

SEDIMENTOLOGY OF THE GODULA FORMATION IN THE MORAVSKOSLEZSKÉ BESKYDY MTS. (OUTER WESTERN CARPATHIANS, CZECH REPUBLIC)

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Abstract: The present account summarizes the results of lithological and facies analysis of representative sections of the Godula Formation, in order to contribute to the understanding of the lithofacies structure of this formation, the processes involved in its development and the character of the depositional environment. The sedimentology of different parts of the Godula Formation was investigated in six representative sections in the western and central parts of the Moravskoslezské Beskydy Mts. The Godula Formation is made up mainly of Upper Cretaceous siliciclastic turbidites and was formed during the most significant depositional phase of the filling of the deep-sea Silesian Basin. On the basis of sedimentological research, five facies classes (including four subclasses) were defined: 1) conglomeratic sandstones, 2) sandstones, 3) sandstones with mudstones, 4) mudstones with sandstones and siltstones, and 5) mudstones with siltstones. The methodology of facies analysis allowed the identification of several facies association, corresponding to the medial and distal parts of a turbidite fan and associated siliciclastic apron. The facies of depositional lobes, lobe transitions and the apron are described. The sandstone and mudstone facies (F3) occurs mostly in the depositional lobes. The sandstone facies (F2) and mudstone with sandstone and siltstone facies (F4) are present only to a lesser degree. The facies of the lobe transitions include lithologic associations of the lobe fringe and channel levee environments. They comprise mainly the mudstones with sandstones and siltstones (F4) and the mudstone with siltstone facies (F5). In the apron deposits, the sandstone facies (F2) and the conglomeratic sandstone facies (F1) predominate. Palaeocurrent analysis from measurements made in selected profiles showed that in the Moravskoslezské Beskydy Mts., the dominant direction of sediment transport was from SW to NE. After applying correction of the known counterclockwise rotation of the nappes of the Outer Carpathians, this corresponds to a longitudinal direction along the original axis of the basin.

Key words: Facies analysis, turbidite systems, siliciclastic deposits, Outer Western Carpathians, Moravskoslezské Beskydy Mts., Cretaceous.

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INTRODUCTION

In deep-sea basins, it is usually possible to distinguish the facies zones of the continental slope, deep-sea fans and the abyssal plain. In flysch sedimentation, the most significant depositional systems are single-point, deep-sea fans with distinctive channels and lobes, ramps, and aprons of rubble (Reading and Richards, 1994; Shanmugam, 2006). The development of facies analysis of the flysch began in the 1970s. The model of the recent submarine fan (Normark, 1970, 1978) was transformed for application to ancient sediments, in which the inner, middle and outer parts of a fan were distinguished (Mutti and Ricci Lucchi, 1972). This concept – with minor modifications – is still in use (e.g., Ricci Lucchi, 1975; Walker, 1978; ; Shanmugam

and Maiola, 1988; Reading and Richards, 1994; Słomka, 1995; Stow *et al.*, 1998; Shanmugam, 2006). Recognition of the characteristics of the deposits and individual facies and their associations is important for the determination of the mechanisms and conditions of deposition. Sedimentation was controlled by several factors, including eustatic sea-level changes, through tectonic activity, and the characteristics of the source of the clastic material (e.g., Pickering *et al.*, 1989; Bouma, 2000). Classification schemes for deep-sea facies are based on their individual, descriptive features (Pickering *et al.*, 1986; Ghilardo, 1992).

Deep-sea, depositional environments are not limited to turbidite systems. They also include other depositional systems,

where gravity sedimentary processes play a larger or dominant role, for example, slope-apron depositional systems (e.g., Słomka, 1995; Shanmugam, 1996; Strzeboński, 2015).

The Godula Formation (Menčík *et al.*, 1983; Eliáš, 1999; Bubík *et al.*, 2008), also referred to as the Godula Beds (Słomka, 1995; Golonka *et al.*, 2006; Ślącza *et al.*, 2006), is an important part of the stratigraphic sequence of the Silesian Unit in the Outer Western Carpathians. It is the most widespread and best exposed formation of the basinal facies zone of the Silesian Nappe (the Godula facies domain). The Godula Formation contributes significantly to the geological make-up of the Moravskoslezské Beskydy, Beskid Śląski (Slezské Beskydy) and the Beskid Mały (Malé Beskydy) mountains.

The initial findings on the lithology and stratigraphy of the Godula Formation were provided in the second half of the 19th century and the beginning of the 20th century (e.g., Hohenegger, 1861; Paul and Tietze, 1887; Uhlig, 1907). Systematic research on the Moravskoslezské Beskydy Mts. was carried out by Beck, whose findings on the nappe structure of the mountains were published in the explanatory notes to the map of the Ostrava-Karviná coal basin (Beck and Göttinger, 1932).

The delineation of the Godula Formation in the Moravskoslezské Beskydy is based on the proportions of sandstone and mudstone and the thickness of the sandstone layers (Menčík and Pesl, 1955), or mainly on the proportions of sandstone, conglomerate and fine-grained, heterolithic facies (Eliáš, 1970, 1979, 1999). An alternative division is based on heavy-mineral associations. Within the Godula Formation, Roth (1980a) defined an older zircon zone, subdivided into a rutile-zircon subzone and a subzone of mixed assemblages, and a younger garnet zone. The biostratigraphy of the Godula Formation is based on agglutinated foraminifera (Hanzlíková, 1973; Geroch and Nowak, 1984; Geroch and Koszarski, 1988) and dinoflagellate cysts (Skupien and Vašíček, 2002, 2003; Skupien and Mohamed, 2008; Skupien *et al.*, 2009). Significant contributions to the lithostratigraphy, the interpretation of the depositional environment and the provenance of the sediments were provided by Książkiewicz (1933, 1953), Roth (1961), Menčík *et al.* (1983), Eliáš (1979, 1999, 2000b), Ślącza *et al.* (1999, 2006) and Słomka *et al.* (2006). A facies analysis of the Godula Formation was presented by Słomka (1995) and Słomka and Słomka (2001). A gamma ray spectrometric characteristic and a facies analysis of sandstones of Godula Formation were provided by Šimiček and Bábek (2013) and Maceček (2018).

The generalised pattern of palaeotransport directions in the Godula Formation was described by Ślącza (1986) and Słomka (1995). These authors noticed a significant predominance of the north-eastern direction of sediment transport, which corresponds well with the original direction of transportation before the counterclockwise rotation of the Carpathian-Pannonian block (Roth, 1980b). According to the authors mentioned above, the palaeotransport directions depended on the position of the Silesian Cordillera, located south of the Silesian Basin, as the main source of sediment, as well as on the inclination of the longer axis of the Silesian Basin, oriented to the east.

The present paper summarizes the results of lithological and facies analysis of the Godula Formation in the representative sections, in order to contribute to the understanding of the lithofacies structure of this formation, the processes involved in its development and the character of the depositional environment.

GEOLOGICAL SETTING

The Silesian Unit is part of the Flysch Belt of the Outer Western Carpathians, representing the marginal, tectonically deformed zone of the Alpine-Carpathian orogenic system (e.g., Golonka *et al.*, 2006). The Silesian Unit within the flysch zone belongs to the Menilite-Krosno Group of nappes (Čtyrský and Stráník, 1995). The Silesian Unit consists of a zone of thrust sheets and fold overthrust (Fig. 1). It has the most complete stratigraphic record within the Menilite-Krosno Group of nappes, including a continuous stratigraphic sequence from the Late Jurassic to the Early Miocene (Aquitaniian). The thickness of the sedimentary fill is up to 6,000 m (Menčík *et al.*, 1983; Picha *et al.*, 2006). It plunges beneath the front of the Magura thrust sheets to the south and slips onto the Subsilesian Unit or the Carpathian Foredeep to the north (Lexa *et al.*, 2000).

The Late Jurassic rifting of the south carbonate part of the North European Platform and the northern parts of the Pieniny-Magura area resulted in the emergence of the Protosilesian Basin (Golonka *et al.*, 2006). The basin reached its greatest width during the Hauterivian–Aptian. Intra-basin elevations were created in the Late Cretaceous, which divided the originally uniform basin into several almost parallel sub-basins – the Silesian, Dukla, Skole and Magura (e.g., Słomka, 1995; Nemčok *et al.*, 2001; Golonka *et al.*, 2006). The sedimentation area of the Silesian Unit was located to the north of the Silesian Ridge, separating it from the sedimentation area of the Magura Group of nappes (Golonka *et al.*, 2006). The main developmental stages of the Silesian sedimentation area can be divided into syn-rift extension in the Tithonian–Hauterivian and post-rift thermal subsidence in the Barremian–Turonian (Nemčok *et al.*, 2001; Skupien *et al.*, 2009). Under the influence of the tension mode, the basin was deepened up to 4,000 m. In the Coniacian, the tectonic mode switched to compression, leading to a very extensive filling of the Silesian Basin with clastic sediments of the Godula and Istebna formations (Eliáš, 1999; Golonka *et al.*, 2005; Słomka *et al.*, 2006). The sediments of individual flysch formations continued to be deposited until the late Palaeogene. Then, as a result of the thrusting of the accretionary wedge, the Silesian Ridge disappeared. It was the main source of the material coming into the Silesian Basin (e.g., Čtyrský and Stráník, 1995; Oszczypko, 2004; Golonka *et al.*, 2005). Owing to processes related to the collision of the European Platform with the Carpathian-Pannonian block during the Early Miocene, there was a counterclockwise rotation (Kováč *et al.*, 2018). The thrust sheets of the Silesian Unit arrived at their current position during the Badenian as a result of the orogenic processes of the Early Styrian tectonic phase of the Alpine folding, when they were moved in a SE–NW direction over several tens of kilometres across the Neogene foredeep and

