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Poznań Clays *versus* Poznań Formation in the upper Neogene of the Polish Lowlands: controversy about meaning, origin and age

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The Poznań Clays, deposited during the late Neogene, form one of the most famous lithological units in Poland, and the Poznań Formation is a lithostratigraphic unit which includes these fine-grained deposits. This formation is divided into the lower Grey Clay Member (MPLS-1 – the first Mid-Polish lignite seam and grey clays) and the upper Wielkopolska Member (green and flame-coloured clays). Nevertheless, the Poznań Clays comprise the uppermost parts of the lower Grey Clay Member and the entire upper Wielkopolska Member. This often causes confusion among researchers who incorrectly assign the position of the Poznań Clays in the lithostratigraphic scheme of the Neogene of the Polish Lowlands. This also results in incorrect determination of the age of the Poznań Clays, which in reality span the time interval between the late Middle Miocene and the earliest Early Pliocene. Such a range of meaning, covering two lithostratigraphic members, impacts the interpretation of the origin of the Poznań Clays. An additional factor complicating the understanding of the problem is the connection between the colour of the Poznań Clays and their stratigraphic position. The Poznań Clays and the Poznań Formation are often ambiguously understood, and these issues require clarification and discussion, as provided in this study.

Key words: central Poland, Miocene–Pliocene, lithostratigraphy, lithology, fine-grained sediments.

INTRODUCTION

In geology, as in other scientific disciplines, clear and universal terminology is of fundamental importance because it allows research findings to be compared both quantitatively and qualitatively. Therefore, every scientist is obliged to precisely define their research objects. In the Earth sciences, the most common information given is the location, distribution and variability of strata in vertical and horizontal directions, stratigraphic position, approximate age, and so on. In the case of the Neogene of the Polish Lowlands, lithostratigraphy plays a dominant role among stratigraphic methods. Therefore, the varied lithological features of the deposit are the basis for the separation of subsequent lithostratigraphic units, such as members and formations (e.g., Racki et al., 2006).

Unfortunately, in scientific studies and geological documentation, there exist two similar names of lithological and lithostratigraphic units, i.e., the Poznań Clays and Poznań Formation, respectively. The term Poznań Clays was created in the second half of the 19th century, while the Poznań Formation was proposed and named in the second half of the 20th century (Piwocki and Ziembińska-Tworzydło, 1995, 1997; Piwocki et al., 2004). Most geologists who are not familiar with the lithostratigraphy of the upper Neogene of the Polish Lowlands do not distinguish between these two units. Others, however, incorrectly determine their position in existing lithostratigraphic schemes and, indirectly, their lithology, genesis and age.

These issues require brief explanation, as introduced in this paper. No such attempts have yet been made, and there is no previous publication comparing the Poznań Clays and the Poznań Formation. Therefore, the current study aims to (1) provide an overview of the lithological and lithostratigraphic names used at different times for the succession in question, (2) characterize the lithology of both lithostratigraphic members forming the Poznań Formation, (3) interpret the origins of the deposits characterized and determine their age, and (4) discuss the position of the Poznań Formation and Poznań Clays in different lithostratigraphic schemes.

GEOLOGICAL SETTING

The Poznań Clays and the Poznań Formation currently have an approximate geographic extent of 74,000–75,000 km^2 in the Polish Lowlands (Fig. 1A). However, during their accumulation in the late Neogene, i.e., from the middle part of the Middle Miocene to the earliest Early Pliocene, their area of occurrence was much larger. Post-depositional erosion associated mainly with the Pleistocene glaciations has reduced their extent (Piwocki, 1992; Piwocki et al., 2004; Widera, 2013a, 2018; Widera et al., 2019).

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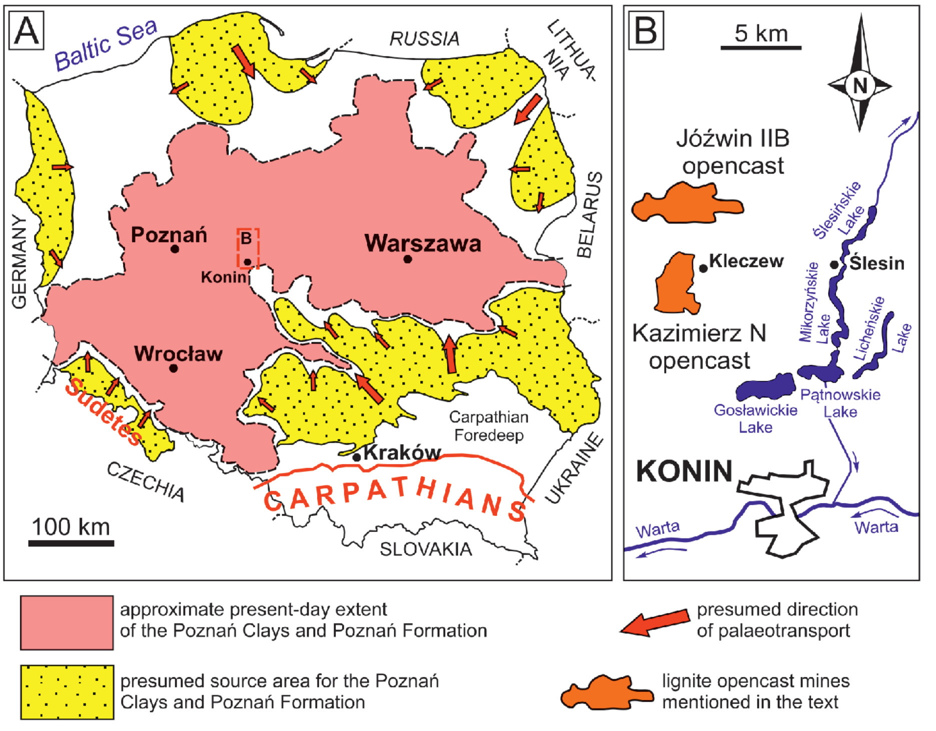

Fig. 1. Current presence of the Poznań Formation with the Poznań Clays and the field locations studied

A – palaeogeography and present-day extent of the succession examined in Poland (modified from Wagner, 1982; Czapowski and Kasiński, 2002; Widera, 2013b); **B** – lignite opencast mines in the Konin region, where detailed fieldwork was conducted

The present-day territory of the Polish Lowlands containing the Poznań Clays and Poznań Formation constituted a late Neogene sedimentary basin, belonging to the easternmost part of the north-west European Paleogene–Neogene Basin (Vinken, 1988). During the accumulation of the Poznań Formation with the Poznań Clays, the source areas of the clastic material were probably located around central Poland (Fig. 1A; Wagner, 1982; Czapowski and Kasiński, 2002; Widera, 2013b). There is no evidence in the geological record for connection of this area with the late Neogene North Sea basin. By contrast, marine ingressions from the Carpathian Foredeep basin into the Poznań Clays basin are well documented (Dyjor, 1968; Ciuk and Pożaryska, 1982).

