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RECONSTRUCTION OF AN EARLY PENNSYLVANIAN FLUVIAL SYSTEM BASED ON GEOMETRY OF SANDSTONE BODIES AND COAL SEAMS: THE ZABRZE BEDS OF THE UPPER SILESIA COAL BASIN, POLAND

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Abstract. The Zabrze Beds (Kinderscoutian), together with the underlying Jejkowice Beds (late Chokerian–Alportian) of local extent, are the oldest deposits of the fully terrestrial phase of sedimentation in the Upper Silesia Coal Basin. The maximum thickness zone of Zabrze Beds is trending SSW–NNE and reflects the migrating narrow zone of basin-floor main subsidence. The westward erosional termination of Zabrze Beds is due to the tectonic thrusting of the Devonian to Mississippian rocks of the Variscan Moravo-Silesian orogen, whereas their eastward thinning and pinch-out towards the craton of Małopolska Block is due to the related forebulge growth. The present-day tectonic structure of the basin, with the east-trending Main Anticline near Zabrze, is due to the Cenozoic northward thrusting of the Carpathian orogenic front. The deposition of Zabrze Beds occurred in a north-trending alluvial valley formed and filled in by a bedload-dominated, sandy river system. In the southern part of the basin, the alluvial deposits are characterized by numerous thick, multistorey, sheet-like channel-belt sandstone bodies with sparse overbank and phytogenic deposits, indicating a braided river system. This alluvial architecture passes northwards – in the basin's area of Main Anticline – into an architecture composed of smaller, isolated sandstone bodies of single-storey channel belts with a much higher relative proportion of overbank and phytogenic deposits, indicating a meandering river system. The down-valley transformation of the fluvial system from braided into meandering is attributed to such factors as a spatially differential sediment supply to the system and a non-uniform axial valley gradient.

Key words: Channel-belt sandbodies, overbank deposits, phytogenic deposits, braided river, meandering river, downstream transformation.

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INTRODUCTION

The Upper Silesia Coal Basin straddles the border areas of southern Poland and north-eastern Czech Republic (Fig. 1). The terrestrial basin formed in the early Pennsylvanian as a subsiding foreland of the Moravo-Silesian orogen. The present-day triangular remnant of an originally larger basin (Unrug and Dembowski, 1971) – squeezed tectonically between the Moravo-Silesian orogen, the cratonic Małopolska Block and the Cenozoic Outer Carpathian thrust front (Fig. 1) – has an area of about 7400 km^2. It is bounded on its NE side by the strike-slip Kraków-Lubliniec Fault Zone (Fig. 1). The southern extent of the basin is known only from deep boreholes drilled through the Outer Carpathian nappes and Miocene foredeep deposits. To the NW, the basin is bounded by a nappe complex of Devonian to Mississippian deposits of the Moravo-Silesian orogen (Fig. 1). The basin formed and subsided as a flexural foredeep (Gradziński, 1982) under the crustal loading of this Variscan nappe complex, with the zone of maximum subsidence parallel to the orogen front and declining eastwards towards the Małopolska Block (Fig. 1). The axial fluvial drainage in the basin was directed to the north (NNE), parallel to the orogenic front, as the basin gradually migrated eastwards and a progressive cannibalisation of its older deposits occurred (Gradziński, 1982). The coal-bearing basin-fill succession comprises the following informal lithostratigraphic units: the basal Paralic Series overlain by the fluvial sandstones and conglomeratic deposits of the Upper Silesia Sandstone Series, which is separated by the floodplain-dominated Mudstone Series from the upper fluvial deposits of the Cracow Sandstone Series (Fig. 1). The lithostratigraphic changes are attributed to an interplay of the basin subsidence rate and the rate of clastic sediment supply from the Variscan orogen (Gra-

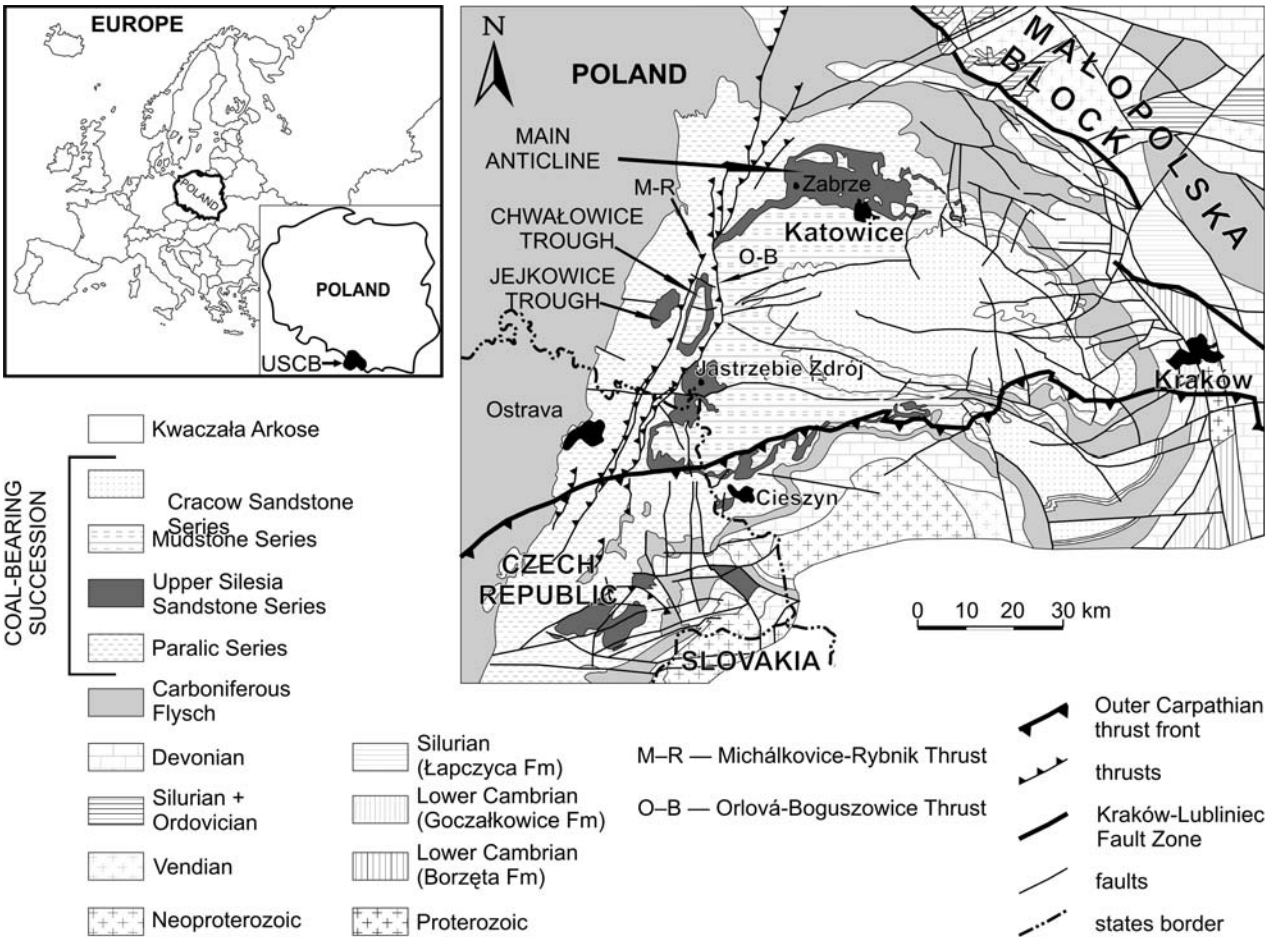

Fig. 1. The location and geological map of the Upper Silesia Coal Basin (based on Buła and Żaba, 2005).

dziński, 1982), with the lateral and vertical variation in phytogenic accumulation controlled mainly by fluvial autogenic factors (Doktor and Gradziński, 2000).

The present study focuses on the Zabrze Beds of the Upper Silesia Sandstone Series, which are alluvial deposits representing the earliest stage of a fully terrestrial sedimentation in the basin. Biostratigraphic dating indicates a Kinderscoutian age of the Zabrze Beds and a major stratigraphic gap (Chokerian–Alportian) separating these deposits from the underlying Paralic Series (Gothan, 1913, *fide* Stopa, 1957a). This regional "floristic break" corresponds to the Mid-Namurian Eustatic Event (MNEE) related to the Erzgebirge tectonic phase of Variscan orogeny, which caused uplift and erosion in many Late Carboniferous basins or a shift from marine to paralic and delta-plain conditions in others (Cleal *et al.*, 2009).

The sedimentological reconstruction of the fluvial system of Zabrze Beds is based on a 3D analysis of the geometry and vertical stacking pattern of channel-belt sandstone bodies and on the relative proportion of associated overbank and phytogenic deposits in the Kinderscoutian basin-fill succession. The Zabrze Beds have almost no surficial outcrops and the analysis is thus based on an archive of lithostratigraphic evidence from more than 1500 boreholes, supplemented with observations from a few available borehole cores and local observations from coalmine galleries. The coal seams and their stratigraphic order (numbers), well-established through the decades of mining, are used as correlative horizons. There are 10 main (mineable) coal seams recognized in the Zabrze Beds in the Polish part of the basin.

The numbering system for coal seams in the Polish part of the basin (Doktorowicz-Hrebnicki and Bocheński, 1952) employs 3-digit numbers, beginning from the youngest seam. The first (index) digit indicates the lithostratigraphic unit and the next two digits indicate the seam's stratigraphic position within the unit. For the Zabrze Beds, the index number is 5 and the coal seams are accordingly numbered as 501 to 510 from the youngest to the oldest. A similar system of coal-seam numbering is used in the Czech part of the basin, but beginning from the oldest seam (see Martinec *et al.*, 2005). The Zabrze Beds there, known as "Vrstvy Sedlove", contain 8 well-correlative and 52 less correlative coal seams – numbered as 504 to 564 from the oldest to the youngest. Yet another, parallel numbering system is also used for the coal seams in the Czech area, with the oldest seam 504 labelled as 40 (Prokop seam) and the youngest seam 564 labelled as 33a (see Dopita *et al.*, 1997, tab. 26).

The use of coal seams as basin-scale correlative horizons obviously requires much caution, because the coal seams tend to split or merge laterally (Doktor and Gradziński, 1985; Gradziński, 1994; Kędzior, 2008). However, coal seams are the only option as possible stratigraphic markers in the present case, and their extensive mining over the last 100 years confirms their numbering system as an acceptable framework for stratigraphic correlations.

The principal aim of this article is to offer a new sedimentological reconstruction and palaeogeographic interpretation of the alluvial system of Zabrze Beds and also to consider a possible sequence-stratigraphic scenario for the late Namurian sedimentation in the Upper Silesia Coal Basin.

STRATIGRAPHY OF THE ZABRZE BEDS

The Carboniferous coal-bearing succession in the Polish part of the basin is divided into two parts (Dembowski, 1972). The lower part, known as the Paralic Series, is characterized by the occurrence of marine and brackish fauna marking marine influences due to eustatic sea-level changes (Doktor and Gradziński, 1999). The upper part, fully terrestrial, is divided into three informal lithostratigraphic units: the fluvial Upper Silesia Sandstone Series (coeval with the lower Karvina Formation in the Czech part of the basin; Dopita *et al.*, 1997), the floodplain-dominated Mudstone Series and the overlying fluvial Cracow Sandstone Series. These units are divided further into subunits referred to traditionally as "beds" (Fig. 2). The Zabrze Beds, known earlier as "Warstwy Siodłowe" ("Anticlinal Beds") (Doktorowicz-Hrebnicki and Bocheński, 1952) and similarly referred to as "Vrstvy Sedlove" in the Czech part of the basin, are underlain in the mid-basin area near Rybnik by the Chokerian coal-lacking sandy/gravelly Jejkowice Beds (Jureczka and Kotasowa, 1988) and are overlain by the Yeadonian Ruda Beds *s.s.* (Fig. 2). The Zabrze Beds, with the underlying Jejkowice Beds of local extent, mark the onset of a fully terrestrial sedimentation in the basin. Beyond the narrow occurrence area of Jejkowice Beds, the Zabrze Beds rest directly on the Grodziec/Poruba Beds, the Arnsbergian youngest unit of the Paralic Series (Fig. 2).

The lower boundary of the Zabrze Beds is generally placed at the base of the widespread coal seam 510 in the Polish part and seam 504 (Prokop seam or No. 40) in the Czech part of the basin. In the area of the occurrence of Jejkowice Beds near Rybnik, SSE of Katowice, this coal seam is absent and the lower boundary of the Zabrze Beds is placed within a thick local unit of coal-lacking coarse-grained deposits. The deposition of Zabrze Beds was preceded by a phase of erosion that removed the topmost part of the Paralic Series and culminated in the localized deposition of fluvial Jejkowice Beds (Fig. 2; Matl, 1965, 1966, 1967, 1969; Jureczka, 1988). The upper boundary of the Jejkowice Beds was placed by Jureczka (1988) at the base of the oldest mineable coal seam of the Zabrze Beds in the area. Kotas *et al.* (1988) and Kotas (1995) considered the Jejkowice Beds to be the oldest part of the Upper Silesia Sandstone Series (Fig. 2), with a hypothetical erosional gap separating the lower part of this coarse-grained clastic unit from its upper part.

The upper boundary of the Zabrze Beds is placed at the top of coal seam 501 in the Polish part or the equivalent coal seam 564 (or 33a) in the Czech part of the basin. However,

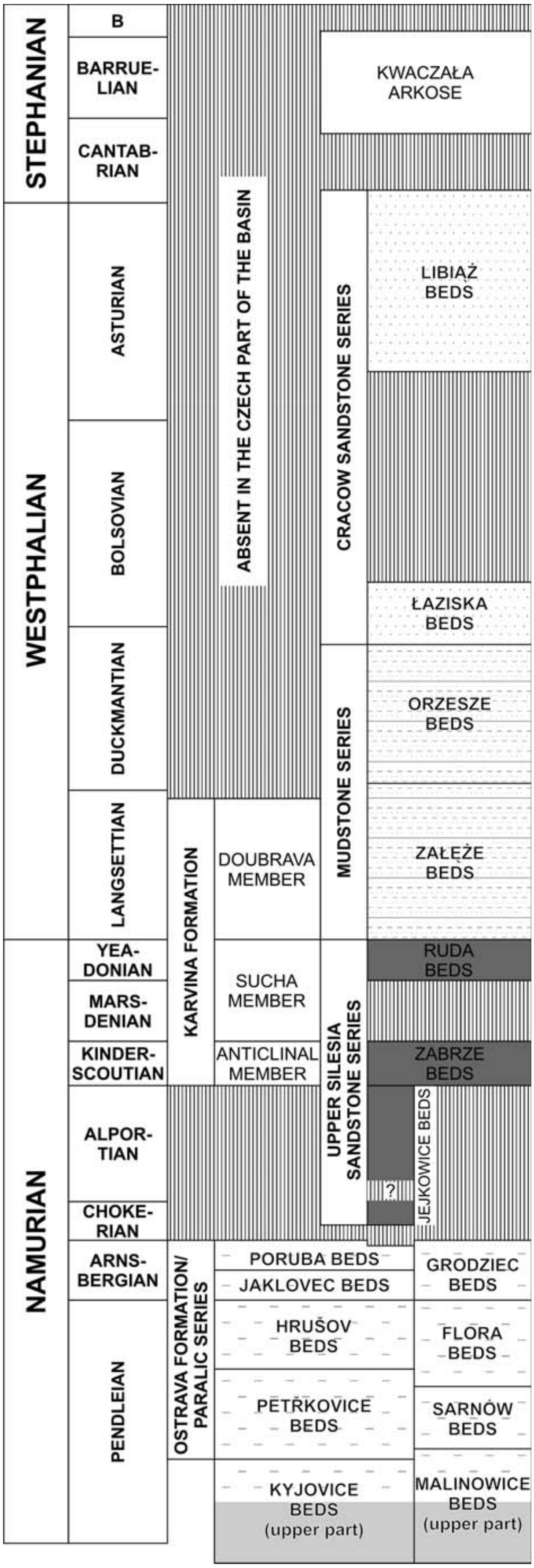

Fig. 2. Pennsylvanian stratigraphy of the Upper Silesia Coal Basin (modified from Cleal *et al.*, 2009).

Fig. 3. The location of boreholes (grey dots) and geological cross-sections (shown in Figs 16–21) in the Upper Silesia Coal Basin.

the boundary is difficult to trace precisely on a regional scale, because this coal seam is laterally discontinuous due to its local erosion and is also locally coalescing with the younger seams ascribed to the Ruda Beds *s.s.* (Stopa, 1957a; Kędzior, 2008).

The succession of Zabrze Beds has an approximate mean thickness of about 150 m. In the best-explored area of Main Anticline in the northern part of the basin (Fig. 1), the thickness of Zabrze Beds (or Warstwy Siodłowe) – within the unit's stratigraphic boundaries defined by Kotas and Malczyk (1972) – decreases from 250 m in the west (Kędzior, 2001, 2008) to a complete eastward wedge-out over a distance of about 40 km. The maximum thickness of Zabrze Beds increases southwards to 280–300 m in the Chwałowice Through and the Jastrzębie Zdrój area near the Polish/Czech border (Fig. 1), and further to about 350 m in the Karvina–Ostrava area of NE Czech Republic (Fig. 1; Pešek *et al.*, 1998). There is a general thinning of the Zabrze Beds in the NE direction, towards the Variscan forebulge zone of Małopolska Block (Fig. 1), with coal-seam coalescence and pinch-out. The western and northern extent of the Zabrze Beds is limited by their erosion, whereas the southern extent is hidden under the Outer Carpathians nappes.

The original depositional area of the Zabrze Beds had an extent considerably larger than the present-day lateral extent of this unit, particularly in the S–N direction (see Unrug and Dembowski, 1971). The deposition of the Zabrze Beds was interpreted to have occurred on a broad alluvial plain (Unrug and Dembowski, 1971; Gradziński, 1982) involving meandering and distal braided sandy rivers (Doktor and Gradziński, 2000; Kędzior, 2008). The thicker sandstone bodies are considered to represent fluvial channel belts, whereas the thinner ones with associated muddy and phytogenic deposits are ascribed to overbank environment (Kotas and Malczyk, 1972; Kędzior, 2008). A preliminary attempt to reconstruct the geometry and spatial trend of channel belts was made by Mirkowski (1999), with a focus on sandstone bodies overlying erosionally the basal coal seam of the Zabrze Beds. The channel belts, made of sandstones and intraformational conglomerates, were shown to be sinuous with a general direction towards the NE, parallel to the Moravo-Silesian orogen front. A similar direction of fluvial drainage was postulated earlier by Gradziński *et al.* (1961) on the basis of cross-strata measurements from coalmine galleries and was also later confirmed by Kędzior (2001).

A contentious issue was the palaeogeographic location of the Namurian marine shoreline. Gradziński *et al.* (1961) tentatively suggested that the sea during the deposition of the underlying Paralic Series was located to the NW or W in relation to the basin, but postulated a change of the NNW direction of fluvial drainage in Namurian A to a SE or E direction in Namurian B, when the basin became fully terrestrial. The marine shoreline since Namurian B might then be located somewhere to the SE or E in relation to the basin. However, the latter palaeogeographic suggestion were highly hypothetical because the measurements of cross-strata directions acquired from coalmine galleries were few and the channel belts were recognized as sinuous, and hence highly varied in their local flow direction. Notably, Paszkowski *et al.* (1995) in a study of the basin's Westphalian paleogeography have postulated a fluvial drainage system directed to the NE along the axis of a narrow Variscan foredeep basin with the main sand and gravel supply from the Moravo-Silesian orogen (NW) and with an elevated eastern (ENE) forebulge flank of the basin. The contemporaneous shoreline would then be located to the NE.

On the account of the foredeep apparent narrowness with an eastward pinch-out of coal seams, the NE trend of early Kinderscoutian channel belts (Mirkowski, 1999; Kędzior, 2001) and the preceding Chokerian–Alportian stratigraphic gap (Fig. 2) – it seems likely that the fluvial drainage system during the deposition of Zabrze Beds was filling in a basin-axis valley and flowing to the NE, towards a deeper-subsided, sea-occupied or endorheic segment of the foredeep.

