GUIDEBOOK

Some current sedimentological controversies in the Polish Carpathian flysch

Guide to field trip B8 • 25–27 June 2015

Stanisław Leszczyński, Piotr S. Dziadzio, Wojciech Nemec

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ORLEN Upstream Sp. z o.o.
ul. Prosta 70 | 00-838 Warszawa
Tel.: +48 22 778 02 00 | Fax: +48 22 395 49 69

Some current sedimentological controversies in the Polish Carpathian flysch

Stanisław Leszczyński[1], Piotr S. Dziadzio[2], Wojciech Nemec[3]

[1]Jagiellonian University, Poland (stan.leszczynski@uj.edu.pl),
[2]Oil and Gas Institute, Poland (dziadzio@inig.pl)
[3]University of Bergen, Norway (wojtek.nemec@uib.no)

Route (Fig. 1): Early evening transfer from Kraków to Gorlice (**accommodation**), ca. 2.5 hours (133 km), by motorway A4 to the slip road Tarnów Zachód and further south by roads 975, 980 and 977. Excursion route on the first day (26 June) from Gorlice by road 977 to Ciężkowice (stop B8.1), then by roads 977, 979 and 28 to Krosno and further by local road to Odrzykoń (**stop B8.2**) and to Czarnorzeki (**stop B8.3**) – with an evening return to Gorlice by roads 991 and 28. Excursion route on the second day from Gorlice to Ropica Górna (**stop B8.4**) by road 977 and back to the southern suburbs of Gorlice (**stop B8.5**), with an early evening return to Kraków by the same roads as used for arrival.

Introduction to the field trip: The Polish Flysch Carpathians

Stanisław Leszczyński

Carpathians are the European largest (~1500 km long) mountain range formed during the Alpine orogeny, extending as an arc (Fig. 2A) from the Czech Republic (3%) in the northwest through the Slovakia/Poland borderland (27%) to Hungary (4%), eastwards to Ukraine (11%) and further southwards to Romania (53%). As a classic collisional orogen, the Polish Carpathians show the complex tectonic structure and tectonostratigraphy of a fold-and-

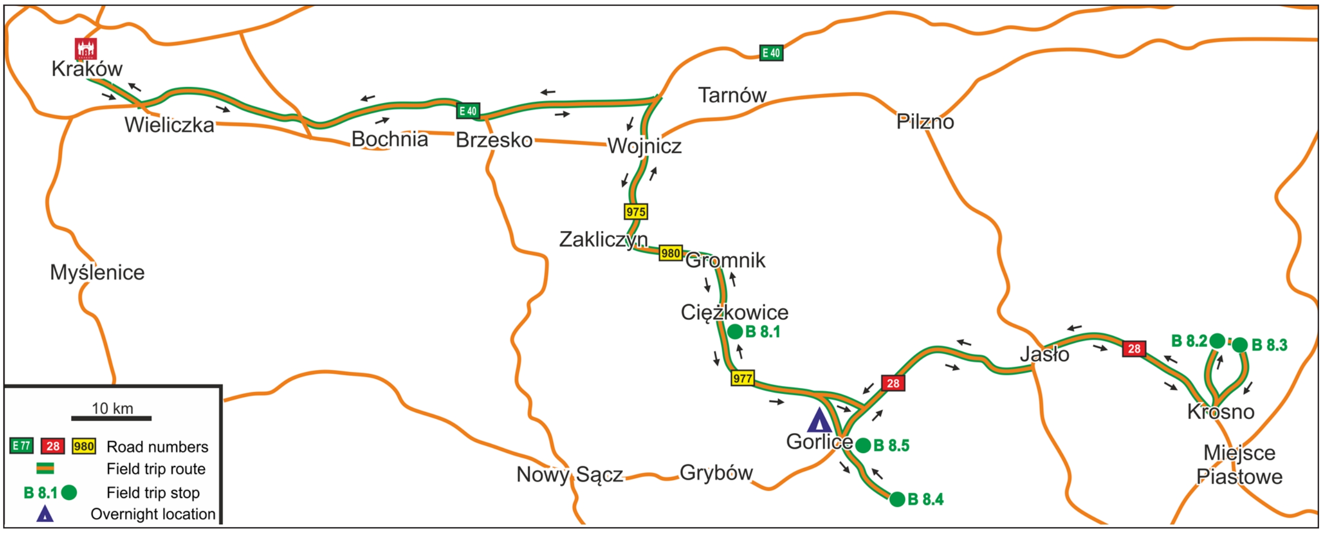

Fig. 1. Route map of field trip B8.

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thrust belt with a general northern vergence. The whole northern, external part of the orogen extending through southernmost Poland (~300 km long and up to 80 km wide) – known as the Outer Carpathians (Figs 2, 3) – is a Cenozoic accretionary prism composed of flysch deposits (*sensu* Studer, 1827; Dżułyński and Smith, 1964), and hence is referred to also as the Flysch Carpathians. The inner part of the orogen, of which only a small part crops out in Poland (Fig. 2), consists of Palaeozoic crystalline rocks and their post-Carboniferous (mainly Mesozoic to Palaeogene) deformed sedimentary cover. The flysch deposits of the Outer Carpathians are up to 6000 m thick, comprising various turbiditic successions of Tithonian to Miocene age (Fig. 4). They are thought to have accumulated on a thin-stretched continental crust of the European Platform's original passive margin in an array of narrow deep-water basins, which were separated by sediment-supplying subaqueous to subaerial ridges referred to as cordilleras and which continued to accumulate sediment during the subsequent active-margin conditions of subduction to collision in the late Cretaceous–Palaeogene time (Książkiewicz, 1956, 1975). The main flysch sub-basins are now represented by the individual nappes of the Outer Carpathians (Figs 2, 3), in their south to north stacking order: the Magura, Sub-Magura/Dukla, Silesian, Sub-Silesian and Skole nappes. The thin-skinned nappes and intra-nappe imbricate thrust-sheets were tectonically stacked in the late Oligocene to early Miocene by being piled up northwards onto the Miocene foreland basin at the flexural margin of the European Platform (Fig. 3). The development of the flysch basins and cordilleras was probably diachronous, as was also their subsequent tectonic stacking as nappes, whereby the exact palaeogeographic evolution of the Outer Carpathians remains to be disputed.

Extensive geological investigations of the Polish Flysch Carpathians commenced in the second half

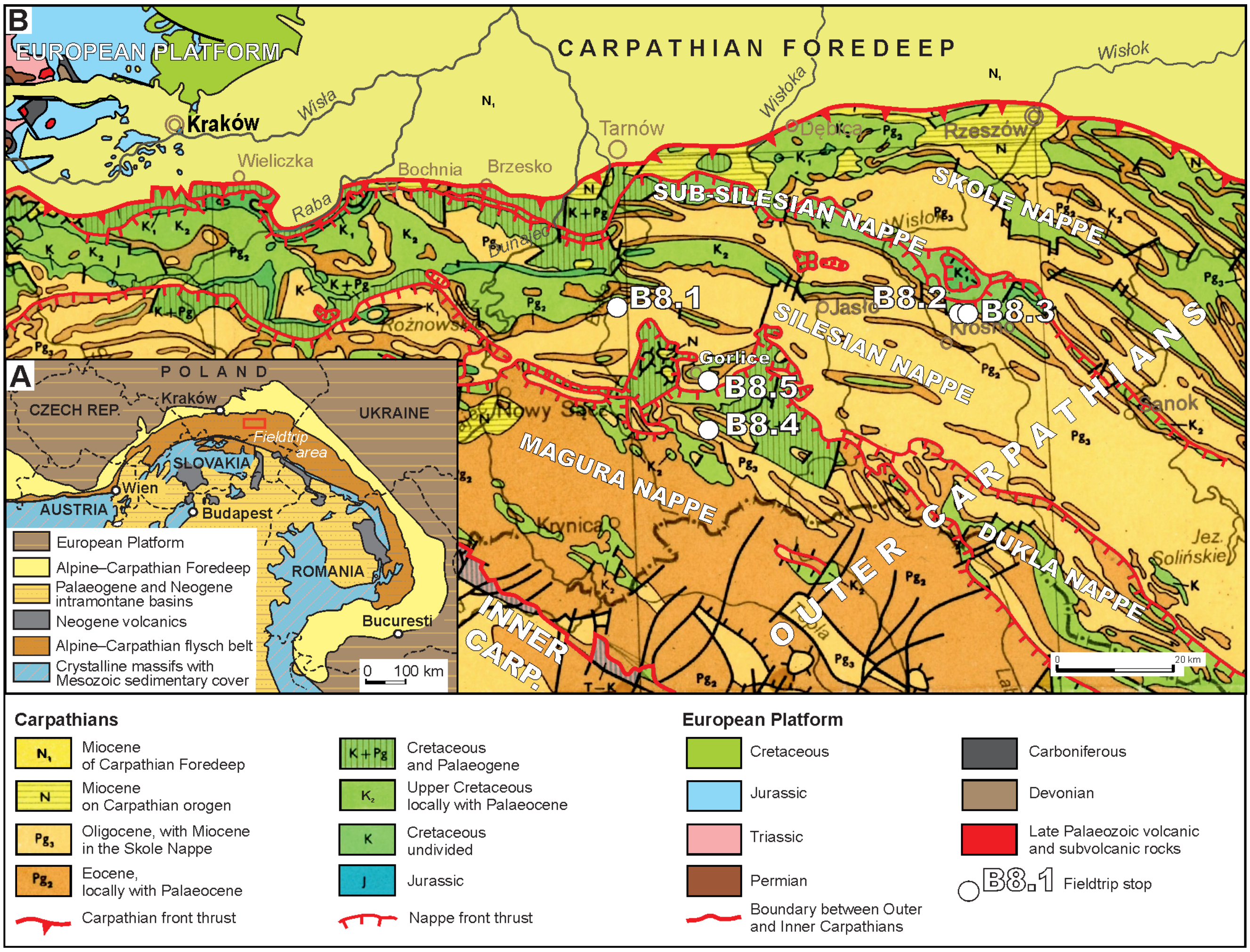

Fig. 2. (**A**) Regional location of the field-trip area within the Outer Carpathian flysch belt and (**B**) the area geological map (based on Geological Map of Poland 1:500 000) with the location of main stops. Note that the stops B8.1–3 and B8.5 are in the Silesian Nappe and stop B8.4 is in the Magura Nappe.

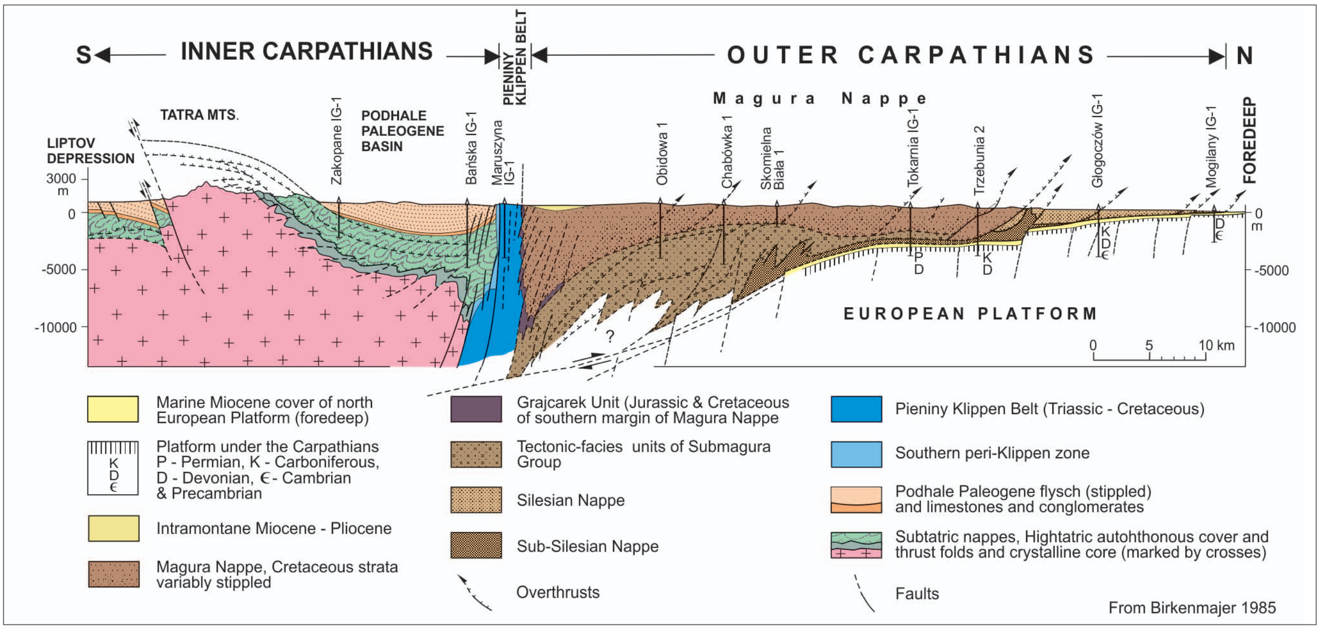

Fig. 3. Geological cross-section through the Polish Carpathians along the S–N traverse Zakopane– Kraków (based on Birkenmajer, 1985).

of the 19th century in connection with the increased demand for hydrocarbons. Detailed sedimentological studies were inspired by the birth of the concept of turbidity current (Kuenen and Migliorini, 1950), as this explanation for the origin of deep-water graded sandstone beds coincided with similar working notions of one of the region's leading investigators – Professor M. Książkiewicz at the Jagiellonian University (e.g., see Książkiewicz, 1948). This is how the so-called 'Kraków School of Flysch Sedimentology' came to life in the 1950s and reached the climax of its prolific activity in the 1960s to 1970s. Inspired by M. Książkiewicz, this informal group of researchers included his most talented disciples: S. Dżułyński, A. Radomski, L. Koszarski, K. Żytko, A. Ślączka, R. Unrug, F. Simpson, J. M. Anketell and many others. Their diligent studies provided new data on the varied sedimentary characteristics of turbidites with suggestions as to their possible origin, including most notably the world's first atlas of flysch lithofacies maps (Książkiewicz, 1962), a comprehensive genetic review and classification of bed solemarks (Dżułyński and Walton, 1965), a pioneering bathymetric interpretation of flysch successions (Książkiewicz, 1975), and a benchmark description of flysch trace fossils and their distribution in sediment successions (Książkiewicz, 1977).

One of the key early discoveries in the Polish Flysch Carpathians was the observation that some of the turbiditic successions consist of sandstone and fine-grained conglomeratic beds whose features cannot be readily explained by Kuenen's original concept of sediment gradual settling from turbulent suspension current. Such abnormal turbidites in the Carpathian flysch were demonstrated to Kuenen by Książkiewicz and Dżułyński during their historical field trip in 1957 and were swiftly mentioned as 'fluxoturbidites' in Kuenen's (1958) next paper, with the term presumably meant to denote fluxes of excessively dense flow within a fully turbulent suspension current. This new term was retained and more elaborately defined by Dżułyński *et al.* (1959). The first day of the present field excursion is focused on such deposits, exemplified by the early Eocene Ciężkowice Sandstone of the Silesian Nappe (Fig. 4), to honour this early pioneering recognition of flows termed later 'high-density' turbidity currents by Lowe (1982) and to compare these deposits with the more recent turbiditic models.

Two other issues are the topic for the second day of the excursion in the Carpathian flysch. One issue pertains to the Glauconitic Magura Beds (late Eocene–early Oligocene, Fig. 4) of the Magura Nappe, where turbidites composed of shelf-derived glauconite-bearing sand tend to be overlain by thick, non-bioturbated dark-grey mudshale capped with a thin, bioturbated greenish-grey mudshale. Can this be evidence of an *en-masse* emplacement of thick, dense co-turbiditic fluidal mud suspension (Baas *et al.*, 2009) or 'linked' mudflow (Haughton *et al.*, 2009), followed by a slow fallout of hemipelagic 'background' mud? The other controversial issue is the origin of the early Oligocene Magdalena Sandstone of the

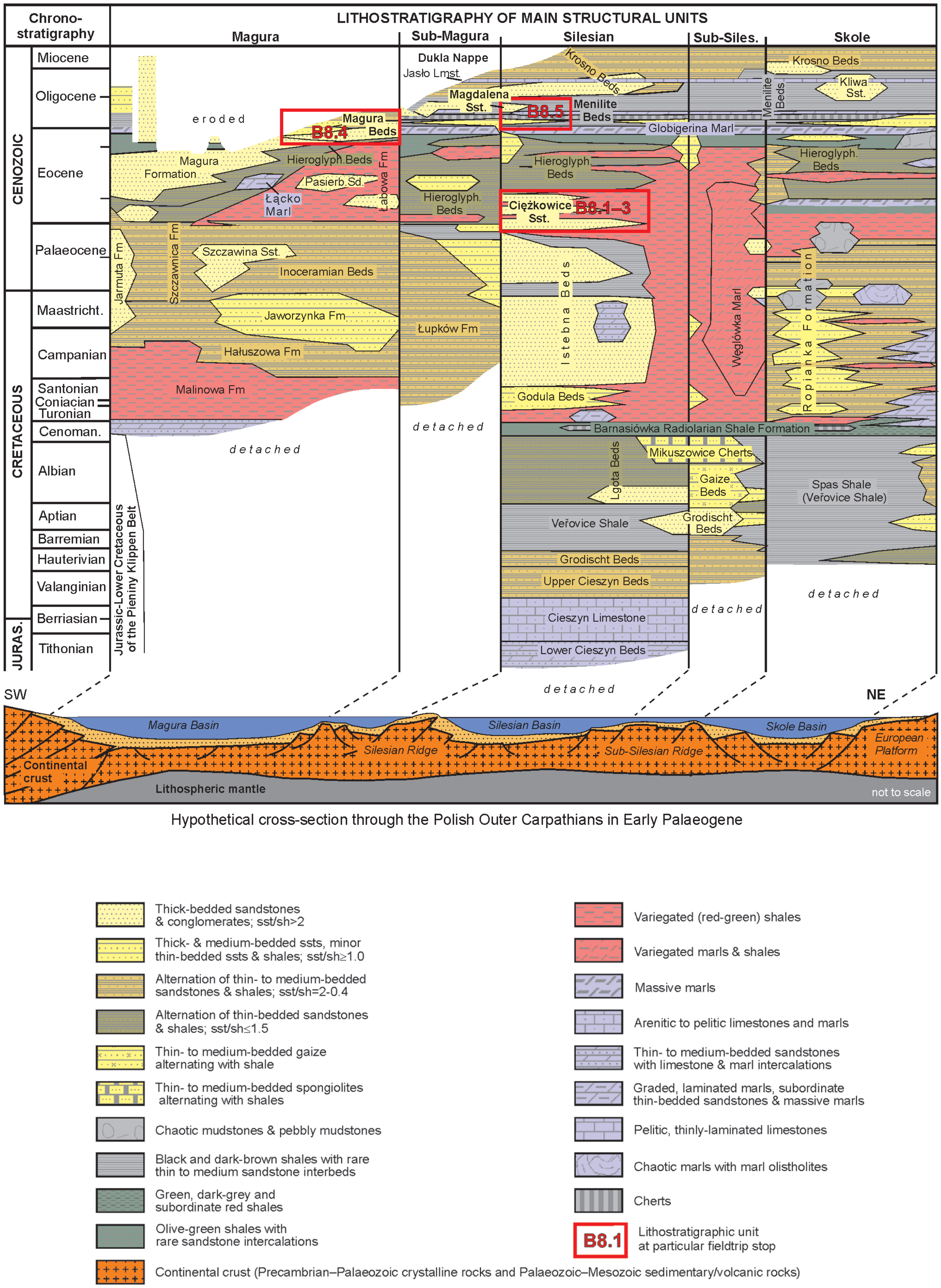

Fig. 4. Lithostratigraphic scheme for the Jurassic–Miocene rock successions of the Polish Outer Carpathians. Modified from Koszarski (1985) and Oszczypko (2004). Note the stratigraphic location of the Ciężkowice Sandstone (field-trip stops B8.1–3), Magura Beds (stop B8.4) and Magdalena Sandstone (stop B8.5).

Silesian Nappe (Fig. 4) near Gorlice: a coarsening-upwards succession (nearly 200 m thick) underlain and overlain by deep-marine flysch, showing heterolithic lenticular and wavy bedding, occasional hummock-like and wave-ripple-like structures and a mouth bar-type bedding architecture towards the top. Can this be an evidence of relatively shallow water and a prograding delta?

Field-trip topic 1: How do the classic 'fluxoturbidites' compare with the latest turbiditic models?

Stanisław Leszczyński, Wojciech Nemec

What are fluxoturbidites?

Until the mid-20th century, sedimentation in deep seas was considered to be almost exclusively pelagic and hemipelagic, with possible sediment mass-transport processes – such as mud slides, slumps and vaguely defined sediment flows – on submarine slopes. Meanwhile, oceanographic data had increasingly indicated deep-water sand dispersal over large areas, and similar evidence of laterally extensive graded sandstone beds came from the successions of ancient deep-marine deposits referred to broadly as flysch (Studer, 1827). This dual evidence, combined with laboratory experiments, had led Kuenen and Migliorini (1950) to the recognition of turbidity currents: sand-laden subaqueous density flows with their sediment load carried in, and gradationally settling from, a fully mixed turbulent suspension. However, the concurrent meticulous studies of the Polish Carpathian flysch had revealed several turbiditic successions – such as the lower Lgota Sandstone (Albian), Istebna Sandstone (Santonian– Palaeocene) and Ciężkowice Sandstone (early Eocene) (Fig. 4) – where deposits were not quite compatible with the original concept of sediment fallout from a fully turbulent density current. For historical reasons, it is worth citing here the original perception of such deposits and notion of their possible origin (Dżułyński *et al.*, 1959, p. 1114):

'A different type of sedimentation is encountered amidst normal turbidites in many places. In this type the grain size is large and the beds tend to be less muddy. The bedding is thick and rather irregular, and the shales between are silty to sandy and thin or even absent. Current sole markings are scarce, load casting is more common, and coarse current bedding of somewhat variable direction is encountered. Indications of slumping are found, and grading is absent, repetitive, irregular, or even inverted, and irregular lenses of coarser grain occur inside the beds. These sandstones may occur as large lenses between normal flysch or shales. In other cases the material or the direction of supply contrast with those of the normal surrounding flysch of the same age. Because characteristics of deposition from turbidity currents appear to be mixed with evidence for sliding, we prefer to call this kind of bed a 'fluxoturbidite'. 'We suggest that the cause for this abnormal type of flysch can be either a deepening of the basin and steepening of the slope, or a quickening of the supply, or a change in position of the supply, for instance the building of a new delta. But whatever the cause, the mode of transportation has changed. Instead of a well-mixed turbulent turbidity current carrying almost the entire load in suspension, one can imagine a turbidity current in which most of the sand and gravel moves in a watery slide along the base. The current is too poor in clay to raise this load in suspension, and the slope is too steep for the load to come to rest until it has spread out in a layer.'

