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The Petřkovice Member (Ostrava Formation, Mississippian) of the Upper Silesian Basin (Czech Republic and Poland)

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Abstract

The Petřkovice Member (Carboniferous, Mississippian, Early Namurian) is in many ways the most interesting lithostratigraphic unit of the paralic part of the Carboniferous coal-bearing Upper Silesian Basin (described as the Ostrava Formation in the Czech part or as the Paralic Series in the Polish part). Petřkovice Member represents a transition between the non-coal-bearing Carboniferous flysch sedimentation of the Moravian-Silesian Basin and the coal-bearing sedimentation of the Upper Silesian Basin. The paper includes maps of the basic sedimentological parameters of this unit - thickness, sand content and coal-bearing capacity.

The thickness of the Petřkovice Member ranges from approximately 50 m in the east of the basin to around 770 m in the west and has a clear polarity in the NNW-SSE direction. Sand content ranges from 23% in the west of the basin to more than 90% in the east. Its polarity is approximately the same as its thickness. The greatest coal-bearing capacity, expressed as total thickness of the coal layers with a thickness greater than 10 cm, is known from the Czech part of the basin, where it exceeds 25 m in places. In the majority of the Polish part of the basin the Petřkovice Member's total coal content is less than 5 m, at times up to 7 m. However, in this part of the basin their level of recognition is very low. On the basis of the above parameters 3 assumed zones of differing mobility in the basin's bedrock are defined in the Petřkovice Member's area.

Key words: Upper Silesian Basin; Early Namurian; Mississippian; Carboniferous;coal-bearing capacity; basin history

1 Introduction

Economically, the Upper Silesian Basin is currently the most important European bituminous coal basin. About 91 million tons of energetic and coking coal is mined annually. The greater part of production (86%) is in Poland (63.4 million t in 2010; Malon and Tymiński, 2011) where approximately two thirds of the basin's surface area is situated. The remaining 14% (10.6 million t in 2009; Starý et al., 2010) is produced in the Czech Republic, where the rest of the basin is found. Hundreds of publications have been written about the geology of the Upper Silesian Basin, though even more texts have remained unpublished in the form of reports, studies and manuscripts. Only rarely does a work address the development of geological phenomena in both the Czech and Polish parts of the basin. To a certain extent this fact affects their results and conclusions. Therefore geologists from the Czech and Polish parts of the basin decided to remedy this shortcoming by working together. The Petřkovice Member is the oldest lithostratigraphical unit in the paralic part of the coal-bearing Carboniferous of the Upper Silesian Basin. Its study contributes to understanding the nature of the transition of the non-coal-bearing, relatively deep-sea sedimentation of the Moravian-Silesian Basin to the coal-bearing paralic development of the Upper Silesian Basin. At the same time it contributes to knowledge of the general patterns of sedimentary evolution of coal-bearing basins in the foreland of the Varsican orogen. The study of the development of Petřkovice Member's thickness, sand and coal content, forms the basic information for synthetic conclusions on these geological processes.

2 Geological setting

The Upper Silesian Basin, 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 orogen and became a part of its outer zones, the so-called Rhenohercynicum and Subvariscicum (Grygar and Vavro, 1995; Fig. 1). In this respect, the Upper Silesian Basin occupies a similar structural position to other European bituminous coal basins aligned in a belt stretching from the British Isles across Germany and Poland to the eastern part of Europe.

The post-erosional boundary of the Upper Silesian Basin has a roughly triangular shape extending from Poland southwards into Czech territory. The area of this important European bituminous coal basin exceeds 7 490 km^2 (Jureczka et al., 2005). The larger part lies in the territory of Poland (5760 km^2), the smaller part lies in the territory of the Czech Republic (1730 km^2).

The basin is filled by some of the youngest sediments overlying the Brunovistulicum (Buła and Jachowicz, 1996; Kalvoda et al., 2008). These 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, specifically sediments of Cambrian, Ordovican, Devonian and Mississippian age. Carboniferous sedimentation starts with pre-flysch carbonates, continue through marine clastic sediments of flysch (Culm facies) stage to the coal-bearing terrigenous molasse (Kumpera, 1990; Dvořák, 1994; Kotas, 1995; Franců et al., 2002). Carbonate rocks diminish in the stratigraphically higher parts (by the late Viséan) of the Carboniferous. The basin fill is overlain mostly by Triassic, Neogene (Miocene) and Quaternary, less by Permian and Jurassic sedimentary sequences, in the southern part of the basin also by the nappes of the Outer Carpathians (Jurassic to Paleogene).

For the purpose of the present study, the southernmost limit is placed on the fault zone of the Beskydy Mts. This paper does not take account of the sparse data on coal-bearing Carboniferous sequences intersected by deep boreholes south of the Beskydy Mts. fault zone (Fig. 1, Purkyňová, 1978; Řehoř and Řehořová, 1978).

FIGURE 1 NEAR HERE

The geology of the Upper Silesian Basin 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. Authors of the substantial monograph dealing with the Polish part of the basin are Kotas and Malczyk (1972 a,b), Porzycki (1972), and Dembowski (1972). Recent publications in English on the geology of the basin include, e.g., Dopita and Kumpera (1993), Kotas (1995), Jureczka and Kotas (1995), Kumpera (1997), and Jureczka et al. (2005).

The types of sediments filling the basin, together with their thickness and extent, are briefly discussed in papers by Dopita et al. (1997) and Martinec et al. (2005). Coal seams containing bituminous coal in the Upper Silesian Basinare are of the Serpukhovian to Moscovian (early Namurian to late Westphalian) age. Two major different sedimentary environments can be distinguished in the coal-bearing Carboniferous: a paralic facies and a continental facies.

The older paralic type of sedimentation ranges over a wide spectrum of sedimentary environments from purely continental with transitions to the marine, frequently with intercalations of pyroclastic material. This kind of sedimentation is characterised by the cyclic alternation of inorganic sediments with coal beds, so called cyclothems. The Early Namurian Ostrava Formation or Paralic Series in the Polish part of the basin consists of the Petřkovice, Hrušov, Jaklovec and Poruba Members (Fig. 2).

FIGURE 2 NEAR HERE

The continental type of the sedimentation (Upper Silesian Sandstone Series, Mudstone Series & Cracow Sandstone Series in Poland, resp. – partly – Karviná Formation in the Czech Republic, Fig. 3) began after a hiatus between the Mississippian and Pennsylvanian (i.e. Early and Middle Namurian). Even here, sedimentary cycles with coal beds can be observed, but in continental facies only. Fining of sediments and reduction in the thickness of individual cycles upwards are characteristic features of this type of continental sedimentation.

The fauna of the Petřkovice Member was processed by: Bojkowski (1972), Řehoř (1977) and Prokop et al. (2005), the flora was studied by Purkyňová (1977, 1996), Migier (1972), and Gastaldo et al. (2009), microspores by Jachowicz (1972). Absolute dating of the volcanosedimentary horizons of the Petřkovice Member was published by Hess and Lippolt (1986), Gastaldo et al. (2009) and Jirásek et al. (2013). The chemical-technological properties of the Petřkovice Member coal is dealt with in the work of Kotas et al. (1983), Sivek et al. (2003), Martinec et al. (2005) and Sivek et al. (2010), coalification by Kandarachevová et al. (2009), Sivek et al. (2008) and Pešek and Sýkorová (2006). The lithology and cyclicity is described by Havlena (1986) and Dopita et al. (1997), sedimentary environment Havlena (1982), Kędzior (1987).

FIGURE 3 NEAR HERE

3 Materials and methods

The main data source for creating the data files intended for modelling the development of the Petřkovice Member are the bore profiles of the exploratory boreholes. In the Polish part of the basin the horizon under study is usually found at considerable depths, thus there was less information available in this area.

The exploratory boreholes were realised over a long time horizon in the second half of the 20th century. It is evident that, in relation to developments in boring technology and data interpretation, the data file is very diverse and it was necessary to approach the inclusion of boreholes into this file individually.

404 exploratory borehole profiles were available from the entire basin. Each one was assessed individually. For various reasons most of them did not give a complete profile of the Petřkovice Member. In 206 boreholes the lithostratigraphical unit's base had not been drilled into, 75 did not contain the upper part of the unit due to erosion. 58 boreholes struck the Petřkovice Member with an eroded roof and at the same time were not deep enough to penetrate the base. 66 verified, complete boreholes were used to create the models along with 3 incomplete boreholes, where was possible to use a correlation with nearby boreholes to replenish the missing section. Incorrect thicknesses were converted to correct ones at intervals with a specific known inclination. To construct the models of the individual parameters of the Petřkovice Member 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 made up of known documentation points, between the last

known points and the border and then extrapolation. In areas without known values adjacent to extrapolated values the models take on the character of an expert judgement.

In the text regional chronostratigraphic units, used for classifying the Late Carboniferous in Western and Central Europe (Namurian, Westphalian, Stephanian), are employed.

4 Thetze boundaries and exploration of the Petřkovice Member

This chapter defines the basic parameters of the Petřkovice Member. An unambiguous definition of the base and roof of the Petřkovice Member and the extent of the unit are the basic limits for development models of the individual parameters. The degree of exploration, given by the density of boreholes and mining works, is fundamental for the reliability of the models in a specific location.