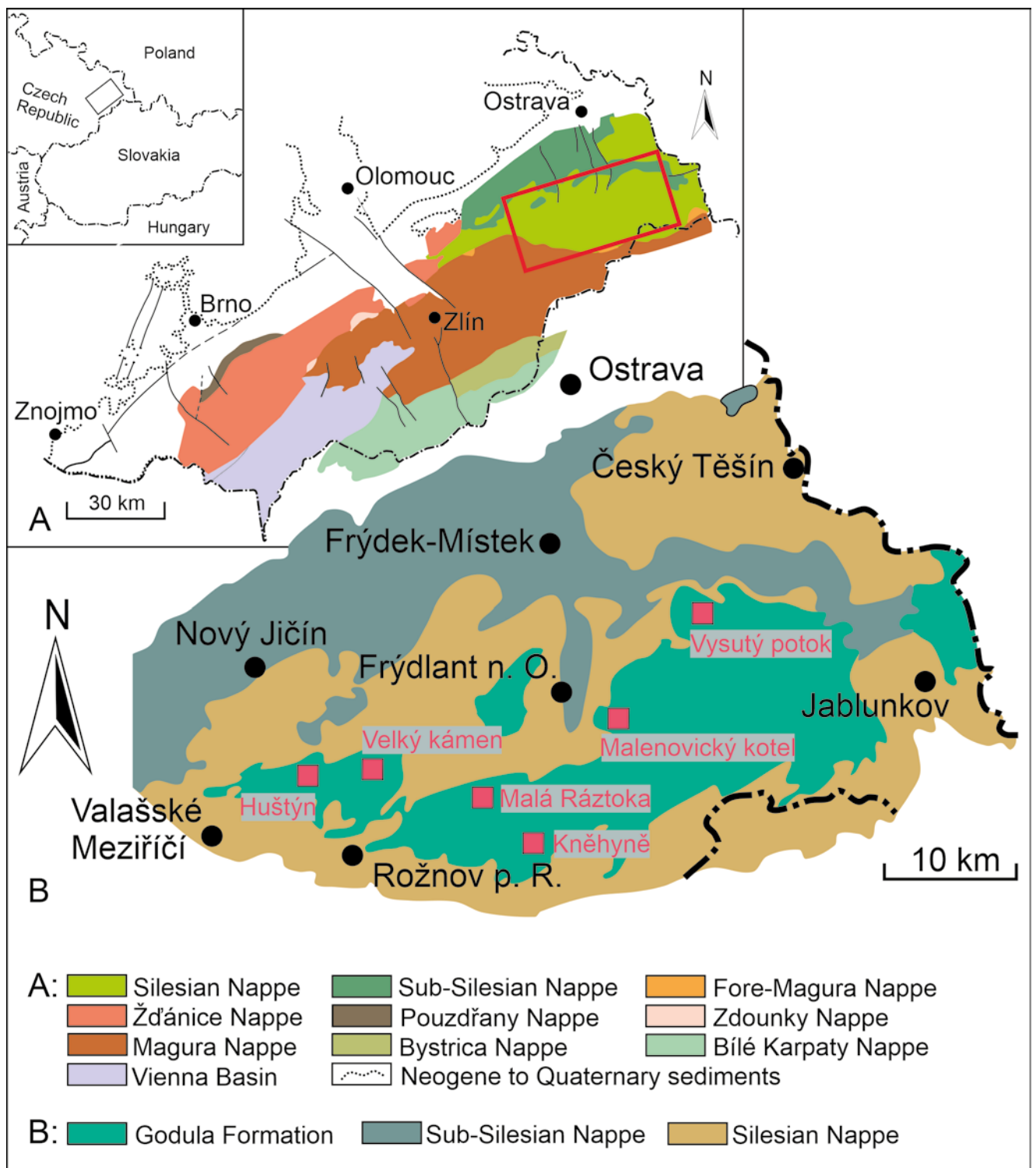


Fig. 1. Map of the main tectonic units of the Outer Western Carpathians in the Czech Republic (after Skupien *et al.*, 2009) and geologic sketch-map of the Silesian Nappe (after Šimíček and Bábek, 2013) with locations of studied sections.

the eastern part of the Bohemian Massif (Menčík *et al.*, 1983; Grzebyk and Leszczyński, 2006; Picha *et al.*, 2006). The rocks of the Godula Formation in the Moravskoslezské Beskydy Mts. were rotated about 40° counterclockwise during this transport (Roth, 1980b).

Currently, three facies successions occur in the Silesian Unit, distinguished on the basis of lithofacies (Matějka and Roth, 1954; Eliáš, 1970; Menčík *et al.*, 1983). The most

widespread of them with the most nearly complete stratigraphic record (Oxfordian–Early Miocene) is the Godula succession, which represents the inner part of the sedimentary filling of the Silesian Basin (Stráník *et al.*, 1993). The Baška succession represents base-of-slope facies in a Tithonian–Paleocene stratigraphic sequence, the sedimentation of which is related to the Štramberk limestone reefs of the Tithonian–Berriasian (Eliáš, 2000a). The Kelč

succession is restricted to the northwest-marginal part of the Silesian Unit. The stratigraphic sequence includes rocks ranging in age from Valanginian to Paleocene (Golonka *et al.*, 2006).

The total thickness of the Godula Formation is highly variable, from 60 m near the village of Hostašovice to 3,100 m in the Morávka River (Menčík *et al.*, 1983). This thickness increases from the W and SW to the area of the Morávka River and decreases from there to the E and NE (Eliáš, 1999). The Godula Formation is underlain by the variegated shale strata of the Mazák Formation (Roth, 1980a) and overlain by the Itebna Formation (Eliáš, 1970; Strzeboński, 2015). The sedimentation is synorogenic, when viewed from a tectonic and facies perspective. The fine to medium, rhythmic flysch was deposited below the CCD (Geroch and Koszarski, 1988). The relatively rapid subsidence in the basin resulted in an increased contribution of clastic material from the source areas (Picha *et al.*, 2006). Over roughly 15 myr, more than 3,000 m of clastic material were deposited (Roth, 1980a). The stratigraphic range of the Godula Formation is from Coniacian to uppermost Campanian (Skupien and Muhammad, 2008). The Godula Formation is divided into three informal members (Fig. 2) called the Lower Member, the Middle Member and the Upper Member (Menčík and Pesl, 1955). The sedimentology and petrology of the Lower

and Upper members of the Godula Formation are similar. They are characterized as predominantly thin-bedded successions of fine- to medium-grained sandstones, siltstones, and mudstones (Słomka, 1995; Eliáš, 1999). Within the Upper Member, local wedges and lenticular bodies of coarse-grained sandstones and fine-grained conglomerates of the Malinowska Skała Conglomerate (Burtanówna *et al.*, 1937; Słomka, 1995; Eliáš, 2000b) as well as the medium- to coarse-grained arkosic sandstones of the Pustevny Sandstone (Eliáš, 2000b) are present. The Middle Member is characterized by a medium- to thick-bedded sandstone succession, dominated by coarse- to medium-grained sandstones (Menčík *et al.*, 1983; Picha *et al.*, 2006).

MATERIAL AND METHODS

During fieldwork, attention was focused mainly on the sedimentological description of selected sections. The sections were selected with respect to lithostratigraphic distinction, so as to represent the entire development of the Godula Formation. This article presents six sections (Tab.1), the total thickness of which is less than 76 m. Facies analysis was used as the primary method, which depends on the determining the characteristic features of individual sedimentary facies: grain-size trend, sedimentary texture, sedimentary