The first detailed documentation of the sedimentary textures and structures of such deposits was given by Unrug (1963) from the Istebna Beds (Fig. 4). His descriptive summary said:

'Fluxoturbidite deposits are characterised by lenticular shapes of beds, coarseness of detrital material, great thickness of beds, low pelite content, prevalence of symmetrical, multiple and discontinuous grading over other types of bedding and occurrence of non-graded beds, traces of strong erosion, lack of sole markings, and poor development of pelitic sediments. Occurrence of armored shale balls arranged in regular layers parallel to the bedding planes within sandstone beds points out to the transition of sand flows into turbidity currents.'

The author referred to the depositional process of fluxoturbidites vaguely as a 'sand flow' and considered it to be a type of mass movement 'intermediate' between a slump and a turbidity current.

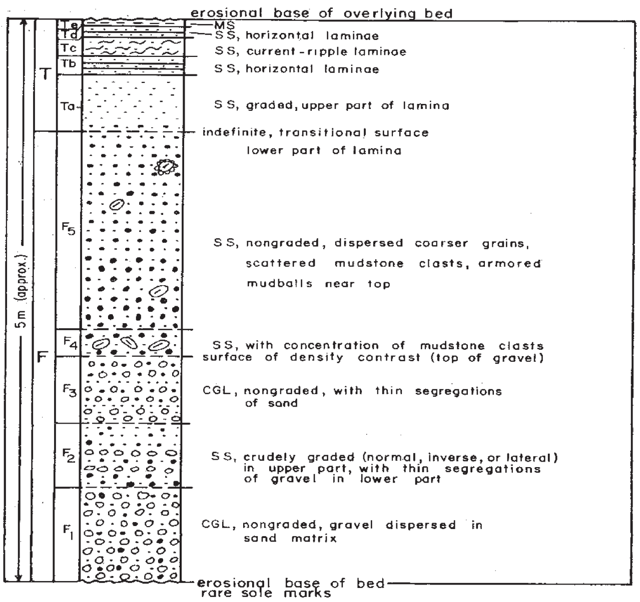

Fig. 5. Model of a complete fluxoturbidite according to Ślączka and Thompson (1981).

Another synthesis of fluxoturbidite characteristics came from Ślączka and Thompson (1981), based on field observations from selected outcrops of the lower Istebna Beds, the Ciężkowice Sandstone and the late Oligocene Krosno Beds (Fig. 4). Their model of a fluxoturbidite deposit (Fig. 5) shows a mainly massive bed of poorly sorted sand and invokes both the possible multitude of grain-support mechanisms in a sedimentgravity flow (Middleton and Hampton, 1973, 1976; Middleton and Southard, 1977) and the Bouma (1962) turbidite divisions as a capping. Fluxoturbidite was suggested to be 'a product of a composite sedimentgravity flow, with a gravity grain flow (or related type) in the lower part and a turbidity flow in the upper part.' Evidence of slumping was said to be unclear. Instead, a liquified flow (*sensu* Lowe, 1979) was implied as a possible initiation mechanism and main component process for the deposition of fluxoturbidites.

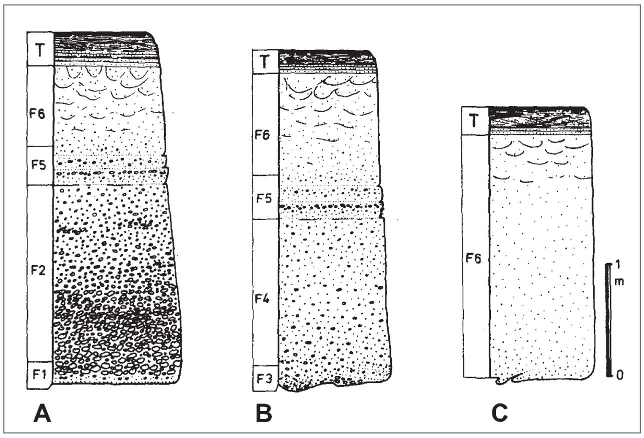

Fig. 6. Models of complete fluxoturbidites according to Leszczyński (1989), showing their (**A**) conglomeratic, (**B**) pebbly-sandstone and (**C**) sandstone bed varieties and their internal divisions.

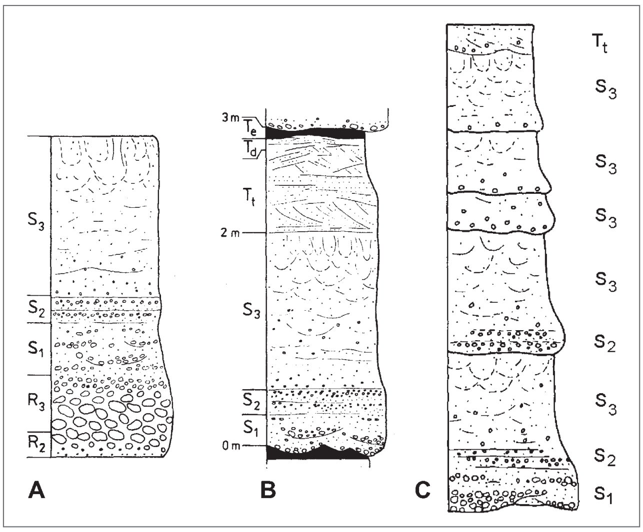

Fig. 7. Models of the deposits of high-density turbidity currents according to Lowe (1982), showing ideal beds of a gravelly (**A**) and a sandy high-density turbidity current (**B**) and a composite bed produced by a multi-surge high-density turbidity current (**C**).

A similar interpretation of fluxoturbidites was given by Leszczyński (1981, 1986, 1989) from a detailed study of the Ciężkowice Sandstone. The deposits showed thick and highly uneven, non-tabular bedding; common erosional amalgamation of beds, with only local separation by relic thin silty or sandy mudshale; poorly developed internal normal grading; massive (non-stratified) internal structure or horizontal to variously inclined parallel stratification, yet with surprisingly thick (2–5 cm) strata; and common diffuse lateral transitions from stratified to massive deposit within a single bed. The models of complete (nontruncated) fluxoturbidite beds (Fig. 6) were attributed to subaqueous high-density bipartite, or two-phase, flows similar to those defined as 'high-density turbidity currents' by Lowe (1982) (Fig. 7), but with a greater emphasis on the role of liquefied flow and cohesionless debris flow as depositional process components. The abundant composite beds were attributed to the amalgamation of successive flow deposits or deposition from multi-surge long-duration flows.

Allaby and Allaby (1999) in their dictionary defined fluxoturbidite vaguely as 'the product of gravity-induced flow in which little turbulent mixing of particles occurs [and which] is transitional between a slump and a turbidity flow.' Such a transitional flow would expectedly be a debris flow (see Middleton and Southard, 1977). Indeed, the deposits of the Istebna Beds originally regarded as fluxoturbidites (Dżułyński *et al.*, 1959; Unrug, 1963; Ślączka and Thompson, 1981) have more recently been interpreted by Strzeboński (2014) as the products of non-cohesive to cohesive sand-gravelly submarine debris flows.

Not surprisingly, the convoluted definition of fluxoturbidites and their somewhat ambiguously inferred mode of deposition have gained little general acceptance. Although many geologists in the Polish Carpathians and elsewhere found it to be a useful label for the flysch facies variety of non-classical turbidites (e.g., Stanley and Unrug, 1972; Schlager and Schlager, 1973) and the term was included in Carter's (1975) early classification of submarine sediment mass-transport processes, several other prominent authors had openly postulated that this term should be abandoned (e.g., Walker, 1967; Hsü, 1989; Shanmugam, 2006) – yet failing to recognize its significance as a genuine precursor of the Lowe (1982) concept

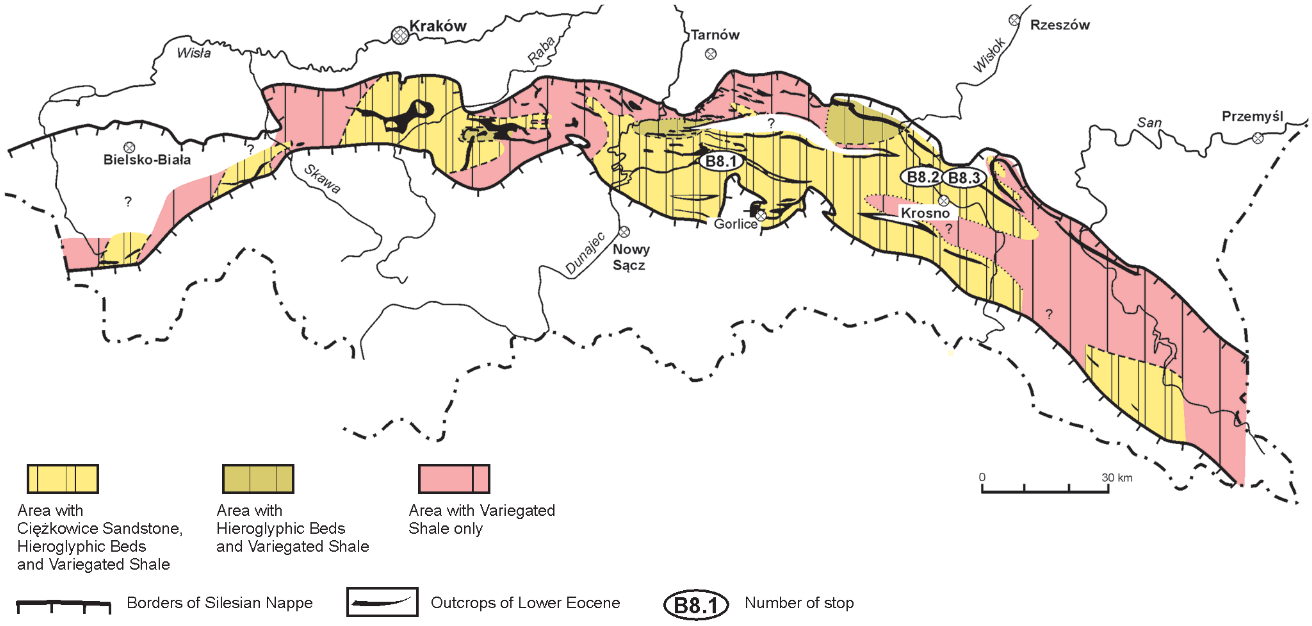

Fig. 8. Interpreted areal distribution of the Ciężkowice Sandstone, Variegated Shales and Hieroglyphic Beds in the latest Paleocene – early Eocene Eocene of the Silesian Basin (modified from Leszczyński, 1986); for lithostratigraphy, see Silesian Nappe in Fig. 4.

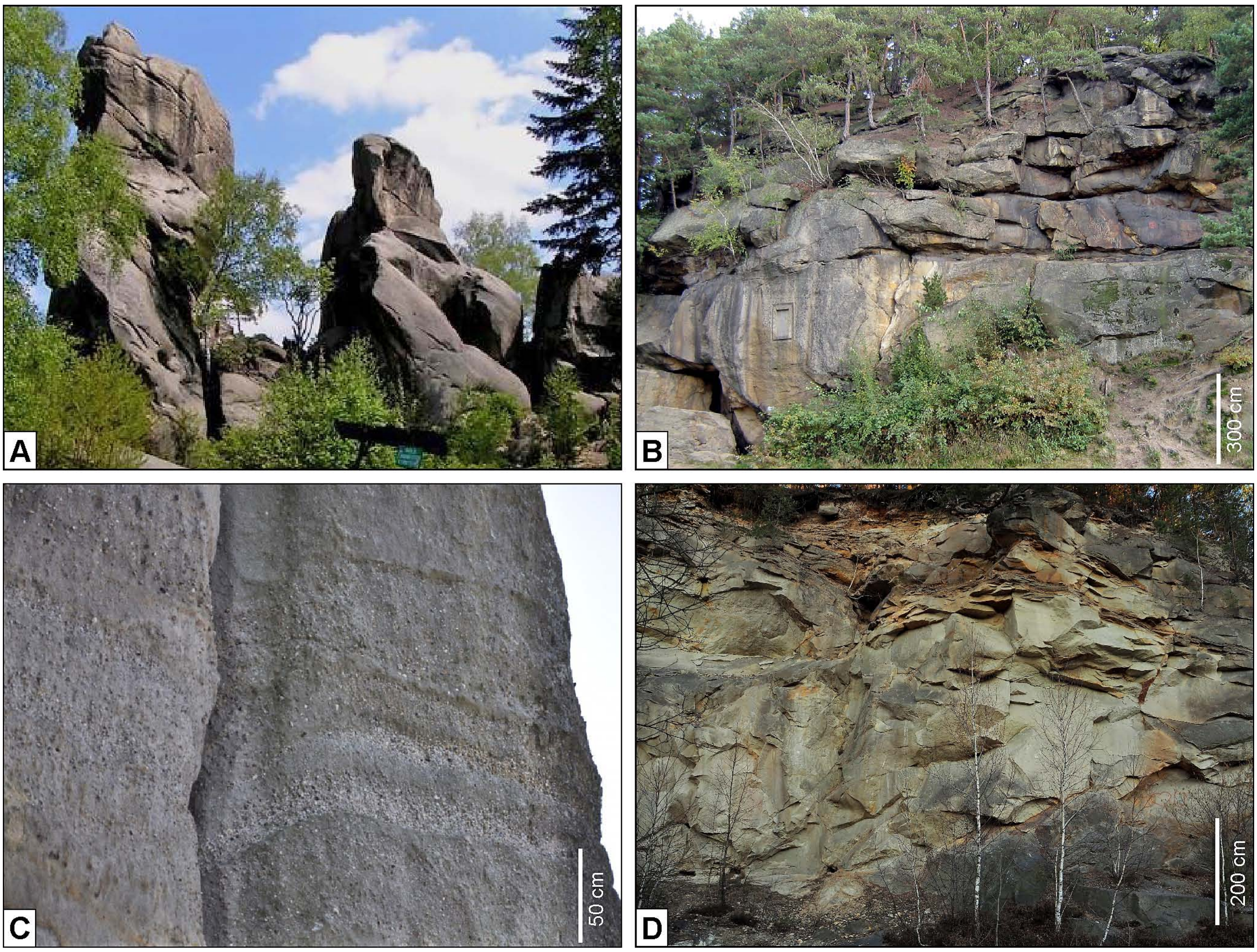

Fig. 9. General characteristics of the Ciężkowice Sandstone. (**A**) Rock tors showing amalgamated thick sandstone beds; nature reserve 'Prządki' (stop B8.3). (**B**) Amalgamated beds of sandstone and granule conglomerate, with the bedding more recognizable to the right; tor 'Grunwald' in the nature reserve 'Skamieniałe Miasto' (stop B8.1). (**C**) Massive and parallel stratified/banded pebbly sandstone and fine-pebble conglomerate, with the conglomerate layers often lenticular and showing inverse to normal grading; rock tor under the northern wall of the Kamieniec Castle (stop B8.2). (**D**) Freshly exposed section of a thick composite unit of amalgamated sandstone beds; quarry in Ostrusza village, SE of Ciężkowice.

of 'high-density turbidity currents'. Some geologists, not only in the Flysch Carpathians, are still using this term nowadays, although not always correctly realizing its original intended meaning (e.g., Huang *et al.*, 2012).

Fluxoturbidites of the Ciężkowice Sandstone

The Ciężkowice Sandstone (latest Palaeocene–early Eocene; Fig. 4) is a sand-dominated lithostratigraphic unit, up to 350 m thick, occurring mainly in the southern to middle part of the Silesian Nappe (Fig. 8). It is one of the nappe's main petroleum-producing units. The unit consists of thick-bedded (mainly 1–4 m), coarse-grained sandstones and granule/fine-pebble orthoconglomerates (Fig. 9) with rare thin interbeds of fine-grained sandstones and silty/sandy mudstones. Sandstones are quartzose to subfeldspathic arenites, subordinately low-grade wackes (Leszczyński, 1981). The coarse-grained beds have sharp, erosional and often loaded bases (Fig. 10), are lenticular in flow-transverse sections and occur as isolated or vertically stacked bodies (bed packages up to >50 m thick) within the succession of Variegated Shales (Fig. 4). Beds are mainly non-graded to normal-graded and massive to parallel stratified (Figs 9D, 11), although the strata are often 'stepped', diffuse and unusually thick (Fig. 11). The thickest beds also show inclined stratification mantling massive sand bodies (Fig. 12), trough-shaped scour-and-fill cross-stratification (Fig. 13A, B) and local internal slumps or rotational slides related to substrate re-scouring. Locally present are sets of tensile wing/horestail fractures (Fig. 13C, D), occasionally misinterpreted as

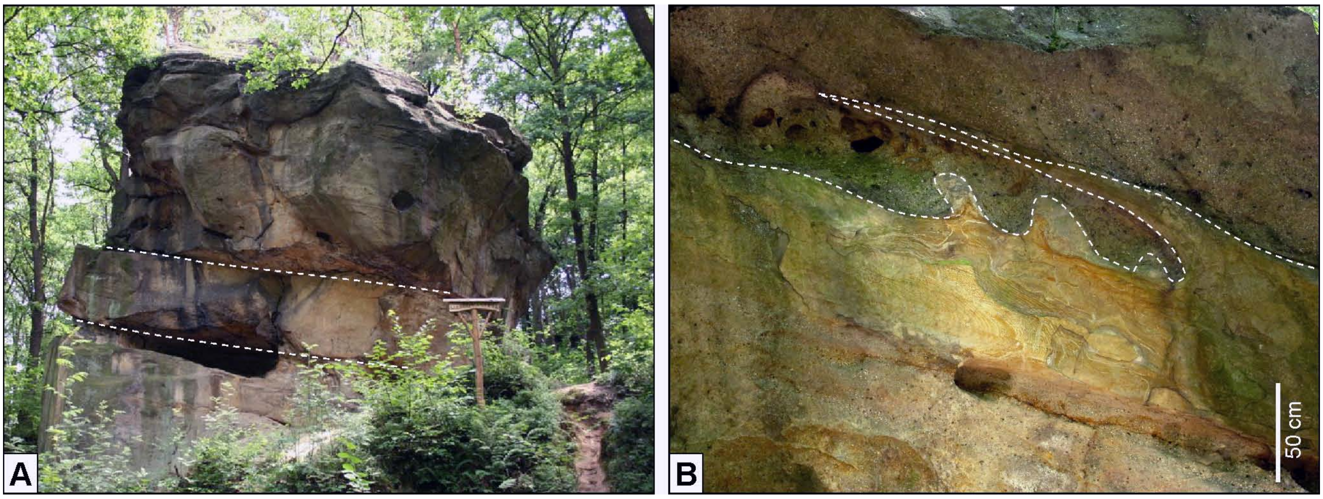

Fig. 10. Variable bed boundaries in the Ciężkowice Sandstone. (**A**) Beds separated by erosional flat surfaces (dashed lines); rock tor 'Warownia Górna' in the nature reserve 'Skamieniałe Miasto' (stop B8.1). (**B**) Highly uneven, loaded erosional contact of fluxoturbidite beds with a large load-flame of sand; detail from rock tor 'Warownia Dolna' in the nature reserve 'Skamieniałe Miasto' (stop B8.1).

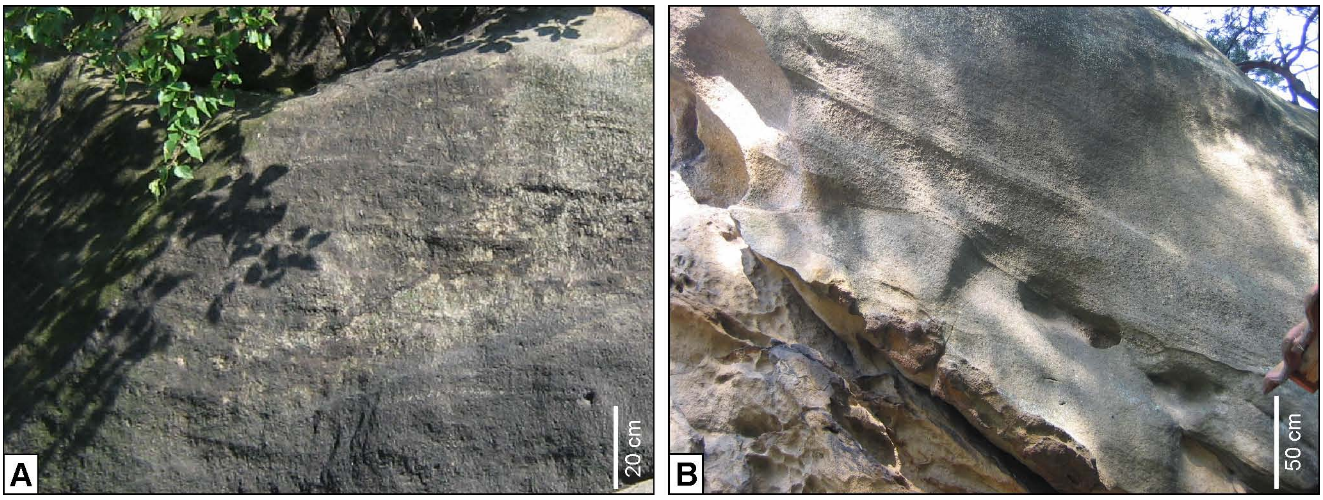

Fig. 11. Variable development of parallel stratification in sandstone beds. (**A**) Diffuse banding and spaced parallel stratification (seen as rock surface ribs), slightly undulating; detail from a rock tor in the nature reserve 'Prządki' (stop B8.3). (**B**) Amalgamated normal-graded sandstone beds, each showing thick banding with spaced parallel stratification and a massive upper part; detail from rock tor at point 3, stop B8.2.

cross-stratification (e.g., Ślączka and Thompson, 1981; Dziadzio *et al*., 2006). Some beds show isolated scour-fill gravel pockets (Fig. 14). Characteristic are short-distance lateral transitions from parallel stratified or shear-band-

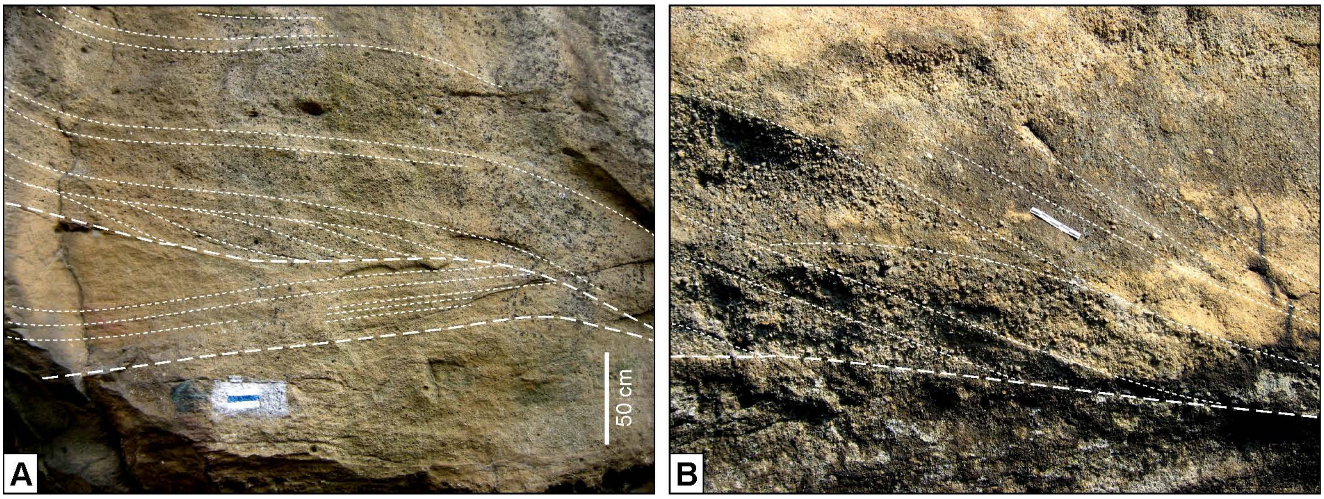

Fig. 12. Cross-stratification in sandstone beds. (**A**) Scour-fill cross-stratification with weak grain-size segregation (see above the upper thick dashed line); detail from rock tor 'Grunwald' in the nature reserve 'Skamieniałe Miasto' (stop B8.1). (**B**) Granule sandstone with planar cross-stratification (above the thick dashed line) scoured to the right and overlain by a massive wedge of granule sandstone mantled with crossstratification; rock tor detail from the nature reserve 'Prządki' (stop 8.3).