4.1 The boundaries of the Petřkovice Member

Stratigraphically the Petřkovice Member are of the Early Namurian (Late Mississippian) age. The name Petřkovice Member was first coined by Helmhacker (1873) – *Petrzkowicer Flötzen*, Gaebler (1909), Gaebler (1898) - *Petrzkowitzer Gruppe* and Gaebler (1909) - *Petrzkowitzer Schichten*. Its definition by Šusta (1928) is, essentially, still used today. The unit's definition, however, underwent a complex historical evolution.

The Petřkovice Member is separated from the older Kyjovice Member by the roof of the Štúr Faunistic Horizons Group and its upper boundary is determined by the roof of the Main Ostrava Whetstone horizon (Fig. 4).

FIGURE 4 NEAR HERE

Determining the boundaries of the Petřkovice Member in real geological situations, however, is much more complicated. In a large number of boreholes, the lower boundary of the Petřkovice Member is difficult to determine, and therefore cannot always be clearly defined. The lithological boundary between the siltstone (and to a lesser extent claystone) of the uppermost part of the Štúr Faunistic Horizons Group (hereinafter also referred to as Štúr f. h. g.) and the sandstone base of the Petřkovice Member is often clear, with erosion phenomena in places. Places are known where the thick complex of sandstones at the base of the Petřkovice Member is missing, or where the sandstones also occur in the Štúr f. h. g. Likewise, the presence of coal seams is not a reliable trait for an accurate determination of the boundaries of the Petřkovice Member, because coal layers occur not only on the base of the productive Carboniferous, but locally in the Štúr f. h. g. and also in its underlying rocks. The development of the Štúrf. h. g. is also complicated. For the largest section of the unproductive Carboniferous in the Czech part of the Upper Silesian Basin, Řehoř (in unpublished study edited by Gerhard Weiss in 1975 from Geological Survey in Ostrava) distinguishes a total of six types of faunistic horizons, some of which have the same character as horizons known from the productive Carboniferous and some are characteristic for the Štúrf. h. g. These concern freshwater and mixed horizons, typically, however, they are monotonous marine horizons with *Posidonia sturi* (Řehoř) and rich marine horizons with a varied fauna. The type of horizon known as a Spirifer Sandstone is very prevalent. This is a calcic, medium to coarse-grain sandstone with the brachiopod *Spirifer bisulcatus* (Sowerby). The boundary between the Kyjovice Member and the Petřkovice Member is then placed on the top of the Spirifer Sandstone. Spirifer Sandstones were described during exploratory drilling in the Staříč I and Staříč II mines. The stratigraphic importance of Spirifer Sandstone is mentioned, for example, by Kumpera (1990). He describes Spirifer Sandstones as clastic layers in the stratigraphically highest part of the Mississippian (Culm) in the Štúr f. h. g., which attains up to 70 m in the southern and south-eastern part of the basin. A layer of these sandstones also occurs in the Polish part of the basin (Kumpera, 1997), where is also present in the upper layers of the Štúrf. h. g. Here it is referred to as Golonog Sandstones. According to Řehoř (in Weiss, op. cit.), the horizon of Golonog Sandstones is conspicuously consistent to the Spirifer Sandstone, therefore it is considered to be the equivalent of the Štúr f. h. g., but this does not exclude the possibility of correlation with a lower part of the Ostrava Formation.

Nowadays the upper boundary of the Petřkovice Member in the Czech part of the basin is considered to be the roof of the basin's most important tuffogenous horizon - the Main Ostrava Whetstone. This is not so in Poland, where the boundary is placed at the base of this horizon. For this work the conventional definition of Czech authors was used, although the Polish variant is considered to be more logical even by some Czech geologists. The Main Ostrava Whetstone is a light grey politic rock with well developed sedimentary textures (ripples etc.), which is characterised by considerable lateral stability, thickness and, in particular, the relative uniqueness of its occurrence. For these reasons, it has been considered a significant correlation guide for a long time. Jirásek et al. (2013) was engaged in the issues of the occurrence, genesis and age of this horizon in detail. The greatest weakness of the Main Ostrava Whetstone as the boundary is the fact that it does not occur throughout the Upper Silesian Basin, only in its western part, approximately west of the Tarnowskie Góry – Frýdek-Místek line (Fig. 5). In places where the whetstone horizon is not developed, the upper boundary of the Petřkovice Member is placed on the top of the marine (sometimes even freshwater and Lingula-bearing, i.e. brackish) horizons of the Naneta group. Stur (1875) first mentions the fauna of this group of horizons. The Naneta group of faunistic horizont is considered a relatively stable horizons, which is found throughout the western part of the basin and has a greater extent than the Main Ostrava Whetstone. Towards the east, however, the horizon changes from marine to freshwater relatively rapidly and was difficult to identify it in the drill cores (Fig. 5). In the remaining parts of the basin, i.e. the entire east, and probably also in the central part, the Main Ostrava Whetstone or the Naneta marine horizon do not occur, and so it is not possible to specify the top of the Petřkovice Member using them as definitions. The only way to determine this boundary in detail would be by correlations of the exploratory borehole profiles supported by analysis of changes in thickness. This work is held back by the small number of boreholes drilled into the Petřkovice Member in the eastern part of the basin; in the basin's central part these boreholes are completely absent. The identification and correlation of the Petřkovice Member in the eastern part of the basin is complicated by a low level of exploration, facies changes, a decline in thickness as well as the lithographic division of the paralic sediments here. It differs from the classical development in the western part of the basin and the Sarnów Beds (see Chapter 4.2) are not completely equivalent to the Petřkovice Member (Fig. 2). In this context, it is necessary to see the outputs of this work on the Petřkovice Member in the eastern part of the basin as generalised information for guidance.

FIGURE 5 NEAR HERE

4.2 The issue of the Sarnów Beds

In 1935, Doktorowicz-Hrebnicki published explanatory notes to a geological map, 1: 25,000, Sheet Grodziec, located in the north-eastern part of the Upper Silesian Basin in the surroundings of what is now the city of Będzin. On the basis of surface mapping and exploratory boreholes, the Sarnów Beds (orig. sarnówskie warstwy) were described and demarcated. They were described as a complex with sandstones and arkosic sandstones prevailing, in which coal only occurs in places as thin intercalations. In the sandstones the remains of flora were sometimes found, of which only the remnants of *Lepidodendron obovatum* (Sternberg) and *Archaeocalamites scrobiculatus* (Schloth.) were determined. The entire complex has a thickness of 150 to 200 m. In general it is made up of three beds of fine to medium-grained sandstones that are separated by a few thin layers of aleuropelites. This complex has Malinowice Beds (Viséan to Lowermost Namurian, see Fig. 2) in the footwall, marine sediments ending with a horizon of Golonog Sandstone. The horizon is not perfectly known, it may be the equivalent of a group of Štúr Faunistic Horizons Group, or the equivalent of one of the marine horizons of the Ostrava Formation (Petrascheck 1919). Doktorowicz-Hrebnicki (1935) placed the top of the Sarnów Beds in the top of the uppermost sandstone beds. The Flora Beds (orig. warstwy florowskie) starting above this have a significantly higher share of aleuropelites. This definition of the Sarnów Beds - as a sandy lithosome – must be understood as a regional lithostratigraphic unit that can be determined on a limited territory, in particular in the north-eastern part of the basin. It should be stated that clear criteria for delimiting the base and top of the Sarnów Beds and also for the boundary between the Petřkovice Member and the Sarnów Beds are missing (Jureczka, 2002). It was necessary to give a working demarcation for the purpose of this work. The boundary was put in places where the unit's sand content is greater than 75% and at the same time its thickness is less than 300 m, which essentially corresponds to the first description of the Sarnów Beds (Doktorowicz-Hrebnicki, 1935). The authors understand that these are considerably simplified assumptions. Therefore it is necessary to see the results about the eastern part of the basin as input information that presents changes to the profile of the Carboniferous roughly stratigraphically corresponding to the Petřkovice Member from the western part of the basin. The results of this work (Fig. 7 to 11) and new lithostratigraphic sections show a fundamentally different nature to the development of the Petřkovice Member in the eastern and western parts of the basin. These differences are so marked that they confirm the validity of the historical detachment of the Sarnów Beds. It concerns completely different facies development of the Petřkovice Member. This fact, however, was realised by Doktorowicz-Hrebnicki (1935), and later Jureczka (2002).

4.3 Post-erosion area of the Petřkovice Member's occurrence in the Upper Silesian Basin

The range of the Petřkovice Member's occurrence is the results of both sedimentary and post-sedimentary development of the lithostratigraphical unit's development. Above all, the post-sedimentary development of the Upper Silesian Basin, in particular erosion and the development of the Carpathian orogene in its close proximity, had a decisive influence on the current post-erosion range of the Petřkovice Member and on the depth of its burial under the current surface and on other factors that affect its position in the basin. These parameters also partly affect the degree of geological exploration of the lithostratigraphical unit. The post-erosional extent of the Petřkovice Member's occurrence is almost identical to the post-erosional area of the Upper Silesian Basin. Thus, currently, the Petřkovice Member is the basin's most widespread lithostratigraphic unit. However, there are areas in the basin where, due to erosion, the Petřkovice Member is lacking. This is so in the basin's Podbeskydí area (Fig. 6), where, in the vicinity of the Orlová Structure's anticline, the Palaeozoic sediments of the Mississippian age extend to the surface (Hýlová et al., 2009). A similar situation occurs in some places on the western edge of Ostrava part of the Ostrava-Karviná area and in two places in the southern part of the basin in Poland. The size of these areas is, however, negligible in comparison with the Petřkovice Member's area of occurrence.

