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Miocene fan delta conglomerates in the north-western part of the Danube Basin: provenance, paleoenvironment, paleotransport and depositional mechanisms

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Abstract: The Blatné Depression located in the NW part of the Danube Basin represents the northernmost sub-basins of the Pannonian Basin System. Its subsidence is associated with oblique collision of the Central Western Carpathians with the European platform, followed by the back-arc basin rifting stage in the Pannonian domain. The conglomerates recognized in the Cífer-2 well document the latest Burdigalian–early Langhian deposition in fan delta lobes situated above the footwall and hanging wall of a WSW–ENE trending fault system, the activity of which preceded the opening of the late Langhian–Serravallian accommodation space with a NE–SW direction. The provenance area of the "Cífer conglomerate" was linked to the Tatric Super-unit complexes. Similar rocks crop out in the southern part of the Malé Karpaty Mts. and are also present in the pre-Cenozoic basement of the Danube Basin. Documented extensive erosion of the crystalline basement and its sedimentary cover lasted until the early/middle Miocene boundary. The "Cífer conglomerate" has distinct clast composition. The basal part consists of poorly sorted conglomerate with sub-angular clasts of metamorphic rocks. Toward the overlying strata, the clasts consist of poorly sorted conglomerates with sub-rounded to well-rounded carbonates and granitoids. The uppermost part consists of poorly sorted conglomerates with sub-rounded to rounded clasts of carbonate, granitoid and metamorphic rock. Within the studied samples a transition from clast to matrix supported conglomerates was observed.

Keywords: Danube Basin, Blatné Depression, lower/middle Miocene, fan delta, conglomerates, sedimentary petrology.

Introduction

The Danube Basin, located at the junction of the Eastern Alps, Western Carpathians and Transdanubian Range, represents the NW part of the Pannonian Basin System. The investigated Cífer-2 well (48°19'52.68" N, 17°28'45.44" E) is situated in the central part of the Blatné Depression (NW Danube Basin). It is bordered by the Malé Karpaty Mts. in NW and by the Považský Inovec Mts. in the NE and passes into the Gabčíkovo–Győr Depression in the south (Fig. 1).

The basin fill consists of marine to freshwater deposits reaching up to 3000 m (Adam & Dlabač 1969; Kilényi & Šefara 1989; Rybár et al. 2016). The early Miocene marine sediments are situated mostly in the north. The main part of the basin fill is represented by the middle Miocene deposits of the Central Paratethys Sea, which are overlain by sequences of the late Miocene Lake Pannon, and the late Miocene to Pliocene alluvial to fluvial sediments (e.g., Kováč et al. 2011; Sztanó et al. 2016). The prevailingly fine grained sedimentary fill is intercalated with sandy to gravely facies, often at the base of Transgression–Regression (T–R) cycles (e.g., Kováč 2000).

The Cífer-2 well (Fig. 2) was drilled to confirm natural gas capacity at the Trnava–Sereď basement elevation located northeast of Cífer village. The pre-Cenozoic basement rocks are formed by crystalline complexes of the Tatric Super-unit (Fusán et al. 1987). The original description of the well was done by Pagáč (1959), and the data were later summarized by Biela (1978). The deepest part of the well yielded conglomerates originally included in the Paleogene (1885–2031 m). These coarse-grained strata are covered by more conglomerate layers originally ranked to the Karpatian/lower Badenian (upper Burdigalian/Langhian) time span (1553–1885 m; Biela 1978). The conglomerates are overlapped by offshore mudstones and sandstones of the upper Badenian (lower Serravallian) Báhoň Fm. (Vass 2002). The sequence ends with the Pannonian lacustrine to alluvial sediments of the Ivanka, Beladice and Volkovce fms. (Šujan et al. 2017).

The aim of this work is to revise the conglomerates from the Cífer-2 well in respect to their age, petrography and provenance. The definition of transport mechanisms and the character of depositional paleoenvironment will be derived from facies analysis, well-logs study, and seismic facies interpretation. The acquired knowledge should contribute to

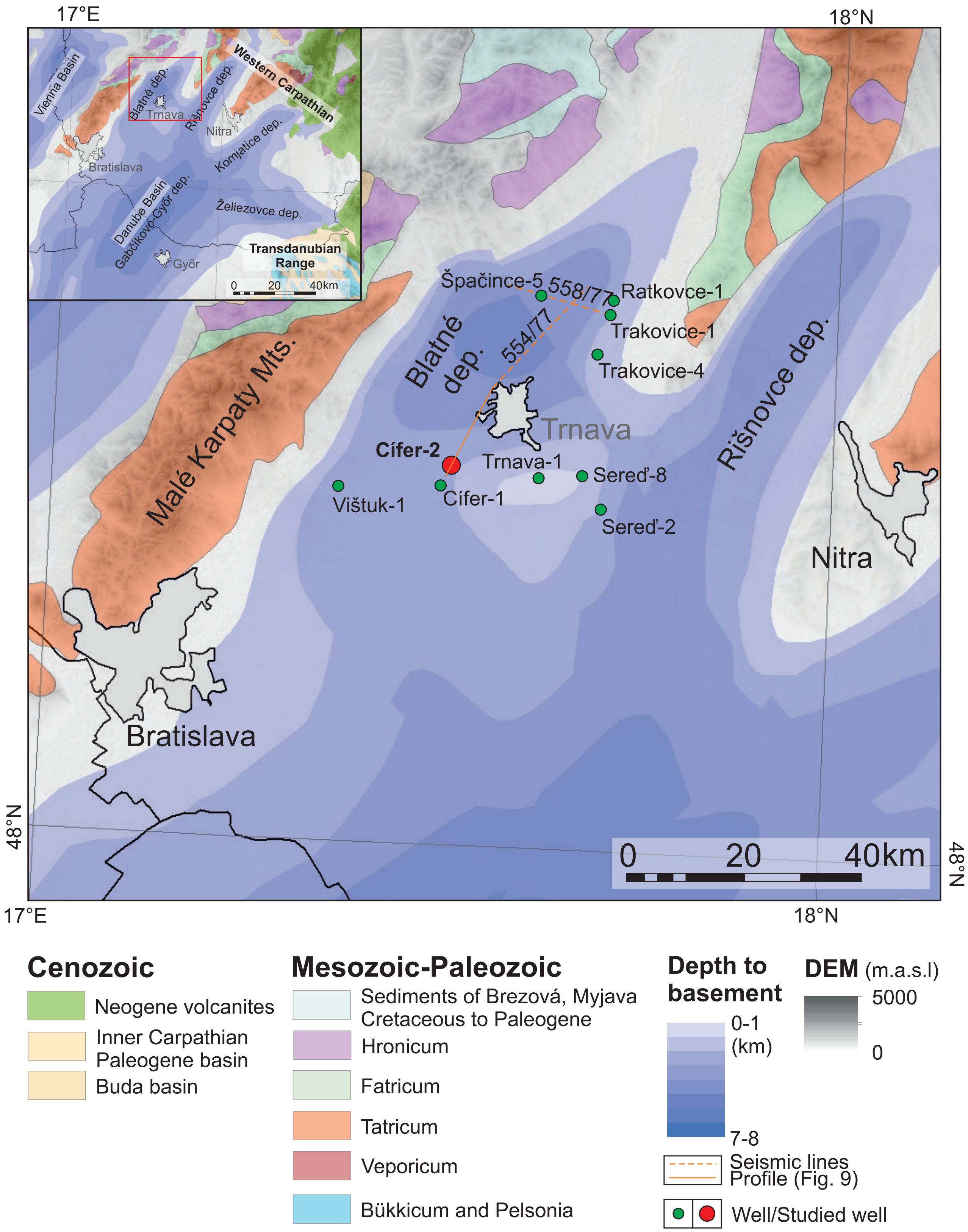


Fig. 1. Location of the Cífer-2 well in the Danube Basin. Map of the pre-Cenozoic basement depth modified from Horváth et al. (2015) and Fusán et al. (1987).

