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ALLEGED CARBONIFEROUS (VISÉAN) VOLCANISM AT THE EASTERN MARGIN OF THE MORAVO-SILESIAN BASIN, KRAKÓW REGION, SOUTHERN POLAND

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Abstract: The volcanic rocks, represented by clasts in the breccias occurring within the Viséan Culm sequence at Głuchówki, previously were considered to provide evidence of the earliest record of Variscan volcanism on the eastern margin of Moravo-Silesian Basin in the Kraków area. The breccias have been described as the deposits of submarine slides, accompanying the Viséan volcanic activity. This paper provides evidence of a different mode of origin. The present study, based on new field observations, combined with petrological and geochemical data, showed that volcanic rocks are major framework constituents of a breccia and are accompanied by clasts of spotty hornfels and Culm mudstone. Some clasts originated in erosion of the nearby Permian Zalas rhyodacite laccolith and the spotty hornfelses of the contact aureole, while other clasts came from the Culm mudstones. The breccia framework components are not rounded and poorly rounded, which reflects their short distance of transport. Therefore, an alternative scenario for the genesis of the breccia is proposed. The breccias represent material deposited in erosional pockets formed along the bedding of the Culm mudstones. The red iron oxide shells around clasts may indicate weathering in a warm continental climate, thus constraining the breccia formation to either the Permian or the Early or Late Triassic. Thus, the only well documented Viséan igneous rock in the study area remains the diabase, known from the Klucze borehole. Conversely, no volcanic rocks of this age have been documented in the area under consideration.

Key words: Viséan volcanism, Culm, rhyodacite, breccias, Zalas laccolith.

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INTRODUCTION

In Europe, extensive volcanic activity during the Late Carboniferous–Early Permian is recorded from Ireland through Britain, into the North Sea, to Germany and Poland, in both foreland and the internal parts of the Variscan orogen (Timmerman, 2004; Awdankiewicz *et al.*, 2013). The volcanic rocks represent syn- and post-orogenic stages. In Poland, the most ubiquitous volcanic rocks are dated as from the turn of the Carboniferous to the Permian (e.g., Harańczyk, 1985, 1989a, b; Czerny and Muszyński, 1997; Awdankiewicz, 1999; Lewandowska *et al.,* 2007, 2010; Nawrocki *et al.,* 2007, 2008, 2010; Awdankiewicz *et al.*, 2013), including the numerous occurrences at the NE margin of Upper Silesian Block (Fig. 1). In the Kraków region, the magmatic system comprises both deep-seated and shallow magmatic and extrusive bodies; most of the igneous rocks possess geochemical characteristics revealing their post-orogenic nature (Żelaźniewicz *et al.,* 2008; Słaby *et al.*, 2010; Wolska, 2012).

Lower Carboniferous volcanics in Europe are less abundant. However, their distribution is crucial for an understanding of the extent of the early orogenic Variscan volcanic arc. There is evidence for its existence in the Southern Vosges and Schwarzwald (Schaltegger *et al.,* 1996; Eisele *et al.,* 2000), and on the eastern margin of the Bohemian Massif (Zachovalová and Leichmann, 2003). However, there are suggestions that it might have been continued further to the east. On the NE margin of the Upper Silesian Block, an Early Carboniferous age was determined (Nawrocki *et al*., 2010) for the diabase recorded from a borehole, north of Klucze (WB-137 borehole, about 50 km northwest of Kraków), and pyroclastics were described from the sequence of the Viséan limestones in the Czatkowice Quarry (Fig. 1; Paszkowski, 1995; Appelt, 1998).

Furthermore, an Early Carboniferous age was assigned to enigmatic porphyritic volcanic rock, represented by clasts in the breccia interbedded with Viséan mudstones,

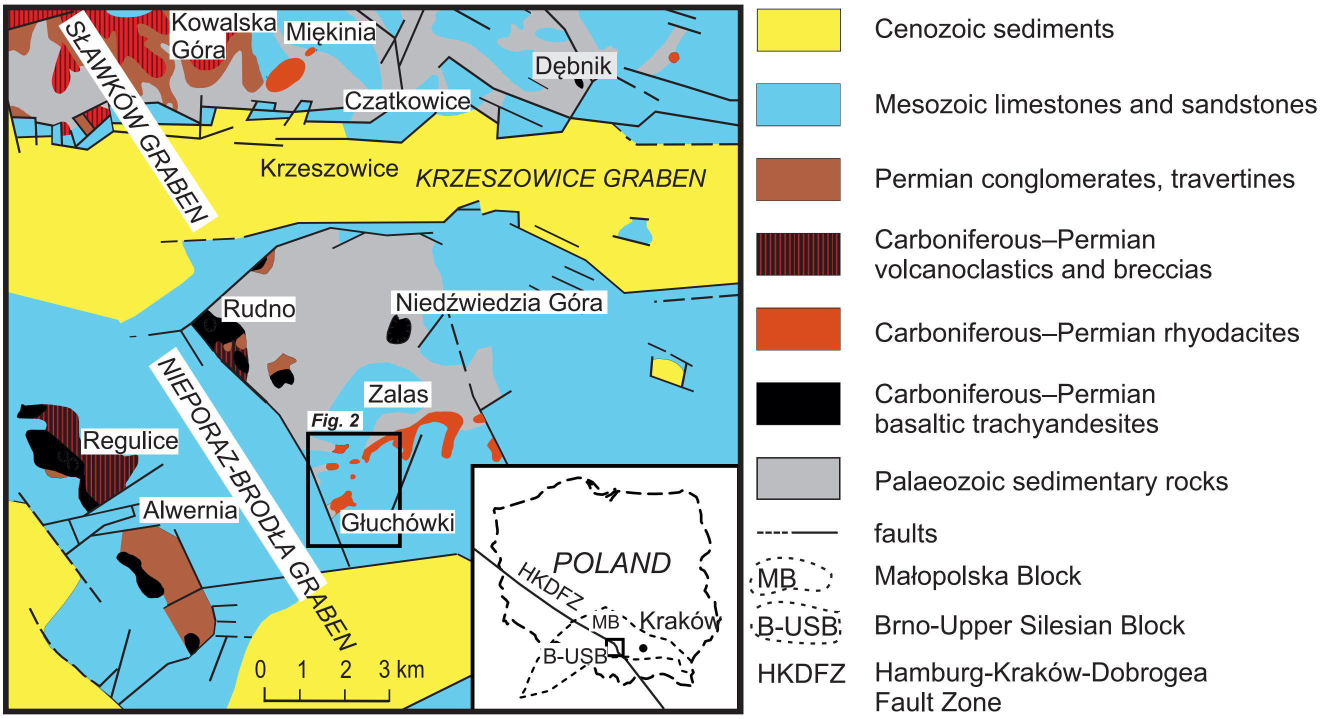

Fig. 1. Simplified geological sketch map of the southern margin of Kraków-Silesian Homocline, showing localization of the Carboniferous-Permian magmatic rock outcrops (after Gradziński, 2009).