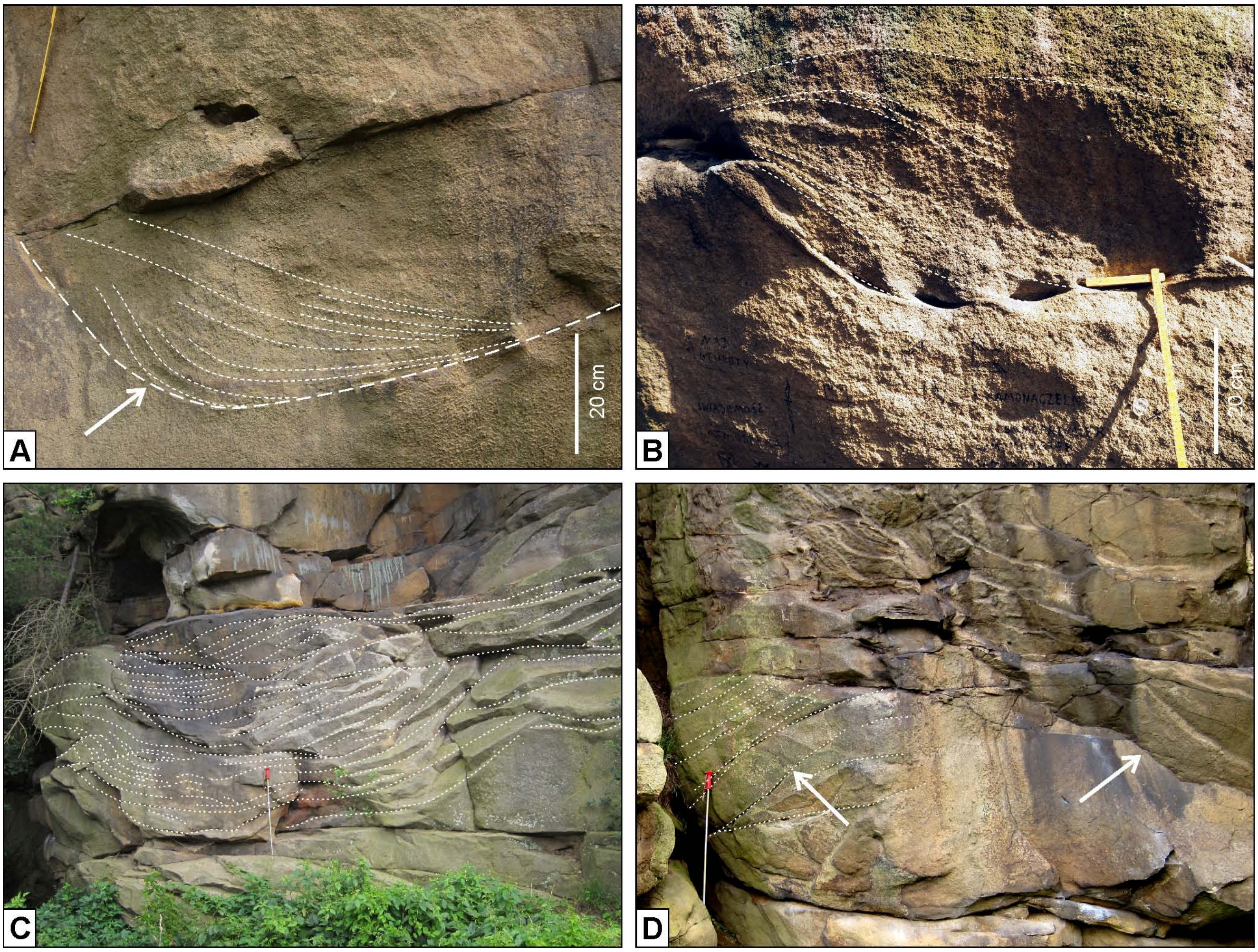

Fig. 13. Pseudo-stratification in sandstone beds. (**A**) Steep shear-banding resembling scour-fill crossstratification; detail from rock tor 'Ratusz' in the nature reserve 'Skamieniałe Miasto' (stop B8.1). (**B**) A similar shear-banding in rock tor "Orzeł" in the same reserve (stop B8.1). (**C**) Sets of wing or horsetail tensile fractures resembling trough cross-stratification; the walking stick (scale) is 1.1 m; from rock tor 'Ratusz' in the same reserve (stop B8.1). (**D**) Similar steep tensile fracturing resembling crossstratification (arrows); the walking stick (scale) is 1.1 m; from rock tor 'Czarownica' in the same reserve (stop B8.1).

ed to massive deposit (Fig. 15). Five main fluxoturbidite facies can be distinguished (Appendix Table 1, Fig. 16). They alternate with one another in amalgamated bed packages, and one facies commonly passes laterally into another within a single bed.

Benthic foraminifers in the 'background' Variegated Shales represent the Recurvoides assemblage of Haig (1979), indicating a bathyal water depth (Olszewska & Malata, 2006). The overlying thin-bedded flysch of the Hieroglyphic Beds, also locally intercalated with the Variegated Shales (Fig. 4), may possibly be almost abyssal (Waśkowska and Cieszkowski, 2014).

The depositional setting of the Ciężkowice Sandstone was interpreted as a submarine fan system with channels and small depositional lobes (Leszczyński, 1981), and was considered to be a basin-floor fan related to a second-order eustatic lowstand (Dziadzio *et al.*, 2006). The stratigraphic alternation of sandstone- and shale-dominated deposits was attributed to third-order eustatic cycles (Dziadzio *et al.*, 2006). Spatial sand distribution (Fig. 8) indicates main sediment supply from both the south and north, with palaeocurrent directions towards the SE and E and locally to the NE. According to Enfield *et al.* (2001a, b) and Watkinson *et al.* (2001), the bodies of Ciężkowice Sandstone show spatial thickness changes and unconformities suggestive of deposition in half-grabens. A similar interpretation of seismic images was given by Dziadzio *et al.* (2006), suggesting deposition in a series of fault-bounded basin-floor depressions. The sand-prone turbiditic system would thus appear to have extended eastwards along an array of basin-floor troughs, perhaps active blind-thrust synclines evolving into fault-bounded half-grabens, with possible sediment supply from the inter-trough ridges. The lack of lateral-accretion bedding indicates non-meandering, cut-andfill channels of low to negligible sinuosity, apparently non-levéed, which might support the notion of flow confinement by intra-basinal topographic troughs.

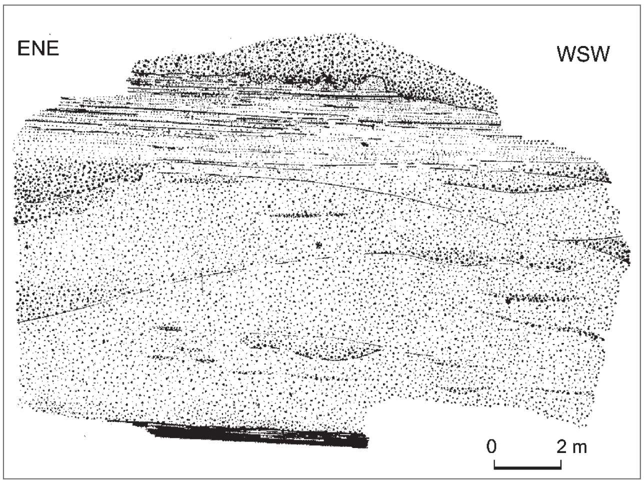

Fig. 14. Graded sandstone with scour-fill gravel pockets, passing upwards into planar parallel- stratified sandstone overlain by a graded pebble conglomerate with load-casted base. Outcrop detail from the old quarry in Kąśna Dolna, 3 km west of Ciężkowice.

Comparison with the latest turbiditic models

As shown by their outcrop review, the Polish Carpathian 'fluxoturbidites' are by no means just a regional curiosity. Such non-classical turbidites are found in flysch

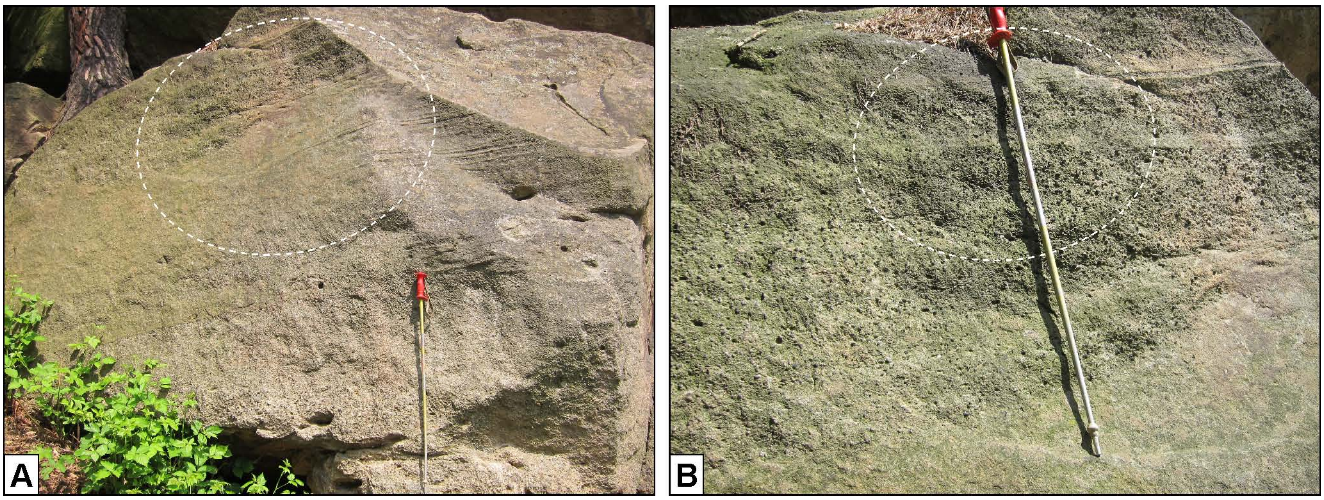

Fig. 15. Short-distance lateral changes in bed structure. (**A**) Granule sandstone bed with planar parallel stratification and traction-carpet banding passing diffusely into massive deposit to the left (encircled). (**B**) Stepped sandy parallel stratification vanishing to the left in a banded granule conglomerate. The walking stick (scale) is 1.1 m. Both details are from detached blocks in the nature reserve 'Skamieniałe Miasto' (stop B8.1).

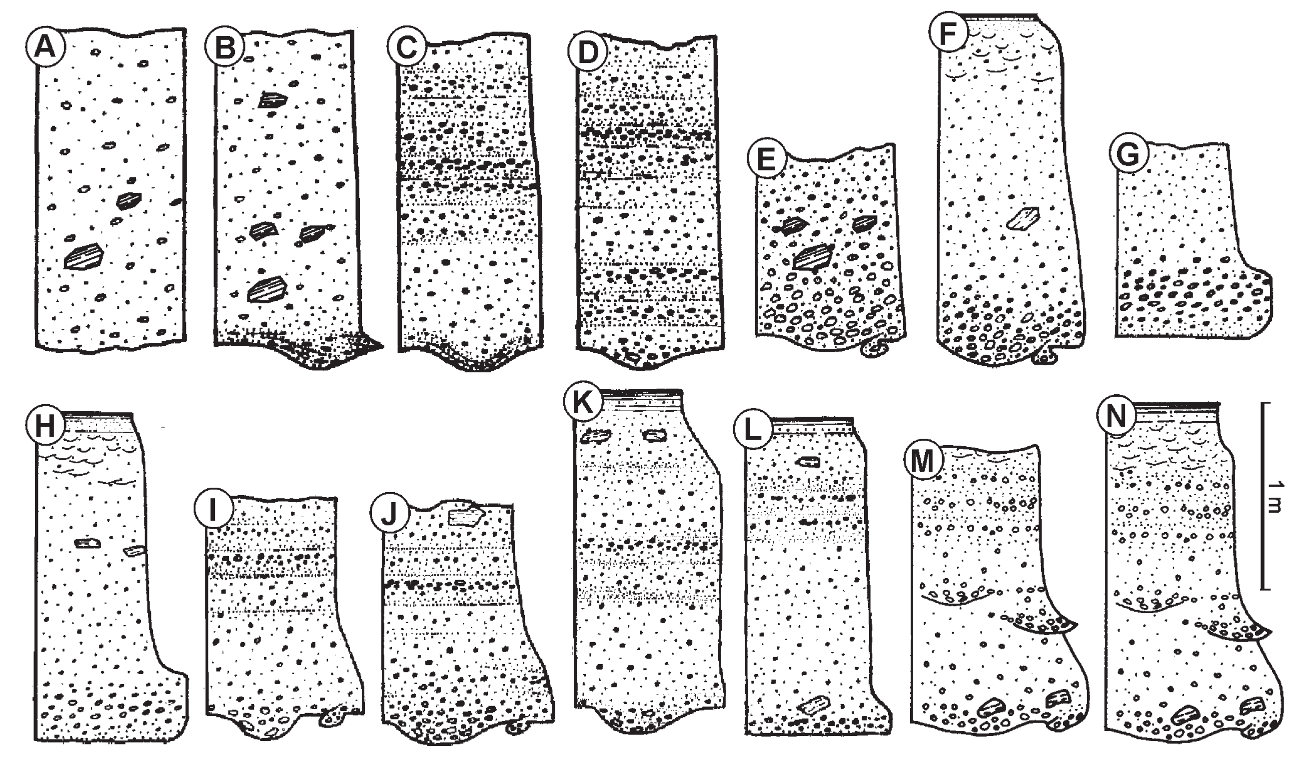

Fig. 16. Summary of the fluxoturbidite facies of Ciężkowice Sandstone (for description, see review in Appendix Table 1). (**A**, **B**) Facies mS: massive, non-graded sandstones with scattered granules/pebbles and local trough-shaped basal scour-fill stratification. (**C**, **D**) Facies tlsS: massive to banded or fully banded beds with local basal scour-and-fill features. (**E**–**H**) Facies gS: graded non-stratified sandstone or conglomerate–sandstone beds. (**I**–**L**) Facies gsS: graded-stratified/banded sandstone and conglomerate-sandstone beds. (**M**, **N**) Facies Scl: graded sandstone beds with lenticular gravel pockets and banded upper part.

basins worldwide. Similar deposits were included in the early turbiditic facies models (see facies A and B of Mutti and Ricchi Lucchi, 1972, 1975; also Walker and Mutti, 1973) and were depicted as channelized-flow facies in the well-known submarine fan model of Walker (1975). The early notion of a high-concentration bipartite (two-phase) turbidity current, highlighted by Dżułyński and Sanders (1962) and Sanders (1965), found its elaborate reflection in Lowe's (1982) benchmark concept of high-density turbidity currents (HDTCs). The depositional mechanisms postulated by Lowe (1982) included: a rapid dumping of graded massive sediment directly from turbulent suspension; in situ or mobile sediment liquefaction; formation of inverse-graded traction carpets, possibly multiple; infilling of syndepositional trough-shaped scours; and a plane- to rippled-bed tractional sediment transport. As pointed out by Leszczyński (1986, 1989), most of the distinctive features of fluxoturbidites could readily be explained by a combination of these various modes of sediment deposition from unsteady or relatively steady HDTCs. The few features not shown in Lowe's (1982) model included bed-scale or localized sediment banding (planar or inclined thick pseudo-stratification, with the sediment layers lacking inverse grading), scour-related local syndepositional sliding, pronounced vertical grain-size fluctuations and the short-distance rapid lateral changes in bed internal characteristics.

However, it is worth noting that Lowe's (1982) depositional model for HDTCs was not faultless. Firstly, he unnecessarily restricted the term 'traction carpet' – originally meant for a laminar-shear dense basal layer of sediment dragged along by turbidity current (Dżułyński and Sanders, 1962) – to denote solely a shearing sediment layer of fallen grains characterized by inverse grading and deposited by frictional freezing when reaching a maximum mobile thickness (see Hiscott, 1994). Secondly, he apparently failed to realize that a certain travel time/distance is required for the inverse grading to develop and that a quickly freezing carpet may thus show little or no such grading, and also that a repetitive pattern of such banded deposition may virtually dominate in a long-duration relatively steady flow. When he later encountered thick banded turbidites composed almost entirely of traction carpets that lacked inverse grading and were attributed to a repetitive combined frictional-cohesive freezing (Lowe and Guy, 2000; Lowe *et al.*, 2003), instead of correcting his initial error – he chose rather to refer to such turbidity currents misleadingly as 'slurry flows'. [The same term was used earlier in Carter's (1975) mass-flow classification to denote cohesive debris flows.]

Various other conceptual models for turbidite deposition have meanwhile proliferated, inspired by the growing evidence from outcrops, well-cores and laboratory experiments. How do the fluxoturbidites relate to these more recent concepts in their historical development? (The following review refers to plates given as appendix illustrations in the digital version of this excursion guide.)

- Postma *et al.* (1988) reported on laboratory experiments where a well-stirred turbulent sediment-water mixture, released from a gate onto a steep (25°) subaqueous slope, had rapidly separated itself into a coarse-grained (pebbly sand) lower non-turbulent phase and a finer-grained (sand), faster-flowing upper turbulent phase (see Plate 1A). The lower phase was flowing chiefly due to its own inertia, while being modestly sheared at the top by the overpassing turbulent flow. The lower inertia flow was subject to laminar shear and came to rest by downward frictional freezing, as a common debris flow. Such a bipartition and combined behaviour of an initially turbulent sediment-gravity flow might explain the thick, non-graded massive lower part of some of the fluxoturbidites (Fig. 16).

- Vrolijk and Southard (1997) reported on laboratory experiments with fast-flowing sandy subaqueous flows, where the sediment dumped from turbulent suspension kept moving as a 'mobile bed' sheared by the overpassing turbulent flow. The mobile bed was freezing upwards as the shear zone was similarly migrating and thinning. The laboratory flows were too thin for recognition of possible shear banding in the deposits, which ranged from non-graded to weakly normal, inverse or inverse-to-normal graded (Plate 1B). Some of the diffusely banded or massive-to-banded and non-graded to weakly graded fluxoturbidites (Fig. 16) might be attributed to this style of deposition.

- Some authors (Mulder and Alexander, 2001; Sohn *et al.*, 2002) suggested a transitional phase of 'hyperconcentrated flow' in the transformation process of a non-turbulent to fully turbulent subaqueous sediment-gravity flow (Plate 2). The fluxoturbidites with their features would fall into this transitional flow category. However, the use of the term hyperconcentrated flow was quite odd, as this term was originally introduced in the literature to denote subaerial flows with 'a behaviour intermediate between that of a common streamflow and that of a mudflow' (Beverage and Culbertson, 1968; see also review and discussion by Nemec, 2009). Notably, neither a fluvial streamflow nor a mudflow is involved in the subaqueous flow transformations envisaged by Mulder and Alexander (2001) and Sohn *et al.* (2002).

- The early concept of a bipartite two-phase flow derived from the Carpathian fluxoturbidites (Sanders, 1965) and the Lowe (1982) concept of HDTCs were both closely followed in the model of a non-turbulent to fully turbulent flow transformation suggested by Mutti (1992) and Mutti *et al.* (2003), where fluxoturbidites would correspond to the turbidite facies F3–F5 and F7– F9 (Plate 3A). It was concurrently argued by Shanmugam (1997, 2000, 2002, 2012) that such high-density flows, with a mainly non-tractional mode of deposition, should rather be regarded as sandy debris flows. (As a paraphrase, it was like saying that a snow scooter is not a scooter because it has sleds instead of wheels. However, it is the sleds that define a snow scooter, just like the non-tractional mode of sediment deposition from turbidity current defines Lowe's HDTC.)

