A petrographic and sedimentologic analysis of clasts in the Kržľa Breccia of the Malé Karpaty Mountains (Western Carpathians, Slovakia)

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Abstract: A section which runs through the Kržľa Breccia, known as the significant ?Upper Cretaceous-Paleocene paleokarst phenomenon, and its contact with the Lower Eocene Jelenia hora Formation in the Malé Karpaty Mts., yield data on the source area of the clasts, paleotectonic settings during the breccia formation, and determine the age of the transgression onset. Analyses of the red clay matrix and the clasts support the idea that the source area of the clasts was situated nearby, and its erosive base did not erode the older formations than the Upper Permian. The breccia bodies fill karstic depresions in the Middle Triassic limestones of the Gutenstein Formation; the eroded material has been mostly derived directly from this formation. The rest of the clasts is represented by siliciclastic material transported from a distant source. The breccia infillings of the karst relief are covered with Paleogene basal marine transgressive facies rich in larger benthic foraminifera, which provide biostratigraphic data on the time of the breccia formation.

Key words: Malé Karpaty Mts., Plavecký Karst, paleokarst, Kržľa Breccia, biostratigraphy, larger benthic foraminifera

1. INTRODUCTION

The Plavecký Karst is one of several karst areas in the western part of the Malé Karpaty Mts. It is bordered by the Dobrá Voda Karst in the north, by the Kuchyňa-Orešany Karst in the south, and by the Smolenice Karst in the east (Mitter, 1983). The karst phenomena have developed in carbonate rocks – limestones and dolomites. It is spatially delineated between the villages of Rohožník, Prievaly, and Trstín (Kullman, 1990; Šmída, 2010).

Among others, the Plavecký Karst features various paleokarst carbonate breccias, made up mostly of carbonate lithoclasts with an argillaceous red matrix. Michalík (1984) divided the breccias into 5 types, among them the Kržľa Breccia, which emerges in the overburden of the Veterlín Nappe in the Sološnica – Malé paseky location (Fig. 1).

The breccia occurs in pockets or troughs in limestones of the Gutenstein Formation (Fig. 2). The matrix of the breccia is composed of a reddish-grayish argillaceous sediment. The clasts are angular or well-rounded, randomly oriented, unsorted, and

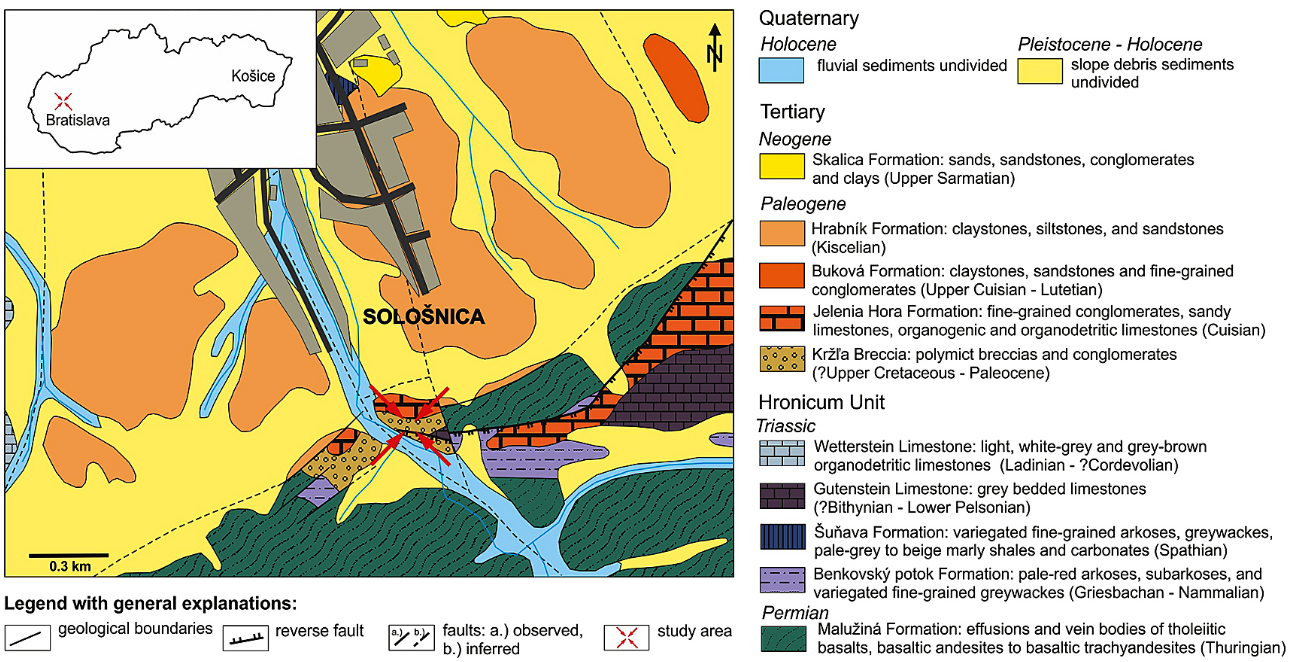

Fig. 1. Geological map of the study area (according to Polák et al., 2011).