near the village of Głuchówki (Dżułyński, 1955), studied herein (Figs 1, 2). The porphyritic rock fragments were of a great interest to geologists, since they were interpreted as the earliest record of Variscan volcanism in the Kraków area (Dżułyński, 1955; Piłat, 1957, 1960; Czarniecki and Łydka, 1958, 1962), similar to that described for the eastern margin of the Bohemian Massif (Zachovalová and Leichmann, 2003). These coarse-grained breccias with abundant volcanic rock clasts were described as being the result of submarine slides (debris flows) triggered by earthquakes that accompanied the volcanic activity (Dżułyński, 1955; Czarniecki and Łydka, 1962). The consistent stratigraphic position of the breccias, concordant with the layering of the Viséan sequence, led Czarniecki and Łydka (1962) to the conclusion that there was contemporaneous sedimentation of the breccias and mudstones. Such a hypothesis was put forward despite the fact that the volcanic clasts possess very similar structure and composition to the rocks forming the large Zalas rhyodacite laccolith that occurs nearby. The Zalas intrusion, exposed in the Głuchówki and nearby Zalas quarries (Dżułyński, 1955), has been dated as being formed at the end of the Carboniferous and start of the Permian (Nawrocki *et al*., 2007, 2008).

The purpose of this study is to combine new field observations together with detailed petrological and geochemical data, in order to shed light on the genesis of the breccias observed among the layers of Viséan mudstones at Głuchówki. An appealing aspect of this study is the recognition of the long-discussed nature and age of the clastic rocks from the Viséan Culm siliciclastic sequence of the Głuchówki area (Dżułyński, 1955; Piłat, 1957, 1960; Czarniecki and Łydka, 1958, 1962; Paszkowski, 1995; Hoffmann *et al.*, 2009), thus contributing to a better understanding of the evolution of Variscan volcanism in Poland.

GEOLOGICAL SETTING

The study area is at the margin of Kraków-Silesian Homocline, bordered by the Carpathian Foredeep to the south. In the west, the rocks of the Permo-Mesozoic cover have been eroded downward into the terrigenous sequence of the Brno-Upper Silesian Coal Basin (Fig. 1), representing the Variscan foredeep basin of the Moravo-Silesian orogeny (Kalvoda *et al*., 2008). The onset of oblique, dextral plate convergence and sedimentation in such a compressional tectonic regime (Grygar and Vavro, 1995) is recorded by the deposition of synorogenic, deep marine siliciclastics, termed Variscan flysch or Culm facies (Unrug, 1977; Kumpera and Martinec, 1995). The age of the siliciclastics is Early Viséan to Early Namurian (Dvořák, 1973; Špaček and Kalvoda, 2000; Kalvoda *et al.,* 2008). Beneath the Permo-Mesozoic cover, there is the tectonic boundary of the Upper Silesian Block (comprising the eastern edge of Brunovistulian Terrane) and Małopolska Block (Fig. 1). In the Carboniferous and Permian turn the formation of the horst-graben system indicated gravitational collapse and extension of the thickened Variscan crustal structure, accompanied by strike-slip activity of the Kraków-Lubliniec Fault Zone (KLFZ; Żaba, 1999), a local segment of the NW–SE trending Hamburg-Kraków-Dobrogea Fault Zone (HKDFZ; Fig. 1) together with the formation of a NNE–SSW fault system (Bogacz, 1980).

On the NE margin of Brno-Upper Silesian Block, the Culm siliciclasitic facies consists of dark grey, poorly laminated mudstones and subordinate siltstones, containing scarce plant debris and fauna. It contains rare intercalations of limestone. The monotonous clastic sequence represents the Zalas Beds of the Moravo-Silesian Culm facies (Kumpera and Martinec, 1995). The Zalas Beds are exposed in the abandoned Orlej Quarry, near the villages of Zalas and Głuchówki (Fig. 2), where in addition interbedded breccias were described (Dżułyński, 1955). Some mudstone strata and especially singular limestone beds contain numerous fossils, represented by brachiopods (Czarniecki, 1955), gastropods (Gromczakiewicz-Łomnicka, 1972, 1974), trilobites (Osmólska, 1970), corals (Nowiński, 1976; Kulicka and Nowiński, 1978), nautiloids (Dzik, 1984), ostracods (Olempska, 1993) and conodonts (Bełka, 1982). The fauna dates the entire sequence as representing the uppermost Viséan. The coarse-grained breccias form two intercalations in almost vertically dipping Culm strata. They first were described as synsedimentary breccias by Dżułyński (1955) and later interpreted as debris flows (Paszkowski, 1995). The same rocks were classified as conglomerates by Piłat (1957, 1960).

