

Castle Conglomerate Unit of the Upper Silesian Basin (Czech Republic and Poland): a record of the onset of Late Mississippian C2 glaciation?

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The Castle Conglomerate Unit in the Poruba Member (Early Namurian, Mississippian) is a lithosome composed of coarse-grained sandstones and conglomerates. Its thickness, lithology and extensive area make it unique in the paralic sequence of the Ostrava Formation of the Upper Silesian Basin. The unit was studied on the basis of information from exploratory boreholes, mines and its outcrop at the type locality in the Lučina Valley in Silesian Ostrava. Locally, the unit attains a thickness of up to 115 m (average 24.4 m). Its present-day area is approximately 992 km². The axis of the conglomerate facies (with character of interbeds) in the unit has a NNE-SSW alignment and coincides with the axis of the basin's maximum subsidence during the sedimentation of the Poruba Member. The maximum aggregate thickness of the conglomerate facies is 60 m; their present-day area of occurrence is approximately 480 km². The Castle Conglomerate Unit represents deposits of a low-sinuosity river system. The upper part of the multistorey channel fill is characterised by channels filled with sand bedforms and occasional bars. Palaeocurrents show a low spread of vectors, primarily to the NNW. The lower part does not crop out; it is known, therefore, only from boreholes. The presence of the unit's coarse-grained clastics inside the basin filling, which is dominated by siltstone and medium-grained sandstone, indicates a major drop in the base level, which is interpreted here as a drop in the sea level. We correlate this event with the major glacio-eustatic sea level drop at 323 Ma that can be connected with the onset of glaciation interval C2 of the Late Paleozoic Ice Age. Because the resolution of available stratigraphic and geochronologic data is not currently sufficient, an alternative explanation of the tectonic origin cannot be ruled out of the discussion and may also be valid in regard to the active Variscan foreland. • Key words: Ostrava Formation, Upper Silesian Basin, Mississippian, Carboniferous, sedimentology, glaciation, paleovalley.

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This study aims to contribute to the on-going debate on the nature of the Late Paleozoic Ice Age. Many studies emerging in recent years have focused on the recognition and timing of glacial periods during the Late Paleozoic and the consequent changes in biota (*e.g.*, Davydov *et al.* 2010, Fielding *et al.* 2008, Groves & Yue 2009, Powell 2008, Rygel *et al.* 2008, Waters & Condon 2012). We focus on a marked sedimentary body, the Castle Conglomerate Unit, which may represent a record of the onset of one of the Late Paleozoic glaciations.

The Poruba Member represents the highest lithostratigraphic unit of the Ostrava Formation, which stratigraphically belongs to the Namurian (Arnsbergian). Its lithology has special features that distinguish it from other lithostratigraphical units of the Ostrava Formation. One of the most notable anomalies is the presence of the Castle Conglomerate horizon, which represents a unique accumulation of coarse-grained clastics, atypical for the paralic development of sedimentary fill. Lateral extent of this unit, which is approximately 1,000 km², average thickness over

20 m and frequent presence of conglomerates with pebble size up to 10 cm makes it the most prominent horizon of its kind in the Ostrava Formation.

In this study, we focus on studying the Castle Conglomerate Unit (“zlepíenec zamecki” in Polish, “zámecký slepenec” in Czech, hereinafter referred to as CCU). Although there are a number of publications that consider its petrographic composition, especially the pebble material and its granulometric characteristic (e.g., Brieda 1972, Doktor & Gradziński 1998, Paszkowski *et al.* 1995), a description of its overall basic geological characteristics throughout its occurrence, *i.e.*, in the Czech and Polish parts of the basin, is still lacking. This publication aims to describe this remarkable sedimentological phenomenon on the basis of maps of the area of occurrence and models of the thickness of its entire lithosome and the conglomerates themselves *sensu stricto*. Likewise, this work attempts to interpret the findings based on these new results and the sedimentological study of the boreholes and outcrop of this unit.

Similar studies concerning large-scale paleovalleys in Carboniferous are not common, but we can mention works of Gibling & Wightman (1994), Opluštil (2005), Henry *et al.* (2010), Belt *et al.* (2011) or Davies & Gibling (2011). This study has implication for sequence stratigraphic analysis of the Late Palaeozoic cyclothems and paleoclimatic analysis of the Late Palaeozoic, a topic of long-term interest (e.g., Hampson *et al.* 1999, Bishop *et al.* 2010, Davydov *et al.* 2010, Jerrett *et al.* 2011, Pointon *et al.* 2012, Schmitz & Davydov 2012, Sweet & Soreghan 2012).

Geological setting

The Upper Silesian Basin (hereinafter referred to as USB), with its bituminous coal deposits, was formed in the final stages of the evolution of the extensive Moravo-Silesian Palaeozoic Basin in the eastern domain of the Central European Variscides. It was developed in the foreland of the Variscan orogene and became a part of its outer zones, the so-called Rhenohercynicum and Subvariscicum (Grygar & Vavro 1995, Kumpera & Martinec 1995).

The post-erosional boundary of the Upper Silesian Basin has a roughly triangular shape that extends from Poland southwards into Czech territory. The area of this important European bituminous coal basin exceeds 7,400 km². The larger part lies in the territory of Poland, and the smaller part lies in the territory of the Czech Republic.

The basin is filled by some of the youngest sediments overlying the Brunovistulicum (Buła & Žaba 2005, Kalvoda *et al.* 2008). These sediments post-date the main phases of the Variscan orogeny and range in age from the Mississippian onwards. The base of the basin is formed by the older sedimentary cover of the Brunovistulicum, spe-

cifically sediments of Cambrian, Ordovician, Devonian and Mississippian age. Carboniferous sedimentation begins with pre-flysch carbonates, continues through the marine clastic sediments of the flysch (Culm facies) stage to the coal-bearing terrigenous molasse (Kumpera 1990, Dvořák 1994). Carbonate rocks diminish in the stratigraphically higher parts (by the late Viséan) of the Carboniferous. The basin fill is overlain primarily by Triassic, Neogene (Miocene) and Quaternary and less by Permian and Jurassic sedimentary sequences; in the southern part of the basin, it is also overlain by Neogene deposits of the Carpathian Foredeep and, further south, by nappes of the Outer Carpathians (Jurassic to Paleogene).

As the stratigraphic level increases (*i.e.*, from the west to the east), the intensity of the diagenetic overprint decreases. In the Hradec-Kyjovice Formation the vitrinite reflectance R_o is generally between 5.5 to 2.0% (unpublished data); in the Ostrava Formation, R_o has been reported in the range of 2.0 to 0.5% (Sivek *et al.* 2003, Kandarachevová *et al.* 2009).

The geology of the USB has been described in a number of published papers, as well as unpublished reports. Dopita *et al.* (1997) summarised the existing knowledge of the geology from the Czech part of the basin. The authors of the latest monograph dealing with the Polish part of the basin are Dembowski (1972a,b), Kotas & Malczyk (1972a,b) and Porzycki (1972). Recent publications in English on the geology of the USB include Dopita & Kumpera (1993), Jureczka *et al.* (2005), Jureczka & Kotas (1995), Kotas (1995), and Kumpera (1997), among others.

The types of sediments filling the basin, together with their thicknesses and extents, are briefly discussed in papers by Dopita *et al.* (1997) and Martinec *et al.* (2005). Coal seams containing bituminous coal in the USB are of the Late Carboniferous (Namurian to Westphalian) age. Two major sedimentary units can be distinguished in the coal-bearing Carboniferous: a paralic facies and a terrigenous facies. The older, paralic type of sedimentation can exist in a wide spectrum of sedimentary environments, from purely continental with transitions to marine, frequently with intercalations of pyroclastic material. This type of sedimentation is characterised by the cyclic alternation of inorganic sediments with coal beds that is known as a cyclothem. The Early Namurian Formation (Ostrava Formation, Paralic Series) consists of the Petřkovice, Hrušov, Jaklovec and Poruba Members (see Fig. 1).

Several authors have reported the cyclicity of the coal-bearing sequences in the Ostrava Formation of the USB. Most prominent among these are Přebyl (1954), Jansa & Tomšík (1960), Zeman (1960) and Havlena (1988), who tried to explain this cyclicity by epeirogenetic movements. Only Skoček (1991) and, later, Gastaldo *et al.* (2009a) attempted to apply the glacio-eustatic fluctuation of the sea