THE DATABASE, METHODS AND TERMINOLOGY

After more than a century of intense coal mining, the Zabrze Beds are no longer a target of exploitation and exploration. The present study is based chiefly on an archive database of more than 1500 boreholes (Fig. 3) drilled over a century of exploration, many of them drilled directly from the surface and some shorter ones drilled underground, nearly all fully cored. The available documentation of borehole profiles is generally limited to the distinction of basic lithofacies, such as conglomerate, sandstone, mudstone (shale), shaly coal and coal. More detailed sedimentological data have been acquired from the available cores of a few latest boreholes drilled in the SW Polish part of the basin and in the area of Darkov Coal Mine in the Czech part. All the borehole data have been compiled in a spreadsheet (available from the author upon request) and used for the construction of cross-sections and maps shown in this paper. The selection of cross-section lines, some of them oblique to the basin axis (see lines B–B' and C–C' in Fig. 3), was guided by the choice of boreholes showing a most complete stratigraphic profile of the Zabrze Beds.

Series of cross-sections were used for the geometrical reconstruction of channel-belt sandstone bodies and coal seams. Stratigraphic correlations were based on the established regional system of coal-seam numbers (see earlier text). For the Czech part of the basin and the Cieszyn area at the Czech/Polish border (Fig. 3), where the complete profile of Zabrze Beds is only locally preserved after the post-Carboniferous erosion, the extensive coal seam 504 (Prokop seam 40) was chosen as the main and most reliable stratigraphic marker. For the area of Jastrzębie Zdrój (Fig. 3), the extensive coal seam 505 (Polish nomenclature) was most useful as a leading marker, because the oldest marker seam (510) is missing there due to semi-contemporaneous erosion and also the identification of the youngest seam (501) is uncertain. For the Rybnik area and the area of the Main Anticline around Katowice (Fig. 3), the youngest coal seam (501) was used the main correlative horizon, although the correctness of this seam identification in mine works is locally uncertain.

The descriptive sedimentological terminology is according to Harms *et al.* (1975, 1982) and Collinson *et al.* (2006), and the sequence-stratigraphic nomenclature is according to Catuneanu (2006) and Helland-Hansen (2009). The classification of fluvial channel-belt sandstone bodies is after Friend (1983). Accordingly, the term "simple channel body" denotes a solitary, isolated channel belt formed by a single episode of channel incision, infilling and abandonment, whereas the term "multistorey channel body" denotes a vertical stack of two or more channel belts superimposed directly upon one another.

LITHOFACIES

Lithofacies (or sedimentary facies) are defined as the basic types of deposits distinguished on the descriptive basis of their bulk macroscopic characteristics, including texture, sedimentary structures and biogenic features (Walker, 1984). Different lithofacies indicate different hydraulic conditions of sediment deposition, and although few lithofacies alone may be environmentally diagnostic – their assemblages are good indicators of sedimentary environments or subenvironments (e.g., Nemec, 1984, 1992; Doktor, 2007). Eleven lithofacies – ranging from conglomeratic and sandy to muddy and coaly deposits – have been distinguished in the present study. They are given letter symbols and short descriptive labels, and their descriptions and interpretations are separated in the text.

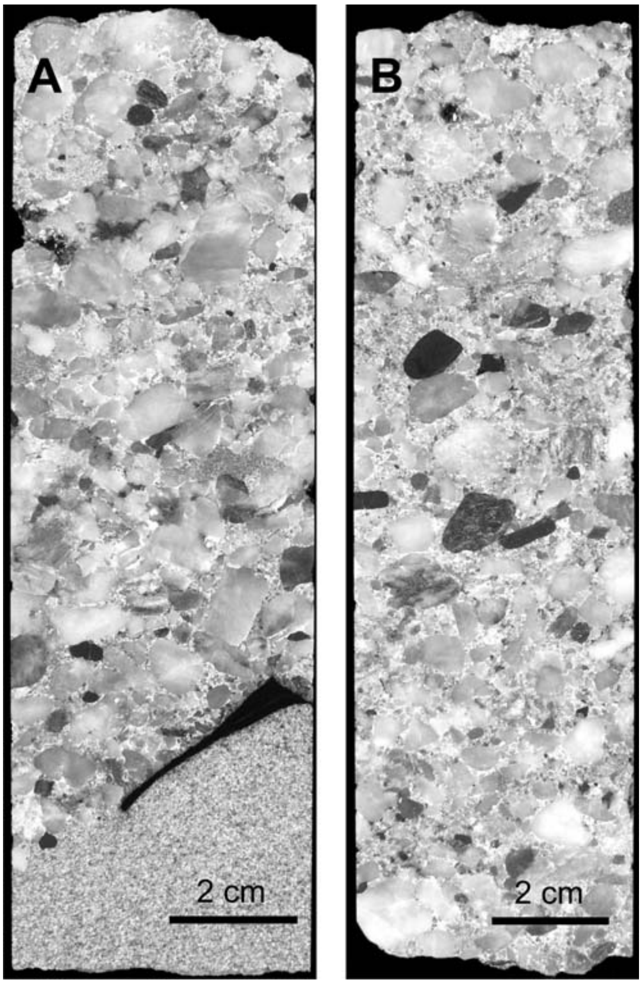

Fig. 4. Examples of lithofacies CG. Borehole cores from the Darkov Coal Mine, depth 78.3 m (**A**) and 88.9 m (**B**).

Lithofacies CG: Conglomerates

Description. The conglomerates (Fig. 4) vary from clast-supported to matrix-supported, often with a single bed, and are generally massive, with no visible stratification, although some plane-parallel alignment of elongate clasts is locally recognizable. Clast composition includes mainly quartz, accompanied by subordinate extrabasinal lithic components (Paszkowski *et al.*, 1995) and also intrabasinal components, such as mudstone, sandstone and coal fragments. Clast size is mainly in the range of 2–3 cm and only occasionally exceeds 5 cm. Clasts are generally rounded, although intrabasinal clasts are commonly subangular to subrounded (Fig. 4). The conglomerate units (beds) occur as isolated and their thickness varies from a few centimetres to nearly 1.5 m. These beds have sharp lower boundaries, often distinctly erosional, whereas their upper boundaries are usually a transition to sandstone.

Interpretation. The thinner conglomerate beds, a few clasts thick, are interpreted as channel-floor lag deposits, variously infiltrated with sand (see Miall, 1977; Nemec and Postma, 1993). The thicker beds probably represent low-relief gravelly longitudinal bars, likewise variously infiltrated with sand and also sand-richer in their downstream tail parts

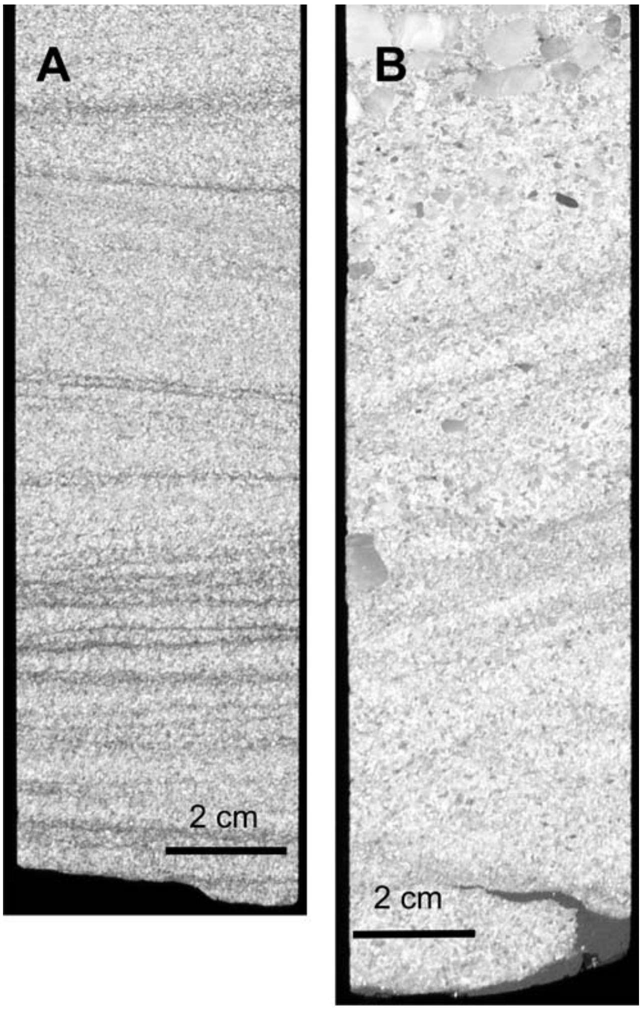

Fig. 5. Examples of lithofacies SL. Borehole cores from the Darkov Coal Mine, depth 127.5 m (**A**) and 99.7 m (**B**). The non-parallel and slightly concave-up boundaries of strata sets in A indicate trough cross-stratification.

(see Rust, 1978; Nemec and Postma, 1993). The lack of high-angle cross-stratification precludes transverse or oblique braid-bars (cf. Steel and Thompson, 1983; Miall, 1996) as well as some fully developed deep-channel longitudinal bars (cf. Bluck, 1976). The gravel bars in the present case apparently formed briefly as transient channel-floor bedforms directly after channel incision, at the stage of highest flow power and gravel transport.

Lithofacies SM: Massive sandstones

Description. These are fine- to medium/coarse-grained sandstones with no clear stratification (Fig. 4A, base), except for faint local traces of indistinct parallel strata. Individual units are a few centimetres and to nearly 2.5 m thick, but mainly in the range of 15–50 cm. They have sharp boundaries where overlain or overlain by lithofacies CG, but show diffuse transitional boundaries where associated with other sandstone facies, typically SH or SL (described below).

Interpretation. Massive sandstones in fluvial settings are commonly attributed to local sediment gravity flows (Jones and Rust, 1983; Rust and Jones, 1987; Turner and Monro, 1987; Wizevich, 1992), typically related to braid-bar incision (Hodgson, 1978) or small gullies resulting from bank collapse (Miall, 1996). In the present case, the characteristics and sedimentary context of massive sandstone units suggest substrate liquefaction under the bed-shearing load of bank-full river discharge with a rapid emplacement of channel-floor gravel lag (Fig. 4A), or – in association with other sandstone lithofacies – may indicate episodes of a non-selective rapid deposition (Lowe, 1988), typical of a hyperconcentrated flow (Nemec, 2009) and generally ascribed to peak-flow events (Conaghan and Jones, 1975; Wasson, 1977, 1979; Conaghan, 1980; Wizevich, 1991, 1992; Benvenutti and Martini, 2002).

Lithofacies SL: Large-scale cross-stratified sandstones

Description. These are mainly medium- to coarse-grained sandstones, showing high-angle (15°–25°) cross-stratification (Fig. 5). The inclined parallel strata are marked by subtle grain-size changes and a local concentration of plant detritus or granule grains. The measured thicknesses of cross-strata sets generally exceed 7 cm (the boundary between ripple and dune bedforms; Ashley, 1990), and their cosets are a few decimetres to nearly 7 m thick. The lithofacies units (cross-strata cosets) have non-erosional, depositional to transitional boundaries where underlain and overlain by lithofacies SH or SM, but the lower boundary is sharp where the underlying lithofacies is CG or SM, or is even slightly erosional where the underlying lithofacies is coaly (C) or fine-grained (HE, FH or FM).

As a cautionary remark, it should emphasized that the distinction between high-angle and low-angle or even horizontal stratification in well-core samples is generally difficult. An arbitrary visual criterion of strata inclination 15° has been used, but this does not preclude that some units of this lithofacies may have been misclassified as lithofacies SH (described below). Furthermore, the small diameter of core samples seldom allows distinguishing between trough and planar cross-stratification, and hence sandstones with either of these stratification types are here lumped jointly into one lithofacies.

Interpretation. Large-scale cross-stratification indicates sand transport and deposition in the form of subaqueous dunes (Ashley, 1990), which means bedforms of the upper part of lower flow regime (Harms *et al.*, 1982). A slightly higher flow power would correspond to 3D dunes (trough cross-stratification), relative to 2D dunes (planar cross-stratification), but the distinction between these dune types in borehole cores is nearly impossible, with some local exceptions (Fig. 5). The formation of dunes requires a water flow depth at least 3 times greater than the dune height (Harms *et al.*, 1982), which generally means a confined, channelized flow. Dunes in fluvial channels are formed as components of migrating channel bars and possibly as bedforms of the late-stage thalweg channel-fill (Collinson, 1970; Miall, 1996; Bridge, 2003).

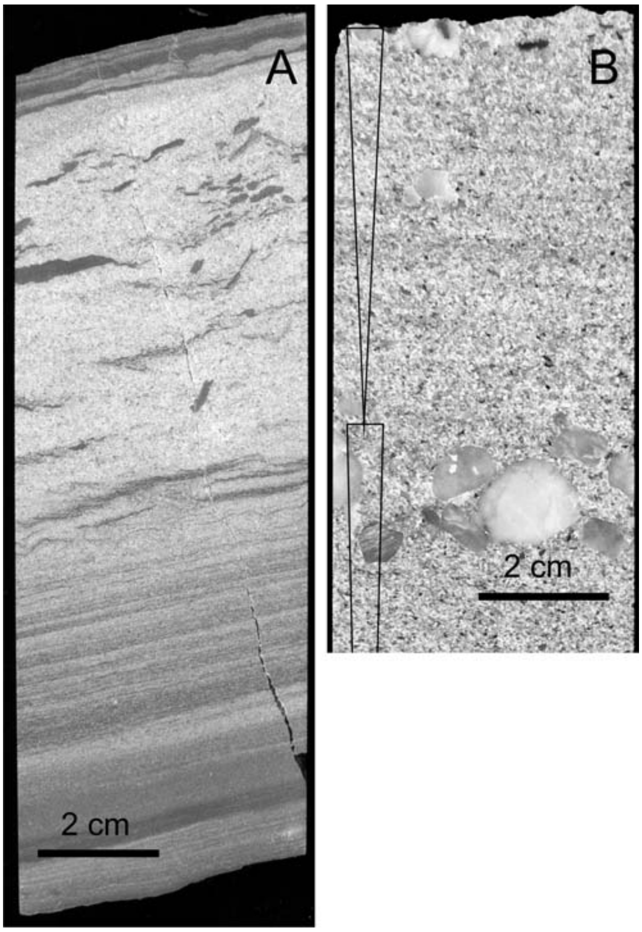

Fig. 6. Examples of lithofacies SH. Borehole cores from the Darkov Coal Mine, depth 189.5 m (**A**) and 76.6 m (**B**). Lithofacies SH passes upwards into lithofacies SW in A. Note the gentle primary inclination of coarsening-upwards strata sets in B.

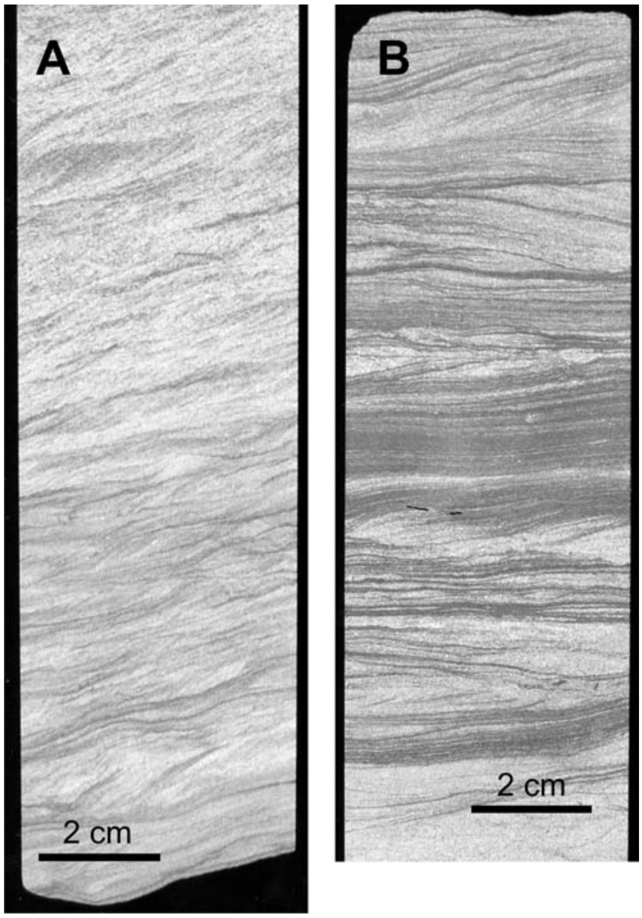

Fig. 7. Examples of lithofacies SR. Borehole cores from the Darkov Coal Mine, depth 44.6 m (**A**) and 96.4 m (**B**).

Lithofacies SH: Planar parallel-stratified sandstones

Description. These sandstones (Fig. 6) range from fine- and medium-grained to very coarse-grained and pebbly, and show plane-parallel stratification, originally horizontal or very gently (<10°) inclined. Stratification is marked by grain-size changes, as well as by the accumulation of minute plant detritus, mud chips (Fig. 6A) or granules and small pebbles (Fig. 6B). Stratification in the coarse-grained varieties of lithofacies SH is often diffuse, showing gently-inclined, coarsening-upwards strata packages 5–10 cm thick (Fig. 6B). The bed thickness of this lithofacies is mainly less than 50 cm, only sporadically exceeding 1 m. The individual units (beds) have gradational to sharp boundaries. The lower boundary is texturally gradational where lithofacies SH is underlain by lithofacies SM, but is sharp where the underlying lithofacies is sandstone SR or SW, or a siltstone or mudstone. The upper boundary tends to be texturally gradational, but is sharp where the overlying lithofacies is siltstone or mudstone.

Interpretation. Planar parallel stratification indicates plane-bed transport and deposition of sand in the upper flow regime (Harms *et al.*, 1982). The depositing flow is subcritical, but its Froude number may be close to $Fr = 1$ (Ashley, 1990), which would generally correspond to flood peak discharges, unless the flow is too shallow for the development of dunes while its velocity is too high for the formation of ripples (Miall, 1996; Bridge, 2003; Collinson *et al.*, 2006). The gentle inclination and coarsening-upward trend of strata packages in the coarse-grained varieties of lithofacies SH, rich in granules and pebble stringers (Fig. 6B), may represent sediment accretion in the downstream "tails" of longitudinal bars by consecutive flood events (cf. Nemec and Postma, 1993).

Lithofacies SR: Ripple cross-laminated sandstones

Description. These sandstones are mainly very fine- to fine-grained, subordinately medium-grained, and show ripple cross-lamination (Fig. 7). The thickness of the individual units of this lithofacies does not exceed 1 m and is mainly less than 50 cm. Cross-lamina sets are mainly 1–3 cm thick. They commonly contain silty (darker-colour) intra-laminae and are capped by such laminae, often enriched in mica flakes, mud and minute plant detritus. Climbing-ripple cross-lamination is only locally recognizable, as its identification in borehole cores depends strongly on the orientation of core-cut surface. The lower and upper boundaries of this lithofacies are texturally gradational where representing an upward transition from/to lithofacies SH, SL, SW or HE

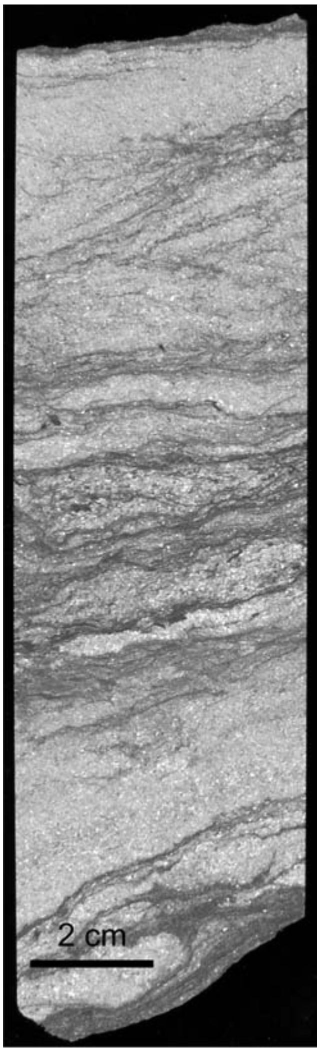

Fig. 8. Example of lithofacies SW. Borehole core from the Darkov Coal Mine, depth 138.6 m.

