Tectonic and sedimentary deformational structures within the first Mid-Polish lignite seam – Konin Basin, central Poland

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Abstract. This paper focuses on deformational structures seen at macro and mesoscales within the first Mid-Polish lignite seam (MPLS-1) currently exploited by the Konin Lignite Mine. In fact, the majority of examples presented herein come from the Jóźwin IIB and Tomisławice opencasts. The deformations are divided into two groups; they are tectonic and sedimentary ones. The first group includes deformations of the floor, faults, cleats, and seismically-induced structures such as breccia and deformed lamination. The second group covers compactionally-induced deformations of MPLS-1 roof, sedimentary breccia, and slumps. All these deformations are described and then briefly interpreted in this paper. Although in a few cases in the formation of sedimentary deformations, the contribution of the tectonic factor as a trigger mechanism seems obvious. This is supported by the fact that the mentioned lignite seam is mined in the areas of grabens that were tectonically active during the development of the Mid-Miocene mires in the Konin Basin.

1. Introduction

Central Poland is characterised by the presence of a great number of lignite deposits. Currently, lignite extraction in a total amount of 6.8 million tons per year (2018) is carried out in the following three opencasts: Drzewce, Jóźwin IIB, and Tomisławice (Figure 1). Continuous mining activity means that together with moving exploitation mining fronts, new parts of the first Mid-Polish lignite seam (MPLS-1) are continuously uncovered. Thus, siliciclastic deposits under, in, and overlying MPLS-1 are also exposed. Sometimes they are deformed both tectonically and sedimentary, as shown in this paper.

Deformational structures within MPLS-1 are particularly well developed in the Jóźwin IIB and Tomisławice opencasts (Figure 1). Some of them are quite common in most European lignite-bearing areas [1-7] such as deformations of floor and roof including folds, faults, and deformed lamination/stratification. On the contrary, other deformations presented are perfectly developed (cleats, slumps) or are unique (sedimentary breccia, seismically-induced breccia), not only in Poland, but also in lignite opencasts around the world [8, 9].

The main aim of this paper is to show that lignite opencasts, including those from the Konin Basin, can provide a great opportunity to study deformation structures. This will be achieved first by depicting these deformations in photographs and with clear descriptions. Then, their origin will be explained.
2. Outline of geology

The Jóźwin IIB and Tomisławice opencasts, owned by the Konin Lignite Mine, are situated in central Poland (Figure 1). The study area belongs to the marginal zone of the Northwest European Paleogene and Neogene Basin [10]. The mined lignite deposits are located in relatively shallow, fault-bounded tectonic grabens [3]. The Mesozoic bedrock is made up of carbonate rocks of Cretaceous age (Figure 2).

The Cenozoic succession starts with Lower Oligocene glauconitic sands of marine origin in the Tomisławice opencast. In the case of Jóźwin IIB however, the oldest deposits resting on top of the Mesozoic bedrock are sub-lignite fluvial sands with carbonaceous intercalations. They represent the Koźmin Formation of Early to Mid-Miocene age (Figure 2). The Poznań Formation, which is divided into the lower Grey Clays Member and the upper Wielkopolska Member, represents the end of the Neogene in central Poland [11].

The Grey Clays Member is the most lignite-bearing lithostratigraphic unit in the study area. It contains the MPLS-1, which is 6.6–6.9 m thick on average (Figure 2). This lignite seam accumulated in low-lying mires (backswamps) [9, 12, 13] in the middle part of the Mid-Miocene, when the climate
was temperate, humid and wet [11, 14-16]. The overlying Wielkopolska Member is composed of fine-grained deposits, that is, channel-fill sands and/or muds, and overbank muds (Figure 2). They were deposited in an upper Neogene fluvial system, probably an anastomosing river [17, 18]. The Neogene succession in the study area is covered by glaciogenic deposits (tills, gravels, sands, muds) of Quaternary age (Figure 2).

3. Material and methods
The study results presented in this paper were obtained in 2007–2019. During fieldwork, a great number of tectonic and sedimentary deformations was identified, described, measured, and documented photographically in the Jóźwin IIB and Tomisławice opencasts. Some photographs, showing the best and most interesting deformational structures, are included in this paper (Figures 3-9).

The simplified cross-section was constructed on the basis of data from 25 borehole profiles, which came from the geological archive of the Konin Lignite Mine. These boreholes are several dozen metres deep, always pierce the lignite seam (MPLS-1), and occasionally reach the Mesozoic bedrock as in the case of a borehole 52/46 (Figure 2). On the basis of the geological cross-section, the stratigraphy, lithology and architecture of Cenozoic deposits are described. Moreover, deformations of the bottom and roof of MPLS-1 are also characterised herein taking into account both the cross-section and field observations.