The portion of the upper Neogene section in the Polish Lowlands examined includes the younger, main Middle Miocene lignite seam (i.e., MPLS-1 – the first Mid-Polish lignite seam) and the Poznań Clays. This simple division becomes somewhat more complex when prevailing lithostratigraphic schemes are taken into account, with the ensuing controversies discussed below. The Poznań Formation and Poznań Clays are, over most of their occurrence area, underlain by Lower–Middle Miocene fluvial sands, locally also by the second Lusatian lignite seam (Ziembińska-Tworzydło, 1974), and overlain by Pleistocene glaciogenic deposits such as glacial tills, glaciofluvial gravels and sands, and limnoglacial muds (e.g., Ciuk, 1970; Piwocki et al., 2004; Widera, 2021; Widera et al., 2021b). However, in south-west Poland, the top of the Poznań Formation with the Poznań Clays is overlain by sandy-gravely deposits of the Gozdnica Formation, dating from the Late Miocene to the Early Pleistocene (e.g., Dyjor, 1968, 1970; Czapowski et al., 2002; Badura and Przybylski, 2004).

DATA AND METHODS

This review and discussion is based on analysis of relevant geological literature, including lithostratigraphic schemes for the Neogene of the Polish Lowlands (Ciuk, 1970; Dyjor, 1970; Piwocki and Ziembińska-Tworzydło, 1995, 1997; Widera, 2007; Kasiński and Słodkowska, 2024 and other references therein). The historical background follows Areń (1964) and Piwocki et al. (2004). Over the last two decades, fieldwork was carried out in surface opencast mines (below abbreviated to “opencasts”) managed by the Konin Lignite Mine, i.e., Kazimierz N and Jóźwin IIB (Fig. 1B). In these lignite opencasts, the lithostratigraphic section of the upper Neogene was the most complete, enabling direct observation of the strata from the floor of the MPLS-1 to the top of the Poznań Clays: the entire Poznań Formation, as illustrated by photographs below.

Given the focus on lithological and lithostratigraphic units, particular attention is paid to lithological characteristics: the standard Wentworth (1922) grain-size scale for siliciclastic deposits and the Shepard (1954) classification triangle for fine-grained lithologies, with a mixture of clay, silt and sand fractions in an amount of at least 20 wt.% each corresponding to mud (e.g., Chomiak et al., 2020; Klęsk et al., 2023). The genetic interpretation of both fluvial and lacustrine siliciclastic facies followed established principles of facies analysis (e.g., Miall, 2006; Boggs, 2012; Zieliński, 2014 and other references therein). The nomenclature of the lignite lithotype associations for MPLS-1 is given mainly by Kwiecińska and Wagner (1997), Markič and Sachsenhofer (1997), and Widera (2016a). Their original depositional environment, i.e. mire type, was interpreted by Teichmüller (1958, 1989), Horne et al. (1978), Diessel et al. (2000), and Markič and Sachsenhofer (2010).

PREVIOUS RESEARCH

Historical background. The stratotype area for both the Poznań Clays and the Poznań Formation is the area around Poznań in central-western Poland (see Fig. 1A). Investigations were conducted there by German geologists in the second half of the 19th century, who distinguished the multi-coloured "Posener Flammenton" (= Poznań Flamy Clay) or "Posener Ton" (= Poznań Clays). These researchers clearly defined the boundaries of the Poznań Clays. Their base was marked by the so-called "Basisflöz" (= MPLS-1) and the top by glaciogenic deposits of Pleistocene age (cf. Piwocki et al., 2004).

Until the 1960s, German and later Polish geologists believed that the Poznań Clays accumulated in a vast "Pliocene Lake", covering almost the entire Polish Lowlands and the easternmost territories of Germany (e.g., Mai and Wähnert, 2000; Kasiński and Słodkowska, 2017) and Belarus (e.g., Planderova et al., 1993): the lacustrine hypothesis (Areń, 1964). At that time, the Poznań Clays began to be divided into secondary units, and in 1970, two terminologically different (beds *vs.* series and horizons) lithostratigraphic schemes were created (Fig. 2). The first one covered the central and eastern part of the Polish Lowlands (Ciuk, 1970), while the second scheme was created for the most western territory of Poland, i.e., Lower Silesia and the Lubusz Land (Dyjor, 1970). Dyjor (1968, 1970) based on rare occurrences of glauconite, foraminifera test fragments and river sands in the marginal parts of the sedimentary basin (near the Sudetes, south-west Poland; see Fig. 1A), proposed a lacustrine–fluvial–marine hypothesis for the deposition of the Poznań Clays.

Modern lithostratigraphic schemes. In the last 30 years, several attempts have been made to formalise the lithostratigraphy of the Neogene in the Polish Lowlands. The first scheme in which the Poznań Formation appeared was proposed by Piwocki and Ziembińska-Tworzydło (1995, 1997; Fig. 2), this being well-known and widely used by Polish geologists to this day. Therefore, the lithostratigraphic units characterized herein will be described in accordance with this scheme. The Poznań Formation is divided into two members, where the lowest Grey Clay Member also contains the MPLS-1. Hence, the stratigraphic range of the Poznań Formation is greater than that of the Poznań Clays (Fig. 2).

Kasiński and Słodkowska (2024) presented the latest lithostratigraphic scheme of the upper Neogene, where the Poznań Formation is differently placed than in that of Piwocki and Ziembińska-Tworzydło (1995, 1997). Simply put, in the scheme of Kasiński and Słodkowska (2024), the Poznań For-