The Culm sequence hosts the large Zalas rhyodacite laccolith (Fig. 2), belonging to the bimodal suite of post-orogenic volcanic rocks formed at the end of the Carboniferous and the start of the Permian, which also includes basaltic-trachyandesites and other rhyodacites (Muszyński, 1995; Czerny and Muszyński, 1997; Nawrocki *et al.,* 2007, 2008; Lewandowska *et al.,* 2009, 2010; Słaby *et al.*, 2010). The volcanic activity was simultaneous with the deposition of tuffs, terrigenous rocks (e.g., Myślachowice Conglomerate) and travertine in trans-tensional basins, like the Sławków Graben and in its continuation to the south, the Nieporaz-Brodła Graben (Fig. 1). The rhyodacites occur at Zalas-Głuchówki, Dębnik and Miękinia. The Zalas rhyodacite laccolith (Dżułyński, 1955) seems to have been solidified at a shallower depth compared to that of the Dębnik rhyodacite, as concluded from the less extensive thermal metamorphism aureole at the contact (Lewandowska *et al.*, 2010). In turn, the position of the Miękinia rhyodacite within the subsided area (not eroded) and the overlying Myślachowice Conglomerate indicates that the Miękinia rhyodacite most likely represents a lava dome. A radiometric age of the Zalas rhyodacite is 294.2 ± 2.1 Ma, a sensitive high-resolution ion microprobe (SHRIMP) age for zircon (Nawrocki *et al.*, 2007, 2008), and is indistinguishable from the age of the Niedźwiedzia Góra diabase 296.6 ± 1.5 Ma (an Ar-Ar age; see Nawrocki *et al.*, 2010).

SAMPLES

Samples of the breccias were collected from the outcrops located along the northwestern escarpment of the old railway line, leading to the abandoned rhyodacite quarry in the Głuchówki Forest, near Głuchówki village (Fig. 2). There, the contact (coordinates: 50°04′01.5″N,019°36′50.6″E) of the rhyodacite with the host rocks, the Viséan dark Culm mudstones, intercalated with a few limestone layers, is exposed. Operations in the quarry were terminated in 1966, and a new documentation of the outcrop was performed in 2015 after massive erosion of the quarry escarpments by heavy rains. The samples were collected from two accessible beds within the steeply dipping (ca. 60°) Culm strata. The sampled site of the first breccia layer has the coordinates 50°03′59.7″N and 019°36′47.5″E. Sample OR-KL-1-24, shown in Figure 3A originated at this site. The second layer is located about 10 m to the southwest (sample OR-KL-2-3, shown in Figure 3B). The thickness of the breccia bodies sampled was about 30 cm, which is much less than the thickness described by Czarniecki and Łydka (1958). The breccia lenses wedge out over a distance of about 50 cm.

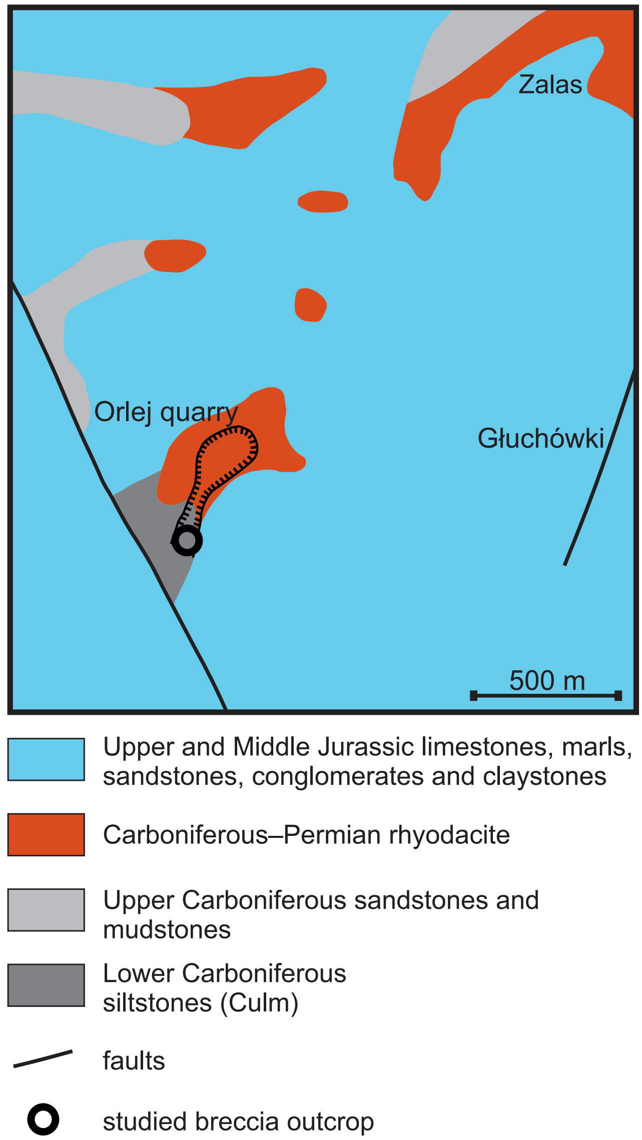

Fig. 2. Simplified geological map of the Zalas-Głuchówki area (after Doktorowicz-Hrebnicki, 1955).

METHODS

Polished thin sections of the breccias and Culm rocks were studied, using a Nikon Eclipse 600Pol petrographic optical microscope, equipped with a digital camera.

X-ray diffraction analyses were performed, using an X'Pert Automatic Powder Diffractometer (APD) with the vertical goniometer PW1830, graphite monochromator in

Institute of Geological Sciences, Jagiellonian University. Geochemical analyses were performed in AcmeLabs, Canada, using inductively coupled plasma emission spectrometry (ICP-ES) and inductively coupled plasma mass spectrometry (ICP-MS) techniques.

RESULTS

Petrography of breccia

The coarse-grained, reddish-brown, clastic rocks, filling pockets in the Culm sequence are composed of not rounded or only poorly rounded rock fragments (Fig. 3). The clasts are poorly sorted, ranging in size from grains in the sand fraction to fragments about 20 cm in size, and are embedded in a poorly sorted sand/siltstone matrix. The breccia is framework-supported. The clasts consist of rhyodacites and mudstones. Studies with the polarizing microscope revealed the presence of two types of mudstone clast: strongly lithified and spotty hornfels fragments, which are accompanied by a range of types of rhyodacite clasts, differing in the level of alteration. The dark brown to dark grey mudstone clasts are often elongated. There are two varieties of the breccias, differing in the proportions of rhyodacite and mudstone clasts in the framework (Fig. 3). The variety with abundant rhyodacite clasts can contain up to about 60 % vol. of rock fragments (Fig. 3A), while the variety with predominating mudstone and spotty hornfels clasts contains only subordinate amounts of rhyodacite debris (Fig. 3B).