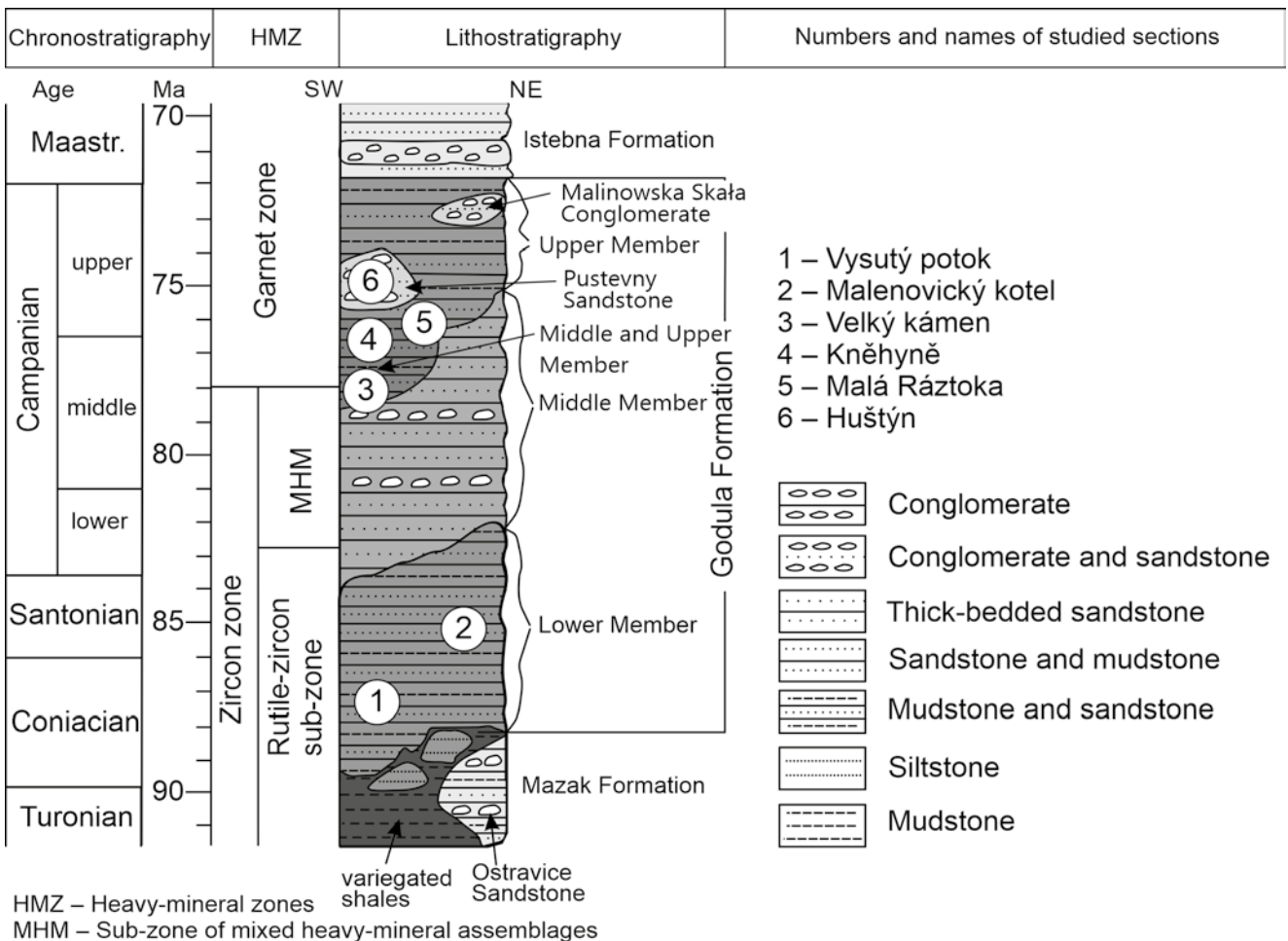


Fig. 2. Lithostratigraphy of the Godula Formation (after Roth, 1980a; Skupien and Mohamed, 2008; Skupien *et al.*, 2009) with the positions of the studied sections.

Table 1

Sections and their GPS coordinates.

Name of section	GPS coordinates
Huštýn	49°55'61.208"N, 18°07'18.856"E
Malenovický kotel	49°55'74.922"N, 18°43'54.650"E
Vysutý potok	49°62'29.247"N, 18°50'52.125"E
Kněhyně	49°48'09.322"N, 18°28'46.811"E
Malá Ráztoka	49°29'56.067"N, 18°15'57.169"E
Velký kámen	49°52'88.953"N, 18°15'15.947"E

structures, biogenic structures, bed thickness and geometry of layers. The symbols used to represent sedimentary structures in the lithological logs are according to Joseph and Lomas (2004). Lithofacies were distinguished on the basis of the sedimentological field research in the selected sections and also employed several classifications (Bouma, 1962; Lowe, 1982; Pickering *et al.*, 1986; Ghibaudo, 1992; Reading and Richards, 1994; Słomka, 1995; Stow *et al.*, 1998; Mulder and Alexander, 2001; Shanmugam, 2006). Facies analysis was supplemented by the study of palaeo-flow indicators, such as cross-stratification and flute casts.

RESULTS OF THE FACIES ANALYSIS

Facies F1

Description: This facies is characterized by predominance of the psammitic fraction over the pefitic one. These are fine- to medium-grained conglomerates with a supporting matrix of sandstone, which grades into coarse- to medium-grained sandstone. The upper layer frequently is separated from the overlying layer by an erosion surface. Occasionally, mudstone intraclasts occur at the base of a bed. Planar stratification near the bed top is rare. Layers of conglomeratic sandstones appear in a set of several beds, locally separated by beds of fine-grained sandstone, siltstone and grey to dark grey, non-calcareous mudstone, several centimetres thick. The conglomeratic sandstone facies has many features that are identical to those of subfacies gSC and glSC (Słomka, 1995) and subfacies gGyS and glGys (Ghibaudo, 1992).

Interpretation: This facies is explained as resulting from the rapid deposition of gravel and sandy material from high-density turbidity currents (cf. Lowe, 1982; Słomka, 1995) or sandy debris flows (cf. Shanmugam, 1996, 2006).

Facies F2

Description: This facies comprises predominantly the psammitic fraction (Fig. 3A, B). Medium-grained sandstones are most widespread and, to a lesser degree, coarse-grained sandstones. At the base of each layer, there are thin conglomerates. The sandstone facies occur in separate layers or as a set of several layers, bounded by amalgamation surfaces or separated by thin beds of dark grey, non-calcareous mudstone. The sandstone layers are 30–110 cm thick,

mostly massive, locally with a weak, normal gradation and rarely with planar lamination in the top parts. Traction carpets are present near the bases of some beds (Fig. 3C). Mudstone or limestone intraclasts are present at the bases of some layers. Basal scours are often present. This facies corresponds to facies S of Ghibaudo (1992) and Słomka (1995).

Interpretation: These sediments also can be interpreted as primarily the sandy deposits of high-density turbidity currents with a transition to traction (Love, 1982; Ghibaudo, 1992; Słomka, 1995), or they resulted from hyperconcentrated density flows (cf. Mulder and Alexander, 2001).

Facies F3

The sandstone and mudstone facies is typically formed by two alternating components, with the sandstone component predominating over the mudstone one. The mudstones in some cases are genetically associated with the underlying sandstones. The sandstones gradually pass into siltstones and subsequently into mudstones, deposited from the same gravity current. This facies corresponds to the lithofacies SM according to Ghibaudo (1992) and Słomka (1995). At the base of the sandstone layers, coarse- and fine-grained conglomerates can be found. Two subfacies (F3a, F3b) are distinguished.

Subfacies F3a

Description: This subfacies consists mainly of medium-grained sandstones (Fig. 3A), locally passing into grey to light grey, non-calcareous mudstones. Normal gradation with conglomerates or coarse-grained sandstones on a layer-to-layer basis, transitioning into medium-grained sandstones, is typical. Massive sandstones are occasionally present. The sandstone layers are 30–100 cm thick. Variable intervals of the Bouma sequence are present. In the thickest beds, Ta and Tb intervals predominate (Fig. 3D). The thinner beds often show Tae, Tade, and Tace intervals. The soles of the beds are flat or uneven, some with flute casts (Fig. 3E) and trace fossils (Fig. 4A, B). Some sandstone layers pinch out. The subfacies F3a has many characteristics identical with those of the subfacies gSM and mSM of Słomka (1995).

Interpretation: Sediments of subfacies F3a were deposited from high-energy currents with a sudden interruption of supply, or resulted from concentrated density flows, the energy of which gradually decreased (Lowe, 1982; Mulder and Alexander, 2001).

Subfacies F3b

Description: This subfacies comprises medium- to fine-grained sandstones, transitioning into mudstones (Fig. 4C). The base of a bed may incorporate a thin layer of coarse-grained sandstone. The thickness of the sandstone layers ranges from 10 to 30 cm. Positive gradation is frequent. The top and bottom layer contacts are flat. Parallel lamination (Fig. 4D), locally cross-lamination and ripple bedding, are present at the upper parts of the layers. Mudstones are non-calcareous and grey to light grey. Exceptionally, turbiditic mudstones (Te) have a thin layer of black-grey,