- An opposite way of subaqueous sediment gravity-flow transformation – from a fully turbulent to bipartite laminar-turbulent flow (see earlier Postma *et al.*, 1988) – was suggested by Kane and Pontén (2012), where the fluxoturbidites would again correspond to the 'transitional flow' category (Plate 3B). The notion of a turbidity current with a downflow-increasing sediment concentration came from Haughton *et al.* (2009); see below.

- Haughton *et al.* (2009) distinguished between turbidity currents with a downflow-decreasing and a downflow-increasing sediment concentration (Plate 4A, upper diagram), although this hypothetical notion apparently pertained chiefly to the behaviour of the turbiditic suspension mud cloud – whether diluting and dying out with time/distance or densifying and turning into a 'linked' mudflow. The sandy deposits of the transitional 'hybrid flows' (Plate 4B) seem to share many features with the fluxoturbidites (Fig. 16). Much less clear is Haughton's own classification of subaqueous sediment-gravity flows (Plate 4A, lower diagram), with the category of 'high-density turbidity current' separated from the Lowe and Guy (2000) 'slurry flow' and the enigmatic 'co-genetic flow'. Several questions arise. First, aren't the two latter kinds of flow just specific varieties of HDTC (*sensu* Lowe, 1982)? Second, if a co-genetic flow = hybrid flow = linked mudflow, as the classification implies, then why are so many different terms needed for one and the same thing? And third, how about the co-genetic basal debris flows: a possible relic of parental debris flow that generated the turbidity current (Hampton, 1972), a debris flow spawned by the turbulent current at the outset (Postma *et al.*, 1988) or spawned by the current underway due to its deceleration or turbulence-suppressing bulking of substrate sediment (Kane and Pontén, 2012)?

- In the most recent classification of subaqueous sediment-gravity flows proposed by Talling *et al.* (2012), the fluxoturbidites with their features would be categorized as the deposits of HDTCs (sensu Lowe, 1982), possibly with a 'melted' core of the parental non-cohesive debris flow or liquefied flow (Plate 5A). The authors pointed to a range of modes of sediment deposition that may result in thick banded or massive beds, with or without grain-size grading (Plate 5B). Depending on the relative rates of bottom shear and grain fallout, the banding may range from common tractional plane-bed parallel stratification or 'stepped' stratification to rhythmically freezing graded or non-graded traction carpets and to mobile-bed diffuse shear layers. Although some of the detailed notions in the models (Plate 5) may be disputable, they jointly give a stimulating ground for conceptual considerations.

In summary, the deposits originally labelled as 'fluxoturbidites' represent laterally non-uniform and highly unsteady to fairly steady, cohesionless high-density and mainly long-duration flows (sustained flows *sensu* Kneller and Branney, 1995). Deposits with a similar range of transient modes of sedimentation now feature prominently in all the more recent turbiditic models. The recognition of fluxoturbidites as a distinct facies in the Polish Carpathian flysch was based also on their regional uniqueness in terms of the high mineralogical and textural maturity and their grain-size coarseness. However, it was probably these very sediment characteristics that also determined the relatively 'unusual' mode of sediment transport and deposition. Today, we know that similar coarse-sandy arenitic to gravelly deposits abound in ancient non-meandering turbiditic channel belts worldwide (e.g., Walker, 1975, 1978; Winn and Dott, 1977; Stanley, 1980; Lowe, 1982; Gosh and Lowe, 1993; Hickson and Lowe, 2002; Janbu *et al.*, 2007). In short, there is nothing specifically 'Carpathian' to the classic fluxoturbidites, except for the region of their early first recognition. As a conclusion, it is suggested that the term 'fluxoturbidites' (Dżułyński *et al.*, 1959) – although discarded by the global sedimentological community at the outset and now nearly forgotten – deserves full recognition as an early precursor of the concept of HDTCs (Lowe, 1982). There is also no reason why this term should not be used as a short and informative general facies label in regional studies, as it continues to be used in the Polish Carpathian flysch.

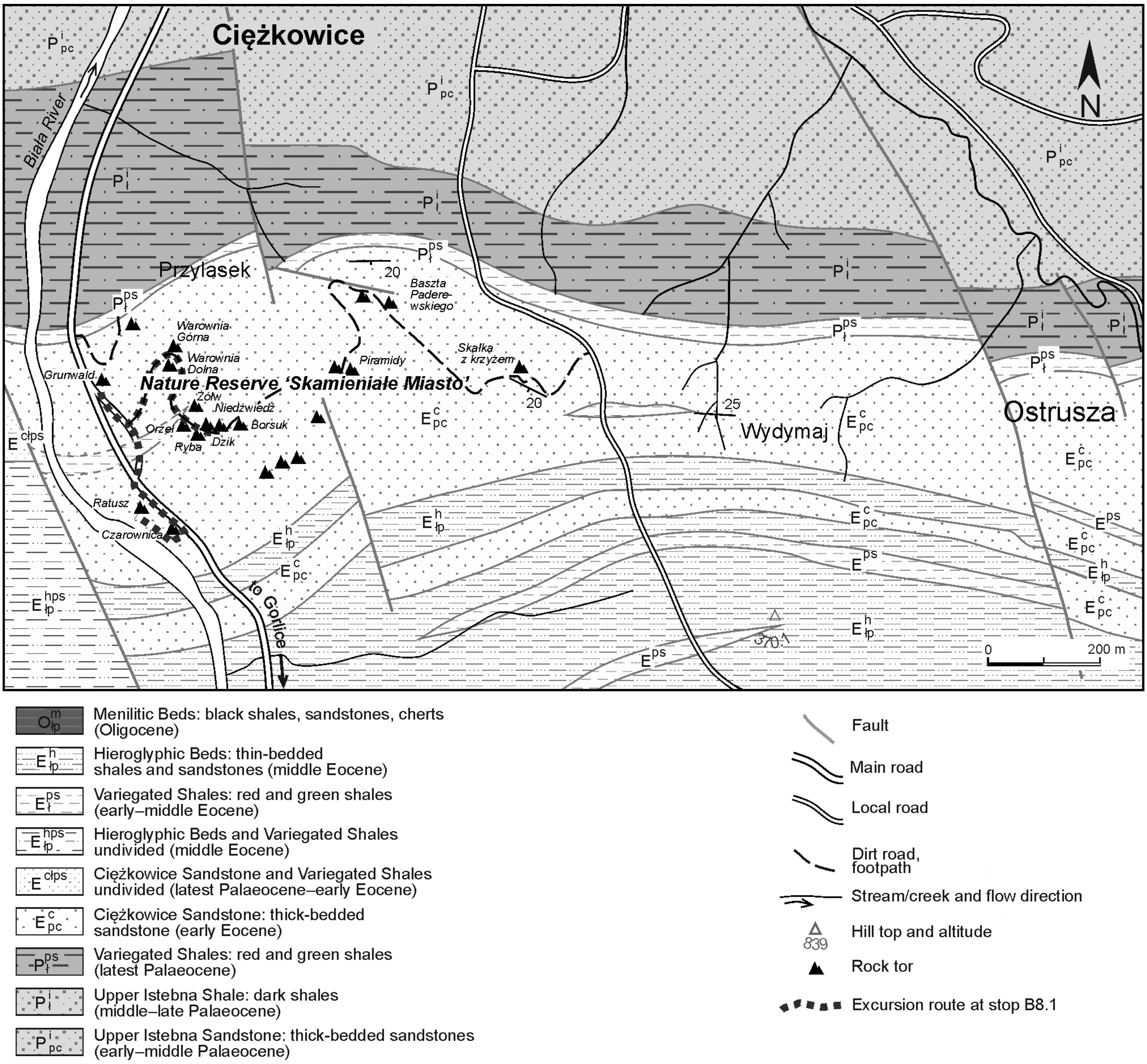

Fig. 17. Geological map of the vicinity of nature reserve 'Skamieniałe Miasto' (modified from Cieszkowski *et al.*, 1991), showing the location of rock tors to be visited at the excursion stop B8.1 (see text).

Stop descriptions for topic 1

Leaders: Stanisław Leszczyński, Wojciech Nemec

The outcrops at stops B8.1–3 are easily accessible by short (5–10 minutes) uphill walks along touristic footpaths. The aim of the field excursion on its first day is to demonstrate and discuss the sedimentary characteristics of classical fluxoturbidites, exemplified by the deposits of the Ciężkowice Sandstone, and to compare these deposits with the more recent turbiditic models published in the sedimentological literature.

B8.1 The nature reserve 'Skamieniałe Miasto'

The nature reserve 'Skamieniałe Miasto (Petrified Town)' is located at the southern outskirts of Ciężkowice (Figs 1, 17). The entrance is free of charge and the reserve has a convenient parking lot with a modest gastronomic facility and with the regulations for visitors displayed. This area in the east-central part of the Silesian Nappe (Figs 2, 8) is considered to be the type locality for the early Eocene Ciężkowice Sandstone (Fig. 4), exposed here as numerous picturesque rock tors scattered in a pine forest. (49°46′36″ N, 20°57′50″ E)

Point 1.1 – The 'Grunwald' tor on the eastern side of the main road, to the left of the main entrance to the reserve (Fig. 17). The outcrop shows thick, amalgamated beds of graded and graded-stratified fine-grained conglomerate to sandstone facies (Fig. 9B). Massive divisions are graded or non-graded. Stratification is mainly planar parallel, thick to thin and marked by grain size segregation, with the fine-grained laminae forming thin ribs on weathered outcrop surfaces (Fig. 12A). Thin parallel stratification (tractional Bouma bdivision) occurs at the top of some beds. Abundant plant detritus occurs on many strata surfaces. The beds are separated by high-relief scour surfaces. Both planar and cross-stratification with inverse grading are visible in the lower part of the outcrop and in the fallen blocks at its foot. Short-distance lateral change from stratified to massive sandstone and granule conglomerate can be seen in a block on the left side of the tor wall (Fig. 15). Holes after armoured mudballs occur in the basal part of the second bed above the tor foot.

Point 1.2 – Tor 'Warownia Dolna (Lower Watchtower)', ca. 100 m to the north-east of the main entrance to

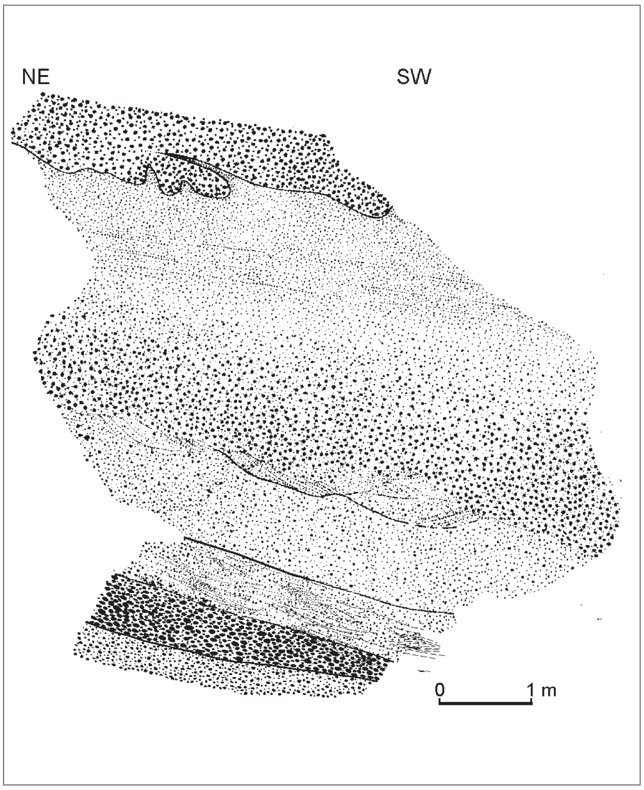

Fig. 18. Outcrop detail from the rock tor 'Warownia Dolna' (stop B8.1, Fig. 17). Note the diffuse parallel banding (traction-carpet layering?), the two levels of trough-shaped multiple scour-fill cross-stratification and the loaded conglomerate base near the top.

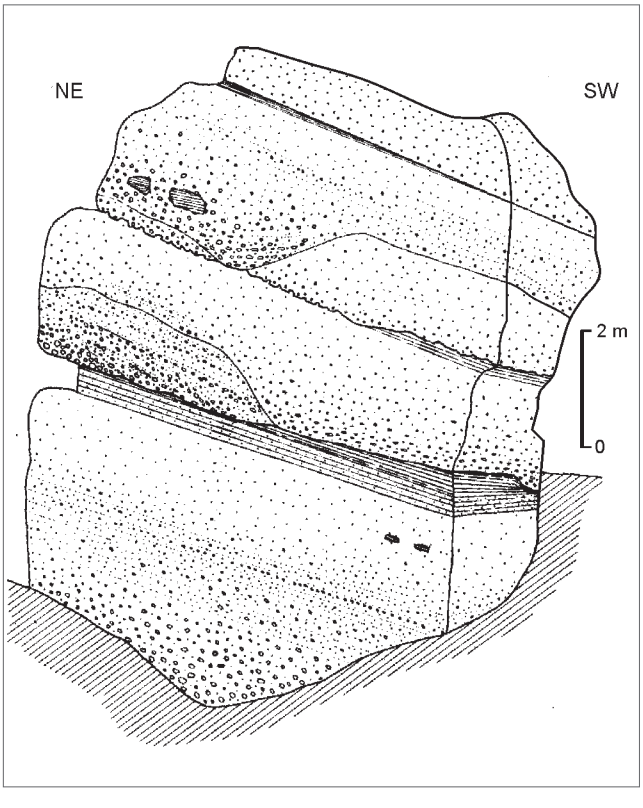

Fig. 19. Amalgamated fluxoturbidites in the north-western wall of 'Warownia Górna' tor (stop B8.1, Fig. 17). Note the evidence of substrate re-scouring by consecutive flows or same-flow surges and the graded-stratified beds with both diffusely banded and well-stratified (Bouma b) divisions.

the reserve (Fig. 17). The outcrop shows thick amalgamated beds of graded and graded-stratified fine-grained conglomerate to sandstone facies (Fig. 18), with common massive, graded or non-graded divisions. Stratification is marked by grain-size segregation and planar parallel, but includes trough cross-strata sets that may represent small 3D dunes or be scour-and-fill features (see in the middle part of the exposed succession on the tor NW and SE walls). The cross-stratification seems to be related to the reworking of substrate sediment by pulse of highly unsteady current. Bed soles are erosional and show load casts, with a large load-flame of fine-grained sand in the tor's upper part (Figs 10B, 18). Visible are also armoured mudballs and holes after their removal by weathering.

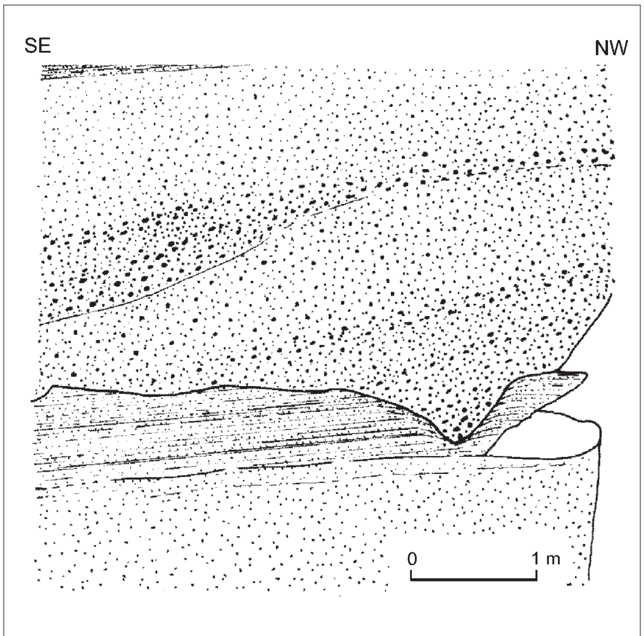

Fig. 20. Graded-stratified sandstone bed overlain erosionally by a granule/pebbly sandstone bed with fluctuating grain size and diffuse banding imitating cross-stratification; detail from the rock tor 'Warownia Górna' (stop B8.1, Fig. 17).

Point 1.3 – Tor 'Warownia Górna (Upper Watchtower)', ca. 20 m to the south-east of point 1.2 (Fig. 17). The outcrop shows amalgamated thick beds of graded and graded-stratified fine-grained conglomerate to sandstone facies (Figs 10A, 19, 20). Bed soles are erosional and show load casts. Graded or non-graded massive divisions irregularly alternate with stratified ones. Planar parallel stratification is marked by segregation of sand and granules, grain composition changes and clast alignment (tractional Bouma b division). However, there is also evidence of shear-banding in the tor's SE wall, indicating an early postdepositional remoulding of sediment by laminar shear. Cross-stratification seems to represent scour-and-fill features, with local syndepositional small-scale rotational sliding. The irregularity of bed divisions indicates highly unsteady currents. Visible are also armoured mudballs and holes after their removal by weathering.

Point 1.4 – Tor 'Orzeł (Eagle)' and the adjacent unnamed tor to the south-east, ca. 100 m to the south of point 1.3 (Fig. 17). Both outcrops show the same beds of graded and graded-stratified sandstone facies. Graded or non-graded massive divisions alternate irregularly with stratified ones. Some of the planar parallel stratification may be laminar shear-banding. Cross-stratification, locally diffuse and unusually steep (Figs 13B, 21), seems to represent scour-and-fill features (slightly deformed by loading) related to the erosive pulses of a highly unsteady current and synsedimentary shearing.

Point 1.5 – Tor 'Czarownica (Witch)' on the western side of the main road, ca. 200 m to the south of the

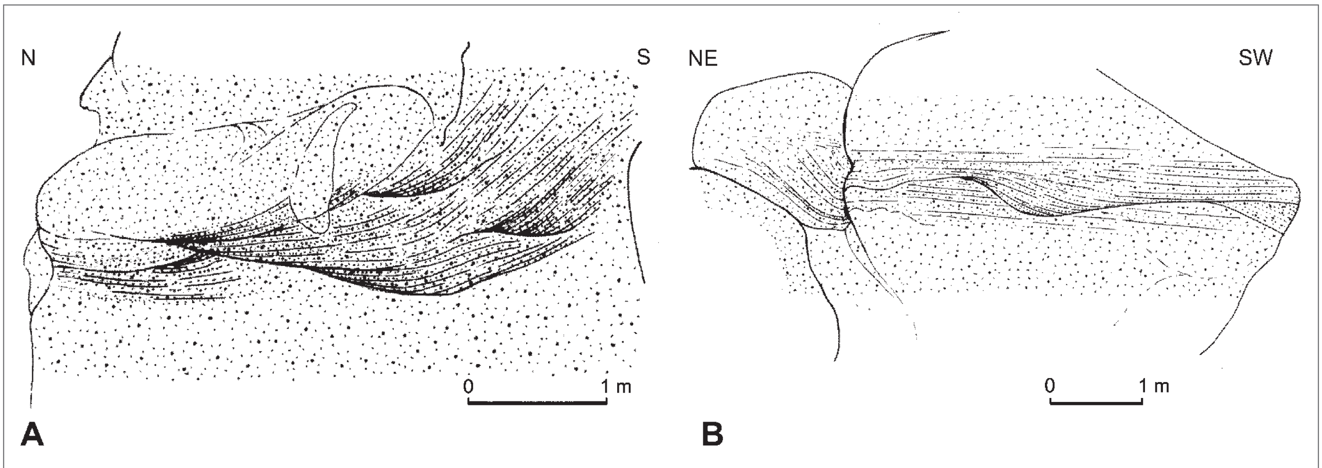

Fig. 21. Diffuse to distinct, multiple scour-and-fill features within thick fluxoturbidites, indicating consecutive flow surges. Both outcrop details (**A**, **B**) are from the 'Orzeł' rock tor (stop B8.1).

main entrance to the reserve (Fig. 17). The outcrop shows another portion of a succession of amalgamated thick beds of graded-stratified and massive coarse-grained sandstones (Figs 13D, 22A). Notable here is the rock frac-

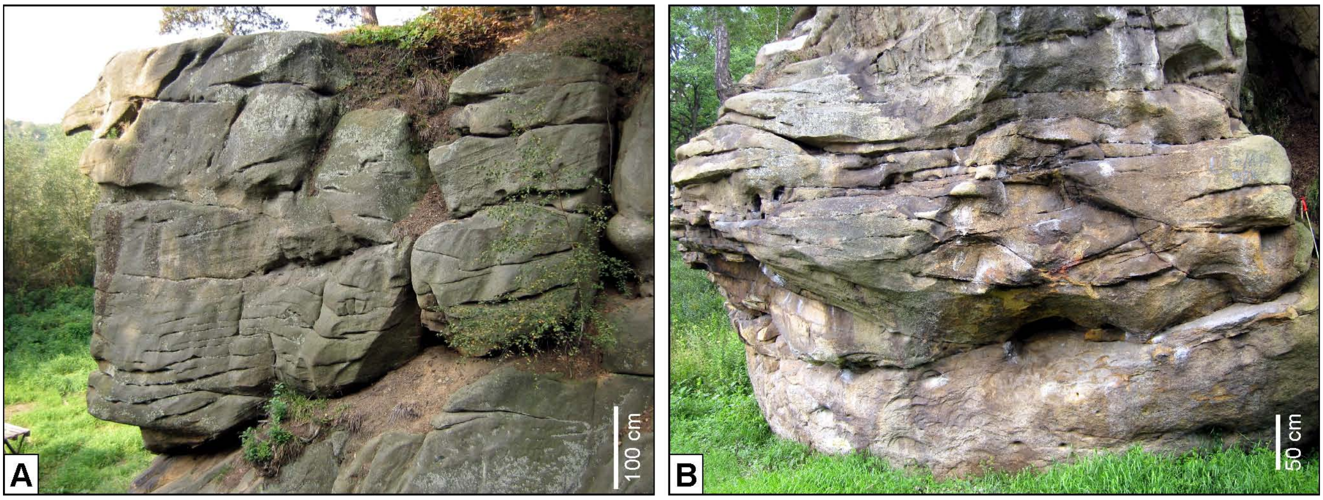

Fig. 22. Sandstone tensile fracturing due to an early post-depositional remobilization by gravitational sliding; rock tor 'Czarownica' at stop B8.1 (Fig. 17). (**A**) The primary leftwards-inclined parallel stratification in the tor southern wall is both accentuated and obliquely cut by sets of concave-upwards fractures imitating trough cross-stratification. (**B**) The tor western wall shows massive sandstone beds cut by sets of similar concave-upwards fractures imitating trough cross-stratification.