The rhyodacite clasts are usually brown or grey rocks with a porphyritic structure. The phenocrysts are feldspars, biotite and rare apatite as well as opaque pseudomorphs of amphibole. The size of automorphic, zoned plagioclase crystals ranges up to 4 mm, whereas biotite crystals reach 2 mm. Amphibole crystals have undergone strong alteration and pseudomorphs 1–2 mm in size were observed. The feldspar phenocrysts possess numerous embayments. The phenocrysts are set in a microcrystalline groundmass (Fig. 4A) that is brown in colour. The groundmass consists of K-feldspar, quartz and minor calcite. The outer zones of the rhyodacite clasts are often altered owing to weathering (Fig. 3A).

The mudstone fragments comprise two varieties: 1) tight, subtly or moderately laminated, grey to black mudstones, which when weathered turn brown or reddish (Fig. 4B) and 2) spotted hornfelses (Fig. 4C, D).

The mudstones are composed of angular or subangular grains of fine sand and coarse silt, set in a scarce argillaceous matrix. The abundant detrital constituents are quartz and white mica and subordinate ones are dark mica, feldspar and opaque material, probably coalified, organic debris. The lamination results from the linear alignment of elongated mica flakes (Fig. 4B, C). These mudstone clasts are like the mudstone that make up the Culm sequence.

The spotted hornfels clasts (Fig. 4C, D) are composed of abundant, isometric porphyroblasts, 20–150 μm in size, representing cordierite pseudomorphs (pinite). They are riddled with submicroscopic crystals of quartz, feldspars, and sheet

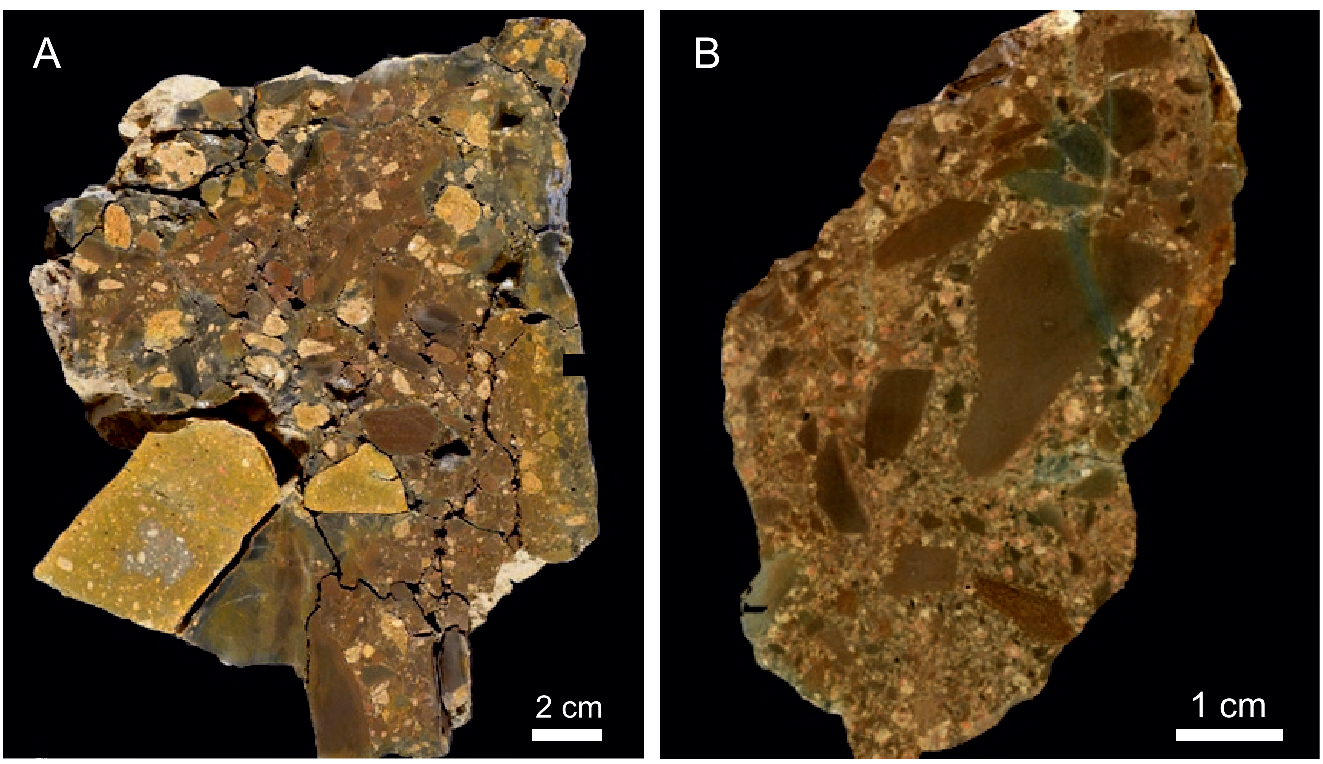

Fig. 3. Hand specimens of the two varieties of breccia. **A.** The variety composed of the dominant rhyodacite clasts. **B.** The variety with abundant mudstone fragments.