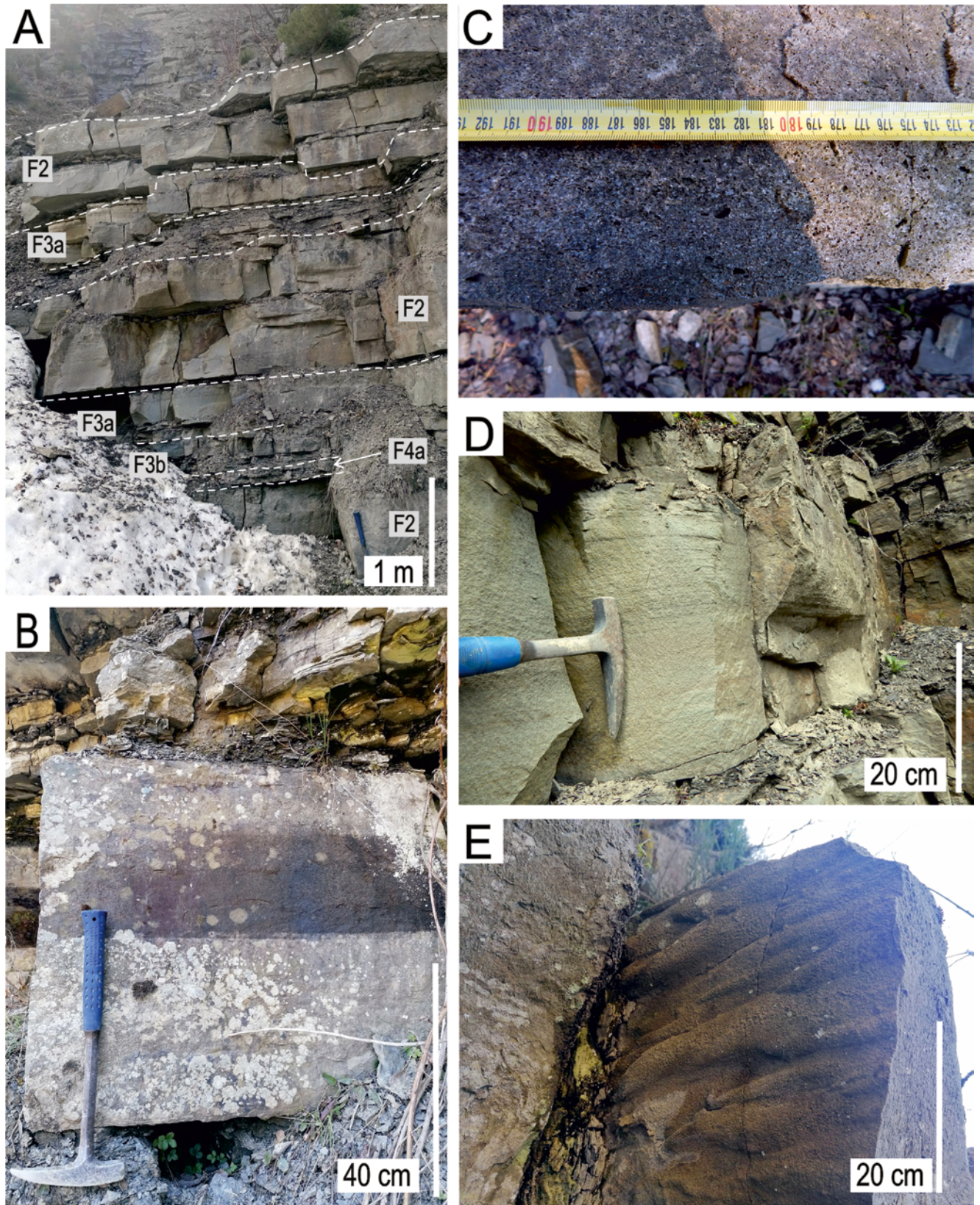


Fig. 3. Sedimentary facies and features of the Godula Formation in the studied sections. **A.** Facies sequence of the proximal part of the depositional lobe, alternation of layers of coarse- to medium-grained sandstones (facies F2 and F3) with intercalations of fine-grained sandstones and siltstones (F4), Kněhyně section. **B.** Massive sandstone layer (facies 2), Kněhyně section. **C.** Traction carpet at the base of the sandstone layer (facies F2), Kněhyně section. **D.** Planar lamination in the upper part of the sandstone layer (subfacies F3a), Kněhyně section. **E.** Flute marks on the sole of the sandstone layer (subfacies F3a), Velký kámen section.

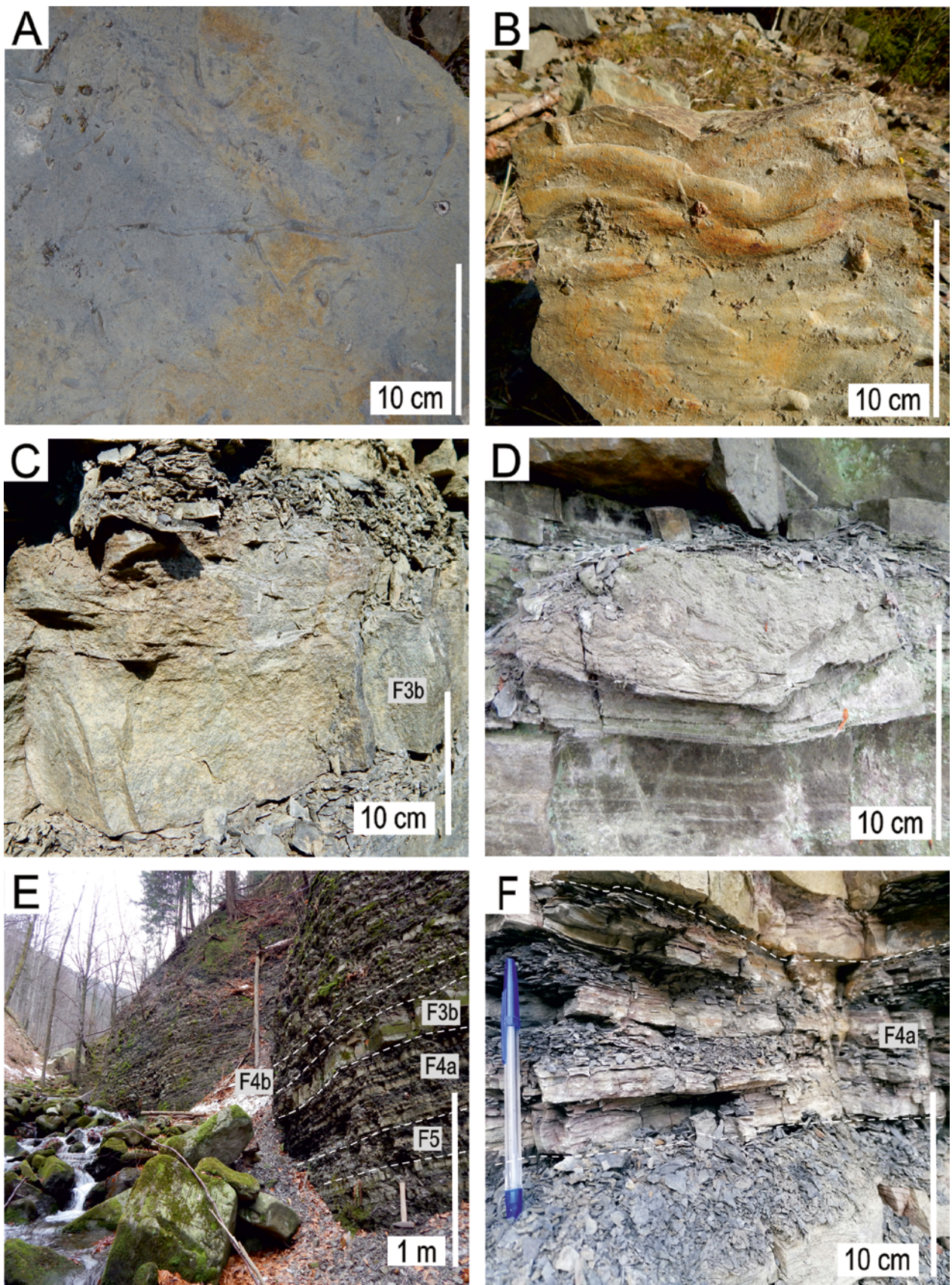


Fig. 4. Sedimentary facies and features of the Godula Formation sandstones in the studied sections. **A.** Hypichnial trace fossil (?*Planolites* sp.), Kněhyně section. **B.** Hypichnial trace fossil *Scolicia strozzii*, Kněhyně section. **C.** Medium- to fine-grained sandstones gradually transitioning to siltstones and mudstones (facies F3b), Velký kámen section. **D.** Sandstone layer with planar lamination and some hydroplastic deformation in the upper part of the sandstone layer (subfacies F3b), Malá Ráztoka section. **E.** Finely rhythmic flysch of the distal parts of the fan with a predominance of mudstone over fine-grained sandstones and siltstones (facies F4 and F5), Malenovický kotel section. **F.** Fine-grained sandstones and siltstones with mudstones (subfacies F4a), Malá Ráztoka section.

spotted, less grey hemipelagic mudstone above them. These turbidites exhibit the Tabcde, Tabce, Tabe, Tace, Tbcde, Tbce Bouma intervals. Trace fossils are present on the lower surfaces of some sandstone beds. Subfacies F3b has many features identical with those of subfacies glSM and ISM by Słomka (1995).

Interpretation: This subfacies is referred to deposition of sandy-clay material from gravity currents (Lowe, 1982); it is interpreted as being a result of deposition from gravity currents of different densities with a rapid transition to traction currents, or from low-energy currents, rapidly passing into the fractions of fine-grained material (Słomka, 1995).

Facies F4

This facies is characterized by the predominance of mudstones over fine-grained sandstones and siltstones. It corresponds to the MS lithofacies by Ghibaudo (1992) and Słomka (1995). Two subfacies (F4a, F4b) were distinguished (Fig. 4E).

Subfacies F4a

Description: This subfacies is represented by layers of fine-grained sandstone with thicknesses of up to 10 cm (Fig. 4F). The sandstones gradually pass into the predominant mudstone-siltstone layer. Planar lamination is frequent and normal graded bedding is rare. The upper contact surfaces of the layers are flat, while the base of each layer tends to be undulating. Trace fossils and sole markings are clearly visible on the lower surfaces of the sandstone layers. The mudstones are non-calcareous and grey, or more rarely, black-grey and spotted. The Tbce, Tbde, and Tbe Bouma intervals are present. The subfacies F4a corresponds to the gMS subfacies of Słomka (1995).

Interpretation: Sediments of subfacies F4a were rapidly deposited from dilute turbidity currents (Słomka, 1995), or from low-density turbidity currents (cf. Lowe, 1982; Ghibaudo, 1992).

Subfacies F4b

Description: This subfacies consists of fine-grained sandstone to siltstone, passing into light grey to grey, non-calcareous mudstone. Exceptionally, the turbidite mudstones (Te) have black-grey, spotted, less grey hemipelagic mudstones above them. Planar lamination is locally present and ripple bedding is rare. The upper contact surface of the layers is undulating, while the base is sharp or undulating. Trace fossils are rarely present on the lower surface. The Tbcde, Tbde, Tcde, Tce intervals are common. Subfacies F4b corresponds to the IMS lithofacies of Słomka (1995).

Interpretation: These sediments were deposited by traction currents with the finest fraction reworked by bottom currents (Słomka, 1995; cf. Shanmugam, 2006).

Facies F5

Description: This facies is characterized by alternating mudstones and siltstones. The mudstones predominate. Sandstone layers several centimetres thick are present. The mudstones and siltstones are often massive, but planar

lamination is also common. The bases of layers are sharp or exceptionally erosional in nature. Black-grey, spotted, less grey hemipelagic mudstones are rarely present. Facies F5 corresponds to the MT facies of Ghibaudo (1992) and Słomka (1995).

Interpretation: The facies F5 was deposited mainly from strongly diluted, low-density turbidity currents and rarely from finely dispersed suspensions (Słomka, 1995).