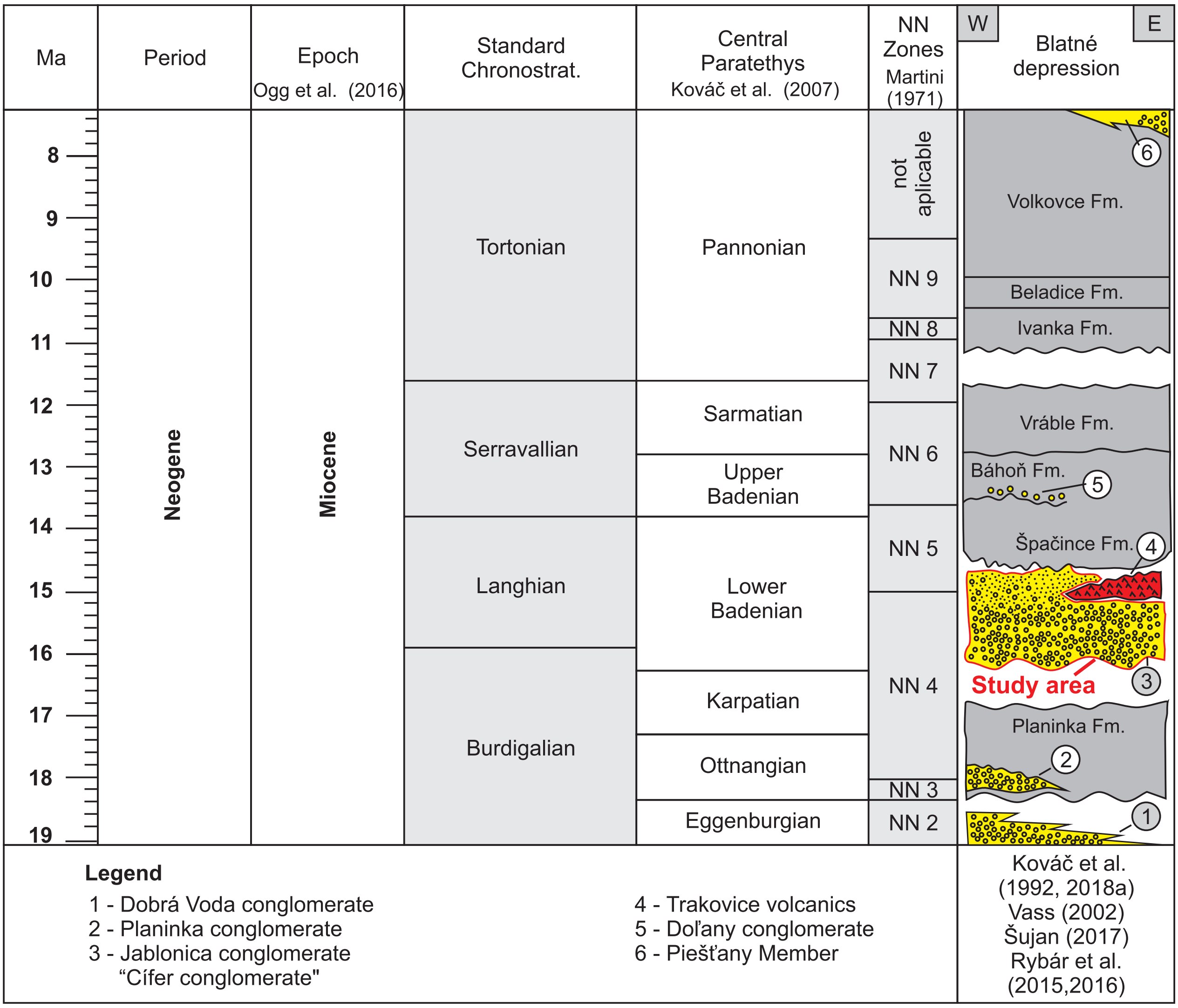


Fig. 2. Lithostratigraphic chart of the study area (time range of NN Zones according to Hohenegger et al. 2014).

confirmations of the geodynamic development model of the area at the Eastern Alpine–Western Carpathian junction during the rifting phase of the Danube Basin (Kováč et al. 2018a). It should also contribute to paleogeographic models before and during the maximal flooding of the Central Paratethys Sea in the back-arc basin system (e.g., Kováč et al. 2017b; Sant et al. 2017).

Material and methods

Well core samples were obtained from the repository of Nafta a.s. — Oil and Gas Company (Gbely). From six well cores twelve samples were taken (spot sampling). For the purposes of provenance and facies analysis the cores were cut in half and scanned. Individual clasts from the sampled conglomerates were divided into 4 grain size fractions (0.2 to 0.8 cm, from 0.8 to 1.5 cm, 1.5 to 3 cm and >3 cm) and 1 was used for the matrix composition (0–0.2 cm). The clasts were measured on the polished side of the well core. It needs to be noted, that the measurements reflect the original clast size only partially. The clast composition was confirmed by seventeen thin sections studied under a polarizing microscope. Abbreviations of minerals follow Whitney & Evans (2010). Grain size classification of clasts follows Wentworth (1922) and the shape classification of clasts follows Powers (1953). The sedimentary structures of the individual well cores were evaluated in the sense of Boggs (2006) and Nichols (2009). The conglomerates classification follows the work of Pettijohn (1975). Carbonate classification follows the work of Flügel (2010).

Two reflection seismic lines were used for the purposes of seismic facies analysis: the NNE–SSW oriented 554/77 line and the line 558/77 with a NW–SE orientation (Fig. 1). Interpretations were made in the Schlumberger Petrel software using the standard methods described by Mitchum & Vail (1977), Brown & Fisher (1980). The well log data was evaluated based on Rider & Kennedy (2011) and Emery & Myers (1996).

Petrography of the conglomerates of the Cífer-2 well

The conglomerate in the core 26 (1999–2005 m; Fig. 3) represents the basal part of the sedimentary succession. The clast supported conglomerate is poorly sorted with chaotic orientation of clasts. This core sample consists only of metamorphic ?cobbles (Qz-mica schists and biotitic paragneisses; Fig. 3). The clasts of biotitic paragneisses are sub-angular and occasionally deformed; the Qz-mica schists are sub-rounded to rounded. In the polarizing microscope chloritic-sericitic and graphitic schists were observed. Segregated clasts of quartz and lydites can also be found. The mineral composition of the paragneisses involves: Qz, Pl, Kfs, Bt (commonly chloritized) and Ms (Fig. 4; with heteroblastic texture). Accessory minerals are represented only by Zrn and Grt. The paragneiss clasts, together with the surrounding matrix are cut and offset by calcite veins (Fig. 4a, b). The clayey-sand matrix is built up by crushed monocrystalline Qz, clasts of metamorphic rocks (medium sand fraction), clay minerals and mica (Fig. 3).

The clast composition of core 25 (1947–1959 m) is more variegated (Fig. 5), but the texture is still clast supported. The matrix is micritic (microsparite), and occasionally clayey–carbonatic. The clasts of metamorphic rocks are represented by paragneisses. Heavily weathered granitoids are also present and are built up by Qz, altered Fs and mica. The majority of clasts represent micritic carbonate rock fragments represented by three types: (i) pale carbonates, (ii) dark carbonates cut by calcite veins (Fig. 6) and (iii) laminated carbonates. Red quartz arenites and clastic quartz were also distinguished. The roundness of carbonate and paragneiss clasts is generally subrounded. The dark carbonates are well rounded (fraction 0.2–0.8 cm). The grain size of granitoids and red quartz arenites varies from medium sand to granule; carbonate rocks vary in size from medium sand to pebble/cobble; clastic quartz vary in size from coarse sand to very coarse sand (Fig. 5).

Core 24 (1900–1905 m), was not available in the repository but abundant carbonate clasts and rare Qz-mica schists were described (Pagáč 1959).

The conglomerates from core 23 (1857–1882 m; Fig. 7) are poorly sorted. They consist of pale and dark carbonate rocks, biotitic paragneisses and chloritic-sericitic schists. Carbonates and paragneisses are rounded to well rounded. The amount of granitoids increases, comparing to the red quartz arenites. The granitoid clasts are sub-rounded and formed by Qz, sericitized Fs and weathered mica. The size of all rock types varies from fine sand to pebble. The texture is clast supported and the matrix is carbonatic.

The conglomerate in core 22 (1794–1799 m; Fig. 8) has similar grain size and roundness of clasts as in core 23, but macroscopically only two clast types were observed: altered granitoids to granitoids and metasandstones. The proportion of granitoids to altered granitoids is 3:1. Carbonates were observed only in the thin sections (Fig. 9). One packstone clast contains thin-valued bivalves and uniserial foraminifers, other clasts are micritic. Compared to all other conglomerates, the main difference is that the conglomerate from core 22 is matrix supported (clayey-carbonatic) and red in colour. In small parts of both samples indistinct normal gradation is observed.

The conglomerates in core 21 (1746–1752 m; Figs. 10, 11) are characterized by variegated clast composition. The texture is matrix supported. The binding material is sparitic, and indistinct normal gradation is observed. Clasts of metamorphic rocks are still present and are accompanied by clasts of granitoides, red quartz arenites to minor carbonates. The clasts of biotitic paragneisses are predominantly cut by calcite veins. However, in contrast to the conglomerates from core 26, the calcite veins are located only inside the clast. One piece of a red chert was found. The carbonate rocks are represented by (i) dark and (ii) laminated carbonates which are micritic or recrystallized. The grain size of biotitic paragneisses, granitoids and carbonates clasts varies from medium sand to pebble. Qz-mica schist clasts vary from medium sand to granule, and red quartz arenites vary from medium sand to coarse sand.

Interpretation of provenance, paleoenvironment, paleotransport and depositional mechanism

The deepest part of the Cífer-2 well (Fig. 12) was previously assumed to be of Paleogene to Karpatian age (Pagáč 1959; Biela 1978; Fig. 13). However, this ranking was not sufficiently constrained. The new data from the Trakovice-1 and Špačince-5 wells (Rybár et al. 2016) allowed the creation of biostratigraphicaly defined horizons, which were then correlated throughout the selected seismic lines. This enabled ranking of the studied "Cífer conglomerate" (2031–1565 m) to the latest Burdigalian to early-middle Langhian (Karpatian/lower Badenian) time span. This can be interpreted from the available seismic lines 554/77 and 558/77 (Figs. 1, 13). The early Serravallian (late Badenian) age of the overlying mudstones (1565–1000 m) is based on the correlation with Cífer-1 well (2 km to the south; Fig. 1). Correlations were made by using SP and RT logs and the age data are derived from the presence of calcareous nannofossil zone NN6 (Ozdínová 2008).

