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# Fluvial sedimentation of sandy deposits of the Słupiec Formation (Middle Rotliegendes) near Nowa Ruda (Intra-Sudetic Basin, SW Poland)

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**Key words:** arid climate, lithofacies analysis, fluvial environment, terminal fan, palaeochannel, Sudetes.

**Abstract** The sandy sediments described in this paper are the lower, approximately 400-meter-thick part of the Słupiec Formation, which is part of lower Permian clastic deposits in the Intra-Sudetic Basin. At their base, the sandy deposits of the Słupiec Formation are bounded by fine-grained lacustrine sediments known as the Upper Anthracosia Shale (Krajanów Formation); upwards, they pass into the Walchia Shale (the upper part of the Słupiec Formation), also regarded to be of lacustrine origin. These sandstones consist chiefly of sublithic to subarkosic arenites and wackes. In places, polymictic conglomerates and fine-grained sediments, and also sublithic to subarkosic mudstones occur. These sediments form a structurally varied facies assembly, presumably fluvial in origin. An analysis of the vertical sequence of lithofacies revealed a distinct tendency towards the formation of simple cyclical sequences with the grain fining upwards and with a distinctly expressed asymmetry in favour of 'high-energy' medium- and coarse-grained facies. The oscillation tendency was marked only in 'low-energy' fine facies, which are sparsely represented in the sequence. The paleochannel analysis yielded results compatible with the outcome of the lithofacies analysis. The paleochannels are very shallow in relation to their width, and have a planar, erosional bottom configuration, and in places a terrace bank morphology. The fluvial system features described here may indicate a terminal fan environment as the possible depositional location place of the Słupiec Formation sandy sediments. The source areas were located at the S and SE margins of the Intra-Sudetic Basin, and the flow was towards the W and NW towards its centre, to shallow inland basins, probably of a playa type. The red colour of the sediments may be indicative of arid or semi-arid climatic conditions in this environment during the Middle Rotliegendes.

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## INTRODUCTION

The Słupiec Formation (Fig. 1), dated at the Middle Rotliegendes (Fig. 2), constitutes a major part of the lower Permian clastic succession in the Intra-Sudetic Basin. The formation is underlain by fine-grained sediments, known as the Upper Anthracosia Shale, which forms the top part of the Krajanów Formation (Lower Rotliegend). At its top, the Słupiec Formation is bounded by conglomerates (fanglomerates) of the Radków Formation of the Upper Rotliegendes (Nemec *et al.*, 1982).

The lower part of the Słupiec Formation, composed chiefly of sandstones and locally containing conglomerates, has been referred to as the Building Sandstone. The sandstone passes gradationally upwards into fine-grained sediments known as the Walchia Shale. The Building Sandstone, together with the Walchia Shale, appears as a fining-up megacyclothem, and is 600 m thick. Petrographically, the sandstones are generally sublithic, seldom subarkosic wackes, and locally represent arenites. The conglomerates display a polymictic character. The fine-grained sediments are mainly mudstones, also sublithic to subarkosic in composition, and contain variable quantities of a fine-sandy fraction and calcareous matter. Moreover, all the textural varieties have a distinct red colour.

The aim of this study was to confirm the fluvial origin of the sandy sediments of the Słupiec Formation, which is often in the literature referred to as the Building Sandstone, and to provide a more precise evidencial insight into their depositional settings, based on facies analysis.

## GENERAL DESCRIPTION OF THE SŁUPIEC FORMATION

**The name** of formation stems from the locality of Słupiec, in the past a miners' settlement south of Nowa Ruda, then an autonomous town from 1967 to 1973, and since 1973 located within the administrative limits of Nowa Ruda as one of its quarters. Two divisions may be distinguished in the sediments composing the Słupiec Formation. The lower part of these sediments is generally described in the older papers as the Building Sandstone. This name refers to the rocks' good technological parameters and to their application as a valuable construction material. The upper part is the Walchia Shale, the name of which stems from the common remains of plants of the genus Walchia (*Walchia piniformis*). These names have historical roots. They are a literal translation through Polish into English of the original German names, i.e. 'Bausandstein' and 'Walchia Schiefer'. In the geological literature, these names have been in use since the early 20th century (Dathe, 1904). In Polish papers, the names 'piaskowiec budowlany' (Building Sandstone) and 'łupki walchiowe' (Walchia Shale) first appeared in the late 1940s (Teisseyre, 1948).

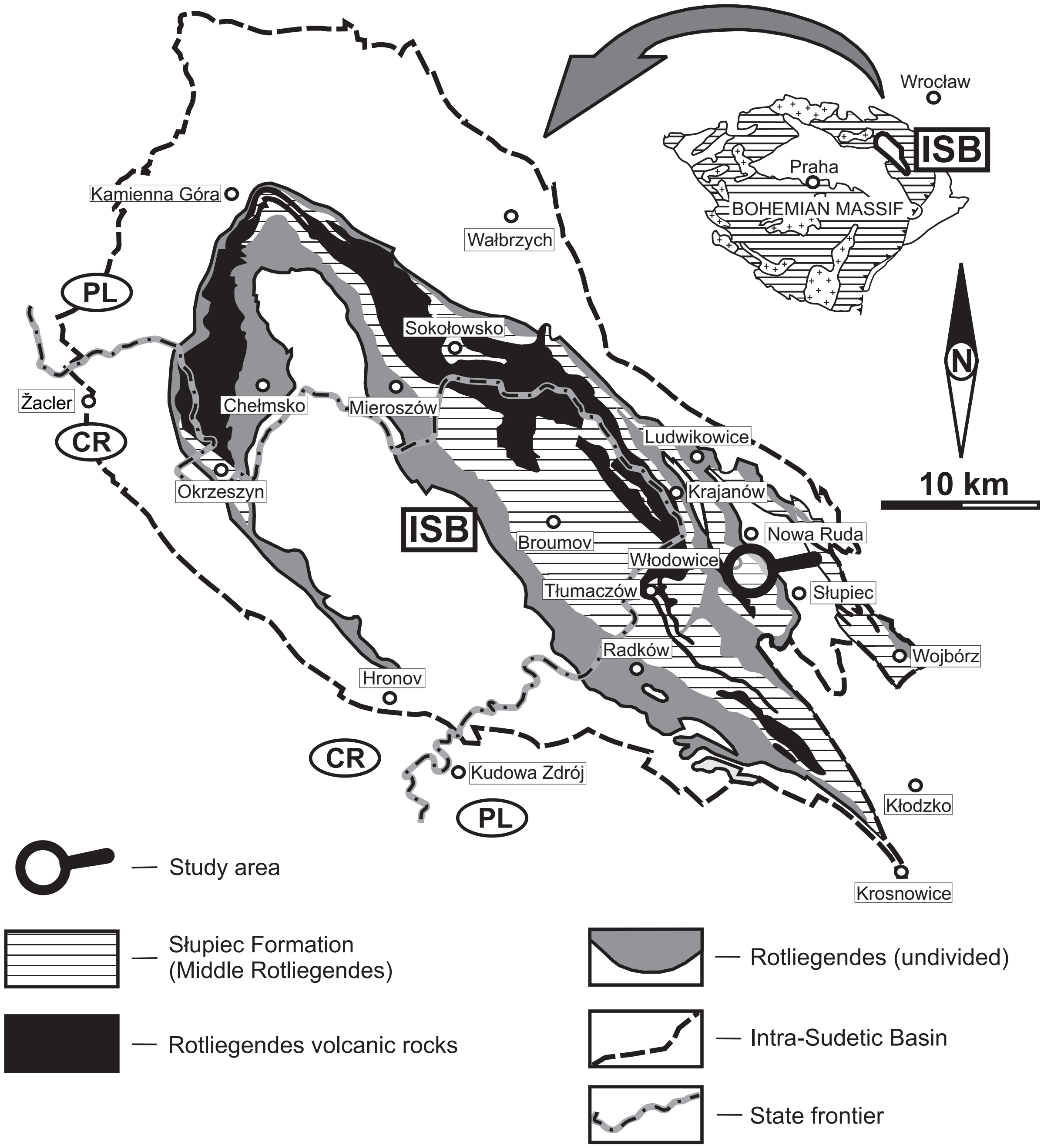


**Fig. 1.** Simplified geological map of lower Permian deposits in the Intra-Sudetic Basin (after Sawicki, 1995). Outline map of the Bohemian Massif (after Franke, 1989) shows location of the ISB: ruled – crystalline domains; crosses – Variscan granites; blank – sedimentary basins; ISB – Intra-Sudetic Basin.

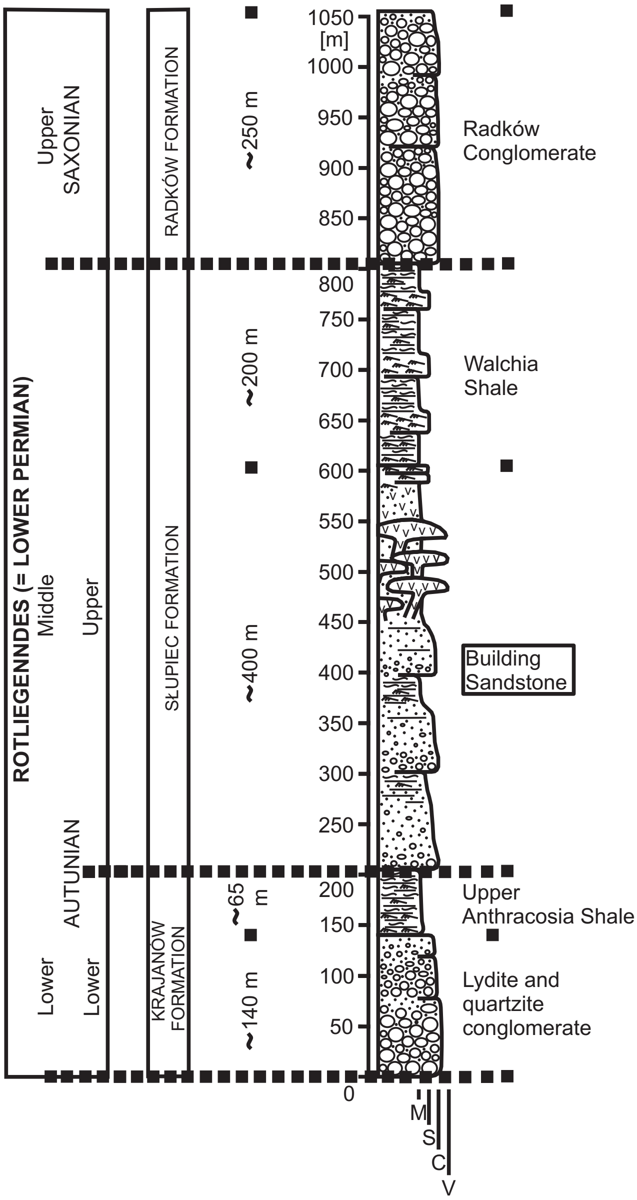


Fig. 2. Stratigraphic scheme of the Lower Permian in the Intra-Sudetic Basin (after Nemec *et al.*, 1982). M – mudstones; S – sandstones; C – conglomerates; V – volcanic rocks.

**The type area** of the Słupiec Formation is the SE region of the Polish part of the Intra-Sudetic Basin, mostly near Nowa Ruda and Słupiec, where the unit was distinguished and described for the first time. The outcrop zone runs from the vicinity of Krosnowice Kłodzkie in the SE, through Tłumaczów, Włodowice, Słupiec, Nowa Ruda, Stary Lesieniec, Grzędy and Sokołowsko, as far as Kamienna Góra in the NW (Fig. 1). A group of outcrops located in an area that in the orographical sense belongs to the Wzgórza Włodzickie Hills may be regarded as the stratotype for the unit. In this locality, in numerous quarries, cross-cuts and natural outcrops, it is possible to observe a large part of the formation profile (Fig. 3).