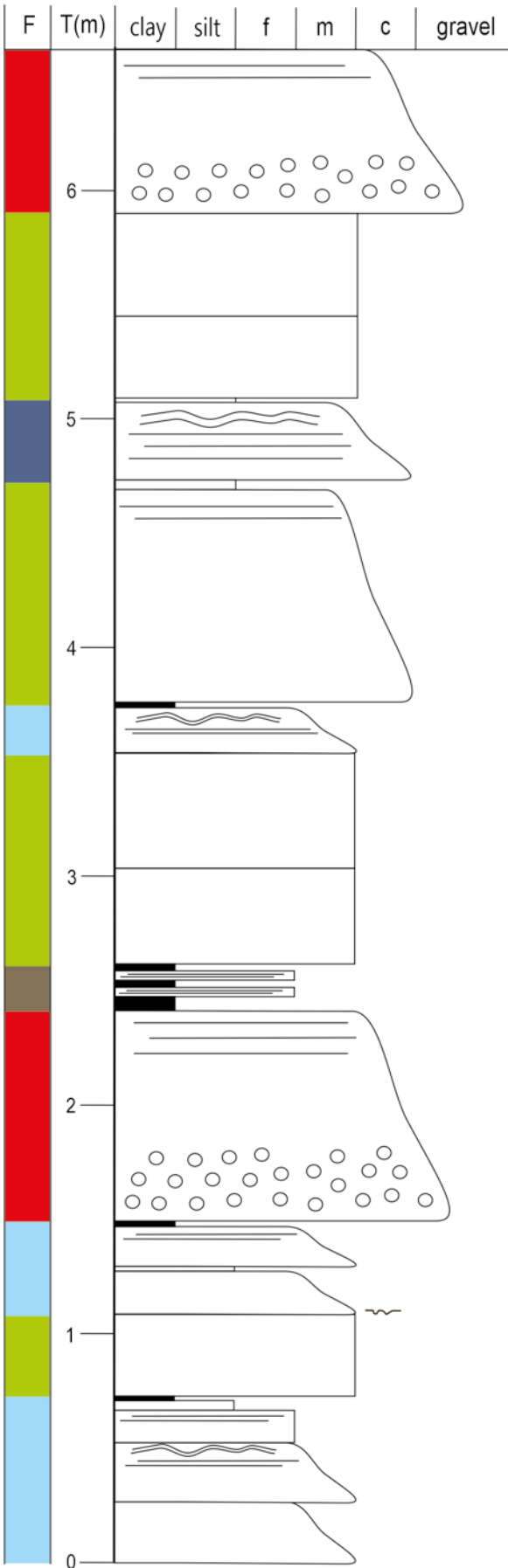
SEDIMENTARY FACIES IN THE MEASURED SECTIONS

The Huštýn section represents coarse and medium rhythmic sedimentation of the Pustevna Sandstone as what appears to be the Upper Member of the Godula Formation (Figs 5, 6). The section is dominated by sandstone facies, accounting for 46.3% of the total thickness of the profile. Conglomeratic sandstone facies (25.3%) and sandstone and mudstone facies (24.3%) are represented subordinately. The mudstone with sandstone and siltstone facies (4.1%) are least represented. The sandstone facies (facies F2) is primarily represented by massive, glauconitic, medium-grained sandstones. The sandstone layers also contain water-escape structures. One sandstone layer shows normal graded bedding. The sandstone layer at the base is coarse-grained. In the upper part of the layer, it passes into medium-grained sandstone with weakly developed planar lamination. The amalgamation of some sandstone layers is evident. The conglomeratic sandstones (facies F1) are normally graded. At the bases of the sandstone layers, there are fine-grained, sandstone-matrix-supported conglomerates, which pass upwards into coarse-grained sandstones. The upper parts of the layers occasionally display traces of planar lamination. The sandstones (facies F3a, 3b) are normally graded. At the bases of these layers, there are coarse-grained sandstones passing into medium-grained sandstones. In the upper parts of the layers, planar lamination and ripple lamination are evident. These sandstone layers pass into siltstones and mudstone. The lower part of the section has a heterolithic character (subfacies F4a). It is formed by parallel-laminated, fine-grained sandstones, siltstones and non-calcareous mudstones.

The Malá Ráztoka, Kněhyně and Velký Kámen sections have a few common features (Figs 5, 7). The facies of sandstones and mudstones (F3) predominates, with subordinate representation of the sandstone facies (F2) and the mudstone with sandstone and siltstone facies (F4).

The Malá Ráztoka section (Fig. 5) has the character of medium-rhythmic flysch at the transition between the Middle and Upper members of the Godula Formation. The sandstone and mudstone facies (64.7%) predominate, with a minor proportion of the mudstone with sandstone and siltstone facies (20%) and the sandstone facies (15.3%). The sandstone layers (facies F3a) are normally graded. In the lower part of the sandstone layers, there are occurrences of coarse-grained sandstone, which pass upwards into medium-grained and locally even fine-grained sandstones. The sandstone layers are covered with siltstones and non-calcareous mudstones. In the upper parts of the

Huštýn



Malá Ráztoka

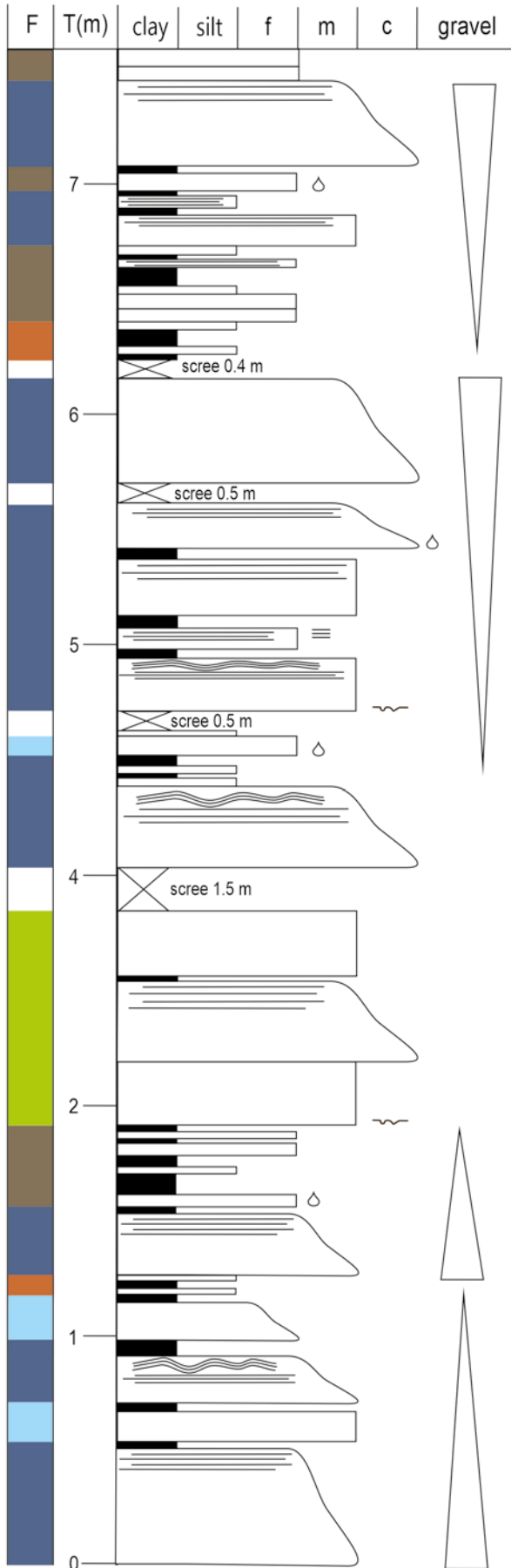


Fig. 5. Sedimentological log of the Huštýn and Malá Ráztoka sections.

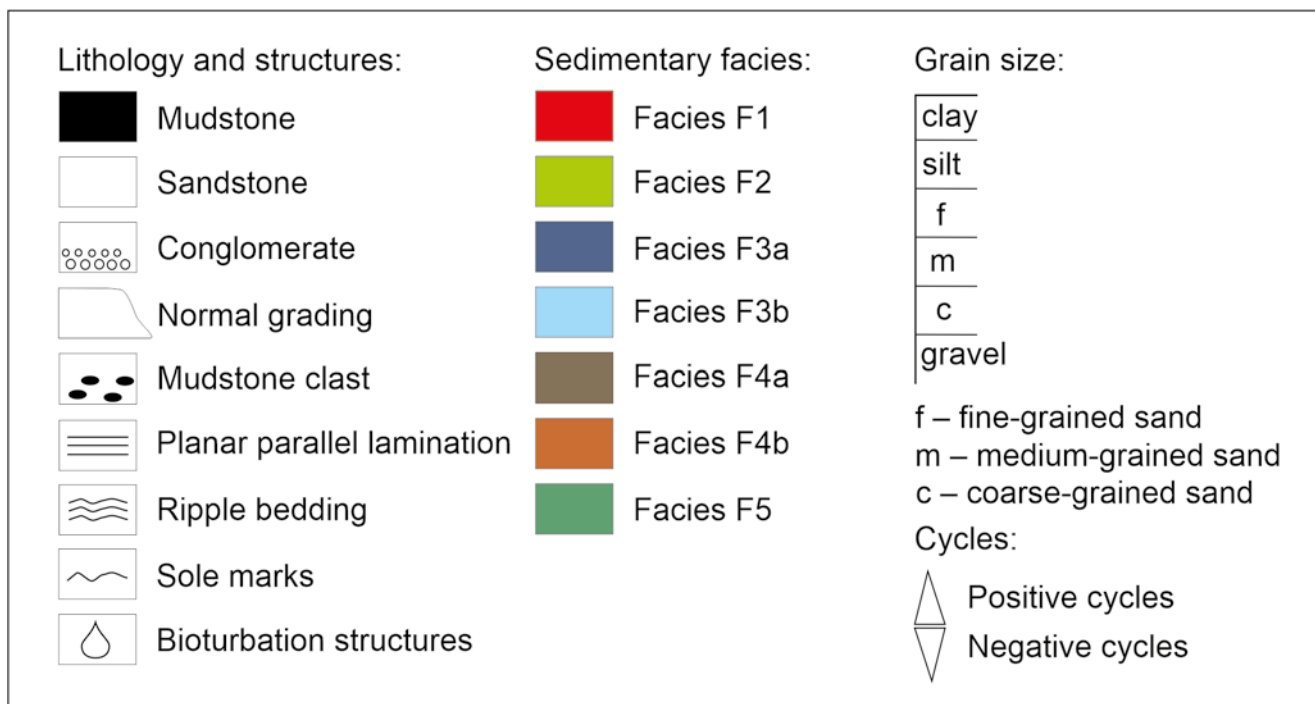


Fig. 6. Explanatory notes to Figures 5, 7, 8.

