

Sieniawa Lignite Mine – extraordinary history, geology and mining achievements during the last decade

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Abstract

In the Lubusz region (western Poland), lignite was already mined in the first half of the 19th century. German exploitation of the lignite proceeded on an industrial scale and continued until the end of World War II. After the war, Poland took up excavations in this area, but exclusively at the Sieniawa Lignite Mine (SLM). This mine, the smallest in Poland, was state-owned for over half a century; since 2002 it has been a private company. Annual lignite production at SLM rarely exceeded 0.1–0.2 million tonnes (Mt), although, in recent years, it has increased significantly, reaching a record level of over 1 Mt. These mining achievements are particularly impressive within the context of the highly complex geological structure of the study area. For over 150 years, SLM has been exploiting one of the most glaciotectionically disturbed lignite seams in the world, first underground and later in opencast. This lignite belongs to the 2nd Lusatian group of seams, is of late Early–early Middle Miocene age, having formed under the conditions of the Miocene Climatic Optimum. The wetland vegetation (swamp forests and shrub bogs) in the warm, near-subtropical climate produced large amounts of peat, which ultimately led to lignite formation. Detritic lignite dominates (followed by xylodetritic lignite) and is characteristically weathered in its upper part, containing numerous traces of wildfires. Finally, despite the energy transformation, SLM has a chance to continue operating for at least several more decades, this being the longest amongst all Polish lignite mines.

Keywords: Mining history, lignite usage, mining climax, complex geology, glaciotectionics, Miocene, western Poland

1. Introduction

The Sieniawa Lignite Mine (SLM) is the smallest mine in Poland, although it is the most interesting in terms of mining and geology. Geographically, SLM is located in western Poland, near the village of Sieniawa. In the last decade, lignite was intensively excavated to the north of Sieniawa, and pro-

gressed towards the village of Wielowieś by the year 2025 (Fig. 1).

SLM has played a symbolic role in the Polish energy system, but an important one in terms of local heating and agriculture, especially horticulture. However, its role in electricity production has become unexpectedly significant over recent years, through the sale of lignite to the power plant near

Konin in central Poland (Frydrychowicz et al., 2024; Widera et al., 2024a, b; Kasztelewicz et al., 2025; Naworyta & Urbański, 2025). It is worth mentioning here that, in relation to other working mines such as Bełchatów, Turów and Konin, SLM has never had a lignite-fired power plant in its > 150-year history.

The aim of the present paper is to introduce a wide range of readers to this extraordinary mine in the vicinity of Sieniawa, western Poland. This will be achieved by: 1) briefly discussing its history, including lignite mining and lignite usage; 2) characterising the complex geological structure in the study area; and 3) presenting the effects of the latest field research and preliminary results of palynological analysis in part of the currently exploited lignite deposit.

2. Material and methods

Fieldwork was first conducted at the Sieniawa opencast mine in September 2015 (saddle VIII), and later in October 2025 (saddle XIII) (see Fig. 1). However, the research results and data obtained during the last visit to SLM are presented mainly in the present paper. The historical overview of lignite mining in the Lubusz region, including the area around Sieniawa, was prepared on the basis of information obtained from literature sources (e.g., Ciuk, 1994; Bik, 2006, 2014; Zdanowicz, 2010; Gontaszewska, 2015; Greinert, 2015; Gontaszewska-Piekarz, 2021; and references therein). Cross sections A–B and C–D were prepared based on data obtained from the SLM geological archives.

During fieldwork in October 2025, the existing small opencast mine operating on saddle XIII was visited. At that time, a lignite wall with an S–N orientation, ~40 m wide and 5–8 m in height, was subjected to more detailed examination (see Fig. 1). First, field sketches and photographs of the

strata exposed were taken. The levels exposed are mainly of Neogene, but in part also of Quaternary age. Subsequently, a sedimentological section was prepared, distinguishing lignite lithotypes and siliciclastic facies using an appropriate codification (Table 1). Finally, 43 samples were taken for laboratory analyses and examined for ash yield (burned at 815°C) at the Institute of Geology, Adam Mickiewicz University, Poznań, Poland.

The siliciclastics studied were interpreted using well-known facies analysis (e.g., Miall, 1977; Zieliński, 2014; and references therein), while the characterisation and reconstruction of the initial mire/

Table 1. Codification of lignite lithotypes after Widera (2021) and siliciclastic facies after Widera et al. (2019).

Lignite lithotypes	
code	description
DLm(fo)	massive detritic lignite, folded
DLh(fo)	horizontally stratified detritic lignite, folded
XDLM(fo)	massive xylodetritic lignite, folded
WDLh(fo)	horizontally stratified weathered detritic lignite, folded
Siliciclastic facies	
code	description
Ym(fo)	massive clay, folded
MCh(fo)	horizontally stratified coaly mud, folded