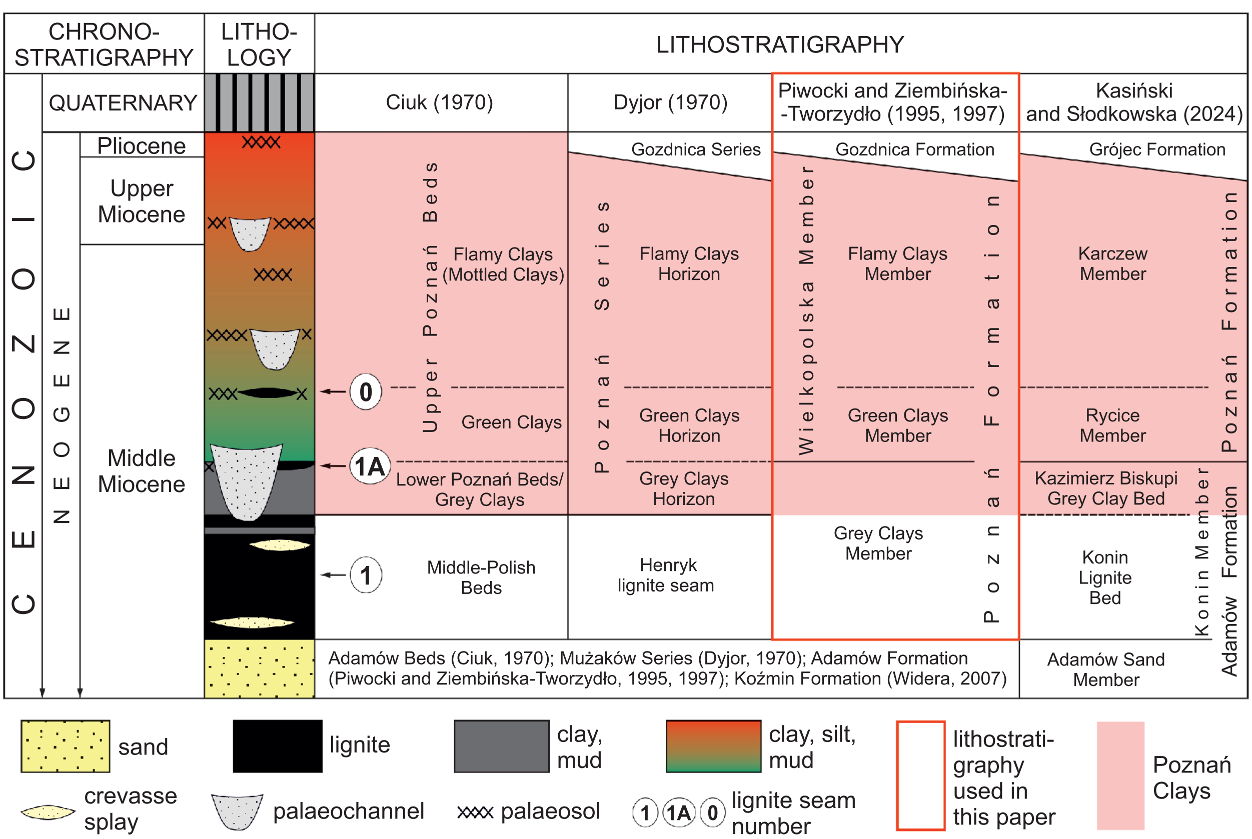

Fig. 2. Development of views on the upper Neogene lithostratigraphy of the Polish Lowlands (modified from Ciuk, 1970; Dyjor, 1970; Piwocki and Ziembińska-Tworzydło, 1995, 1997; Kasiński and Słodkowska, 2024)

Lignite seams: 1 – the first Mid-Polish (MPLS-1), 1A – the first A Oczkowice, 0 – the zero Orłowo; note the various names of the same lithostratigraphic units, as well as the different range of the Poznań Formation according to Piwocki and Ziembińska-Tworzydło (1995, 1997), and Kasiński and Słodkowska (2024) mation does not include the lowest layers of the Poznań Clays, called the Kazimierz Biskupi Grey Clay Bed. Moreover, in both cases, the Poznań Clays are divided into only three lithological subunits (members and/or beds) based on their colour changes (Fig. 2). This simplification also causes confusion among researchers working on the upper Neogene in the Polish Lowlands, as discussed in detail below in this paper.

RESULTS

GREY CLAY MEMBER

General characteristics. The Grey Clay Member constitutes the lower part of the Poznań Formation (Piwocki and Ziembińska-Tworzydło, 1995, 1997). It includes the MPLS-1 and the so-called "grey clays" (see Fig. 2). The MPLS-1 is also called the Konin lignite seam in the Konin region (Sadowska and Giża, 1991), as well as the Henryk lignite seam in the Lower Silesia and Lubusz Land territories (Dyjor, 1968, 1970). It covers an area of ~74,000 km^2 and reaches its greatest thickness in the Konin area, where it has been extensively exploited for over 80 years (Piwocki, 1992; Piwocki et al., 2004; Widera, 2021; Kasztelewicz et al., 2025). Macropetrographically, the MPLS-1 consists mainly of the xylodetritic and detroxylitic lignite lithotype associations, while others (such as detritic, xylitic and occasionally weathered or fusitic) play a secondary role (Kwiecińska and Wagner, 1997; Widera, 2016a; Widera et al., 2021a). In addition, the MPLS-1 contains numerous sand lenses up to 1.4–5.0 m thick and/or clay layers up to 0.8 m thick (e.g., Widera, 2016b; Chomiak et al., 2019, 2020; Widera et al., 2023; Wachocki et al., 2025 and other references therein).

The name of the Grey Clay Member is more appropriate for the area of Poznań, where the scheme of Ciuk (1970) was created. There, thin (up to 1–2 m) beds of lignite (MPLS-1) are separated by layers of grey clay several times thicker, in the top of which there is locally a lignite layer up to 0.3 m thick, representing the first A Oczkowice seam (Fig. 2). Similarly, the Grey Clay Member is developed in the Lower Silesia area (Dyjor, 1970). It is lithologically the same in the Konin region, but the proportions are diametrically different. It predominantly (>99 vol.%) contains the MPLS-1 up to 19.8 m thick, averaging 6.6 m, and a discontinuous layer of grey clay on its roof up to 5 m thick, averaging 0.3–0.6 m (Fig. 3). Their most important feature is the macroscopically visible presence of dispersed organic matter and fossilised wood fragments >1 cm in size, i.e., xylites (Fig. 4).

Interpretation of origin and age. The xylodetritic and detroxylitic lignite lithotype associations dominate within the MPLS-1, which was/is mined exclusively in central Poland, i.e., in the Konin and Adamów lignite mines (e.g., Widera, 2021). The detroxylitic lignite is attributed to a wet swamp forest, while the xylodetritic lignite is more characteristic of a bush moor (Markič and Sachsenhofer, 1997, 2010). They are also tree and shrub swamps: respectively a *Taxodium–Nyssa* swamp and Myricaceae–Cyrillaceae swamp (Teichmüller, 1958, 1989). During their formation, the groundwater table had to change from relatively low to high (Horne et al., 1978; Diessel et al., 2000; Słodkowska and Widera, 2021, 2022; Worobiec et al., 2021, 2022). The time of the peat accumulation which subsequently transformed into the MPLS-1, is determined at ~15.1–14.3 Ma, i.e., the middle part of the Middle Miocene: middle Langhian (Widera et al., 2021a, 2024).