**The thickness** of the Słupiec Formation is up to 600 m. The thickness of the lower part of the unit, i.e. of the Building Sandstone is assessed at 400 m. In the upper

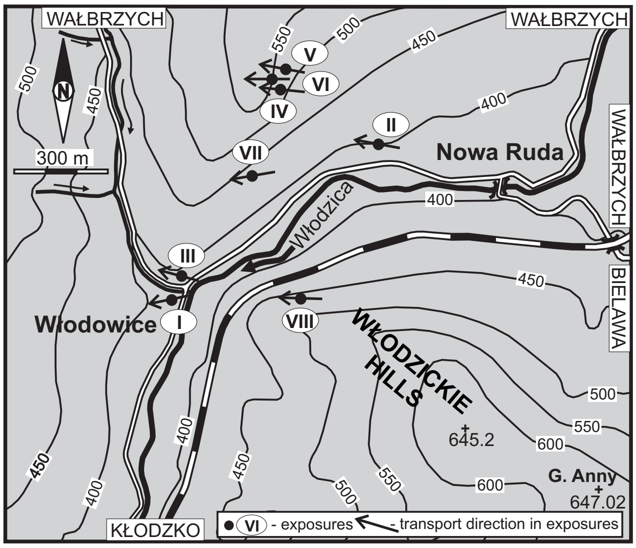


Fig. 3. Location scheme of the Słupiec Formation (Building Sandstone) outcrops.

part of the Building Sandstone profile, products of intensive volcanic activity are present. As stressed by various authors (Don 1961; Dziedzic 1961), this activity did not significantly affect the clastic sediment deposition process/this activity clearly affected the clastic sediment deposition process. The sediments, appearing both within the volcanic rocks and their overburden, bear a strong resemblance to the sediments deposited earlier. In the uppermost part of the profile, fine-grained material dominates: this is the Walchia Shale, which forms the upper part of the Słupiec Formation.

**The lithology** of the Słupiec Formation is varied. The most widespread rocks are sublithic to subarkosic wackes or arenites with diverse textures. Fine-grained sediments are slightly less common; there are mainly mudstones and clay shales that show textural, structural and petrographic diversification and in places contain intercalations of calcareous rocks. The sandstones and mudstones contain interbeddings and lenses of medium- to coarse-grained, suboligomictic para- or orthoconglomerates. The sediments' colour is most commonly red-brown. In places, the fine-grained sediments are dark-grey to black due to the presence of bituminous matter.

**Boundaries.** Within the type area, the Słupiec Formation sedimentary rocks overlie the Krajanów Formation and underlie the Radków Formation (Fig. 2). The base of the Słupiec Formation is precisely determined. It runs along a contact of the red-coloured Building Sandstone with the Upper Anthracosia Shale of the underlying Krajanów Formation. The contact is concordant; however, it is probably accompanied by a minor sedimentary gap (Don, 1961). The contact may be observed in natural outcrops on the NE slope of the Góra Wszystkich Świętych Mt., and on the NE slope of the Góra Anny Mt. (Fig. 3). The Słupiec Formation's upper boundary is easy to identify along the top of the black-coloured, bituminous Walchia Shale contacting with the Radków Formation fanglomerates, dated at the Saxonian. At the contact of these

**Table 1**

Sedimentary facies of the Building Sandstone

| No. | | Facies association symbol | Facies code after A. D. Miall (1985) | Structure description | Interpretation |
|---|---|---|---|---|---|
| I | 1 | G (coarse grained facies group) | Gms | Matrix supported conglomerates and sandy conglomerates with no preferred bedding orientation, commonly with fractional bedding with symmetrical or reversed symmetrical gradation | Gravity flow products - deposits of debris and mud-debris flows |
| | 2 | | Gm | Massive conglomerates and sandy conglomerates; in places imbrication and pebbles lineation | Deposits of bottom channel parts, internal parts of channel bars |
| | 3 | | Gc | Thin pebble layers; common imbrication and pebbles lineation | Outwashed channel deposits, channel pavement |
| | 4 | | Gt | Conglomerates and conglomerate sandstones with trough cross-bedding | Fillings of minor alluvial channels |
| II | 4 | S (medium grained facies group) | Sm | Medium- to coarse-grained sandstones with no preferred bedding orientation, commonly with addition of fine gravel | Fillings of shallow channels; products of a sudden discharge of material transported |
| | 5 | | Sh | Fine- to coarse-grained sandstones with horizontal bedding; frequent current lineation | Deposition in the upper planar bed conditions |
| | 6 | | Sl | Fine- to medium-grained sandstones with low-angle cross-bedding | Effect of shallow channels filling in the upper flow regime conditions (antidunes phase) |
| | 7 | | Sp | Medium to coarse-grained sandstones with planar cross-bedding, in tangential sets, commonly with intraclasts and addition of gravel fraction | Transversal bars, mostly, however, side bars; rhythmical transport at antidunes bottom configuration |
| | 8 | | St | Fine- to coarse-grained sandstones with trough cross-bedding; frequently with mudstone intraclasts and addition of gravel fraction | Deposition in various channel depth zones in rhythmical transport phase, at antidunes bottom configuration |
| | 9 | | Sr | Fine-grained sandstones with ripplemark lamination | Fillings of minor channels in the lower range of rhythmical transport phase, at ripplemark bottom configuration |
| III | 10 | F (fine grained facies group) | Sr/Fl | Interbeddings of fine- to very fine-grained sandstones and mudstones with lithologically complex bedding; most commonly with wavy and lenticular bedding | Deposition on flood plain at ceasing flow (lower range of rhythmical transport) and lower planar bottom conditions |
| | 11 | | Fl | Mudstones with horizontal lamination | Deposition on flood plain in lower planar bed conditions |

units, there is a minor sedimentary gap (Don, 1961). In the typical area, however, it is not possible to observe the upper boundary of the Słupiec Formation directly in outcrops.

**The extent** of the Słupiec formation is limited. As mentioned before, the main area of its occurrence in the Polish part of the Intra-Sudetic Basin is in that basin's south-eastern fragment (Fig. 1) – 'the eastern area' according to Dziedzic (1961). Farther to the NW (the central and the western areas, after the author cited) the zone of outcrops of this unit forms a narrow belt with sparse minor outcrops, which are poor or unsitable for sedimentological investigations.

**The age of the Słupiec Formation** was determined as Upper Autunian (Middle Rotliegendes) (Nemec *et al.*, 1982). In the Rotliegendes deposits, fossils of stratigraphic significance are extremely rare. In the geological literature, there are reports (see: Dathe, 1904) of fossil flora and fauna (e.g. *Walchia piniformis*, *Callipteris conferta*, *Amblypterus vratislaviensis*) occurring in the Słupiec Formation sediments (mainly in the Walchia Shale); unfortunately, these species are useless for age assignments. These sediments were deposited in continental conditions, in a fluvial and lacustrine environment. The sedimentation process probably took place in a semi-arid climate with periods of warm and humid conditions. The environment and the climate were responsible for a significant diversification in the lithology of the sediments, thus the lithostratigraphic subdivisions of the Rotliegendes sedimentary rocks of the Słupiec Formation, were based on the lithology (Dathe, 1904) and palaeoclimatic considerations (Petraschek, 1922; Scupin, 1922).

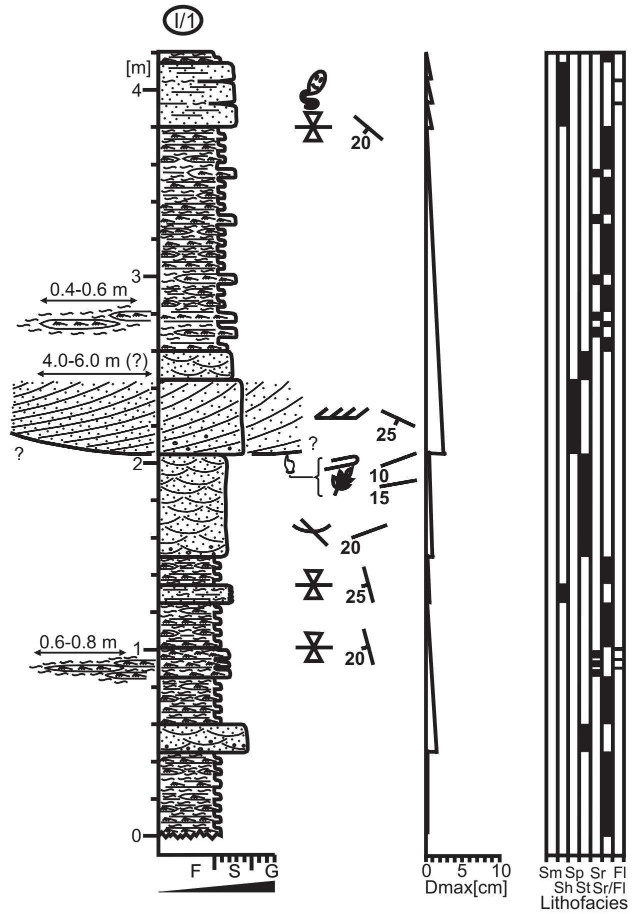


Fig. 4. Example graphic log of the Building Sandstone, an outcrop near Nowa Ruda. (Precise location – see: Fig. 3; additional markings – see: Fig. 6).

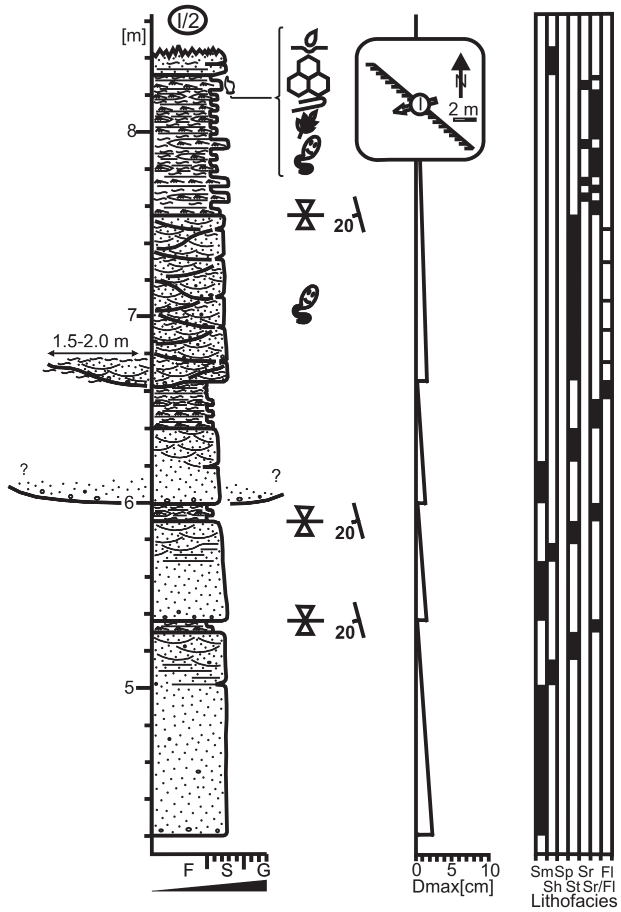


Fig. 5. Example graphic log of the Building Sandstone, an outcrop near Nowa Ruda. (Precise location – see: Fig. 3; additional markings – see: Fig. 6).

**Regional correlations.** In terms of regional age correlations, the Słupiec Formation can be correlated with the Broumov Formation in the SW part of the Intra-Sudetic Basin in the Czech Republic (Fig. 1), and with the Wielisławka Formation in the North-Sudetic Basin (Mastalerz & Raczyński, 1993).

## LITHOFACIES CHARACTERISTICS OF THE BUILDING SANDSTONE

On the basis of major differences in grain size, three facies groups were distinguished: coarse-grained (G), medium-grained (S) and fine-grained (F). Differences in sedimentary structure assemblages made it possible to create a detailed description of individual rock varieties within the groups. To achieve this, the author applied the facies code proposed by Miall (1985) which is commonly used in sedimentological investigations of similar rock sequences. The lithofacies types that were distinguished and their brief description are presented in Tab. 1.