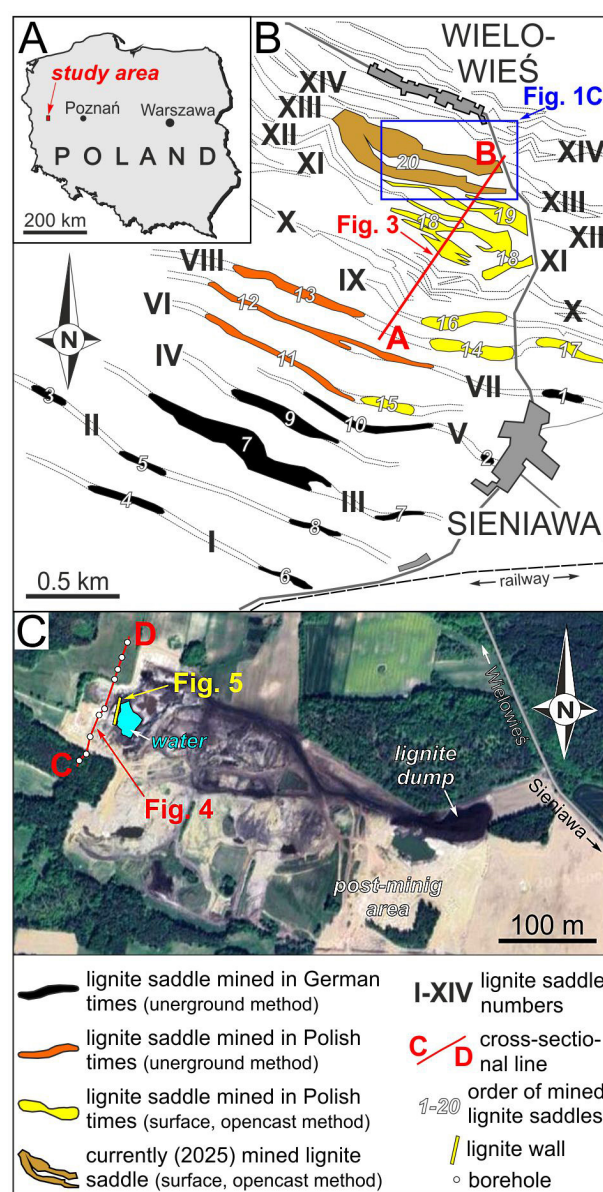


Fig. 1. Location maps. A – Study area; B – Lignite saddles mined in the vicinity of Sieniawa (based on SLM data); C – Lignite saddle XIII mined in 2025 (based on Google Maps).

swamp subenvironments were done using the pioneering works of Teichmüller (1958, 1989). For the purposes of the present study, eight samples (S1, S5, S12, S18, S26, S36, S41 and S43) were analysed for palynological content at the W. Szafer Institute of Botany PAS, Kraków. Standard methods of palynological maceration were used (Moore et al., 1991). It turned out possible to identify the most typical representatives of flora from the Lower/Middle Miocene transition and to characterise the climate at that time (Table 2). More information on the palynological analytical procedure and Miocene vegetation may be found in Worobiec (2009), Kasiński & Słodkowska (2016), Worobiec et al. (2021, 2022, 2025), and references therein.

3. Research results

3.1. Mining history in brief

3.1.1. German period

This time period covers the years 1853–1945. Mining in the Sieniawa area began in 1853, when the Imperial Prussian Mining Office granted a licence for lignite exploitation in the ‘Emiliensglück’ mine. In actual fact, lignite mining did not commence until 1872 (Zdanowicz, 2010). The Sieniawa mine, operating under the name of ‘Vereinigte Emiliensglück’ from 1898 onwards, was initially owned by the von Bockelberg family and later, from 1918 onwards, it belonged to the ‘Anhaltische Kohlenwerke AG’ of Halle in present-day eastern Germany. In those days, mining was conducted underground in saddles I–IV (see Fig. 1C). Prior to 1939, maximum lignite production occasionally reached 0.08 Mt *per annum*, but, during World War II, the Sieniawa mine was almost completely destroyed (Gontaszewska, 2015; Greinert, 2015).

3.1.2. Polish period

The Polish history of the Sieniawa mine did not begin until 1950, when it was rebuilt after having suffered war damage (Ciuk, 1994; Bik, 2006, 2014). Lignite exploitation commenced in the same year, and has continued uninterrupted to this day. In the years 1950–1997, underground mining was still carried out. Lignite excavation, loading and underground transportation were initially carried out entirely by hand (Greinert, 2015). Later, until 1960, horses were used to pull carts, to be followed by electric locomotives. Lignite from the shaft was transported by cable car to the sorting and loading facility in Sieniawa, where it was finally loaded onto railway wag-

ons and trucks. The cable car was decommissioned in 1986 (Zdanowicz, 2010). Fortunately, some traces of the old mining technology have been preserved to this day (Fig. 2). In the years 1979–1997, simultaneous with underground mining, SLM exploited

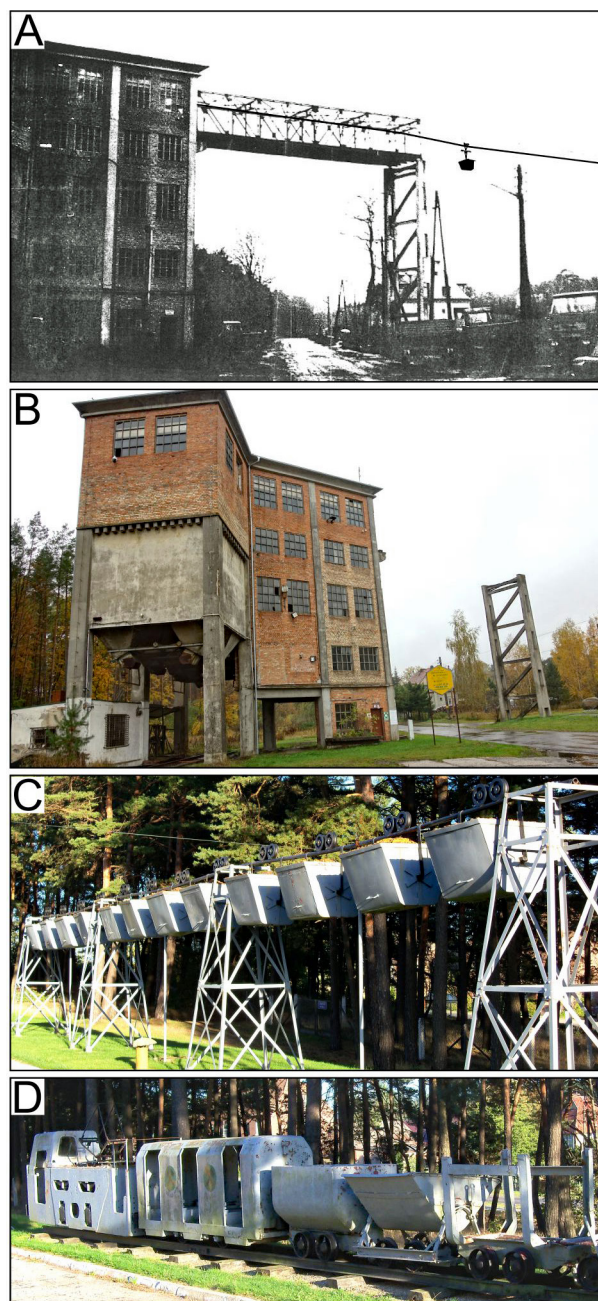


Fig. 2. Preserved traces of old mining technology in the village of Sieniawa. **A** – Lignite loading/sorting facility and cable car used until 1986 (see <https://klimatylagowskie.pl/index.php?pg=start17>); **B** – Same view as in Figure 2A in October 2025; **C, D** – Renovated cable car and underground train located in front of the SLM management in Sieniawa, September 2015 (photographs 2B–D by authors).