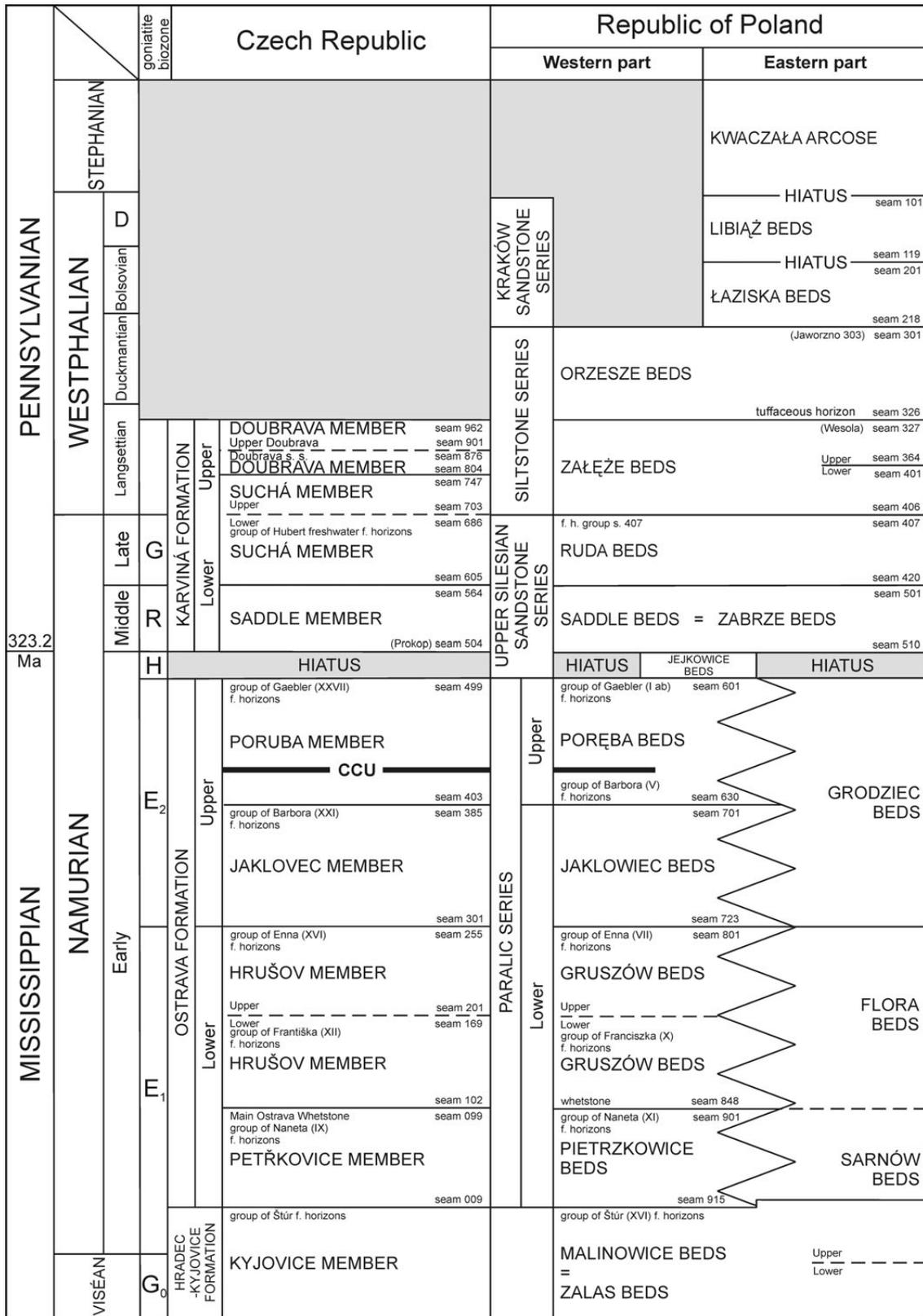


Figure 1. Lithostratigraphic division of the Czech and Polish parts of the Upper Silesian Basin, according to (Polish part) Dembowski (1972a), modified by Jureczka (1988) and Kotas *et al.* (1988), and (Czech part) Sivek *et al.* (2003), which was modified. Radiometric dating according to Davydov *et al.* (2012), goniatite biozones according to Řehoř (1970). Position of the Castle Conglomerate Unit is indicated by bold line.

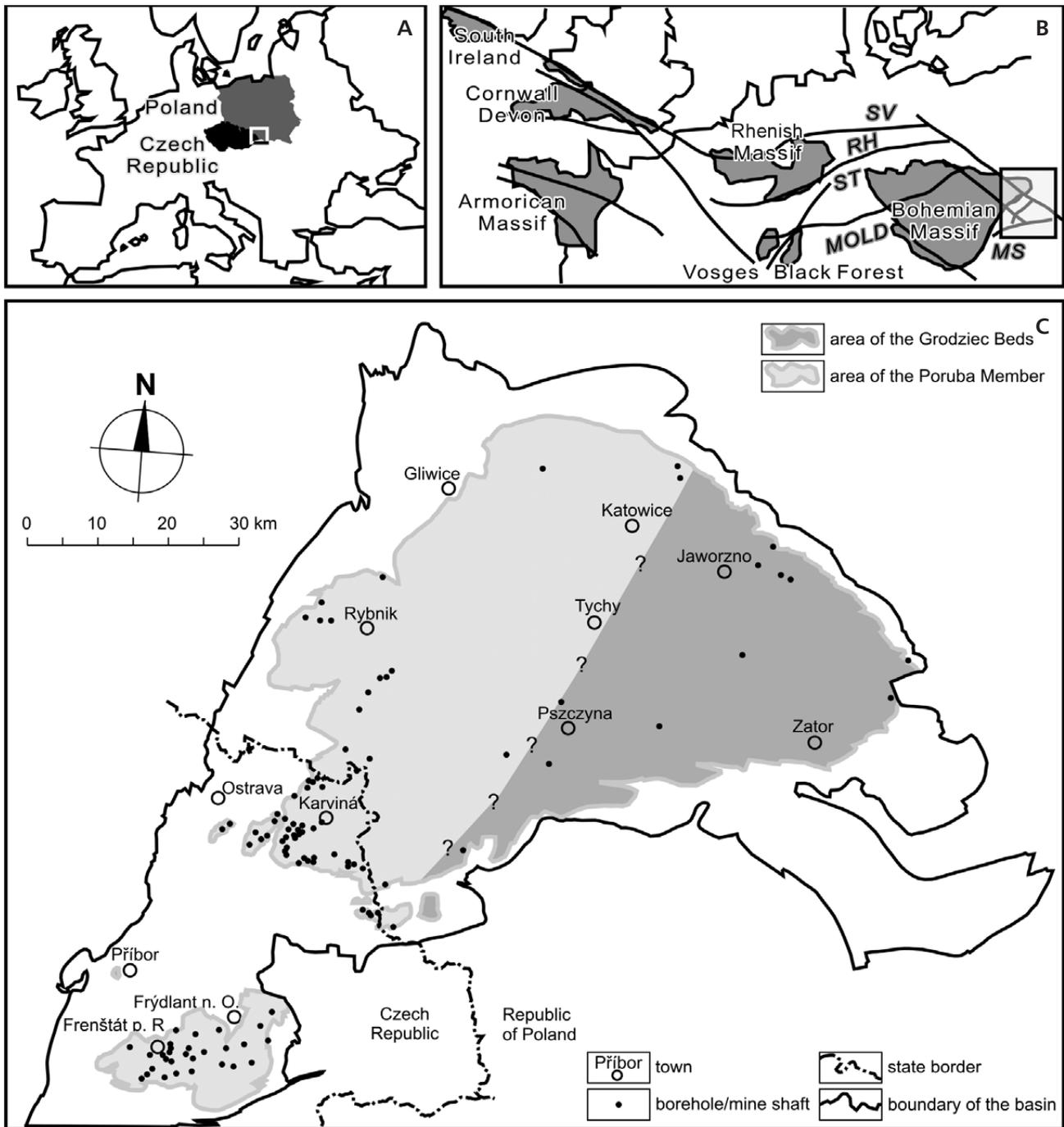


Figure 2. A – location of the Czech Republic and Poland within Europe. • B – location of the Bohemian Massif and the study area within European Variscides. Major tectonic elements: SV – Subvariscan Zone, RH – Reno-Hercynian Zone, ST – Saxo-Thuringian Zone, MOLD – Moldanubian Zone, MS – Moravo-Silesian Zone (according to Hýlová *et al.* 2013). • C – location of the exploratory boreholes and mine shafts used in the work.

level to explain the origin of cyclothems in the USB. An ideal cycle of the Ostrava Formation consists of (from the base upward): 1. carbonate cemented sandstone or biotitic arkose; 2. aleuropelites, at the top with root casts (seathearth); 3. coal; 4. massive mudstone to siltstone with large plant remains or bituminous muscovitic aleuropelite

enclosing fresh-water fauna, sometimes with brackish or marine fauna. The cycle thickness varies from 6 to 20 m; average is 15 m. Cycles of higher order are mesocycles and megacycles (Ostrava Formation comprises 6 megacycles). The studied part of the sedimentary record belongs to the Megacycle F according to Jansa & Tomšík (1960).

Material and methods

The primary data source for creating the data files intended for modelling the development of the Castle Conglomerate Unit are the well-logs of the exploratory boreholes. The exploratory boreholes were realised over a long period of time in the second half of the 20th century. Thus, it is evident that, with respect to developments in boring technology and data interpretation, the data file is very diverse. As a result, it was necessary to approach the boreholes included in this file individually and to re-evaluate the data.

Sixty-two documentation points that describe the complex's complete profile were used to create the models (Fig. 2). Additionally, 63 documentation points, in which the complex was not developed in the corresponding stratigraphic level, were used to form the boundary of the extended unit. All profiles were individually assessed. Apparent stratal thicknesses were converted to true thicknesses at intervals with a specific known inclination. Specifically, the boreholes used to create the models were NP 164, NP 321, NP 339, NP 340, NP 388, NP 416, NP 417, NP 475, NP 477, NP 486, NP 499, NP 522, NP 523, NP 531, NP 533, NP 539, NP 541, NP 544, NP 545, NP 546, NP 550, NP 551, NP 552, NP 554, NP 556, NP 671, NP 672, NP 673, NP 675, NP 687, NP 718, NP 729, NP 818, NP 819, NP 821, NP 822, NP 824, NP 825, NP 826, NP 827, NP 830, NP 840, NP 891, NP 905, NP 906, NP 908, NP 910, 199/XXXIX, 930/XLIII, C-17, C-32/87, D-5/86, D-34/87, D-71/08, D-72/08, D-73/08, D-74/08, D-75/08, D-76/08, D-77/08, D-78/09, D-79/09, D-80/09, ČSM 68/85, ČSM 111/88, ČSM 112/85, SuSto 515/89, SV 2 (Czech Republic) and CieIG-1, G-381, JeIG-1, Je-4, Je-5, Ma-18, Ma-32, Ma-34, Ma-39, Ma-41, Pi-32, RupIG-1, Sum-5 and Wa-2 (Poland). The following cross-adit and mine shaft profiles were also used: Evžen 1, Hedvika 2, Ludvík 3/1, Pokrok 1/3, Václav 1, Zárubek (Hermenegild), Žofie 5/1 (Czech Republic).

To construct the isopach models of the Castle Conglomerate Unit in the basin, the method of bisecting the distances between the positive and the negative boreholes was used. Map outputs were created by program products from Bentley Systems, Inc. – InRoads and MicroStation 8.5. The inner part of the model used interpolation between the triangles constituting known documentation points; the points of each triangle included the last known point, the border and the extrapolated point. In areas without known values adjacent to extrapolated values, the model is estimated by an expert's best judgement (Kandarachevová *et al.* 2008).

The seam numbering used in the text is from the Czech part of the Upper Silesian Basin (Dopita 1959), whereas the regional chronostratigraphic units used for classifying the Late Carboniferous in Western and Central Europe (Namurian, Westphalian, Stephanian) are used.

The sedimentological study is based on two core logs, four outcrop logs and three outcrop photomosaics. The approach to interpreting the geometric features of facies assemblages (architectural elements) essentially follows that of Miall (1985) and Bridge (1993). The petrology of the primary facies types was also studied in 20 thin sections of core D 80-09 using standard optical transmitted light microscopic techniques.