FIGURE 6 NEAR HERE

4.4. The level of geological exploration of the Petřkovice Member in the Upper Silesian Basin

The area and depth of geological exploration of the Petřkovice Member is a function of a series of geological, mining and economic phenomena. Among the most important are coal-bearing capacity, depth below the surface and the nature of the geological structures. The highest degree of geological exploration (the densest network of exploratory boreholes) of the Petřkovice Member is along the western and north-eastern border of the Upper Silesian Basin (Fig. 6). In these areas, the Petřkovice Member (or its equivalents) protrudes on the post-erosion surface of the epi-Variscan platform. Likewise, in these parts of the basin the coal seams of this unit were mined in some of the mining fields. In the Czech part, it concerns the mining fields Přívoz, Heřmanice, Petřkovice, Mariánské Hory, Paskov, Svinov and Staříč

(Fig. 6). In the Polish part, coal from the upper section of the Petřkovice Member was mined in the Gliwice Mine. In the remaining areas of the basin the degree of geological exploration of the Petřkovice Member is considerably lower. Towards the east, younger lithostratigraphical units are preserved in the Petřkovice Member's overburden. In these areas, especially in the Polish part of the basin, the Petřkovice Member is at depths that make exploitation technically and economically impossible (Fig. 7). The Petřkovice Member's coal-bearing capacity drops in approximately the same directions. The low degree of exploration in the eastern part of the basin in Poland is especially related to the development of the Sarnów Beds (see section 4.2). Here the sediments in the overburden of barren marine deposits have practically no coal and thus have no economic potential justifying a more detailed geological survey. In the southern, respectively, SSE direction the thickness of the covering formations increases, so that the coal bearing deposits of the Upper Silesian Basin sink beneath the Outer Carpathians. The degree of geological exploration in the Petřkovice Member should be taken into account when using the results of this work. It is necessary to add that today there are no indications that in the near future, any surveying of the coal seams in the basin would focus on the Petřkovice Member. On the contrary, it is very likely that the Petřkovice Member's current degree of geological exploration will not change in the future.

FIGURE 7 NEAR HERE

5 Results

The results of this study of the Petřkovice Member's development are based on the newly created models of three basic geological parameters of the sedimentological studies of coal bearing units: strata thickness, sand content and coal-bearing capacity. These models and lithological correlation profiles, complemented by a study of other geological phenomena (such as cyclicity and the lithological character), could be the basis for interpreting the depositional environment of the Petřkovice Member.

5.1 Thickness of the Petřkovice Member

The thicknesses of the Petřkovice Member varies greatly between 53 m and 767 m (Fig. 8). The greatest verified thickness was found in Poland in the western part of the basin in the Olza Uchylsko 1 borehole, which is located in the vicinity of the Czech-Polish border (OU-1 in Fig. 7). The lowest recorded thickness of the Petřkovice Member occurs on the eastern edge of the basin in the area in which the layers are developed in a different facies development and are referred to as the "Sarnów Beds".

FIGURE 8 NEAR HERE

In principle, the development of the Petřkovice Member's thickness corresponds to the intensity of basin subsidence when the Petřkovice Member was formed. In terms of mobility the basin can be split into the following three zones (Fig. 9):

1. **The zone of maximum basin subsidence** includes almost the entire western part of the Upper Silesian Basin. This zone running in a NNE-SSW direction occupies a large area, which includes the surroundings of Gliwice, Rybnik and Ruda in Poland, and in the Czech part Ostrava, Karviná and Příbor. Its actual southern and northern extent is unknown. It is likely that to the north and south it continued on beyond the current post-erosion boundary of the Petřkovice Member. The sediment thickness in this zone exceeds 500 m (the maximum is 767 m).
2. **The zone of medium (transitional) basin subsidence** skirts the eastern edge of the maximum mobility zone. It rises around Frenštát pod Radhoštěm, includes the area of Žukov, and, in the Polish part of the basin, it goes through the central part of the basin, between the towns of Katowice, Tychy and Tarnowskie Góry. This is a transitional zone between the area with the greatest sediment thicknesses in the west and the area in the basin's east, where they are the least. The sediment thickness values in this zone range between 300 to 500 metres.
3. **The minimum basin subsidence zone** borders the eastern edge of the medium basin mobility zoneand occupies the eastern part of the Upper Silesian Basin. The western boundary of the minimum mobility zone runs roughly in the line of Katowice, Tychy, passing Cieszyn, Český Těšín and Třinec. The sediment thickness in this zone does not exceed 300 m, to the east it drops to 50 m. De facto this zone corresponds to the range of the Sarnów Beds.

FIGURE 9 NEAR HERE

The maximum mobility zone was able to transmit fold and fault deformations to its sedimentary cover. The localisation of this zone and its mobility was undoubtedly primarily affected by the burden of the distorting Variscan rhenohercynian zone. This mobile zone, remotely fits the “foredeep”, as referred to by Havlena (1982) in his concept of the development of the paralic molasses of the Upper Silesian Basin. Towards the east, the intensity of the basin’s mobility decreases in relation to a fall in the incorporation of the brunovistulic bedrock of the basin into the tectonically crumpling Variscans neighbouring the Upper Silesian Basin.

5.2 Sand content in the Petřkovice Member

The presence of sandstone layers is characteristic for the Petřkovice Member. It is usual to meet with sandstone layers that are 20 to 30 m thick. In exceptional cases, the sandstone layers can attain 50 m and 60 m. It is the presence of sandstone layers that is one of the typical lithological traits that makes the Petřkovice Member different from the underlying, non-coal bearing Kyjovice Member of the Hradec-Kyjovice Formation.

Sand content is expressed in the study by the isolines of the sandstone layers’ percentage of the overall thickness of the unit (Fig. 10). The maximum value of sand content, over 90 %, was detected in the Borek Szlachecki 1 borehole on the eastern border of the Polish part of the basin (BSz-1 in Fig. 7). In this part of the basin, however, it is not possible to clearly define the base and the top of the Petřkovice Member (Sarnów Beds), thus the Kotas and Malczyk (1972) interpretation was used. The lowest value is found in the north western part of the basin, north of Gliwice in the direction of Toszek, where sand content is approximately 23%.

The spatial layout of the isolines exhibits some clearly definable patterns:

1. The dominant direction of the isolines of the Petřkovice Member’s sand content in the basin is NE-SW.

2. An area of the Petřkovice Member with sand content over 75% follows the eastern margin of the Polish and adjacent Czech parts of the basin. The sand content gradually decreases to the NW basin margin. The lowest sand content values (up to 25%) are found in the NW from the line joining the Rudy (in vicinity Rybnik, Fig. 3), Gliwice and Tarnowskie Góry. In this

area it is assumed the closeness of the sea had a strong impact as seen in the unit's sedimentation with numerous ingressions, a decrease in the representation of sandstones and the dominance of the fine-grained sediments.

3. In the Czech part of the basin the isolines keep roughly the same direction as in the Polish part. The whole Czech part of the basin, however, belongs to the medium (25-75%) sand content zone of the Petřkovice Member. On the western erosional boundary of the basin, in the section from the national borders to the vicinity of the city Příbor, a zone of increased sand content with values greater than 50 % extends into the area of the basin from the NW.

4. East of the zone of increased sand content described in the previous section there is an area of lower sand content (25 to 50 %) running roughly through the centre of the Czech part of the basin in a NNE - SSW direction.

FIGURE 10 NEAR HERE

5.3 Coal-bearing capacity of the Petřkovice Member

Coal-bearing capacity is a parameter that is traditionally used to study the developmental history of coal-bearing basins. In this study the coal-bearing sedimentation of the Petřkovice Member in the Upper Silesian Basin is characterised by isoline model of coal content including coal layers thicker than 10 cm (Fig. 11). The spatial arrangement of the isolines has the following patterns:

1. Apart from the isolines of sediment thickness and sand content the coal content isolines of the Petřkovice Member does not copy the characteristic NE-SW direction corresponding to the axis of the basin subsidence. This fact, in turn, results in dominantly a north-south polarity of the coal-bearing capacity. An indicated bytheisolines model (Fig. 11) higher values occurs only in the Czech part of the basin and significantly decreases NNE ward. Consequently, in the Polish part of the basin, the coal-bearing capacity is low. The disproportion in the amount of data from the Polish and the Czech part of the basin, and generally poor level of available data on the Petřkovice Member in the Polish part of the basin should, however, be borne in mind.

2. By comparing the coal-bearing capacity model with model of thickness development, a certain similarity can be found, especially in the areas between Ostrava and Český Těšín and between Příbor and Frenštát pod Radhoštěm. Models expose a higher power of both parameters.

Coal-bearing capacity depends on a number of geological factors and reacts very sensitively to their changes. Some of these parameters are governed by the basin's subsidence. These include the unit's lithological development and a number of other influences. In terms of the paralic molasse, there is no direct relationship between unit's sand content and coal-bearing capacity. This can be seen in vicinity of town Příbor (Figs. 10 and 11), where are areas with high both sand content and coal-bearing capacity.

FIGURE 10 NEAR HERE

6 Discussion

This paper presents the first comprehensive and verifiable data supported by the geological characteristics of the Petřkovice Member in the Polish and Czech parts of the Upper Silesian Basin. It points out the imperfection of their original definition and proposes a possible solution to the issues of determining their base and top. It also shows some of the geological trends that were suppressed during research in both national parts.