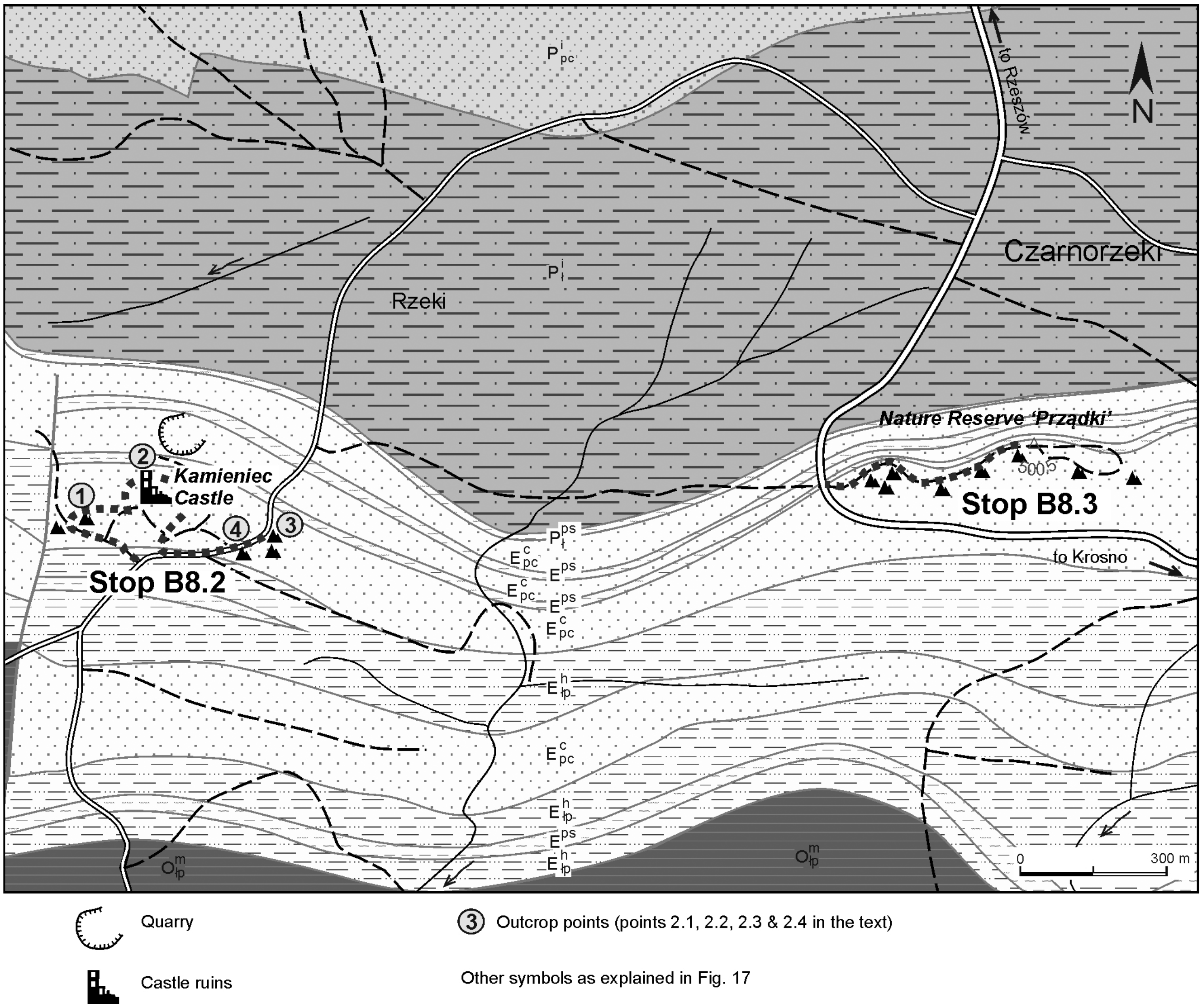

Fig. 23. Geological map of the vicinities of the Kamieniec Castle (stop B8.2, points 1–4) and the nature reserve 'Prządki' (rock tors at stop B8.3). Map modified from Świdziński (1933).

turing that imitates scours and geometrically unusual cross-stratification (Fig. 22B), and which is thought to represent differential synsedimentary shearing with tensile wing cracks at the base of a gravitationally sliding package of deposits.

Point 1.6 – Tor 'Ratusz (Town Hall)' on the western side of main road, half-way between point 5 and the main entrance to the reserve (Fig. 17). The outcrop shows a similar or perhaps the same (if unrecognizably faulted) succession of amalgamated thick beds of graded-stratified and massive coarse-grained sandstones (Figs 13A, C). Also here, a fracturing zone imitates scours and geometrically unusual crossstratification, which is thought to represent early synsedimentary shearing with tensile horsetail or wing cracks at the base of a slowly sliding soft-sediment package of deposits.

B8.2 The hill of Kamieniec Castle in Odrzykoń

(49°44′32″ N, 21°47′04″ E)

The rocky hill hosting the ruins of the 14th-century Kamieniec Castle (Figs 1, 23, left) offers another exposure of the fluxoturbidites of the Ciężkowice Sandstone, with both a broad view and details of syndepositional sediment remobilization and deformation features. Point 2.1 – The tors at the western foots of the castle hill show amalgamated beds of graded and nongraded, massive to faintly planar-stratified fine-pebbly sandstones. The parallel stratification is characterized by thick strata with grain size segregation. Beds on the NE side of the eastern tor show distribution normal grading, low-angle diffuse stratification and syndepositional sediment-remoulding features. The inclined stratification suggests a flow-oblique accretion of sediment mantling a 'frozen' debris flow or liquefied flow. The overlying massive bed of granule conglomerate grades upwards into sandstone and shows basal load casts, with load flames inclined to the south-east. Point 2.2 – Outcrop beneath the NW segment of the castle wall shows pebbly sandstone beds with multiple normal-graded conglomeratic lenses suggesting an unusually thick plane-parallel stratification (Fig. 9C). This crude layering is attributed to highly unsteady, pulsating (multi-surge) long-duration flows. Point 2.3 – Tor on the eastern side of the castle ruins, near the main road (with a roadside shrine), shows a thick graded-stratified bed of granule conglomerate passing upwards into coarse-grained sandstone, with a thick plane-parallel stratification marked by grain size segregation. This sediment layering is thought to represent rapid 'freezing' of the current's successive basal layers of laminar flow. Point 2.4 – Tor on the south-eastern side of castle ruins and near the main road, ca. 60 m to the SW of point 2.3, shows erosionally superimposed graded-stratified thick fine-pebbly sandstone beds. The parallelstratified sandy upper part of beds shows grain size-segregated, yet unusually thick, layering which may represent syndepositional shear-banding.

B8.3 The nature reserve 'Prządki (Spinners)', south of Czarnorzeki

(49° 44′32″ N, 21°47′59″ E)

The rock tors at this locality (Figs 1, 23, right) expose the same stratigraphic level of the Ciężkowice Sandstone as that seen at the previous stop B8.2. The sedimentary succession consists of thick amalgamated beds of massive to faintly parallel-stratified fine-pebbly/granule coarse-grained sandstones (Fig. 9A), with laminar shear-banding and scour-fill or mantling cross-stratification recognizable in the southern wall of the highest tor (Fig. 12B). Visible in one of the tors is also synsedimentary fracturing (cf. outcrop points 1.5 and 1.6), here apparently superimposed on primary cross-stratification.

Field-trip topic 2: Is some thick mud deposited fast and other thin deposited slowly in deep-sea settings?

Stanisław Leszczyński, Ewa Malata[1], Wojciech Nemec, Wojciech Schnabel[1], Sabina Hawryłko[1]

[1]Jagiellonian University, Poland

Introduction

Mud is an immanent component of deep-sea sedimentation, supplied as a hemipelagic to pelagic background suspension and derived from episodic sediment-gravity flows, particularly turbidity currents. The mode and rate of mud supply and its composition and pattern of intrabasinal dispersal may vary greatly, depending up on the basin internal and external conditions (see Stow *et al*., 1996; Schieber, 1998). Similarly variable may be the mechanism of mud deposition. As pointed out early by Dżułyński *et al*. (1959), the turbiditic mud suspension is seldom an ideal dispersion of clay or clay/silt particles; instead, it commonly involves various particle aggregates: from faecal pellets and clay floccules to mud clots/crumbs and small chips (see also Potter *et al*., 2005). The traditional deep-sea scenario of a spatially uniform, steady or fluctuating 'rain' of slowly settling mud suspension has recently been challenged in a major progress in our understanding of mud deposition. Evidence from laboratory experiments and microscopic mudrock studies indicates that some mud can be deposited in hydraulically more energetic conditions than previously assumed (Stow *et al*., 1996; Schieber, 1998; Schieber *et al*., 2007; Schieber and Southard, 2009) or be emplaced en masse as a gravity-driven, rheologically fluidal to plastic mudflow (Haughton *et al*., 2003; Baas *et al*., 2009) generated by the near-bottom densification of a settling mud suspension. The recognition of these various modes of mud deposition, along with the spatial pattern of mud dispersal in a basin, may have important implications for the basin's sedimention conditions and basin-fill stratigraphy.

This sedimentological topic is addressed by the field trip at its stop B8.4 in the context of the Glauconitic Magura Beds (late Eocene–early Oligocene) of the Carpathian Magura Nappe, a regionally extensive succession of turbiditic sandstones commonly capped with mudshales up to a few metres thick. The shale thicknesses correlate negatively with the sandstone bed thicknesses. The key contentious issues are: Are these mudshale beds just regular 'turbidite shales', as originally considered by Radomski (1960), or maybe representing prolonged quiet periods of hemipelagic suspension fall-out? Or perhaps they represent some other modes of mud emplacement, possibly quite rapid? The discussion of field evidence will focus on the thickness, colour variation, grain-size composition, ichnofabric and microfauna content of mudshale beds, as well as on the depositional nature, relative thickness and palaeocurrent directions

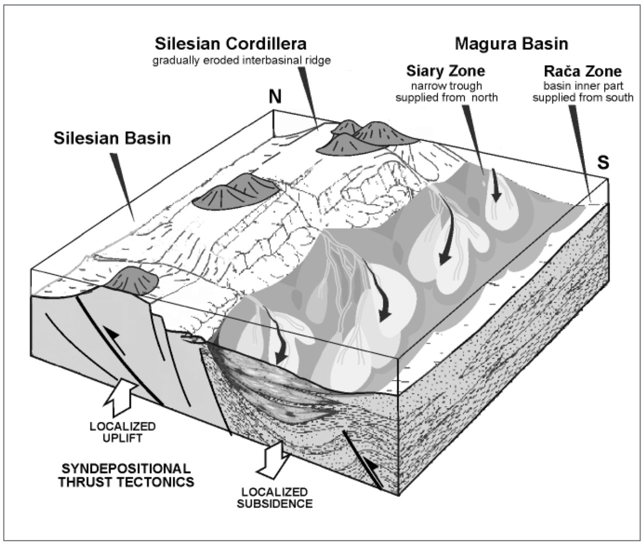

Fig. 24. Depositional model for the Glauconitic Magura Beds (modified from Leszczyński and Malata, 2002).

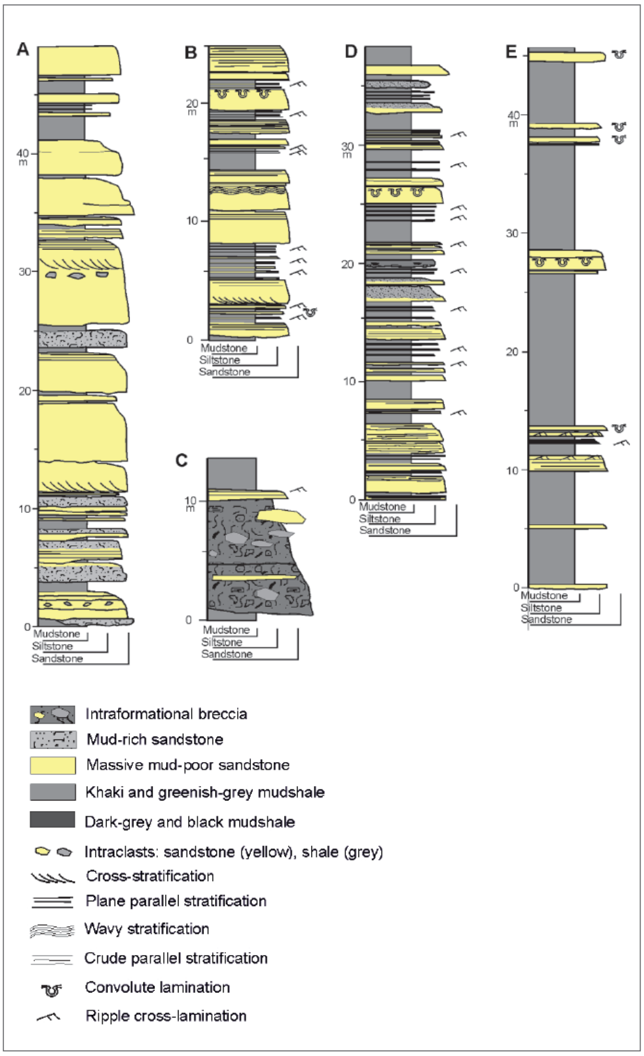

Fig. 25. Facies assemblages of the Glauconitic Magura Beds (modified from Leszczyński *et al*., 2008). (**A**) Assemblage dominated by very thick sandstone beds (channel/lobe transition deposits); Wątkowa Sandstone near Folusz village, east of Gorlice. (**B**) Assemblage dominated by thin to thick sandstones interbedded with shales (lobe axial deposits); Siary village, NW of Ropica Górna. (**C**) Assemblage with prominent intraformational breccia beds (lobe-flank to interlobe deposits); Ropica Górna. (**D**) Assemblage of thin to medium sandstones and shales (lobe-margin deposits); Siary village. (**E**) Assemblage dominated by very thick shales interspersed with thin/medium sandstones (interlobe deposits); Małastów village, south of Ropica Górna.

of the associated sandstones and their contacts with mudshales.

The Glauconitic Magura Beds

The sedimentary succession known as the Glauconitic Magura Beds (GMB) in the Polish Outer Carpathians forms the uppermost stratigraphic part of the Magura Nappe (Fig. 4) in its frontal northern zone. The Magura Basin was bounded from the north by the Silesian Cordillera, at the foot of which a deep narrow trough formed in the late Eocene–early Oligocene and hosted the GMB base-of-slope depositional system supplied with sediment from the cordillera (Fig. 24). In the regional literature, this narrow northern zone of the Magura Basin is referred to as the Siary Zone. The GMB stratigraphic unit is up to 2000 m thick (Oszczypko-Clowes, 2001) and overlies conformably the Łabowa Formation (Fig. 4) dominated by variegated shales. The GMB unit consists of quartzose to subfeldspathic sandstone beds, thin to thick (Fig. 25), generally glauconite-bearing and commonly mud-rich (wackes); subordinate are beds of granule conglomerate and intraformational sedimentary breccia. The associated mudshale beds (Fig. 25) range from clayey to silty and from calcareous to non-calcareous. Isolated outcrops indicate that the sandstone net/gross (N/G) varies both vertically on a scale of several tens of metres and laterally, along the depositional strike, on a scale of several kilometres. As a broad regional stratigraphic trend, the low N/G lower member of the succession (referred to as the Zembrzyce Beds) passes upwards and also sideways into the high N/G middle member (the Wątkowa Sandstone), which is overlain by the lowest N/G upper member (the Budzów Beds).

The coarse-grained deposits in the GMB range from non-graded to normal-graded and from massive to stratified. The thin sandstone beds are mainly Bouma-type turbidites Ta-c with siltstone to mudstone Tde caps. The mud-poor thick sandstone and granule conglomerate beds are typically normal-graded, massive to banded/stratified (Fig. 25A, B), similar to the fluxoturbidites of Dżułyński *et al.* (1959), and are attributed to deposition by high-density turbidity currents (*sensu* Lowe, 1982). The mud-rich sandstones and intraformational breccia beds are generally massive and poorly graded, occasionally with a graded-stratified upper part (Fig. 25A, C, D), and are considered to be deposits of cohesive debris flows (Lowe, 1982; Nemec and Steel, 1984) and hybrid sedi-

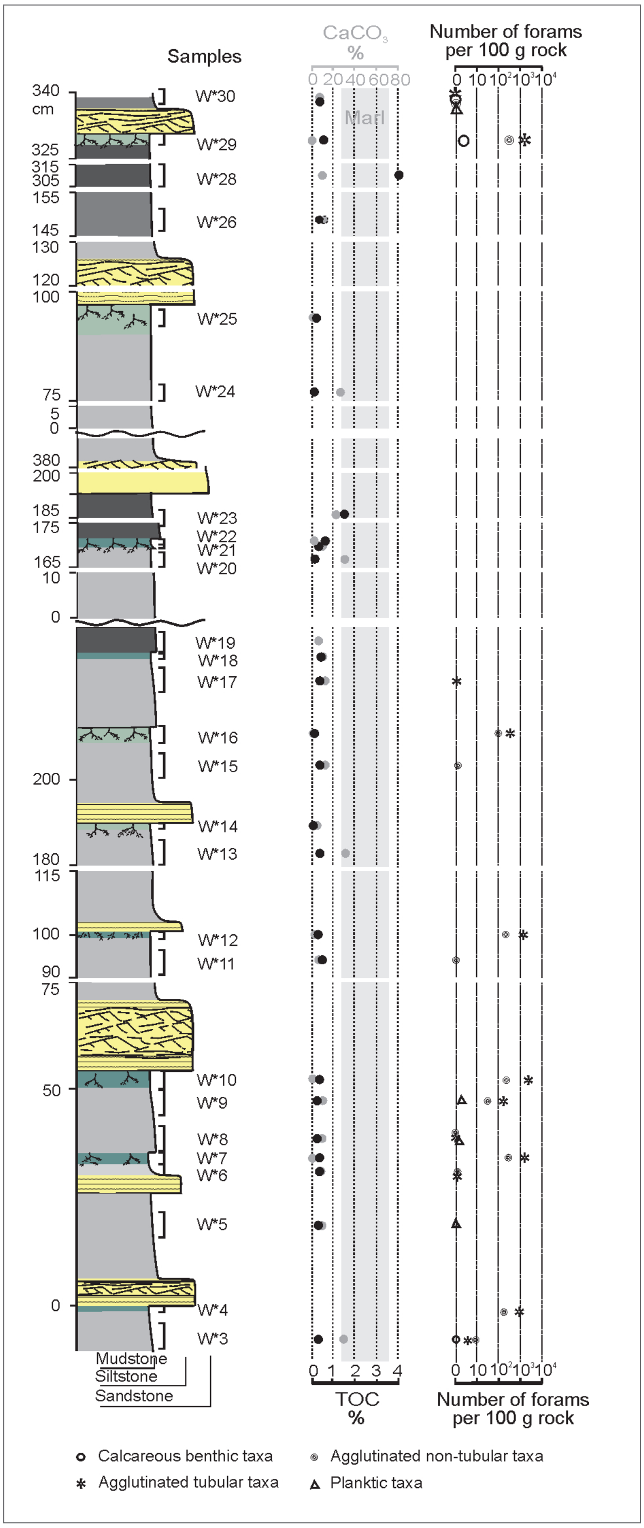

Fig. 26. Vertical variation in the content of $CaCO_3$ and TOC and the frequency and variety of foraminifers in the mudshales of Glauconitic Magura Beds; outcrop section in Węglówka village, ca. 50 km south of Kraków. In the profile, note the tectonic unconformities (wavy lines) and the thickness gaps due to removal of thick sandstone beds; note also the association of burrowing with the green shales. From Leszczyński and Malata (2002).

ment-gravity flows (*sensu* Haughton *et al.*, 2009; Kane and Pontén, 2012).

The mudshale beds have a much greater thickness range and are thickest (occasionally up to 20 m) in the stratigraphic intervals with the lowest N/G (e.g., Fig. 25E), such as the upper Budzów Beds. Calcareous mudshales predominate and the rock colour varies from brownish yellow-green (khaki), greyish-green and greenish-grey to dark-grey and black. The dominant grey and black calcareous shales are commonly overlain or separated by a thin (mainly <1 cm) layer of non-calcareous green shale (Fig. 26). The total organic carbon (TOC) content is generally low (<1%) and the black shales are only slightly richer in organic carbon than the grey or green shales (Fig. 26).