Provenance

The provenance of all processed conglomerates points to the Central Western Carpathian source. The source of granitoids can be associated with biotitic granodiorites exposed in the Modra Massif of the Malé Karpaty Mts. The described clasts of metamorphic rocks (chloritic-sericitic schists, graphitic schists and biotitic paragneisses) are exposed in the upper part of the crystalline complexes of the Pezinok Group in the Malé Karpaty Mts. The protolith of chloritic-sericitic schists was a psammitic rock together with some rare pelitic sediment (Cambel & Čorná 1974). The closest occurrence is situated around the Mešťanková elevation (Modra–Harmónia area; Polák et al. 2012). Minor occurrences of such rocks are also found in the south-eastern part of the Tribeč Mts. (e.g., Badice;

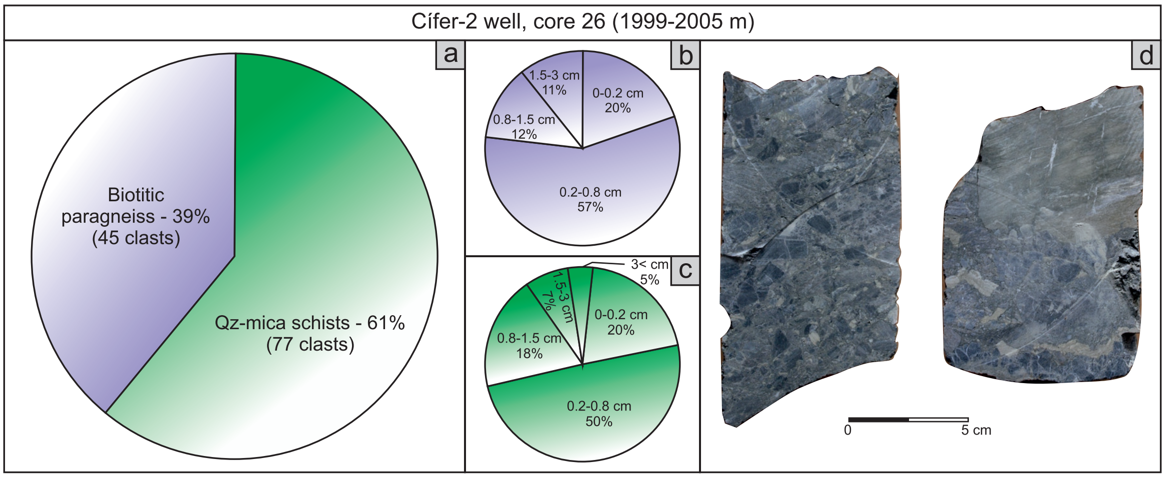


Fig. 3. Well core 26, macroscopic analysis: **a** — clast composition; **b, c** — proportion of individual lithological types in various grain size classes: (b) biotitic-paragneisses, (c) Qz-mica schists; **d** — samples from core 26.

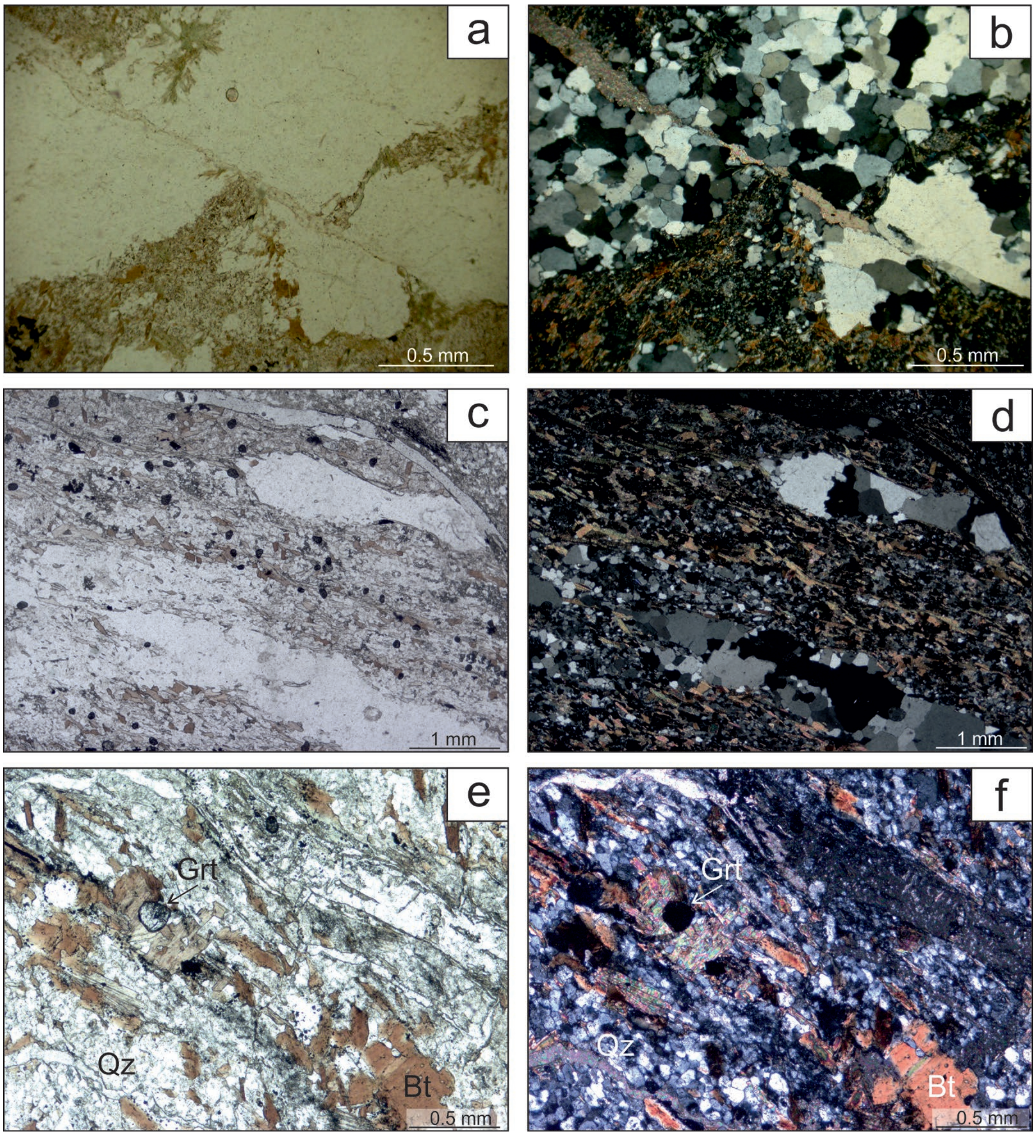


Fig. 4. Microscopic analyses from the depth of 1999–2005 m (core 26): **a, b** — brittle deformation of a Qz-mica schists clast in: (a) plane polarized light (II), (b) in crossed nicols (X); **c, d** — biotitic-paragneisses; **e, f** — clast of biotitic-paragneisses with garnet.

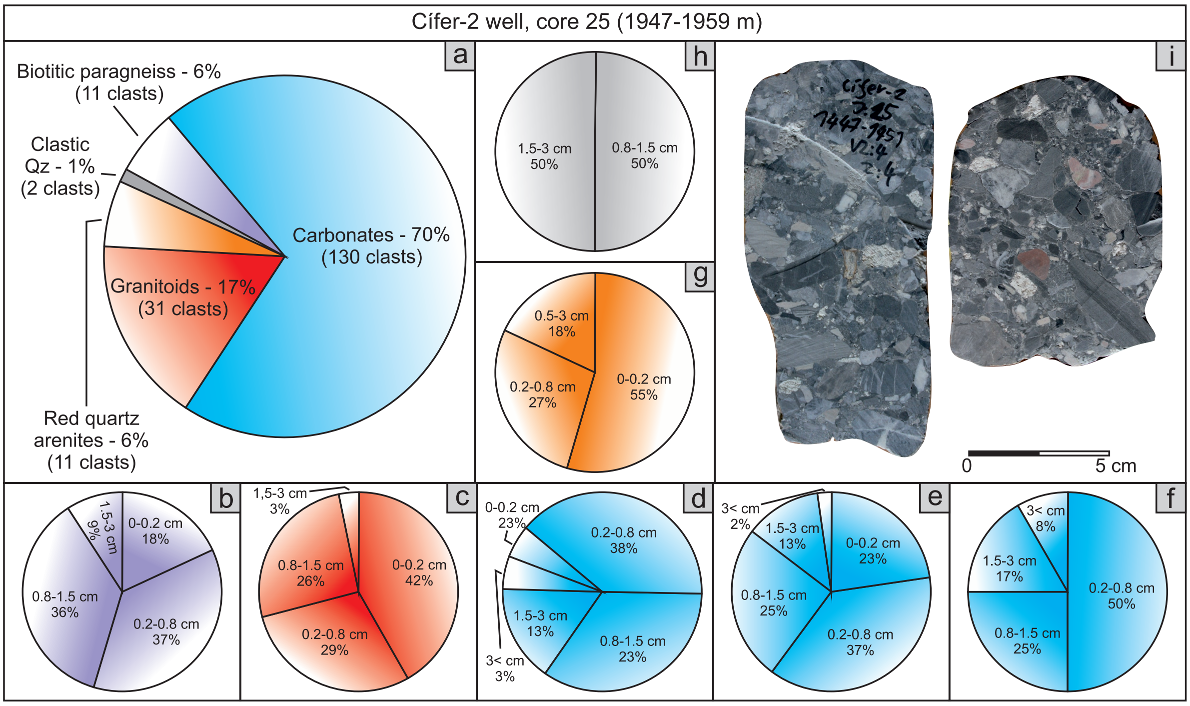


Fig. 5. Well core 25, macroscopic analysis: **a** — clast composition; **b–h** — proportion of individual lithological types in various grain size classes: (b) biotitic paragneisses, (c) granitoids, (d) pale carbonates, (e) dark carbonates, (f) laminated carbonates, (g) quartz arenite, (h) clastic quartz; **i** — samples from core 25.