### COARSE-GRAINED FACIES GROUP

#### Lithofacies Gms – matrix supported conglomerates and conglomeratic sandstones

Conglomerates and conglomeratic sandstones occur as parts of composite beds. These sediments are concentrated in the central or marginal parts of beds, and, depending on the setting, gradually pass into other facies, most commonly sandy-conglomerate and sandy varieties, towards the top and the base or towards the centre of those beds. Such composite beds as a whole display fractional bedding with normal and reverse gradation, and grain size changing within the beds (Figs. 6 and 18). The thickness of the conglomerate and conglomeratic sandstones amounts to around 80 cm. The sediment is poorly sorted. Clast size ranges from 1–1.5 to 10–16 cm. The clasts are characterised by medium to good roundness (3–6 in Powers[1] scale, 1953). Poorly rounded clasts do also occur (1–3). The clasts display various shapes, but bladed clasts (Zingg, 1935) predominate. Macroscopically, the clast petrographic composition are recognizable clasts of quartz and siliceous rocks (lydite, quartzite), and minor clasts of sedimentary rocks (sandstone, tuff (?)), volcanic (porphyry) and metamorphic (amphibolite, gneiss) rocks.

1 Further in the paper all data on the roundness are given in the Powers (1953) scale.

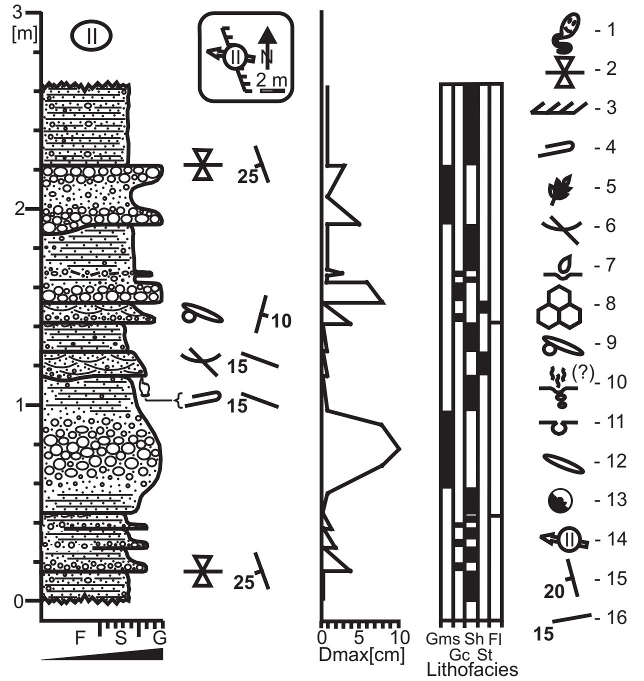


**Fig. 6.** Example graphic log of the Building Sandstone, an outcrop near Nowa Ruda. Precise location – see: Fig. 3. F – mudstone, S – sandstone, G – conglomerate; *1* – trace fossils, *2* – bedding, *3* – planar cross-bedding, *4* – current marks, *5* – plant remains, *6* – trough axes, *7* – raindrop imprints, *8* – shrinkage cracks, *9* – imbrication, *10* – outgassing structures, *11* – load structures, *12* – pebbles lineation, *13* – mudstone-clayey concretions, *14* – resultant transport direction in outcrop, *15* – planar structures orientation, *16* – linear structures orientation.

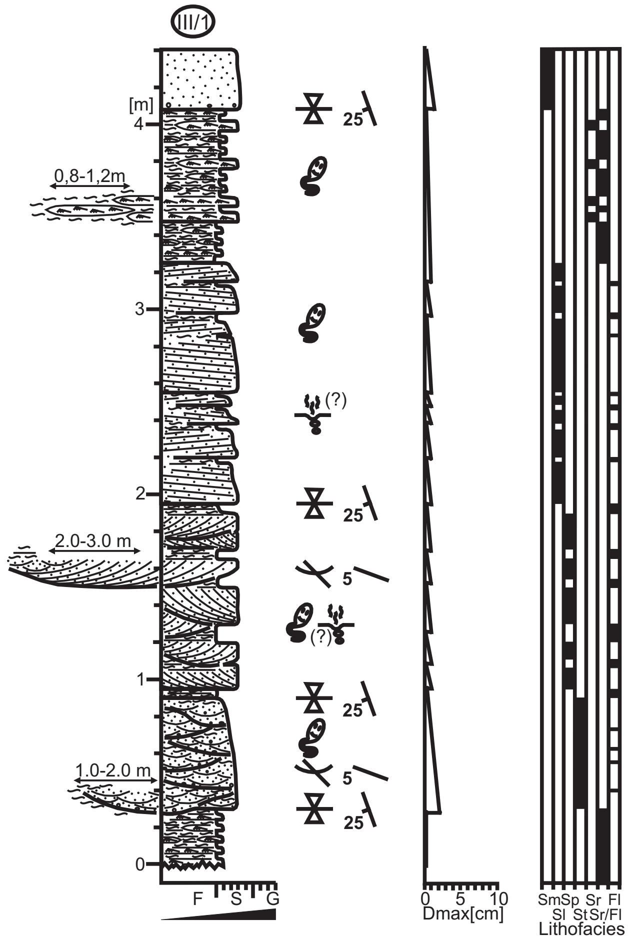


**Fig. 7.** Example graphic log of the Building Sandstone, an outcrop near Nowa Ruda. (Precise location – see: Fig. 3; additional markings – see: Fig. 6).

The relatively low textural maturity of the Gms lithofacies and the occurrence of a reversed to normal clast size grading within the beds indicate gravity flow as a possible transport mechanism for the conglomerates and conglomeratic sandstones of the lithofacies of the Gms formation (Rust, 1978).

**Lithofacies Gm – massive conglomerates and conglomeratic sandstones**

Massive conglomerates and conglomeratic sandstones do not form separate beds but occur in composite beds. The conglomerates are clast supported, while the conglomeratic sandstones are (by definition) matrix supported. These sediments occur in the lower part of the beds and gradually pass into other, chiefly sandy facies towards the top. Such beds as a whole have normal graded bedding (Figs. 9, 10, 13, 17). The thickness of conglomerate and conglomeratic sandstone intercalations reaches 40 cm. The sediment is moderately sorted, with clast size varying from 1–1.5 to 8–12 cm, and clast roundness ranging from medium to good (3–6). The clasts have various shapes, but bladed ones seem to be the most widespread. In these sediments, clast lineation and imbrication are also encountered. The clast petrographic composition resembles that of the Gms lithofacies.

The moderate to good textural maturity of the Gm lithofacies, the presence of clast lineation and imbrication, and the occurrence of normal gradation within the beds all indicate that the conglomerates and sandy conglomerates of the Gm lithofacies reflect conditions of high energy flow. This lithofacies can be regarded both as the fill of bottom channel parts (Steel & Thompson, 1983) and as forming the interior of longitudinal channel bars (Hein & Walker, 1977).

**Lithofacies Gc – clast layers in sandstones**

As with the other coarse-grained facies sediments, the clast layers in the sandstones do not form separate beds but constitute thin intercalations in various parts of composite beds (Figs. 6, 17, 19). The clast layers in the sandstones show good sorting. The grain size ranges from 2 to 6 cm, though some clasts of up to 8–10 cm occur. The clasts have good roundness (4–6) and display mainly spherical and bladed shapes. Locally, there are also tabular and prolate clasts, frequently characterised by a linear arrangement of the longest axes (prolate clasts) and imbrication (tabular clasts). The clast petrographic composition is similar to that of the Gms and Gm lithofacies, i.e. quartz and siliceous rock (lydite and quartzite) clasts dominate, and there are also clasts of sedimentary rocks (sandstones), extrusive rocks with porphyritic structure and metamorphic rocks whose origin is manifested by a distinct directional texture. Intraformational mudstone clasts are also frequent in the

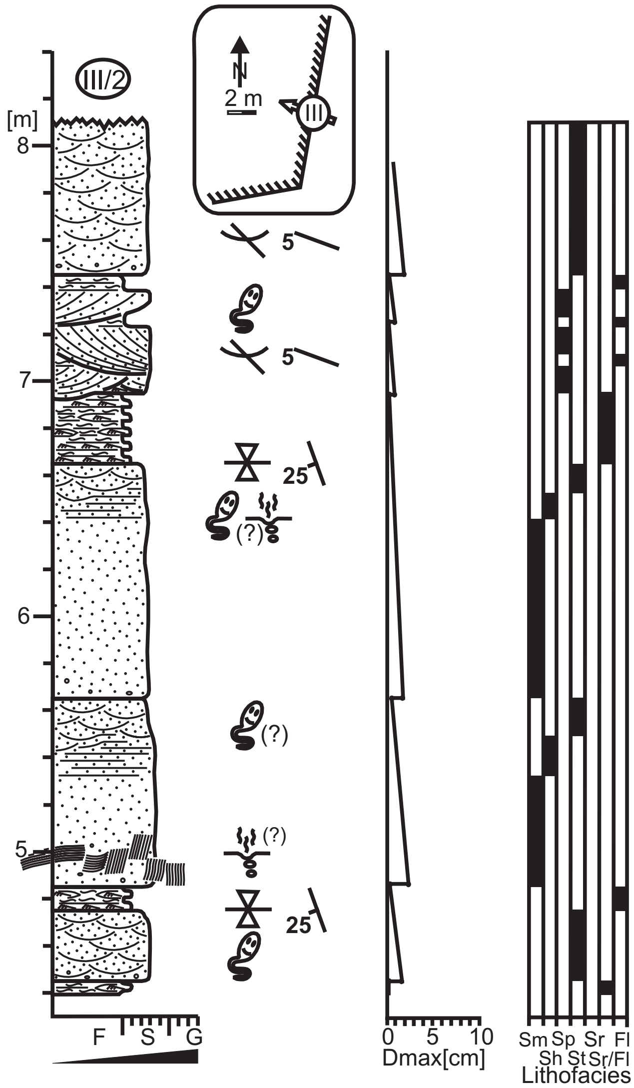


Fig. 8. Example graphic log of the Building Sandstone, an outcrop near Nowa Ruda. (Precise location – see: Fig. 3; additional markings – see: Fig. 6).

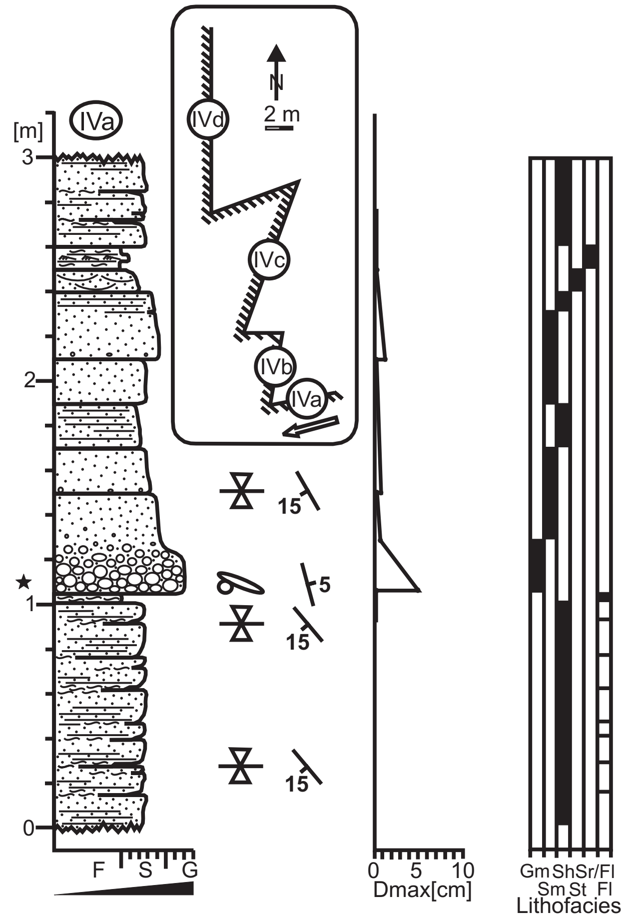


Fig. 9. Example graphic log of the Building Sandstone, an outcrop near Nowa Ruda. (Precise location – see: Fig. 3; additional markings – see: Fig. 6).

Gc facies, and they locally form the only component of such layers (Figs. 8, 20, 22). The layers tend to be thin, from a few to 10 cm, and as a rule their thickness does not exceed 2–3 average diameters of the clasts, while their lateral extent is large, in most cases exceeding the observation possibilities in the scale of the outcrops available.