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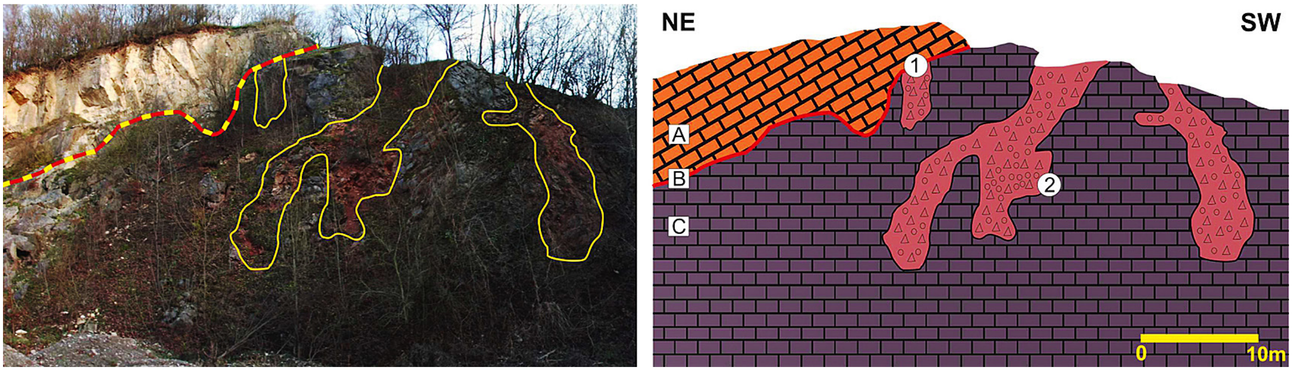

Fig. 2. Sološnica – Malé paseky Quarry. A - Jelenia hora Fm.; B - transgressive surface (dashed line); C - limestones of the Gutenstein Fm. with breccia pockets (yellow line). Numbers mark the sampling points.

composed of carbonates and siliciclastics. Transgressive Eocene sediments cover the limestones of the Gutenstein Fm. and seal the pockets filled with the breccia. The breccia was considered to be of the Late Cretaceous or the Paleogene in age (Michalík, 1984), thus originating during the uplift of the Malé Karpaty Mts. It is assumed that the abundant rainfall and high average annual temperatures led to the karst formation process and the formation of the breccia (Činčura et al., 1991; Aubrecht, 2012). The studied paleokarst is considered a karst-formed relief that is covered with younger sediments, or more precisely, buried beneath them.

2. METHODS

The studied locality of Sološnica - Malé paseky is situated 1.5 km southeast of the village of Sološnica in an abandoned quarry (48°27'16.8''N, 17°14'23.5''E). Field work was focused on the petrological analysis of breccia clasts and sampling of the breccia matrix for the micropaleontological analysis. More coherent breccia samples were crushed into smaller fragments, and the lithoclasts were extracted. The remaining fragments of mostly psephitic rocks or breccia fragments were exposed to glacial acetic acid (CH_3COOH) of 99.7% concentration for seven days. The partially reinforced matrix was dissolved, while the carbonate lithoclasts and siliciclastic sediments remained intact. By use of this method, a larger amount of small fraction clasts was obtained. Separated clasts were washed in hot water and sieved through a 4 by 10 mm mesh. Thin sections were prepared from macroscopically selected lithoclasts of each type (carbonates and siliciclastics). The analysed set of clasts was classified on the basis of petrographic features, size, and degree of abrasion. The Dunham scheme (1962) was used to classify the carbonate microfacies, and the Pettijohn scheme (Pettijohn et al., 1987) to classify the sandstones.

3. GEOLOGICAL SETTING

In the Malé Karpaty Mts., limestones of the Gutenstein Formation underwent karstification and contain pockets filled with sediments of the so-called Kržľa Breccia (Fig. 1). These breccias are covered with younger transgressive sandy-organodetritic limestones of the Paleogene age (Polák et al., 2012).

The Middle Triassic succession of the studied area belongs to the Veterlin Nappe and is mostly represented by carbonates of the Gutenstein Fm. of the Anisian age. It includes both limestones and dolomites, the latter ones forming lenticular or continuous stratiform bodies within the limestones. The formation consists of various, bioturbated, dark-gray microcrystalline limestones with a layer thickness between 20 and 100 cm, bright laminated microcrystalline limestones, and light-gray fine-grained dolomites. According to Buček (1988) and Buček et al. (1991), the limestones were deposited on a shallow carbonate ramp with a low dip and relatively low dynamics. Graded layers of tempestites are present. Michalík (1984) refers to them as the Annaberg Limestone, with common foraminifera (Michalík et al., 1986; Buček et al., 1991), green algae (*Dasycladaceae*), and conodonts (Jendrejáková & Papšová, 1989).

The Triassic carbonates are covered by Paleogene deposits of the Malé Karpaty Group (Buček in Polák et al., 2012). Pre-transgressive sediments are represented by very coarse carbonate breccias and conglomerates of alluvial material, which are deposited in paleokarst spaces formed during a warm palaeoclimate (Činčura, 1992). During the Paleogene transgression (Early Ilerdian – Late Cuisian), a new sedimentation cycle was initiated, forming the Jelenia hora Formation (Buček in Polák et al., 2012), known as the Borové Formation by some authors (Aubrecht, 2012). The transgressive formation consists of clastic rocks such as dolomitic sandstones with dolomite microbreccias and limestone breccias with fine-grained conglomerates. According to Polák et al. (2012), two different lithofacies were deposited in the Jelenia hora Fm. during the Ilerdian and Cuisian. Lithofacies of the Ilerdian age are composed of fine-grained carbonate conglomerates, foraminiferal fine-grained calcareous sandstones, as well as sandy and organodetritic limestones. The lithofacies of the Cuisian age consist of breccias, conglomerates, and calcareous sandstones with sandy limestones, fine-grained conglomerates, organogenic and organodetritic limestones.