Characteristics of the Castle Conglomerate Unit

The aim of this work was to build on previously published data on the Poruba Member and the Castle Conglomerate, which were based on data from the Czech and Polish parts of the basin, to describe the overall geological picture of this remarkable phenomenon. The models are the first interpretation of the development of the Castle Conglomerate Unit and its conglomerate facies in the Upper Silesian Basin. The sedimentological interpretation is also novel.

The unit's definition and boundaries and its position in the Poruba Member

The first to name the lithosome of sandstones with conglomerate layers the "Castle Conglomerate" was likely Šusta (1928a), in a brief report that immediately preceded the release of the monograph "Coal mines in the Ostrava-Karviná district". In the monograph itself, this name is used by Patteisky & Folprecht (1928) and Šusta (1928b). Patteisky & Folprecht (1928) state that Šusta named the conglomerate, although no literary source is cited. The facts concerning the first description are not well known by the professional public and are very often cited incorrectly. This rock succession acquired its name from the surface outcrop, which is located in the vicinity of the Silesian-Ostrava Castle (which was converted to a chateau between 1534 and 1548). Works published prior to 1928 (*e.g.*, Petrascheck 1910) present this horizon of conglomerates with coarse-grained sandstones but do not name it specifically.

The Castle Conglomerate Unit is understood to be a lithosome of coarse- to medium-grained sandstones with conglomerate facies. It is located in the lower part of the Poruba Member (Namurian) of the Ostrava Formation of the Upper Silesian Basin (Fig. 3). Its base is primarily erosive and is situated at approximately the same stratigraphic level throughout the basin, *i.e.*, above the Filip (403) coal seam group. In the Ostrava part of the basin, 3–4 incomplete cycles of the František (413) seam above the Filip coal seam group are preserved (Brieda 1972; Fig. 4). The Frenštát part of the basin (southernmost part of the USB), where the Castle Conglomerate Unit totally eroded the

basal part of the Poruba Member and a significant part of the Jaklovec Member (boreholes NP 821, NP 822, NP 824, NP 826 and NP 552 at Fig. 5), is exceptional.

The unit's roof is blurred, forming its transition to the finer-grained sediments. In the unit's roof, there was a previously developed, easily identifiable sequence of marine sediments of the Gabriela marine horizon. Locally developed coal seams were observed between the marine sediments and the unit's roof, as well as within the unit itself.

CCU itself can be locally used as an important correlation horizon. Nevertheless, the faunistic horizon Gabriela, which lies in the unit's nearby roof, is used for confirmation of the correct identification in boreholes. The marine horizon Gabriela is the stratigraphically lowest faunistic horizon of the Koks faunistic horizon group (XXIII) and is the most significant one within it. It is developed on the top of the Gabriela (418) coal seam. Its faunistic assemblage is very variable. Bivalves predominate over cephalopods (mostly *Goniatitida*) and gastropods (represented by *Bellerophon-tacea*) and were described by Řehoř & Řehořová (1985).

Area of the unit's occurrence and unit's outcrops

To understand the origin and development of the Castle Conglomerate Unit, models of its area and thickness have been created that include the area and the overall thickness of the conglomerate layers in this unit (Fig. 7). The Castle Conglomerate Unit is not developed in the entire area of the Poruba Member's development in the Upper Silesian Basin (Fig. 2). The greatest thickness occurs at the western post-erosive border, where, in certain locations, the thickness exceeds 100 m. The area of maximum thickness is located in the Jejkowice and Chwałowice Brachysynclines (west of the town Rybník) and in the Ostrava, Petřvald and western segment of the Karviná parts of the basin (approximately between the cities of Ostrava and Havířov). The unit's maximum thickness is thus located west of the Orlová Structure. In the areas of the unit's maximum thickness, 1 to 4 seam cycles occur in some places (seams 413, 415, 416, 417). Towards the east, the unit pinch out far from the Grodziec Bed's transition area (Fig. 7, see below). Additionally, as the unit's thickness decreases to the east, signs of its cyclic structure gradually disappear.

The area in which the conglomerate facies are developed is approximately 480 km² and constitutes approximately 48 % of the unit's total area. The model of the conglomerate bodies' development in the unit (Fig. 7) has features similar to the development of the entire unit. The maximum thickness (and number) of the conglomerate beds is situated at the western post-erosive border of the Poruba Member. The greatest thickness of the conglomerate beds occurs in the Petřvald sub-basin and in the western

part of the Karviná sub-basin (approximately between the cities of Ostrava, Havířov and Karviná – Fig. 6), where their number reaches 6 and their combined thickness reaches 60 m. In these places, the conglomerate layers constitute up to 67% of the total thickness of the unit. Further to the east, behind the Orlová Structure, the conglomerate bodies of the CCU sharply pinch out. In the same direction, the sandstones become finer, and the primarily coarse-grained sandstones towards the east become medium-grained to fine-grained. This development was known to the authors of earlier work (*e.g.*, Brieda 1972, Doktor & Gradziński 1998, Strakošová 1973, Ševčík 1989).

In the eastern part of the Upper Silesian Basin, the Poruba Member is present in the development of the so-called Grodziec Beds. Doktorowicz-Hrebnički (1935) reported a relatively general definition of these beds around the city of Dąbrowa Górnicza. Most likely, they represent the equivalent of amalgamated Jaklovec and Poruba Members in development, with a very low coal-bearing capacity and reduced thickness. The hypothetical extent of the Grodziec Beds is shown in Fig. 2. The Castle Conglomerate Unit has not been identified beyond this threshold, and its existence is very unlikely. In the framework of the Grodziec Beds, the sediments of the Gabriela marine horizon are not present; thus, the occurrences of sandstone bodies cannot be correlated with the Castle Conglomerate Unit.

Because of its greater resistance to erosion, the Castle Conglomerate Unit is preserved in outcrop in several places. The most extensive series of outcrops stretches in a belt in the valley on the right bank of the Lučina River from the bridge at Podzámčí Street (N 49° 49' 45.7" E 018° 18' 05.6") 760 m eastward along the coordinates N 49° 49' 37.8" E 018° 18' 41.6" (Fig. 2). The largest two outcrops are at N 49° 49' 44.5" E 018° 18' 15.0" (Fig. 11) and N 49° 49' 40.7" E 018° 18' 24.4". This series of outcrops, which is close to the Silesian-Ostrava Castle, was the reason the horizon was given its name and is described in detail in following chapter.

Židková *et al.* (1997) describe the road cut by the Trojice Mine, Lučina Valley, vicinity of the Václav Colony and neighbourhood of the church wall in Orlová as another outcrops of the unit. Through critical assessment based on a study of uncovered geological maps and a lithologic correlation of the mine's cross-sections and profiles, it can be said that, apart from the Lučina Valley, outcrops of the Castle Conglomerate may also be found at the Žofie Mine. Due to the high degree of anthropogenic changes to the surface, the possible presence of other CCU outcrops is very small.

Sedimentary facies and architectures

The Ostrava Formation is composed almost entirely of cyclothems formed by coal seams, fine- to medium-grained

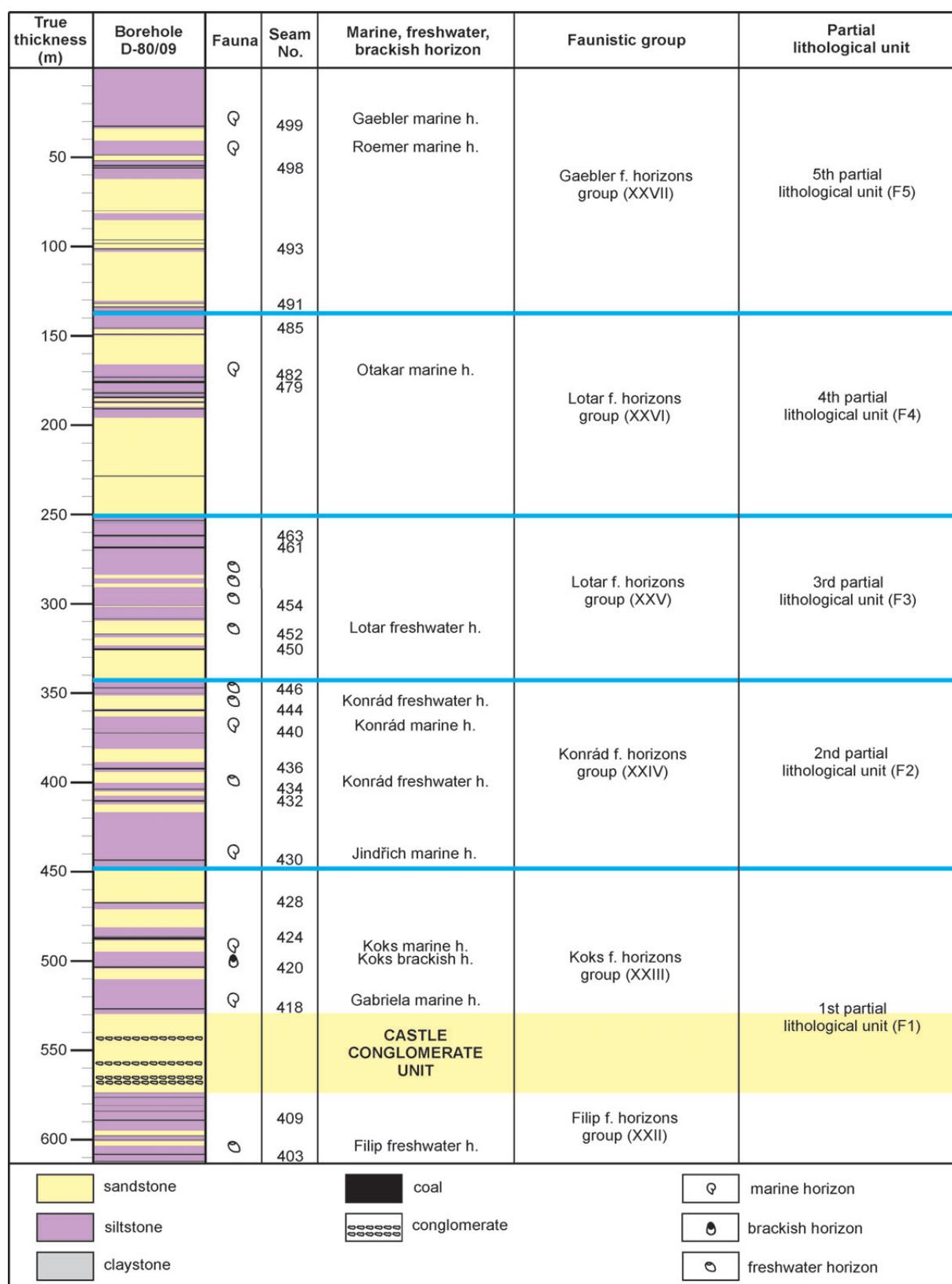


Figure 3. Stratigraphic position of the Castle Conglomerate Unit in simplified borehole D-80/09 in the Ostrava part of the Upper Silesian Basin. The position of the borehole is indicated in Fig. 2.