The sandy intercalations occurring within the MPLS-1, particularly those in the Konin lignite opencasts, are interpreted as crevasse splays (Chomiak et al., 2019; Chomiak, 2020; Widera et al., 2022; Dziamara et al., 2023; Wachocki et al., 2025 and other references therein). They were formed during overbank flooding on the Middle Miocene mire (backswamp) surface. Some of the crevasse-splay deposits accumulated in flowing water, and others in standing water, i.e., lakes. Some of them are strongly syn-depositionally deformed, in both ductile and brittle styles. Therefore, the interpreted crevasse-splay sandbodies are the most numerous and genetically most diverse among all exploited Polish lignite seams (Widera et al., 2023, 2024). In the case of interseam clays, they accumulated from suspension in a long-lasting and relatively extensive lake (its area measured in km^2) that existed in the backswamp area (Chomiak et al., 2020). In central Poland (the vicinity of Konin), only one clay layer is known within the MPLS-1 (up to 0.8 m thick), while in central-western Poland (the vicinity of Poznań), Lower Silesia and Lubusz Land there are one to three such beds, and their total thickness exceeds 10–15 m (Piwocki et al, 2004; Widera, 2007).

As with the interseam clays noted above, the layer of grey clay resting on the roof of the MPLS-1 can be interpreted similarly. However, their bigger area and thickness, as well as the presence of xylites, indicate some differences (cf. Figs. 3 and 4). In the last three decades, it has been commonly assumed that they constitute the final stage of the Middle Miocene mire development in the Polish Lowlands. Therefore, Piwocki and Ziembińska-Tworzydło (1995, 1997) combined them with the underlying MPLS-1 into one lithostratigraphic unit: the Grey Clay Member (cf. Figs. 2 and 3). Most likely, these clays were formed under regional subsidence conditions when organic sedimentation was replaced by mineral sedimentation (e.g., Zagwijn and Hager, 1987; McCabe and Parrish, 1992; Mach et al., 2013, 2014; Widera, 2015, 2024; Kasiński and Słodkowska, 2016), with locally varied peat/lignite compaction (Widera, 2013a: fig. 13). Thus, in places where the deposition surface was lowered (>2 m water depth; Diessel et al., 2000; Bos et al., 2009; Widera, 2016b), the accumulation of fine-grained sediments (clay, silt, mud) predominated, while in shallower parts, the peat/lignite seam roof was eroded, including by wave action (Widera, 2007). Locally in western Poland, a lignite layer (1A Oczkowice seam) with a thickness of 0.3–34.5 m, was formed at their top. This maximum thickness was documented from the Oczkowice lignite deposit (halfway between Poznań and Wrocław), which is, however, affected by post-depositional glaciotectonism. The accumulation of the grey clays with xylites (and locally with the 1A lignite seam) started ~14.3 Ma (= end of the MPLS-1 sedimentation) and ended ~13.8 Ma (Widera et al., 2021a).

WIELKOPOLSKA MEMBER

General characteristics. The upper part of the Poznań Formation includes the Wielkopolska Member (Fig. 2; Piwocki and Ziembińska-Tworzydło, 1995, 1997). This covers a slightly larger area, i.e., ~75,000 km^2, than the Grey Clay Member described above (Piwocki et al., 2004). The thickness of the Wielkopolska Member is very variable in the Polish Lowlands and is in the range of 0–160 m, on average 40–60 m. It is thinnest in marginal parts of its current extent and thickest in tectonic depressions (including Cenozoic lignite-rich tectonic grabens) and Pleistocene zones of glaciotectonic deformation in terminal moraines (Areń, 1964; Piwocki et al., 2004). Traditionally, the Wielkopolska Member includes layers/beds of green and flame-coloured (or "flamy") clays (Figs. 2 and 5). Such a di-

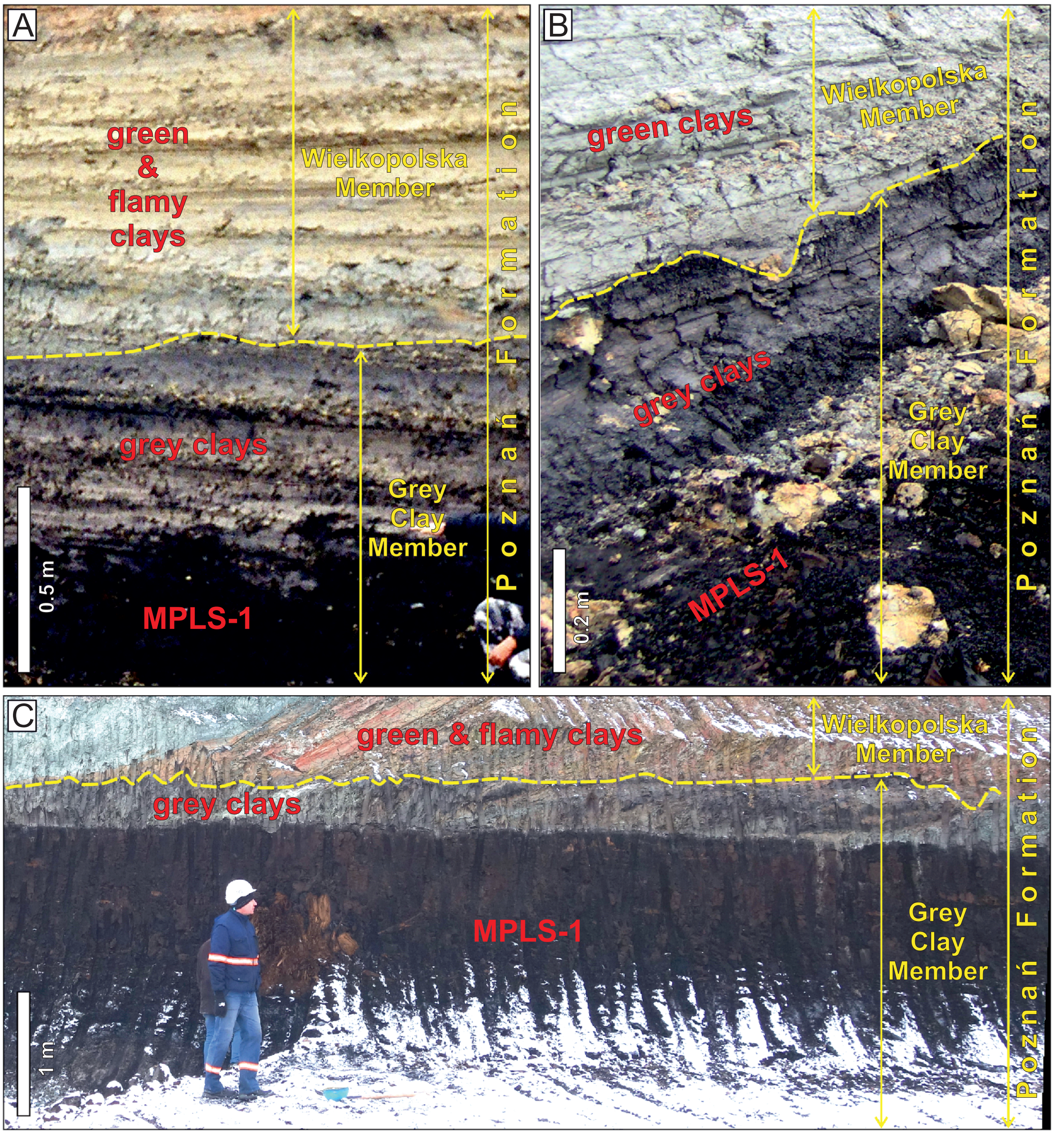

Fig. 3. Lithostratigraphic section of the Poznań Formation in the Konin lignite opencast mines

A – Kazimierz N opencast; **B, C** – Jóźwin IIB opencast; note the depositional boundary between lithostratigraphic units and the facies transitions between the multi-coloured clays both vertically and horizontally

vision does not correspond to geological reality; it is even misleading, and so requires in-depth discussion.