The clast layers of the Gc lithofacies are probably the product of selective bottom erosion. Initially, in certain flow conditions, sand fraction grains were mobilized and transported farther, while larger grains were concentrated at the erosional plane and created clast layers. This process may have taken place in the channel; thus, such layers could be treated as typical examples of a channel pavement. When the process took place on a much wider scale in sheet-flood conditions, then one would expect such a pavement to have a considerably wider extent (Collinson, 1986). In both cases, the pavement formed in high energy flow conditions, which at first enabled the erosion of the sandy material and next the sedimentation of this material in upper planar bed conditions.

**Lithofacies Gt – trough cross-bedded conglomerates and conglomeratic sandstones**

Conglomerates and conglomeratic sandstones with trough cross-bedding are rare within the coarse-grained facies. The beds of this facies are clast supported. Their bases are sharp and distinctly erosionally incised. Upwards, gradational transitions to sandy-rich conglomerates are observed (Fig. 18). The beds are 30–40 cm thick, and their lateral extent probably does not exceed several meters. The sediment is moderately sorted. The size of clasts is 2.0–3.0 cm on average, and rarely reaches 6.0 cm. The clasts have various shapes and medium to good roundness (3–6). The petrographic composition of grains is similar to the composition of the other sediments in the coarse-grained facies group. A feature specific to these sediments is the trough cross-bedding, marked with distinctly expressed lower planes of the sets. The sets are 12.0–15.0 cm thick and 0.8–1.2 m wide.

The relatively high textural maturity and the presence of the trough cross-bedding indicate that the Gt lithofacies may have been formed as the result of transport and deposition of a sediment in the upper range of the dune bed phase. Gt forms the fill of minor alluvial channels (Harms *et al.*, 1975).

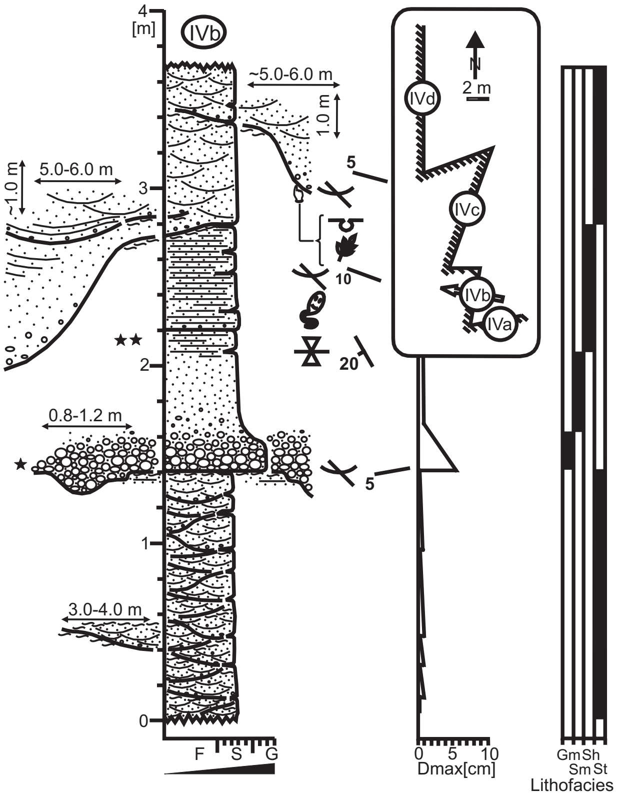


**Fig. 10.** Example graphic log of the Building Sandstone, an outcrop near Nowa Ruda. (Precise location – see: Fig. 3; additional markings – see: Fig. 6).

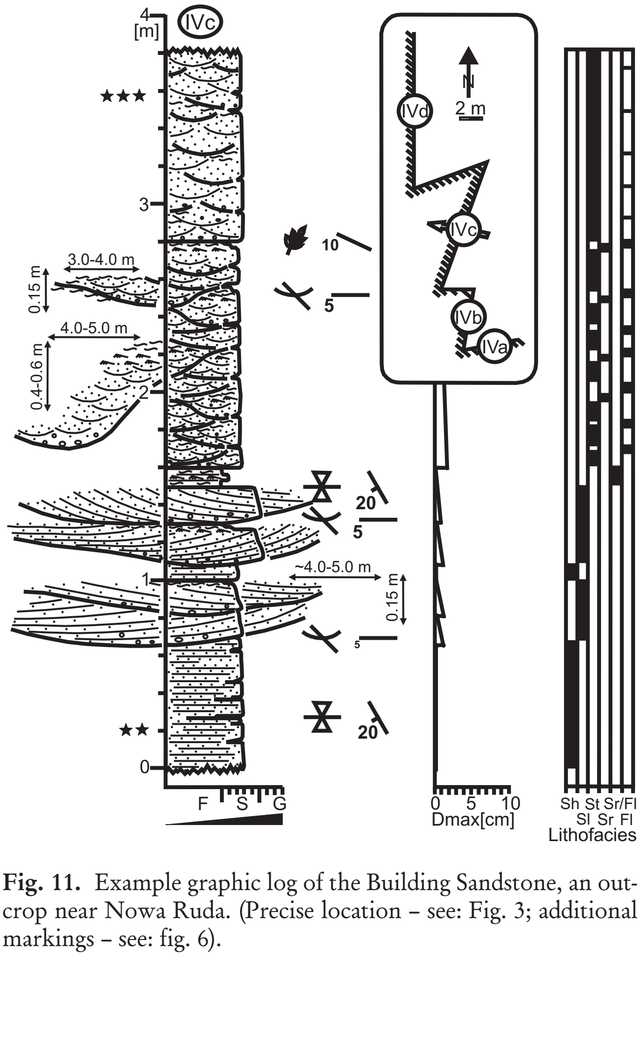


**Fig. 11.** Example graphic log of the Building Sandstone, an outcrop near Nowa Ruda. (Precise location – see: Fig. 3; additional markings – see: fig. 6).

## MEDIUM-GRAINED FACIES GROUP

### Lithofacies Sm – massive sandstones

In the massive sandstones, no macroscopic internal stratification has been found, i.e. the rocks show no preferred grain orientation. They form separate beds with sharp tops and bases, and do not exceeding 30–40 cm in thickness (Figs 7, 9, 12). They may also occur as parts of composite beds. In the latter case, this facies forms the lower parts of beds and passes upwards into bedded sandstone varieties, mainly Sh and St. The thickness of the massive sandstone division in such beds ranges from 20–30 to around 80 cm (Figs. 5, 8, 14, 16). They are fine- to medium-grained rocks. In the grain composition apart from quartz, one may macroscopically distinguish white grains of feldspars and tiny mica flakes. The cement in these sandstones is siliceous clay, with the distinct red-brown pigment of iron compounds. Petrographically, these rocks are sub-

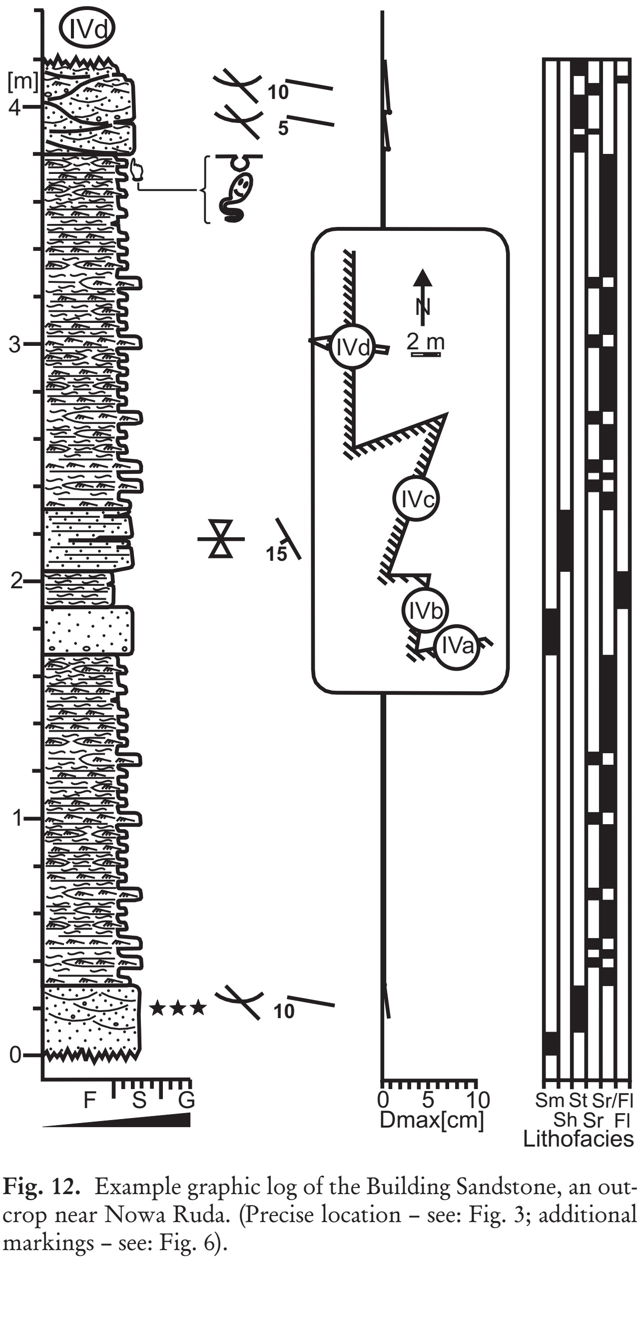


**Fig. 12.** Example graphic log of the Building Sandstone, an outcrop near Nowa Ruda. (Precise location – see: Fig. 3; additional markings – see: Fig. 6).

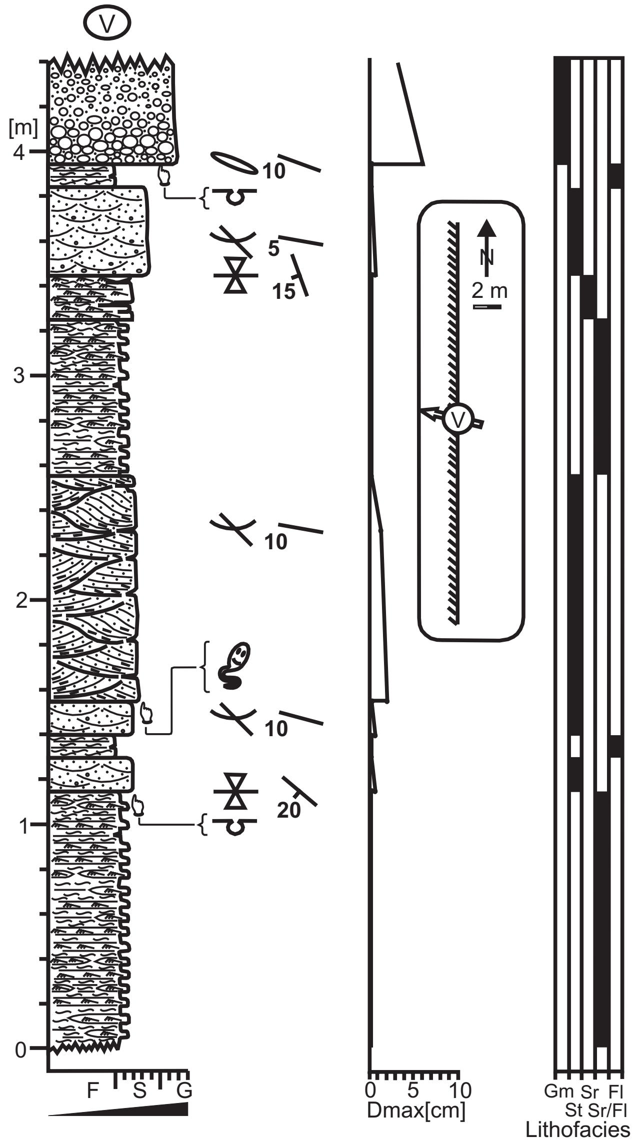


**Fig. 13.** Example graphic log of the Building Sandstone, an outcrop near Nowa Ruda. (Precise location – see: Fig. 3; additional markings – see: Fig. 6).