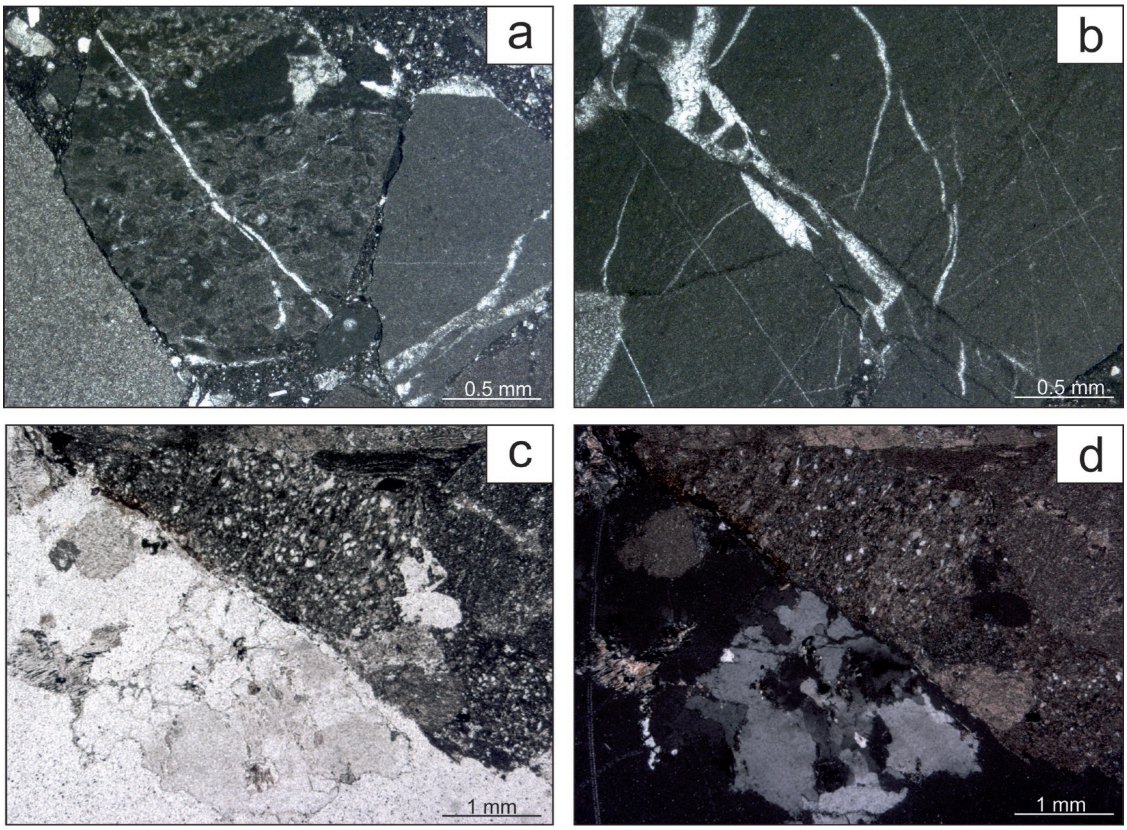


Fig. 6. Microscopic analyses from the depth of 1947–1959 m (core 25): **a** — clasts of limestone with calcite veins (II); **b** — broken clast of limestone (II); **c, d** — granitoid and micritic limestone clasts: (c) II, (d) X.

Kamenec — 293 m.a.s.l.). The source of quartz arenites may be in the Lúžna Fm. (Lower Triassic) which represents a sedimentary cover of the Tatric Super-unit. Similarly, dark carbonates with calcite veins without fossils may belong to the Gutenstein Fm. (Middle Triassic) of the Tatric Super-unit sedimentary cover. Nonetheless sourcing from the Fatric and the Hronic nappe units cannot be excluded. The pale, sandy limestones which microscopically occur in core 22 may belong to the Paleogene sediments.

Based on the clast composition the studied conglomerates were divided into 3 groups (Table 1). The clasts of the 1st group (core 26, 2005–1999 m) consists only of Bt-paragneiss and Qz-mica schists which point to a different source area, then in the overlying 2nd and 3rd group. They may be derived from the southernmost part of the pre-Cenozoic basement of the Blatné Depression, which is built up of crystalline rocks, overlapped by sediments of Serravallian age (late Badenian/ Sarmatian; see Biela 1978; Fusán et al. 1987).

Beside crystalline rocks, the 2nd and 3rd groups contain clasts from the sedimentary cover or nappe units. The main difference between these groups is the degree of weathering of granitoid clasts and content of carbonate clasts. Group 2 (core 25, 1959–1947 m and core 23, 1882–1857 m) consist of heavily weathered granitoids (17–47 %; Figs. 5, 7) and a large proportion of carbonates (70–45 %; Figs. 5, 7). Group 3 (core 22, 1799–1794 m and core 21, 1752–1746 m) comprises non-weathered granitoids (9–43 %; Figs. 8, 10) and a low proportion of carbonates (2–8 %; Figs. 8, 10). Increase of granitoid clasts and decrease of their degree of weathering points to gradual erosion of the source area. The provenance can be linked to an area, which was similar in geological structure to the Malé Karpaty Mts. southern part. It needs to be noted, that in the time of denudation the eroded area was much larger and extended further to the east up to the Kráľová stratovolcano (Hrušecký 1999).

Transport mechanism and depositional environment

Interpretation of the transport mechanism and depositional environment can be drawn from the 2D seismic profile 554/77 and from the SP (Spontaneous potential) and RT (Resistivity) logs (Figs. 12, 13). The seismic facies of the "Cífer conglomerate" are arranged in sigmoid prograding clinoforms which dip toward the N, NE (Fig. 13) and can be interpreted as a fan delta body.

The reflexes are discontinuous with high amplitudes which indicates coarse-grained deposits. The negative excursions on the SP log and the high resistivities recorded by the RT log also indicate coarse grained character what is additionally confirmed by the physical well core samples. Moreover, the high excursions point to saturation by fluids and/or gas (cylindrical and symmetrical trends).

The conglomerate in the deepest core, interpreted as the 1st group, contains clasts which are broken together with their surrounding matrix. Therefore, crushing during drilling can be excluded. The offsets (Fig. 4) indicate that the conglomerate must have been lithified before further tectonic events. So, we can deduce that group 1 was derived from the Danube Basin crystalline basement. Based on these facts, together with the different clast composition documented by the 2nd and 3rd groups, the 1st group is interpreted as a boulder of an older conglomerate which was incorporated into the latest Burdigalian–early-middle Langhian (Karpatian/ lower Badenian) "Cífer conglomerate". This situation can be seen in recent deposits in the Gulf of Suez (Bosworth & McClay 2001), where uplifted rift flanks are being eroded and produce large boulders similar to those in the group 1 (this study). These are transported to a recently active alluvial fan (Fig. 14).

The conglomerates in the 2nd and 3rd groups are poorly sorted with rounded to sub-rounded clasts. Moreover, indistinct normal gradation is observed in all samples which indicates gravity transport (Fig. 8). The conglomerates of the 3rd group are clinostratified and have higher proportions of matrix, in some places they are even matrix supported. Altogether, the 2nd group can be interpreted as a proximal facies of a fan delta and the 3rd group as a facies of a distal fan delta, which is supported by higher portion of carbonate matrix (sub-aqueous deposition). The fan delta character of both aforementioned groups can be backed up by the sigmoid clinoform visible on the seismic line 554/77 (Fig. 13).

Tectonic context

The sedimentation of the coarse clastic facies is generally influenced by tectonic activity (Vail et al. 1977). From the paleogeographical point of view, the accommodation space of the "Cífer conglomerate" was connected with the early Miocene WSW–ENE oriented fault system, active until the earliest-middle Miocene (Marko et al. 1991; Fodor 1995; Marko & Kováč 1996; Hrušecký 1999; Hók et al. 2016; Kováč et al. 2018b). This process in a transtensional/extensional tectonic regime, associated with the lateral extrusion of the ALCAPA lithosphere eastward (Ratschbacher et al. 1991), which led to the opening of new depocenters situated between the Eastern Alps and Western Carpathians (e.g., lower Miocene terrestrial to marine deposits of the Styrian, Eisenstadt and Danube Basin; Kováč et al. 2003, 2017a). It was partly coeval to the basin opening of Dinaride Lake System in the southwest (Mandić et al. 2012).