sandstone layers, parallel lamination or ripple lamination are present. Trace fossils are present on the lower surfaces of some layers. The sandstone facies (F2) is represented by massive, glauconitic, medium-grained sandstones. Planar lamination is clearly visible in the upper parts of the sandstone layers. Heterolithic deposits (facies F4) are made of fine-grained sandstones mainly. The sandstone layers are planar laminated in the upper parts. Trace fossils are present at the lower surface of the sandstones.

The Kněhyně section (an abandoned quarry) represents the transition between the Middle and Upper members of the Godula Formation (Fig. 7). The sandstone and mudstone facies predominate (52%), while the mudstone with sandstone and siltstone facies constitutes 20.5% and the sandstone facies 19.5%. The remaining 8% represent the sandstone and mudstone facies (F3), the mudstone with conglomeratic sandstones (F1) and the mudstone and siltstone facies (F5). The sandstone and mudstone facies (F3), the mudstone with sandstone and siltstone facies (F4) and the mudstone and siltstone facies (F5) and have the same characteristic structure and texture as in the Malá Ráztoka profile. At the bases of the sandstone layers of the sandstone facies (F2), mudstone clasts are present locally. Above the turbiditic mudstones (Te), a thin layer of black and grey, spotted, hemipelagic mudstones can be rarely found. Almost all layers show erosion scours, flute marks and trace fossils on their lower surfaces.

The Velký Kámen section (Fig. 7) is composed of a medium to coarse, rhythmic flysch at the transition between the Middle and Upper members of the Godula Formation. The sandstone and mudstone facies (48.5%) together with the sandstone facies (32%) predominate. The mudstone with sandstone and siltstone facies (F4) is represented but to a lesser degree.

The Vysutý potok section (Fig. 8) represents the fine to medium rhythmic deposits of the Lower Member of the Godula Formation. It is formed mainly by the sandstone and mudstone facies (51.7%), the mudstone with sandstone and siltstone facies and the mudstone with siltstone facies (37%) and to a lesser degree by the sandstone facies (11.3%). Layers of glauconitic, predominantly medium-grained, and massive sandstones (facies F2 and subfacies F3a) alternate with sandstones, which often exhibit normal graded bedding and planar lamination (subfacies F3b). Heterolithic deposits are formed by facies of mudstones with fine-grained sandstones and siltstones (facies F4 and F5). The fine-grained sandstones (subfacies F4a) are massive and contain planar stratification. On the lower surfaces of the sandstone layers, trace fossils occur. Coarsening- and thickening-upward packages of strata are present (negative cycles), but there are also positive cycles, with fining and thinning trends.

The Malenovický kotel section (Fig. 8) displays a fine, rhythmic flysch of the Lower Member of the Godula Formation. The mudstone with sandstone and siltstone facies (F4) and the mudstone with siltstone facies (83%) prevail. The sandstone and mudstone facies is present only to a lesser degree (17%). The contribution of the mudstone layers within the thickness of the whole profile is greater than 40%. Massive and often parallel-laminated, fine-grained sandstones (subfacies F4a) pass into siltstones and mudstones (subfacies F4b and facies F5). Above the turbiditic mudstones, a thin layer of hemipelagic mudstones occasionally occurs. In the sandstones (subfacies F3b), normal graded bedding is often present. In the upper parts of the sandstone layers, parallel lamination and ripple lamination occur.

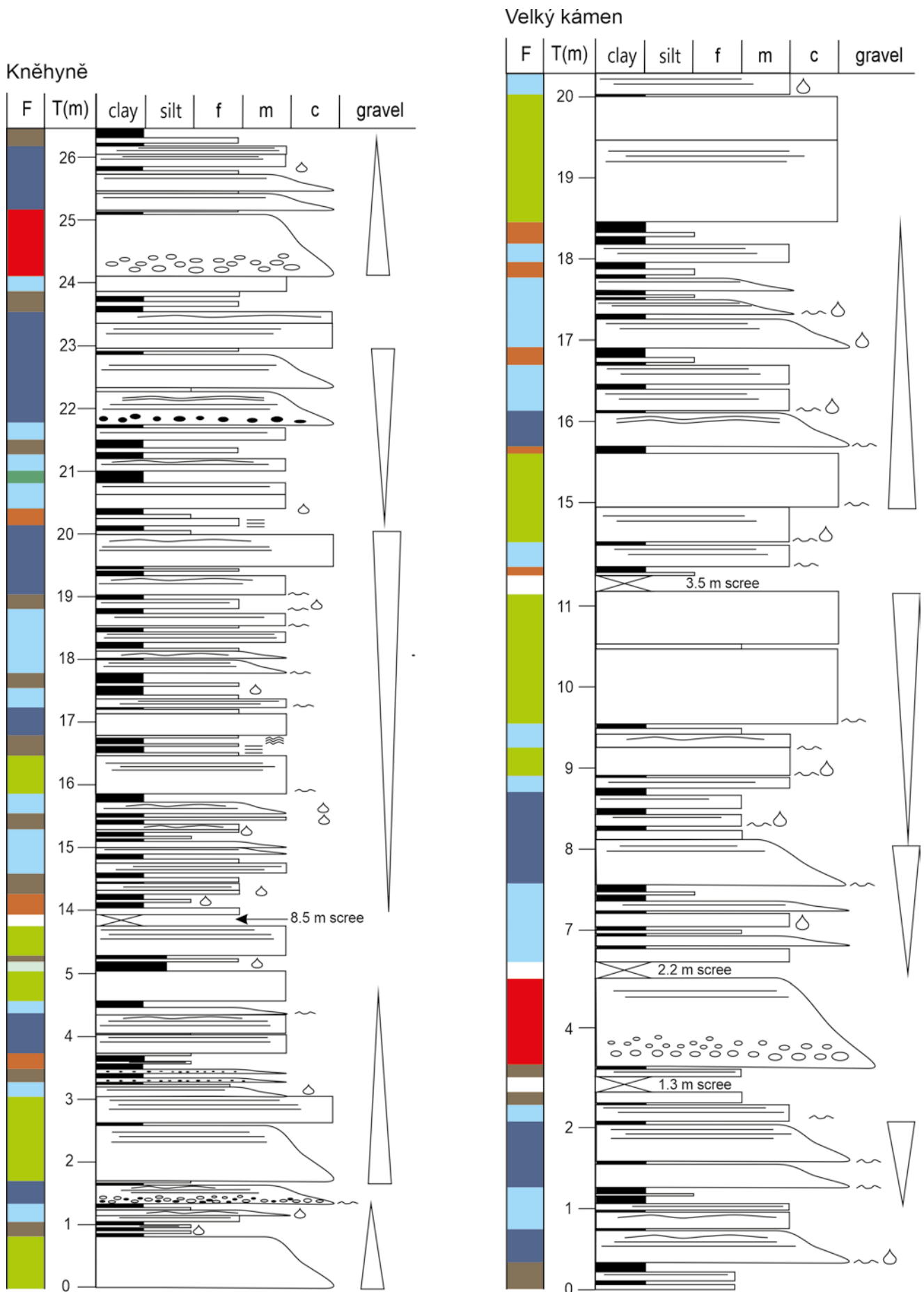


Fig. 7. Sedimentological log of the Kněhyně and Velký kámen sections.