(described below), but are sharp where the adjoining lithofacies is muddy or coaly.

Interpretation. This lithofacies represnts sand transport and deposition in the form of migrating ripples, generally small, by currents in the lowest part of lower flow regime (Harms *et al.*, 1982). Silty inter-laminae and ripple drapes indicate a highly pulsating, waning–waxing and generally weak flow. Climbing-ripple cross-lamination indicates a high rate of sediment suspension fall-out relative to the rate of ripple migration (Harms *et al.*, 1982; Collinson *et al.*, 2006).

Lithofacies SW: Wavy- and flaser-bedded sandy heterolithic deposits

Description. This lithofacies (Fig. 8) comprises sand-dominated heterolithic deposits showing flaser to wavy bedding (*sensu* Reineck and Wunderlich, 1968). The sandstone layers are mainly very fine- to fine-grained, up to 3 cm thick, and show ripple cross-lamination, commonly deformed hydroplastically by sedimentary loading. They are irregularly draped with thin (1–3 mm), darker-colour mudstone or siltstone interlayers, laterally discontinuous or continuous

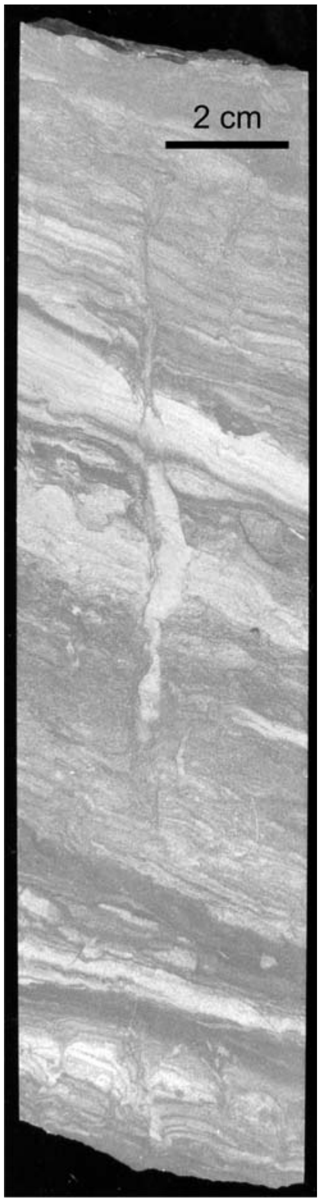

Fig. 9. Example of lithofacies SRR; the vertical plant-root traces suggest a channel levee deposit inclined to the right. Borehole core from the Darkov Coal Mine, depth 113.7 m.

on the scale of core-sample width. The muddy layers are enriched in mica and contain fine-grained, coalified plant detritus. The units of this lithofacies have thicknesses from a dozen to several tens of centimetres and are most commonly underlain and/or overlain by lithofacies SR or HE, with transitional boundaries.

Interpretation. The depositional conditions of lithofacies SW are thought to have resembled those of lithofacies SR, with a weak and highly fluctuating flow, but with more pronounced episodes of flow slackening – when the silty and muddy drapes formed by suspension fall-out. The depositing current was apparently unidirectional, as no evidence of palaeocurrent reversals have been found. Such depositional conditions are generally characteristic of alluvial floodplains, butmay also occur in abandoned fluvial channels (Miall, 1996; Bridge, 2003). The intercalation of lithofacies SW with lithofacies SR and HE supports this interpretation.

Lithofacies SRR: Sandy palaeosols

Description. These deposits range from fine-grained sandstones to sand- or mud-dominated heterolithic layers, a dozen to several tens of centimetres thick, which are characteristically penetrated by plant roots (Fig. 9). Several successive generations of plant roots are commonly recognizable as superimposed upon one another after consecutive episodes of sediment vertical accretion (Fig. 9). The individual root traces are mainly less than 5 mm wide, only sporadically recognizable as branching, and their discernible depth of substrate penetration is usually around a dozen centimetres. The primary structure of root-hosting clastic sediment is often blurred or partially erased by phytogenic bioturbation, but is readily recognizable in units with only isolated root traces and appears to be no different than in the underlying non-bioturbated deposit (Fig. 9). The lower boundary of the units of this lithofacies is always texturally transitional. The individual units are occasionally covered with a thin coaly lithofacies C (described below), but are otherwise overlain sharply by sandy or sand-dominated heterolithic deposit in the studied borehole cores.
Interpretation. The units of this lithofacies are interpreted to be palaeosol (seatearth) horizons. Although not a depositional lithofacies in the same hydraulic sense as the other ones, palaeosols are a recognizable record of specific environmental conditions – with an active plant growth, water-soaked substrate and minimized input of clastic sediment. The vegetated substrate apparently ranged from sandy to heterolithic, which may represent such alluvial subenvironments as gently sloping channel-bank levees (cf. Fig. 9), overbank floodplain areas or abandoned river channels. The multi-generational plant rooting indicates subenvironments with a persistent vegetation growth, but with little or no potential for peat accumulation and burial. In the studied borehole cores, only some of the lithofacies SRR units are overlain by thin coaly lithofacies C, which indicates that the associated peat deposit was either removed by erosion or destroyed by a temporal fall of groundwater level and peat oxidation (rotting). These interpretative notions are supported by both the occurrence of other sandstone lithofacies directly above lithofacies SRR and the scarcity of carbonaceous plant-root filaments (cf. Retallack, 1990). The regional palaeoclimate was apparently humid to promote the growth of vegetation, but the groundwater level probably fluctuated between river-flood events and the substrate was only locally and episodically hospitable to the accumulation and burial of peat deposits (cf. Nemec, 1992).

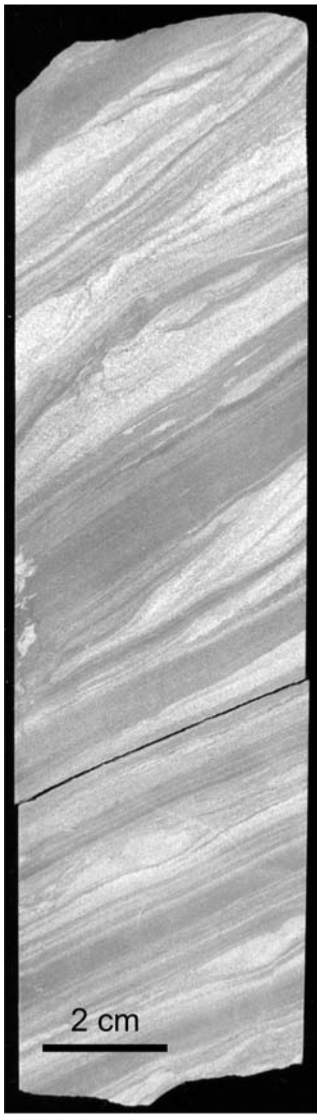

Fig. 10. Example of lithofacies HE Borehole core from the Darkov Coal Mine, depth 173.3 m.

Lithofacies HE: Lenticular-bedded muddy heterolithic deposits

Description. These deposits are planar parallel-laminated mudstones with silty streaks and interlaminae, interlayered with very fine- to fine-grained sandstones showing ripple cross-lamination (Fig. 10). The thickness of sandy and muddy layers is up to round 2 cm. The lateral continuity of sandy layers is difficult to assess in core samples, but their shape is wavy to mainly lenticular (Fig. 10; lenticular bedding *sensu* Reineck and Wunderlich, 1968). The thickness of the units of lithofacies HE is less than 50 cm, and their boundaries are usually gradational, with a transition to adjacent lithofacies SW or FH. The lower boundary is sharp only where the underlying deposit is coaly lithofacies C (described below).
Interpretation. Lenticular bedding indicates a sand-starved muddy slack-water environment. The silty streaks and interlaminae in mudstone represent an unsteady, pulsating delivery of fine-grained sediment suspension. The cross-laminated sandy lenses are starved ripples representing episodic tractional delivery of sparse sand by weak currents, insufficient to cover continuously a muddy substrate. Such deposits may characterize submerged distal levees and overbank floodplains with slack-water ponds, but may occur also in abandoned river channels or even as drape high on a point bar (Allen, 1963; Miall, 1996; Bridge, 2003).

Fig. 11. Examples of lithofacies FH. Borehole cores from the Darkov Coal Mine, depth 45.6 m (**A**) and 43.9 m (**B**).

Lithofacies FH: Planar-laminated mudstones and siltstones

Description. These deposits are mudstones and muddy siltstones showing flat, plane-parallel lamination (Fig. 11). Lamination is marked by a variable content of clay and minute plant detritus, reflected in the sediment colour. The laminae in siltstone and the silty interlaminae in mudstone are occasionally grouped into small lenses a few millimetres thick (Fig. 11), apparently representing some tiny starved ripples. The units of this lithofacies are a few centimetres to nearly 2.5 m thick and are typically associated with those of lithofacies HE, SW or FM, showing mainly transitional boundaries. The boundary is sharp only in sporadic association with lithofacies SH and C.
Interpretation. This lithofacies represents a sand-devoid slack-water environment with an unsteady, fluctuating supply of muddy to silty sediment suspension and with only sporadic transient "whiffs" of very weak tractional transport (small isolated silt ripples). Such depositional conditions typify distal floodplain ponds, but may also occur in the oxbow lakes of abandoned river channels (Miall, 1996; Bridge, 2003).

Lithofacies FM: Massive mudstones and muddy siltstones

Description. These deposits are texturally similar to those of lithofacies FH, but are strongly homogenized and show little or no recognizable primary lamination. The units of this lithofacies are mainly no thicker than 50 cm, rarely up to around 1 m. They are typically associated with those of lithofacies FH or C, showing gradational boundaries. The upper boundary is sharp and probably erosional where the overlying deposit is sandstone of lithofacies SH, SL or SM. Lithofacies FM occurs also as isolated thin (<5 cm) layers embedded in lithofacies CG or coarse-grained SH, but it is difficult to recognize from core samples as to whether these occurrences are primary deposits or simply large intraclasts.
Interpretation. This lithofacies is thought to represent depositional conditions similar to those of lithofacies FH, but with the sediment homogenized due to a strong, pervasive bioturbation by plant-root systems. Its direct association with lithofacies FH and C supports this interpretation. This lithofacies would then represent vegetated ponds of distal floodplain areas free of sand supply (Rust, 1978; Miall, 1996; Bridge, 2003), and its environmental significance as a mature palaeosol (*sensu* Retallack, 1990) would be similar to that of the immature palaeosols of lithofacies SRR. The sporadic isolated occurrences of lithofacies FM embedded in lithofacies CG/SH, if not representing mudclasts, may be a product of the low-stage ponding of muddy suspension in local bar-top depressions in a temporarily abandoned and partly vegetated braided-river channel (Rust, 1978; Miall, 1996).

Lithofacies C: Coal and coaly shales

Description. This lithofacies consists of coal and/or coaly shale, and its units range from isolated layers a few centimetres thick to economic seams several metres in thickness (Fig. 12). Seams up to 24 m thick occur in the NE part of the basin. Coals are generally bituminous, mainly bright, banded or dull, and their main lithotypes are vitrino-clarine, durino-clarine, clarino-vitrine and clarino-durine. Their mean ash content is about 5 wt.% (Jurczak-Drabek, 2000). Coaly shales are fissile and occur both at the basis and within coal seams, occasionally accompanied by thin sandy or heterolithic layers. Thicker clastic interbeds tend to split coal seams into separate benches (Kędzior, 2008).

In comparison to the other coal-bearing lithostratigraphic units of the basin, the coals in the Zabrze Beds are characterized by the lowest ash content and a predominance of vitrinite group in association with the highest contents of inertinite (Knafel, 1983). Sapropelic coals are only sporadically found. The lower boundaries of lithofacies C units are usually transitional contacts with lithofacies FM. Thin layers are underlain by some of the lithofacies SRR units. A sharp and erosional upper boundary is observed where the overlying lithofacies is sandstone or conglomerate.
Interpretation. Lithofacies C indicates accumulation of phytogenic material, with a variable and often negligible input of clay as slack-water suspension. The intimate association of lithofacies C with palaeosols (lithofacies FM, spo-

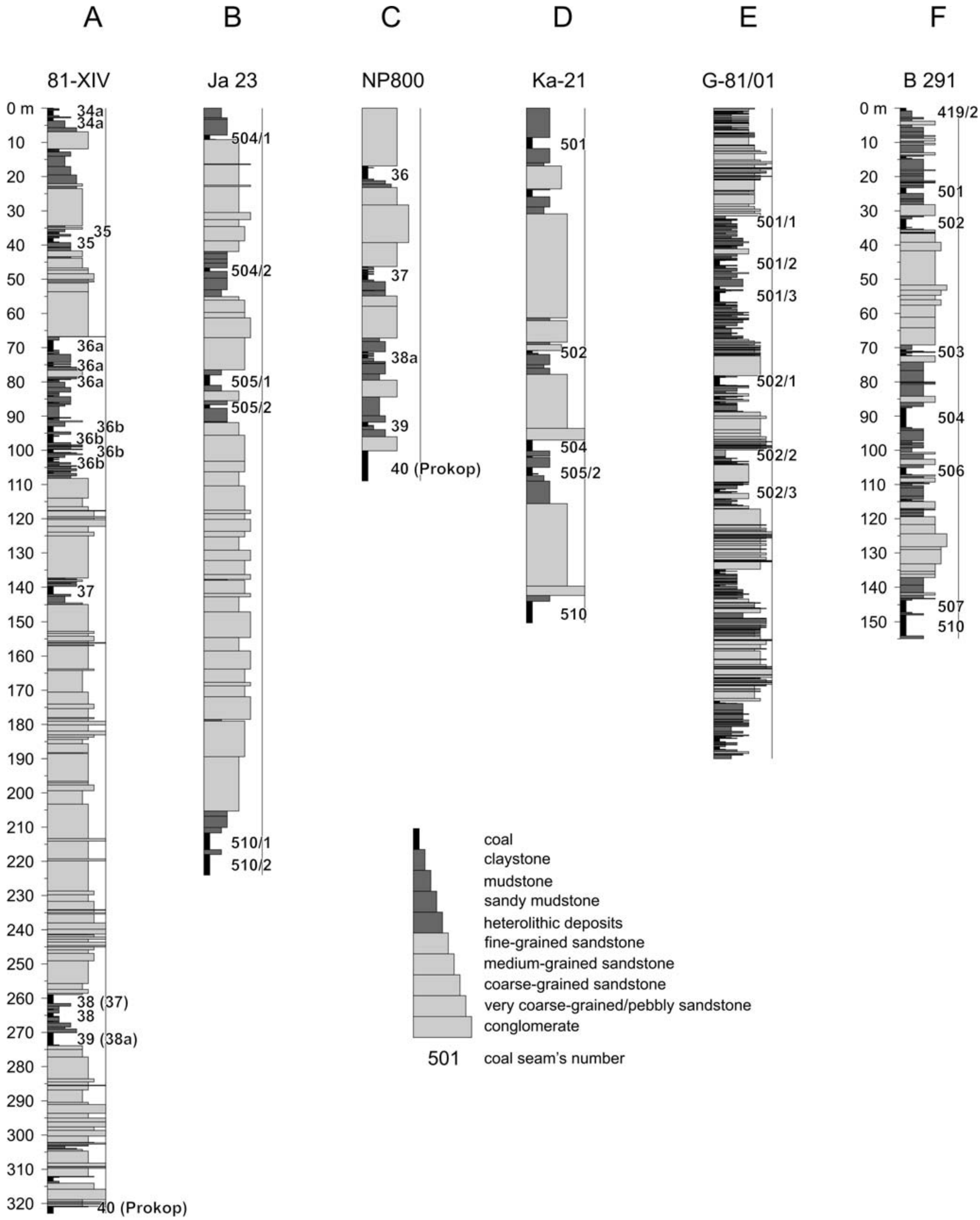

Fig. 12. Selected borehole logs from the main areas. **A**. Karviná–Ostrava. **B**. Jastrzębie Zdrój. **C**. Frenštat. **D**. Cieszyn. **E**. Rybnik. **F**. the Main Anticline. For the location of areas, see Fig. 3.

radically SRR) indicates an autochthonous nature of the phytogenic deposits. Their common association with muddy lithofacies (Fig. 12) indicates preferential deposition in sand-devoid mires of distal floodplain areas. The generally humic character of coals and their petrographic signature (Knafel, 1983) suggest peat bogs in poorly drained forested swamps.

LITHOFACIES ASSOCIATIONS

Spatially and genetically related lithofacies are regarded as lithofacies associations and considered to represent specific sub-environments of the sedimentary system. Two basic associations have been distinguished, one dominated by sandy and conglomeratic deposits and the other by muddy, heterolithic and phytogenic deposits. These lithofacies assemblages are for simplicity given informative interpretive genetic labels, but their descriptions and interpretations are separated in the text.

Fluvial channel-belt deposits

Description. This facies assemblage is composed mainly of fine/medium- to coarse-grained sandstones (lithofacies SL, SH, SM and SR) and some associated conglomerate beds (lithofacies CG). The conglomerate or a coarse-grained pebbly unit of lithofacies SH occasionally underlies a thick (10–20 m) package of alternating sandstone lithofacies (e.g. Fig. 12D) or separates such vertically stacked packages, but the majority of sandstone packages – although erosionally based – virtually lack basal conglomeratic lithofacies. Furthermore, their tops commonly lack a distinct "fine member" (*sensu* Allen, 1970) composed of lithofacies SR passing upwards into heterolithic and muddy lithofacies. The sandstone packages lack also a well-defined fining-upwards trend, although many show some fining-upwards component bed sets 1.5 m thick (Fig. 12). The classical "fining-upwards fluvial cyclothems" (Allen, 1970) are generally absent, particularly in the SW segment of the basin.

The thickness of sandstone successions in borehole profiles varies spatially from less than 5 m to 114 m (Figs 13, 14), depending on the location in the basin and whether the erosionally-based sandstone packages are solitary (vertically isolated) or multistorey (superimposed directly upon one another). The thickest successions are found along the basin axis, particularly in the SW segment of the basin (see Fig. 12A, B), and markedly thinner ones occur towards the basin's eastern flank (Kędzior, 2001, 2008). Both their mean and median thickness decreases systematically along the basin towards the NE (Table 1). The modal thickness class in the Karvina–Ostrava, Jastrzębie Zdrój and Cieszyn areas is 5–15 m or even 15–25 m, but is only 5 m in the Frenštat, Rybnik and Main Anticline (Katowice) areas (Figs 13, 14). A different spatial trend is shown by the maximum observed thicknesses and the cumulative thickness percentage of sandstones in the succession. For example, the Cieszyn area has the highest modal thickness class of 5–25 m (Fig. 14A), but the lowest maximum thickness of sandstone packages (Table 1). In contrast, the Rybnik area to the north (Fig. 3)

Table 1

The average, median and maximum thickness of sandstone packages (in metres) in the individual subareas of the Upper Silesia Coal Basin (see location in Fig. 3)

Area	Average	Median	Max
Karvina	23.52	20.05	114
Jastrębie	27.57	22.55	104.4
Frenštat	21.51	18.5	44.8
Cieszyn	16.79	16.2	42.1
Rybnik	19.93 (22.02)	17.1 (17.7)	65 (161)
Main Anticline	15.54	12.1	74.7

has the lowest modal thickness class of 5 m (Fig. 14B), but a high maximum thickness (Table 1) and a net sandstone content exceeding 50%. The Main Anticline area, further to the NE (Fig. 3), is also dominated by relatively thin sandstone packages, mainly no thicker than 15 m (Fig. 14C), but has a net sandstone content generally less than 50%. The sandstone packages there tend to be isolated, of single- storey type, and occasionally show a recognizable fining-upwards signature of classical "fluvial cyclothems" (*sensu* Allen, 1970) (Fig. 15). The gradual change in alluvial architecture along the basin axis, towards the NE, is further illustrated by the series of interpretive borehole-correlation panels in Figs 16–21 (for the location and geographic orientation of panels, see Fig. 3).