Due to their centuries-long use for the production of red building ceramics, the fine-grained deposits of the Wielkopolska Member, the most clay-rich over most of the Polish Lowlands, have been extensively investigated. Hence, mineralogical studies dominated for many years, investigating the composition of the clay fraction (e.g., Wiewióra and Wyrwicki, 1974, 1976; Wyrwicki, 1975; Wagner, 1982; Górniak et al., 2001; Duczmal-Czernikiewicz, 2010, 2013 and other references therein). Recently, however, special attention has been paid to explaining the causes of the different colours of these deposits (Fig. 5; Klęsk et al., 2022, 2023).

In general, the Wielkopolska Member is composed of multi-coloured clay, silt and fine sand or a mixture of these. Until the beginning of the 21st century, mainly based on borehole data, sandy or sandy-muddy lenses within the Wielkopolska Member were noted in numerous geological documents and publications (see Badura and Przybylski, 2004; Piwocki et al., 2004 and other references therein). Occasionally, among these fine-grained deposits, for example, from the Jarowszów brickyard near Wrocław, individual sand-gravel lenses and palaeosol ho-

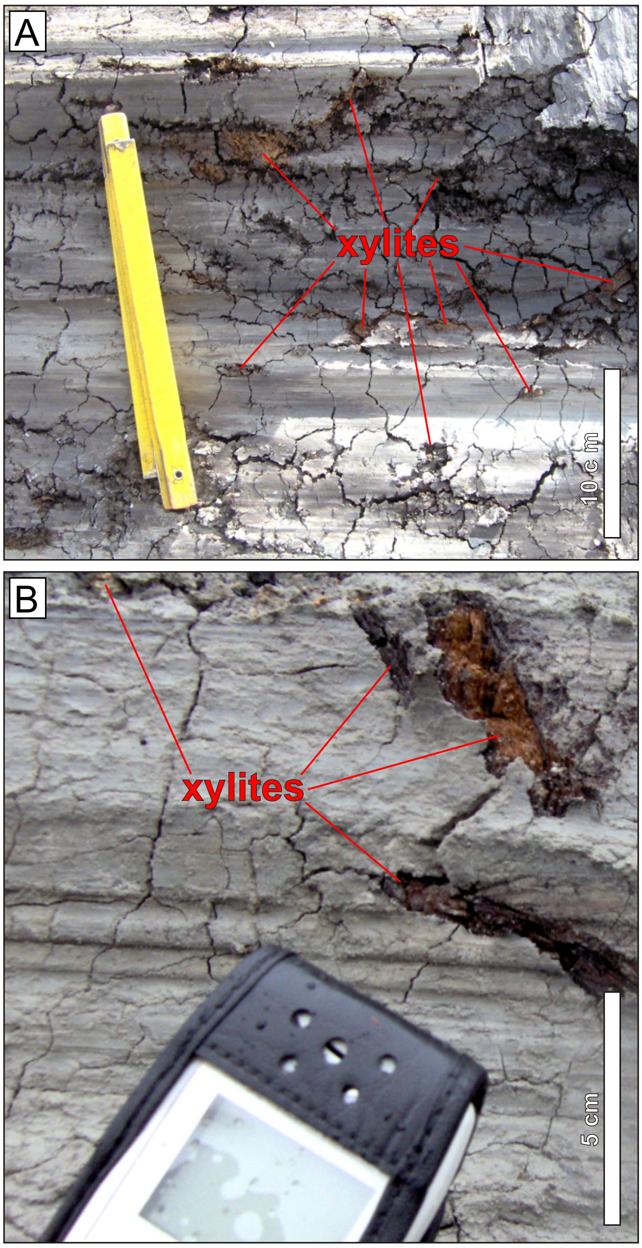

Fig. 4. Grey clays (lowermost part of the Poznań Clays – upper part of the Grey Clay Member), containing dispersed organic matter (plant detritus) and pieces of fossil wood (xylites) from the Kazimierz N lignite opencast

A – note the numerous, small xylites and the zone (dark grey) enriched with plant detritus; **B** – note the xylites with the preserved internal structure (brown) of the wood

rizons were also described (Czapowski et al., 2002). However, it is only in the last two decades that >30 such lenses have been documented and sedimentologically examined in the Konin region, i.e., in the Kazimierz N and Jóźwin IIB lignite opencasts (e.g., Kasiński and Czapowski, 2002; Widera et al., 2019; Zieliński and Widera, 2020 and other references therein). They are up to 12 m thick and up to 150 m across, while their average width/thickness ratio is <15 (Widera, 2013b; Widera et al., 2019). Additionally, in these opencasts, palaeosol horizons with thin (up to 0.3 m) layers of lignite were identified (Maciaszek et al., 2020; Klęsk et al., 2023; Wachocki et al., 2025).

Interpretation of origin and age. These sandy, sandy-muddy or muddy lenses, constituting <5 vol.% of the Wielkopolska Member, are interpreted as infills of fluvial palaeochannels. On the basis of their cross-sectional geometry (relatively narrow and deep; width/thickness ratio <15), they can be called ribbons (Gibling, 2006). This means that these palaeochannels were generally stable, i.e., their lateral migration (meandering) was very limited due to the strong cohesion of the extra-channel (overbank) clayey sediments. On the other hand, the occurrence of small-scale (e.g., heterolithic bedding: flaser, wavy, lenticular) and large-scale (e.g., trough, planar) stratification is characteristic of the filling of these palaeochannels, which indicates extreme fluctuations in water flow energy (e.g., Miall, 2006; Boggs, 2012; Zieliński, 2014). Moreover, their plan-view pattern (mapped in the Jóźwin IIB opencast) shows that the palaeochannels separate and join at an angle close to 90°. Considering all the information, these palaeochannels are interpreted as typical of the late Neogene anastomosing (e.g., Widera, 2013b; Widera et al., 2019) or anastomosing-to-meandering transitional fluvial system (Zieliński and Widera, 2020).

