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Palaeomagnetic age constraints indicate post-Variscan orgin of massive breccia in Wietrznia Quarry (Holy Cross Mountains, Central Poland)

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Palaeomagnetic study has been carried out to resolve the controversy over the age and origin of the massive breccia body exposed in Wietrznia Quarry in the Holy Cross Mountains. The breccia studied consists of variously sized angular fragments of Frasnian and Fammenian limestone and shale infilling a palaeodepression within Frasnian limestone. For this purpose, the conglomerate test has been applied that enables determination of the relative age of remanence components and formation of the breccia. Palaeomagnetic analysis of breccia clasts reveals the presence of two characteristic components of magnetization. The observed components are akin to those previously described from *in situ* rocks at Wietrznia Quarry and from other Devonian carbonates from the Holy Cross Mountains. Such components have been interpreted as early synfolding and postfolding overprints of Viséan and Early Permian age. The palaeomagnetic conglomerate test performed in this study are positive results, indicating that the breccia postdates both components. This implies that the breccia is not of synsedimentary character and postdates Variscan deformation.

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INTRODUCTION

In this paper, we focus on the age estimation of the massive breccia exposed in Wietrznia Quarry located in the Holy Cross Mountains (HCM; Fig. 1). This spectacular megabreccia body is distinguished by its considerable size (500 × 150 × 50 m, according to Szulczewski, 1995) and is composed of unsorted fragments of Frasnian and Fammenian rocks of various dimensions, up to a few metres in diameter.

Based on field observations, the structure was described as “fitted megabreccia” formed as a result of Permian post-orogenic karstification (Szulczawski, 1995). A similar origin for the breccia was suggested by Lewandowski (1971) and Urban (2007). There are also alternative interpretations linking the origin of breccia with synsedimentary tectonics (Lamarche, 1999; Lamarche *et al*., 2003). Therefore, determination of age constraints of this massive breccia body is important for understanding the Late Palaeozoic evolution of the HCM since it constrains the scale of synsedimentary deformation as well as the course of post-Variscan exhumation processes.

This issue is examined here, with a palaeomagnetic conglomerate test being applied to determinate the time-relationships between the formation of breccia and acquisition of individual remanence components. It is worth noting that the conglomerate test is commonly used for age determination of geological events (e.g., Convert *et al*., 2006). This method is especially effective since the natural remanent magnetization (NRM) structure of the strata has been characterized in previous studies.

Palaeomagnetic studies performed over the last three decades on Devonian carbonates of the HCM reveal the occurrence of several components of secondary magnetization (Lewandowski, 1981, 1985, 1999; Grabowski and Nawrocki, 1996, 2001; Grabowski *et al*., 2006). More recent outcomes of detailed studies of the Devonian carbonates of the HCM enable definition of two widespread episodes of remagnetisation shown by individual palaeomagnetic components (Zwing, 2003; Szaniawski, 2008). Fold tests performed within the first order Variscan folds of km-scale wavelength document an early synfolding origin for the Viséan component (B) and a postfolding origin of the Early Permian (A) overprint (Szaniawski, 2008). Thus, the results of the breccia test enable determination of the age of breccia formation relative to Variscan folding.