The Danube Basin pre-Cenozoic basement is built up in its central part by crystalline complexes of the Tatric Super-unit (Fusán et al. 1987). Gradual Oligocene–early Miocene uplift of these complexes is documented in the Malé Karpaty Mts. by AFT (Apatite Fission Track) cooling ages ~52 to 20 Ma (Králiková et al. 2016). The initial rifting at the western border of the Pannonian domain led to development of horsts and grabens within the pre-Cenozoic basement (Hók et al. 2016; Kováč et al. 2018b). This may have led to erosion and deposition of coarse clastics on the southern margin of the middle Miocene Blatné Depression in the form of the "Cífer

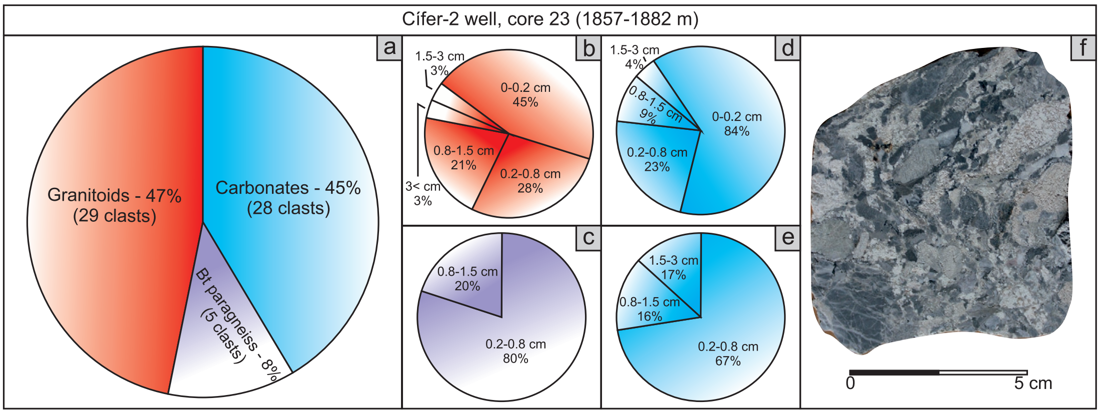


Fig. 7. Well core 23, macroscopic analysis: **a** — clast composition; **b**–**e** — proportion of individual lithological types in various grain size classes: (b) granitoids, (c) biotitic paragneisses, (d) pale carbonates (e) dark carbonates; **f** — samples from core 23.

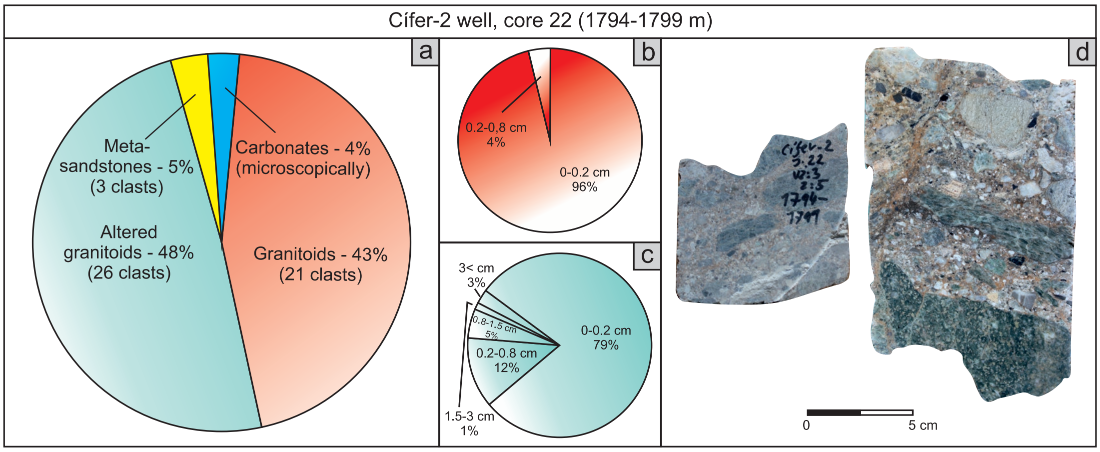


Fig. 8. Well core 22, macroscopic analysis: **a** — clast composition; **b, c** — proportion of individual lithological types in various grain size classes: (b) granitoids, (c) biotitic paragneisses; **d** — sample from core 22.

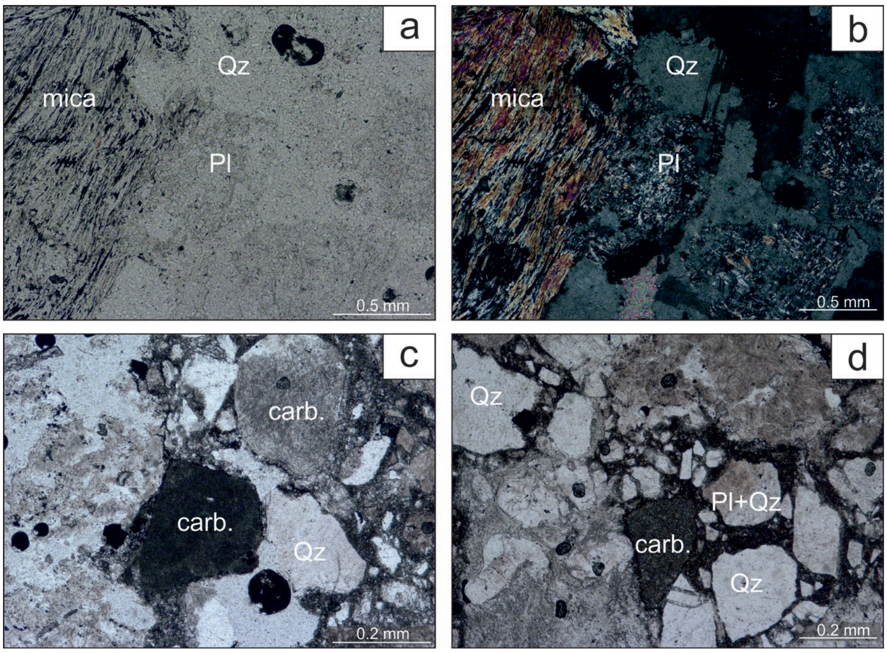


Fig. 9. Microscopic analyses from the depth of 1794–1799 m (core 22): **a, b** — granitoid created by Qz, sericited Pl and mica; **c, d** — composition of sandy grains in the conglomerate (carb. — carbonate, Pl+Qz — granitoide clast; II).

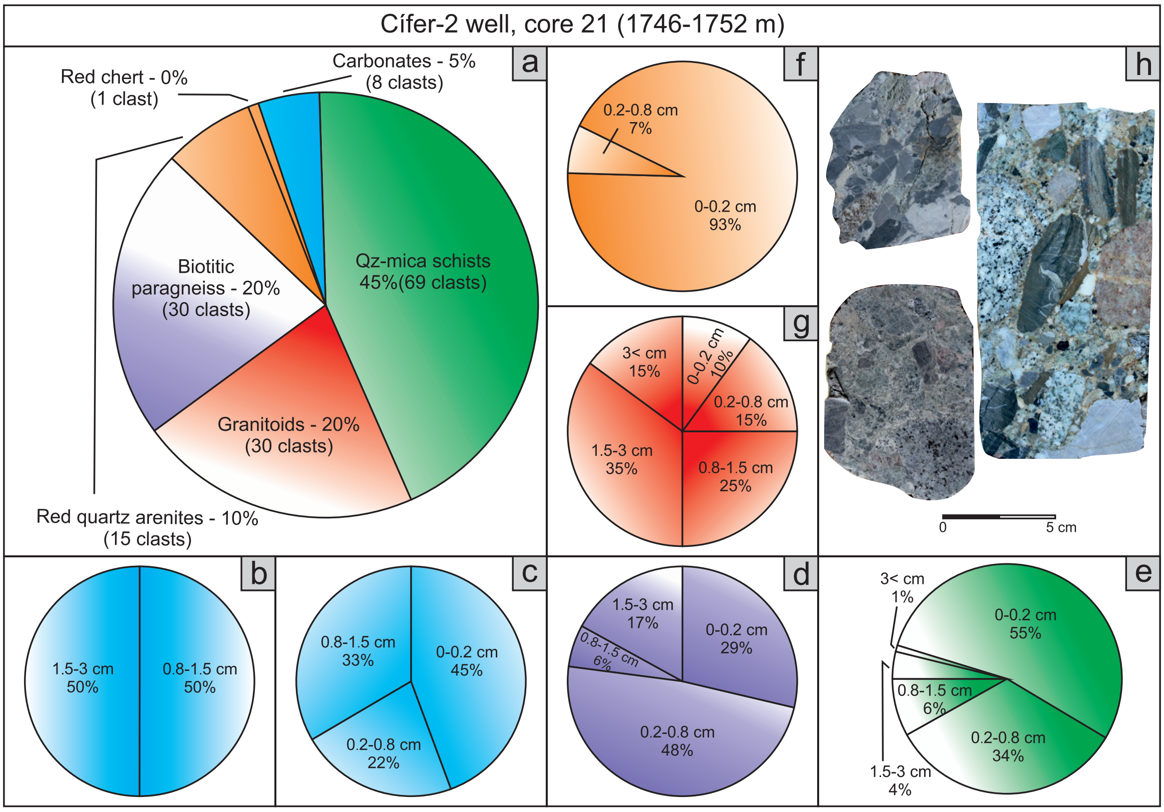


Fig. 10. Well core 21, macroscopic analysis: **a** — clast composition; **b**–**g** — proportion of individual lithological types in various grain size classes: (b) pale carbonates, (c) dark carbonates, (d) biotitic paragneisses, (e) Qz-mica schists, (f) quartz arenite, (g) granitoids; **h** — samples from core 21.