Interpretation. The erosionally-based sandstone packages, occasionally underlain by conglomeratic facies, are considered to represent fluvial channel-belt bodies (*sensu* Bridge, 2003). They are up to 5 m thick where isolated as single-storey "simple channel bodies" (*sensu* Friend, 1983), but are most commonly stacked upon one another into much thicker, composite packages as "multistorey channel bodies" (*sensu* Friend, 1983). The mean, median, modal and maximum thicknesses of these multistorey channel-belt bodies decrease markedly along the basin axis towards the NE (Table 1, Figs 13, 14), which indicates that the tendency for vertical stacking of channel belts was much stronger in the SW segment of the basin and decreasing towards the NE segment.

The multistorey and multilateral character of channel-belt sandstone bodies and their lack of fining-upwards signature in the SW part of the basin (Figs 16–20) suggest that the NE-directed fluvial system there was probably braided, with laterally shifting, unstable channels up to around 5 m (cf. Galloway, 1985; Sanchez-Moya *et al.*, 1996). Poorly developed stratification indicates rapid deposition and occasional hyperconcentrated discharges, which suggests a bed-load-dominated fluvial system heavily charged with sediment. Subordinate fining-upwards bed sets are attributed to an incremental aggradation driven by consecutive river-flood events. The incision of river channel was apparently followed by rapid aggradation, with the development of sandy mid-channel and side bars (lithofacies SL, SH and SR) and with the initial formation of gravel pavement and gravelly longitudinal bars (lithofacies CG and gravelly SH) in narrow channel-thalweg branches; hence the spatially limited occurrence of conglomerates in the channel belts. In

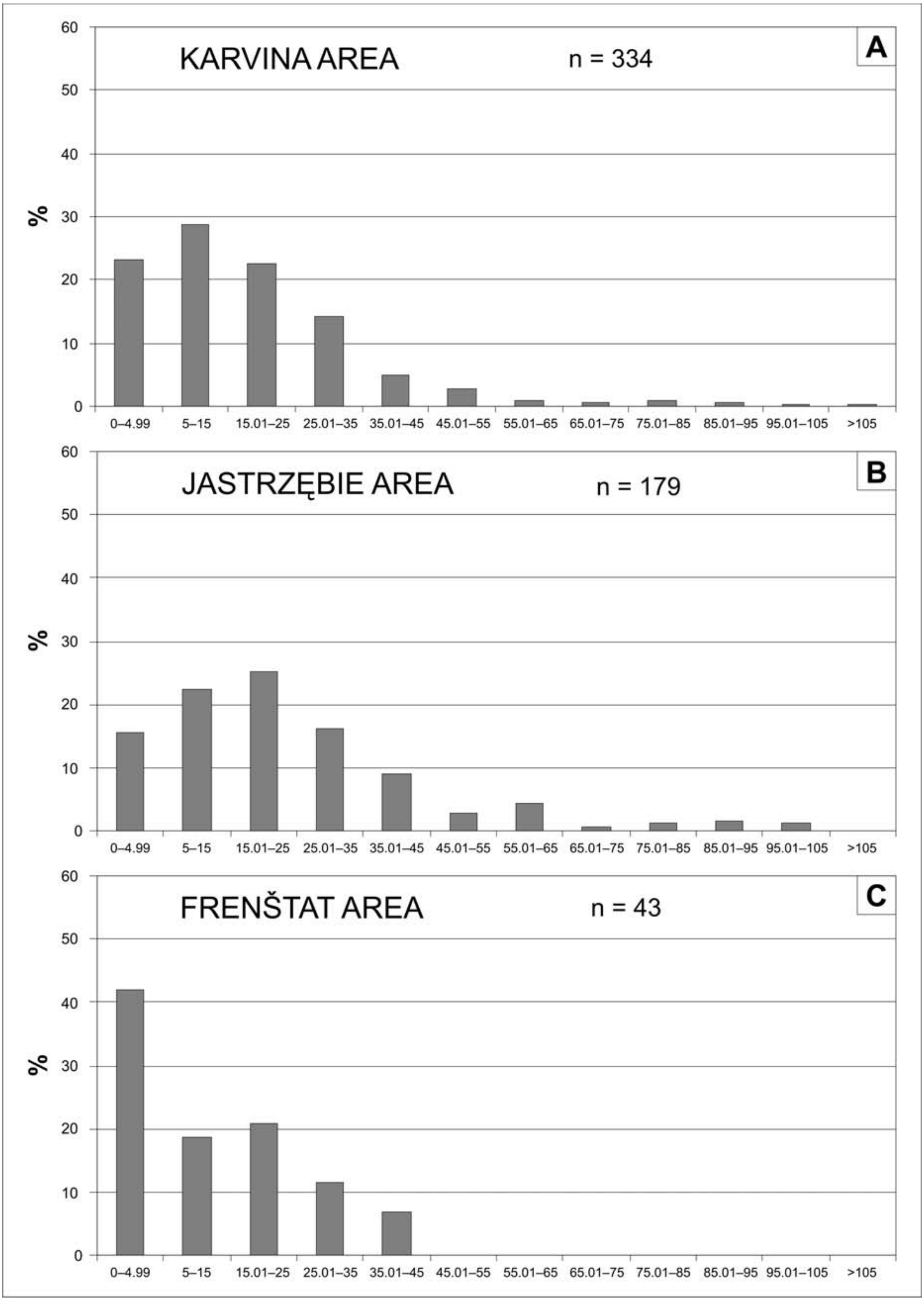

Fig. 13. Frequency distribution of the thicknesses (in metres) of sandstone packages interpreted as single-storey (< 5 m) and multistorey channel-belt bodies. Data from borehole profiles in the Karviná (**A**), Jastrzębie Zdrój (**B**) and Frenštat area (**C**); see location in Fig. 3. The n-value is the number of local measurements. Note the strongly skewed, log-normal distribution of the thicknesses.

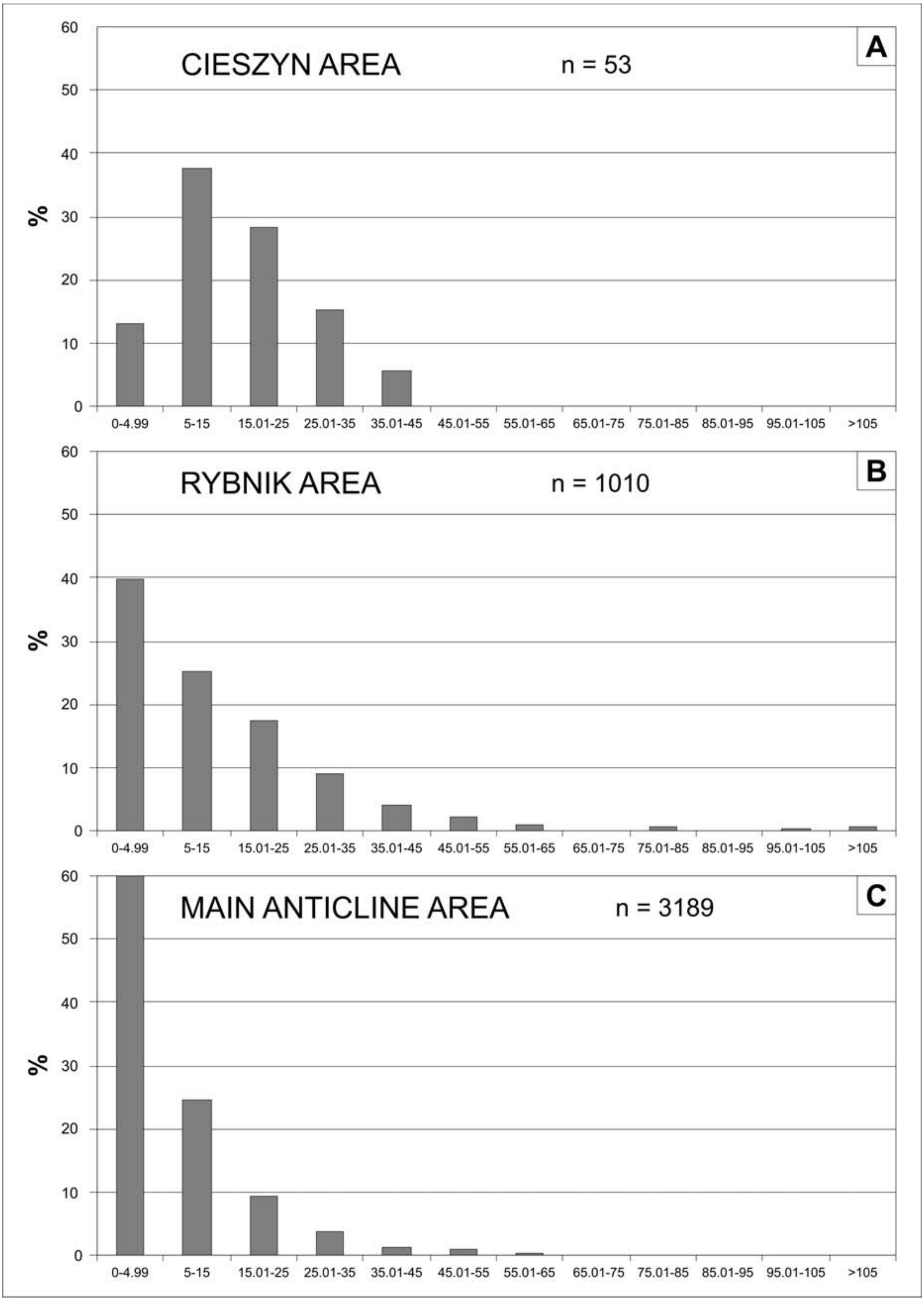

Fig. 14. Frequency distribution of the thicknesses (in metres) of sandstone packages interpreted as single-storey (< 5 m) and multistorey channel-belt bodies. Data from borehole profiles in the Cieszyn (**A**), Rybnik (**B**) and Main Anticline area (**C**); see location in Fig. 3. The n-value is the number of local measurements. Note the strongly skewed, log-normal distribution of the thicknesses.

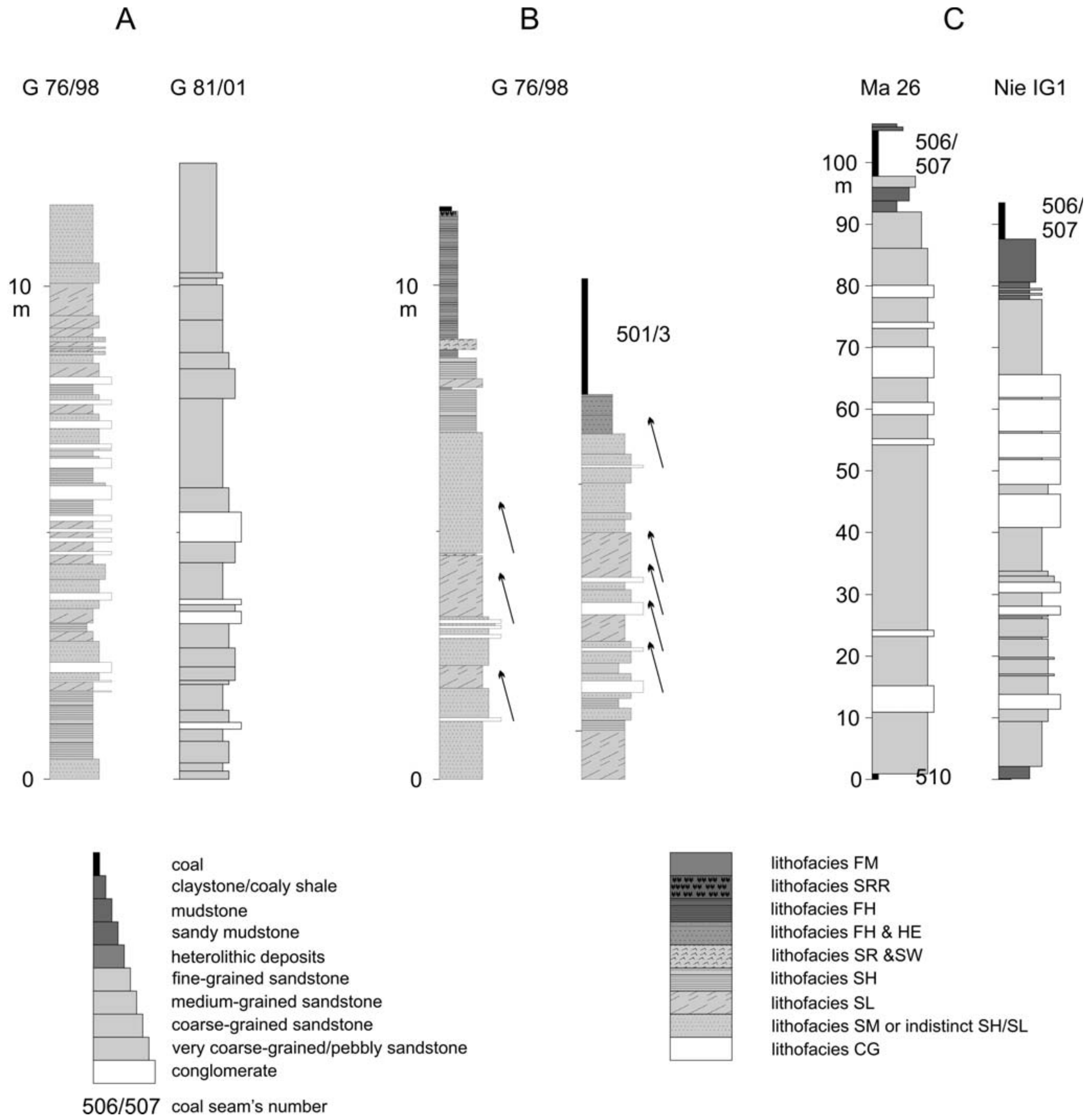

Fig. 15. Example portions of borehole logs showing multistorey sandstone bodies of the channel-belt lithofacies association. **A**, **B.** Logs G 76/98 and G 81/01 are from underground boreholes in the Rydułtowy Coal Mine; note the component fining-upwards bed sets. (**C**) Logs from boreholes Marklowice 26 (left) and Niedobczyce IG1 (right).

terms of the Miall (1977, 1992) idealized end-member fluvial models, the channel belts in the SW segment of the basin would be braided and of low sinuosity, with most belts evolving from an initial transient stage resembling model 3 (Donjek type) to the main depositional stage resembling model 4 (combined South Saskatchewan/Platte type).

The channel-belt sandstone bodies in the NE segment of the basin are often stacked laterally (multilateral), but tend to be vertically isolated (mainly single- or double-storey), have a better pronounced fining-upwards signature and are embedded in well-developed overbank deposits (Figs 15, 21). This evidence suggests a system of avulsive but relatively stable meandering channels. In terms of Miall's (1992) fluvial models, the channel belts in this segment of the basin would be meandering, perhaps initially resembling model 5 or 6 and commonly evolving into model 7 with extensive peat-forming floodplain mires.

Overbank floodplain deposits

Description. This lithofacies association consists of the muddy lithofacies FH, HE and FM intercalated with the

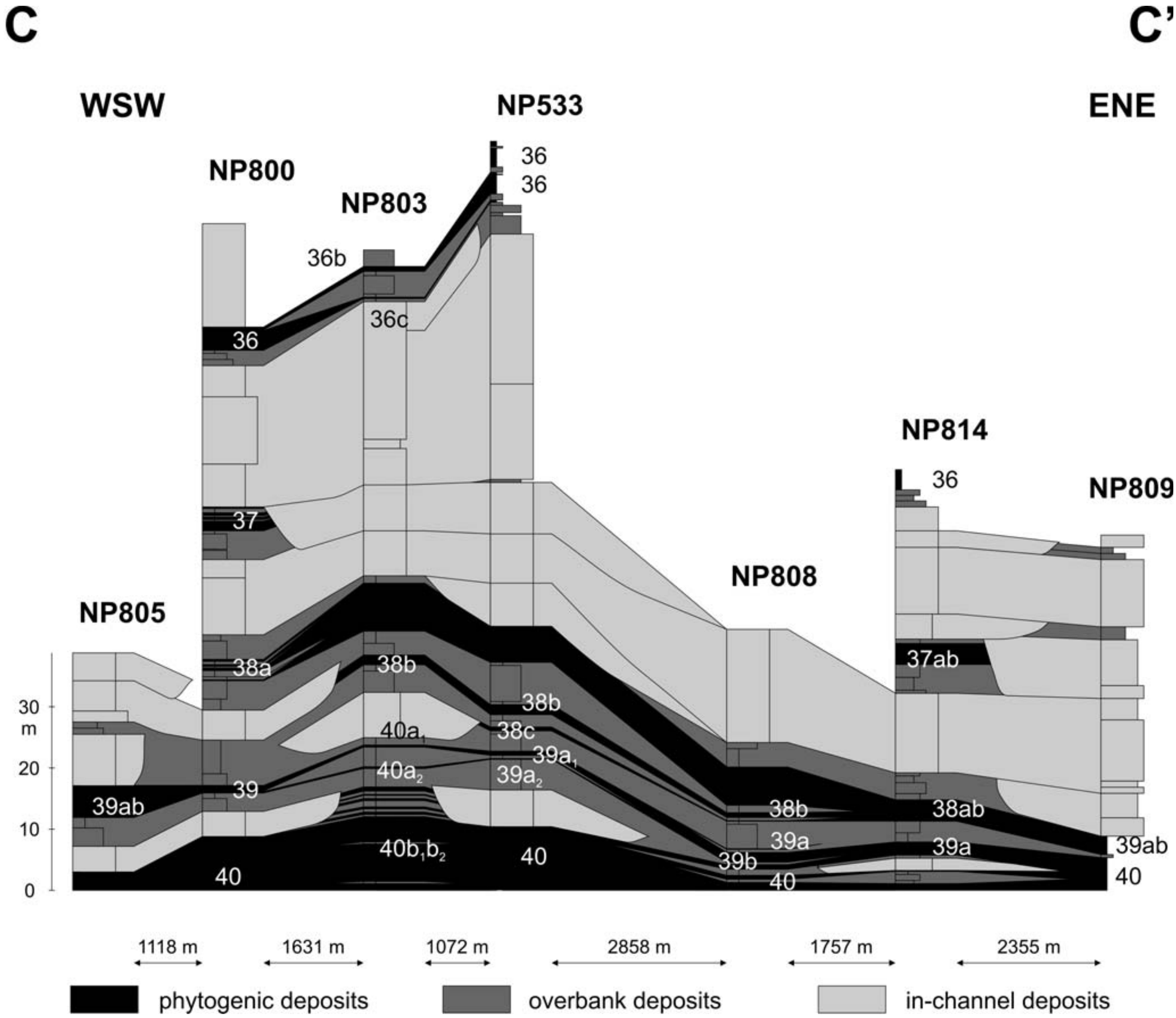

Fig. 16. Borehole correlation panel C–C' (see location in Fig. 3) showing the geometry and spatial distribution of sandstone bodies and coal seams in the Zabrze Beds. Coal-seams numbers are according to the regional mining nomenclature.

coaly lithofacies C and locally with thin to moderately thick (<2 m) units of fine- to medium-grained sandstone lithofacies SR, SW, SL and SRR (Fig. 22). Detailed observations from borehole cores in the Rybnik area (Fig. 3) indicate that lithofacies FH predominates, whereas lithofacies FM is relatively uncommon, often underlain by SRR and generally associated with coal. Single plant-root traces are common, even in some of the medium-grained sandstones of lithofacies SL. Among the component clastic lithofacies, the units of muddy lithofacies are the thickest, attaining up to 2.5 m (Fig. 22), although mainly no thicker than 1 m. The heterolithic lithofacies HE is common, but rarely exceeds 0.5 m in thickness. Relatively abundant are fine- to medium-grained sandstones of lithofacies SR and SH, whereas lithofacies SL is subordinate. The thicknesses of sandy lithofacies are markedly small, mainly less than 0.5 m and rarely up to 1.4 m.