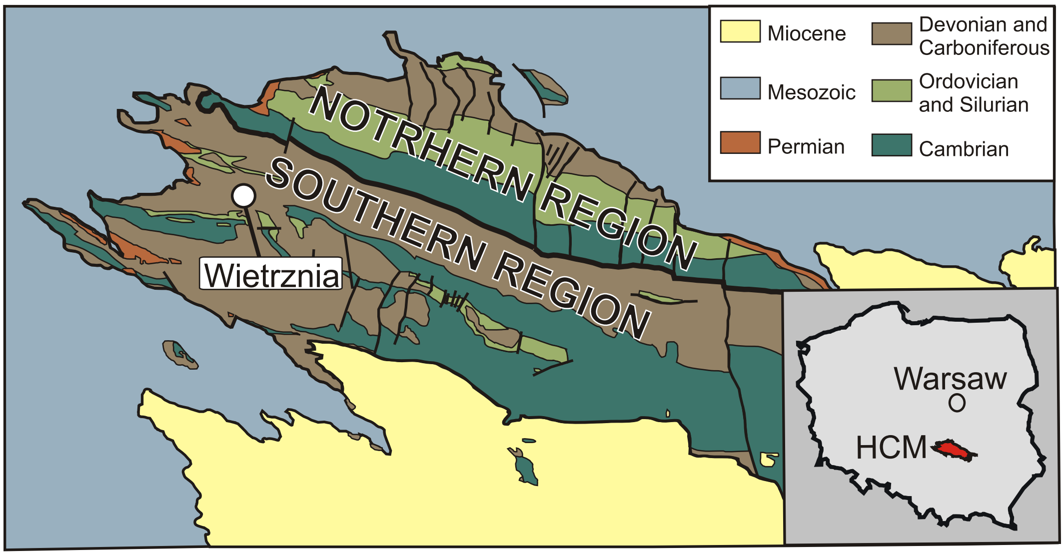

Fig. 1. Geological map of the Holy Cross Mountains (after Czarnocki, 1938) showing location of Wietrznia Quarry

GEOLOGICAL SETTING AND METHODS

In Wietrznia Quarry, situated within the Palaeozoic outcrop of the HCM, that comprises massive Givetian–Frasnian carbonates overlain by Famennian basinal deposits represented by thin-bedded carbonate and marls (Szulczewski, 1971). The quarry is situated on the southern limb of the Kielce Syncline characterized by a regional WNW–ESE tectonic trend (Fig. 1). Accordingly, the strata seen in this exposure are characterized by a general dip towards the NNE. The breccia studied is located in the central part of the quarry.

To perform the palaeomagnetic conglomerate test, six variably oriented blocks of the breccia body were sampled. From each block, three independent hand samples were collected and the orientation of the bedding plane was measured (without the roof/till determination). It is worth noting that palaeomagnetic investigations of the *in situ* rocks were performed in a previous study (Szaniawski, 2008) where seven hand samples were collected from the continuous Frasnian limestone succession bordering the breccia body.

The samples were subsequently drilled in the laboratory to give standard specimens of 24 mm diameter. Part of the samples were utilized for studies of magnetic mineralogy including acquisition of isothermal remanent magnetization (IRM) and the Lowrie test (Lowrie, 1990). Such analyzes were performed with a *2G SQUID* cryogenic magnetometer plus *Magnetic Measurements MM-1* furnace and pulse magnetizer. The same magnetometer and furnace were utilized for analysis of natural remanent magnetization (NRM) where a thermal demagnetization technique was applied. The magnetic susceptibility was monitored after subsequent steps of thermal cleaning using the *KLY-2* bridge. To calculate the palaeomagnetic directions, principal components analysis (PCA) was employed (Kirschvink, 1980) utilizing the software of Chadima and Hrouda (2006).

PALAEOMAGNETIC RESULTS

The IRM acquisition curves obtained show a typically rapid increase of magnetic remanence after application of relatively low magnetic fields of 0–16 mT, indicating the presence of low-coercivity magnetic minerals (Fig. 2A). The samples studied were almost completely saturated in a field of 30–40 mT showing practically no increase of magnetization up to the 3 T field. Results of Lowrie tests (Fig. 2B) confirm that the magnetic mineralogy is dominated by low-coercivity minerals that show maximum unblocking temperatures (Tub) of 450°C.

These results are generally in line with the published data of Grabowski *et al*. (2006). The low coercitivity magnetic phase of moderate blocking temperatures most probably represents maghemite or non-stochiometric magnetite. The maximum blocking temperatures observed in the Lowrie test are similar to the unblocking temperatures of A and B components described by Zwing (2003) and Szaniawski (2008).

Results of thermal demagnetisation indicate that the general NRM structure observed in the breccia clasts is equivalent to those known from *in situ* deposits from Wietrznia Quarry and from other carbonates of the HCM (Szaniawski, 2008). After demagnetization of the soft magnetization (up to 250°C), interpreted as a recent viscous overprint, two components of roughly opposite directions are noticeable (Fig. 2C, D). They are distinguished by a characteristic increase of magnetic signal in temperatures of 250–350°C and by linear segments of demagnetization plots within the indicative spectra of Tub.