The interpretation of the remaining multi-coloured deposits of the Wielkopolska Member seems obvious (Fig. 5). They represent extra-channel (overbank) fine-grained deposits of this late Neogene fluvial system (e.g., Widera et al., 2021a, b and other references therein). This is consistent with the fluvial hypothesis of the Wielkopolska Member proposed by Badura and Przybylski (2004), and Piwocki et al. (2004). These sediments, accumulating on the floodplains, were then subjected to soil processes. Therefore, their colour diversity depends on the hydrological (redox) conditions prevailing during and after deposition in the inter-flood periods. Sedimentary facies with red, orange and yellow colours are relatively enriched in hematite, goethite or jarosite, while blue-green ones are depleted in these minerals but may contain pyrite, anatase, green 'illite' and traces of organic matter (Duczmal-Czernikiewicz, 2013; Klęsk et al., 2022). These coloured minerals can locally be masked by organic matter, which causes the deposit to appear grey or even black (Klęsk et al., 2023). This interpretation is consistent with that of Piwocki et al. (2004).

Finally, the multi-coloured layers (bands) should lie almost horizontally. However, in most cases in the Polish Lowlands, they are disturbed, i.e., folded at various scales, as a result of compaction and/or glaciotectonics (Fig. 5). The beginning of Wielkopolska Member accumulation (i.e., the end of the Grey Clay Member deposition) is dated at ~13.8 Ma (Widera et al., 2021a). However, the time when accumulation of this lithostratigraphic unit ceased is more loosely estimated as the earliest Early Pliocene, i.e., around 5 Ma (Sadowska, 1977; Troć and Sadowska, 2006). This large uncertainty results from Pleistocene erosion by successive Scandinavian ice sheets and their meltwaters.

DISCUSSION

DEPOSITIONAL ENVIRONMENTS

Based on the results of sedimentological, macropetrographic, palynological and geochemical studies, it is possible to reconstruct the late Neogene depositional environments in the Polish Lowlands and provide their modern analogues (Fig. 6). The MPLS-1 (lower Grey Clay Member) started to form during the last peak of the Middle Miocene Climatic Optimum (MMCO, ~15.1–15 Ma) and continued after this when the climate began to cool slightly (Kasiński and Słodkowska, 2016; Słodkowska

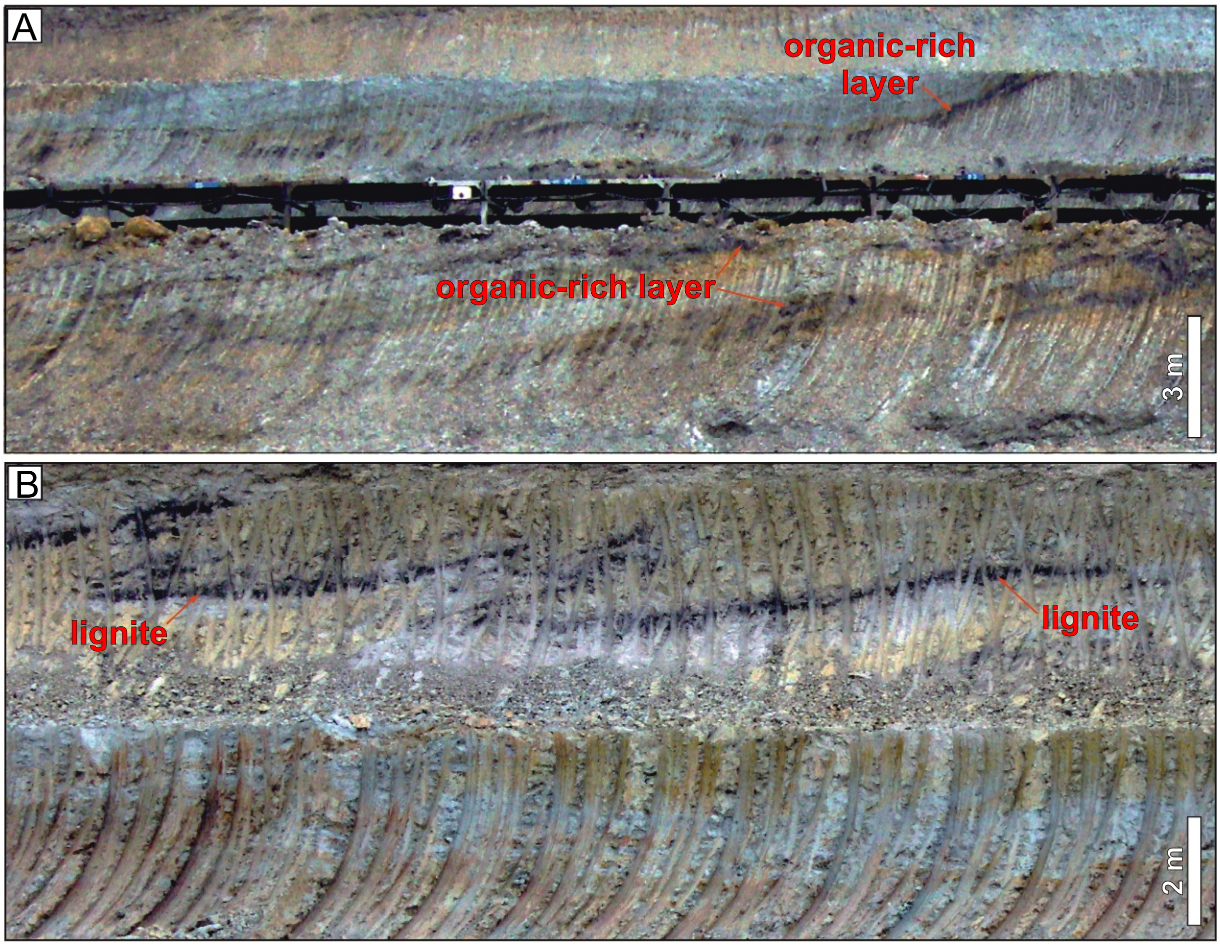

Fig. 5. Examples of the stratigraphic architecture of the multi-coloured clays of the dominant, upper part of the Poznań Clays (Wielkopolska Member) in the Kazimierz N lignite opencast

A – note the slight undulations of the multi-coloured layers caused by uneven compaction; **B** – note the glaciotectonically folded layer of lignite and surrounding fine-grained deposits; in both examples, note that the colours change vertically and horizontally frequently

and Kasiński, 2016; Słodkowska and Widera, 2021, 2022; Worobiec et al., 2021, 2022 and other references therein). In favourable climatic (mean annual temperature, 15.7–20.5°C; mean annual precipitation, 1300–1500 mm) and tectonic (prolonged slow subsidence) conditions in the wet swamp forests dominated by *Taxodium/Glyptostrobus–Nyssa*, peat seams up to 40 m thick accumulated. Currently, similar environmental conditions, in terms of climate and plant communities, prevail in south-east China and south-east USA (Fig. 6A–C; e.g., Christensen, 2000; Richardson, 2003; Utescher et al., 2009).