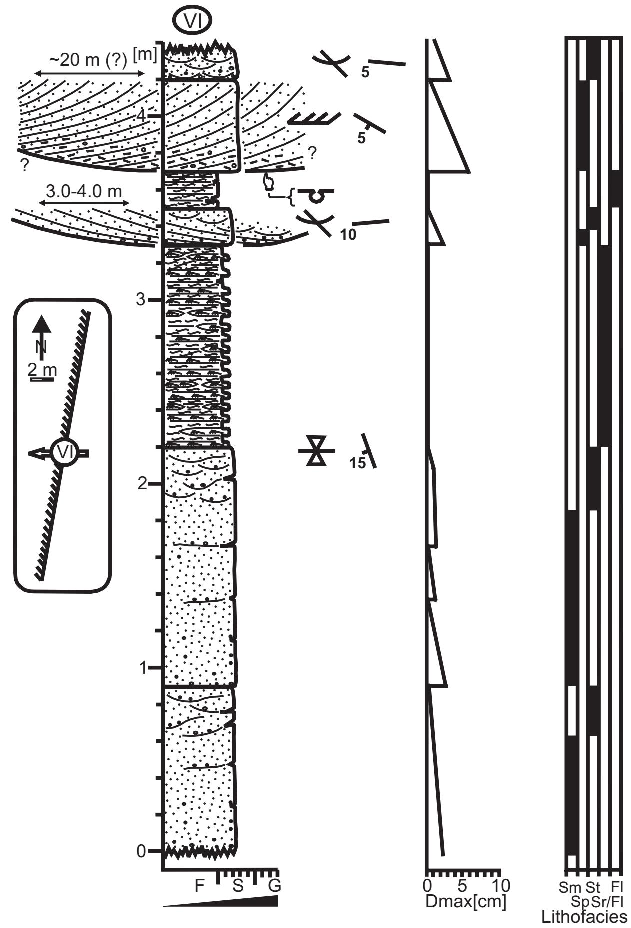


**Fig. 14.** Example graphic log of the Building Sandstone, an outcrop near Nowa Ruda. (Precise location – see: Fig. 3; additional markings – see: Fig. 6).

lithic and subarkosic arenites and wackes. Within the beds and intercalations of the lithofacies Sm sandstones, mainly in their basal parts, there are small mudstone intraclasts and single quartz clasts; their size does not exceed 1.5–2.5 cm.

The well-defined bases of the massive sandstone beds and intercalations of the Sm lithofacies in the composite beds point to an erosional character of the beds' base. This and the absence of bedding in the studied sedimentary rocks are in turn indicative of their transport and sedimentation in high energy flow conditions. Accumulation probably took place in the axial parts of channel zones, and might have been a result of violent changes in the hydrodynamic conditions and a periodic overloading with sediment (Harms *et al.*, 1975). Such changes may have resulted in a sudden discharge of transported sandy material and in its deposition.

### Lithofacies Sh – horizontally bedded sandstones

A characteristic feature of the beds of this lithofacies is pervasive horizontal bedding. As in the case of the massive sandstones (Sm), there may be separate beds with distinctly marked boundary planes, which are several to 60–90 cm thick (Figs. 10, 11, 19, 21); they may also be part of the composite beds. In such cases, the sandstones with horizontal bedding form intercalations up to 20 cm thick, and depending on the situation, pass towards the base of the bed into massive sandstones (Figs. 8, 14, 16), and towards the top, into sandstones with trough bedding – St (Figs. 5, 8, 21, 22); they may also occur together with coarse-grained sediments (Fig. 6). The Sh lithofacies sandstones are mainly the medium-grained varieties, whereas those accompanying conglomerates are medium- to coarse-grained and rich in a very coarse sand fraction with additional fine gravel and single clasts up to 1.5–2.0 cm in diameter. Red-brown colour of these rocks and the petrographic composition of the grains and the type of cement are macroscopically similar to those of the massive sandstones (Sm). On the boundary planes of the facies Sh lithosomes, one may also observe common raindrop imprints, shrinkage cracks, current marks, plant remains print and abundant trace fossils (Fig. 5).

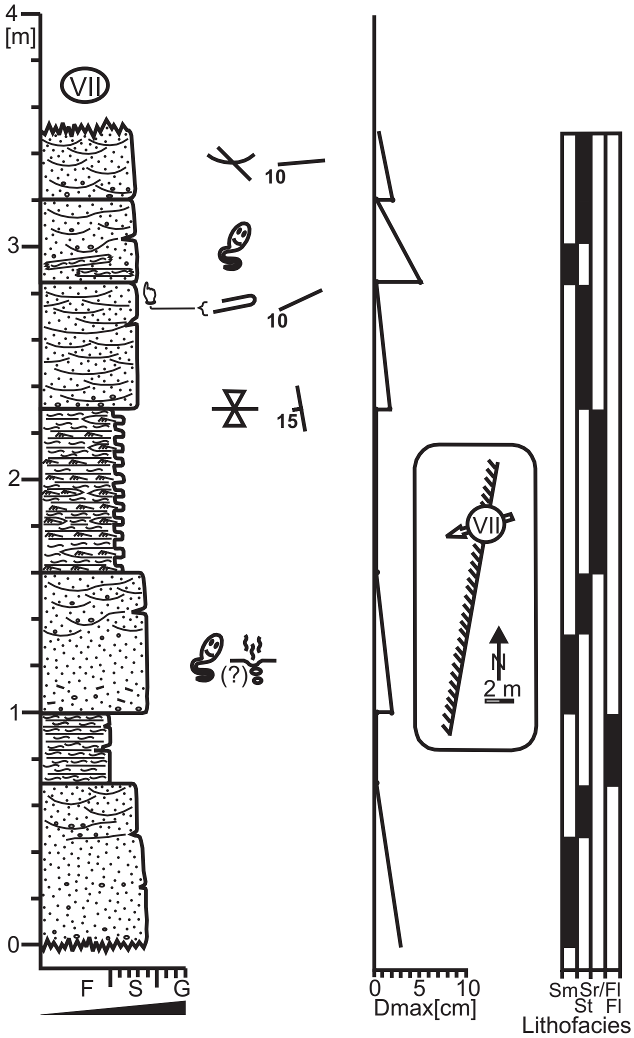


**Fig. 15.** Example graphic log of the Building Sandstone, an outcrop near Nowa Ruda. (Precise location – see: Fig. 3; additional markings – see: Fig. 6).

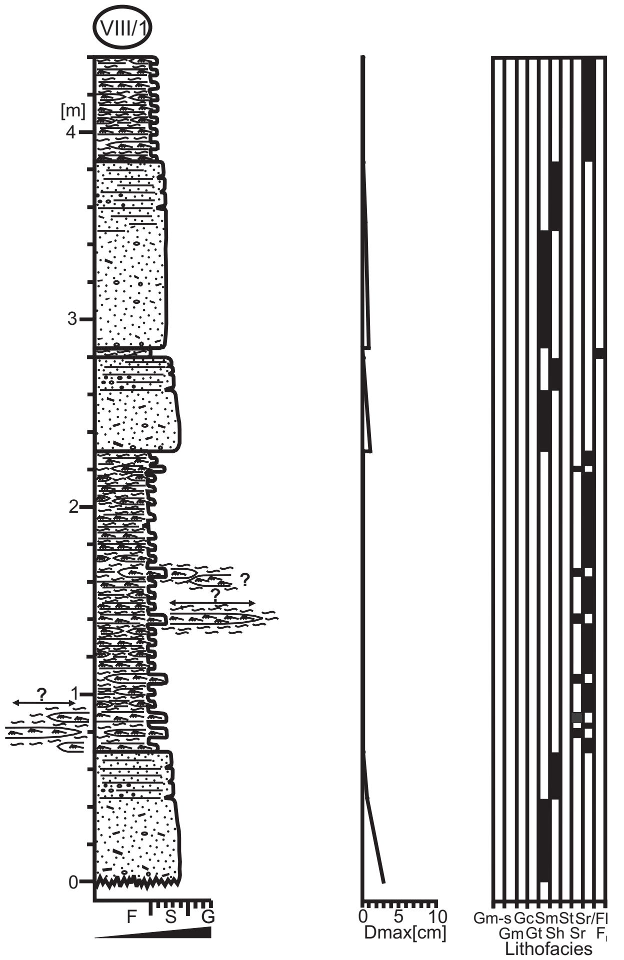


**Fig. 16.** Example graphic log of the Building Sandstone, an outcrop near Nowa Ruda. (Precise location – see: Fig. 3; additional markings – see: Fig. 6).

The description above suggests that the horizontally bedded sandstones may have a two-fold nature. Those present in the composite sandy beds were probably deposited in channel zones under varied hydrodynamic conditions, as indicated by structural variations observed within the sediment. The overloading with sediment combined with an insignificant energy decrease resulted in the deposition of massive sandstones (Sm). Upper plane bed flow conditions allowed the sedimentation of the horizontally bedded sandstones (Sh), and the transition to the dune bottom configuration, led to the deposition of sandstones with a large-scale trough cross-bedding (St) (Allen, 1984). The horizontally bedded sandstones that form separate beds and beds accompanying conglomerates may have deposited in flood conditions (?). In the depositional environment of these sediments, periodic sheet-flooding may have occurred, bringing periods of high-energy flow to a vast area. The energy regime reflected upper planar bed conditions and enabled the deposition of sandy material with horizontal bedding (Sh). A momentary increase in energy might have resulted in periods of selective erosion of the sandy material and as a consequence led to the formation of the clast horizons which commonly underlie the lithofacies Sh sandstones (Fig. 6). Also, in the conditions of high energy and at the saturation of the sediment with water, larger masses of rock material may have been mobilized and gravitationally transported. A result of this process could be conglomerate interbeddings in the horizontally bedded sandstones, which in this paper are interpreted as gravity flow sediments (Fig. 18). In some cases the sandy deposits of the Sh lithofacies were subject to subaerial conditions, as implied by raindrop imprints and shrinkage cracks.

**Lithofacies Sl – low-angle cross-bedded sandstones**

These sandstones form separate beds with a clearly marked base and top, and their typical feature is the occurrence of low-angle cross-bedding. In the log, they form individual beds but occur in turn, rather as cosets (Fig. 7). In the cases observed, the thickness of such sets reached 130–150 cm, and the thickness of individual beds within the sets was 30–40 cm. The boundary planes between individual constituent beds are marked by thin intercalations of fine-grained material, 2.0 to 5.0 cm thick; this is mainly laminated mudstone that belongs to the lithofacies Fl. Within these sediments, there are abundant trace fossils

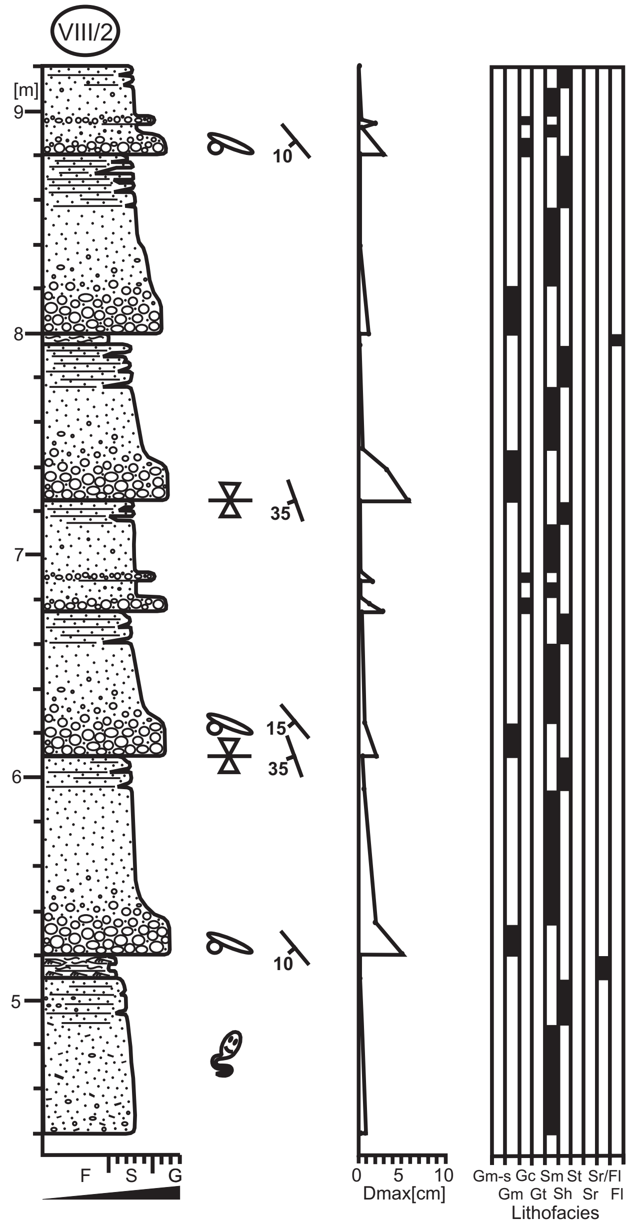


**Fig. 17.** Example graphic log of the Building Sandstone, an outcrop near Nowa Ruda. (Precise location – see: Fig. 3; additional markings – see: Fig. 6).