lignite using the opencast (surface) method, and later become an entirely opencast operation.

In June 2002, SLM turned private, as a limited liability company, abbreviated SLM Ltd. The opencast exploitation of lignite began on saddle IX – west (no. 15 in Fig. 1B; Zdanowicz, 2010; Galiniak et al., 2011, 2015), followed by saddle VIII – east (no. 17 in Fig. 1B). In these two opencast mines, lignite from the Sieniawa 1 deposit (Kozula, 2002) was exploited. In 2018, lignite mining from the Sieniawa 2 lignite deposit (Gruszecki, 2010) started, i.e. on saddles XI–XIII (nos. 18–20 in Fig. 1B). The production volume and directions of use of the lignite from SLM is discussed below (Subsection 3.4).

3.2. Geomorphology and geology

3.2.1. Geomorphological sketch

Based on the physical and geographical division of Poland outlined by Kondracki (2009), the SLM territory belongs to the Lubusz Lakeland macroregion and the Łagów Lakeland mesoregion. The latter is a strongly glaciotectionically disturbed hilly moraine plateau. Most of the land surface lies above 120 m a.s.l. and the highest hill is known as Bukowiec, which reaches an elevation of 225.4 m a.s.l. Otherwise, relative heights of the terrain range from a few metres to over 100 m (e.g., Studencki, 2000; Winnicki, 2004).

3.2.2. Geological setting

General information. In the study area, the sub-Cenozoic basement is composed primarily of Creta-

ceous-aged marls and limestones. These rocks are found at average levels of 180–160 m b.s.l., with the possible occurrence of grabens and horsts (Studencki, 2000). Thus, the surroundings of Sieniawa belong to the Szczecin Segment of the Szczecin–Miechów Synclinorium (Żelaźniewicz et al., 2011). In sharp contrast to most Polish lignite deposits, the Sieniawa deposit was completely deformed by the Scandinavian ice sheets during the Pleistocene. Therefore, the lignite beds studied are genetically classified as glaciotectionic types, and fold and thrust/sliced subtypes (Ciuk, 1968; Kasiński & Piwocki, 2002; Widera, 2016).

Comparable to most Polish Lowlands, the Cenozoic depositional history in this area is characterised by relatively marked stratigraphical gaps, i.e. in the Paleocene–Eocene, upper Oligocene and Lower Pliocene–Lower Pleistocene. Hence, the oldest Cenozoic strata are mainly marine glauconitic sands, with terrestrial coaly muds and thin lenses of lignite of early Oligocene age. They form a continuous layer with a thickness of 40–80 m and are, generally, not glaciotectionically deformed (Studencki, 2000; Widera, 2021).

Due to glaciotectionics, and in sharp contrast to the Paleogene, Neogene sediments range in thickness between a few metres and > 300 m (Kozula, 2002; Winnicki, 2004). Their base is dominated by sandy sediments interbedded with gravels, muds and the 3rd Ścinawa lignite seam. Higher in the succession, the sediment grains become finer and ‘coaly mud’ appears with the 2nd Lusatian lignite seam (LLS-2; Piwocki & Ziemińska-Tworzydło, 1997; Kasiński et al., 2019; Widera, 2021), this being

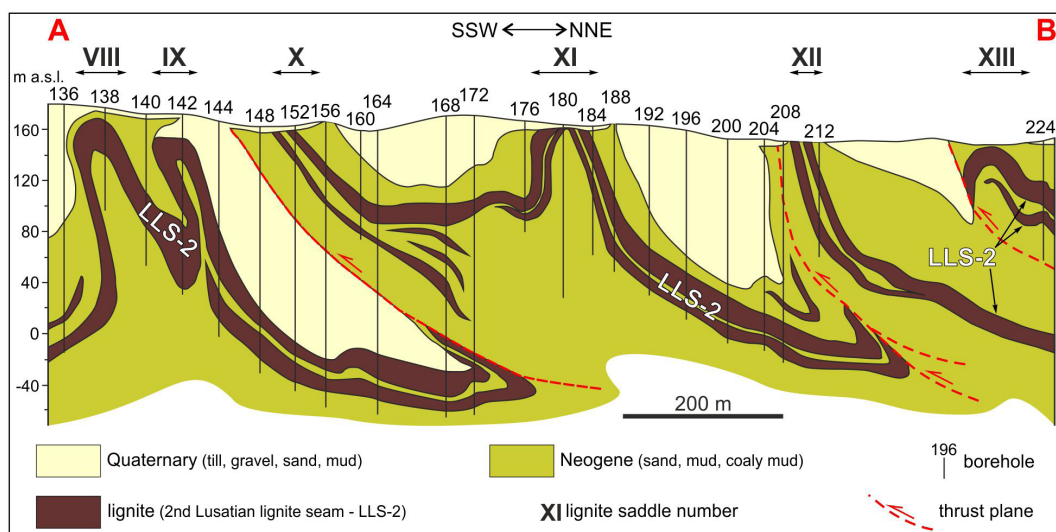


Fig. 3. Geological cross section A–B through the lignite saddles VIII–XIII (based on Winnicki, 2004; Kot & Widera, 2018; Kasiński et al., 2019). Note the deeply disturbed sediments including lignite seam; for location cross sectional line A–B see Figure 1B.

the subject of exploitation by SLM. The sediments are glaciotectionally arranged in folds and thrusts/nappes, the higher anticlinal parts of which are called saddles (compare Figs. 1 and 3). The depth of these deformations even exceeds 200–250 m (Ciuk, 1968; Winnicki, 2004; Gontaszewska-Piekarz, 2021).