It presents the basic characteristics of the sedimentary filling of this lithostratigraphic unit. These were deliberately defined according to simple criteria, so that it would be possible to realistically determine them from the available geological documentation. This concerns thickness and coal-bearing capacity and the predominantly lithological nature of the sediments. Their analysis is based on borehole documentation and a set of special lithological - correlation profiles designed for the purposes of this study (unpublished in the text).

The thickness of the Petřkovice Member (Fig. 8) generally declines from west to east. The trend reflects a relatively uniform transition from the marine sedimentation to the terrigenous sedimentation. Sand content also has a similar increase to the southeast connected with disappearance of typical cyclic sedimentation. This trend may be related with the directions of the sedimentary material transport with the configuration of the basin's depocentre topography. Of the selected parameters, coal-bearing capacity (Fig. 11) is the most variable and points to the complicated conditions when the coal-forming peat swamp was rather a local affair and rarely did good conditions last in one place for the development of vegetation and the subsequent conservation of the necromass.

It is not possible to simply compare thickness model with previously published once. All published maps were constructed either only for Czech or only for Polish parts of the basin, and/or were constructed for stratigraphically differently defined seqences (isopachous map of paralic sediments of merged Petřkovice + Hrušov Members of Havlena et al. (1982); isopachous maps for the whole Ostrava Formation in Adamusová et al. 1992 or Pešek et al., 1998). In majority of them is not described methodology of modelling and not published a list of used data (boreholes), so it is not possible to compare them from this point neither.

On the basis of studying the Petřkovice Member's thickness and sand content, three main zones were identified of varying mobility in the basin's basement, which are reflected in the unit's geological characteristics. These zones are roughly parallel and their direction is roughly NNE-SSW. Today the zone of greatest mobility of the basin's background or its subsidence axis is preserved on the western edge of the Petřkovice Member. As with all foreland basins the basin was asymmetric (e.g. Ruhr basin – Drozdewski (1993) and Donets basin - Sachsenhofer et al. (2012), summary of their features Einsele, 2000) and today only its eastern wing is preserved. The area of increased sand content, right on the western edge of the Czech part of the basin (Fig. 10), could be interpreted as relics of its west wing. This would fit the situation that high sand areas existed along the western margin of the basin, and later were almost totally eroded due to progressive migration of deformation front. Higher sand content along the eastern margin of the basin could indicate that former basin margin was not so far behind the present-day erosional margin and the basin is less eroded along its eastern part. However, another explanation could be A/S ratio (ratio between accommodation and sediment supply, e.g. Martinsen et al., 1999) between unity and zero, favorable for deposition of coarser-grained clastics. There is only weak evidence that such mosaic diffreneces in basement (old Brunovistulian terrane with its sedimentary cover) mobility already existed (compare Fig. 8), so we incline to the first type of explanation.

From this study of the Petřkovice Member's sediments it can be surmised that the defining environment in which these sediments formed was a coastal accumulation plain (Havlena, 1982). This is further testified to by the spatial layout of the sedimentation environments in the basin. Kędzior et al. (2007) came to similar conclusions. Likewise he considered the basis of the Upper Silesian Basin's sedimentation environment to be a coastal plain and assigns it first place in a listing of basic sedimentary environments of the Upper Silesian Basin's paralic molasse.

It should be borne in mind that any interpretation of the Petřkovice Member's geology throughout the Upper Silesian Basin come upon two fundamental problems. The first is the very uneven coverage of the exploratory boreholes (Fig. 7). While the geological data of the western third of the lithostratigraphical unit are fairly certain, nowhere in the basin's central part has the Petřkovice Member's entire profile been fully drilled, thus the data are lacking. The second problem is the impossibility of perfectly correlating the Petřkovice Member and the Sarnów Beds, so the data in the eastern third of the basin must be taken as an expert guess based on the current state of knowledge. These problems must always be considered when working with the published information.

7 Conclusions

This paper should serve as a basic information about Petřkovice Member and Sarnów Beds, which roughly stratigraphically correspond to the Petřkovice Member, in Upper Silesian Basin. In the article is explained adnd described complex issue of the base and the top of the unit. Summary of the basic literature reference sis given.

Maps of the basic sedimentological parameters of the unit (thickness, sand content and coal-bearing capacity) were made. Thickness of the Petřkovice Member ranges between 53 m and 767 m has a polarity in the NNW-SSE direction. Sand content varies from 23% to more than 90%. Its polarity is roughly the same as thickness of the unit. The coal-bearing capacity, expressed as total thickness of the coal layers with a thickness greater than 10 cm, exceeds 25 m in the Czech part of the basin.

Newly generated models can serve as a basis for sedimentological interpretations of the Petřkovice Member.

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Figure captions

Fig. 1 Location of the Czech Republic and Poland within Europe. Location of the Bohemian Massif within European Variscides. Simplified geological map showing major tectonic zones, geological units and the position of the Upper Silesian Basin (according to Kandarachevová et al., 2009, modified).

Fig. 2 Lithostratigraphic division of the Czech (CR) and Polish (PR) parts of the Upper Silesian Basin. According to: Polish part Dembowski (1972), Jureczka (1988), Kotas et al. (1988), Czech part Sivek et al. (2003), modified.

Fig. 3 Geological map of the sedimentary filling of the Upper Silesian Basin indicating the main lithostratigraphic units. According to Jureczka et al. (2005), Aust et al. (1997), modified.

Fig. 4 Important identification and correlation horizons of the Petřkovice Member in their ideal development at the western edge of the Czech part of the Upper Silesian Basin. Absolute dating according to Jirásek et al. (2013), lithological units and groups of faunistic horizons according to Dopita et al. (1997).

Fig. 5 Lateral extent of horizons identifying the top of the Petřkovice Member in the Upper Silesian Basin.

Fig. 6 Location of mining fields mentioned in the text.

Fig. 7 Location of exploratory boreholes depicting the Petřkovice Member in the Upper Silesian Basin. An indicative scheme of the base of the stratiform unit in places with low borehole density according to Jureczka et al. (2005).

Fig. 8 Thickness of the Petřkovice Member in the Upper Silesian Basin.

Fig. 9 Division of the Upper Silesian Basin during sedimentation of the Petřkovice Member from the standpoint of the assumed mobility of its basement.

Fig. 10 Sand content of the Petřkovice Member in the Upper Silesian Basin.

Fig. 11 Coal-bearing capacity of the Petřkovice Member in the Upper Silesian Basin.

KML File (for GoogleMaps)

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- Complete determinations of Petřkovice Member and Sarnów Beds.
- First complete maps of thickness, sand content and coal bearing capacity.
- Thickness 50 to 770 m, sand content 23 to > 90%.
- Total coal bearing capacity locally over 25 m.
- 3 zones of different in the basin's bedrock were detected.

Fig_1

International journal of coal geology. 2013, vol. 106, s. 11-24.
http://dx.doi.org/10.1016/j.coal.2013.01.004

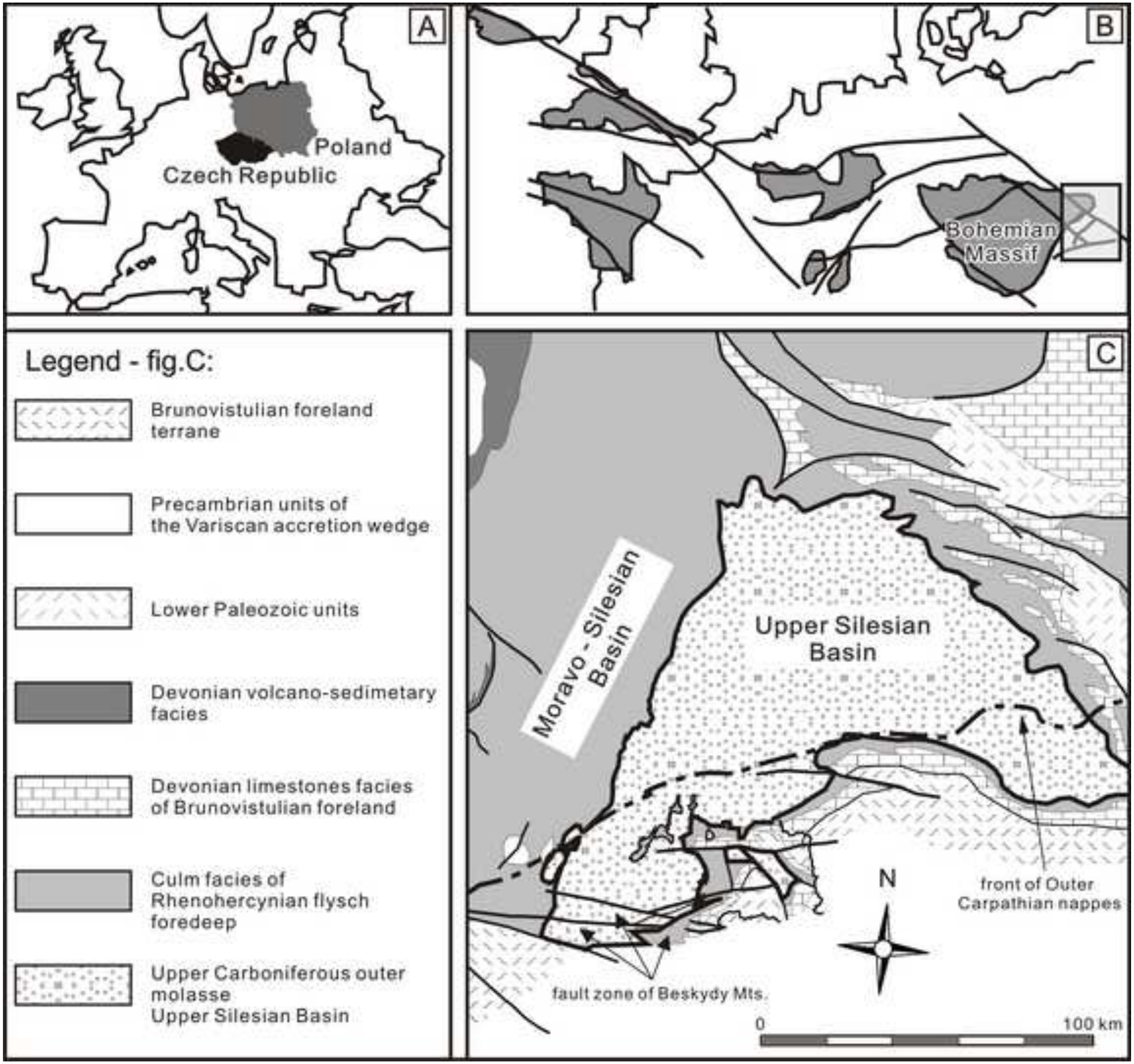

Fig_2

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http://dx.doi.org/10.1016/j.coal.2013.01.004