According to their generally opposite directions and characteristic Tub ranges of 250–375°C and 350–450°C, the components were recognized as A and B respectively, both known from previous studies (Szaniawski, 2008). Separation and calculation of these components was frequently difficult due to partial overlapping of their unblocking temperatures spectra as well as to thermochemical alteration (over 350°C) shown by

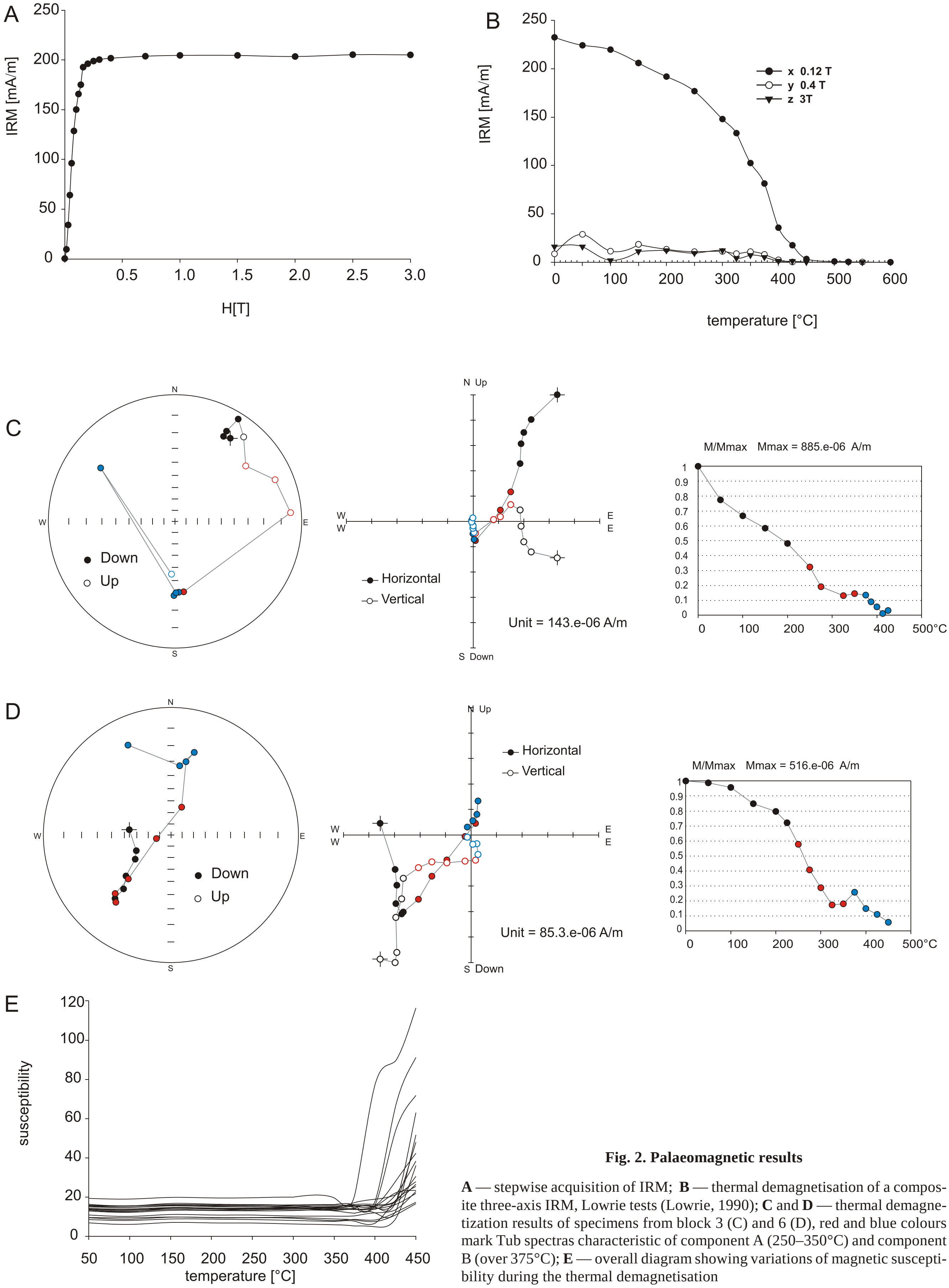

Fig. 2. Palaeomagnetic results

A — stepwise acquisition of IRM; **B** — thermal demagnetisation of a composite three-axis IRM, Lowrie tests (Lowrie, 1990); **C** and **D** — thermal demagnetization results of specimens from block 3 (C) and 6 (D), red and blue colours mark Tub spectras characteristic of component A (250–350°C) and component B (over 375°C); **E** — overall diagram showing variations of magnetic susceptibility during the thermal demagnetisation