The Neogene is mainly capped by glaciogenic Quaternary, consisting of tills, gravels, sands and muds (Kozula, 2002; Gruszecki, 2010), all subjected to glaciotectional deformation; hence their thickness is very diverse and ranges from 0 to ~200 m along

the cross sectional line A–B (Fig. 3). For more data on macro- and mesoscale glaciotectional deformation of both Quaternary and Neogene sediments at SLM outcrops, reference is made to Kot and Widera (2018).

Field research. *Description:* At the end of 2025, mining activities in SLM were carried out on saddle XIII (see Fig. 1B, 1C). The nearest geological cross section (C–D) is almost parallel to the lignite wall (Fig. 4). Thus, it quite accurately reflects what was seen in the field, i.e., in the opencast mine and its

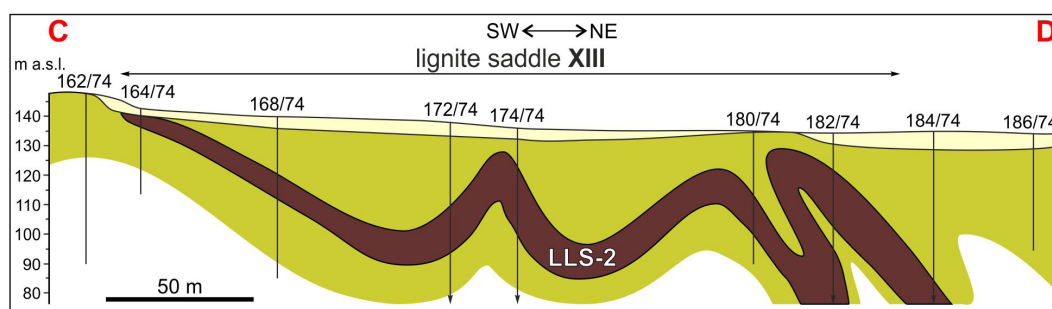


Fig. 4. Geological cross section C–D through the lignite saddles XIII (based on SLM data). For location cross sectional line C–D see Figure 1C and for explanations see Figure 3.

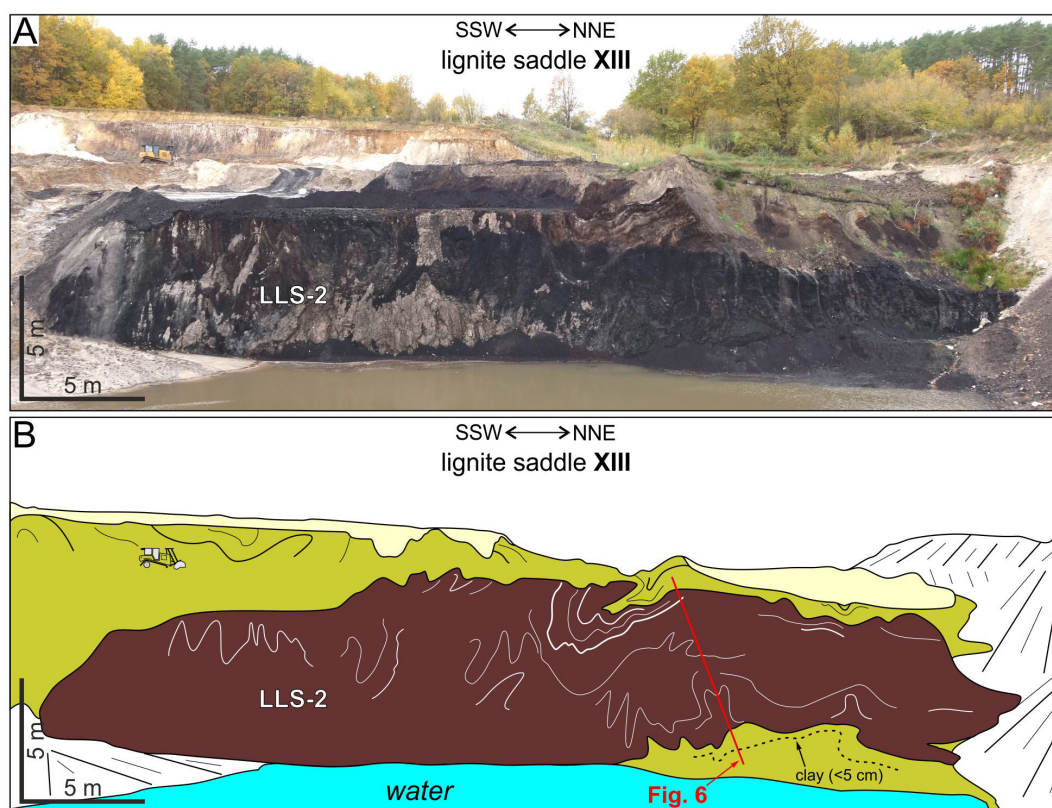


Fig. 5. Lignite wall and accompanying siliciclastics exposed in October 2025. **A** – Broad westward view of lignite open-pit mine; **B** – Corresponding line-drawing of what is seen in Figure 5A. Note the complex internal structure of the lignite fold (anticline) and the location of the section examined in detail in Figure 6; for location of lignite wall see Figure 1C and for explanations see Figure 3.

surroundings. It should be noted that SLM only exploits lignite to groundwater level (Fig. 5). Therefore, part of the fold exposed in the field approximately corresponds to what is shown between boreholes 180/74 and 182/74, down to a depth of 120 m a.s.l. (compare Figs. 4 and 5).