The dark shales show a gradational contact with the underlying siltstone or silty sandstone of turbidite bed top. The shale basal part commonly shows normal grading and faint plane-parallel lamination in the basal part. An admixture of very fine sand-sized grains (mainly quartz) occurs in the basal and topmost parts of shale beds, but also as diffuse horizons within the beds (Fig. 27;

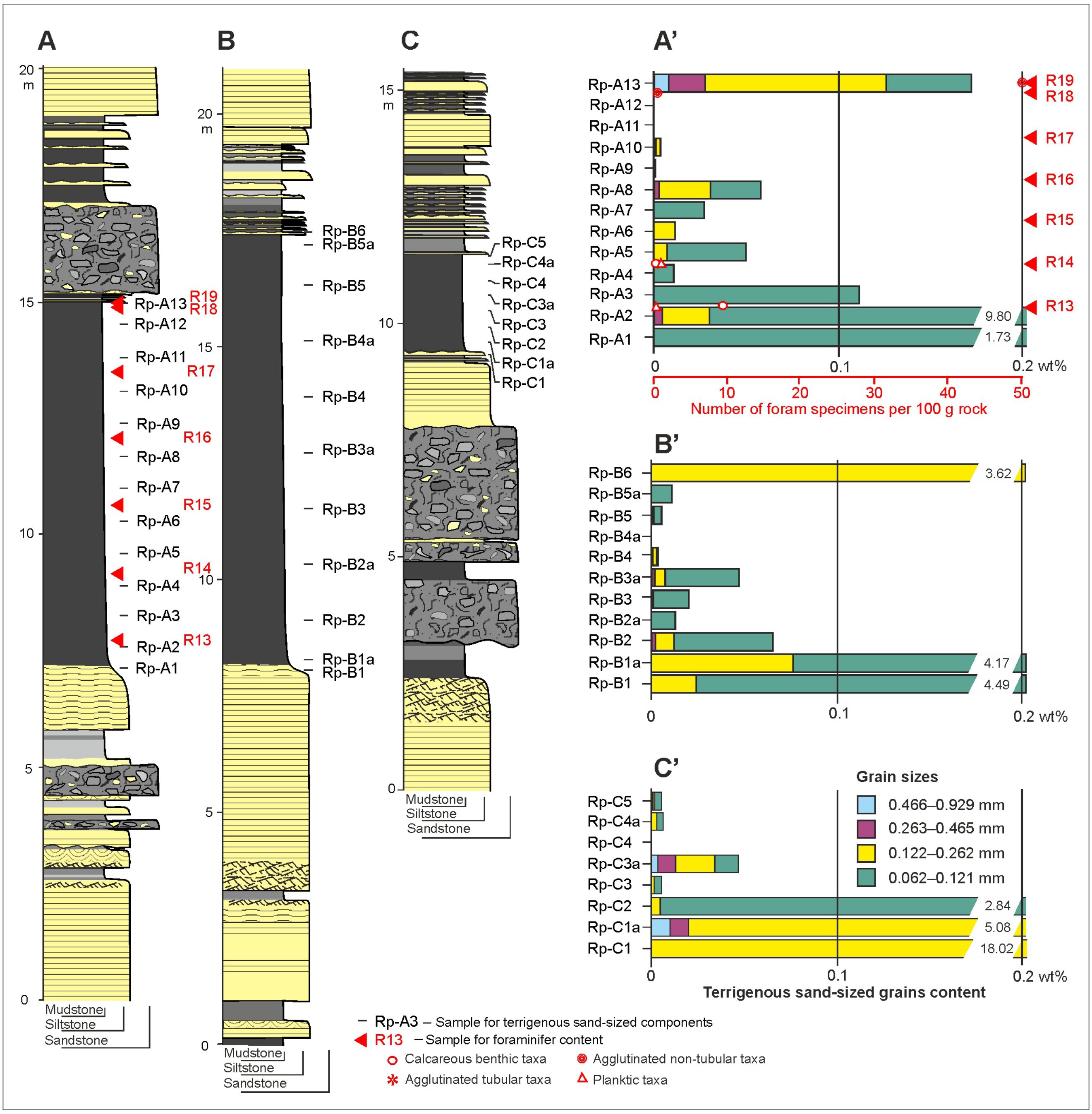

Fig. 27. Vertical changes in sand content and the frequency and type of foraminifers within a thick mudshale unit in the Glauconitic Magura Beds in Ropica Górna (stop B8.4, see outcrop points along the Sękówka river in Fig. 28). (**A**) Outcrop section at point 4.2. (**B**) Outcrop section at point 4.3. (C) Outcrop section ca. 500 m upstream from point 4.3.

Hawryłko, 2009; Schnabel, 2011). Shale beds thicker than 20 cm typically show burrows only in their uppermost part, less than 10 cm thick, with the bioturbation degree and foraminifer content increasing upwards and reaching maxima at the shale top and in its greenish capping.

The non-calcareous green shales contain benthic foraminifers, almost exclusively agglutinated taxa, including: *Nothia excelsa, Rhabdammina cylindrica, Psammosphaera sp., Glomospira glomerata, Haplophragmoides parvulus, Haplophragmoides sp., Paratrochamminoides spp., Ammsphaeroidina pseudopauciloculata and Recurvoides contortus.* The assemblages indicate bathyal water depths, below the present-day calcite lysocline (Leszczyński and Malata, 2002). The calcareous dark shales bear only sporadic planktic and benthic taxa, both calcareous and agglutinated, and chiefly in the basal and topmost part of a bed (Figs 26, 27; Leszczyński and Malata, 2002; Hawryłko, 2009; Schnabel, 2011).

Interpretation of mud deposition

Their intimate association and gradational contact with turbiditic sandstones indicates that the volumetrically dominant grey/black calcareous mudshales are of turbiditic origin, whereas the non-calcareous, foraminifer-rich and heavily bioturbated green mudshales apparently represent hemipelagic 'background' sedimentation. The rate of dark mud deposition must have been very high, preventing bioturbation, whereas the deposition rate of the thin green mud layers was incomparably lower. The glauconite-bearing turbiditic sand suggests resedimentation from a shelf zone (Starzec, 2009), probably narrow and subject to erosion (Fig. 24), with the deposition taking place in a base-of-slope ramp system (*sensu* Reading and Richards, 1994). The resedimentation was vigorous, leaving relatively little time for the background mud fallout. (The following text refers also to plates given as appendix illustrations in the digital version of this excursion guide.)

The large volumes of dark mud are thought to have been entrained by turbidity currents as a turbulent suspension, as indicated by basal normal grading, and were derived probably from the outermost shelf zone or basin-margin slope (Leszczyński and Malata, 1982) by the bypassing erosive currents – remobilizing and sucking-in mud in their wake (Fig. 24). The turbulent mud suspension often followed the parental current in

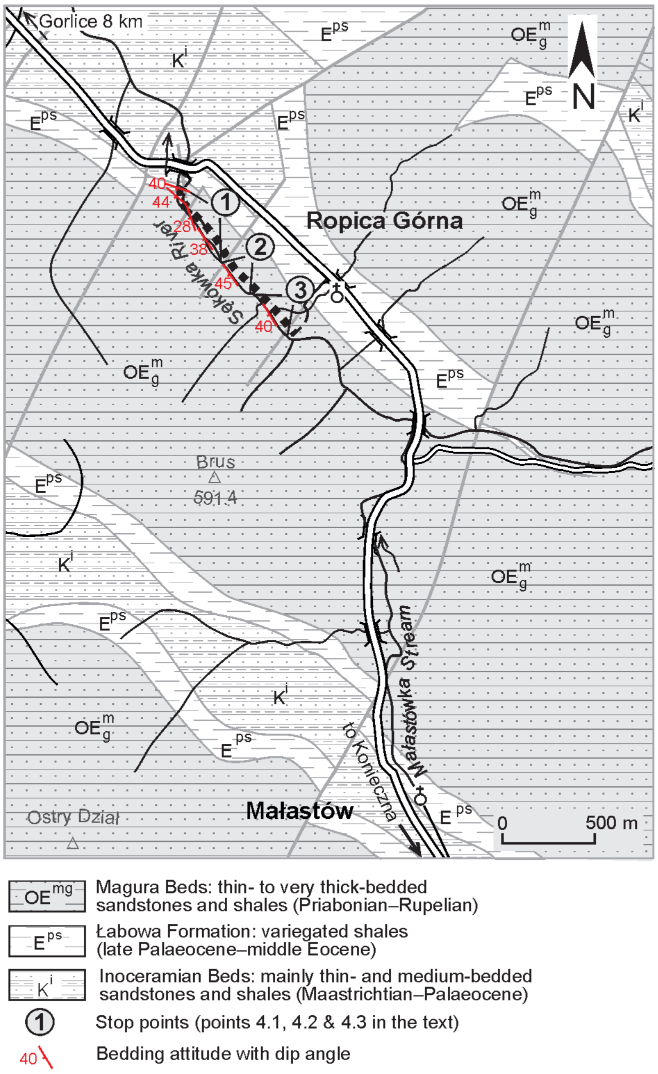

Fig. 28. Geological map of the vicinities of Ropica Górna (stop B8.4); modified from Kopciowski (1996). Note the location of outcrop points (river segments) 4.1–4.3 in the excursion route up the Sękówka river.

two or more successive surges, as indicated by the sand-content fluctuations in mudshale beds. The diffusely parallel-laminated initial stage of mud deposition resembles that of the Bouma turbiditic d-division. The settling of the current-entrained turbulent mud suspension was probably causing its near-bottom densification, turning it into an increasingly laminar flow (see Plate 6A; Baas *et al.*, 2009). The shear pattern and mode of fluid mud emplacement would vary with its volumetric concentration and flow rate (Plate 6; see Baas *et al.*, 2009). Turbulent shear would allow settling of the coarsest grains and development of normal grading. When reaching quickly the non-shearing 'plug flow' phase (*sensu* Baas *et al.*, 2009), the mud might continue to move slowly as a 'linked' mudflow (*sensu* Haughton *et al.*, 2003), possibly carrying scattered sand grains and/or floating mud chips (Plate 6B; see also Torfs *et al.*, 1996; Amy *et al.*, 2006; Talling *et al.*, 2012). Mud chips in a rock are visually difficult to distinguish from a mud matrix of similar composition, but the routine laboratory disintegration of shale samples with Glauber's salt in the present case had indicated some relatively hard mudrock bits which could well be chips/crumbs of a compacted primary mud.

The trailing and densifying thick mud suspension would tend to be driven by gravity independently of the parental fast turbidity current, thereby commonly outrunning the spatial distribution of turbiditic sand (as evidenced by the dark shale beds separated with thin green shale horizons, Fig. 26) and also being drifted sideways into the inter-lobe topographic depressions of the depositional ramp system (Figs 24, 25E). This latter notion is supported by the 'compensational' spatial thickness distribution of shales relative to sandstones and by the observed variability of palaeocurrent directions.

If this hypothetical interpretation is correct, the emplacement of the thick beds of dark mud in the GMB succession might have been nearly as rapid as the deposition of the turbiditic sand and granule gravel beds. The regional stratigraphic significance of the low N/G local successions in the Glauconitic Magura Beds would then need to be reconsidered in terms of the depositional system's morphodynamics and its specific mode of sediment supply.

Stop description for topic 2

Stanisław Leszczyński, Wojciech Nemec

The outcrops at stop B8.4 are in the river bedrock banks and floor, and hence wellingtons (high rubber boots) are needed. The excursion aim at this first stop on the second day is to demonstrate and discuss the sedimentary characteristics of the GMB succession with a special focus on its variety of mudshale beds. The area is in the northern frontal zone of the Magura Nappe (Fig. 2), known as the Siary Zone (Fig. 24), and the GMB succession here is 1000-1400 m thick (Leszczyński *et al.*, 2008). The outcrops in Ropica Górna show a mud-rich inter-lobe part of the

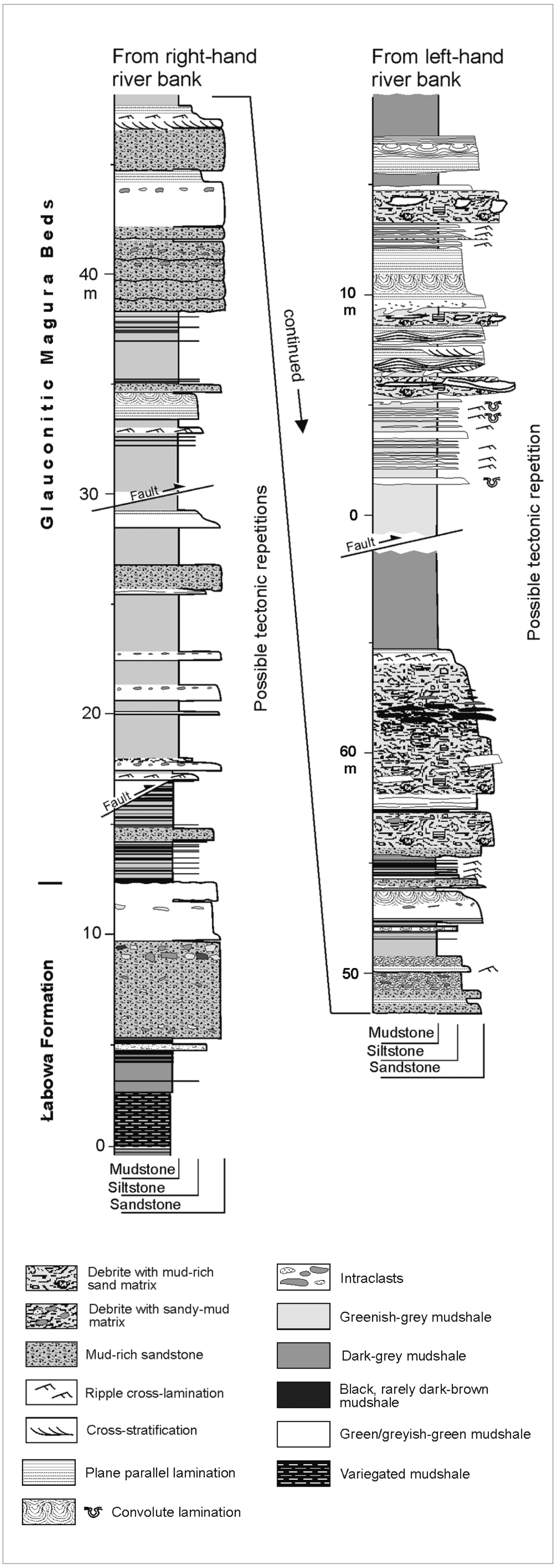

Fig. 29. Sedimentological log of the lower part of Glauconitic Magura Beds and the underlying Łabowa Formation in Ropica Górna (see stop B8.4 in Fig. 28, outcrop point 4.1).

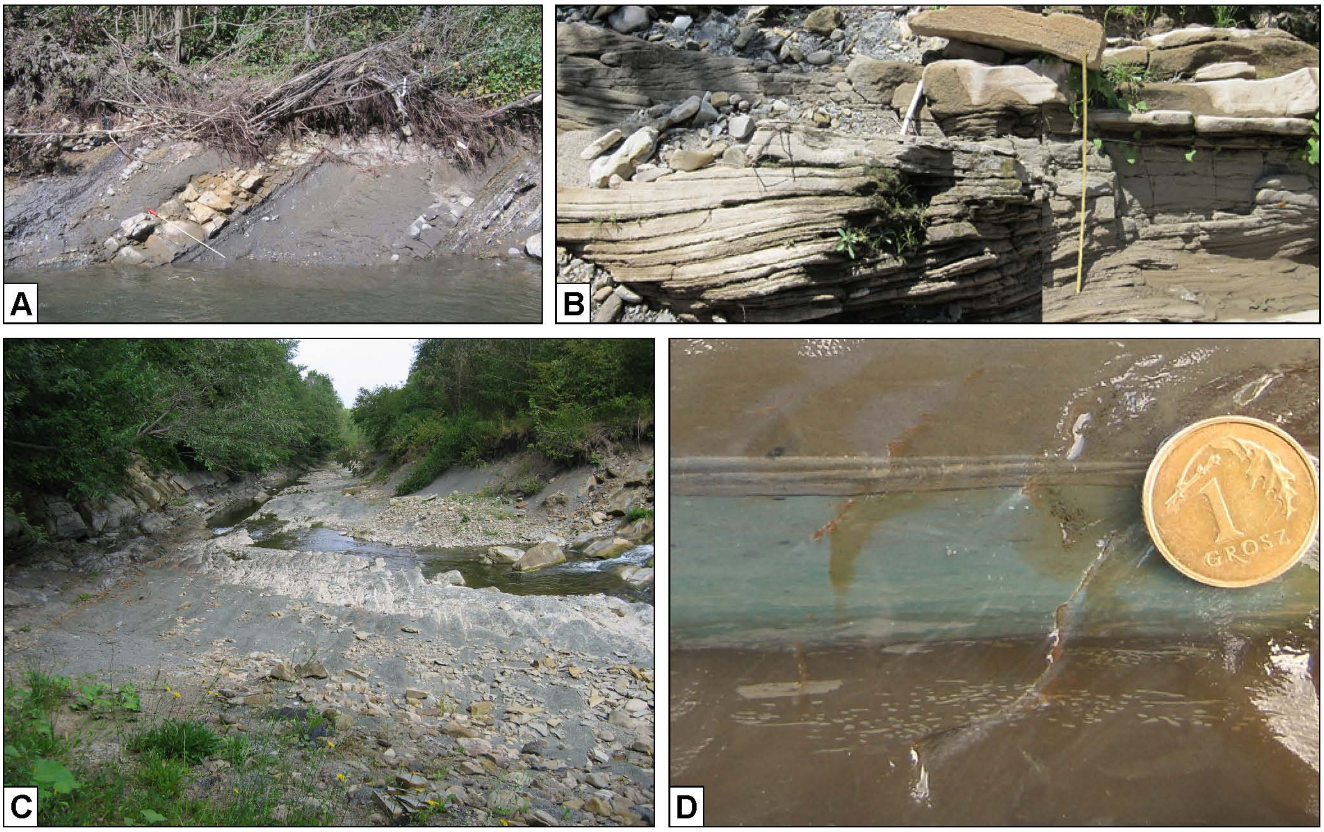

Fig. 30. Outcrop details of the Glauconitic Magura Beds in Ropica Górna (stop B8.4, Fig. 28). (**A**) Succession dominated by mud-rich sandstone and intraformational breccia beds at point 4.1; the walking stick (scale) is 1.1 m. (**B**) Apparent hummocky stratification in a sandstone bed at the upstream end of point 4.1; the measuring stick is 0.9 m. (**C**) The Sękówka river floor exposing an 8-m thick mudshale unit overlain by a 4-m package of beds dominated by intraformational breccias; the upstream end of outcrop point 4.2. (**D**) Close-up detail from the upstream part of outcrop point 4.3, showing calcareous greyish brown mudshales separated by a thin layer of non-calcareous green mudshale; the coin size is 1.5 cm. The brown shales show light-colour silt streaks and the lower one shows clusters of *Chondrites intricatus* burrows. The green shale has a transitional lower boundary and sharp top, and is strongly bioturbated. Analyses of 100-g rock samples show that the brown shales contain only 17–179 foraminifer specimens (calcareous and benthic species), whereas the green shale contains nearly 11 000 specimens of exclusively agglutinated foraminifers.

Siary turbiditic ramp system, passing laterally along the depositional strike into an adjacent sand-rich lobe part within a distance of less than 10 km to the east (see Leszczyński *et al*., 2008).

B8.4.1-4 Ropica Górna

Outcrops at the banks and floor of river Sękówka.
(49°36′02″ N, 21°13′27″ E to 49°35′34″ N, 21°13′58″ E)

The bedrock banks and floor of the north-flowing Sękówka river in Ropica Górna (Fig. 28) afford a nearly continuous outcrop section of the lower part of the GMB succession (Fig. 29), ca. 100 m thick, dated to the latest Eocene (Oszczypko-Clowes, 2001). The GMB succession has a tectonized lower boundary and is cut by a few *en echelon* faults, but contains a marker megabed of sedimentary breccia, 5 m thick, which allows the succession stratigraphy to be followed and its local offset by faults to be estimated at ca. 10–20 m. The consecutive points of the excursion route are in the upstream direction (see Fig. 28).

Point 4.1 – The river floor above the bridge of the main road Gorlice–Konieczna in the northern part of the village (Fig. 28). The basal contact of the GMB with the underlying variegated shales of the Łabowa Formation (Fig. 29, lower left) is disturbed by tectonic thrusting. The lowest part of the GMB (4.6 m thick, Fig. 29) is dominated by dark brownish-grey and greyish-green calcareous shales interbedded with thin glauconitic sandstones, considered by Oszczypko-Clowes (2001) to represent the Zembrzyce Beds. This basal part is separated by a fault from the overlying part (ca. 30 m thick, Fig. 29, left), exposed in the river right-hand bank and composed of dark calcareous and subordinate greenish non-calcareous mudshales intercalated with thin to thick beds of massive arenites and wackes; it is cut by a minor fault in the middle and its proportion of sandstones increases upwards.

The higher part of the succession, ca. 30 m thick (Fig. 29, right), crops out in the river left-hand bank (Fig. 30A). This part of the succession seems to have been repeated by a thrust (Fig. 29, upper right) and can be followed upstream along the strike over a distance of ca. 250 m (Fig. 28), although its exposure is fragmentary and limited mainly to the river floor, The thick mudshale beds here lack bioturbation, whereas the associated sandstone beds show trace fossils on their soles. The succession includes a 10-m package of thick sandstone beds showing trough or scour-and-fill cross-stratification as well as enigmatic hummocky stratification (Fig. 30B). A several metres thick package of interbedded sandstones and dark-grey/black and brown/green mudshales forms the top part of the succession. Common are muddy sandstone beds rich in mudclasts, and also the marker breccia megabed is reached at the upstream end of the strike section, offset by another fault.

Sandstone beds indicate deposition by turbidity currents, cohesive debris flows and intermediate 'hybrid' flows (see Haughton *et al*., 2003; Amy *et al*., 2006; Kane and Pontén, 2012; Talling *et al*., 2012). Short-distane lateral changes in bed thicknesses indicate an uneven depositional topography. The thick non-bioturbated mudshale beds imply rapid emplacement, with an immediate post-depositional colonization by fauna indicated by trace fossils on the overlying sandstone soles. Unclear is the origin of apparent hummocky stratification (first recognized here by Piotr S. Dziadzio).

Point 4.2 – The next upstream segment of the river (Fig. 28), ca. 200 m long, is a strike section of deposits about 10 m above the marker breccia megabed. Prominent here is a very thick (ca. 8 m) unit of massive, dark-grey mudshale (Figs 27A, 30C). The underlying sandstone-rich package and the overlying shale-rich package of turbidites contain isolated subordinate beds of intraformational breccia (Fig. 27A).

A systematic sampling of the thick mudshale unit's vertical profile indicates irregular changes in both its sand content and the abundance and variety of foraminifers (see Fig. 27A and plot A'). This hidden heterogeneity suggests that the shale unit is probably composite, emplaced in at least four successive surges of fluidal mud ranging from weakly turbulent and crudely graded to increasingly non-turbulent, with a sand-bearing rigid plug (see Baas *et al*., 2009).

Point 4.3 – The last upstream segment of river Sękówka, ca. 300 m long, is a strike section of the marker breccia megabed, 5 m thick, exposing it from the top to base. The sedimentary breccia has a muddy sand matrix and contains large rafted fragments of sandy and heterolithic turbidites as well as mudshale blocks as large as 1.7 x 5 m. It is underlain by a 2-m mudshale unit whose top part consists of greyish brown calcareous shale layers (4–4.5 cm thick), with sporadic *Chondrites* and *Phycosiphon* burrows and infrequent foraminifers (solely benthic species, both calcareous and agglutinated), intercalated with strongly bioturbated layers (1–1.5 cm) of green noncalcareous shale (Fig. 30D) rich in exclusively agglutinated foraminifers. The breccia megabed is covered by a sandstone turbidite T(a)bc, 20 cm thick, and further by a calcareous, dark-grey massive mudshale with an exposed thickness of 2.5 m.

At the upstream end of this river segment, across two closely-spaced faults, the thick dark-grey mudshale unit of point 4.2 (Fig. 27A) is exposed in the river left-hand bank, here reaching a thickness of 9.4 m (Fig. 27B). It is underlain by thick sandstone beds and covered with thinly-bedded heterolithic turbidites. The mudshale unit in its vertical profile shows similar fluctuations of sand content (Fig. 27, diagram B') as in its outcrop at point 4.2 (cf. diagram A'). Analogous fluctuations are observed in an outcrop ca. 500 m farther upstream, where the mudshale unit decreases in thickness to 2.6 m (Fig. 27C, diagram C').