The packages of this mud-dominated lithofacies separate the sandstone bodies of the previous lithofacies association (Figs 16–21) and their thickness of varies from less than a decimetre to more than 30 m, with no obvious regional trend. The thicknesses are less than 20 m in the Cieszyn and Jastrzębie areas (Figs 17, 19), reach 22 m in the Karvina–Ostrava and Frenštat areas (Fig. 6) and exceed 35 m in the Rybnik and Main Anticline areas (Figs 20, 21). In the easternmost part of the latter area, this fine-grained lithofacies association constitutes the entire succession of Zabrze Beds (Kędzior, 2001, 2008).

The net coal content of the Zabrze Beds in the borehole profiles is highly variable, ranging from less than 6% to as much as 100% in some boreholes in the Main Anticline area, where the whole profile of Zabrze Beds is represented by a single coal seam about 24 m thick (Kotas and Malczyk, 1972). The thickness of the individual coal seams in Zabrze Beds varies from a few centimetres to more than 18 m, with some seams apparently reaching 24 m. Regional variation in coal-seam thicknesses is summarized in the form of frequency histograms in Fig. 23. Relatively thin (<1 m) coal seams predominate in almost all areas of the basin, although

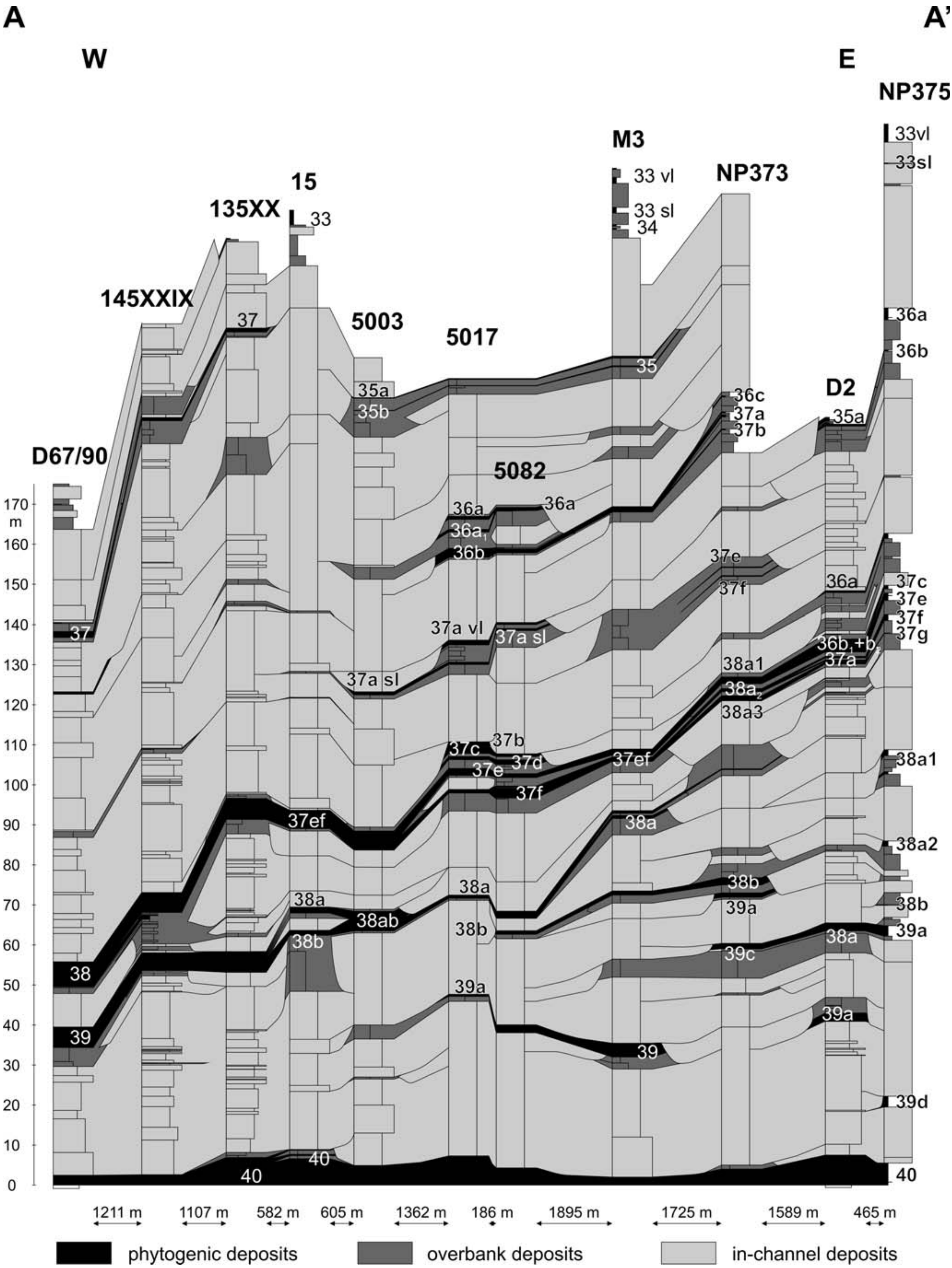

Fig. 17. Borehole correlation panel A–A' (see location in Fig. 3) showing the geometry and spatial distribution of sandstone bodies and coal seams in the Zabrze Beds. Coal-seams numbers are according to the regional mining nomenclature.

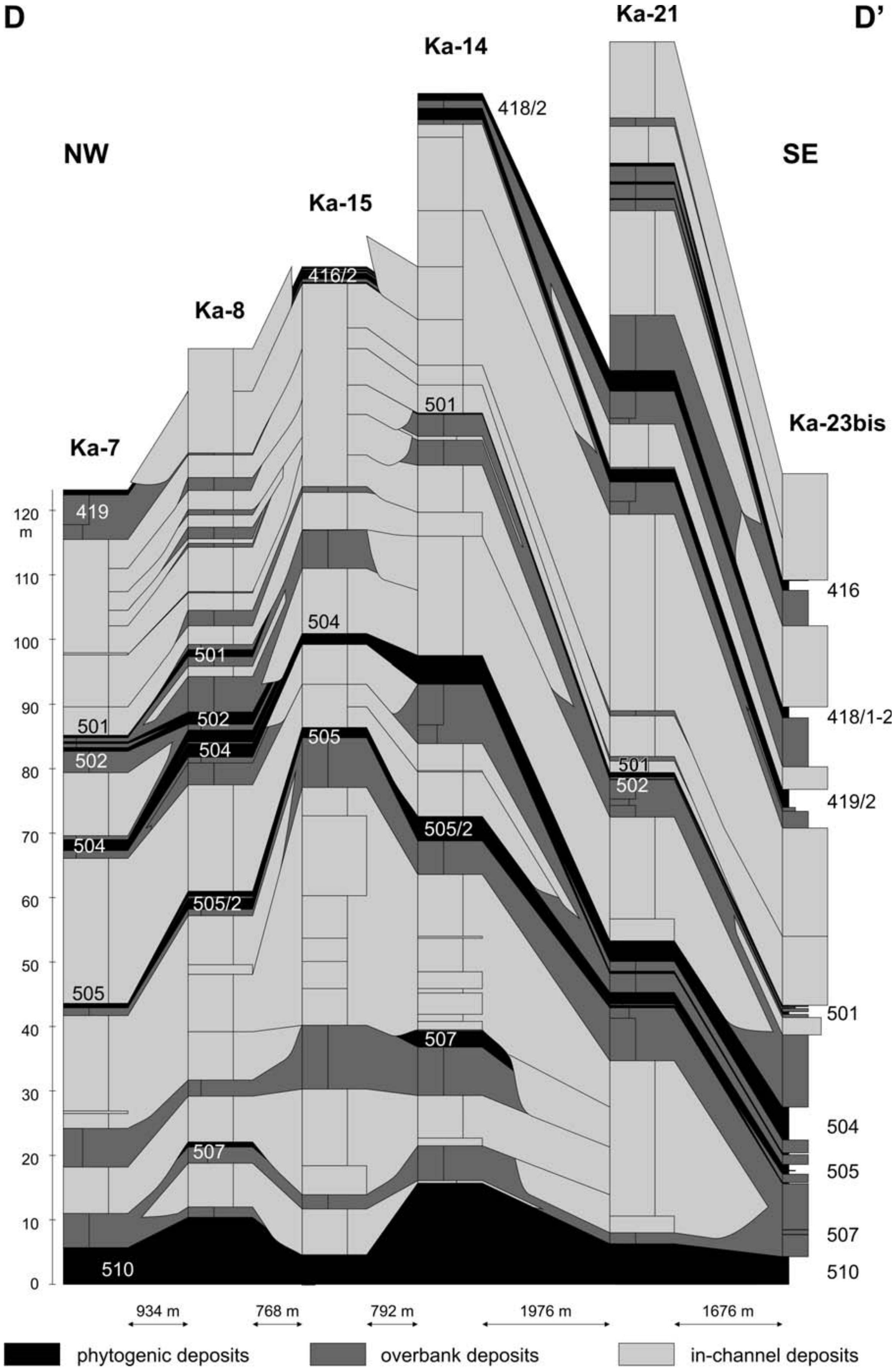

Fig. 18. Borehole correlation panel D–D' (see location in Fig. 3) showing the geometry and spatial distribution of sandstone bodies and coal seams in the Zabrze Beds. Coal-seams numbers are according to the regional mining nomenclature.

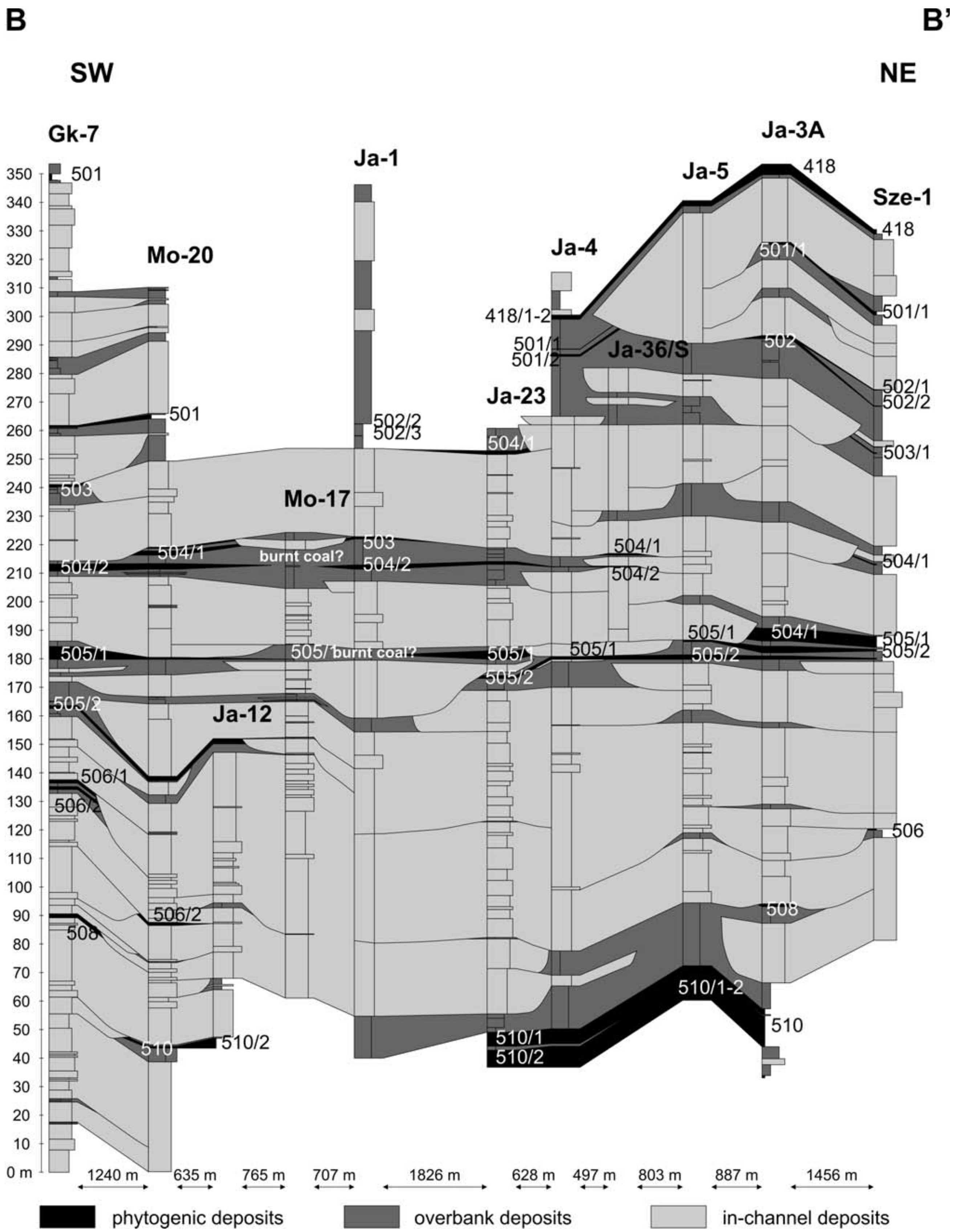

Fig. 19. Borehole correlation panel B–B' (see location in Fig. 3) showing the geometry and spatial distribution of sandstone bodies and coal seams in the Zabrze Beds. Coal-seams numbers are according to the regional mining nomenclature.

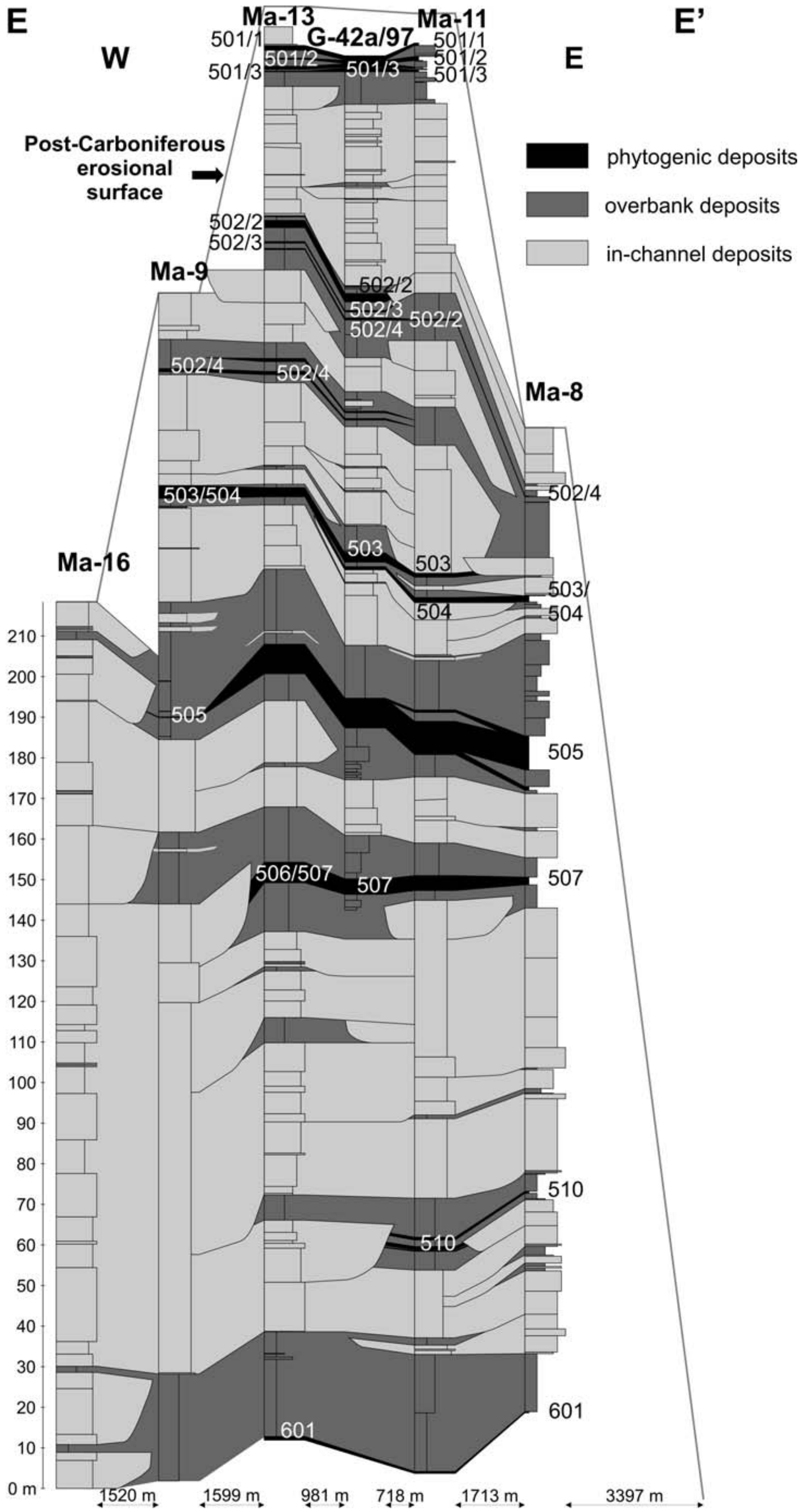

Fig. 20. Borehole correlation panel E–E' (see location in Fig. 3) showing the geometry and spatial distribution of sandstone bodies and coal seams in the Zabrze Beds. Coal-seams numbers are according to the regional mining nomenclature.

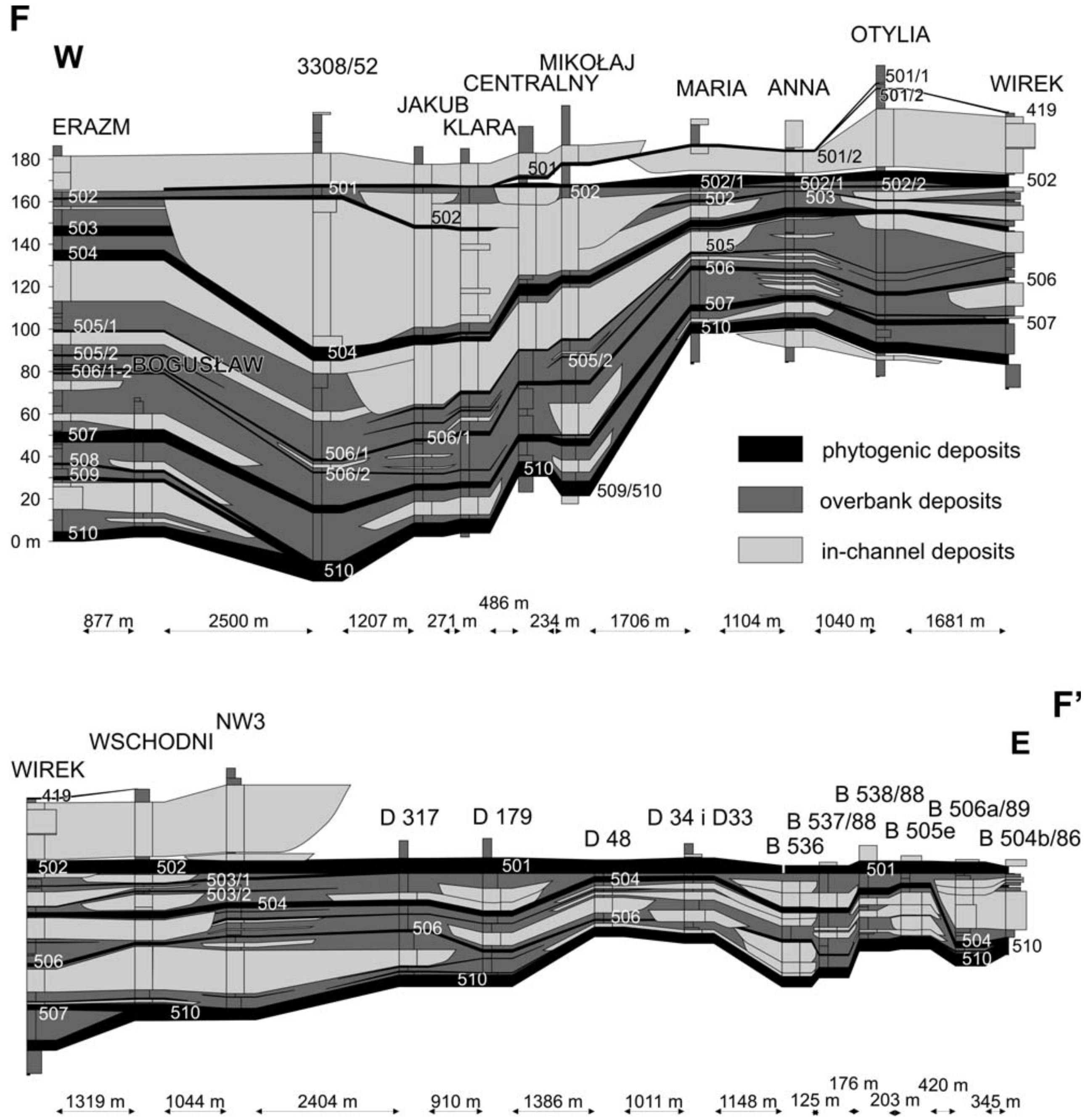

Fig. 21. Borehole correlation panel F–F' (see location in Fig. 3) showing the geometry and spatial distribution of sandstone bodies and coal seams in the Zabrze Beds. Coal-seams numbers are according to the regional mining nomenclature.

seams 1–3 m thick are locally the most common. Except for the log-normal frequency distribution in the Frenštat area (Fig. 23C), the frequency distributions in the other areas seem to be more or less bimodal, with recognizable modes in the thickness classes of 0.1–0.3 m and 1–3 m (Fig. 23).