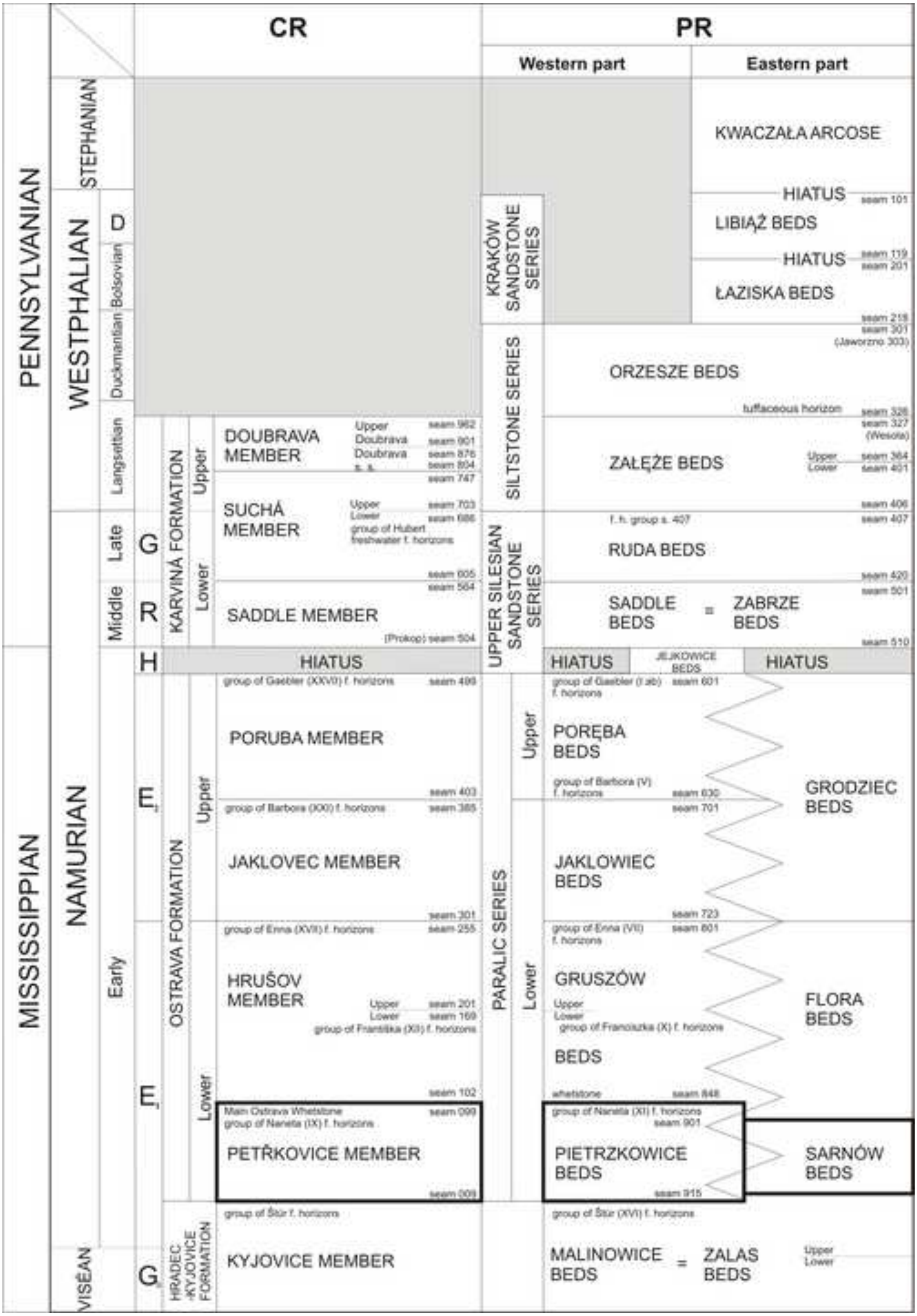

Fig_3

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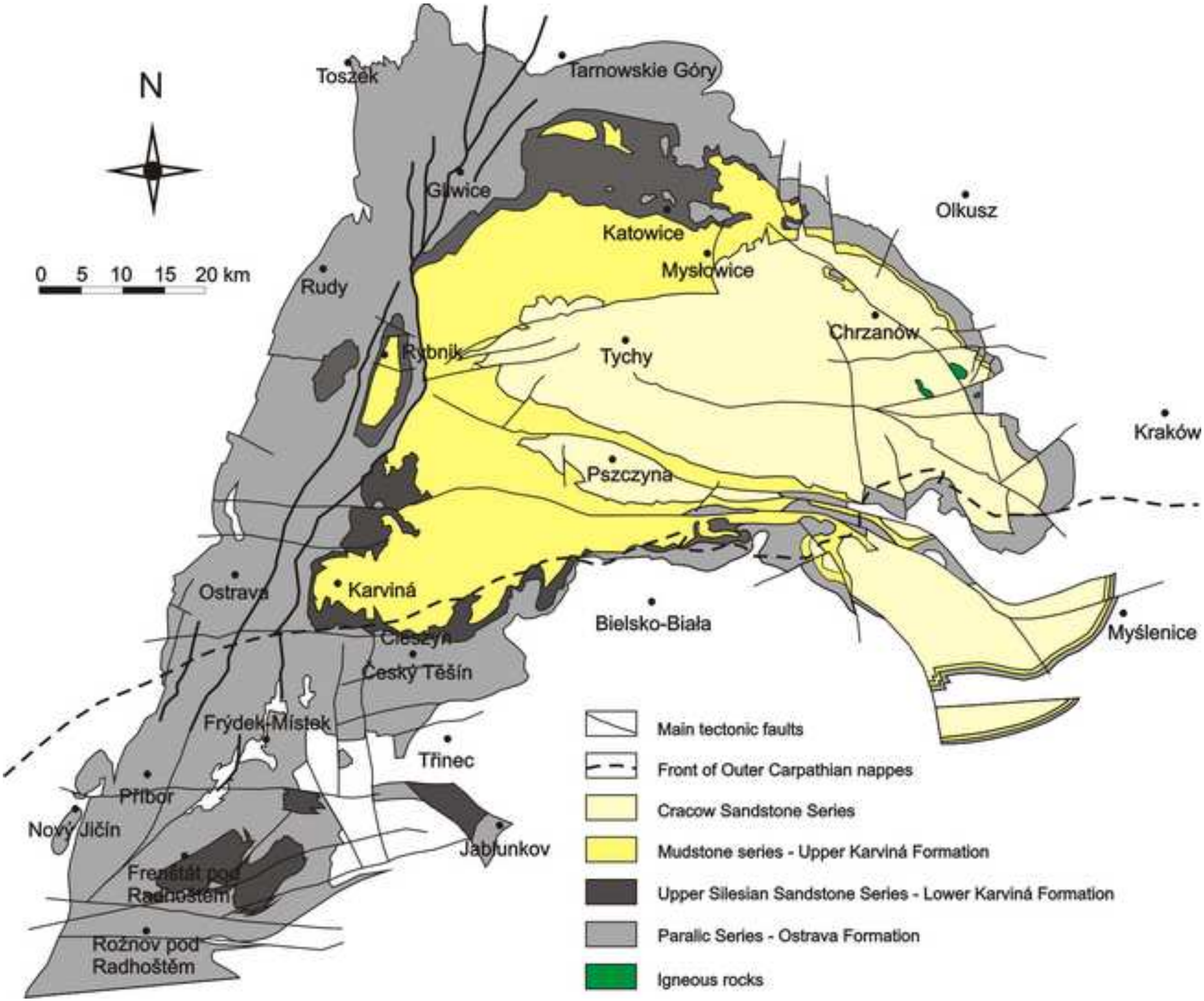