4. Results and discussions
The results obtained in this study include the effects of tectonic and sedimentary processes that caused deformation of MPLS-1 and the accompanying clastic sediments. It is worth saying that large-scale glaciotectonic and erosional structures are not the subjects of the research presented herein. Thus, tectonic deformational structures are discussed first, then sedimentary ones.

4.1. Tectonic deformations
4.1.1. Seam floor. The examined MPLS-1 floor, like the floors of another lignite (coal) seams around the world, is strongly deformed. This is clearly visible both in the geological cross-section and in the field. The differences in the position of the seam floor are up to 10–30 m (Figure 2), while those observed in the lignite opencasts are smaller, reaching up to 10 m (Figure 3).

Figure 3. Morphology of MPLS-1 floor (i.e., the top of the underlying deposits) in the Kazimierz North opencast (closed in 2012).

Similar shapes in the Mesozoic top and MPLS-1 base may be indirect evidence of syn- and/or post-depositional tectonics in the study area. This means that during and/or after the evolution of the Mid-Miocene mires, there was tectonic subsidence. Such relationships are better documented in other
Polish lignite-bearing areas, where the thickness of lignite seams ranges from several dozen to over 250 m [3–6, 19, 20].

4.1.2. Faults. As stated above, both syn- and post-depositional tectonics affected the base and/or top of the mire, now called the MPLS-1 floor/roof. This is evidenced by the presence of numerous small-scale faults in the uppermost layers of sandy deposits underlying MPLS-1 (Figure 4a). On the other hand, sporadically occurring large-scale faults in the top beds of the seam demonstrate both post-depositional tectonics and strongly-differentiated peat/lignite compaction on both flanks of the presented faults (Figure 4b).

![Figure 4](image_url)

**Figure 4.** Photographs of small- and large-scale faults in the deposits under- and overlying MPLS-1 in the Jóźwin IIB opencast.

In the last case, the mentioned research problem remains unsolved. This is due to the fault’s location in the marginal part of the Jóźwin IIB opencast and not the exposed floor of MPLS-1. Therefore, the thickness of MPLS-1 on both sides of the fault is unknown, which makes it impossible to compare the effects of compaction.

4.1.3. Cleats. The Jóźwin IIB opencast belongs to a class of global lignite-bearing areas, where cleats are best developed and known [21, 22]. Cleats are opening-mode fractures, consisting of two orthogonal sets both almost perpendicular to the bedding of MPLS-1. The primary set is called the face cleats, while the secondary set is called the butt cleats (Figure 5). These two sets are perpendicular to each other, and their orientations are northeast-southwest and northwest-southeast, respectively. The cleats dip very steeply (averaging ~86°), the average spacing is ~12.5 cm, and the average aperture of these cleats is ~0.8 cm.

![Figure 5](image_url)

**Figure 5.** Photographs showing well-developed cleats within MPLS-1 in the Jóźwin IIB lignite opencast; (a) butt cleats, (b) face cleats.

Cleat genesis is still controversial because some researchers point to tectonogenesis and others to nontectonic origins such as dehydration, devolatilisation, matrix shrinkage, etc. [23, 24]. The most prominent face cleats are characterised by the northwest-southeast orientation, which is parallel to the elongation of the main tectonic units, including the extent of deep-seated salt structures. Therefore, at least the orientation of interpreted cleats should be associated with the tectonic activity of the bedrock.
4.1.4. Seismically-induced structures. Very unique deformations of siliciclastic deposits occur within MPLS-1 in the Jóźwin IIB opencast (Figure 6). These sandy deposits split the lignite seam and are considered to be typical of a crevasse-splay microdelta formed in the overbank zone of the Mid-Miocene mire, that is, backswamp [9]. The deposits are strongly disturbed with both ductile and brittle deformation. Ductile deformations, for example, in the form of deformed lamination are located only in the lower part of the sandy interbedding (Figure 6b). In contrast, almost the entire microdelta deposits are brecciated (Figures 6c, 6d).

Figure 6. Photographs showing seismically-induced soft-sediment deformations in crevasse-splay microdelta in the Jóźwin IIB lignite opencast.

Ductile deformations were created first and they then brecciated. This means that the brecciation process took place later. These two types of deformation were most likely generated by tectonic activity in the graben area [9, 25, 26]. Thus, seismic shocks caused liquefaction of the deposits resulting in hydroplastic disturbances (Figure 6b) and/or hydraulic fracturing (Figure 6c, 6d).

4.2. Sedimentary deformations

4.2.1. Seam roof. The roof of MPLS-1 is flatter than its floor as described above in Section 4.1.1. The maximum differences in the position of the floor, seen in cross-section, do not exceed 20 m (compare Figure 2). On the other hand, it is gently folded; however, a sudden and steep slope of the seam roof was observed. In such a case, at a distance of up to 50 m, the differences in the height of the MPLS-1 roof reach up to 5–8 m (Figure 7).