Around 14.3 Ma, the area of the Polish Lowlands was subject to accelerated regional subsidence, resulting from tectonic movements of the Alpine-Carpathian orogen, which ended peat growth, and its uneven compaction began. In the lakes, deposition of clays and redeposited organic matter (including xylites) from the eroded roof layers of the MPLS-1 took place: hence, the grey to black colour of these deposits (Widera, 2007). Such lakes, where mineral deposition is accompanied by the accumulation of organic matter, occur quite commonly in various climatic zones, for example, on the Rhine–Meuse delta (Bos et al., 2009). However, the closest in terms of climate are the swamp lakes in Everglades National Park in Florida, south-east USA (Fig. 6D; e.g., Christensen, 2000).

Sudden climatic changes in the foreland of the Alpine-Carpathian orogen occurred at ~13.8 Ma when the mean annual temperature dropped by as much as 7°C (Peryt, 2006). At that time, the Badenian Salinity Crisis began in the Carpathian Foredeep, which has been precisely dated radiometrically by de Leeuw et al. (2010) and Bukowski et al. (2018): see above. Then, the depositional environments in the Polish Lowlands also changed rapidly. Under conditions of progressive cooling and climate seasonality, the multi-coloured sediments of the Wielkopolska Member accumulated in a fluvial environment (e.g., Widera et al., 2021a, b). Nowadays, similar conditions prevail in SE Australia (e.g., Fagan and Nanson, 2004; Page et al., 2009; Kemp and Pietsch, 2024), especially in the Murray-Darling Basin, for example, in the Darling River (Fig. 6E). This is a river with a suspended-load (mainly mud) and is laterally stable, as was the case with the upper Neogene rivers of the Polish Lowlands. Additionally, the Darling River floods occur every few decades, which results in a short-term anastomosing channel pattern. In long-term inter-flood periods, the overbank sedi-

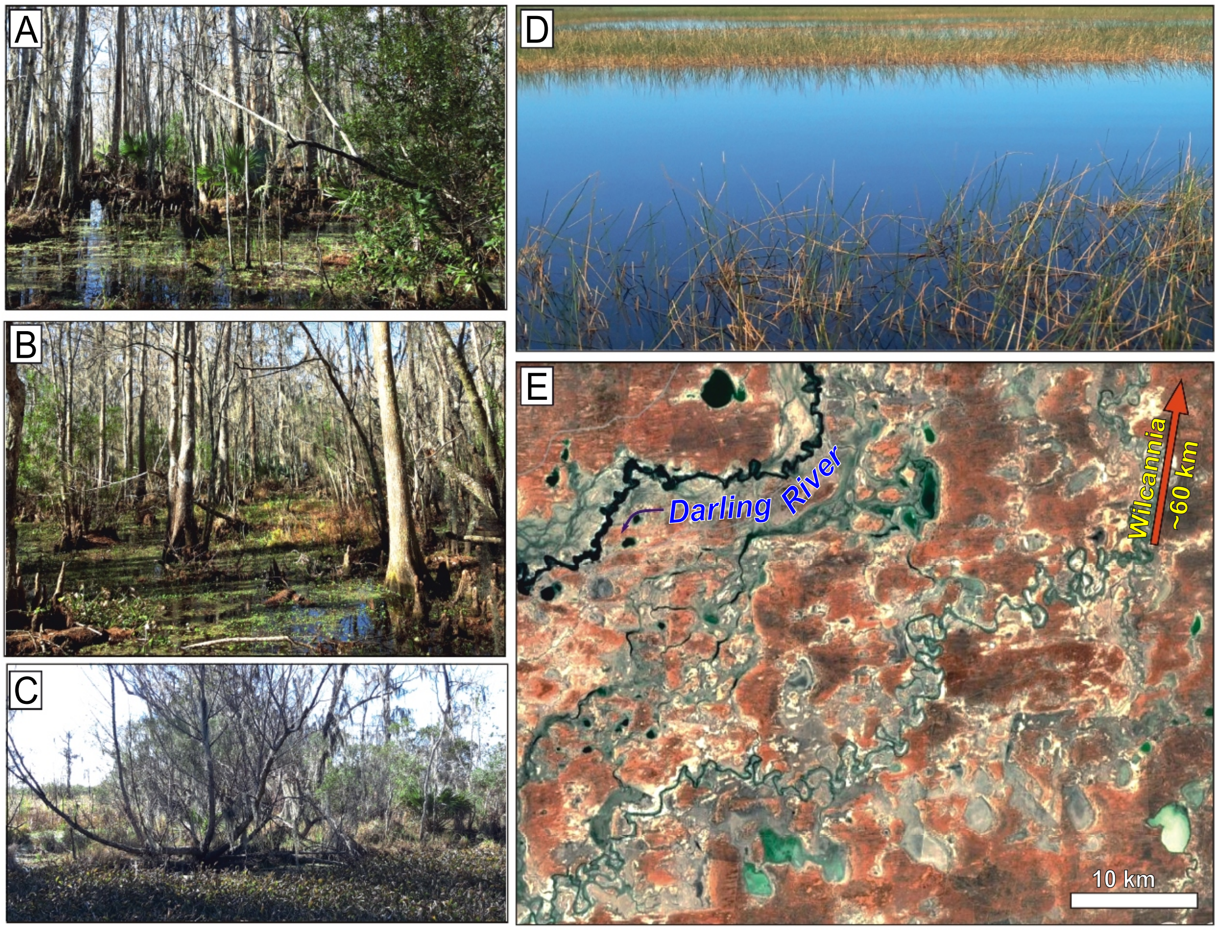

Fig. 6. Modern analogues of the upper Neogene depositional environments prevailing during the accumulation of the Poznań Formation in central Poland

A–C – wet forest swamp (A, B) and bush moor (C) with woody and herbaceous vegetation in the Bayou Sauvage National Wildlife Refuge, the Mississippi River Delta region near New Orleans in south-central Louisiana, USA; **D** – fen, open water with herbaceous vegetation in the shallow parts (<2 m) and mineral accumulation in the deeper parts (>2 m) of the lake, Everglades National Park near Miami in Florida, USA (the photographs A–D from L. Chomiak); **E** – the Darling River near Wilcannia in NW New South Wales, Australia (an aerial photograph from Google Earth)

ments are subjected to soil weathering processes. Thus, most of the fine-grained sediments above the groundwater table are yellow to red in colour (cf. Figs. 5 and 6E).