Fig_5

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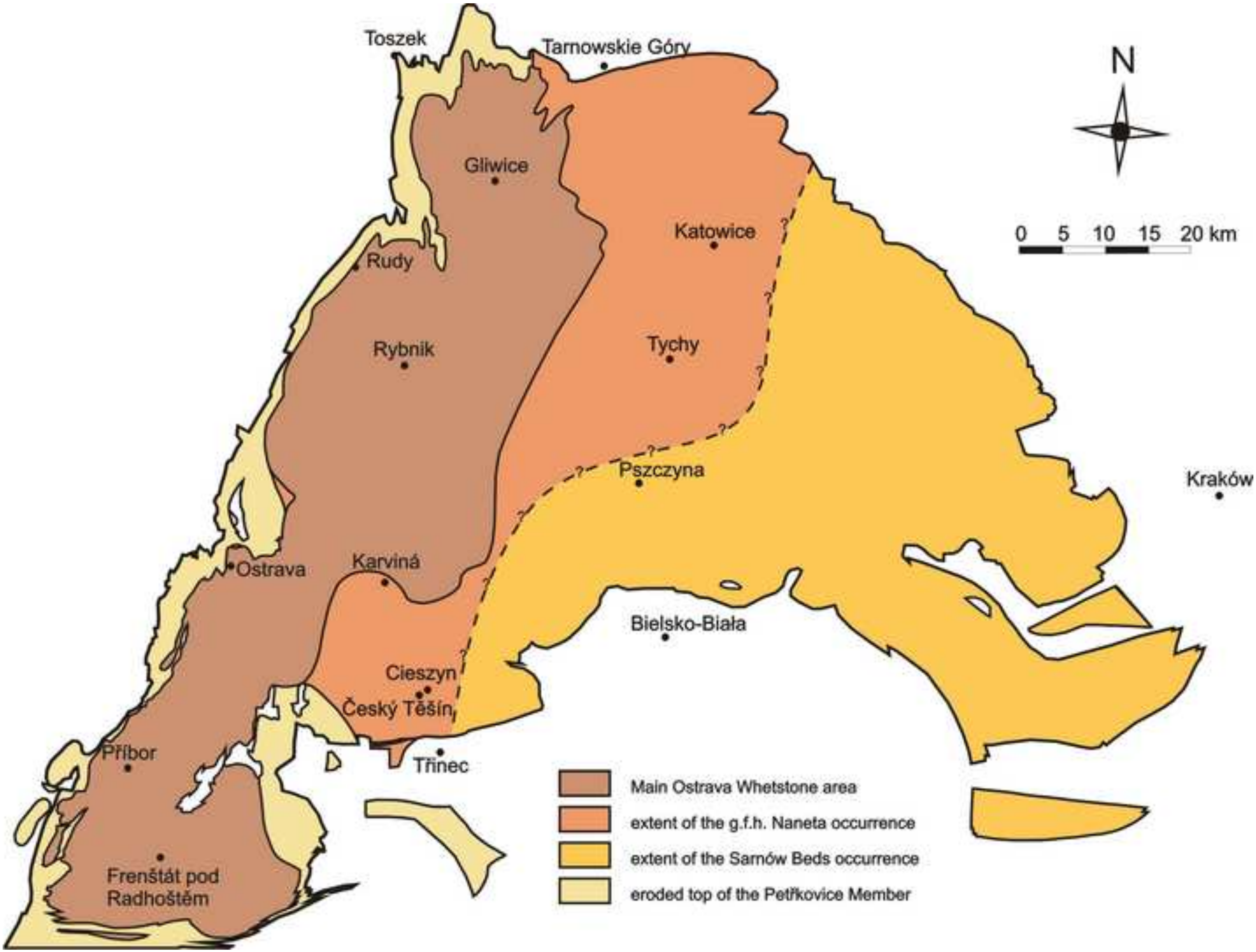

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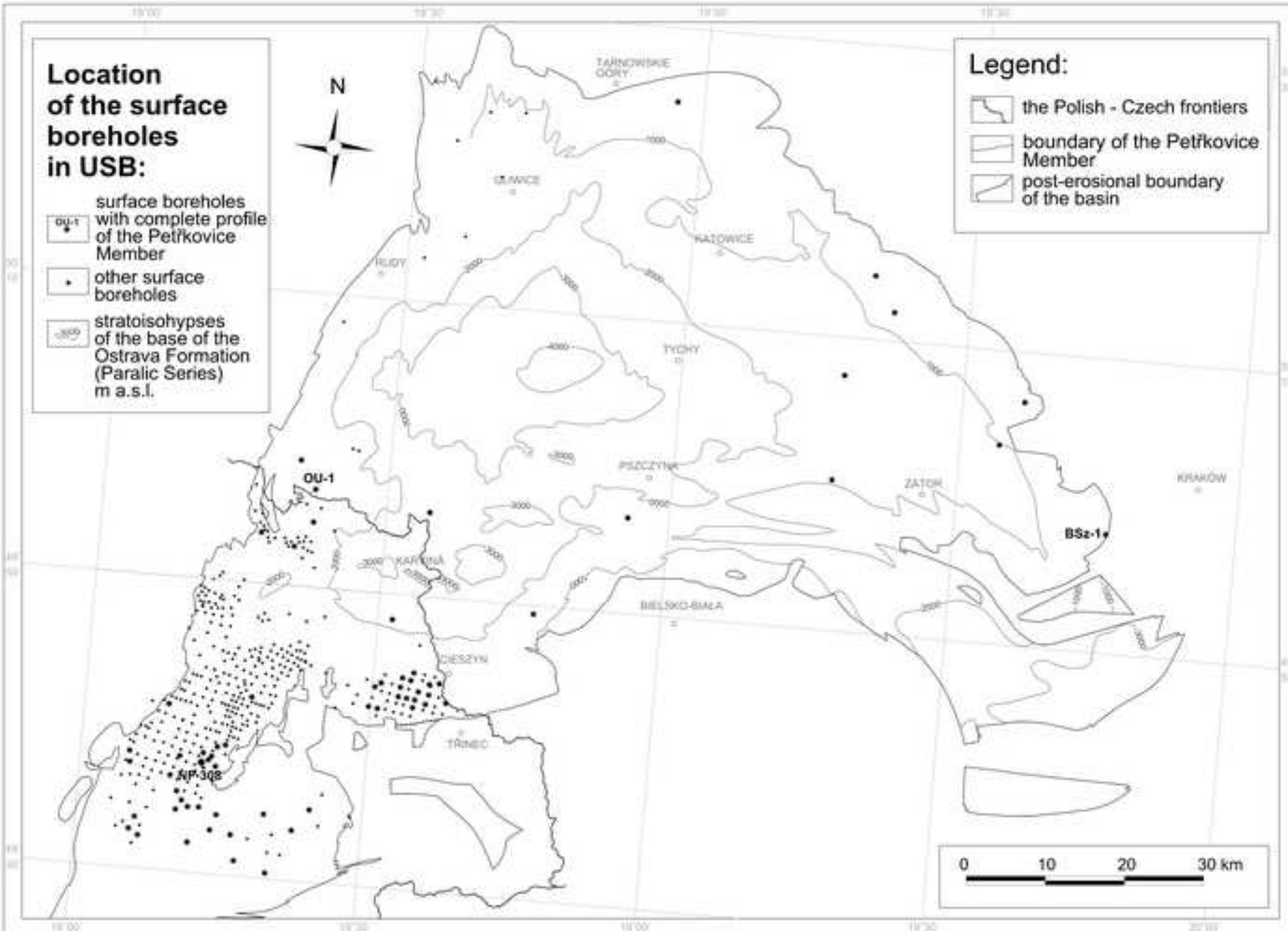