Interpretation: The visible part of the lignite seam represents a standing, and slightly asymmetrical, fold on a macroscale. In contrast, at mesoscale, it is characterised by a very strongly disturbed internal structure, which allows it to be classified as a disharmonic fold (Fig. 5; Davis et al., 2011).

Description: The sedimentary section which was examined in detail is 8 m in length and includes both underlying lignite and overlying lignite deposits, as well as the main lignite seam, i.e. LLS-2. The underburden and overburden consists mainly of coaly mud with an ash yield in the range 64–90 wt%. In contrast, the lignite seam mentioned (with a thickness of 5.6 m) is characterised by ash yield in the range 4–18 wt% and an average of approximately 11.5 wt%. Attention should be paid to the low values of this parameter in samples S18 and S19

($A^d = 4\text{--}5$ wt%), as well as the significantly higher value in sample S12 ($A^d = \sim 15$ wt%) (Fig. 6).

Interpretation: In the samples analysed from LLS-2, there is a clear difference between lignite (samples S8–S40) and non-lignite sediments (samples 1–7 and S41–S43). In the case of this seam, samples S18 and S19 indicate an ombrotrophic mire ($A^d < 5$ wt%), while the remaining ones document a rheotrophic mire ($A^d > 5$ wt%) (e.g., Opluštil et al., 2024). On the other hand, the abrupt increase in ash yield in sample S12, in relation to the surrounding lignite samples, can be interpreted as a result of flooding in the mire area (e.g., Chomiak, 2020).

Description: In the lower part of the lignite seam (LLS-2), two lithotypes were distinguished. The first is a massive and folded detritic lignite (DLm(fo)), while the second is also massive and folded but a xylo-detritic lignite (XDLM(fo)). The upper part of LLS-2 includes alternating detritic (black) and weathered detritic (light brown) lignites with an initially horizontal, folded structure (DLh(fo) and WDLh(fo), respectively). It should be emphasised that, in the more weathered layers (but not only

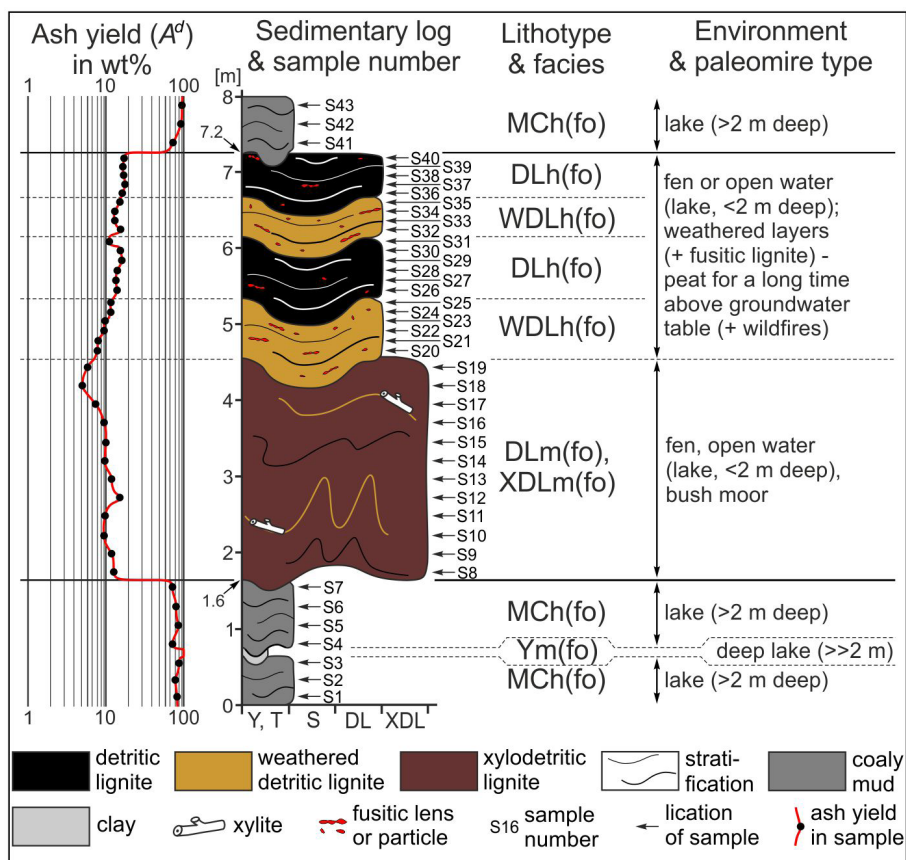


Fig. 6. Sedimentological log, ash yield, siliciclastic facies and lignite lithotypes with palaeoenvironmental interpretation along the section studied in detail. Note the folded structure of all sediments, as well as the presence of xylites and fusitic fragments within the lignite seam; for location of examined section see Figure 5B; for explanations of facies and lithotype codes see Table 1.

those layers), there are lenses, occasionally laminae, and single particles of fusitic lignite, i.e. palaeocharcoal. The accompanying Neogene siliciclastics are mainly horizontally laminated and folded coaly (carbonaceous) muds (MCh(fo)). A thin layer of massive and folded clay (Ym(fo)), was also macroscopically distinguished in the field, reaching a thickness of up to 5 cm (Fig. 6).