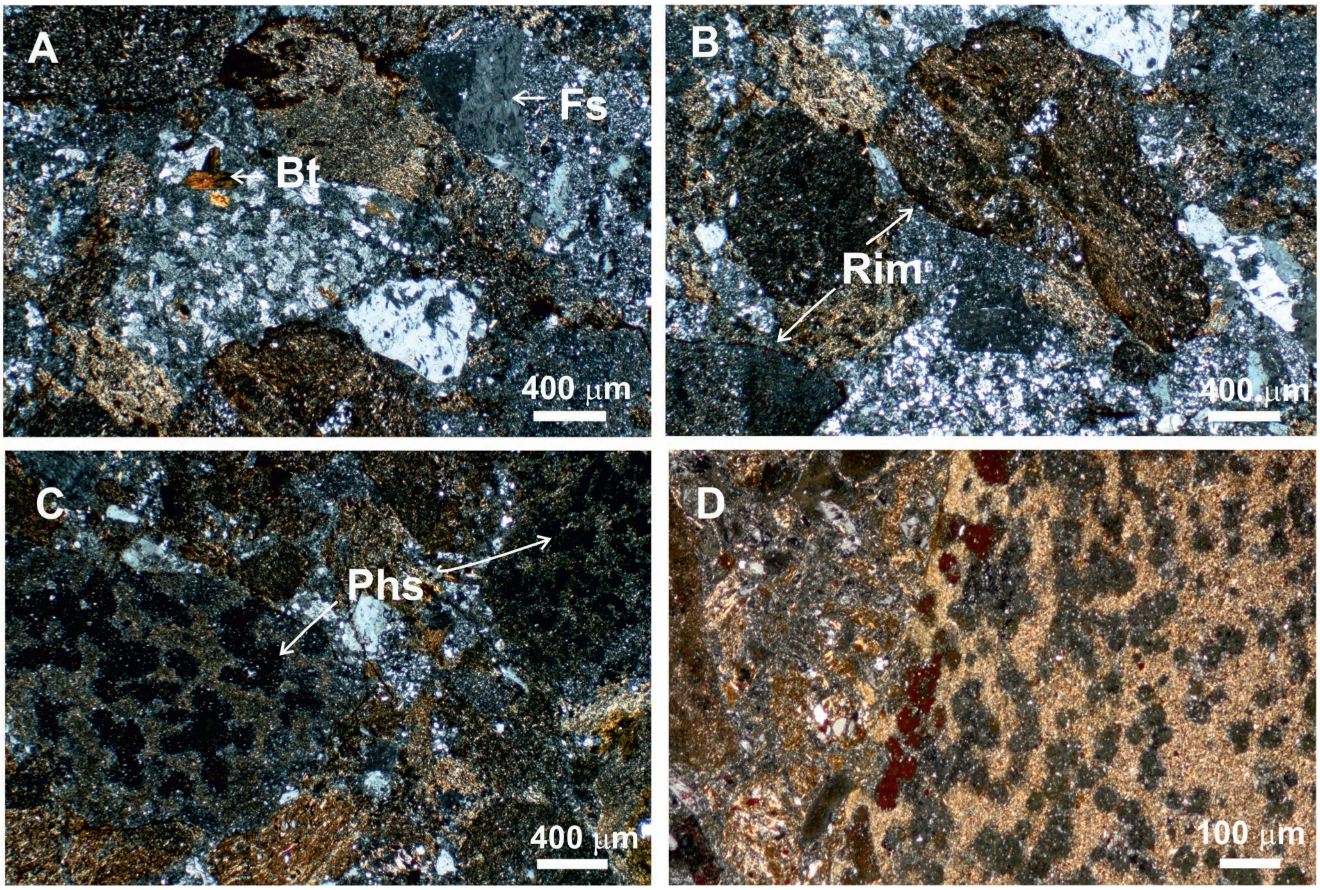

Fig. 4. Microphotographs of breccia clasts and matrix. **A.** Clasts of the rhyodacite with biotite (Bt) and feldspar (Fs) phenocrysts in a microcrystalline groundmass surrounded by clasts of mudstone set in an argillaceous matrix, comprising quartz, feldspar, biotite grains. **B.** Clasts of laminated mudstone defined by the alignment of mica grains are often rimmed (Rim) by reddish Fe-oxides. **C.** Two spotted hornfels clasts with pinite pseudomorphs of cordierite (Phs) differing in size. **D.** Fragment of a spotted hornfels clast (right) with a reddish weathering rim formed by iron oxides. All photographs under polarizing microscope, crossed polars.

silicates. At clast surfaces, the porphyroblasts tend to change in colour from greyish to red (Fig. 4D), owing to submicroscopic hematite/goethite inclusions that have resulted from weathering. Weathering alterations sometimes cover entire clasts or only the edges of the clasts. The cordierite pseudomorphs are set in a fine-crystalline, argillaceous mass.

The breccia matrix, which is reddish in colour, is rich in argillaceous content. The XRD analysis of the matrix revealed abundant quartz, orthoclase and the presence of 10 Å micas and minor chlorites.

Geochemistry of rhyodacite clasts

The chemical composition of the volcanic rock clasts was plotted in the silica *vs* total-alkali and potassium classification diagrams (Fig. 5A, B; Table 1) as well as the trace elements discrimination diagrams (Fig. 5C, D) of Winchester and Floyd (1977). The clasts show about 67 wt % of SiO_2 and a high potassium content of up to 9.7 wt % of K_2O (Fig. 5A, B), which classifies them as high-K rhyolites. However, the trace-element data were plotted in a Zr/Ti *vs*. Nb/Y diagram, which eliminates the influence of subsequent alterations and weathering (Winchester and Floyd, 1977) and shows that the rock plots in the rhyodacite-dacite field.

DISCUSSION

Previous hypothesis on the alleged Viséan volcanism

The provenance of the volcanic clasts in the Głuchówki breccias has been somewhat enigmatic so far (Czarniecki and Łydka, 1958; 1962; Paszkowski, 1995), although they were considered to provide indirect evidence of Viséan volcanic activity. The two types of breccias were described, consisting either of dominant porphyritic rhyodacite or mudstone clasts. The rhyodacite clasts were usually better rounded, compared to the mudstones. Such a textural diversification of the clasts resulted in different approaches to rock description: the rock was classified either as conglomerate (Czarniecki and Łydka, 1958, 1962; Piłat, 1960) or as breccia (Dżułyński, 1955; Paszkowski, 1995).