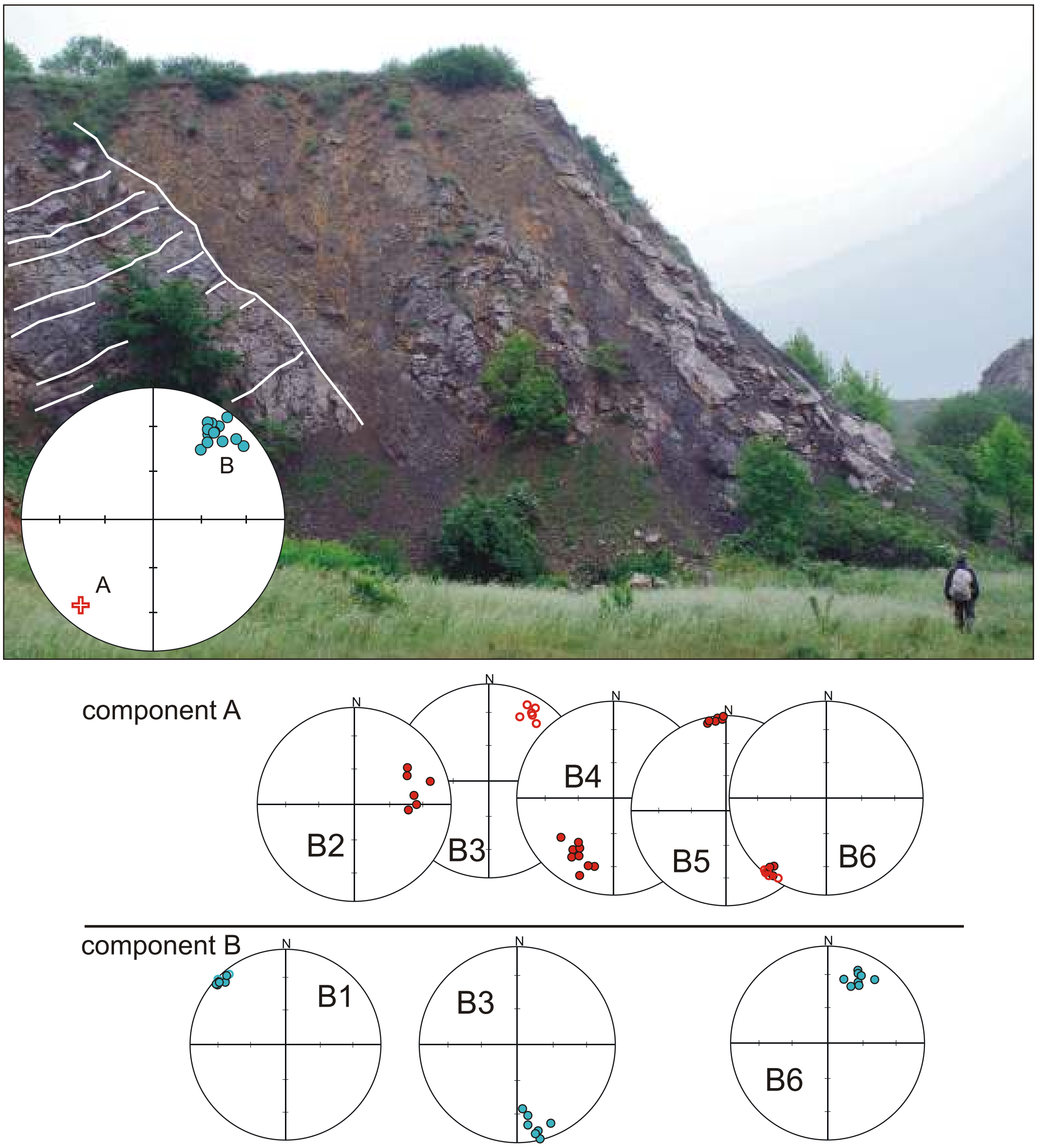

Fig. 3. Fragment of the breccia studied from Wietrznia Quarry with equal area diagrams showing palaeomagnetic data (all diagrams before tectonic correction)

Isolated diagram on the photo shows previous results of Szaniawski (2008), direction of component B from *in situ* rocks of Wietrznia Quarry (blue dots) and reference site mean direction of component A (red cross). Diagrams below show results of this study derived from individual blocks (B1–B6). Solid (open) symbols represent downward (upward) palaeomagnetic directions

chaotic behavior of the remanance accompanied by an increase in magnetic susceptibility (Fig. 2E). Finally, the application of PCA enables determination of the direction of component A in five blocks and component B in three blocks (Table 1; Fig. 3).