The earliest Late Cretaceous age is suggested for the breccia by several authors (Michalík, 1984; Činčura, 1990; Činčura et al., 1991) due to the emergence and karstification of the Central

Western Carpathians during its Paleoalpine and Epipaleoalpine geodynamic development. Kvitkovič & Plančár (1979) pointed out that during the Late Cretaceous and Paleocene, the Central and Inner Western Carpathians emerged, which is indicated by the absence of marine sediments of this particular age, however, relics of limnic sediments were reported by Mišík & Sýkora (1980) and Pipík et al. (2009). Emerged areas were exposed to weathering in humid conditions of the tropical climate, which is proved by the presence of laterites (Ťapák, 1967).

Based on the material, dimensions and composition of the clasts, Michalík (1984) defined 5 types of breccias in the Malé Karpaty Mts., among them the Kržľa-type breccia. The breccia is formed by chaotically arranged clasts except for its basal parts. The degree of abrasion of the clasts is low, similar to the Bartalová-type breccia (Michalík, 1984). The petrographic content of the Kržľa Breccia is different, however, since it is more homogenous and contains 75% of clasts derived from the Annaberg Limestone, while the rest is composed of detritic limestones, dolomites and the limestones of the Reifling and Pseudo-Reifling fms. (Michalík, 1984). The matrix represents about 2-5% of the sediment, is pelitic red, and contains small gray limestone clasts. Similar breccia, that have lenticular layers of red laminated limestones with horizons of poorly rounded limestone clasts, occurs also on the Vápenná Mt. (Michalík, 1984). The base of this breccia is erosive, filling deep gorge-like fissures which extend tens or even hundreds of meters into the basement.

Činčura (1990) estimated the paleokarst origin of the breccia. A low degree of abrasion and sorting of the clasts could suggest the destruction of larger underground cavities caused by the collapse of their ceilings and walls. The author suggests the destruction of surficial karstic forms as well. The potentially subsurface origin is suggested due to the lenticular layers of red marlstones with gravel surrounded by breccia. Činčura (1990) compared them with cave sediments resulting from fluvial transport. Similar sediments described by Činčura et al. (1991) were found in the quarry near Buková and in the Prepadlé Zvony locality, containing also fragments of speleothems.

4. RESULTS

4.1. Lithostratigraphy of the breccia and contact with marine transgressive sediments

The studied locality shows a succession of Anisian limestones of the Gutenstein Fm. overlain by Eocene limestones of the Jelenia hora Fm. (Fig. 2). Small caverns filled with breccia are documented in the Anisian limestones and are interpreted as the Kržla-type Breccia. The breccia is relatively well-lithified and consists of two distinct depositional events. The first one is represented by the infilling of caverns with breccia deposits of alluvial origin (Fig. 3, Member A1). The matrix is fine (pelitic) and clast-supported with characteristic red colouration. Among the frequent limestone clasts, unevenly distributed rounded variegated sandstone clasts can be found (gray to reddish). The clast size varies between 0.2 and 5 cm. The second one is represented by overlying marine transgressive breccia deposits (Fig. 3, Member A2). The contact between these two breccias is indistinct, with a gradual change from the red coloured matrix to yellowish coloured matrix (Fig. 3). This 2 m thick marine breccia contains mostly unsorted carbonate clasts, usually well-abraded and with random orientation. Debris flow features are visible within the sediment structure. The size of the carbonate clasts is between 0.5 and 5 cm, and these are mostly gray and hardly reddish in colour.

The overlying formation (Jelenia hora Fm.) can be divided into 3 members (marked as B, C and D in Fig. 3). The first one consists of a 1 m thick massive fine-grained fossiliferous sandy limestone containing mostly red algae and shallow water larger benthic foraminifera. The colour of the limestones is beige, however, it turns gray if weathered. The second member is a massive layer of beige sandy limestones with common lithoclasts. The clasts are polymict, 1–1.5 cm in size with a