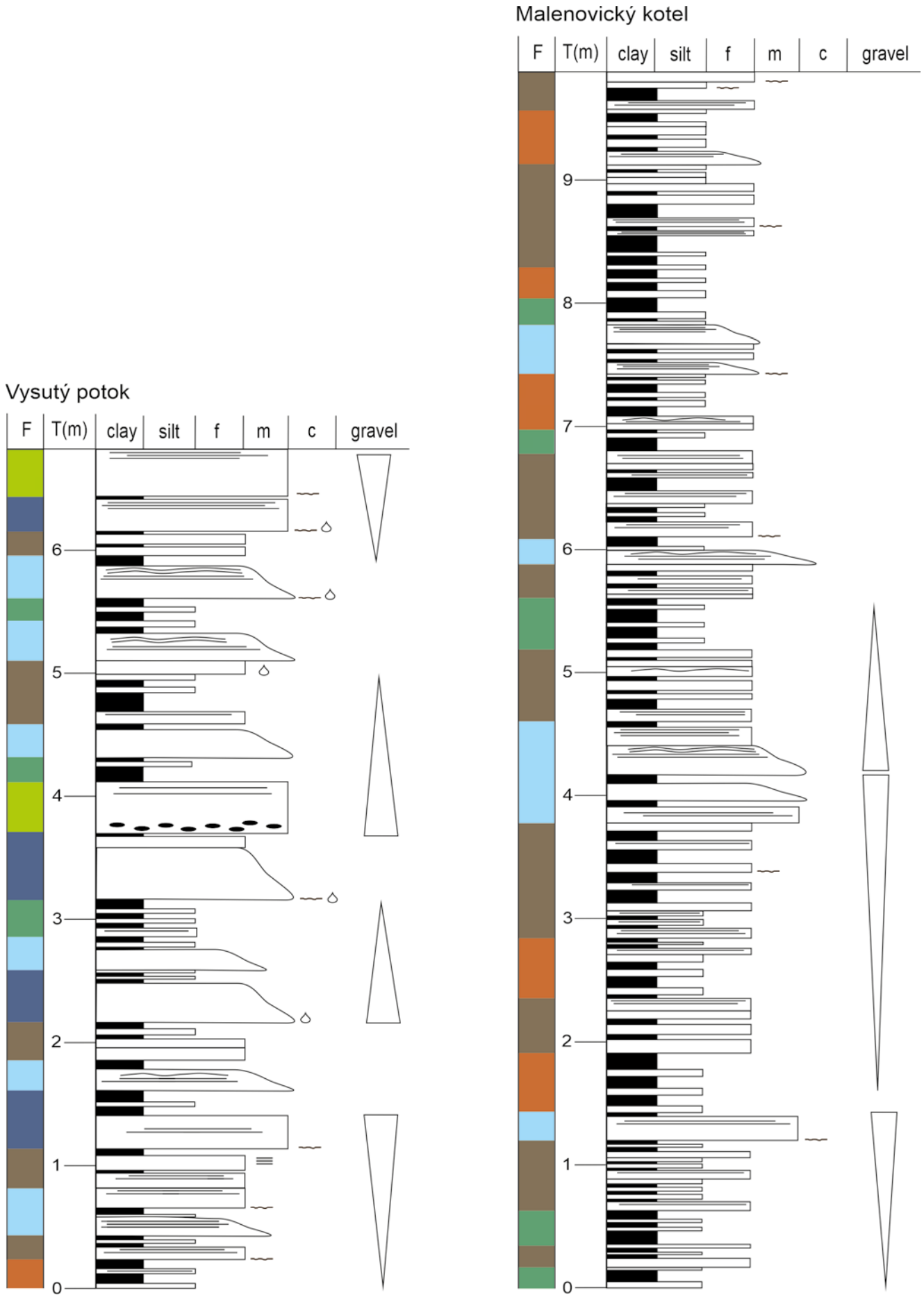


Fig. 8. Sedimentological log of the Vysutý potok and Malenovický kotel sections.

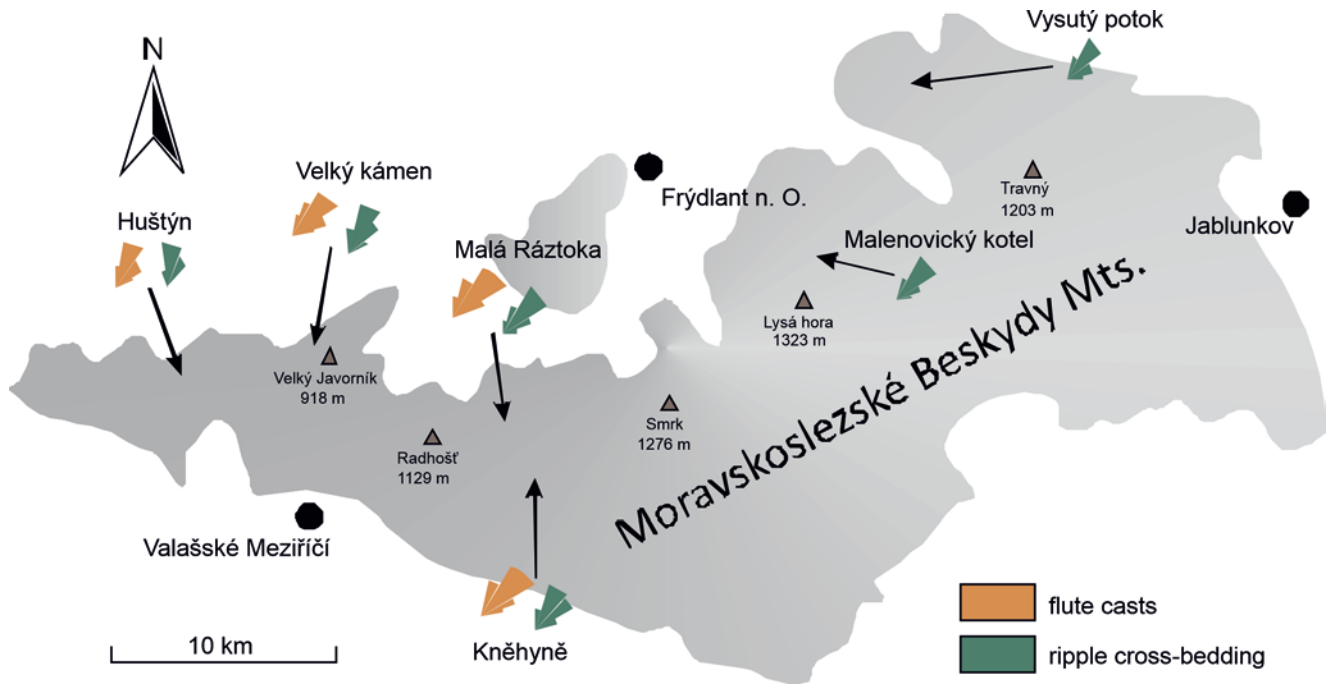


Fig. 9. Palaeocurrent directions in the studied sections of the Godula Formation in the Moravskoslezské Beskydy Mts.

PALAEOCURRENT ANALYSIS

In the measured values of palaeocurrent indicators (Fig. 9), one can see smaller differences between flute marks at the bases of turbidites and ripple cross bedding in the upper parts of the sandstone layers. In the flute marks occurring at the lower surfaces of the sandstone layers of the conglomeratic sandstone facies (F1), the sandstone facies (F2) and the sandstone and mudstone subfacies (F3a), the dispersion of the measured values is insignificant. The main direction is towards the NE while NNE and ENE directions are present to a minor extent. These palaeocurrent indicators were measured at the Kněhyně, Malá Ráztoka and Velký kámen sections, where the NE direction dominates. Near the Huštýn section, the NNE direction predominates.

A more significant variance in the measured values of planar cross-bedding was recorded in the sandstone facies (F2), the sandstone and mudstone facies (F3) and the mudstone with sandstone and siltstone subfacies (F4a). The measured values correspond to the NNW, N, NNE, NE, ENE and E directions. These measured values show the predominance of the NE direction even here. Planar cross-bedding was recorded in all sections. At the Malá Ráztoka, Malenovický kotel and Vysutý potok locations, the NE direction of sediment transport predominated. In the Kněhyně and Velký kámen sections, the NNE direction predominated and the NE direction was subordinate. At the Huštýn section, the N and NNE directions predominated.

DISCUSSION

The association of sedimentary facies, together with the sedimentary structures described, show that deposition took place in a deep-sea turbidite fan and a slope apron. In the Godula Formation, several facies sequences, typical

for the inner, middle, and outer parts of the fan and a basin plain, are distinguished (Słomka, 1995). The channel facies are typical of the inner and middle parts of a fan. The inner part of the fan consists of the main channel, which is represented by thick beds of predominantly coarse-grained turbidites (Shanmugam and Maiola, 1988). In the middle part, the main channel branches into a few smaller distributary channels (Mutti and Ricci Lucchi, 1972; Shanmugam and Maiola, 1988; Mutti *et al.*, 2009). There is an intensification of sedimentation in the form of poorly sorted sand-gravel sediments with the minor occurrence of fine-grained material.

Another important group of facies in deep-sea turbidite fans belongs to depositional lobes, which can reach lengths of up to several tens of kilometres and are fed at the mouths of canals. The sediments of these depositional lobes gradually pass into the sediments of the basin plain (Pickering *et al.*, 1989; Bouma, 2000). Sandstone and mudstone facies predominate. The mudstone with sandstone and siltstone facies and the sandstone facies are less represented. The occurrence of these facies is limited primarily to the middle parts of the turbidite fan. Other characteristic features for depositional lobes are the varying thicknesses of the sandstone layers, as well as the differences in grain size towards the tops of these layers, the flat and regular contact surfaces of sandstone layers, and the presence of upward thinning and/or thickening trends (Słomka, 1995; Mutti *et al.*, 2009).

The group of so-called transitional deposits includes sediments that were deposited among the well-described lithologic associations of the channels and depositional lobes. Channel levees are associated with channel facies. The spaces between channels are filled with the interchannel facies, which are formed by sediments deposited from the overflow of currents over the channel levees (Słomka, 1995; Shanmugam, 2006; Mutti *et al.*, 2009). Sediments deposited

between the depositional lobes and the basin plain are also considered to be transitional facies. These are the fringes of the depositional lobes and the fringes of the deep-sea fan in general (Mutti *et al.*, 2009). Some authors also consider the channel margins to be sediments of the transitional facies (Pickering *et al.*, 1989).

Beside the deep-sea turbiditic fans, siliciclastic slope aprons are important depositional systems. Their characteristic features are the absence of typical deep-sea fan facies successions and the lack of trends in layer thickness and grain size (Słomka, 1995; Shanmugam, 2006). In the studied sections, facies of the depositional lobes, the transitional deposits and probably the siliciclastic apron are identified (Fig. 10).