Figure 7. Morphology of MPLS-1 roof in the Jóźwin IIB lignite opencast

Compaction had the greatest impact on the present-day shape of the MPLS-1 roof. It is worth recalling that the mire top was nearly horizontal at the end of peat accumulation. Then the compaction
process started, and the thickness of the peat began to gradually decrease, transforming it into lignite [4, 5]. As a result, the lignite seam is about twice as thin as the thickness of the peat seam from which it was created because the compaction ratio of ~2.0 was estimated for MPLS-1 [27]. However, post-depositional tectonics cannot be excluded in the discussed case (Figure 7).

4.2.2. Sedimentary breccia. Between two benches of MPLS-1, at the top of unnoticeably disturbed crevasse splay, have been identified brecciated deposits for the first time in all Polish lignite deposits (Figure 8a). They are built of fine-grained sandy or silty-sandy blocks with a coaly-silty sand matrix, and their internal structure is chaotic and folded to thrust-faulted with noticeable shear surfaces (Figures 8b, 8c).

![Figure 8. Photographs of brecciated deposits atop of crevasse-splay sands in the Tomisławice lignite opencast; (a) broad view, (b) and (c) close-up view.](image)

These poorly-lithified and strongly-deformed deposits have been recognised as sedimentary breccia [8]. It developed during the initial stages of overbank flooding after the formation of the underlying crevasse-splay succession. Most likely, this sedimentary breccia represents a debris flow triggered by saturation of the natural levee deposits with rapidly increasing in-channel water. In such conditions, these originally sub-horizontally stratified levee deposits were first folded by liquefaction and then brecciated [8].

4.2.3. Slumps. Folded deposits within MPLS-1 were exposed in the Tomisławice opencast in 2019. They are typical of the most proximal zone of the crevasse splay that split the lignite seam. The base is erosional and concaved up while the top is almost flat (Figure 9a). These deposits consist of sands and muds, and they are predominantly trough cross-stratified on a large scale. However, only the middle part of the siliciclastic succession is strongly deformed in the form of recumbent folds (Figure 9b).

The folds are still being studied. Therefore, the following two hypotheses should be regarded as preliminary. In both cases, the relatively thick siliciclastics were deposited on top of poorly-compacted and water-saturated peat. First, the original stratification may have been disturbed shortly after deposition, when the increase in pore pressure caused the expulsion of water upwards. Second, the slumping process could also cause sediment deformation. This hypothesis is supported by the fold geometry, which indicates their slope is almost perpendicular to the direction of the paleotransport (Figure 9b).
Figure 9. Photographs of folds within crevasse-splay sands and muds in the Tomisławice lignite opencast; (a) broad view, (b) and (c) close-up view depicting recumbent folds

5. Conclusions

Long-term and systematic observations of the lignite seam (MPLS-1) in the Jóźwin IIB and Tomisławice opencasts provide important information on tectonic and sedimentary deformations. Some of them have been known for years from most of the world's lignite deposits. They are floor and roof deformations of the seam, as well as faults. Cleats are perfectly developed in the Jóźwin IIB opencast. However, they are relatively common in lignite-bearing areas. Other deformations, both sedimentary, seismically-induced breccias and slumps, are unique and have not been previously described in other lignite opencasts around the world.

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References

[1] A. Diamantopoulos, D. Dimitrakopoulos, and I. Fountoulis, Quaternary deformation of the Mavropigi Lignite Field (western margin of Ptolemais–Kozani Graben, NW Macedonia, Greece). Bull. Geol. Soc. of Greece, vol. 36, pp. 310–319, 2004.
[2] H. Yilmaz, S. Over, and S. Ozden, Kinematics of the East Anatolian Fault Zone between Turkoglu (Kahramanmaras) and Celikhan (Adiyaman), eastern Turkey. Earth Planets Space, vol. 58, pp. 1463–1473, 2006.
[3] M. Widera, Litostratygrafia i paleotektonika kenozoiku podplejstoceńskiego Wielkopolski. Seria Geologia, 18, Wyd. Nauk. UAM, Poznań, pp. 1–224, 2007.
[4] M. Widera, Changes of the lignite seam architecture – a case study from Polish lignite deposits. Int. J. of Coal Geol., vol. 114, pp. 60–73, 2013.
[5] M. Widera, Characteristics and origin of deformations within the lignite seams – a case study from Polish opencast mines. Geol. Quart., vol. 60, 179–189, 2016a.
[6] M. Widera, Tectonic and glaciotectonic deformations in the areas of Polish lignite deposits. Civil and Environmental Engineering Reports, vol. 28, pp. 182–193, 2018.
[7] M. Rajchl, D. Uličný, R. Grygar, and K. Mach, Evolution of basin architecture in an incipient continental rift: the Cenozoic Most Basin, Eger Graben (Central Europe). Basin Research, vol. 21, pp. 269–294, 2009.
[8] M. Widera, Sedimentary breccia formed atop a Miocene crevasse-splay succession in central
Poland. *Sed. Geol.*, vol. 360, 96–104, 2017.