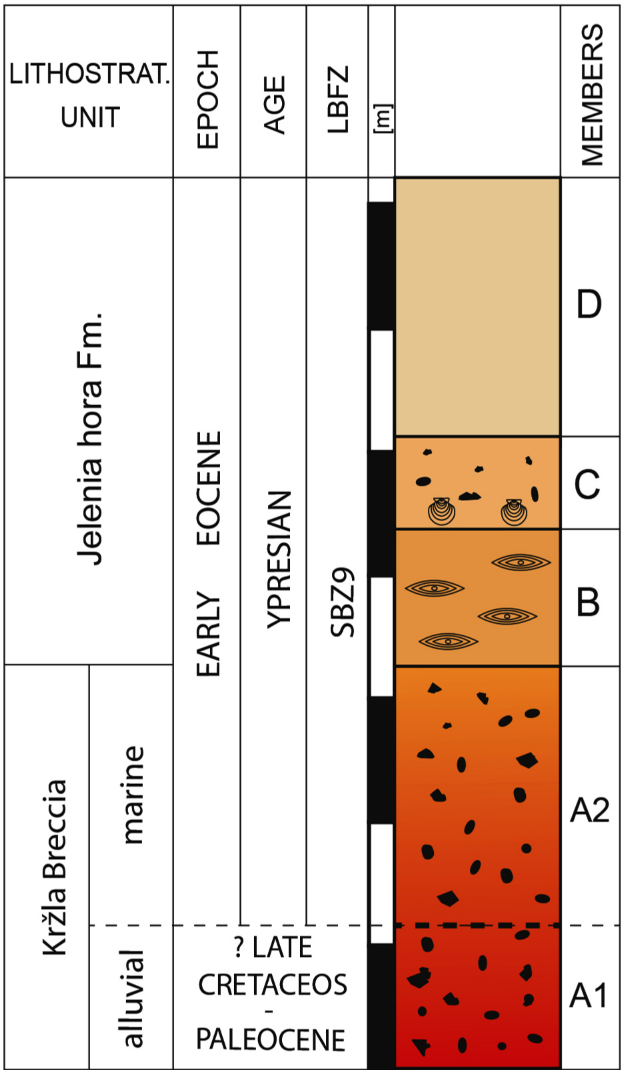

Fig. 3. Schematic section throught the Kržľa Breccia and the Jelenia hora Fm. in the Sološnica - Malé paseky Quarry. (A1) The alluvial (lower) and (A2) the marine (upper) part of the Kržľa Breccia. (B) Nummulite limestones. (C) Sandy limestones with lithoclasts and bivalve debris. (D) Sandy limestones.

high degree of abrasion. Oysters and other bivalve debris were noted on the base of this layer. The third member is a 2 m thick layer of massive beige sandy limestones. The difference between the dip of the stratified parts of the breccia and the overlying deposits of the Jelenia hora Fm. varies between 16 and 25°.

4.2. Biostratigraphic analysis of the marine part of the Kržľa Breccia

The benthic foraminifers *Alveolina – Alveolina trempina* (Hottinger) (Fig. 4E) and *Glomalveolina lepidula* (Schwager) were occasionaly observed in the marine part of the Kržľa Breccia.

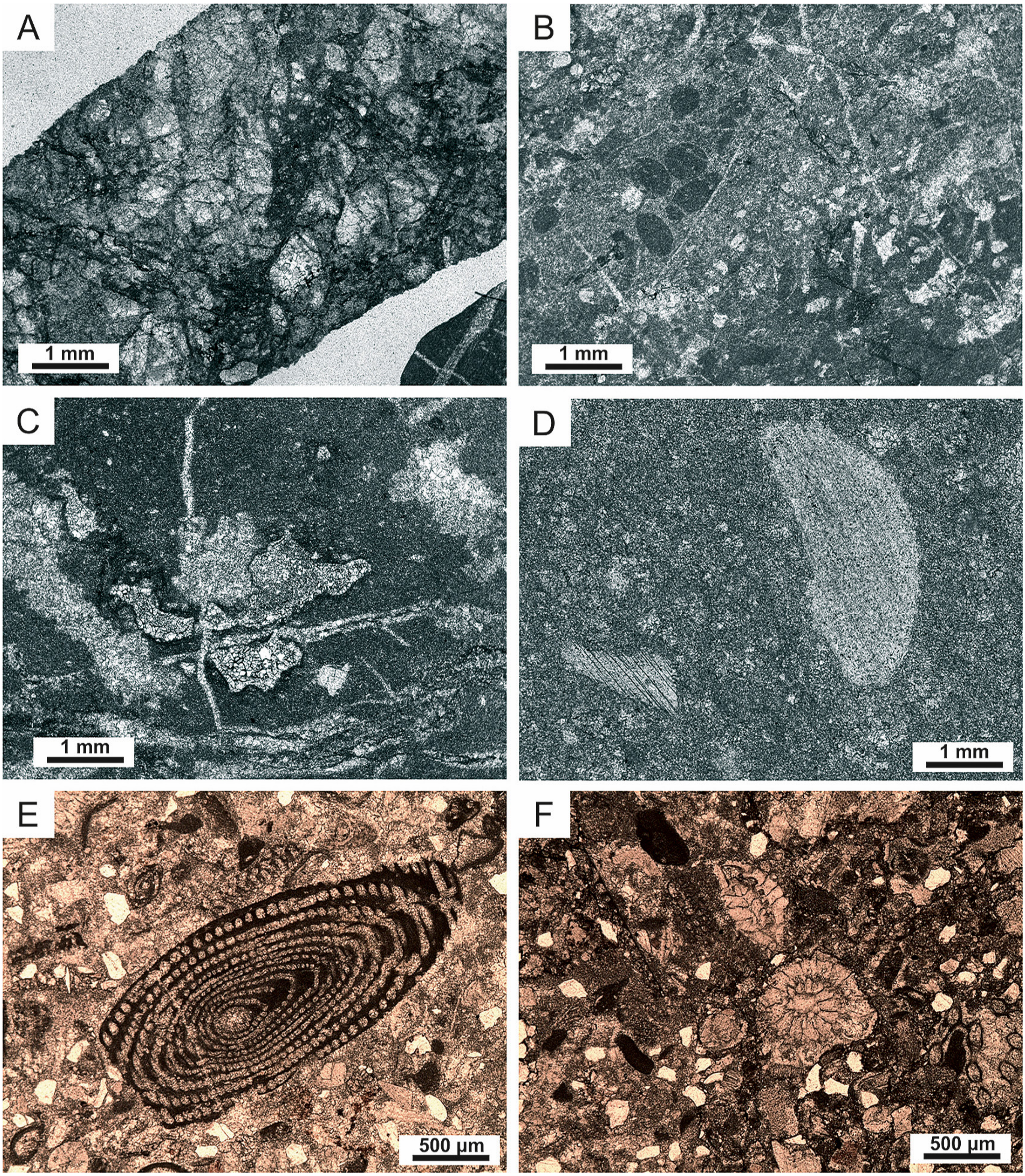

Fig. 4. **(A)** Dolomite cataclastic breccia (sample K03). **(B)** Peloidal micritic limestone (sample K06). **(C)** Fenestral pores in limestone (sample K05). **(D)** Wackestone with larger echinoderm fragments (sample K10). **(E)** *Alveolina trempina* Hottinger (sample SOL4, marine part of Kržľa Breccia). **(F)** *Miscellanea miscella* (d'Archiac & Haime) (sample SOL2, marine part of Kržľa Breccia). **A-D** photographed in polarised light.