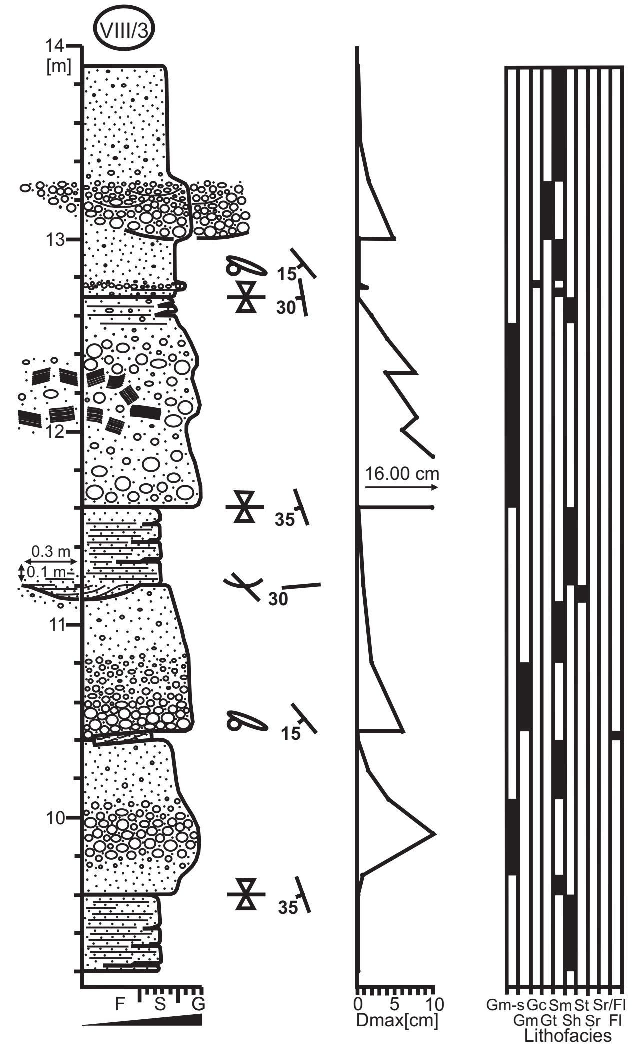


**Fig. 18.** Example graphic log of the Building Sandstone, an outcrop near Nowa Ruda. (Precise location – see: Fig. 3; additional markings – see: Fig. 6).

(*Scolithos ?*) and rare spherical voids, more or less vertically arranged, interpreted here as the result of outgassing of the sediment (outgassing structures ?). The sandstones of the Sl lithofacies are fine- to medium-grained rocks; they are red-brown and their petrographic composition resembles that of the massive sandstones (Sm) and horizontally bedded sandstones (Sh).The sandy lithosomes of the Sl lithofacies probably form the fillings of minor channels, erosional outwash structures (?) the initial depth of which roughly corresponded to the present thickness of beds and whose lateral extent (the channel width) in some cases exceeded 3.0 m (difficult to assess precisely in the scale of an outcrop). The textural features of these sandstones, like the low-angle cross-bedding, and the high width/depth ratio, in extreme cases exceeding 20, indicate deposition in high energy flow conditions, probably corresponding to the antidunes phase (Miall, 1978).

**Lithofacies Sp – planar cross-bedded sandstones**

The sandstones of this lithofacies occur in the Słupiec Formation as separate lithosomes, 40–60 cm thick (Figs. 4, 14), or as cosets, 120–140 cm thick; single constituent sets may be several to 20–25 cm thick (Figs. 7, 8, 11). In both cases, the boundaries of the Sp lithofacies are distinct, in places marked with a several-centimetre-thick intercalation of a laminated mudstone (Fl lithofacies). In the cross section, the lower boundary reveals a trough outline in numerous places. On its surface, there are common tiny erosional and deformational structures (flute marks, crescent marks, load structures) and plant parts – probably Walchia twigs. A specific feature of the Sp lithofacies sandstones is the presence of planar cross-bedding in tangential sets. Like in the other sandstone facies, trace fossils and outgassing structures are also present here. These sandstones are coarse-grained, and in their lower part, commonly contain a fine-gravel fraction and mudstone intraclasts. They are

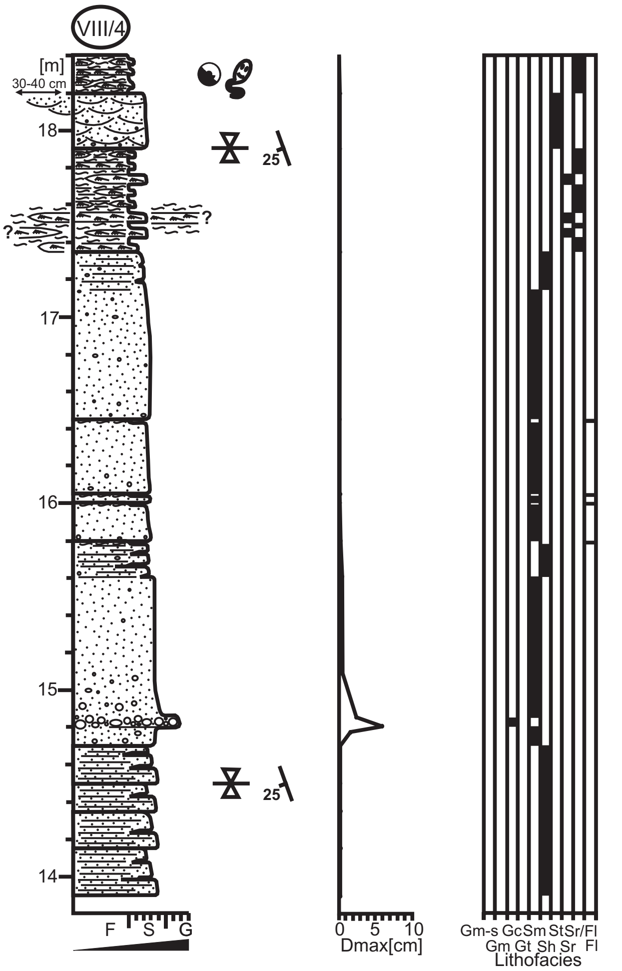


**Fig. 19.** Example graphic log of the Building Sandstone, an outcrop near Nowa Ruda. (Precise location – see: Fig. 3; additional markings – see: Fig. 6).

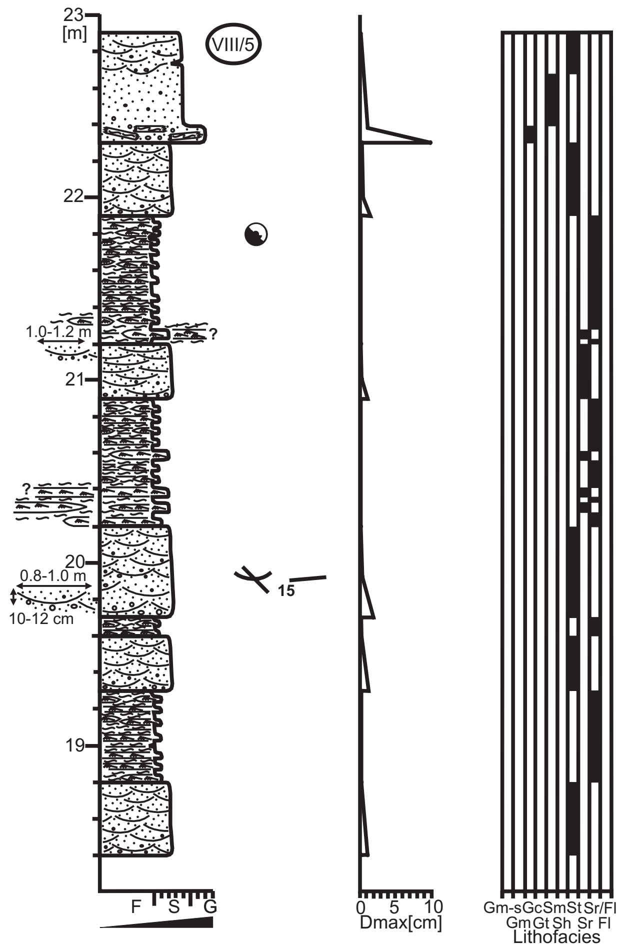


**Fig. 20.** Example graphic log of the Building Sandstone, an outcrop near Nowa Ruda. (Precise location – see: Fig. 3; additional markings – see: Fig. 6).

red-coloured, and in their petrographic composition, apart from lithic grains and mica grains, there are abundant macroscopic feldspar grains. These sediments may be described as sublithic or subarkosic arenites and wackes.

The characteristic trough outline of the base surface of the sets and the presence of abundant gravel material and mudstone intraclasts in this zone point to the erosion at the top of the underlying bed before the overlying set was deposited. Thus, the lithosomes of this lithofacies form the fillings of alluvial channels. The channel dimensions were varied. The depth of the largest ones which could play a major role in the drainage system of the unit, corresponded to the thickness of single sets of the Sp lithofacies sediments and amounted to 40–60 cm. Their lateral extent is difficult to assess in the scale of an outcrop. From field observations, it may be inferred that the width of the channels was not less than 6–8 m, and could reach from a dozen or so to around 20 meters as a maximum. Thus, the width/depth ratio of the channel cross-section for such channels was not less than 10–15. The depth of minor channels that functioned only for a short time and locally in the drainage system corresponded to the thickness of the single sets occurring in the groups and amounted to around 25 cm, whereas their width probably did not exceed 2–3 m, which, as in the earlier case, renders the width/depth ratio of the channel cross-section not lower than 10. These channels were filled with sandy material with planar cross-bedding, in tangential sets, at the base rich in fine gravel and mudstone intraclasts, as mentioned above. Thus, it is likely that deposition took place in conditions of moderate energy within bed forms of a transversal sand bar type, growing in the direction of the flow (Costello & Southard, 1981). However, paleoflow data does not support such a conclusion, as the cross laminae in the Sp lithofacies dip transversely with respect to the channel axis. Therefore, the sandstones of this lithofacies were probably deposited as side bars (Rust, 1978), and their sedimentation was related to the separation of the stream in the channel (bed ?) of a braided river. Such a channel type is implied by the high width/depth ratio of the cross-section.