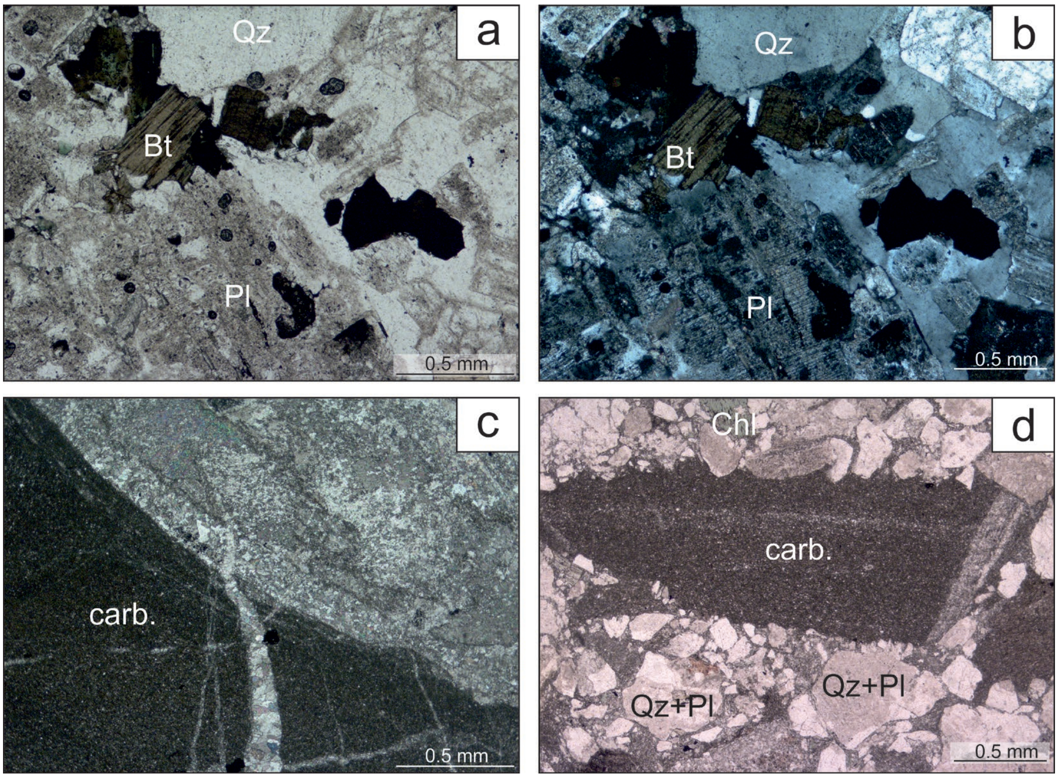


Fig. 11. Microscopic analyses from the depth of 1746–1752 m (core 21): **a, b** — granitoid created by Qz, Pl and Bt; **c, d** — clast of micritic limestones (carb. — carbonate, Pl+Qz — granitoide clast; II).

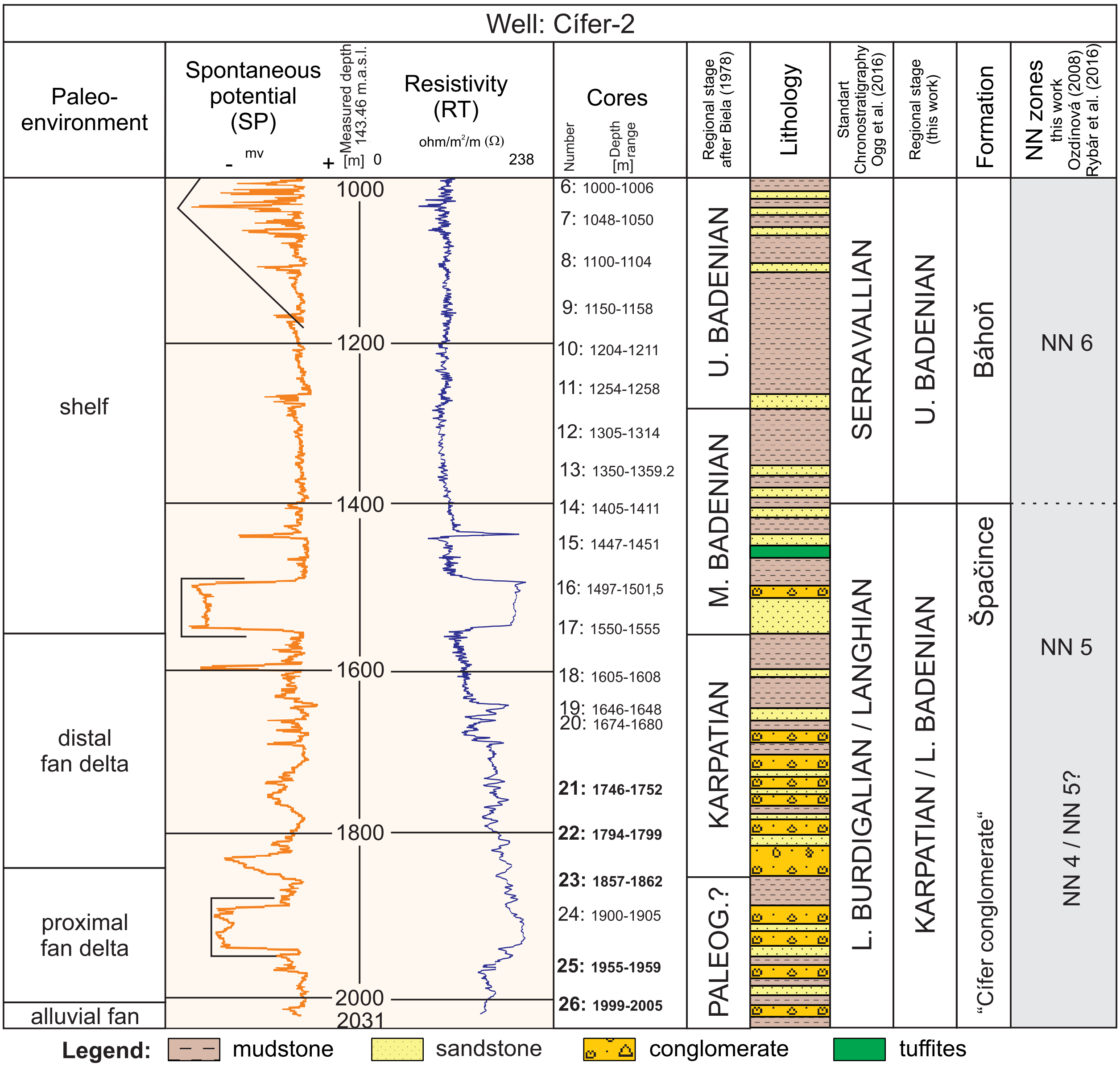


Fig. 12. Lithostratigraphy of the Cífer-2 well showing interpretation of Biela (1978) and our reinterpretation.

conglomerate" during the synrift phase of the Danube Basin (Kováč et al. 1999, 2011; Rybár et al. 2016)

The "Cífer conglomerate" clasts composition shows erosion of the basin's pre-Cenozoic horsts during the latest Burdigalian–early Langhian (Karpatian–earliest Badenian) time. The transport direction can be deduced from dip of the clinoforms, which seems to be prograding from S-SW to N-NE (Fig. 13). This is in accordance with the above presented results of the provenance analyses. Latter, in the middle-late Langhian, the accommodation space was enlarged (Kováč et al. 1999). The opening of the Blatné Depression in its present form was a result of the oblique collision of the Central Western Carpathians, with a spur of the Bohemian Massif, representing the margin of the European platform (e.g., Hók et al. 2016; Kováč et al. 2017a, b).

The stratigraphical assignment of the "Cífer conglomerate" and correlations with related conglomerates

The "Cífer conglomerate" (Table 1) is deposited directly on the pre-Cenozoic basement of the Tatric Super-unit crystalline complexes (Trnava–Sereď basement elevation, Fusán et al. 1987). This is indirectly indicated by the Trnava-1 well (7 km to the E) which drilled the pre-Cenozoic basement to the depth of 959.6 m (Biela 1978), as well as by the low amplitude, discontinuous seismic facies which occur below the Cífer-2 well which can be interpreted as basement rocks (Fig. 13). The lateral extension of the "Cífer conglomerate" may be much larger, since synchronous conglomerates are recorded around the Trnava–Sereď basement elevation. However, they were