The rock composed of mudstone clasts set in a red matrix with macroscopically visible feldspars has been interpreted as an intrusive breccia (Dżułyński, 1955) that is the result of the disintegration of the host mudstones by intruding magma of the apophyses of the Zalas rhyodacite laccolith. However, the breccia bodies occur within only slightly thermally altered Culm mudstones at a distance ca. 50 m from the contact aureole of the Zalas rhyodacite (vide Czarniecki and Łydka, 1958, fig. 1). A closer examination of the brec-

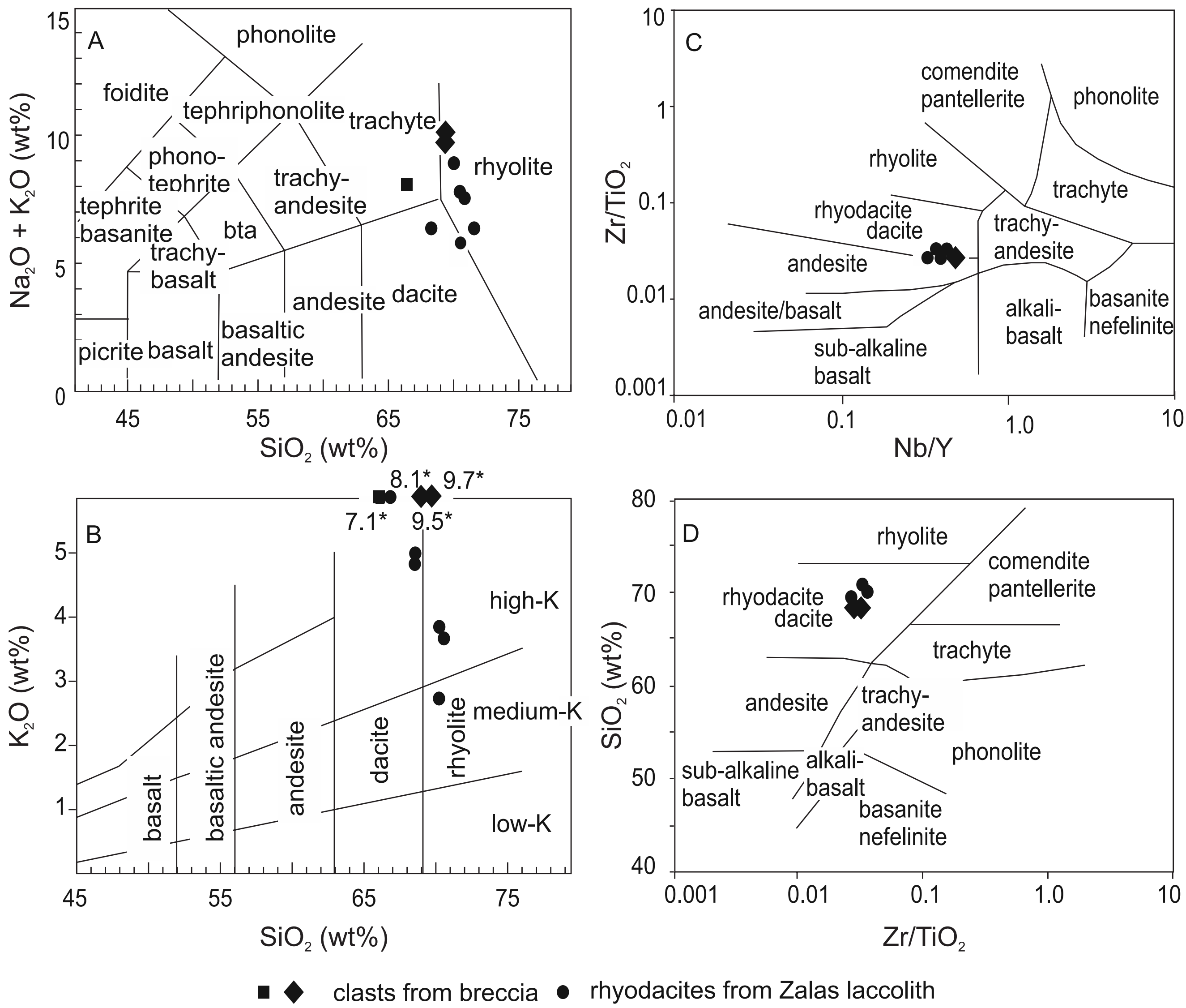

Fig. 5. Comparison of the geochemistry of the Głuchówki breccia volcanic clasts (solid diamonds and solid square) and the Zalas laccolith rhyodacite (solid circles), based on **A.** Total alkali-silica diagram. **B.** SiO_2 *vs* K_2O diagram showing potassium enrichment of the volcanic clasts *vs* rhyodacites from Zalas laccolith. **C.** The Winchester and Floyd (1977) Nb/Y *vs* Zr/TiO_2 classification diagram. **D.** SiO_2 *vs* Zr/TiO_2 diagram showing great similarity of both populations. *K_2O wt. % content see Table 1, rock analyses by Piłat (1957) – solid square, Czerny and Muszyński (1997) and Słaby (2010) – solid circles, were also included.

cia matrix reveals predominant quartz and K-feldspar grains within the argillaceous material not confirming its magmatic nature and abundant clasts of spotty hornfelses and rhyodacites indicating another origin of the breccias.

The fact that the breccia bodies are concordant with the layering of the sequence and contain numerous volcanic rocks together with the mudstone clasts led to the hypothesis that the breccias were deposited as a result of submarine slumps, triggered by tectonic activity associated with volcanism (Dżułyński, 1955; Czarniecki and Łydka, 1958). The clasts of the volcanic rocks were assumed to have been eroded from volcanic edifices and deposited from episodic mass flows, accompanying mudstone sedimentation in a deep, marine environment. Czarniecki and Łydka (1958) described the breccias as marine deposits on the basis of the marine fauna found in the neighbouring Culm mudstones. The late Viséan age of the sequence was proposed on the basis of the micro- and macrofossils found in the sedimentary sequence (Czarniecki, 1955). These all led the authors (Dżułyński, 1955; Czarniecki and Łydka, 1958) to the conclusion that the breccias represent an indirect record of early Variscan volcanic activity in the Kraków region. On closer inspection, however, several lines of evidence indicate a different scenario for their formation.

A new scenario of breccia formation

By combining new field observations on their geological setting together with detailed petrological and geochemical data, an alternative mode of breccia formation is proposed (Fig. 6).

The breccia bodies do not form laterally continuous beds, but instead form lenticular pockets, parallel to the layering. The pockets wedge out at the distance of about half a metre

Table 1.

Major and trace element composition of the volcanic clasts investigated from the Głuchówki breccias.