**Lithofacies St – trough cross-bedded sandstones**

Trough cross-bedded sandstones are a relatively common element in the Building Sandstone facies assemblage. These sediments may occur either as separate beds with a clearly marked top and base (Figs. 4, 5, 7, 8, 10), or as cosets in the upper parts of composite beds (Figs. 5, 8, 15). The sandstones are most commonly medium-grained, and in

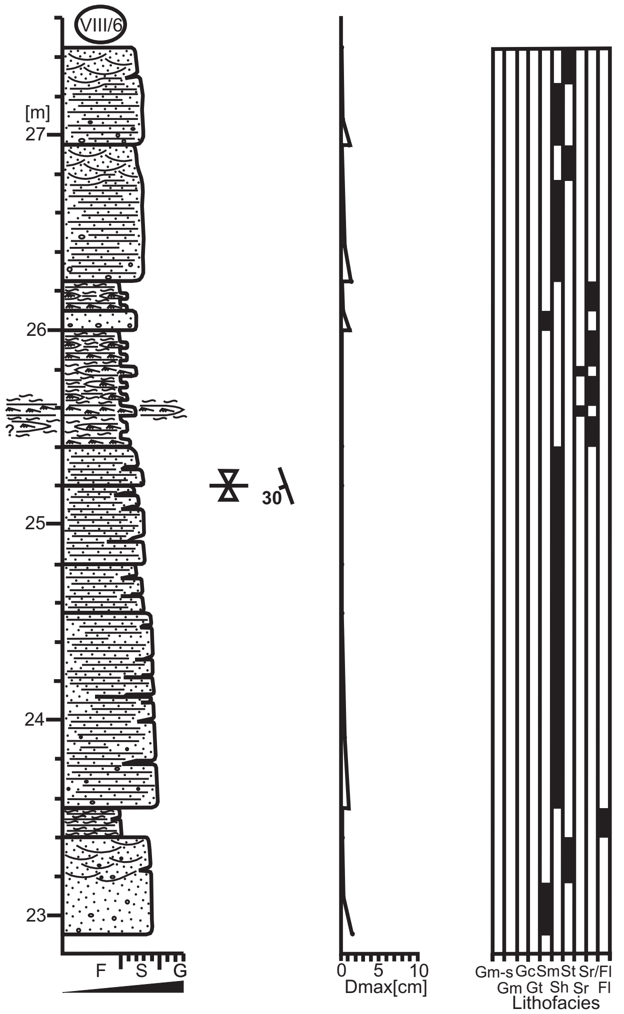


**Fig. 21.** Example graphic log of the Building Sandstone, an outcrop near Nowa Ruda. (Precise location – see: Fig. 3; additional markings – see: Fig. 6).

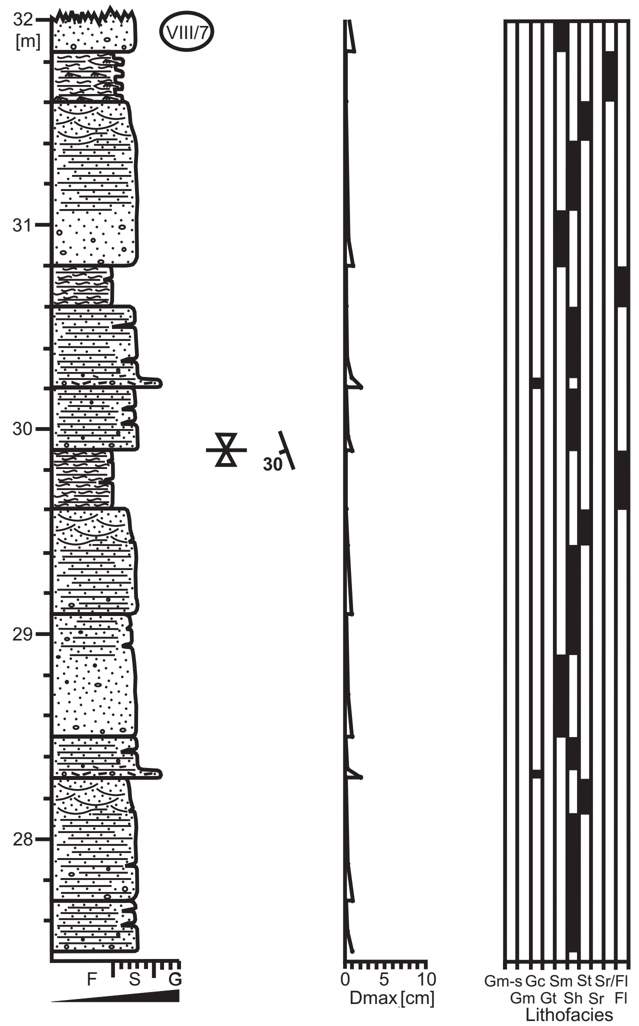


**Fig. 22.** Example graphic log of the Building Sandstone, an outcrop near Nowa Ruda. (Precise location – see: Fig. 3; additional markings – see: Fig. 6).

places coarse- and fine-grained; in larger sets, they contain rare single clasts up to 1.5–2.0 cm in diameter. The thickness of the trough cosets in the composite beds generally does not exceed 20–30 cm, while the depth and the width of individual sets amounts to 8–12 cm and 40–60 cm, respectively. Separate beds may, however, have various thicknesses – in the cases observed: from around 20 cm to over 1.0 m. Individual trough sets in these beds very commonly have dimensions like those quoted above. In places, chiefly in thin coarse-sand beds, the trough dimensions may vary. The differences are mainly in the decrease in the thickness of the sets to 4–6 cm while their lateral extent (40–60 cm) is preserved. Also, in certain single beds, mainly in those with the greatest thickness, two generations of troughs are observed. The bigger ones, the boundary of which planes are marked with thin (up to 2–3 cm) intercalations of mudstone to very fine-grained material of a character corresponding to the Fl lithofacies sediments, are from 1.0 m to around 2.0 m wide and about 15–25 cm deep. Within them, smaller trough sets occur, 4–6 cm wide and 30–40 cm deep. On the base planes of the trough sets, irrespective of their scale, minor current marks, load structures and trace fossils (*Scolithos?*) are relatively common.

The majority of the sandstones described above, with the trough cross-bedding, formed as a result of deposition in a braided river-channel zone environment. The multisets in the upper parts of the composite beds probably represent the terminal stage of the filling of the large channels in stable flow conditions. In the initial stage, under conditions of overloading with sediment and high energy, massive sandstones were deposited (compare: lithofacies Sm). At the transition to the conditions of the upper planar bed, sets of sandstones with horizontal bedding were formed (compare: lithofacies Sh). Finally, in the phase of rhythmic transport, at the dune bottom configuration, sandstones with trough cross-bedding were deposited (compare: lithofacies St) (Harms *et al.*, 1975). Separate beds with trough bedding also resulted from the filling of large channels under conditions of prolonged stable flow conditions, corresponding to the dune bed phase. Beds in which two generations of troughs were distinguished are also the result of the sediment deposition in the channel environment. The larger ones were formed during short episodes of erosion and the formation of a minor channel system. The smaller ones are a product of their filling in conditions similar to

**A**

Difference count matrix

| | Gms | Gm | Gc | Gt | Sm | Sh | St | Sr | Sr/Fl | Fl |
|---|---|---|---|---|---|---|---|---|---|---|
| Gms | | | | | 0.293 | 0.321 | | | | |
| Gm | | | | | 0.787 | | | | | |
| Gc | | | | | 0.480 | 0.111 | | | | |
| Gt | | | | | 0.794 | | | | | |
| Sm | 0.017 | | 0.049 | 0.026 | | 0.330 | | | | 0.049 |
| Sh | 0.023 | 0.029 | 0.035 | | | | 0.120 | | | 0.075 |
| St | | | 0.065 | | | | | | 0.273 | 0.065 |
| Sr | | | | | | | | | 0.770 | |
| Sr/Fl | | 0.016 | | | | | 0.083 | 0.410 | | |
| Fl | | 0.155 | | | 0.380 | 0.011 | | | | |

**B**

Value of "Z" statistics

| | Gms | Gm | Gc | Gt | Sm | Sh | St | Sr | Sr/Fl | Fl |
|---|---|---|---|---|---|---|---|---|---|---|
| Gms | | | | | | | | | | |
| Gm | | | | | 4.71 | | | | | |
| Gc | | | | | 3.67 | | | | | |
| Gt | | | | | 1.97 | | | | | |
| Sm | | | | | | 4.29 | | | | |
| Sh | | | | | | | 1.85 | | | |
| St | | | | | | | | | 2.44 | |
| Sr | | | | | | | | | 7.32 | |
| Sr/Fl | | | | | | | | 6.34 | | |
| Fl | | 2.35 | | | 2.90 | | | | | |

**C**

Value of "Z" statistics [%]

| | Gms | Gm | Gc | Gt | Sm | Sh | St | Sr | Sr/Fl | Fl |
|---|---|---|---|---|---|---|---|---|---|---|
| Gms | | | | | | | | | | |
| Gm | | | | | 14 % | | | | | |
| Gc | | | | | 11 % | | | | | |
| Gt | | | | | 6 % | | | | | |
| Sm | | | | | | 13 % | | | | |
| Sh | | | | | | | 6 % | | | |
| St | | | | | | | | | 7 % | |
| Sr | | | | | | | | | 22 % | |
| Sr/Fl | | | | | | | | 19 % | | |
| Fl | | 7 % | | | 9 % | | | | | |

**D**

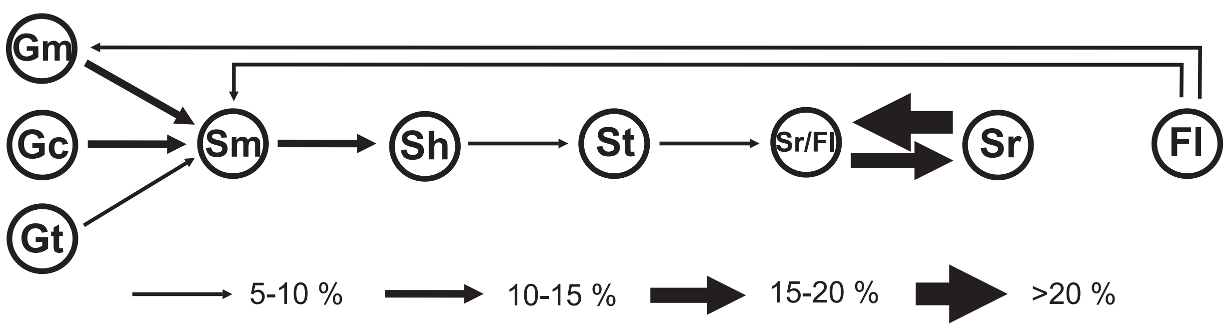


**Fig. 23.** **A** – difference count matrix; **B** – value of "z" statistics; **C** – value of "z" statistics in [%]; **D** – graphic model of facial transitions; further explanations in the text.

those described above. Thin intercalations of mudstones represent the final episode of their filling. Certain lithosomes of this facies may also develop by deposition of a sandy sediment in morphological forms of the crevasse splays type.

**Lithofacies Sr – ripple cross-laminated sandstones**

The sandstones of this lithofacies do not form thick beds with clearly marked boundaries in the sediments described here. They occur as thin intercalations or clearly visible lenses within the Sr/Fl lithofacies. These are fine- and very fine-grained sandstones whose typical feature is a small-scale cross-bedding related to ripplemarks. When observed macroscopically, their petrographic composition is not different from that of the other facies in this group. The thickness of these sediments is varied and ranges from 2–4 cm to around 10 cm, whereas their extent is difficult to asses in the scale of an outcrop in the case of intercalations, and in the case of lenses falls within a range from 0.4–0.6 m to about 0.8–1.2 m (Figs. 4, 5, 7, 12, 20).

The sandstones of this lithofacies are probably a product of the flood plane surface outwash in the final stage of a flood. As a result of such a process very shallow channels/outwash structures may form, to be later filled with fine-grained sandy material under low energy flow conditions, in the lower phase of the rhythmic transport at the ripplemark bottom configuration (Harms *et al.*, 1975).