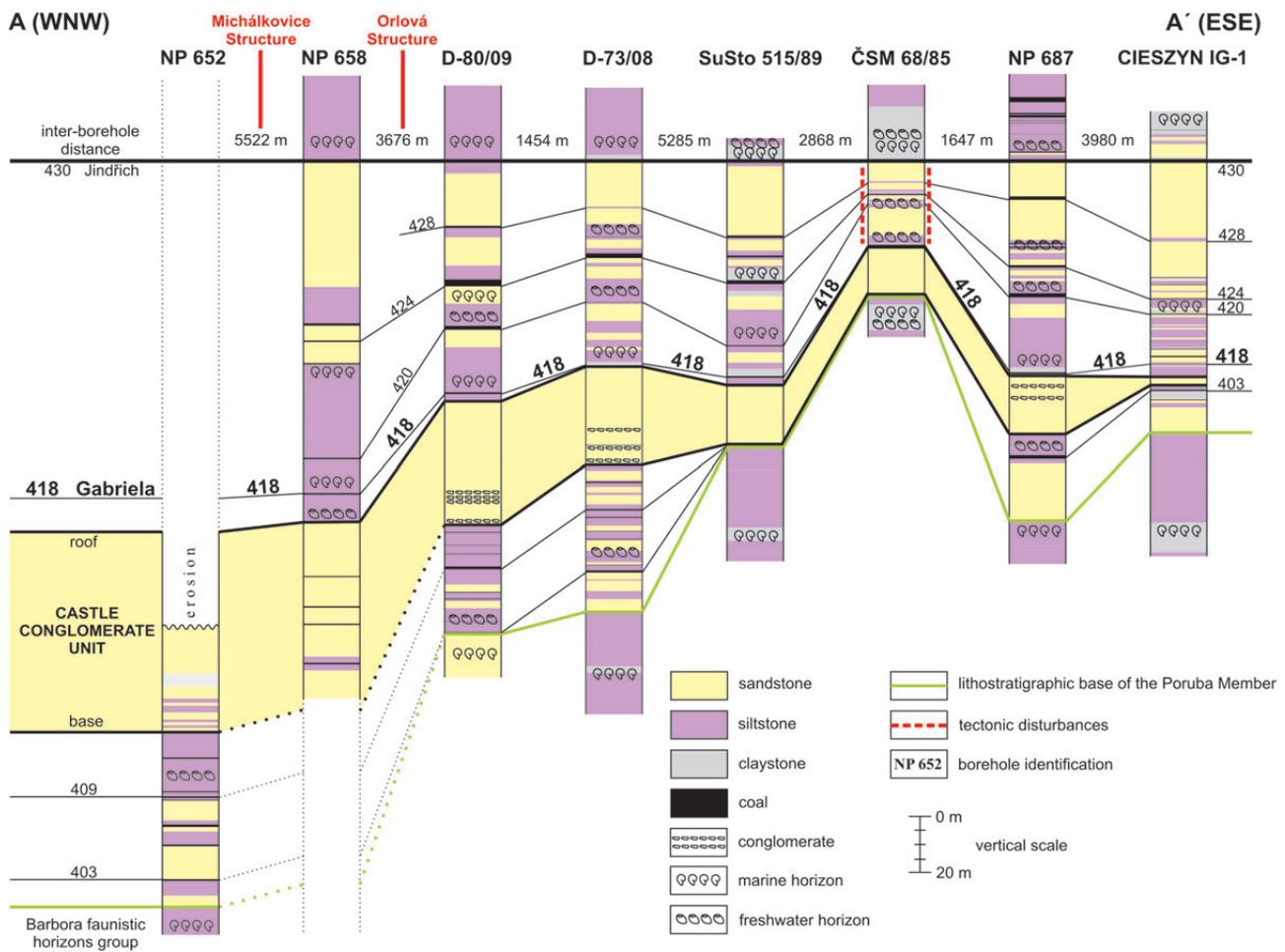


Figure 4. Development of the lower part of the Poruba Member with the Castle Conglomerate Unit in the cross-section A-A' (from Ostrava to Karviná part of the basin). The position of the cross-section is indicated in Fig. 7. Boreholes are levelled to Jindřich marine horizon.

sandstones with ripples, flaser bedding, wavy bedding, load casts (tidal flat deposits), mudstones with fauna (marine or brackish or freshwater) and occasional fluvial deposits (mudstones, fine- to medium-grained sandstones); for example Havlena (1982), Kędzior *et al.* (2007). The Castle Conglomerate Unit is a unique lithosome within this relatively fine-grained paralic succession due to its thickness, which averages more than 20 m; its lithology, which is primary medium- to coarse-grained sandstones and conglomerates; and also its lateral extent, which can be traced over an area of approximately 1,000 km².

Facies

Four main facies were distinguished within the Castle Conglomerate unit (CGL1, CGL2, SST1 and SST2), and one facies (HET) of the underlying and overlying succession was identified (Fig. 8):

Facies CGL1. – Clast-supported conglomerate: Pebble to

cobble medium- to well-sorted oligomictic and polymictic conglomerates could be either clast-supported or matrix-supported. The matrix is formed by coarse-grained, medium- to well-sorted sandstone, the clasts of which are mostly subangular. Pebbles and cobbles are usually medium- to well-rounded and primarily quartz (monocrystalline as well as polycrystalline, Fig. 10A); chert, volcanics and crystalline rocks can also be present. Rip-up mudstone, siltstone and coal clasts are very common (Fig. 9A, B). Conglomerates are mostly cross-bedded, but they can also be massive. Individual beds range in thickness from centimetres to 1 m, with sharp or erosional bases. They form successions up to 4 m thick, which may show fining upwards trends; the uppermost parts may be formed by coarse-grained sandstone with a pebble admixture.

Facies CGL2. – Matrix-supported conglomerate: The medium-sorted oligomictic and polymictic matrix-supported conglomerates are usually pebble and occasionally cobble. The matrix is formed by medium- to coarse-grained

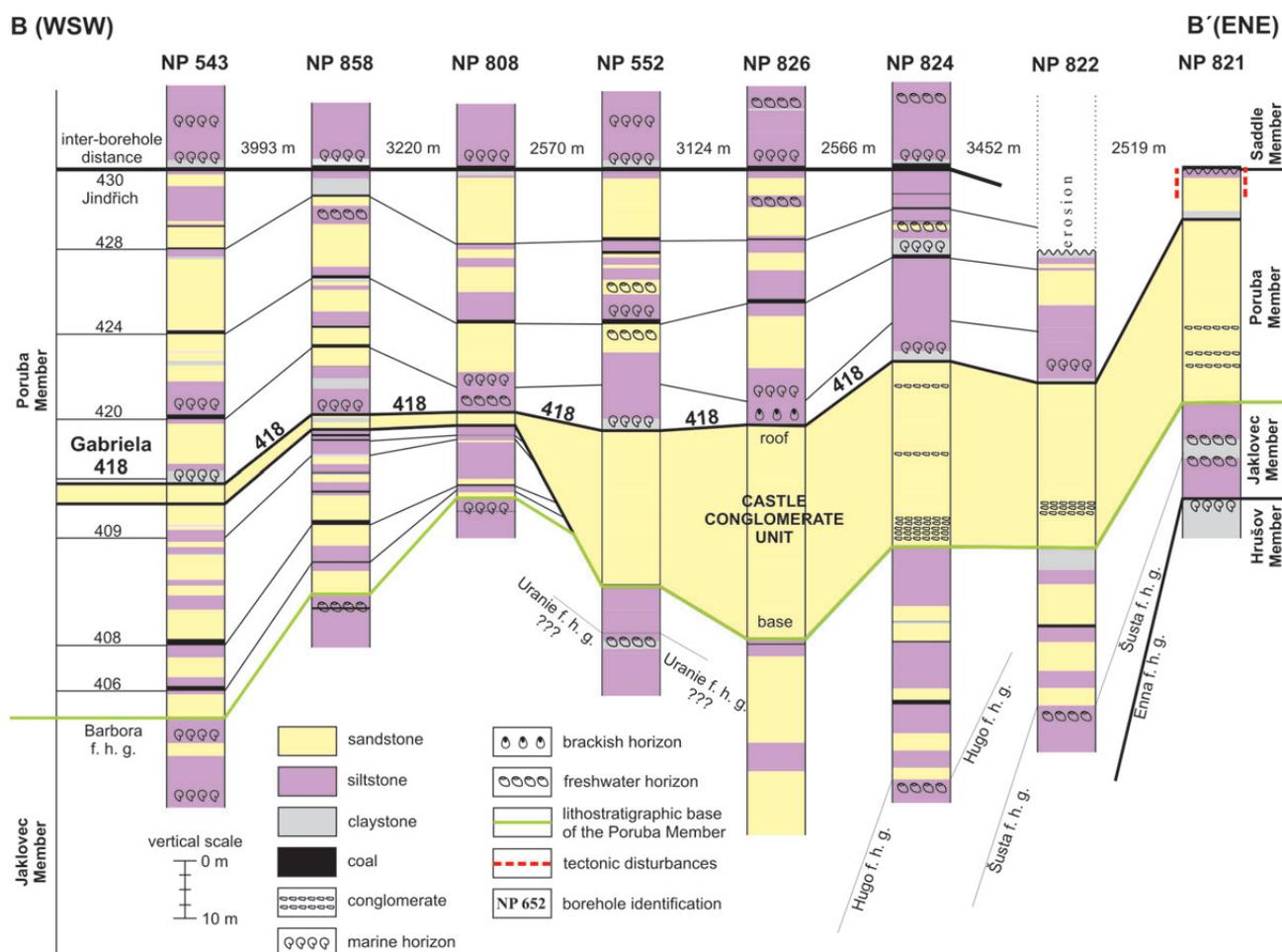


Figure 5. Development of the lower part of the Poruba Member with the Castle Conglomerate Unit in the cross-section B-B' (Frenštát area). The position of the cross-section is indicated in Fig. 7. Boreholes are levelled to Jindřich marine horizon.

medium-sorted clayey silty sandstone, the clasts of which are mostly subangular. Pebbles and cobbles are usually medium- to well-rounded and primarily quartz (monocrystalline as well as polycrystalline); chert, volcanics and crystalline rocks can also be present. Rip-up mudstone, siltstone and coal clasts are very common (Fig. 9C). Conglomerates are cross-bedded. Individual beds are 0.8 to 1.4 m thick, with sharp bases.