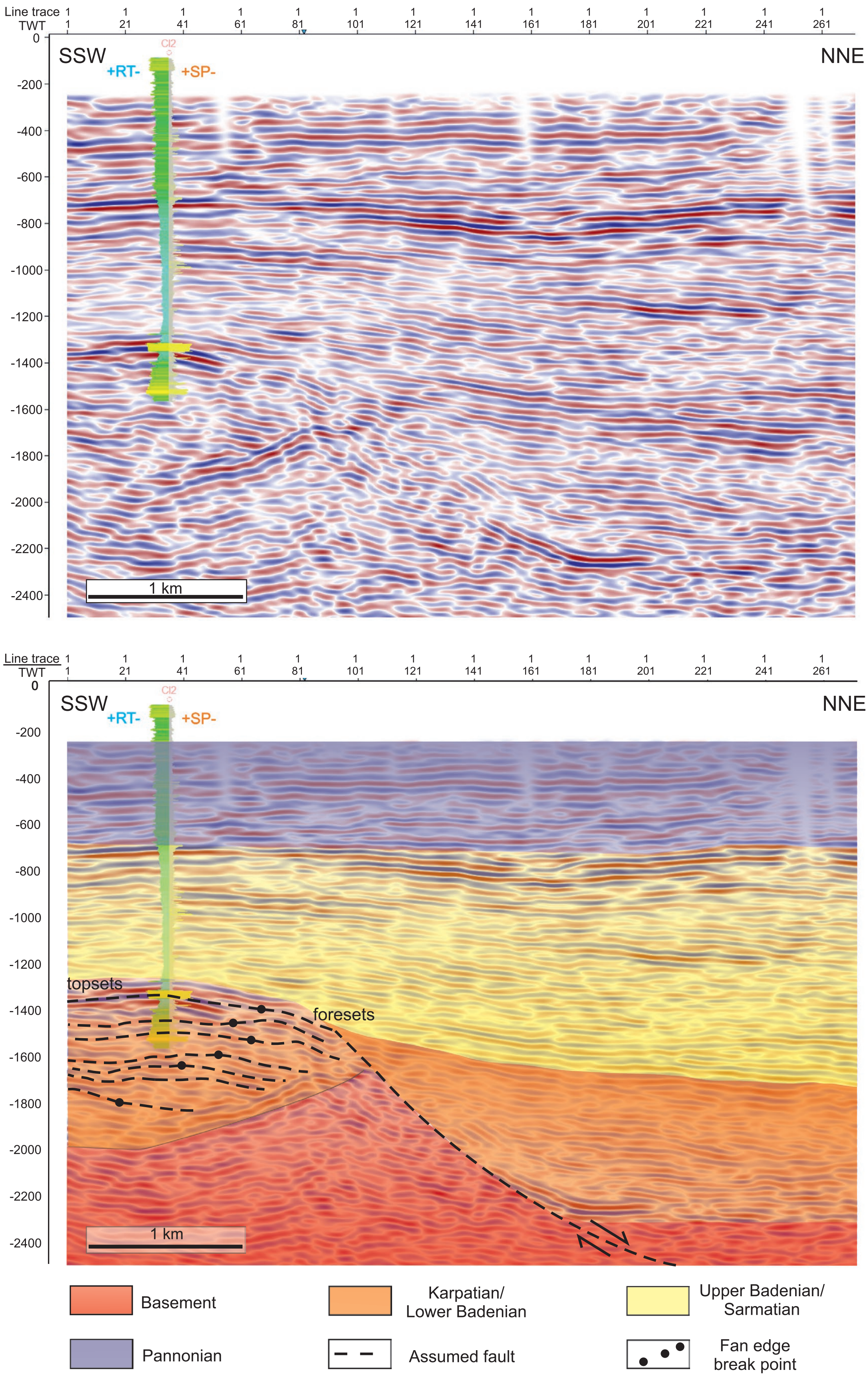


Fig. 13. 2D reflection seismic line 554/77 tied to Cífer-2 well oriented from NNE to SSW.

Table 1: Sampled cores with interpreted paleoenvironment and nomenclature.

Well Cífer-2	Nomenclature						
Core	**Texture**	**Composition**	**Source**	**Structure**	**Matrix**	**Paleo-environment**	**Group**
21	Para-conglomerate	Polymict	Extraformational	matrix supported	sparitic	distal part of fan delta	3
22	Ortho-conglomerate	Polymict	Extraformational	matrix to clast supported	clayey-micritic	distal part of fan delta	3
23	Ortho-conglomerate	Polymict	Extraformational	clast supported	micritic	proximal part of fan delta	2
25	Ortho-conglomerate	Polymict	Extraformational	clast supported	microsparit/clay	proximal part of fan delta	2
26	Ortho-conglomerate	Polymict	Extraformational	clast supported	clayey-sandy	alluvial fan	1

not studied in detail (e.g., Sereď-2, 5; Vištuk-1 wells, Biela 1978).

The Langhian age of the conglomerate upper boundary can be deduced from the presence of the early Serravallian NN6 nanoplankton zone (*sensu* Martini 1971) in the fine-grained deposits in overlying strata (Appendix 1), confirmed by Ozdínová (2008) in the neighboring Cífer 1 well respectively. Moreover, the southernmost part of the pre-Cenozoic basement of the Blatné Depression is built up from crystalline rocks, which are overlapped by Miocene sediments of Serravalian age (Late Badenian/Sarmatian; *see* Biela 1978; Fusán et al. 1987). In addition, the core samples from depth interval 1405–1680 m contain calcareous nannofossils of the NN5 Zone. Further constraints come from volcanic sandstones in core 20, bearing nannoplankton of NN5 Zone (Appendix 1 and Fig. 12), which are similar to tuffites from the Trakovice-4 well, also assigned to the NN5 Zone (Rybár et al. 2016). Core 23 (1857–1862 m) yielded nanoplankton of the NN4 Zone, which document the age of deposition or it was redeposited from older sediments (Appendix 1).

As noted in the introduction, the Blatné Depression sedimentary fill contains several conglomerate bodies, generally at the base of T–R cycles (e.g., Kováč 2000). The oldest, Burdigalian (Eggenburgian) Dobrá Voda conglomerates belong to the Lužice Fm. (Vass 2002) and onlap onto the pre-Cenozoic basement in the northern part of the Malé Karpaty Mts. In comparison to studied samples, they consist of monomict carbonate pebbles and cobbles (Buday et al. 1963).

The younger, pebbly mudstone of middle Burdigalian age represents the Ottnangian Planinka Fm. (Kováč et al. 1992; Fordinál et al. 2012) which has a polymict character, similar to the early-middle Langhian (Karpatian–earliest Badenian) Jablonica conglomerate.

The Jablonica conglomerate assigned to the early-middle Langhian is mainly found on the northern slopes of the Malé Karpaty Mts. and in the vicinity of the Dobrá Voda depression (Vass 2002; Maglay et al. 2011). The conglomerate is matrix supported with calcareous–sandy matrix and the depositional environment is linked to the littoral zone or to a deltaic environment (Kováč 1985; Kováč et al. 1989). The conglomerates are composed of staurolite–garnet schists, Devonian metamorphic limestones, Wetterstein and Reifling limestones (Mišík 1986). Based on their stratigraphic position the "Cífer conglomerate" may be synchronous or a bit older (latest Burdigalian to early-middle Langhian) than the Jablonica conglomerate. Nevertheless, the Jablonica conglomerate from the Cerová–Lieskové locality yields a much lower portion of crystalline schists and granitoids than were documented in the "Cífer conglomerate" (Table 2). However, the clast composition in conglomerates is generally of local provenance. So, conglomerates may be very different in composition, but still synchronous.

Devínska Nová Ves Fm. occurs on the western slopes of the Malé Karpaty Mts. and is ranked to the Langhian (lower Badenian; Vass et al. 1988; Fordinál et al. 2010, 2012). The sediments were deposited in the terrestrial environment of an alluvial fan. The clasts are represented by siliciclastics, carbonates, and crystalline rocks which can be derived from the Malé Karpaty Mts.; and their vertical distribution (MKZ-1 well) shows gradual erosion of the provenance area. The base of the MKZ-1 well is mainly formed by clasts of metamorphic rocks with rare carbonates, and granitoids, but the highest part of the well is formed exclusively by granitoid rocks (Fordinál et al. 2012). The terminal part of the coarse-grained formation shows reworking by waves in the littoral zone, beyond the frontal part of the alluvial fans. Toward the Vienna Basin, the formation intercalates with the middle-late Langhian (lower Badenian) Jakubov Fm. (Vass 2002; Zlinská 2015) that contains calcareous nanoplankton of the NN5 Zone. Like the "Cífer conglomerate", the Devínska Nová Ves Fm. is covered by mudstones containing the NN6 nanoplankton zone (*sensu* Martini 1971).

The younger Doľany conglomerate Mb. (Vass 2002), occurs on the eastern slopes of the Malé Karpaty Mts. It is coarse-grained, has poorly rounded clasts and calcareous–sandy matrix; some breccias are present as well. The clasts are composed of metamorphic and carbonate rocks. Most importantly the Doľany Mb. was deposited around the lower/upper Badenian boundary (Buday 1957; Cicha 1957) between the Špačince and Báhoň fms. (Vass 2002). According to Ogg et al. (2016) this time interval corresponds to the late Langhian–early Serravallian. This time span can be characterized by the accelerated uplift of the NE–SW orientated horst structure of the Malé Karpaty Mts. and synrift subsidence of the Blatné Depression (Kováč et al. 2018b).

The comparison of the Doľany and Devínska Nová Ves conglomerates (position and petrographic composition of clasts) may point to their origin at the edges of the uplifting Malé Karpaty Mts. The provenance of the Planinka, "Cífer" and Jablonica conglomerates can be additionally identified as a source situated south of the Blatné Depression.