A. trempina indicates the latest Ilerdian shallow benthic foraminiferal Zone SBZ9, while *G. lepidula* has a much broader stratigraphic distribution from SBZ5 to SBZ9 (Hottinger, 2009; Serra-Kiel et al., 1998; Mözgen-Erdem et al., 2007). Besides abundant *Nummulites, Discocyclina* and *Orbitoclypeus* are commonly present. Abraded larger benthic foraminifera of the Late Paleocene age were reworked in the Early Eocene assemblage in the lower part of the marine part of the Kržla Breccia. Taxonomic analysis revealed the presence of *Laffitteina bibensis* Marie, *Miscellanea julliettae* (Leppig) and *Miscellanea miscella* (d'Archiac & Haime) (Fig. 4F). These foraminifera are typical for the Thanetian (Afzal et al., 2009; Hottinger, 2009).

4.3. Petrographic and granulometric analysis of the breccia clasts

Among the set of 138 analysed clasts, 15.9% were larger than 10 mm. Clasts are formed by siliciclastic rocks (71.6%) and carbonates (28.4%). These larger clasts are sharp edged, illustrating a very low degree of abrasion, and are exclusively composed of limestones. The remaining analysed fraction consists of a clast with the size between 4 and 10 mm. Compared to the larger fraction, these clasts are usually better-rounded, however, sharp-edged clasts are also occasionally present. Well-distinguished, 10 or more centimetre-thick layers of rounded clasts are sometimes observable within the breccia body.

Microfacies analyses of the carbonate clasts revealed the presence of common packstones to wackestones with mostly undeterminable bioclasts, wackestones with rare bioclasts represented by echinoderm fragments, and/or shell debris from brachiopods and bivalves (Figs. 4D). One sample of bioclastic packstone with abundant echinoderm fragments (Fig. 5C) contained fragments of vertebrate bones with preserved haversian canals of about 4 mm in size (Fig. 5B, 5D). Less common or scarce are cataclastic breccias with dolomite clasts (Fig. 4A) and peloidal limestones (Fig. 4B). Fecal pellets are common in the micritic matrix. A single occurrence of a micritic limestone with fenestral structures was noted as well (Fig. 4C). Microfacies of these types are typical for the Middle Triassic shallow water facies. Most of the bioclasts are recrystallized and undeterminable (Fig. 5A).

The clasts of siliciclastic rocks are formed by sandstones and siltstones. Only a minor part of the sandstone clasts is subrounded; most of them are well-rounded, showing a high degree of abrasion (Fig. 6A). Both poorly-sorted sandstones (Fig. 6B,D)