Facies SST1. – Cross-bedded sandstone: Medium to coarse-grained sandstones are usually medium to well sorted with subangular clasts (Fig. 10B). Cross-bedding, pebble admixture and mudstone, siltstone and coal rip-up clasts are very common (Figs 9D–F, 10C). Individual beds are dm to 2.8 m thick and have sharp bases. They form successions up to 11 m thick.

Facies SST2. – Flaser-bedded sandstone: The medium to coarse-grained clayey silty sandstones are usually medium sorted with moderately rounded clasts. The most common sedimentary structure is flaser bedding, but it may also be

massive. Mudstone, siltstone and coal rip-up clasts are common as well as mud, silt and, especially, coal drapes (Figs 9G, 10D, E). High mud content up to the thin sandy mud layers can be present locally. Individual beds are 0.6 m to 2.2 m thick. They form successions up to 3.9 m thick.

Facies HET. – Heterolithics: Heterolithic facies are dominated by siltstones and fine-grained sandstones (Figs 9H, 10F); mudstones and medium- to coarse-grained sandstones are less abundant. Sandstones are moderately sorted and moderately to well rounded. Individual lithologies alternate frequently, forming mm, cm and dm thick beds and laminae. Lamination, flaser bedding, lenticular bedding, current ripples, water-escape (convolution) structures, roots and plants are common.

Architectures and vertical succession

The geometry of the sedimentary bodies was studied at outcrops in the vicinity of the Silesian-Ostrava Castle. Unfortunately, the outcrops represent only the uppermost 8–9 m

of the Castle Conglomerate Unit, and only sandstone facies SST1 and SST2 are cropping-out (Fig. 8). All sedimentary bodies observed have erosional bases, a channel shape and a through-cross bedded sandstone fill (Fig. 11). It is likely that these bodies represent channel fill sand bedforms. Flat-based bodies, interpreted as sand bars, occur occasionally. Paleocurrent vectors were measured using cross-bedding planes; they show a low spread, primarily in the NW-NNW direction.

There is a major erosional surface at the base of the Castle Conglomerate Unit and a general fining upwards trend. The main, thickest (up to 4 m thick), conglomeratic facies are at the base of the succession, while the top is formed by the thickest sandstone facies succession (up to 8 m thick). Five fining upwards subunits were distinguished. They are formed by the CGL1 and CGL2 facies at the base, overlaid by the SST1 and SST2 sandstone facies. The conglomeratic bases of these subunits are erosional. Thin (5–10 cm thick) mudstone and coal interbeds are interpreted as larger rip-up clasts because no roots are present below the coal, and the core is only 4 cm in diameter.

Petrographic description and identification of the pebble material

The majority of the published studies concerning the Castle Conglomerate Unit have paid a great deal of attention to its petrographic composition. Among them, the most important are the works of Brieda (1972), Kumpere & Martinec (1995), Paszkowski (1994), Paszkowski *et al.* (1995), Patteisky & Folprecht (1928), Petrascheck (1910) and Zeman & Kupka (1958).

The Castle Conglomerate Unit can be characterised as a lithosome of coarse- to medium-grained (fine in places) feldspathic sandstone containing up to 6 layers of polymictic conglomerates in places. The conglomerate layers do not have a fixed stratigraphic position and do not form continuous layers; instead, the layers form long elongated lenticular bodies. Various authors have reported the maximum pebble size from different places in the range of 5 to 10 cm. The pebbles are well rounded (Fig. 9A–C).

The most detailed petrography of the conglomerate clasts is described by Paszkowski *et al.* (1995). Approximately 60% of the clasts are vein quartz (older works from the Czech part of the basin present 80% to 95%), whereas approximately 15% of the clasts are metamorphic rocks (gneisses, quartz-muscovite schists, deformed granitoids and pegmatites), 10% are cherts, 5% are clastic silicic rocks (mostly quartz arenites), 5% are metacherts, and 5% are metaquartzites. The accessories include silicified peat, silicified limestones, phosphorites and jaspilites. Brieda (1972) described coal fragments from the unit and the abundant occurrence of carbonised plant fragments at the

base of each cycle of the František (413) seam in the Ostrava part of the basin. Of the transparent heavy minerals in the unit, garnet and apatite dominated, subordinated by rutile (Kumpere & Martinec 1995).

Of the other conglomerates in the Upper Silesian Basin, the fossiliferous clasts were dated (Paszkowski *et al.* 1995), although these clasts were not, unfortunately, from the Castle Conglomerate Unit. From the Saddle Member and other stratigraphically higher units of the USB, the chert clasts acritarch assemblages indicate an Early Silurian age, radiolarite clasts with Radiolaria represent the Late Devonian age, graptolites from the chert clasts of the Łaziska Beds represent the Early Silurian (Llandovery), chert clasts with conodonts from the Mudstone and Sandstone Cracow Series are Late Devonian (Famennian) or Early Carboniferous (Tournaisian), graptolites from chert clasts from the Łaziska Beds represent the Early Silurian (Llandovery), and trace fossils from quartz arenite clasts from Łaziska Beds represent the Cambrian or, more likely, Ordovician. It is likely that the clasts with the same petrographic composition in the Castle Conglomerate Unit will have the same source areas and, thus, an identical age.

Discussion

Lateral extent of the unit

The models of the thickness of the Castle Conglomerate Unit and its conglomerate layers *sensu stricto* (Fig. 7) clearly show that the unit, in its classic form, is developed in the maximum subsidence axis of the Poruba Member. Towards the north and the east, its overall thickness declines, and the conglomerate layers disappear. This confirms the local observations of Brieda *et al.* (1973) from the north of the Ostrava sub-basin and the Petřvald sub-basin and Strakošová (1973) in structural boreholes Stonava SV 2 and Ševčík (1989) from the area of the Dukla Mine. In contrast, its occurrence is significantly larger than that described in the map presented by Doktor & Gradziński (1998). In the Czech (mines ČSM, Lazy, Darkov) and the Polish areas (*e.g.*, boreholes Cieszyn IG-1 and Ruptawa IG-1), the Castle Conglomerate Unit clearly extends beyond the Orlová Structure, although the majority of the unit is only in a sandstone development without conglomerate facies. The Orlová Structure was not active during the unit's sedimentation. Its later influence mainly consists of the fact that it shortened the Poruba Member by eroding its upper anticlinal part.

Source material and area

The source area of the material in the unit is almost unknown. On the basis of the petrographic analysis, it is clear

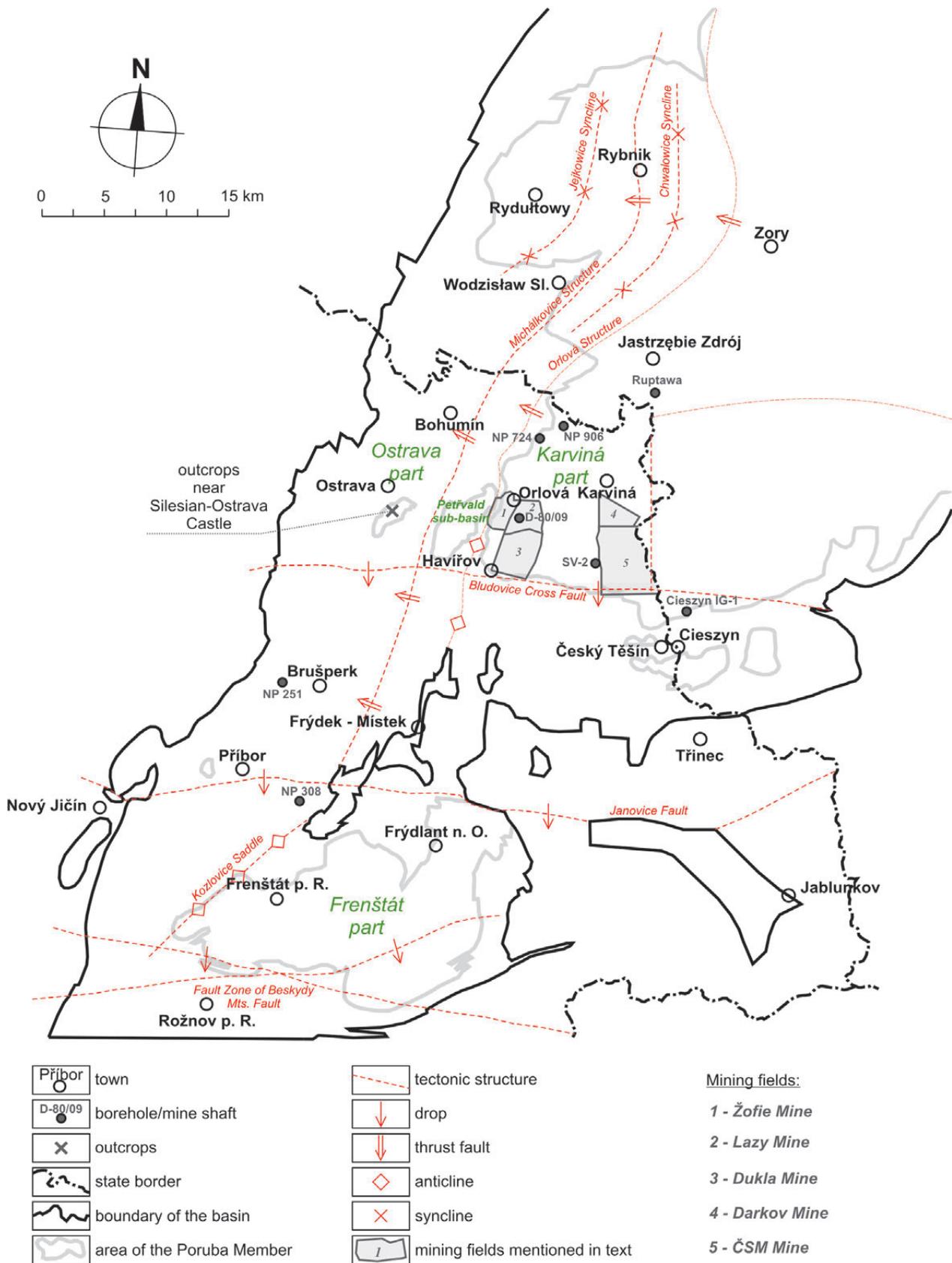


Figure 6. Locations of towns, mining fields, boreholes and important geological structures mentioned in the text.