Interpretation: Based on the composition of the lignite lithotype, it is possible to determine the initial mire type approximately. Thus, the dominant detritic lignite association (DL) formed in mire sub-environments related to a fen, open water (lake) or a treeless marsh (sea coast), by the following vegetation: aquatic plants, sedges and reeds (Kolcon & Sachsenhofer, 1999; Ticleanu et al., 1999; Widera, 2021; and references therein). According to these researchers, the xylodetritic lignite association (DXL) is attributed to the bush moor. This mire type is also referred to as the Myricaceae–Cyrillaceae swamp (Teichmüller, 1958, 1989). Obviously, the occurrence of the fusitic lignite in SLM is evidence of natural fires (i.e. wildfires) in the mire area and/or within the peat seam (Kwiecińska & Wagner, 1997; Markič & Sachsenhofer, 1997). Less (i.e. massive) or more (i.e. horizontal) stratified lignite structures either formed syn-depositionally or post-depositionally, as a result of hydrological changes in the Neogene

mires. In contrast, the folded (and thrust/napped) structure certainly formed post-depositionally, as a result of Pleistocene deforming processes (Ciuk, 1968; Kasiński & Piwocki, 2002; Widera, 2016; Kot & Widera, 2018). The interpreted mineral and organic-mineral sediments from Ym to MCh (compare Table 1 and Fig. 6) were deposited in the lake at deeper (>>2m deep) to shallower zones (>2 m deep), respectively, i.e. outside the reach of reed/sedge-like vegetation (e.g., Kwiecińska & Wagner, 1997; Diessel et al., 2000; Zieliński, 2014; Widera, 2021; and references therein).

3.3. Preliminary palynological analysis

All samples yielded well-preserved palynomorphs, including pollen grains and spores of plants. Conifers are represented by Pinaceae (mainly *Pinus*), Cupressaceae (*Taxodium*/*Glyptostrobus* and *Sequoia*) and *Sciadopitys*. Angiosperms are more diverse, including such characteristic Miocene taxa as *Tricolporopollenites pseudocingulum*, *Quercoidites henricii* and *Edmundipollis*. Pollen grains of Ericaceae, Engelhardioideae, Myricaceae, *Nyssa*, *Ilex*, *Symplocos*, *Liquidambar* and Cyrillaceae/Clethraceae are also present (Table 2) along with many others. In addition, some moss spores (*Sphagnum*) and ferns, as well as fun-

Table 2. The main elements of palynological spectra from the Sieniawa profile and their indication. For location of samples analysed see Figures 5B and 6.

Samples studied	The most frequent and characteristic elements of the palynomorph assemblage (botanical affinity in brackets)	Environment and vegetation
S43 S41	<i>Pinuspollenites</i> (<i>Pinus</i>), <i>Myricipites</i> (Myricaceae), <i>Sciadopityspollenites</i> (<i>Sciadopitys</i>), <i>Cathayapollis</i> (<i>Cathaya</i>), <i>Ericipites</i> (Ericaceae), <i>Ilexpollenites</i> (<i>Ilex</i>), <i>Tricolporopollenites pseudocingulum</i> (Fagaceae?, Styracaceae?), <i>Momipites</i> (Engelhardioideae), <i>Periporopollenites</i> (<i>Liquidambar</i>), freshwater algae	freshwater environment, shrub bog, mixed mesophytic forest, riparian forest
S36 S26	<i>Pinuspollenites</i> (<i>Pinus</i>), <i>Tricolporopollenites pseudocingulum</i> (Fagaceae?, Styracaceae?), <i>Quercoidites henricii</i> (<i>Quercus</i> , evergreen), <i>Ericipites</i> (Ericaceae), <i>Myricipites</i> (Myricaceae), <i>Edmundipollis</i> (Cornaceae, Mastixiaceae, Araliaceae), <i>Sciadopityspollenites</i> (<i>Sciadopitys</i>), <i>Ilexpollenites</i> (<i>Ilex</i>), <i>Nyssapollenites</i> (<i>Nyssa</i>), <i>Neogenisporis</i> (e.g., <i>Gleicheniaceae</i>) charcoal particles in S26	shrub bog, mixed mesophytic forest, wildfires
S18 S12	<i>Inaperturopollenites</i> (<i>Taxodium</i> , <i>Glyptostrobus</i>), <i>Pinuspollenites</i> (<i>Pinus</i>), <i>Nyssapollenites</i> (<i>Nyssa</i>), <i>Sequoiapollenites</i> (e.g., <i>Sequoia</i>), <i>Tricolporopollenites pseudocingulum</i> (Fagaceae?, Styracaceae?), <i>Ericipites</i> (Ericaceae), <i>Quercoidites henricii</i> (<i>Quercus</i> , evergreen), <i>Symplocoipollenites</i> (<i>Symplocos</i>), <i>Momipites</i> (Engelhardioideae), <i>Myricipites</i> (Myricaceae)	swamp forest, mixed mesophytic forest, shrub bog
S5 S1	<i>Pinuspollenites</i> (<i>Pinus</i>), <i>Sequoiapollenites</i> (e.g., <i>Sequoia</i>), <i>Inaperturopollenites</i> (<i>Taxodium</i> , <i>Glyptostrobus</i>), <i>Tricolporopollenites pseudocingulum</i> (Fagaceae?, Styracaceae?), <i>Quercoidites henricii</i> (<i>Quercus</i> , evergreen), <i>Ericipites</i> (Ericaceae), <i>Momipites</i> (Engelhardioideae), <i>Sciadopityspollenites</i> (<i>Sciadopitys</i>), <i>Myricipites</i> (Myricaceae), dinoflagellate cysts (<i>Dinophyceae</i>)	marine influence, swamp forest, mixed mesophytic forest, shrub bog

gal micro-remains, were encountered. The composition of the spore-pollen spectra studied confirms that this lignite belongs to the 2nd Lusatian group of seams (LLS-2).

Samples from the lowermost part of the section (S1 and S5) contain dinoflagellate cysts. These salt-water palynomorphs constitute about 10% of the total spectra, clearly indicating a marine influence. Pollen grains and spores found in this part point to the occurrence of swamp forests (with *Taxodium* and/or *Glyptostrobus* plus *Nyssa*) and, to a lesser extent, shrub bogs with *Ericaceae*, *Myricaceae* other shrubs, and possibly *Pinus*, *Sequoia* and *Sciadopitys* (Table 2). Later (samples S12 and S18), swamp forests may have spread to cover permanently flooded areas, similar to modern swamp forests in the southwestern United States (Barnes, 1991). As water levels dropped, shrub bogs spread (samples S26 and S36), peat may have dried out and wildfires may have occurred. Evidence of the latter is provided by the abundance of (palaeo)charcoal in sample S26. The uppermost part of the section (samples S41 and S43) formed in a freshwater environment, as evidenced by the presence of freshwater algae.