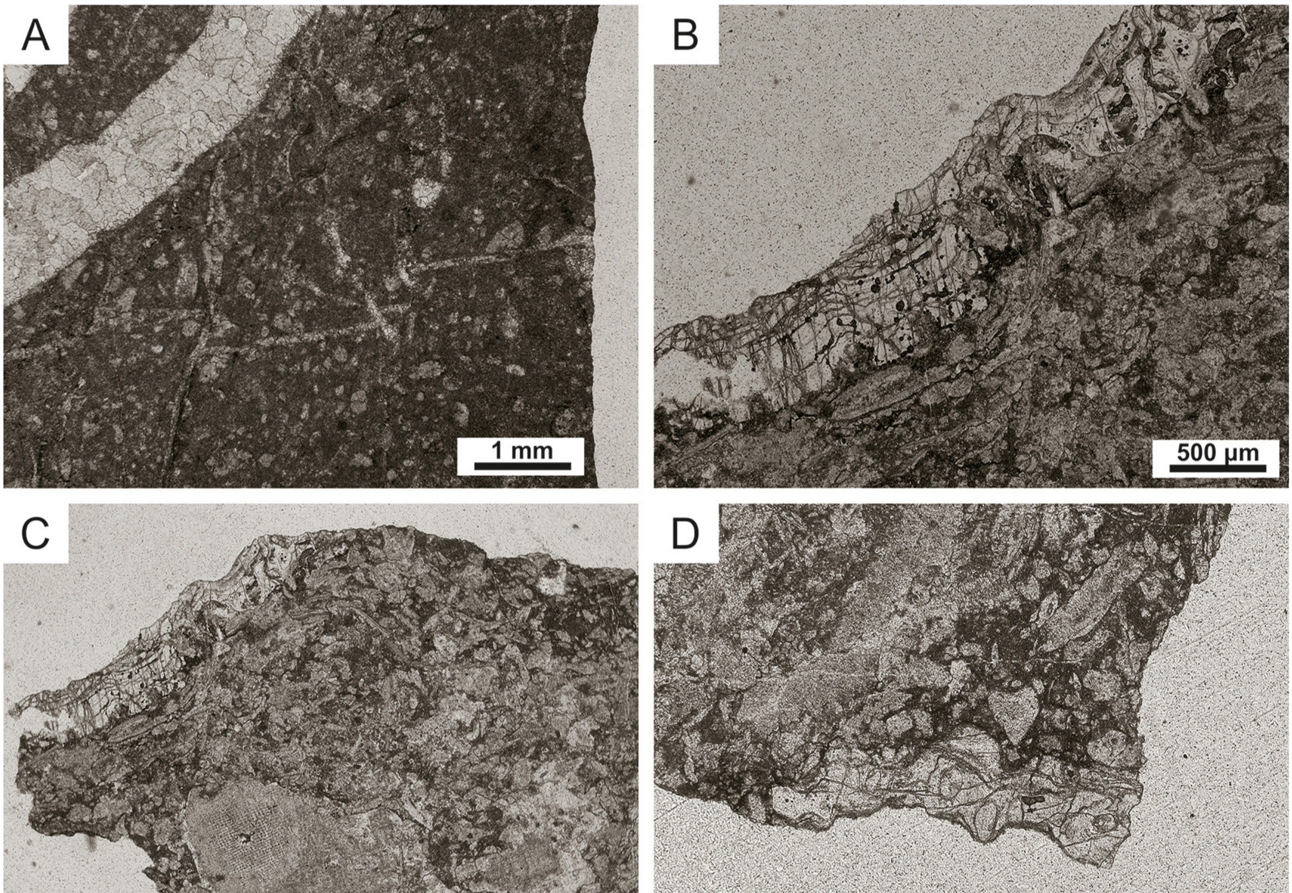

Fig. 5. (A) Limestone with filaments and unidentified small bioclasts (sample K08). (B-D) Bone fragments in the bioclastic packstone (sample K09).

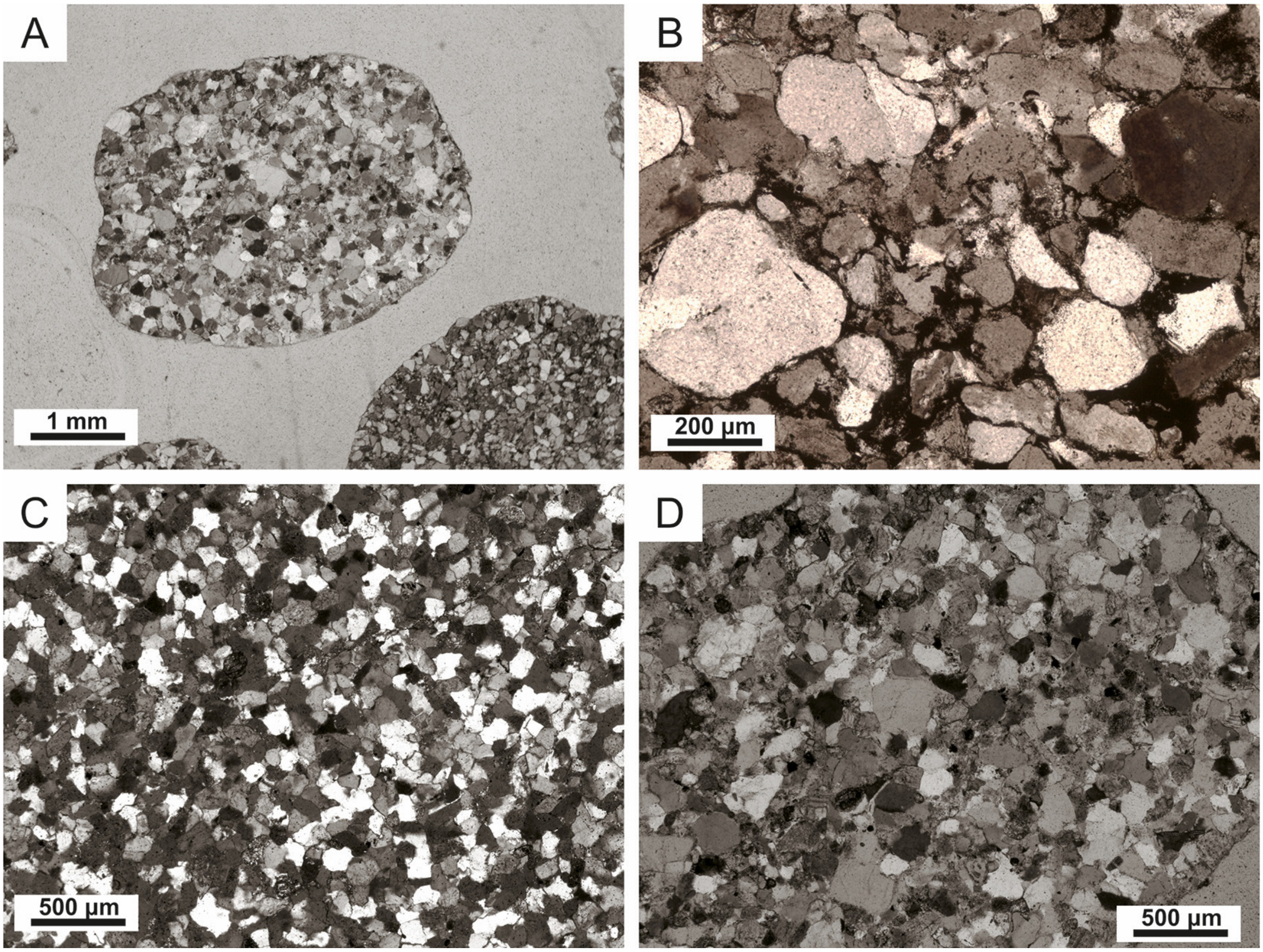

Fig. 6. (**A**) Well rounded clast of poorly sorted sandstone (sample K19). (**B**) Poorly sorted sandstone (sample K17). (**C**) Fine-grained well sorted sandstone (sample K15). (**D**) Poorly sorted medium-grained sandstone (sample K19).