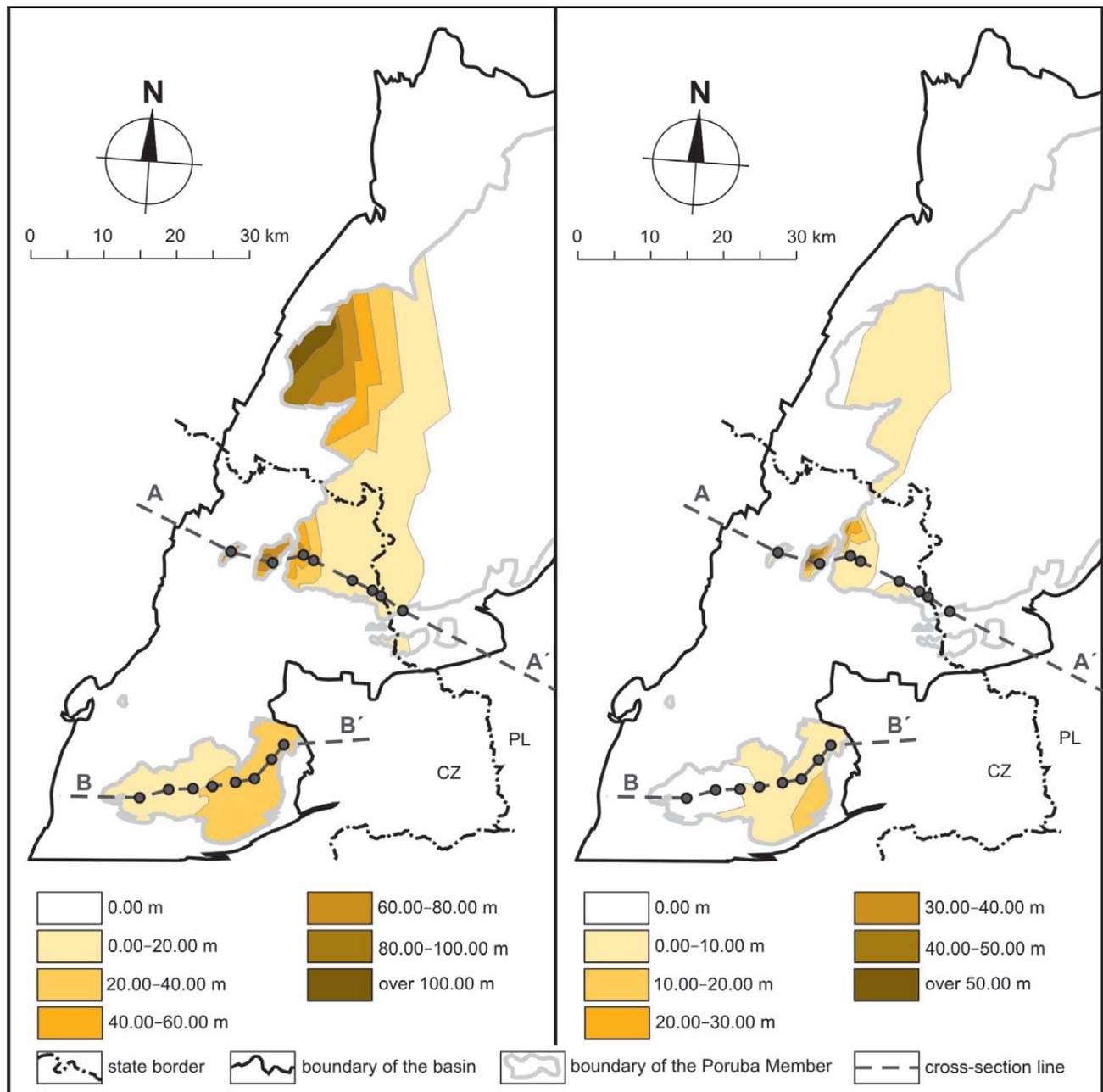


Figure 7. A – model of the area of occurrence and the thickness of the Castle Conglomerate Unit in the Upper Silesian Basin. • B – model of the overall thickness of the conglomerate beds in the Castle Conglomerate Unit.

that, of the identifiable clastic material, material from the crystalline complex in the basin's bedrock predominates, *i.e.*, from the Brunovistulicum and its covering units, which are known in the basement of the southern edge of the Upper Silesian Basin (Buła & Żaba 2005). The origin of the clasts' other materials can be found in the dissected magmatic arc and other source fields (Świerczewska 1995). A source of coal clasts in the complex is the cannibalism of Carboniferous sediments containing coal seams (Pešek & Sýkorová 2006). The only absolutely dated mate-

rial from the unit is detritic muscovite, which was dated by Banaś *et al.* (1995) using the K-Ar method to 313.2 ± 7.0 Ma. This result is obviously incorrect because the detritic mica would have to be significantly younger than the Poruba Member itself.

The change in the sandstone composition (size and petrology of the clasts) within the CCU and other sandstones/conglomerates in the Upper Silesian Basin cannot be ascribed only to the long-term evolution of the source areas. The distinct differences are likely to have

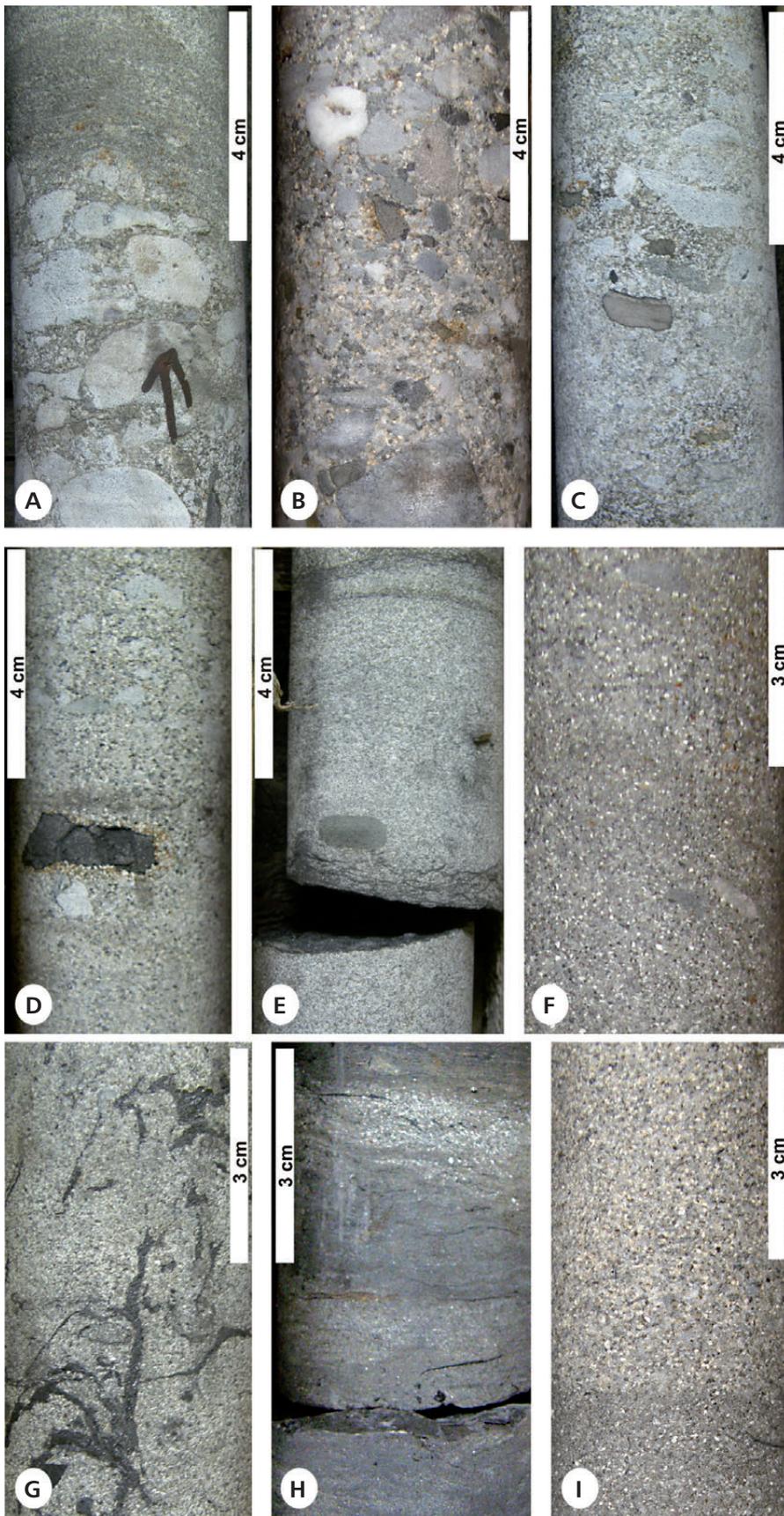


Figure 9. Photographs of the main facies in core D 80-09. The core is 4 cm in diameter. • A – clast-supported oligomictic conglomerate with mostly well-rounded crystalline pebbles and cobbles, 571.15 m, facies CGL1. • B – clast-supported polymictic conglomerate with well-rounded crystalline pebbles and cobbles and sub-angular siltstone rip-up pebbles, 566.25 m, facies CGL1. • C – polymictic matrix-supported conglomerate with siltstone rip-up clasts, 573.10 m, CGL2. • D – coarse-grained sandstone with pebbles and coal rip-up clasts, 566.34 m, SST1. • E – coarse-grained sandstone with mudstone and coal rip-up clasts and flaser bedding, 558.75 m, SST1. • F – cross-bedded coarse-grained sandstone, 541.40 m, SST1. • G – medium-grained sandstone with flaser bedding and coal drapes, 563.95 m, SST2. • H – mudstone, siltstone and fine-grained sandstone interbeds with flaser and wavy bedding, coal drapes and rip-up clasts, structures partly obliterated by water escaping or pedogenesis, 529.85 m, HET. • I – upper part of CGL2 facies represented by clayey pebbly coarse-grained sandstone sharply overlaid by well-sorted coarse-grained sandstone of SST1 facies, 538.30 m.