Interpretation. This mud-dominated facies association, with palaeosols and coals, is a typical assemblage of alluvial floodplain deposits (see Reinfelds and Nanson, 1993; Bridge, 2003). The floodplain environment was developing repeatedly in the overbank areas of laterally-shifting fluvial channel belts (Figs 16–21), tended to be quickly vegetated and hosted peat-forming mires. Some of the peatbogs were long-lasting features of this environment, allowing local formation of up to 24 m of bituminous coal, which may mean accumulation of up to 150–170 m of the original peat (see Elliott, 1965; Teichmüller and Teichmüller, 1982).

The relatively sand-rich bed sets of alternating lithofacies SR, SW, SH, HE and FH, locally up to 4.5 m thick (Fig. 22A), are interpreted as channel levee deposits (see Brierley *et al.*, 1997; Bridge, 2003). These deposits are very gently inclined (Fig. 10), commonly contain coalified plant detritus and locally show plant-root bioturbation. Sharply-based bed sets 0.5 to 3 m thick, composed of the fine-grained sandstone lithofacies SH and SR and capped with the muddy lithofacies FH or HE, are interpreted as crevasse-splay deposits, especially if showing a coarsening or

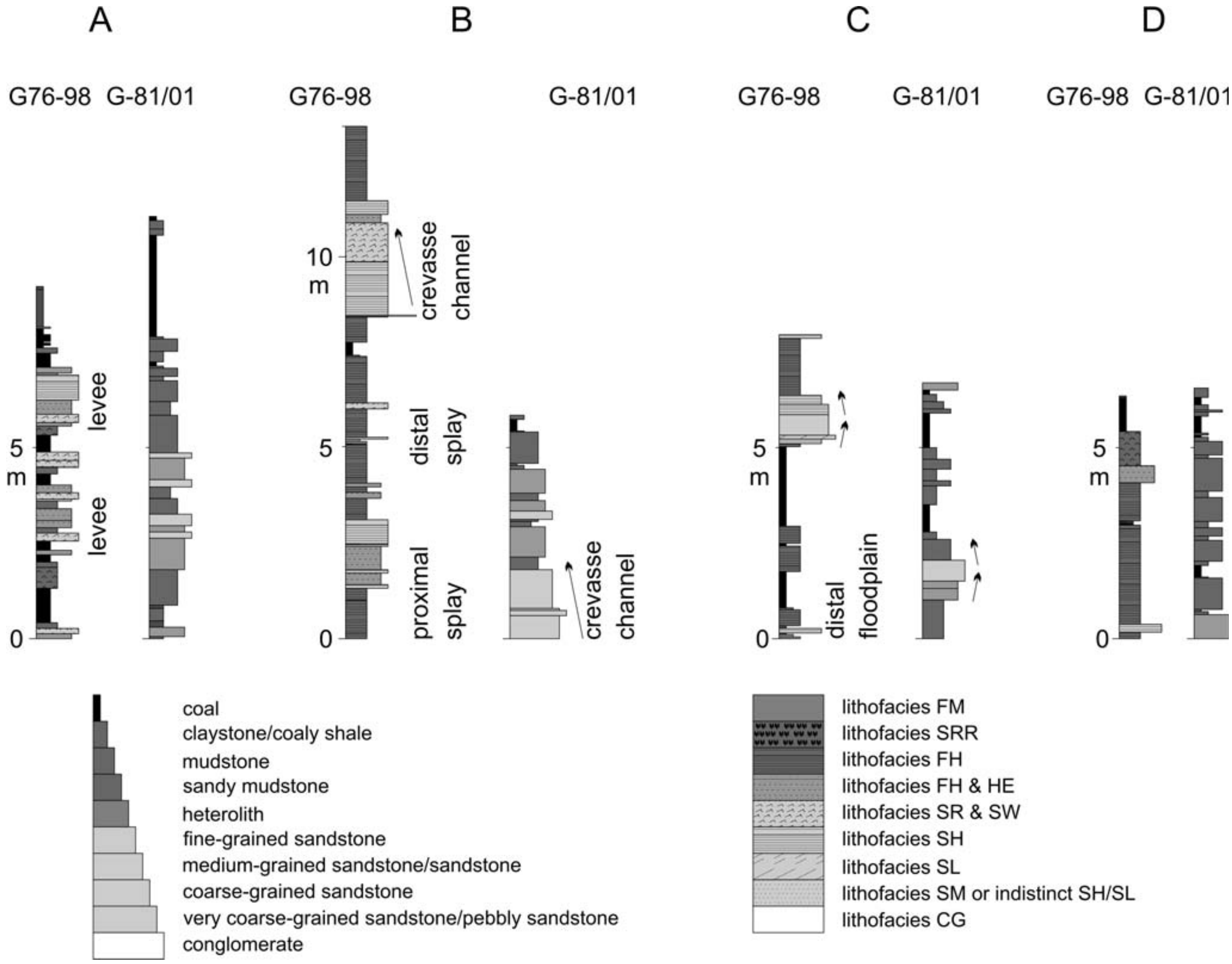

Fig. 22. Example portions of borehole logs showing the overbank lithofacies association; boreholes G 76/98 and G 81/01 in the Rydułtowy Coal Mine. **A**. Channel-levee bed sets. **B**. Fining-upwards crevasse channel-fill and splay bed sets. **C**. Pensymmetrical crevasse channel-fill bed sets. **D**. Distal floodplain deposits.

coarsening-to-fining upward trend (Fig. 22C) (see Baganz *et al.*, 1975; Flores, 1981; Gersib and McCabe, 1981; Miall, 1996; Bridge, 2003). The thickest of such bed sets may represent vertical stacking of two or more crevasse splays (see Mjøs *et al.*, 1993). Similar bed sets – but erosionally-based, containing lithofacies SL and showing a fining-upwards trend (Fig. 22B) – are considered to be crevasse channel-fill deposits (see Flores, 1981; Gersib and McCabe, 1981; Bridge, 2003). The most widespread and volumetrically dominant bed sets of muddy lithofacies FH, FM and HE, intercalated with coaly shales and coal (lithofacies C) or with minor sandy interlayers of lithofacies SRR, SW and SR (Figs 15, 22), are interpreted as more distal floodplain deposits (see Farrell, 1987; Bridge, 2003). They represent low-lying areas of turbid floodwater ponding, where poorly drained mires formed and phytogenic deposition occurred, and where silt and fine sand were only episodically delivered as thin flood sheets and the feather-edge pinch-out termini of distalmost crevasse splays (Bridge, 2003). A genetically similar range of overbank lithofacies assemblages with phytogenic deposits has been widely reported from modern (e.g., Farrell, 1987; Smith *et al.*, 1989) and ancient alluvial floodplains (e.g., Ethridge *et al.*, 1981; Galloway, 1981; Doktor and Gradziński, 1985; Farrell, 1987; Fielding and Webb, 1996; Jorgensen and Fielding, 1996; Miall, 1996; Halfar *et al.*, 1998; Bridge, 2003).

Nearly all overbank lithofacies packages, and also some of the channel-belt sandstone packages, show evidence of local plant growth, which means that the regional climate was favourable to vegetation. Plants are capable of colonizing a wide range of alluvial subenvironments (Diessel, 1992), and the accumulation of peat is generally contemporaneous with fluvial activity (Fisk, 1960; McCabe, 1984), as in the present case (Figs 16–21). The most favourable for peatbog formation were the distal floodplain areas of floodwater ponding. Coal maceral analyses from the Jastrzębie Zdrój area (Gabzdyl, 1969) show a high content of vitrinite and fusinite, which may indicate some well-drained forest moors dominated by high, tree-type vegetation. Variation in the maceral content in coal-seam profiles may reflect water-table fluctuations. Some coal seams or their parts may represent reed moors dominated by herbaceous plants, or sporadic open moors with sapropelic coals (see Kędzior *et al.*, 2007).

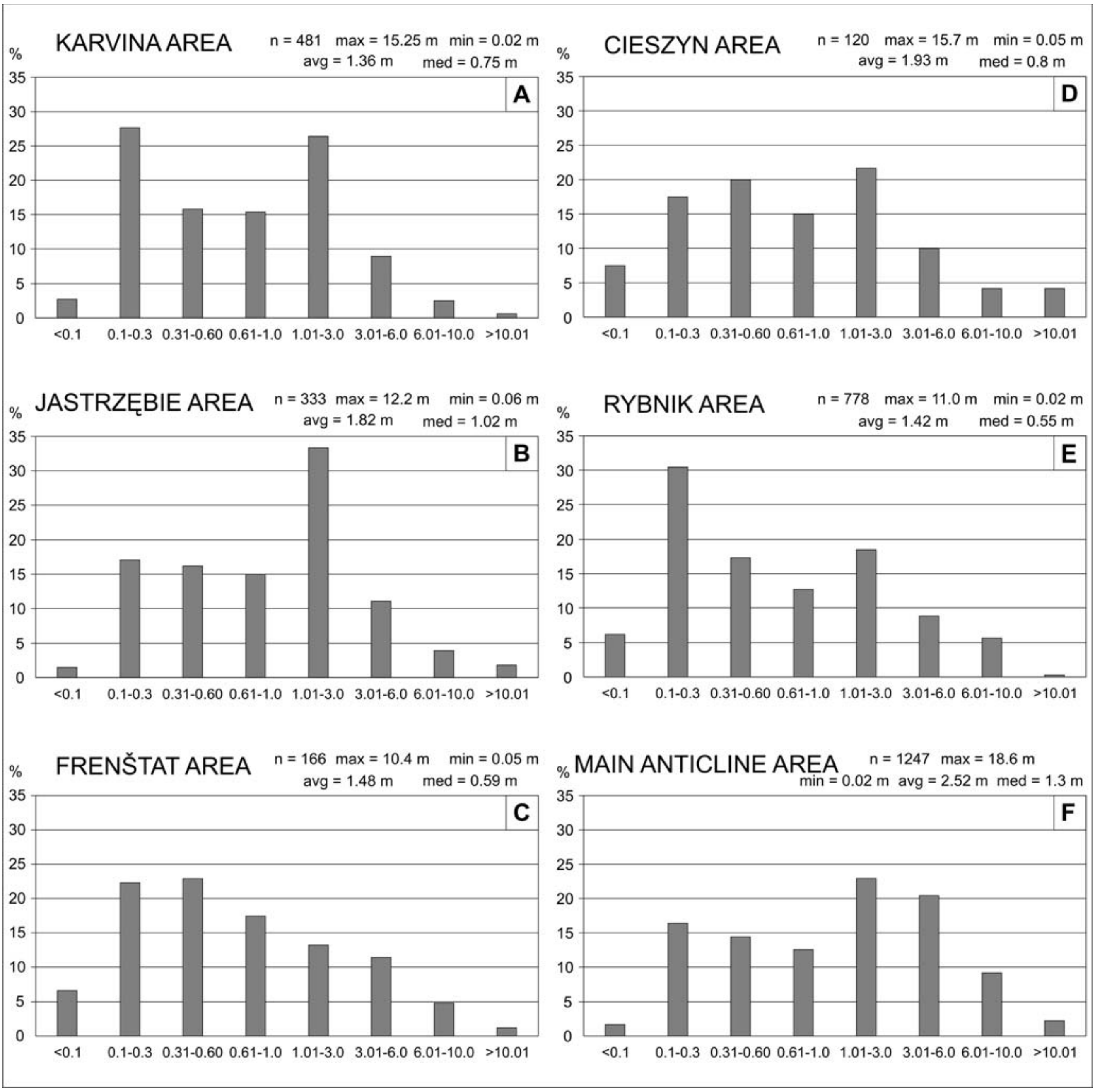

Fig. 23. Frequency distribution of coal-seam thicknesses (in metres), as measured in borehole profiles in the areas of Karviná (**A**), Jastrzębie Zdrój (**B**), Frenštat (**C**), Cieszyn (**D**), Rybnik (**E**) and the Main Anticline (**F**); see location in Fig. 3. Letter symbols: n – local number of measurements; max – maximum local thickness; min – minimum local thickness; avg – local average thickness; med – local median thickness.

The thick coal seams are commonly split by broad lenses, wedges or thin sheets of clastic sediments (Figs 16–21), which reflects an intense contemporaneous fluvial activity and the lateral instability of river channels. The clastic splits range from local to regional in scale (see Doktorowicz-Hrebnicki, 1945; Stopa, 1959; Kotas, 2005; Kędzior, 2008). Large-scale splits are usually attributed to an uneven basin-floor subsidence (Diessel, 1992) and/or syndepositional growth-fault activity (Kędzior, 2008).

The thickness of coal seam is generally considered to be a function of the effective time available for peat accumulation (Teichmüller and Teichmüller, 1982; McCabe, 1984). Therefore, it is worth noting the apparent bimodality of coal-seam thicknesses, with the recognizable modal classes of 0.1–0.3 m and 1–3 m (Fig. 23). As pointed out by Nemec (1992), the accumulation of peat in an alluvial environment is an opportunistic process controlled chiefly by the fluvial system and its morphodynamics, with the local peat growth limited to the "time windows" provided by the fluvial-system behaviour. It is thus possible that the two modal tendencies of coal thickness reflect simply the two basic modes of fluvial-system dynamics: the shorter-term phenomenon of a lateral expansion of braided channels or lateral migration of meandering channels, and the longer-term phenomenon of an avulsive broader shifting of river channels within the available basin space (cf. Miall, 1996; Bridge, 2003). This interpretive notion might then also explain the observed variability in the character of coal-seam clastic splits.

RELATED LARGE-SCALE ASPECTS OF THE ZABRZE BEDS

Spatial thickness distribution

The zone of the greatest thickness of Zabrze Beds is a long (>150 km) and relatively narrow (10 km) belt trending in the SSW–NNE direction and considered to reflect the maximum subsidence zone (depoaxis) of the Upper Silesia Coal Basin in the late Namurian. The greatest thickness of 350 m is found in the Karviná–Ostrava area and decreases northwards only slightly, to 320 m, in the Jastrzębie Zdrój area (Fig. 24). The modest and irregular thickness variation along the basis depoaxis (Fig. 24; see also Kędzior, 2001, fig. 2) is mainly due to the variable local proportion of channel-belt and overbank deposits, particularly coal (Figs 16–21), with the resulting differential net compaction of the alluvial succession.

Markedly greater are thickness changes transverse to the basin. The westward abrupt termination of Zabrze Beds along the Variscan thrust front is due to syn- and post-orogenic erosion, whereas their general eastward thinning with coal pinch-out reflects the topography of forebulge flank (Kumpera and Martinec, 1995). In the Frenštat area to the south (Fig. 3), the measured thickness decreases eastwards from about 140 m to 70 m over a distance of 10 km. A similar thickness decrease is observed to the east of the basin depoaxis in the Karviná–Ostrava area (Fig. 24), with no more than 50 m in the Cieszyn area and only 30 m in the former Morcinek Coal Mine (Fig. 18). In the Main Anticline area to the north, the depoaxis of Zabrze Beds is located to the NW of Zabrze (Fig. 24) and their maximum measured thickness of 256 m decreases eastwards to 3 m near Sosnowiec over a distance of 35 km and wedges out further to the east (see Kędzior, 2008, fig. 3).

Lateral variability of sandstone lithosomes

The Zabrze Beds in the SW part of the basin, in Karviná–Ostrava and Jastrzębie Zdrój areas (Fig. 24), are dominated by sandstones with numerous conglomeratic interbeds (Fig. 12A, B). Packages of multistorey channel-belt bodies are up to 100 m thick, but mainly 30–40 m, and have a lateral extent of a few kilometres (Figs 17, 19). Isolated single-storey channel belts, encased in overbank deposits, are lacking. Packages of overbank deposits are subordinate and mainly no thicker than a few metres, only locally a dozen metres or so.

In the Cieszyn area (former Morcinek Coal Mine) and Frenštat area to the south (Fig. 24), the local sandstone lithosomes are significantly thinner and only sporadically exceed 40 m in thickness (Figs 12C, D, 16, 17). The lithosomes are multistorey and only sporadically single-storey channel-belt bodies, with a lateral extent similar as in the Karviná–Ostrava area. They are separated by relatively thin but laterally extensive packages of coal-bearing overbank deposits (Figs 16, 17).

In the Rybnik area to the north of Jastrzębie Zdrój (Fig. 24), the thickness of Zabrze Beds increases only slightly, but the sandstone lithosomes there are thinner, mainly around 30–40 m and only occasionally up to 60 m in thickness (Figs 12E, 20). Most lithosomes are multistorey channel belts, but also isolated single-storey channel belts are common. The intervening packages of overbank deposits are distinctly thicker, up to 30 m, with a higher number and greater thicknesses range of the associated coal seams, some of them several metres thick (Fig. 23E).

In the Main Anticline area around Zabrze farther to the north (Fig. 24), the thickness of sandstone lithosomes decreases and single-storey channel belts prevail, separated by more frequent and thicker packages of overbank deposits (Fig. 21). The overbank deposits virtually predominate towards the east, where they are occasionally developed as a thick single coal seam.

The net thickness of channel-belt sandstone bodies in the basin decreases gradually to the north (Fig. 25), which is consistent with the notion of an alluvial drainage system evolving northwards from braided into meandering (see interpretation of channel-belt deposits earlier in the text). The full primary width of the basin is unpreserved due to post-Carboniferous erosion, but the bulk of the Kinderscoutian sedimentation was apparently limited to a relatively narrow axial zone, which suggests the infilling of an alluvial valley (Fig. 24).

Coal-seam geometry

The coal seams in the SW part of the basin, in the Karviná–Ostrava and Jastrzębie Zdrój areas, are usually underlain by the fine-grained overbank deposits and sharply, erosionally overlain by channel-belt sandstones (Figs 17–19). This contemporaneous erosion of peat deposits by the lateral shifting of fluvial channels is thought to have been a major factor for the observed variation in coal-seams thicknesses. Except for the coal seams fully encased in muddy overbank deposits, the majority of coal seams are probably erosional relics of better or poorer preserved primary peat deposits. Many thin peat deposits were likely erased by erosion or destroyed by subaerial exposure. As a rule, only coal seams thicker than 3 m are sufficiently extensive laterally to allow correlation over long distances, although many complications arise due to coal-seam splitting.