Fig_8
 http://dx.doi.org/10.1016/j.coal.2013.01.004

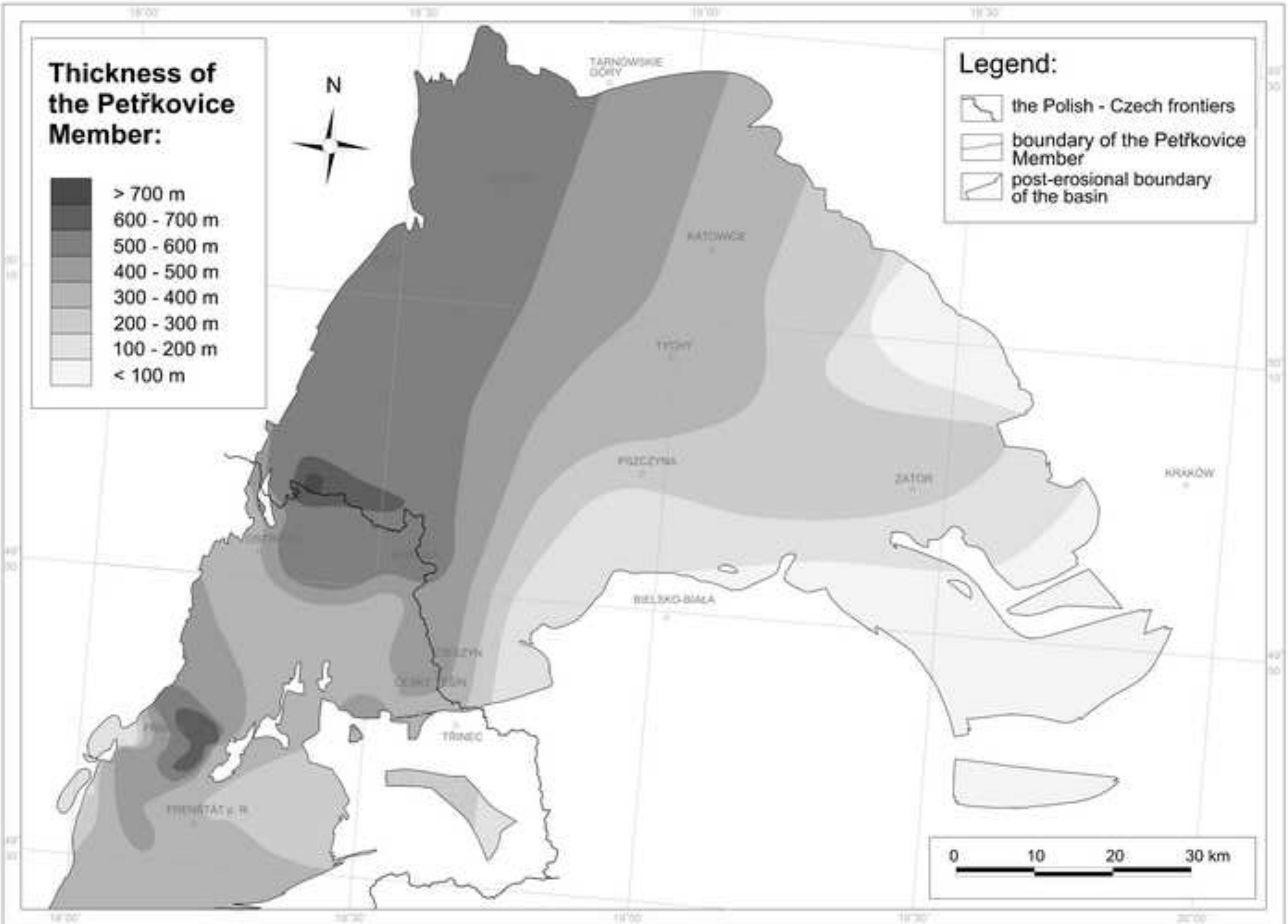

Fig_9

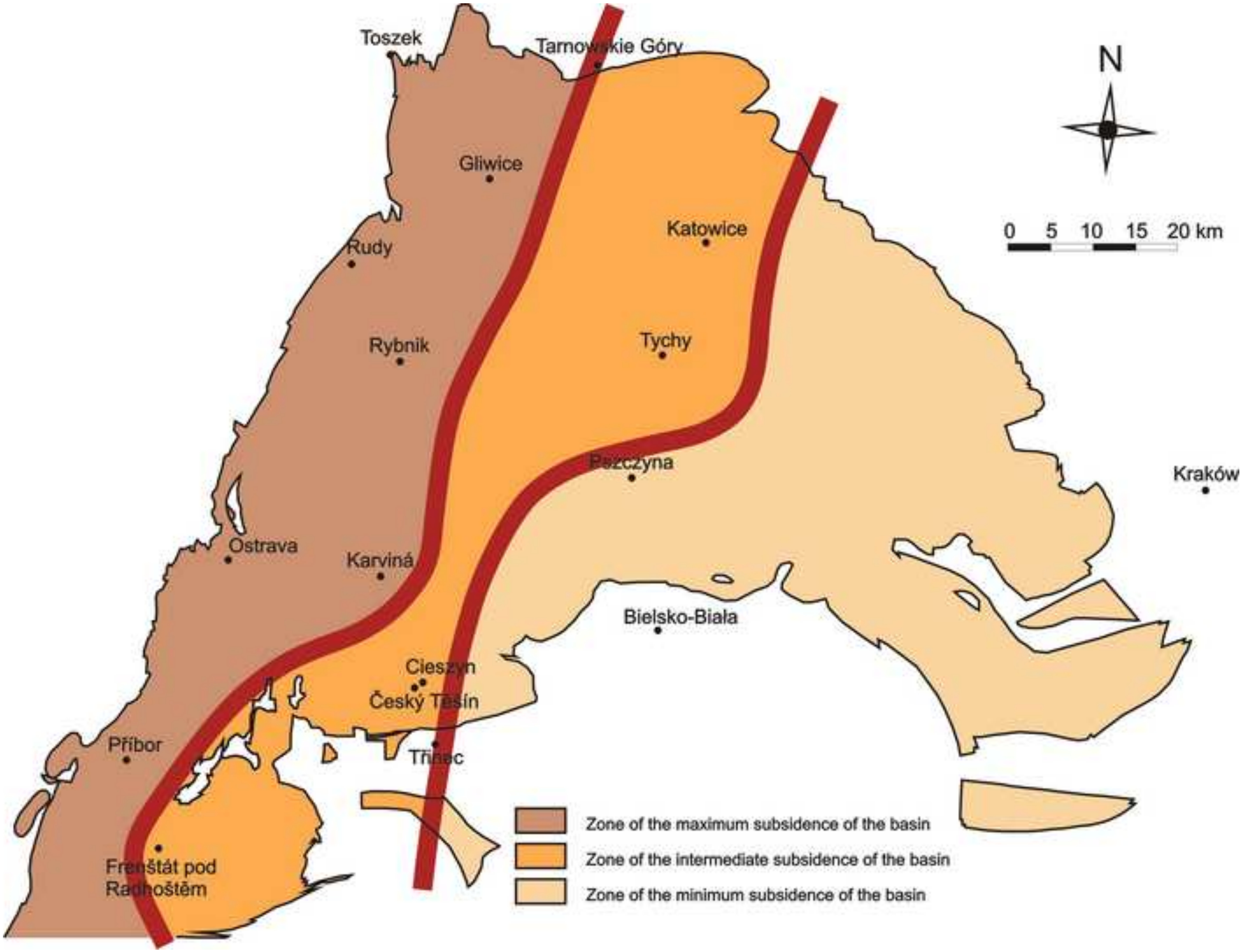
Toszek
Tarnowskie Góry
N
Gliwice
0 5 10 15 20 km
Katowice
Rudy
Rybnik
Tychy
Pszczyna
Kraków
Ostrava
Karviná
Bielsko-Biała
Cieszyn
Český Těšín
Příbor
Třinec
Zone of the maximum subsidence of the basin
Zone of the intermediate subsidence of the basin
Zone of the minimum subsidence of the basin
Frenštát pod
Radhoštěm

Fig_10

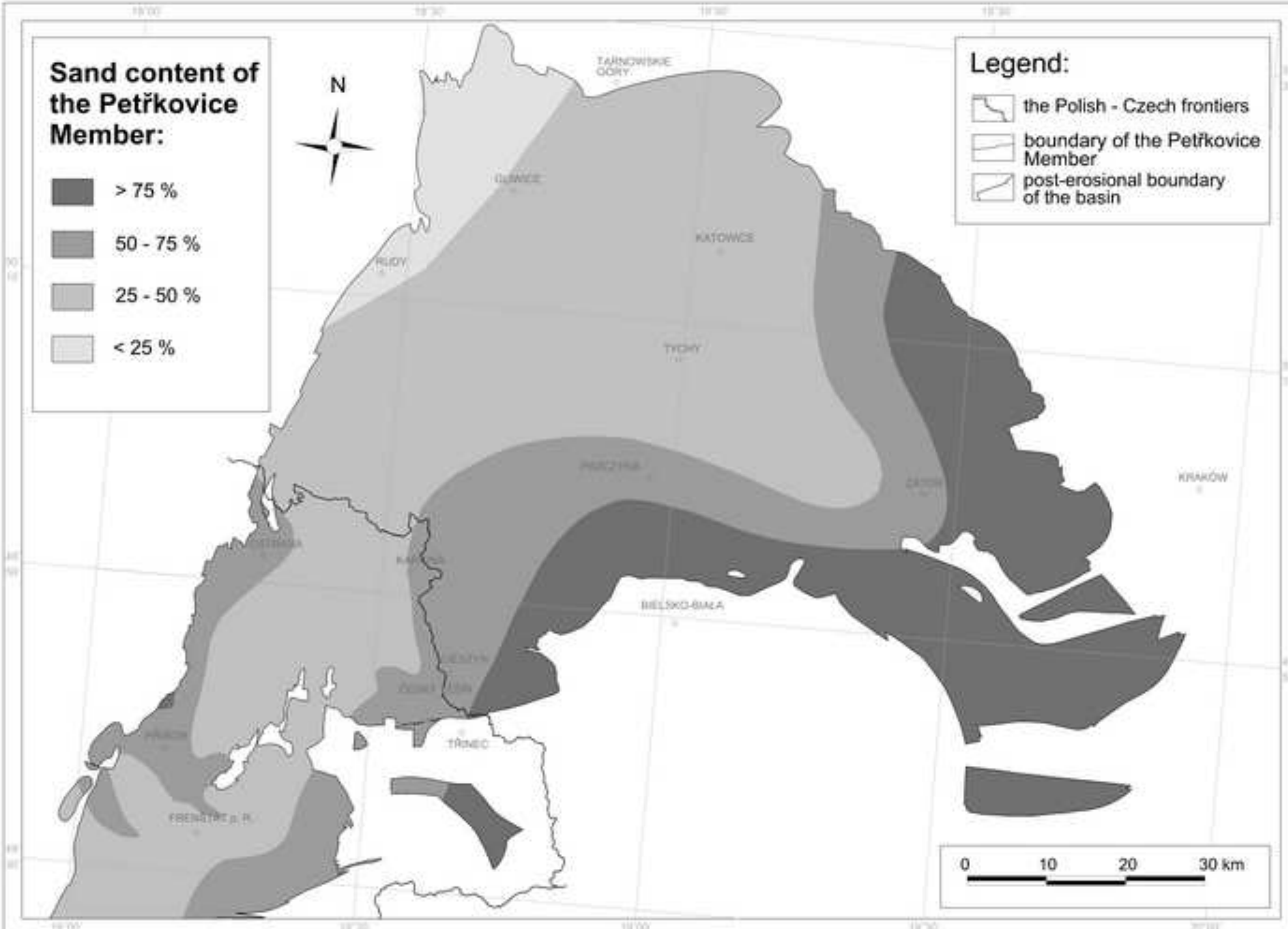
Sand content of the Petřkovice Member:
> 75 %
50 - 75 %
25 - 50 %
< 25 %
N
Legend:
the Polish - Czech frontiers
boundary of the Petřkovice Member
post-erosional boundary of the basin
0
10
20
30 km
TARNOWSKIE GÓRY
KATOWICE
TYCHY
BIELSKO-BIAŁA
KRAKÓW