Sample	OR-KL 1-12	OR-KL 1-6	Sample	OR-KL 1-12	OR-KL 1-6
	w %			ppm	
SiO_2	66.91	66.99	La	23.1	23
Al_2O_3	14.83	15.13	Ce	44	45.5
FeO^*	2.13	2.1	Pr	4.98	5.16
MnO	0.05	0.04	Nd	18	19.5
MgO	0.72	0.9	Sm	3.07	3.37
CaO	1.56	1.2	Eu	0.82	0.86
Na_2O	0.86	0.53	Gd	2.86	3.13
K2O	9.22	9.41	Tb	0.44	0.46
TiO_2	0.43	0.44	Dy	2.17	2.46
P_2O_5	0.1	0.11	Ho	0.47	0.49
Cr_2O_3	bdl	bdl	Er	1.35	1.3
LOI	2.9	2.9	Tm	0.19	0.19
SUM	99.71	99.75	Yb	1.22	1.28
	ppm		Lu	0.18	0.19
Ba	1503	1077	Mo	2.9	5.3
Be	bdl	2	Cu	13.7	16.4
Co	19.2	24.3	Pb	16.1	41.3
Cs	1.8	2.4	Zn	38	92
Ga	16.4	15.6	Sn	bdl	bdl
Hf	3.5	3.7	W	190.3	267.1
Ni	4.1	8.2	As	12.5	29.4
Nb	8.5	8.8	Cd	PLW	0.2
Rb	170.2	167.7	Sb	0.4	0.5
Sr	52.9	30.4	Bi	0.2	0.1
Ta	0.7	0.8	Ag	bdl	bdl
Th	7.5	7.3	Hg	bdl	bdl
U	1.7	2.1	Tl	0.2	0.2
V	50	51	Se	0.6	0.5
Zr	133	144.1	Sc	6	6
Y	12.3	13.5	Au	1.3	0.6

FeO^*– total iron
bdl – below detection limit

from the surface. Rock bodies of such limited size cannot represent submarine slumps. The reverse grading of the volcanic rock clasts with large, angular fragments at the top of layers, as described by previous researchers (Czarniecki and Łydka, 1958), resembles that of debris flow deposits.

The clasts of volcanic rocks of the breccia framework can be classified as rhyolites on the basis of geochemical data on the major elements with a higher potassium content than the neighbouring Zalas rhyodacites. However, the high potassium content of the clasts corresponds to that observed in rocks of the outer zones of the laccolith with about 8 wt % of K_2O. The potassium enrichment was attributed by Słaby (1987) to the zones of later hydrothermal adularization or potassium metasomatism (Siedlecki, 1954; Lewandowska and Rospondek, 2003). The influence of the subsequent alteration on the position of rocks in the classifications (Fig. 5) can be minimized by using classification diagrams for the immobile trace elements like those of Winchester and Floyd (1977). In the Zr/Ti *vs* Nb/Y diagram, the comparison of the geochemistry of the framework volcanic rock clasts with that of the neighbouring Zalas rhyodacite intrusion reveals that they are indistinguishable, forming a tight cluster of points in the rhyodacite-dacite field (Fig. 5C, D).

This compositional similarity and most importantly the presence of spotty hornfels clasts, eroded from the Zalas rhyodacite contact aureole, requires that the post-intrusive and post-metamorphic period for the breccia deposition must be taken into account.