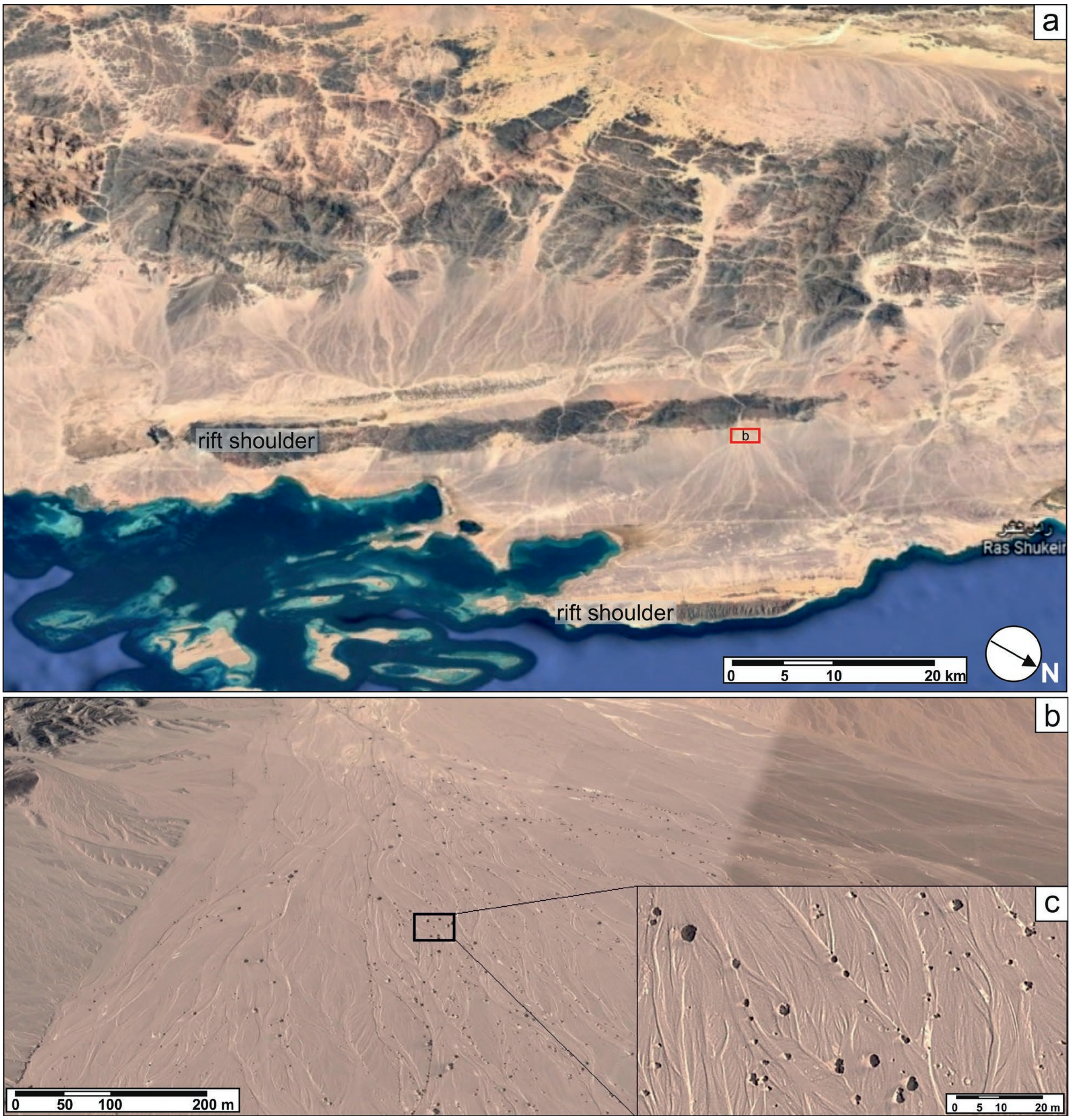
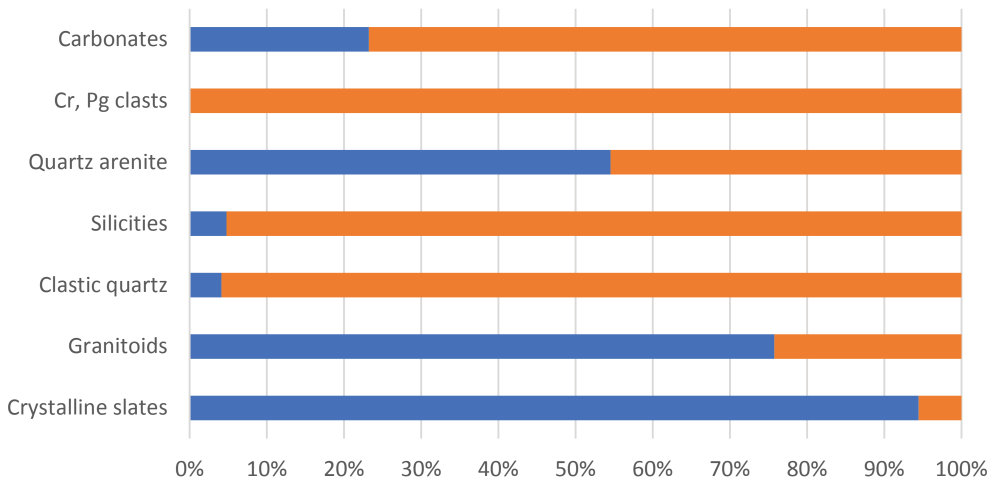


Fig. 14. Gulf of Suez (27°51’39” N, 33°17’06” E; Source: Google Earth; February 16, 2018): **a** — note the eroding rift shoulders and alluvial fans and fan deltas evolving between them; **b** — close up on one of the alluvial fans; **c** — detail of the eroded blocks incorporated in the alluvial fan which is equivalent to group 1 of the “Cífer conglomerate”.

Conclusions

- The conglomerates of the Cífer-2 well can be divided in respect to composition and structure into three different groups:
  1. Group 1 is represented by conglomerates from core 26 — they are composed only of clasts of metamorphic rocks, which are tectonically affected, what indicates their older age. This group is interpreted as a conglomerate boulder incorporated into the “Cífer conglomerate”.
  2. Group 2 comprises conglomerates from cores 25 and 23 which are massive or poorly graded and have a limited amount of matrix. The clasts of this group consist mostly of carbonate rocks and weathered granitoids. They are interpreted as deposits of the proximal fan delta.
  3. Group 3 comprises conglomerates from cores 22 and 21 — clasts of this group consist mostly of metamorphic rocks and non-weathered granitoid rocks. They have higher amounts of carbonate matrix, and therefore are interpreted as deposits of fan delta lobes in a distal position.

Table 2: Comparison of overall clast composition in the Cífer-2 conglomerates and in the Jablonica conglomerate from the Cerová-Lieskové section.



	Crystalline slates	Granitoids	Clastic quartz	Silicities	Quartz arenite	Cr, Pg clasts	Carbonates
Cífer-2 conglomerate	51.40%	21.90%	0.30%	0.10%	3.60%	0%	22.70%
Jablonica conglomerate (loc.: Cerová-Lieskové)	3%	7%	7%	2%	3%	3%	75%

- The stratigraphic assignment of the “Cífer conglomerate” is based on the seismo–stratigraphic correlation (line 554/77, 558/77) and nannofossil zonation in the Cífer-2 well with additionally support from the Trakovice-1, Špačince-5 and Cífer-1 wells. The conglomerate upper boundary was set within the NN5 nannoplankton zone. Considering the provenance, transport direction and petrological composition of clasts the conglomerates are considered to be synchronous or a bit older than the Jablonica Fm. However, the estimated latest Burdigalian to lower-middle Langhian age, inside of the uppermost part of the NN4 and NN5 nannoplankton zone (*sensu* Martini 1971) was not sufficiently proved.
- The provenance area of the “Cífer conglomerate” was linked to similar rock complexes to those outcropping in the southern part of the Malé Karpaty Mts. and vicinity (Tatric Super-unit — crystalline basement plus sedimentary cover or nappe units).
- The latest Burdigalian to lower-middle Langhian conglomerates represent deposition in fan delta lobes situated above the footwall and hanging wall of WSW–ENE trending fault system. The fault system activity preceded opening of the middle-late Langhian to Serravallian Blatné Depression with a NE–SW direction. Basin subsidence is associated with oblique collision of the Central Western Carpathians with the European platform and the back-arc basin synrift stage in the Pannonian domain.

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Appendix 1

Calcareous nannofossils zonal markers found in the Cífer-2 well

Depth (m)	Core	Discipline	Zone/Subzone	Event
1350–1259.2	13	N	NN6	PRES *Reticulofenestra pseudoumbilicus* 6 and >7 µm, *Helicosphaera wallichii, Sphenolithus abies*
1405–1411	14	N	NN5	TOP *Helicosphaera scissura, Coronocyclus nitescens,* BASE *Helicosphaera walbersdorfensis*
1447–1451	15	N	Unassigned	Poor sample, PRES *Coccolithus pelagicus, Reticulofenestra haqii, R. minuta, Thoracosphaera*
1674–1680	20	N	NN5	PRES *Sphenolithus heteromorphus,* ABSENCE *Helicosphaera ampliaperta*
1857–1862	23	N	NN4	TOP *Helicosphaera euphratis,* BASE *Calcidiscus tropicus, Reticulofenestra pseudoumbilicus*

Calcareous nannofossils were studied from 5 core samples of Cífer-2 well. Top sample core 13 is assigned to NN6 Zone (Martini 1971) based on the presence of *Reticulofenestra pseudoumbilicus* 6 and >7 µm, *Helicosphaera wallichii* and *Sphenolithus abies*. Core 14 contains *Helicosphaera scissura, Coronocyclus nitescens* and *Helicosphaera walbersdorfensis* and is thus assigned to NN5 Zone. Core 15 is poor in recovery due to tuffitic composition of the sediment. Entire sample contains only *Coccolithus pelagicus, Reticulofenestra haqii, R. minuta* and *Thoracosphaera* thus NN Zone cannot be assigned. Core 20 contains *Sphenolithus heteromorphus* a marker for NN5-NN4 zones but due to absence of *Helicosphaera ampliaperta* (NN4–NN2) NN5 Zone can be suggested. Core 23 contains *Helicosphaera euphratis, Calcidiscus tropicus* and *Reticulofenestra pseudoumbilicus* so NN4 Zone is assigned. All studied samples contain reworking of Early Miocene (e.g., *Reticulofenestra lockeri, R. bisecta, R. stavensis*) Oligocene (e.g., *Isthmolithus recurvus, Reticulofenestra umbilicus*), Eocene (e.g., *Chiasmolithus grandis, Pontosphaera pulcheroides*) and Late Cretaceous (e.g., *Micula staurophora, Prediscosphaera cretacea, Watznaueria barnesiae*) nanofossils.