Field-trip topic 3: The Lower Oligocene – still deep-water turbidites or rather shallow-marine deposits?

Piotr S. Dziadzio

Introduction

Palaeobathymetry has been a central and controversial issue in the analysis of the flysch basins of the Polish Outer Carpathians, now represented by the individual nappes. Until 1937, the Carpathian flysch was thought to have been deposited in shallow-water conditions, because of the abundance of sandstones and conglomerates. Sujkowski (1938) was probably the first who suggested that the Carpathian flysch was deposited at water depths 'greater than those of the North Sea'. This view soon gained strong support from Książkiewicz (1948), who found the origin of shale-capped graded sandstone beds difficult to reconcile with shallow-water conditions. After the publication of turbidity current hypothesis by Kuenen and Migliorini (1950), the notion of sediment gravity flows and deep-water conditions was swiftly adopted by the Carpathian leading flysch researchers (Vašiček, 1953; Książkiewicz, 1954). On the basis of foraminifer studies, Książkiewicz (1958) suggested that the water depth in the Carpathian flysch basins was mainly bathyal (200–3500 m), but probably varied in space and time, with some deposits possibly neritic. A deepwater origin of the Carpathian flysch was postulated further by Dżułyński *et al.* (1959), Dżułyński and Walton (1965) and several other authors. Koszarski and Żytko (1965) suggested that the flysch basins were relatively shallow during the Early Cretaceous, but attained abyssal depths in the Late Cretaceous and Palaeocene–Eocene before becoming gradually shallower again in the Oligocene. The early bathymetric reconstructions of the Polish Outer Carpathian flysch, based on foraminifers and trace fossils, were given in the benchmark publications by Książkiewicz (1975, 1977).

However, the notion of a deep-water origin of the Carpathian flysch was also concurrently questioned by several researchers in the region (e.g., Hanzlikova and Roth, 1963; Watycha, 1963; Draghinda, 1963; Bieda, 1969). According to Bieda (1969), the flysch formations containing solely agglutinated foraminifers were deposited in lacustrine environments, enclosed shallow-water bays and river-mouth areas, whereas formations with mixed assemblages of agglutinated and calcareous foraminifers were deposited in littoral to neritic environments. This hypothesis was discarded by Książkiewicz (1975) on the basis of the modern distribution of foraminifers. He reinforced the opinion that the Polish Outer Carpathian flysch was deposited at bathyal water depths, perhaps mainly in the upper bathyal zone of 200–600 m.

The latter view was later enhanced by Ślączka and Kaminski (1998), who suggested that all the Jurassic to Miocene deposits in the Polish Outer Carpathians were of deep-water origin. A bathyal to abyssal water depth was postulated by several authors for the Early Cretaceous to

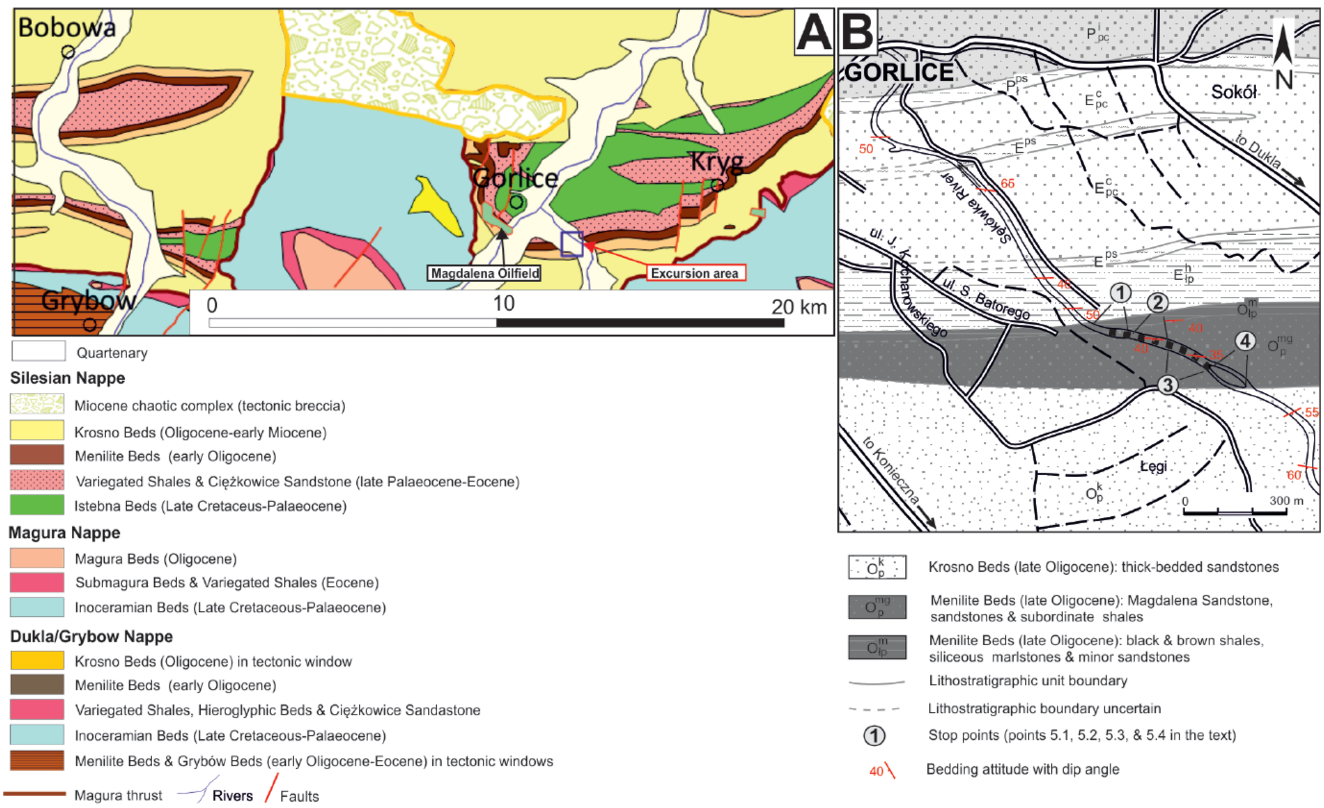

Fig. 31. (**A**) Geological map of the Gorlice area (see also excursion stop 8.5 in Figs 1, 2, 4), showing the location of the excursion area in Menilite Beds and the Magdalena oilfield; map modified from Świdziński (1954). (**B**) Detailed geological map of the excursion area with the location of stops 5.1–5.4; map modified from Szymakowska (1977); for complete legend, see Fig. 17.

Eeocene flysch deposits (Uchman at al., 2006; Słomka *et al*., 2006; Olszewska and Malata, 2006; Waśkowska and Cieszkowski, 2014). Słomka *et al.* (2006) suggested a marked shallowing of the bathyal basins (ca. 1000 m depth) in the late Eocene to late Oligocene. A possible occurrence of shelf environments was inferred by Olszewska and Malata (2006) on the basis of foraminifers for the early Oligocene Menilite Beds.

The regional studies as a whole leave little doubt that the vast majority of the Polish Outer Carpathian flysch was deposited in deep-water settings, bathyal and perhaps locally even abyssal. However, for an evolving array of tectonically active wedge-top basins (*sensu* DeCelles and Giles, 1996) it is also quite likely that many transient zones of shallow-water sedimentation would form and that their deposits, if not cannibalized by erosion, might occasionally be preserved within the ultimate nappe stack. This hypothesis is suggested here to be the case with the Magdalena Sandstone member at the top of the early Oligocene Menilite Beds formation in the Silesian Nappe, at its boundary with the overlying Sub-Magura/ Dukla Nappe (Figs 2, 4). The deposits in question, nearly 200 m thick, are both underlain and overlain by deep-water turbiditic successions. The contentious issue is: Can these deposits, in the middle of a very thick deep-marine flysch succession, be of shallow-marine origin?

The Menilite Beds and their uncertain palaeobathymetry

The early Oligocene shale-rich Menilite Beds form a regional lithostratigraphic unit present in all the Polish Outer Carpathian nappes (Fig. 4), which may suggest a palaeogeographic stage of a very broad deep-water basin. The origin of the organic carbon-rich black Menilite shales has long attracted research interest in regional studies (e.g., Kuźniar, 1952; Badak and Grudzień, 1961; Gabinet and Jurczakiewicz, 1962; Köster *et al*., 1998a, b; Koltun, 1992; Koltun *et al*., 1995, 1998; Matyasik and Dziadzio, 2006; Kotarba *et al*., 2013, 2014), with much less focus on the associated sandstones complexes (e.g., Żgiet, 1963; Dżułyński and Smith, 1964; Koszarski, 1965; Ślączka and Unrug, 1966; Kotlarczyk, 1976; Jankowski *et al*., 2012). A possible non-turbiditic origin of sandstone complexes in the Menilite Beds has been suggested briefly by Dżułyński and Kotlarczyk (1962), Dżułyński and Smith (1964) and Jankowski *et al.* (2012).

The Menilite Beds in all nappes, except for the Magura Nappe (Fig. 4), overlie synchronously the regionally-extensive unit of Globigerina Marls (lowest Rupelian) and commence with dark-brown bituminous shales interlayered with cherts and siliceous marls (Gucwa and Ślączka, 1972; Olszewska 1985; Ślączka and Kaminski, 1998). The shaly succession contains three main sandstone complexes: the Cergowa Sandstone in the Dukla Nappe, the Magdalena Sandstone in the Silesian Nappe near Gorlice, and the Kliwa Sandstone in the Skole nappe (Ślączka and Kaminski, 1998). The upper boundary of the Menilite Beds is diachronous, older to the south (Dukla Nappe) and younger, Chattian/Aquitanian to the north (Skole Nappe) (Koszarski and Żytko, 1961; Gucwa and Ślączka, 1980; Olszewska, 1985; Ślączka and Kaminski, 1998; Kotlarczyk *et al*., 2006).

Planktic and benthic foraminifers in the Menilite Beds indicate deposition at sublittoral to upper bathyal water depths (Olszewska, 1985; see also Olszewska and Malata, 2006). Abundant ichtiofauna indicates fish assemblages dwelling in water depths of 200 to 2000 m, but also includes some shallow-water species (Jerzmańska, 1968, Jerzmańska and Kotlarczyk, 1988; Kotlarczyk *et al*., 2006).

More recent sedimentological studies of the Menilite Beds in the Gorlice area (Enfield *et al*., 1998; Dziadzio *et al*., 1998; Watkinson *et al*., 2001; Dziadzio *et al*., 2006) have postulated a shallow-marine origin of this succession including the Magdalena Sandstone with a long-producing hydrocarbon reservoir (eventually abandoned in 2012). The occurrence of features interpreted as hummocky cross-stratification implies deposition above the storm wave base, which means a water depth no greater than 100 m and perhaps less than 50 m on the account of the landlocked nature of the Carpathian Paratethys seaway (Rögl, 1998). As pointed out by Jankowski *et al.* (2012), it could only be the lack of detailed sedimentological studies that allowed these and possibly also some other deposits in the Outer Carpathian flysch to be lumped with the vertically-adjacent deposits as deep-water turbidites. The Menilite Beds with the controversial Magdalena Sandstone are the topic of the excursion stop B8.5 in the Gorlice area (Fig. 31).

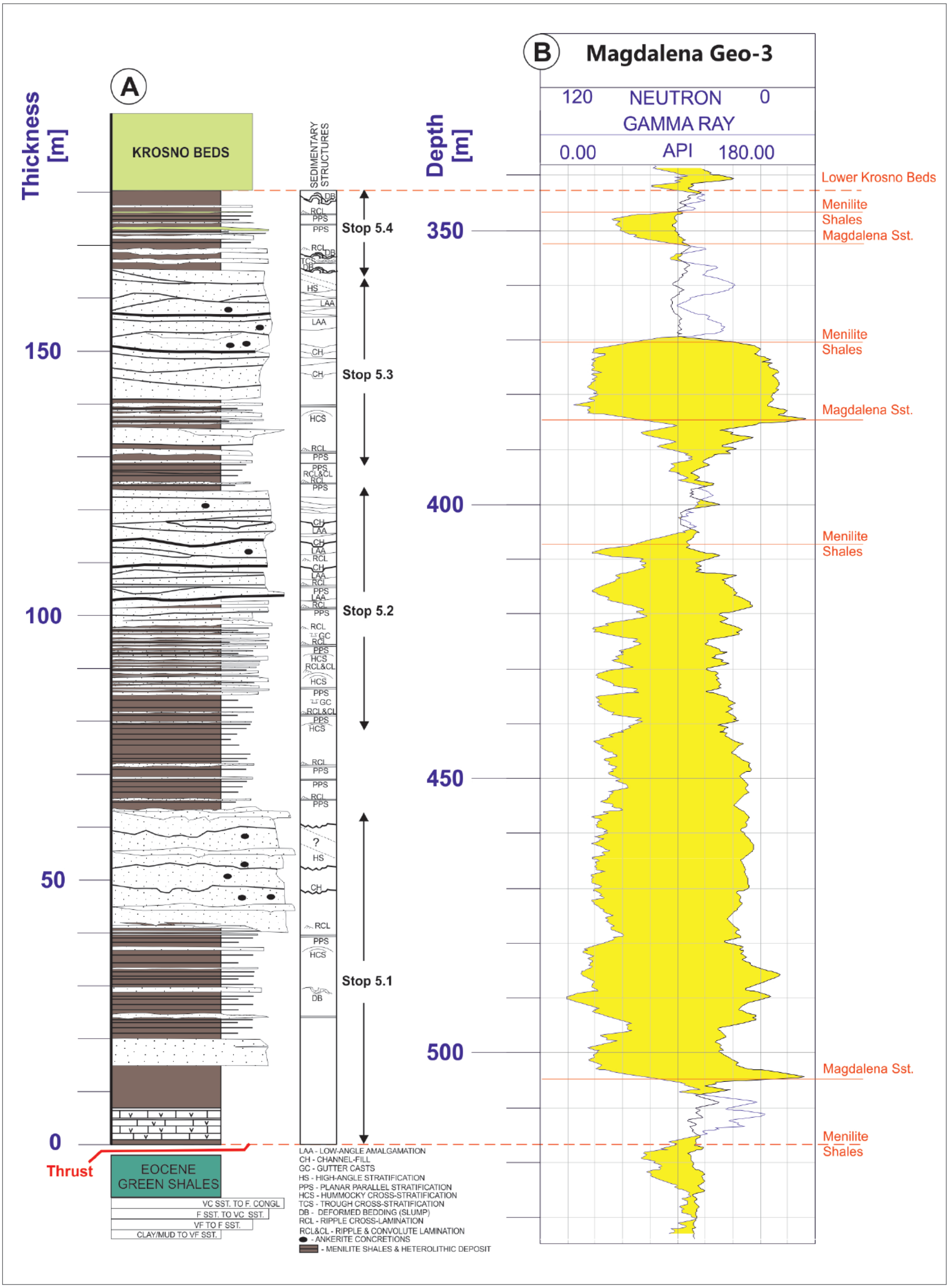

Fig. 32. (**A**) Sedimentological log of the Menilite Beds from the outcrop section in Sękówka river (excursion stop B8.5, Fig. 31B) (**B**) An example geophysical well-log from the nearby Magdalena oilfield (see location in Fig. 31A). The low values of neutron and gamma-ray signals indicate sandstones, whereas the high gamma-ray values indicate shales. The sandstone net thickness in the well is ca. 120 m and the shale net thickness is ca. 60 m (Dziadzio *et al.*, 2006).

The Menilite Beds in Gorlice area

The Menilite Beds succession in the Gorlice area was described stratigraphically by Szymakowska (1979), Karnkowski (1999) and Dziadzio *et al*. (2006). A tectonic thrust separates this unit from the underlying Eocene green shales (Fig. 32), and the unit here differs from its typical other appearances in the Silesian Nappe and in the Skole Nappe (Szymakowska 1979). Siliceous marls, instead of cherts, occur in its lowest part; typical cherty 'menilitic' shales are rare; and the succession is dominated by the quartzose arenites of the Magdalena Sandstone (Fig. 32). The Magdalena Sandstone, named after an estate and oilfield in Gorlice, consists of thick-bedded, coarse- to very coarse-grained and subordinate fine-grained quartz-glauconite sandstones and quartz-rich conglomerates. Cement is calcite with iron compounds. Sandstone beds range from nearly massive to well-stratified. Shale-dominated parts of the succession (Fig. 32) consist of the thin (10–20 cm) to thick (occasionally >1 m) beds of greyish brown, dark-grey and black, organic-rich noncalcareous shales, mainly laminated, with common heterolithic intervals of shale thinly interlayered with greyish white fine-grained sandstones and showing classical lenticular, wavy and flaser bedding. The top part of the succession, at its transition to the turbidites of the Krosno Beds (Fig. 32), shows slump features and consists of shales and heterolithic deposits alternating with thin beds of both the Magdalena-type quartz-glauconite sandstones and the Krosno-type quartz-muscovite calcareous sandstones.

The shales are a good-quality source rock for hydrocarbons. They have a fairly low degree of thermal maturation (T_{max} = 414°C), are rich in organic matter (TOC = 10.12%), and their hydrocarbon yield potential is ca. 45 mg HC per 1 g of the rock. Oil-prone kerogen of type II dominates, with the hydrocarbons rich in aliphatic and naphtenic compounds. However, the content of sulphur is high, which reduces the shale's HC-generation potential. Biomarkers indicate sediment deposition in anoxic conditions. The content of C_{29} hopanes is much higher than that of C_{30} hopanes, which may suggest deposition in a shallow shelf environment (Matyasik and Dziadzio, 2006).

The thickness of the Menilite Beds in the Magdalena oilfield south-west of Gorlice (Fig. 31A) is in the range of 150–180 m. The thickness in the excursion area along the Sękówka river (Fig. 31B) is 180 m (Fig. 32A), but decreases along the strike both westwards (Fig. 31B) and eastwards (Szymakowska, 1979). The unit is only 75 m thick near the village Kryg, 7 km to the east of Gorlice (Fig.

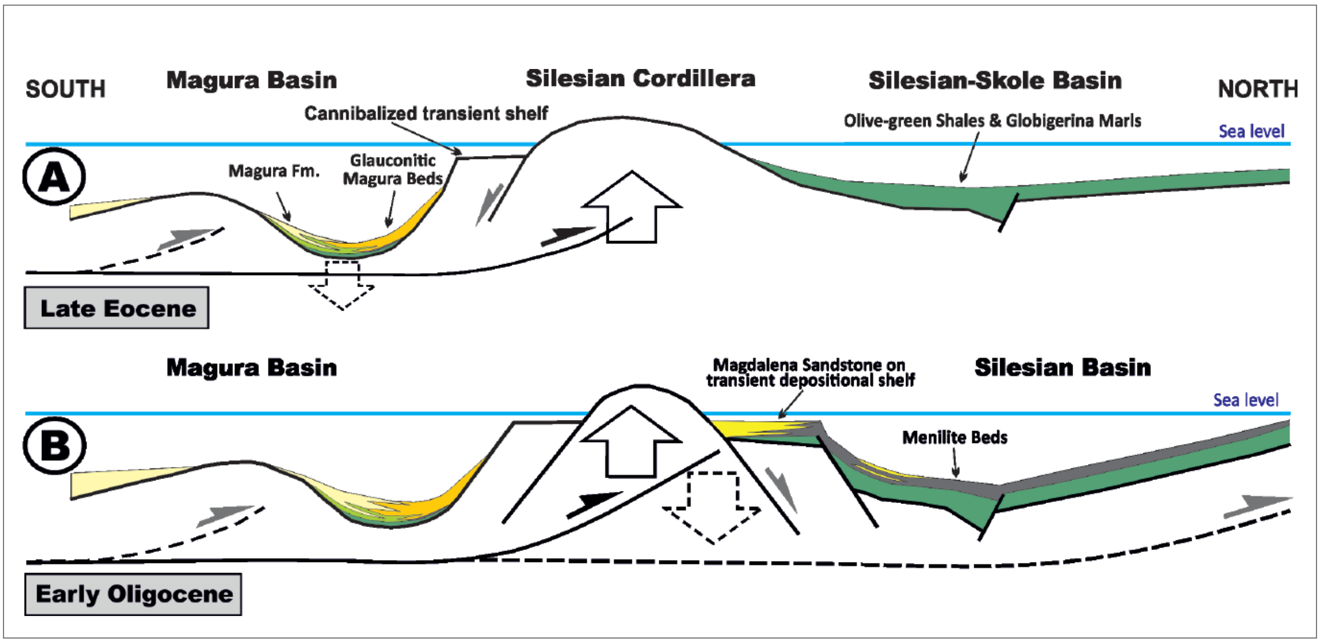

Fig. 33. Schematic hypothetical model (not to scale) for the late Eocene to early Oligocene sedimentation on the flanks of the emerging Silesian Cordillera between the Magura Basin and Silesian Basin. (**A**) Narrow synclinal trough forms at the southern foot of the cordillera, where the late Eocene base-of-slope Glauconitic Magura Beds succession is deposited with sediment derivation from a cannibalized narrow transient shelf (see Fig. 24). (**B**) A narrow transient depositional shelf forms on the northern flank of the cordillera, where the early Oligocene Magdalena Sandstone succession is deposited and becomes preserved by burial when the shelf eventually founders and the Silesian Basin is separated by another blind-thrust anticlinal cordillera from the Skole Basin.