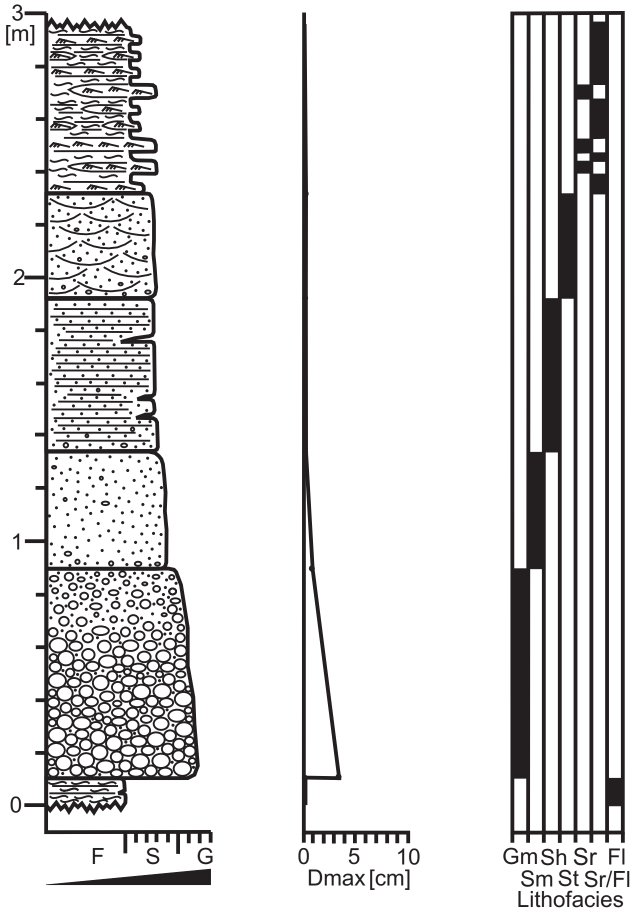


**Fig. 24.** Ideal graphic log of the Building Sandstone based on the result of the vertical facial changes investigations.

## FINE-GRAINED FACIES GROUP

**Lithofacies Sr/Fl – interbedded sandstones and mudstones**

Sandstone and mudstone intercalations are a relatively common member of the facies sequence within the Słupiec Formation sandy sediments. They form distinct beds of varied thickness, which, in the profiles described, ranges from 10–15 cm to around 1.6 m (Figs. 4, 5, 12, 13). Within the thickest beds of these sediments, there are frequent tiny (up to a dozen or so centimetres thick) intercalations of other facies, mainly Sr, in places St and even Sh (Fig. 4). The sediments are of a heterolithic character and are dominated by wavy and lenticular bedding. The sandstones are fine-and very fine-grained, have a varied silt content, and only in rare places bear cross-lamination. The thickness of the sand beds reaches from 3 to 5 mm. The mudstones, on the other hand, are characterised by a delicate horizontal lamination. The colour of the sediments is red-brown. Locally, in these sediments, there are also red-coloured spherical clayey clusters of a concretion type, 8.0–10.0 cm in diameter.

The heterolithic nature of these sediments indicates relatively regular changes in the transport and sedimentation conditions. The sandy fraction was deposited under lower flow regime conditions at the ripplemark bottom configuration (Harms *et al.*, 1975). During stagnation periods, laminated mudstone sediment was deposited. The structural and textural features of these sediments point to their deposition in flood conditions. Thus, the thin intercalations of sandstones and mudstones represent the overbank parts of the flood plane. The intercalations of other facies, mainly of St, may be connected with sand deposition in crevasse splays .

**Lithofacies Fl – mudstones with horizontal lamination**

Horizontally laminated mudstones are rare in the Słupiec Formation. They are frequently hard to unequivocally distinguish from the sediments of the Sr/Fl lithofacies described earlier. They most commonly form thin (not more than several centimetre thick) intercalations within other facies varieties (Figs. 7, 8, 11, 12). No other lamination than horizontal was observed in them either; the thickness of a single lamina ranges from tenths of a millimetre to around 1 millimetre. The colour of these mudstones is red-brown.

The mudstones of the Fl lithofacies were formed as a result of the deposition of fine-grained material under the conditions of flow stagnation (the lower planar bottom). They could represent flood plain sediments (Allen, 1965). The slight thickness of the lithosomes of this facies and their spatial location within other facies varieties, mainly St, Sl and in places Sh indicate that they were formed in the terminal stage of the filling of channels in the fluvial system of the sandy sediments of the Słupiec Formation.

## VERTICAL FACIES CHANGES

The next step in the analysis presented in this paper, is the presentation of a model of a vertical facies changes in the Building Sandstone sediments. For the purpose of the analysis, the author selected a sequence of outcrops in the cross-cut of the railway line from Nowa Ruda towards Kłodzko (Fig. 3). These outcrops are easily accessible and representative of the whole unit. Their graphic documentation is given in (Figs. 16–22). The analysis was carried out on an over 30-metre thick, continuous, undisturbed part of the section that comprises almost 10% of the total thickness of the Building Sandstone sequence. Around 150 facies transitions were observed in the profile, and this number was found to be sufficient for the description of the evolution of significant trends of vertical facies changes.

Vertical facies changes were analyzed by means of embedded Markov chains (e. g. Nemec, 1981). The reasoning concerning facies changes was based on a difference count matrix which allows the detection of transitions occurring with a frequency higher than random. 'Z' statistics which was used to test statistical significance of such transitions (Radomski & Gradziński, 1978) helped to eliminate those which were unimportant in the deposition processes. The interpretation was solely focused on transitions of a significance level higher than the critical value of $z = 1.64$ (=5%). The transitions which meet this condition are significant for the reconstruction of the depositional processes. A positive value of the difference count matrix may be applied in the establishing of a modal sequence of lithofacies (Radomski & Gradziński, 1978). The analytical results are presented in Figure 23.

In the "ideal" profile of the Building Sandstone (Fig. 24), a very well defined tendency is expressed to form simple cyclical sequences, showing upward fining in terms of the grain size. There is also a conspicuous asymmetry to the sequences with the coarse and medium-grained facies dominant. The tendency to oscillation is mainly visible within fine-grained facies, whereas it is more weakly defined in the coarser-grained facies. These features unequivocally point to an alluvial environment dominated by channel processes. The dominance of facies transitions within a set of coarse and medium-grained deposits may point to rivers of low sinuosity, probably of a braided type. Their riverbeds were shallow, unstable and showed a tendency to migrate sidewise. The initial stage of each channel cycle deposition took place under high energy flow conditions. The conditions became more stable in the

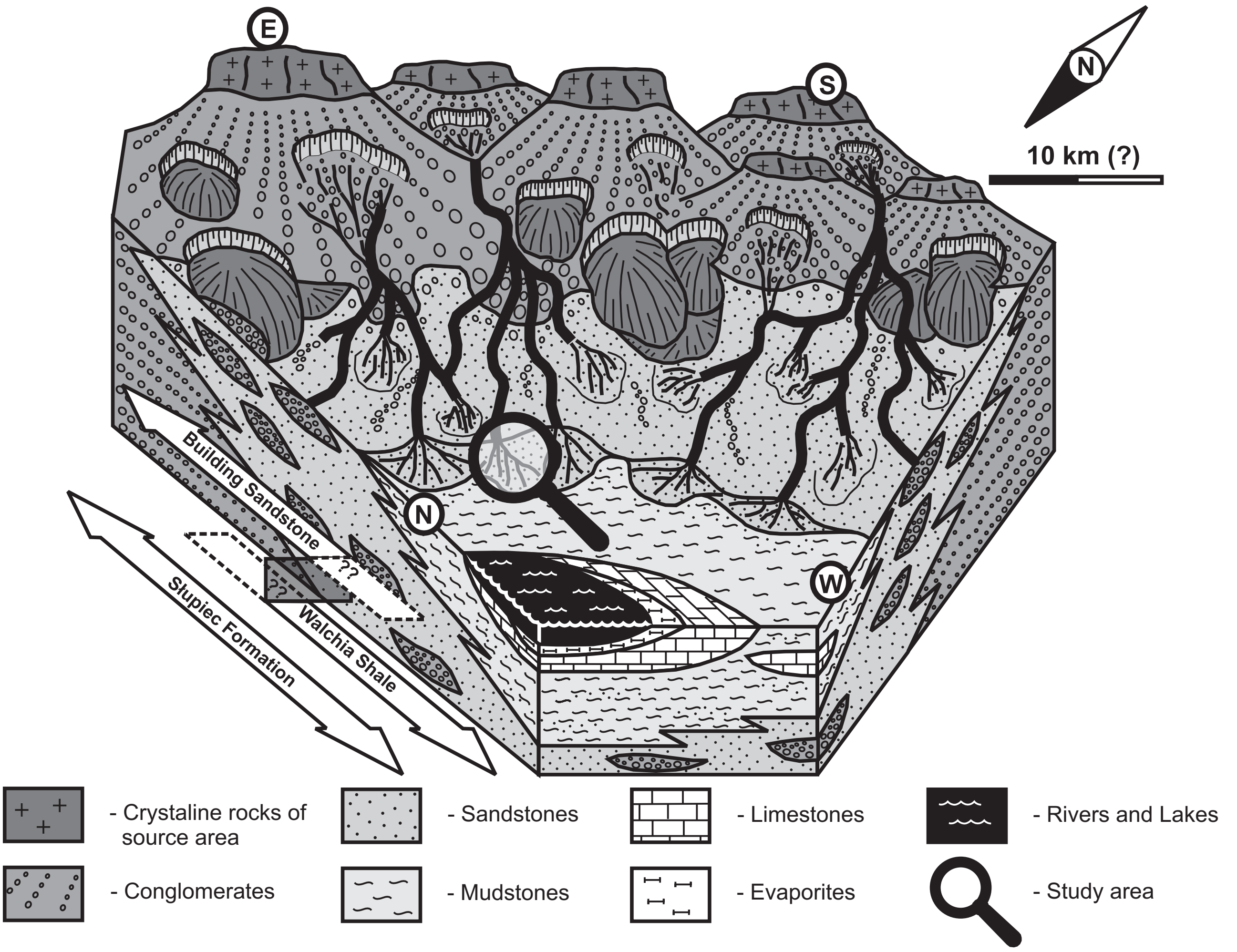


**Fig. 25.** Sedimentary-environmental model of the Słupiec Formation (Building Sandstone).

final stage, and most probably reflected a rhythmic transport phase. Overbank sedimentation was limited to levees and the adjacent flood plain zones. Crevasses and crevasse splay were a commonly developed form.

## THE FACIES ARCHITECTURE OF THE BUILDING SANDSTONE – CONCLUSIONS

The facies analysis of the Słupiec Formation sandstones indicates depositional conditions that were rather uncommon in the fluvial environment. In these sediments, the most abundant facies are channel facies deposited in high energy conditions, i.e. conglomerate (Gm, Gc) and sandstone, chiefly of the Sm, Sh and Sl facies. They generally represent products of the upper flow regime (the upper planar bed condition and the antidunes phase) or correspond to at least a high range of the rhythmic transport phase. Channel facies related to lower energy (Sp, St, Sr) and overbank facies corresponding mainly to lower planar bed conditions (Sr/Fl and Fl) are not so common. A quite important feature of the sediments under investigation is the occurrence of the Gms lithofacies, interpreted as a product of gravity flow transport (compare: Tab. 1). Analysis of the palaeochannel forms rendered results consistent with the results of the lithofacies analysis. The palaeochannels are generally very shallow in relation to their width, and the width/depth ratio of the channel cross-section is generally not below 10 to 15 (20). Another characteristic feature is a planar, clearly erosional configuration of their bottom (Figs. 4, 7, 11, 14). In places, an interesting terrace bank morphology may be observed (Fig. 10). Such features are typical of periodic, quickly filled channels with high energy flows. The channels played a minor role in the drainage system of the unit. Apart from these very widespread, small channels, rare large channels occur here (Figs. 10, 14), filled with gravel and gravel-sand material (Gm, Gc, Sm, Sp, St); these may have been major discharge paths in the whole fluvial system of the Słupiec Formation. The orientation of the directional depositional structures (Figs. 5, 6 8–15) unequivocally points to the transport of the clastic material towards the west, with a slight deviation to the north (280°–285°).

The features of the fluvial system presented here point quite unequivocally to a terminal fan environment (Kelly & Olsen, 1993). The source areas of the sandy deposits of the Słupiec Formation were located on the S and SE margins of the Intra-Sudetic Basin, and the flow was directed to the W and NW towards shallow lake basins, probably of a playa type, situated in the central part of the Basin during the Middle Rotliegendes. The red colour of the sediment may be indicative of the development of the fans in the conditions of an arid or semi-arid climate. A graphic model of the depositional environment of the Building Sandstone is presented in Figure 25.

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