and well-sorted fine-grained sandstones are present (Fig. 6C). Apart from quartz, rare light mica or sericitized feldspar were observed. According to the sandstone classification of Pettijohn et al. (1987), they are represented by subarcoses, sublitarenites and transitional types of sandstones (Fig. 7). All four of the fractions, coarse-grained, medium-grained, fine-grained and very fine-grained, are present. The total average sand grain size is 0.2 mm, which, according to the QFL diagram, falls into the category of small-grained sand. The very fine-grained sandstones account for 15.2% of the total number of the clasts, and the average grain size is 0.1 mm. The average size of the grains of fine-grained category is 0.18 mm. This category represents 63.6% of the analysed sandstone clasts. The average size of the medium-grained sandstone grains is 0.317 mm, and they represent 18.2% of the analysed set. The average grain size of a single clast of coarse-grained sandstone was 0.5 mm.

5. DISCUSSION

5.1. Biostratigraphy

The previous studies from the same locality include larger foraminiferal species which determine the Early Eocene (Ypresian) age of the Jelenia hora Fm. (Vaňová, 1963; Polák et al., 2012). Buček (in Polák et al., 2012) also reported *Alveolina triestina*

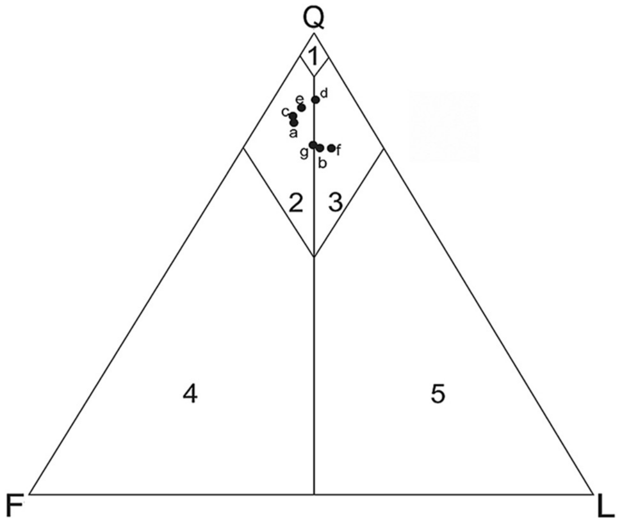

Fig. 7. QFL diagram of sandstone composition – arenites (in accordance with Pettijohn et al., 1987). (a) sample K02, (b-e) sample K12, (f-g) sample K04. 1 – quartz arenite, 2 – subarcose, 3 – sublithic arenite, 4 – arcosic arenite, 5 – lithic arenite. Q – quartz, F – feldspar, L – lithic fragments.

(Hottinger), which is indicative of the SBZ8 and lower part of the SBZ9 zones (Serra-Kiel et al., 1998). Upper Paleocene larger benthic foraminifera have also been documented within similar breccia of Mt. Roštún (Soták & Michalík, 2016). The matrix of the breccia did not yield any Cretaceous marine microfauna as described by different authors from other localities (Gašpariková et al. 1992; Soták & Michalík 2016).

5.2. Sedimentary features and provenance of the clasts

Clast analysis revealed that the Kržľa Breccia represents clastic sediment with a variable roundness of the clasts, containing carbonates (mostly limestones) and sandstone clasts. The matrix of the breccia is pelitic. The sandstone clasts are usually well-rounded and smaller than the carbonate clasts (4-10 mm).

The relatively poor clast abrasion and the smaller diversity of lithotypes of carbonate clasts indicate that the source area was relatively proximate. According to the classification of Blair & McPherson (1994), sorting and the sediment mode in the stratified parts of the breccia point to the features created by fluvial activity. The clastic material however, underwent short transport and most of the unstratified parts of the breccia show the features of debris flows and rock slides of alluvial fan deposits. Lithology and microfacies of the limestones correspond exclusively to facies of the Anisian limestones of the Gutenstein Fm. (Fig. 8). Microfacies, which could suggest the presence of limestones of the Reifling or Pseudo-Reifling fms. that were reported by Michalík (1984), were not found.

The source of the siliciclastic material, represented by quartzites-arenites, was probably derived from the Upper Paleozoic-Lower Triassic formations of the Hronic Unit. The clasts are rounded and were likely transported over long distances. Shales of Šuňava Fm., which were observed by Činčura et al. (1991) from the Buková locality in similar breccia, were not observed in the studied breccia (Fig. 8).

In contrast to the locality of Mt. Roštún (Veľká Vápenná), described by Soták & Michalík (2016), the breccia does not contain any clasts of basalts from the Ipoltica Group of the Malužiná Fm. If we suggest a subhorizontal dip of the Hronic Unit during the Cretaceous – Paleocene, the absence of paleobasalts means that erosion did not reach the volcanic parts of the Ipoltica Group. The recent south-vergent structure of the Malé Karpaty Mts. was formed during the Early Miocene (Marko et al., 1991, 1995). During this tectonic event, the blocks rotated into their current position and placed the Triassic formations in direct tectonic contact with the paleobasalts.

Concerning the cave origin of the breccia, the studied outcrop did not yield any direct indication for such interpretation. Sinter fragments from speleothems mixed within Paleogene breccia deposits were collected from a few other localities (Činčura et al., 1991), however, they are absent in the studied locality. The karst origin of this breccia was also denied by Šmída (2010).