The wetland vegetation documented, inclusive of swamp forests and shrub bogs, produced large amounts of peat, from which the lignite seam (LLS-2) was formed. Less humid places in this area may have been covered with floristically rich mesophytic forests. These forests contained thermophilic plants, such as evergreen oaks and *Symplocos*, indicating a warm, near-subtropical climate.

3.4. Lignite production and utilisation

As mentioned above, during the German period, up to 0.08 Mt of lignite was excavated from SLM *per*

Table 3. Total lignite production at the Sieniawa Lignite Mine (SLM) in the years 2015–2024 (based on data from the Polish Geological Institute and SLM). Compare with Figure 7.

Year	Lignite production [in thousands of tonnes]
2015	73
2016	70
2017	84
2018	111
2019	296
2020	213
2021	359
2022	531
2023	763
2024	1,072

annum. In 1950, when it reopened as a Polish mine after the devastations during World War II, only 8,600 tonnes of lignite were exploited. However, production grew rapidly, reaching ~0.14 Mt in 1958 and ~0.17 Mt in 1973. The next production peaks were recorded in the years 1983 and 1987, at ~0.21 and ~0.22 Mt, respectively. In total, between 1950 and 2001, the state-owned SLM produced ~6.1 Mt of lignite, comprising ~5.0 Mt from underground and ~1.1 Mt from opencast mines (Bik, 2006; Zdanowicz, 2010).

The initial years of SLM as a private company were not easy. In the years 2002–2014, lignite production fluctuated from ~0.014 Mt in 2002 to ~0.17 Mt in 2009 (Galiniak et al., 2011, 2015). During the last decade, SLM also started with a relatively low level of lignite exploitation, i.e. ~0.07 Mt in 2015 and 2016. Surprisingly, since 2016, lignite production has been increasing almost continuously, reaching ~1.072 Mt in 2024 (Fig. 7; Table 3), which was a record for SLM exploitation. These huge amounts of lignite, compared to previous exploitation, were sold mainly for electricity generation at the Pątnów II Power Plant, which is located over 230 km away, near Konin in central Poland (Frydrychowicz et al., 2024; Widera et al., 2024a, b; Kasztelewicz et al., 2025; Naworyta & Urbański, 2025). The remaining lignite was sold to local customers and used for chemical processing. In the years 2002–2024, the privately owned SLM mined ~4.67 Mt of lignite by exclusive opencast mining.

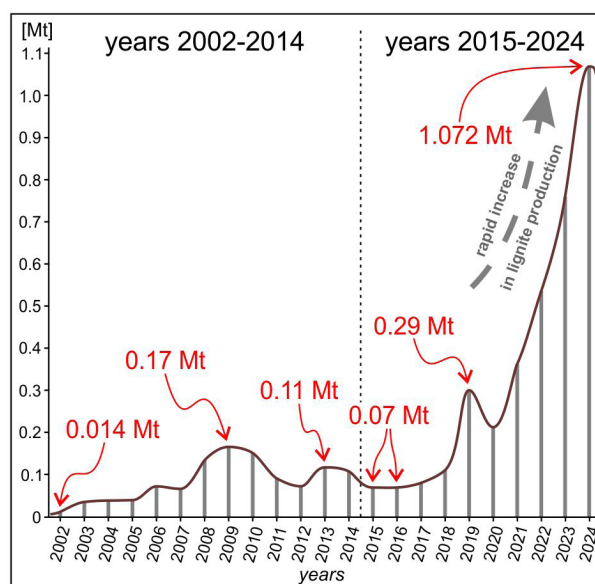


Fig. 7. Amount of lignite exploited in SLM from 2002 to 2024. Note the sudden increase in lignite mining from 2019 onwards (based on data from the Polish Geological Institute and SLM).



Fig. 8. The most famous product of SLM, of lignite origin, awarded with many pro-quality medals.

The basic commercial activity of SLM is quite diverse. It primarily sells lignite to local customers, for heating residential and industrial buildings, greenhouses, etc. This lignite is characterised by good chemical and technological parameters, the best among all lignites mined in Poland: the average net calorific value is 9–10 MJ/kg, ash yield <9 wt% and sulphur content <0.9 wt%. SLM also offers a wide range of Scandinavian stone types, well suited as wonderful decorative material. In addition, SLM is famous for products used in agriculture, especially in horticulture. At this point, it is worth mentioning NEWCOAL and FLORAHUMUS, which are sources of organic carbon, including humic acids. The latter won several prestigious pro-quality awards in several national competitions in 2024 (Fig. 8).

4. Discussion

4.1. Environmental protection

For many years, SLM has been attaching great importance to the reclamation of post-mining areas, mainly directed towards agriculture, forestry and