SEDIMENT COLOUR AS A STRATIGRAPHIC CRITERION

In the case of the Poznań Clays, sediment colour should not be used as a stratigraphic criterion. This concerns intermittently only the grey clays containing xylites (Grey Clay Member) among which, in the Kazimierz N opencast, a clay lens up to 1.8 m thick, light grey and yellow in colour was found (Widera, 2007: plate VE; see also Fig. 3C). This is a record of the periodic elevation of lacustrine sediments above the groundwater level and their oxidation. By contrast, with the green and flame-coloured clays, their colour does not depend at all on their position in the stratigraphic section (cf. Figs. 3C and 5).

In the Grey Clay Member, green to flame-coloured clay occurs extremely rarely, as observed from thousands of borehole profiles (e.g., Wagner, 1982; Górniak et al., 2001; Piwocki et al., 2004; Widera, 2021 and other references therein) and direct field observations including the Konin lignite opencasts (Klęsk et al., 2023; Wachocki et al., 2025). For example, based on borehole information, Wagner (1982) described seven layers of flame-coloured clays within the green clays of the Wrocław area, while Górniak et al. (2001) distinguished only three such layers in the Konin region. In reality, the colour diversity is much greater, as shown by recent detailed field research in the Jóźwin IIB lignite opencast. There, along a 4.7 m long section, 14 layers of different colours and shades were distinguished (Klęsk et al., 2023: fig. 2). Within these green and flame-coloured clays, there are almost always lenses/beds of clays with colours ranging from grey to black (see Fig. 5).

Finally, it is necessary to consider the situation in which the Poznań Clays underwent minor and major erosion. To simplify the reasoning, we have adopted a hypothetical section (e.g., a borehole profile or a vertical exposure) subjected to post-depositional erosion of very different magnitudes (Fig. 7). In the first case, it is likely that almost the entire sedimentary section is present. Thus, the age of these multi-coloured deposits can be estimated as from the late Middle Miocene to the earliest Early Pliocene (cf. Figs. 2 and 7A). In the second case, with deep erosion, it might be wrongly assumed that a complete, condensed

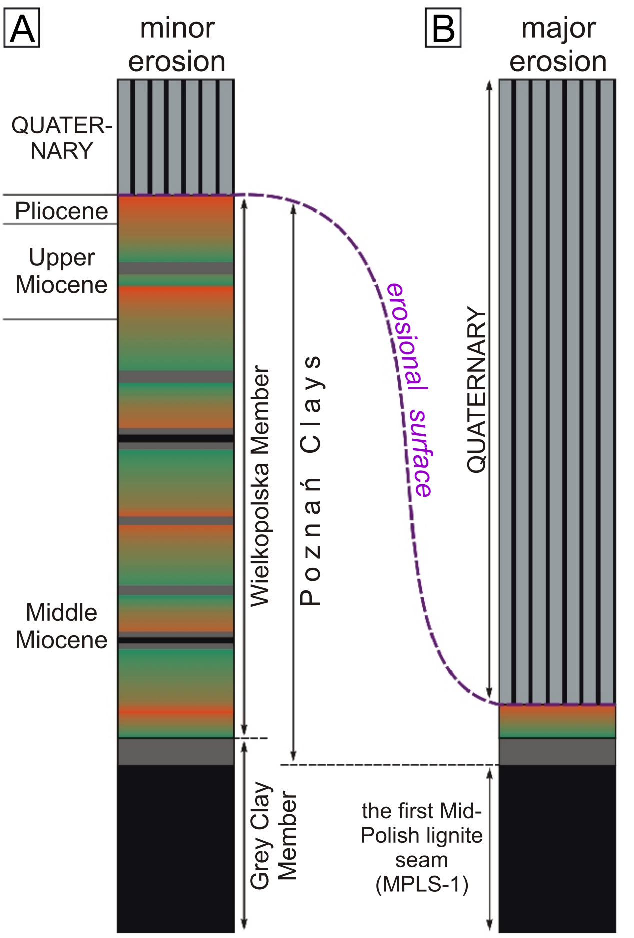

Fig. 7. Colour of clay sediment as a misleading criterion in the lithostratigraphy of the upper Neogene in the Polish Lowlands

A – note that almost the entire section (numerous multi-coloured layers) of the Poznań Clays is preserved – minor erosion; **B** – note that only the lowest section (a single multi-coloured layer) of the Poznań Clays is preserved, because of major erosion

section (i.e., grey-green-flame-coloured sequence) of the Poznań Clays has been preserved (Fig. 7B). Such a situation occurs very often in the Polish Lowlands and may lead to inappropriate lithostratigraphic correlation, as well as the incorrect genetic and age interpretation of the strata in question.

However, estimating the magnitude of erosion based on borehole data is often difficult, and it is easier to do this in large field exposures, e.g., in lignite or clay opencasts. Therefore, in such a situation, palynological data from the uppermost layers of the Poznań Clays can be very useful (e.g., Sadowska, 1977; Piwocki and Ziembińska-Tworzydło, 1997; Troć and Sadowska, 2006; Kasiński and Słodkowska, 2024 and other references therein). These allow us to determine which part of the Middle-Upper Miocene or the lowest Pliocene the samples examined represent.

CONCLUSIONS

Across a significant part of the Polish Lowlands, the youngest strata are multi-coloured fine-grained deposits of late Neogene age, which are called the Poznań Clays or the Poznań Formation. The first of these is a lithological unit of historical value, while the second one is a lithostratigraphic unit; hence, they cannot be used interchangeably. The Poznań Clays have a lithological justification because they include clayey deposits that are younger than the first Mid-Polish lignite seam (MPLS-1) and older than the glaciogenic Quaternary. The Poznań Formation also contains the MPLS-1 in the older, current lithostratigraphic scheme. By contrast, in the latest lithostratigraphic scheme proposed, its scope does not cover either the MPLS-1 or the lowest layers (so-called grey clays) of the Poznań Clays.

In the older scheme, the Poznań Formation is genetically divided into the lower Grey Clay Member and the upper Wielkopolska Member. The first member contains the MPLS-1 with grey clays at the top, representing a changing depositional system from swamp to lacustrine. The second member includes the so-called green and flame-coloured clays, among which there are palaeochannels and palaeosol horizons with thin lignite layers. Thus, the multi-coloured clay deposits of the Wielkopolska Member represent a fluvial depositional system.

The colour of the deposits in question shows frequent changes vertically and horizontally from black through grey, blue and green to yellow, orange and red. This reflects syn- and post-depositional redox conditions, including the content of organic matter. Therefore, in the case of the upper Neogene clay deposits in the Polish Lowlands, the use of colour as a stratigraphic criterion should be abandoned.

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