Towards the east (Cieszyn area) and north (Rybnik area), the number and thickness of coal seams increase and they are almost exclusively embedded in overbank deposits (Figs 18, 20). The role of contemporaneous erosion there was thus negligible, and the thickness variation within and between coal seams reflects chiefly the primary depositional controls – which means the effective "time windows" provided by the local environment conditions for peat accumulation (see Nemec, 1992). As suggested earlier in the text, the apparent bimodality of coal-seam thicknesses (Fig. 23) may reflect two different time scales of the duration of

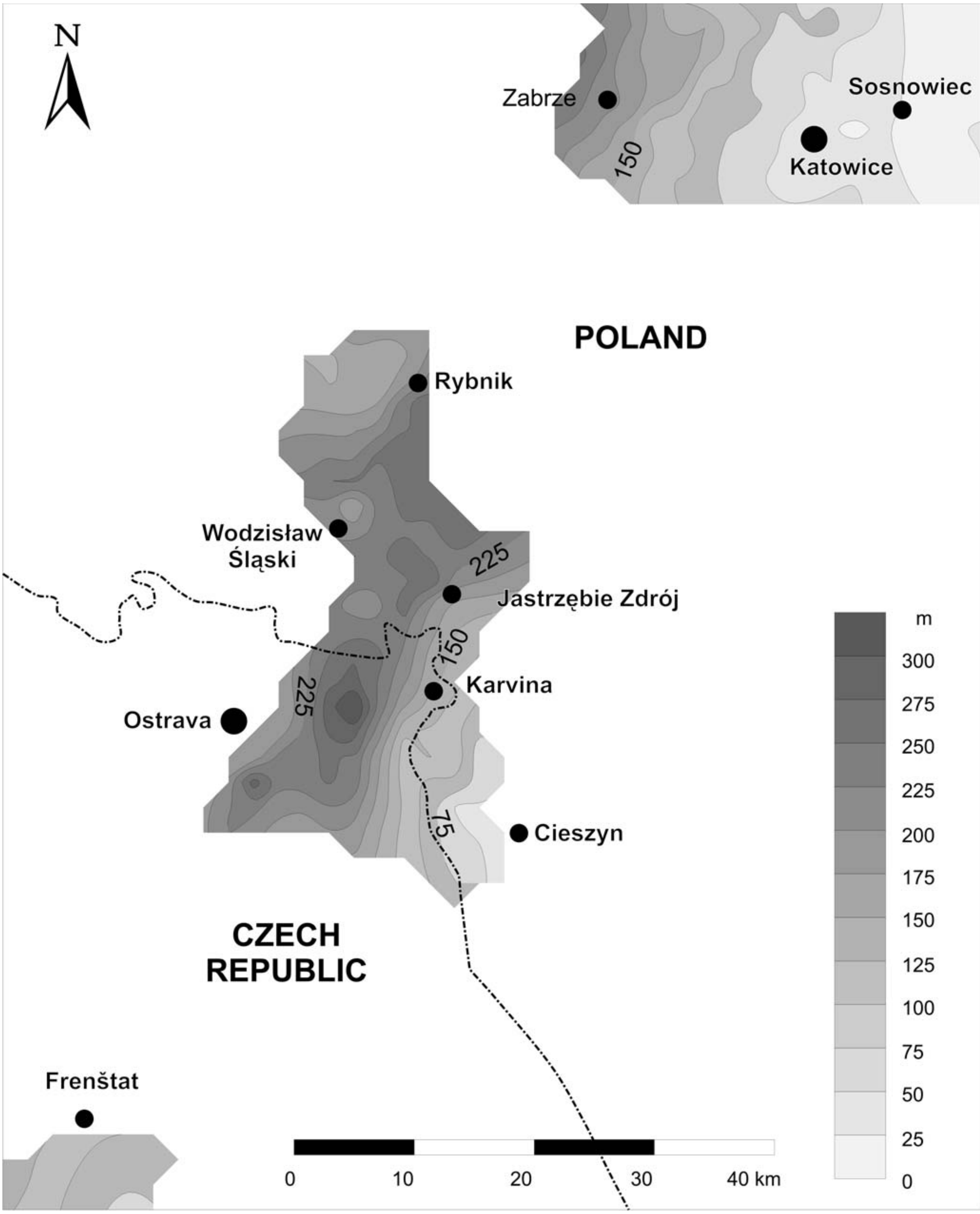

Fig. 24. Thickness map of the Zabrze Beds in the study area.

such environmental "windows" for local phytogenic deposition.

The primary depositional controls played a major role also farther to the north in the basin, in the Main Anticline area, where the net coal content of Zabrze Beds is considerably higher and where several generations of peatbog were locally superimposed upon one another (Kędzior, 2008). Coal seams there are laterally extensive, but their splitting is

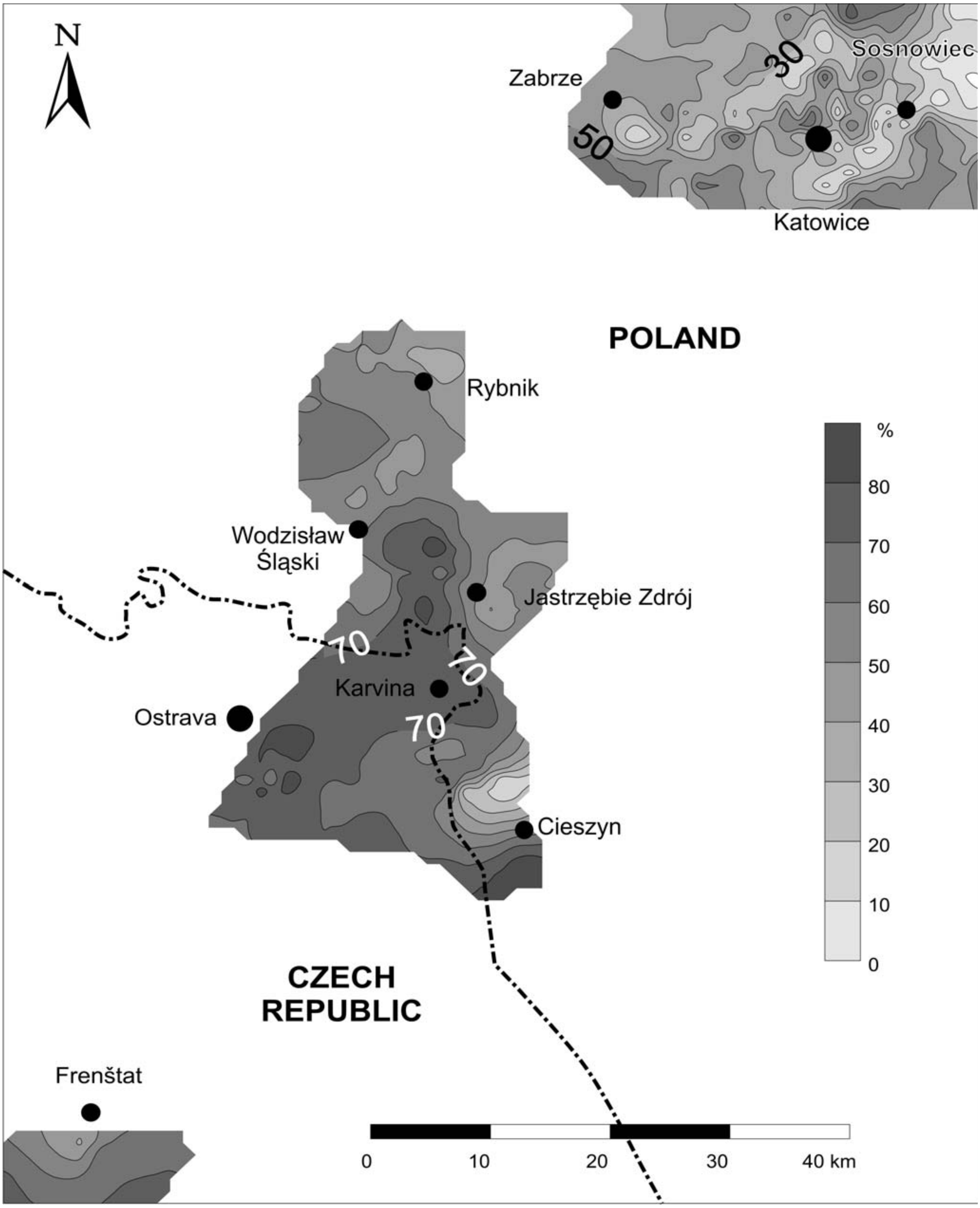

Fig. 25. Map of the net thickness per cent of fluvial sandstones in the Zabrze Beds.

common and also large local wash-outs by fluvial erosion occur (see also Grzybek, 1996; Mirkowski, 1999). The eastward thickness decrease of the Zabrze Beds, particularly in the Main Anticline area, is characterized by irregular and often abrupt local changes – with a thickness decrease or increase by a few tens of metres over a distance of a few hundred metres – which can be attributed to syndepositional normal growth-faults associated with the forebulge flank

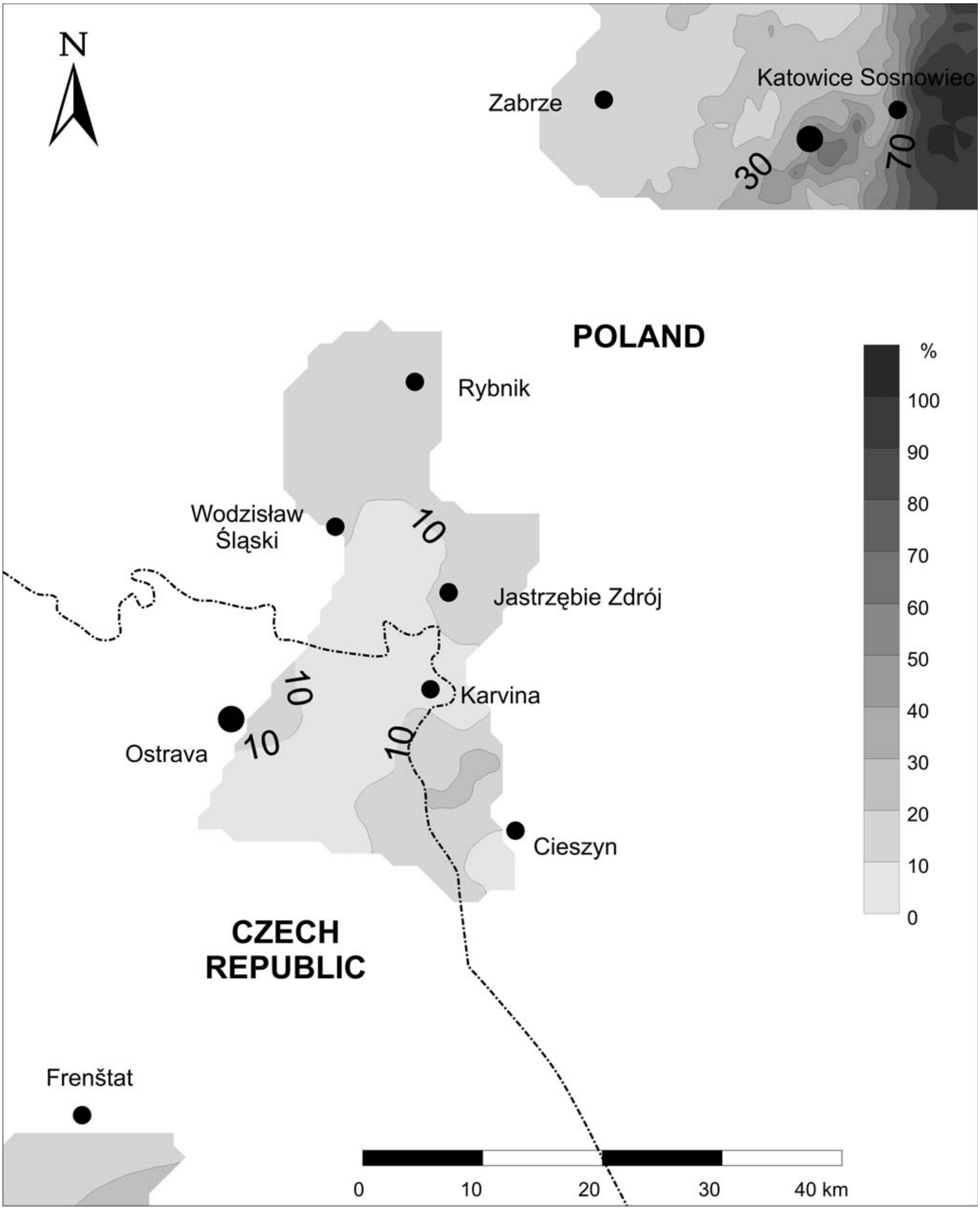

Fig. 26. Map of the net thickness per cent of coal deposits in the Zabrze Beds. Note the preferential deposition on the synclinal basin's eastern flank; the western flank is non-preserved.

(e.g. see Fig. 21, eastern part). A diagnostic feature of growth-faults is the lateral correlativity or even continuity of lithofacies packages with their abrupt thickness change across the fault plain (see Dadlez and Jaroszewski, 1994). Growth-faulting and related local-scale differential subsidence has been reported worldwide from various coal basins (e.g. Sitian *et al.*, 1984; Ferm and Weisenfluh, 1989; Dressen *et al.*, 1995).

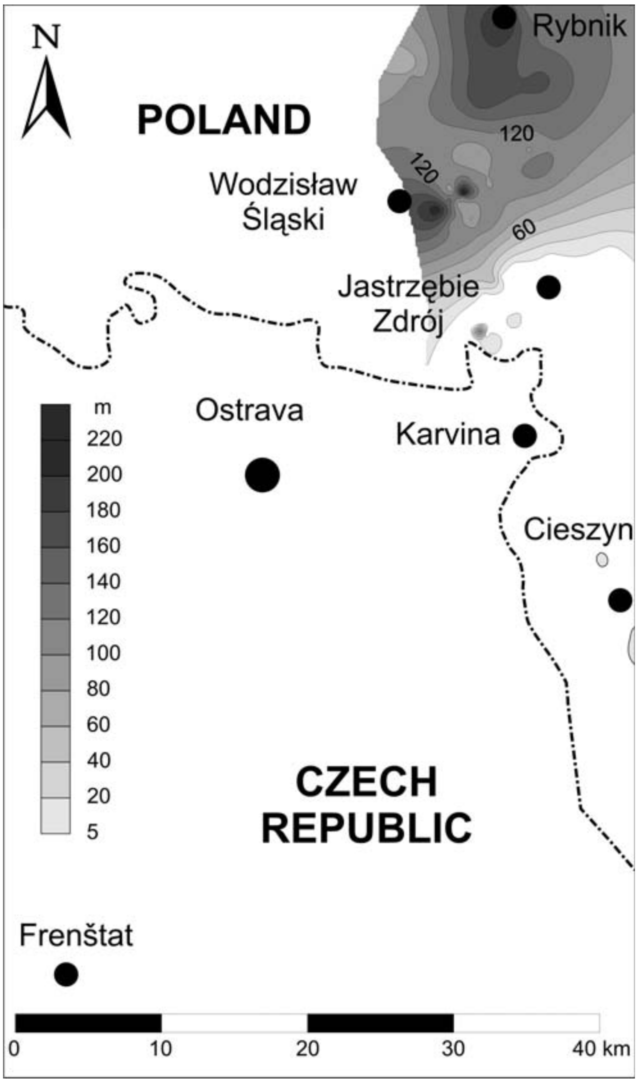

Fig. 27. Map of the thickness of Jejkowice Beds *s.l.*, consider as the coal-barren succession between the Paralic Series and the oldest coal seam of the Zabrze Beds (see Figs 2, 29E).

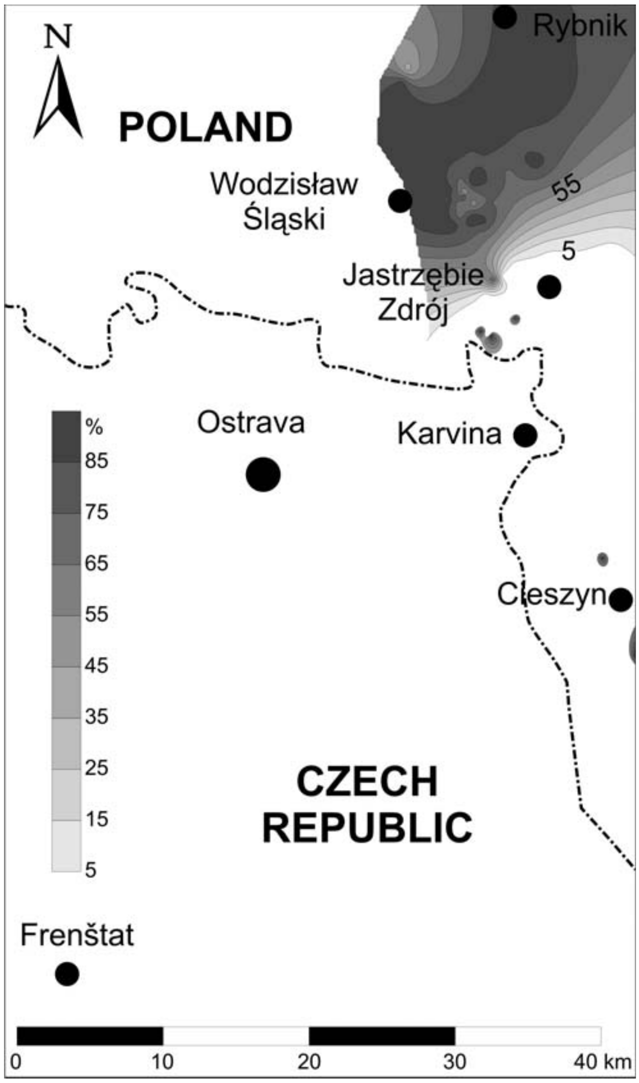

Fig. 28. Map of the net thickness per cent of fluvial sandstones coal deposits in the Jejkowice Beds *s.l.*, consider as the coal-barren succession between the Paralic Series and the oldest coal seam of the Zabrze Beds (see Figs 2, 29E).

When compared with the thickness map of the Zabrze Beds (Fig. 24), the spatial distribution of their net coal content in the basin (Fig. 26) indicates that the most favourable areas for phytogenic deposition where apparently zones of relatively small basin-floor subsidence – even if differential on a local scale towards the east.

DISCUSSION

The pre-Kinderscoutian onset of terrestrial sedimentation

In the Rybnik area (Fig. 3) – within a couple of NE-trending narrow neighbouring synclines uplifted piggyback by the Variscan Orlová-Boguszowice and Michálkovice-Rybnik thrusts and referred to, respectively, as the Jejkowice and Chwałowice troughs (see Jureczka *et al.*, 2005) – the Kinderscoutian alluvium of the Zabrze Beds is underlain by the Jejkowice Beds (Fig. 2; Jureczka, 1988). The Jejkowice Beds *de facto* begin the post-Arnsbergian, post-paralic terrestrial sedimentation in the basin and pass upwards into the coal-bearing Zabrze Beds of a considerably broader extent (Fig. 2). This coarse-clastic succession of fluvial origin consists mainly of sandstones and associated conglomerates (75–95% net thickness), contains a couple of noneconomic coal-seam lenses and is generally considered to be up to 70 m thick (Jureczka, 1988; Jureczka and Kotasowa, 1988; Kotas, 1995). However, the upper boundary of the Jejkowice Beds is unclear and disputable, whereby these deposits are often lumped together with the overlying "coal-barren section of the Zabrze Beds" (Matl, 1966) and considered jointly to be nearly 140 m thick. Their joint thickness distribution and coarse-clastic content are shown in Figures 27 and 28, respectively. It is worth noting that this early belt of fluvial sedimentation is much narrower than that of the subsequent coal-bearing Zabrze Beds alluvium and that the depositional axis of the latter is significantly offset to the east relative to the axis of the former (cf. Figs 24, 28). Boreholes have recognized this coal-barren, coarse-clastic basal succession only in the area between Wodzisław Śląski and

Rybnik, as this lithostratigraphic unit apparently wedges out rapidly both to the SE and to the NW (Figs 27, 28). No lithostratigraphic equivalent of the Jejkowice Beds has been recognized in the basin areas to the south, which suggests that this narrow belt of coarse-clastic deposits is a solitary feature trending from the SW to NE (Fig. 28). As a non-economic unit extending obliquely to the coal measures of Zabrze Beds, it has thus far escaped exploration and more detailed regional recognition.

