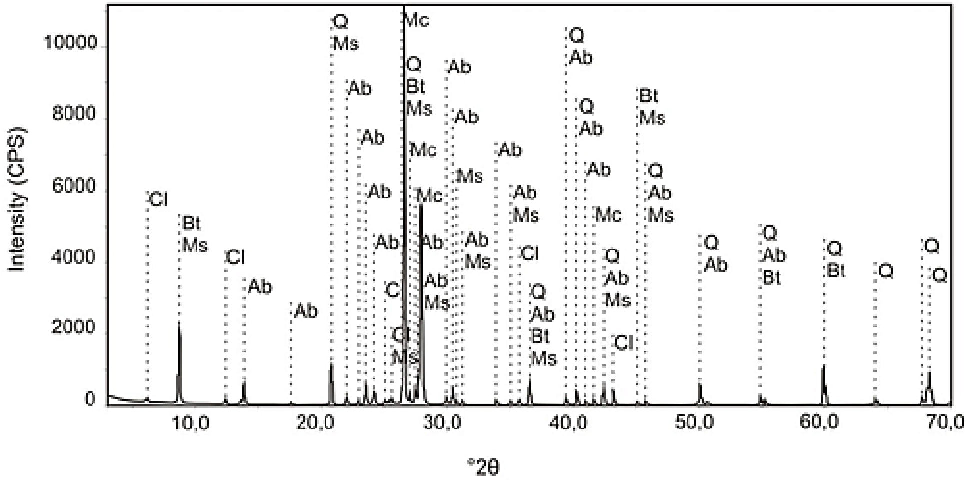

Fig. 6. Example of diffractogram (obtained from sample S18). Cl – chlorite, Bt – biotite, Ms – muscovite (sericite), Ab – albite, Q – quartz, Mc – microcline

was interpreted as a consequence of partially digested xenoliths from metamorphic cover being incorporated into the magmatic body (Pieczka et al. 2015). In the remaining rocks from Krucze Skały this mineral may possibly have the same origin. Corundum, as a mineral typically associated with metamorphic rocks (example: Manecki and Muszyński 2008) according to Oberc-Dziedzic (1985), has metamorphic genesis connected to the occurrence of Karkonosze Pluton, but when this author described Izera gneisses to the north of the Karkonosze Pluton corrundum was found coexisting with other typical metamorphic minerals: cordierite, sillimanite, andalusite and hercynite. In the Krucze Skały excavation, the presence of these minerals was not confirmed. This can be explained by the existence of a fault, that caused the destruction of the metamorphic halo near Kowary (Zagożdżon 2008).

Intrusions are most abundant in northern parts of the central rock. There they are biggest and discordant – not parallel to fractures in rocks. Smaller, concordant intrusions are more widespread across the excavation. They seem to utilise the most horizontal set of fractures in rocks and they are nearly perpendicular to the foliation in rocks. In these intrusive rocks granophyric intergrowths are very common. Quartz inside the intrusion features very strong undulose extinction, which means that it may have been subjected to directed pressure (Passchier and Trouw 2005).

According to Szełęg (2010) present in this pegmatite present are: quartz (as its colourless variety or as a morion), plagioclase (albite), alkali feldspars (orthoclase and microcline) and micas (biotite and muscovite). According to Kozłowski's and Sachabiński's research (2007), the present type of plagioclase is Na-rich, microcline is more abundant than orthoclase, biotite is more abundant than muscovite and perthites are present. These results are similar to results obtained by the author of this paper, so main mineral composition and common micas from pegmatite are quite similar to the main mineral composition and micas from the rest of rocks from Krucze Skały. Taking this into consideration, these intrusions may have appeared shortly after the Kowary Gneisses' placement, probably before the compressional event.

The structures and fabric of rocks differ along the excavation. In the northern part, gneisses with porphyritic texture are prevalent and in the southern part gneisses and granite-gneisses with seriate texture are predominant. Transitions between those types of rocks are very gradual.

Found mainly in the southern part of the excavation, signs of dynamic recrystallisation in quartz (such as undulose extinction and embayed boundaries or bulging) as well as kinking – slightly curved plagioclases polysynthetic twinnings are evidences that those rocks were subjected to directed pressure (Passchier and Trouw 2005). According to Mazur and Kryza (1996) this may be a result of the compressional event. Jeřábek (2016) linked lobate quartz boundaries to the S1 and S2 deformations of the D1 stage, when temperature reached 450-500^{0}C. That, according to Mazur (1995) was connected to the MP-LT metamorphism in upper greenschist facies.

The higher amount of quartz aggregates and ribbons and the fragmentary foam structure of quartz, observed in the northern part of the excavation are signs of static recrystallisation (Passchier and Trouw 2005). These numerous, recrystalized quartz grains can be connected to S3 deformation, in D2 stage, when pressure decreased and temperature lowered to 300^{0}C (Jeřábek 2016). They also may have been appeared when the Kowary unit was subjected to HT-LP metamorphism, but it is hard to say if it was connected to the Karkonosze Pluton placement or to the rapid uplift and decompression of this unit (Mazur 1995). The biotite present in the examined rocks is often altered to chlorite and opaque minerals. According to Mazur (1995), chlorite joined the stable mineral assemblage at the end of the D2 stage, meaning during the extensional event. Megacrysts appear mailny in northern part of excavation. They can possibly be relict magmatic porphyrocrystals, mentioned by Jeřábek (2016). The rounded inclusions of quartz, present in the bigger grains of feldspars, and the common reddish-brown colour of biotite, may also possibly result from the influence of the Karkonosze Pluton (Oberc-Dziedzic 1985).

Myrmekites most likely have metasomatic genesis (Manecki and Muszyński 2008) this this may possibly also apply to the rounded inclusions of quartz in feldspars (Borkowska and Smulikowski 1973).

The very commonly observed process of sericitisation has since long been connected to hydrothermal activity (Creasey 1966).

The second-most common accessory mineral in the examined rocks, rutile, commonly arises during the decomposition of other minerals containing titanium (Borkowska and Smulikowski 1973). It can form during hydrothermal alteration (chloritisation) of Ti-rich biotite (Carruzzo et al. 2006), which probably explains the common occurrence of this mineral near chloritised biotite in the examined rocks.

Conclusions

The study shows that the rocks from Krucze Skały contain records of numerous geological events leading to the arise of the Karkonosze-Izera Massif. The examination found records of the magmatic genesis of these rocks protolith. Evidence of dynamic recrystallisation during MP-LT metamorphism was present mainly in the southern part of the excavation, and signs of LP-HT metamorphism and static recrystallisation were found mainly in the northern part. Also, signs of metasomathosis and hydrothermal activity were present.

Disclosure statement

No potential conflict of interest was reported by the author.

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