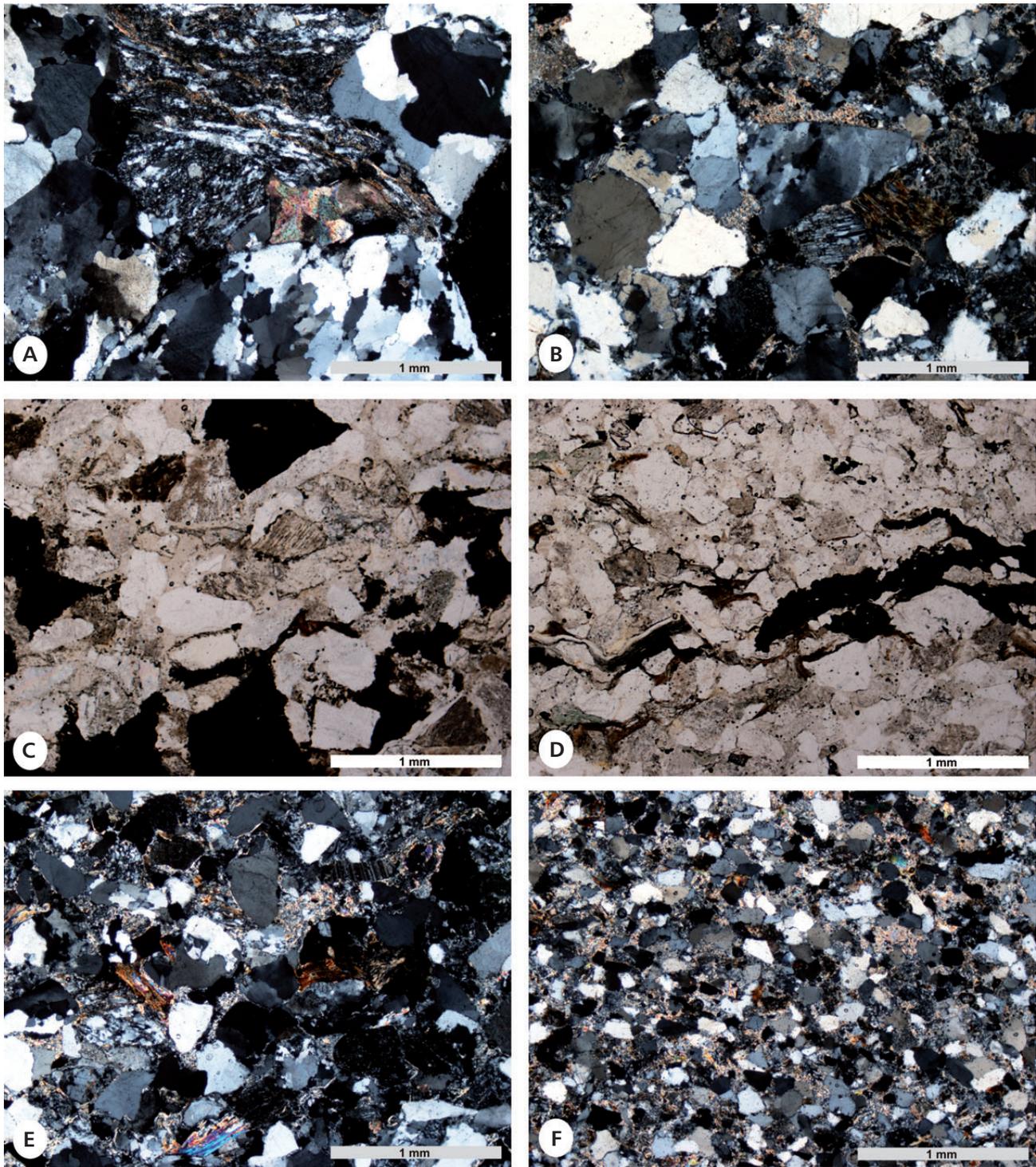


Figure 10. Microphotographs of the main facies in core D 80-09. All photographs have a longer side that is 3 mm long. A – facies CGL1, several polycrystalline quartz grains surrounding partly silicified and highly compacted siltstone (top centre), sample 5, 541.1 m, crossed nicols. • B – facies SST1, coarse-grained arcose sandstone with subangular clasts, sample 1, 530.1 m, crossed nicols. • C – facies SST1, coarse-grained arcose sandstone with coal rip-up clasts, sample 13, 568.7 m, single nicol. • D – facies SST2, medium-grained sandstone with large muscovite flakes and coal drapes, both deformed by compaction, sample 8, 554.3 m, single nicol. • E – facies SST2, medium-grained arcose sandstone with. • F – facies HET, fine-grained clayey moderately sorted sandstone, sample 20, 574.9 m.

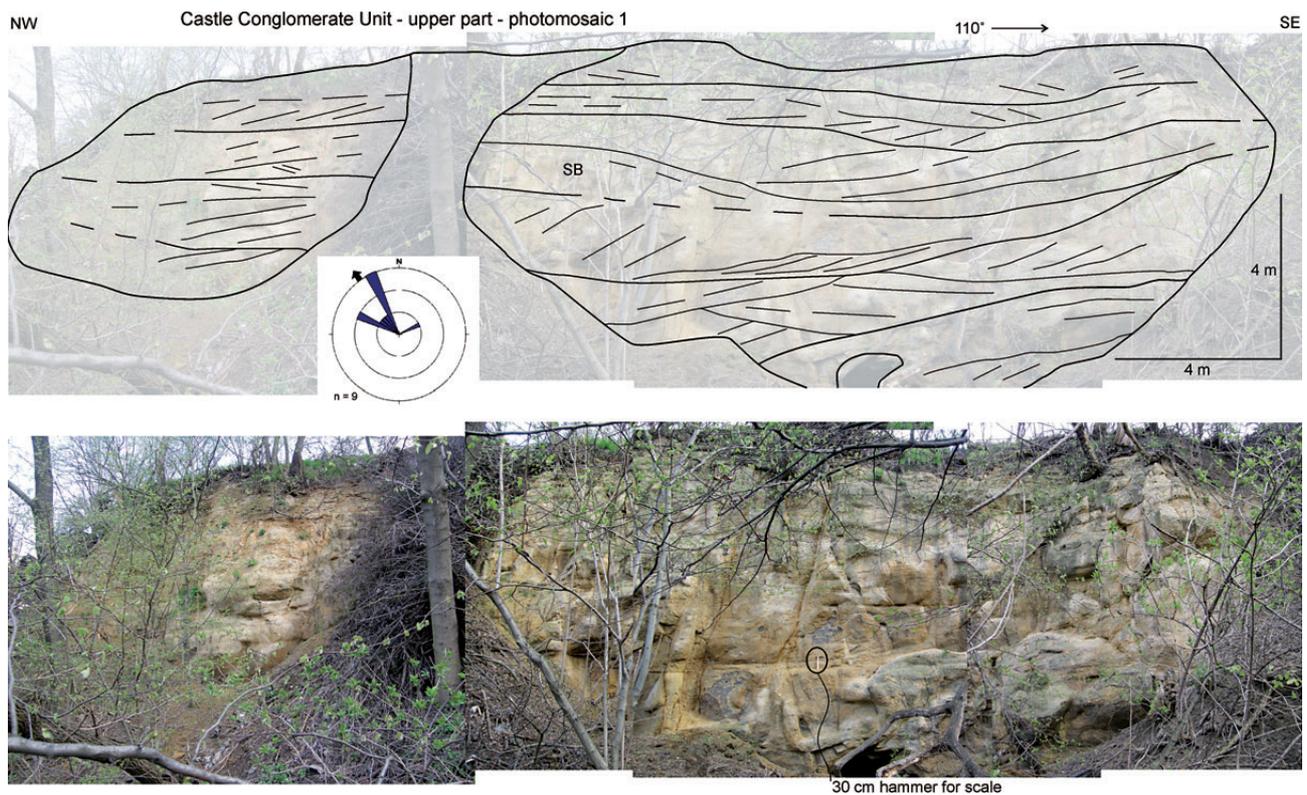


Figure 11. Outcrop (N 49° 49' 44.5" E 018° 18' 15.0") photomosaic with interpreted sediment body geometries. Channels are primarily filled with sand bedforms; sand bars (SB) also occur. Paleocurrent vectors show a low spread, and the main direction is to the NW-NNW. The black arrow represents the mean paleocurrent vector.

been caused by unique changes (glacieustatic or tectonic) that led to sedimentation from remote areas beyond the south-eastern edge of the basin.

Depositional environments

The lithologies, microstructures and sedimentary structures observed on the outcrop and in the cores indicate that traction currents are the main transporting mechanism. Sand body geometries correspond to fluvial channels. The absence of ripples, fine-grained deposits and point-bars, as well as the dominance of channel geometries and the low spread of paleocurrent vectors, support a low sinuosity (braided) river system. The Castle Conglomerate Unit represents a multi-storey channel fill of a low sinuosity (braided) river system.

Four main facies can be defined in the unit: clast-supported conglomerate, matrix-supported conglomerate, cross-bedded sandstone and flaser-bedded sandstone. These facies represent the different environments of a multistorey channel fill. Their occurrences confirm the speculations of Zeman & Kupka (1958) and Dopita & Havlena (1960) about the nature of the unit's sedimentation environment.

From both older reports (Zeman & Kupka 1958) and new measurements (Figs 7 and 11), it appears that the direction of the unit's sedimentary material transport was approximately from south to north. This information is further evidence of the direction of the clastic material transport in the rocks of the Ostrava Formation. Together with an identical direction of transport in other lithostratigraphical units of the Ostrava Formation (Jansa 1967, Havlena 1982, Filák 2006), it appears that the direction of the transport from south to north functioned in parallel with the orogenic front from the Early Carboniferous (Kumpera & Martinec 1995), at least until the end of the sedimentation of the Ostrava Formation. However, it is still questionable whether this was the only direction of material transport in the basin.