The Jejkowice Beds overlie the paralic Poruba Beds with an erosional stratigraphic gap (Fig. 2) and reportedly contain an internal erosional gap (Kotas, 1995), which would imply some kind of depositional bipartition. The lower part of the Jejkowice Beds is generally ascribed to the Pennsylvanian (Namurian A) and the upper part to the Mississippian (Namurian B), although the exact age determinations from fossil flora are somewhat confusing and controversial. The evidence from macroflora indicates a Mississippian (Arnsbergian, zone E_2) taxon affinity (Kotasowa, 1988; Kotasowa and Migier, 1995), whereas miospore assemblages indicate zones SO and KV of the Pennsylvanian (Kmiecik, 1995). The miospore study by Miklasińska-Oliwkiewicz (2002) suggests that the deposition commenced in the latest part of zone SO and proceeded into zone KV. The miospore data indicate no stratigraphic gap between the Jejkowice Beds and the Zabrze Beds, but also suggest that the deposition occurred without major breaks from the latest Arnsbergian through Chokerian and Alportian to Kinderscoutian. However, this latter notion is probably incorrect on the account of the marked erosional and macrofloral stratigraphic gap at the base of the Jejkowice Beds and the high potential for miospores to be resedimented in a fluvial environment, where erosion processes abound. It is thus hypothetically suggested that the deposition of Jejkowice Beds commenced probably not earlier than in the late Chokerian (Fig. 2).

Notably, the Jejkowice Beds were deposited on an erosional surface which elsewhere in the basin corresponds to an even larger (Chokerian–Alportian) stratigraphic gap and is overlain by the oldest coal seam 510 of the Zabrze Beds. It is an open question whether the lack of coal seam 510 in the belt of Jejkowice Beds is due to non-deposition (i.e. unfavourable local conditions) – as suggested in the present study – or is due to erosion by the fluvial system of Zabrze Beds, as suggested by Havlena (1982). The thickness of coal seam 510 is, indeed, locally reduced by erosion, as seen in the western part of the Jastrzębie Zdrój area (Fig. 17). The evidence from Jejkowice Beds is inconclusive, as the two thin (80 cm) coal-seam lenses found in this succession may be either a local depositional equivalent or an erosional relic of the elsewhere prominent coal seam 510.

On the basin of the evidence reviewed above, the deposition of the Jejkowice Beds is interpreted to have occurred in a narrow fluvial valley trending from the SW to NW, incised into the substrate of paralic Poruba Beds near the end of Arnsbergian (Fig. 29A). The valley was widened by the surrounding substrate denudation and reached a maximum of incision in the late Chokerian, when the deposition of the Jejkowice Beds commenced (Fig. 29B). An eastward diachroneity of the Jejkowice Beds (Miklasińska-Oliwkiewicz, 2002) probably reflects their onlap onto the SE valley-side slope. The valley-fill belt of Jejkowice Beds *s.s.* in the study area is up to 70 m thick and 22 km wide (Matl, 1965). The

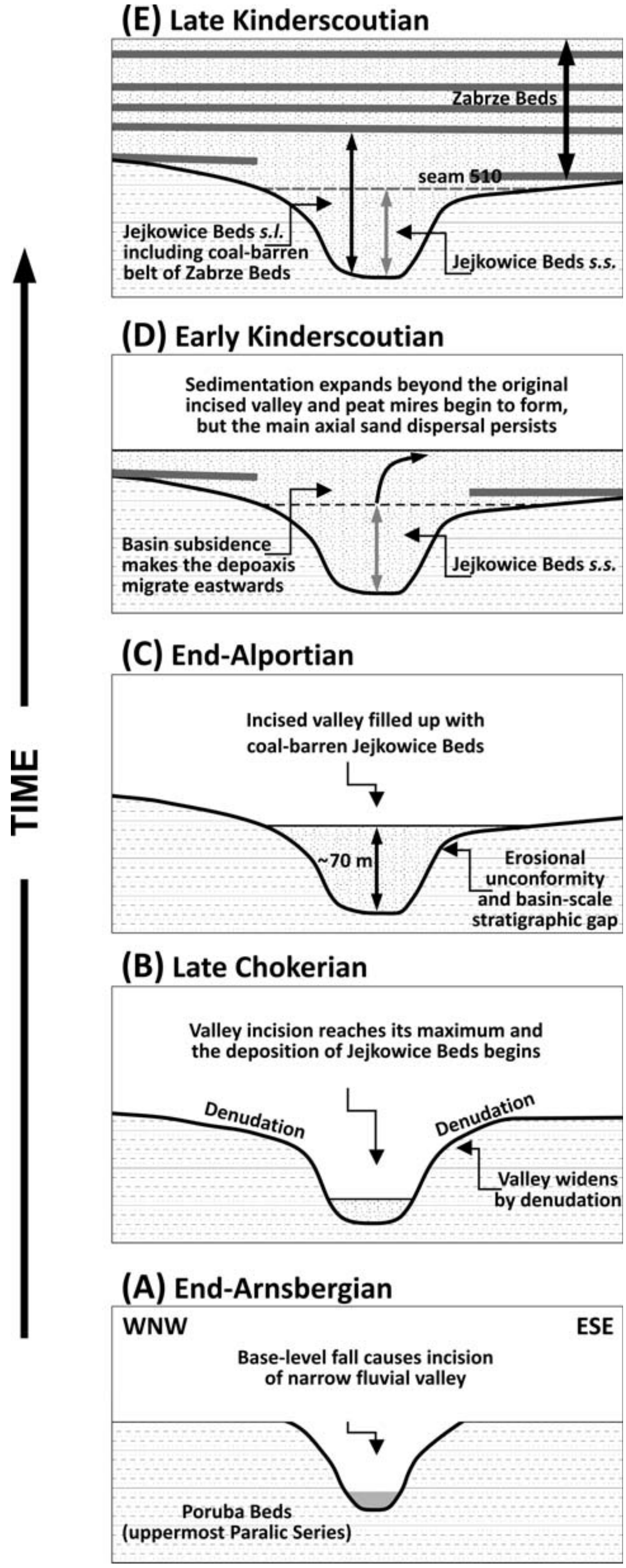

Fig. 29. The onset of terrestrial sedimentation in the Upper Silesia Coal Basin: schematic model for the stratigraphic relationship between the Jejkowice Beds and the overlying, coal-bearing Zabrze Beds.

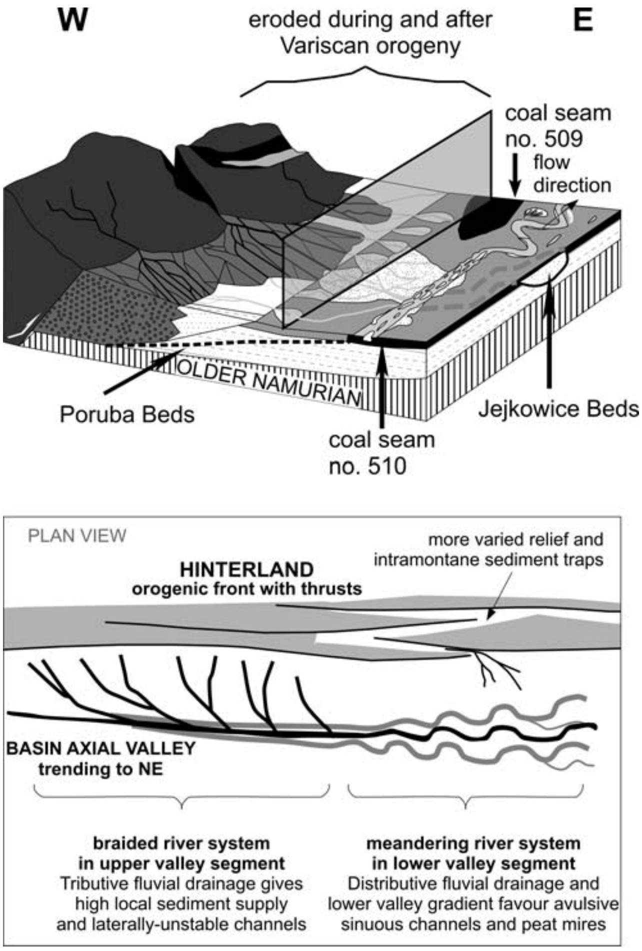

Fig. 30. Schematic model for the fluvial system of Zabrze Beds. The blockdiagram (upper part) points out that the western part of the basin is presently non-preserved due to erosion. The plan-view diagram (lower part) explains the downstream transformation of the fluvial system.

valley itself was likely deeper, perhaps nearly 100 m in relief, and was broadened by its catchment denudation (Fig. 9B), while vegetation and pedogenic processes prevailed extensively farther beyond in the basin area. The valley was filled up to a critical height of 70 m by the end of Alportian (Fig. 29C), whereby the alluvial sedimentation extended beyond the palaeovalley margins, extensive peatbogs began to form and the Kinderscoutian deposition of the coal-bearing Zabrze Beds commenced (Fig. 29D). The inherited primary axis of fluvial sand dispersal remained initially unchanged, and hence the local lack of coal seam 510, but the axis of basin subsidence had gradually shifted to the east (cf. Figs 24, 28), while the effective lateral space for fluvial channel shifting and sand dispersal had markedly increased. The deposition of the Zabrze Beds (Fig. 29E) is thought to have occurred within the synclinal confinement of a narrow foredeep basin, resembling to some extent a large-scale, basin-axis alluvial valley. This interpretive model explains both the post-Arnsbergian basin-scale stratigraphic gap (Fig. 2) and the controversial stratigraphic relationship between the Jejkowice Beds and the overlying Zabrze Beds (Fig. 29E).

The Kinderscoutian alluvial system

The Kinderscoutian alluvial system of the Zabrze Beds was confined to the axial zone of the foredeep syncline trending SSW–NNE (Fig. 24), which may suggest a slight tectonic change in the direction of the basin subsidence axis. The preceding analysis of the alluvial architecture of Zabrze Beds indicates that the NNE-flowing fluvial drainage system involved channel belts up to around 5 m thick and evolved in the downstream direction from braided into meandering. This interpretation concurs with the earlier notion of Doktor and Gradziński (2000) that both types of rivers were involved. The fluvial system in its upper (SSW) reaches was probably tributive, richly supplied with sediment and favouring braided channel pattern, but was distributive in the lower (NNE) reaches, promoting more stable meandering channels and allowing broad back-swamps to form (cf. Bridge, 2003). This downstream change entailed a considerable change in the alluvial architecture when it comes to the stacking pattern of channel-belt sandstone bodies and their lateral/vertical interconnectedness.

The downstream transformation of the fluvial system from braided into meandering (Fig. 30) can be attributed to such tectono-geomorphic factors as a northwards decreasing axial gradient and increasing width of the foredeep syncline (cf. Ouchi, 1985; Miall, 1996; Holbrook and Schumm, 1999), which are spatially-varied parameters controlled by the flexural rigidity of the underlying crustal basement and the structural growth of the orogen (Beaumont, 1981; DeCelles and Giles, 1996). A non-uniform growth of the orogen along its front may have also created a more varied morphology of the Variscan hinterland to the north, with better developed intramontane sediment traps and a lower direct sediment delivery to the foredeep basin.

The meandering fluvial system, with its more stable channel belts, promoted development of extensive peat-forming mires in floodplain areas. The river channels in such a system – especially if distributive – migrate laterally by increasing their sinuosity, but the channel belts tend to be stable for appreciable time periods and shift laterally by avulsion (Allen, 1978; Leeder, 1978; Bridge and Leeder, 1979; Smith *et al.*, 1989; Bryant *et al.*, 1995; Heller and Paola 1996; Jones and Schumm, 1999).

Coal-seam splitting and its variability in the Zabrze Beds have been described since the mid-20th century (Doktorowicz-Hrebnicki, 1945; Stopa, 1959; Kotas, 1995; Kędzior, 2001, 2008). The clastic splits range from thin overbank flood sheets and thicker crevasse splays to distal levee wedges. The controlling factors were probably the frequency and magnitude of river floods, the peatbog distance from an active channel and the frequency and lateral scale of channel avulsion (cf. Elliot, 1965; Ryer and Langer, 1980; Gradziński *et al.*, 1995; Jorgensen and Fielding, 1996; Herbert, 1997). The abrupt invasion of a thin layer of clastic sediment merely interrupts the accumulation of peat, but if the thickness of the invading sediment is considerable – a temporal cessation of peat growth may occur, although the accompanying compaction of a fresh buried peat creates an accommodation space for renewed peatbog formation (cf. Thiadens and Haites, 1944; Fallini, 1965; Ryer and Langer, 1980; Gradziński and Doktor, 1995). Beyond the lateral extent of clastic split, the successive generations of peat merged into a single seam. As pointed out by Kędzior (2008), the splitting of coal seams is locally due to the contemporaneous growth-faults trending SSW–NNE, with the clastic-split seam on the hanging wall and its non-split thinner equivalent on the footwall. A similar phenomenon has been reported from other coal basins (e.g., Rahmani and Flores, 1984; Sitian *et al.*, 1984; Calder, 1993; Dressen *et al.*, 1995).

The thickness of coal seams generally depends upon the time available for effective peat accumulation in a particular floodplain area (Teichmüller and Teichmüller, 1982; McCabe, 1984). The apparent bimodality of coal-seam thicknesses (Fig. 23) may thus suggest two different time-scales of the environmental "time windows" for peat accumulation (*sensu* Nemec, 1992), with their opening and closing in accordance with the dynamics of the fluvial-system behaviour. The thickness mode of 0.1–0.3 m may represent relatively short-lived peatbogs formed close to the laterally migrating or expanding fluvial channels and subject to occasional, once-a-century catastrophic flooding, whereas the thickness mode of 1–3 m may represent the longer-lived peatbogs located far away from contemporaneous channels and controlled by the time scale of the channel broader shifting by avulsions. This interpretation is hypothetical, as it cannot be precluded that the formation of shorter- and longer-lived peatbogs was hydrologically controlled by climatic and/or base-level changes (see Ramsbottom, 1977; Phillips and Peppers, 1984; Wright and Vanstone, 2001; Falcon-Lang, 2003, 2004), even though there is no palynological evidence of frequent climatic changes in the region and it is also uncertain whether the base level of the fluvial system was the Namurian sea level or just the level of an adjacent endorheic segment of the basin.

Sequence-stratigraphic interpretation

In an interpretive sequence-stratigraphic scenario, the Chokerian–Alportian regional stratigraphic gap (Fig. 2) – with the incision of a NE-trending axial fluvial valley nearly 100 m deep and a pedogenic stasis beyond its catchment (Fig. 29A) – represents a marked forced regression (*sensu* Catuneanu, 2006). The character of the end-Arnsbergian unconformity varies laterally from erosional along the basin axis to non-depositional pedogenic farther beyond. Clastic sedimentation resumed with the deposition of the Jejkowice Beds, which – according to Kotas (1995) – contain an internal erosional gap and hence show some kind of depositional bipartition. The early fluvial valley-fill deposits of the lowest Jejkowice Beds *s.s.* (Fig. 29B), below this inferred gap, would then represent the latest forced-regressive to lowstand systems tract (*sensu* Helland-Hansen, 2009) with the gap itself reflecting a prolonged stage or possibly multiple stages of lowstand sediment bypass. The remaining, higher part of the Jejkowice Beds *s.s.* and the overlying Zabrze Beds (Fig. 29E) would represent a transgressive systems tract (*sensu* Helland-Hansen, 2009) with an upwards-decreasing rate of vertical aggradation and the local axis of basin subsidence shifting eastwards and rotating to a SSW–NNE trend. The highstand systems tract of the uppermost Zabrze Beds is probably non-preserved, as indicated by the Marsdenian erosional gap separating the Zabrze Beds from the overlying fluvial deposits of the Ruda Beds (Fig. 2).

A similar next stratigraphic sequence, or cycle of base-level change (Catuneanu, 2006), in the Polish part of the basin (Fig. 2) is represented by the Marsdenian erosional stratigraphic gap (forced-regressive systems tract) followed by the Yeadonian deposition of alluvial Ruda Beds (transgressive systems tract) and the Langsettian encroachment of a mud-dominated lacustrine environment of the Załęże Beds (highstand systems tract). The Załęże Beds are separated from the overlying Orzesze Beds by a belt of sandy fluvial deposits, up to 50 m thick, which suggests another forced regression and incision of a new fluvial valley filled up by a transgressive systems tract.

Orogen foredeeps are some of the most tectonically active sedimentary basins, where the subsidence axis may rotate with time – both horizontally and vertically – and the effects of local tectonics commonly overwhelm the eustatic sea-level control. The wavelength and axis direction of foredeep syncline are thus neither uniform nor steady features, and their spatial-temporal variation is a physical consequence of the orogen nappe stacking and sediment loading on an elastic lithosphere (Beaumont, 1981; DeCelles and Giles, 1997). The tectonic advance of orogenic front is spatially non-uniform, with each pulse of nappe thrusting and adjacent foredeep subsidence followed by elastic crustal rebound and forebulge uplift. This variable tectono-dynamic style of foredeep development may explain shifts of basin depositional axis and the lateral stratigraphic differences between the Polish and Czech segments of the Upper Silesia Coal Basin (Fig. 2).

The stratigraphic history of the non-preserved northern part of the Variscan foredeep in Upper Silesia is unknown. It is therefore uncertain for how long it was occupied and controlled by the Carboniferous sea level and when it eventually turned into an independent, lake-occupied endorheic terrestrial environment. The evidence from the preserved Polish segment of the basin suggests that this change occurred probably at the end of Arnsbergian, because none of the subsequent base-level highstands had brought in any new marine invasion. Instead, a lake-hosting and peat-forming alluvial floodplain formed repeatedly. However, this evidence does not preclude the possibility that the alluvial floodplain was actually the upper distributary plain of a bayhead-type deltaic system discharging into a sea-occupied northern segment of the basin.

CONCLUSIONS

This sedimentological study of the Kinderscoutian Zabrze Beds in the Upper Silesia Coal Basin leads to the following main conclusions:

– The coal basin formed as a NW-trending synclinal foredeep of the Variscan Moravo-Silesian orogen and was dominated by an axial fluvial drainage;

– The post-Arnsbergian terrestrial phase of Namurian sedimentation in the basin commenced with a forced regression and the incision of an axial fluvial valley, about 100 m deep. The vegetated basin area outside the valley catchment was subject to an environmental stasis with pedogenic processes, resulting in a Chokerian–Alportian non-depositional stratigraphic gap;

– The incised valley in the late Chokerian–Alportian time was nearly filled up by the coal-barren fluvial succession of Jejkowice Beds, up to 70 m thick, before the alluvial sedimentation had extended beyond the valley limits, broad peat-forming mires began to form and the Kinderscoutian deposition of the Zabrze Beds commenced;

– The Kinderscoutian fluvial drainage followed the axis of basin maximum subsidence, which had meanwhile shifted slightly to the east and acquired a NNE trend due to the Variscan orogen growth. The fluvial system was tributive, heavily charged with sediment and braided in its upper (SSW) reaches, but was distributive and meandering in the lower (NNE) reaches – in the area of the basin's present-day Main Anticline in Poland;

– This downstream transformation of the fluvial system is attributed to a spatially varied tectonic geomorphology of the foredeep basin, with its local width increasing and axial topographic gradient decreasing towards the north;

– The northernmost part of the basin is non-preserved, and hence it is unclear whether the axial fluvial system was debouching into the sea or a lake-hosting endorheic terrestrial environment. This latter possibility is more likely, since none of the subsequent base-level highstands had brought a return of a marine-influenced paralic environment.

Acknowledgements

I dedicate this paper to the memory of the late Professor Ryszard Gradziński – a dear friend and highly inspiring mentor, an eminent sedimentologist and a leading investigator of the Upper Silesia Coal Basin. I thank Petr Martinec for data from the Czech part of the basin and Marek Doktor for helpful discussions. The geological staff of the Marcel Coal Mine kindly helped in preparing borehole correlation panels for the Rybnik area, and the geological staff of the Darkov Coal Mine in Czech Republic kindly provided core samples. The manuscript was reviewed by Martin Gibling and Janusz Jureczka and edited by Wojciech Nemec, who helped to improve significantly its contents.

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