In order to verify the presented results we determined the angles between component B and the bedding plane within individual blocks. The values are: 7° for block 1, 23° for block 3 and 6° for block 6. These results are comparable with previous outcomes derived from *in situ* strata (Szaniawski, 2008) where the angle between the bedding plane and component B is 21°. The latter observation, keeping in mind that component B is of early-synfolding origin (Szaniawski, 2008) and strata in the quarry are of generally similar orientation, argues in support of the reliability of the results presented here.

INTERPRETATION AND DISCUSSION

The results of this study indicate that component A is well preserved and is possible to extract in most of the breccia blocks studied. In the *in situ* rocks of Wietrznia Quarry the occurrence of component A was also observed but capable of separation utilizing the PCA technique (Szaniawski, 2008). This minor difference in the remanence record is not surprising since the Upper Palaeozoic carbonates from the HCM commonly show various NRM structures both between sampling sites, as well as between individual specimens derived from the same hand sample (Grabowski *et al*., 2006; Szaniawski, 2007). Nevertheless, the postfolding component A was precisely eval-

Table 1

Palaeomagnetic results

Site/block	component A					component B			
	Dir/dip	*D/I*	*k*	α	N_1/n_1	*D/I*	*k*	α	N_1/n_1
Block 1	239/42	–	–	–	–	315/3	151	6	3/6
Block 2	63/89	76/35	29	13	3/6	–	–	–	–
Block 3	50/15	32/-18	131	5	2/7	170/16	31	11	2/7
Block 4	265/59	212/30	42	8	3/9	–	–	–	–
Block 5	234/54	354/42	303	4	3/7	–	–	–	–
Block 6	299/70	217/2	152	4	3/9	25/27	86	6	3/8
WC	39/39	–	–	–	–	37/19	68	5	5/13

Dir/dip — tectonic orientation of the strata plane (for blocks without the roof/till determination); *D/I* — declination and inclination before tectonic correction (specimen level); *k*, α — statistical parameters, N_1/n_1 — number of samples/specimens used in calculations, WC — results of previous studies (Szaniawski, 2008) from *in situ* limestones from Wietrznia Quarry (before tectonic correction)

uated in other localities during a previous study (Szaniawski, 2008) and this data can by used as reference for the breccia test (Table 1; Fig. 3).

The directions of both components, A and B, obtained within the breccia show good grouping within separate breccia blocks (Fig. 3). In contrast, directions of components A and B differ significantly between individual breccia blocks as well as differing from the reference directions known from *in situ* rocks. This clearly implies the positive result of the conglomerate test, e.g. the age of the breccia postdates the acquisition time of both components, A and B.

The precise properties of components A and B were described previously based on results from 13 sampling sites (Szaniawski, 2008). Outcomes of the fold tests performed within the first order, km-scale Variscan folds indicate the early synfolding origin of component B (dated to the Viséan) and post-folding acquisition of the Early Permian component A. Thus, results of conglomerate test imply that the breccia studied postdates the main Variscan folding and is younger than Early Permian.

The data obtained contradict the hypothesis of a synsedimentary origin for this breccia as suggested by Lamarche (1999) and Lamarche *et al*. (2003) who argued that the breccia body shows sedimentary stratification. Conversely, the results of this study support models suggesting post-orogenic formation of the breccia body and its relation to karstification (Szulczewski, 1995; Urban, 2007). Szulczewski (1995) suggested that the breccia originated as a result of abrupt “displacement of intensely karstified Devonian carbonates along the fault system” and noticed that it covers an older generation of “rock-matrix breccia” of presumably Permian age. This model was extended by Urban (2007) who inerpreted this breccia as a coluvium developed on the slope of the palaeokarst depression. Urban (2007) remarks also that hydrothermal calcite “różanka” replaces the matrix of the breccia studied. In conjunction with the results of the present study it implies that “różanka” hydrothermal mineralization post-dates the acquisition of component A.

CONCLUSIONS

1. Blocks of studied breccia record two remanence components known from previous studies: components A and B.
2. Results of the conglomerate test are positive, indicating that the breccia post-dates the acquisition of both components.
3. The studied breccia is not of synsedimentary origin since it post-dates the Variscan folding and the Early Permian component A.
4. It is suggested that the acquisition of component A post-dates the mineralization of “różanka” hydrothermal calcite.

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