6. CONCLUSIONS

The new biostratigraphical, as well as petrographical and sedimentological data, lead us to the conclusion that the lower part of the Kržľa Breccia was deposited during the Early-Middle Paleocene in the continental setting, however, the Late Cretaceous, suggested by several authors cannot be excluded as well. The clast composition, compared to other localities in the Malé Karpaty Mts., is more monotonous. The clasts are derived from two sources and are represented only by carbonates and sandstones. The breccia contains mostly smaller carbonate clasts with a relatively poor degree of abrasion. The sandstone clasts are generally rounded or subrounded, depending on the rock competence. The morphology of the pockets and the typical sediment mode suggest a karstic origin of the depresions, at least partially filled with fluvial sediments. The deposition by

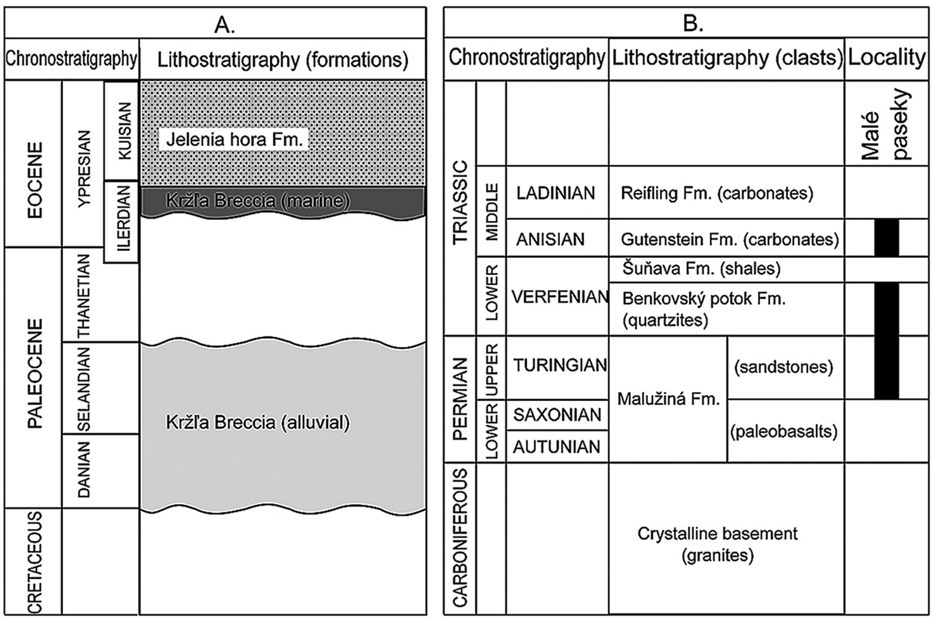

Fig. 8. Stratigraphy and the provenance of the studied clasts of the Kržľa Breccia. **A.** Stratigraphic overview of the Jelenia hora Fm. and the Kržľa Breccia. **B.** Lithostratigraphy of the clastic material from Solośnica - Malé paseky section (this study).

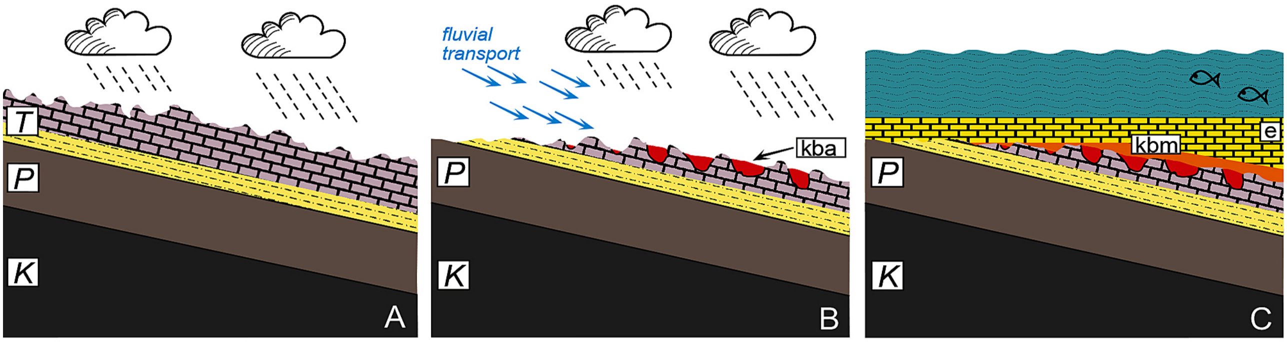

Fig. 9. Tectonosedimentary reconstruction of the Kržľa Breccia. (A-B) erosion and deposition of the breccia in a scarp during the ?Late Cretaceous-Paleocene. (C) Marine transgression and sealing of the breccia body in the Early Eocene. e – Eocene sediments of Jelenia hora Fm. (nummulitic limestones), T – Middle Triassic carbonates of the Gutenstein Fm. (limestones and dolomites) and Lower Triassic quartzites of the Benkovský potok Fm., P – Permian siliciclastic sediments of the Malužiná Fm. (quartzites and sandstones), K – Lower Permian part of Malužiná Fm. with paleobasalts and other volcaniclastics, kba – alluvial part of the Kržľa Breccia, kbm – marine part of the Kržľa Breccia.

debris flows or rock slides from a nearby alluvial fan, or directly derived from the pocket surfaces, are probable.

The upper part of the breccia is a marine transgressive deposit, forming a thick layer sealing the top of breccia pockets. It contains a relatively rich large benthic foraminiferal fauna of the Early Eocene age. However, the presence of reworked Upper Paleocene foraminifera indicates the onset of marine sedimentation already in this time period.

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