Fig_6

International journal of coal geology. 2013, vol. 106, s. 11-24.

http://dx.doi.org/10.1016/j.coal.2013.01.004

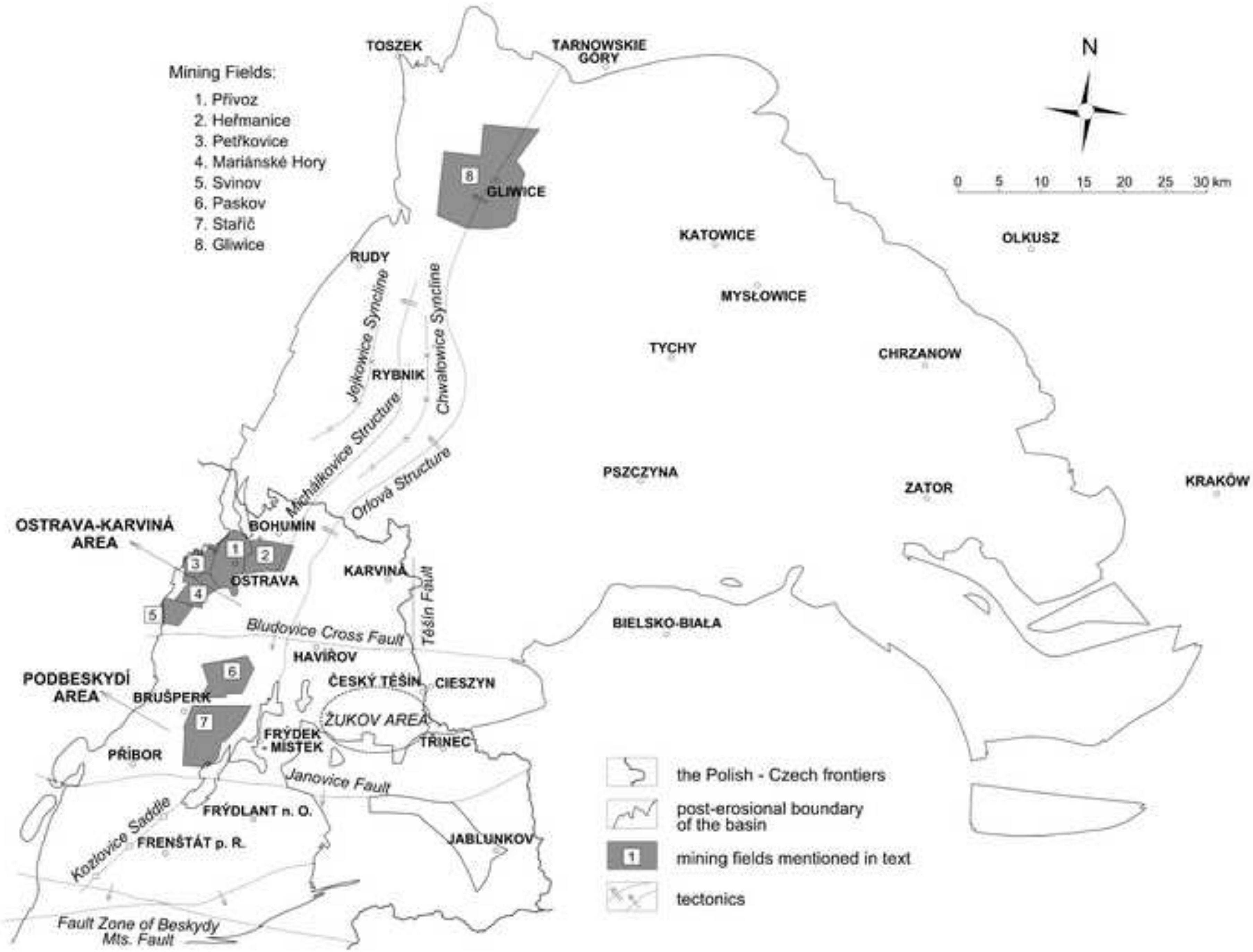

Fig_11

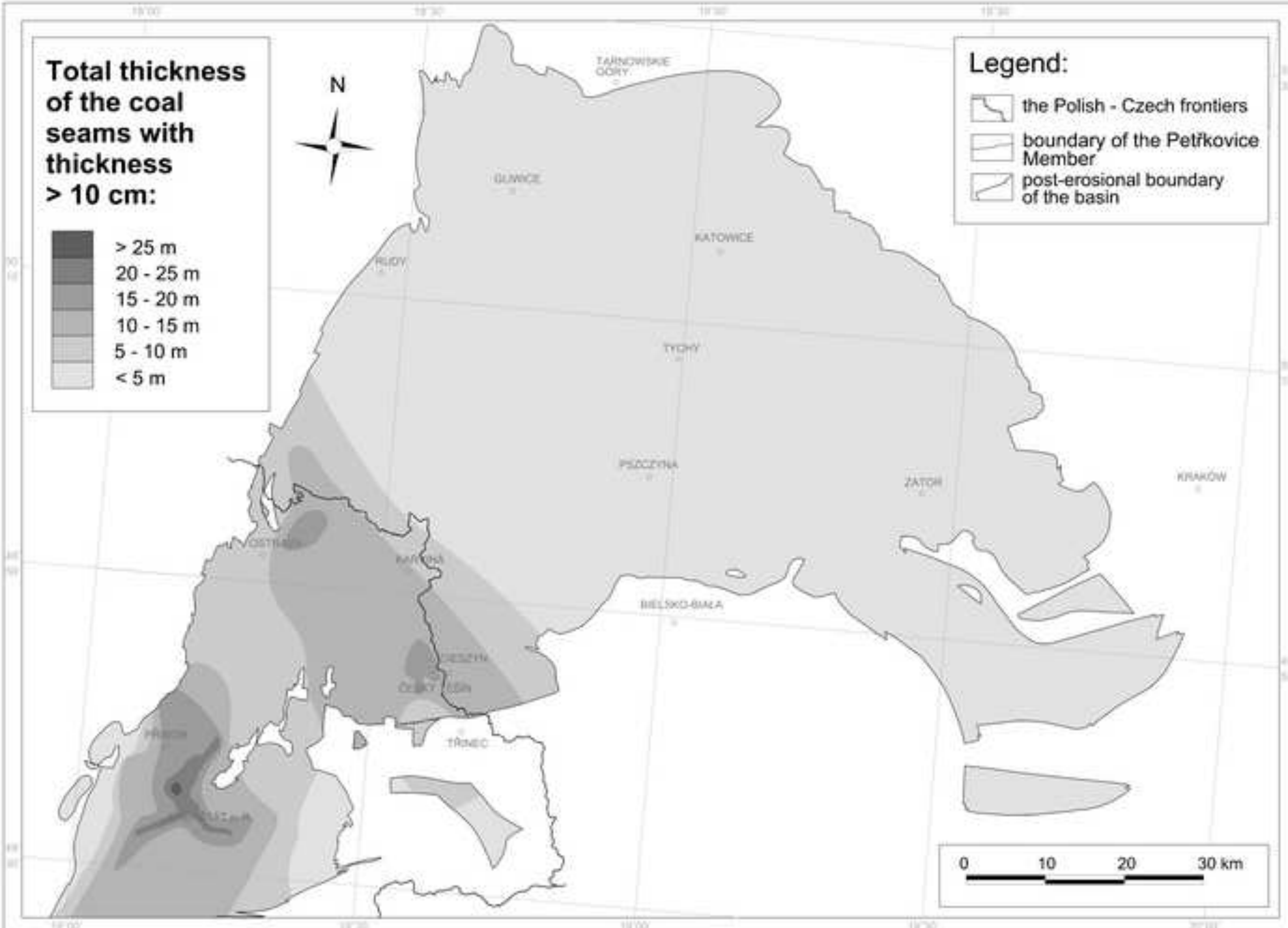
Total thickness of the coal seams with thickness > 10 cm:
> 25 m
20 - 25 m
15 - 20 m
10 - 15 m
5 - 10 m
< 5 m
N
Legend:
the Polish - Czech frontiers
boundary of the Petřkovice Member
post-erosional boundary of the basin
0
10
20
30 km
TARNOWSKIE GÓRY
GLIWICE
KATOWICE
RUDY
TYCHY
PSZCZYNA
ZATOR
KRAKÓW
OSTRAVA
KARVINÁ
BIELSKO-BIAŁA
CIESZYN
ČESKÝ TĚŠÍN
TŘINEC

Fig_4

International journal of coal geology. 2013, vol. 106, s. 11-24. http://dx.doi.org/10.1016/j.coal.2013.01.004