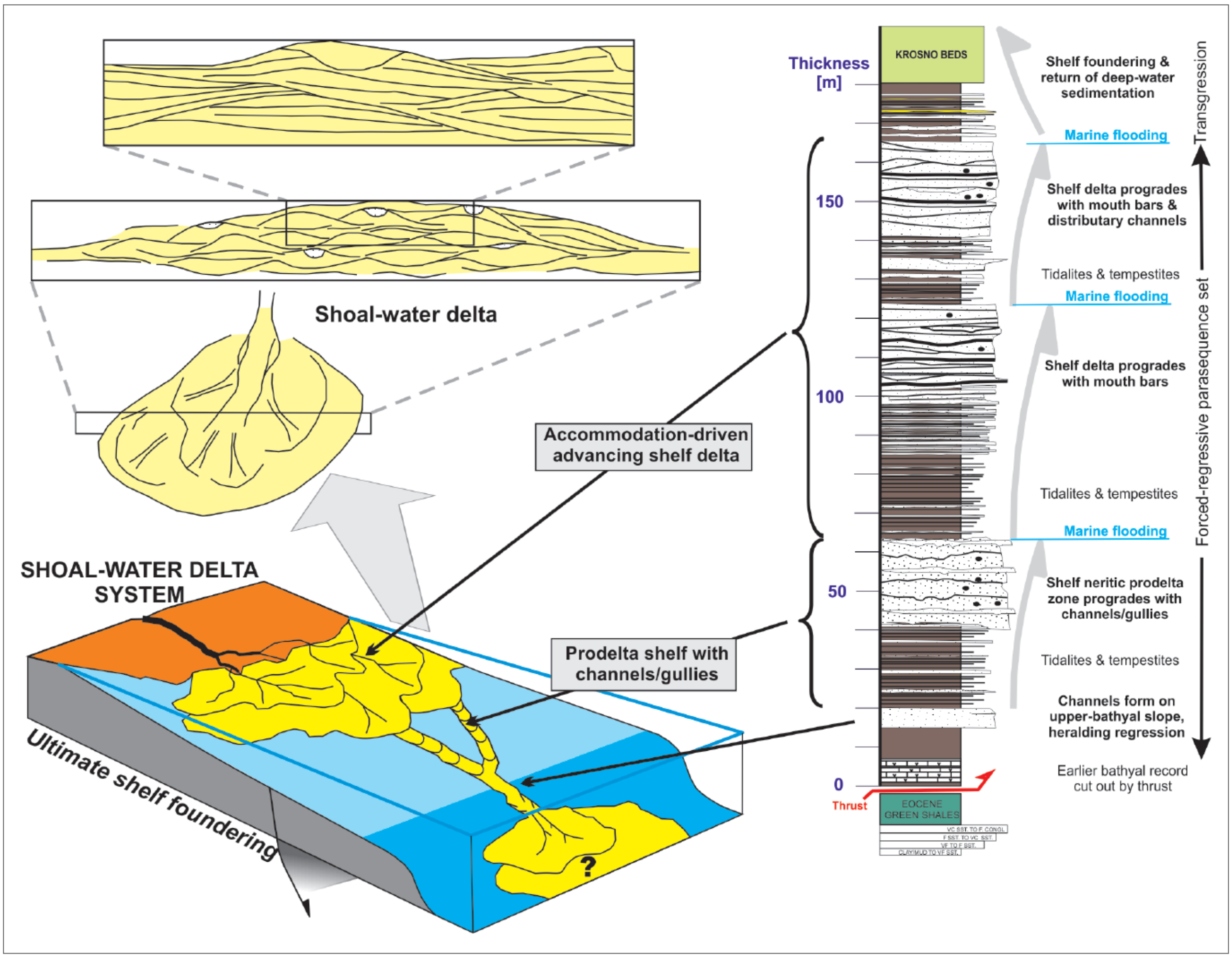

Fig. 34. Stratigraphic interpretation of the Menilite Beds succession in the excursion area in terms of a depositional model of a tide- and storm-influenced narrow shelf onto which a shoal-water delta progrades (see also Fig. 33B); for further interpretive details, see text.

31A), where its profile also shows only two 20-m sandstone packages (Kozikowski, 1966). The thickness of the Menilite Beds decreases to ca. 60 m over a distance 15 km to the north and north-west (Birecki, 1964; Karnkowski, 1959) and to the west (Świdziński, 1950, 1953), where the compositionally different Kliwa Sandstone deposits (Koszarski, 1965) begin to appear laterally. The Magdalena Sandstone occurs in only some wells to the south and virtually pinches out northwards, which jointly indicates a lenticular sandstone complex with an estimated strike-parallel (W–E) width of at least 35 km and a basinward dip-parallel (S–N) extent of ca. 20 km.

Interpretation of the Magdalena Sandstone

The cordilleras separating Carpathian flysch basins, when diachronously uplifted by thrusting, are thought to have developed narrow transient shelf zones hosting neritic to littoral sedimentation (Fig. 33). Most of these fringing shelves were cannibalized by excessive uplift and erosion, as in the case of the Glauconitic Magura Beds (stop B8.4, Fig. 33A), but some others might escape destruction and preserve their shallow-marine deposits when subsiding. This is thought to have been the case with the Magdalena Sandstone – deposited on an uplifted bathyal fringe of the Silesian Basin and then buried when the shelf tectonically foundered (Fig. 33B) and deep-water sedimentation resumed.

The Menilite Beds succession in the present case (Fig. 34, profile) has upper-bathyal but quite atypical 'menilitic' shales at the base, which can be attributed to deposition in the basin's shallowing fringe zone (Fig. 33A). The occurrence of first sand-filled channels (Fig. 34, profile) is a signal of an impending forced regression driven by tectonic uplift, and the subsequent appearance of heterolithic deposits with tidalites and tempestites marks the onset of shelf conditions. The first coarsening-upwards package of deposits (Fig. 34, profile) is a regressive parasequence recording shelf shallowing and formation of shelf-crossing channels.

As discussed by Lewis (1982) in his review of modern and ancient cases, such shelf-crossing channels/gullies – possibly extending down beyond the shelf edge (see Plate 7) – tend to form in the forefront of highly-constructive (i.e., strongly prograding) deltas. They can be formed by: (1) strong rip currents generated by storms on a low-relief coast; (2) down-dip progression of sediment mass failures on a tectonically steepened shelf; (3) retrogressive slumping initiated at the shelf edge or on the slope; or (4) a combination of these processes.

The second coarsening-upwards regressive parasequence (Fig. 34, profile), deposited after an episode of abrupt marine flooding, culminated in a sandy package of offset-stacked distal deltaic mouth-bar lobes – heralding encroachment of a wave-worked shoal-water delta (*sensu* Leeder *et al*., 1988; Postma, 1990) or mouth bar-type delta (*sensu* Dunne and Hempton, 1984; Wood and Ethridge, 1988). The delta advance was interrupted by another episode of abrupt marine flooding, attributed – same as the previous one – to a rapid tectonic subsidence of the shelf (see Fig. 33B).

The third and last regressive parasequence (Fig. 34, profile) culminated in a sandy package of offsetstacked deltaic mouth-bar lobes with distributary channels (see top-left inset diagram in Fig. 34), which indicates an even greater advance of the shoal-water delta. The shelf subsequently foundered and deep-water sedimentation resumed (Fig. 34, profile top) due to progressive thrusting, when also the Silesian Basin was separated from the Skole Basin (Fig. 33B).

As a whole, the Menilite Beds succession in the excursion area is considered to be a parasequence set recording

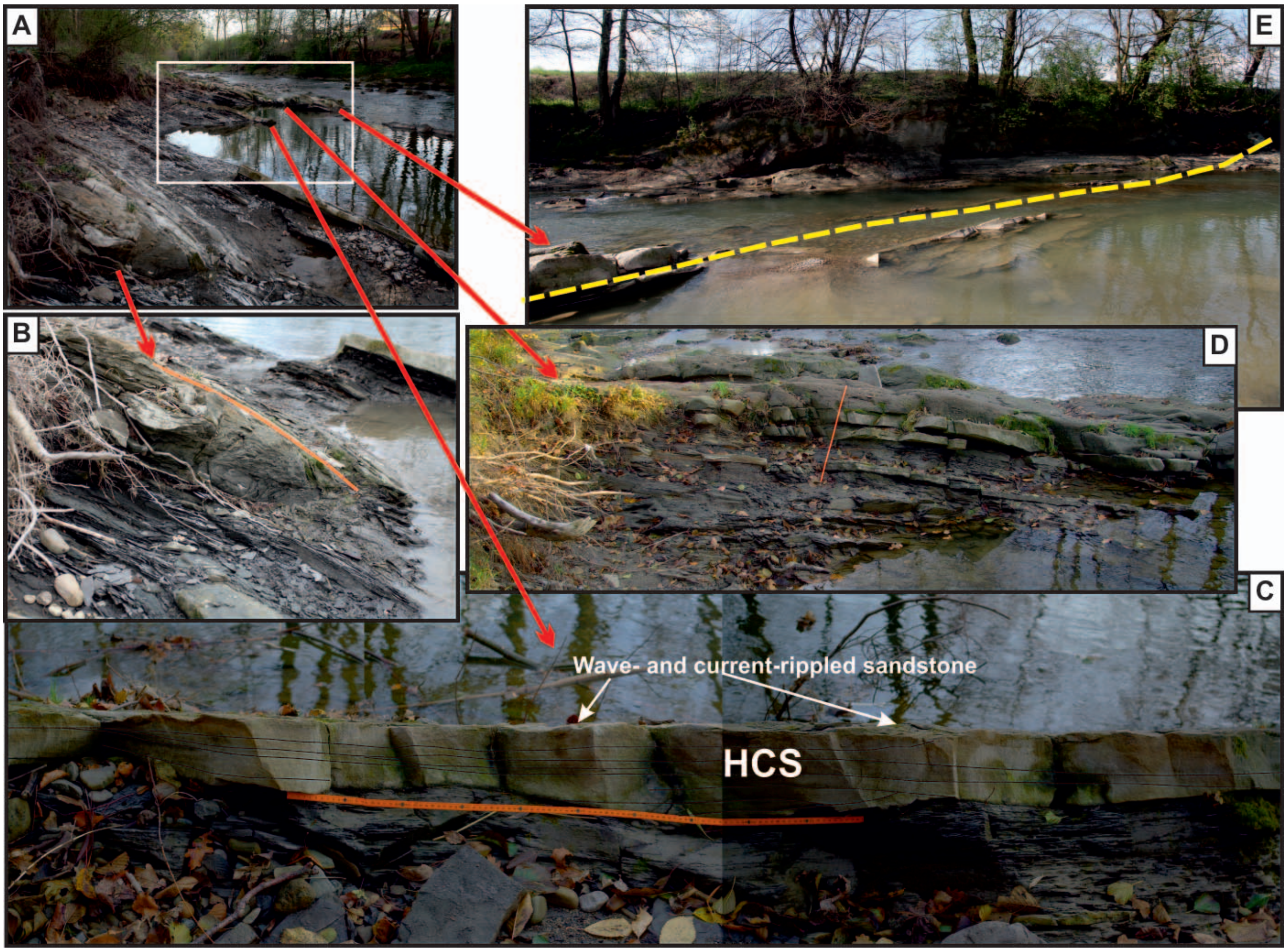

Fig. 35. Outcrop details from the excursion point 5.1 (Figs 31B, 32). (**A**) A typical outcrop of the Menilite Beds in the banks and floor of the Sękówka river. (**B**) Hydroplastically deformed sandstone bed in a heterolithic package, ca. 30 m above the succession base (see log in Fig. 32); the yellow measuring stick is 1 m. (**C**) Sandstone bed with apparent hummocky stratification (HCS), draped with wave- and current-ripple cross-lamination; the yellow measuring stick is 1 m. (**D**) A small-scale coarsening-upwards package of heterolithic deposits capped with hummocky-stratified sandstone beds; the yellow measuring stick is 1 m. (**E**) The sharp erosional base of the sandstone at the top of the heterolithic succession at point 5.1 (see log height of ca. 42 m in Fig. 32).

a tectonically-forced regression punctuated by marine flooding events due to episodic shelf subsidence (incipient structural foundering). The deltaic system is thought to have been 'accommodation-driven' (*sensu* Porębski and Steel, 2003) and hence readily reaching the margin of a narrow shelf. As a shelfedge delta, the Magdalena system and its forefront channels may have supplied considerable volumes of turbiditic sand to the adjacent part of the Silesian Basin where the Menilite Beds were deposited (Fig. 33B; see Porębski and Steel, 2003; Sanchez *et al*., 2012).

Stop description for topic 3

B8.5 Gorlice

Leader: Piotr S. Dziadzio

The outcrops at stop B8.4 also are in the river bedrock banks and floor, and hence wellingtons (high rubber boots) are needed. The excursion aim at this last stop (Fig. 31B) is to show and discuss the key evidence for a shallow-marine origin of the Magdalena Sandstone: the sandstone bodies interpreted as shelf-to-slope palaeochannels; the thinly-bedded heterolithic deposits interpreted as outer-shelf tidalites and distal tempestites; the thicker sandstone beds with apparent HCS and wave-ripple cross-lamination, interpreted as mid-shelf prodelta tempestites; and the offset-stacked parallel-stratified sandstone bodies interpreted as distal to proximal deltaic mouth-bar complexes.

B.5.1–4 (Fig. 31B)

Outcrops in the banks and floor of river Sękówka in its 600-m segment from Gorlice Sokół (49°38′51″ N, 21°10′43″ E) to Gorlice Łęgi (49°38′43” N, 21°11′10″ E)

Point 5.1 – The Sękówka river here (Fig. 31B) exposes the lower boundary and basal part of the Menilite Beds. The Menilite Beds succession commences with a package of grey to brownish-grey siliceous marls that overlie sharply the late Eocene green shales (Fig. 32). Their contact is a tectonic thrust, but perhaps only a few metres of deposits are missing, because the dark brownish-grey shales characteristic of the Menilite Beds occur already as thin interlayers in the underlying package of green shales. Missing here is the regional stratigraphic marker unit known as the Globigerina Marls (Leszczyński, 1997), but the basal part of Menilite Beds, a few metres

Fig. 36. A small-scale coarsening-upwards succession of heterolithic deposits in the middle part of the Menilite Beds profile at the excursion point 5.2 (see Fig. 31B and log in Fig. 32); the measuring stick is 1 m.

Fig. 37. A small-scale coarsening-upwards succession of heterolithic deposits with wave-ripple cross-lamination, overlain by a hummocky-stratified sandstone bed; outcrop detail from the excursion point 5.2 (see Fig. 31B and log in Fig. 32). The measuring stick in the upper photograph is 50 cm.

Fig. 38. Packages of broadly convex-upwards sandstone beds stacked in an offset 'compensational' manner, interpreted to be shingled distal mouth bars of an advancing shoal-water delta (see Fig. 34, upper left). Outcrop detail from the excursion stop 5.3 (see Fig. 31B and log in Fig. 32).

thick, consists of grey and greyish-brown marls above which the typical shales of Menilite Beds appear. These are black and dark-brown, thinly laminated clayshales, with a variable amount of organic matter, interlayered with mudshales and thin siltstones. The shales are sharply, erosively overlain by a thick (5 m) body of poorly sorted, massive sandstone – interpreted as a shelf-margin palaeochannel plugged with sandy deposits of debris flows (*sensu* Lowe, 1982).

The overlying package of heterolithic deposits (22 m thick), with lenticular, wavy and flaser bedding, is intercalated with sheet-like beds of very fine- to fine-grained and occasionally coarse-grained glauconitic sandstones, 10 to 30 cm thick, sporadically up to 60 cm. The sandstone beds occur at random or form, with the underlying heterolithic deposits, small (0.5 to 4 m thick) coarsening-upwards successions (Fig. 35A, D). Some sandstone beds are graded-massive, whereas others show planar parallel stratification, current- and wave-ripple cross-lamination, and occasional hummocky-like stratification (Fig. 35C). Bed tops often show convolutions and some beds are hydroplastically deformed throughout by slump-style folding (Fig. 35B). The sandstone beds are thought to be tempestites (*sensu* Dott and Bourgeois, 1982; Duke *et al*., 1991) and storm-generated turbidites (*sensu* Walker, 1969, 1984) emplaced in a tidally-influenced outer shelf zone. The overlying thick (up to 20 m) body of fine- to very coarse-grained glauconitic sandstones (Fig. 32A) with a sharp erosional base (Fig. 35E), mudclasts and crude upward fining is interpreted to be a shelf-crossing palaeochannel filled through multiple cut-and-fill stages.

Point 5.2 - The river floor here (Fig. 31B) exposes the overlying, coarsening-upwards package of heterolithic deposits (ca. 35 m thick, Fig. 32A) interspersed with sheet-like sandstone beds. The heterolithic deposits often form small-scale coarsening-upwards successions (Fig. 36). The origin of this apparent cyclicity is unclear, but the small parasequences may possibly reflect the impact of the Milankovitch astronomical cycles on the tide and wave climate of the shelf (see De Boer and Smith, 1994; Westerhold *et al*., 2005). The tabular sandstone beds, interpreted as tempestites and storm-derived turbidites, tend here to be thicker than earlier in the succession. Some of the thickest beds show hummocky stratification (Fig. 37). Local gutter casts (Fig. 36) with a SE trend indicate storm-generated geostrophic currents flowing parallel to the shelf strike, as is generally expected for an outer shelf zone (Walker, 1984). The coarsening-upwards heterolithic succession culminates in a 25-m thick sandstone unit (Fig. 32A) composed of broadly lenticular, gently convex-upwards, offset-stacked packages of thin sandstone beds with planar parallel stratification and minor wave-ripple cross-lamination. The lenticular bed packages are interpreted to be shingled, waveworked distal mouth bars of an encroaching shoal-water delta (Fig. 34).

Point 5.3 – The river floor in this segment (Fig. 31B) exposes the next package of coarsening-upwards heterolithic deposits interspersed with sheet-like sandstone beds and culminating in another sandstone unit ca. 25 m thick (Fig. 32A). The heterolithic package again shows small-scale coarsening-upwards cyclothems, some capped with hummocky-stratified sandstone beds. The overlying sandstone unit, much like the previous one (stop 5.2, Fig. 32A), consists of broadly lenticular, gently convex-upwards packages of sandstone beds (Fig. 38) with planar parallel stratification and occasional current- or wave-ripple crosslamination. Many of these offset-stacked packages here are cross-cut by shallow palaeochannels filled with very coarse-grained to pebbly sand. The general palaeotransport direction is to the NE (Szymakowska, 1979), with the palaeochannels trending towards the NE or NNE. This sandstone complex is thought to represent shingled proximal mouth bars of a re-advancing shoal-water delta (Fig. 34).

Point 5.4 – The river floor here (Fig. 31B) exposes the uppermost part of the Menilite Beds succession and its transition to the overlying Krosno Beds (Fig. 32A) whose thick-bedded, quartz-muscovite calcareous sandstones are widely considered to be deep-water turbidites. The top part of the Menilite Beds is heterolithic, with at least two thick (ca. 1 m) erosive beds of massive to trough cross-stratified and ripple-laminated quartz-glauconite sandstone underlain by deformed heterolithic deposits. The Magdalena-type non-calcareous sandstones and Krosno-type calcareous sandstones occur alternatingly in the heterolithic transitional part of the succession. Large slump features occur at the very top of the Menilite Beds succession and are attributed to the shelf instability due its ultimate tectonic foundering (Figs 33, 34).

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Appendix Table 1. Fluxoturbidite facies of the Ciężkowice Sandstone.

Facies (bed varieties)	**Descriptive characteristics**
Facies mS massive non-graded sandstone	Beds of massive (non-stratified) and non-graded coarse sandstone, usually rich in granules, with erosional bases (Fig. 16A, B). Beds are up to a few metres thick and often amalgamated into thicker packages. The deposit is a mixture of sand, granules/small pebbles and some silt. Bedding-parallel alignment of clasts indicates laminar shear, but internal textural discontinuities, inclined local shear banding and relics of scour-fill cross-strata suggest incremental deposition and transient flow turbulence. Some beds show dewatering structures. Rip-up mudstone clasts occur, up to several decimetres in size and usually armoured. These deposits shows locally lateral transition into normal-graded sandstone or conglomerate–sandstone, or planar-stratified sandstone.
Facies tlsS thickly stratified (layered or banded) sandstone	Beds of massive coarse sandstone and granule/fine-pebble conglomerate up to a few metres thick, often erosionally amalgamated, showing thick faint to distinct parallel stratification or banding (Fig. 16C, D). The strata, marked by grain size segregation, are planar or inclined and several millimetres to decimetre in thickness. They form thin laminae sets of fine to medium sand separated by massive coarser-sand layers, or form thicker bands of finer and coarser sand. The inversely- graded layers of fine/medium to coarse sand or granule gravel resemble both the S_2 division of Lowe (1982) and the 'spaced/stepped-laminated' division $T_{B\text{-}3}$ of Talling et al. (2012). The faint stratification is usually slightly undulating, made visible on rock surfaces as alternating delicate, concave/convex bands or spaced ribs by differential weathering. Otherwise, the beds show no overall grading. Some beds have thick massive lower division. An inclined banding or diffuse scour-fill cross-stratification are sporadically observed at the bed bases.
Facies gS graded massive sandstone or fine conglomerate to sandstone	Beds of graded massive coarse sandstone (often with scattered pebbles) or fine-grained conglomerate passing upwards into coarse sandstone (Fig. 16E–H), up to a few metres thick, isolated or amalgamated into thicker packages. Bed bases are erosional and occasionally show load casts. This is the most common facies of the Ciężkowice Sandstone. The gravelly division is inversely graded in its basal part in some cases. Mudstone rip-up clasts, up to a few decimetres in size and usually armoured, occur in the lower or upper part of some beds, particularly at the transition from coarse- to finer-grained sandstone. The massive sandstone shows locally dewatering structures in the upper part. The flat bed tops are occasionally capped with a thin Bouma-type turbidite Tbcd or Tde.
Facies gsS graded-stratified sandstone or fine conglomerate to sandstone	Beds of graded-stratified coarse sandstone or fine-grained conglomerate passing upwards into sandstone, up to a few metres thick (Fig. 16I–L). The lower parts of beds are usually massive and normally graded, but the conglomeratic ones occasionally show inverse grading at the base. Mudstone rip-up clasts, up to several decimetres in size and usually armoured, occur in the massive part of some beds. Stratification resembles that in facies tlsS and is most visible at the conglomerate/sandstone transition, including planar, inclined and trough-shaped scour-fill varieties. Pebbles tend to show flow-aligned imbricate fabric. Beds with flat, non-truncated top are usually capped with a Bouma-type fine-grained turbidite Tbcd or Tde. Beds with a massive upper part tend to show dewatering structures.
Facies Scl sandstone with conglomerate lenses	Beds of graded-stratified coarse sandstone or fine-grained conglomerate passing upward to sandstone, up to a few metres thick (Fig. 16M, N). Stratification is accentuated by flat lenses of granule and/or fine-pebble conglomerate, isolated or multiple, occurring in bed lower parts. The upper parts of beds show planar parallel stratification as in the Bouma turbidite b-division.

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