Significance of the unit

The Castle Conglomerate Unit's stratigraphic importance is not too large. In the places where this unit occurs (Fig. 7), it can serve as a local marker on the horizon. The existence of less significant phyto-paleontological changes in the conglomerate unit, presented by Šusta (1928b), is now supported by the work of Dybová & Jachowicz (1957a, b),

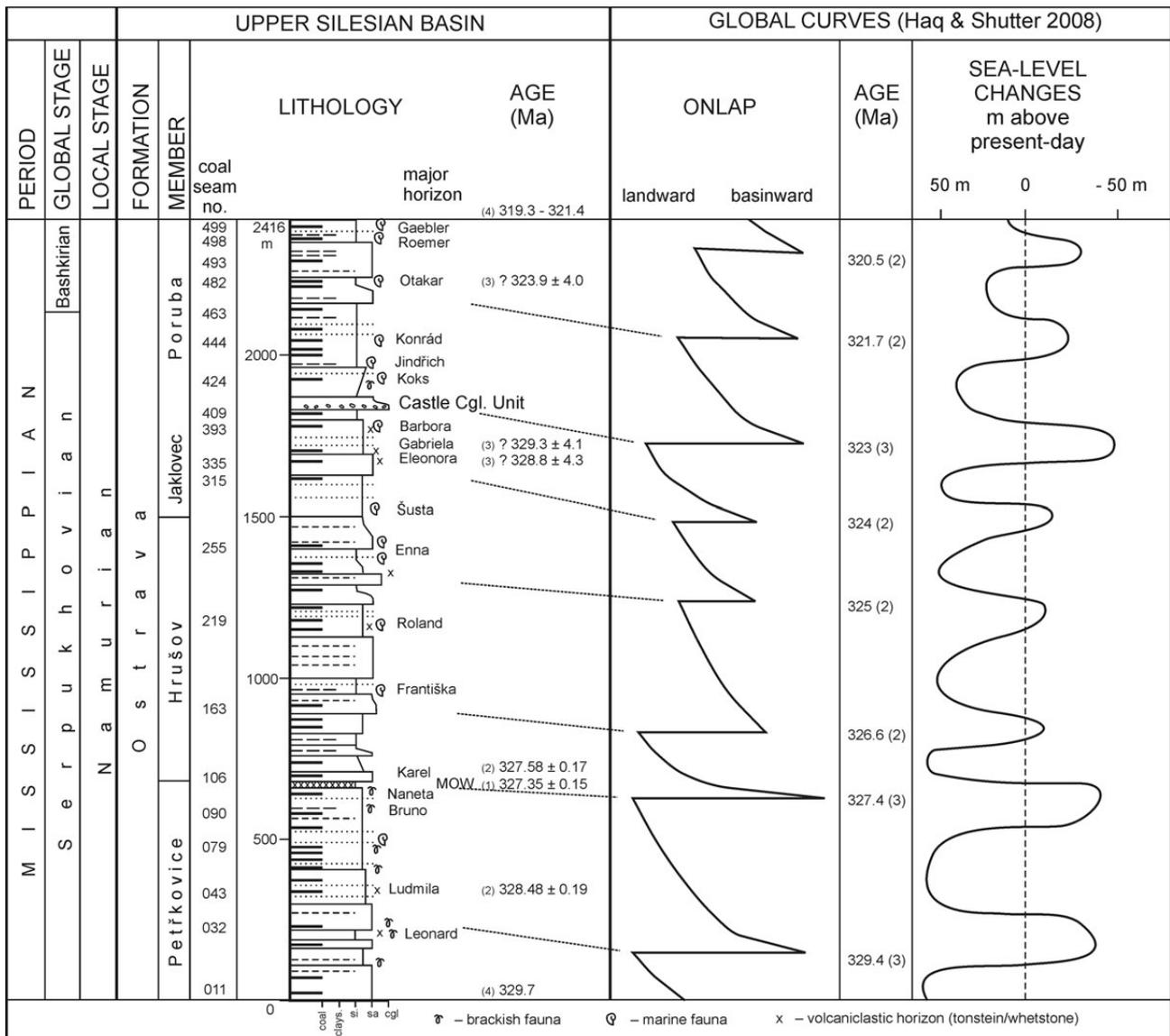


Figure 12. Hypothetical correlation of Ostrava Formation units with global glacioeustatic curves of sea level changes and the onlap of Haq & Shutter (2008). Global curves show two prominent drops in the sea level that are correlated with the Castle Conglomerate unit (323 Ma) and the Main Ostrava Whetstone (MOW, 327.4 Ma). The lithology and paleontology of Petřkovice M. are based on well-log NP 308; Hrušov M. is from NP 251, Jaklovec M. is from NP 724 and NP 906, and Poruba M. is based on D-80/09. For the locations of the wells see Fig. 6. Geochronological data are from (1) U-Pb zircon CA-TIMS of Jirásek *et al.* (2013), (2) U-Pb zircon CA-TIMS of Gastaldo *et al.* (2009b) reinterpreted by Jirásek *et al.* (2013) and (3) Ar/Ar of Hess & Lippolt (1986), reinterpreted by Gastaldo *et al.* (2009b). (4) was calculated using the CA-TIMS data in combination with cyclostratigraphic approach; see the text. A semiquantitative measure of the relative magnitude of each short-term global sea level event is shown in parentheses after the relevant age (medium (2) 25 to 75 m; and major (3) > 75 m).

who place the interface between Namurian microspore zones N6 and N7 (or IVb and V) into Seam No. 7 (413) in the direct base of the unit. Modern microspore research (Bek 2008), however, indicates a fairly steady change in communities that can be attributed to gradual changes in the environment. The work of Gastaldo *et al.* (2009b) also does not report a pronounced change in the Castle Conglomerate Unit.

Inferred driving mechanisms

The nearest horizons with data on their absolute age are the volcanoclastic horizons (tonsteins) of the Otakar (485) seam in the upper part of the Poruba Member and the Gabriela (365) seams in the Jaklovec Member. Their $^{40}\text{Ar}/^{39}\text{Ar}$ sanidine-based depositional ages were determined by Hess & Lippolt (1986) and recalibrated by Gastaldo *et al.* (2009b) to 323.9 ± 4.0 Ma and 329.3 ± 4.1 Ma, respecti-

vely. These data are not very reliable because the sedimentation rates calculated using these data are substantially variable – from 116 to 686 m/Ma – and not very useful for further discussion. According to recent U-Pb zircon CA-TIMS dating of the Main Ostrava Whetstone (MOW), Karel and Ludmila horizons (see Fig. 12, Jirásek *et al.* 2013, and Gastaldo *et al.* 2009b), the 330 m thick interval between Ludmila tonstein and MOW dates to 1.13 Ma, which corresponds to a sedimentation rate of 292 m/Ma. These values are consistent with the sedimentation rate of the entire Ostrava Formation, which was 232 m/Ma (2,416 m thickness, approximately 10 Ma intervals, based on *e.g.*, Gastaldo *et al.* 2009a). More interestingly, assuming that each coal seam represents a complete cyclothem, we can calculate the average duration of cyclothem within the Ludmila-MOW interval. This interval consists of 56 coal seams and spans the interval of 1.13 Ma, which yields a duration of 20.2 kyr per cyclothem. This result could be interpreted as orbital forcing within the Milankovitch band of the axial precession climatic cycles. Assuming the same sedimentation rate for the entire Ostrava Fm., we dated the base of the Ostrava Fm. to 329.7 Ma; the same result is obtained using 20.2 kyr per coal cyclothem (there are 43 coal seams below Ludmila). The top of the Ostrava Fm. yields a date of 321.4 Ma when the 292 m/Ma value is used (for the interval above MOW) or 319.3 using 20.2 kyr per coal cyclothem (there are 456 coal seams above MOW).

The presence of the unit's coarse-grained clastics inside the basin fill, which is dominated by siltstone and medium-grained sandstone, indicates a major drop in the base level, which is interpreted here as a drop in the sea level. The event that caused the sedimentation of the Castle Conglomerate Unit cannot be correlated with tectonic events because we do not have independent evidence for major tectonic events. However, tectonic forcing for the CCU should not be ruled out. Certain tectonic influence is very likely in such a foreland basin. The deep erosion of the base of the CCU at the southern part of the basin (refer to the cross-section in Fig. 5) could be the result of a drop in the sea level.

Although we do not have sufficient reliable geochronological data, orbital climatic forcing appears to be the simplest explanation of the cyclothem's driving mechanism (Davydov *et al.* 2010, Pointon *et al.* 2012, Schmitz & Davydov 2012, Sweet & Soreghan 2012). The two major coarse-grained and most laterally persistent units of the Ostrava Formation are correlated with two major glacieustatic sea level drops (Haq & Schutter 2008): the Castle Conglomerate Unit at 323 Ma and the stratigraphic level of the Main Ostrava Whetstone at 327.4 Ma (see Fig. 12). The CCU event can be connected with the glacieustatic drop of sea level during the onset of glaciation interval C2 of the Late Paleozoic Ice Age recognised by Fielding *et al.* (2008) in Australia as occurring

322.5–319.5 Ma. Alternatively, a sudden increase in humidity could theoretically cause such a sedimentary event (*e.g.*, Martinsen *et al.* 1999, Leeder *et al.* 1998). Rapid slowing of the subsidence also can, theoretically, cause such drops of the base level in the sedimentary record, but it would be a much more gradual process; in a present state of geological knowledge we cannot find sufficient evidence for such a process in the Upper Silesian Basin.

Conclusions

The Castle Conglomerate Unit represents the most significant occurrence of coarse-grained sediments (medium- to coarse-grained sandstones and conglomerates) in the paralic Ostrava Formation of the Upper Silesian Basin. Other distinct horizons of coarse clastics are known to exist in the basin's fill in the overlying terrigenous units. Unlike the nearby, stratigraphically close oligomict conglomerates in the Saddle Member, polymict conglomerates occur in the Castle Conglomerate Unit (Dopita 1968). The strong petrographic dissimilarity of the conglomerates in the unit from the other Late Carboniferous conglomerates in the basin was also described by Kumpera & Martinec (1995) and is interpreted here as the most prominent erosional event within the Ostrava Formation.

The Castle Conglomerate Unit is interpreted as sediment of a low sinuosity (braided) river system in a broad "valley"; four main facies were defined in this unit: clast-supported conglomerate, matrix-supported conglomerate, cross-bedded sandstone and flaser-bedded sandstone. These facies represent the different particular environments of a multistorey channel fill. The majority of paleocurrent vectors are oriented towards the NNW.

The presence of the unit's coarse-grained clastics inside the basin filling, which is dominated by siltstone and medium-grained sandstone, indicates a major drop in the base level, which is interpreted here as a drop in the sea level. We correlate this event with the major glacieustatic sea level drop that occurred 323 Ma, which can be connected with the onset of glaciation interval C2 of the Late Paleozoic Ice Age.

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