[9] L. Chomiak, R. Wachocki, P. Maciaszek, M. Widera, and T. Zieliński, Seismically-induced soft-sediment deformation in crevasse-splay microdelta deposits (Middle Miocene, central Poland). *Geol. Quart.*, vol. 63, pp. 162–177, 2019a.

[10] R. Vinken (compiler), The Northwest European Tertiary Basin. *Geol. Jb A.*, vol. 100, pp. 1–508, 1988.

[11] M. Piwocki, M. Ziembińska-Tworzydło, Neogene of the Polish Lowlands – lithostratigraphy and pollen-spore zones. *Geol. Quart.*, vol. 41, pp. 21–40, 1997.

[12] M. Widera, Depositional environments of overbank sedimentation in the lignite-bearing Grey Clays Member: new evidence from Middle Miocene deposits of central Poland. *Sed. Geol.*, vol. 335, pp.150–165, 2016b.

[13] M. Widera, L. Chomiak, D. Gradecki, R. Wachocki, Osady glifu krewasowego z miocenu Polski środkowej w okolicach Konina. *Prz. Geol.*, vol. 65, pp. 251–258, 2017a.

[14] J. R. Kasinska, B. Słodkowska, Factors controlling Cenozoic anthracogenesis in the Polish Lowlands. *Geol. Quart.*, vol. 60, pp. 959–974, 2016.

[15] E. Worobiec, M. Widera, G. Worobiec, B. Kurdziel, Middle Miocene palynoflora from the Adamów lignite deposit, central Poland. *Palynology*, vol. 44, doi: 10.1080/01916122.2019.1697388, 2020.

[16] A. Bechtel, M. Widera, M. Woszczyk, Composition of lipids from the First Lusatian lignite seam of the Konin Basin (Poland): relationships with vegetation, climate and carbon cycling during the mid-Miocene Climatic Optimum. *Org. Geochem.*, vol. 138,103908, 2019.

[17] M. Widera, E. Kowalska, M. Fortuna, A Miocene anastomosing river system in the area of Konin Lignite Mine, central Poland. *Ann. Soc. Geol. Pol.*, vol. 87, pp. 157–168, 2017b.

[18] M. Widera, L. Chomiak, T. Zieliński, Sedimentary facies, processes and paleochannel pattern of an anastomosing river system: an example from the Upper Neogene of Central Poland. *Jour. Sediment. Res.*, vol. 89, pp. 487–507, 2019b.

[19] M. Widera, Genetic classification of Polish lignite deposits: A review. *Int. J. of Coal Geol.*, vol. 58, 107–118, 2016b.

[20] M. Widera, A. Hałuszczak, Stages of the Cenozoic tectonics in central Poland: examples from selected grabens. *Z. Dt. Ges. Geowiss.*, vol. 162, pp. 203–215, 2011.

[21] M. Widera, What are cleats? Preliminary studies from the Konin lignite mine, Miocene of central Poland. *Geologos*, vol. 20, pp. 3–12, 2014a.

[22] M. Widera, Lignite cleat studies from the first Middle-Polish (first Lusatian) lignite seam in central Poland. *Int. J. of Coal Geol.*, vol. 131, 227–238, 2014b.

[23] I. V. Ammosov, I. V. Eremin, Fracturing in coal. IZDAT Publishers (Moscow)/Office of Technical Services, U.S. Department of Commerce (Washington, DC), pp. 1-109, 1963.

[24] X. Su, Y. Feng, J. Chen, J. Pan, The characteristics and origins of cleat in coal from Western North China. *Int. J. of Coal Geol.*, vol. 47, pp. 51–62, 2001.

[25] L. Chomiak, R. Wachocki, P. Maciaszek, M. Widera, T. Zieliński, Seismically-induced soft-sediment deformation in crevasse-splay microdelta deposits (Middle Miocene, central Poland) – reply. *Geol. Quart.*, vol. 63, pp. 429–433, 2019b.

[26] A. J. van Loon, Seismically-induced soft-sediment deformation in crevasse-splay microdelta deposits (Middle Miocene, central Poland) – comment. *Geol. Quart.*, vol. 63, 424–428, 2019.

[27] M. Widera, Compaction of lignite: a review of methods and results. *Acta Geol. Pol.*, vol. 65, 367–368, 2015.