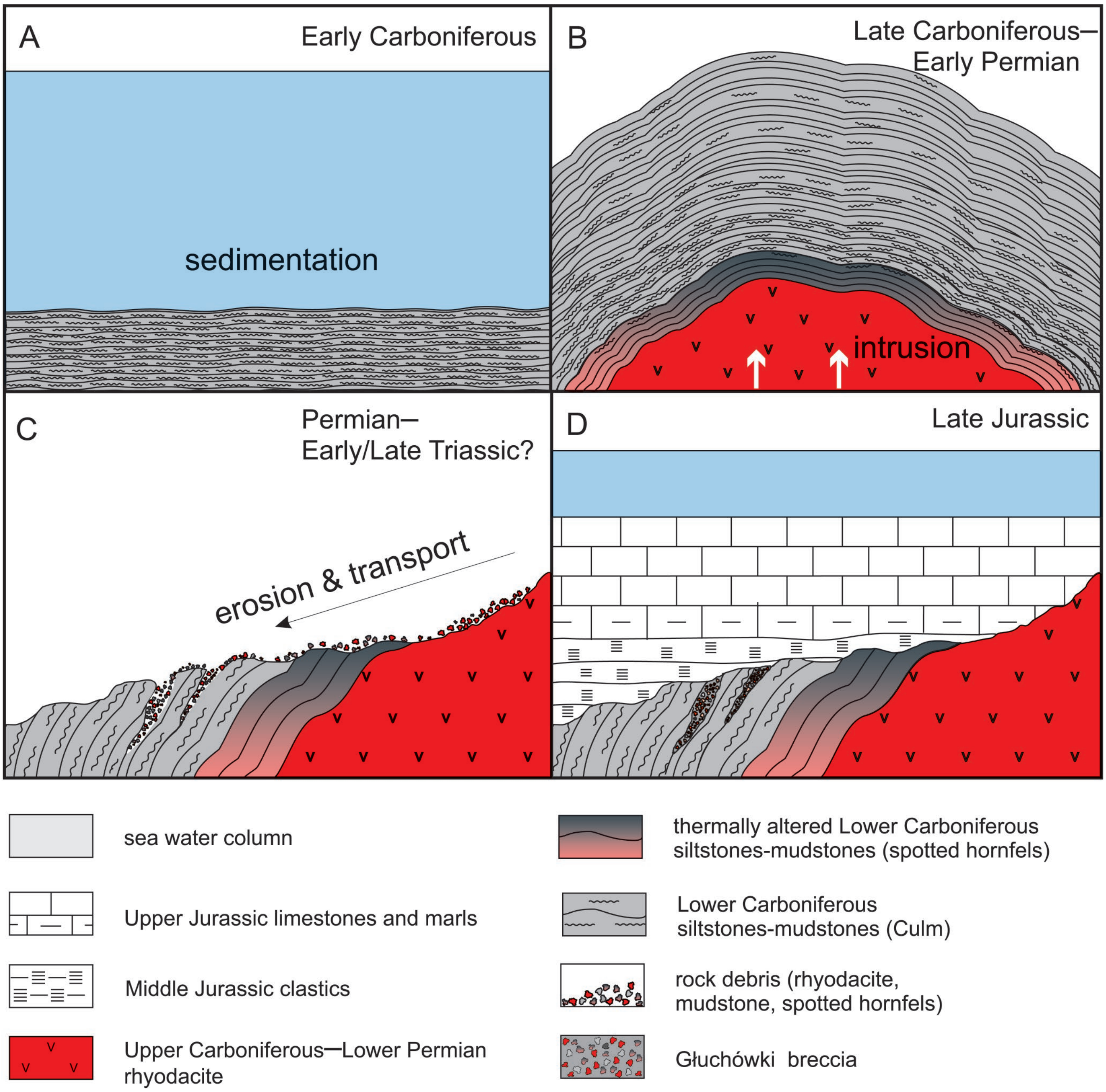

Fig. 6. Schematic sketch of a scenario to explain the formation of the breccia in the Culm sequence in the Głuchówki area, **A.** Sedimentation of the Culm sequence (Viséan). B. Intrusion of the Zalas rhyodacite laccolith, accompanied by formation of the contact aureole of the spotty hornfels (end-Carboniferous and Permian). **C.** Erosion and weathering (Permian to Early Jurassic) of the uplifted area. **D.** Formation of the sedimentary cover (Late Jurassic).

The following sequence of processes leading to the formation of the Głuchówki breccia is proposed. Deep, marine sedimentation (Fig. 6A) of the monotonous Culm sequence in the Variscan foredeep basin was terminated by the eastern margin of the basin in Namurian A time (Kumpera and Martinec, 1995). Probably, Upper Carboniferous siliciclastic molasse was initially present and later eroded in the area under the investigation. The tectonic reconstruction of the Variscan foreland at the end of the Carboniferous and the beginning of the Permian brought intensive volcanic activity with the emplacement of the Zalas rhyodacite laccolith, causing thermal metamorphism of the Culm sequence that was dominated by mudstones, thus leading to the formation of the contact aureole composed of spotty hornfelses (Fig. 6B). The magmatism and volcanism were associated with strike-slip faulting in the entire area, leading to the formation of the horst-graben system. The uplifted area underwent extensive peneplanation, as erosion progressed rapidly downward to produce coarse-grained clastic material.

The eroded rocks often accumulated locally, building up alluvial fans in morphological depressions: an example is Myślachowice Conglomerate in the Nieporaz Brodła and Sławków grabens (e.g., Lewandowska *et al.,* 2010). In a similar tectonic regime, the Głuchówki breccias were deposited, although the geological settings of these two coarse-grained units differ. The Myślachowice Conglomerate were contemporaneous with the volcanic activity, as evidenced by the conglomerate fans set within the Filipowice Ignimbrite cover (e.g., at Kowalska Góra). In contrast, the Głuchówki breccias clearly postdate the Early Permian volcanic activity. They formed after major uplift, which allowed erosion to reach the level of the subvolcanic intrusion, thus wearing away the spotty hornfelses of the contact aureole and the top part of the rhyodacite laccolith. The eroded fragments making up the breccia framework were not rounded or only poorly rounded owing to the very short distance of transport. The spotty hornfels clasts originated from erosion of the zone of thermally altered Culm mudstones, which is 20 m thick. Indeed, the distance from the contact aureole to the site of deposition of the breccias is short, amounting to about 50 m. The origin of the volcanic fragments constituting the breccia framework in the Zalas laccolith is evidenced by the same rock fabric and the mineral and incompatible element composition of both (Fig. 5C, D).

Such material was eroded, transported and deposited in the erosional or tectonic pockets formed along the bedding of the mudstones of the steeply dipping Culm sequence (Fig. 6C). Poor sorting and roundness and correlation of the framework constituents with the surrounding rocks nearby are characteristic features of topographically controlled deposition. The red matrix and weathering rims of the rock fragments point to a warm, continental climate during deposition of the breccia. Such constrains on the climate during deposition of the Głuchówki breccias could indicate their formation either during the Permian, or the Early or Late Triassic. The subsequent Middle and Late Jurassic deposition led to the formation of the sedimentary cover, consisting of lacustrine kaolinite deposits (Glinki Grojeckie = = Grojeckie Clay) and transgressive quartz arenites, together with conglomerates and finally marls and limestones (Fig. 6D). An Early Jurassic time of formation of the breccias is unlikely, owing to the lack of kaolinite in the breccia matrix, a mineral that predominates in the continental deposits (Glinki Grojeckie) of this period.

Thus, in the Kraków area there is no evidence for Viséan volcanism; the only well documented Viséan igneous rock is diabase, penetrated in a borehole at a depth of about 500 m near Klucze (Nawrocki *et al.,* 2010), close to the major Hamburg-Kraków-Dobrogea Fault Zone. Thus, the source of tephra deposited in the Viséan limestones (Appelt, 1998) must have been related to distant volcanism. Owing to unknown, but probably significant translation along the aforementioned fault zone, the Viséan volcanics in the Lublin area (Grocholski and Ryka, 1995) probably are not spatially related to those of Moravo-Silesian volcanism.

CONCLUSIONS

The volcanic rocks described from the Viséan Culm sequence do not record the earliest Variscan volcanic activity phase at the eastern margin of Moravo-Silesian Basin, as previously was suggested. The clasts of volcanic rocks (rhyodacites) of the Głuchówki breccia were eroded from the Zalas rhyodacite outcropping nearby, as evidenced by the great similarity in the composition of major and trace elements and in the fabrics of the rocks. The framework components also include Culm mudstones as well as spotted hornfels clasts, originating in the contact aureole, indicating that the formation of the breccia postdated major uplift and erosion of the rocks, which host the intrusion. The poor sorting and low degree of roundness of the clasts indicate topographically controlled deposition in a warm, continental climate.

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