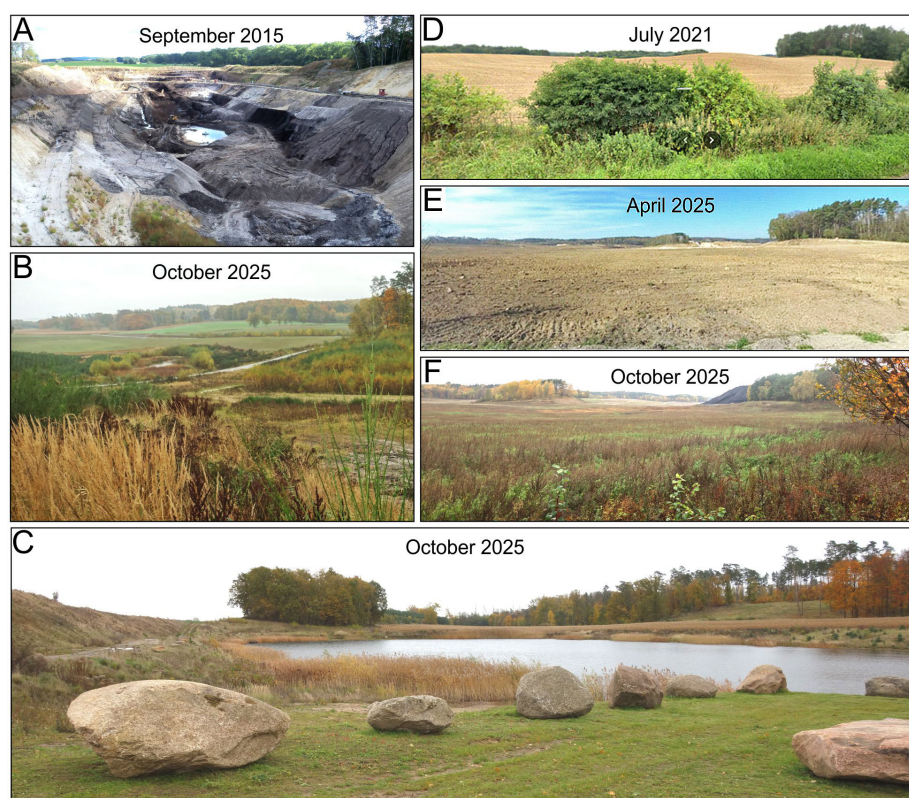


Fig. 9. Selected examples of land reclamation in SLM carried out during the last decade. **A–C** – Saddle VIII east; **D–F** – Saddle XIII west. Lignite extraction in the shown parts of lignite saddles ended at: **A, B** – March 2016, **C** – June 2018, **D, E, F** – September 2024 (photographs 9A–C, F by authors; photographs 9D, E from Google Maps).

water (e.g., Bik, 2006; Zdanowicz, 2010; Galiniak et al., 2011, 2015; Galiniak & Bik 2012; Greinert, 2015). Formerly reclaimed areas, however, are difficult to distinguish from their natural surroundings. Therefore, only opencast mines, where lignite was exploited during the last decade, allow for observing the reclamation process. Good examples of this are saddles VIII and XIII (Fig. 9). It is worth adding, however, that the reclamation of the area after the former underground mining creates problems with its agricultural and forestry use (e.g., Galiniak et al., 2015; Greinert, 2015).

In the case of saddle VIII, mining was completed in 2018. Clean-up and reclamation work began immediately. As a result, plant succession has been growing in the post-mining territory for several years and, in two areas, small lakes have formed (Fig. 9B, C). In the case of saddle XIII, it is possible to monitor the progress of the reclamation of an area that was hilly 3–4 years ago. At the beginning of 2025, following the end of lignite mining, the area was levelled, in relation to the adjacent slopes, and sown with appropriate species of vegetation (Fig. 9D–F). Thus, SLM is considered to be one of the most environmentally friendly mining companies in Poland.

4.2. Future of lignite mining

SLM holds a licence to exploit lignite from the Sieniawa 2 deposit from 2013 to 2063. It once contained lignite reserves of ~17 Mt (Bik, 2014); however, due to environmental conditions, the process of reducing lignite combustion in commercial power plants and individual boilers is underway. In line with this trend, SLM has been working on introducing agricultural products based on lignite to the market, including FLORAHUMUS (Fig. 8), NEWCOAL, fertiliser mixtures and animal feed additives for chickens and pigs. This is exactly where SLM sees its future.

The planned lignite consumption for the above-mentioned lignite-based production will be in the range 0.2–0.3 Mt *per annum*. This will also determine the estimated lignite extraction level until 2060. As soon as the Sieniawa 2 deposit will be exhausted, the mine liquidation process (i.e. at SLM) will be carried out through deposit settlement and final reclamation works.

5. Conclusions

The Sieniawa Lignite Mine (SLM) is the longest-operating mine in Poland. From 1872 to 1997, lignite

was mined underground, and from 1979 onwards, in opencast. Until the end of World War II, SLM was in German hands, and later become Polish. It was originally a state-owned company but from 2002 it has been a private concern.

SLM is a geological phenomenon because it is the sole lignite mine in the world where the deposits are completely glaciotectionally disturbed. Therefore, lignite mining was first carried out underground but is now exclusively done in opencast, from the so-called lignite saddles (anticlines and nappes) down to groundwater level.

The 2nd Lusatian lignite seam (LLS-2), of Early/Middle Miocene age, is exploited at SLM. It comprises folded detritic and xylodetritic lignites, with increasingly thicker interbedded, strongly weathered detritic lignites in the upper part of the seam. Inside these, although of a mostly weathered lithotype, are fusitic fragments, i.e. fossilised charcoal.

Preliminary palynological results indicate that the mined seam (LLS-2) formed under conditions of a warm, near-subtropical climate. The study area was dominated by swamp forests and shrub bogs, although non-wetland locations could be determined from floristically rich mesophytic forests as well. At the current stage of research, it can be stated that the sub-lignite coaly muds were deposited in coastal lakes, while the over-lignite ones accumulated in freshwater lakes.

Traditionally, SLM has been selling lignite for heating purposes and chemically processes it into products which are useful in agriculture; average annual production is up to 0.1 Mt. However, in the years 2019–2024, lignite mining increased dramatically to over 1 Mt, which is related to sales to a distant power plant near Konin in central Poland.

Finally, SLM has been reclaiming post-mining land for many years. Impressive results may be observed, although such were completed only during the last decade. It is worth emphasising that, in the remaining areas formerly occupied by SLM, it is difficult to find any traces of mining activity. Most likely, SLM will continue to exploit lignite at the level of 0.2–0.3 Mt *per annum* until 2060, thus become the longest operation in Poland.

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Authors' contributions

M.W.: conceptualization, methodology, original draft preparation, review, editing, investigation and supervision; A.B. and J.J.: original draft preparation, review, editing, investigation and supervision; E.W.: original draft preparation, review, editing, investigation, palinological analysis and supervision. All authors have read and agreed to the published version of the manuscript.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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