A characteristic feature of the Huštýn section is the predominance of the F2, F1 and the beds of massive sandstone beds (F2 facies), the absence of positive and negative cycles, as well as the absence of trace fossils and flute casts (except for one sandstone layer of the F2 facies) on the lower surfaces. These features are characteristic for facies of the siliciclastic apron (Słomka, 1995; Shanmugam, 2006). The Huštýn section (Fig. 2) contains wedges and lenticular bodies of the local Pustevny Sandstone (Eliáš, 2000b). Sandstones and conglomerates of the Malinowska Skala Conglomerate as well as the Pustevny Sandstone are considered as lithosomes deposited within an apron (Słomka, 1995). This interpretation is problematic in terms of the higher representation of facies F3 in the Huštýn section (Fig. 5). The lower part of the profile (2.6 m) rather corresponds to the depositional lobe. A characteristic feature of such a lobe is the predominance of facies F3 and F1. Facies F4 is represented to a lesser degree.

The facies architecture of the Malá Ráztoka, Velký kámen and Kněhyně sections (Figs 6, 7) best corresponds to the deposits of depositional lobes (cf. Słomka, 1995; Mutti *et al.*, 2009). A characteristic feature is the predominance of the F3 facies. Facies F4, F2 and F1 are represented to a lesser degree. The typical features are thickening-upward and coarsening-upward turbidite sequences. Another characteristic feature is the presence of negative cycles. In the Kněhyně section, both positive and negative cycles, as well as a higher proportion of mudstone layers, are present. Some parts of all three sections may possibly belong to transitional facies of the lobe fringe.

The Vysutý potok section (Fig. 8) corresponds to the lobe fringe (cf. Słomka, 1995). Facies F3 and F4 predominate here. The F5 facies is less common.

The Malenovický kotel section (Fig. 8) probably corresponds to channel levee accumulations, although its distinction from interchannel formations is very difficult, owing to the lack of typical features. A characteristic feature of this section is the high proportion of mudstone layers (Słomka, 1995; Mutti *et al.*, 2009).

The sections from the Moravskoslezské Beskydy Mts. described above made possible definition of the facies types of individual parts of the siliciclastic, deep-sea turbidite fan or a siliciclastic slope apron (cf. Mutti and Ricci Lucchi, 1972; Reading and Richards, 1994; Słomka, 1995; Shanmugam, 2006; Mutti *et al.*, 2009). The facies sequences of individual sections correspond to the medial to distal parts of the turbidite fan, described by the authors cited (Fig. 10). The middle and upper parts of the Huštýn profile coincide with the facies sequence of the siliciclastic apron.

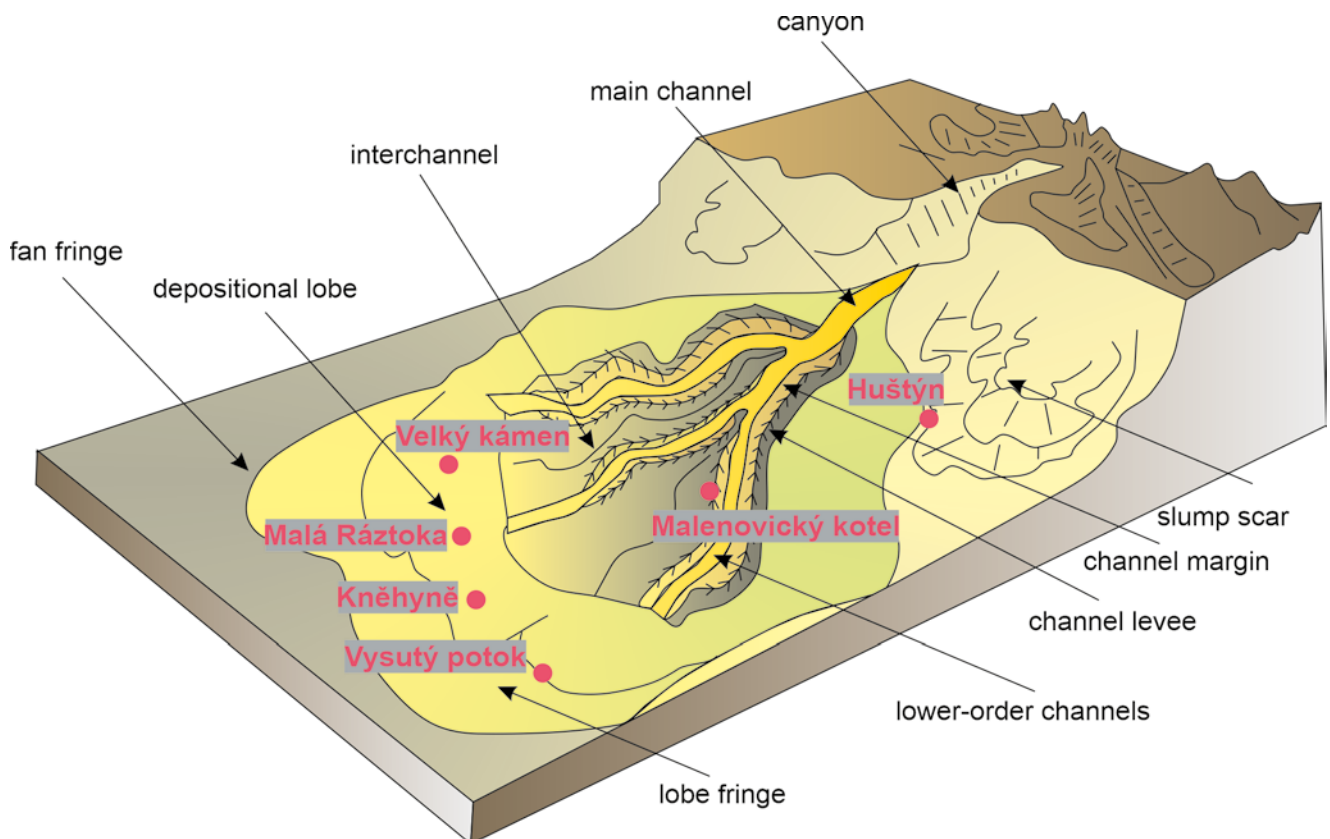


Fig. 10. Model of deep-sea fan system of the Godula Formation in the Moravskoslezské Beskydy Mts.

The lower part of the Huštýn profile rather corresponds to the depositional lobe. On the basis of their characteristics, the Malá Ráztoka, Velký Kámen, Kněhyně and Vysutý Potok sections can be assigned to the distal parts of the turbidite fan. The Malenovický kotel section corresponds to the channel levee associated with the channel facies. Therefore, it can be included in the medial part of the turbidite fan.

The interpretation of palaeocurrent measurements have to be referred to palaeomagnetic data, which indicate that the rocks of the Godula Formation were rotated 40–50° counterclockwise during their Miocene tectonic transport (Roth, 1980b; Oszczytko and Salata, 2005; Márton *et al.*, 2009; Kováč *et al.*, 2018). The original orientation of the main trough of the Silesian Basin during the Late Cretaceous matches the Sudetes direction of NW to SE (Roth, 1980b). Palaeotransport indicators in the Moravskoslezské Beskydy Mts. are in good agreement with the data published by Polish authors (Ślączka, 1986; Słomka, 1995). Among the measured values, the NE direction predominates, which corresponds to the original E direction of transportation during sedimentation of the Godula Formation (Coniacian–uppermost Campanian), before the counterclockwise rotation of the Silesian Unit. The directions NNE and N are represented to a lesser extent. The relatively uniform mode of sediment transport indicates that this part of the Silesian Basin was continuous, without significant segmentation. The main source of the sediment supplied was the Silesian Ridge. The transport of the clastic material was controlled by the general trend of the longer axis of the basin towards the E (Ślączka, 1986). Individual measured values of directions to the ENE and E in thin layers of sandstone with planar cross-bedding in the Malá Ráztoka, Malenovický kotel and Vysutý potok sections may indicate the presence of contour currents in the Silesian Basin (Strzeboński, 2015).

CONCLUSIONS

The sedimentology of the Godula Formation (Coniacian–uppermost Campanian), representing different facies sequences, was studied in six sections in the western and central part of the Moravskoslezské Beskydy Mts. Field research and facies analysis yielded the following results:

1. Five facies, including four subfacies, were distinguished, including conglomeratic sandstones (F1), sandstones (F2), sandstones and mudstones (F3a, F3b), mudstones with sandstones and siltstones (F4a, F4b) and mudstones and siltstones (F5).
2. Facies F3 and F4 predominate in the profiles described. Facies F1 is subordinate.
3. The dominant processes of deposition were gravity currents, varying in energy and density, mainly as high- to low-density turbidity currents. The rapid deposition of gravel and sandy material from high-density turbidity currents also is explained as arising from sandy debris flows. Sporadically, there was deposition from traction currents and to a negligible extent from dispersed suspensions.
4. The sedimentary facies identified are characteristic of siliciclastic, turbidite deep-sea fans and siliciclastic slope aprons. The sequences show features indicative of deposition within an apron (Huštýn section). Channel

- levee facies are characteristic of the middle part of the fan (Malenovický kotel section). The distal parts of the fan are represented by depositional lobe facies (Malá Ráztoka, Velký Kámen, Kněhyně sections) and the transitional facies of the lobe fringes (Vysutý Potok section).
5. The measured palaeocurrent indicators show the direction of material transport of the Godula Formation towards the N, NNE and NE. The NE direction significantly predominates. Considering the original orientation of the Silesian Basin axis in the Late Cretaceous before its counterclockwise rotation, an approximately E direction of material transport predominated in the N and NW parts of the Silesian Basin.

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